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Hydrogen Bubble Dispersion and Surface Bursting Behaviour

J Ingram, A Averill, P Battersby, P Holborn and P Nolan

Explosion and Fire Research Group

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Why Study Hydrogen Bubbles ?
(1) Sources

- H_2 is a concern for nuclear waste storage & decommissioning operations.
  - Hydrogen produced in liquids and sludges
    - Corrosion of metals particularly Mg
    - Radiolysis
- Release in form of bubbles
    - Small bubbles – often slow steady releases
    - Large volumes , 100’s L – disturbance of sludge beds or containers

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Why study hydrogen bubbles?
(2) Concerns

- Hydrogen releases could form flammable atmospheres and be ignited.
- Typical Questions:
  - Extent of flammable region above surface
  - How quickly is it dispersed
  - Build up in roof space possible?
- Data useful for model development and validation

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Visualising hydrogen in air

- Rapid, transient phenomenon
- Non-invasive measurement
- Simultaneously at different positions
- Schlieren photography
  - Available
  - Concentration gradient
  - Reasonable sensitivity - H_2-air mix from pipe visible at 4% H_2

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Experimental apparatus

- Toughened glass tank
- Bubbles from
  - Various size submerged pipes
- Schlieren system
- Second camera
  - Bubble sizing (with retractable rod)
  - Rise time and speed
  - Filming bursting process

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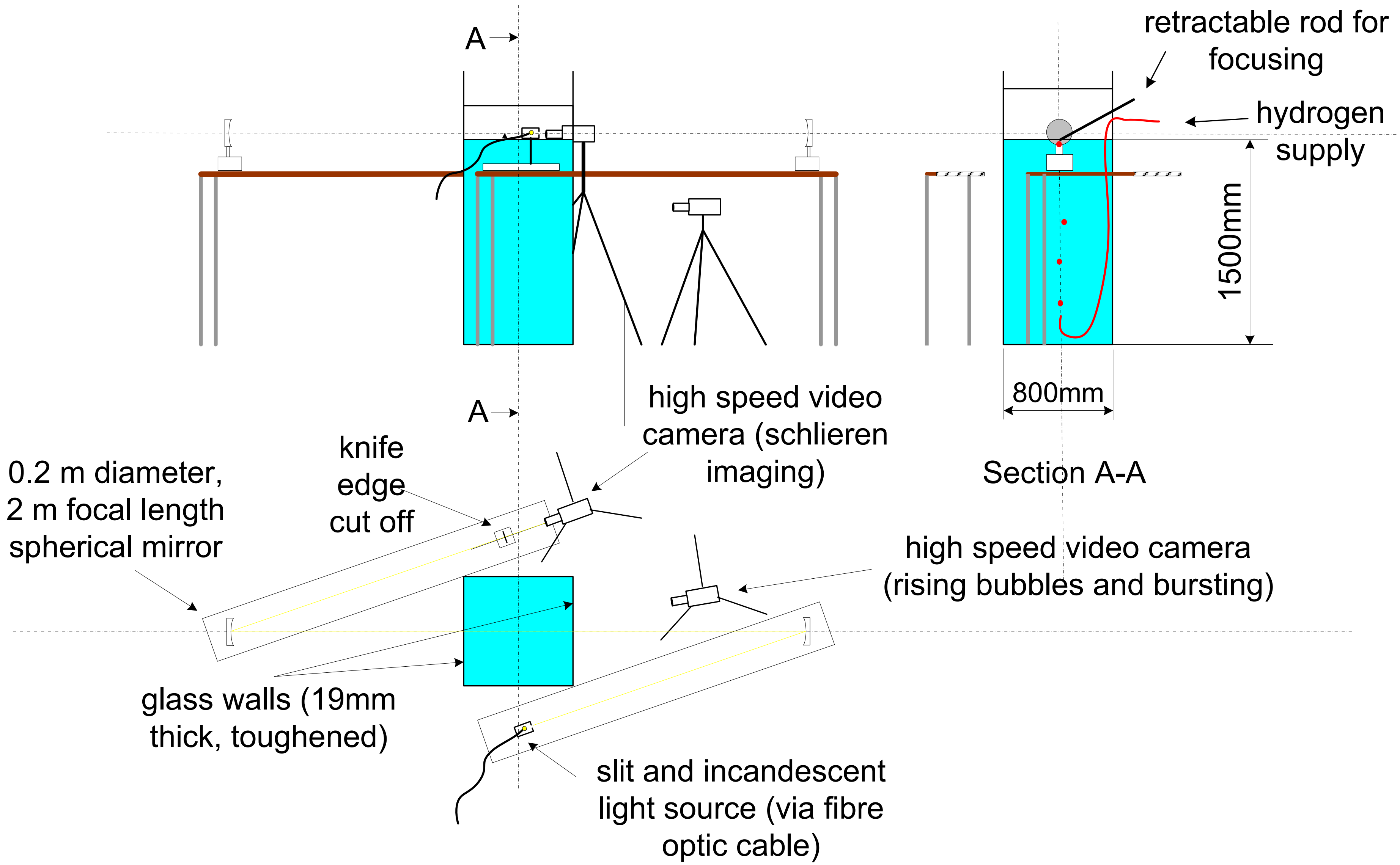

