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Probabilities of failure & prescriptive FR guidance

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A career of two halves

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- A researcher – interested in the minutiae

- A consultant – managing risk and uncertainty
- Less bothered about the minutiae, more interested in the bigger picture

A general description of success

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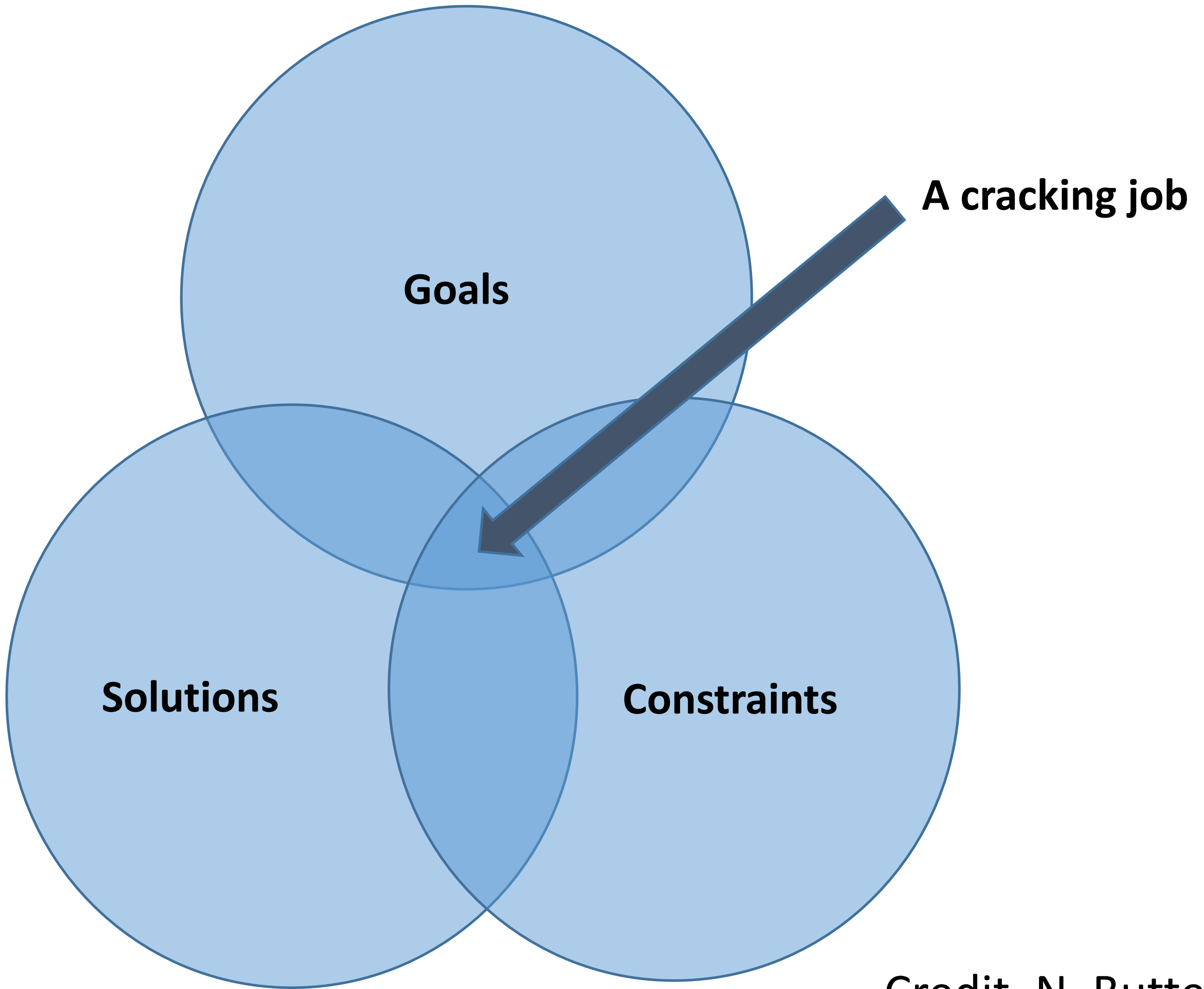

Credit. N. Butterworth

A quantitative description of success

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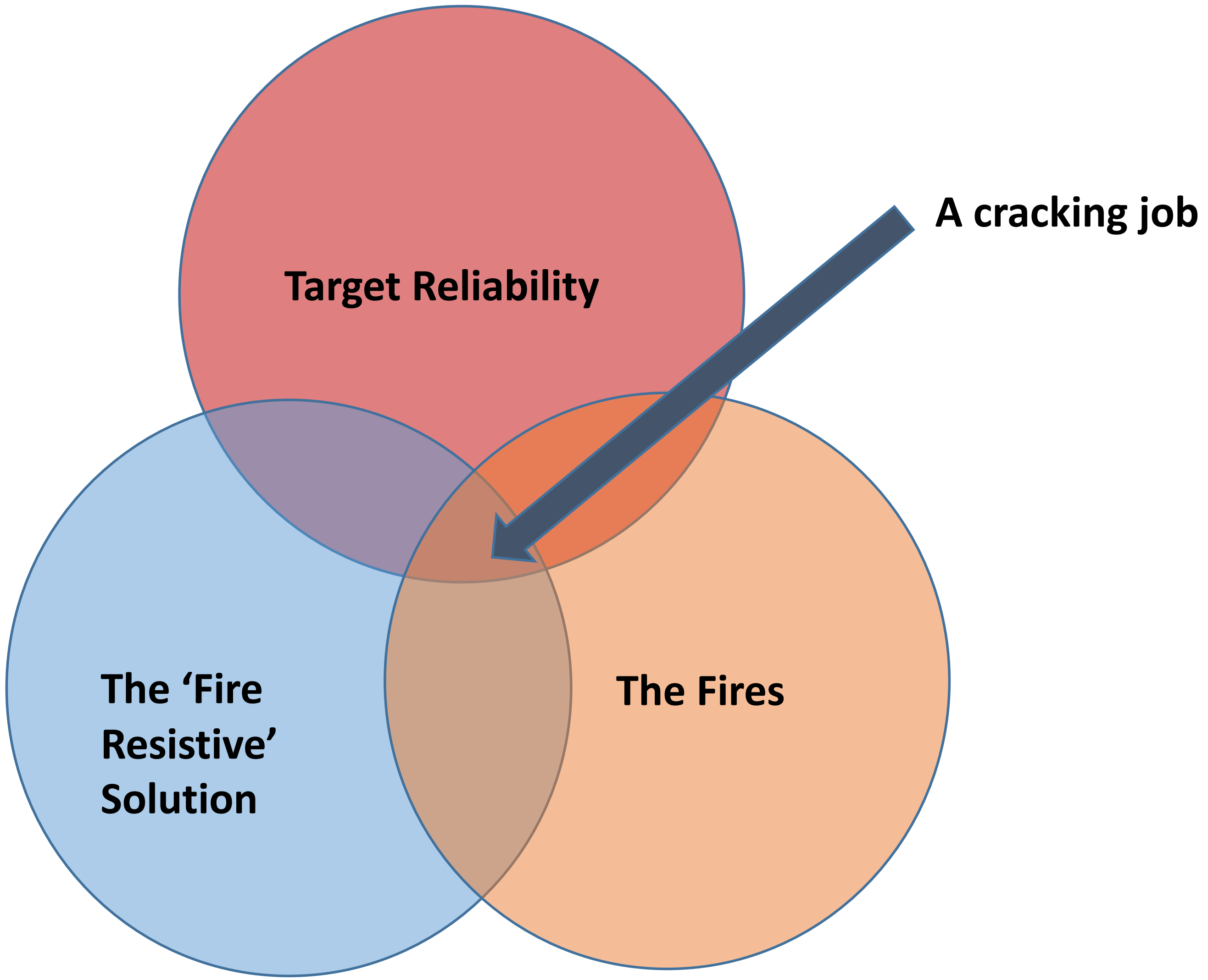

