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On Estimating Heat Release Rate for a Design Fire in Sprinkler Protected Area

20 min Presentation

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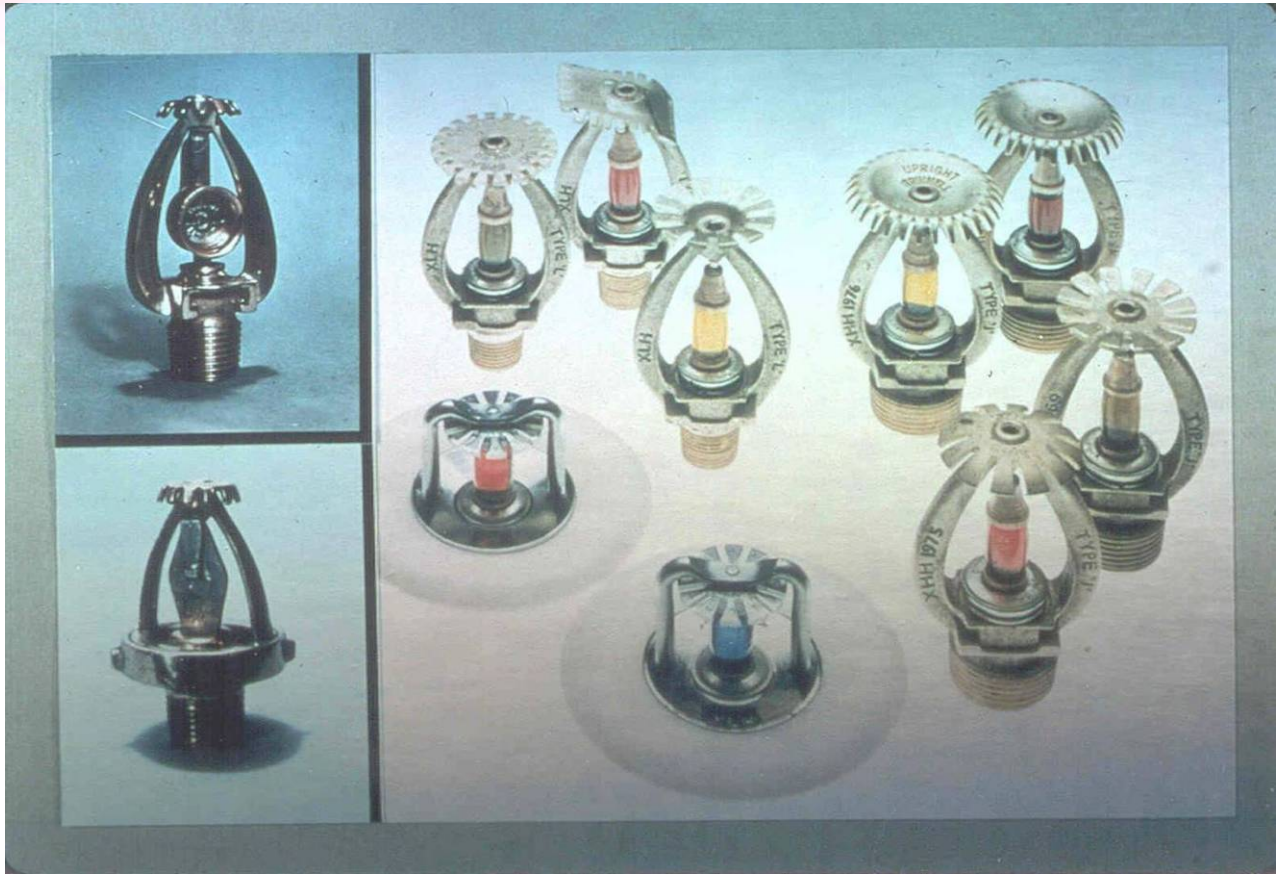
HKARMS3.ppt

- **In implementing engineering approach for fire safety design (in fact performance-based design) in Hong Kong, heat release rate for a design fire has to be estimated.**
- **Results are then applied to determine the fire safety provisions.**
- **For example, design fire is a key factor in sizing the dynamic smoke exhaust systems.**
- **Much higher exhaust rates are required for high heat release rates.**

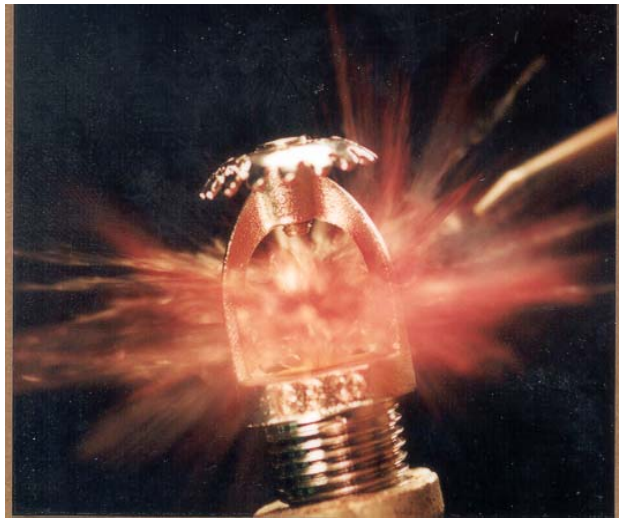
- **For areas protected by sprinkler, the sprinkler activation time is deduced from a thermal balance equation based on the ceiling jet equation.**
- **The heat release rate is commonly determined from some reported functions such as the NFPA t^2-fire, by assuming that the fire can be controlled at a certain value.**



