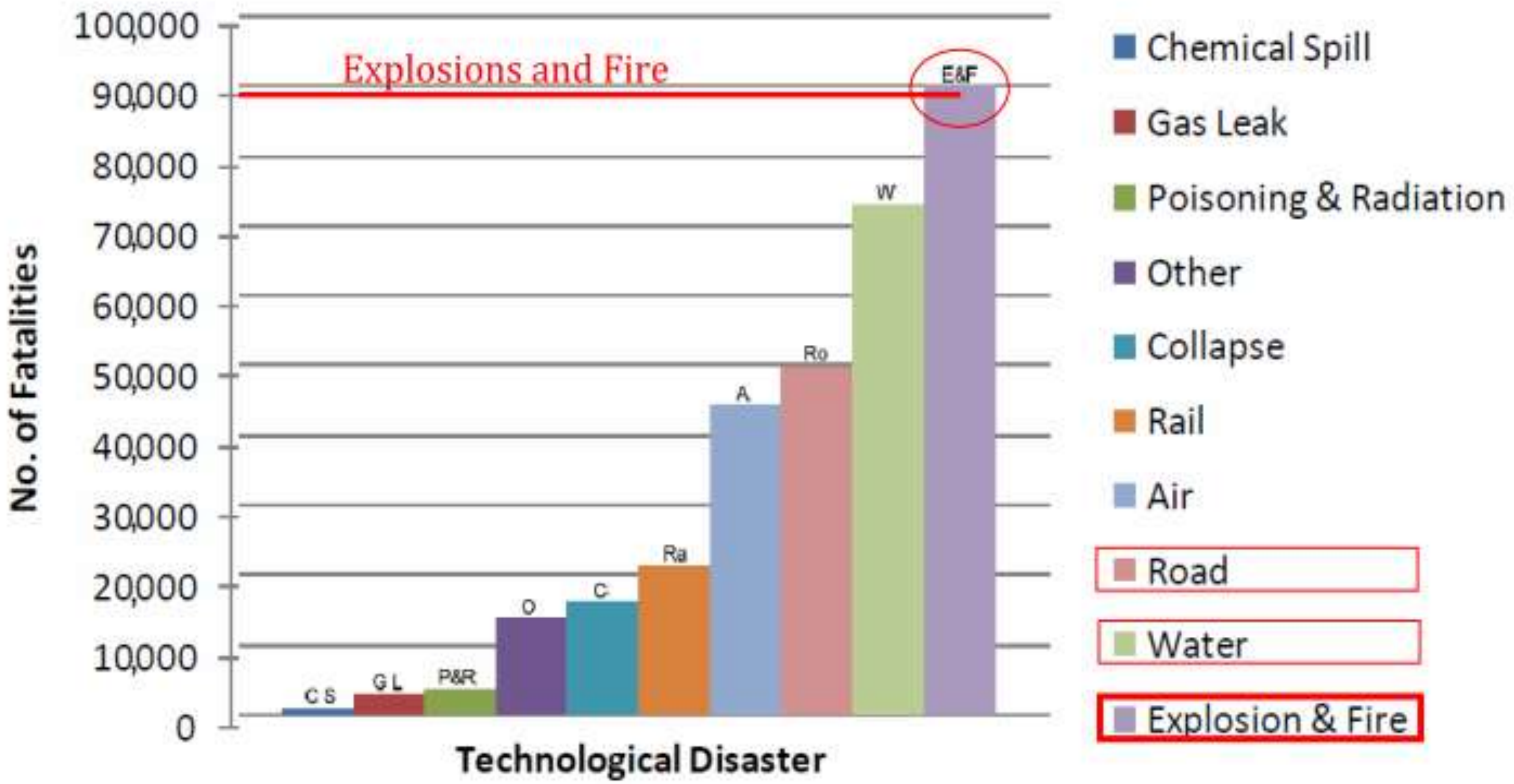
INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

Fire Safety Engineering
Challenges and Opportunities

Mohammad Heidari

Fire Phenomena

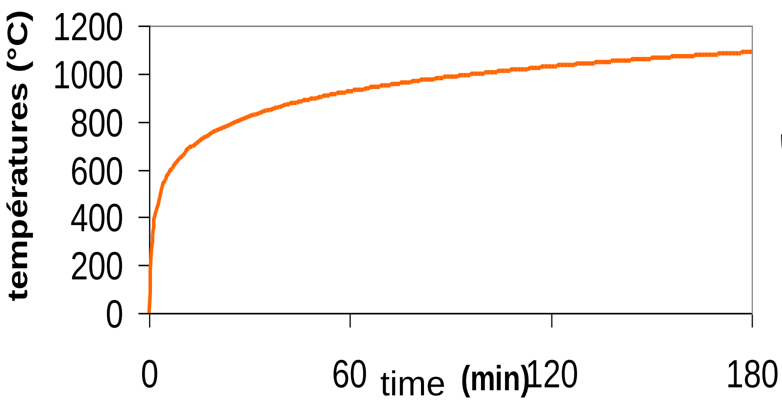
Technological Disaster 1900-2010



EM-DAT International Disaster Database, Université catholique de Louvain, Belgium. www.emdat.be

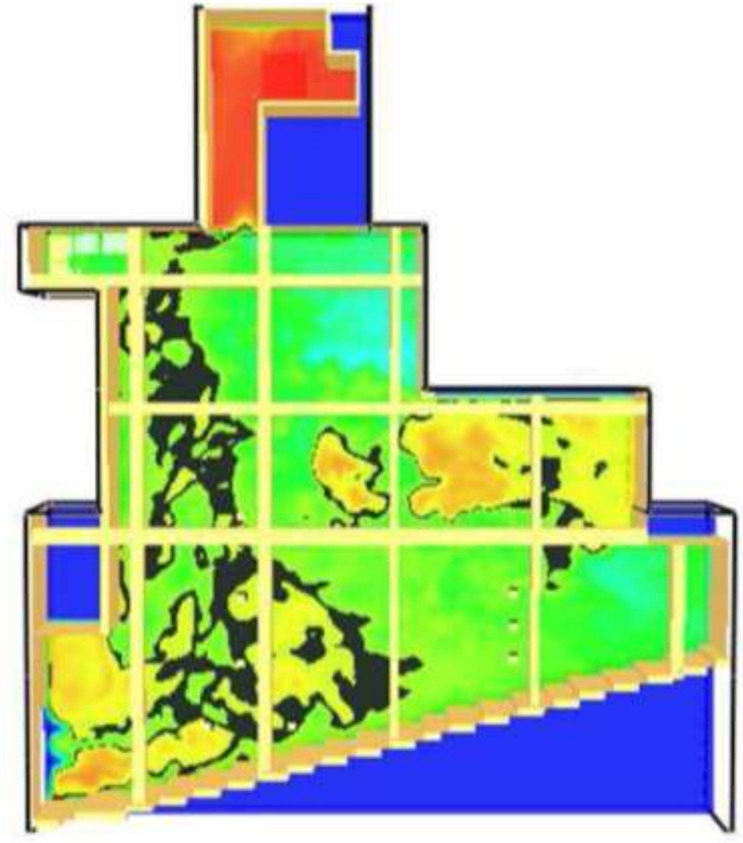
Fire Safety Engineering

PRESCRIPTIVE CODES	PERFORMANCE BASED CODES
Prescribe what to do in a specific case	**Express defined objectives and allow the designer to use any acceptable approach to achieve the required results**



Fire Engineering Approach

- Structured framework
- Objective Assessment
- Alternative approach
- Should not compromise safety



The use of engineering principles
for the achievement of fire safety

British standard Institution

BSI, Application of fire safety principle to the design of buildings,2001, 2003

Is it possible with prescriptive approach?

- Large and Complex building
- Bespoke Design
- Delivers Value
- Flexibility in the design – Choice and Options
- Optimising the design – Cost Saving


GLA building, Great Britain

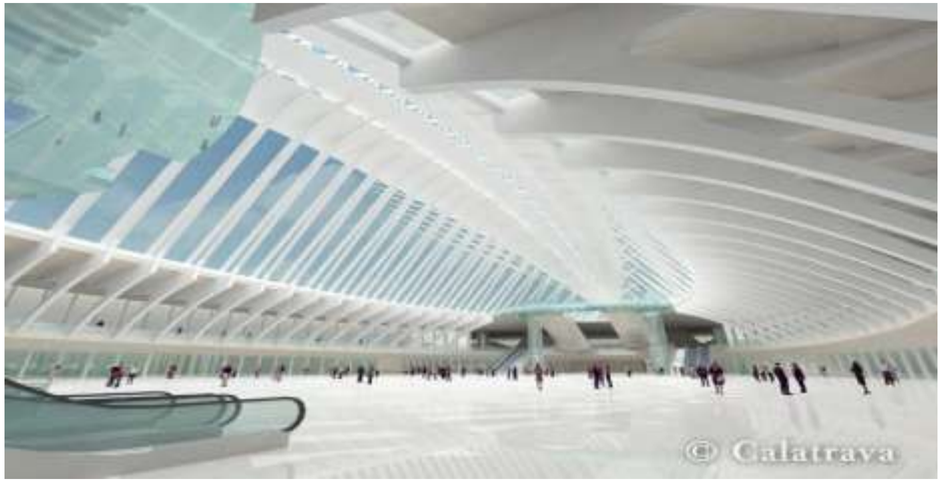

Aix les Milles Carrefour, France


Gran Teatro Nacional de Lima

How is structural fire safety achieved?