An inconsistency of 'crudeness'

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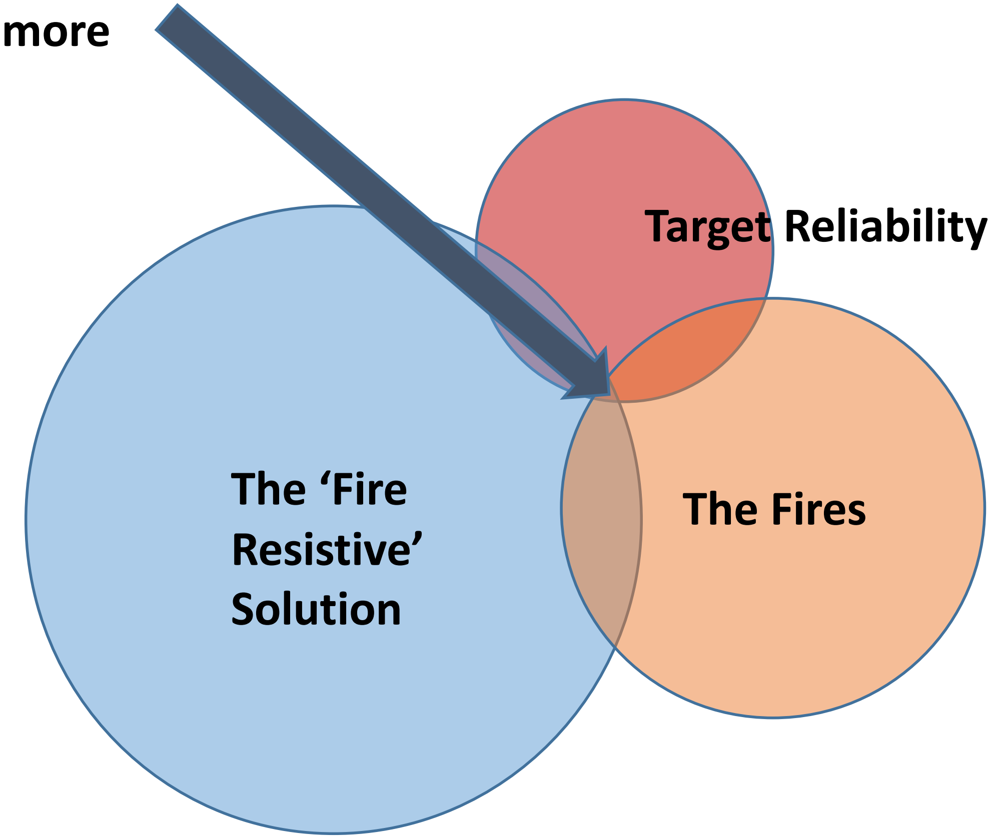
Doing a cracking job is a bit more tough



Our vs. society's life safety expectation?

