OIL & GAS

Rewriting the Handbook for Investigation of Gas Explosions in Dwellings

A Better Understanding of Gas Explosions:

Cause, Prevention and Investigation

Gary Tomlin

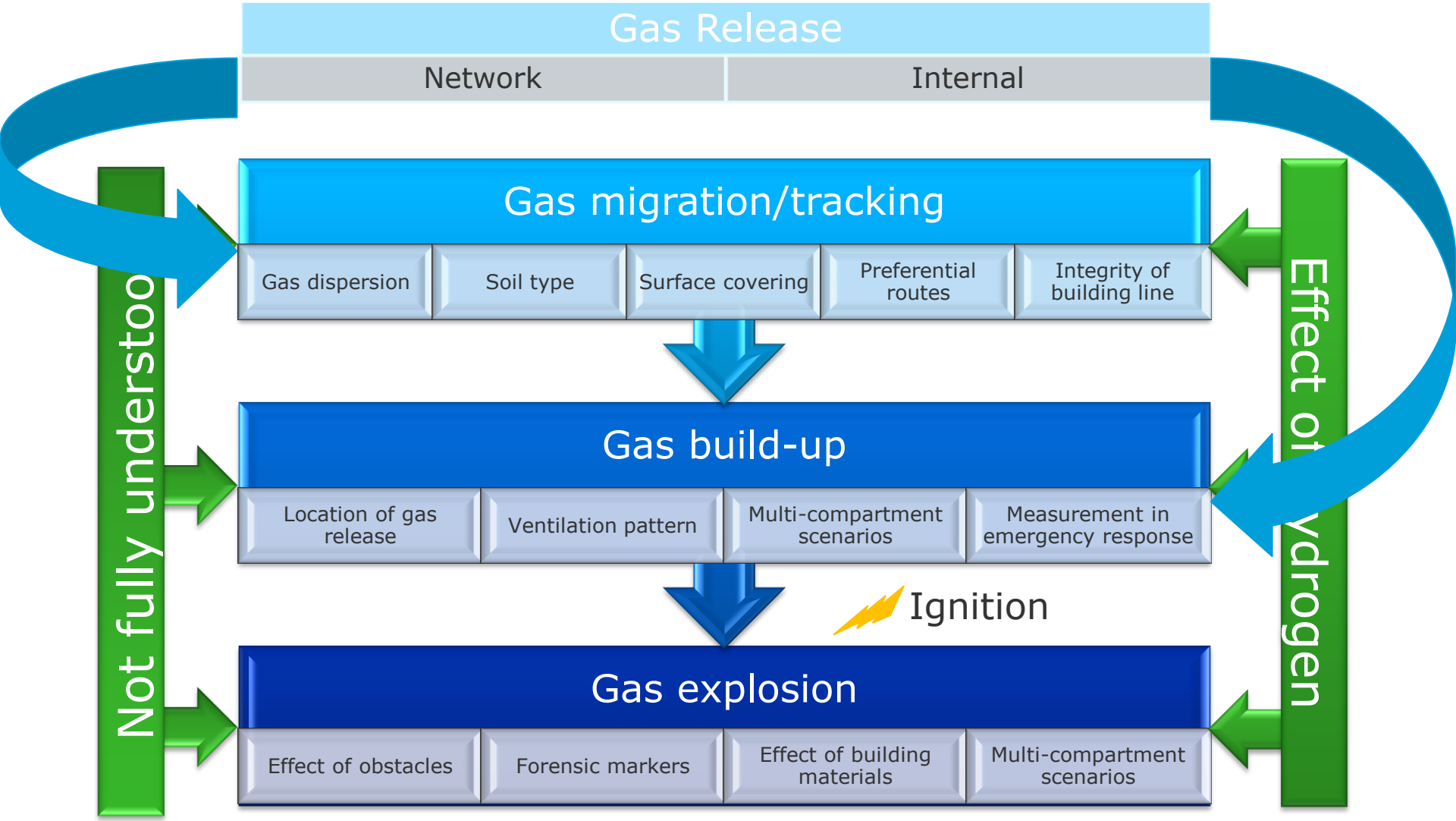
22nd September 2016

Overview

Background

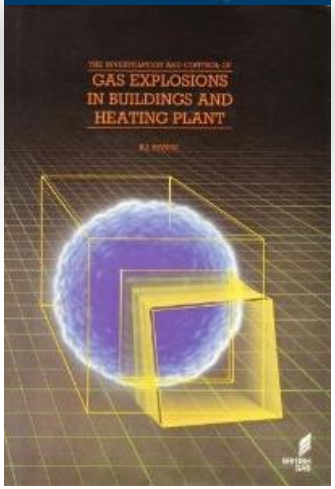
- Better understanding of gas explosions
  - Cause
  - Prevention
  - Investigation
- Future Network changes
- Assessing risk & mitigation
- Emergency response
- Investigation methodology & forensic evidence