2 cm^3 H_2 bubble rising to a water surface

length of video clip 600 ms

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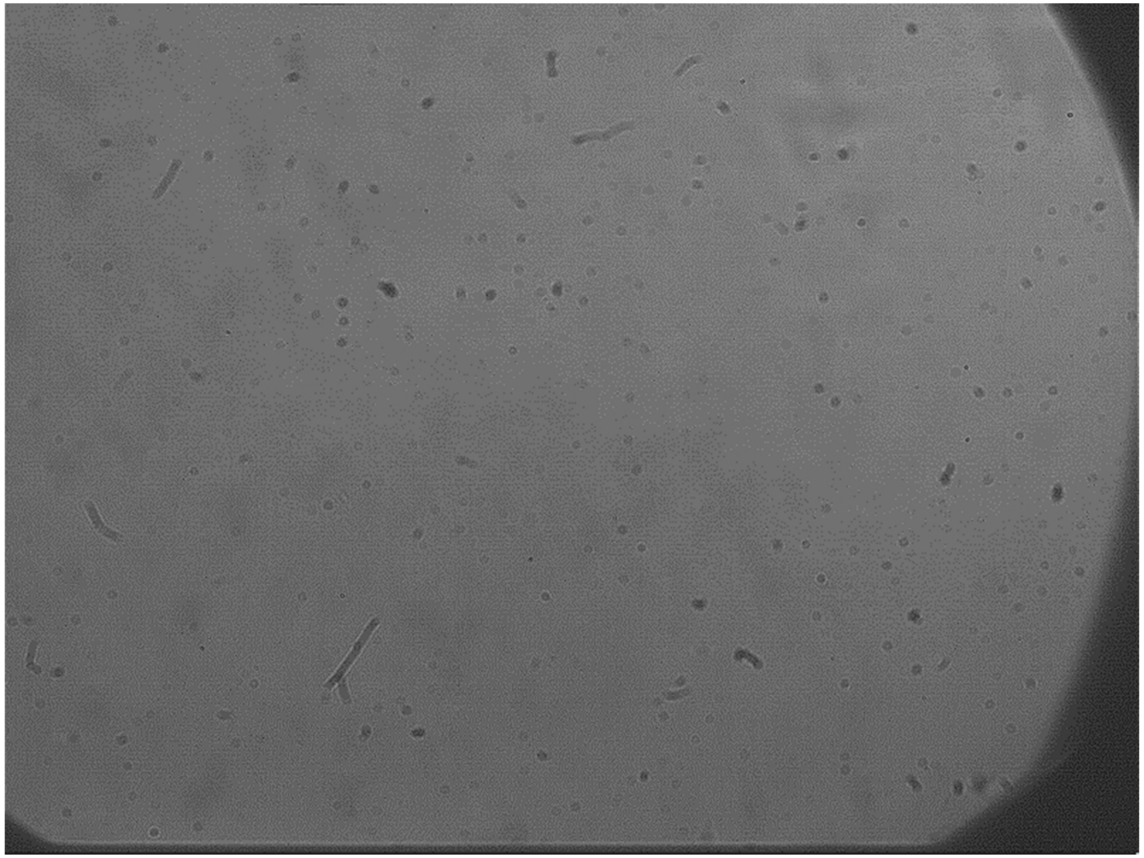
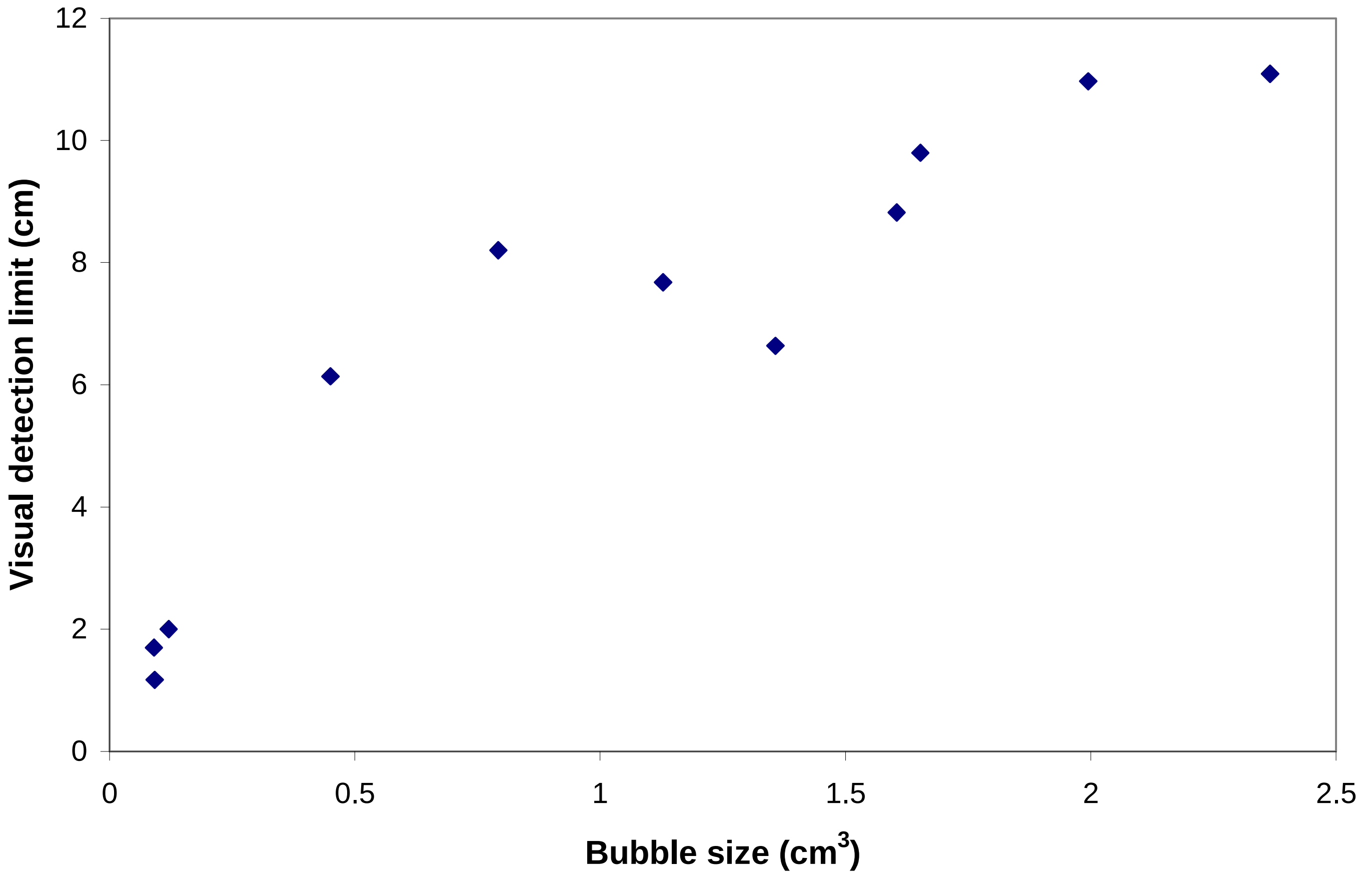


