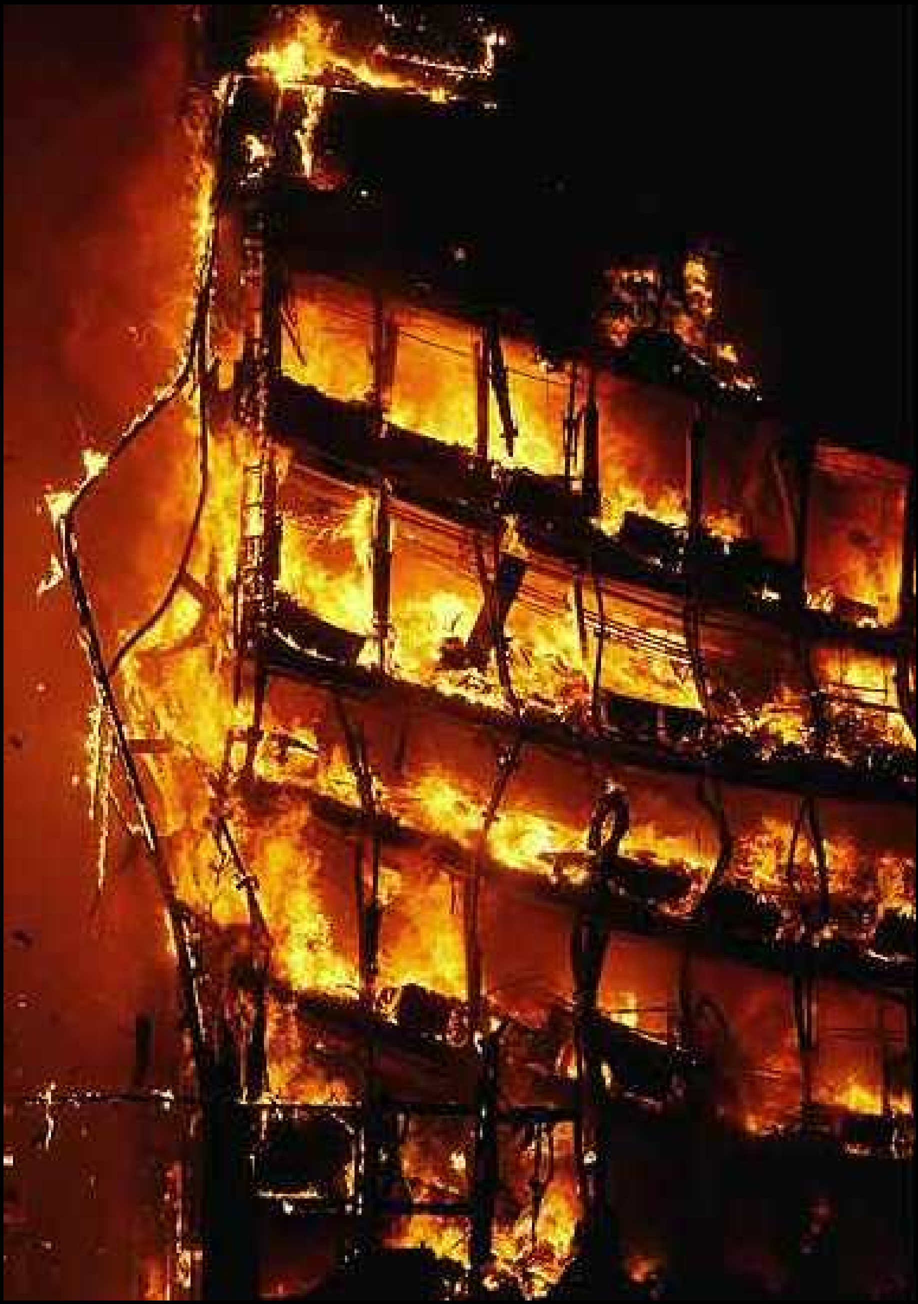
Performance Requirements and Acceptance Criteria for Safety in Case of Fire



Report of the IRCC Workshop
Vienna, Austria
10 October 2007

NOTICE

Foreword

Building regulations are legal instruments intended to ensure that buildings, when constructed in accordance with the regulations, provide socially acceptable levels of health, safety, welfare and amenity for building occupants and for the community in which the buildings are located. This is typically accomplished through regulatory controls on the design, construction and operation of buildings, covering such diverse areas as structural stability, fire safety, heating, lighting, ventilation, plumbing, sanitary facilities, indoor air quality, and energy.

Historically, these regulatory controls have generally been highly prescriptive in nature (e.g., the maximum travel distance to an exit shall not exceed 30 meters), allowing limited flexibility in alternative compliance options, and have often been based on reaction to significant events (e.g., fires, earthquakes, hurricanes, etc.). In the last 20 years, however, there has been a growing transition to objective-, functional- and performance-based building regulations. In these regulations, the focus has shifted from prescribing solutions to identifying objectives, functional requirements, and performance expectations (e.g., design the building so that occupants not intimate with the fire source can safely exit the building before untenable conditions are reached in egress paths), and allowing for a wider selection of compliance options.

One discussion focus in the performance environment is fire safety, which was chosen as the topic of an IRCC workshop, held at the Hotel de France in Vienna, Austria, on 10 October 2007. The intent of the workshop was to provide a forum for IRCC members to ask questions of, and gain insight from, invited experts with experience and expertise in fire science, fire safety engineering, and fire risk and performance concepts in regulation. In an area where functional and prescriptive regulations prevail, the lack of quantitative performance requirements makes it especially difficult to assess the compliance of alternative design solution which are based on fire safety engineering methods.

The Workshop presentations and discussions were necessarily wide-ranging, yet proved to be extremely insightful and beneficial to the IRCC members. Although it is impossible to capture the full extent of discussions and perspectives, the following provides a summary of some of the key issues that were discussed.

As performance-based building regulations will become more risk-informed and soundly based on quantitative performance criteria in the future, the discussions and professional connections made at this workshop shall help set the foundation for facilitating global cooperation and advancement in this important area.

Brian J. Meacham, Ph.D., P.E.
Editor

Acknowledgments

The success of any workshop is due ultimately to the participants, and this workshop is no exception. The core of the workshop participants – the source of issues to be addressed and factors to be considered – were the members of the IRCC. As representatives of organizations responsible for the development and support of nationally-adopted building regulations in eleven countries, the challenges you face and the experience you bring shaped the breadth and depth of discussion.

To help the IRCC expand their knowledge of fire and performance issues, a small group of invited experts participated in the workshop, sharing their insights and experience, and making the workshop an incredibly valuable experience for all:

- Dr. Arthur Eisenbeiss, Institute for Fire Prevention, Linz, Austria
- Mr. Jukka Hietaniemi, VTT, Finland
- Dr. Björn Karlsson, Iceland Fire Authority
- Dr. Mamoru Kohno, National Institute for Land and Infrastructure Management, Japan
- Dr. Johan Lundin, WSP Fire & Risk Engineering, Malmö, Sweden
- Dr. Brian Meacham, Arup / Worcester Polytechnic Institute, USA
- Dr. Rainer Mikulits, Austrian Institute of Construction Engineering, Vienna, Austria
- Prof. Dr. Ulrich Schneider, Technical University of Vienna, Austria
- Dr. Paul Stollard, Scottish Building Standards Agency

We sincerely thank each of you for your generosity in sharing your time, experience and expertise with the IRCC – your participation is deeply appreciated.

Finally, no workshop happens without planning, organization and administrative support. IRCC extend their sincere appreciation to Dr. Rainer Mikulits and OIB for providing financial, administrative, program and technical support.

Executive Summary

Over the past twenty years, numerous countries have developed and implemented performance-based (functional, objective-based) building regulations, and the trend continues. With each new country that moves towards a performance building environment, lessons learned in other countries are shaping the form and direction of performance regulation. In addition, those countries with the earliest performance building regulations are taking account of lessons learned, and as part of the next generation of their own regulations, are including a number of advancements and improvements into the next generation regulations.

One area that has experienced some challenges over the first twenty years of performance regulation is fire safety. In the early days of performance regulation, many countries did not include quantitative performance criteria. In addition, the conditions under which the building should be tested were often ill-defined, and the methods of assessment were variable. As a result, many countries have experience considerable variability in the application of fire safety engineering, and there is some concern that the level of fire safety provided in the resulting buildings is quite variable as well. To address these concerns, several countries have been investigating the quantification of fire performance for use in regulation.

To help the members of the IRCC obtain a better understanding of the state of fire safety engineering, the challenges in quantification of fire performance, and the related work being conducted in different countries, the IRCC sought experts to present a number of different perspectives and experiences at an international workshop on the topic of fire safety in a performance environment. The aim of the workshop was to seek a common set of challenges, potential solutions, and opportunities for collaboration.

Given the wide range of backgrounds and perspectives, it was expected that there may be difficulty in identifying common ground. Surprisingly, there was a great deal of commonality, and a rather small number of themes were repeated throughout the workshop:

- The state of fire safety engineering (FSE) has advanced considerably in recent decades, and the technology exists to undertake rather good analyses of well-defined problems wherein the fire scenarios, loads, and criteria, the building, and the occupants' response can be well-bounded and agreed. However, data are lacking in key areas, such as occupant response to fire effects, and uncertainty and variability needs to be better addressed throughout the process.
- One of the major current challenges is that the target level of fire safety / risk is not quantitatively defined, which makes it difficult for the engineer and approving authority to evaluate the appropriateness of engineered fire safety designs. Without quantitative risk values, or design fires, or acceptance criteria – which adequately account for uncertainty and variability and recognize that there is no such thing as zero risk – there will continue to be difficulties in gaining agreement on suitability of designs.
- In trying to benchmark tolerable (acceptable) levels of risk, difficulties arise from the lack of political will to set quantitative risk criteria and the lack of common and widely agreed characterizations for fire "loads" and acceptance criteria internationally. Although the current level of fire safety seems to be acceptable in most countries, it is not clear if that is a result of good design, or the fact that fire is a rare event, or the combination of these factors. To move forward there needs to be agreement as to how regulations and engineers quantitatively describe tolerable (acceptable) fire performance in terms of occupants, the building and emergency responders.
- While performance based requirements/criteria are needed to assess engineered fire safety designs - especially for complex buildings - prescriptive requirements need to be maintained for common types of buildings. However, the challenge is not only to establish such

quantitative performance requirements, but to ensure consistency with the prescriptive requirements. In both approaches the safety level should be the same.

- Furthermore, not even for the prescriptive requirements the resulting safety level is a constant line, but varies with the individual design. Hence the first significant challenge will be to determine the safety level provided by the present prescriptive requirements to begin with.

It was also interesting to note that efforts to establish risk-informed, quantified performance criteria, design fires, and verification methods (or a sub-set thereof) is underway in a number of countries, including Australia, Finland, Japan, and New Zealand, and that there is interest in other countries, including Austria, Sweden and the United States. In fact, the commonality of current efforts cries out for an international collaboration of sorts, which could help facilitate the exchange of information, concepts, research and outcomes, with the aim of helping to foster internationally-consistent fire safety engineering data, tools, methods and guidelines, as well as common fire safety acceptance criteria.

Although groups such as BSI, ISO, and SFPE have created guidance documents for fire safety engineering, there is some argument for the next advancements – specifically related to acceptance criteria – to be driven by a group such as the IRCC. The reason for this is the fact that "tolerable" or "acceptable" safety or risk is not an engineering decision; rather, it is a public policy decision, which is embodied in large part in the building regulations. Although there are many actors, including the insurance industry, building owners and developers, engineers, architects, and approval authorities, at the end of the day it is the regulations (in most countries) which embody the political and societal expectations of safety. As such, the IRCC should play a role in bridging the gap between the various stakeholder groups and helping to facilitate quantitative values which are politically acceptable, technically feasible and economically appropriate. This workshop was seen as a first step in this direction, but further steps are required.

Background and Introduction

Performance-, functional- or objective-based building regulatory systems are in use or under development in numerous countries world-wide. In some instances, such as in England and Wales, functional-based building regulations have been in use for more than 20 years, while in Canada, objective-based codes are just being promulgated. In New Zealand and Australia, major modifications are underway to the performance-based regulations, including a focus on better quantifying performance criteria, exploring different levels of performance which might be expected for different types of buildings, and investigating how risk might be used as a basis for establishing performance levels and criteria.

The fact that so many countries are developing and promulgating performance-, functional- or objective-based codes, that the various countries can learn from one another and take advantage of joint research and learning opportunities, and can help transfer this knowledge to others are just some of the issues that led to the formation of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC).

The IRCC, formed in 1996, is an unaffiliated committee of eleven of the lead building regulatory agencies and organizations of ten countries (http://www.ircc.gov.au):

- The Austrian Institute of Construction Engineering, Austria
- The Australian Building Codes Board, Australia
- The China Academy of Building Research, China
- The Department of Building and Housing, New Zealand
- The Department for Communities and Local Government, England and Wales
- The Institute for Research in Construction, National Research Council, Canada
- The International Code Council, USA
- The Ministry of Housing, Spain
- The Ministry of Land, Infrastructure and Transport, Japan
- The National Institute for Land and Infrastructure Management, Japan
- The National Office of Building Technology and Administration, Norway
- The Scottish Building Standards Agency, Scotland

In addition to meeting at least twice annually to discuss issues and share experiences, over the past ten years, the IRCC has developed guidelines for the introduction of performance-based building regulations (1998), has held global summits on issues in performance-based building regulation (Washington, DC, 2003) and sustainability (Gold Coast, Australia, 2005), and has started a series of workshops on specific topics impacting performance-based building regulations, the first being a workshop on the use of risk concepts in performance regulation (San Francisco, CA, 2006).

To help the IRCC learn more about issues associated with fire safety in a performance regulatory environment, the focus of the most recent workshop was on the topic of fire safety in a performance environment.

Invited Speakers

Dr. Arthur Eisenbeiss

Dr. Eisenbeiss is CEO at the Institute for Fire Prevention Ltd (BVS), Managing Director of the Institute for Fire Safety und Conformity Ltd. (ISC), and Managing Director of the Upper Austrian Association for Lightning Protection Ltd. in Linz, Austria. He acts also as a Vice-President of the "Professional Technical Association" within the Austrian Association of Engineers and Architects. He is member of several technical committees and chairman of the Technical Committee 006 "Reaction to fire of Building Materials and Components" in the Austrian Standards Institute. Further commitments include his membership in the Supervisory Board, Upper Austrian Testing Laboratory for Building Materials and Geotechnology Ltd.

Dr. Jukka Hietaniemi

Dr. Hietaniemi is senior research scientist at VTT Technical Research Centre of Finland, where he works as the Team Leader of the Computational and Structural Fire Safety research team. He is the project leader in several large national projects focusing on fire risk assessment and fire simulation. Since 2003, Dr. Hietaniemi has been the chairman of the Finnish Fire Research Board. He is a member of a committee that establishes the Finnish national research programme of fire safety and rescue services. He was the coordinator and principal scientist of VTT in the Risk-Based Fire Resistance Requirements project (2000-2004), which laid the technical basis for setting fire resistance requirements in the National Building Laws on the grounds of their impact on the fire risks in buildings. Dr. Hietaniemi worked as a Guest Researcher at the National Institute of Standards and Technology (NIST), Maryland, USA, and participated in several EU-funded projects. He is author or co-author of 120 publications, 35 of which have appeared in referred scientific journals or conference proceedings.

Dr. Björn Karlsson

Dr. Karlsson is Fire Marshal and General Director of the state run Iceland Fire Authority, Reykjavik, Iceland. He is also an associate professor at the Department of Environmental and Civil Engineering at the University of Iceland, vice-chairman of the Icelandic Association of Chartered Engineers, chairman of the Heating and Venting Association and the secretary of the Association of Directors-General in Iceland. He sits on the board of the International Association for Fire Safety Science (IAFSS, www.iafss.org), is the Chairman of the IAFSS Education subcommittee, member of the editorial board of Fire Technology and member of the editorial board of the International Journal on Engineering Performance-Based Fire Codes. Earlier, he worked as associate professor at the Department of Fire Safety Engineering at Lund University, Sweden and was a Visiting Professor at the University of Maryland. Dr. Karlsson has written a number of books and articles in the field of fire safety.

Dr. Mamoru Kohno

Dr. Kohno is a Research Coordinator for Quality Control of Building with National Institute for Land and Infrastructure Management, where he leads research related fire resistance of steel structures and risk-based building regulatory systems in fire safety. He has more than twenty five years experience in structural stability, structural reliability, structural fire resistance and risk-informed performance-based design and regulation. Dr. Kohno has written more than 100 publications on the topics of structural reliability, fire, risk and performance. He has served on numerous committees, including the sub-committee on Fire Resistance Design of Steel Structures in Architectural Institute of Japan, ISO TC92/SC2, TC92/SC4, and CIB TG37. Dr. Kohno holds a Bachelor and Master's Degrees in Architecture from Kyoto University, Japan, and a Doctoral Degree in Structural Engineering from Nagoya University, Japan. Dr. Kohno had been an Associate Professor of Nagoya University before being the researcher of the current institute. He has taught many subjects including Steel Structure Design, Structural Reliability, and Risk and Safety to graduate and undergraduate students at Nagoya University.

Dr. Johann Lundin

Dr. Lundin is a technical director and project manager at WSP's Fire and Risk Engineering team and involved in WSP's multi-disciplinary Risk network. He is working with a wide range of risk management and fire safety engineering projects in the areas of land-use planning, property, transport and infrastructure, for example as WSP's chief risk engineer in the City Rail Line project. Dr. Lundin has 10 years of experience from research and education at the Faculty of Engineering at Lund University and is specialised in fire safety engineering and risk management. He has been the Director of Studies for the Master's Programme in Risk Management and Safety Engineering at Lund University. During the time at Lund University, Dr. Lundin worked with a number of research projects related to the following topics: fire safety design linked to quantitative risk analysis (QRA), vulnerability analysis, uncertainty analysis including Monte Carlo simulation, risk management and its processes, safety management systems and decision analysis.

Prof. Dr. Brian Meacham

Dr. Meacham is an associate professor in the department of Fire Protection Engineering at Worcester Polytechnic Institute (WPI) in Worcester, MA, USA. He is widely recognized as a leading authority on risk-informed performance-based approaches to engineering and regulation, having undertaken research, participated in the development of guidance documents, and consulted to governments on these topics. He has more than 120 publications in the areas of fire engineering, risk and regulatory policy. As a member or numerous national and international codes, standards and guidance development committees, he helps facilitate the transfer of knowledge between research, practitioners and policy-makers. Dr. Meacham is currently Chair of the IRCC. He holds an M.S. in Fire Protection Engineering from Worcester Polytechnic Institute (WPI), and a Ph.D. in Risk and Public Policy from Clark University. He is a licensed Professional Engineer in Connecticut and Massachusetts, a Chartered Engineer Member of the Institute of Fire Engineers in the UK, and a Fellow of the Society of Fire Protection Engineers.

Dr. Rainer Mikulits

Dr. Mikulits is managing director of the Austrian Institute of Construction Engineering (OIB) in Vienna, Austria. He has thorough knowledge of building regulations in Austria and in Europe and is, in his capacity as director of OIB, responsible for the drafting of building codes (OIB-guidelines) in Austria. He is an specialist on construction products, is member of the EU-Standing Committee on Construction and has participated as an expert in a number of EU-training programmes in new EU-member states and candidate countries. As the head of the official accreditation body of the Austrian provincial governments for testing laboratories, inspection bodies and certification bodies in the field of construction, he has also large experience in accreditation. Dr. Mikulits was elected president of the European Organisation for Technical Approvals in 1999-2003 and published many articles and lectures on the topics Building Regulations, Building Control, New Approach and Construction Products Directive. He is also editor of "OIB aktuell", an Austrian journal on technical and legal issues related to construction products, and member of the advisory board of "baurechtliche blätter", a journal on building law.

Prof. Dr. Ulrich Schneider

Dr. Schneider is a full professor with the Department of Civil Engineering at the Vienna University of Technology, where he is also the head of the Centre for Building Material Research and Fire Safety. He is a member or numerous national and international standards and scientific committees. His scientific research areas encompass beside fire safety engineering, fire safety standards and fire and smoke simulation in buildings also concrete and high perfomance concrete, corrosion of building materials, building chemistry, rehabilitation of buildings, ecology of materials and structural elements (LCA), material development and testing and temperature behaviour of concrete and concrete structures.

Dr. Paul Stollard

At the time of this workshop, Dr. Stollard was the Chief Executive of the Scottish Building Standards Agency. In this role he was responsible for the development of the technical requirements on buildings and the surveillance of building control activities in Scotland. Dr. Stollard is associate of the Royal Incorporation of Architects in Scotland, associate member of the Royal Institution of Chartered Surveyors, and Chartered Engineer Member of the Institution of Fire Engineers. Earlier, he was Research Director at the Institute of Advanced Architectural Studies, York University and Director of Abrahams Stollard Ltd, and Rosborough Stollard Ltd, fire engineers. He acted also as a visiting professor of architecture at the Queen's University of Belfast. Dr. Stollard is author of five books and numerous technical articles on related topics.

Workshop Program

09:00 – 09:10	Welcome and Introduction	Rainer Mikulits, Austrian Institute of Construction Engineering
09:10 – 09:30	Fire Safety Engineering: State of the Art	Björn Karlsson, Iceland Fire Authority
09:30 – 09:50	Performance Requirements and Acceptance Criteria for Safety in Case of Fire: Some Aspects of the Problem	Johan Lundin, WSP
09:50 – 10:20	Discussion	
10:20 – 10:40	Practical Experiences in Austria	Arthur Eisenbeiss, Institute for Fire Prevention
10:40 – 11:00	*Coffee break*	
11:00 – 11:30	Scientific Perspective and Application of Deterministic Fire Safety Engineering Methods	Ulrich Schneider, Technical University of Vienna
11:30 – 11:50	Performance Requirements & Criteria for FSE in Performance-Based Regulations	Brian Meacham, Arup/WPI
11:50 – 12:30	Discussion	
12:30 – 13:30	*Lunch break*	
13:30 – 13:50	Performance Requirements & Criteria for FSE: Directions in Australia, New Zealand and USA	Brian Meacham, Arup/WPI
13:50 – 14:10	Development of 2nd-Phase Performance-Based Fire Regulations in Japan	Mamoru Kohno, National Institute for Land and Infrastructure Management, Japan
14:10 – 14:30	Developments of FSE Design Acceptance Criteria in Finland	Jukka Hietaniemi, VTT, Finland
14:30 – 14:40	Fire Safety Standards in Scotland	Paul Stollard, Scottish Building Standards Agency
14:40 – 15:40	Panel discussion	
15:40 – 16:00	*Coffee break*	
16:00 – 16:20	Conclusions and Next Steps	Brian Meacham, Arup/WPI (IRCC Chair)
16:20 – 16:30	Closing Statement	Rainer Mikulits, Austrian Institute of Construction Engineering

Presentation Summaries

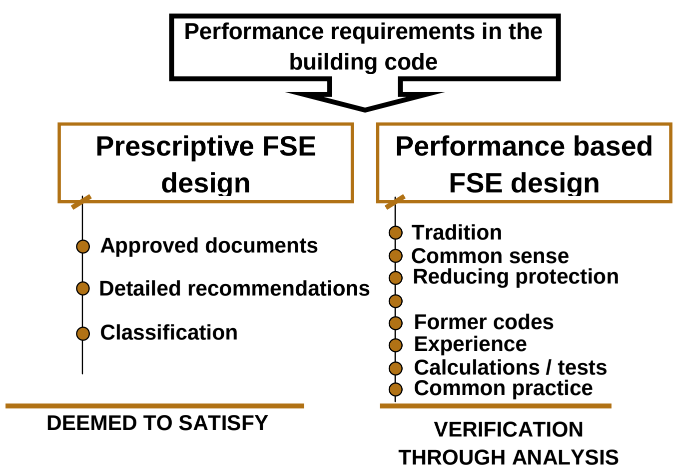
Björn Karlsson

Dr. Karlsson started out the workshop with an overview of fire safety engineering – its history and where we are at today, including aspects of research, education and design practice. He also provided some insights into how Iceland is treating fire safety engineering in a performance environment.

Although he noted that fire safety engineering (FSE) has a solid research base, with well defined and well known terminology, educational programs established in many universities, and an abundance of textbooks, handbooks, and design tools (such as computer programs) to assist the fire safety designer, Dr. Karlsson cautioned that FSE is not a mature engineering discipline and that there remains much to do. In many ways, this observation went to the core purpose of the workshop – understanding where the state of practice is, how we can use that information for establishing fire safety criteria and assuring compliance therewith, and identifying where additional research, data, tools and methods are needed to reach our objectives for performance-based fire safety design.

One facet of FSE that can be both a benefit and a detriment is its multi-disciplinary nature. FSE requires knowledge of physics and chemistry of fire and materials, structural performance under elevated temperature, human behavior in fire, fire hazard and risk assessment, and design of various fire protection systems and strategies. To help prepare practitioners, there are a number of dedicated university programs around the world in FSE, including at the B.Sc., M.Sc. and Ph.D. levels. Some of the more widely known universities offering one or more of these programs include Lund University in Sweden, the University of Maryland and Worcester Polytechnic Institute in the USA, the University of Canterbury in New Zealand, Victoria University in Australia, and University of Edinburgh in Scotland.

Over the past two decades, the solid fire research base and FSE educational offerings, combined with a move towards performance-based codes, has seen a broader application of FSE in the design environment. This is seen as positive advancement within the fire science and engineering community, and an illustration of the relationship between performance codes and design is shown below.



However, Dr. Karlsson points out that not everyone sees this as a positive situation, especially since rapid development within the global building industry has resulted in larger and more complex buildings, utilizing increasingly innovative materials and technologies, being designed and constructed within shorter and shorter timeframes. Although progress in the understanding in fire phenomena, risk concepts and human behavior has been rapidly increasing as well, it is not clear whether information transfer from research into practice is keeping pace, and whether we are adequately addressing uncertainty and variability adequately along the way.

Helping, and also complicating the situation, is the availability of (a) design guidelines and (b) numerous computational models for simulating fires and simulating movement of people. With respect to guidance documents for fire engineers, there are currently a large number of guidelines and codes of practice published by such entities as the International Organization for Standardization (ISO), the British Standards Institute (BSI), the Society of Fire Protection Engineers (SFPE), and even the IRCC (which publishes the International Fire Engineering Guidelines (IFEG) through its members). Although the intent is to provide some uniformity in application, which it does in many cases, it also sets the stage to allow engineers, who may not be fully qualified in fire engineering concepts, to follow the process and attempt fire engineering.

Likewise, current computational models have progressed to the stage where they can be more easily applied (if not appropriately applied) by engineers who lack fire science fundamentals. In the recent past, when computational modeling capability was more limited, and the scope of the problems being addressed were limited by the availability of data, engineering tools, and expertise, the field of FSE was somewhat self-limiting to those who had a good understanding of the fundamental principles. However, as computational tools become more widely available, and building owners, developers and architects look to push the limits of building design, the combination results in FSE being applied more and more, and not always appropriately.

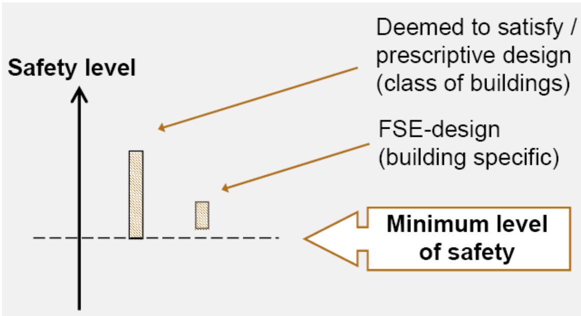
Recognizing these challenges, Iceland decided upon a more measured approach to performance codes and design as compared with countries such as New Zealand, which involved small and simple revisions to the existing code, rather than a wholesale change. In brief, descriptions of fundamental criteria for structural safety, fire safety, egress and related factors were added to the beginning of the code, and descriptions of performance criteria were then added in a paragraph at the start of each chapter. The prescriptive requirements were unchanged. A paragraph was then added to the end of each chapter stating that solutions other than the prescriptive one were allow so long as the performance criteria are fulfilled. In the end, this allowed the introduction of performance fire engineering options without significantly changing the existing regulatory or design environment. Dr. Karlsson suggested that this may be an option for other countries as well as they ponder the transition to performance codes and design, and urged continued support for education across all industry sectors to help assure proper application of performance fire engineering concepts.

Johan Lundin

The focus of Dr. Lundin's presentation was to highlight the effects of the introduction of performance-based regulations on the ability of society to control fire safety in buildings, with a key point being that the effects very much depend on how the performance requirements are formulated and which attributes of the multi-faceted concept of safety are addressed. His presentation also identified and summarized some of the problems encountered in achieving a satisfactory level of safety in case of fire when applying the performance-based regulations.

The basic problem, noted Lundin, is that we want to provide an opportunity to achieve the potential benefits of fire safety engineering while keeping the drafting of regulations and verification of designs to a reasonable effort, and at the same time achieving an *acceptable level of safety*[1] with limited variation within a class of buildings. To accomplish this, the aim is to define rules for the *safety output* required by the system, i.e., a clear set of performance requirements for the building and its fire protection measures.

[1] Not be worse off with regards to fire safety compared to when deemed to satisfy solutions are used.

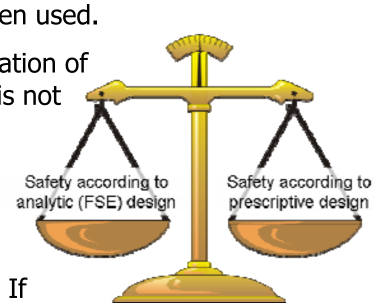


In concept, the rules which are developed may express the 'acceptable' risk explicitly or indirectly by expressing the attributes or functions of a system directly connected to safety. The concept of 'acceptable' risk is challenging because not all stakeholders may have a say in what risks they are accepting, risk is difficult to quantify, and the 'acceptability bar' may change over time (e.g., after a major fire event). Likewise, although simple in concept, challenges arise with respect to expressing attributes of a system directly connected to safety because of the large number of attributes used to define safety, such as complexity, reliability, sensitivity, vulnerability, and so forth.

In his study of the issues, Lundin notes that a number of problems regarding the possibility of verifying safety have been identified and can be divided into the following main types:

- lack of quantitative design criteria determined in the regulations,
- relative risk comparison with prescriptive design,
- risk comparison with absolute acceptance criteria,
- uncertainty in the result of the analysis, and
- lack of risk evaluation methods.

In concept, one could envision a government organization establishing quantitative risk-informed performance criteria. In reality, however, this is not simple decision made by a single person or group, but is influenced and formed through political decisions, accident investigations, experience from other regulated areas or applications, or sometimes derived from the existing (implicit) safety level(s). As a result, relative comparisons are often used.



Although relative risk comparison seems promising, basing verification of analytic design on a relative comparison with prescriptive design is not without problems. Having to first design fire protection solutions using prescriptive design takes time and costs money, and it is not certain that prescriptive design leads to good fire protection in all buildings.[2] Another problem lies in choosing the premises from a certain class of buildings to be used as the reference building, i.e. the object with which to compare the risk. If there are no recommendations regarding the choice of reference building, this building may be systematically designed with too low a level of safety, and because the reference building is purely fictitious and will never actually be built, it can be designed neglecting other competing objectives, which means that the fire safety measures can be minimized. Comparison to such a building would be misleading as the risk level used as the acceptance criterion would be too low.

The approach of risk comparison with absolute acceptance criteria has significant challenges where quantitative criteria do not exist in the regulations. In this case the decision on acceptability often occurs at the local level and significant variability can be expected between buildings and jurisdictions. Complicating the situation is the lack of specified risk evaluation methods, which coupled with the lack of benchmark data leads to significant uncertainty in the results of any risk analysis.

Moving on to challenges in verifying performance in practice, Lundin noted a number of areas of concern, including lack of specified and tested verification methods, use of too few and too mild fire scenarios, and as above, the arbitrary selection of criteria for acceptance (and the variability

[2] Lundin, J. Safety in Case of Fire – The Effects of Changing Regulations, Dept. of Fire Safety Engineering, Lund University, Lund, 2005.

resulting in the building stock as different criteria are applied). To help address some of these concerns, he suggests that regulatory agencies develop guidelines for analytic design, or limit the scope for the introduction of new solutions, since the effects on safety cannot be adequately verified by designers at this time. He also suggests that mechanisms be established that require, and assist, local building officials in checking compliance when analytic design is applied, to force adaptation to higher standards in verification procedures where needed. By establishing a national committee to conduct investigations of large projects in which analytic design has been employed, for example, national consensus and support for local building officials may be achieved.

In the end, Lundin cautions that although performance-based codes and design offer benefits, they also create risks, including the risk that an ill-defined and monitored performance approach could lead to unsafe buildings being constructed and a major loss occurring. To help avoid such a situation, effort is needed to address the concerns he has raised.

Arthur Eisenbeiss

As a lead in to his presentation on the situation in Austria, Dr. Eisenbeiss began by asking why should we discuss the creation of performance based codes. The reason for the question was not so much to be provocative, but to start with an understanding of why a country might look to an approach different from that which has been in place for decades, and which generally seems to be working fairly well.