Important Factors



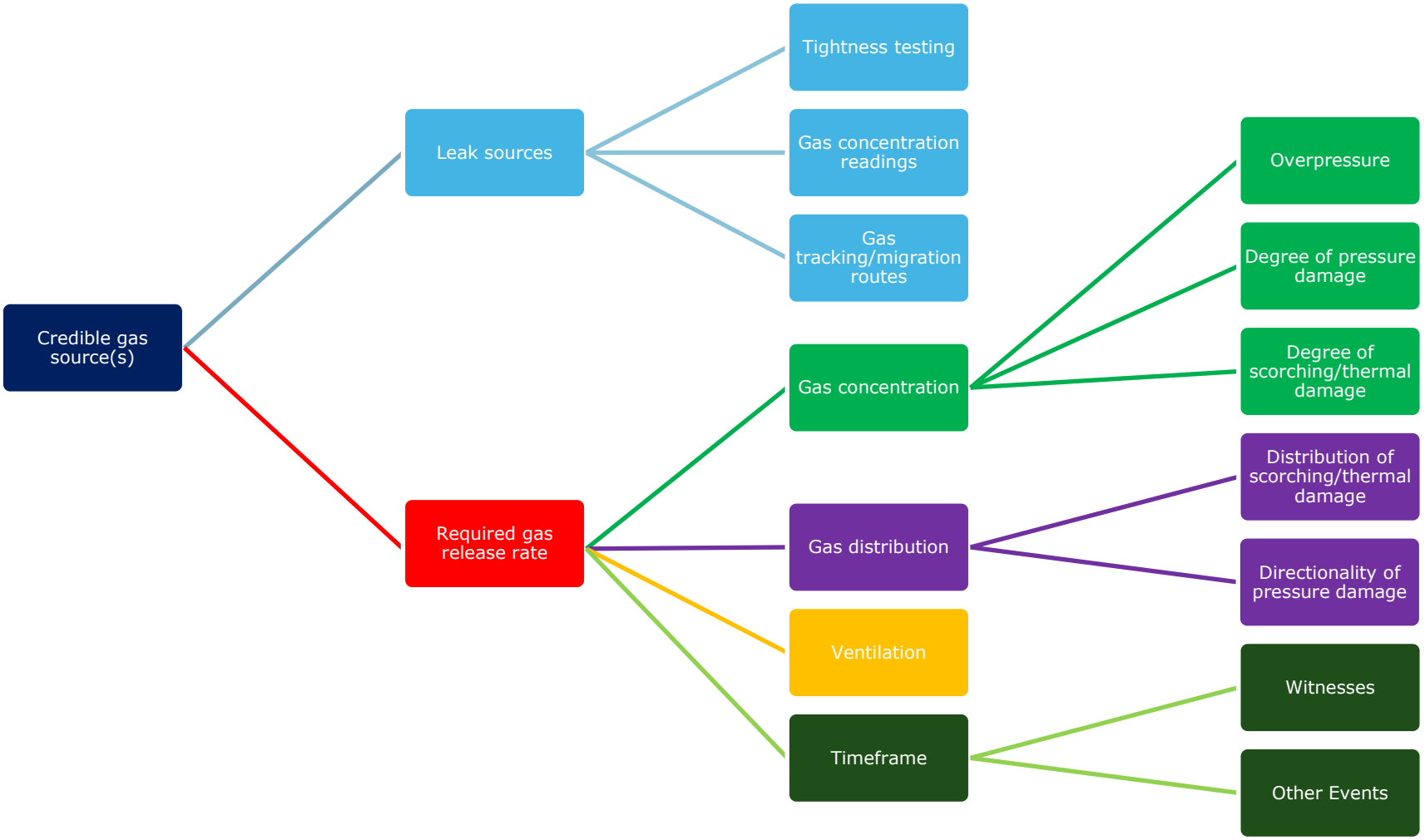
Current Industry Guidance

- NFPA 921.
- US guidance.
- Data collection.
- Refers to RJ Harris.



- RJ Harris.
- British Gas Research & Development.
- The investigation and control of gas explosions in buildings and heating plant., 1983.
- Industry standard text book.
- Revised version for GL Noble Denton.

Explosion Investigation Methodology



Rule of Thumb

- Minimal structural damage and little evidence of thermal damage
  - Indicative of a lean fuel/air mixture
- Minimal structural damage and significant evidence of scorching
  - Indicative of a rich fuel/air mixture

- Significant structural damage and extensive scorching, blistering etc.
  - Indicative of an ignition of a near stoichiometric fuel/air mixture

Previous Research

Vented Explosion Research

Explosion Research

- Virtually all vented explosion research has been carried out in single empty vessels
- This is obviously not representative of a domestic premise:
  - Multiple rooms
  - Can have two or more floors
  - May have open plan staircase
  - Furniture

Vapour Cloud Explosion Research

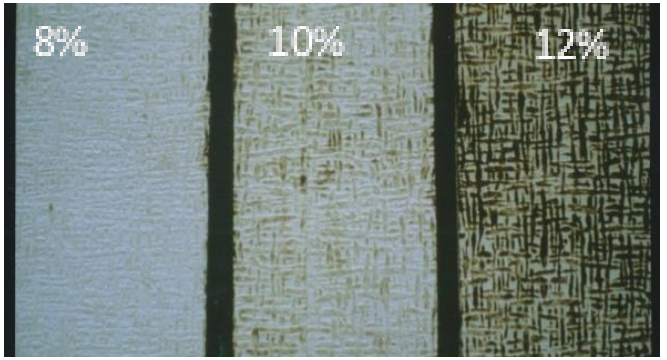
Flame Stretching and Turbulence

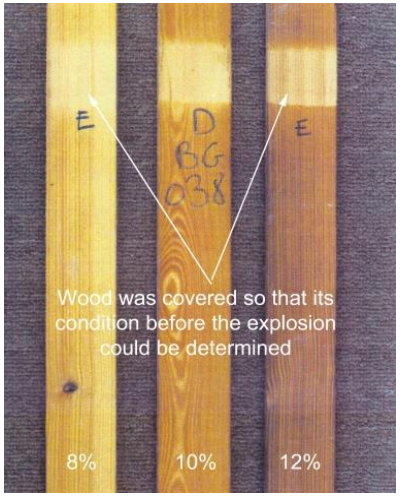
- Flow around furniture in a room will cause flame stretching
- Flow through interconnecting doors in multi-compartment explosions can generate turbulence in the secondary room, significantly increasing the pressure developed in an explosion

Sensitivity to Thermal Damage

Thermal marker tests

- Scorching, a discolouration of the materials surface due to the transient flame radiative and contact heat transfer
- Severity of the discolouration depends on:
  - Flame temperature
  - Duration of its exposure/contact with the surface
  - Thermal properties of the material
- The severity of thermal damage increases with gas concentration over the range (8% – 12%)
- Possible to estimate the natural gas concentration prior to ignition





