Experimental Investigation of Potential Confined Ignition Sources for Vapour Cloud Explosions

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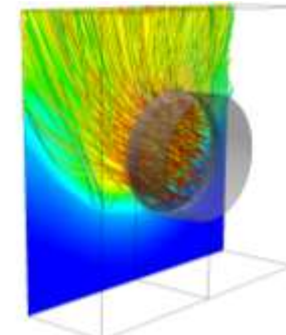
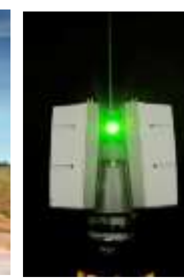
Background to HSE Science & Research Centre at Buxton, United Kingdom

- Multi-disciplinary laboratory:
  - Fire and process safety
  - Computational modelling
  - Exposure control
  - Toxicology etc.
- Approx. 400 staff
- 550 acre test site
- Fire galleries and burn hall
- Impact track
- Anechoic chamber
- Thermal test chamber





VCE Incidents Reviewed

A review was conducted by HSE of historical VCE Incidents (HSE research report RR 1113)

- Unexpected findings:
  - Majority of incidents showed vapor clouds that spread in all directions around the source
  - These appear to have been the result of dispersion in low/nil wind resulting in gravity driven pancake clouds that have persisted for long periods until ignition
    - In these instances there is a likelihood that the eventual ignition source will be confined

Atkinson, G., Hall, J. & McGillivray, A. (2017) Review of Vapor Cloud Explosion Incidents. *HSE Research Report RR1113* http://www.hse.gov.uk/research/rrhtm/rr1113.htm

VCE Incidents: Gravity Driven Dispersion

- Dense gas clouds become laminar on upper layer in far field
  - Slow mixing and dilution, nearly uniform concentrations across wide area

Jack Rabbit 1
Trial 2
Wind speed = 0.6 m/s

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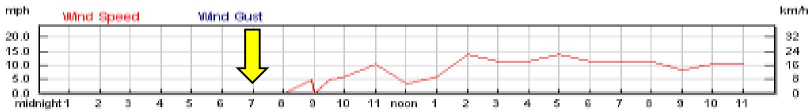
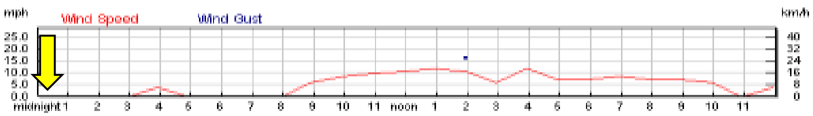
VCE Incidents: Wind speeds

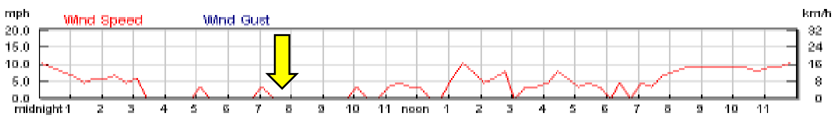
Wind speeds measured at nearest met stations



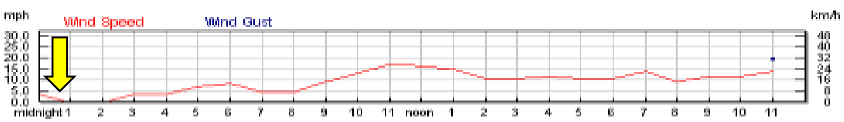
Brenham, Texas (7:00am)



San Jan, Puerto Rico (00:23 am)



Big Spring , Texas



Newark, New Jersey (0:10 am)

Vapor cloud structure

Dense vapor cloud spreads in all directions around the source in nil/low wind speeds

