BLEXCOM model to assess consequences of an LH2 BLEVE explosion

ELVHYS – International Stakeholders' Seminar

Federico Ustolin

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Content

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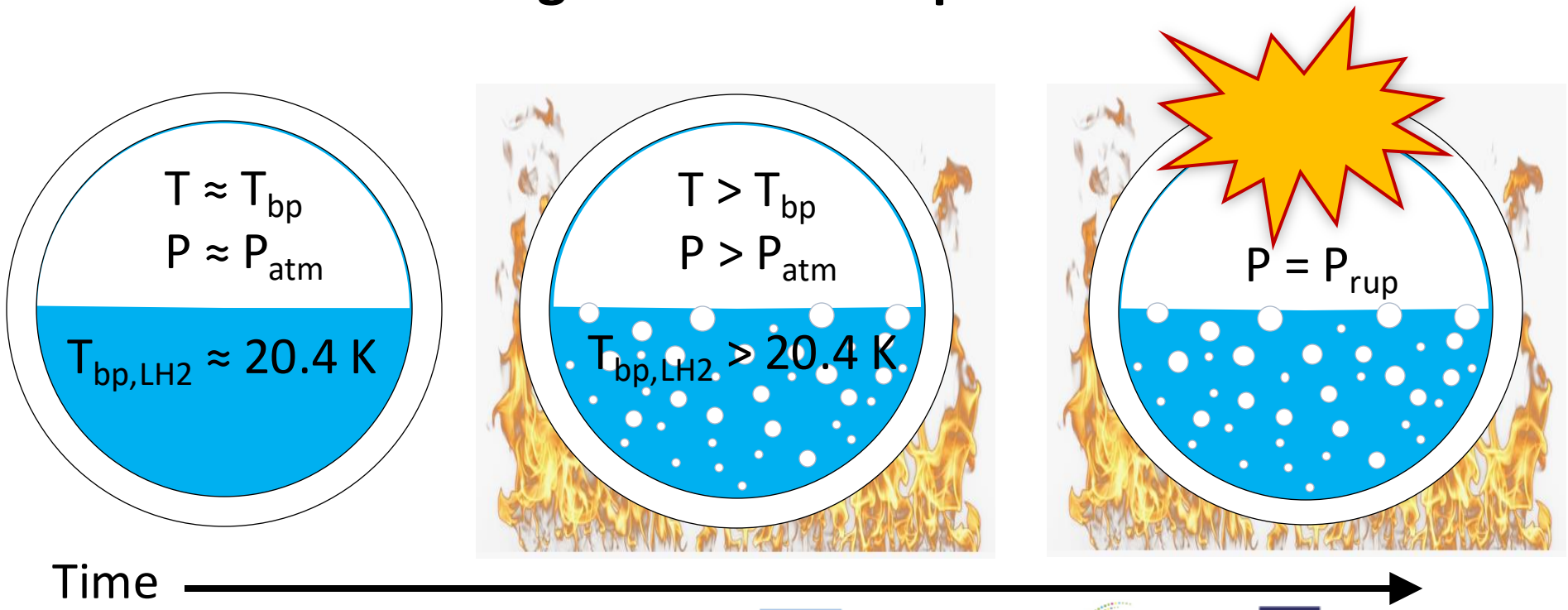
1. Introduction on BLEVE explosion

Boiling Liquid Expanding Vapour Explosion (BLEVE) is a physical explosion might result from the catastrophic rupture of a tank containing a superheated liquid due to the rapid depressurization.

Chain of events leading to the tank rupture

Valid for cryogenic substances

BLEVE may occur also w/o fire scenario, e.g. due to insulation failure



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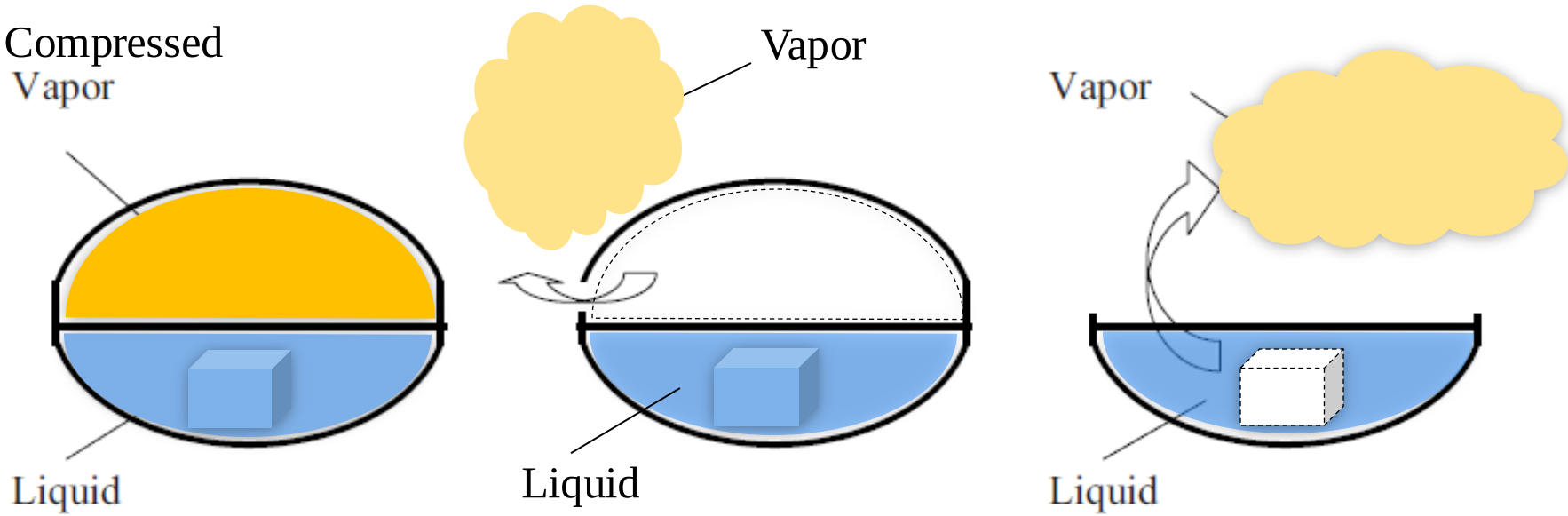
1. Introduction on BLEVE explosion