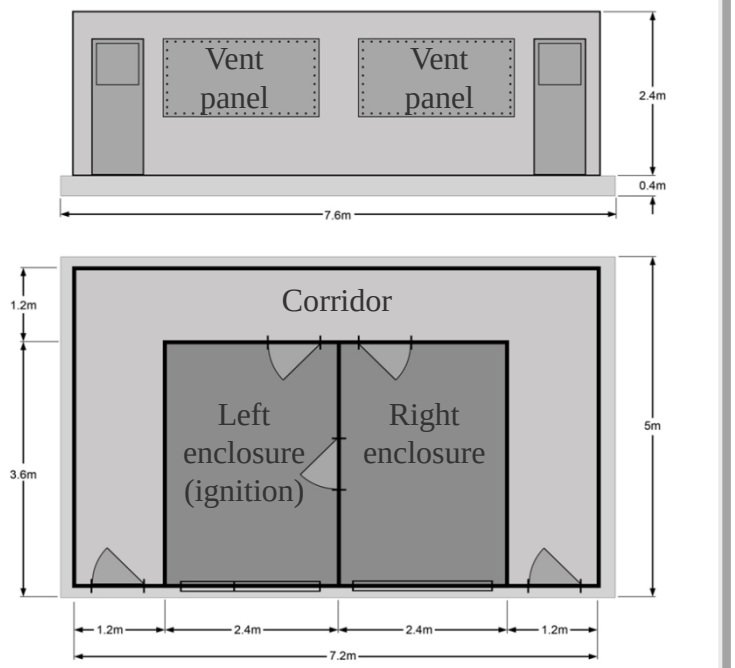
Effect of Hydrogen

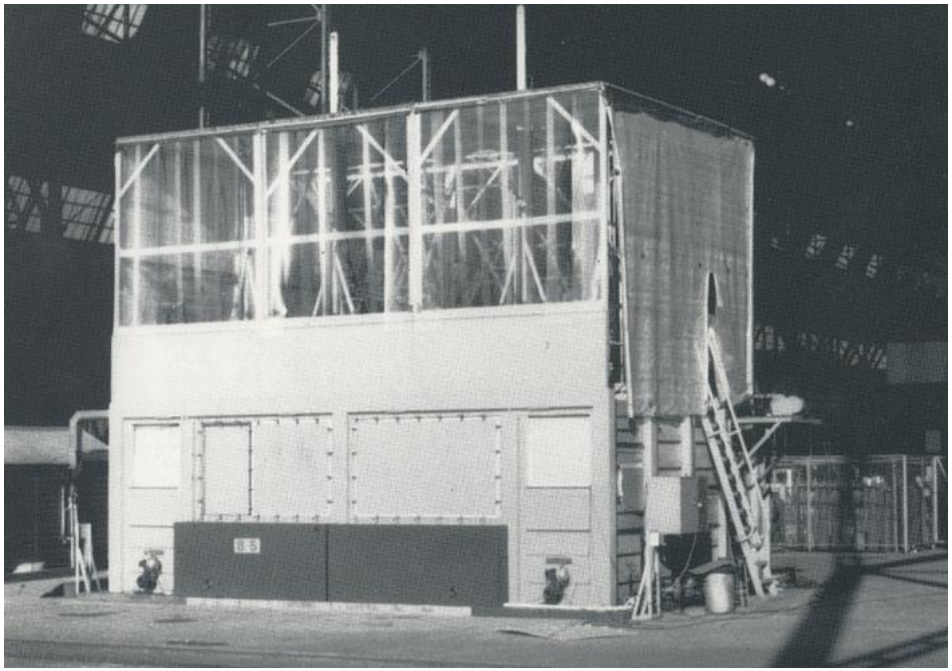
Effect of Hydrogen

- Hydrogen increases buoyancy and severity of explosion
- Previously studied in EU project NaturalHy
- Examined wide range of issues, including safety
- Assessed specific elements of potential consequences of release
- Idealised and simple configurations
- No understanding on overall impact on risk in realistic conditions

Complexities

Experimental





- Two adjoining compartments
- 20.7 m^3 volume (each compartment)
- 2.4 m (w) x 3.6 m (l) x 2.4 m (h)

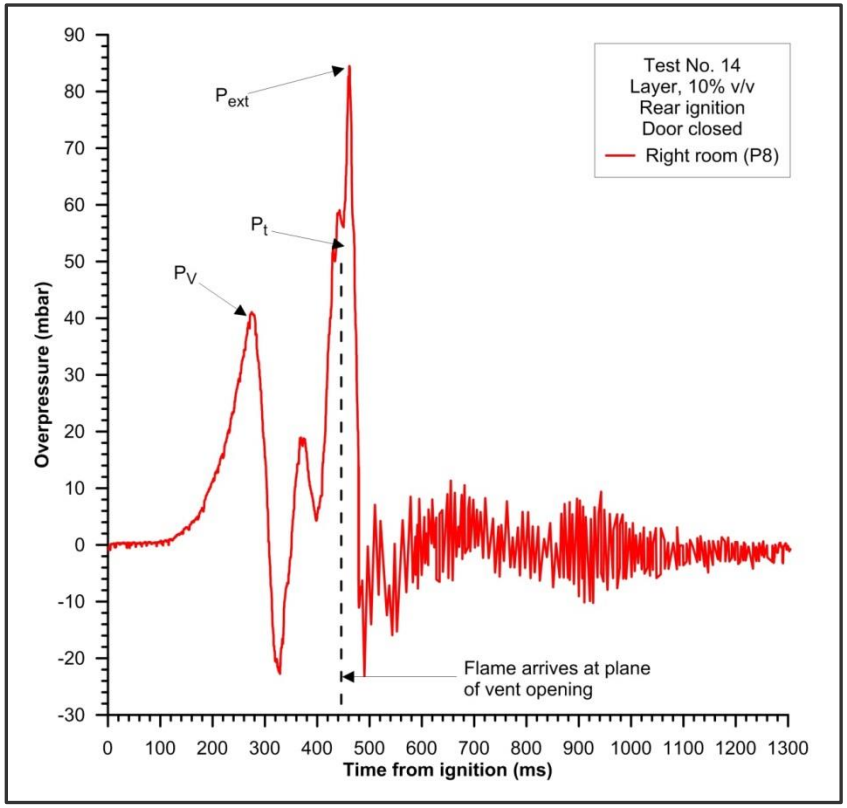
- Fortuitous explosion reliefs (designed to simulate a failing window)
- Vent openings 2.48 m^2, 1.49 m^2 or 0.74 m^2
- K_A = 2.4, 4 or 8

