# Reliability-based methodology for determining the effects of sprinkler and fire brigade intervention on post-flashover fire temperature development

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STRUCTURES IN FIRE FORUM

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# Outline of presentation

- Introduction - Fire intervention methods and why they are needed
- Current methods of incorporation of intervention methods in fire safety design and limitations
- Assessment of current methods – is it appropriate?
- Proposed methodology
- Conclusion and future work

# Introduction – the need for active fire protection

## Fire protection methods

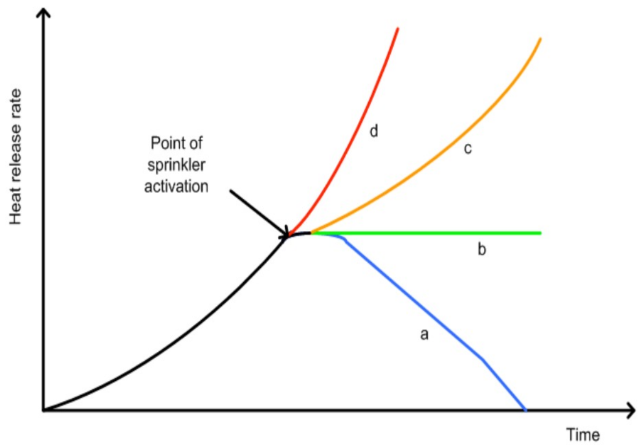
**Passive**
- Coating
- Fire doors
- Firewalls
- etc.

**Active**
- Sprinklers
- Fire brigade intervention
- Fire and smoke alarms
- etc.

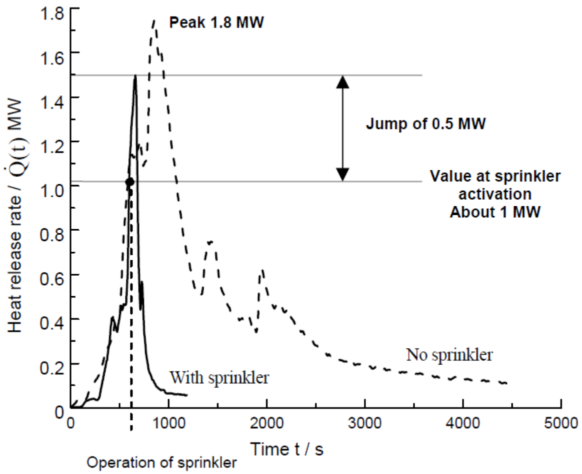
**<u>The need for active fire protection:</u>**

- Control continuous production of smoke
- Control spread of smoke
- **<u>Slow down</u> temperature rise in fire compartment and structural elements**

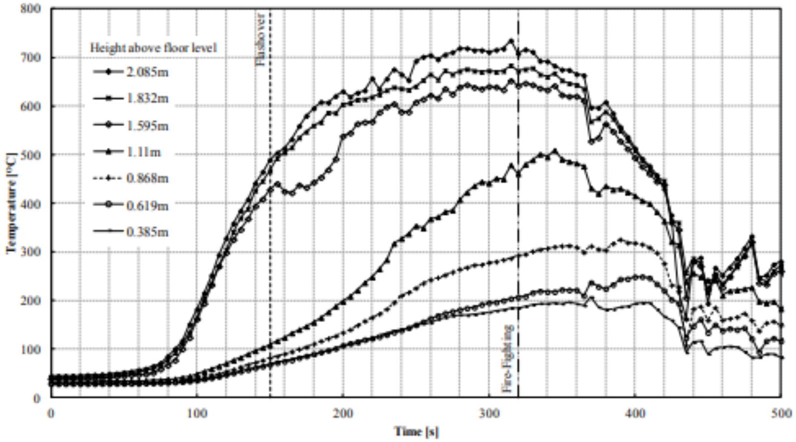
# Introduction – effect of active fire intervention on temperature rise




Effect of sprinkler systems on fire development
*(Source: British Automatic Sprinkler Association)*




Heat Release Rate for an office fire test (Chow 2006)




Heat Release Rate for an office fire test (Alarifi 2006)

