# Speaker Profile

- Dr Simon Gant, CEng FIMechE
- Fluid Dynamics Team, Risk Group
- 15 years experience at HSE
- Scientific support to incident investigations, regulation, guidance and standards, consultancy

HSE
Health & Safety Executive

# Flammable mist hazards involving high-flashpoint fluids

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# Outline

- Background / motivation
- Aims
- MISTS1 Joint Industry Project
- Updated review of mist incidents
- MISTS2 Joint Industry Project
- Summary

# Background / Motivation

- EU ATEX Directive on explosive atmospheres
- Implemented as UK DSEAR Regulations
- Employers must:
  - Identify and classify areas of the workplace where explosive atmospheres may occur
  - Ensure appropriate certified safe equipment is used in the hazardous zones

# Background / Motivation

- Guidance on flammable mists from high-flashpoint fluids?
  - BS EN 60079-10-1 Annex D: limited guidance on flammable mists (only qualitative, not quantitative)
  - Energy Institute EI15
    - High-flashpoint fluid mists / sprays treated as Category C Fluids and hazard radii are provided (see next slide), but…
    - "There is little knowledge on the formation of flammable mists and the appropriate extents of associated hazardous areas."

# Energy Institute EI15 Guidance

## MODEL CODE OF SAFE PRACTICE PART 15
## AREA CLASSIFICATION FOR INSTALLATIONS HANDLING FLAMMABLE FLUIDS

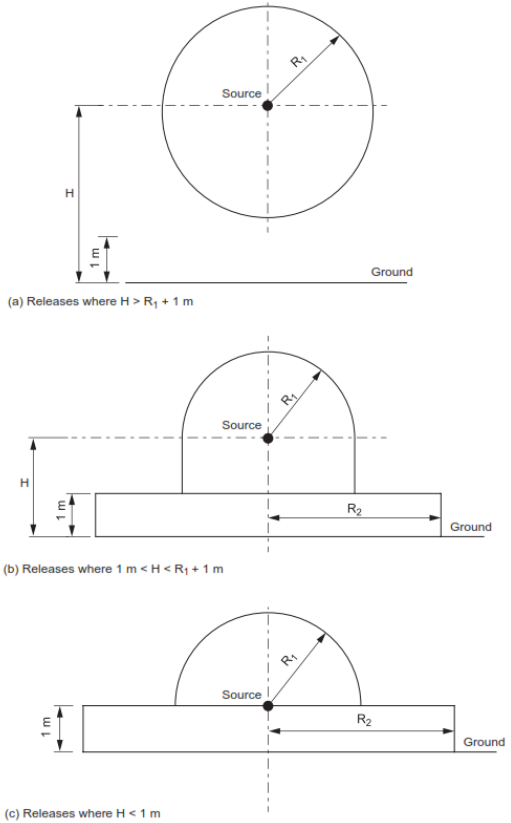



**Figure 3.6: Shape factors for pressurised releases**

**Table C4: Hazard radii $R_1$ and $R_2$ for pressurised releases**

| Fluid category | Release pressure see note 4 (bar(a)) | Hazard radius $R_1$ (m) | | | | Hazard radius $R_2$ (m) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Release hole diameter | | | | Release hole diameter | | | |
| | | 1 mm | 2 mm | 5 mm | 10 mm | 1 mm | 2 mm | 5 mm | 10 mm |
| A | 5 | 2 | 4 | 8 | 14 | 2 | 4 | 16 | 40 |
| | 10 | 2,5 | 4 | 9 | 16 | 2,5 | 4,5 | 20 | 50 |
| | 50 | 2,5 | 5 | 11 | 20 | 3 | 5,5 | 20 | 50 |
| | 100 | 2,5 | 5 | 11 | 22 | 3 | 6 | 20 | 50 |
| B | 5 | 2 | 4 | 8 | 14 | 2 | 4 | 14 | 40 |
| | 10 | 2 | 4 | 9 | 16 | 2,5 | 4 | 16 | 40 |
| | 50 | 2 | 4 | 10 | 19 | 2,5 | 5 | 17 | 40 |
| | 100 | 2 | 4 | 10 | 20 | 3 | 5 | 17 | 40 |
| C | 5 | 2 | 4 | 8 | 14 | 2,5 | 4 | 20 | 50 |
| | 10 | 2,5 | 4,5 | 9 | 17 | 2,5 | 4,5 | 21 | 50 |
| | 50 | 2,5 | 5 | 11 | 21 | 3 | 5,5 | 21 | 50 |
| | 100 | 2,5 | 5 | 12 | 22 | 3 | 6 | 21 | 50 |
| G(i) | 5 | < 1 | < 1 | <1 | 1,5 | < 1 | < 1 | 1 | 2 |
| | 10 | < 1 | < 1 | 1 | 2 | < 1 | < 1 | 1,5 | 3 |
| | 50 | < 1 | 1 | 2,5 | 5 | < 1 | 1,5 | 3,5 | 7 |
| | 100 | < 1 | 1,5 | 4 | 7 | 1 | 2 | 5 | 11 |
| G(ii) | 5 | < 1 | <1 | 1,5 | 3 | < 1 | < 1 | 2 | 4 |
| | 10 | < 1 | 1 | 2 | 4 | < 1 | 1 | 2,5 | 5 |
| | 50 | < 1 | 2 | 4 | 8 | 1 | 2 | 6 | 11 |
| | 100 | 1 | 2 | 6 | 11 | 2 | 3 | 8 | 14 |
| LNG | 1,5 | 2,5 | 3 | 6 | 10 | 2 | 3 | 7 | 30 |
| | 5 | 3 | 5 | 10 | 17 | 2 | 4 | 11 | 40 |
| | 10 | 3 | 5,5 | 10 | 20 | 2,5 | 4,5 | 13 | 37,5 |

High-flashpoint mists / sprays treated as Category C fluids

# Flammable Mist Incidents

IChemE SYMPOSIUM SERIES NO. 155 Hazards XXI 

## MIST FIRES AND EXPLOSIONS – AN INCIDENT SURVEY†

R C Santon
Health and Safety Laboratory, Harpur Hill, Buxton, SK17 6PJ

The ignition of mist formed from flammable liquids at temperatures below their flash point is a well known phenomenon. The more frequent consequence of ignition is fire, although a very small number of explosions have often been quoted as examples. A literature survey has exposed a significantly larger number of incidents than had been previously listed. Together with other incident records already noted, a total of 27 relevant records detailing 37 incidents including 20 explosions have been listed. It is notable that nine incidents alone were collectively responsible for a total of 29 fatalities.