Experimental

Interconnected Rooms & Thermal marker tests

- A total of 87 tests were undertaken using natural gas/air mixtures
- Full room and layered explosions
- Concentrations of 6%, 8%, 10%, 12% and 13% gas in air
- Ignition in left chamber, at height of 1.22 m from the ceiling, both centre and rear locations

Interconnected rooms with large vent of equal size



Effect of Interconnecting Door

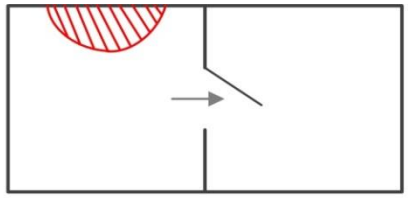
- Overpressure-time profiles significantly different from open door tests
- New peak, P_t , developed during explosion
- P_{ext} superimposed on P_t peak

Findings
Interconnected rooms with large vent of equal size

A

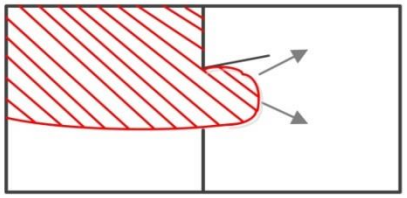
Initial pressure rise.

B



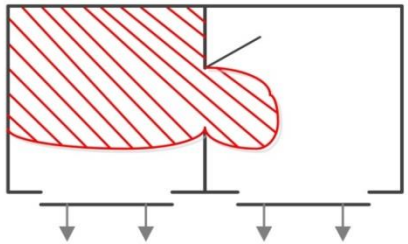
Door opens, flow into right enclosure creating turbulence.

C



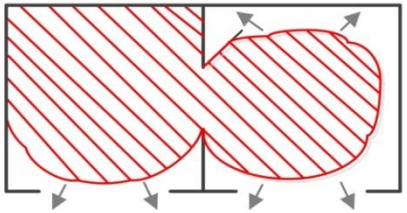
Flame enters right enclosure and ignites turbulent mixture.

D



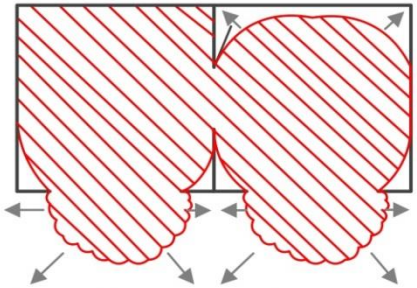
Vents open, flame front distorts towards vent opening, pressure drops inside enclosure causing P_V.

E



Rapid flame expansion as flame front moves towards rear of enclosure causing P_t.

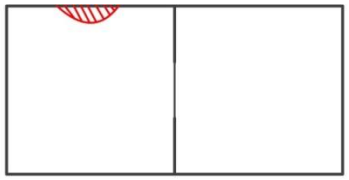
F



Onset of burnt gas venting results in dip in P_t, followed almost immediately by external explosion giving P_{ext}.

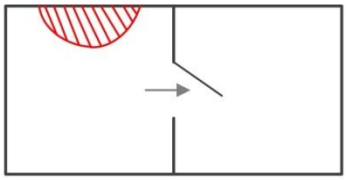
Findings
Vents of Different Size (large vent in ignition enclosure)

A



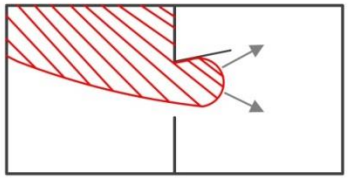
Initial pressure rise generates pressure differential between rooms.

B



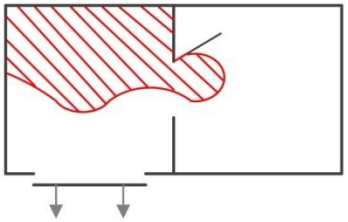
Pressure differential overcomes inertia and the door opens, flow into right enclosure generating turbulence.

C



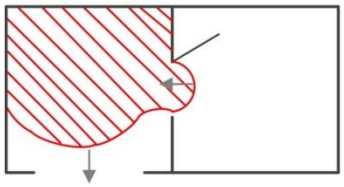
Flame enters right enclosure.

D



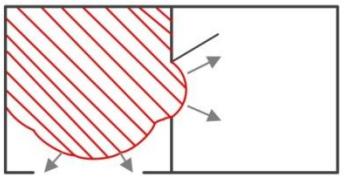
Vent opens in left enclosure, pressure drops causing $P_{V(L)}$.

E



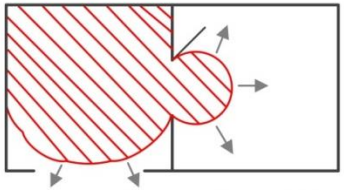
Flow reverses, flows from right to left enclosure.

F



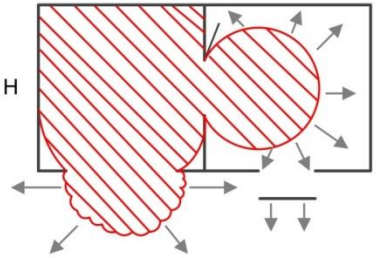
Flow reverses into right enclosure.