Sprinkler heads

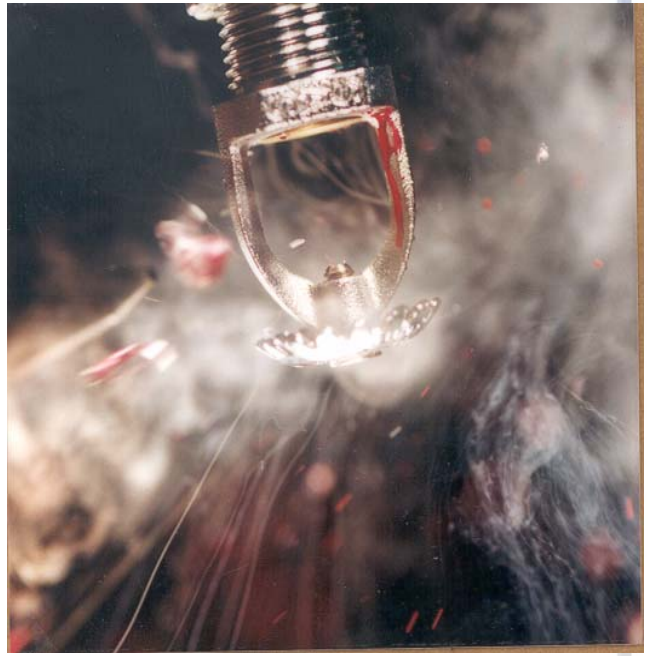
Operation Mechanism of Sprinkler Head

★ Temperature rating 68 °C

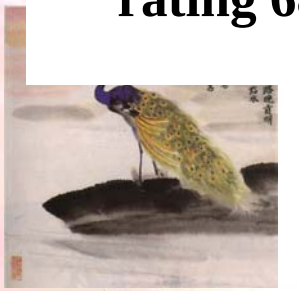


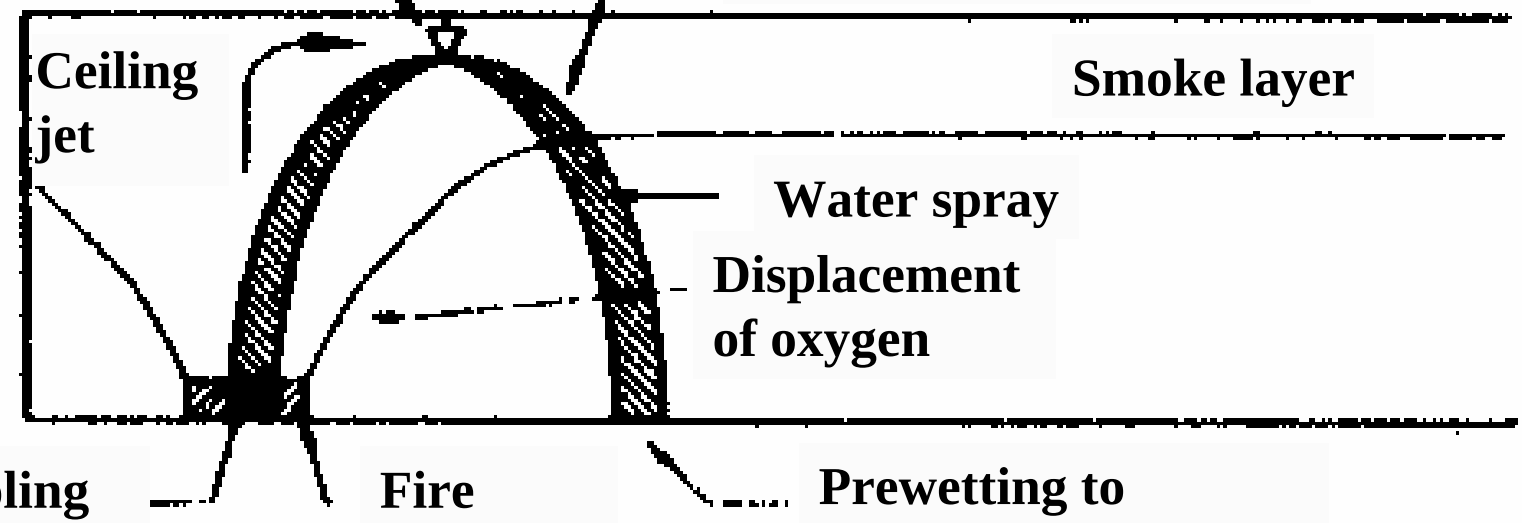
★ The sprinkler was heated by a gas fire

★ The bulb exploded after 15 sec



★ Sprinkler head after the thermal sensing element exploded




Sprinkler head
Cooling the smoke layer
Ceiling jet
Smoke layer
Water spray
Displacement of oxygen
Cooling the fuel
Fire source
Prewetting to prevent fire spread

Direct Cooling

- **However, activating the sprinkler system might not necessarily control the fire at that instance. The fire would still be burning to give much higher heat release rates.**
- **Note that a low fire load density might give high release rates, depending on the ventilation provision.**
- **There might be problems in deciding the time at which the fire can be controlled. This point will be discussed in this paper.**
- **Data measured from full-scale burning tests on fires with and without sprinkler are used to support the argument. Fire hazard assessment on the risk impact will also be discussed.**

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Topics to cover in this talk

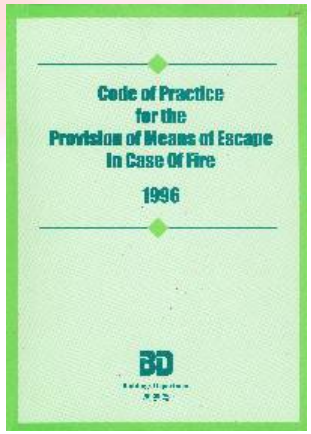
- ★ **Performance-Based Design**
- ★ **Importance of Heat Release Rate**
- ★ **Extinguishment, Suppression and Control**
- ★ **Estimation of Heat Release Rate**
- ★ **Full-scale Burning Tests**
- ★ **Importance on Hazard Assessment**
- ★ **Conclusion**

1. Performance-Based Design

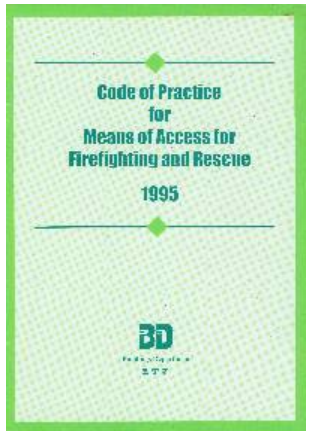
- **Local approval of fire safety designs and inspection of buildings upon completion are held responsible by the Buildings Department (BD) and Fire Services Department (FSD).**
- **Normally, the building design shall be submitted to BD for checking against all fire aspects for approval; and the requirements and installation of fire protection system shall be determined by FSD.**
- **The prescriptive codes are basically on passive construction checked by BD on the fire resistance construction (FRC), means of escape (MoE) for occupants, means of access (MoA) for firefighting, and active firefighting systems or called fire services installation (FSI) checked by FSD.**

★ **The prescriptive codes, basically on**

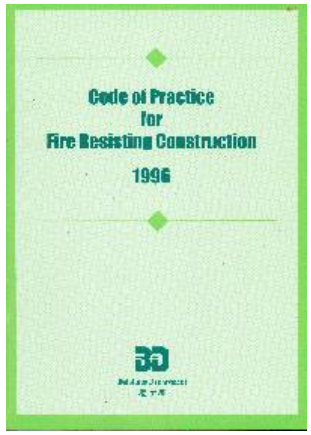
BS5588?



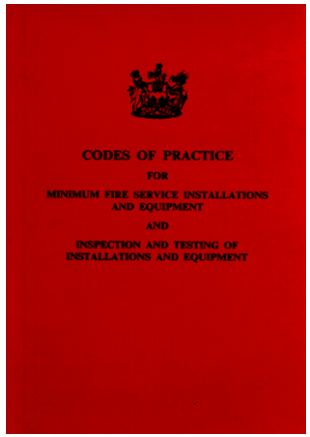
MoE Codes



MoA Codes



FRC Codes



FSI Codes

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★ **may not be sufficient for providing fire safety in some buildings with special designs.**

- **These codes are demonstrated to work for traditional buildings, such as those of height up to 40 levels. However, they may not be sufficient for providing fire safety in some buildings with special designs.**
- **Supertall buildings are obvious examples in having total evacuation time longer than half an hour even in using lifts for escape.**

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How can those codes apply to ultra highrise building?

