Critical analysis of the state of the art and research priorities

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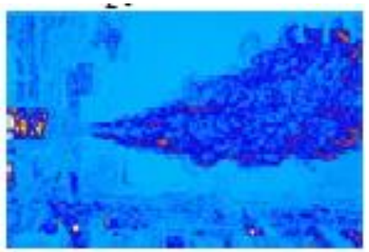
Pre-normative REsearch for Safe use of Liquid HYdrogen

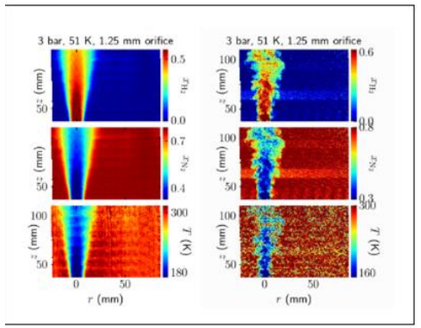
Outline

- Motivation
- Literature Review
- PIRT
- Conclusion

Release and mixing phenomena : Knowledge gaps

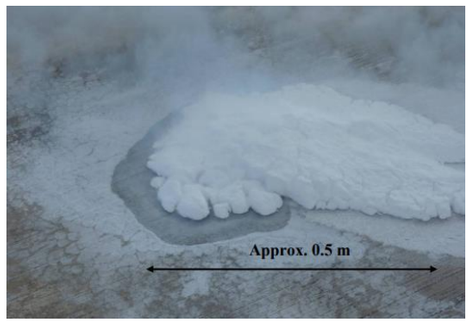
1. **Characteristics of flashing, multiphase releases and spillages in well defined conditions (subcooled, saturated) including rainout, pool evaporation, droplet granulometry & concentration**
2. **Mass and heat transfer including phase transition (evaporation, condensing and freezing of contaminants) in LH_2 releases and spillages**
3. **Free cryo jet structure, morphology and behaviour in realistic conditions (impingement and surface effects)**
4. **Heavy gases and transition to buoyant dispersion**
5. **Possible interaction with active barriers: water spray, mist, curtains ...water foam**

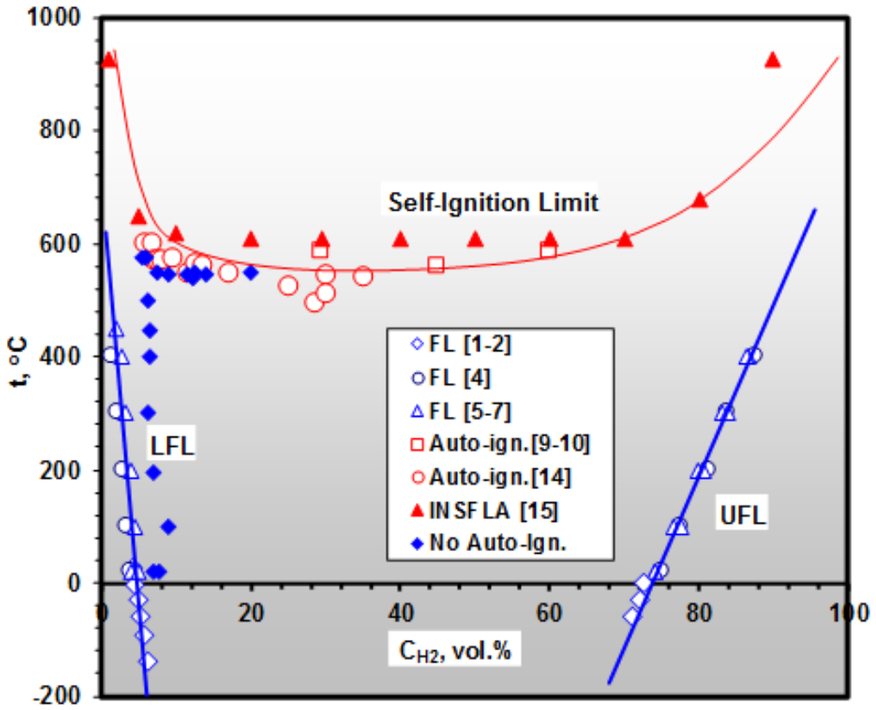




Ignition phenomena : Knowledge gaps

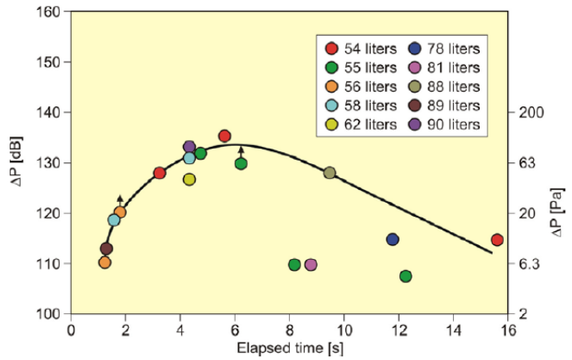
- **Influence of low T° on horizontal and downward flammability limits and MIE**
  - Important to consider a credible flammable cloud
- **Electrostatic charging and ignition**
- **Ignition of LH_2 / condensed (solid) air**





Combustion phenomena : Knowledge gaps

1. **Unconfined obstructed explosion of cold mixtures**
2. **Laminar flame speed at low initial T°**
3. **Turbulent flame speed at low initial T°**
4. **Flame acceleration in tubes for cold mixtures**
5. **Critical expansion ratio of cold mixtures**
6. **Detonation cell size for cold mixtures**
7. **Rapid phase transition / BLEVE**



What is a PIRT ?