# Current method of incorporation of active fire measures

$$q_{f,d} = m.\delta_{q1}.\delta_{q2}.\delta_{n}.q_{f,k}$$

$$\Theta_g = 20 + 1\,325\,(\,1 - 0{,}324\,e^{-0{,}2t^*} - 0{,}204\,e^{-1{,}7t^*} - 0{,}472\,e^{-19t^*}\,)$$

Where,

$$t^*_{max} = t_{max} \cdot \Gamma$$

$$t_{max} = \max\,[(0{,}2 \cdot 10^{-3} \cdot q_{t,d} / O)\,;\,t_{lim}\,]$$

BS EN 1991-1-2, Annex E, Table E.1

| Compartment floor area $A_f$ [m²] | Danger of Fire Activation $\delta_{q1}$ | Danger of Fire Activation $\delta_{q2}$ | Examples of Occupancies |
|---|---|---|---|
| 25 | 1,10 | 0,78 | artgallery, museum, swimming pool |
| 250 | 1,50 | 1,00 | offices,residence, hotel, paper industry |
| 2 500 | 1,90 | 1,22 | manufactory for machinery & engines |
| 5 000 | 2,00 | 1,44 | chemical laboratory, painting workshop |
| 10 000 | 2,13 | 1,66 | manufactory of fireworks or paints |

BS EN 1991-1-2, Annex E, Table E.2

| $\delta_{ni}$ Function of Active Fire Fighting Measures | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Automatic Fire Suppression | | Automatic Fire Detection | | | Manual Fire Suppression | | | | |
| Automatic Water Extinguishing System | Independent Water Supplies (0 / 1 / 2) | Automatic fire Detection & Alarm by Heat | Automatic fire Detection & Alarm by Smoke | Automatic Alarm Transmission to Fire Brigade | Work Fire Brigade | Off Site Fire Brigade | Safe Access Routes | Fire Fighting Devices | Smoke Exhaust System |
| $\delta_{n1}$ | $\delta_{n2}$ | $\delta_{n3}$ | $\delta_{n4}$ | $\delta_{n5}$ | $\delta_{n6}$ | $\delta_{n7}$ | $\delta_{n8}$ | $\delta_{n9}$ | $\delta_{n10}$ |
| 0,61 | 1,0 / 0,87 / 0,7 | 0,87 or 0,73 | | 0,87 | 0,61 or 0,78 | | 0,9 or 1 or 1,5 | 1,0 or 1,5 | 1,0 or 1,5 |

- Load factors are based on the Natural Fire Safety Concept (NFSC) project

# Derivation of fire load factors

Natural Fire Safety Concept (NFSC) Project

Two Levels:

- Level 1: Semi-probabilistic
- Level 2: Use of load factors

- Level 0: Full probabilistic

**Building Data:**
Design life, building type, floor area, area of openings and total area

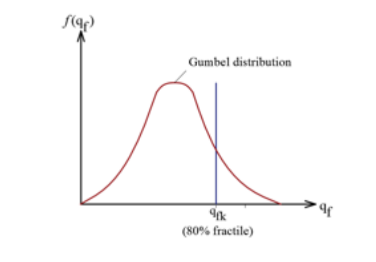
**Probability of Fire:**
P(fully engulfed fire) = $P_{fi}$ = P1.P2.P3.P4

**P1** = P(fire occurrence).P(fire not stopped by occupants and FB)
**P2** = reduction factor based on FB type and time of intervention
**P3** = reduction factor based on presence of automatic fire detection and alarm transmission
**P4** = Probability of failure of sprinkler system

**Target Probability of Failure:**
$P_t$(structural failure) = $7.23 \times 10^{-5}$
$P_{t,fi}$(structural failure in case of fire ) = $P_t/P_{fi}$

**Target Reliability Index:**
$\beta_{t,fi} = \phi^{-1}(P_{t,fi})$

**Fire Load:**
$q_{fk}$= 80% fractile, COV = 0.3

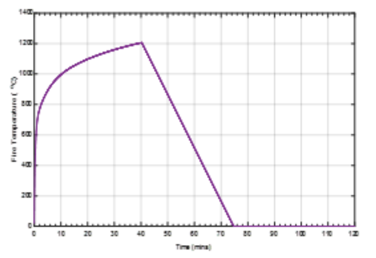



**Design Fire Load:**

$$q_{f,d} = \gamma_{SD} m_{qf} \left\{ 1 - \frac{6}{\sqrt{\pi}} V_{qf} \left[ 0.577 + \ln\left( -\ln \phi\left( -0.9\beta_{fi,t} \right) \right) \right] \right\}$$