In answering his question, he noted that descriptive regulations necessarily address the majority of buildings, generalizing the level of safety level without respect to specific building circumstances. As a consequence, however, what one gets are generalized packages of fire safety measures specified by the regulations, and different safety levels for buildings. A performance-based approach, on the other hand, makes it possible to specify measures which are suited to a specific building safety level, as defined by performance objectives and requirements in the code. This has the additional benefits of optimizing the investment while satisfying the required safety level, providing flexibility in addressing the needs of large and complex buildings otherwise inadequately addressed by descriptive codes, and speeds the time to implementation of innovative materials and products.

As a starting point for Austria, Eisenbeiss suggests that the essential requirements in the EC Construction Products Directive (CPD) for ‘safety in case of fire’ can serve as performance objectives:

> The construction works must be designed and built in such a way that in the event of an outbreak of fire:
>
> - The load bearing capacity of the construction can be assumed for a specific period of time
> - The generation and spread of fire and smoke within the works are limited
> - The spread of the fire to neighbouring construction works is limited
> - Occupants can leave the works or be rescued by other means
> - The safety of rescue teams is taken into consideration

From that starting point, one approach would be the use of quantitative metrics. This assumes that quantitative safety goals are established, which in turn requires require quantitative values for accepted risks and that necessary data are available (primarily adequate statistical data for Quantitative Risk Assessment (QRA)). There are challenges to such an approach, as discussed by Lundin previously, including that to prove specific risk probabilities are lower than accepted risk values, the ‘acceptable’ levels must be known, and a quantitative risk assessment has to be performed, yet the statistical data which are needed are not widely available. As a result, the number of situations where QRA is applicable, and where accepted risks are defined, is very low and the fundamental approach is mostly not applicable. This leads to the possibility of a more qualitative approach.

To some extent, a qualitative performance-based approach already applied in Austria in cases of complex buildings: those which have not been considered when the descriptive building codes were defined, and those for which a fire safety concept is requested in the OIB regulation. These include:

- Assembly place for more than 1000 people
- Hospitals
- Prisons
- Residential and nursing homes for aged people
- Other complex buildings, e.g. large shopping centers, multi-functional buildings

In current practice, all measures which are not reflected in the building regulations, or which are intended to deviate from descriptive building regulations, must be designed and proven by experts using appropriate fire safety concepts, and accepted by experts in administrative procedure. However, since there are no clear metrics and few performance design standards, the solutions typically reflect the knowledge- and experience-based feeling of the experts that the fire safety concept which have been designed or accepted offers the same general safety level as – from an overall point of view – as is implicitly given in the descriptive building regulation. As noted by Lundin earlier, however, there are no stringent guidelines which ensure that experts will in all cases make the same decisions, so the level of safety is less certain than with the descriptive code.

To move forward, Eisenbeiss suggests that a number of issues need attention. There is a need to quantify a "standard scenario" or a "standard event" or "standard values" on which the descriptive codes rely. Quantification of the qualitative assumptions on which the descriptive regulations are based is necessary in order to find a precise and consistent link between performance-based regulations and descriptive ones. This link needs to work both ways: informing the performance-based approach and enhancing the descriptive code. There is also a need to adequately define the boundary conditions that serve as the basis for the descriptive codes for use in the performance environment. Many of these boundary conditions may have a basis in science and technology, but may be set as a result of socio-political definitions and socio-political desires, for example, accepted time for exposure to smoke, quantity and distribution of disabled population and how to address from a safety perspective, time required for the fire brigade to begin effective suppression activities as a function of distance, crew size, equipment, and whether arson fire should be addressed. In the end, in addition to performance-based regulations, standardization of boundary conditions as input parameters and verification criteria are needed, and will ultimately become an implicit expression of the socio-political "accepted risk".

Ulrich Schneider

In his presentation, Professor Ulrich Schneider addressed some of the many challenges associated with using quantified fire performance criteria in fire safety engineering, and the need to address uncertainty and variability in the fire safety engineering process.

To set the context for his discussion, he noted that although use of fire safety engineering methods (FSEM) is increasing, many of the FSEM currently in use are simplified deterministic approaches (equations, correlations, computational models), and that more complete determination of mechanical, physical and chemical fire effects in buildings is needed in some cases. He cautioned that simulation (calculation) of fire phenomena is not a trivial task and is still part of scientific research, that significant sources of uncertainty and variability exist, and that improper use of fire safety engineering methods can lead into dangerous errors.

Regarding acceptance criteria for FSEM, Prof. Schneider focused on life safety criteria, noting that two main approaches are used: discrete values (e.g., maximum gas temperature of 50 °C at 2m above floor level), which are sometimes associated with a discrete time period (e.g., maximum gas temperature of 50 °C at 2m above floor level for 60 seconds), and the fractional effective dose (FED) methods, which consider time-dependent exposures and thresholds. In practice, discrete values, although often conservative, are widely used because they are simple to work with, have low sensitivity to changes in the materials burning, and are generally well accepted. Examples of discrete criteria with and without factors of safety are provided in the table below.

Criteria	**Condition**	**Condition with safety factor**
Radiation	< 20 [kW/m2]	< 10 [kW/m2]
Oxygen Concentration	> 12 Vol.-%	> 14 Vol.-%
Carbon dioxide Concentration	< 6 Vol.-%	< 5 Vol.-%
Carbon monoxide Concentration	< 1400 ppm	< 700 ppm
Smoke interface height	> 1.50 m	> 1.80 m
Minimal visibility	> 10 m	> 20 m
Temperature upper layer (property)	< 600 °C	< 300 °C
Temperature upper layer (people)	< 65 °C	< 50 °C

FED values, on the other hand, are complex to work with, are highly dependent upon the actual materials burning, and are therefore not as widely accepted. Prof. Schneider used toxic effects of fire as an example. In fires, three major toxic effects are important: (1) the concentration of irritant gases likely to impair escape efficiency or cause incapacitation (sensory irritation), (2) the exposure doses (C*t*) of asphyxiant gases likely to cause incapacitation through confusion and loss of consciousness, or to be the immediate cause death, and (3) the exposure dose of irritants likely to cause death through lung edema and inflammation after the fire. With respect to the toxic effect of fire gases, incapacitation or death occurs when the victim has inhaled a particular C*t* product dose of toxicants. To make some estimate of the likely hazard in particular fire, it is therefore necessary to determine at what point in time during the course of the fire exposure the victim will have inhaled a toxic dose. This can be achieved by integrating the area under the fire profile curve for the toxicant under consideration.

In order to make some estimate of the likely hazard in particular fire it is therefore necessary to determine at what point in time during the course of the fire exposure the victim will have inhaled a toxic dose. This can be achieved by integrating the area under the fire profile curve for the toxicant. When the integral is equal to the toxic dose the victim can be assumed to have received a dose capable of producing the toxic effect. A practical method for making this calculation is the concept of fractional effective dose (FED), which is the ratio of dose received at time *t* (C*t*) divided by the effective C*t* dose required to cause incapacitation or death (Purser, D.A, *Toxicity Assessment of Combustion Products*). The FED acquired over a each period of time during the fire are summed until total FED_{IN} reaches unity, at which point incapacitation is predicted. In order to allow for differences in sensitivity and to protect susceptible human subpopulation a factor of 0,1 FED should allow for safe escape of nearly all exposed individuals. Death is predicted at approximately two to three times the incapacitating dose. Prof. Schneider provided several examples of the use of FED in his presentation.

Moving on to the challenges of uncertainty and variability in FSEM, and referencing the *SFPE Engineering Guide to Application of Risk Assessment in Fire Protection Design,* Prof. Schneider noted that many aspects of FSEM are prone to uncertainty, including the in the scope of the project (discrepancy between the stated scope and the intended scope), in the performance objectives, metrics (criteria), and acceptability thresholds, in the identification of hazards (e.g.

fire loads) and scenarios (geometries, ventilation), and in the data, tools, and methods applied. He pointed out the additional challenges that not all types of error can be meaningfully quantified and that in many cases one needs to assume that the use of fire safety engineering methods was completed consistent with good engineering practices and is therefore free of ordinary analytical mistakes (e.g. incorrect unit conversion, mathematical errors, software bugs).

If one considers selecting scenarios and criteria for life safety, for example, we typically do not know many key factors, such as the probability of a specific fire occurring, the fuels involved, the amount smoke produced and the percentages of constituent products of combustion, the population exposed and their psychological and physiological responses, or how uncertainty is addressed in the data, analytical tools or methods. To account for this, the FSEM should include a systematic approach to identifying error sources and making high-level decisions on how each type or source of error will be addressed, developing error analysis strategies for specific types of error, quantifying uncertainties associated with each part of use of a FSEM, propagating the uncertainties throughout the process, and evaluating the impact.

To illustrate how one might address uncertainty in FSEM for life safety, Prof. Schneider presented an example using a '4-state model' which utilized limit states based on different conditions (states) and responses. The aim of the project he used as an example was to determine, with the help of scientific equipment, the state of personal safety in underground railway stations/tunnels. This was made by determination of the smoke layer situations from selected tunnel/station ranges via numeric fire simulation and from views of evacuation via computations. To assess the findings of the investigations, four limit states were defined, to which a degree of exposure with respect to the possibility of self-respectively external-rescue has been allocated. The bases for the four states were discrete acceptance criteria based on survival conditions with different safety factors for defined smoke layers. States and criteria are shown below.

State Descriptions

Name	State Description	Options of Escape / Rescue
State A (degree of exposure 1)	Safe escape possible, small effects on fleeing persons by the fire	Self- rescue possible
State B (degree of exposure 2)	Direct and indirect fire effects on fleeing persons but no life-threatening impacts; small risk of injury.	Self-rescue possible, external-rescue where required necessary
State C (degree of exposure 3)	Massive direct and indirect fire effects on fleeing persons; high risk of injury, circumstances potentially life-threatening	Self-rescue only to a limited extent possible, external-rescue necessary
State D (degree of exposure 4)	Circumstances directly life-threatening	Self-rescue not possible, external-rescue necessary, external-rescue where required only to a limited extent possible

Acceptance Criteria

State	Critical value in the lower layer for	
	CO2-Concentration (R)	**Temperature (T)**
State A	x ≤ 0,1 Vol.-%	x ≤ 35°C
State B	0,1 Vol.-% < x ≤ 0,5 Vol.-%	35°C < x ≤ 50°C
State C	0,5 Vol.-% < x ≤ 5,0 Vol.-%	50°C < x ≤ 65°C
State D	x > 5 Vol.-%	x > 65°C

Prof. Schneider closed with a set of recommendations for application of FSEM and criteria, including: evaluation of design fire scenarios should be risk-informed (probabilistic), uncertainty and sensitivity analyses for FSEM should always be conducted, life safety FED criteria of FED=1.0 should never be used and that safety factors of at least 10% should be applied (particularly FEDs for survival conditions for short time periods), and that whatever safety factors are selected should be done so in the context of the design and associated boundary conditions (e.g., fire, building and occupant characteristics).

Brian Meacham (I)

Following the discussion on challenges with selection of criteria and application of fire safety engineering methods, Dr. Brian Meacham provided a complementary presentation on issues associated with performance requirements and criteria for fire safety engineering for use in performance-based regulations, addressing many of the same concerns as previous speakers.

To set a baseline for discussion, Dr. Meacham identified the first challenges as being how one defines 'safety in case of fire' – what does it mean, how do we measure it, how do we regulate it and design for it – and who establishes the definitions? Historically, fire safety engineering (FSE) goals include protection of people, property, mission, heritage, the environment and community welfare. When looking internationally, however, not all countries address each of these issues in building regulation, and they do so at different levels. Furthermore, most existing building regulations (performance-based or otherwise) do not contain specific FSE performance criteria, so the decision as to which criteria are used is left to the fire safety engineer.

As result, although the fire physics do not change from country-to-county or building-to-building, the level of fire safety, and the metrics used to established acceptability of fire safety designs, can vary significantly. The situation is further complicated, as Prof. Schneider noted previously, because the most common approach to FSE involves the use of discrete criteria and deterministic evaluation. However, in reality, there is no such thing as 'zero risk' or absolute safety. Even if such a target were set, there are resource limitations to consider, so balancing costs of fire mitigation versus expected losses is needed.

To address the challenges of variability in selection of criteria and resulting variation in levels of building fire safety, and the fact that resources are limited, it is suggested that the regulatory objective should be to protect most of the people, most of the time, with the level of risk/safety appropriately balanced with cost to society of risk mitigation and potential consequences. To meet this objective, one needs to regulate for performance/risk levels, loads, and criteria. It is suggested that this can be accomplished by applying an approach that includes defining and agreeing a methodology for assessing fire and life safety, characterizing the population of concern (building occupants), identify risk/performance groups/levels based on occupant, building and fire characteristics, select appropriate metrics for factors such as fire/smoke spread, tenability limits, and safe egress time (tolerable impacts), define the magnitude of the design fire load/scenario, and identify and account for uncertainty and variability in the people, buildings and processes.

Focusing on safety to life as an example, one can follow the above approach and define performance levels and criteria for use in building regulation.

First, a methodology for life safety analysis must be selected. In many countries, the ASET/RSET approach is used (Available Safe Egress Time/Required Safe Egress Time). Using this approach, and assuming the target is to allow time for those not intimate with initial fire develop to reach a place of safety, one can assess the estimated time to untenable conditions (ASET) and the estimated time required to or occupants to evacuate a building (RSET), and as long as RSET is greater than ASET, the target level of safety can be shown to be achieved.

The next step is to characterize the population of concern: the building occupants. This involves identifying risk factors, which may be attributes of individuals (e.g., awake or asleep, ability, familiarity with building, age, dependencies, relationships, physiology) or of groups (e.g., population size, density and distribution, roles and responsibilities) that impact on their risk to life in a fire. One can then use this information to group buildings based on risk factors of occupants (e.g., group those that need to be protected in place versus self-preserving into a common performance group) and establish corresponding building performance indicators and associated tolerable levels of impact.

The performance levels and tolerable impacts are set using a combination of policy-level analysis of risk acceptability (coming from the risk characterization, stakeholder consultation, etc) and technically and scientifically based criteria (just because a criterion can be scientifically established, such as determining that a person can survive under a hot gas layer of 100 °C for 60 seconds, does not mean that that criterion is necessarily politically or socially acceptable, and needs to be vetted through a policy activity).

Various challenges with identifying and selecting scientifically and socially acceptable criteria for life safety have been address by previous speakers, including the fact that there is no one common source of acceptance criteria that is universally referenced. For example, consider the criterion of clear height between a descending smoke layer and the floor level of egress. A quick review of four different documents (guidance documents, codes and standards) reveals four different values: 2.50m (BS7974), 2.00m (BCA), 1.83m (SFPE Design Guide), and 1.80m (BSL). In the two cases where the value is in the building regulation, the "right" value to apply is clear. In the case where a building regulation leaves the decision to the engineer, what is the "right" value to use? To avoid this problem, the building regulation needs to be clear.

The next step is to define the magnitudes of design-basis fires (fire loads, fire scenarios) to be used in the regulation. In concept, this should be possible in much the same manner as structural or seismic loads are defined for buildings (deterministically or stochastically). It is a bit more difficult, however, because the magnitude of fire in a building is related to the fuel, building, fire protection systems and occupants. This often leads to a scenario-based approach rather than load-based approach (NFPA 101 and NFPA 5000 have defined 8 design fire scenarios which must be applied, for example). However, this approach is typically qualitative, relying on the engineer to establish the actual design fire curves. For the purpose of regulation, and to provide consistency across building design, it would be preferred to quantitatively specify design fire loads (deterministically or stochastically).

Finally, as discussed by Prof. Schneider, uncertainty and variability must be identified and addressed – in the regulatory development process as well as fire safety engineering. At a minimum, sensitivity analysis should be conducted, wherein parameters are varied one at a time to look for critical variations, especially those that might make a 'safe' outcome an 'unsafe' outcome, and the analysis is then used to focus in on parameters of concern.

In conclusion, Dr. Meacham suggested that the basic approach currently used for performance objectives in building regulations is 'ok' as a starting point, but that more consistency and predictability can be gained by undertaking risk characterization, establishing risk/performance levels, characterizing tolerable impacts and fire events (loads, scenarios), select performance criteria (from existing sources), test the combinations, and incorporate appropriate loads and criteria into the regulations. Design fire scenarios in regulation should reflect realistic challenges to buildings, taking into consideration that contents, arrangement and ventilation can vary, and that system reliability is not 100%. Selection of performance criteria should be based on accurate reflection of current knowledge, accounting for uncertainty. In the end, specification of design fire scenarios (loads) and criteria does not limit innovation, but provides better understanding of performance being delivered (at least as designed), and such an approach is needed to account for risk, cost, uncertainty and variability in a defensible manner.

Brian Meacham (II)

In addition to getting a sense of the critical issues associated with performance criteria for safety in case of fire, a key focus of the workshop was to gain an understanding of how various countries were moving towards incorporation of fire criteria into performance-based building regulation. In his second presentation of the workshop, Dr. Brian Meacham provided some insight into activities in the United States, New Zealand and Australia in this regard.

The **United States** does not have a national building regulatory system. The decision to regulate building design and construction falls under the jurisdiction of the states, which may choose to allow municipalities to establish local regulations as well. To help provide some commonality between state and local building regulations, a number of private-sector model code development organizations were formed in the early 1900s. By the late 1900s, however, the groups consolidated into two organizations: the National Fire Protection Association (NFPA) and the International Code Council (ICC). The NFPA produces one model building code, NFPA 5000, *Building Construction and Safety Code* (NFPA 5000). NFPA 5000 is a predominantly prescriptive building code. However, it includes a performance-based option, which has its roots in the performance option to NFPA 101, the *Life Safety Code®* (NFPA 101). The ICC produces the International Building Code (IBC), a prescriptive-based model building code, and the ICC Performance Code (ICCPC), a performance-based model building code. The most widely adopted code in the United States is the IBC. The ICCPC and the performance option in the NFPA 5000 are used primarily in an 'administrative' manner, where the performance framework is used as a guide but is not enforced by law. The performance approach in NFPA 5000 and the ICCPC are quite different, so an overview of each was provided.

In brief, the performance option in NFPA 5000 allows one to undertake performance-based analysis and design as an alternative to complying with the traditional, prescriptive code requirements. It does this by providing a set of objectives that must be met, along with eight fire design scenarios that must be used to test the design alternative with respect to meeting the objective:

1. Typical occupancy-specific fire. Must explicitly state: occupant activities, number and location of occupants, room size, furnishings and contents, fuel properties and ignition source, ventilation conditions, and first item ignited and its location.
2. Ultra-fast developing fire in primary means of egress, with interior doors open at the start of the fire.
3. Fire starts in unoccupied room, can endanger large number of occupants in a large room or other area.
4. Fire originates in concealed wall or ceiling space adjacent to a large, occupied room.
5. Slow developing fire, shielded from fire protection systems, in close proximity to high occupancy area.
6. Most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building.
7. Outside exposure fire.
8. Fire originating in ordinary combustibles in room or area with each passive or active fire protection system or feature independently rendered ineffective. (Not required for fire protection systems for which both the level of reliability and the design performance in the absence of the system or feature are acceptable to the authority having jurisdiction.)

In practice, a fire protection engineer applies one of the generally accepted fire safety engineering frameworks (those published by the SFPE, IRCC (IFEG), ISO, and BSI being prevalent) to the building of concern, and as discussed by Schneider, Karlsson and others, identifies design fires and acceptance criteria, and evaluates fire performance against the fires and criteria. The most significant difference between using this 'standard' FSE approach in conjunction with NFPA 5000, as compared with other building codes, is that the engineer must use the specified scenarios. Although use of the define scenarios provides more consistency in application from one building to another, the fact that acceptance criteria are not specified and are still selected by the engineer continues to result in variability.

The approached taken by the ICC in development of the ICCPC was different. Instead of defining specific scenarios, they adopted an approach used in the seismic engineering arena, which focuses on grouping buildings by 'importance level' and defining performance targets under different magnitudes of events. The ICC expanded the focus beyond importance levels to also include aspects related to the hazards of concern, the risk to occupants and property, and social and community welfare. A risk characterization process was applied to guide categorization of building uses into performance groups, to establish performance objectives, and to characterize events of concern and their magnitude. These factors are discussed in the attached paper, but the relationship is illustrated in the diagram below.

		INCREASING LEVEL OF BUILDING PERFORMANCE →→→→→→→→ → →→→→→→ **PERFORMANCE GROUPS**			
		PG I	**PG II**	**PG III**	**PG IV**
MAGNITUDE OF EVENT INCREASING MAGNITUDE OF EVENT ↑↑↑↑↑↑	VERY LARGE (Very Rare)	SEVERE	SEVERE	HIGH	MODERATE
	LARGE (Rare)	SEVERE	HIGH	MODERATE	MILD
	MEDIUM (Less Frequent)	HIGH	MODERATE	MILD	MILD
	SMALL (Frequent)	MODERATE	MILD	MILD	MILD

Briefly, buildings with common risk characteristics, importance factors and expected performance are categorized by performance groups. For any given event magnitude, such as LARGE, the expected impact on the facility changes by performance group (PG): *SEVERE* impact for PG I (low risk to life / importance), *HIGH* for PG II, *MODERATE* for PG III, and *MILD* for PG IV (important buildings). Those familiar with seismic design guidance in the USA and New Zealand, among others, will be familiar with this approach.

Although **New Zealand** was one of the first countries to promulgate a performance-based building code (1992), the code had few quantitative performance criteria. As result, most decisions regarding criteria were left to engineers. Although many reference standards and guidelines included criteria which the engineers could apply, use of those criteria was not guaranteed because it was not required by the code. Over time, this led to numerous issues, including concerns over consistency in performance delivered in the built environment. In the early 2000s, the situation became more complicated as a large number of buildings were observed to have moisture-related failures.

Details of the moisture-related problems can be found elsewhere (including in the appended paper by Meacham). However, a significant outcome of the public scrutiny resulting from the problems was that the Building Industry Authority, which had responsibility for the Building Code, was abolished, and a new government department, the Department of Building and Housing (DBH) was established. Some of the very first charges for the DBH included crafting language for revisions to the Building Act, addressing requirements for licensed practitioners, and undertaking a review of the building code. As part of the review of the building code, DBH had an objective to better quantify performance, and there was a desire to consider risk as a basis for performance quantification. Outcomes regarding use of risk as a basis for performance included:

- It is possible to establish risk-based criteria, in terms of annual expected risk to life (or other measures). This is done in various countries, such as the UK (HSE) and the Netherlands. Depending on political will, stakeholder agreement on data, and time to conduct analysis, level(s) of acceptable fire risk can be established.
- The concept of performance levels (importance levels) for fire is suggested. It is further suggested that these follow the seismic importance levels. Certain values may need to be adjusted (such as occupant population numbers), but the concept is useful in identifying the performance expectations for buildings.
- A key difference between the seismic / structural approach and fire is that currently the system lacks a good set of representative fire loads (either strictly deterministic, probabilistic, or in combination). Some potential approaches to codifying design fire loads are suggested, but it will require research and development to actually quantify any such design fire loads before they should be adopted into the Code.
- At the specific performance requirement level, it is possible to develop specific criteria in terms of such factors as temperature, radiant heat flux, species concentrations, and the like. It is even possible to create distributions around values, if one accepts subjective approaches to probability quantification.
- Although criteria can be quantified, the selection of detailed criteria is very closely coupled with verification methods (and data availability). As such, it is not recommended to place specific criteria in the Code without simultaneously defining the related verification methods. (Also, fixing criteria could in some cases limit innovation.)

Based on these findings, DBH staff established working groups to investigate application of the risk-informed performance-based approach to the Building Code of New Zealand. A recent DBH internal discussion report suggests that the risk-informed performance framework has provided a very good basis for developing rational design for structure and fire, and provides guidance for other areas as well. These concepts were published for public consultation in a May 2007. Specific to fire, the Fire Working Group is in the process of testing a framework which merges concepts from the NFPA (scenarios), ICC (tolerable impacts, performance groups and impact levels), and design guidelines (performance criteria). The target outcome is to define performance groups, impact levels, design scenarios, design fires, and acceptance criteria for incorporation into the building code.

At about the same time as the building code review was being conducted in New Zealand there were reviews of the building regulatory system in **Australia** as well. Although the Building Code of Australia (BCA) is performance-based, much like in New Zealand there are few performance criteria in the code. Following on issues raised in New Zealand with 'leaky buildings' and quantification of performance, as well as the Campbell report on Quality in Buildings, which identified some quality problems in buildings in New South Wales, and the Productivity Commission review and report on Reform of Building Regulation, it was decided that performance should be better quantified in the BCA. As a result, a protocol for quantifying performance in the BCA was developed, and ABCB staff has been using the protocol, internally developed performance assessment sheets, and a well-defined process to identify performance requirements and performance measures. (Some of the principles which went into the protocol are outlined in the paper in the appendices.)

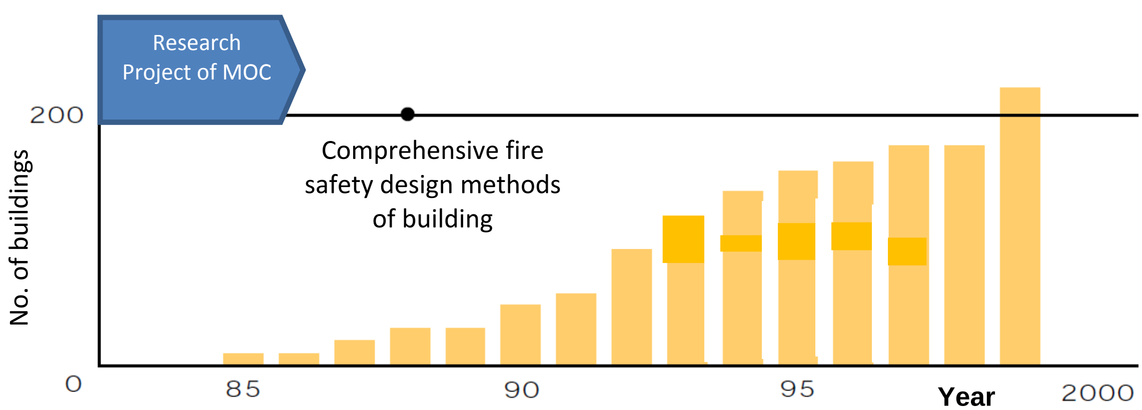
Following the development of the protocol, an effort was undertaken to outline a process for quantifying fire and life safety performance in the BCA. Initially, the intent was to consider a quantitative risk approach. However, given that a quantitative risk approach would most likely require some period of time for stakeholders to embrace, it was suggested that it would be better to have more of a focus on fire scenarios, criteria and verification methods than on a quantitative risk assessment approach to identifying fire safety objectives. This resulted in the following process – very much similar to the approach being taken in New Zealand:

- Analyze the existing fire loss data to understand better the types of fires that have been experienced, the response to those fires, and the resultant risk tolerance levels,
- Apply risk characterization techniques, using the available fire loss statistics, variations in building configuration allowed by the BCA, and stakeholder input, to gain an understanding of the perceived fire performance and risk with code-compliant buildings, and develop a risk ranking / indexing scheme for building classes and configurations,
- Develop representative design fire loads / scenarios, and fire and life safety performance (acceptance, design) criteria, which reflect realistic fire performance in code-compliant buildings and are informed by the fire loss statistics, other pertinent fire and life safety data, and risk characterization outcomes (b), along with acceptable evaluation / verification methods, to evaluate the performance of code-compliant buildings,
- Evaluate the performance of code-compliant buildings using fire loads (scenarios), performance criteria and methods (as per (c) above) in comparison to the risk levels identified in (b) using an ASET/RSET approach, and
- Develop recommendations for changes to risk levels / classifications of buildings (if needed), develop recommendations for fire scenarios, criteria and verification methods which can adequately assess building fire performance within the risk levels, and develop recommendations related to what aspects of fire scenarios, criteria and verification methods should go into the IFEG and which can be brought up into the BCA.

A key aspect to the fire quantification processes in Australia and New Zealand is a focus on sensitivity analyses to gain a better understanding of the parameters that have a significant impact on fire and life safety analysis, and the subsequent treatment of key source of uncertainty and variability in a manner that is conducive to building regulation as well as fire safety design.

Mamoru Kohno

The next perspective was provided by Dr. Mamoru Kohno, who provided an overview of the situation with respect to fire safety criteria in Japan. Until the early 1980s, the Building Standards Law (BSL) was prescriptive only. From the late 1980s until 2000, there was a provision in BSL Article 38, Chapter 2, which exempted strict compliance with stated structural safety and fire safety provisions if the Minister (through the Ministry) confirms that the 'effect' of an alternative solution is equal to or better than prescriptive solutions. The enactment of that provision in part resulted from a Ministry of Construction research project, "comprehensive fire safety design methods of building," which was carried out from 1982-1987. This effort significantly enhanced the use of fire safety engineering (FSE), and as a result, many buildings which utilized new materials, construction methods, and fire safety equipment were approved and constructed. This is illustrated in the figure below.



However, the changes to the BSL did not include clear performance criteria, and with approval required from the Minister, application was practically limited to large building projects. In the mid 1990s, another project was undertaken which aimed to provide sufficient information and guidance to allow a third option: an alternative route for demonstrating compliance for some fire and life safety provisions. This effort resulted in the introduction of performance-based provisions in the BSL in the 2000 revision. Although most of the prescriptive provisions remained unchanged, there were significant new additions related to the alternate route.

Under the 2000 revisions, performance verification methods are specified in the BSL as 'alternative route' for some prescriptive provisions. Specifically these include the fire resistance verification method (FRVM), evacuation safety verification method (ESVM), and fire compartment verification method (FCVM). Under this structure there are two options: compliance with the prescriptive provisions or demonstration of compliance via the specified verification methods. For example, a fire-resistive building can be either an assembly of prescriptive constructions or a building verified by the FRVM. For life safety, some of the evacuation-related prescriptive provisions are exempted if the fire safety of a story or a building is verified by the ESVM. When the verification method option is used, either a building official or a designated confirmation body can issue 'confirmation' that the building has been verified by the prescriptive verification methods.

With the verification method approach, not all performance requirements are specified explicitly. Instead, calculation methods are prescribed within the verification methods. For example, with the FRVM, calculation methods are provided for duration of fire in a room and for the required fire resistance time of columns, walls, beams, floor, etc., against the fire, and the fire duration must be shown to be less than the retained fire resistance time for all principal building parts. With respect to ESVM, calculation methods are provided for the time required for all occupants in a room to complete evacuation, and the time required for gas or smoke produced by a fire to descend to a level detrimental for evacuation (1.8 m), and it must be shown that the evacuation time is less than the smoke descend time for all habitable rooms (ASET/RSET).

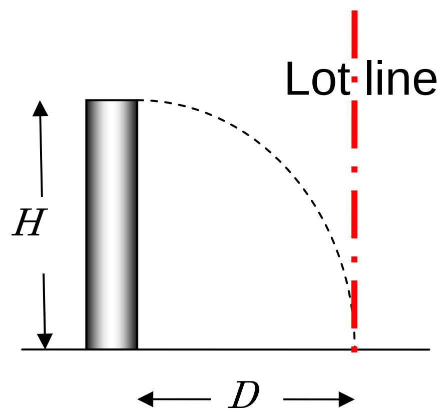
If someone desires to use something different than the prescriptive methods (FRVM or ESVM), an alternate route is possible using a fire and smoke simulation program (e.g., BRI-2000) and/or verification by an physical experiment. If this route is selected, ministerial approval is necessary (as was the case prior to 2000). This approach is called 'Route-C' (the performance approach by prescriptive verification methods being 'Route-B' and compliance with prescriptive provisions being 'Route-A'). It should be noted, however, that an 'alternative method' is not equal to an 'alternative solution,' in the current BSL framework, and that the scope of performance verification is limited to fire-resistance or evacuation safety (the two cannot be combined).

Even with the incorporation of verification methods and an alternate approach (routes C and B), Dr. Kohno noted that there were still some questions being raised. For example, a 3-story office building in quasi-fire preventive district can be quasi-fire-resistive building, but if the owner would like to make it a 4-story building, it must be a fire-resistive building. Likewise, a 3-story school is designated a 'special building' in the BSL and must be fire-resistive irrespective to its location, redundant evacuation measures, or neighboring conditions. With no clear rationale as to 'why' these buildings are designated so, or what triggers an increase in protection, there is interest in taking the performance-based approach another step further.

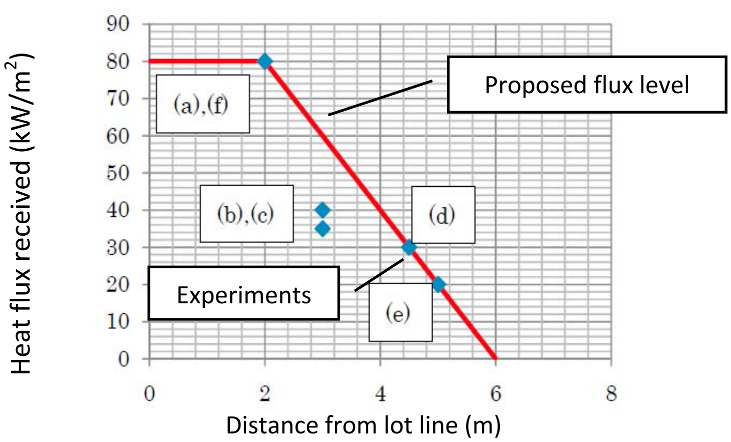
The second phase in the development of performance-based fire provisions involves reformulation of the current, semi-performance-based provisions around five fire safety objectives: F1, protection of life safety, F2, prevention of damage to neighboring buildings, F3, prevention of frequent ignition, F4, prevention of ignition from neighboring fire in urban area, and F5, support for emergency responders. It is intended that risk-based considerations will be included to some extent, and that revision of BSL is scheduled in 2 years.