P

$T = T_s(P)$

$h_l = h_l(T)$

$h_g = h_g(T)$

$P_o = 101.3\ kN\ m^{-2}$

T

$h_l(T, P_o) \approx h_l(T)$

metastable/unstable

$P_o = 101.3\ kN\ m^{-2}$

$T_o = T_s(P_o)$

$h_{lo} = h_{lo}(T_o)$

$h_{go} = h_{go}(T_o)$

Hot liquid in tank undergoing sudden depressurization (adapted from Casal, 2008)

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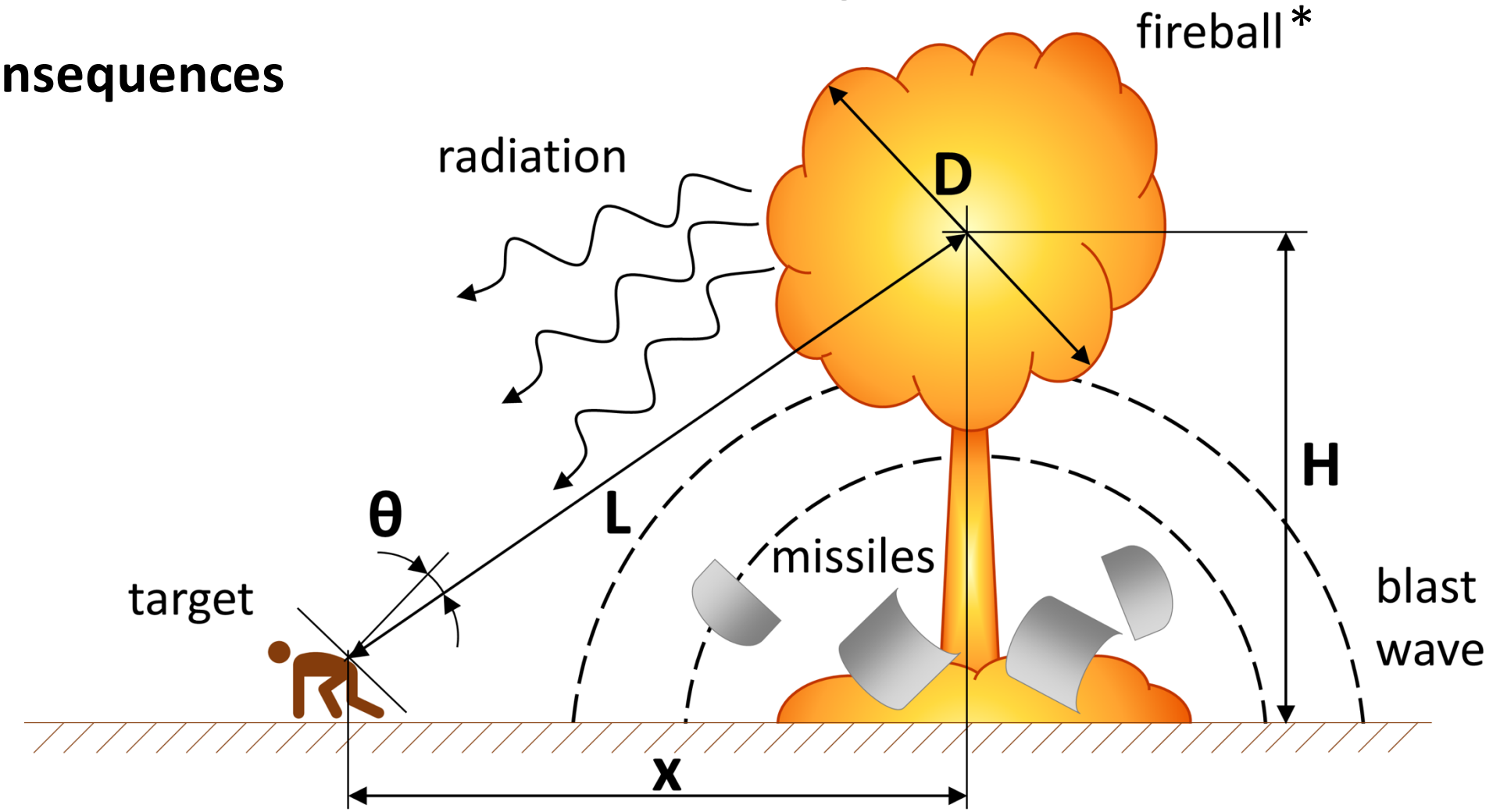
1. Introduction on BLEVE explosion

BLEVE consequences



*Fireball develops if substance is flammable, and ignition source is present

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2. Liquid hydrogen BLEVE tests

Two fire tests were previously carried out with LH2 tanks:

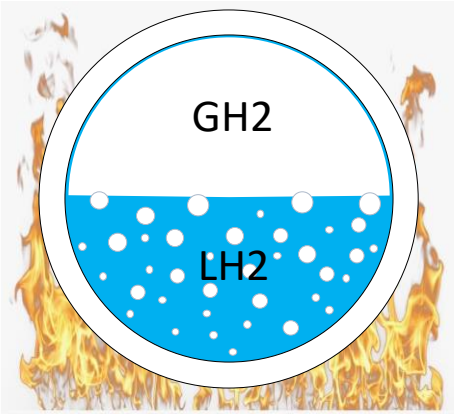
1. BMW (Pher, K.(a) 1996)
2. SH2IFT (Ødegård et al., 2021)

One BLEVE test was performed on LH2 tanks:

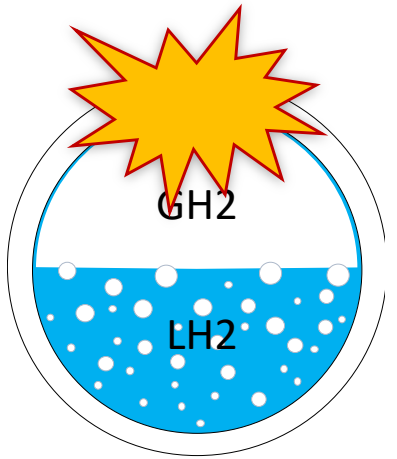
1. BMW bursting tank scenario (Pher, K.(b) 1996)

Two additional tests on LH2 hoses will be carried out in the framework of the ELVHYS project:

1. BLEVE test by means of a shock tube filled with LH2
2. Fire tests of LH2 double-walled pipe segments



Fire tests



Bursting tank tests (tank ruptured with explosives)

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2. Liquid hydrogen BLEVE tests

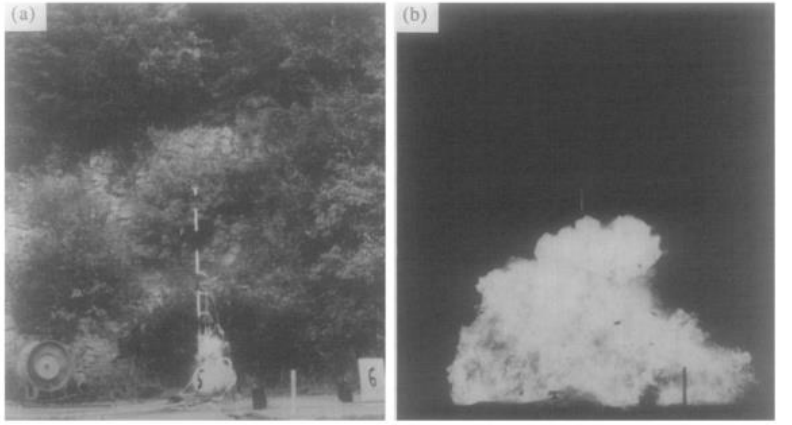
2.1 BMW safety programme

Fire tests: double walled vessel filled at 50% fully engulfed in propane fire.

Bursting tank scenario (BLEVE) test: ten vessels (0.120 m^3) filled with different amount of LH2 (1.8 ÷ 5.4 kg) were wrecked by means of cutting charges.

In this presentation, the simulation results of the BMW bursting tank scenario test will be provided.

Figure 11: Bonfire test of a liquid hydrogen fuel tank (Source: BAM)



Development of a fireball. (a) Ignition; (b) 250 ms after ignition

A 7 Series BMW with hydrogen IC engine and LH_2 storage

[Pehr K. Aspects of safety and acceptance of LH2 tank systems in passenger cars. Int J Hydrogen Energy 1996;21:387–95]

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2. Liquid hydrogen BLEVE tests

2.2 SH2IFT project fire tests

Three double walled vacuum-insulated tanks were tested (engulfed in propane fire, with Pressure Relief Valve, PRV, closed) at the Bundesanstalt für Materialforschung und –prüfung (BAM) in Horstwalde, Germany.

The maximum allowable working pressure of the vessels was 10 bar (burst pressure 36 bar).

Test no.	Degree of filling	Orientation	Insulation
1	35-40%	Horizontal	Perlite
2	35-40%	Horizontal	MLI
3	35-40%	Upright	Perlite

[A. Ødegård et al. (2022). D5.4: SH2IFT final project report]

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2. Liquid hydrogen BLEVE tests

2.2 SH2IFT project fire tests

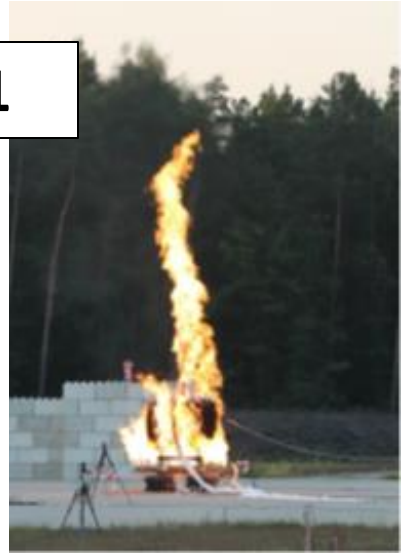
Results

Test 01 (perlite, Horiz.): tank reached 23 bar. Leakage started through seal of the blind flange connection at the filling valve on top of the vessel after 1 h 15 min

Test 02 (MLI, Horiz.): PRV opened at 40 min when the pressure was 50 bar. Tank failed after 68 min

Test 03 (perlite, Vert.): tank reached 60 bar and resisted for 4 h without failing. No leakages occurred

Test 01



Test 03

Test 02

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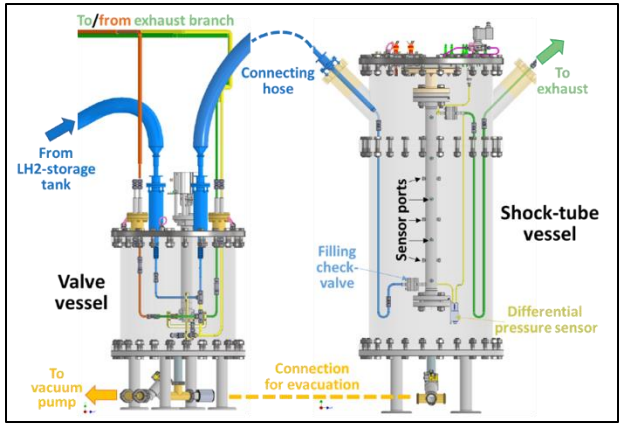
2. Liquid hydrogen BLEVE tests