Might be OK for these !

- **There are no engineering performance-based fire codes (EPBFC) in Hong Kong yet.**
- **“Fire engineering approach FEA” for passive fire safety designs is accepted by the authority (i.e. BD) since 1998.**

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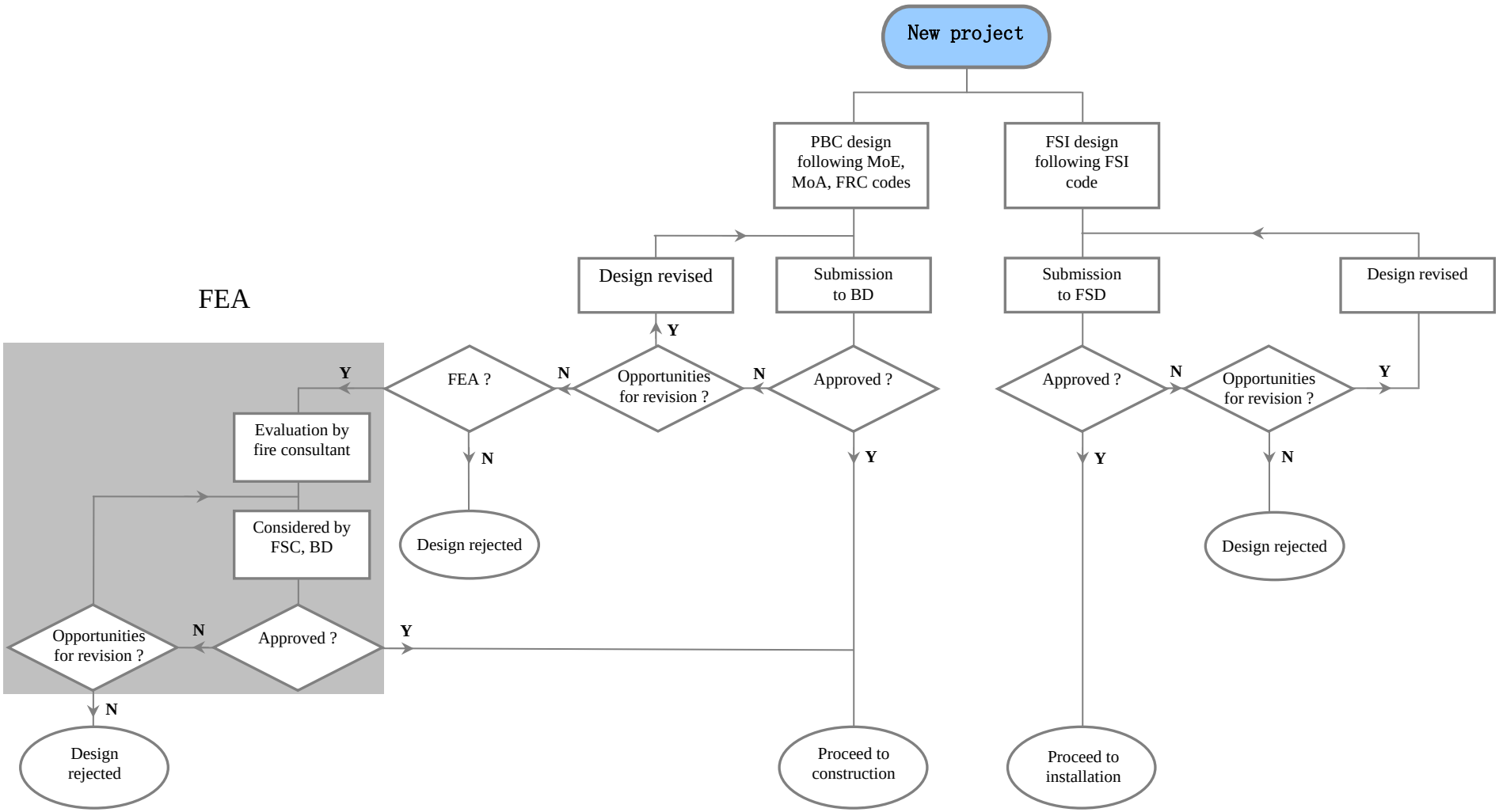

Process for Approving Fire Safety Designs

- **This is basically performance-based design on demonstrating adequate safety. It is useful for buildings with special hazards requiring individual design considerations but not yet included in the prescriptive codes.**
- **But doing this without strong scientific fire research for local safety provisions is impossible.**
- **For projects considered in the past, FEA is basically to demonstrate that the safety of the design is equivalent to those specified in the existing codes.**

- **Knowledge of fire science and engineering was applied together with practical experience under local conditions.**
- **Mathematical fire models, either zone models or field models (application of Computational Fluid Dynamics CFD or Numerical Heat Transfer NHT), had been used to analyze potential fire scenarios.**
- **Full-scale burning tests, scale models studies and site measurements on evacuation pattern might be required to demonstrate the safety of the design.**

- **There are not yet standard methods for assessing those designs. A government consultancy project on reviewing the code started a few years ago.**
- **However, it took 10 years to develop some guides useful for performance-based designs in the U.K.**
- **There, most of the buildings are not so complicated, their living style is much well-organized and the consultancy team developing the guides has published numerous papers.**

- **It appears to be rather difficult for Hong Kong to work out such EPBFC within a few years supported by in-depth research including relevant full-scale burning tests.**
- **There are so many complicated buildings and the living style is very different.**
- **In-depth research is necessary for working out something meaningful.**
- **The heat release rate is important in fire hazard assessment. This point will be discussed in this paper.**

2. Importance of Heat Release Rate

- ★ **The heat release rate of a design fire has to be estimated in applying Fire Engineering Approach for projects having difficulties to comply with the prescriptive codes.**
- ★ **There had been lots of arguments on the heat release rate of a design fire. Very low values down to 0.5 MW for normal scenarios were suggested, though 2 MW was used eventually.**
- ★ **But as pointed out by FSD, what they encountered in big fires, accidental or arson, were not under normal conditions.**

- **A flashover fire with a long duration in a restaurant.**
- **Used to be taken as example by FSD on showing how big the fire is.**

Restaurant fire due to flashover
(Apple Daily, 7 January, 2005)

Examples on fire outbreak

- **The big Garley Building fire is a painful lesson to learn.**

The Big Garley Building Fire
(South China Morning Post, 21 November, 1996)

Examples on fire outbreak

- **Cause of that fire is still under debate, whether the building management or the authorities should do more is another issue.**
- **Anyway, temporary fire protection should be provided while removing all lift doors for replacing new lift for a rather long time.**

- **This concern is in fact on assessing the heat release rate to answer a common question on hazard assessment:**

  How big is a fire?