**Fire Load Factor:**

$$\gamma_{qf} = \frac{q_{f,d}}{q_{f,k}} = 1.05 \frac{\left\{ 1 - \frac{6}{\sqrt{\pi}} V_{qf} \left[ 0.577 + \ln\left( -\ln \phi\left( -0.9\beta_{fi,t} \right) \right) \right] \right\}}{\left\{ 1 - \frac{6}{\sqrt{\pi}} V_{qf} \left[ 0.577 + \ln\left( -\ln 0.8 \right) \right] \right\}}$$

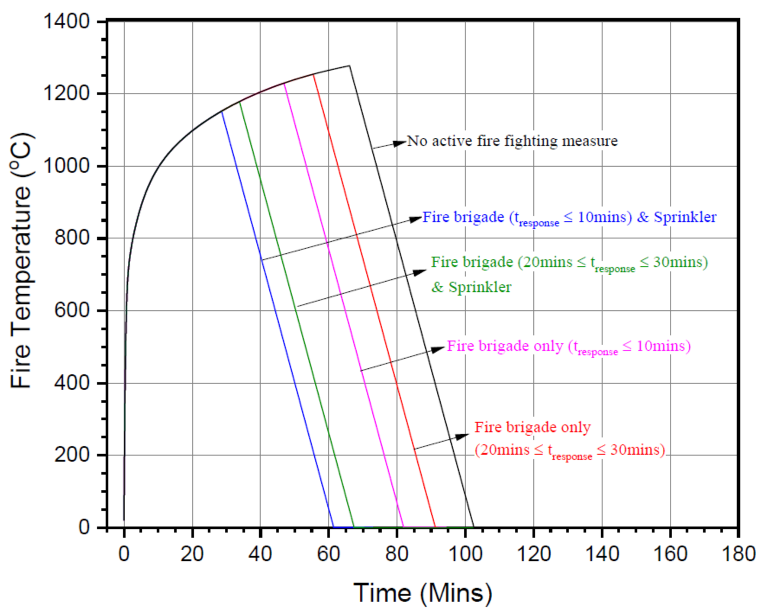


# Limitations in the current method

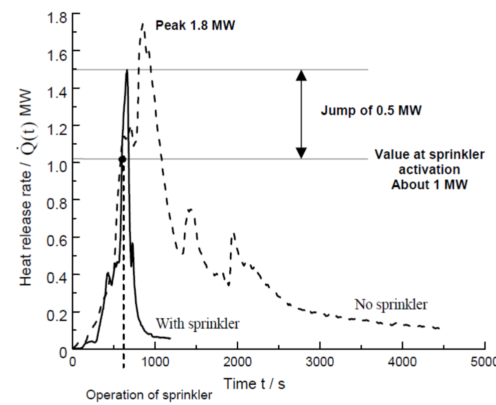
## Two major limitations:

I. Data used in developing the fire load factors were based on fire protection statistics between 1983 – 1997 (over 20 years ago)

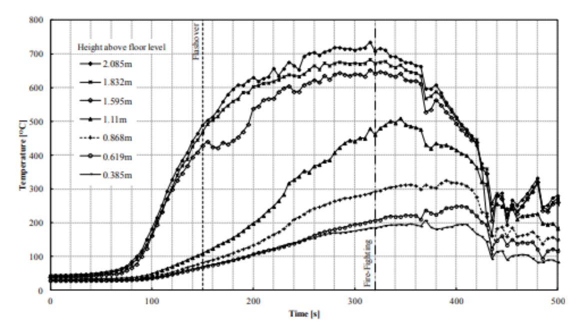
II. The current approach does not capture the effects of fire brigade intervention and sprinkler activation on changing the ascending rate of fire temperature-time curve.