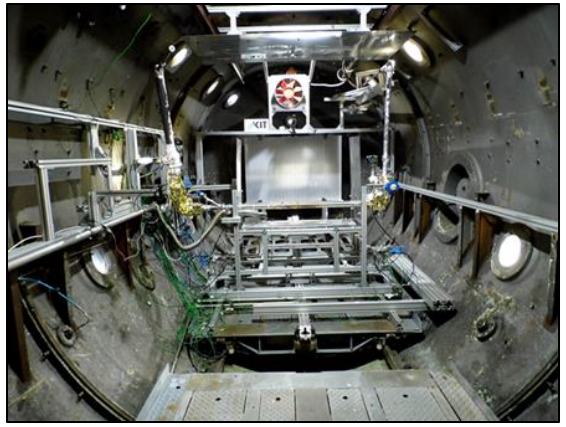
2.3 ELVHYS project BLEVE and fire tests (to be performed)

Nr.	Phenomenon investigated	WP	Location	Performed by
4	BLEVE tests with a shock tube	4	Germany	KIT
5	Fire tests of short LH2 transfer line elements	4	Germany	KIT

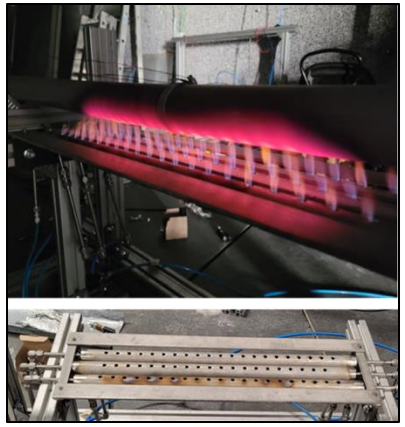
HYKA safety vessel V220 at KIT



ELVHYS experimental setup



Inside HYKA H110 safety vessel A1 at KIT



ELVHYS experimental setup

(images courtesy of KIT)

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3. BLEXCOM development

BLEVE Explosion Consequence Model (BLEXCOM)

BLEXCOM is an engineering tool that will soon be capable of estimating all the consequences generated by the BLEVE explosion for different liquefied gases, including liquid hydrogen, stored in tanks.

BLEVE consequences:

- Pressure wave
- Fragments
- Fireball

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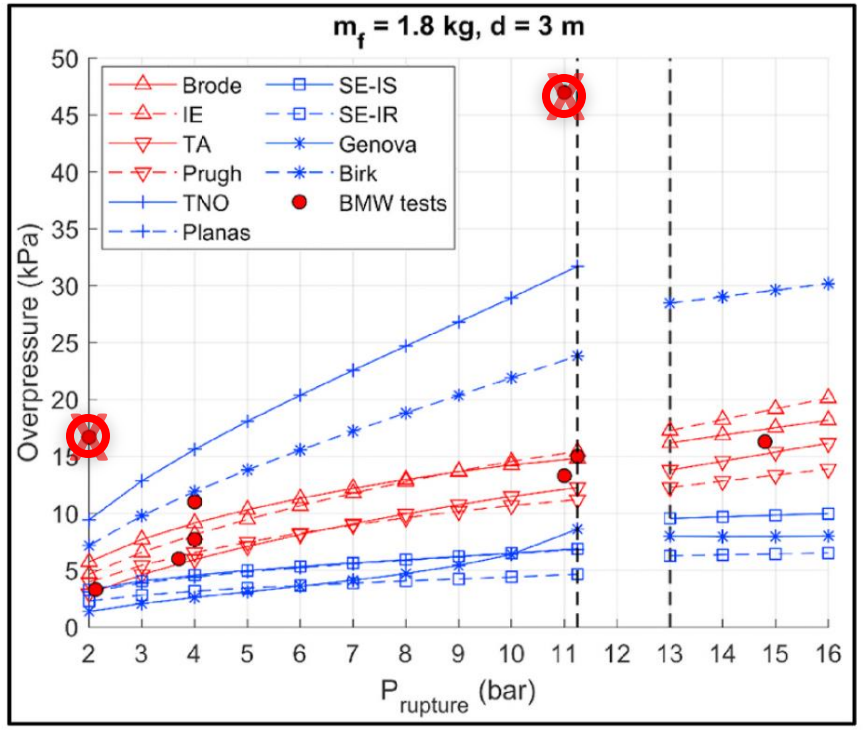
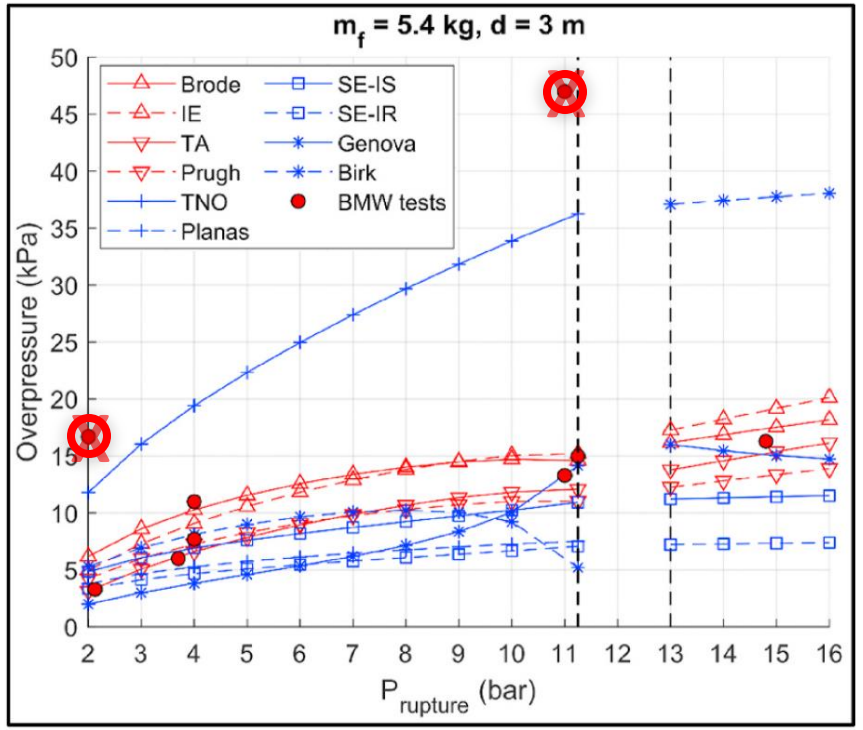
3. BLEXCOM development