Schlieren imaging of 2 cm^3 bubble burst

length of video clip 600 ms

Visible extent of plume



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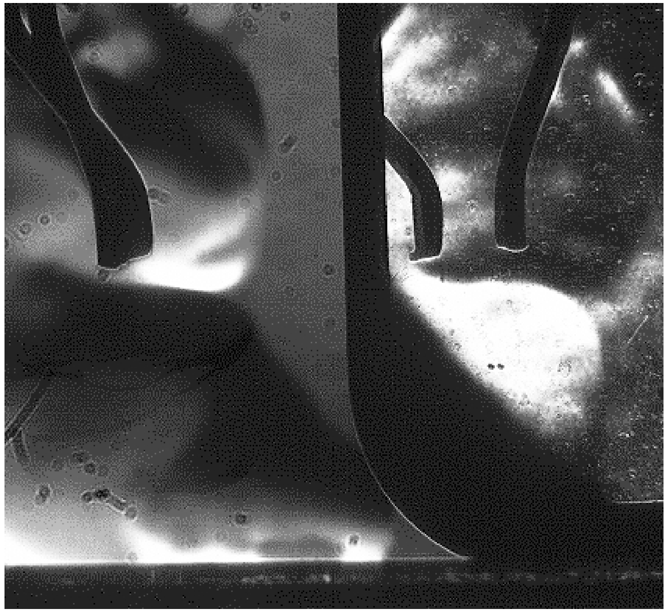
Visible schliere and flammability

- Can visualise 4% H_2 but schliere depends on conc. Gradient
- Deliberate ignition bubble burst
- Modified, orthogonal apparatus
- Confirmed visible extent greater than ignitable extent



Igniter Height, mm	Ignition Frequency
40	22/31
53	6/30
65	0/27

2.5 cm^3 bubble, visible extent ~ 10 cm

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Bubble burst mechanism

- Experiments undertaken to visualise bursting in more detail.
- Same apparatus, but higher frame rates
- Gain better understanding of bursting process
  - Explore modelling approaches
  - Aerosol production