- **The heat release rate gives the most important information on how much heat will be released in burning the combustibles.**

- **Once the heat release rate is known, the resulted fire environment such as smoke temperature, smoke layer thickness, smoke flow rate, radiation heat flux, possibility to flashover, and the effects on adjacent combustibles and construction elements in the office, and hence the building as a whole, can all be estimated with empirical expressions or fire models.**

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- **Heat release rates of burning combustibles in typical building arrangements should be measured experimentally in a full-scale burning facility with and without discharging the fire suppressing agent.**
- **The results can then be applied for scenario analysis in performance-based design.**

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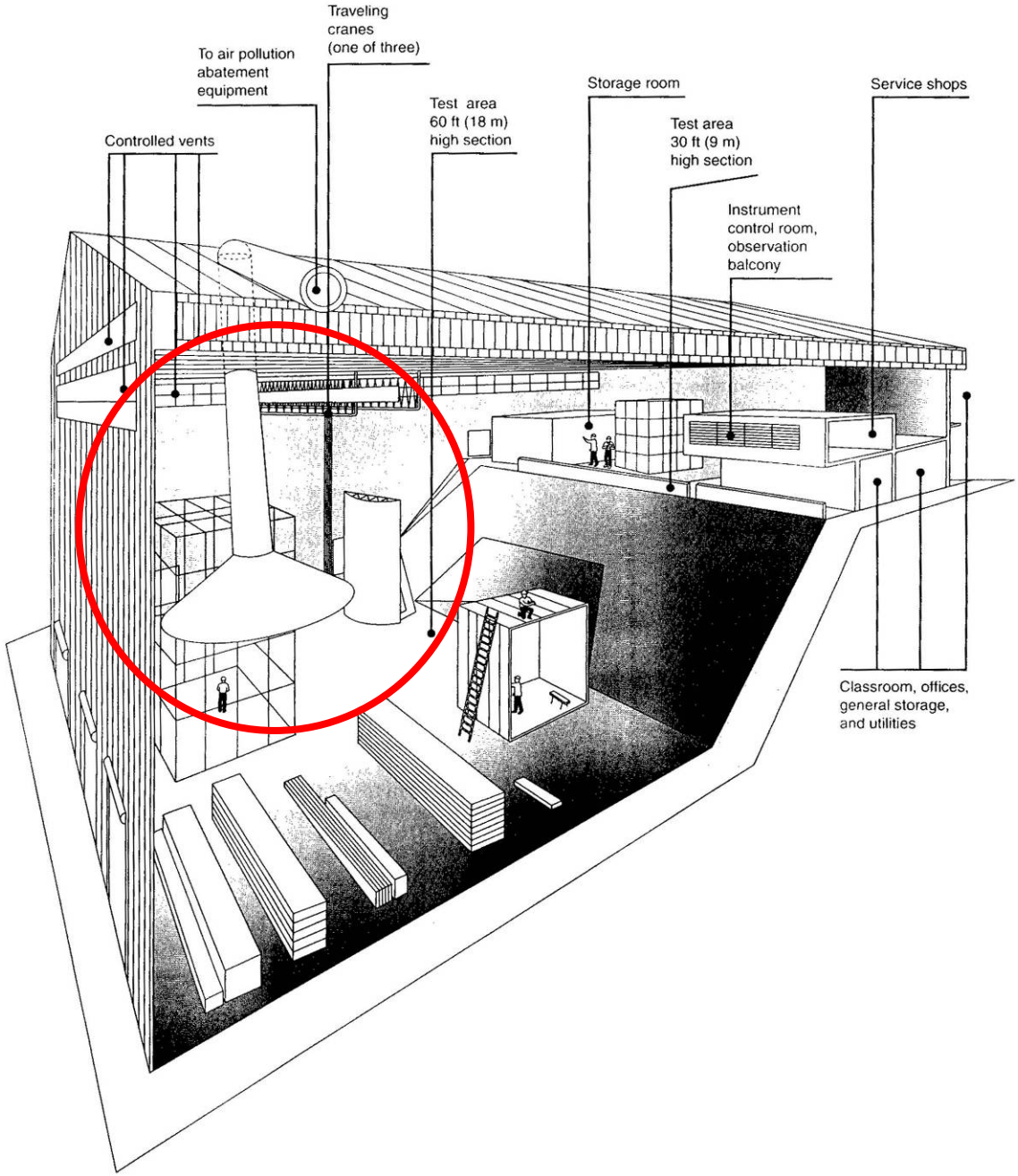
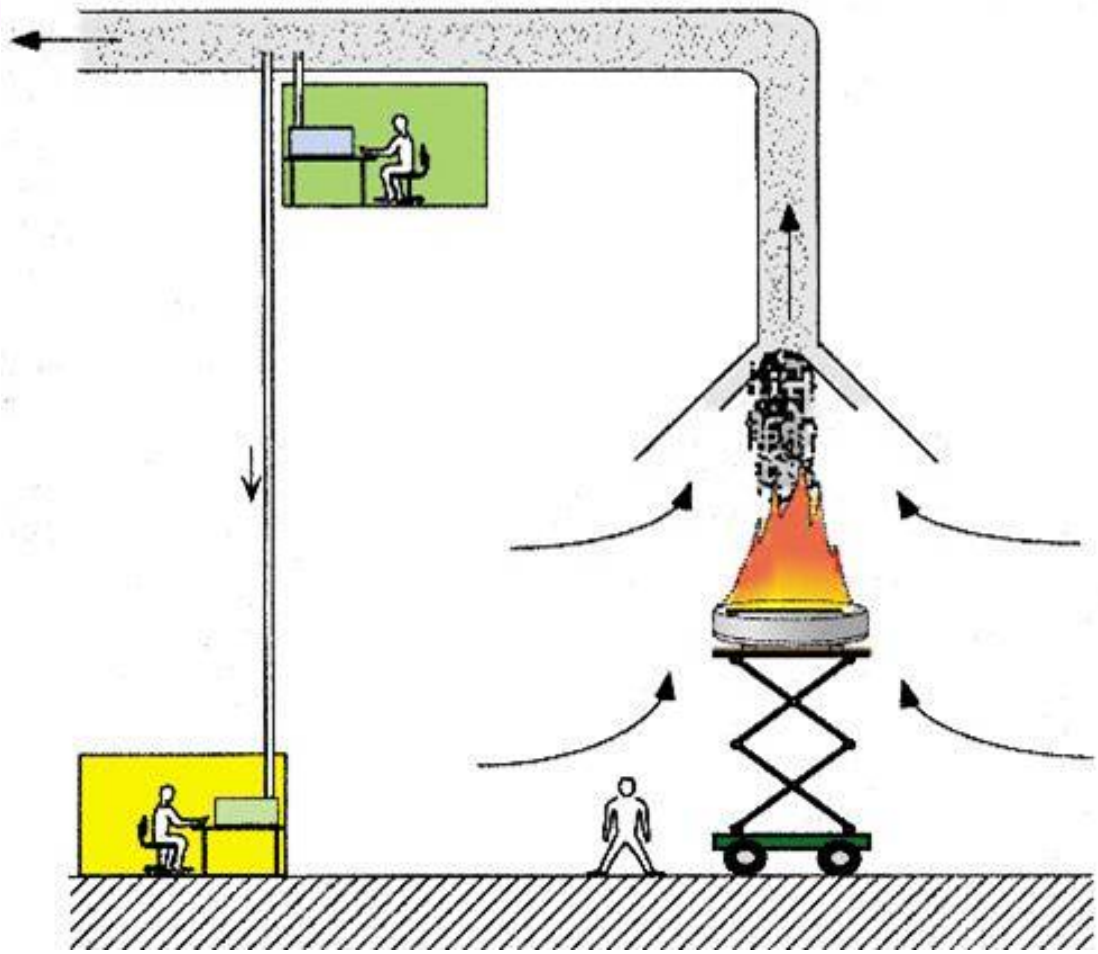