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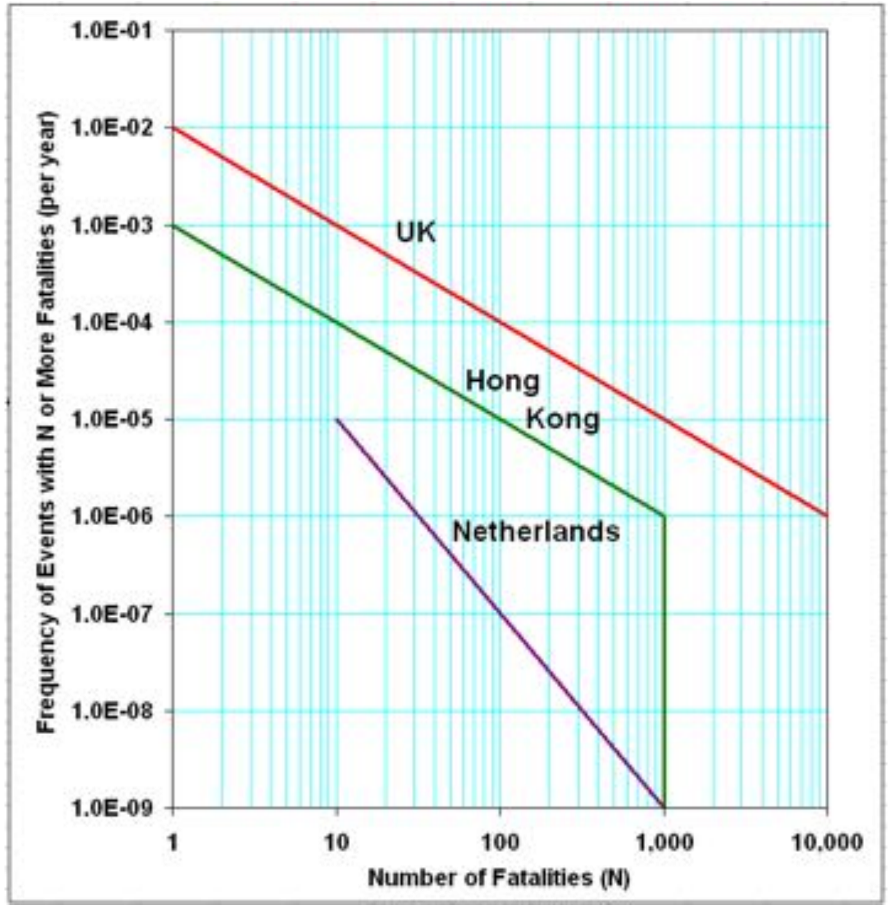
- Safety infinitum?
- That's not what society expects
- If a 'satisfactory' level of safety is our only goal, safety infinitum isn't a great investment
- Tolerable risk (and reliability) is central to what 'we' do



In structural engineering

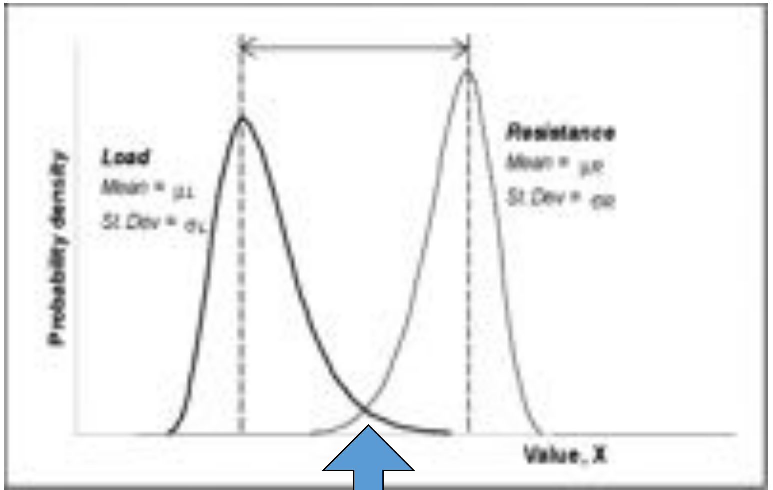
$$P_f(p) = P[R - S < 0]$$

Consider the consequences of failure

Consequences Class	Description	Examples of buildings and civil engineering works
CC3	**High** consequence for loss of human life, *or* economic, social or environmental consequences **very great**	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)
CC2	**Medium** consequence for loss of human life, economic, social or environmental consequences **considerable**	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)
CC1	**Low** consequence for loss of human life, *and* economic, social or environmental consequences **small or negligible**	Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses

Define the acceptable probability of failure

Reliability Class	Minimum values for β	
	1 year reference period	50 years reference period
RC3	5,2	4,3
RC2	4,7	3,8
RC1	4,2	3,3

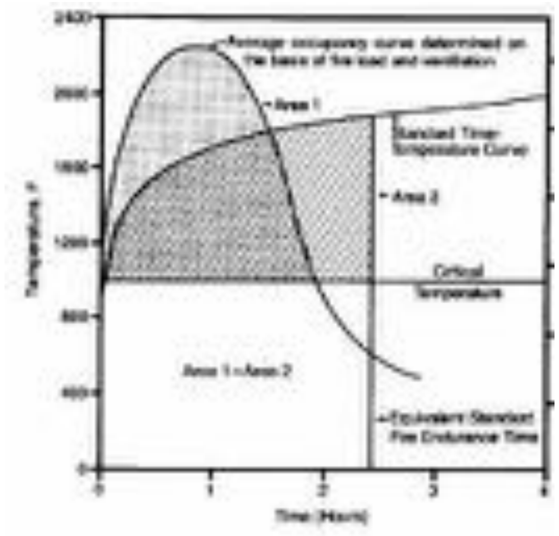


Reduce this to an appropriate level

For most applications 1.3E-06 for a 1YRP

In ‘fire engineering’

- Reasonable = full duration of <u>appropriate</u> fires



Fuel Load[2]		Fire Resistance[3]
MJ/m²	BTU/ft²	minutes
456	40,000	30
912	80,000	60
1,368	120,000	90
1,824	160,000	120
2,736	240,000	180
3,590	320,000	270

- The appropriate fires depend upon the risk (likelihood & consequence)

In ‘fire engineering’ (2)

Table A2 Minimum periods of fire resistance

Purpose group of building	Minimum periods of fire resistance (minutes) in a:					
	Basement storey [1] including floor over		Ground or upper storey			
	Depth (m) of a lowest basement		Height (m) of top floor above ground, in a building or separated part of a building			
	More than 10	Not more than 10	Not more than 5	Not more than 18	Not more than 30	More than 30
1. Residential:						
a. Block of flats						
– not sprinklered	90	60	30*	60**†	90**	Not permitted
– sprinklered	90	60	30*	60**†	90**	120**
b. Institutional	90	60	30*	60	90	120#
c. Other residential	90	60	30*	60	90	120#
2. Office:						
– not sprinklered	90	60	30*	60	90	Not permitted
– sprinklered [2]	60	60	30*	30*	60	120#
3. Shop and commercial:						
– not sprinklered	90	60	60	60	90	Not permitted
– sprinklered [2]	60	60	30*	60	60	120#
4. Assembly and recreation:						
– not sprinklered	90	60	60	60	90	Not permitted
– sprinklered [2]	60	60	30*	60	60	120#
5. Industrial:						
– not sprinklered	120	90	60	90	120	Not permitted
– sprinklered [2]	90	60	30*	60	90	120#