VCE Incidents: Time to Ignition

Incidents that occurred in nil/low–wind conditions		Vapor release rate (kg/s)	Duration prior to ignition (s)
Brenham, TX, 1992	LPG Storage	100	3600
Newark, NJ, 1983	Gasoline storage	35	>900
Big Spring, TX, 2008	Refinery	not known	not known
San Juan, Puerto Rico, 2009	Gasoline storage	50	1560
Skikda, Algeria, 2004	LNG facility	~10	<300s
Buncefield, UK, 2005	Gasoline storage	19	1380
Amuay, Venezuela, 2012	Refinery LPG storage	13	>5000
Jaipur , India, 2009	Gasoline storage	34	4500
Incidents that probably occurred in nil/low-wind conditions			
St Herblain, France, 1991	Gasoline storage	~10	1200
Geismer, LA, 2013	Petrochemicals	not known	not known
Naples, Italy, 1995	Gasoline storage	20	5400
La Mede, France, 1992	Refinery	25	600
Incidents that occurred in light/moderate winds			
Baton Rouge, LA, 1989	Refinery	681	150
Norco, LA, 1988	Refinery	257	30
Pasadena, CA, 1989	HDPE	643	60
Flixborough, UK, 1974	Petrochemicals	670	45

Buncefield Ignition Source

Ignition source for Buncefield was probably a star-delta switch enclosure, located inside a pumphouse.

Purpose

- Electrical control boxes are prolific on high VCE hazard sites. So much so that there has been research on using them as pressure indicators after VCE events (Chen, et al 2015)
  - They offer a credible confined ignition source in widely dispersed persistent cloud scenarios, such as Buncefield

(Chen, A., Louca, L. A. & Elghazouli, A. Y. (2015) Blast assessment of steel switch boxes under detonation loading scenarios. International Journal of Impact Engineering 78:51-63).

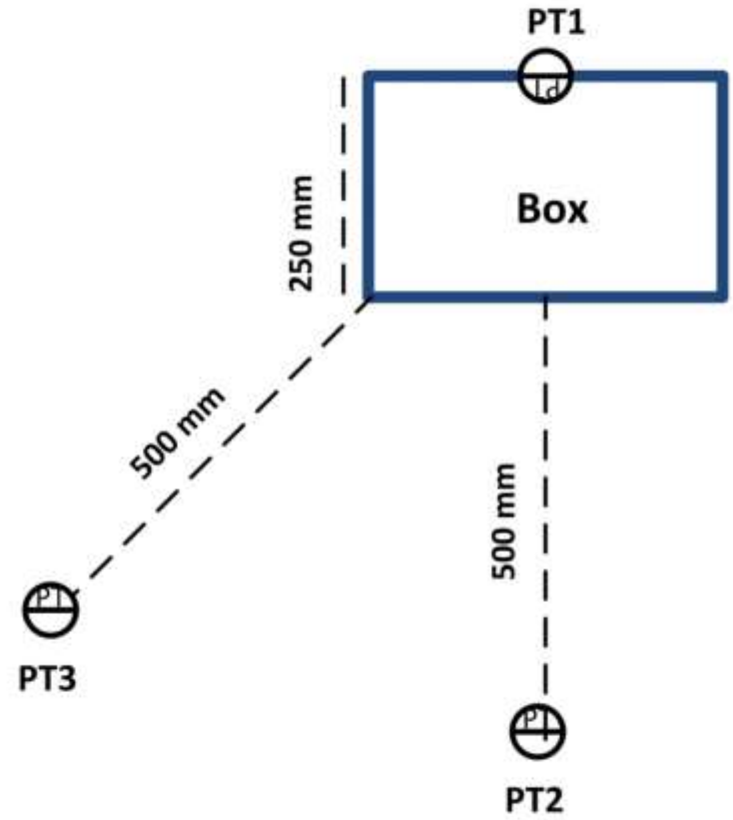
Aims

- To understand the venting and flame exit characteristics of explosions propagating from an electrical control box and its effect on the resultant explosion in an external flammable cloud
- A further aim is to try to understand the effects if this control box is situated in a building and is therefore a nested 'bang-box'

Method

- 600 x 400 x 250 mm steel control boxes with 3-point door catches were filled with stoichiometric propane/air and ignited with a tungsten hotwire ignitor
- The effect of using the supplied doors or foil replacement as a vent covering was measured using high speed videography and pressure measurements
  - Due to the shape of the vent orifice it was only possible to tape the film vent coverings

The Rig



The Results

- The foil and door tests showed comparable pressure measurements
- There was little or no external explosion overpressures measured
- The internal pressure seems to be dominated by the vent burst pressure
  - Lower pressures were measured in test 2 where the tape used to attach the foil started to detached before the foil tore

