Half-day laboratory visit
Research Engineering Development Limited (RED), Lung Kwu Tan 龍鼓灘測試場
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FIRE TESTING IN HONG KONG

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1. Introduction

- Not much combustibility data available for local combustible products.
- Fire behaviour of building materials and contents should be assessed by appropriate tests.
- Useful risk parameters such as heat release rate should be compiled for hazard assessment.

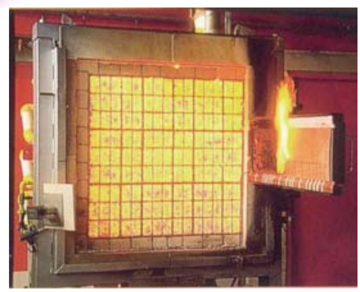
2. Current fire tests in Hong Kong

- Standard tests on assessing the fire behaviour of materials specified by the local government departments.
- British Standards 476 are referred to on testing:
  - ignitability,
  - non-combustibility,
  - surface spread of flame and
  - fire resistance.

Ignitability : BS476 Part 5

- Note that updated standards, e.g. BS476 Part 5 becomes Part 12 might not be accepted by the Authority so quickly.
- Something new passed BS would take time to pass in other place.

Data acquisition system for Non-combustibility test



Surface Spread of Flame Test for Materials

- The standard fire tests on fire resistance are on assessing stability, integrity and insulation of construction elements.

Fire Resistance Furnace

- Apart from the fire resistance test, the others are on smaller samples of materials with a single component.
- They are not appropriate in testing materials with several components such as sandwich panels.
- Further, these tests were developed years ago on assessing whether the materials can be ignited by a pilot flame without applying radiation heat flux.

3. Why carrying out fire tests ?

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- meeting a regulatory requirement
- demonstrating that a product has adequate fire safety performance

How to select the fire test methods ?

the product and its end-use

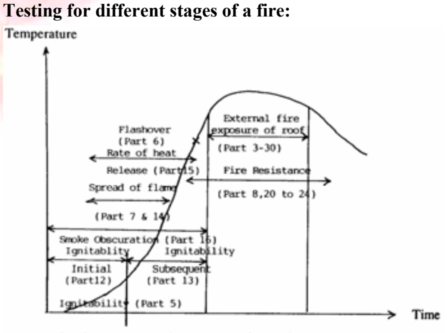
- the performance requirements
- regulatory requirements

Classification of Fire Test

- **Ease of ignition -** How readily will a material ignite? to what kind of ignition source? a cigarette, a match, a large open flame?
- **Flame spread** - How rapidly will fire spread across a material surface? Horizontal, upward, downward, across a ceiling?
- **Heat release rate** - How much heat is released? How quickly?

- **Fire endurance -** How rapidly will fire penetrate a wall, floor, or ceiling, or other barrier (fire penetration)?
- **Ease of extinction -** How easily will the fire to out?
- **Smoke release -** How much smoke is released? How quickly?
- **Toxic gas evolution -** How potent and how rapidly are toxic gases released? Are they irritating? Are they corrosive?

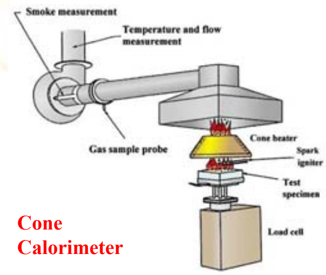
- ★ **Standard fire tests such as BS 476 have the following parts**
- ★ **Testing for different stages of a fire:**



4. Heat release rate

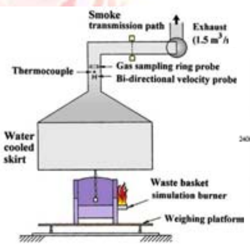
- The heat release rate of burning materials is believed to be the basic element in understanding how big is the fire.
- It provides
  - an indication of the size of the fire,
  - the rate of fire growth, and consequently the release of smoke and toxic gases, (such as sizing of smoke exhaust system)
  - the time available for escape or suppression,
  - the types of suppressive action that are likely to be effective, and
  - other attributes that define the fire hazard.

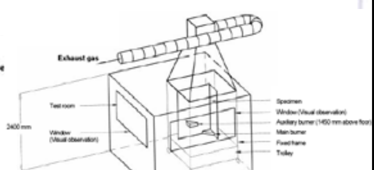
- This can be assessed by a bench-scale cone calorimeter.