3.1 BMW BLEVE tests - Overpressure results (integral models)

Combustion contribution was not considered

TNT equivalent mass method





Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: http://www.elsevier.com/locate/jlp

An innovative and comprehensive approach for the consequence analysis of liquid hydrogen vessel explosions

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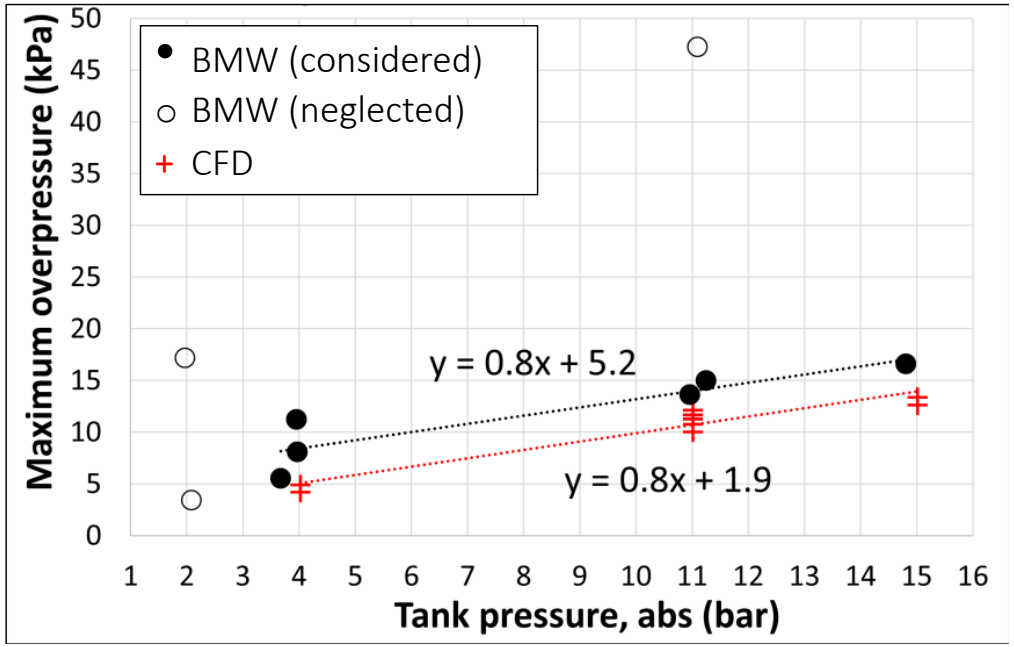
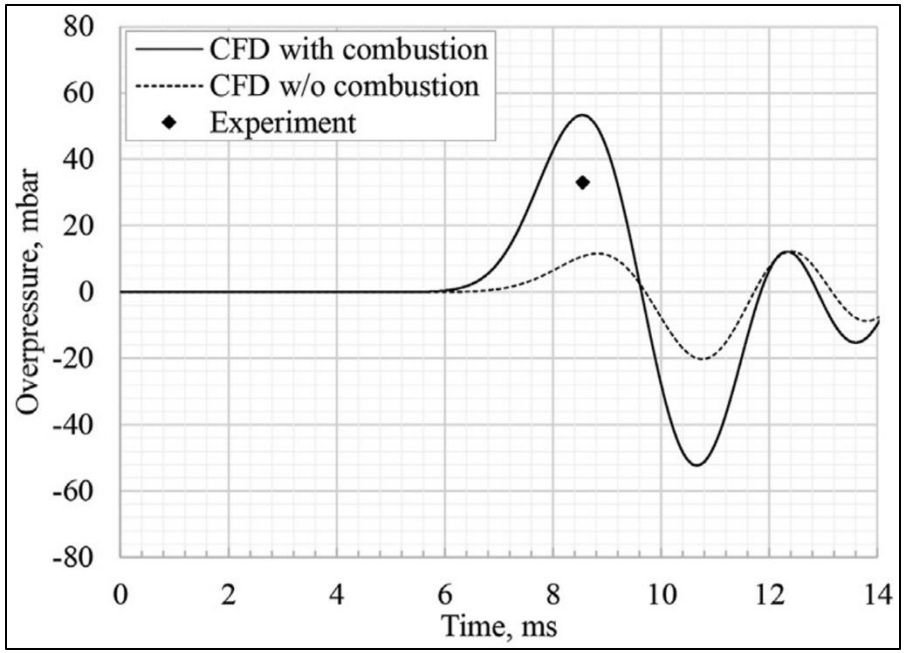
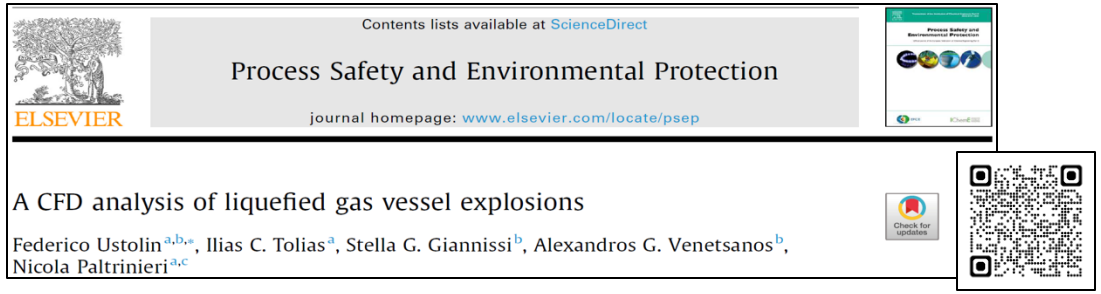
3. BLEXCOM development

3.1 BMW BLEVE tests - Overpressure results (CFD analysis)



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A CFD analysis of liquefied gas vessel explosions

Federico Ustolin[a,b,*], Ilias C. Tolias[a], Stella G. Giannissi[b], Alexandros G. Venetsanos[b], Nicola Paltrinieri[a,c]


Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

Rethinking "BLEVE explosion" after liquid hydrogen storage tank rupture in a fire

Donatella Cirrone*, Dmitriy Makarov, Vladimir Molkov

Ulster University, HySAFER Centre, BT37 0QB, Newtownabbey, Northern Ireland, UK

Speculation: the difference in overpressure is caused by the combustion process (chemical energy)

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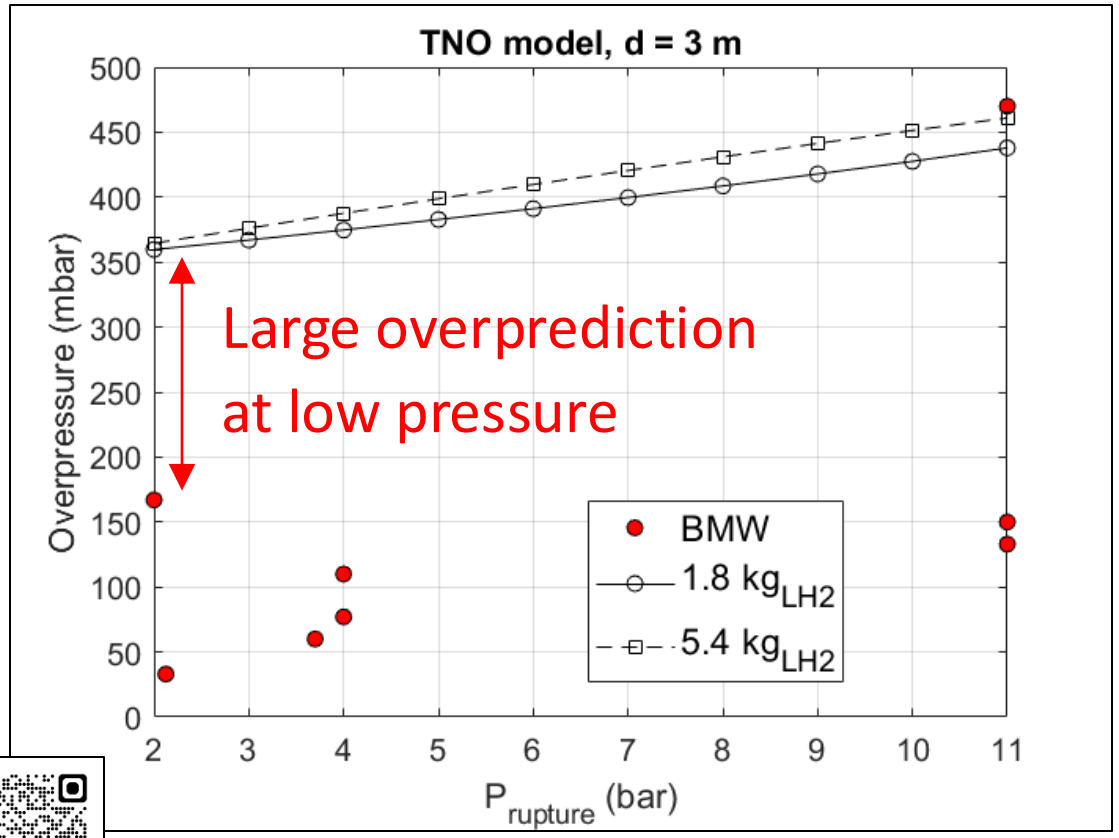
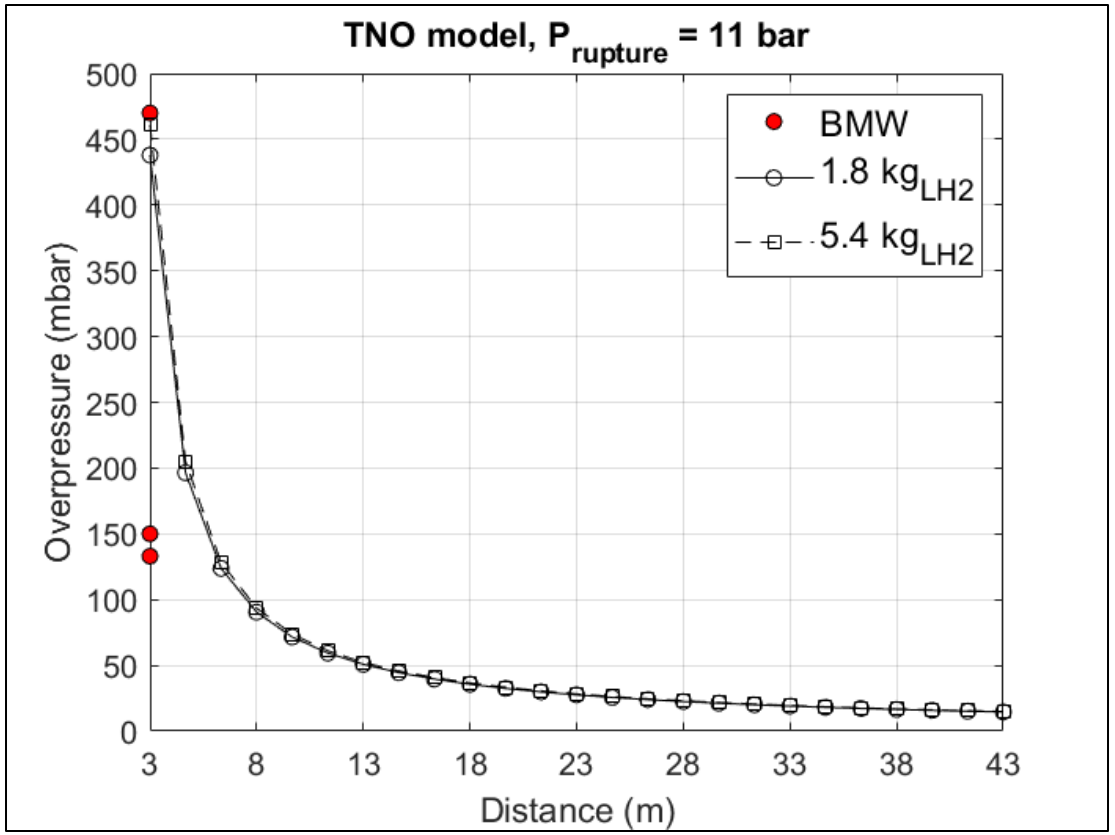
3. BLEXCOM development

3.1 BMW BLEVE tests - Overpressure results (integral models)





Considering chemical energy contribution (5%) to overpressure. TNO (most conservative model).