The paper includes summaries of all the incidents, and, so far as possible, comments on the fuels and sources of ignition.

# Aims of this presentation

- Provide an overview of the work led by HSE on flammable mists over the last decade
- Review records of flammable mist incidents
- Summarise preliminary results from an ongoing joint-industry-funded project

# Joint-Industry Project: MISTS 1

- Aims: to undertake scientific research that can be used to develop guidance on:
  - Formation of flammable mist
  - Mitigation measures
  - Area classification zone and extent
  - Protected equipment concepts, and equipment selection

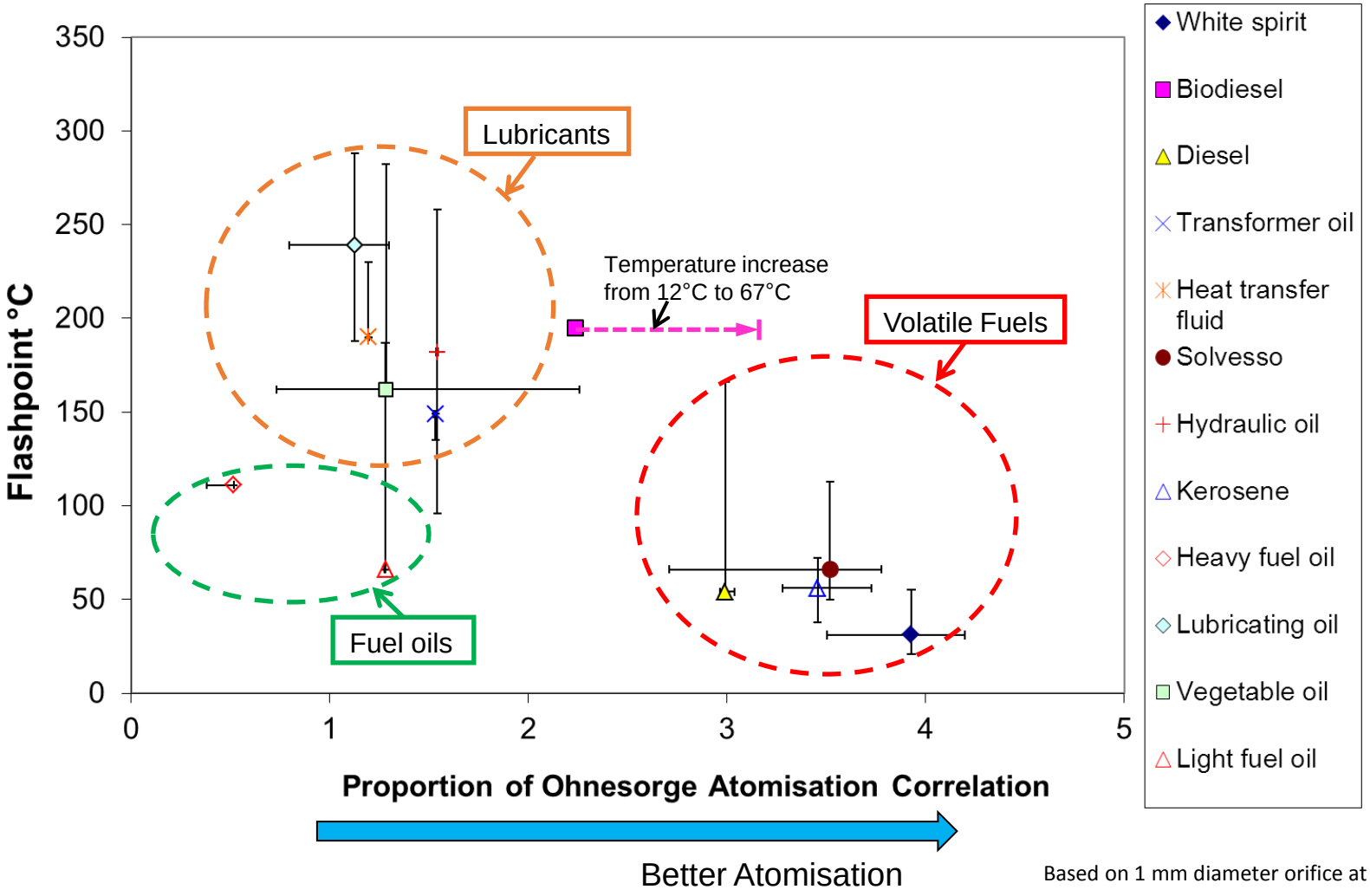
# Joint-Industry Project: MISTS 1

- Scope: mists/sprays/aerosols of liquids that are below their flashpoint at ambient temperature
  - Included: Hydraulic oil, lubricating oil, fuel oils, heat transfer fluids, vegetable oil
  - Excluded: flashing fluids (e.g. propane) and low-flashpoint fluids (e.g. gasoline)
- Timescale 2011-2015, budget: £0.5M ($0.6M)
- Sponsors: HSE, ONR, RIVM, GE, Siemens, EDF/British Energy, RWE, Maersk Oil, Statoil, BP, ConocoPhilips, Nexen, Syngenta, Aero Engine Controls, Atkins, Frazer Nash, Energy Institute