- Different approaches

  - Prescriptive-based
  - Prescriptive & Performance-based
  - Performance-based engineering



How is structural fire safety achieved?

- ***Prescriptive-based* design** (***past*** & present):
  - A set of rules for how a building must be constructed
  - Structural elements protected to remain under a certain temperature
  - Fire scenario so that they retain adequate strength and stiffness to continue to carry loads. This has been the traditional approach

Requirement	*Limits on application*
Internal fire spread (structure)	
B3. (1) The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.	
(2) A wall common to two or more buildings shall be designed and constructed so that it adequately resists the spread of fire between those buildings. For the purposes of this sub-paragraph a house in a terrace and a semi-detached house are each to be treated as a separate building.	
(3) Where reasonably necessary to inhibit the spread of fire within the building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following: (a) sub-division of the building with fire-resisting construction; (b) installation of suitable automatic fire suppression systems.	Requirement B3(3) does not apply to material alterations to any prison provided under Section 33 of the Prison Act 1952.
(4) The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited.	

Approved Document B, Section B3

How is structural fire safety achieved?

- ***Prescriptive Based***
  - "The building should be constructed so that in the event of fire, its stability will be maintained for a reasonable period"

Table A1 Specific provisions of test for fire resistance of elements of structure etc

Part of building	Minimum provisions when tested to the relevant part of BS 476 [1] (minutes)			Minimum provisions when tested to the relevant European standard (minutes) [3]	Method of exposure
	Loadbearing capacity [2]	Integrity	Insulation		
1. **Structural** frame, beam or column.	See Table A2	Not applicable	Not applicable	R see Table A2	Exposed faces
2. **Loadbearing wall** (which is not also a wall described in any of the following items).	See Table A2	Not applicable	Not applicable	R see Table A2	Each side separately
3. **Floors** [4]					
a. between a shop and flat above;	60 or see Table A2 (whichever is greater)	60 or see Table A2 (whichever is greater)	60 or see Table A2 (whichever is greater)	REI 60 or see Table A2 (whichever is greater)	From underside [5]
b. Any other floor – including compartment floors.	See Table A2	See Table A2	See Table A2	REI see Table A2	
4. **Roofs**					
a. any part forming an escape route;	30	30	30	REI 30	From underside [5]
b. any roof that performs the function of a floor.	See Table A2	See Table A2	See Table A2	REI see Table A2	
5. **External walls**					
a. any part less than 1000mm from any point on the relevant boundary; [6]	See Table A2	See Table A2	See Table A2	REI see Table A2	Each side separately

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Fire resistance of element

Fire resistance time for building types

Approved Document B, Section B3

How is structural fire safety achieved?

- ***Prescriptive & Performance-based*** (present & ***future***):
  - Prescriptive guidance. A set of rules for how a building must be constructed, but include some refinements in the method

Fire resistance, insulation and integrity of the structural elements

→but level of hazard are added...

BS9999-Section 7

Table 25 Fire resistance periods for elements of structure (independent of ventilation conditions)

OC[A)]	Use	Sprinklered or unsprinklered[B)]	Minimum periods of fire resistance, in minutes					
			Depth below access level of lowest basement		Height[C)] of top occupied storey above access level			
			More than 10 m	Not more than 10 m	Not more than 5 m	Not more than 18 m	Not more than 30 m	More than 30 m
A	Office	Unsprinklered	90	60	30	60	90	Not allowed
		Sprinklered	60	60	30	30	60	120
A	Industrial: high hazard	Unsprinklered	N/A[D)]	120	90	120	150	Not allowed
		Sprinklered	150	90	60	90	90	120
A	Industrial: ordinary hazard	Unsprinklered	N/A[D)]	120	60	90	120	Not allowed
		Sprinklered	90	60	30	60	60	90
A	Industrial: low hazard	Unsprinklered	90	60	30	60	90	Not allowed
		Sprinklered	60	30	30	30	60	60
A	Storage: low hazard	Unsprinklered	90	60	30	60	90	Not allowed
		Sprinklered	60	30	30	30	60	60
A	Car parks:							
	– open-sided car park	Unsprinklered	—	—	15[E)]	15	30	30
	– any other car park	Unsprinklered	90	60	30	60	90	120
B	Shops and commercial	Unsprinklered	90	60	60	60	90	Not allowed
		Sprinklered	90	60	30	60	60	120
B	Assembly: high hazard	Unsprinklered	N/A[D)]	90	60	90	120	Not allowed

Prescriptive & Performance-based

- Determine a risk profile
- Occupancy characteristic
- Fire growth rates
- Minimum provision determination
- Minimum fire protection measures

Fire Growth Rate

Table 3 Fire growth rates

Category	Fire growth rate	Examples	Fire growth parameter [A] kJ/s³
1	Slow	Banking hall, limited combustible materials	0.002 9
2	Medium	Stacked cardboard boxes, wooden pallets	0.012
3	Fast	Baled thermoplastic chips, stacked plastic products, baled clothing	0.047
4	Ultra-fast	Flammable liquids, expanded cellular plastics and foam	0.188

[A] This is discussed in PD 7974-1.

Risk Profile

Risk profiles

Occupancy characteristic (from Table 2)	Fire growth rate		Risk profile
A (Occupants who are awake and familiar with the building)	1	Slow	A1
	2	Medium	A2
	3	Fast	A3
	4	Ultra-fast	A4 [A]
B (Occupants who are awake and unfamiliar with the building)	1	Slow	B1
	2	Medium	B2
	3	Fast	B3
	4	Ultra-fast	B4 [A]
C (Occupants who are likely to be asleep)	1	Slow	C1 [B]
	2	Medium	C2 [B]
	3	Fast	C3 [B], [C]
	4	Ultra-fast	C4 [A], [B]

[A] These categories are unacceptable within the scope of BS 9999. Addition of an effective localized suppression system or sprinklers will reduce the fire growth rate and consequently change the category (see 6.5).

[B] Risk profile C may be divided into sub-categories, viz. Ci1, Cii1, Ciii1, etc.

[C] Risk profile C3 will be unacceptable under many circumstances unless special precautions are taken.

BS9999-Section 7

Prescriptive & Performance-based

- Useful conceptually
- Prescriptive guidance
- Design principles are based on **RISK** associated with **TIME**
- Good for small variations from prescriptive approach
- Need to apply all document for gains
- Additional Measures – Clear Benefit!
- Limits of Applicability

How is structural fire safety achieved?

- ***Performance-based*** **design** (present & ***future***):
  - A set of goals for how a building must perform under a wide range of conditions
  - Allows designers to use any fire safety strategy they wish, provided that adequate safety can be demonstrated
  - Engineer must show structure meets certain criteria
  - Requires understanding of behaviour

Performance-based design (PBD)

Example:

- Prescription-based :

  The distance to an emergency exit shall not exceed 30 m

- Performance-based:

  The distance to an emergency exit can be any distance as long as the building can be evacuated safely

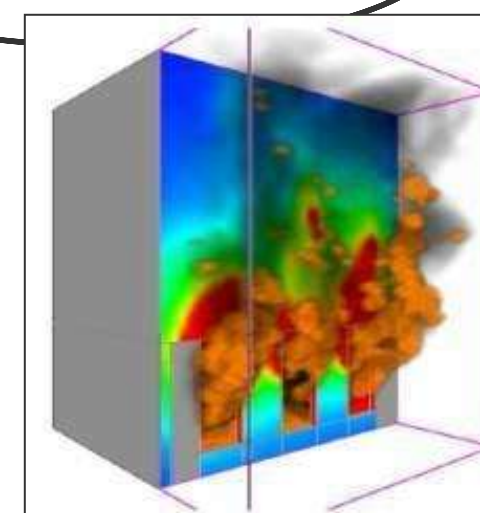
What is Performance Based Design ?