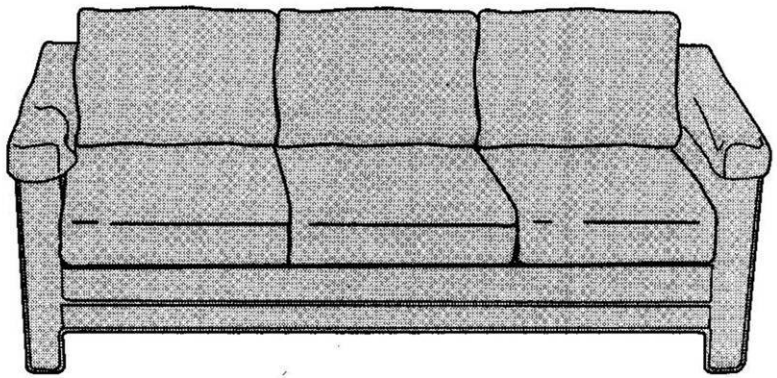
Figure 3-4.49. *The Factory Mutual Research Corporation's Test Center at West Gloucester, Rhode Island, where large-scale fire tests are performed.*

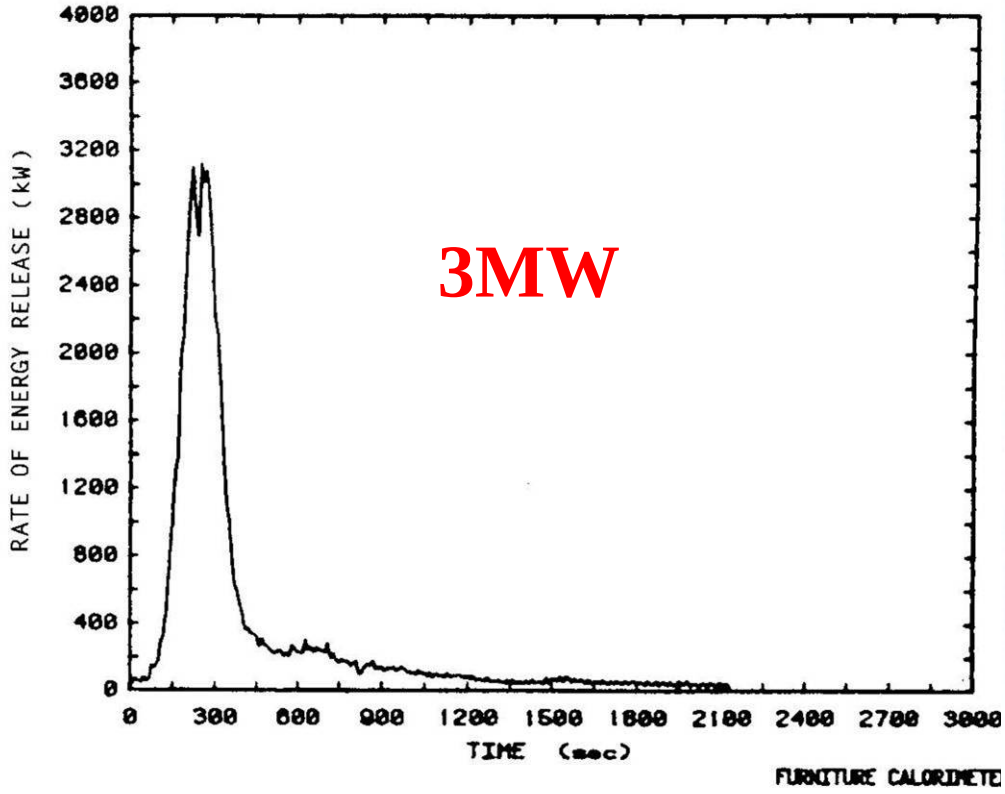
Factory Mutual, USA

"Hazard Calculations", SFPE handbook of fire protection engineering. Quincy, Mass. : National Fire Protection Association ; Bethesda, Md. : Society of Fire Protection Engineers, 3rd ed. (2002).

INDUSTRY Calorimeter:
at SP, Sweden







3MW

Figure 6-17 *Sofa. After Gross, Ref. 8.*

From: Quintiere, J.G. , Principles of fire behavior, Delmar Publishers, Albany, N.Y., 1998.

4. Extinguishment, Suppression and Control

- **However, activating the sprinkler does not mean the fire can be controlled at that certain value immediately.**
- **The three terms – 'control', 'suppression' and 'extinguishment' have to be understood by following NFPA 13 and NFPA 750:**
  - **Fire control in NFPA 13 means limiting the size of a fire by distribution of water so as to decrease the heat release rate and pre-wet adjacent combustibles, while controlling ceiling gas temperatures to avoid structural damage.**
  - **Fire extinguishment in NFPA 750 means the complete suppression of a fire until there are no burning combustibles.**
  - **Fire suppression in NFPA 13 means sharply reducing the heat release rate of a fire and preventing its regrowth by means of direct and sufficient application of water through the fire plume to the burning fuel surface.**