Fire curve for different combinations of fire brigade intervention and sprinkler activation using NFSC approach




Effect of sprinkler on fire development




Effect of fire brigade on fire development

# Recent data on sprinkler reliability and fire brigade response times

**Summary of Report of Sprinkler Effectiveness in the UK (from analysis of fire service data (2011 – 2016))**

| | |
|---|---|
| Total no. of fire incidents with sprinklers | **2294** |
| | |
| Sprinkler activated/working | 41.19% of total |
| Sprinkler contained or controlled fire | 62% |
| Sprinkler extinguished fire | 37% |
| Total Sprinkler performance effectiveness/reliability | 99% |
| Sprinkler working but fire not contained or extinguished | 1% |
| | |
| Sprinkler present but not working | 57.37% of total |
| Sprinkler expected to work but NOT working | 6.5% |
| Sprinkler NOT expected to work and does not work | 93.5% |
| | |
| Combined Sprinkler reliability | 99*93.5 = **92.6%** |
| Corresponding fire load factor using the NFSC Level 2 approach | **0.75** |

In the current method, a sprinkler reliability of **98%** was used to determine a fire load factor of **0.61** for sprinklers. This is the factor adopted in the current EN-1991-1-2 and also in the UK NA

# Recent data on sprinkler reliability and fire brigade response times

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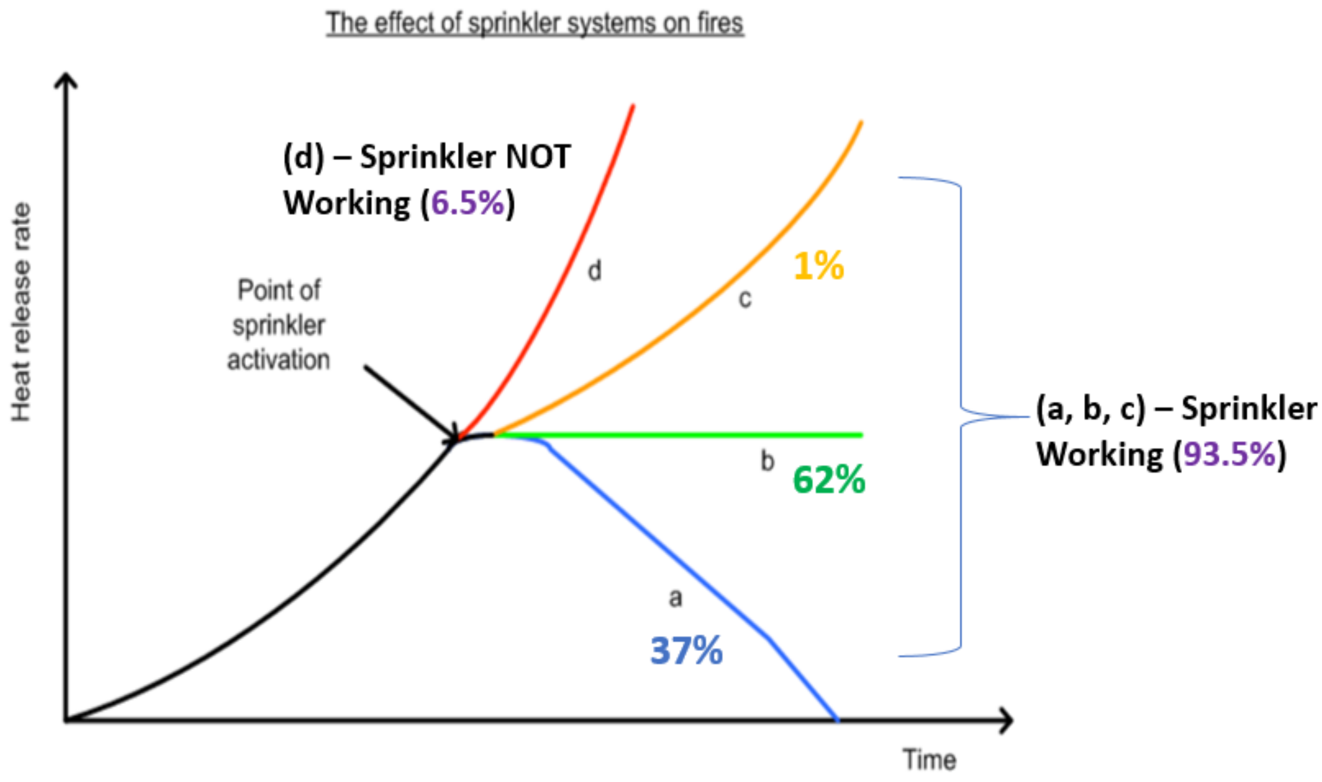
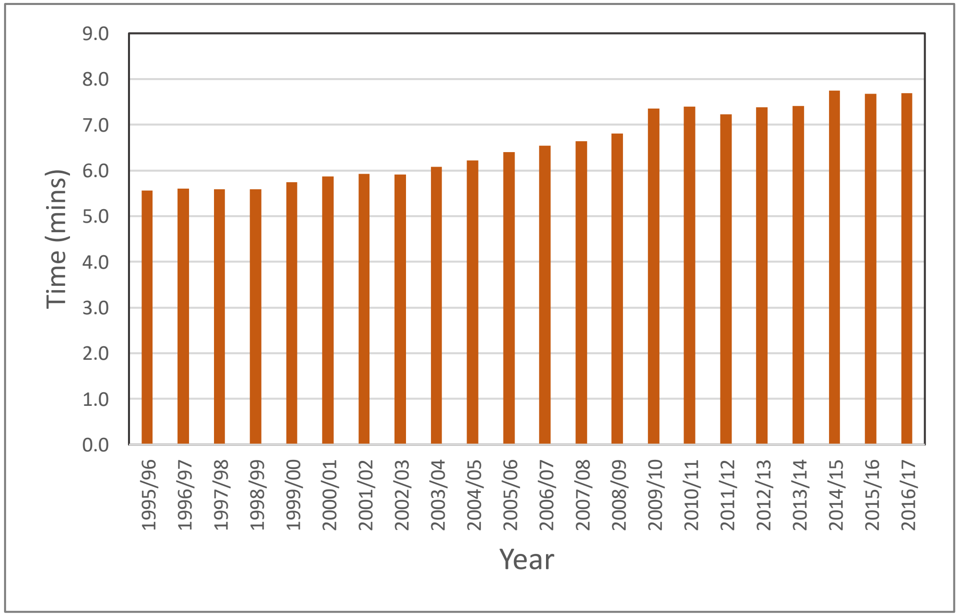
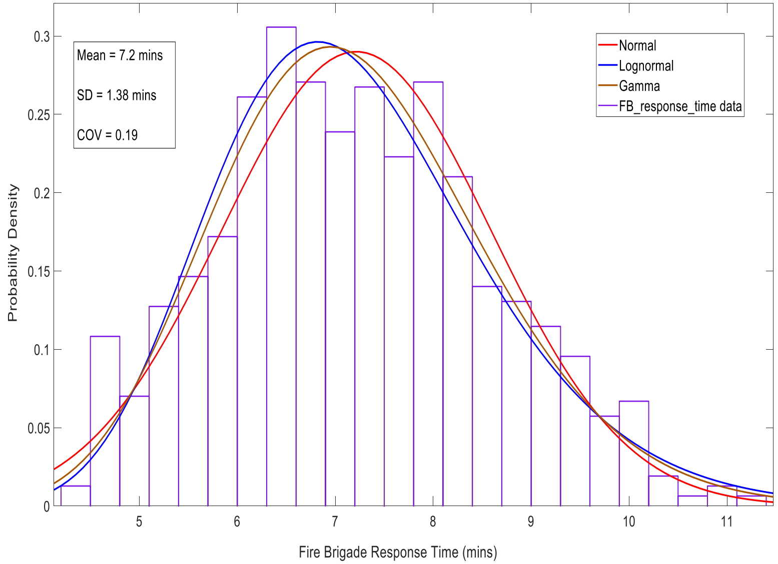


# Recent data on sprinkler reliability and fire brigade response times

## Average response time by Fire Brigade for England




Probability of failure of fire brigade for different response times used in the NFSC project

| $p_f^{FB}$ / Type of firemen | Time between alarm and action of the firemen ≤ 10' | 10' < t ≤ 20' | 20' < t ≤ 30' |
|---|---|---|---|
| Professional | 0,05 | 0,1 | 0,2 |
| Not-professional | 0,1 | 0,2 | 1 |