G



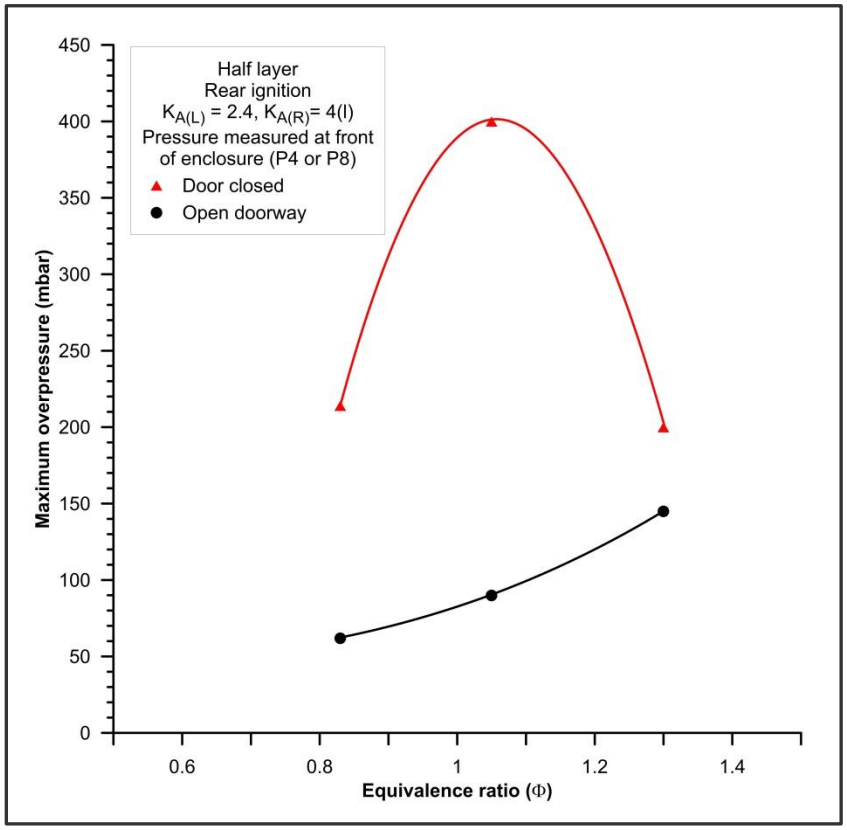
Turbulent combustion fully established, rapid flame expansion.

H



Turbulent combustion from external explosion increases internal pressure and turbulent combustion inside enclosure cause rapid increase in pressure causing right vent to fail and generating maximum pressure peak.

Vents of Different Size (large vent in ignition enclosure)



Effect of Concentration

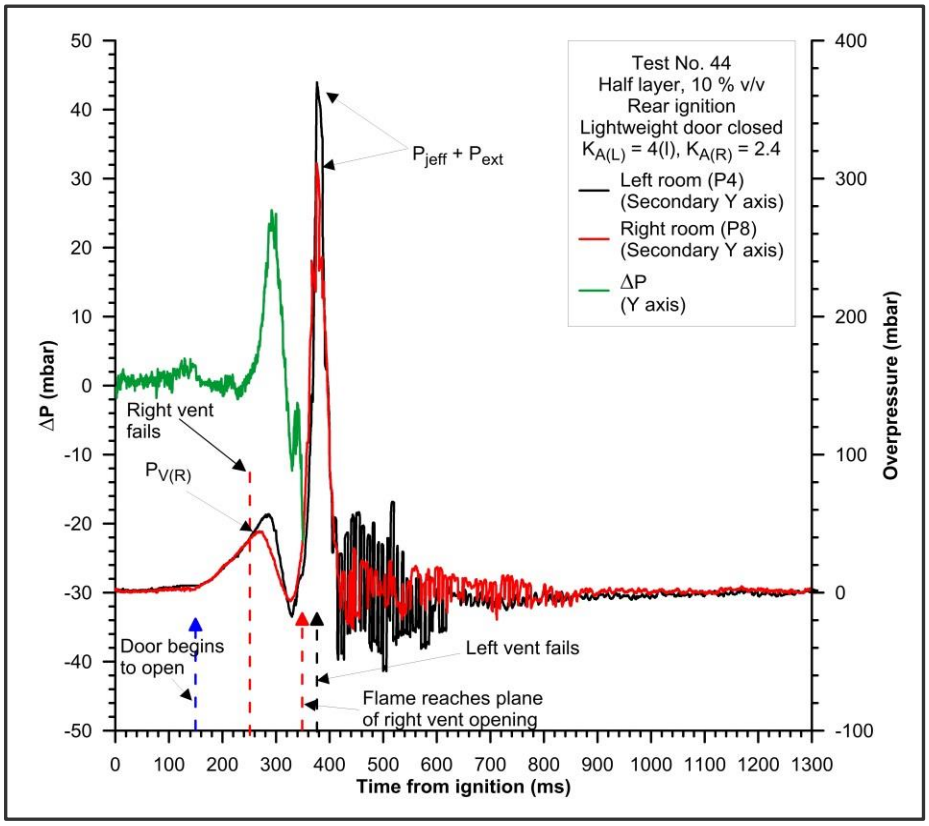
- Open doorway tests dominated by external explosion
  - Consequently the overpressure increases with concentration.
- Closed doorway tests are dominated by turbulent combustion
  - Consequently the overpressure curve follows that of burning velocity.

Findings

Summary of tests where adjacent room had smaller vent

- Maximum overpressure recorded was 414 mbar.
- Tests were characterised by two dominant pressure peaks.
  - 1st peak corresponded to the failure of the left (ignition enclosure) vent.
  - Second pressure peak was considerably higher than the comparable peak observed in tests with identical vents. In most cases, this was caused by rapid turbulent combustion in the right (secondary) enclosure.
- Flow reversals increase turbulence, giving rise to overpressures more than double in magnitude.
- With central ignition, the flame entered the right enclosure much earlier than was the case with rear ignition tests.
  - The interval between the door opening and the flame front entering the room was short
  - Period of turbulence generation was also shorter than was the case with rear ignition, with reduced pressures.