Objectives ❶

❷ Calculate scenario risk

Scope of the project

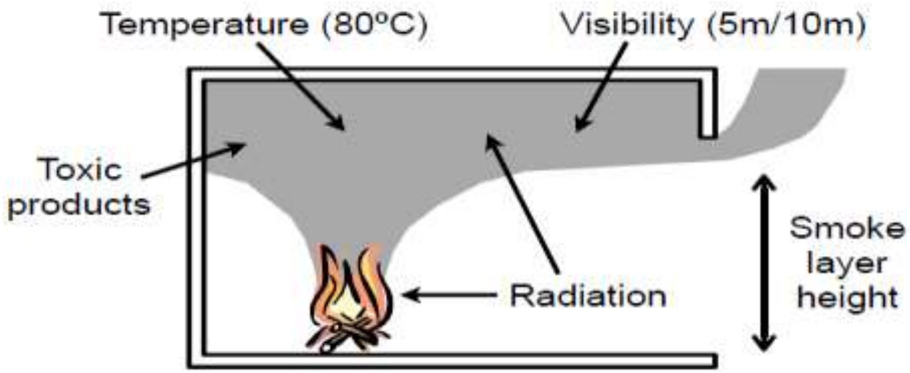
❸ Evaluation



❹ Is performance criteria satisfied ?

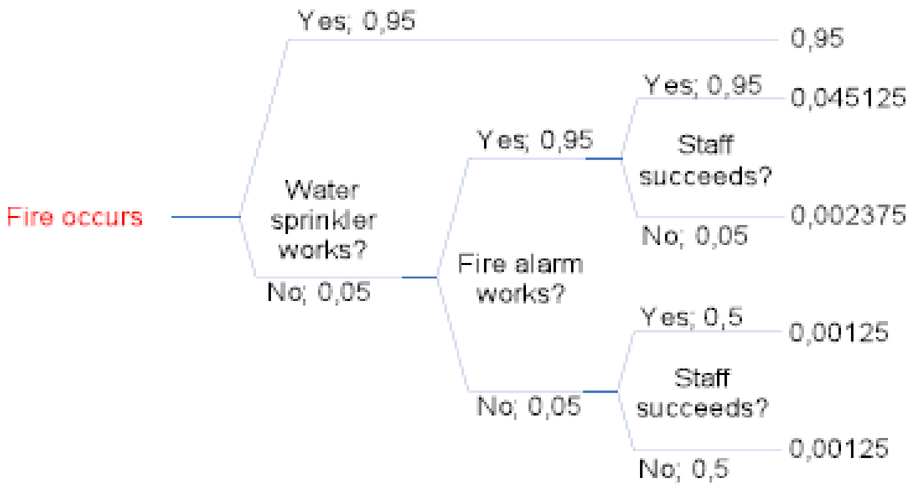
Objective-PBD

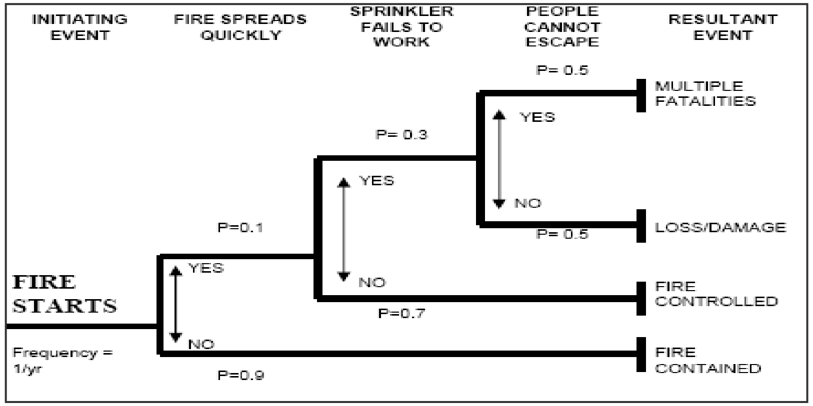
- Identification of fire safety objectives and performance criteria:
  - ➢ Life safety:
    - ✓ Protect occupants not intimate with initial fire development
    - ✓ Improve survivability of occupants intimate with initial fire development
  - ➢ Damage to property:
    - ✓ No spread of fire beyond the enclosure of origin



Risk Scenario-PBD

- Hazards identification scenario clusters and representative scenarios
- Estimate probability & consequences
- Calculate scenario risk

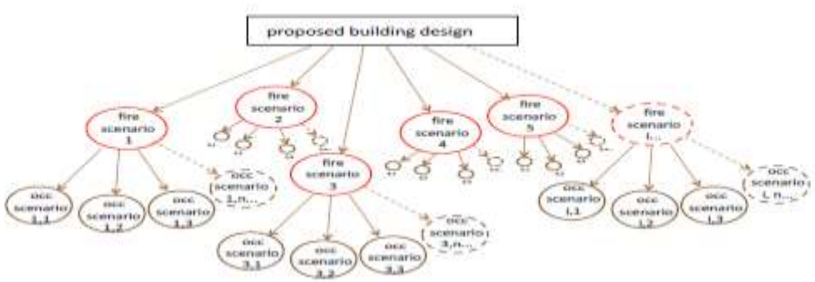




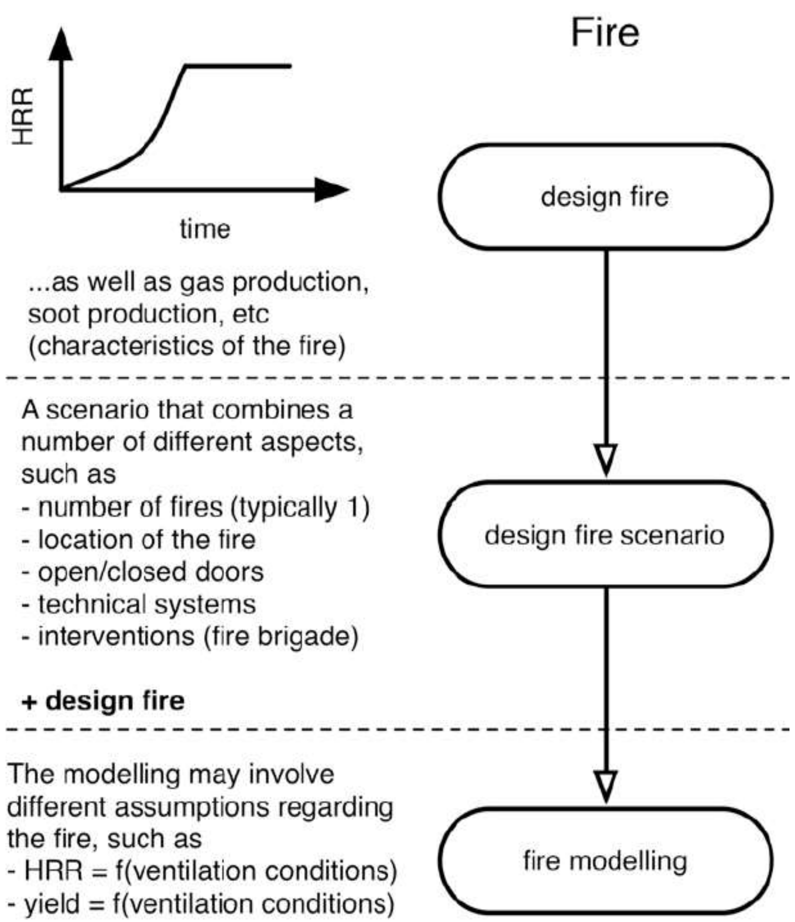
Evaluation-PBD

Design fire

Design fire scenario evaluation



Fire modelling



performance criteria- PBD

Is performance criteria satisfied ?

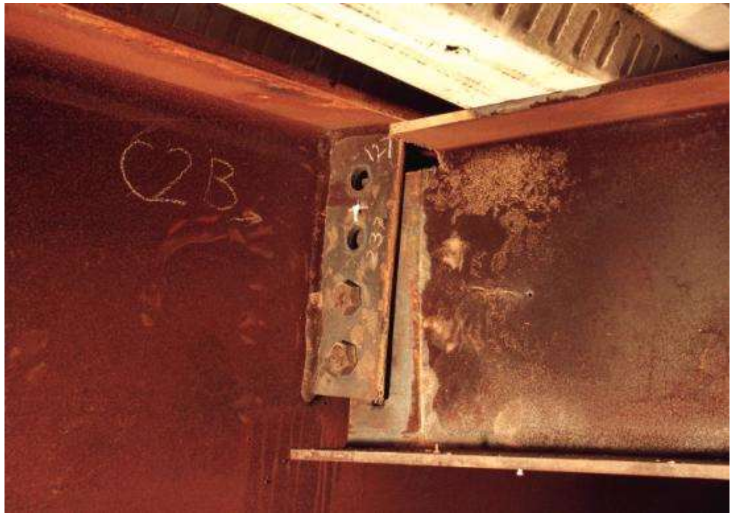
- YES : Implementation of design plan
- NO : New fire safety design plan

How do we know that a building is safe?