The life safety objective, F1, aims to enable full evacuation of occupants to a safe place away from the building. This applies to self evacuation for most buildings and assisted-evacuation in buildings such as hospitals and aged-care facilities. It also aims to facilitate rescue activities for occupants such as elderly, the handicapped or those who for other reasons are unable to evacuate. To meet this objective, evacuation routes and structural stability must be appropriately maintained during evacuation and rescue activity. The F1 provision will include performance criteria in the form of ASET/RSET, where evacuation time must be less that time to untenable conditions, measured in smoke layer height above floor level, temperature or radiant heat flux. Additional criteria will include evacuation time being less than the structural stability limit, and rescue time being less that fire resistance rating of the compartment and structural stability limit. It is expected that there will be new verification methods to go along with the new objectives and criteria. It is also expected that research is needed to further support some areas, such as rescue time, issues associated with evacuation of people with disabilities, and structural stability of various construction assemblies, especially those with combustible components.

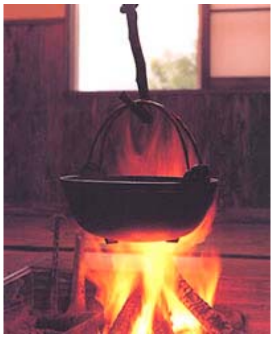
Regarding objective F2, damage to neighboring buildings, the aim is that a building should be constructed such that it does not damage the neighboring buildings by collapse, radiation, or fire brands as a result of its fire. In this case, criteria have been established related to the height of the building (H) and the distance to the property boundary (lot line), (D). As currently drafted, if H is greater than D, then collapse of building is not allowed until the end of the fire. This is under review, as some are concerned that this may be too restrictive. If $H_p > 4D^2$, then no part at height H_p should fall down until end of fire.



Criteria for objective F2 also include radiant heat flux levels related to the potential for igniting adjacent buildings. These are given in two forms: (1) the radiant flux received by a virtual adjacent building must be less than 12.5 kW/m^2 (where the adjacent building is at least 5 m from the lot line, and (2) the cumulative radiation, I^2t, received by a virtual adjacent building, must be less than 6.37x10^6 (kW)^{2}m^{-4}s. In the case of (1), there is a value for occupancy-dependent constant radiation from unprotected openings (108.4 kW/m^2 - similar to criteria in the National Building Code of Canada, Building Regulations for England and Wales, New Zealand Building Code, and NFPA 80A). For (2), estimation requires integration over fire duration, the adjacent building to be at the same distance from the lot line, and the radiation calculated from fire temperature, with a limiting value from cumulative radiation by a 30 minute standard fire.



For objective F4, ignition by urban fire, the focus is on ignition by radiant heat flux, but there are no specific criteria for ignition. Rather, there is a relationship between distance and construction type (longer distance required for less fire-resistive construction). Objective F4 is required only for buildings in urban areas.



Objective F3, prevention of frequent ignition, is targeted at common heat sources such as ovens, stoves and boilers. The criteria relate to no ignition of building materials by the heat from the source. Objective F5, support for emergency responders, has been difficult given that quantitative data in this area are limited.

In summary, Dr. Kohno noted that Japan has more than 20 years of fire safety engineering experience in regulatory framework, and that the performance-based approach has been increasingly used following the 2000 BSL revision, especially for evacuation safety verification. With this increase in performance-based approaches, it has been determined that more guidance is needed, and so a more rational, performance-based and risk consistent fire regulation is under development.

Jukka Hietaniemi

From Japan the focus shifted to Finland, where Mr. Jukka Hietaniemi provided and overview of the development and use of fire safety engineering (FSE) and associated criteria in Finland, as well as some insight into how FSE is being looked to in some eastern European countries. To set the context for his presentation, Mr. Hietaniemi suggested that there are three challenges to FSE: defining the input for analysis, gaining acceptance of the analysis, and assuring the management of the building fire safety measures over the life of the building. The fire is problematic because of the stochastic nature of fire, making it difficult to select 'design fires' outside of a probabilistic framework. Sensitivity analyses, he suggested, are meaningless if probabilities are not taken into account. The issue of acceptance echoed many of the points raised earlier by Lundin – how does one determine if the building design is safe, or perhaps more appropriately, safe enough. As discussed by Lundin, Meacham and others, there will be some risk, but how much (or how little) is part of the question. This carries over into the building management aspect as well: a design is only as good as the boundary of the design and the expectations for operation of safety features, material control, occupant characteristics and the like.

Although others had raised some concerns with computational tools for use in FSE, Mr. Hietaniemi suggested that the tools are not a major part of the problem: as compared to the data that we have, the tools for predicting fire effects, evacuation and structural performance simulation are sufficient. In other words, if we have the design fire figured out properly, its consequences can be predicted with sufficient precision and accuracy in FSE design. He notes that there is need for further developments, with the hope that someday we will have a fire simulator that can actually predict fire growth and spread merely on the basis of the physical properties and layout of the fire load and fire room. If we had such a tool, then the problems associated with input data will practically disappear. His guess, however, is that none of us will live to see such a tool.

With or without such a tool, critical issues that require focus include how to determine whether the design solution is 'safe enough' and how to address this question with suitable criteria and safety margins. For example, Mr. Hietaniemi referenced a situation in Finland where in town A, a design was accepted where RSET was 5 minutes and 50 seconds, and ASET was determined to be 6 minutes and 10 seconds (quite close!), yet in town B, a design was rejected where RSET was about 5 minutes and ASET was estimated are about 10 minutes – on the surface a much more conservative design. This type of situation can occur in part due to lack of education and agreed standards. Since 1997, prescriptive and FSE-based fire design options have equal legal basis in Finland. As a result, FSE design is applied increasingly in major building projects. However, with no properly established education, demand for FSE design continuously exceeds the supply, and without standards, design and approval consistency is quite variable.

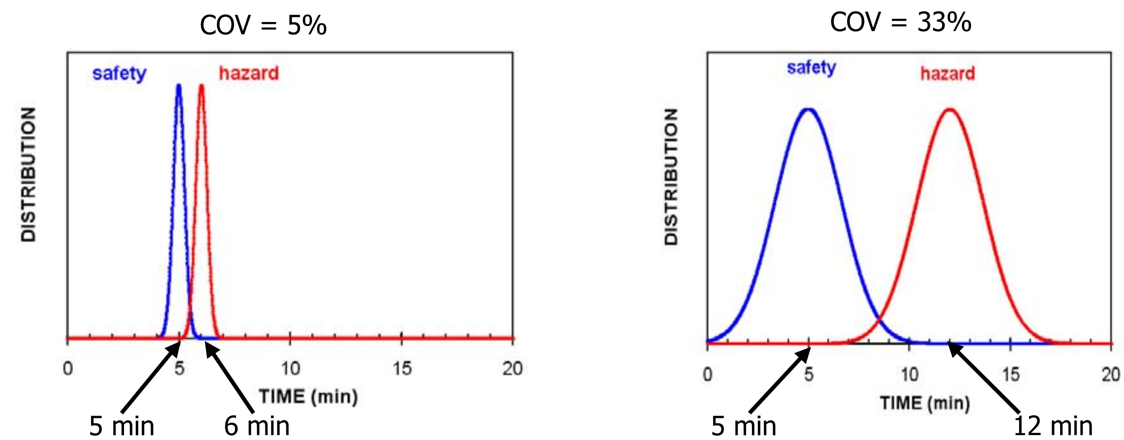
The situation is a bit different in Finland's neighboring countries. In Estonia, the fire regulations are basically similar to those in Finland, i.e., there are no restrictions to FSE-based fire designs. However, the use of FSE design is rare, as there is an almost complete void of properly educated designers and authorities. In Latvia and Lithuania the fire regulations are basically those in force in the former Soviet Union. However, these countries are EU members and as such should adopt the Eurocodes, which treat nominal and FSE-based thermal actions on equals basis. In concept this should in open the way to structural FSE, and as evacuation safety design is simpler and more reliable than structural FSE, there should be potential for life-safety FSE. However, with the lack of education and qualified practitioners, and limited use of Eurocodes, this is not happening.

The fire regulations in Russia are the same as in the former Soviet Union, where potential acceptance of FSE designs is based on certification of the fire consultant (as a point of reference, there is one certified consultant in Finland). Undoubtedly, opening up the Russian markets for FSE is major task, which would be greatly facilitated if the international FSE community would have similar, well- established and quantitative rules for FSE application and acceptance. Overall, the Eastern European countries constitute a major potential new market area for FSE consultancies. It can be estimated than merely through renovation and retrofitting building markets are tens of milliards of Euros. In order to open these markets, however, Mr. Hietaniemi suggests we need internationally agreed, quantitative rules for use of FSE, especially rules for the approval of FSE designs.

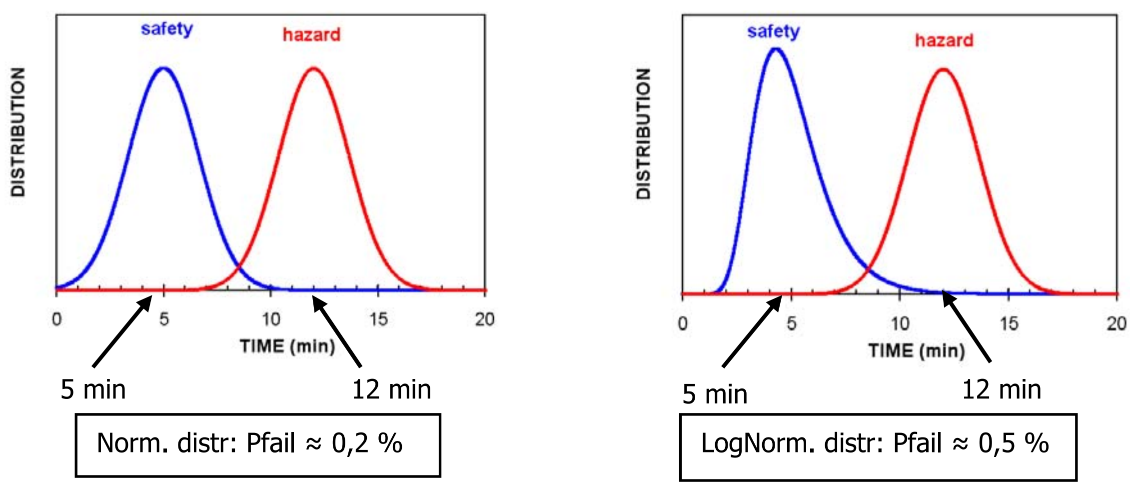
As part of the FSE approvals approach, a key factor is that the entire process must be justified – data, analysis, synthesis, assumptions, limitations and boundary conditions – there is no room for guesswork. Although many parts of the system are in place, the criteria, and the way we handle them, needs much more attention. In particular, how safety factors are addressed is critical. This paralleled earlier comments by Schneider, Meacham and others. In Finland at the present, criteria are the same NKB-based rules as Sweden, i.e., gas layer temperature of 100 °C, radiant heat flux of 1 kW/m^2, smoke layer above floor of 1.6 m + 10%×H, and so forth. The challenge is that these may be okay – or not – we do not know for certain due to variability in the population. Because of the variability, the problem with the use of these criteria is mainly in the safety factors that should be applied. To address this, a project has been started to check the basis of the numerical acceptance criteria.

Coordinated and executed by VTT, this is a major national endeavor involving all relevant authorities, including the Ministry of the Interior (FBs and active fire safety systems), Ministry of the Environment (fire regulations, structural fire safety), all Finnish rescue services, building authorities of the largest cities, and the insurance sector. The focus of the project is to look at where the criteria have emerged from and what is data behind them, to verify their validity - and if necessary amend the values, to establish the uncertainties involved in these criteria, and to establish uncertainties involved in results of fire simulation and evacuation calculations (including skewness of distributions). The outcome is expected to be validated quantitative acceptance criteria with quantitative rules of applicable safety factors.

Hietaniemi noted that addressing the uncertainty is important because when we know the load (hazard) and resistance (safety) with good accuracy, a small safety margin may be suitable. However, if there is large uncertainty in either value, a large safety margin is needed to assure the target level of safety is achieved. This is illustrated below.



In addition, the shape of the distributions is also important, because if distributions are skewed towards the "dangerous direction," the required safety margins also increase.



In addressing the criteria and safety margins, an issue that cannot be avoided is that of the acceptable/tolerable level of risk. In the end, the safety margins depend completely on the risk level applied, the hardest task in the project is that regulators need to establish quantifiable minimum tolerable risk levels. As discussed earlier in the workshop (as well as in the IRCC Workshop on Use of Risk in Regulation, November 2006), a key issue is how to get a politician to admit (in public forum) that there is no such thing as zero risk? In Finland, VTT aims to help the authorities by establishing the present risk levels of the most important bldg types where FSE is applied, e.g., shopping centers, large offices, etc., through massive computational analyses. It will be interesting to see how this will be received in the end.

In closing, Mr. Hietaniemi reiterated that there are two major problems in application of FSE design: 1) input data and 2) acceptance criteria. With respect to acceptance criteria there are two components: quantitative expression of physical conditions that are considered to cause unwanted consequences, and quantitative rules of relevant safety margins. At present, Finland is carrying out a major project in which an attempt is made to solve the problems related to acceptance criteria, or at least establish rules that will written to guidance supporting the fire regulations (hence giving the rules authoritative status and make them the practice applied throughout the country). Finally, for FSE design to survive and become a well-established engineering branch equal to other branches of engineering (e.g. structural or electrical), we need acceptance criteria/rules that are agreed upon unanimously by the international FSE community.

Paul Stollard

The final country perspective was provided by Dr. Paul Stollard, who presented an overview of the Scottish building standards system and the manner in which fire criteria are addressed. Within the Scottish system, there is a combination of the Building Standards, which are functional standards, technical handbooks, which provide for prescriptive and performance approaches, and alternative solutions.

Dr. Stollard noted that requirements for fire safety are addressed in Section 2 of the Building Standards through fifteen functional standards, along with two handbooks: domestic and non-domestic buildings. If one chooses to take a fire safety engineering (FSE) approach, either the British Standards (7974 series) or the International Fire Engineering Guidelines (IFEG) can be used. As discussed earlier in the workshop, both the BSI and IFEG approach provide a process for engineers to follow, which includes assessment of risk and hazard, development of fire scenarios, selection of performance criteria, and evaluating the scenarios using a variety of fire safety strategies (e.g., fuel control, passive protection, active protection, means of escape, etc). A review undertake for the Scottish Building Standards Agency, which compared the BSI and IFEG approaches, found them similar enough in scope that either could be used, resulting in both being identified as alternative solutions.

At present there are no quantitative performance criteria for fire in the standards. The functional requirements are specified, but as is the case in several other countries, selection of appropriate criteria is currently a decision primarily of the engineer. For example, clause 2.9 on Escape reads, "Every building must be designed and constructed in such a way that in the event of an outbreak of fire within the building, the occupants, once alerted to the outbreak of the fire, are provided with the opportunity to escape from the building, before being affected by fire or smoke." Following one of the alternative solutions, the fire safety engineer would review the building, its configuration, contents and occupants, and develop a fire safety strategy that provides the target function in a fire situation.

Dr. Stollard pointed out that, as in several other countries, the fire and life safety requirements are periodically reviewed. One are currently being reviewed is escape, with the aim to restructure the requirements from first principles. The review will start with escape requirements in homes and flats, but will be extended to non-domestic buildings as well. Within homes, the major areas of focus are escape from the room of fire origin and escape from the house.

Discussion, Observations and Summary

Surprisingly, although the IRCC specifically targeted speakers from a number of different countries in order to obtain a broad perspective on challenges in fire performance quantification for regulation, number of common themes were repeated throughout the workshop, including:

- The state of fire safety engineering (FSE) has advanced considerably in recent decades, and the technology exists to undertake rather good analyses of well-defined problems wherein the fire scenarios, loads, and criteria, the building, and the occupants' response can be well-bounded and agreed. However, data are lacking in key areas, such as occupant response to fire effects, and uncertainty and variability needs to be better addressed throughout the process.
- One of the major current challenges is that the target level of fire safety / risk is not quantitatively defined, which makes it difficult for the engineer and approving authority to evaluate the appropriateness of engineered fire safety designs. Without quantitative risk values, or design fires, or acceptance criteria – which adequately account for uncertainty and variability and recognize that there is no such thing as zero risk – there will continue to be difficulties in gaining agreement on suitability of designs.
- Since there are no clear metrics and few performance design standards, engineered fire safety designs typically reflect only a knowledge- and experience-based judgment of the experts that the solution which has been designed or accepted offers – from an overall point of view – the same general safety level as is implicitly given in the descriptive building regulations. However, there are no stringent guidelines which ensure that experts will in all cases make the same decisions, so the level of safety is not necessarily equal to the one which would have been achieved by applying the descriptive code.
- Furthermore, descriptive regulations can only address the majority of buildings, generalizing the level of safety level without respect to specific building circumstances. As a consequence, the resulting safety levels may be different for different buildings.
- In trying to benchmark tolerable (acceptable) levels of risk, difficulties arise from the lack of political will to set quantitative risk criteria and the lack of common and widely agreed characterizations for fire "loads" and acceptance criteria internationally. Although the current level of fire safety seems to be acceptable in most countries, it is not clear if that is a result of good design, or the fact that fire is a rare event, or the combination of these factors. To move forward there needs to be agreement as to how regulations and engineers quantitatively describe tolerable (acceptable) fire performance in terms of occupants, the building and emergency responders.

It was also interesting to note that efforts to establish risk-informed, quantified performance criteria, design fires, and verification methods (or a sub-set thereof) is underway in a number of countries, including Australia, Finland, Japan, and New Zealand, and that there is interest in other countries, including Austria, Sweden and the United States. In fact, the commonality of current efforts cries out for an international collaboration of sorts, which could help facilitate the exchange of information, concepts, research and outcomes, with the aim of helping to foster internationally-consistent fire safety engineering data, tools, methods and guidelines, as well as common fire safety acceptance criteria.

Although groups such as BSI, ISO, and SFPE have created guidance documents for fire safety engineering, there is some argument for the next advancements – specifically related to acceptance criteria – to be driven by a group such as the IRCC. The reason for this is the fact that "tolerable" or "acceptable" safety or risk is not an engineering decision; rather, it is a public policy decision, which is embodied in large part in the building regulations. Although there are many actors, including the insurance industry, building owners and developers, engineers, architects, and approval authorities, at the end of the day it is the regulations (in most countries) which embody the political and societal expectations of safety. As such, the IRCC could play a role in bridging the gap between the various stakeholder groups and helping to facilitate quantitative values which are politically acceptable, technically feasible and economically appropriate.

Participants

Invited Speakers

Dr. Arthur Eisenbeiss, Institute for Fire Prevention, Linz, Austria

Mr. Jukka Hietaniemi, VTT, Finland

Dr. Björn Karlsson, Iceland Fire Authority

Dr. Johan Lundin, WSP Fire & Risk Engineering, Malmö, Sweden

Prof. Dr. Ulrich Schneider, Technical University of Vienna, Austria

IRCC Members

Mr. Denis Bergeron, Institute for Research in Construction, National Research Council, Canada

Mr. Ron de Veer, Australian Building Codes Board, Australia (for Mr. Mike Balch)

Ms Shona Dunn, Department of Communities and Local Government, England

Ms Megumi Hata, Ministry of Land, Infrastructure, Transport and Tourism, Japan

Dr. Mamoru Kohno, National Institute for Land and Infrastructure Management, Japan

Ms Lisbet Landfald, National Office of Building Technology and Administration, Norway

Prof. Dr. Brian Meacham, Arup / Worcester Polytechnic Institute, USA

Dr. Rainer Mikulits, Austrian Institute of Construction Engineering, Austria

Mr. Richard Okawa, International Code Council, USA

Mr. Javier Serra, Ministry of Housing, Spain

Mr. Mike Stannard, Department of Building and Housing, New Zealand

Dr. Paul Stollard, Scottish Building Standards Agency, Scotland

Ms. Suzanne Townsend, Department of Building and Housing, New Zealand

Guests

Mr. Thomas Auer, Austrian Institute of Construction Engineering

Mr. Paul Everall, Local Authorities Building Control, England

Mr. Robert Jansche, Office of the Provincial Government of Styria

Dr. Vidar Stenstad, National Office of Building Technology and Administration, Norway

Mr. Franz Vogler, Office of the Provincial Government of Tyrol

Appendices

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Iceland Fire Authority

Fire Safety Engineering, state of the art

IRCC, Vienna, Oct. 2007
Dr. Björn Karlsson

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Iceland Fire Authority

Background, Björn Karlsson

- Civ Eng, Edinburgh, 1980-85
- Dept. Fire Safety Eng., Lund, 1985 – 2001
- Visiting Professor, University of Maryland 1996
- **Director, Iceland Fire Authority**
- Ass. Prof. at Dept. of Env. and Civ. Eng. University of Iceland
- Vice-chairman Association of Chartered Eng
- Chairman, Education subcommittee, IAFSS, International Association for Fire Safety Science, (www.iafss.org)
- Editorial board; Fire Technology and Journal of Performance Based Fire Codes

Fire Safety Engineering (FSE)

1. To provide a view FSE we will present a brief discussion of:
   – Fire Safety Engineering **research**
   – Fire Safety Engineering **education**
   – Fire Safety Engineering **design**

2. Iceland: A very simple path towards a performance based building code

Fire Safety Engineering (FSE)

What is a mature engineering discipline?

1. A very solid research base
2. A well defined and well known terminology
3. Educational programs established in many universities
4. An abundance of design handbooks, design tools, computer programs, to assist the designer

=> FSE is not a mature engineering discipline, but enormous progress has been made the last few decades

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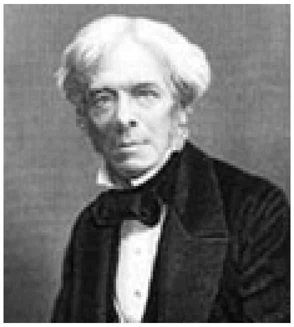
Fire Safety Engineering **research**

Michael Faraday (1791 – 1867):



- Son of a blacksmith
- Director of the Royal Institute 1825
- Was "experimentalist"
- Extremely productive, mainly work of electric nature, electro-magnetic induction, the battery, the dynamo, the electric arc (plasmas), etc
- Held yearly "Christmas Lectures" ca 1830-60

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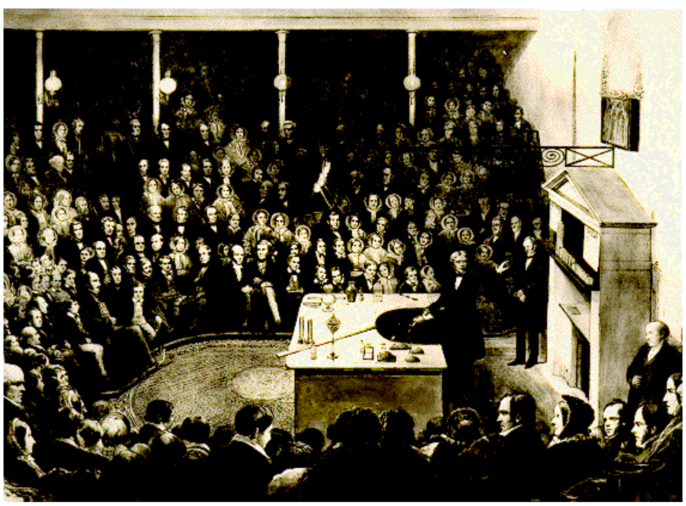
"The Chemical History of a Candle"



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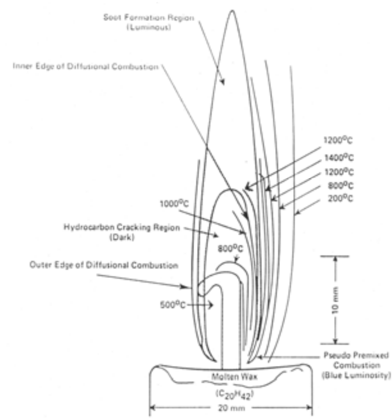
Fire Safety Engineering **research**

Michael Faraday said:

"There is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle."



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The candle and classical science

- Phase changes (solid, liquid, gas)
- Chemistry ($CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$)
- Heat of combustion ΔH_c =
- Conservation of mass
- Mass transport (various processes)
- Conservation of energy
- Energy transport (conduction, convection, radiation)
- Fluid dynamics (laminar flow, turbulent flow)
- And very much more!

=> FSE is a very multi-disciplinary field of research

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Fire Safety Engineering **research**

- **Fire Physics** — including flame spread, fire growth, compartment fires, radiative and convective heat transfer in fires, fire fluid dynamics, CFD modeling, wildfires, post-earthquake fires, explosion
- **Fire Chemistry** — ignition, smoke generation, soot, kinetics, toxicity, self-heating to ignition, heat release rate control
- **Structural Response and design** — compartmentalization, material response to fire, protection of steel, concrete and wooden components
- **Human Behavior —** human factors, response patterns, egress design, exit velocities, special needs
- **Risk Assessment, Performance based Design -** quantitative risk assessment, hazard evaluation, reliability, performance- based design, statistical analysis
- **Suppression, Detection, and Smoke Management –** detector design, suppression agents, halon replacement, smoke control, sprinkler research
- **Many other topics –** fire investigation, fire reconstruction, fire service needs, transportation fires, industrial fires

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Fire Safety Engineering **education**

- FSE either taught as
  - 1 or 2 special courses within a B.Sc Eng Program
  - 1 or 2 special courses within a M.Sc Eng Program
  - full M.Sc program on top of any B.Sc engineering degree
  - full undergraduate FSE program (B.Sc)
- Full programs taught at a number of universities around the world, best known are Lund University, University of Maryland, Worchester Polytechnic (near Boston), University of Canterbury (New Zealand), University of Edinburgh, etc, etc

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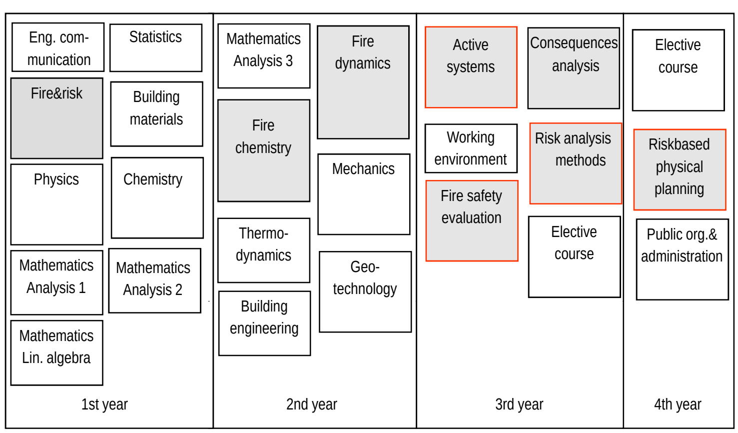
Lund University: 3.5 years to B.Sc. in FSE



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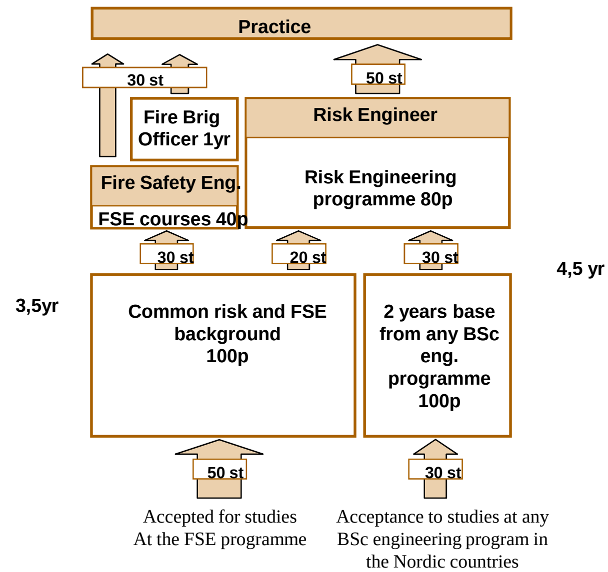
4.5 years to M.Sc in Risk Engineering



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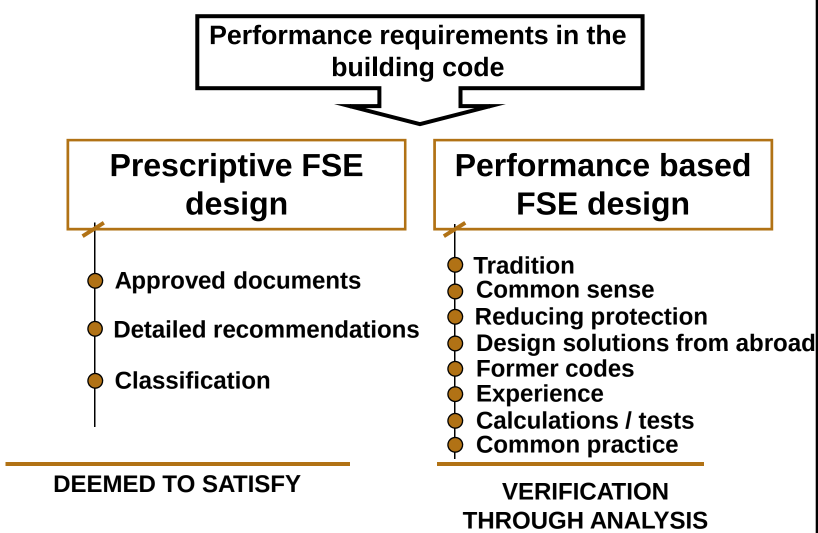
Fire Safety Engineering **design**

- Some new factors
  - Rapid development in the building industry, larger and more complex buildings, more complex technologies, design and materials
  - New building regulations based on performance requirements
  - Progress in the understanding in fire phenomena, risk concepts and human behaviour has been rapidly increasing
  - Many models available for simulating fires and simulating movement of humans

FSE Design methods



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Fire Safety Engineering **design**

- Performance based Design Guidelines and handbooks
  - ISO
  - British Standard Institute (BSI)
  - New Danish Building Regulation
  - Swedish regulation and handbooks
  - Society of Fire Protection Engineers, USA
  - Australian Fire Engineering Guidelines
  - New Zealand, South Africa, etc
- The use of new design tools, for example CFD codes (Computational Fluid Dynamics) and evacuation simulation

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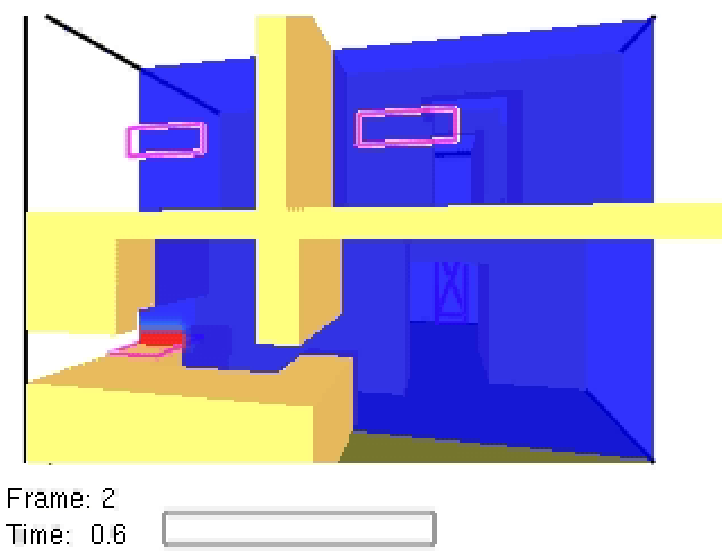
Computational Fluid Dynamics, CFD



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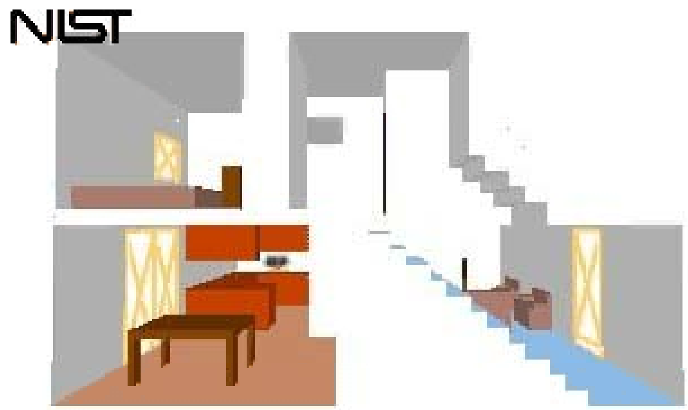

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Deflagration experiment

Fire burns in a container, dies out due to oxygen depletion, gas continues to be produced.