# MISTS 1 JIP: Work Packages

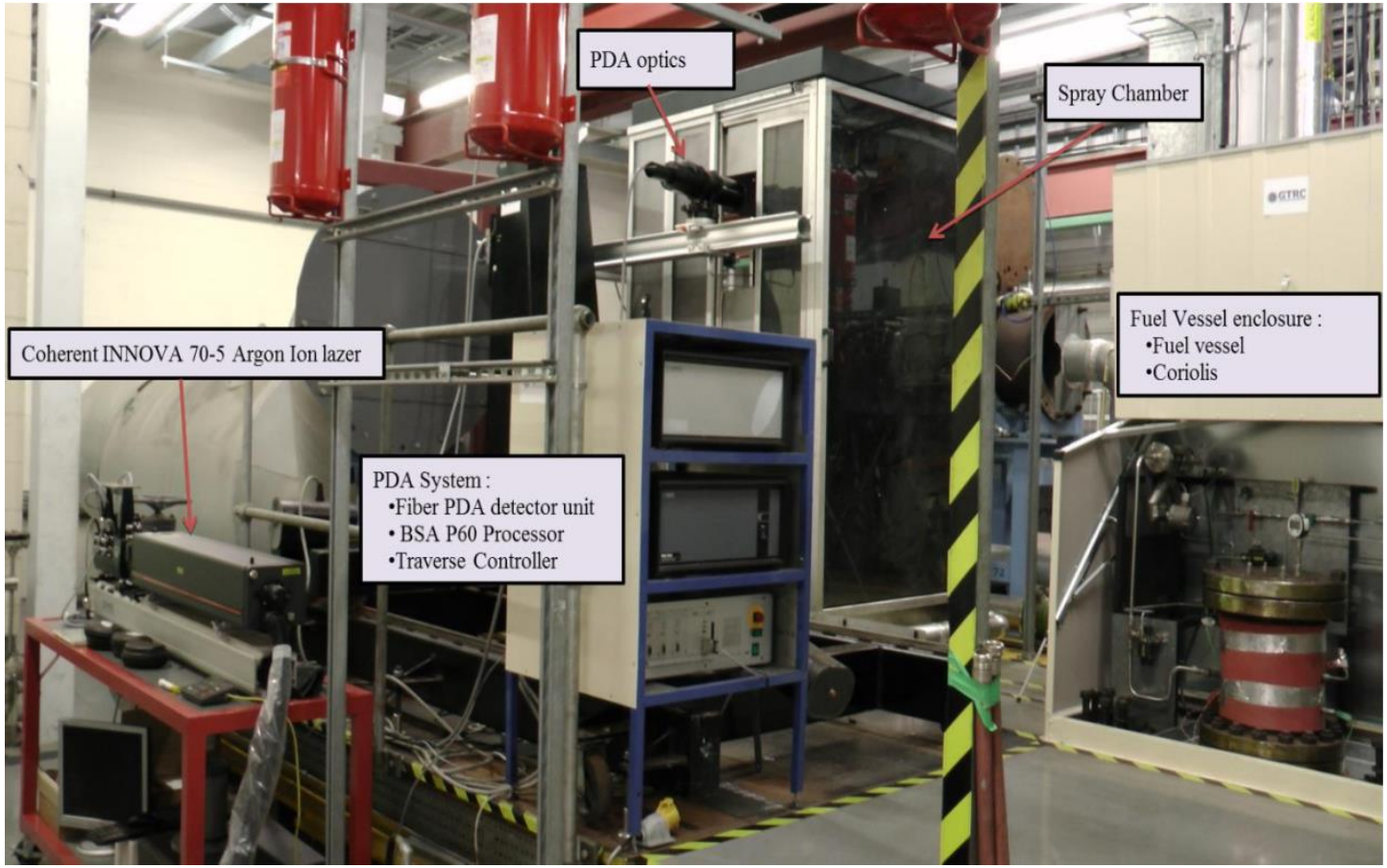
1. Literature review
   - When is a mist flammable?
   - How do you generate a flammable mist?
   - Review data on: LEL, MIE, MIC, MESG, MHSIT
   - Mitigation measures
2. Fluids classification
3. Experiments
4. CFD modelling
5. Comparison of CFD to Energy Institute EI15 guidance
6. Development of (tentative) guidance

# 2. Fluids Classification




Based on 1 mm diameter orifice at 10 bar

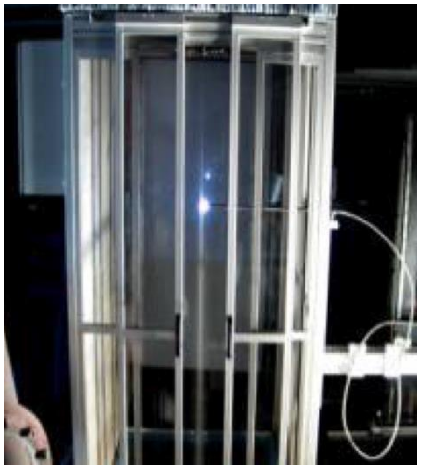
# 3. Experiments at GTRC, Cardiff



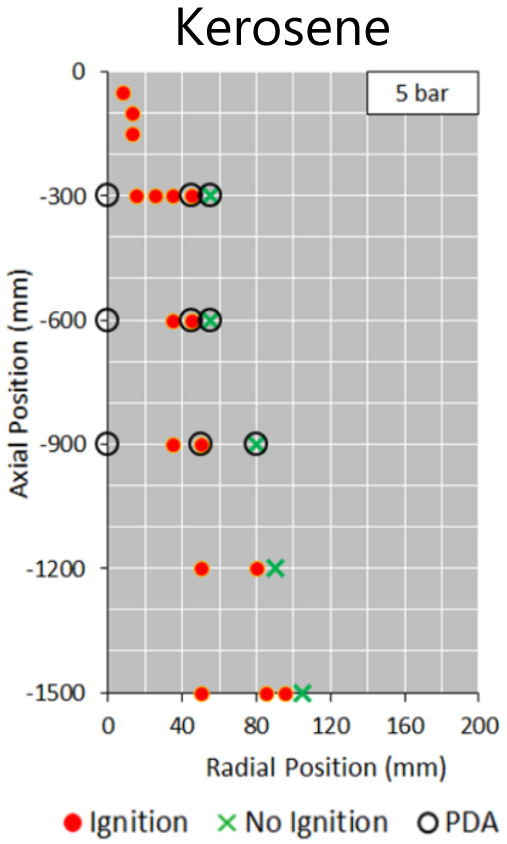
# 3. Experiments at GTRC, Cardiff

- Fluids tested: Jet A1 kerosene, hydraulic oil, light fuel oil
- 1 mm dia, L/D = 2, plain circular orifice
- Pressures mostly 5 – 20 barg
- 1 J spark igniter, PDA droplet sizing