Likelihood & Consequence

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Reliability Targets for Fire Exposed Structures – Some Calculations

Acceptance criterion in PBD

- Absolute -
  - A reasonable worst case - subjective
  - Kirby, et. al. - limited applicability to multi-use
  - EN 1990 / NFSC – quite generalised
  - LQI – estimation of fatalities and awareness of costs

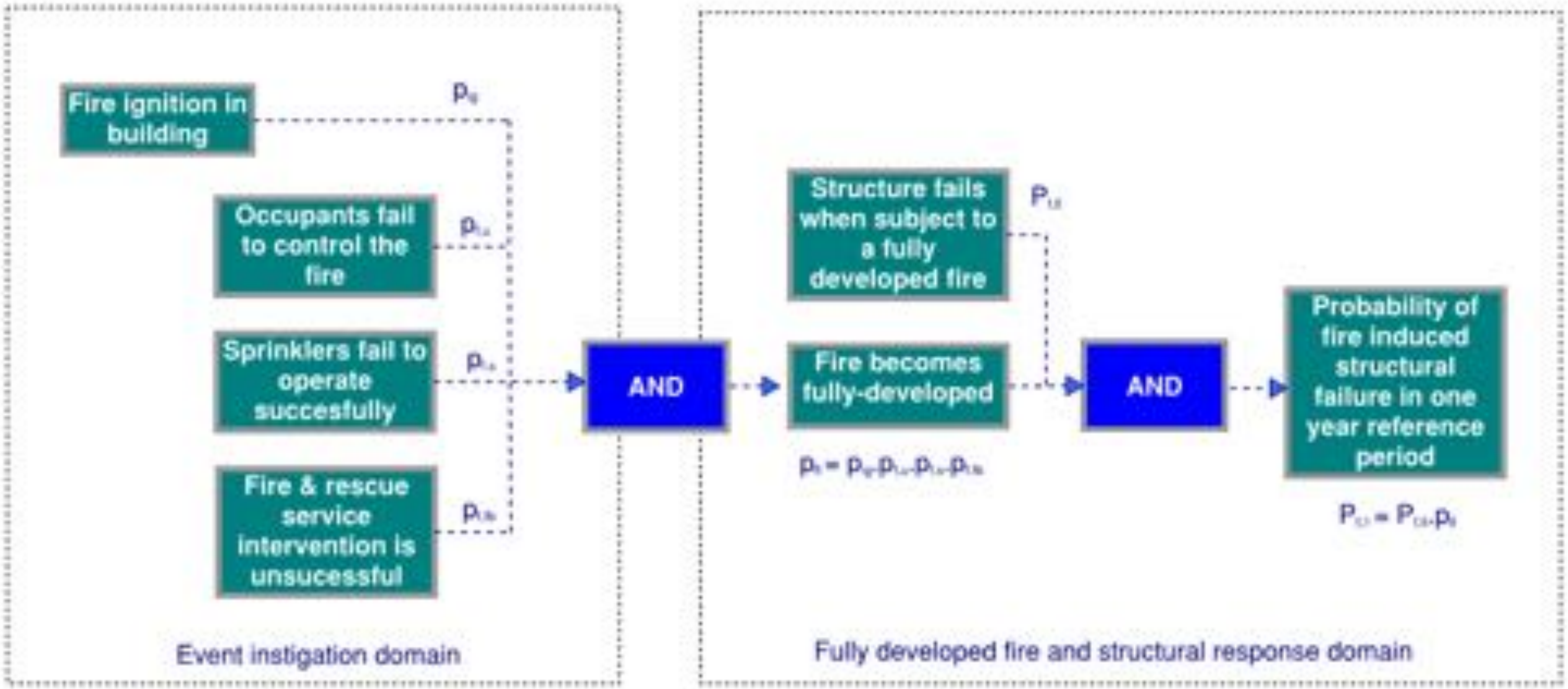
$p_t = 1{,}3 \cdot 10^{-4}$ for normal evacuation p_t [1/year]
$p_t = 1{,}3 \cdot 10^{-5}$ for difficult evacuation (hospitals, etc.)
$p_t = 1{,}3 \cdot 10^{-6}$ for no possible evacuation (f.i. high rise building).