# Recent data on sprinkler reliability and fire brigade response times

**Sensitivity of fire load factors to fie brigade response time**

| Probability of fire brigade response | Load factor for fire brigade |
|---|---|
| **P(Response time > 3mins) = 1.0** | 1.0 |
| **P(Response time > 5mins) = 0.967** | 0.997 |
| **P(Response time > 7mins) = 0.5285** | 0.5285 |
| **P(Response time > 10mins) = 0.0347** | 0.668 |

BS EN 1991-1-2, Annex E, Table E.2

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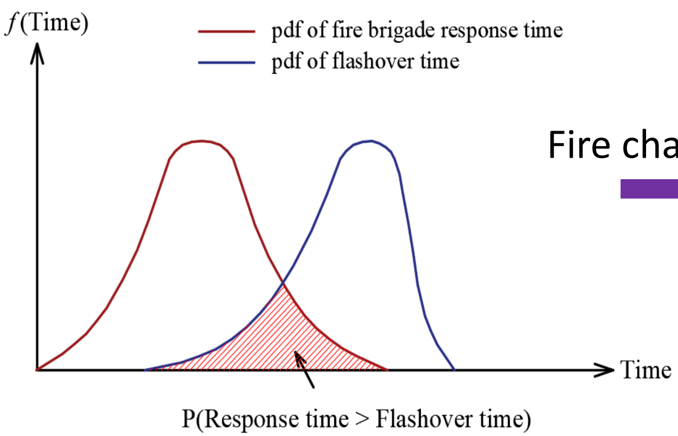
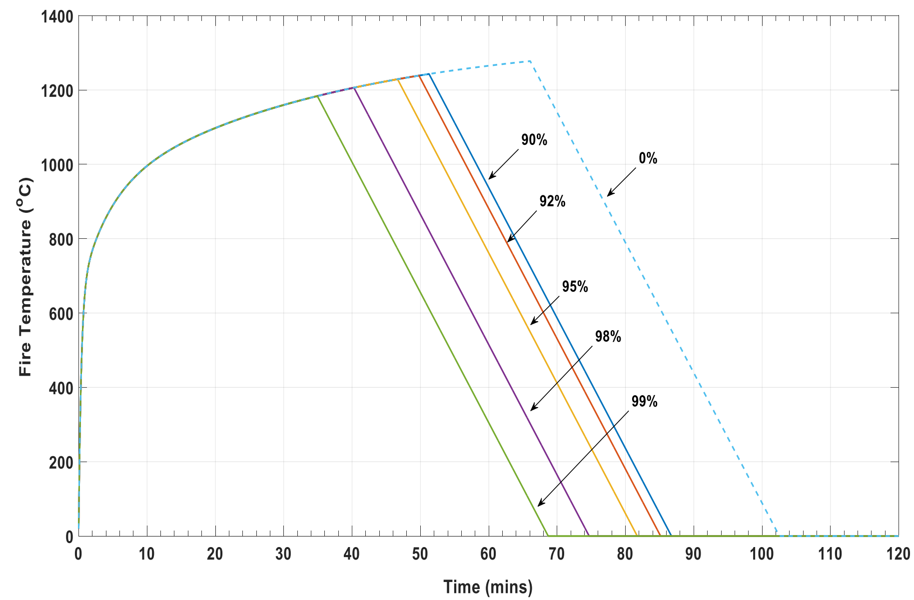
# Proposed method for assessing current NFSC approach




Fire characteristics




Carryout explicit reliability analysis to determine probability of structural failure through a Monte Carlo Simulation