Larger Vent in the Adjoining Enclosure

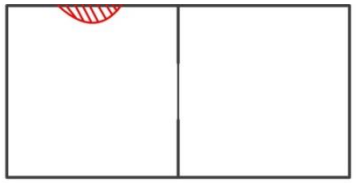


Jetting Expanding Flame Front

- Like other test types there were two dominant peaks
- Presence of a closed door made a difference to the maximum overpressure
  - Less pronounced than tests where the vent was smaller in the adjoining enclosure in particular
- Following the failure of the vent in the right enclosure, the flow through the doorway 'drives' the flame front towards the right vent opening and this sudden expanding flame front creates a pressure peak P_{jeff}

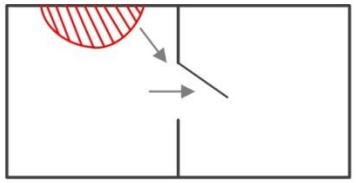
Findings
Larger Vent in the Adjoining Enclosure

A



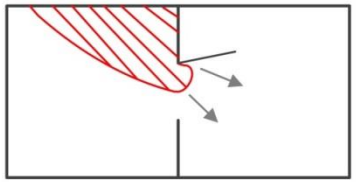
Initial pressure rise.

B



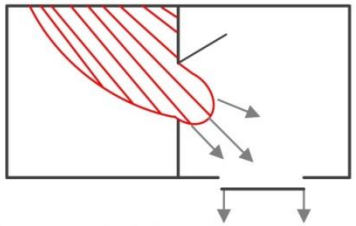
Door opens, flow into right enclosure.

C



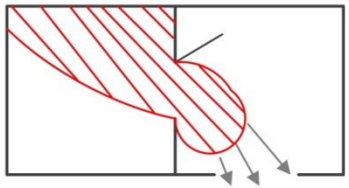
Flame enters right enclosure.

D



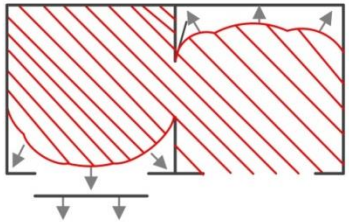
Vent opens in right enclosure, pressure drops.

E



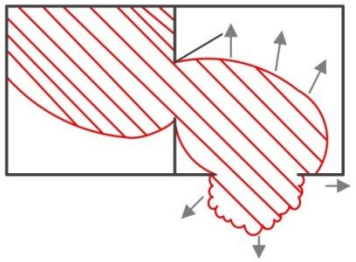
Flame dragged towards vent opening increasing flame surface area.

G



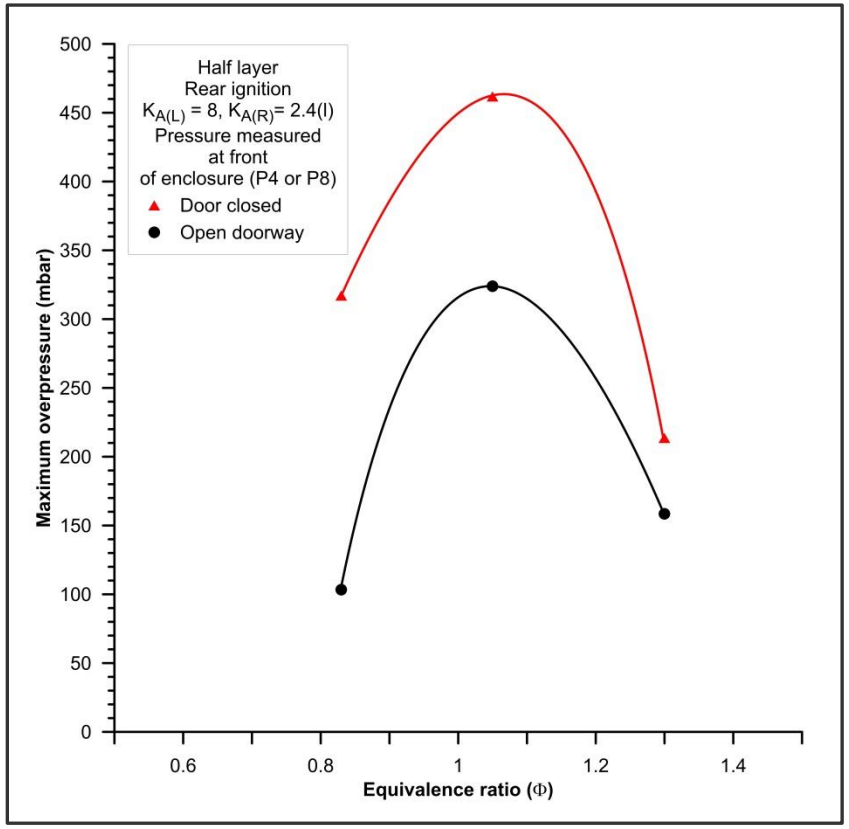
High pressure in the right enclosure causes flow reversal into the left enclosure resulting in rapid combustion in both enclosures. Vent fails in left enclosure.

F



Large increase in flame surface area. External turbulent combustion, rapid pressure rise in right enclosure.