Door opens, new oxygen comes in, mixes with gases, spark, explosion

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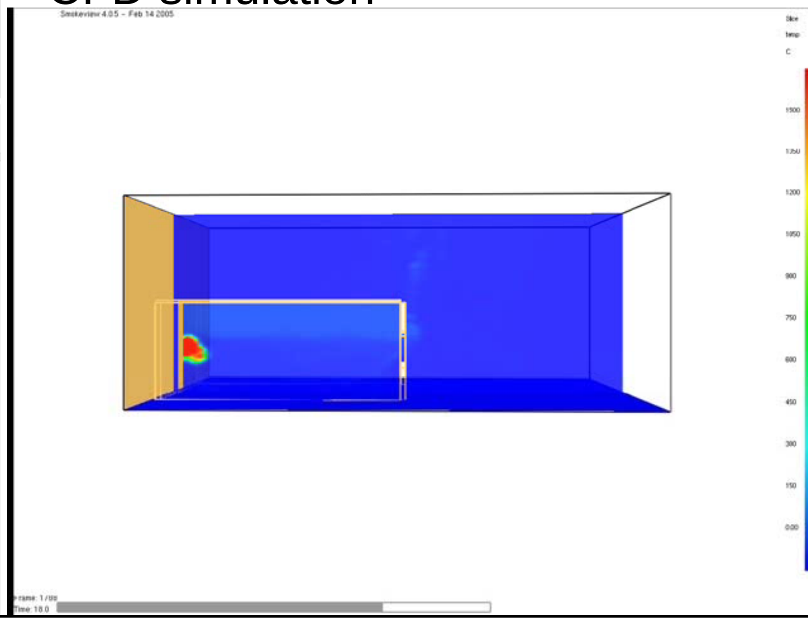
CFD simulation



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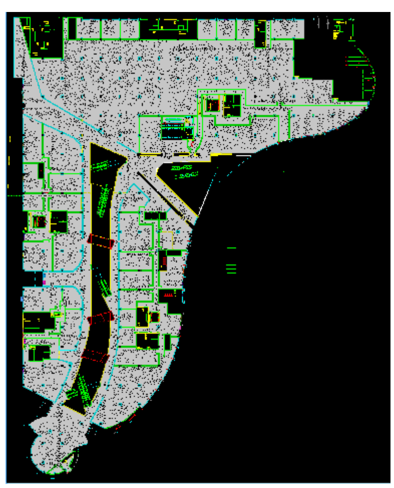
Evacuation simulation



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2. Iceland: A very simple path towards a performance based building code

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Iceland: A very simple path towards a performance based building code

- Iceland has a very small population (300.000 inhabitants)
- We do not have the resources to go through a lengthy and costly revision of the building code
- However, progress in the building sector, increased complexity of construction, is exactly the same as everywhere else
- We have exactly the same demands from architects etc to provide a flexible, performance based building code
- Iceland opted for a very simple way of turning a prescriptive code to a performance based code

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Iceland: A very simple path towards a performance based building code

- A simple revision of the building code was conducted
- Descriptions of fundamental criteria for structural safety, fire safety, etc, were added at the beginning of the code
- Description of performance criteria were added as a paragraph at the top of each chapter of the code
- Prescriptive rules were kept unchanged
- A final paragraph was added to each chapter, stating that other soulutions were allowed, if performance criteria are fulfilled

Brunamálastofnun

Iceland Fire Authority

Conclusions

- Building industry is changing fast, larger and more complex buildings, more complex technologies, design and materials
- FSE is rapidly becoming an acknowleged area of engineering
- University degree courses are established in an increasing number of countries
- Great advances have been made in Fire simulations and Escape simulations
- Most important limitations are lack of education and slow overall technology transfer
- Prescriptive codes can be changed to Performance based codes in a simple way, probelm may still be lack of education and experience with designers and code officials

Performance Requirements and Acceptance Criteria for Safety in Case of Fire

some aspects of

"Presentation of the problem"

Johan Lundin, Ph.D.
WSP Fire and Risk Engineering

IRCC Workshop, 10 October 2007, Vienna, Austria.

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The basic problem

We want to supply the opportunity to achieve the potential benefits of fire safety engineering with a *reasonable effort* in terms of writing regulations and exercising verification, and at the same time achieve an *acceptable level of safety** with limited variation within a class of buildings.

* not be worse off with regards to fire safety compared to when deemed to satisfy solutions are used.

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Performance-requirements (basic concept)

- The task is to define rules for the *safety output* required by the system, in this case the building and its fire protection measures. The rules may express the acceptable risk explicitly, or indirectly by expressing the attributes or functions of a system directly connected to safety.

... i.e. a clear set of performance requirements

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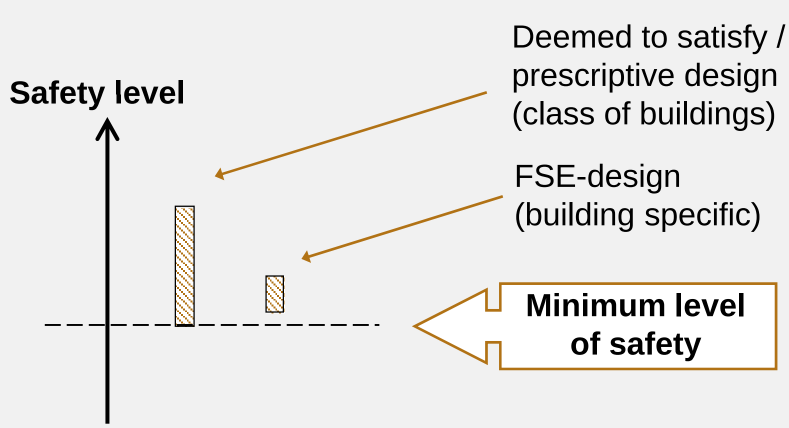
The general idea with regards to safety



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Visualisation of performance-based design

Safety in Case of Fire

- Functional objectives
  – Structural
  – Occupants
  – Rescue service
  – Internal and external fire spread
  – Property (?)

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One problem seldom comes alone …

- Which attributes are used to define safety?
  – function,
  – human action/performance,
  – complexity of the fire safety strategy,
  – complexity of the fire protection system,
  – flexibility,
  – sensitivity,
  – reliability,
  – Vulnerability,
  – Etc.

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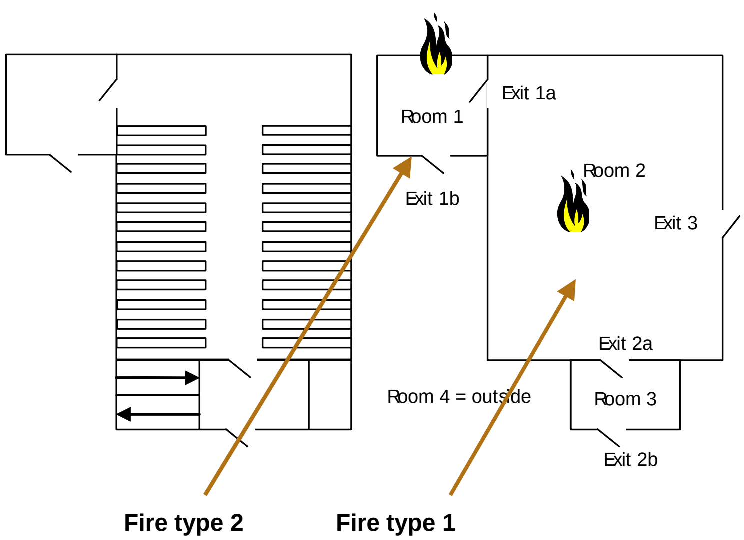
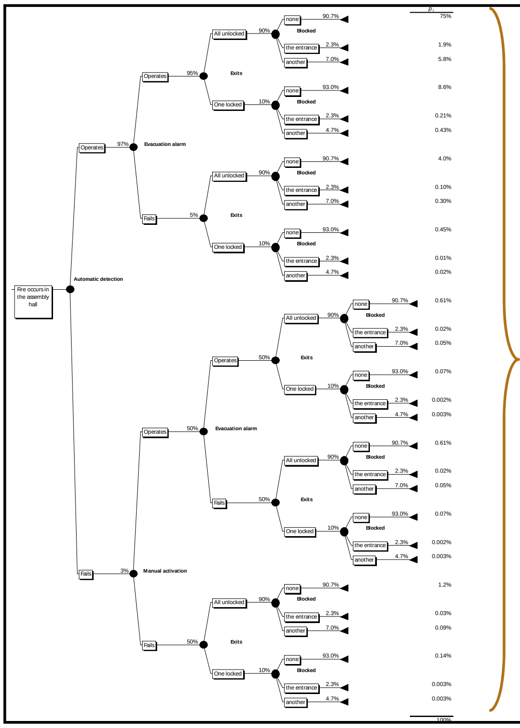
One problem seldom comes alone …

- How to determine the required level of performance?
  - through political decisions,
  - based on accident investigations,
  - founded on levels from other areas or applications, or
  - derived from the existing implicit level.

A class of buildings (assembly halls)



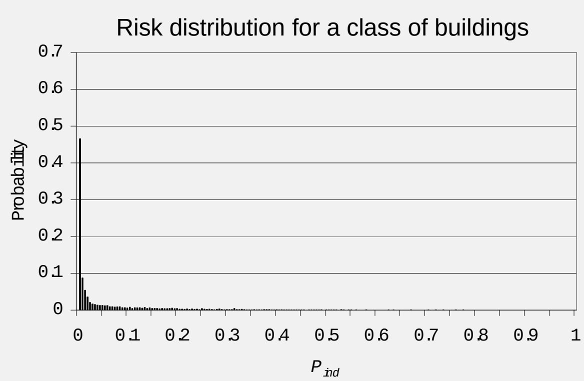


The mean risk

The individual risk

The risk exposure of the most vulnerable individual

Example of results (prescriptive design)



One problem seldom comes alone …

- How to pick a reference building?

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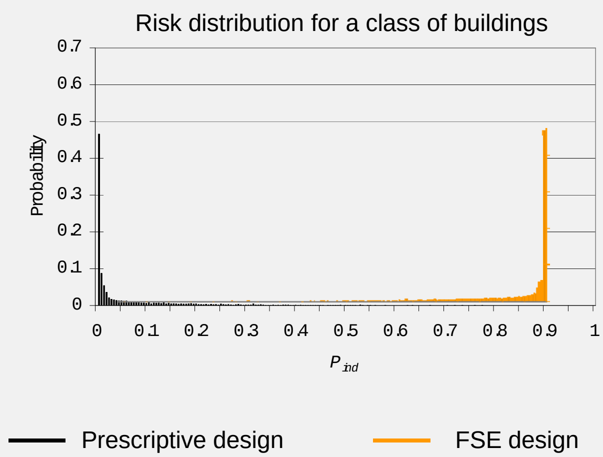
Potential problem



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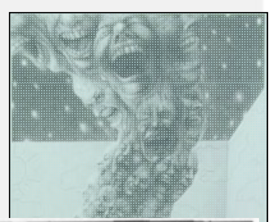
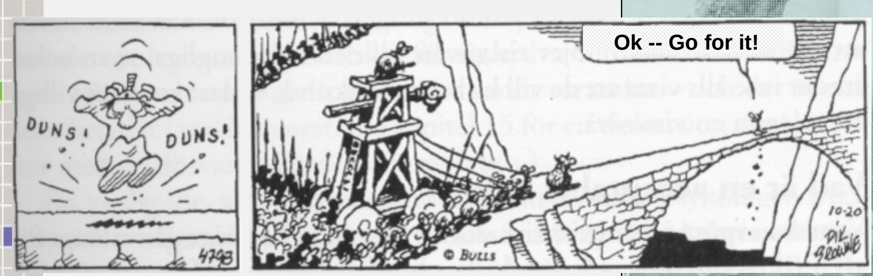
One problem seldom comes alone …

- The base for, and validity of, the trial evaluation (i.e. verification) and its documentation





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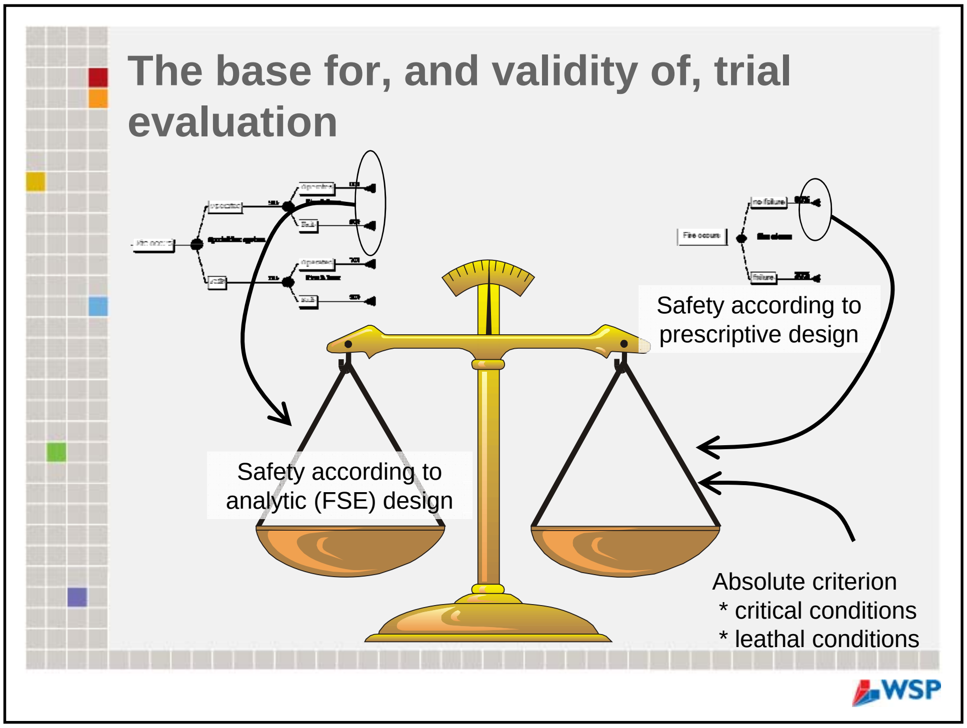
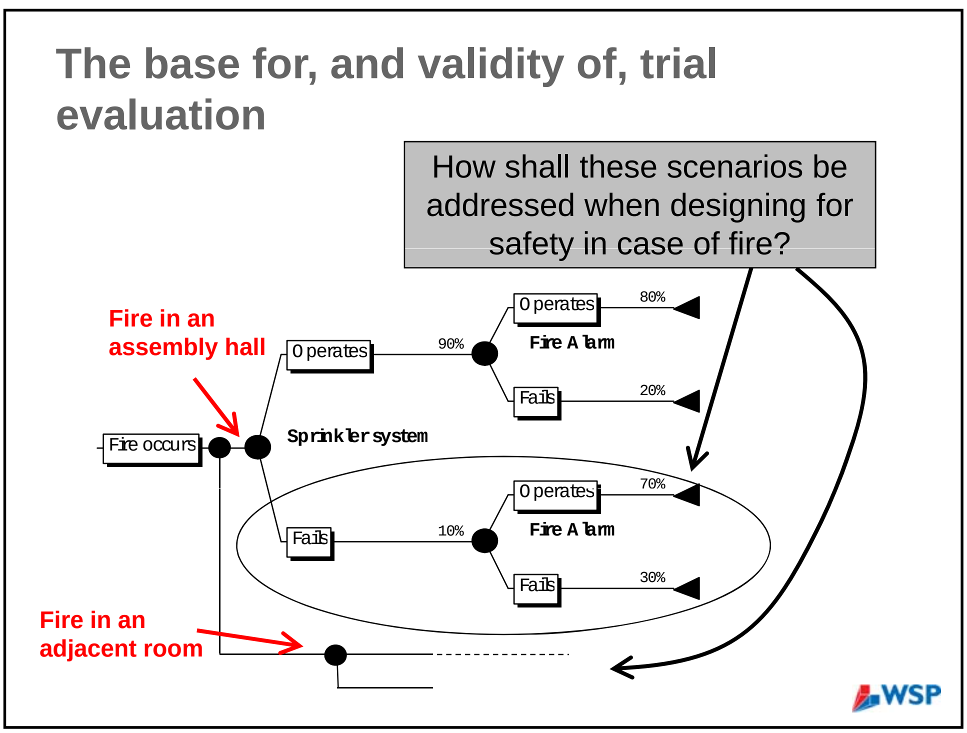

The base for, and validity of, trial evaluation
Safety according to prescriptive design
Safety according to analytic (FSE) design
Absolute criterion
* critical conditions
* leathal conditions
WSP


The base for, and validity of, trial evaluation
How shall these scenarios be addressed when designing for safety in case of fire?
Fire in an assembly hall
Fire occurs
Sprinkler system
Operates
90%
Fire Alarm
Operates
80%
Fails
20%
Fails
10%
Fire Alarm
Operates
70%
Fails
30%
Fire in an adjacent room
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Performance-requirements (basic concept)

- Performance-based regulations aim at defining rules for the safety output required by the system, in this case the building and its fire protection measures. The rules may express the acceptable risk explicitly, or indirectly by expressing the attributes or functions of a system directly connected to safety.

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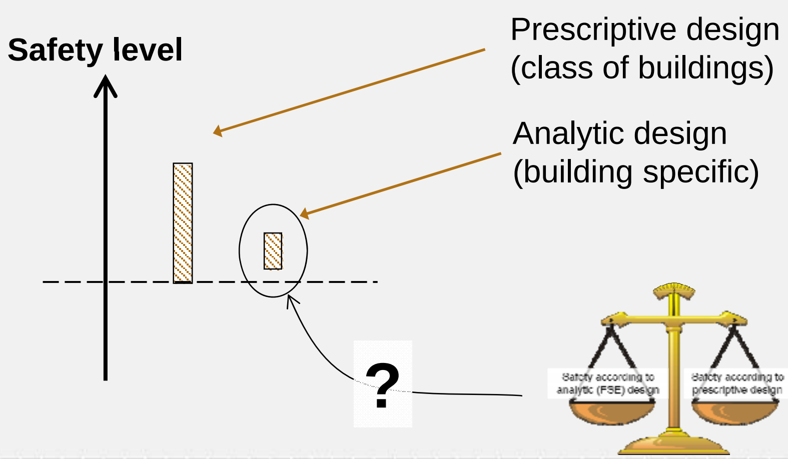
The base for, and validity of, trial evaluation



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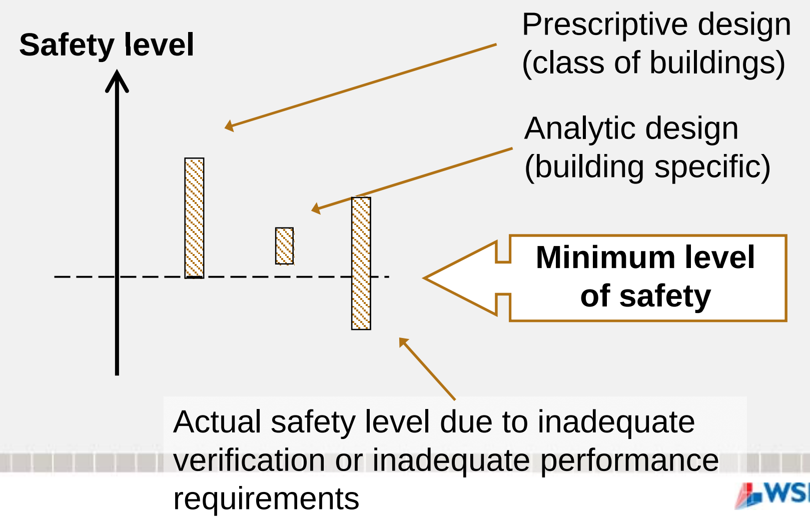
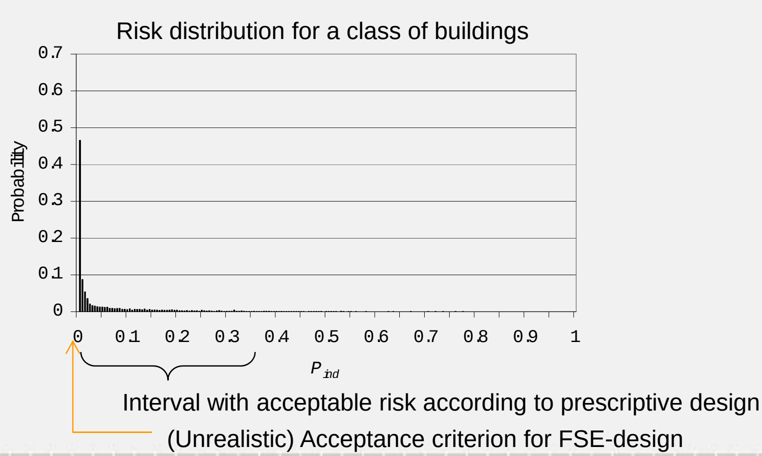
The general idea with regards to safety



Can result in inconsistent definition of acceptable risk



One problem seldom comes alone …

- The hybrid mixture of the prescriptive and FSE-method requires flexibility
  - The scope of analysis varies from project to project.
  - Appropriate boundaries need to be determined case by case, both on a systems basis and spatial delimitations of the building.
  - Simplicity versus accuracy.
  - Scope of analysis versus time available for analysis.

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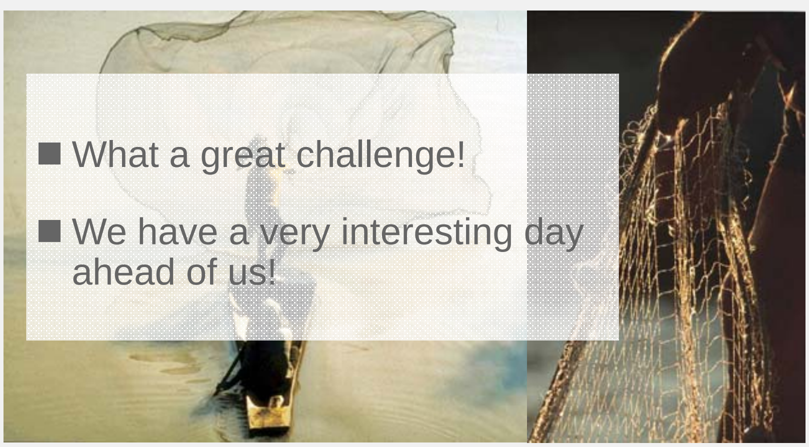
A clear set of performance-requirements



- What a great challenge!
- We have a very interesting day ahead of us!

… has to capture the implicit attributes, the appropriate safety level and result in a valid trial evaluation!

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Achieving Fire Risk Control with a Performance-Based Regulatory System – threats and challanges

Johan Lundin, Ph.D.
WSP Fire and Risk Engineering
Slagthuset, SE-211 20 Malmö, Sweden
Phone: +46 40 699 6200, Fax: +46 40 699 6250
E-mail: johan.lundin@wspgroup.se
Website: http://www.wspgroup.com

1. INTRODUCTION

The requirements concerning fire protection in buildings in the Swedish building regulation *(BBR)*[1] were reformulated a decade ago. Detailed demands on the technical design of buildings and their fire protection systems were replaced by requirements addressing the goals of fire protection, by using performance-based requirements. Such rules may express the acceptable risk explicitly, or indirectly by expressing the attributes or functions of a system directly connected to safety. In order to satisfy these requirements, solutions recommended by the authorities may be used (prescriptive design), or the designer may choose to demonstrate compliance with the regulations through *verification* of other solutions (denoted analytic design or fire safety engineering design). Verification is similar to the concept of evaluation of trial designs which is used in many design guidelines. A prerequisite to determine whether the demands are fulfilled, an unambiguous definition of what is to be measured, and the quantitative level or amount is required. Unfortunately this seems to be the "holy grail" in the area of fire safety engineering.

2. OBJECTIVES

Through the introduction of performance-based regulations, society has released its strict control of fire safety by specifying specific safety measures and building limitations and now relies on the ability of the developer and design team. This paper will emphasise on the problems regarding risk control in order to give input to the ongoing development and revision of performance-based codes in several countries. The main objective of the paper is to elucidate the effects of the introduction of performance-based regulations on the ability of society to control fire safety in buildings. The effects very much depend on how the performance requirements are formulated and which attributes of the multi-faceted concept of safety that is addressed. Another objective is to identify and summarize the problems encountered in achieving a satisfactory level of safety in case of fire when applying the performance-based regulations. An analysis of possible shortcomings of the new regulations will provide information on the development required.

Through out the paper the Swedish building regulations will be used to exemplify the identified problems. The structure and contents of the majority of different countries performance-based regulations are similar on a genereal level, but not necessarily in every detail.

3. RISK CONTROL PROBLEMS RELATED TO THE CONTENT AND STRUCTURE OF THE PERFORMANCE-BASED REGULATIONS

The ambition of the Swedish building regulations is to be performance-based, i.e. the regulators have tried to formulate fire safety requirements on this level so that fire safety engineering methods can be applied in the design work. The designers are supposed to verify with calculations that a design solution is sufficiently safe. The regulators have succeeded so far as there are no formal obstacles in the form of administrative rules or restraints which impose restrictions on the fire safety design itself. On the other hand, there are no measurable goals, acceptance criteria or operational design criteria formulated yet. This indicates that the process of chaning the regulatory system is still not completed.

A number of problems regarding the possibility of verifying safety have been identified through the study of fire safety protection documentation, active participation as a reviewer in design projects, and discussions with designers and reviewers. These problems can be divided into the following main types:

- lack of quantitative design criteria determined in the regulations,
- relative risk comparison with prescriptive design,
- risk comparison with absolute acceptance criteria,
- uncertainty in the result of the analysis, and
- lack of risk evaluation methods.

3.1 Lack of quantitative design criteria determined in the regulations

The level of fire safety achieved in buildings will become evident, in the long run, from the number of fires and the resulting number of injuries and fatalities. This type of data constitutes a kind of *safety output* from the national stock of buildings. Today's building regulations contain no quantitative criteria even indirectly linked to *safety output*. As the performance requirements are not expressed as measurable quantities it is difficult to verify that they have been fulfilled, and it will also be difficult to check the verification, irrespective of who performs the review. If it is not known which level is acceptable, it will be difficult (or impossible) to decide whether the requirements have been fulfilled or not. A corresponding problem in checking that the regulations have been followed has been noted in many other areas where performance-based regulations have been introduced, and poses a dilemma that may be difficult to circumvent[2].

In earlier building regulations, the acceptable fire safety level has been indirectly defined by demands on direct risk control in the regulations (prescriptive requirements). Now that the regulations have changed in character and claim to be performance-based, a need for design criterion has been created so that verification is possible. Verifiable performance demands are a prerequisite if it is to be possible to control the level of risk through regulations directed towards this level of control in fire safety.

Despite the fact that there are no acceptance criteria such as quantified performance objectives, or explicit levels formulated in *BBR*, it is still demanded that risk analysis be used when necessary in certain kinds of buildings (*BBR* 5:13), but the demands are not linked to a particular model or type of risk analysis. In *BBR* 5:13 it is stated that only analytic design is to be used when a fire could result in great risk of personal injury, e.g. buildings higher than 16 storeys, buildings with certain types of assembly halls or auditoria, nursing homes, and complex buildings below ground level. It is not possible to use prescriptive design to derive a reference building in order to make a relative comparison in such cases. The obvious question is, what should be used instead? Since the performance requirements are not explicitly stated it is difficult to identify in which situations the prescriptive method is inappropriate.

The authorities could formulate design criteria for the control of safety in two ways. The first is as a probabilistic criterion in the form of an acceptable level of risk, in combination with extensive demands on uncertainty analysis. The alternative is to give a deterministic criterion including safety factors for one or several specified scenarios. However, it is far from clear how safety performance should be defined and measured, which means that the application of analytic design brings with it certain problems. Defining a deterministic criterion requires the development of design expressions and that uncertainties can be treated in a suitable way.

A number of different approaches considered to be used to determine a probabilistic design criterion in terms of an acceptable risk, i.e. acceptable level of *safety output*, are summarized, all of which have advantages and disadvantages;

- through political decisions,
- based on accident investigations,
- founded on levels from other areas or applications, or
- derived from the existing implicit level.

It is important to bear in mind that *Boverket* did not have the explicit mandate of improving fire safety in buildings by requiring more fire protection measures when the regulatory regime was changed, i.e. *BBR* introduced. This narrows down what the level of performance in the regulations must be calibrated against. If a level of risk based on what is acceptable in another area is applied, the risk of fire may be higher or lower than it is today. It is not especially likely that the level of risk in other areas really reflects society's values when it comes to the need for fire protection. It would also mean that the levels of risk would vary depending on whether analytic design or prescriptive design was used, which would lead to inconsistent building regulations. It is possible to modify the prescriptive design method to achieve a new risk level, but this would require a considerable amount of work on the part of the regulating authority, i.e. *Boverket*.

Uncertainty in the input data and lack of knowledge on how this uncertainty varies with the type of building, the activities carried out therein and other factors, lead to difficulties in quantifying and applying an absolute level of risk. There is, on the other hand, sufficient knowledge to make relative comparisons based on quantitative analysis and to rank the various alternatives. There is actually no need to determine an absolute risk level for the fire protection of buildings, as long as there is a method of determining what constitutes adequate fire protection. The requirement on such a method is that the fire protection of buildings is equal to or better than when the prescriptive design method is used.

3.2 Relative risk comparison with prescriptive design

Even though a relative risk comparison seems promising, basing verification of analytic design on a relative comparison with prescriptive design is not without problems. Having to first design fire protection solutions using prescriptive design takes time, and costs money. Also, it is not certain that prescriptive design leads to good fire protection in all buildings[3].

Yet another problem lies in choosing the premises from a certain class of buildings to be used as the reference building, i.e. the object with which to compare the risk. Prescriptive design leads to a variation in the level of safety in a certain class of buildings[4,5], which is unavoidable since all the variables that affect safety are not included (or controlled) in this design method. As there are no recommendations regarding the choice of reference building, this building may be systematically designed with too low a level of safety. Because the reference building is purely fictitious and will never actually be built, it can be designed neglecting other competing objectives, which means that the fire safety measures can be minimized. Comparison to such a building would be misleading as the risk level used as the acceptance criterion would be too low.

This might seem surprising from a building-specific point of view. All buildings designed with the prescriptive method are regarded as acceptable, and thus the highest risk level resulting from prescriptive design ought to define the acceptable level. On what basis can this risk level be rejected as a suitable acceptance criterion? One must bear in mind that the prescriptive design method was not designed so that each building in the class meets a specific risk target, but was instead developed in a reactive way for classes of buildings. The design method will lead to design solutions where the safety level varies between the specific buildings, but where the group as a whole is deemed acceptable. It is by no means certain that the building with the highest risk, as a result of the prescriptive design method, corresponds to the risk level that society regards as appropriate. However, this building can be seen as a necessary result due to uncertainties that can not be reduced in the design method, but is not a good representation of the target level of risk for all buildings in the class. If this risk level is used as an explicit design criterion when analytic design is used, the average risk level in that building class on a national level will be greater than if prescriptive design had been used. If the risk level is increased on a national level, a higher number of fatalities due to building fires are to be expected, which is not a desired outcome of introducing analytic design[6].

If, on the other hand, the highest risk level resulting from the prescriptive design method defines the minimum acceptable safety, this should be made clear. In such cases it is up to the designer to determine how much safety, in addition to the minimum requirement, is appropriate.

3.3 Risk comparison with absolute acceptance criteria

In order to verify the fire protection systems in buildings where the analytic design method is the only option according to *BBR* 5:13, the designer must determine an explicit acceptance criterion. In such situations, this is usually done in collaboration with the building committee. This is an unreliable procedure for many reasons. For example, legislation provides no recommendations on the correct explicit level of safety. This process in Sweden often suffers from a lack of time and is not scientifically-based, which results in considerable variations on a local level, which is in conflict with the intentions of both the building regulations[1] and the Civil Protection Act[7]. The need for development and guidance in this area is thus considerable. If the designer defines the level of safety required in order to satisfy the mandatory provisions, this means that society is not in control of safety, and this is undesirable for several obvious reasons[3]. The appropriate level of safety should be determined by investigating the level of safety in prescriptive design in building classes where this design method is suitable. Current knowledge of this level, and how it varies in different building classes is poor.

3.4 Uncertainty in the results of analysis

By stating goals for *safety output,* e.g. specifying a target risk level, uncertainty in the risk analysis can cause major problems in exercising risk control. During the process of risk analysis, a number of subjective choices and assumption must be made, which means that different designers may obtain different results. The results of such analyses will, to some degree, be arbitrary. Apart from this, there are uncertainties in both the models and the input data that contribute to uncertainties in the final results. Even if an acceptable level of risk can be established, the resulting risk of fire in the building with this approach will not be controlled due to the uncertainties in the risk analysis calculations. Rules on how to assess these uncertainties are necessary.

3.5 Lack of risk evaluation methods

One of the difficulties in comparing risks, e.g. in verification, is that it is unclear how trade-offs should be made between probability and consequences in the risk calculations. This problem originates from the difficulties of how to combine probability and consequence into an adequate risk measure. The mean risk is used as the risk measure in risk comparisons in many areas, which assumes that the decision maker's attitude is risk neutral. This means that the risks are ranked according to magnitude based on the product of the probability and the consequences. If the probability is halved while the consequences are doubled, this would have no effect on the magnitude of the risk, according to this approach. There is, however, evidence that this is not the way in which society regards risk, e.g. the risk criterion used for land-use planning in the Netherlands[8]. However, questions that arise in risk evaluation in verification are:

- If it is reasonable that serious consequences with a low probability are regarded in the same way as slight consequences with a high probability?
- How can several small injuries be compared with one event leading to severe injury?
- Should scenarios with severe consequences be assessed on the same grounds as other scenarios, i.e. based on the risk, or do we assess catastrophes as being more serious than the risk indicates?
- How then can the risk of a serious accident be limited by design criteria?
- Should a limit be set on the extent of the consequences regardless of the probability of such an accident happening?
- Is it reasonable to determine this limit based on the worst case scenario in a building designed using prescriptive design?

The lack of guidance on how to assess these issues in practical design work indicates that the design procedure for analytic design is incomplete.