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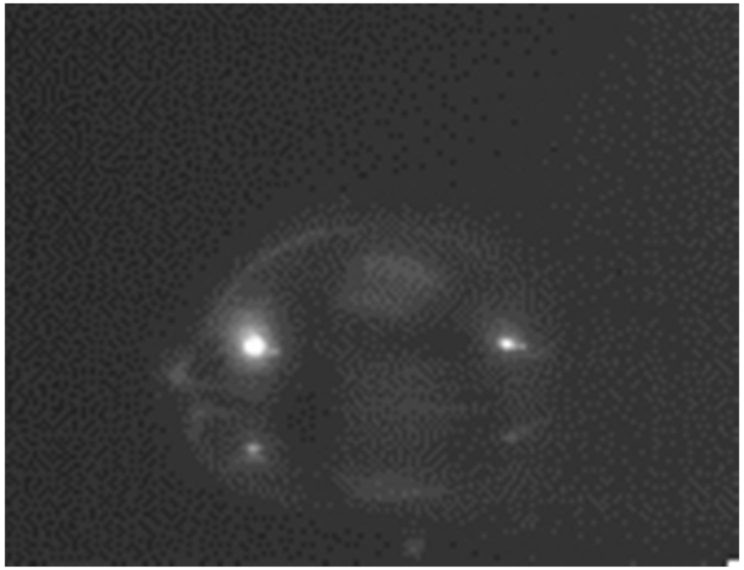
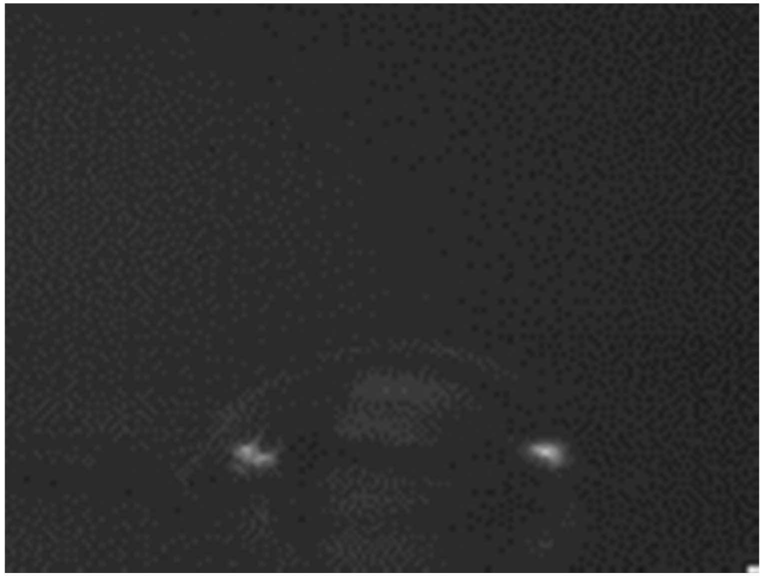
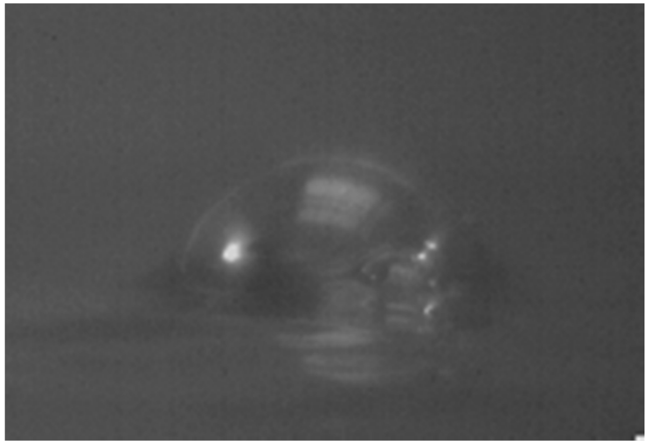


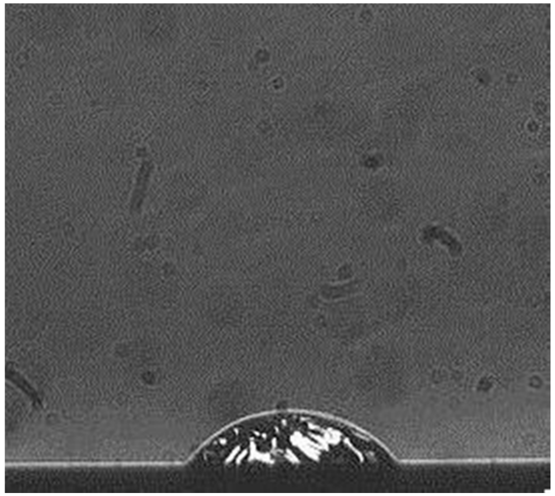
1.5 cm^3 bubble – rear burst
length of video clip 12 ms



1.5 cm^3 bubble – side burst
length of video clip 8 ms



12 ms video clip



60 ms video clip

Normal and schlieren video of same 1.5 cm^3 bubble

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Discussion- Flammable extent of plume

- Ignition experiments indicate limit of visible schliere bounds flammable extent
- Obtained data for visible schliere limit vs bubble size
- Compared with Sellafield in-house model – buoyant expanding sphere
  - Visible limit ~ 50% model prediction