"...the conditions in the building shall not become such that the limiting values for *critical conditions are* exceeded during the time needed for escape." (BFS 2002:19)

Steel Industry and PBD

- Beginning in the 1990's, the Steel Industry embraced and largely promoted performance-based design for fire



What does the steel industry do ?

Cactus Shopping Centre, Luxembourg

Type: Shopping Centre
Inauguration: 2003
max. Height: 9.13 m
Ground Plan: 28.51 m x 48.16 m

Portal frame with a span of 20 m
Frames are connected by purlins (IPE 200)
Steel columns (HE 500 B) made of S235
Cambered cellular beams (final height 590 mm) made of S235

Fire safety concept :
An audit by the NFSC design (Natural Fire Safety Concept) allowed for unprotected steel (R90 initially required by local authorities).

What does the steel industry do ?

Impacts on French Regulation:

For warehouses, Order of 15 April 2010 relating to general requirements for warehouses covered under the system of registration under the heading No. 1510:
"The whole structure is a minimum R 15”.

R30 and R60 previously required depending on the height of the building and the type of item.

Fire Engineering Approach

- Time based Approach
  - ➢ Optimisation of the Design
  - ➢ Not increasing risk

How do we know that a building is safe?

"...the conditions in the building shall not become such that the limiting values for *critical conditions are* exceeded during the time needed forescape." (BFS 2002:19)

Time Based Approach

Modifying RSET

- RSET– Required Safe Escape Time
  - Change ignition to alarm time
  - Change pre-movement time
  - Change travel time
  - What is desired, what is cost effective

ASET

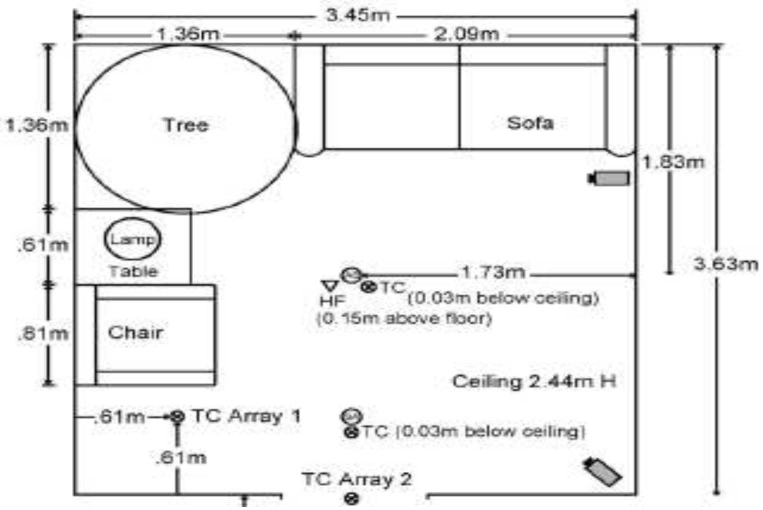
0.30 1.15 2.15

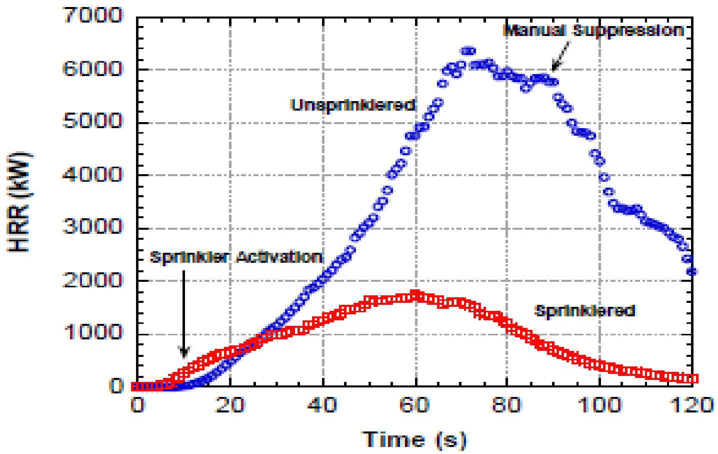
3.00 3.17 3.20

A little bit of fire dynamics

Modify ASET

- ASET – Available Safe Egress Time
  - ➢Smoke Control
  - ➢Compartmentation
  - ➢Sprinklers

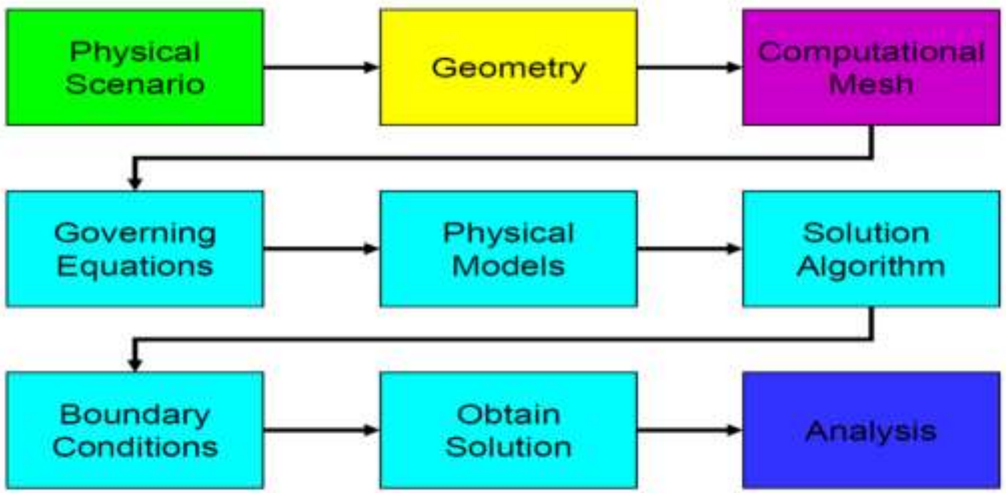


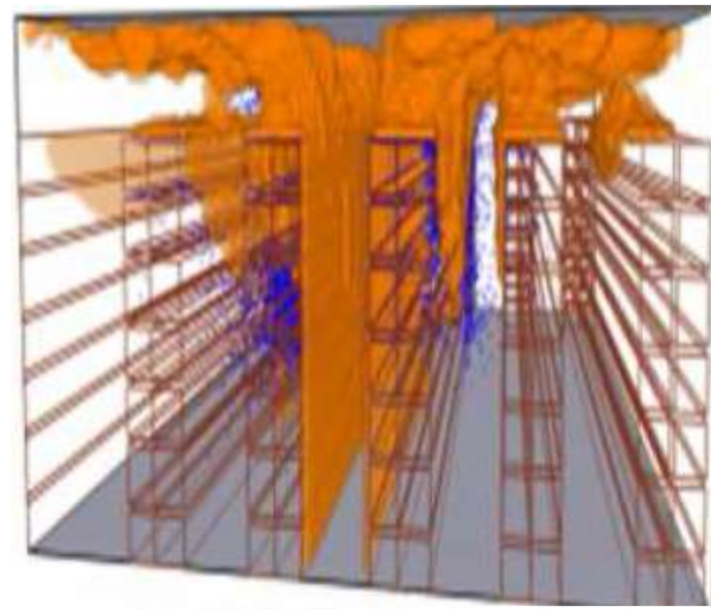


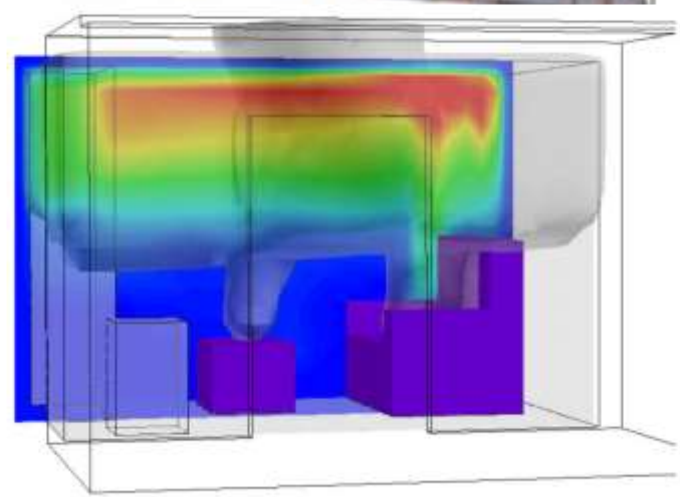
Impact of a residential sprinkler on the heat release rate of a Christmas tree fire, Madrzykowski, NIST IR 7506, 2008

ASET

- Quantifying ASET carefully
  - ➢ CFD Modelling







- Quantify ASET very accurately

Why do we need fire engineering?