Today it is not clear how trade-offs can be made between probability and consequence. In analytic design new protection systems are sometime used, which have several positive effects. If the intention is not to improve current safety levels, but to use the protection system to replace another system or to compensate for an increase in risk, e.g. allowing more people in the premises, then the questions posed above become pertinent. Since any kind of system can fail, there is a certain probability that a scenario will occur in which the consequences are greater than would have been the case before the system was installed. The question is, to what degree we can allow this.

4. RISK CONTROL PROBLEMS RELATED TO APPLICATION OF THE PERFORMANCE-BASED REGULATIONS

The ability to control fire safety through specifying rules is not only affected by how the regulations are formulated since it is crucial how they are implemented by the professionals involved. Drawing up regulations involves a compromise between being in control, from the authorities' point of view, and affording freedom to the designer and user of the building. By studying which regulations govern safety, and how they are applied, problems and flaws in society's ability to control fire safety protection can be identified.

In the study performed on fire protection documentation and the relation between documentation and regulation, a number of problems were identified. These were divided into different categories and are discussed in the following sections:

- verification procedures and general problems, and
- problems associated with elements of the verification procedure.

4.1 Verification procedures and general problems

An abundance of methods and models are in use today in *verification*, in some cases proprietary software. The question is whether all of them are appropriate, or whether some should be rejected. If it is in the interest of the designer to prove that a design solution is safe, aiming at meeting minimum standards, rather than managing the fire risks appropriately, then there is a risk that poor solutions will accepted based on inadequate analysis. The level of fire safety will then be too low. The quality of the verification is not only dependent on the method of evaluation or the protection system being verified, but on how the designer chooses and applies the models. The conditions for verification change from one project to another, and what is suitable for one case may give misleading results in another.

Inadequate verification means that the demands in *BBR* will not be fulfilled and that solutions leading to inadequate protection will not be revealed. If designers regard verification only as an academic exercise, and rely solely on their instincts when determining the appropriateness of a design solution, the societal risk control intended in *BBR* will not be achieved.

A study of the fire protection documentation[3] showed that serious events are not considered in verification, for example, if a system fails or if a serious fire breaks out. Despite the fact that it is impossible to completely prevent the consequences of such events, measures can be taken to limit the damage. Not considering such events at all seems counter intuitive from a risk management perspective. Protection against serious accidents must be included as part of a building's total fire protection, despite which design method is used. The design of such protection is not dealt with explicitly in today's building legislation. If the contribution to the risk from these types of scenarios is not included in verification, protection against serious accidents will be undermined at the same rate as the use of analytic design. It is a sobering fact that society has no way of knowing whether this is happening or not.

4.2 Problems associated with elements of the verification procedure

The problems and shortcomings presented in the previous section were identified by studying how the possibility of changing traditional fire protection has been used in practice when the analytic design method was applied. Some of the problems associated with this design method and the consequences of these problems in safety control are discussed in more detail below.

4.2.1 Hazard identification

In fire risk assessment, the choice of risk analysis method, criteria in terms of threshold for critical conditions, input data, calculation models, etc. are often of great concern for all involved parties. Little or no attention is paid during the design process to the first and most important phase in the risk assessment process, i.e. hazard identification or, What has to be analysed in order to prove that the safety of the design is equivalent, i.e. sufficient?

This phase is the most important part of risk assessment[9] as the scope of the analysis is determined, which indirectly influences the outcome of the analysis. If hazard identification is not carried out properly then verification will miss some of the relevant aspects of fire safety in the building and several important scenarios which could cause the design to fail may be overlooked. Shortcomings in the choice of scenarios are one of the most serious threats to the quality of risk assessment when used for safety evaluation purposes[10]. As a result, the *verified as equivalent* design might not meet the demands laid out in the building regulations, and it is possible that the level of fire safety will be inadequate, but will remain unnoticed in the design solutions. If such mistakes occur, they should at least be identified in the design review, which must form an integral part of all design projects.

4.2.2 Serious scenarios

One consequence of using inadequate or inappropriate risk analysis in verification is that the protection against serious accidents can be reduced without this being noticed. Protection against serious fires was often completely forgotten or neglected in the verification of that the safety objectives were met in the cases studied. In this context, protection against serious events concerns the ability of the building to resist the consequences of serious fires, i.e. a fire greater than those normally used for design, or a fire in a particularly unfavourable location. Examples of this are fires that start in an adjacent room and which grow before being discovered. Such a fire can result in a ventilation controlled fire (potentially vitiated conditions) where the yield of species (i.e. combustion products), toxicity, visibility, rate of heat release, risk for flash over etc. can be quite different compared to a well-ventilated fire. Another situation when the consequences can be serious is when one or several fire protection systems do not work as they are intended to.

When the prescriptive design method is used, the protection will provide a certain protective effect in all scenarios, even if the consequences are not zero. It does not seem reasonable to expect society to accept an uncontrolled reduction in fire protection in these scenarios, while the solution is still regarded as affording sufficient safety. When analytic design is used in the way it is today, there will be an imminent risk that fire protection in the case of serious accidents will be overlooked.

4.2.3 Choice of single design scenarios

In an effort to find specific criteria with which to compare solutions in order to prove that the total fire protection of the building has not become worse than if prescriptive design had been used, the demands laid out in *BBR* 5:31 and *BBR* 5:36 are often used as the starting point.

BBR 5:31 General
”Buildings shall be designed so that satisfactory escape can be effected in the event of fire.”

BBR 5:36 Design conditions
”In design with respect to the safety of escape, the conditions in the building shall not become such that the limiting values for critical conditions are exceeded during the time needed for escape.”

These demands are in general interpreted as meaning that a limit-state must not be exceeded. The limit-state for evacuation safety is defined as a time margin, i.e. the difference between the time before critical conditions are reached, and the evacuation time when this interpretation of *BBR* 5:31 is used. Verification is performed by analysing the time margin for a design scenario. If the time margin is positive, the solution is regarded as being sufficiently safe.

One advantage of this method is that it is specific, and easy to understand, but there are several problems. One of the most serious is that it is not clear which scenario should be used as the design scenario. There are very many possible fire scenarios that can occur in a building. Should all scenarios be investigated, or just one representative one, and how should this one be chosen? Since the number of possible scenarios is more or less unlimited a complete scenario analysis is out of the question. However a single scenario (or a few) constitutes a very limited representation of the complete set of scenarios, i.e. the total risk.

In scenarios where one or more protection systems fail, it can be difficult to evacuate the building before critical conditions occur. If such scenarios are used to verify a solution in relation to the time margin, then few or no designs will be acceptable. Prescriptive designs would not pass such a test either, which indicates that it is unreasonable to demand that everyone should be able to escape before critical conditions occur in every scenario.

In order to circumvent this problem while still using the established method attempts have been made to use conditions that will cause injury or fatality in order to define a limit-state for slightly more serious scenarios than the ones normally analysed. In practice, this means that more serious consequences are accepted in the more serious scenarios since many people may be affected by critical conditions for a long time before anyone dies. An alternative method that gives the same result is allowing a certain negative time margin for these scenarios, but still measuring the consequences at critical conditions. The question still remains: *For which scenarios is this valid?*

The performance requirement in *BBR* 5:36 is more of a political description of the aim of fire safety, than the demands on the performance which can be verified. The demand may reflect the desired performance or the level of fire protection when all systems work as they should, but is inadequate as a design criterion as a number of different scenarios may arise. It is not clear which level of performance of the fire protection system can reasonably be demanded when one or more systems fail. There is no guidance on how to determine the adequate level of protection in these scenarios.

The method of using limit-state functions was developed for the design of load-bearing structures, but the concepts have been uncritically transformed to the design of evacuation safety. This approach has been found to be unsuitable from a risk control perspective for fire safety design[3].

4.2.4 Arbitrary choice of the risk measure in risk comparison

Another problem associated with defining the consequences of scenarios using a time margin is that it is difficult to determine the number of people affected. If the time margin in a scenario is -10 seconds, this may mean that one person had to walk a long way to the exit, or equally that 10 people will not have time to evacuate the building. Whether a negative time margin of 10 seconds is considered long or not depends entirely on the course of evacuation. In a comparison between different designs where the course of evacuation varies, the time margin may thus not be a suitable risk measure. Neither is it probably suitable to express general acceptance criteria or safety margins in terms of this measure. In most cases it is better to define the consequence endpoint as the number of people not having time to leave the building before critical conditions occur, in order to avoid this problem.

A suitable acceptance criterion, e.g. critical conditions, is actually not based on what people can withstand (which is a level associated with high variablility). The purpose of the acceptance criterion is to be able to evaluate if a design offers an acceptable level of safety by evaluating the conditions in the design with a certain method. In order to do so, the acceptance criterion must be derived and connected to a design method, assessment of uncertainties in the calculations, and selection of values of input data and other variables. The safety achieved when verification has proven a design acceptable is a combination of the criterion used, the severity of the scenario tested and how the uncertain input variables were selected. If the criterion and fire scenario investigated are not well determined, the results of the verification will be very uncertain. Giving an acceptance criterion without referring to the design method leads to a false impression that the required level of safety has been achieved.

5. NEED FOR DEVELOPMENT OF PERFORMANCE-BASED REGULATIONS

Shortcomings and difficulties in interpretation indicate a considerable need for the continued development of the performance-based demands in *BBR*, and a number of clarifications from the authorities. It is difficult for a single designer to find answers the following questions which are crucial for risk control:

- How far can the boundaries be stretched? In other words, to what degree can traditional fire protection be changed?
- Can trade-offs be made between different functional requirements?
- How extensive should the analysis be for a specific case?
- What is a suitable definition of risk?
- Which properties or attributes of a solution should be considered in verification?
- How should scenarios be chosen to ensure a sufficient basis for evaluation of the effects on the total safety in a relative comparison?
- How does one determine if a model adequately describes the case in question?

- How does one define an acceptable level of risk against which the solution can be verified?
- How should a reference building be defined if a relative comparison is used for risk evaluation?
- How can a basis for verification be obtained for the kinds of buildings in which prescriptive design is not applicable?

The building regulations must be interpreted, to a high degree, at the local level as decisions on what constitutes an acceptable solution have not been made at the national level, and guidance is therefore lacking. The uncertainties arising from the above questions mean that design is arbitrary, and factors other than those related purely to safety govern the verification. The idea was that designers should use their innovative capacity to design new buildings and new solutions for fire protection, not for the interpretation of the level of safety sought by society. The latter is to be determined by the regulating authority in question.

It is strongly suggested that *Boverket* develops guidelines for analytic design, or limits the scope for the introduction of new solutions, since the effects on safety cannot be adequately verified by designers and thereby threatens the societal control. Another suggestion is that *Boverket* requires, and assists, local building committees to check compliance when analytic design is applied, to force adaptation to higher standards in verification procedures. National coordination is necessary for efficient development of tools and to prevent differences between local authorities. By establishing a national committee to conduct investigations of large projects in which analytic design has been employed, national consensus and support for local building committees can be achieved.

6. DISCUSSION

Are the problems discussed above acute? According to fire statistics, Sweden is no worse than any other country[11], and no trends towards an increase in the number of fatalities due to fire since the introduction of *BBR* can be seen[12]. There is thus no acute danger, but in the longer run, the consequences may be serious in several respects. Experience from other countries, e.g. Japan[13], show that it takes time before new design methods become widely established and used. It is thus probable that the use of analytic design will increase in Sweden, while a highly doubtful practice in the application of this method spreads throughout the country. The consequence will be that society will lose its ability to control fire safety in buildings. The present review system will not be able to handle the problems. Changes in traditional fire protection will continue, and the limits on the kinds of solutions that are accepted will be continuously tested. The problems identified in this work are not expected to decrease, but rather to increase.

One expected result of this is that the number of fires with serious consequences will increase in the longer perspective. As fire is a relatively rare phenomenon, it is reasonable to believe that it will take time for the erosion of fire protection quality to become clear. The political consequences of this, when such fire actually occurs, may well lead to the revision of legislation according to new directives. The opportunities for designers themselves to design suitable technical solutions will, with all probability, be limited. There is thus a risk that several of the solutions used today will not be accepted in the future, even if they provide sufficient safety. It is difficult to foresee the consequences of this for *Boverket*, but there is considerable risk that the public will lose confidence in building regulations, which may lead to serious repercussions for this authority.

7. CONCLUSIONS

In Sweden it seems as designers exercise greater freedom than intended by the regulations having the possibility to subjectively and arbitrarily interpret both the methods used for verification and the level of performance requirements. This can result in solutions being accepted although they do not comply with the regulations. Such practice is a major threat to societal risk control, since the decision about what is an acceptable safety level is moved from the authorities to the designer, which was not the intention when introducing *BBR*.

The present situation is the result of deregulation in a sector where insufficient resources have been invested in the risk governance system in order to safeguard public safety. If no action is taken regarding the quality of verification, there is a risk that many of the advantages of performance-based regulations will be lost in future revisions of the building regulations not unlikely to be initiated by a major accident.

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Practical Experiences in Austria

Dipl.-Ing. Dr. Arthur EISENBEISS
Geschäftsführer

IRCC – Conference
Vienna 10th October 2007

Why performance based regulations?

- Descriptive regulations deliver different safety levels and generalized measures
  Performance based regulations deliver generalized levels and different measures
- Optimizing investment AND safety level
- Complex buildings are not covered by descriptive reg.
- Future products, trends,… are automatically covered
- Reduced number of regulations?

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Essential Requirements (CPD)

- The load bearing capacity of the construction can be assumed for a specific period of time
- The generation and spread of fire and smoke within the works are limited
- The spread of the fire to neighbouring construction works is limited
- Occupants can leave the works or be rescued by other means
- The safety of rescue teams is taken into consideration

QUANTITATIVE APPROACH requires

- Figures for accepted risks
- Statistic data which – sometimes – do not exist
  - break down probability 10^{-5}
  - ~~effect of R 30/R 90~~

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COMPLEX BUILDINGS

- Assembling place for more than 1000 people
- Hospital
- Prison
- Residential and nursing home for aged people
- Other complex buildings, e.g. large shopping centres, multi-functional buildings

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Austrian smoke and heat venting systems regulation

- Assisting the fire fighting action of the fire brigade in order to reduce temperature and smoke to such an extent that a well equipped fire brigade is able to act
- Safety of the building, in order to remove heat energy to keep the temperatures in acceptable ranges
- To achieve smoke free escape routes in order to enable people to leave

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Austrian smoke and heat venting systems regulation

Definition of safety goals represents a rudimentary performance based approach

- **we assume the world to offer not more than 3 variations**
- **numerous additional descriptive requirements**

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Socio – political boundary conditions

- **Accepted time of persons exposure to smoke, toxic atmosphere, temperature,…**
- **Distribution of persons mobility to calculate escape time (dependant on utilization,…)**
- **Time for the fire brigade to be effective as a function of distance, crew size, equipment,…**
- **Have arsonist fires, vandalism and terrorism to be taken into account and if yes to what extent?**
- **…**

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CONCLUSION

- Building Projects with a high level of fire hazard require PBC
- Most benefit of PBC
- Stringent deduction of descriptive regulations out of PBC
- „Boundary Conditions“ need to be defined

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Fire Death (1997 – 1999) [4]

Country	Deaths per 100,000 persons
Singapore	0.18
Switzerland	0.62
Spain	0.64 [1996-98]
Netherlands	0.68 [1994-96]
Australia	0.69
Austria	0.76
Italy	0.77 [1996-98]
Germany	0.82
France	0.95
New Zealand	1.10
Czech Republic	1.13
Slovenia	1.15
UK	1.18
Belgium	1.27 [1993-95]
Greece	1.34
Norway	1.37
Canada	1.38
Poland	1.41
Denmark	1.49
USA	1.56
Sweden	1.62
Japan	1.69
Finland	1.98
Ireland	2.02 [1996-98]
Hungary	2.14

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Fire Death (1999 – 2001) [4]

Country	Deaths per 100,000 persons
Singapore	0.12
Switzerland	0.56 (1998-2000)
Australia	0.66
Spain	0.67
Italy	0.68
Netherlands	0.68 (1994-96)
Germany	0.74
Slovenia	0.84
France	0.97 (1998-2000)
Czech Republic	1.04
UK	1.04
New Zealand	1.08 (1998-2000)
Canada	1.26 (1998-2000)
Norway	1.34
Belgium	1.35 (1995-97)
Poland	1.36
Austria	1.38
Sweden	1.39
Denmark	1.50
Greece	1.52
Japan	1.69
USA	1.83*
Finland	1.84
Ireland	1.89
Hungary	2.06

* Calculated after allowing for 2,791 deaths in 2001 arising from 9/11.

IRCC – Conference
Vienna 10th October 2007

Presentation to be held at IRCC
(Inter Jurisdictional Regulatory Collaboration Committee) Conference,

Vienna, 10th October 2007

Practical Experiences in Austria

Dipl.-Ing. Dr. Arthur A. Eisenbeiss

Conference Topic:

Is it possible to find a general set of
performance requirements/criteria for safety in case of fire
which could be adopted in building regulations?

Table of contents

1) Introduction

Why should we discuss creating performance based codes? Do not decades of experience in fire safety and fire prevention satisfy our needs sufficiently?

There are a number of advantages in characterizing performance based regulations, among others can be cited

- Descriptive Regulations need to cover the majority of building projects generalizing the safety level without respect to specific building circumstances. Consequently one finds different safety levels for buildings but generalized packages of measures. Performance based regulations make it possible to find a package of measures which is suited to the specific building leading to a generalized safety level defined by performance based codes.

- A building specific package of safety measures simultaneously optimizes the investment and satisfyies the requested safety level.

- Large and complex buildings with numerous different applications, utilizations and functions cannot be covered by generalizing prescriptive standards. Performance based codes include these categories of complex buildings as well.

- The industry need of large area manufacturing sites, the use of newly developed construction products, creative architecture and all other new developed or created products and trends are automatically covered by performance based codes whereas descriptive have to be worked out laboriously and will react to modern trends too slowly anyway taking into account typical periods needed to provide a new standard.

- At least at the first sight we could hope that the number of performance based regulations can be held much lower in comparison to descriptive regulations.

Essential requirements as an expression of performance can be found in the CPD and are the starting point for “safety in case of fire”:
The construction works must be designed and built in such a way that in the event of an out break of fire:
- The load bearing capacity of the construction can be assumed for a specific period of time
- The generation and spread of fire and smoke within the works are limited
- The spread of the fire to neighbouring construction works is limited
- Occupants can leave the works or be rescued by other means
- The safety of rescue teams is taken into consideration

2) Quantitative Approach

A quantitative approach to performance based codes can be developed if there are data available consisting of:

- Quantitative safety goals, which require quantitative values for accepted risks
- Data Bases, mainly adequate statistical data, for Quantitative Risk Assessment

2.1) Quantitative Safety Goals and Accepted Risks:

A safety level of 100 % can never be achieved. All safety considerations have to be compared with an accepted value for a maximum credible accident (MCA).

Considering an accepted risk in a simplified condensation, some of the Scandinavian tunnels are designed to collapse due to a fire accident with a probability of maximum 10^{-4}/year. So, a collapse is accepted every 10,000 years [2]. Data about accepted risks with respect to personal safety, loss of property and lack of infrastructure are common in the nuclear power plant industry but very rare in the building industry.

2.2) Quantitative Risk Assessment (QRA)

To be able to prove that specific risk probabilities are lower than accepted risk values, a quantitative risk assessment has to be performed. In most cases, the statistical data which is available for an elaboration of a QRA, if they exist, do not include important details or lack sufficient background information about how the data have been gathered.

In Germany, for example, intensive investigation has been done to get information about the break down probability in factory buildings. It was found to be 10^{-6} events/year for large buildings and 10^{-5}.events/year for other buildings [3].

There was a lot of work done to get the figure but it would exceed the acceptable volume of work to investigate statistical data in more detail and the number of samples decreases to a value which makes sound statistic results impossible. The questions of, for example, how the fire resistance R 90 compared to R 30 in public spaces influences the losses due to fire in factory buildings, or how the fire resistance requirement influences the number of fire deaths, are not covered by statistics.

If statistical data are available, background information about the data base is essential.
For example: Comparison of the World Fire Statistics (The Geneva Association) of fire death in 1999 shows a substantial difference in the ranking for Austria compared to the 2000 statistics [4]. In 1999 Austria was at place 6 and in 2000 17th, due to the Kaprun accident in 2000 with 155 fatalities due to fire, compared with the typical 80 fire deaths per year in Austria. Despite a significant increase in the 5 years average value, it would be the wrong conclusion to modify building codes.

As a consequence, the number of concepts where QRA is applicable and where accepted risks are defined is very low and the fundamental approach is mostly not applicable.

3) Qualitative Approach:

3.1) Rudimentary Performance based Prescriptions are present practice

To some extent, a performance based approach is traditionally done in cases of complex buildings. Complex buildings are those which have not been considered when the (descriptive) building codes were defined and those for which a fire safety concept is requested in the OIB regulation. Among those are:

- Assembling place for more than 1000 people
- Hospital
- Prison
- Residential and nursing home for aged people
- Other complex buildings, e.g. large shopping centres, multi-functional buildings

In present practice, the lack of descriptive regulations stipulates prescriptions which are justified by the safety goal and this represents a (rudimentary and very basic) performance based approach.

Example Shopping Center
A detail of the safety concept could be to have a sprinkler covered area separated by REI 90 fire walls and covered with an R 0 ceiling, in order to prevent fire from spreading out horizontally, even in the improbable case of overruling the sprinkler, and an R 0 ceiling meaning that the fire brigade has an easier access with water from the top.
This design of different requirements for fire resistance could never be part of descriptive regulations, because they only make sense in light of the entire plan (e.g. dimensions, in particular height of the building, smoke extraction system, sufficient opportunities for the fire brigade to attack, escape route concept,…. and the interaction of all systems and organisational procedures).

Example smoke and heat venting systems (e.g. in factory buildings)
In case of smoke and heat venting systems design, a very rudimentary performance based approach already exists.
The Austrian smoke and heat venting systems regulation [5] foresees three different safety goals when designing the smoke and heat venting systems:
a) Assisting the fire fighting action of the fire brigade in order to reduce temperature and smoke to such an extent that a well equipped fire brigade is able to act
b) Safety of the building, in order to remove heat energy to keep the temperatures in acceptable ranges
c) To achieve smoke free escape routes in order to enable people to leave
These 3 opportunities represent safety goals, representing a performance based approach. This approach is rudimentary because we assume the world to offer not more than 3 variations and there are numerous descriptive requirements in addition.

Whenever building regulations describe 1:1 solutions descriptive codes offer an easy and comfortable process. Currently all measures taken in case of buildings which are not reflected in the building regulations or which are intended to deviate from descriptive building regulations are proved and designed by experts in a fire safety concept and accepted by experts in administrative procedure. They reflect the knowledge based and experience based feeling of the expert from which he is convinced that the fire safety concept which he designed or accepted offers the same general safety level as – from an overall point of view - it is implicitly given in the descriptive building regulation. Although there are standards and literature [6] [7] [8] [9] there are no stringent guidelines which ensure that experts will in all cases make the same decision in building projects which are not reflected in prescriptive building codes due to the lack of performance based regulations.

3.2) What else do we need to quantify "performance" and/or to define a "stringent guideline"

a) We need to quantify the "standard scenario" or a "standard event" or "standard values" on which our descriptive codes rely. In some cases, but not in all cases we know more or less precisely on which calculable or measurable quantities our descriptive building codes are based.

E.g. building codes for residential areas originate from standard furnishing and do not take into account any explosives. We need to quantify that this means e.g. 600MJ/m² is usual for residential areas.

Another obvious example is the ISO 834 standard time/temperature curve, which is the base for almost all fire resistance tests and which is already quantified.

Another example can be found in the OIB RL 2 – Factory Buildings, Table 1 [10] which describes how large an area within one fire compartment can be.
Base of table 1 is a fire load of 1400MJ/m². Development of a guideline [11] how to extrapolate the maximum acceptable area within one fire compartment would be fully descriptive.

Quantification of the qualitative basic assumption on which our descriptive regulations are based is necessary in order to find a precise and consistent link between performance based regulations and descriptive ones. It must be required that a safety concept deducted out of quantified performance based codes must end up in the descriptive codes.

b) Descriptive Codes rely on "standard boundary conditions" as well. Those "standard boundary conditions" origin from socio-political definitions and socio-political desires.

Among those are e.g.:

- Accepted time of persons exposure to smoke, toxic atmosphere, temperature,…
- Distribution of persons mobility to calculate escape time (dependant on utilization,…)
- Time for the fire brigade to be effective as a function of distance, crew size, equipment,…
- Have arsonist fires, vandalism and terrorism to be taken into account and if yes to what extent?
- …

Let us assume we have a package of performance based regulations. However they look, we need some "boundary conditions" defined. To be able to calculate how safe the escape concept is, we need the quantitative persons mobility distribution as an input and we need the figure for the time period during which a quantitative given CO exposure to persons is accepted under the assumption that this event will take place at most a few times per life. [12] [13]. Furthermore it must be defined weather vandalism shall be taken into account, and if so, to what extent, as these parameters will drastically influence the primary fire scenario.

As a consequence, in addition to performance based regulations, we need standardisation of “boundary conditions” which will become input parameters. The result of this standardisation work is an implicit expression of the socio-political ”accepted risk”.

4) Conclusion

The prevailing number of building projects can be satisfied by prescriptive code.
BUT:
Our goal is fire safety and therefore the extent of fire hazard is the decisive parameter and not the number of building projects.
In all cases of building projects which show an extraordinary potential of fire hazard we are missing performance based regulations in particular. The absence of performance based regulations applies first and foremost to public buildings designed for a huge number of users and occupants, multi-functional buildings and factory buildings, all of them of high material values.

Fortunately, the above cited building categories are those which gather the biggest safety and financial benefit from a building tailored safety concept.

Traditional buildings, e.g. residential buildings, can furthermore follow descriptive codes. As a matter of fact it is required that a safety concept derived from of quantified performance based codes end up in the descriptive codes as they stand.

In addition to performance based regulations, we need standardisation of “boundary conditions” which will become input parameters together with a continuously running renewal process which is already given by collaborative institutions like IRCC [1] or standardization institutions.

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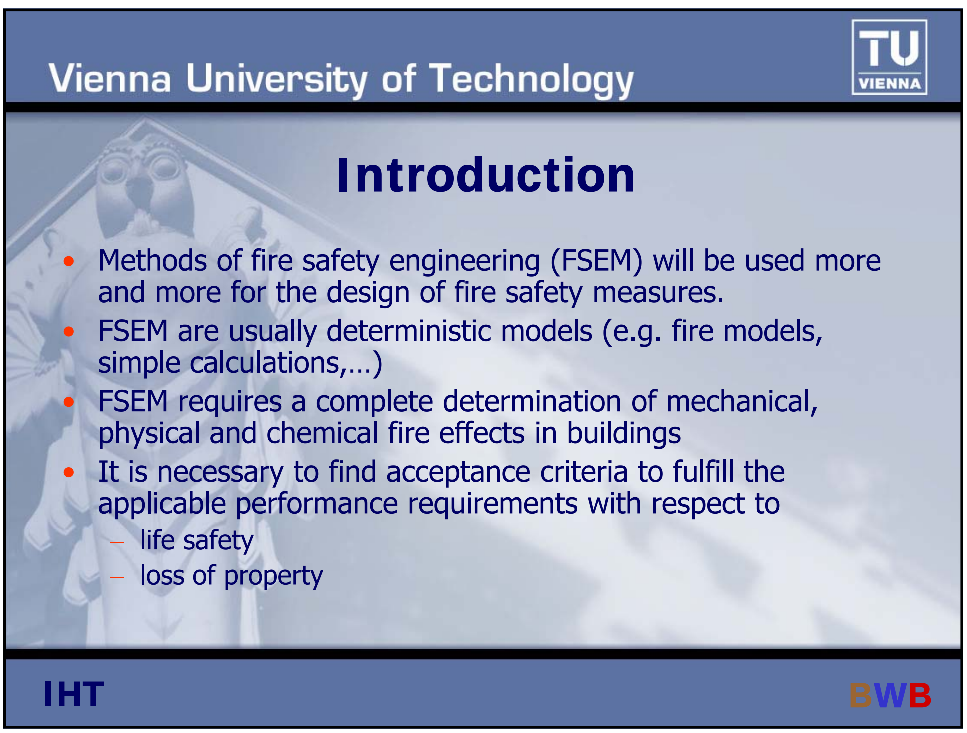
Vienna, 10th October 2007
Scientific perspective
and application of deterministic fire safety engineering methods
o. Univ. Prof. Dr. techn. Dr. h.c. Ulrich Schneider
Institute for Building Construction and Technology
Vienna University of Technology
IHT
BWB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Introduction
• Methods of fire safety engineering (FSEM) will be used more and more for the design of fire safety measures.
• FSEM are usually deterministic models (e.g. fire models, simple calculations,…)
• FSEM requires a complete determination of mechanical, physical and chemical fire effects in buildings
• It is necessary to find acceptance criteria to fulfill the applicable performance requirements with respect to
– life safety
– loss of property
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Vulnerability of FSEM

- Use of fire safety engineering methods can lead into dangerous errors
- Simulation (Calculation) of fire phenomena is not a trivial task and still part of scientific research
- Lot of uncertainties and variabilities exist
- Uncertainty analyses are highly recommended

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Acceptance criteria's for FSEM

- Various sources for acceptance criteria's
- different approaches

Main approaches are:

- Discrete values (mainly based on standards, laws, usually applicable for a discrete time period -> 30 min, engineering approach)
- FED methods (Purser, scientific approach)

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Comparison discrete values vs. FED

	Discrete values	FED methods
Usability	simple	complex
Sensitivity (e.g. changes of the burning material)	low	high – very high
Acceptance	high	high

FED: Fractional Effective Dose

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Recommended discrete Acceptance Criteria I

- e.g. Schneider et.al.
  - safety of persons
    - discrete value for layer interface > 2,5 m
    - temperature < 50 °C in the lower layer
    - CO_2 < 0.5 Vol% in the lower layer
  - safety of fire fighters
    - discrete value for layer interface > 2,0 m
    - temperature < 100 °C in the lower layer
    - temperature < 300 °C in the upper layer

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Acceptance Criteria II

- Different sources for survival conditions

Criteria	Condition	Condition with safety factor
Radiation	< 20 [kW/m²]	< 10 [kW/m²]
Oxygen Concentration	> 12 Vol.-%	> 14 Vol.-%
Carbon dioxide Concentration	< 6 Vol.-%	< 5 Vol.-%
Carbon monoxide Concentration	< 1400 ppm	< 700 ppm
Smoke interface height	> 1.50 m	> 1.80 m
minimal visibility	> 10 m	> 20 m
Temperature upper layer	< 600 °C	< 300 °C
Temperature upper layer	< 65 °C	< 50 °C

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Acceptance Criteria III

- Vfdb-Leitfaden “Ingenieurmethoden des Brandschutzes” (chapter 8)
  - Optic smoke concentration
  - Visibility range
  - Toxic effect of fire gases→ (FED)
  - Thermic effect of fire gases

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Toxic Potency [1]

Toxic potency can be considered in terms of:

- An individual toxic gas (for e.g. CO, HCl)
- A mixture of toxic products occurring in fire
- The mixture of toxic products evolved from the thermal decomposition under defined conditions of a particular material or product (such as wood etc.)

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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Toxic Potential of individual fire gases and mixtures

In fires three major toxic effects are important:

1. The concentration of irritant gases likely to impair escape efficiency or cause incapacitation (sensory irritation)
2. The exposure doses (Ct) of asphyxiant gases likely to cause incapacitation through confusion and loss of consciousness (or the cause of death)
3. The exposure dose of irritants likely to cause death through lung edema and inflammation after the fire

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Toxic effect of fire gases

- incapacitation or death occurs when the victim has inhaled a particular C*t* product dose of toxicants
- to make some estimate of the likely hazard in particular fire it is therefore necessary to determine at what point in time during the course of the fire exposure the victim will have inhaled a toxic dose
- This can be achieved by integrating the area under the fire profile curve for the toxicant under consideration

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Fractional Effective Dose [1]

- In order to make some estimate of the likely hazard in particular fire it is therefore necessary to determine at what point in time during the course of the fire exposure the victim will have inhaled a toxic dose
- This can be achieved by integrating the area under the fire profile curve for the toxicant.
- When the integral is equal to the toxic dose the victim can be assumed to have received a dose capable of producing the toxic effect

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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Fractional Effective Dose [1]

- practical method for making this calculation is the concept of fractional effective dose (FED)

$$\text{FED} = \frac{\text{dose received at time } t(\text{C}t)}{\text{effective C}t \text{ dose to cause incapacitation or death}}$$

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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FED: Incapacitation and Death [1]

- The FED acquired over a each period of time during the fire are summed until total FED_{IN} reaches unity, at which point incapacitation is predicted
- In order to allow for differences in sensitivity and to protect susceptible human subpopulation a factor of 0,1 FED should allow for safe escape of nearly all exposed individuals
- Death is predicted at approximately two to three times the incapacitating dose

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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The exposure of fire victims to heat [1]

There are three basic ways in which exposure of fire victims to heat may lead to incapacitation and death:

1. By heat stroke
2. By body surface burns, and
3. By respiratory tract burns

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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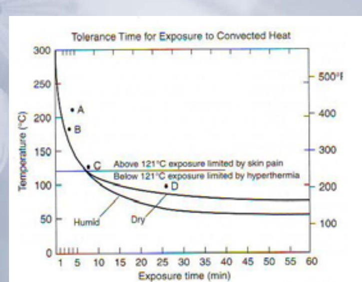
Heat stroke (Hyperthonia) [1]

Thermal tolerance for humans at rest, naked skin exposed, with low air movements



[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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Skin burns [1]

- Pain from the application of heat to skin occurs when the skin temperature at a depth of 0.1 mm reaches 44,8°C
- The temperature increases of the skin for the situation in which constant radiant heat is absorbed by the upper surface of the skin or heat from hot air current is applied to the skin.