The Results

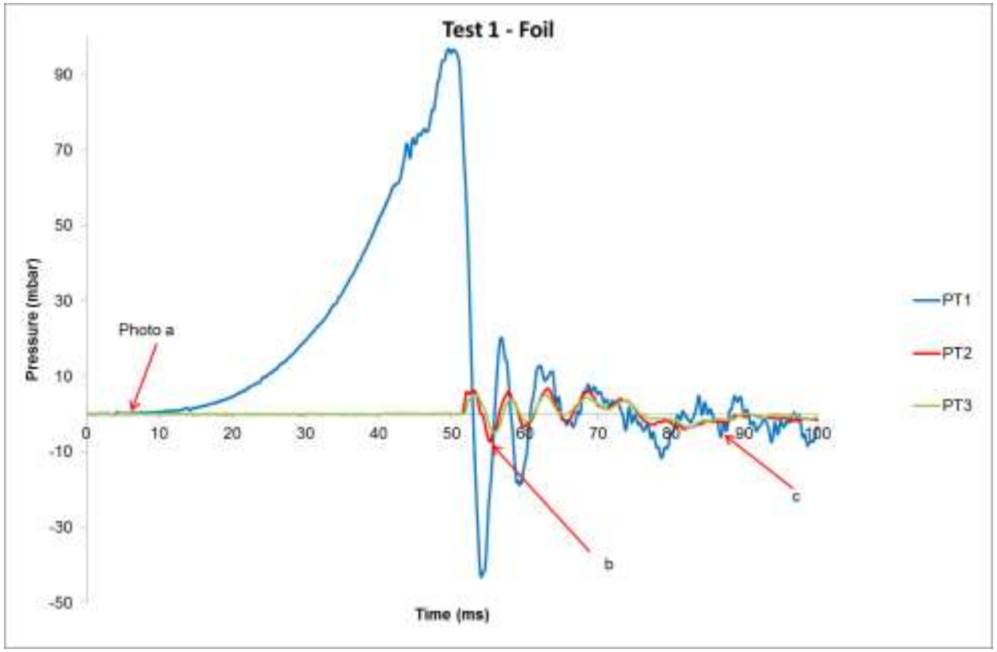
Test	Vent covering	PT1 (mbar)	PT2 (mbar)	PT3 (mbar)
1	foil	97	5	5
2	foil	72	3	3
3	door	75	-	-
4	door	90	4	7
5	door	78	2	4

Results – foil tests

The foil stretches to tearing point and then tears quickly and is rapidly moved away from opening.

The venting gases form a rolling vortex bubble giving rise to a mushroom shaped flame as it follows the vented gases.

The flame extends to around 2 metres out from opening.