- Large and Complex building
- Bespoke Design
- Delivers Value
- Flexibility in the design – Choice and Options
- Optimising the design – Cost Saving

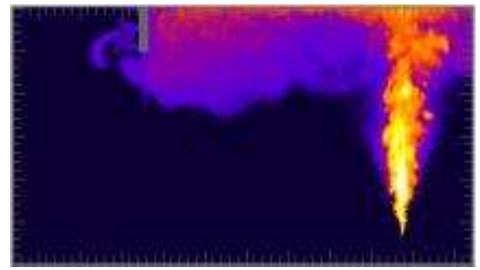
GLA building, Great Britain

Aix les Milles Carrefour,France

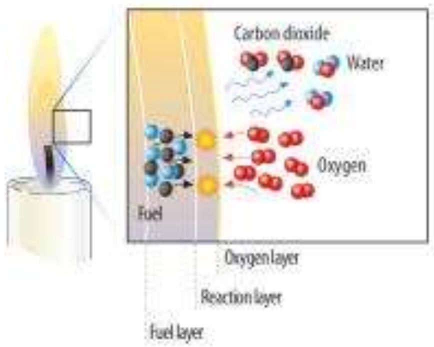
Gran Teatro Nacional de Lima

Fire Engineering Skills

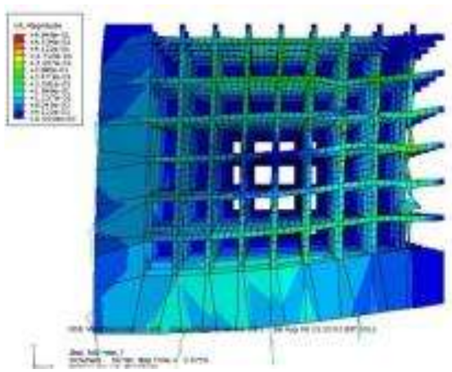
Material degradation



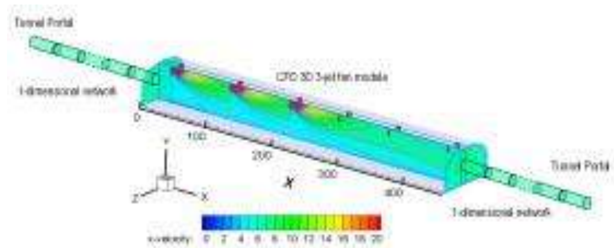
Fluid Mechanics



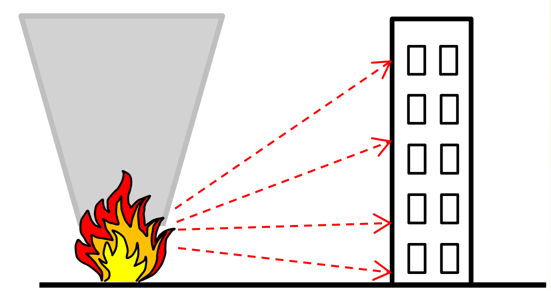
Combustion and gas production



Structural behaviour



Computational Modelling



Heat transfer

Tools

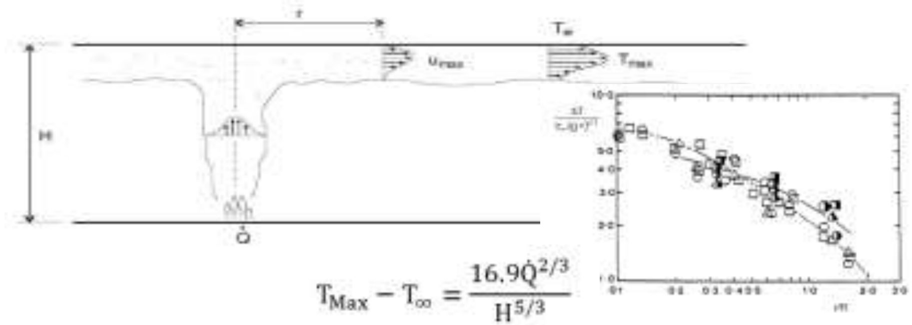
Example

Analytical equations

$$\frac{1}{\sqrt{t_{ign}}} = \frac{2}{\sqrt{\pi}\sqrt{k\rho c}}\frac{\dot{q}_e''}{(T_{ign} - T_\infty)}$$

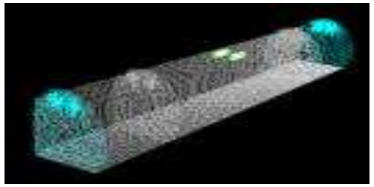
Ignition

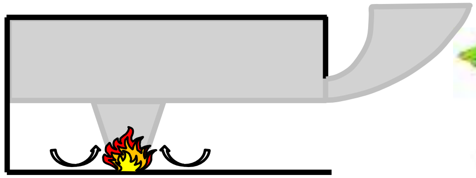
Semi impericql equations



$$T_{Max} - T_\infty = \frac{16.9\dot{Q}^{2/3}}{H^{5/3}}$$

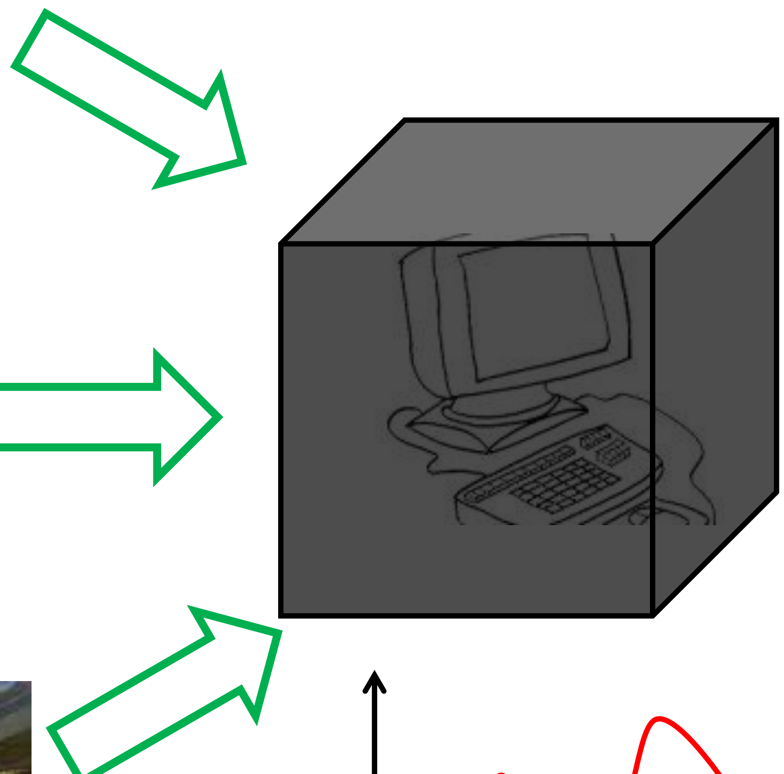
Numerical Modelling
(different level of complexity)

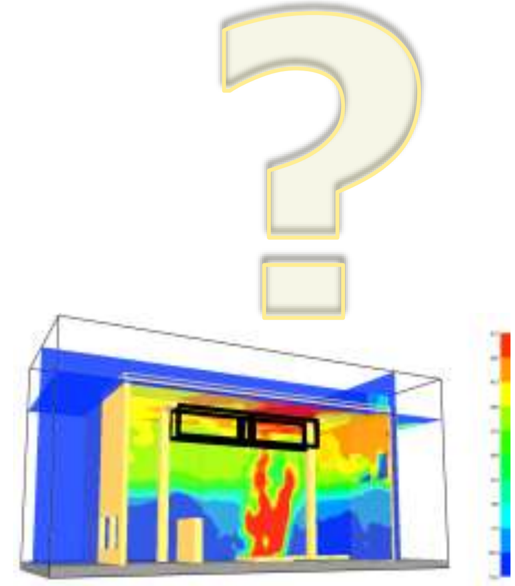




Experiences
(different scales)