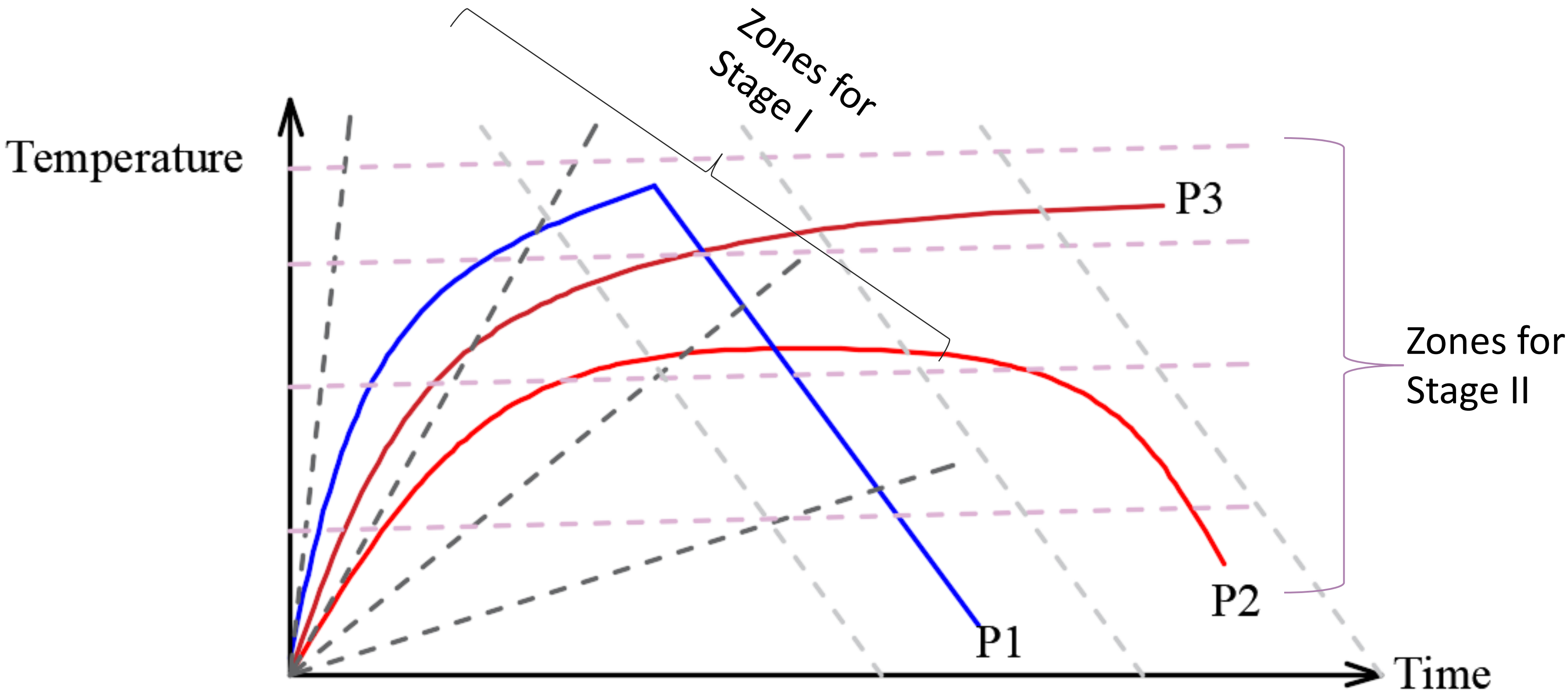
Compare results with implied probability of failure in the NFSC approach ($7.23 \times 10^{-5}$)

- Preliminary results show difference in the probabilities of failures

# Proposal for a new method of incorporating fire brigade and sprinkler action

- Based on analyzing actual compartment fire temperature-time curves
- Greater Manchester Fire and Rescue Service have agreed to provide temperature measurements from actual fire fighting
- The method is based on defining zones for the three post-flashover stage of fire based
- The probability of a curve being in each zone will be evaluated based on characteristics of the fire and the compartment
- A final compartment fire temperature-time curve will be constructed with associated probability of occurrence
- A similar approach will be developed for sprinklers

# Proposal for a new method of incorporating fire brigade and sprinkler action



# Major conclusions and future work

- Statistics upon which current fire load factors are based are old, new factors have been determined using updated statistics
- Probabilities of failure are very sensitive to variability in fire brigade response time
- The fire temperature-time curve obtained using current method of incorporation of fire brigade action and sprinkler activation through the use of fire load factors do not capture the effect of the active measures in changing ascending rate of fire.
- A new method based on analysis of actual fire temperature measurements from the database of Fire Service in Manchester (scaling up to other counties is also planned)
- Future work will involve combination with reliability of passive fire protection (intumescent coating) for estimation of allowable trade-offs in both active and passive fire protection systems to be installed.

# THANK YOU