Kerosene



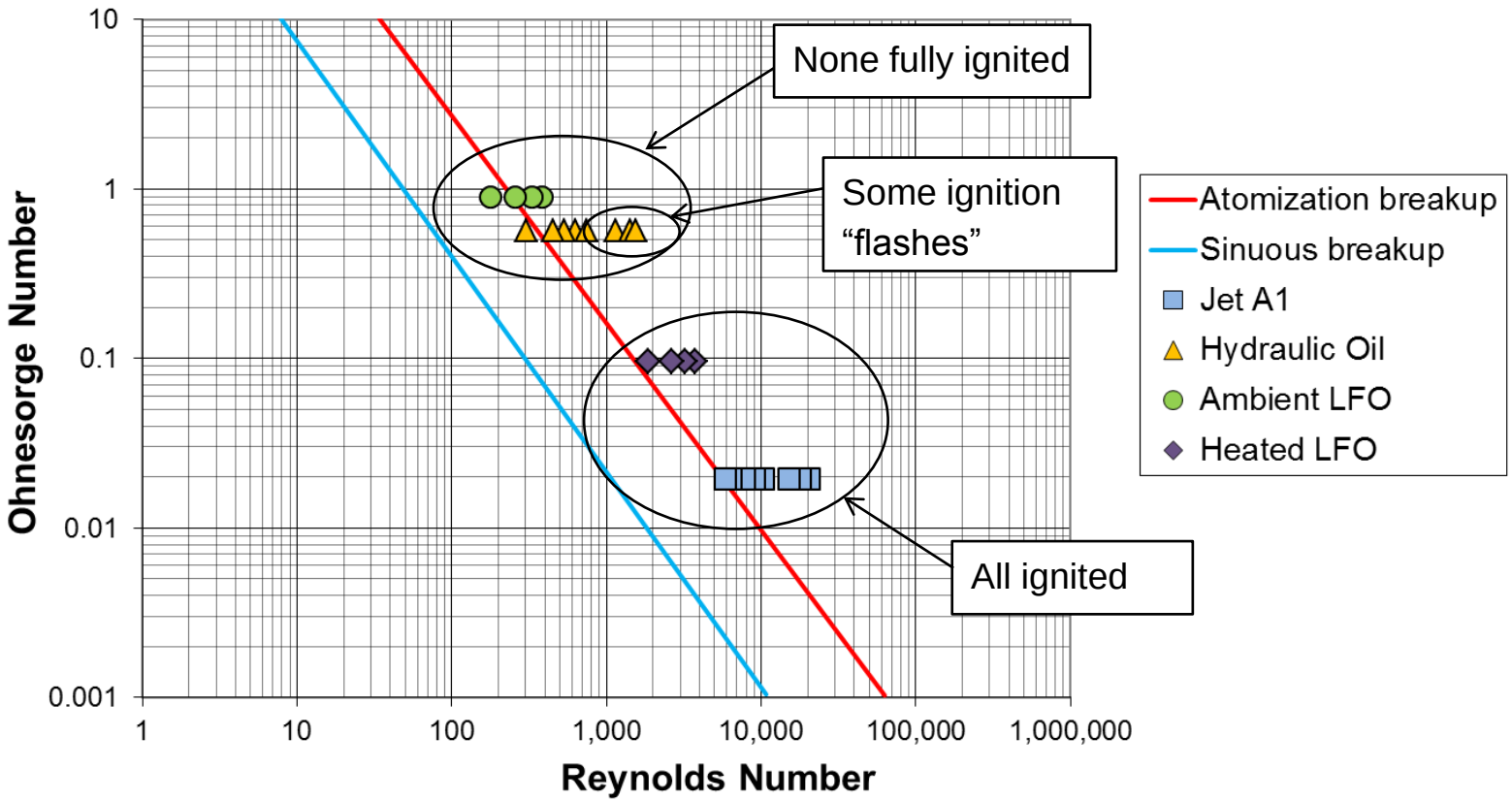
Hydraulic oil



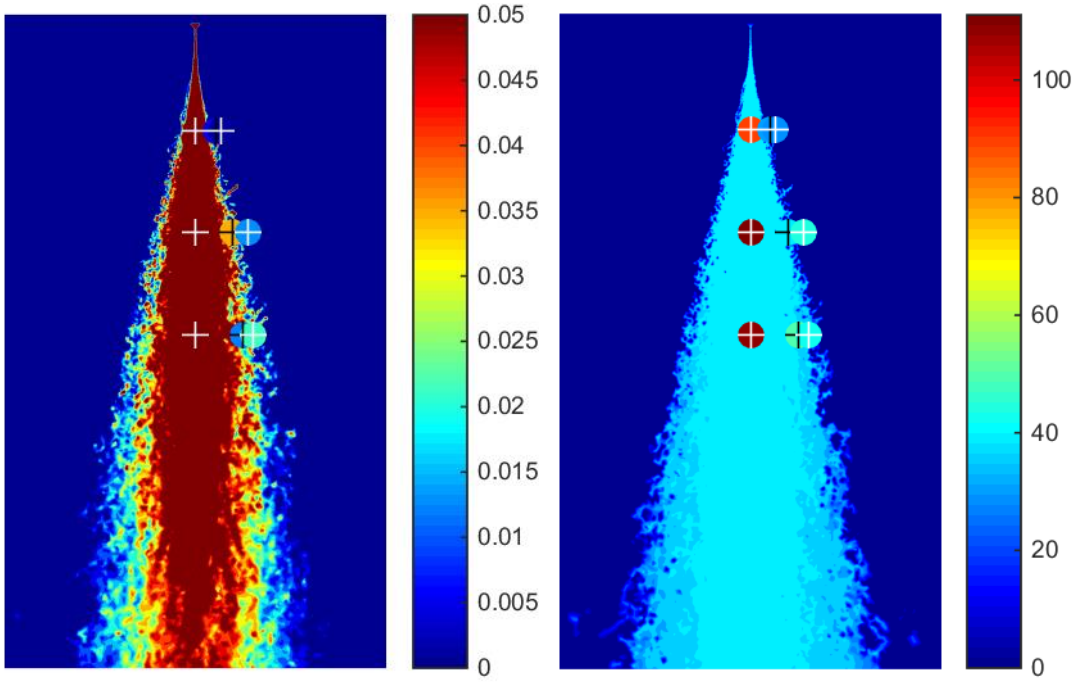
# 3. Experiments at GTRC, Cardiff

| Spray Geometry | Fluid | Pressure (barg) | Temperature | Ignited? |
|---|---|---|---|---|
| Free spray | Jet A1 | 1.7, 2, 3, 4, 5, 10, 15, 20 | Ambient | At all pressures |
| Free spray | Hydraulic oil | 5, 10, 15, 20, 30, 70, 110, 130 | Ambient | No, but some "flashes" at highest pressures |
| Free spray | Light fuel oil | 5, 10, 15, 20 | Ambient | No |
| Free spray | Light fuel oil | 5, 10, 15, 20 | 70 °C | At all pressures |
| Impinging | Hydraulic oil | 5, 10, 15, 20 | Ambient | No |