[1] Purser, D.A, : Toxicity Assessment of Combustion Products

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UNCERTAINTY ANALYSIS

- Uncertainty is a quantification of the magnitude and sources of error, in this case error in the use of fire safety engineering methods (i.e. simulations)
- Not all types of error can be meaningfully quantified
- Assume that the use of fire safety engineering methods was completed consistent with good engineering practices and is therefore free of ordinary analytical mistakes (e.g. incorrect unit conversion, mathematical errors, software bugs)
- The human factor is a main source of errors in the application of FSEM

SFPE Engineering Guide to Application of Risk Assessment in Fire Protection Design

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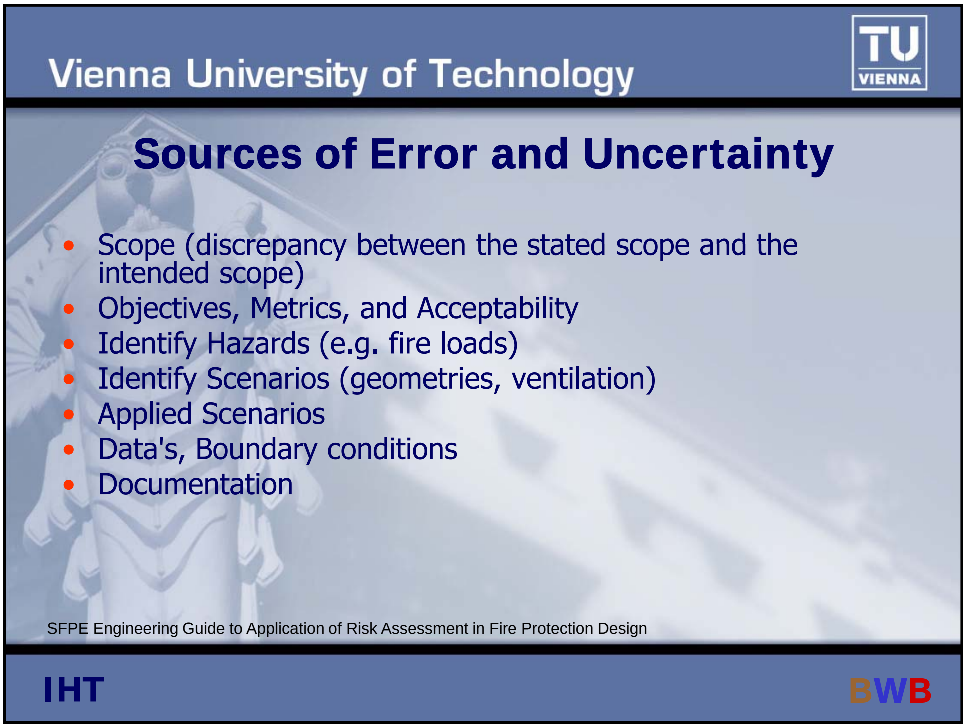
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Sources of Error and Uncertainty
Scope (discrepancy between the stated scope and the intended scope)
Objectives, Metrics, and Acceptability
Identify Hazards (e.g. fire loads)
Identify Scenarios (geometries, ventilation)
Applied Scenarios
Data's, Boundary conditions
Documentation
SFPE Engineering Guide to Application of Risk Assessment in Fire Protection Design
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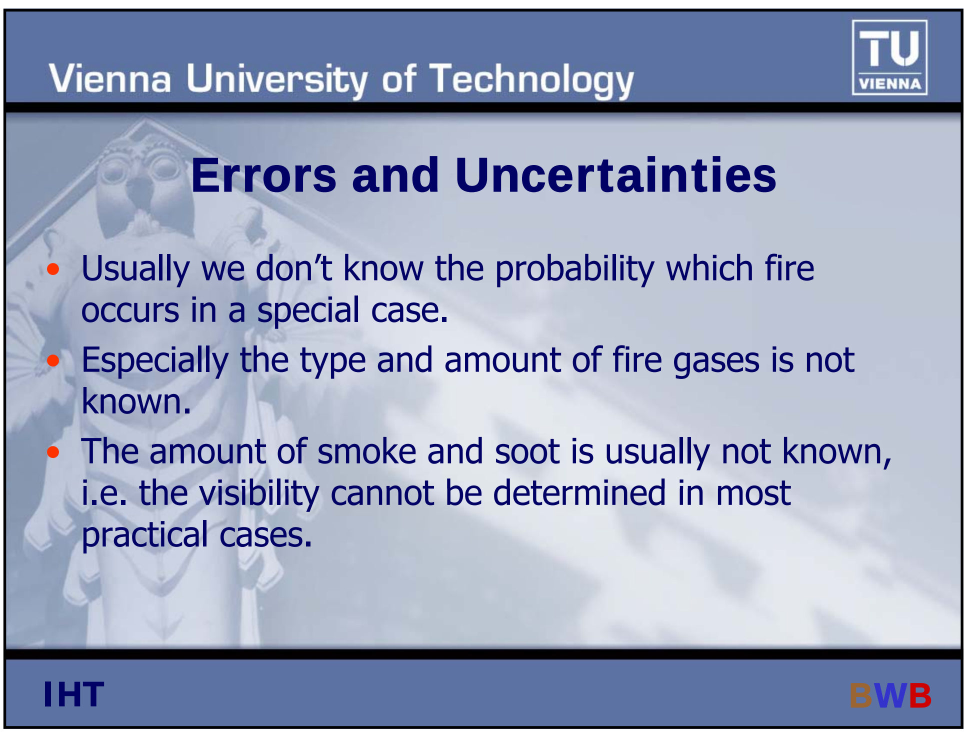
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Errors and Uncertainties
Usually we don’t know the probability which fire occurs in a special case.
Especially the type and amount of fire gases is not known.
The amount of smoke and soot is usually not known, i.e. the visibility cannot be determined in most practical cases.
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Recommended Steps for Estimating the Uncertainty

- Identify error sources and make top-level decisions on how each type or source of error will be addressed
- Develop error analysis strategy for specific types of error
- Quantify uncertainties associated with each part of use of a fire safety engineering method
- Propagate uncertainties
- Evaluate impact

SFPE Engineering Guide to Application of Risk Assessment in Fire Protection Design

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Safety level

- Examination of pre-defined design fire scenarios
- Often the design fire scenarios will be defined on heuristic knowledge (e.g. the most frequent fire based on the experience of the authorities or engineers)
- In very few cases "worst case" scenario will be used
- The distribution of the possible fire scenarios is usually unknown

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Safety factors I

- Acceptance criteria's itself are variable (usually not constant)
- For the evaluation of results from FESM safety factors are necessary because:
  - variability of effects (e.g. FEDs for different people)
  - uncertainties in the application of FSEM (does the examined design fire scenario apply)

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Safety factors II

- Purser recommended a safety factor of 0.1 for using FED for differences in sensitivity and to protect susceptible human subpopulation.
- Additional safety factors for uncertainties in application of FSEM and unknown probability design fire scenario are necessary

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Practical Example for the use of Acceptance Criteria at the Institute for Building Construction and Technology

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Description of the Problem

- The aim of the project was to determine with the help of scientific equipments the state of personal safety in underground railway stations/tunnels.
- This was made by determination of the smoke layer situations from selected tunnel/station ranges via numeric fire simulation and from views of evacuation via computations with the procedure after Predtetschenski and Milinski.

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Acceptance criteria (4 state model)

For the appraisal of the findings of the investigations 4 ultimate states have been defined, to which a degree of exposure with respect to the possibility of self- respectively external-rescue has been allocated.

Base for the 4 states were discrete acceptance criteria based on survival conditions with different safety factors for defined smoke layers

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4 State model

Name	State Description	Options of Escape / Rescue
State A ↓ ↓ **degree of exposure 1**	Safe escape possible, small effects on fleeing persons by the fire	Self- rescue possible
State B ↓ ↓ **degree of exposure 2**	Direct and indirect fire effects on fleeing persons but no life-threatening impacts; small risk of injury.	Self-rescue possible, external-rescue where required necessary

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4 State model

Name	State Description	Options of Escape / Rescue
State C ↓ ↓ **degree of exposure 3**	Massive direct and indirect fire effects on fleeing persons; high risk of injury, circumstances potentially life-threatening	Self-rescue only to a limited extent possible, external-rescue necessary
State D ↓ ↓ **degree of exposure 4**	circumstances directly life-threatening	Self-rescue not possible, external-rescue necessary, external-rescue where required only to a limited extent possible

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Acceptance criteria

State	Critical value in the lower layer for	
	CO_2-Concentration (R)	Temperature (T)
State A	x ≤ 0,1 Vol.-%	x ≤ 35°C
State B	0,1 Vol.-% < x ≤ 0,5 Vol.-%	35°C < x ≤ 50°C
State C	0,5 Vol.-% < x ≤ 5,0 Vol.-%	50°C < x ≤ 65°C
State D	x > 5 Vol.-%	x > 65°C

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Recommendations I

- From the scientific viewpoint the following recommendations for use of FSEM and acceptance criteria should be considered
  - Evaluation of probability of the selected design fire scenarios
  - Safety factors should be at least 0.1 (e.g. for FEDs or survival condition for a short period)

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Recommendations II

- Uncertainty and sensitivity analyses for FSEM should be always performed (e.g. parameter variations)
- The selected safety factor should always discussed in context with the boundary conditions (design fire, behavior and condition of people)
- Survival conditions or FED=1.0 should never be used

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Thank you
for your
attention!
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Interjurisdictional Regulatory Collaboration Committee

Performance Requirements & Criteria for FSE in Performance-Based Regulations

Brian J. Meacham
Arup / Worcester Polytechnic Institute

IRCC Workshop on Performance Requirements and Acceptance Criteria for Safety in Case of Fire

Hotel de France, Vienna, Austria – 10 October 2007

WPI ARUP

Interjurisdictional Regulatory Collaboration Committee

Safety in Case of Fire

- What does it mean?
- How do we define it?
- How do we measure it?
- How do we regulate it and design for it?

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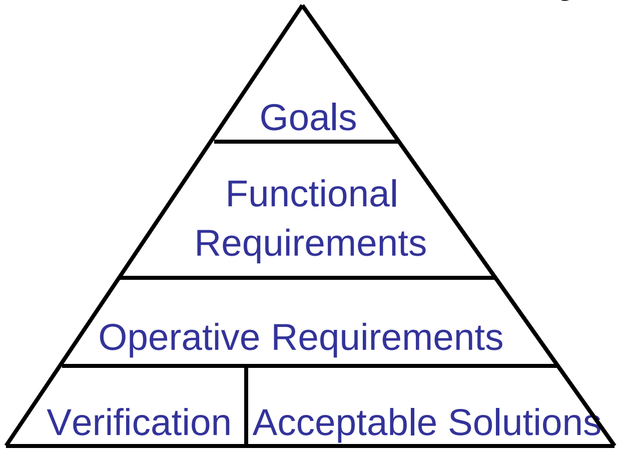
NKB 5-Tier Hierarchy



Classic FSE Goals

- Protection of people
- Protection of property
- Protection of mission
- Protection of heritage
- Protection of the environment
- Protection of community welfare

- Functional Requirement: Means of Egress
- England and Wales, 1991

  "B1 - The building shall be designed and constructed so that there are means of escape in case of fire from the building to a place of safety outside of the building capable of being safely and effectively used at all material times."

- Performance Requirement: Means of Egress
- New Zealand, 1992

  "C2.2 - Buildings shall be provided with escape routes which:

  (a) Give people adequate time to reach a safe place without being overcome by the effects of fire, and

  (b) Give fire service personnel adequate time to undertake rescue operations."

- Performance Requirements: Means of Egress
- Norway, 1997

  "7-27.1 - Construction works shall be designed and executed for rapid and safe escape. The time available for escape shall exceed the time necessary for escape from the construction works. Allowances shall be made for a satisfactory margin of safety."

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- Performance Requirement: Means of Egress
- NFPA 101, 2000

  "4.2.1 - A structure shall be designed, constructed and maintained to protect occupants who are not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place."

WPI | ARUP

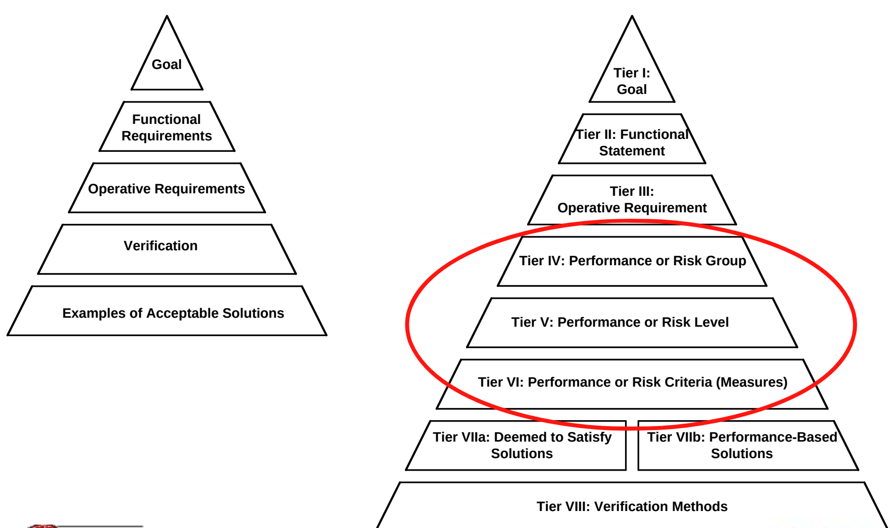
- Performance Requirement: Means of Egress
- ICC Performance Code for Buildings and Facilities, 2001

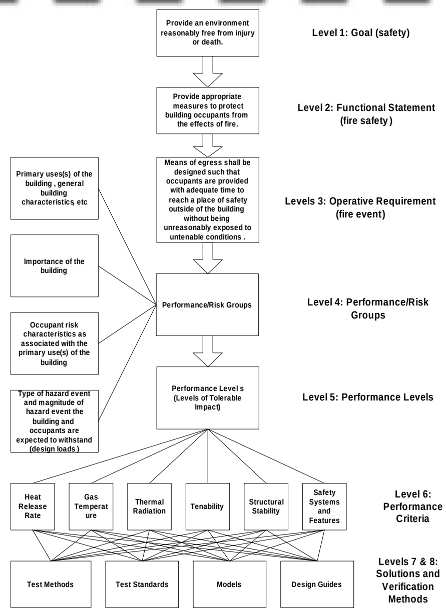
  "1901.2 - Enable occupants to exit the building, facility and premises, or reach a safe place as appropriate to the design performance level determined in Chapter 3."

Challenges with Existing

- In most cases, level of performance is unclear (adequate time? safe? under what conditions and assumptions?), loads are undefined, and criteria are not regulated
- Most codes assume 'deemed-to-comply' or 'approved documents' achieve a tolerable level of safety/risk, but rarely tested

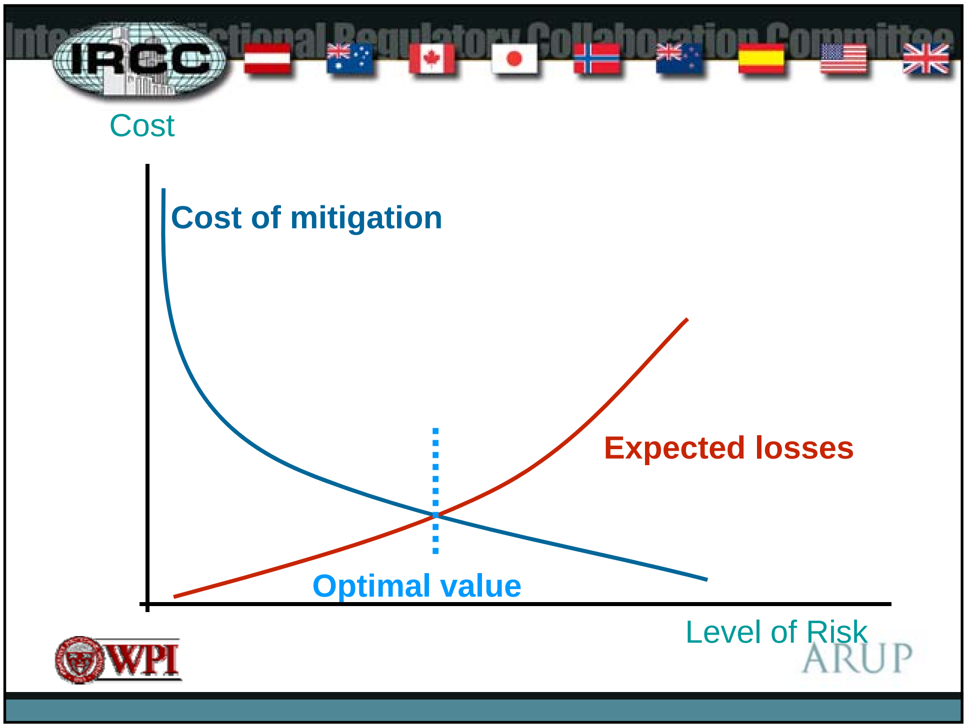
- NKB 5-tier Hierarchy
  - Level 1: Goals – essential interests of the community at large (society) with regard to the built environment.
  - Level 2: Functional Requirements – qualitative requirements of buildings or specific building elements
  - ***Level 3: Operative Requirements – actual (qualitative or quantitative) requirements, in terms of performance criteria or expanded functional descriptions.***
  - Level 4: Verification – instructions or guidelines for verification of compliance.
  - Level 5: Examples of Acceptable Solutions – supplements to the regulations with examples of solutions deemed to satisfy the requirements.

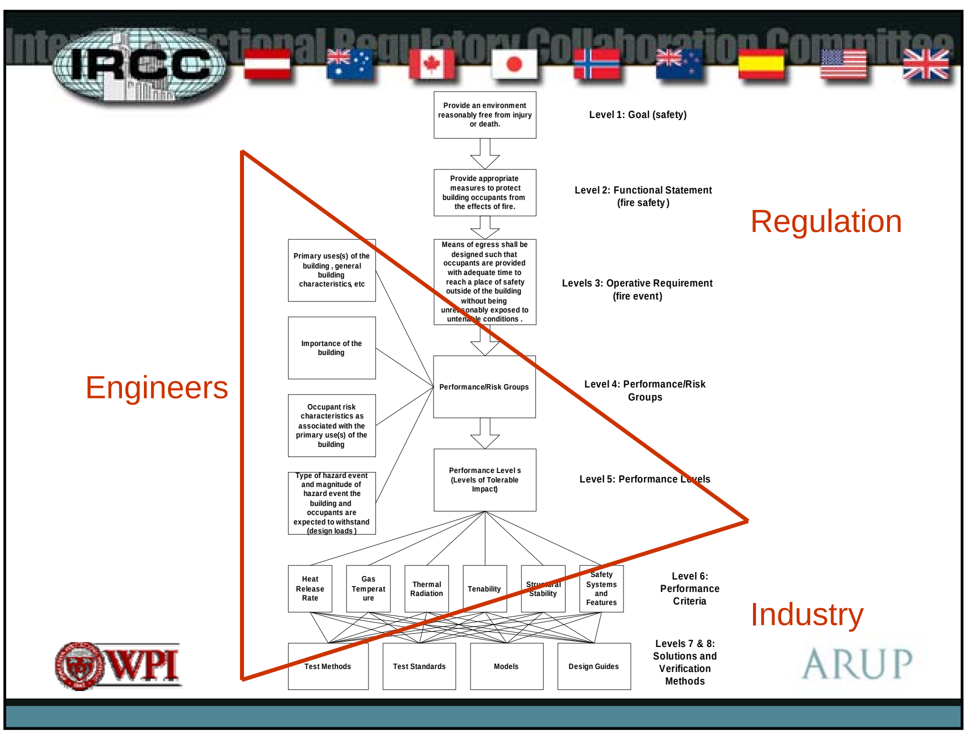


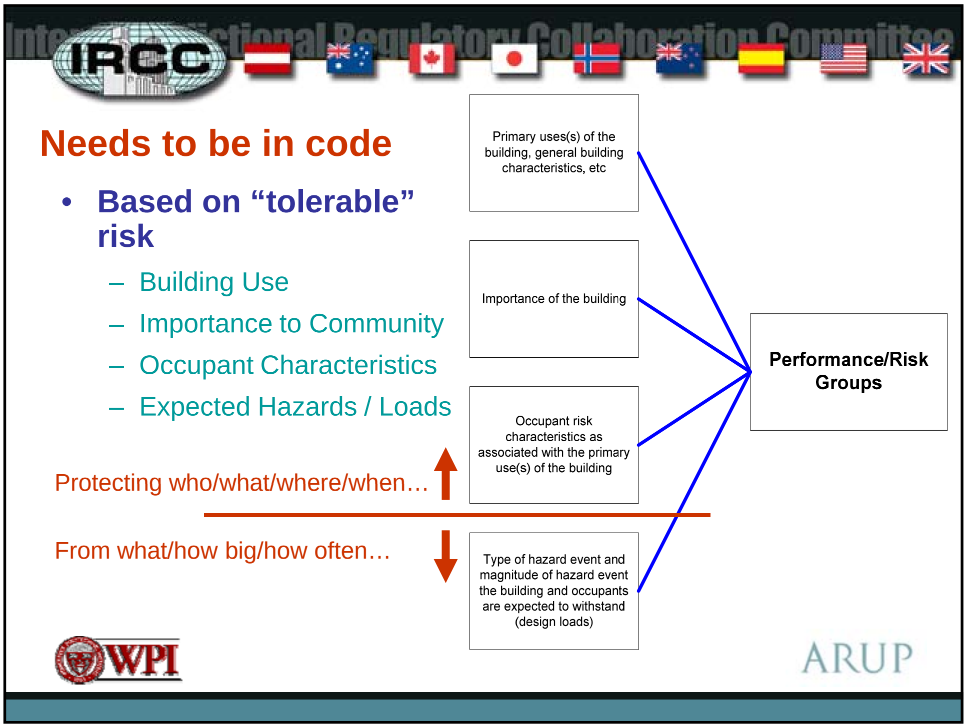


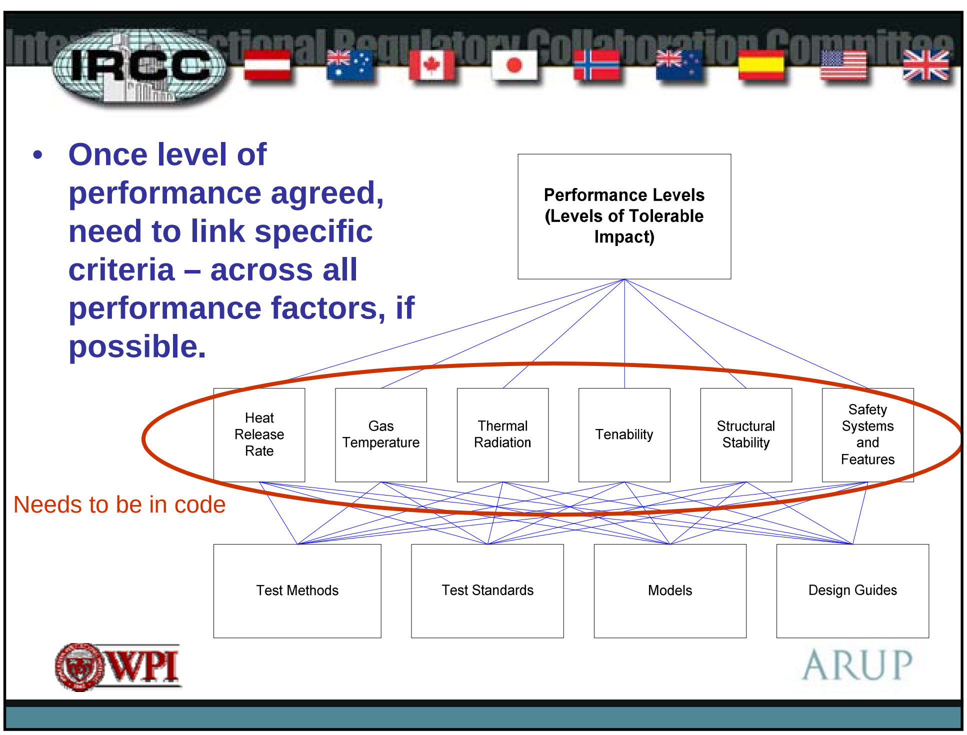
FSE Goals and Reality

- There is no such thing as ‘zero risk’ or absolute safety
- The objective is to protect most of the people, most of the time, with the level of risk/safety appropriately balanced with cost to society of risk mitigation and potential consequences
- Need to regulate for performance/risk levels, loads, and criteria


IRCC
Cost
Cost of mitigation
Expected losses
Optimal value
Level of Risk
WPI
ARUP


IRCC
Provide an environment reasonably free from injury or death.
Level 1: Goal (safety)
Provide appropriate measures to protect building occupants from the effects of fire.
Level 2: Functional Statement (fire safety)
Regulation
Primary uses(s) of the building , general building characteristics, etc
Means of egress shall be designed such that occupants are provided with adequate time to reach a place of safety outside of the building without being
Levels 3: Operative Requirement (fire event)
Importance of the building
Engineers
Performance/Risk Groups
Level 4: Performance/Risk Groups
Occupant risk characteristics as associated with the primary use(s) of the building
Type of hazard event and magnitude of hazard event the building and occupants are expected to withstand (design loads)
Performance Level s (Levels of Tolerable Impact)
Level 5: Performance
Heat Release Rate
Gas Temperat ure
Thermal Radiation
Tenability
Stability
Safety Systems and Features
Level 6: Performance Criteria
Industry
Test Methods
Test Standards
Models
Design Guides
Levels 7 & 8: Solutions and Verification Methods
WPI
ARUP

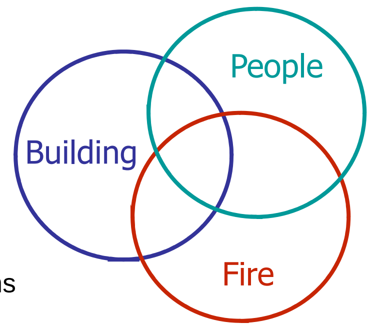

International Regulatory Collaboration Committee
IRCC
Needs to be in code
Based on "tolerable" risk
– Building Use
– Importance to Community
– Occupant Characteristics
– Expected Hazards / Loads
Protecting who/what/where/when…
From what/how big/how often…
Primary uses(s) of the building, general building characteristics, etc
Importance of the building
Occupant risk characteristics as associated with the primary use(s) of the building
Type of hazard event and magnitude of hazard event the building and occupants are expected to withstand (design loads)
Performance/Risk Groups
WPI
ARUP


International Regulatory Collaboration Committee
IRCC
Once level of performance agreed, need to link specific criteria – across all performance factors, if possible.
Performance Levels (Levels of Tolerable Impact)
Heat Release Rate
Gas Temperature
Thermal Radiation
Tenability
Structural Stability
Safety Systems and Features
Needs to be in code
Test Methods
Test Standards
Models
Design Guides
WPI
ARUP

Fire is Complex Problem

Architecture
Aesthetics
Comfort
Useability
Accessibility

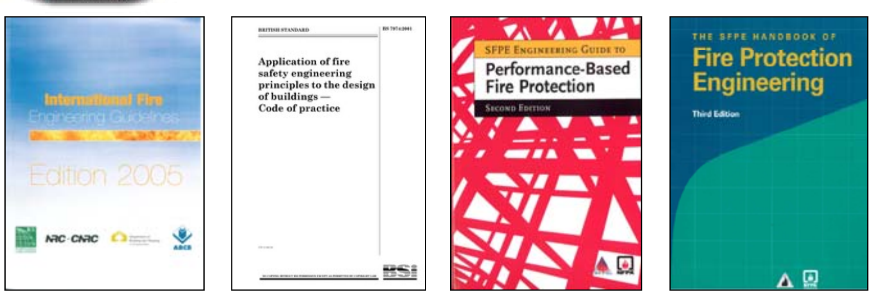
Materials
Geometry
Contents
Ventilation
Protection systems



Demographics
Abilities
Physiology
Decision-making
Response to hazards
Risk Tolerance

Fuel type
Arrangement
Load

WPI ARUP



BS7974 Code of Practice – Application of fire safety engineering principles to the design of buildings							
BSPD7974-0	BSPD7974-1	BSPD7974-2	BSPD7974-3	BSPD7974-4	BSPD7974-5	BSPD7974-6	BSPD7974-7
Guide to design framework and fire safety engineering procedures	Initiation and development of fire within enclosure of origin	Spread of smoke and toxic gases within and beyond the enclosure of origin	Structural response and fire spread beyond the enclosure of origin	Detection of fire and activation of fire protection systems	Fire service intervention	Evacuation	Probabilistic risk assessment

WPI ARUP

Approach for Fire Safety

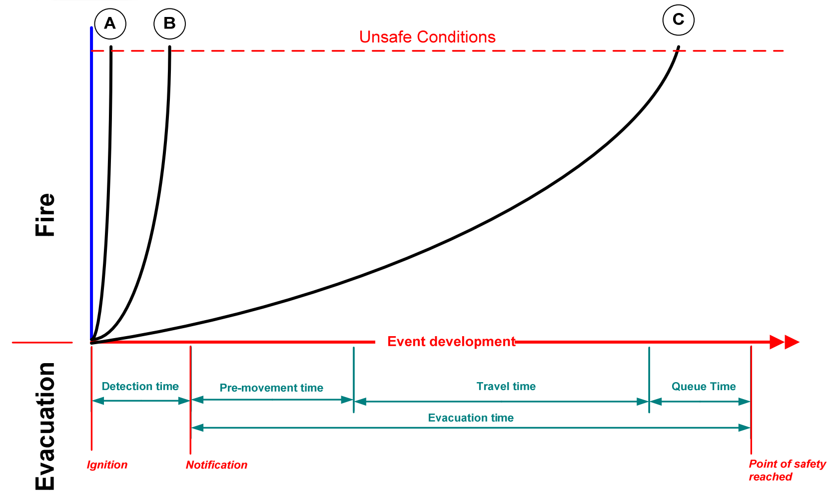
- **Define methodology for assessing fire / life safety**
- **Characterize the occupants**
- **Identify risk/performance groups/levels**
- **Select appropriate metrics for factors such as fire/smoke spread, tenability limits, and safe egress time (tolerable impacts)**
- **Define the magnitude of the design load/scenario**
- **Account for uncertainty, variability, sensitivity**

WPI ARUP

Life Safety

- Allow time for those not intimate with initial fire develop to reach a place of safety
- Generally accepted approach for dealing with safety to life in fire is ASET/RSET
  - ASET: available safe egress time (time to untenable conditions)
  - RSET: required safe egress time (time it is estimated to take people to get out)

WPI ARUP



Occupant Characterization

- Identify risk factors
  - Awake or asleep, ability, familiarity with building, age, dependencies, relationships, physiology
- Address by risk/performance groups and performance indicators
  - For example, buildings with large groups of people, or people who cannot care for themselves, may need more protection

ARUP

Performance Criteria

- Life safety
  - Deterministic
    - Criteria include time-dependent temperatures, radiant heat flux, clear layer, visibility, optical density, species concentration, FED, …
  - Probabilistic
    - Risk-informed / risk-based / frequency-based

WPI ARUP

Protection of Property

- Based on objectives in code
  - No fire spread beyond compartment of fire origin / floor or area of origin / building of origin
  - No damage to another's property
  - No collapse before occupants out and reasonable fire fighting operations
  - No collapse

WPI ARUP

Performance Criteria

- Protection of property
  - Deterministic
    - Ignition temperature, damage/failure temperature, radiant heat flux,… resistance to ignition, resistance to flame spread, resistance to temperature, …
  - Probabilistic
    - Risk-informed / risk-based / frequency-based

WPI ARUP

Performance Criteria

Smoke layer interface	2.5m @ 200 degC	
Temperature	100 degC <10% H_2O	8 minutes
	180 degC <10% H_2O	1 minute
Heat flux	2.5 kWm-2	30 minutes
	10 kWm-2	4 minutes
Smoke density	10 m	Large buildings
	5 m	Small buildings
CO concentration	800 ppm	5 min exposure (fuel contains nitrogen >2% by mass)
	125 ppm	30 min exposure (fuel contains nitrogen >2% by mass)
	1200 ppm	5 min exposure (fuel contains nitrogen <2% by mass)
	275 ppm	30 min exposure (fuel contains nitrogen <2% by mass)

WPI ARUP

Performance Criteria

- Clear height above floor (example)
  - 2.50m (BS7974)
  - 2.00m (BCA)
  - 1.83m (SFPE Design Guide)
  - 1.80m (BSL Japan)

WPI ARUP

Performance Criteria

- Clear height above floor (example)
  - 2.50m (BS7974)
  - 2.00m (BCA)
  - 1.83m (SFPE Design Guide)
  - 1.80m (BSL Japan)
- What is the “right” value?