Cone Calorimeter

- Intermediate scale tests such as the furniture calorimeter and single burning item (SBI) are useful.

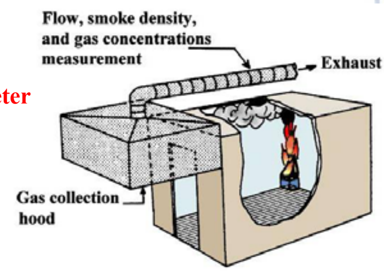




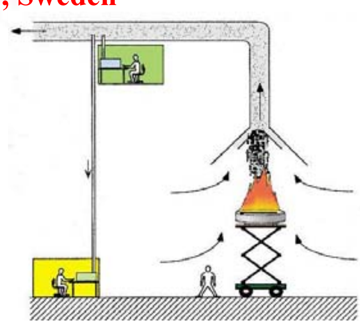
Furniture Calorimeter

- Further, the new ISO room-corner fire test is a full-scale burning test to measure fire spread, heat release rate and time to flashover.

Room Calorimeter



INDUSTRY Calorimeter:
at SP, Sweden



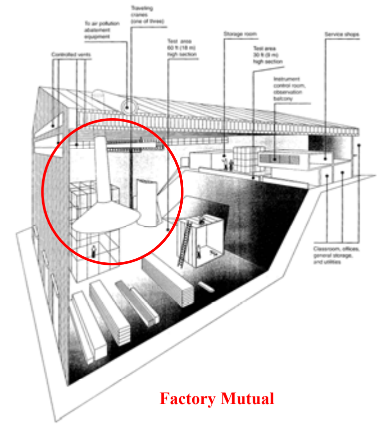
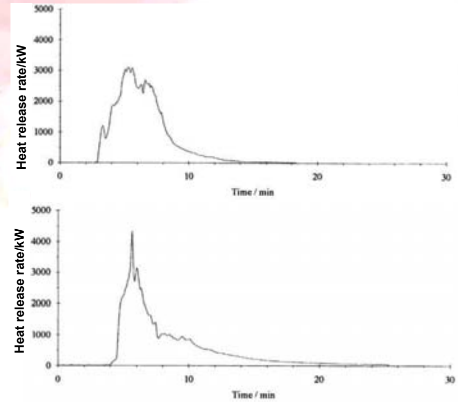


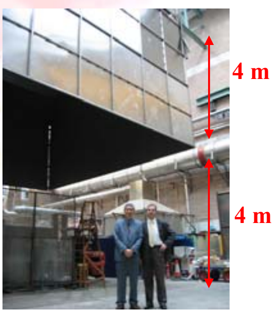
Figure 3-4.49. *The Factory Mutual Research Corporation's Test Center at West Gloucester, Rhode Island, where large-scale fire tests are performed.*

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

Factory Mutual



A 10 MW Exhaust Hood at Ulster, Ireland



★ **Such a full-scale burning facility, should be developed.**

50 MW Exhaust Hood at NIST, USA

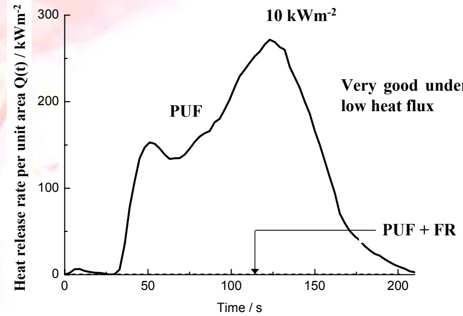
Smoke Treatment

HRR Display Screen

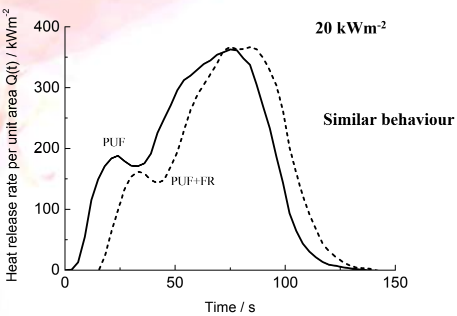
5. Use of the cone calorimeter

It is necessary to study the following areas in more detail:

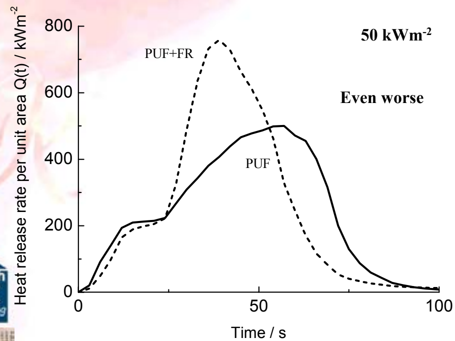
- Ignition under radiation heat flux.
- Heat release rate.
- Smoke emission rate.
- Smoke toxicity.
- Flame spreading.
- Acceptance criteria.
- Data for fire safety design.