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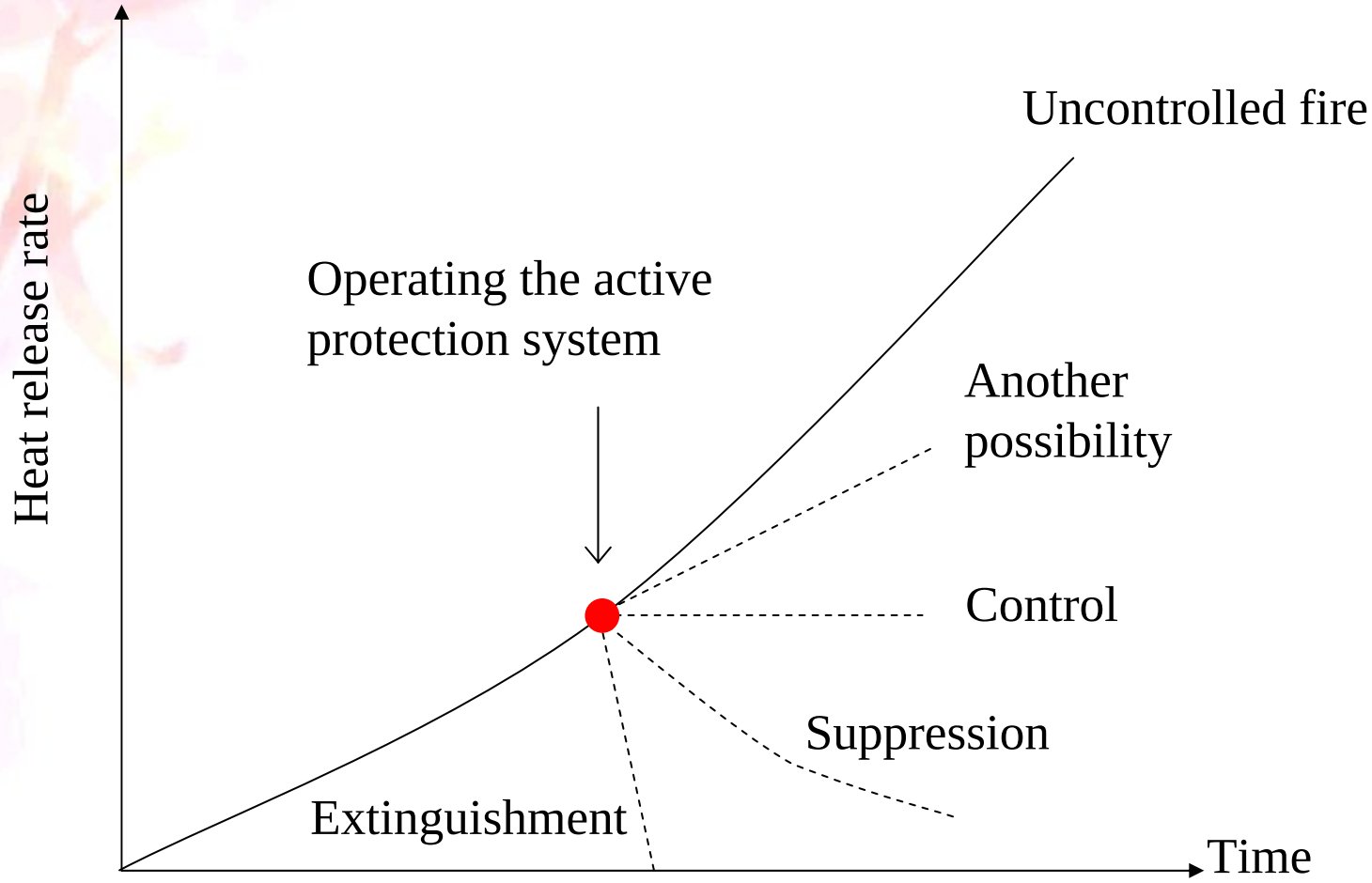
★ **All these can be illustrated by plotting the heat release rate against time.**



- **It is obvious that it would take time to control the heat release rate at a certain value. The value can be much higher than that estimated from equation (3), depending on the scenario concerned.**
- **Note that the 'design fire scenario' is one of the primary uncertainties in fire safety engineering.**
- **A design fire depends on the geometry and use of the building; the combustibles used and stored; and most importantly, the ventilation provision.**
- **It cannot be decided without understanding the above.**
- **Recent results indicated that a very low combustible content can give very high heat release rates, though the fire might only last for a shorter time.**

3. Estimation of Heat Release Rate

- **Data on heat release rate available in the literature are very limited, even fewer on products used and manufactured in the Far East.**
- **There are no reliable data on local products for determining a design fire.**
- **Different values were used by the designers for different purposes in the past in designing fire protection systems for terminal halls; shopping malls; atria; and train compartments.**
- **Very low values of 0.3 MW to 0.5 MW were estimated in some designs.**
- **The same value was accepted in one project, but rejected in another similar project. This is due to the lack of a database for local products.**

A site is needed for full-scale burning test ! to get a database

A full-scale burning facility is just developed by Chow at Lanxi, Harbin, Heilongjiang, China for measuring heat release rate


Harbin 哈爾濱
Beijing 北京
Hong Kong 香港

Harbin

哈尔滨市街区

呼蘭河之西


Lanxi 蘭西
Harbin 哈爾濱市
黑龍江省
Heilongjiang Province
齐齐哈尔
长途电话区号：0452
邮政编码：161005

ISO-Room Corner Fire Test

Preparation

Retail shop fire

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No Budget to Burn Money !

No Money No Talk !

- **In estimating the probable heat release rate for a design fire in a sprinkler protected area, a common practice is to apply an empirical equation for the maximum ceiling jet temperature rise ΔT_{max} at a ceiling height H (in m) due to a fire of convective heat release rate $\dot{Q}_c$ (in kW):**

$$\Delta T_{max} = \frac{16.9 \dot{Q}_c^{3/2}}{H^{5/3}} \qquad \textbf{(1)}$$

- **Results will be combined with a thermal balance equation on relating the activation temperature of the thermal sensing element of the sprinkler heads with a certain Response Time Index (RTI).**
- **The activation time t_a will be calculated based on RTI from a heat balance equation.**
- **Upon activation of sprinkler, the heat release rate is assumed to be kept at a constant value.**

★ **For example, a t^2-fire with a heat release rate $\dot{Q}(t)$ (in kW) at time t (in s) given by the equation through a constant t_g :**

$$\dot{Q}(t) = 1000\left(\frac{t}{t_g}\right)^2 \qquad \textbf{(2)}$$

where t_g is 75 s, 150 s, 300 s and 600 s respectively for ultra-fast, fast, medium and slow t^2-fire.