[F. Ustolin, L. Giannini, G. Pio, E. Salzano, N. Paltrinieri (2022). On the Mechanical Energy Involved in the Catastrophic Rupture of Liquid Hydrogen Tanks, Chemical Engineering Transactions, 91]

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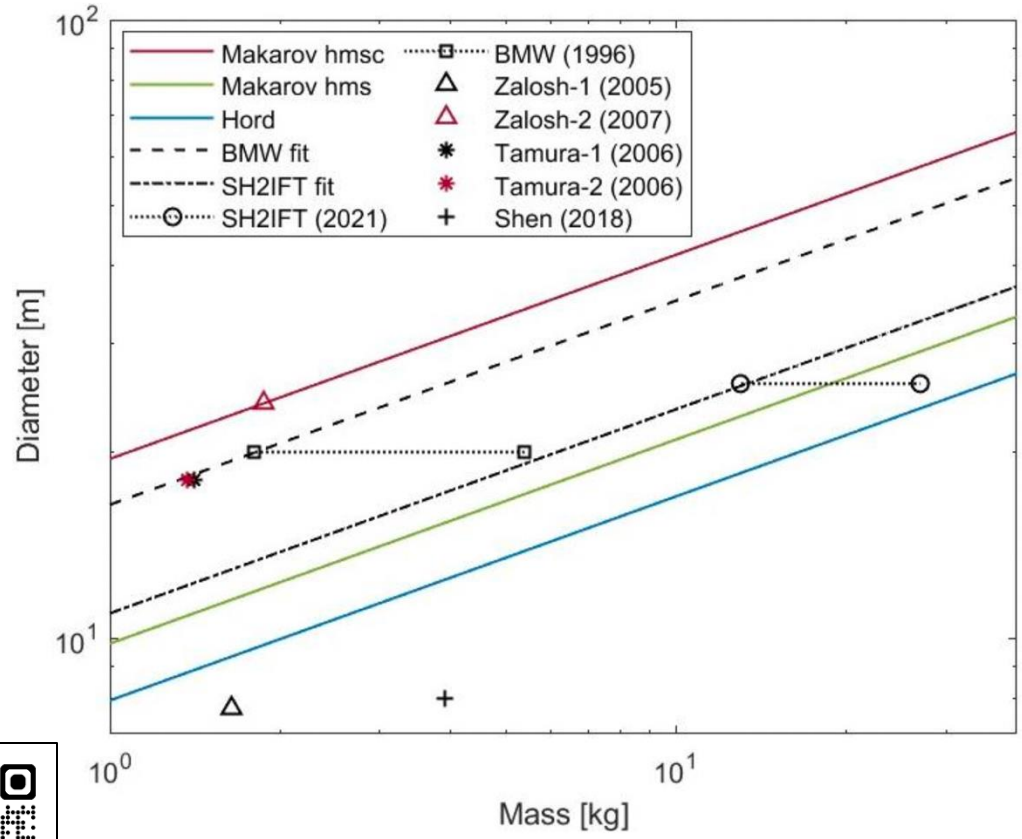
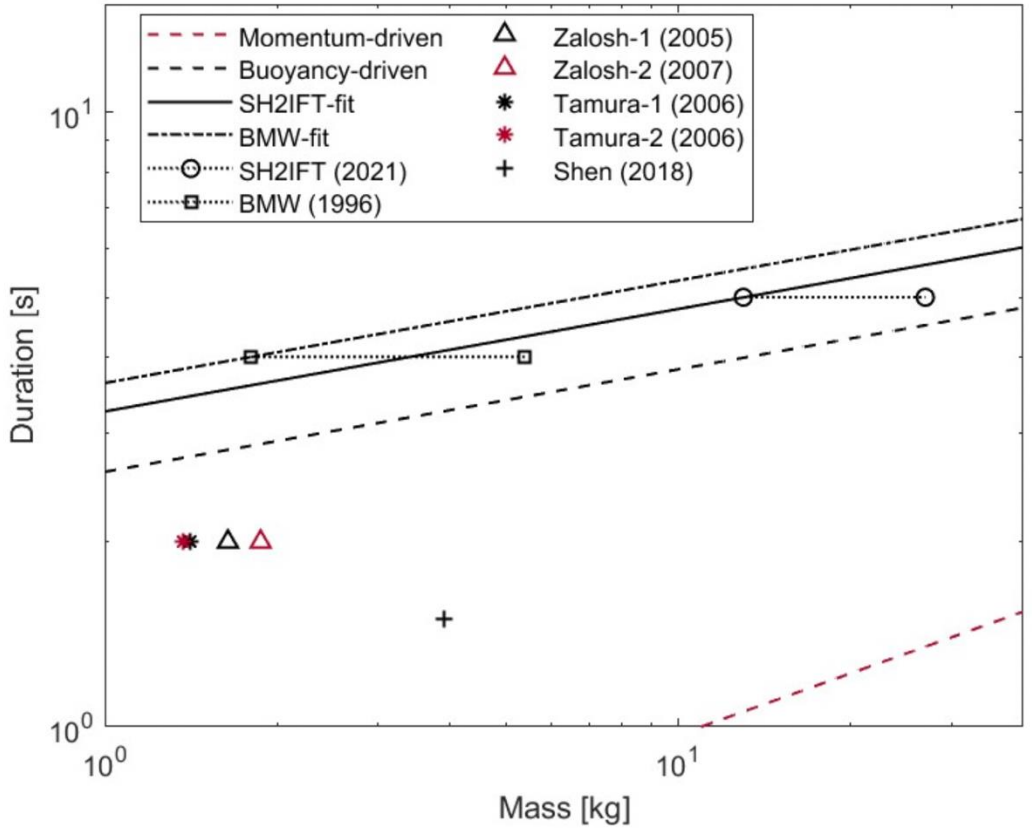
3. BLEXCOM development

3.2 Fireball correlations - Results





Comparison between GH2 and LH2 experimental data and predictions. The uncertainties concerning the LH2 BLEVE masses are indicated by the thin dashed lines.