- Comparative –
  - Requires an understanding of what the guidance delivers…

2. Office:						
– not sprinklered	90	60	30*	60	90	Not permitted
– sprinklered (2)	60	60	30*	30*	60	120#

Approx. P_f inherent within ADB FR Periods

- Probabilistic events leading to a fire induced structural failure

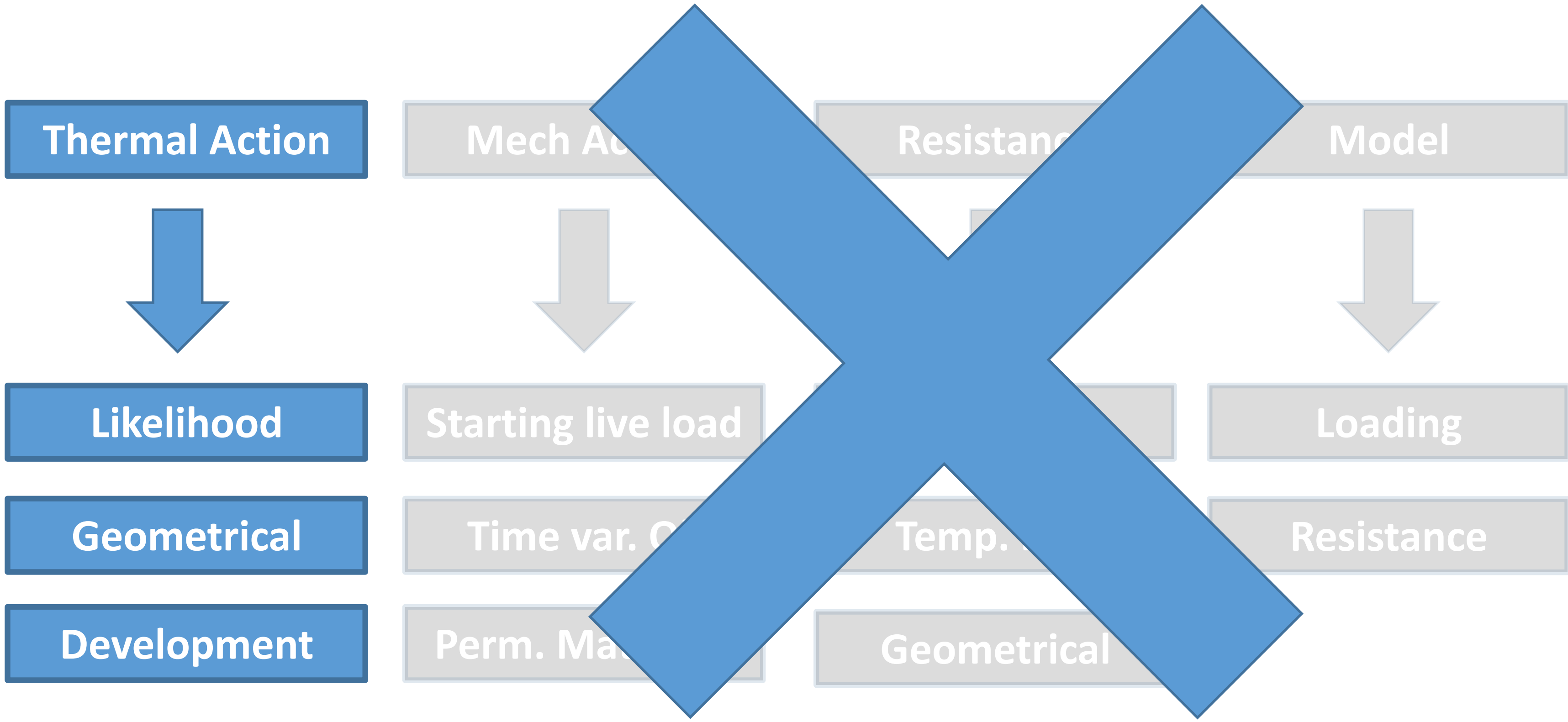


Credit. R. Van-Coile

Some Sources of Uncertainty

Thermal Action	Mech Action	Resistance	Model
Likelihood	Starting live load	Strength	Loading
Geometrical	Time var. Q_k	Temp. Dep	Resistance
Development	Perm. Materials	Geometrical	

Sources of Uncertainty (2)



Some 'simple' enclosures

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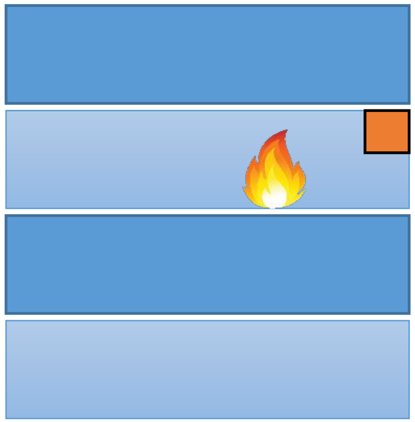
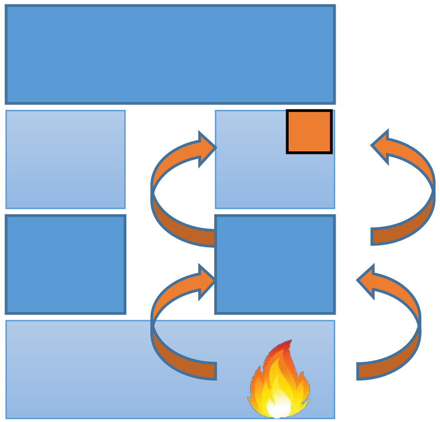
Metric / Input	Office	Residential
Area (sq.m)	500	30
Height (m)	3.0	2.4
Ventilation Area (sq.m)	175	6.0
Glazing Fraction (-)	0.1 – 1.0	0.1 – 1.0
Linings	GYPB	GYPB

Some key assumptions



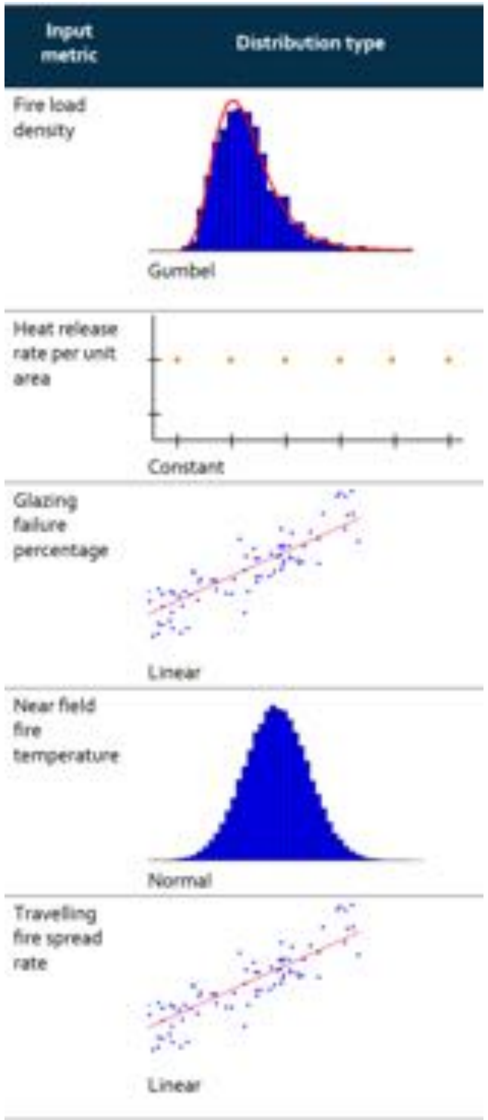
Element affected by the fire is on the floor of origin



No vertical fire spread

Only area of the compartment of origin influences P_{ig}

Some ‘stochastic’ inputs



As per the NFSC – C.O.V = 0.3

As per PD 7974-1

A best guess….