WPI ARUP

Magnitude of Fire Event

- Difficult to quantify in the same manner as natural hazard because of human factor
- Instead of 'return period' approach perhaps use a 'scenario based' approach
- To provide some consistency, need to characterize 'design fire loads' (scenarios) for specific building uses / occupant risks

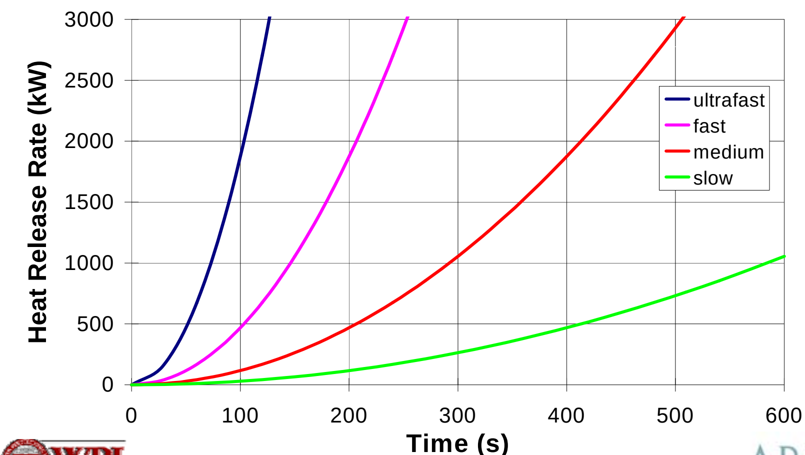
NFPA 101 and NFPA 5000

- 8 design fire scenarios specified
  - Occupancy specific scenario
  - Ultra-fast fire in the primary means of egress
  - Fire originates in a normally unoccupied room
  - Fire originates in a concealed space
  - Slowly developing, shielded fire
  - Most severe fire given largest expected fuel load
  - Outside exposure fire
  - Fire with failure of active and passive FP systems

Design Fire Scenarios/Loads

- Design fire scenarios
  - Deterministic
    - From ignition to extinguishment
    - Ignition temperature, flame spread, rate or heat release, growth rate, species production rate, …
    - Representative set of scenarios
  - Probabilistic
    - Risk-informed / risk-based / frequency-based

Design Fires – Growth and HRR



Uncertainty and Variability

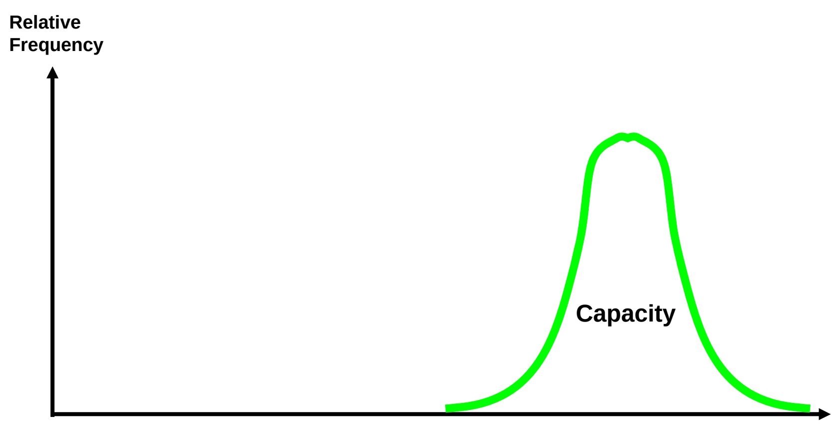
- Uncertainty and variability exist in all parts of the problem – characterizing occupants, selecting criteria, defining fires, application of analysis methods
  - Uncertainty can be reduced with more knowledge (burning rate of material)
  - Variability is a function of randomness and cannot be reduced by more knowledge (number of disabled in any given building)

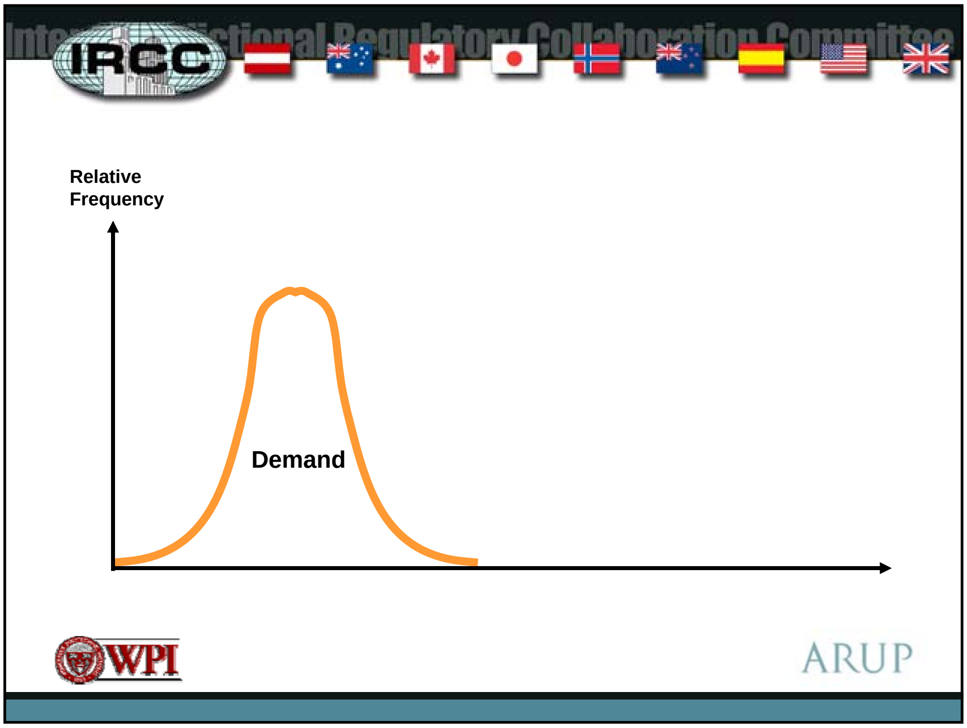
Sensitivity Analysis

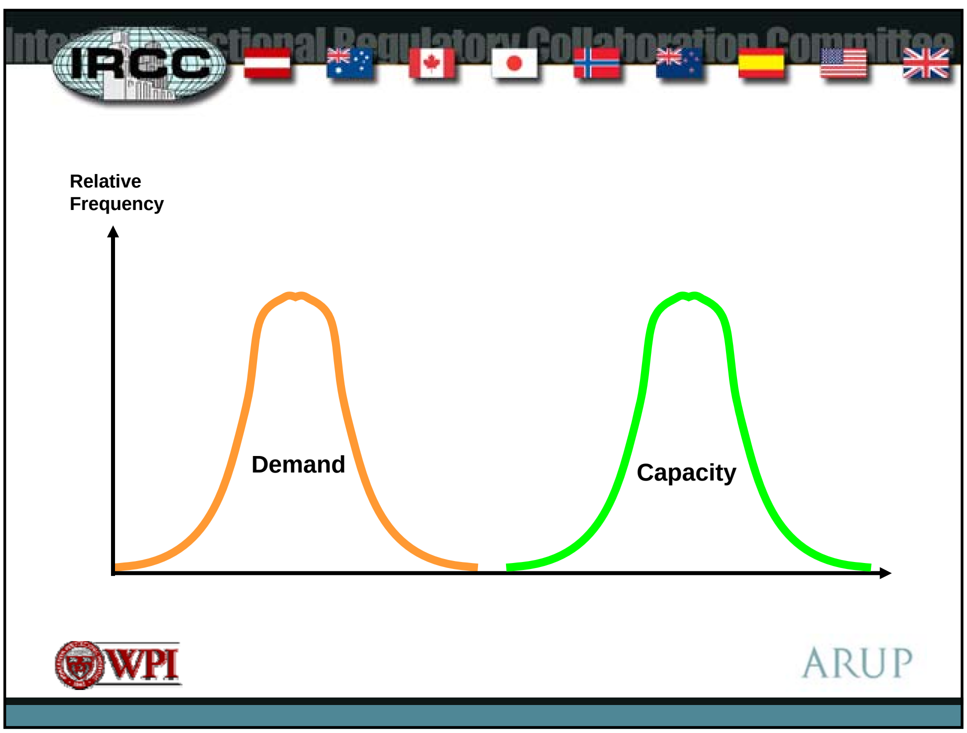
- Vary parameters one at a time to look for critical variations, especially those that might make a 'safe' outcome an 'unsafe' outcome
- Use to focus in on parameters of concern

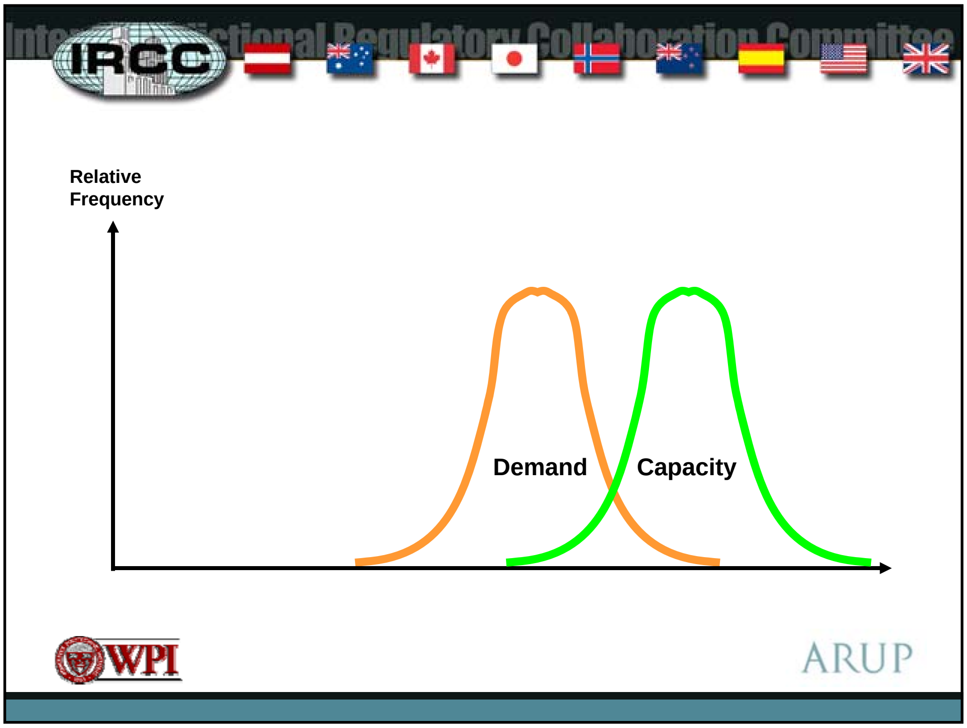
Addressing Uncertainty & Variability

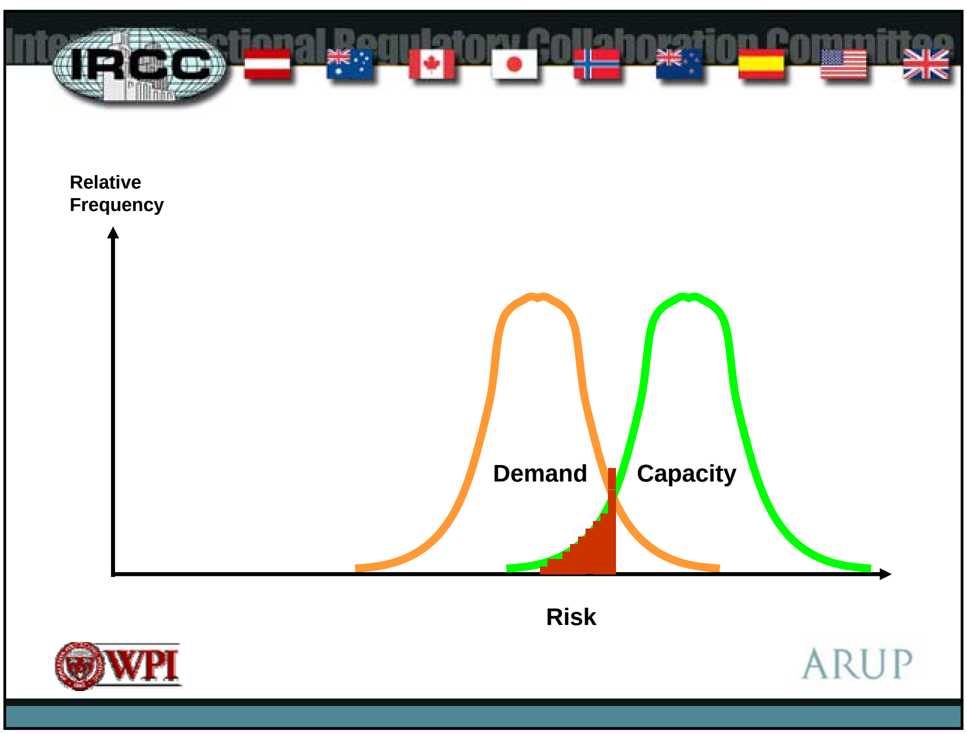
- A reasonable approach for fire may be in the structural safety analogy – safety index, or load and resistance factor design
- Has been discussed by Magnusson and others some 20 years ago, but concepts not widely used or refined for regulation




IRCC
Relative Frequency
Demand
WPI
ARUP


IRCC
Relative Frequency
Demand
Capacity
WPI
ARUP


Interjurisdictional Regulatory Collaboration Committee
IRCC
Relative
Frequency
Demand
Capacity
WPI
ARUP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IRCC
Relative
Frequency
Demand
Capacity
Risk
WPI
ARUP

Summary / Suggestions

- The basic approach to performance objectives in codes is ok as a starting point
- However, many codes need to establish risk/performance levels, characterize the occupants and fire events (loads, scenarios), select performance criteria (from existing sources), test the combinations, and incorporate appropriate loads and criteria

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Summary / Suggestions

- Design fire scenarios should reflect realistic challenges to buildings, taking into consideration that contents, arrangement and ventilation can vary, and that system reliability is not 100%.
- Selection of performance criteria should be based on accurate reflection of current knowledge, accounting for uncertainty.

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International Regulatory Collaboration Committee

IRCC

Summary / Suggestions

- Specification of design fire scenarios (loads) and criteria does not limit innovation, but provides better understanding of performance being delivered (at least designed).
- Need to account for risk, cost, uncertainty and variability in a defensible manner.

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Performance Requirements & Criteria for FSE: Directions in USA, New Zealand and Australia

Brian J. Meacham
Arup / Worcester Polytechnic Institute

IRCC Workshop on Performance Requirements and Acceptance Criteria for Safety in Case of Fire

Hotel de France, Vienna, Austria – 10 October 2007

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USA

- Performance code exists, but mostly prescriptive code used with 'alternative methods' clause invoked for FSE
- Guidance is general – loads are undefined and criteria are not regulated – current level of performance is unclear (difficult to assess 'equivalency')

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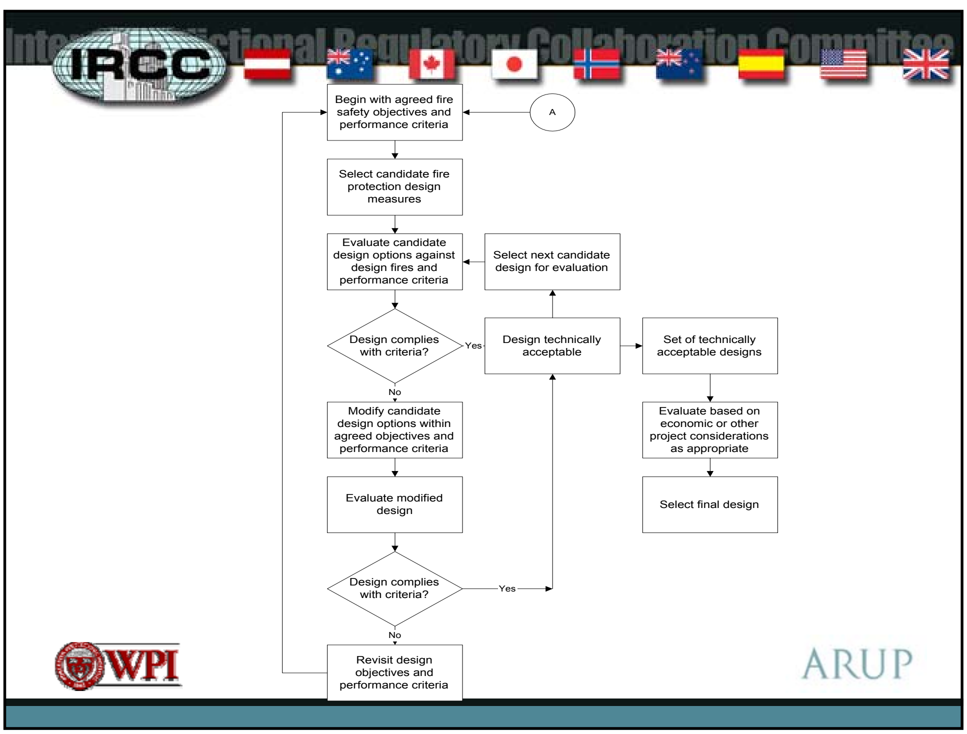
Inter-Jurisdictional Regulatory Collaboration Committee
IRCC
ICC Performance Code for Buildings and Facilities
2001
International Building Code
2000
2003 EDITION
BUILDING CONSTRUCTION AND SAFETY CODE
NFPA 5000
NFPA 101
Life Safety Code
2000 Edition
THE SFPE HANDBOOK OF
Fire Protection Engineering
Third Edition
SFPE ENGINEERING GUIDE TO
Performance-Based Fire Protection
SECOND EDITION
Engineering Guide
Fire Risk Assessment
November 2006
International Fire Engineering Guidelines
Edition 2005
WPI
ARUP


Inter-Jurisdictional Regulatory Collaboration Committee
IRCC
Begin with agreed fire safety objectives and performance criteria
A
Select candidate fire protection design measures
Evaluate candidate design options against design fires and performance criteria
Select next candidate design for evaluation
Design complies with criteria?
Yes
Design technically acceptable
Set of technically acceptable designs
No
Modify candidate design options within agreed objectives and performance criteria
Evaluate based on economic or other project considerations as appropriate
Evaluate modified design
Select final design
Design complies with criteria?
Yes
No
Revisit design objectives and performance criteria
WPI
ARUP

ICC - Measures of Performance

- ICC Performance Code Performance Groups
    - Based on Use, Risk Factors, Importance Factors
  - Building Performance Levels (Tolerable Levels of Impact)
    - Based on perceptions and expectations of risk, past experience, social tolerability, cost/benefit
  - Magnitude of Design Hazard Events
    - Based on loss data, deterministic and/or probabilistic analysis

ICC - Measures of Performance

INCREASING LEVEL OF BUILDING PERFORMANCE →→→→→→→→→→→→→→→→→→→

PERFORMANCE GROUPS

MAGNITUDE OF DESIGN EVENT (INCREASING MAGNITUDE OF EVENT ↑)	Performance Group I	Performance Group II	Performance Group III	Performance Group IV
VERY LARGE (Very Rare)	SEVERE	SEVERE	HIGH	MODERATE
LARGE (Rare)	SEVERE	HIGH	MODERATE	MILD
MEDIUM (Less Frequent)	HIGH	MODERATE	MILD	MILD
SMALL (Frequent)	MODERATE	MILD	MILD	MILD

Design Fire Scenarios - NFPA 5000

- There are **eight** required fire design scenarios that must be applied to each proposed design.
  - These fire design scenarios were developed through consultation with NFPA Technical Committee members, originally as part of the development of the performance option in the Life Safety Code, and later carried over into NFPA 5000.
  - The intent of the consultation was to obtain a broad perspective from a diversity of interest groups as to significant factors that may impact the severity of a fire.

Design Fire Scenarios - NFPA 5000

- *Fire Design Scenario 1*: Occupancy-specific design scenario representative of a typical fire for the occupancy. This scenario must explicitly state the following:
  - Occupant activities
  - Number and location of occupants
  - Room size
  - Furnishings and contents
  - Fuel properties and ignition sources
  - Ventilation conditions
  - First item ignited and its location

Design Fire Scenarios - NFPA 5000

- *Fire Design Scenario 2*: An ultra-fast developing fire in the primary means of egress, with interior doors open at the start of the fire.
- *Fire Design Scenario 3*: A fire that starts in a normally unoccupied room that can potentially endanger a large number of occupants in a large room or other area.
- *Fire Design Scenario 4*: A fire that originates in a concealed wall or ceiling space adjacent to a large, occupied room.

Design Fire Scenarios - NFPA 5000

- *Fire Design Scenario 5*: A slow developing fire, shielded from fire protection systems, in close proximity to a high occupancy area.
- *Fire Design Scenario 6*: The most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building.
- *Fire Design Scenario 7*: An outside exposure fire.

Design Fire Scenarios - NFPA 5000

- *Fire Design Scenario 8*: A fire originating in ordinary combustibles in a room or area with each passive or active fire protection system or feature independently rendered ineffective.
  - This scenario is not required for fire protection systems for which both the level of reliability and the design performance in the absence of the system or feature are acceptable to the authority having jurisdiction.

NZ Building Code

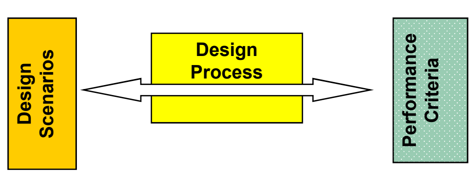
- Currently the level of performance is unclear (adequate time? safe? under what conditions and assumptions?), loads are undefined, and criteria are not regulated
- NZBC assumes 'deemed-to-comply' requirements achieve a tolerable level of safety/risk, but this has not been tested

Review of the NZ Building Code

- Motivated by perceived weakness in the building code quite separate from the fire
- Involves a complete review of the structure and content of the Building Code to match the requirements of the Building Act 2004.
- Proposed to adopt the 8-tier Inter-jurisdictional Regulatory Collaboration Committee (IRCC) hierarchy.

Tolerable Impacts

Design Event	Performance Group I	Performance Group II	Performance Group III	Performance Group IV
Very Large (Very Rare)	Severe	Severe	High	Moderate
Large (Rare)	Severe	High	Moderate	Mild
Medium (Seldom)	High	Moderate	Mild	Mild
Small (Frequent)	Moderate	Mild	Mild	Mild



NZ - Design Fire Scenarios

- Chose to adapt NFPA 5000 scenarios due to comprehensive nature of the scenarios.
- Explored ETA approach of ISO16733 *Selection of Design Fires Scenarios and Design Fires*.
  - Group not convinced work required to carry out such analysis would result in substantially different set of scenarios.
  - Group did not believe there was sufficient reliable data to carry out event tree analysis in all occupancies
  - Timeline for completion of the project did not allow the event tree analysis

WPI ARUP

NZ - Design Scenarios

1. Occupancy specific fire scenarios
2. Fire blocks a primary means of escape
3. Fire that starts in normally unoccupied room
4. Fire that starts in a concealed space
5. Smouldering fire in sleeping area
6. Fire exposing neighbouring property
7. Fire external to the building exposing façade
8. Fire involving surface linings

WPI ARUP

International Regulatory Collaboration Committee

Use of Space	Fire Growth Rate (°) (kW/s²)	FLED (MJ/m²)	Peak HRR (kW/m²)	Species Production	References
Crowd Activities					
Auditoriums	Fast	400	100 (1)	2	
Backstage areas	Fast	400		2	
Baggage handling	Fast	800		1	
Bars	Fast	400		1	
Cafeteria	Fast	400		2	
Chapel Fixed seating	Fast	400		2	
Airport check-in areas	Fast	800*		1	
Childcare (Non Sleeping)	Fast	400	250 (2)	1	
School Classrooms	Fast	400	290 (3)	2	
Computer labs	Fast	400	290 (3)	2	
Computer rooms (Low occupant load)	Fast	400	290 (3)	2	

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International Regulatory Collaboration Committee

NZ - Tenability Criteria for Life Safety

- Simple Criteria
  - Minimum clear layer height of 2.5 m
  - Maximum upper layer temperature of 200°C
- Detailed Criteria PD 7974-6
  - Fractional Effective Dose (FED) for Narcotic Gases
  - Fractional Effective Dose (FED) for Radiant and Convective Heat
  - Visibility

WPI ARUP

NZ - Tenability Criteria – FED

- Fractional Effective Dose for Narcotic Gases
  - Accounts for cumulative effects of CO, O_2 depletion & CO_2 effects on respiration rate.
  - **FED ≤ 0.3** → suitable for most general occupancies
  - FED's may be determined at a height of **2.0m**

NZ - Tenability Criteria – FED

- Fractional Effective Dose for Radiant and Convective Heat
  - Accounts for cumulative exposure to skin to radiant heat (2nd degree burns) and to convective heat from air.
  - **FED ≤ 0.3** → suitable for most general occupancies.
  - FED's may be determined at a height of **2.0m**

Tenability Criteria - Visibility

- Visibility not less than 5 m, for rooms/spaces ≤ 100 m²
- Visibility not less than 10 m, for rooms/spaces > 100 m² (or distance to nearest exit, if < 10 m)
- Visibility may be determined at a height of **2.0m**
- Calculation Methods: can be determined based on predicted smoke/soot concentration in the gas layer.

NZ - Uncertainty

- Uncertainty exists in designs because
  - Of a lack of research results and data
  - Differences in assumed and actual fires in a building (conditions that will prevail)
  - Designers will use some inputs to drive calculations, which will therefore contain uncertainty

NZ - Dealing with Uncertainty

- At least two ways to deal with uncertainty
- Fire scenarios could be conservative so that the acceptance criteria is weighted towards the side of safety
  - Rather blunt approach
  - Not clear where the factors of safety are

NZ - Dealing with Uncertainty

- Calculations could rely on the best available estimates for parameters with factors of safety added along the way
  - Clearly more transparent
  - Not clear what the factors of safety are, or should be for the compliance document

NZ - Ongoing Assessment

- 11 case study buildings have been chosen representing a range of typical C/AS1 compliant buildings (residential, commercial, storage and public)
- Tested for life safety, against the proposed tenability criteria, for the eight design fire scenarios using the fire loads described for the appropriate use.

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NZ - Ongoing Assessment

- The aim of the work is to ensure the proposed framework generates the same level of performance as the existing compliance document.
- For this to be true the case buildings should pass the design fire scenarios, but not wildly exceed them.

WPI ARUP

Australia

- Currently the level of performance is unclear (adequate time? safe? under what conditions and assumptions?), loads are undefined, and criteria are not regulated
- BCA assumes 'deemed-to-comply' requirements achieve a tolerable level of safety/risk, but this has not been tested

WPI ARUP

Australia

- Council of Australian Governments – Principles and Guidelines for National Standard Setting and Regulatory Action by Ministerial Councils and Standard-Setting Bodies-
  - Regulation should be performance based and focussed on outcomes
  - Regulation should be compatible with relevant international standards and practices to minimise impediments to trade
- 2002 – Campbell Report on Quality in Buildings (NSW) –
  - Application of the BCA in NSW to clearly prescribe "Performance Requirements" with measurable and objective criteria to reduce disputes and uncertainty in home building matters

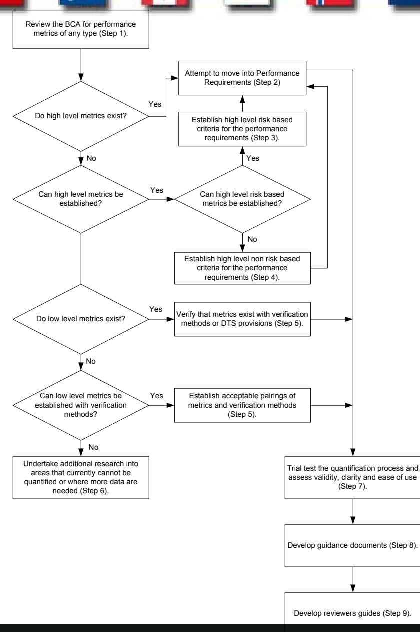
WPI ARUP

Australia

- 2004 – Productivity Commission Report on Reform of Building Regulation - recommended ABCB should enhance efforts to-
  - Make the BCA performance based requirements more effective by providing measurable criteria to aid judging compliance and clarifying the assessment process to be used
  - Ensure all DTS offer an equivalent level of building performance to the performance requirements
- 2006 – ABCB Intergovernmental Agreement - BCA requirements are to be performance based and verifiable based on appropriate international standards

Australia

- 2006 -2008 ABCB work program – Quantification of performance provisions-
  - Commissioned Brian Meacham to develop Protocol for Quantification of Performance; and Strategy for Quantifying Fire Safety Performance in BCA
  - Developed standardised assessment process
- 2007 Strategic Review of the BCA against COAG Principles –
  - high level of stakeholder support for current BCA



Australia - Observations

- The current level of fire risk / safety / performance in Australia is tolerable, albeit un-quantified.
- There is an aim to provide mechanisms for practitioners and authorities to evaluate alternative designs with the objective of providing a level of fire risk / safety / performance that is equivalent or higher than the levels achieved by complying with the deemed-to-satisfy provisions of the BCA.

Australia - Observations

- In order to achieve the above objectives, it is necessary to somehow describe the current level of building fire risk / safety / performance in Australia.
- Assuming that agreeable levels of building fire risk / safety / performance in Australia can be adequately described, these can be use to calibrate design fire scenarios, performance criteria and verification methods aimed at delivering equivalent levels.

Australia - Observations

- In targeting an appropriate level of analysis, it is recognized that at one end of the spectrum, a full 'first principles' performance analysis option exists, and there is no intent to prohibit this option. At the other end of the spectrum there are deemed-to-satisfy provisions, which offer little insight regarding quantified level of performance achieved through compliance. The aim therefore is to provide an option somewhere in between, where a combination of fire scenarios, performance criteria and verification methods can be identified that, when applied, will provide for alternate designs which are calibrated to the level of risk / performance achieved through compliance with deemed-to-satisfy provisions.

Australia – Next Steps

- Analyze the existing fire loss data to understand better the types of fires that have been experienced, the response to those fires, and the resultant risk tolerance levels,
- Apply risk characterization techniques, using the available fire loss statistics, variations in building configuration allowed by the BCA, and stakeholder input, to gain an understanding of the perceived fire performance and risk with code-compliant buildings, and develop a risk / performance ranking / indexing scheme for building classes and configurations,

Australia – Next Steps

- Develop representative design fire loads / scenarios, and fire and life safety performance (acceptance, design) criteria, which reflect realistic fire performance in code-compliant buildings and are informed by the fire loss statistics, other pertinent fire and life safety data, and risk characterization outcomes, along with acceptable evaluation / verification methods, to evaluate the performance of code-compliant buildings,

Australia – Next Steps

- Evaluate the performance of code-compliant buildings using fire loads (scenarios), performance criteria and methods in comparison to the risk / performance levels identified using an ASET/RSET approach, and

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Australia – Next Steps

- Develop recommendations for changes to risk / performance levels / classifications of buildings (if needed), develop recommendations for fire scenarios, criteria and verification methods which can adequately assess building fire performance within the risk levels, and develop recommendations related to what aspects of fire scenarios, criteria and verification methods should go into the IFEG and which can be brought up into the BCA.

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Australia – Approach

- Characterize the risk / performance level of the target building with respect to compliance with the BCA and available fire loss data. (May require looking across all building classes and characterizing risk / performance by class.) Clearly identify features to impact risk / performance level (e.g., fire hazard present, occupant characteristics, etc). Will require characterizing the occupant population, expected range of fire scenarios, potential performance criteria, and critical assumptions necessary to undertake a fire engineering analysis in the target building.

Australia – Approach

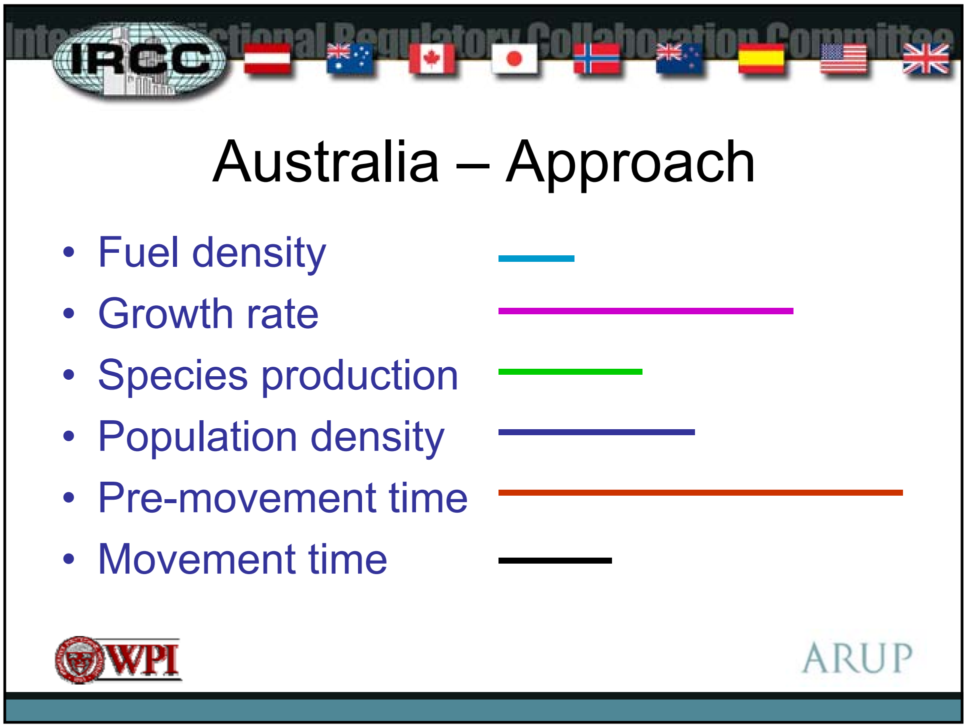
- Identify three characteristic values – which are representative of the median and both ends of the range (such as likely/frequent/small, median, and rare but extreme/very large) – for each of the above parameters (i.e., occupant population, expected range of fire scenarios, potential performance criteria, and critical assumptions) (based on review of literature and sensitivity analysis, as appropriate).