Heat release rate per unit area for foams with and without fire retardant



Heat release rates for foams with and without fire retardant



Heat release rates for foams with and without fire retardant

Thermal Parameters

- Time to ignition, TTI (in s)
- Peak heat release rate, pk RHR (in kWm^{-2})
- Time to pk RHR after ignition, t_{fp} (in s)
- Average heat release rate in 60 s after ignition, $\overline{Q}_{60}$ (in kWm^{-2}), given by:

$$\overline{Q}_{60} = \frac{1}{60}\int_{TTI}^{TTI+60} Q_{cone}(t)dt$$

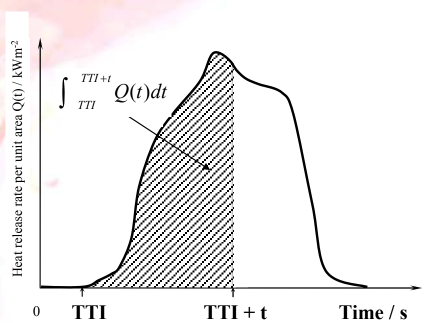
- Average heat release rate in 180 s after ignition, $\overline{Q}_{180}$ (in kWm^{-2}), given by:

$$\overline{Q}_{180} = \frac{1}{180}\int_{TTI}^{TTI+180} Q_{cone}(t)dt$$

- Total heat released, THR (in MJm^{-2}), calculated from:

$$THR = \int_{0}^{\infty} Q_{cone}(t)dt$$

- Mass loss percentage of sample, m_L (in %)
- Average effective heat of combustion, (in $MJkg^{-1}$)



$$\int_{TTI}^{TTI+t} Q(t)dt$$

Smoke Parameters

- Total smoke released TSR (a non-dimensional quantity) at the end of the test can be calculated by integrating the S_R (in s^{-1}) curve over the burning time t_B:

$$TSR = \int_0^{t_B} S_R \, dt$$

- The concentration LC_{50} of a material or fire effluent that causes death in 50% of the animals for a specified exposure time is the toxic potency, a parameter commonly used for assessing smoke toxicity.
- LC_{50} means the concentration of a sample causing 50% mortality in a standard toxicity test on the specified species over a specific period of time.

- In following ASTM E1678, fractional effective exposure dose (FED) is defined as "the ratio of the concentration and time product for a gaseous toxicant produced in a given test to that product of the toxicant that has been statistically determined from independent experimental data to produce lethality in 50% of test animals within a specified exposure and post-exposure period".
- FED can be expressed mathematically in terms of the concentration c_i of the i^{th} toxic component by summing up all the n species as:

$$FED = \sum_{i=1}^{n} \int_{t_0}^{t} \frac{c_i}{(ct)_i} \, dt$$

- Note that $(ct)_i$ is the specific exposure dose (concentration-time product) of the i^{th} toxic component required to produce the toxicological effect.
- When FED is equal to 1, the mixture of the gaseous toxicants would be lethal to 50% of the exposed animals.
- Mathematically, if the exposure time can be cancelled, FED becomes the ratio of the average concentration of a gaseous toxicant to its LC_{50} value for the same exposure time.

- The peak FED can be calculated from the measured concentration of toxic gases in a cone calorimeter.
- Since only CO and CO_2 were commonly measured and the toxic potency LC_{50} for CO_2 is much greater than that for CO (i.e. 5000 ppm), FED was calculated from the peak concentration of CO denoted by pk[CO] :

$$FED = \frac{pk[CO]}{5000}$$

Risk Diagram: 3 parameters

- The first parameter is the flashover propensity

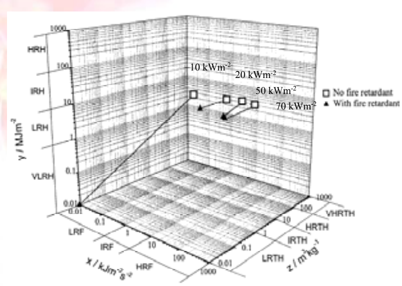
$$x = \frac{pkHRR}{TTI}$$

- The second parameter is

$$y = THR$$

- The third parameter is taken as reciprocal of LC50 to quantify the smoke hazard:

$$z = \frac{1000}{LC_{50}}$$



Risk diagram

Based on the experimental results, materials can be rated in an arbitrary scale of as:

Low risk to flashover	LRF	: 0.1 to 1.0
Intermediate risk to flashover	IRF	: 1.0 to 10
High risk to flashover	HRF	: 10 to 100

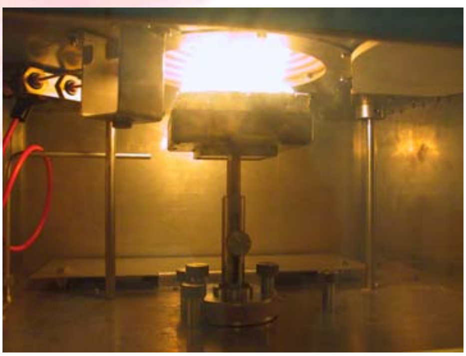
Materials are rated by z:

Very low risk of heat generation	VLRH	: 0.1 to 1.0
Low risk of heat generation	LRH	: 1.0 to 10
Intermediate risk of heat generation	IRH	: 10 to 100
High risk of heat generation	HRH	: 100 to 1000

Similarly, materials are rated as:

Low risk of toxic	LRTH	: 0 to 1.0
Intermediate risk of toxic hazard	IRTH	: 1.0 to 10
High risk of toxic hazard	HRTH	: 10 to 100
Very high risk of toxic hazard	VHRTH	: > 100

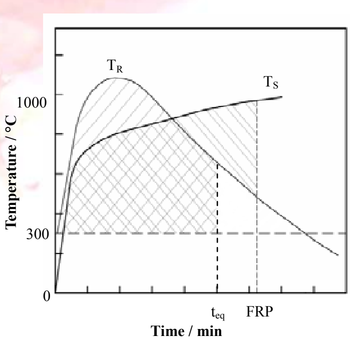
Alternate: With a cabin to control relative humidity



7. Test under big fires

Question:

Performance of a fire shutter of fire resistance period 2 hours under a big fire?



The equal area hypothesis

The equivalent time t_{eq} is:

$$\int_0^{t_{eq}} (T_R - 300)\, dt = \int_0^{FRP} (T_S - 300)\, dt$$

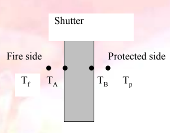
Site at Chengdu 成都: 西南交大 (SWJTU)

The new campus at SWJTU

The fire shutters

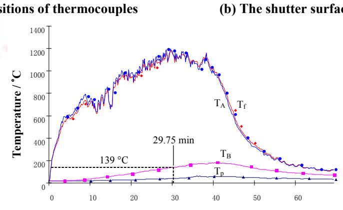
The Test

7 MW



(a) Positions of thermocouples

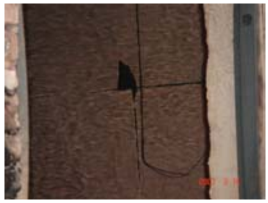
(b) The shutter surface



Temperatures at the two sides of the shutter

- The fire shutter failed to satisfy the integrity criterion with smoke leaking through at 8 minutes.
- The thermal insulation criterion failed at 29.75 minutes with the temperature on the protected side Tp heated up to 139 °C.

After Test



8. Conclusion

- Standard tests specified in the existing codes for assessing the fire behaviour of new materials should be considered carefully.
- Tests on assessing materials used years ago should be watched.
- Current standard tests on assessing the fire behaviour of materials should be reviewed.
- New materials with more than one component such as sandwich panel might not be applicable.

- Updated tests developed in the literature should be justified for suitability for local use.
- Scenarios simulated in such tests might not be applicable for local buildings, local environment and local living style.
- Fire safety regulations cannot be set up without support from research for local products.
- Fire tests for combustibles must be clearly understood.
- It is obvious that carrying out full-scale burning tests would be very expensive. But such study is necessary, especially in performance-based design.

Bench-scale test

Intermediate-scale test

Full-scale test

Real-scale fire