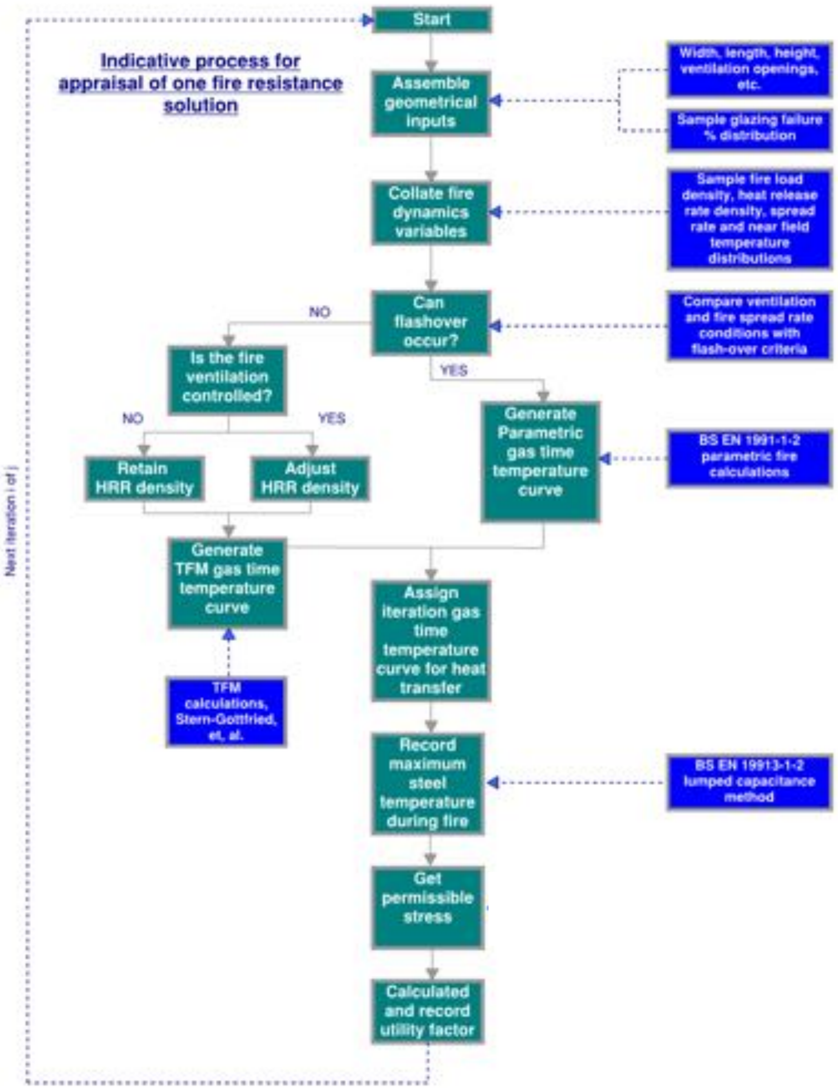
After J. Stern-Gottfried (mean 1,050°C)

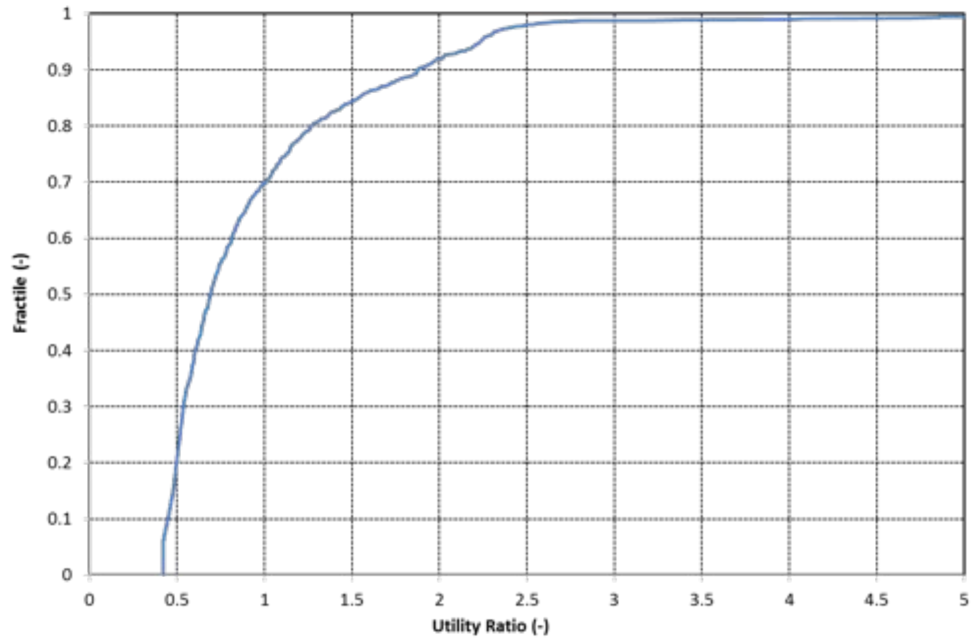
Anecdotal – min 5 mm/s – max 20 mm/s

A simple structural element

- Steel beam supporting a concrete slab
- Protected with gypsum board
- FLS utilisation corresponding to a limiting temperature of 620°C
- For 355 MPa steel → 150 MPa applied
- Test different protection regimes for FR30 – FR120
- Element / sub-frame failure:
  - Utility ratio > 1.0
  - Utility 150 / $k_{y\theta} f_y$