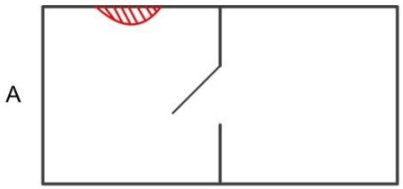
Findings
Larger Vent in the Adjoining Enclosure



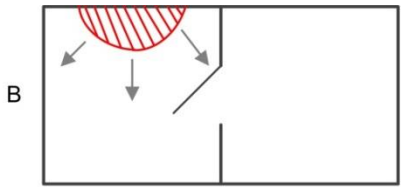
The Effects of Gas Concentration

- In these tests the curves for both open and closed door experiments follow the variation of burning velocity with concentration
- This demonstrates that the dominating factor in pressure generation was turbulent combustion within the enclosure rather than the external explosion

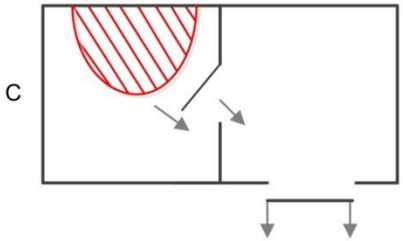
Findings



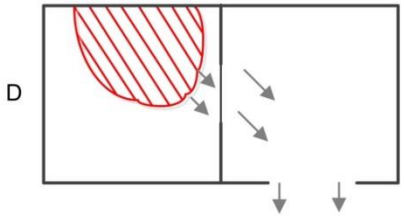
Initial pressure rise.



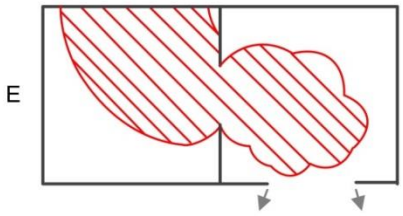
Pressure continues to rise, equal in both rooms.



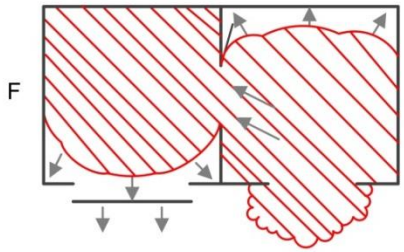
Right vent fails, relieving pressure and causing flow into room.



Door forced closed by sudden flow towards doorway. Pressure in left room starts to rise again, venting continues in right room creating pressure differential.



Door fails causing jetting flame to drive towards vent opening. Rapid increase in turbulent combustion causes $P_t + P_{jeff}$ peak. Pressure falls briefly in left room giving intermediate pressure peak.



Flow reversal into left enclosure. Turbulent combustion well established in both enclosures, left vent fails. External explosion at right vent contributes to maximum overpressure.

Door Hinged to Open into the Ignition Enclosure

- Significant rise in overpressure if door was open at an angle of 45°.
- Overpressure twice that of comparable test with door closed

Findings

Comparison of Test Types

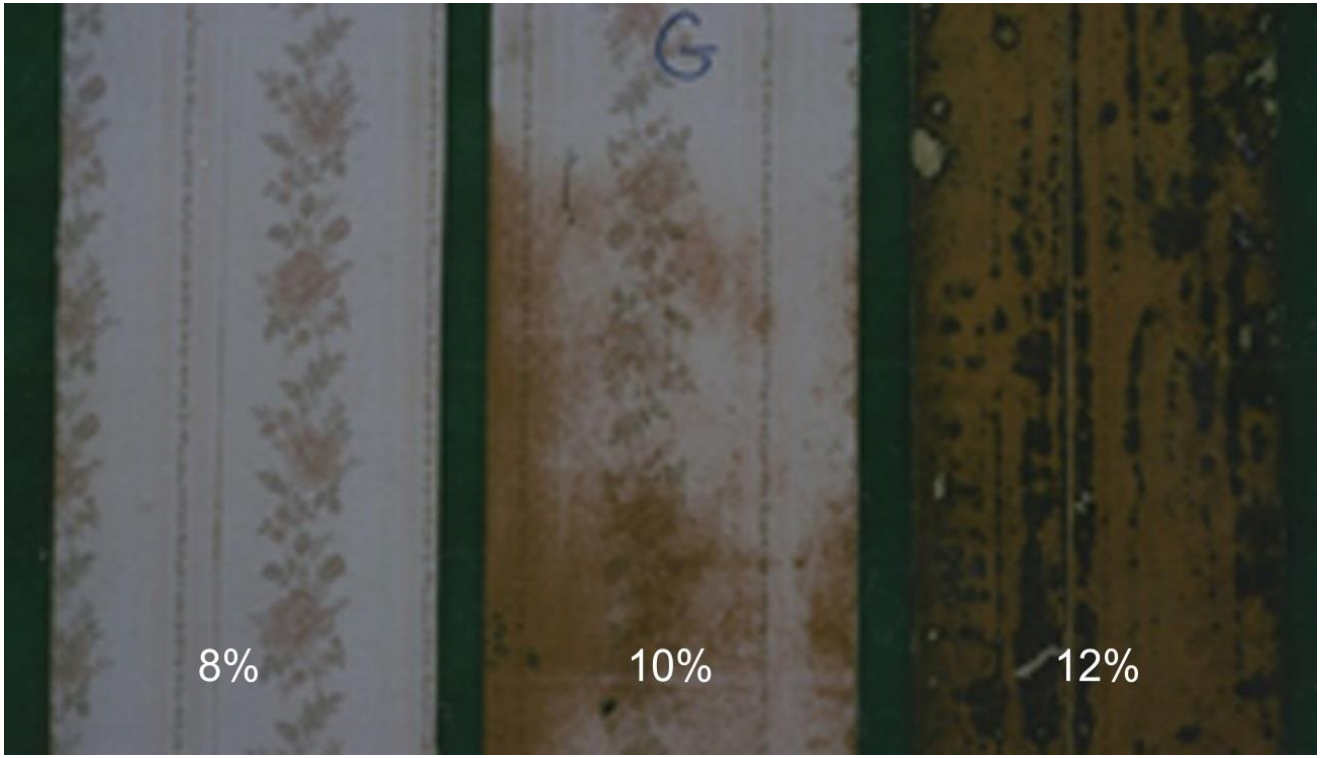
- Four main mechanisms that develop the maximum pressure peak:
  - The external explosion
  - The sudden turbulent combustion in the adjoining room
    - Occurs where the failure pressure of the vent relief is higher in the adjoining room and where there is an interconnecting door that is initially closed.
  - The sudden increase in flame surface area as a consequence of a jetting flame into the adjoining room
    - Occurs where the failure pressure of the vent relief is lower in the adjoining room and where there is an interconnecting door that is closed.
  - A combination of turbulent combustion and a rapid increase on flame surface area as a consequence of a jetting flame into the adjoining room
    - Occurs where the failure pressure of the vent relief is lower in the adjoining room and where there is an interconnecting door that is partially open.