- **PIRT : Phenomena Identification and Ranking Table**

- **PIRT ⇒ Systematic way of gathering information from experts on a specific subject**
  - Ranking the importance of the information, in order to meet some decision-making objective, e.g., determining what has highest priority for research on that subject.

- **Developed and applied in the late 80s to many nuclear technology issues**

LH_2 PIRT description

- **Development of a list (hopefully exhaustive) of physical phenomenas with PRESLHY partners and others volunteers for the 3 exp and modelling WPs :**

  - WP3 : Release and mixing phenomena
  - WP4 : Ignition phenomena
  - WP5 : Combustion phenomena

Scoring process (½)

- **For each phenomena identified, the expert gives a value between 1 to 5 for :**
  a. General level of understanding
  b. Level of maturity of engineering modelling
  c. Level of maturity of CFD modelling
  d. Availability of experimental data
  e. Criticality for enabling LH_2 in populated areas
  f. Expert Level

- **For a, b, c ⇒ from 5 for well known to 1 for explorary**
- **For d ⇒ from 5 for many experiments to 1 if no experiments**
- **For e ⇒ from 5 for very critical to 1 for no criticality**
- **Expert level ⇒ Self evaluation (subjective !) - Finally not used in the analysis**

Scoring process (2/2)

- **Calculation of a Knowledge Score**
  - KS = a * b * c * d
- **Calculation of a Global Score**
  - GS = KS / e (criticality) ⇒ Ranking
- **The lower GS, the most important is the knowledge gap**

- **Google Form questionnaire**
- **24 Experts**
- **8 nationalities**
- **Expert self-evaluation :**
  - WP3 > WP5 > WP4

WP3 : Release and mixing : PIRT Global score

- **Interaction with rain, water sprays & water curtains & foams ⇒ 2**
- **Internal Heat transfer flashing in pipes ⇒ 5**
- **Condensation and freezing of air, CO_2 & humidity ⇒ 5**
- **Droplet size / distribution / evaporation ⇒ 6**
- **High pressure release in complex environment : obstacles, impingement, surface ⇒ 6**
- **External Flashing & Rainout ⇒ 8**
- **Cryogenic spillage interaction with materials (boats) : spillage & 2-phase jet ⇒ 8**
- **Source term - discharge rate ⇒ 10**
- **Pool evaporation on different surfaces including water ⇒ 13**
- **Thermophysical properties ⇒ 15**
- **Pool spreading on different surfaces including water ⇒ 17**
- **Heavy gas (cold) atmospheric dispersion / transition to buoyant ⇒ 18**
- **Buoyant low velocity release ⇒ 19**
- **High pressure release : concentration decay & fluctuations ⇒ 25**
- **H_2 build-up in confined / semi-confined areas ⇒ 34**

WP4 : Ignition : PIRT Global score

- **Electrostatic charging and ignition above LH_2 pools ⇒ 1**
- **LH_2/ Condensed O_2 mixture ignition ⇒ 1**
- **Electrostatic charging and ignition in cryo jets ⇒ 2**
- **Shock-diffusion ignition at low T°⇒ 3**
- **Electrostatic properties of LH_2 releases ⇒ 3**
- **Ignition energy at low T°⇒ 5**
- **Ignition above pools ⇒ 5**
- **Ignition in cryo jets ⇒ 6**
- **Flammability limits at low temperatures (horizontal, upward and downward) ⇒ 7**

WP5 : Combustion : PIRT Global Score

- **Run-up distances and DDT for cold H_2/air ⇒ 1**
- **Detonation cell size for cold H_2/air ⇒ 2**
- **Critical gap size for cold H_2/air ⇒ 2**
- **Turbulent flame speed at low T° ⇒ 2**
- **Rapid phase transition ⇒ 2**
- **Flame acceleration in tubes for cold H_2/air ⇒ 3**
- **Critical expansion ratio of cold mixtures ⇒ 3**
- **Laminar flame speed at low initial T° ⇒ 3**
- **Unconfined obstructed explosion of cold H_2/air ⇒ 3**
- **BLEVE ⇒ 4**
- **Cryogenic surface and impinging jet fire ⇒ 4**
- **Unconfined Unobstructed Cold Vapour Cloud Explosion ⇒ 8**
- **Vented explosion for cold H_2/air ⇒ 8**
- **LH_2 insulated vessel heat-up in fire ⇒ 9**
- **Pool fire ⇒ 11**
- **Cryo free jet fire ⇒ 15**

Conclusions

- **Knowledge gaps were identified based on literature review**
- **PIRT analysis was used to prioritize the needed R&D**
- **On this basis, PRESLHY experimental program has been adjusted**
- **R&D priorities :**
  - **WP3 : Physics of the liquid releases (internal & external flashing, droplets, rainout, condensation, …)**
  - **WP4 : Electrostatic ignition and LH_2 / solid air ignition**
  - **WP5 : Deflagration, detonation and flame acceleration in cold H_2/air mixtures**

Questions ?