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Discussion - Bubble bursting behaviour

- Burst mechanism:
  - Appearance of bubble
  - Nucleation of small tear/hole
  - Rapid retraction of film (a few ms) gives rim instability and formation of ligaments/droplets.
  - Some hydrogen is forced out of hole as bubble collapses, but much remains in place
  - Variation in nucleation site and initial amount of dispersion
- Modelling – OpenFOAM
  - Able to reproduce some of the behaviour but computationally very demanding

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Conclusions

- Schlieren & deliberate ignition used to estimate extent of flammable plume
- Significant momentum imparted to hydrogen
  - Simple Sellafield models conservative
- Bubble bursting complex
  - Very fast ~3 ms, films peels back from initial hole, rim formation
  - Variation in nucleation site, time to collapse and initial dispersion

Further Investigations – Larger Releases

- New apparatus commissioned
- Lens and grid schlieren system
  - Visualise much larger area
    - Large diameter optics not required
    - But reduced sensitivity
- Used to visualises H_2 releases up to 22 litres in ~ $1m^3$ volume

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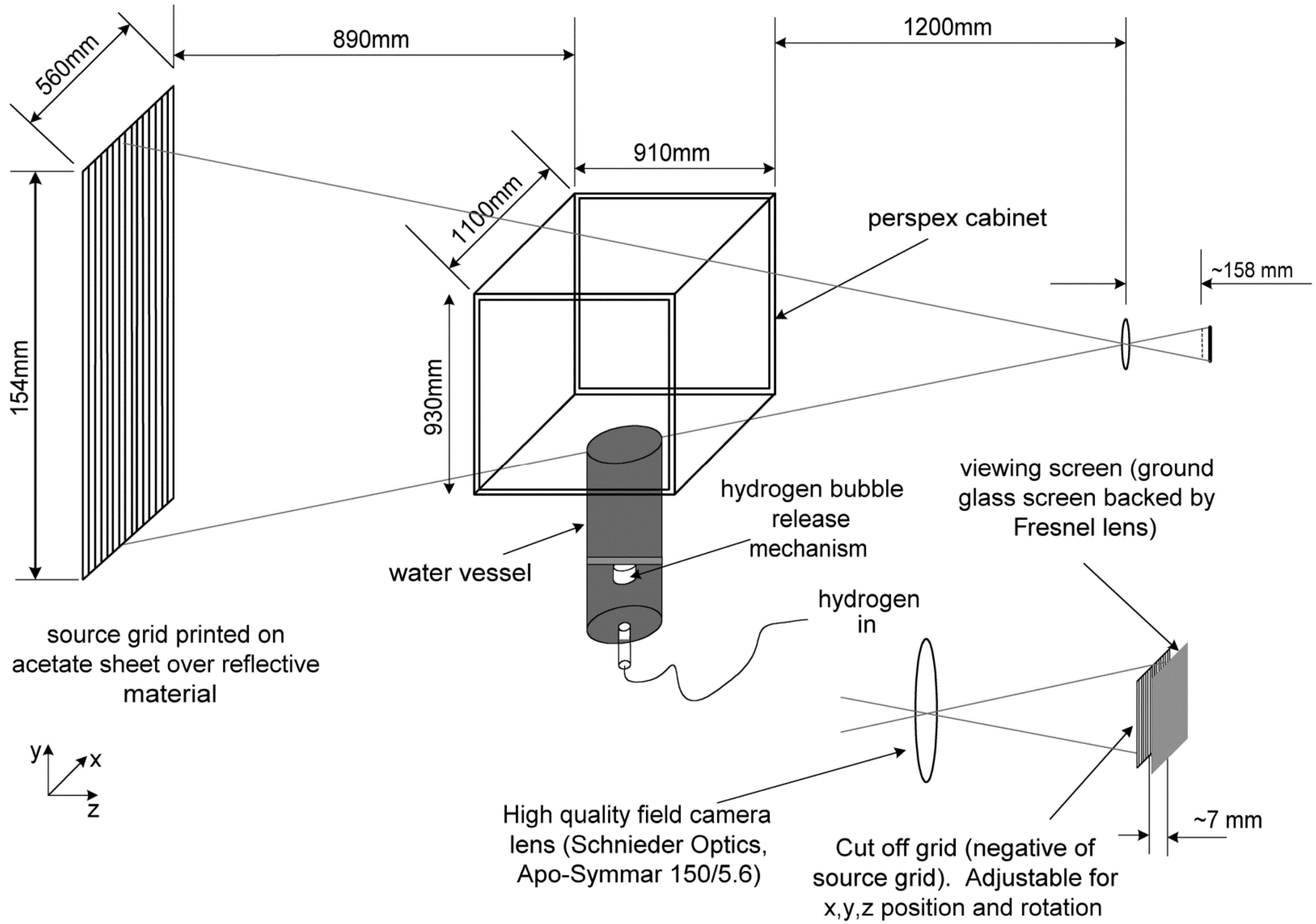