Fire fragility curve - LHS





Utility vs. fractile for one FR60 protection solution

From fragility to Pf

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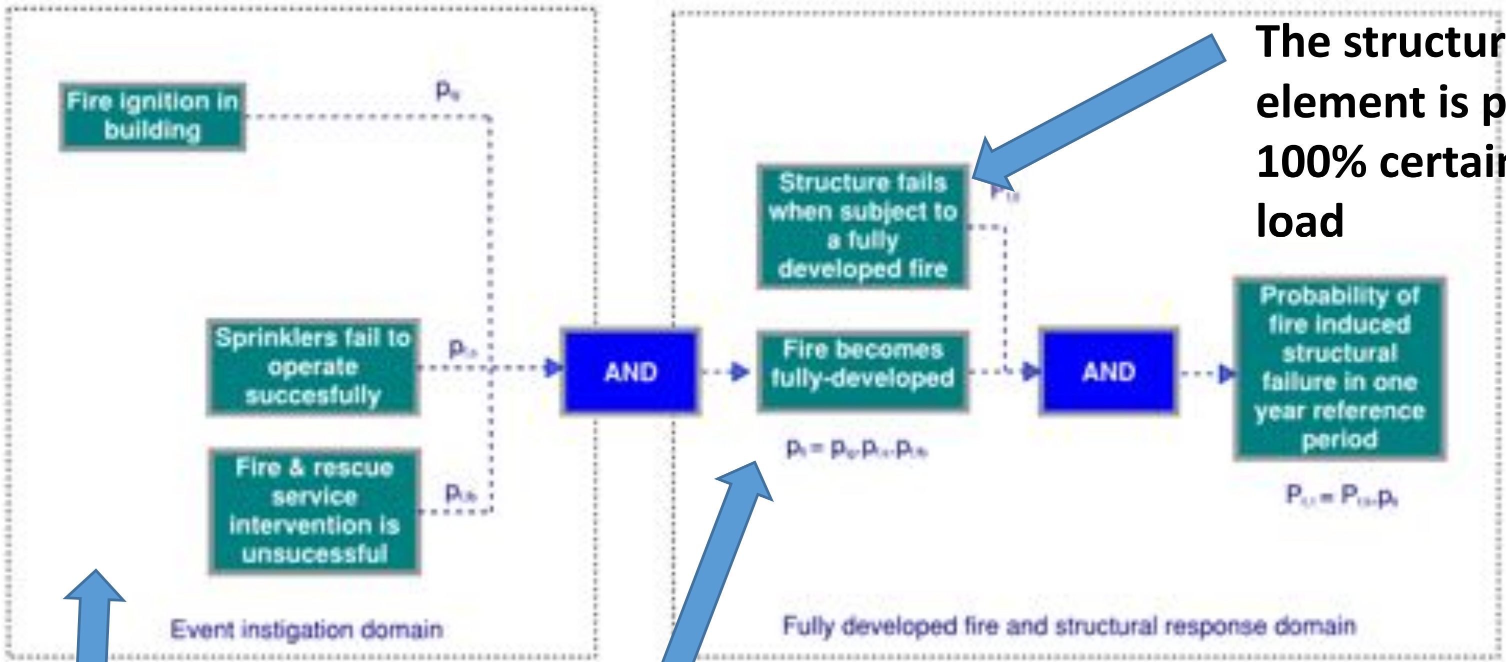
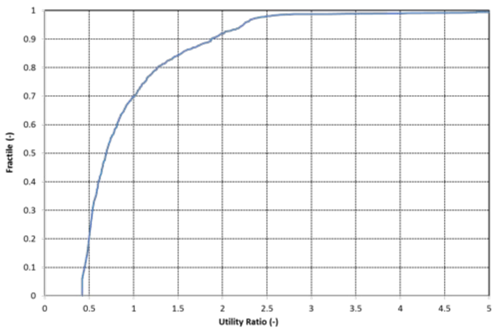
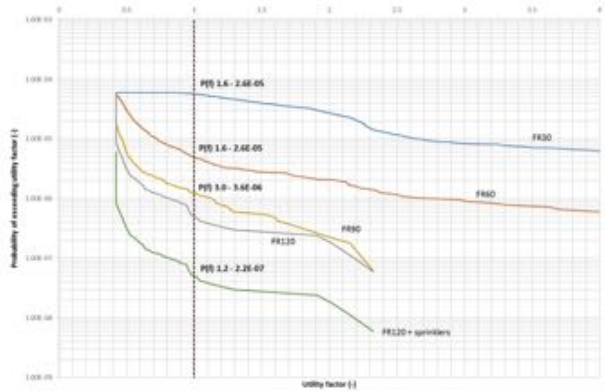
The structural element is perfect! 100% certainty of load



Occupancy/Activity	p_1 [10^{-7}/(m^2 ·year)]
Office	2 – 4
Dwelling	4 – 9
Industrial	5 – 10