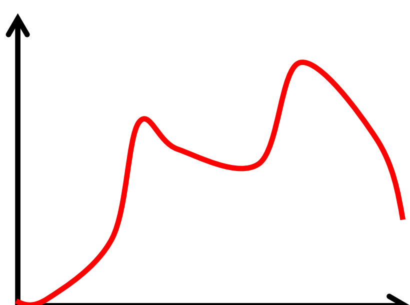
Fire Simulation- CFD





Colour For Directors !
Confusion For Dummies !
Computational Fluid Dynamics

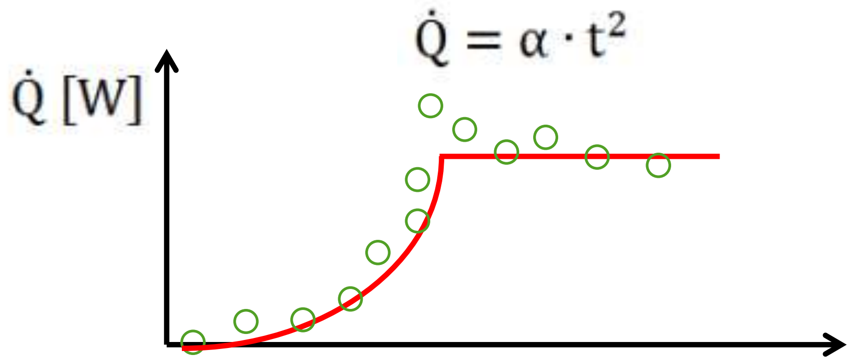
T [°C]



Fire Dynamics

Definition of Fuel

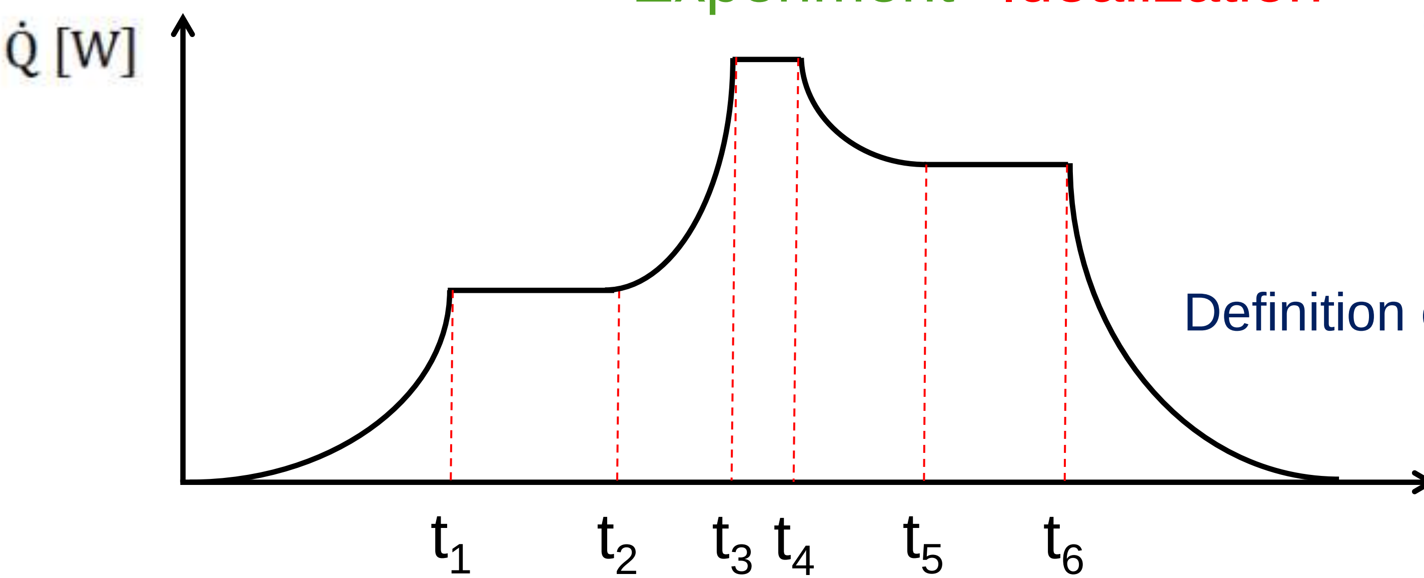
Heat released during combustion



Experiment Idealization

α [W/s^2]

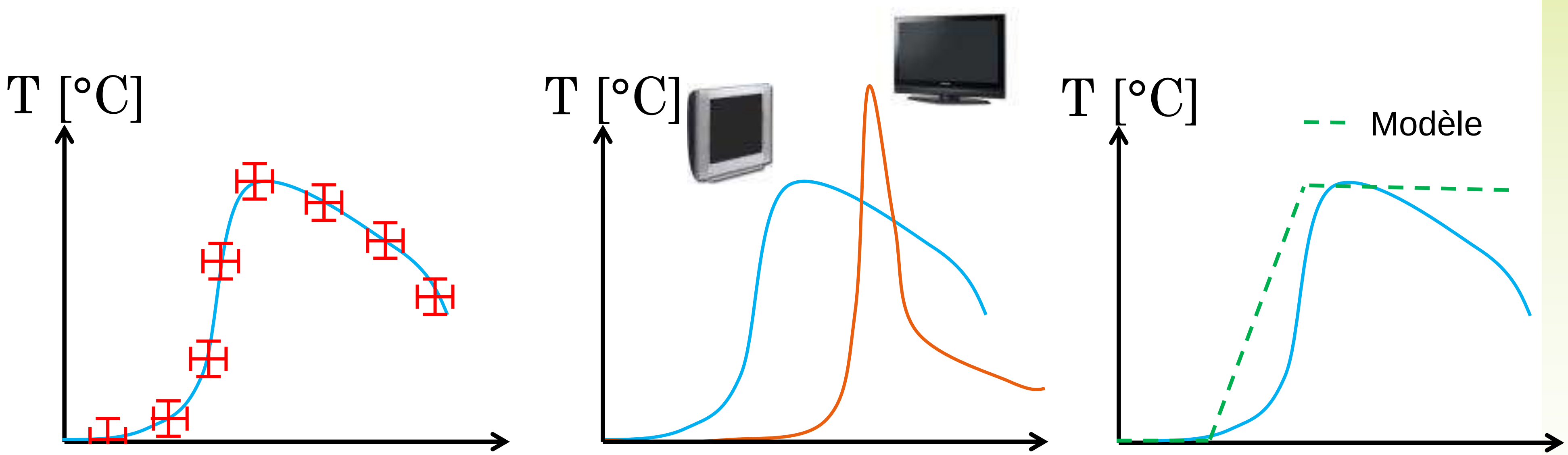
$\dot{Q}_{MAX}$ [W]



Definition of propagation

Uncertainties

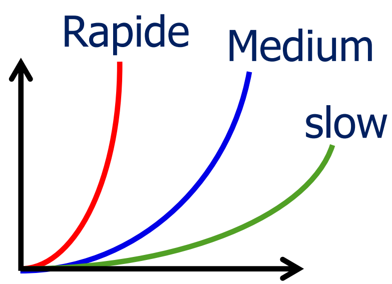
- Mainly three types of uncertainties:
  - Experiment
  - Input data
  - Predictive ability of the models