★ **The heat release rates $\dot{Q}_{des}$ of the design fire were estimated in many projects by:**

$$\dot{Q}_{des} = 1000\left(\frac{t_a}{t_g}\right)^2 \qquad \textbf{(3)}$$

- **The objective of putting in sprinkler is to control the heat release rate at a certain value at steady state.**
- **The maximum possible heat removed by the sprinkler water spray depends on the volumetric flow rate of the sprinkler system and latent heat of vaporization.**

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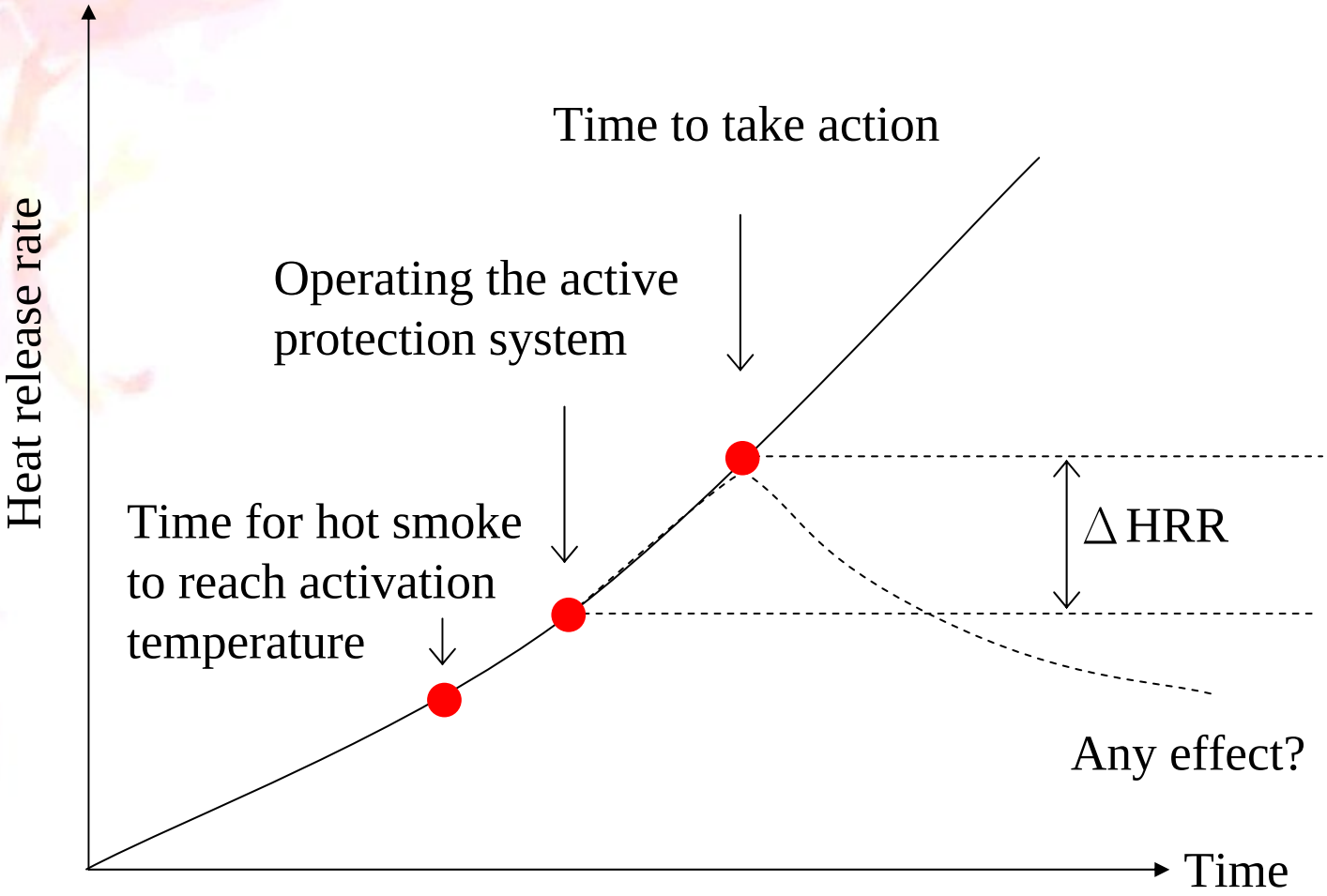
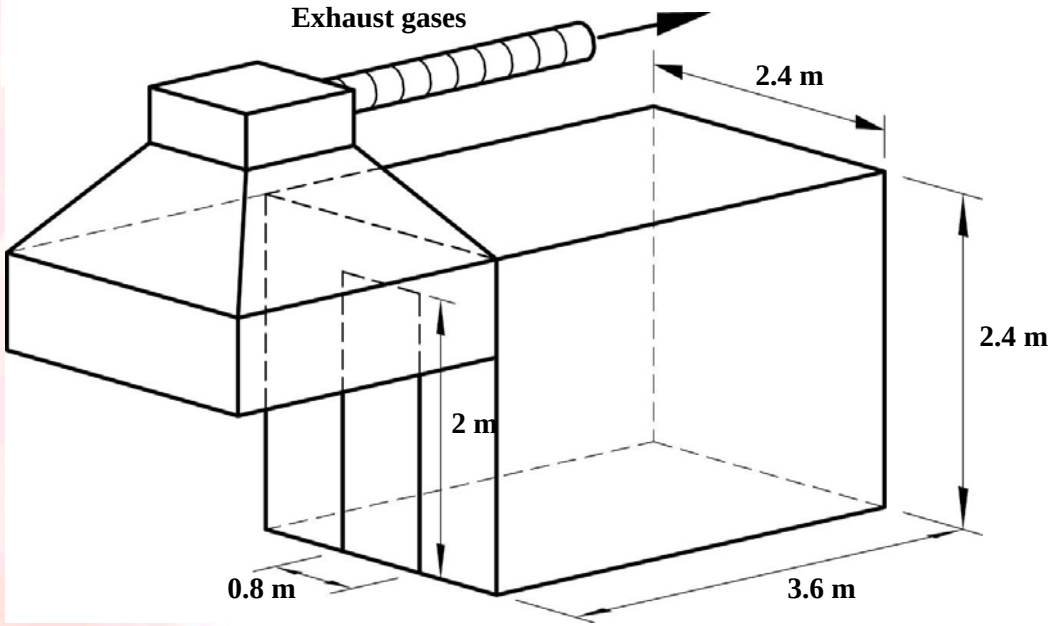

Heat release rate
Time to take action
Operating the active protection system
Time for hot smoke to reach activation temperature
ΔHRR
Any effect?
Time

5. Full-scale Burning Tests

- ★ To assess how sprinkler would control a fire, full-scale burning tests were carried out. Office fire scenarios with and without the operation of sprinkler were considered.
- ★ A full-scale burning facility known as the Chinese Assembly Calorimeter was developed by the author with strong support from the Harbin Engineering University.
- ★ This facility is located at the remote area Lanxi at about 150 km from Harbin, Heilongjiang, China.
- ★ Flashover office fires were studied in the summer of 2004.

★ An office scenario is considered.