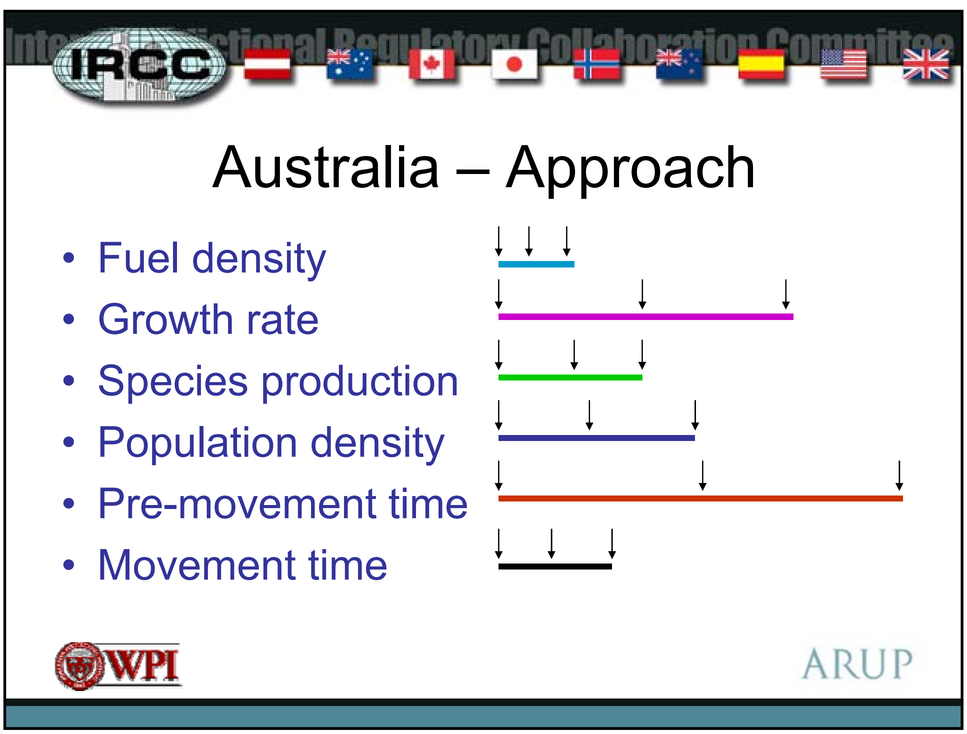
Australia – Approach

- Undertake analysis (modeling) of the identified building over the range of all combinations of the above parameters (e.g., small/slow/smoldering fire, low occupant density, non-conservative pre-movement times and tenability criteria; medium/fast fire, low occupant density, non-conservative pre-movement times and tenability criteria; ultra-fast fire, low occupant density, non-conservative pre-movement times and tenability criteria; etc).

Australia - Approach

- Clear height above floor (example)
  - 2.50m (BS7974)
  - 2.00m (BCA)
  - 1.83m (SFPE Design Guide)
  - 1.80m (BSL Japan)


IRCC
Australia – Approach
• Fuel density
• Growth rate
• Species production
• Population density
• Pre-movement time
• Movement time
WPI
ARUP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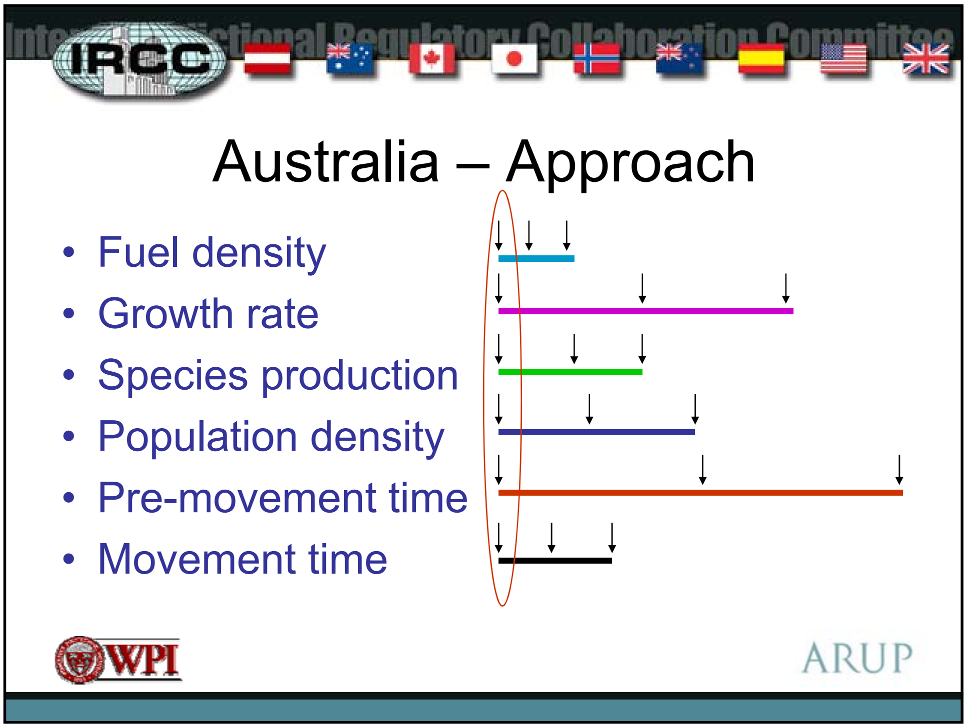
Inter-jurisdictional Regulatory Collaboration Committee
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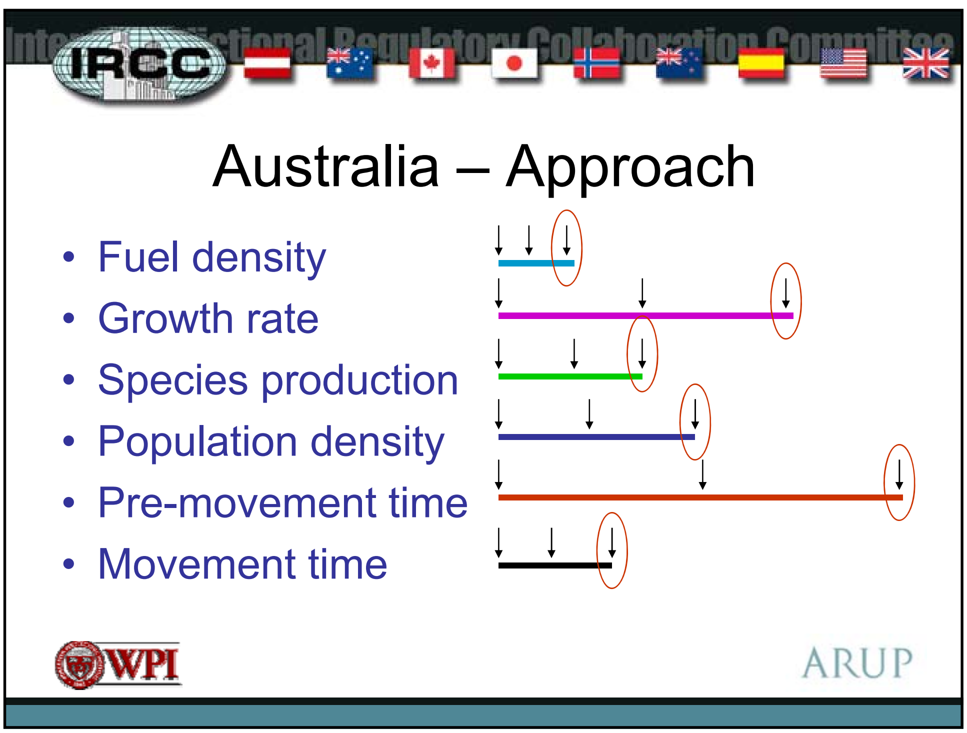
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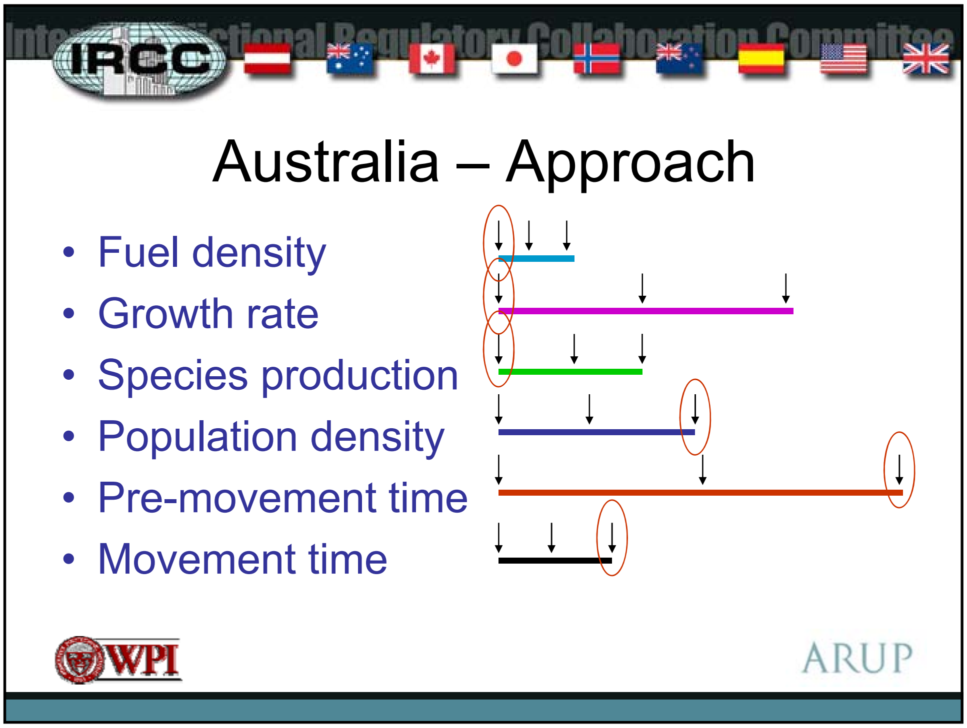
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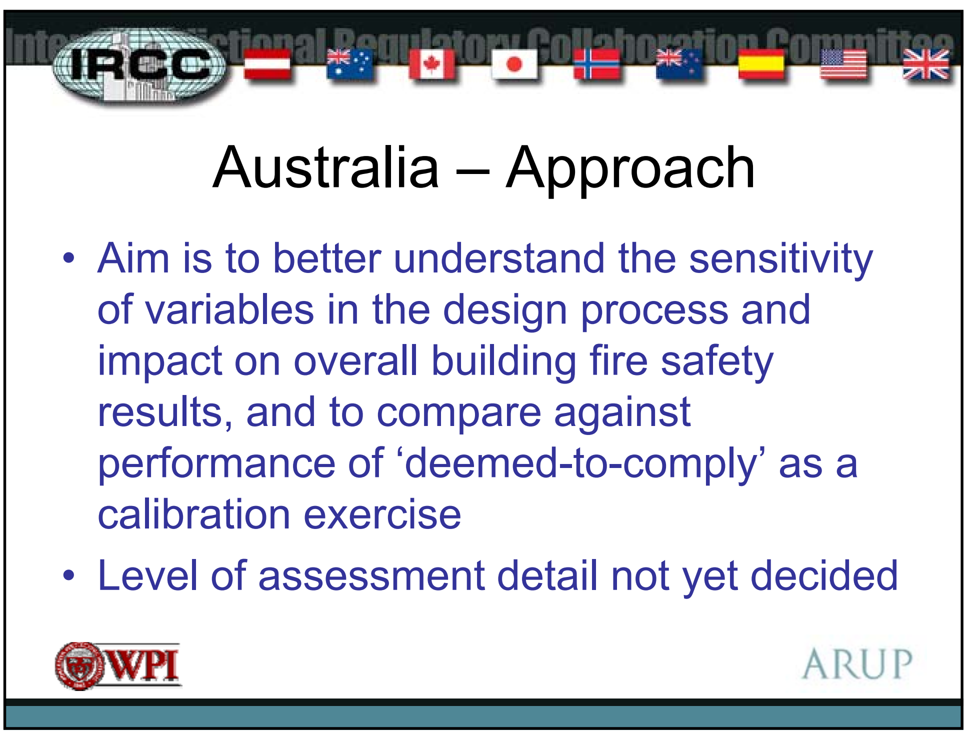

Inter-jurisdictional Regulatory Collaboration Committee
IRCC
Australia – Approach
• Aim is to better understand the sensitivity of variables in the design process and impact on overall building fire safety results, and to compare against performance of 'deemed-to-comply' as a calibration exercise
• Level of assessment detail not yet decided
WPI
ARUP

Development of 2nd-phase P-based fire regulations in Japan

Mamoru KOHNO
NILIM, Japan

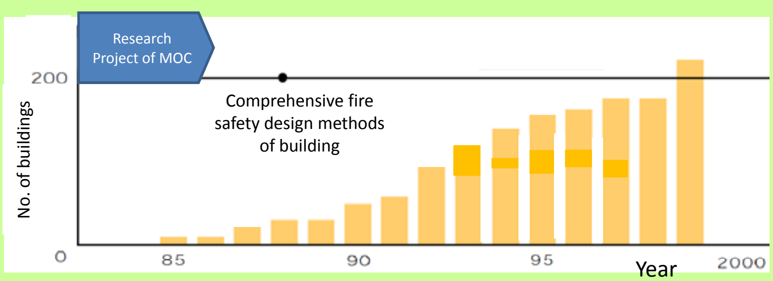
Brief Historical Review of Fire Regulations in Japan

- Prescriptive only (till early 1980’s)
- BSL-Article 38 era. (late 1980’s to 2000)
- ‘Performance-based’ regulation (2000 to now)

BSL-Article 38 Era.(1/2)

- (BSL Article 38) The provisions in Chap. 2, (related to structural safety and fire safety), are exempted if the Minister confirms that the 'effect' of an alternative solution is equal to or better than prescriptive solutions.
- "Comprehensive fire safety design methods of building," the output of 1982-1987 research project of MOC, enhanced the use of FSE.
- Many building which utilized new materials, construction methods, fire-safety equipment were approved and constructed.

BSL-Article 38 Era. (2/2)



- Limited to large building projects.
- No 'clear' performance requirements/criteria.

P-based Regulation (1/3)

- Introduced in 2000 BSL revision.
- Most prescriptive provisions unchanged.
- Performance verification methods are specified as 'alternative route' for some provisions.
  - Fire resistance verification method (FRVM)
  - Evacuation safety verification method (ESVM)
  - Fire compartment verification method (FCVM)
- Two patterns:
  - (fire resistance) a fire-resistive building can be either an assembly of prescriptive constructions or a building verified by the FRVM.
  - (evacuation) some of the evacuation-related prescriptive provisions are exempted if safety of a story or a building is verified by the ESVM.
- A building official, or designated confirmation body, can issue 'confirmation' for the building verified by the prescriptive VMs.

P-based Regulation (2/3)

- Not all performance requirements are specified explicitly. Instead, calculation methods are prescribed in the VMs.
- (FRVM)
  - Calculation methods for:
    - duration of fire forecast to occur a room
    - retained fire resistance time of column, wall, beam, floor, etc., against the fire
  - Criteria (fire duration) < (retained fire resistance time), for all principal building parts.
- (ESVM)
  - Calculation methods for:
    - time required for all occupants in a room to complete evacuation
    - time required for gas or smoke produced by a fire to descend to a level detrimental for evacuation (= 1.8 m)
  - Criteria (evacuation time) < (smoke descend time) , for all habitable rooms.

P-based Regulation (3/3)

- An alternative method to the prescriptive methods (FRVM or ESVM) is possible.
  - Use of smoke simulation program (e.g. BRI-2000), verification by an physical experiment, etc.
- Ministerial Approval is necessary in this case. This approach is called 'Route-C.'
  - 'Route-B' for performance approach by prescriptive VMs.
  - 'Route-A' for prescriptive approach.
- BSL Article 38 deleted in 2000 BSL revision.
- 'Alternative method' not equal to 'alternative solution,' in current BSL framework.
- Scope of performance verification is limited to fire-resistance or evacuation safety. Two cannot be combined.

Discussions/Complaints to Current Fire Regulation in BSL

- Example-1: A 3-story office building in quasi-fire preventive district can be quasi-fire-resistive building. But it shall be fire-resistive building if it goes up to 4-story. *WHY?*
- Example-2: A 3-story school, one of the special buildings in BSL, shall be fire-resistive building irrespective to its location, redundant evacuation measures, or neighboring conditions. *WHY?*
- Need for new framework.

Development of 2nd Phase P-based Fire Regulation

- Reconstruction of current (semi-) P-based regulation in view of 5 fire safety objectives.
  - F1: Protection of life safety
  - F2: Prevention of damage to neighboring buildings
  - F3: Prevention of frequent ignition
  - F4: Prevention of ignition from neighboring fire in urban area
  - F5: Support for emergency responders
- Risk-based considerations will be included to some extent.
- Revision of BSL is scheduled in 2 years.

F1: Life Safety(1/3)

- Enable full evacuation of occupants to safe place from the building.
  - Self-supported evacuation in general building.
  - Aided-evacuation in building such as hospitals and aged-care facilities.
- Enable rescue activity for occupants such as elderly, handicapped or who accidentally fail to evacuate.
- Evacuation route and structural stability should be appropriately maintained during evacuation and rescue activity.

F1: Life Safety(2/3)

- Performance criteria include:
  - Evacuation time < Tenability limit time(1),
    - tenability measure; smoke height, temperature or radiation.
  - Evacuation time < Fire resistance time of compartment(1),
  - Evacuation time < Structural stability limit time(1),
  - Rescue time < Tenability limit time(2),
  - Rescue time < Fire resistance time of compartment(2), and
  - Rescue time < Structural stability limit time(2).

  (1) and (2) may be different. (1) < (2) ?

F1: Life Safety(3/3)

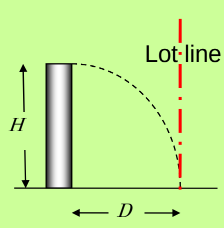
- New comprehensive VM through combination of existing VMs to verify the criteria.
  - Combination of ESVM, and FCVM and FRVM.
  - further research needed for evaluation of :
    - rescue time,
    - mobility of people with disabilities,
    - stability of more fragile constructions than fire-resistive construction, such as quasi-fire-resistive and fire-preventive constructions (timber members).

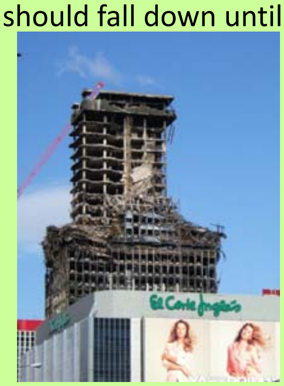
F2: Damage to Neighboring Buildings (1/3)

- A building should be constructed such that it does not damage the neighboring buildings by collapse, radiation, or fire brands as a result of its fire.
  - F2-1: Damage due to collapse of building or falling of part of building,
  - F2-2: Damage due to radiation, and
  - F2-3: Damage due to fire brands.

F2: Damage to Neighboring Buildings (2/3)

- Criteria (F2-1):
  - If $H > D$, then the collapse of building not allowed until end of fire. (This may be too restrictive.)
  - If $H_p > 4D^2$, then no part at height H_p should fall down until end of fire.



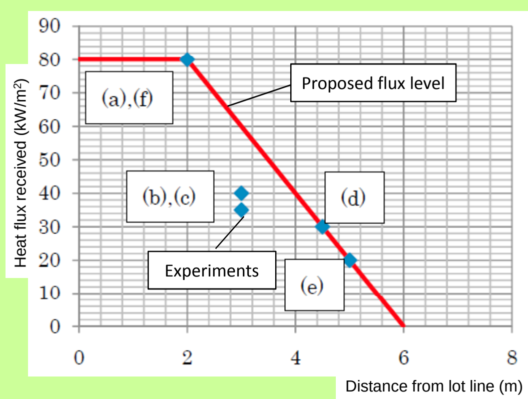


F2: Damage to Neighboring Buildings (3/3)

- Criteria (F2-2):
  - (1) Radiation flux received by a virtual adjacent building less than 12.5 kW/m^2 .
    - adjacent building at 5 m apart from the lot line.
    - occupancy dependent constant radiation from unprotected opening (108.4 kW/m^2).
  - (2) Cumulative radiation, I^2t, received by a virtual adjacent building less than $6.37x10^6$ $(kW)^2m^{-4}s$.
    - integration over fire duration.
    - adjacent building at the same distance from the lot line.
    - radiation calculated from fire temperature.
    - limiting value from cumulative radiation by 30 min. standard fire
- Similar criteria for (1) in NBC of CAN, a.d. of ENG and NZL, and NFPA 80A.

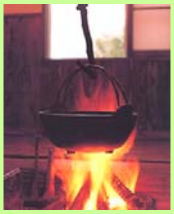
F4: Ignition by Urban Fire

- Heat from 'urban fire'.
- Criteria, no ignition by heat flux
  - longer distance for less fire-resistive construction
- Required only buildings in urban area.



F3, F5

- F3 (frequent ignition)
  - Heat source such as oven, stove, boiler.
  - Criteria; No ignition of building materials by the heat.
- F5 (emergency responders)
  - Quantitative data limited.



Concluding Remarks

- Japan has more than 20 years of FSE experience in regulatory framework.
- P-based approach is increasingly used especially for evacuation safety verification, after 2000 BSL revision.
- More rational, P-based and risk consistent fire regulation is under development.
- Suggestions from IRCC members and others are greatly appreciated.

DEVELOPMENTS OF FSE DESIGN ACCEPTANCE CRITERIA IN FINLAND

Jukka Hietaniemi
VTT

VTT

MY VIEW OF THE MAJOR PROBLEMS IN FSE DESIGN

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THE MAJOR PROBLEMS IN FSE

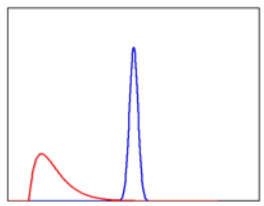
INPUT → **RESULT ACCEPTANCE** → **MANAGEMENT OF SAFETY DURING WHOLE BLDG LIFE TIME**

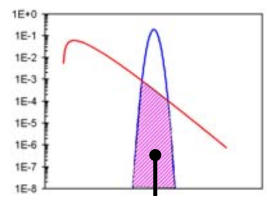
1) How big the fire is

2) Sensitivity analysis: what if?
⇒ meaningless unless the probability aspects are taken into account

Is it safe?

Or - actually – is it safe enough?





there is always a risk: it just must be small enough

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- Note that computational tools were <u>not</u> included in the Major Problems
  - for example, as compared to the data that we have, the tools for fire, evacuation and structural performance simulation are superior
    - e.g., if we have the design fire figured out properly, its consequences are predicted with precision and accuracy sufficient in FSE design
  - of course there is need for further developments
  - e.g., when we will have a fire simulator that can actually predict fire growth and spread merely on the basis of the physical properties and lay-out of the fire load and fire room, then the problems associated with input data will practically disappear
    - but: my guess is that none of us will live to see such a tool!

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TOPIC OF THIS PRESENTATION

- IS THE DESIGN SOLUTION SAFE ENOUGH
- HOW CAN THIS ISSUE BE SETTLED
  - criteria & safety margins
- HOW SHOULD THE CRITERIA BE FORMULATED SO THAT THEY CAN BE USED IN PRACTISE
  - condensed, clear-cut rules

Example of the situation today in Finland:

In town A, a design was accepted where RSET was 5 min 50 s and ASET 6 min 10 s

In town B, a design was rejected where RSET was ~ 5 min and ASET ~ 10 min

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BEFORE GETTING TO THE POINT: some miscellaneous thoughts

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STATUS OF FSE DESIGN IN FINLAND AND SOME OF ITS NEAR NEIGHBOURS

Finland

Since 1997 Prescritive and FSE-Based fire design options are alternative approaches with equal legal basis

FSE design is applied increasingly in major building projects

With no properly established education, demand for FSE design continuously exceeds the supply

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STATUS OF FSE DESIGN IN FINLAND AND SOME OF ITS NEAR NEIGHBOURS

Estonia

The fire regulations are basically similar to those in Finland, i.e., FSE-Based fire design has no legal restrictions

Use of FSE design is rare as there is an almost complete void of properly educated designers and authorities

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STATUS OF FSE DESIGN IN FINLAND AND SOME OF ITS NEAR NEIGHBOURS

Latvia and Lithuania

The fire regulations are basically those in force in the former Soviet Union

Yet, these countries are EU members and as such should adopt the Eurocodes, which treat nominal and FSE-based thermal actions on equals basis; this should in practise open way to structural FSE; and, as evacuation safety design is simpler and more reliable than structural FSE, there should be potential for life-safety FSE; but…

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STATUS OF FSE DESIGN IN FINLAND AND SOME OF ITS NEAR NEIGHBOURS

Russia

The fire regulations are the same as in the former Soviet Union

Potential acceptance of FSE designs is based of certification of the fire consultant, e.g. there is one certified consultant in Finland

Undoubtedly, opening up the Russian markets for FSE is major task, which would be greatly facilitated if the international FSE community would have similar, well- established and quantitative rules for FSE application and acceptance

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STATUS OF FSE DESIGN IN FINLAND AND SOME OF ITS NEAR NEIGHBOURS: SUMMARY

The Eastern European Countries constitute a major potential new market area for FSE consultancies; it can be estimated than merely renovation and retrofitting building markets are tens of milliards of euros.

In order to open these markets, we need internationally agreed, ***quantitative*** rules for use of FSE, especially rules for the approval of FSE desings

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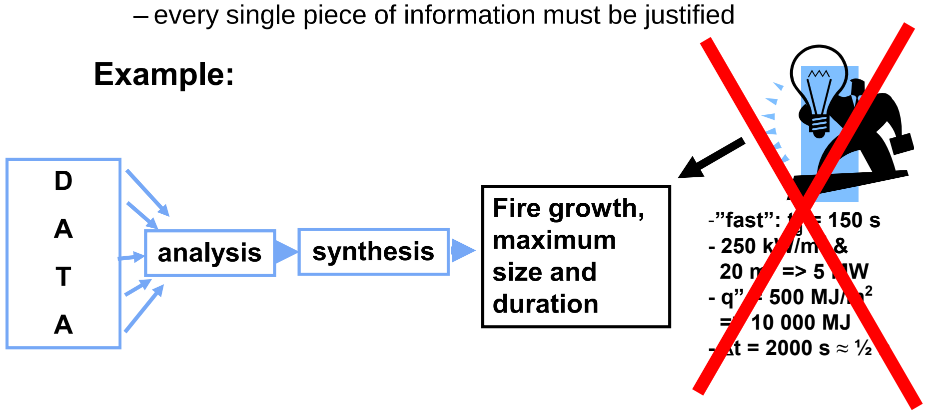
PRINCIPLE FOR OVERCOMING THE FSE PROBLEMS

- **NO GUESSWORK!**
  - every single piece of information must be justified

Example:



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DEVELOPMENT OF FSE ACCEPTANCE CRITERIA IN FINLAND

- Status now: we have the same NKB-based rules as Sweden
  - i.e., 100 C, 1 kW/m^2, 1,6 m + 10%×H, etc.
  - these may (or may not) be quite OK
- The problem is mainly in the **safety factors** that should be applied
- A project has been started in August to
  - check the basis of the numerical acceptance criteria (no guewsswork!)
    - where have they emerged, what is data behind them
  - verify their validity - and if necessary amend the values
  - establish the uncertainties involved in thse criteria
  - establish uncertainties involved in results of fire simulation and evacuation calculations (including skewness of distributions)
  - **outcome: validated quantitative acceptance criteria with quantitative rules of applicable safety factors**

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DEVELOPMENT OF FSE ACCEPTANCE CRITERIA IN FINLAND, cont'd

- A major national endeauvor with all relevant authorities involved
  - Ministry of the Interior (FBs and active fire safety systems),
  - Ministry of the Environment (fire regulations, structural fire safety);
  - all Finnish rescue services;
  - building authorities of the largest cities
  - insurance sector
- Coordinated and executed by VTT

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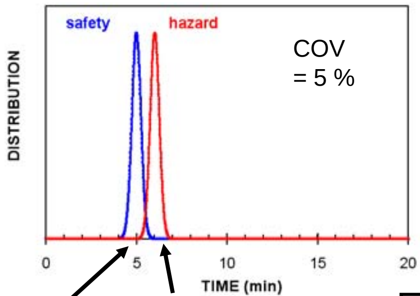
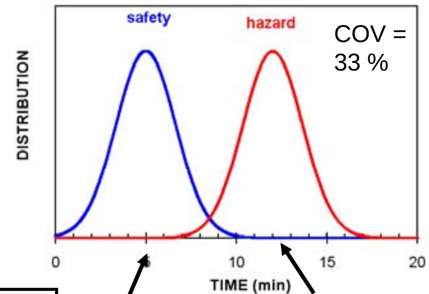
Why the uncertainties are so important?

- When we know the ”safety” (or resistance) and ”hazard” (load) with good accuracy, a small safety margin is enough
- If there is large uncertainty, a much more larger safety margin is needed



5 min 6 min



Pfail ≈ 0,2 %

5 min 12 min

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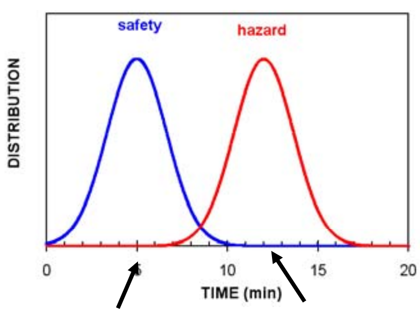
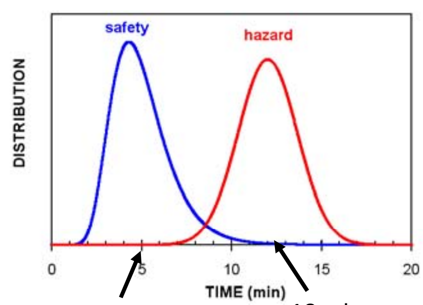
Why the distribution shapes are so important?

- If distributions are skewed towards ”dangerous direction”, required safety margins increase



5 min 12 min

Norm. distr: Pfail ≈ 0,2 %



5 min 12 min

LogNorm. distr: Pfail ≈ 0,5 %

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Issue that can not be avoided: what is acceptable/tolerable level of risk

- Safety margins depend completely on the risk level applied
  - e.g. in the FORM formulation $\beta = -\Phi^{-1}(\mathbf{p}_{risk})$ and safety margin ~ β
- **The hardest task in the project is that regulators need to establish quantifiable minimum tolerable risk levels**
  - how to get a politician to admit (in public forum) that there is no such thing as zero risk?
- VTT will help the authorities by establishing the present risk levels of the most important bldg types where FSE is applied, e.g., shopping centres, large offices, etc. through massive computational analyses

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SUMMARY

- There are two Major Problems in application of FSE design: 1) input data and 2) acceptance criteria
- Acceptance criteria have two components:
  - quantitive expression of physical conditions that are considered to cause unwanted consequences
  - quantitative rules of relevant safety margins
- Finland is carrying out a major project in which an attempt is made to solve the problems related to acceptance criteria
  - or at least establish rules that will written to guidance supporting the fire regulations (hence giving the rules authorative status and make them the practise applied throughout the country)
- **Finally, for FSE design to survive and become a well-established engineering branch equal to other branches of engineering (e.g. structural or electrical), we need acceptance criteria/rules that are agreed upon unanimously by the international FSE community**

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THANK YOU!

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FIRE SAFETY STANDARDS IN SCOTLAND

PAUL STOLLARD
SBSA

Scottish System

- Functional Standards
- Technical Handbooks
  – Performance
  – Prescriptive
- Alternative Solutions

Fire

- Section 2
- 15 Functional Standards
- 2 Handbooks
  - Domestic
  - Non-Domestic
- 2 Alternative Solutions
  - British Standards
  - International Fire Safety Engineering Guidelines

Escape 2.9

- Every building must be designed and constructed in such a way that in the event of an outbreak of fire within the building, the occupants, once alerted to the outbreak of the fire, are provided with the opportunity to escape from the building, before being affected by fire or smoke

Current Review of Escape

- Being Re-structured from first principles
- Homes
- Flats
- Non-Domestic

SCOTTISH BUILDING STANDARDS AGENCY

Homes

- Escape from Room of Origin
- Escape from the House

SCOTTISH BUILDING STANDARDS AGENCY

Flats

- Escape from Room of Origin
- Escape from Flat of Origin
- Protection to Other Flats
- Protection of Vertical Circulation

sbsa SCOTTISH BUILDING STANDARDS AGENCY

Non-Domestic

- Escape from Room of Origin
- Escape from Compartment of Origin
- Escape from Floor of Origin
- Escape to Planned Safety at Ground Level

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Performance Requirements and Acceptance Criteria for Safety in Case of Fire

Report of the IRCC Workshop
Vienna, Austria
10 October 2007