Findings

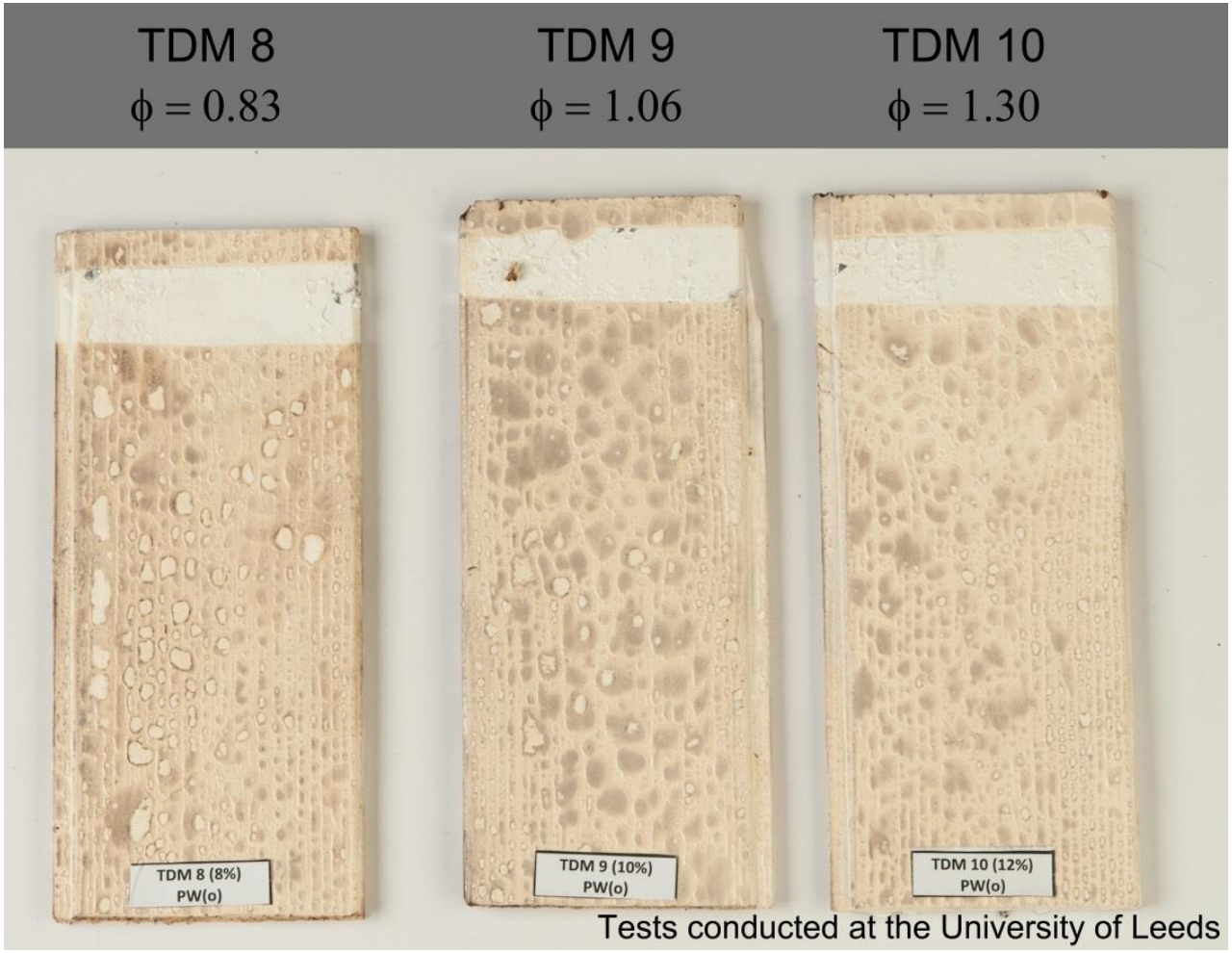
Structural Damage

- Overpressures greater than 200 mbar can structurally damage a building.
- It is clear from the results, that damaging overpressures can be produced by mixtures across the flammable range, given the right set of circumstances.
- An important finding
  - Not in agreement with the most widely used reference sources used in the investigation of gas explosions.

Thermal Damage
The effects of gas concentration



Findings
Thermal damage to white gloss painted wood



Findings
Thermal damage to quick drying white gloss painted wood

Proposed Research

Discussion

- Possible to use thermal damage to determine the gas concentration and its distribution throughout the building prior to ignition
- Building and decorating materials have changed, little information on materials susceptibility to thermal damage from explosions

- Interconnecting doors can significantly affect the pressure developed in an explosion
- The position and type of door can significantly affect the explosion mechanism
- There is the potential for increased turbulence in the gas-air mixture in the secondary room, leading to a larger flame area

- Furniture causes turbulence during an explosion, giving rise to higher overpressures
- The large scale turbulence also breaks up the flammable layer making interpretation of gas distribution difficult
- Hydrogen will change the risks and nature of the evidence

A Better Understanding

Proposed Research

- Potential for explosions with significant damage to be miss-interpreted.
- Research required:
  - Multiple rooms
  - Two floors
  - Interconnecting doors
  - New building materials
  - Hydrogen in natural gas
- Data required:
  - Gas tracking and build-up
  - Mechanism of explosion
  - Thermal damage
  - Can rule of thumb still be used?
- New monograph

Thank you for your attention

gary.tomlin@dnvgl.com

www.dnvgl.com

SAFER, SMARTER, GREENER