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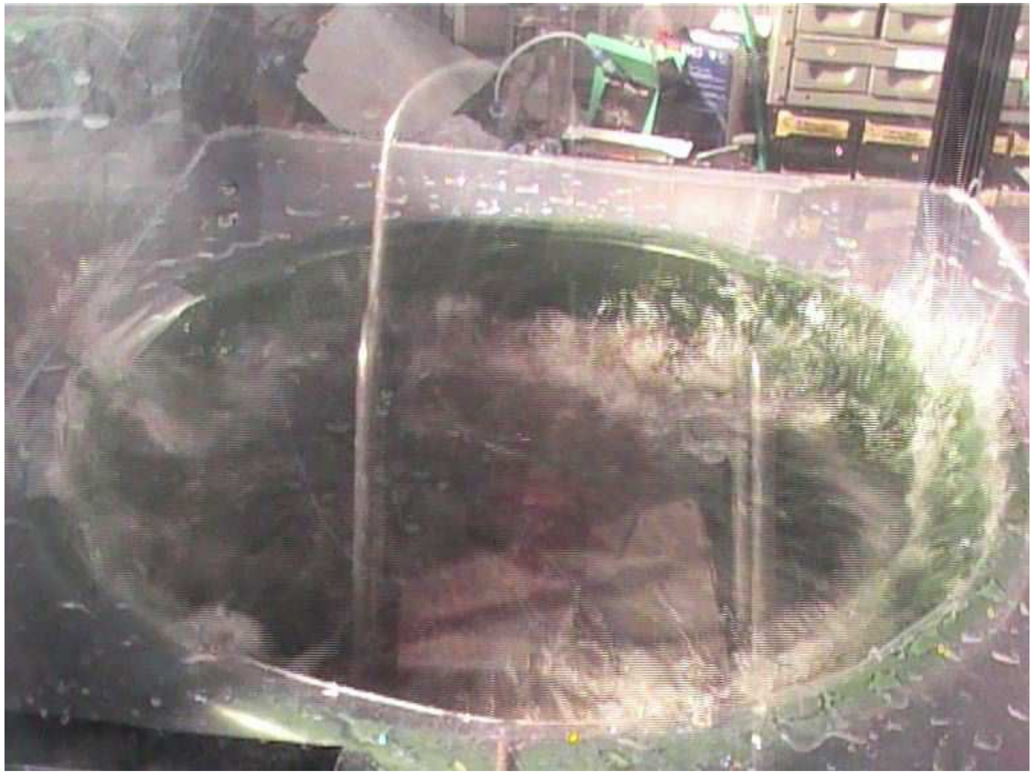
14 Litre Hydrogen Release