| Impinging | Light fuel oil | 15, 20 | Ambient | At 20 barg only |
| Impinging | Light fuel oil | 5, 10, 15, 20 | 70°C | At all pressures |

# 3. Experiments at GTRC, Cardiff



# 4. CFD Modelling




Droplet concentration ($kg/m^3$)

Droplet Sauter Mean Diameter (μm)

- DNV Phase III JIP RR droplet size correlation gave results within factor-of-two of measurements for concentration and diameter with Jet A1
- CFD model assumed atomised spray of droplets: poor agreement with non-atomizing hydraulic oil and light fuel oil

# 5. Comparison of CFD and EI15 guidance

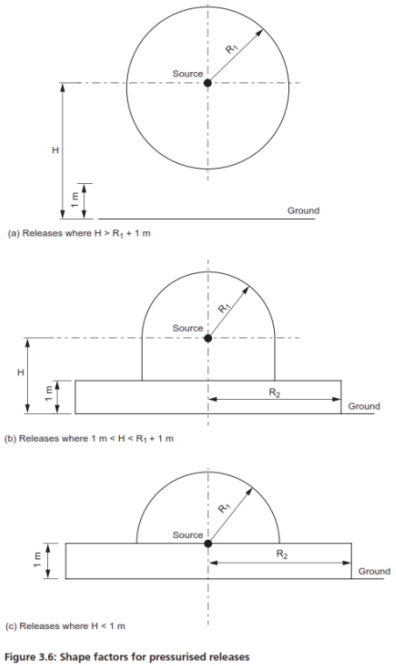
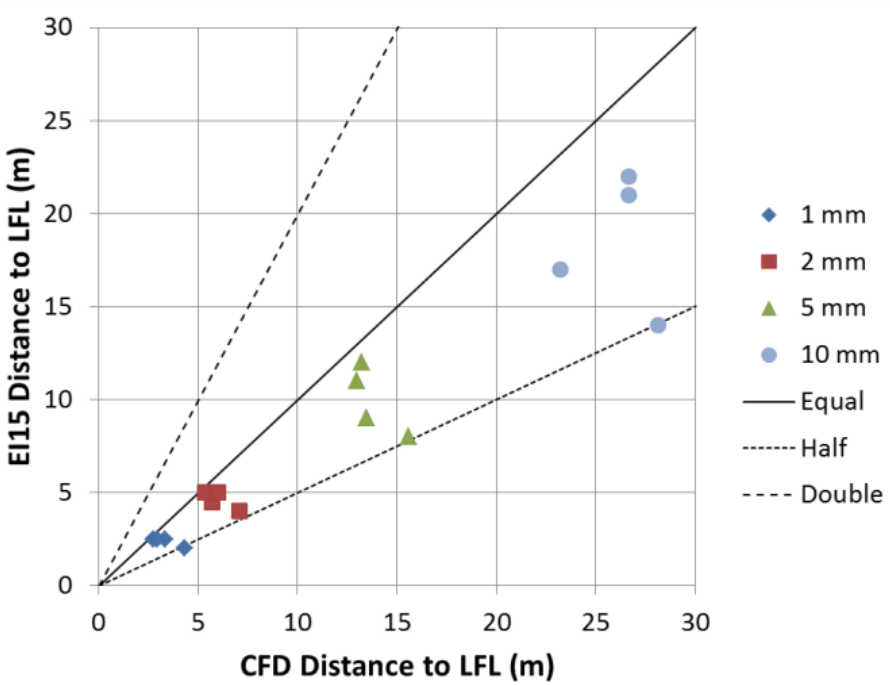
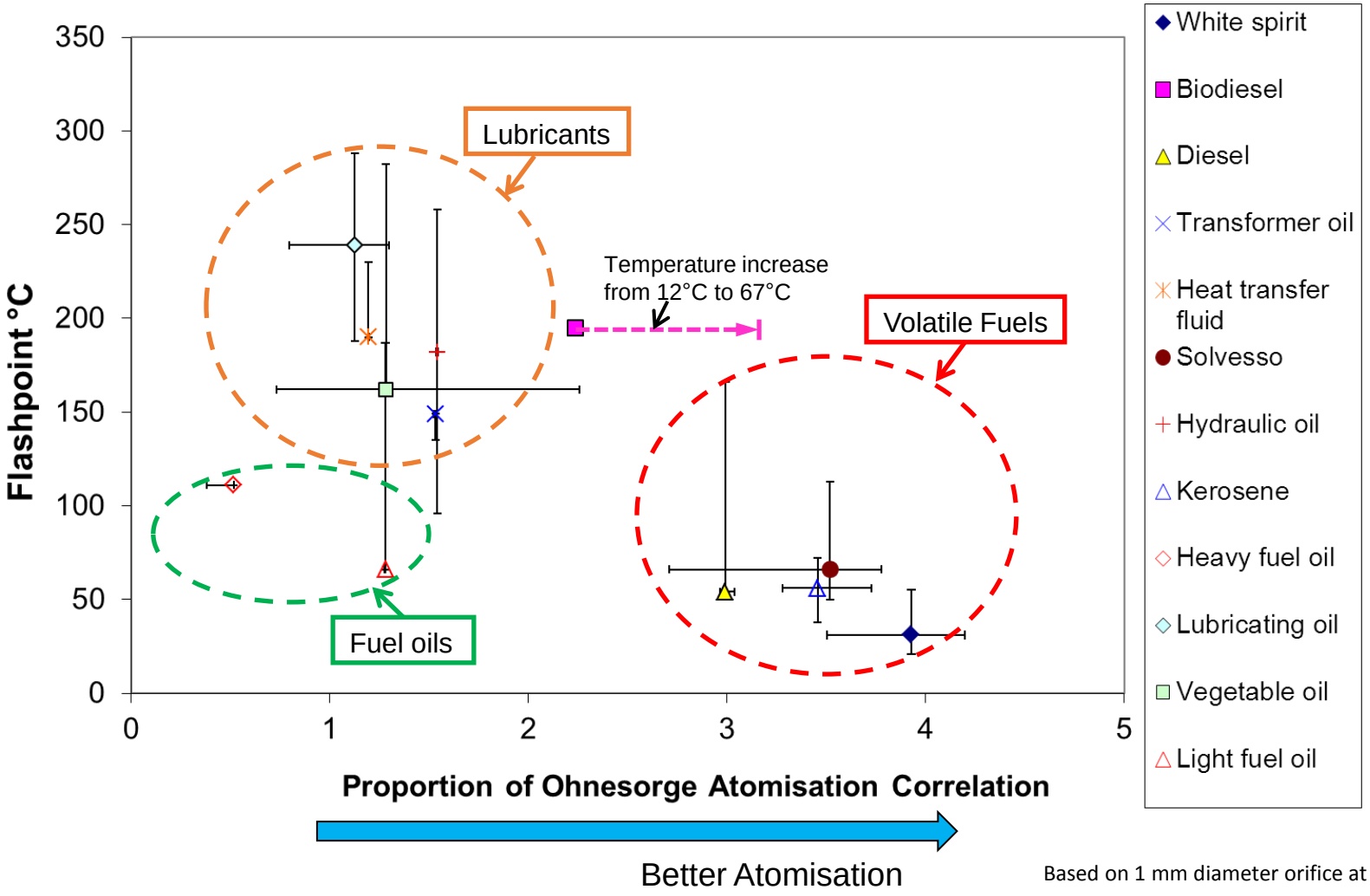