[L. Giannini, G. Tincani, G. Collina, E. Salzano, V. Cozzani, F. Ustolin (2023). Modelling of Fireballs Generated after the Catastrophic Rupture of Hydrogen Tanks. Chemical Engineering Transaction, 104.]

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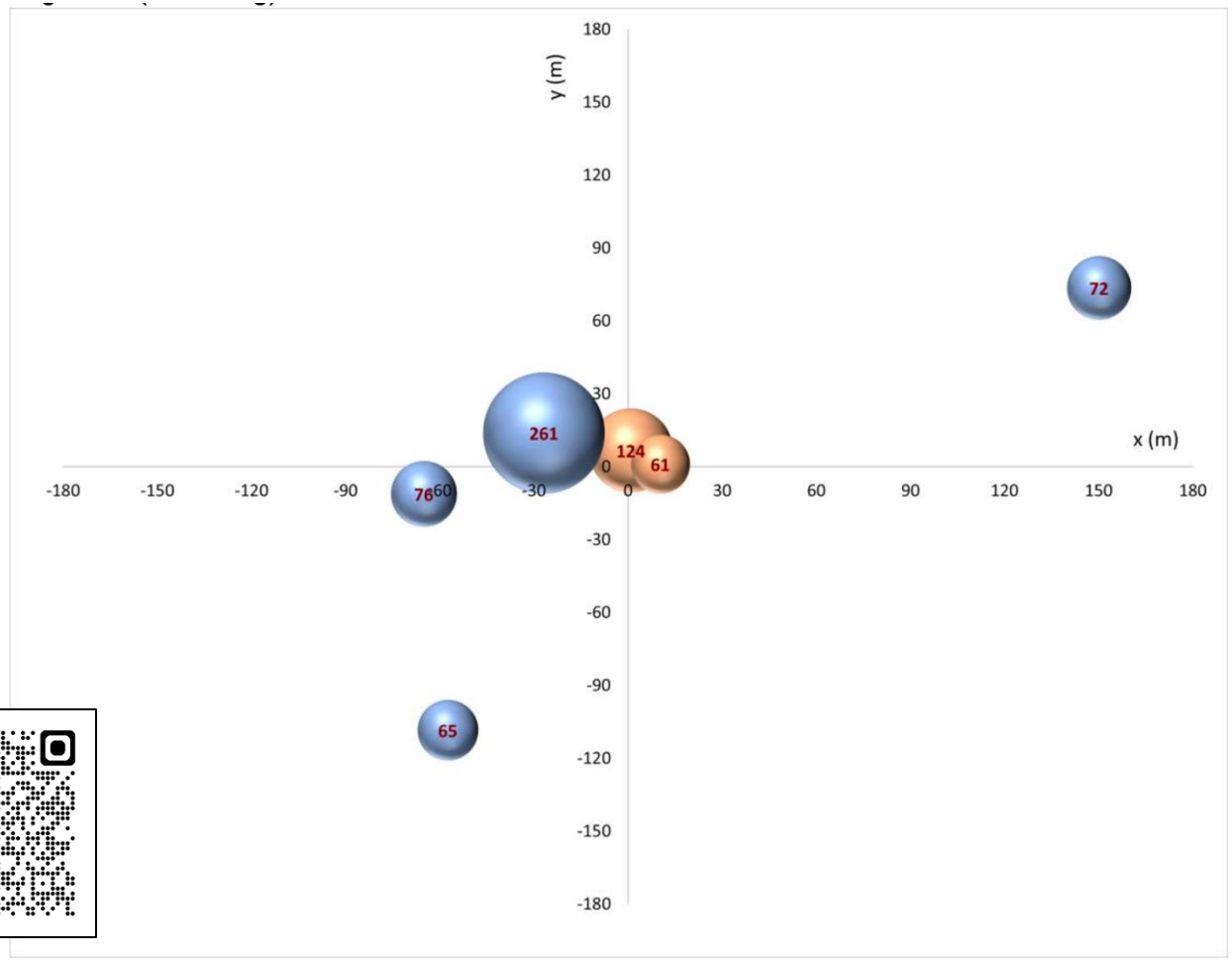
3. BLEXCOM development

3.3 Fragments range correlations

Analysis of distribution of main fragments (m > 60 kg) of SH2IFT test 02 explosion. The size of the bubbles is related to the mass (red label) of each fragment of the tank. Blue bubbles for the outer vessel and red bubbles for the inner vessel.

This analysis was used to test existing correlations and provide new ones (not published yet).



[G. Collina, F. Ustolin, G. Tincani, L. Giannini, E. Salzano, V. Cozzani (2023). Fragments Generated during Liquid Hydrogen Tank Explosions. Chemical Engineering Transactions, 99]

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4. Conclusions & future activities

Conclusions

- BLEXCOM model is capable of assessing the consequences (blast wave, fireball, fragments range) of LH2 BLEVE explosions.
- Contribution of the combustion process is taken into account to estimate the blast wave overpressure.
- New correlations were proposed to predict fireball diameter and duration.
- Fragments range of the SH2IFT test were modelled.

Future activities

- Publish new model validations of BMW and SH2IFT tests.
- Include the blast wave impulse, fireball radiation, fragments range in the previous assessments.
- Simulate ELVHYS tests and further validate the model.

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Thank you for your attention

federico.ustolin@ntnu.no

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