time = 0.60 s

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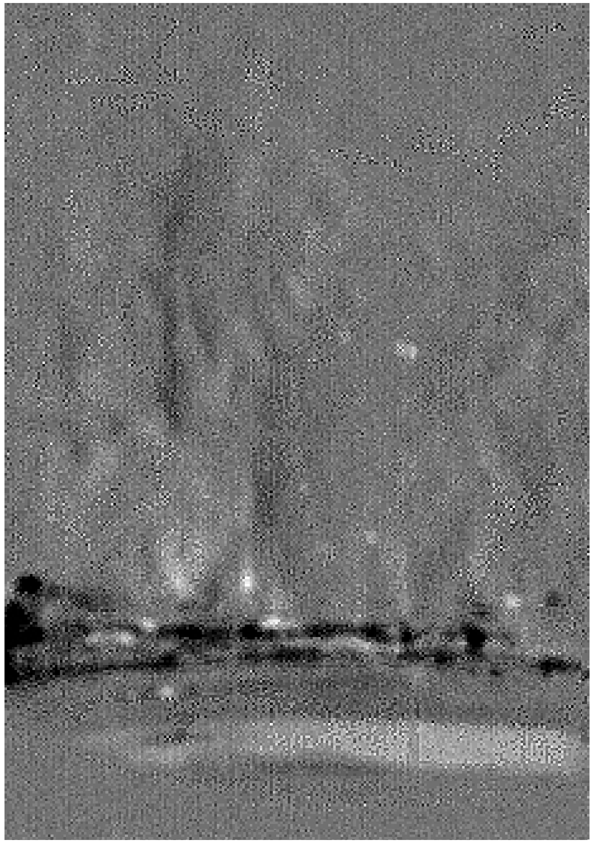
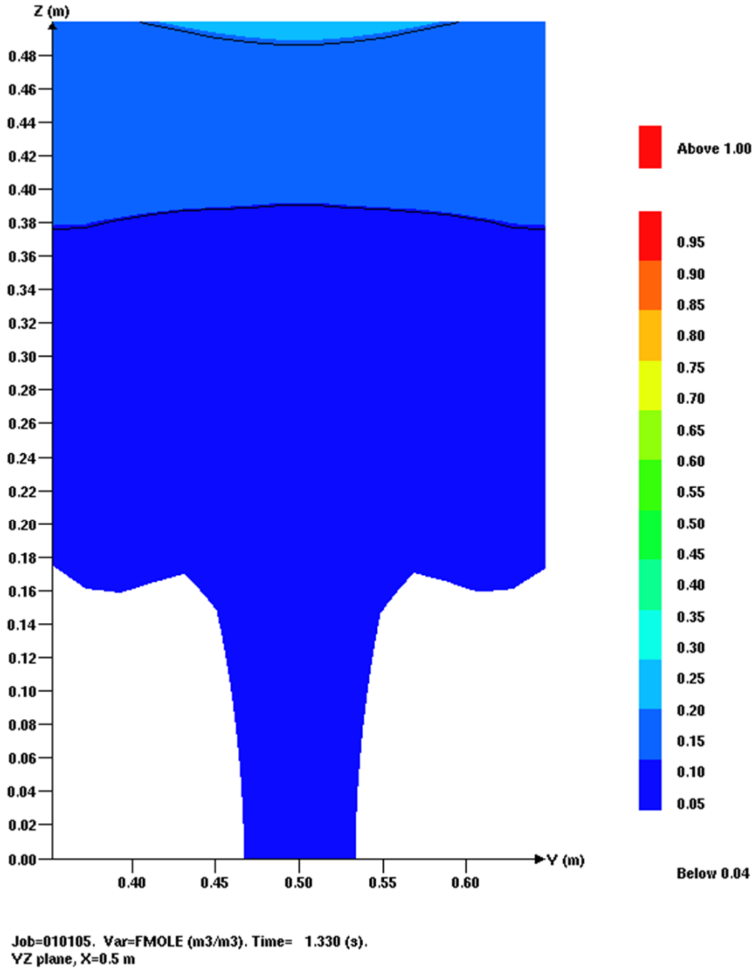
14 L Hydrogen Release

LSBU Experiment



time = 1.33 s

CFD Simulation



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Thank You
For
Listening