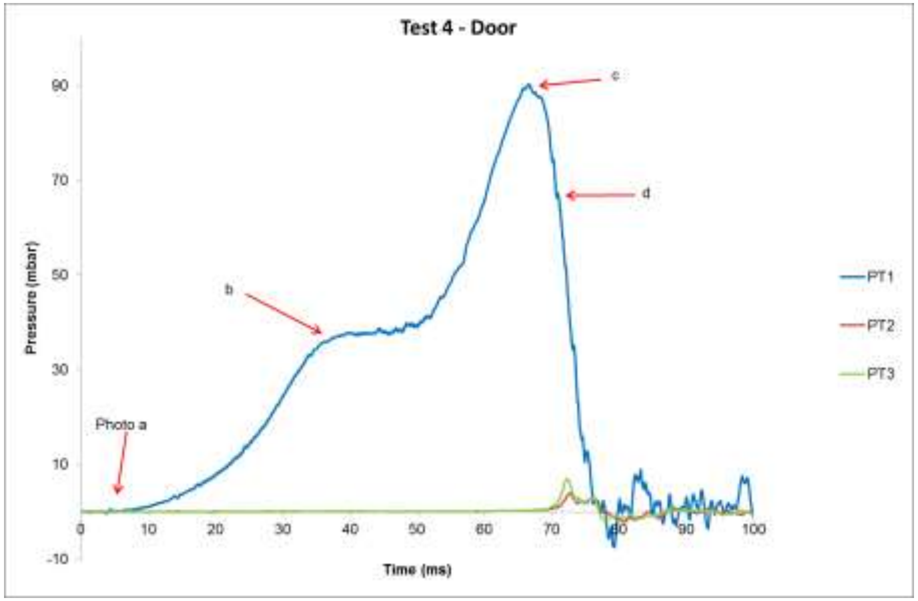
Results – Foil test ~1/10 speed

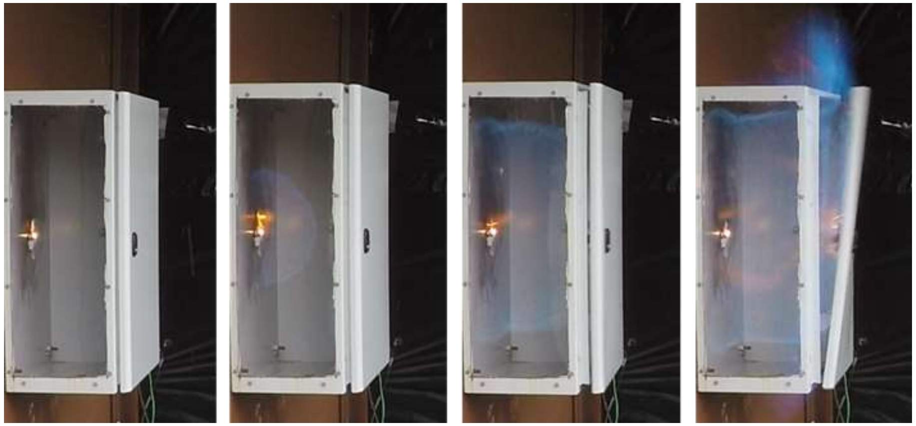
Results – door test

The door deflects to allow partial venting which stalls the pressure rise.

Most of the venting occurs through a very thin crack in the door, most of this unburnt vented gas will be diluted.

The event finishes before the door is fully open.





Results – Door test ~1/10 speed

Results - flame shapes

The flame shapes between the foil and doors tests is drastically different, highlighting the different venting mechanisms.

There will also be differences in turbulent interaction between vented gases and external cloud

Turbulence Comparisons

Recent work at Ineris studying propagation from a 0.7 m vent into an external flammable cloud showed little turbulent mixing and the two explosions were described as "disconnected"

Fig. 13. Simulated flow field in front of the vent and experimental observation (test 2).

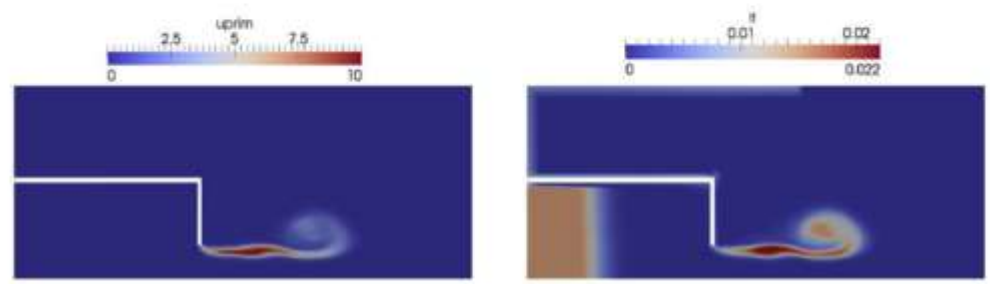


Fig. 14. Turbulent intensity U' (m/s) and turbulent length scale lt (m) (test 2).

Daubech, J., Proust, C. & Lecocq, G. (2017) Propagation of a confined explosion to an external cloud. *Journal of Loss Prevention in the Process Industries* **49**:805-813.

Turbulence Comparisons

HSE

When the vent size was reduced to 0.2 x 0.2 m the venting formed a jet, increasing turbulence and dramatically increasing the severity of the explosion in the external cloud

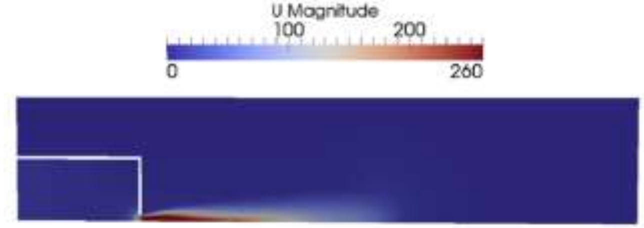


Fig. 15. Flow velocity in the 54 m^3 chamber at 210 ms (test 5).