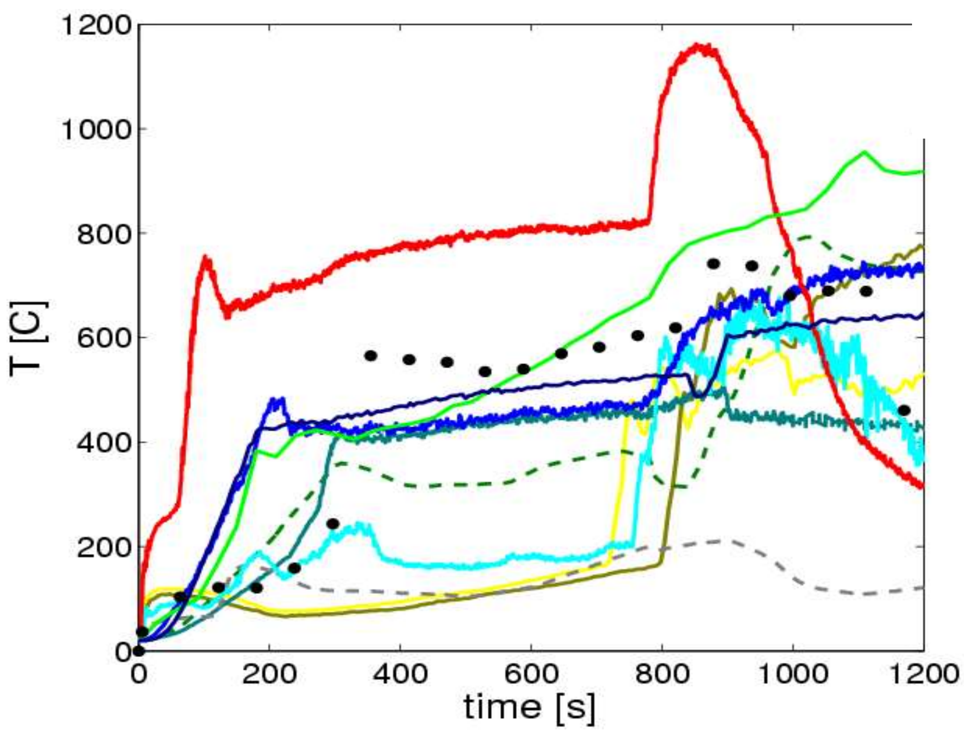


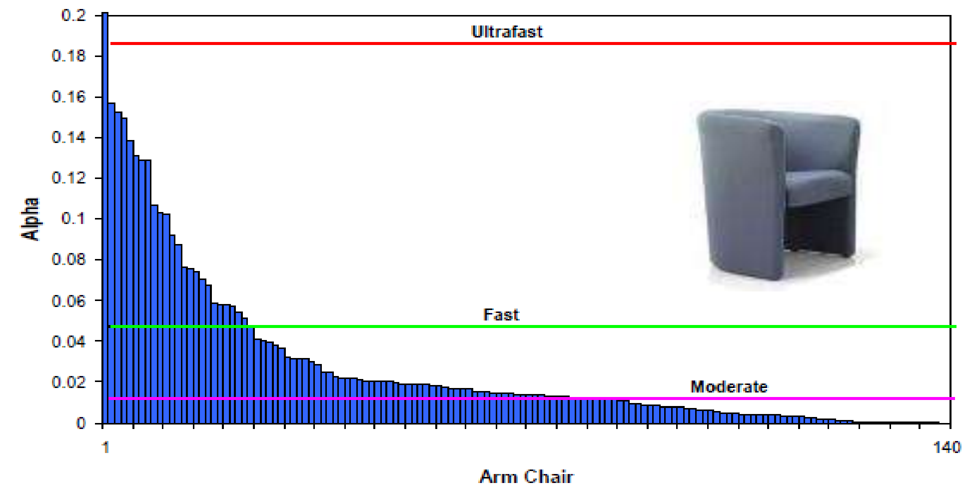
Uncertainties

Example: The input data

$$\dot{Q} = \alpha \, t^2$$







Is prescription the future of performance-based design, C. Fleischmann, Proc. Fire Safety Science 10, 2011

Influence on the time needed to reach critical temperature or tenability limits

⟶ Need to characterise the impact of this uncertainty

G.Rein et al.,The Dalmarnock fire tests: experiments and modelling,. 2007

PBD-Opportunities with Concrete?

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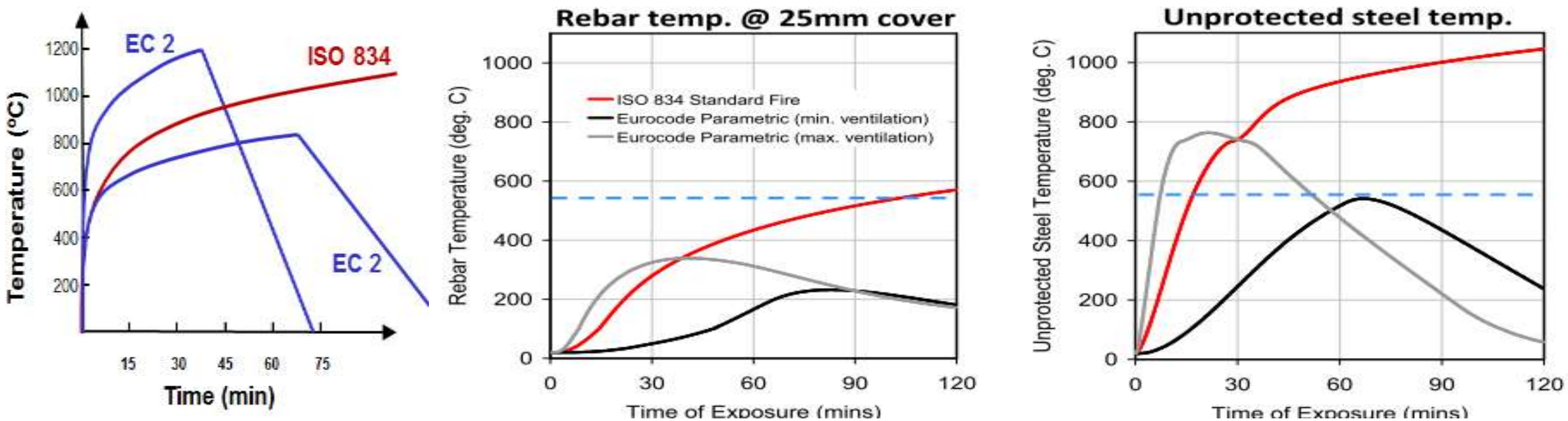
THE UNIVERSITY OF EDINBURGH

PBD-Opportunities with Concrete ?

The most basic possible assessment…



L. Bisby, Engineering solutions for structural fire safety,2013

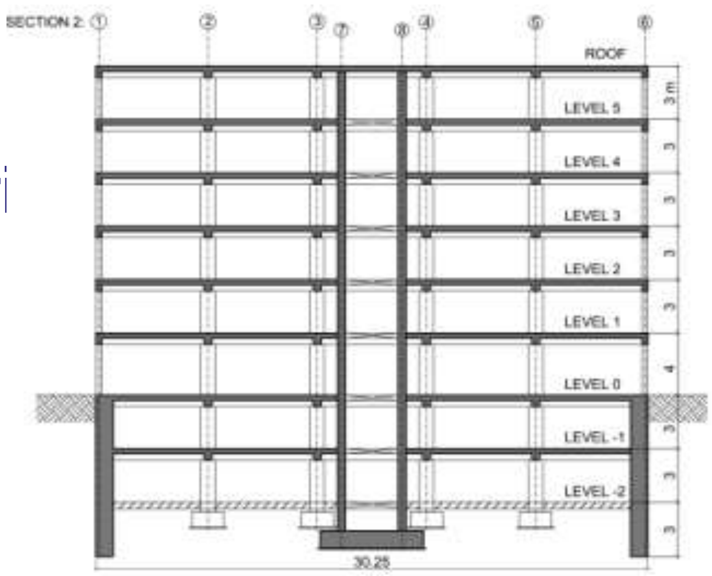
Opportunities:

- Overall analysis of concrete building
- Definition of thermal actions and design fires for large compartments type (open-plan offices)
- Validation of models for large areas compartments

European Concrete Platform

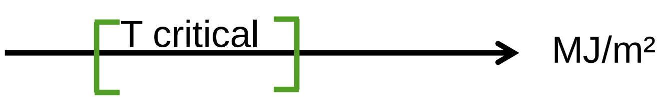
Office/residential building

- ➢ 6-storeys building (+ 2-storey underground)
- ➢ Reinforced cast on site concrete
- ➢ Fire occurring on ground floor : office open to public
- ➢ Ambient temperature design construction (Eurocode)



Objective:

✓ To identify the worst realistic fire scenari
✓ Overall analysis of concrete building



European Concrete Platform

✓Design fire scenarios and design fires

❑**Post-flash over**

❖EC-1991-1-2 (Parametric fires)

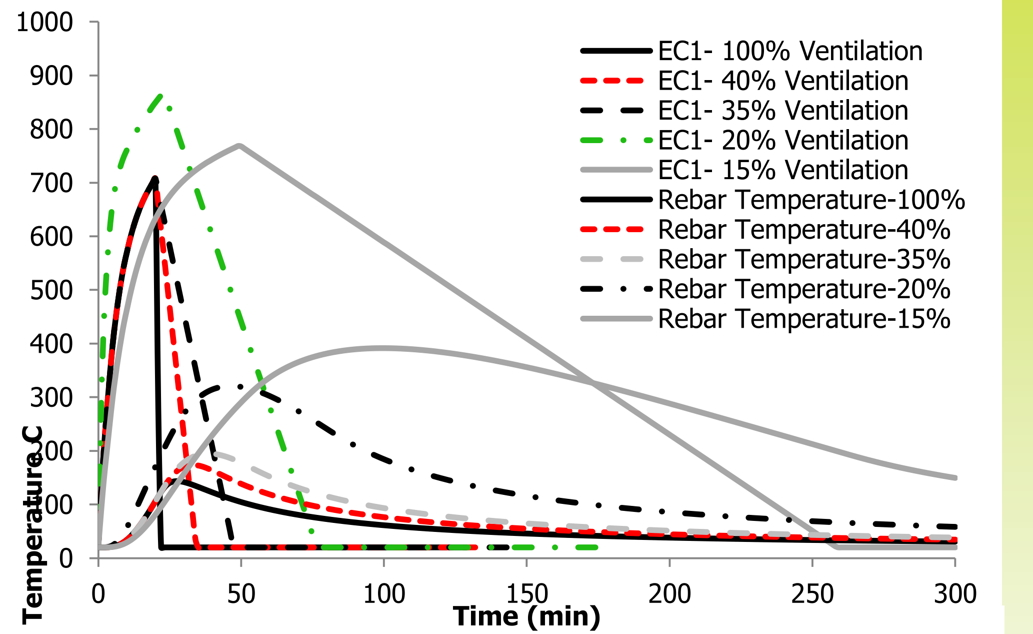
❖A sensitivity analysis

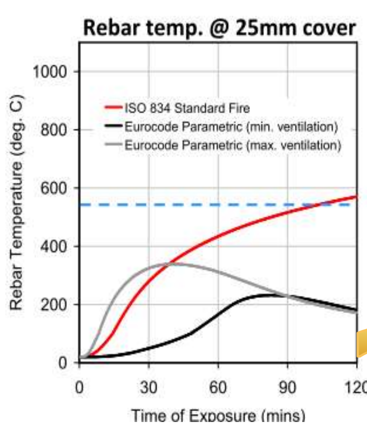
❖OAT (one-factor-at-a-time)