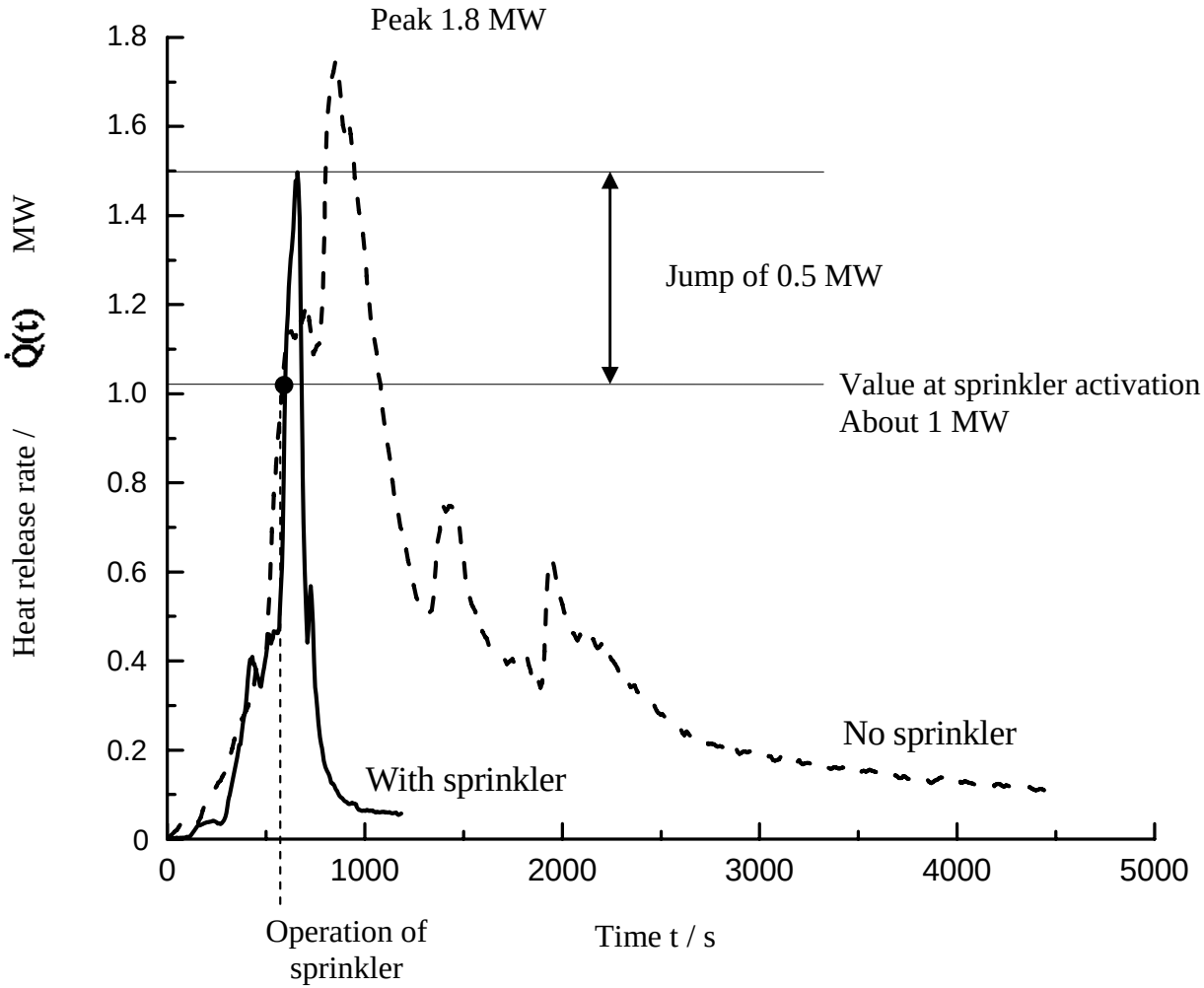
(a) Room calorimeter

(b) Office fire scenario

Office fire test

- **There were a chair, a desk with paper and books on top, a computer box and a cupboard were placed in a burn room.**
- **This setup was burnt under an accidental fire to give flashover for determining the heat release rate.**
- **Tests were then repeated by operating a sprinkler system at pressure 0.52 bar and flow rate 60 litres/min.**

★ **The resultant heat release rate curves for the scenario with and without sprinkler :**



Heat release rate with and without sprinkler

- **It is observed that operating the sprinkler could control the fire for this scenario.**
- **However, the heat release rate did not stay at the value once the sprinkler was activated, but moved up to 1.5 MW.**
- **Note that the value was about 1 MW at the time of discharging water. There is a jump of 50% of the value at sprinkler activation. It is not too wrong to say, though local data is insufficient, that even operating the sprinkler will give 1.5/1.8 or over 80% of the possible maximum heat release rate!**
- **Note that this scenario gave a small fire of peak heat release rate less than 1.8 MW, only burning for about half an hour.**

6. Impact on Hazard Assessment

- ★ **As defined in ASTM 1546-2003, fire hazard is the potential for harm associated with fire.**
- ★ **Fire hazard assessment is a process for measuring or calculating the potential for harm created by the presence of a material, product, or assembly in the relevant fire scenarios.**

- **Procedures for fire hazard assessment were further proposed to include at least seven steps:**
  - **Step 1: Defining the scope.**
  - **Step 2: Identifying the measure of harm to be assessed.**
  - **Step 3: Identifying and describing the scenarios of concern.**
  - **Step 4: Identifying the test methods or calculation procedures needed to produce the measures of fire hazard.**
  - **Step 5: Using the scenarios to define key parameters of the test method or calculation procedures.**
  - **Step 6: Identifying the types and sources of data required to support the test methods or calculation procedures.**
  - **Step 7: Identifying the criteria or procedures for evaluating the fire hazard measures relative to the degree of harm.**

- **Following this procedure with the above measured results, the heat release rate for the scenario with sprinkler protection should be 50% higher than that estimated from the cut-off value when sprinkler is activated.**
- **The hazard measures due to the extra heat released will give a quicker smoke filling rate and higher temperature distribution.**
- **In view of the heat release rate curve of the office fire scenario as shown in Figure 5, generating an additional 0.5 MW of heat release rate is quite dangerous. Adjacent items might be ignited to further generate much more heat.**

7. Conclusion

- ★ **It is observed that even under a small office fire as in the above test, the heat release rate cannot be controlled at the value once the sprinkler system is activated.**
- ★ **The heat release rate can be up to 80% of the maximum value, and about 50% higher than the value at the time of discharging water.**
- ★ **Therefore, in estimating the heat release rate for sprinkler protected area with a t^2-fire, the 'cut-off' value at activation time should not be taken as the design figure. Much higher heat release rates will be resulted, depending on the scenario.**

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- **More full-scale burning tests on different scenarios are required to confirm the result as the probable heat release rate depends on the scenario.**
- **Sprinkler can control the fire at a value, but how much is unknown. It is no good to copy something from the literature for a scenario that does not quite match with the actual design.**
- **Performing an actual fire test is necessary to demonstrate safety.**

Acknowledgement

★ **This paper is partly funded by a research grant on "Fire safety provisions for workplaces in non-industrial sectors" by the Occupational Safety and Health Council, Hong Kong.**