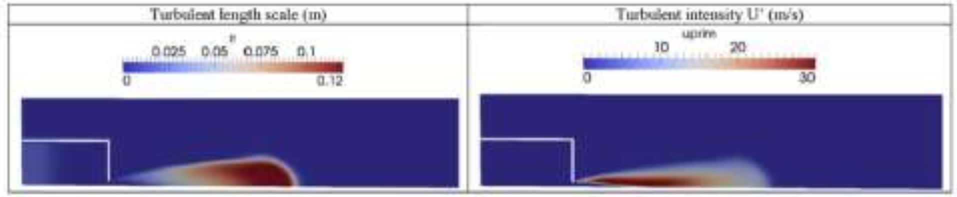
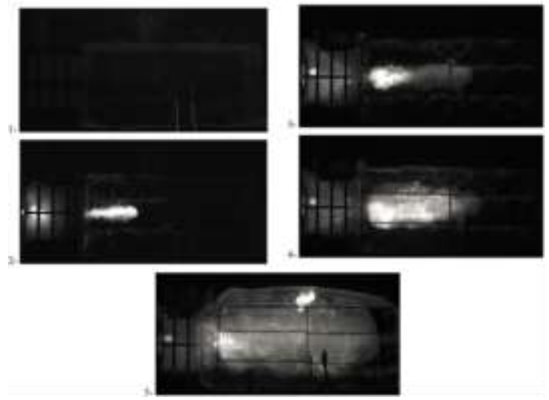


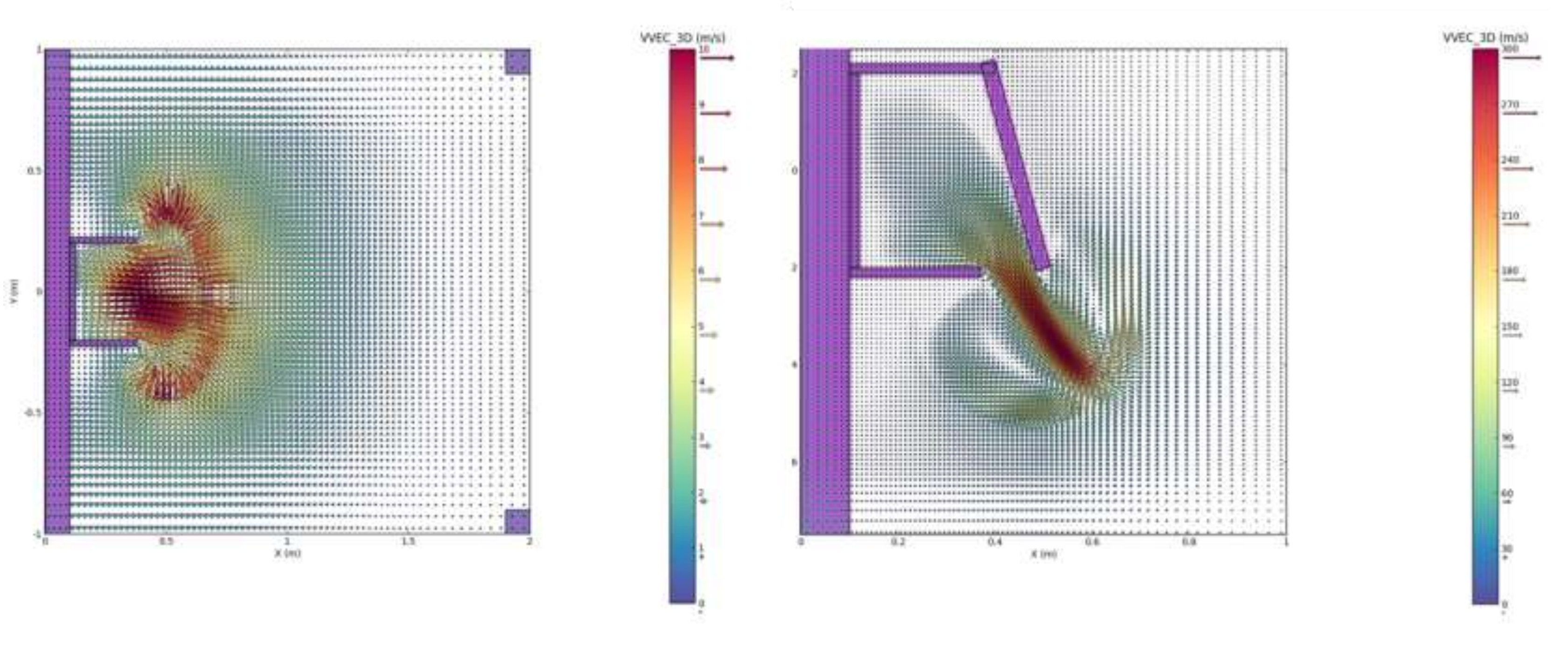
Fig. 16. Turbulent structure of the flow.