Figure 3.6: Shape factors for pressurised releases



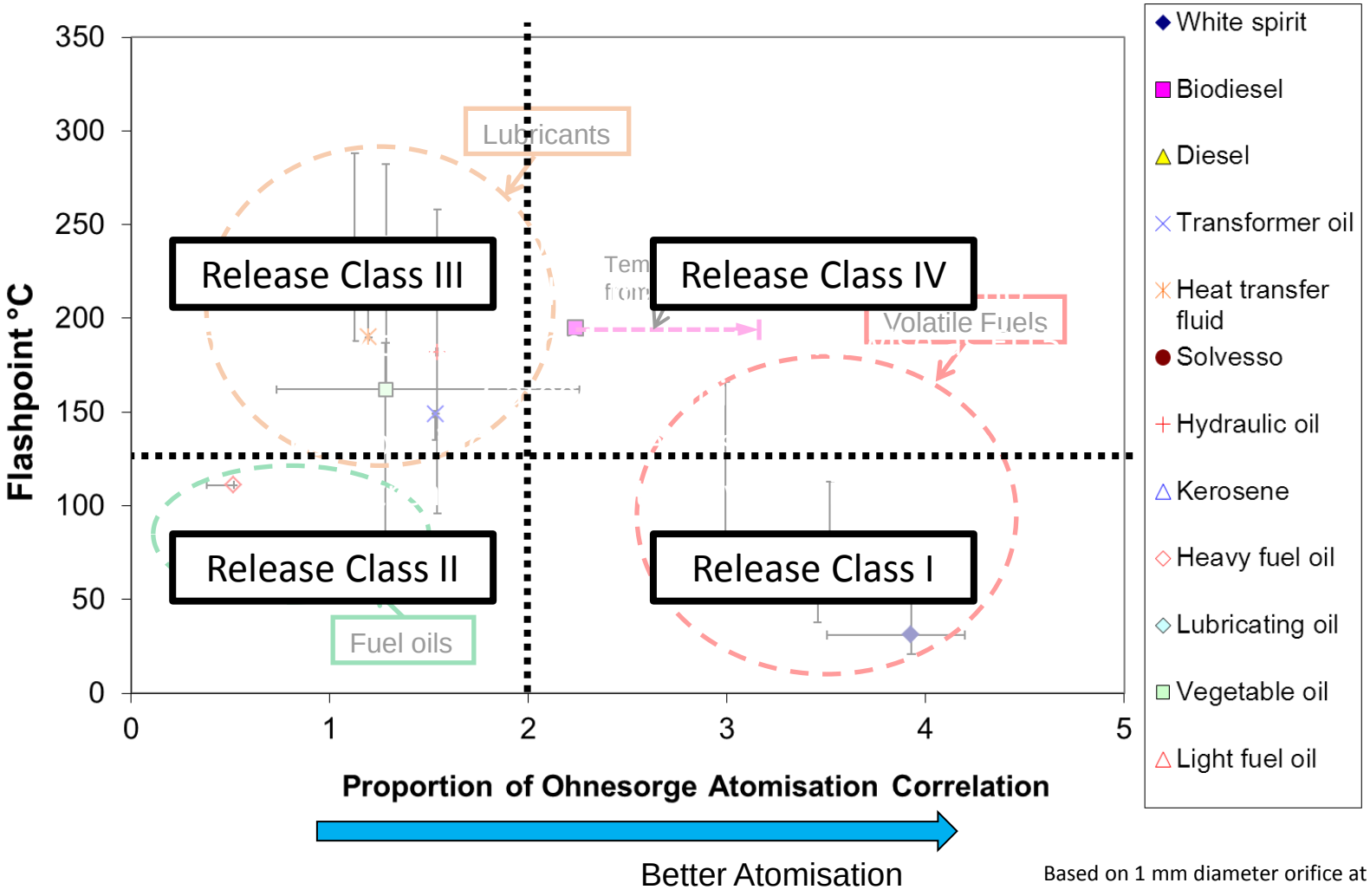

- Results broadly consistent between CFD and EI15
- Hazard range may be larger than given in EI15 for vertically downwards releases, especially at lower pressures