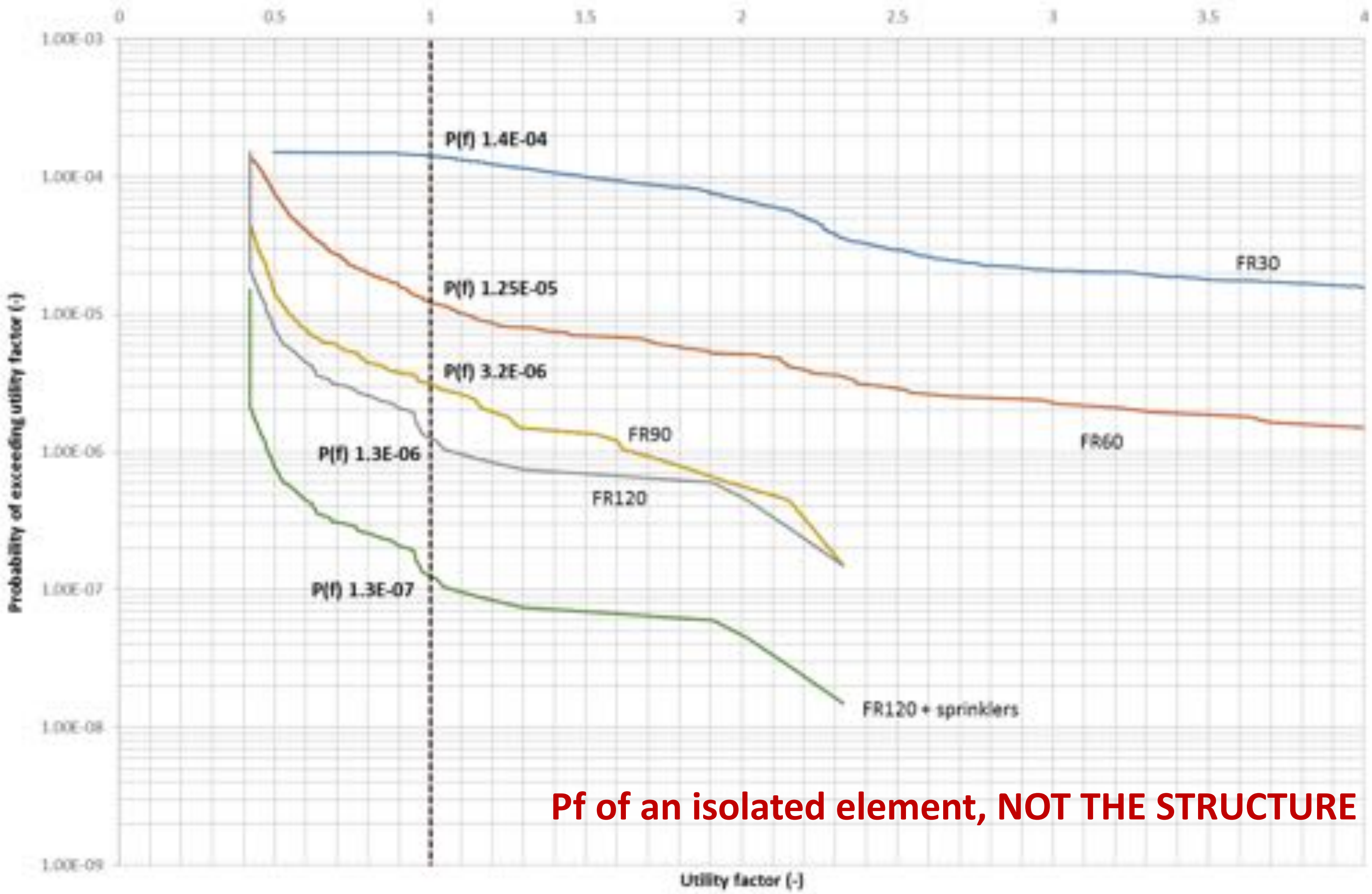
TABLE 5.2: Frequency of fire start and growth to severe fire including standard public fire brigade





$P_{f,s}$ = 0.10

Results – 500 sq.m Office



Results – 30 sq.m Apartment

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Pf of an isolated element, NOT THE STRUCTURE

Summary & Comparison

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Pf of an element when afforded different FR solutions

Fire Resistance Solution (min)	Pf – Office (500 sqm)	Pf – Apartment (30 sqm)
30	1.4E-04	2.2E-05
60	1.3E-05	1.9E-05
90	3.2E-06	1.2E-05
120	1.3E-06	6.8E-06
120 + Sprinklers	1.3E-07	6.8E-07

For comparison – the NFSC (Annex B WG5)

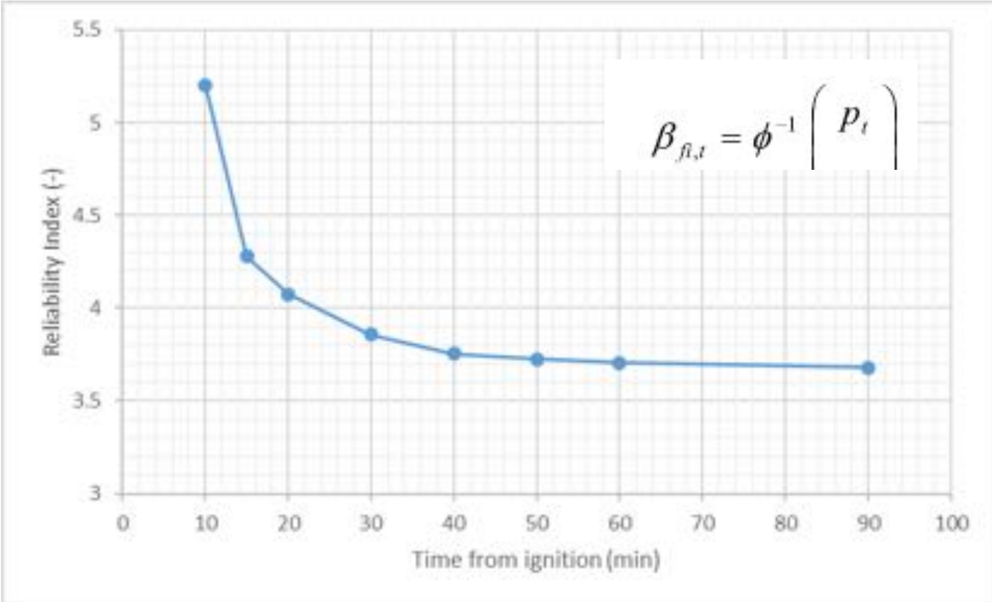
Potentially excessive?

$p_t = 1,3 \cdot 10^{-4}$ for normal evacuation p_t [1/year]
$p_t = 1,3 \cdot 10^{-5}$ for difficult evacuation (hospitals, etc.)
$p_t = 1,3 \cdot 10^{-6}$ for no possible evacuation (f.i. high rise building).

For comparison – EN 1990 (Ambient)

- RC1 – 1E-05
- RC2 – 1E-06
- RC3 – 1E-07

A WiP....



The need for two acceptance criteria?

Transient variation in reliability index – FR30 – 500 sqm office

Closing Remarks

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- The inherent life safety P_f for an isolated element within ADB have been crudely estimated
- They are very sensitive to area and, thus, the choice of benchmark
- The order of magnitudes noted are broadly consistent with those tentatively proposed in the NFSC
- The P_f values give a means of estimating what FR is required of elements in straightforward buildings for differing consequences & likelihood
- FR120 + sprinklers → RC3

High consequence for loss of human life, *or* economic, social or environmental consequences **very great**	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)

Closing Remarks

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- The concept of forming two life safety FLS:
  - A target for the evacuation phase (where failure is less tolerable)
  - A target for the burnout phase (where failure might be an acceptable outcome)
  - Convergence of the two targets for high-rise
- Further work:
  - A proper reliability assessment – the additional sources of uncertainty
  - A continuous description of the target P_f as a function of likelihood and consequence

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Thanks for your time

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