Daubech, J., Proust, C. & Lecocq, G. (2017) Propagation of a confined explosion to an external cloud. *Journal of Loss Prevention in the Process Industries* **49**:805-813.

Turbulence Comparisons

We can't model the dynamic venting in this case, but we can cheat, break the rules and produce an indicative only model using the door as a fixed entity



Actual door vent area (Frame interval 4.17 ms)

Implications

- The venting from the door is likely to induce much more turbulence in the external cloud
  - This is before we consider that induced by the movement of the door
- This shows that the vent membrane medium is highly important when considering vented explosions and that it should be as 'real-world' as possible

Current work (to be reported soon)

- These boxes are usually full of equipment and we have been exploring the effect of congestion on the venting mechanisms
- We are also exploring the effect of propagation into an external flammable cloud

Future Work?

- Light weight steel cladding panels are used to construct many process buildings; the Buncefield pump house was mainly constructed of these. Our previous work has shown these panels can have an escalating affect on explosion severity as it fails.
  - We need to understand what happens when an explosion in a control box ignites a cloud in a steel panel building, which ignites an external unconfined cloud.
    - Any offers???

VCEs in steel-clad structures

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Vapour cloud explosions in steel clad structures

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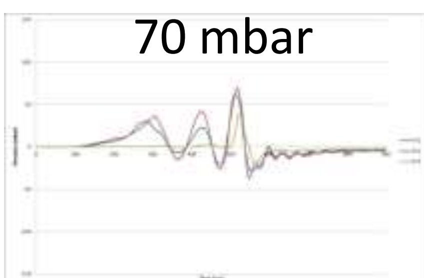

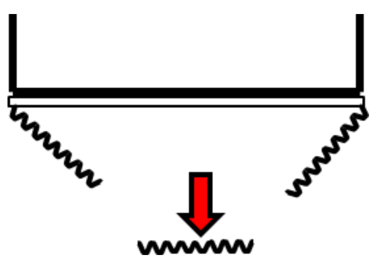

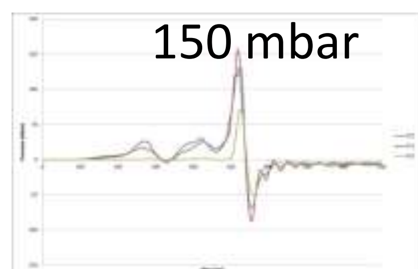

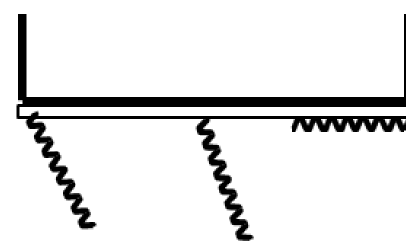

VCEs in steel-clad structures

Summary

- Dispersion method observed in many VCE events increase the likelihood of a confined ignition source
- A hinged door behaves much differently to a bursting membrane, much more turbulence is generated in the venting of unburnt gases
- The effects of a nested ignition of this type needs to be understood, as the building failure method may also escalate the effects

Acknowledgment

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Thank you

Questions?