# 6. Tentative Area Classification Guidelines




Based on 1 mm diameter orifice at 10 bar

# 6. Tentative Area Classification Guidelines

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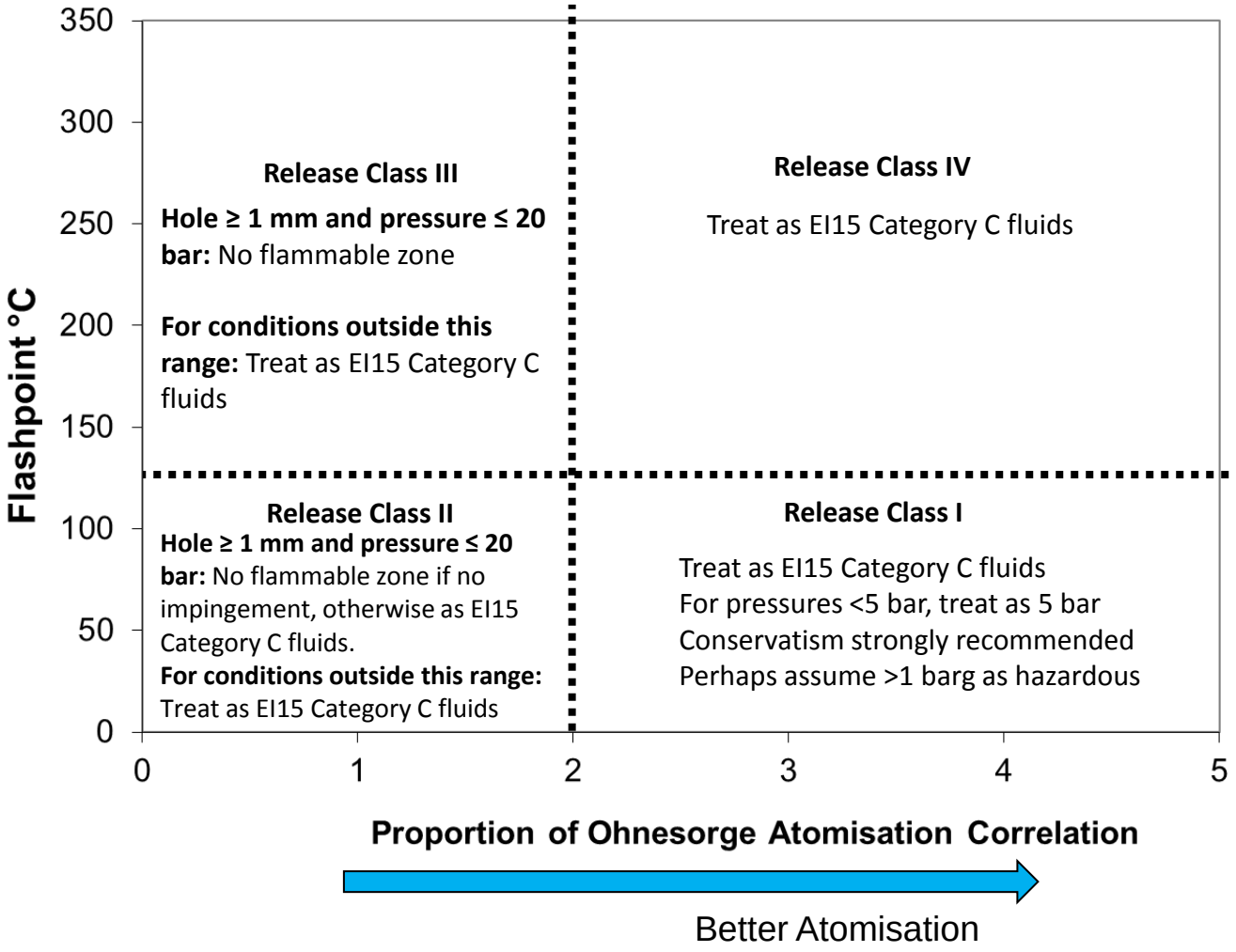
# 6. Tentative Area Classification Guidelines



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# Updated review of incidents

- Aim: to update Santon (2009) review of incidents
- Collaboration: HSE, INERIS, Université de Lorraine
- UK offshore hydrocarbon release database
  - Over period 2016 – 2018: 258 total incidents inc. 25 mists / sprays
- French ARIA incident database
  - 9,725 atmospheric releases: 40 mist / spray incidents
- German ZEMA incident database
  - 464 atmospheric releases: 19 mist / spray incidents

# Joint-Industry Project: MISTS 2

- Timescale: 2018-2020
- Sponsors: HSE, Shell, EDF, ONR, Energy Institute, INERIS
- Aims: to address knowledge gaps following MISTS1
- Work packages:
  1. Where does **diesel** fit into the classification scheme?
  2. How does the **hole shape** affect ignitability?
  3. What is the **maximum extent of the flammable zone**?
  4. (Are mist explosions the same as gas explosions?)