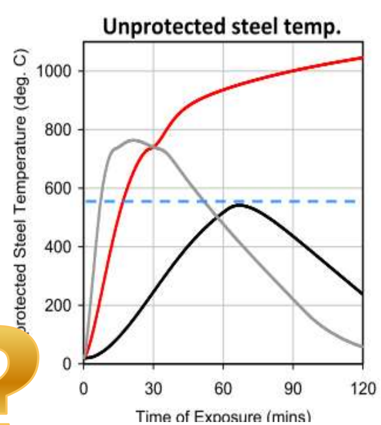
❖Monte Carlo

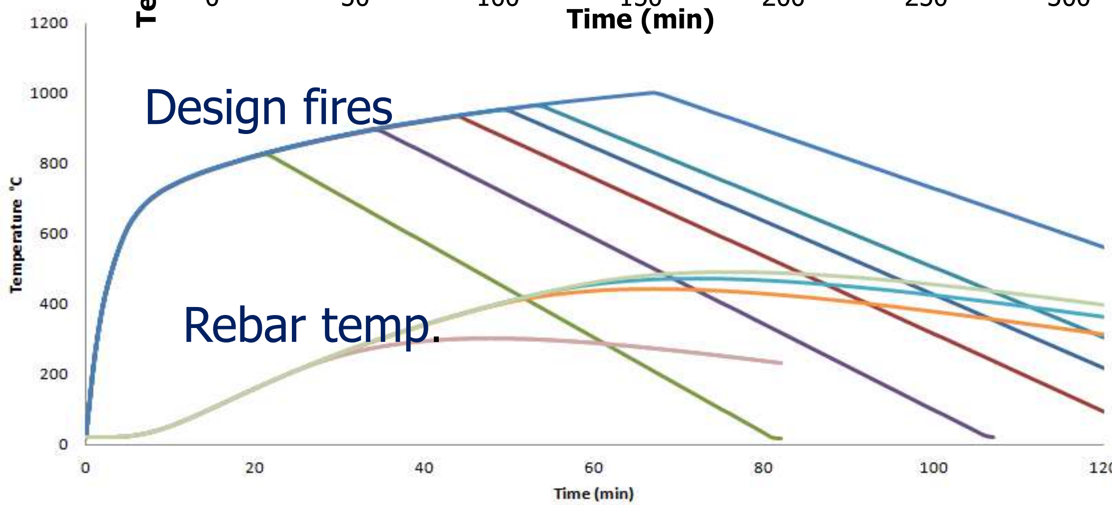
❑**Localized fire**

❖fire models and validation









PBD-Opportunities with Concrete

Travelling Fires: design fires for structural design in a large compartment

- Objective: Definition of thermal action for a large open compartment
- Content: Promote the concept of traveling fires (non-uniform temperature in a lare compartment, the result of observations scale testing one of Dalmarnock, worst impact on the structure)

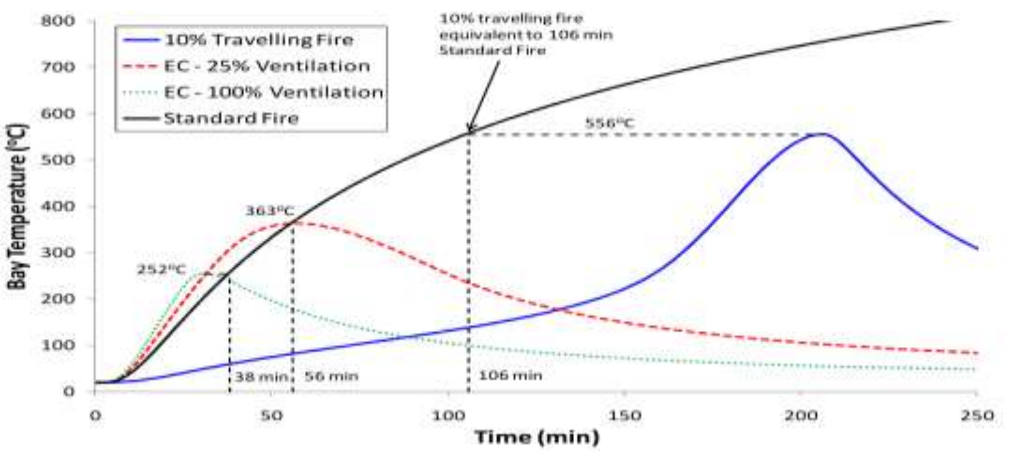
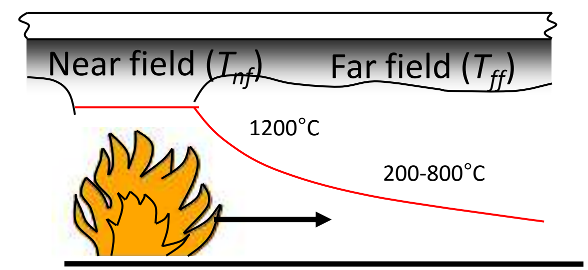
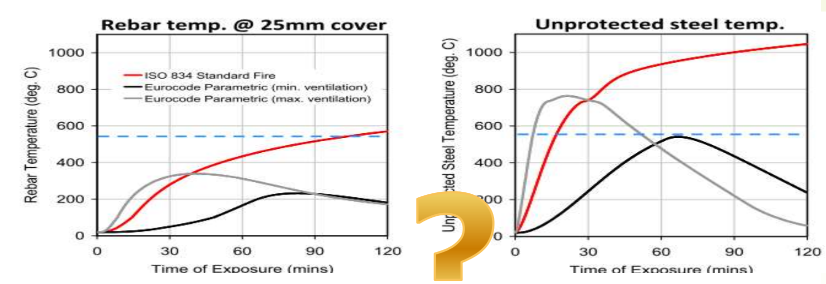


Figure 3.9: Comparison of rebar temperatures calculated using a 10% fire size from the TFM, the standard fire, and two Eurocode parametric temperature-time curves in a similar generic concrete frame as shown in Figure 3.8 [38].





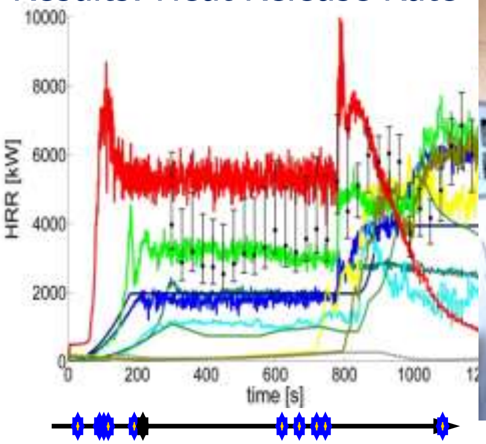
G. Rein, Stern-Gottfried J. Travelling fires for structural design-Part II: Design methodology. Fire Safety Journal [Internet].

PBD-Opportunities with Concrete

Validation of Fire Modeling in large compartments

- Objective: Prediction of temperature fields in large compartments (large open areas, warehouses)
- Content: Comparison between numerical results and experimental results

Results: Heat Release Rate



- During the growth phase: 20 to 500% error in hot layer temperature. 20 to 800% in local temperatures
- A posteriori level of agreement is:10 to 50% for average hot layer temperature

G. Rein et al. Round-Robin Study of a priori Modelling Predictions of The Dalmarnock Fire Test One, Fire Safety Journal 44 (4) pp. 590-602, 2009

Fire Safety Engineering Definition

- The State Of The Art

> *"the application of scientific engineering principles, rules [codes], and expert judgment, based on an understanding of the phenomena and effects of fire and of the reaction and behaviour of people to fire, to protect people, property and the environment from the destructive effects of* fire"

The Institute of Fire Engineering

R. Chitty, Building Research stablishment, 2003

Thanks!