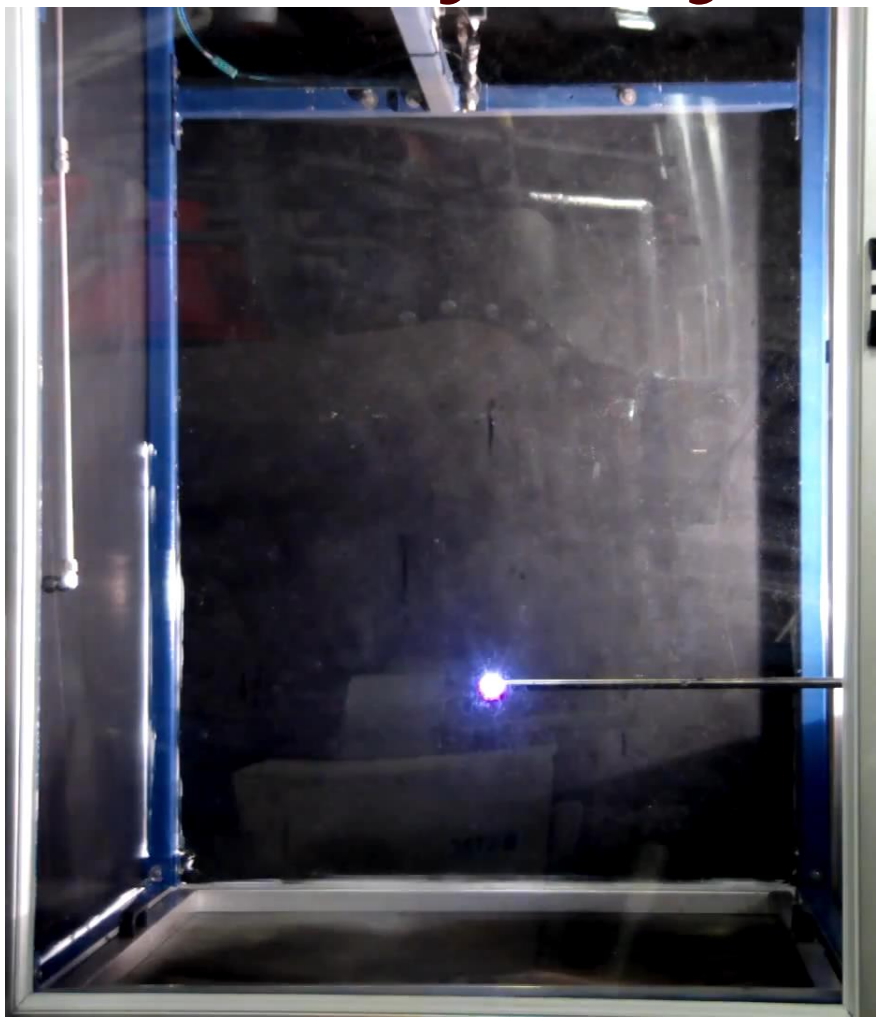
# Joint-Industry Project: MISTS 2

- Ultra-low sulphur diesel, bio-diesel
- 1 mm dia, L/D = 2, plain circular orifice
- 1 J spark igniter, PDA droplet sizing

Findings to date:

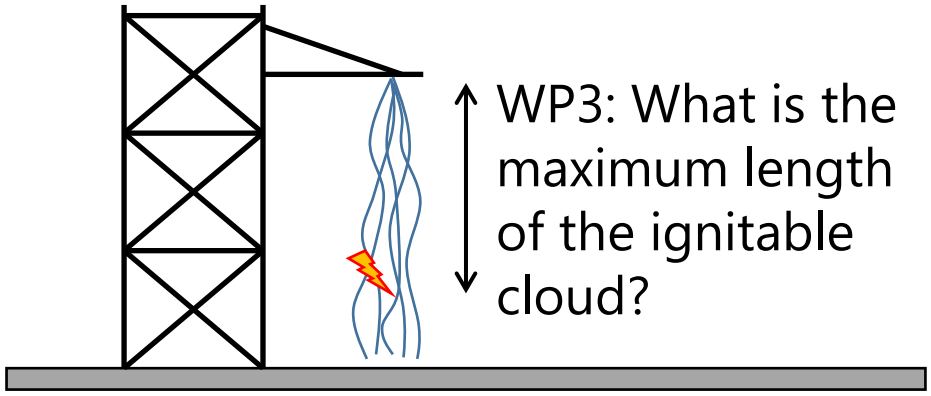
- Ultra-low sulphur diesel
  - Ignited at 5 – 20 barg (not at 3 barg)
- Biodiesel
  - Ignited at 20 barg (but not at 5 – 15 barg)

# Joint-Industry Project: MISTS 2



Video of 5 barg ultra-low sulphur diesel ignition test

# Joint-Industry Project: MISTS 2




- Cardiff university soon to start work on Work Package 2: orifice shape
- Currently constructing rig in HSE burn hall for Work Package 3
- Project planned completion Dec 2020

# Summary

- Overview provided of:
  - MISTS1 and MISTS2 Joint Industry Projects
  - Mist incident reviews in 2009 and 2019
- MISTS1 findings:
  - Jet A1 kerosene ignited at pressures ≥ 1.7 barg
  - Tentative guidance based Release Classes I - IV
- MISTS2 findings:
  - Diesel ignited at pressures of ≥ 5 barg
  - Work ongoing on orifice shape and zone extent
- Please contact us if you are interested in future work

# References


- Santon, R. (2009) "Mist fires and explosions – an incident survey", IChemE Hazards XXI Conference, https://www.icheme.org/media/9551/xxi-paper-054.pdf
- Gant, S.E. (2013) Generation of flammable mists from high flashpoint fluids: literature review", Health and Safety Executive, Research Report RR980 http://www.hse.gov.uk/research/rrhtm/rr980.htm
- Bettis R., Burrell G., Gant S.E., Coldrick S., Mouzakitis K. and Giles A., (2018) "Area classification for oil mists - final report of a Joint Industry Project", HSE Research Report RR1107 http://www.hse.gov.uk/research/rrhtm/rr1107.htm
- Lees P., Gant S.E., Bettis R., Vignes A., Lacome J.-L. and Dufaud O. (2019) "Review of recent incidents involving flammable mists" IChemE Hazards 29 Conference https://www.icheme.org/media/12613/hazards-29-paper-31-review-of-recent-incidents-involving-flammable-mists.pdf

# Thank you

# Any Questions?

The work presented here was funded by HSE and the following sponsors: Aero Engine Controls, Atkins, BP, ConocoPhillips, EDF, Energy Institute, Frazer Nash, GE, Maersk Oil, ONR, RIVM, RWE, Shell, Siemens, Statoil and Syngenta. The contents of this presentation, including any opinions and/or conclusions expressed or recommendations made, do not supersede current published HSE policy or guidance.