ACRONYM: HyTunnel-CS

TITLE: Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces

European Hydrogen Week

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Project Overview

- Call year: 2018
- Call topic: FCH-04-1-2018, Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces
- Project dates: 01/03/19–28/02/22 (31/07/22)
- % stage of implementation on 03/12/2021: 80%
- Total project budget: €2.5M
- FCH JU max. contribution: €2.5M
- Other financial contribution: N/A
- Partners: 13 partners from 11 countries

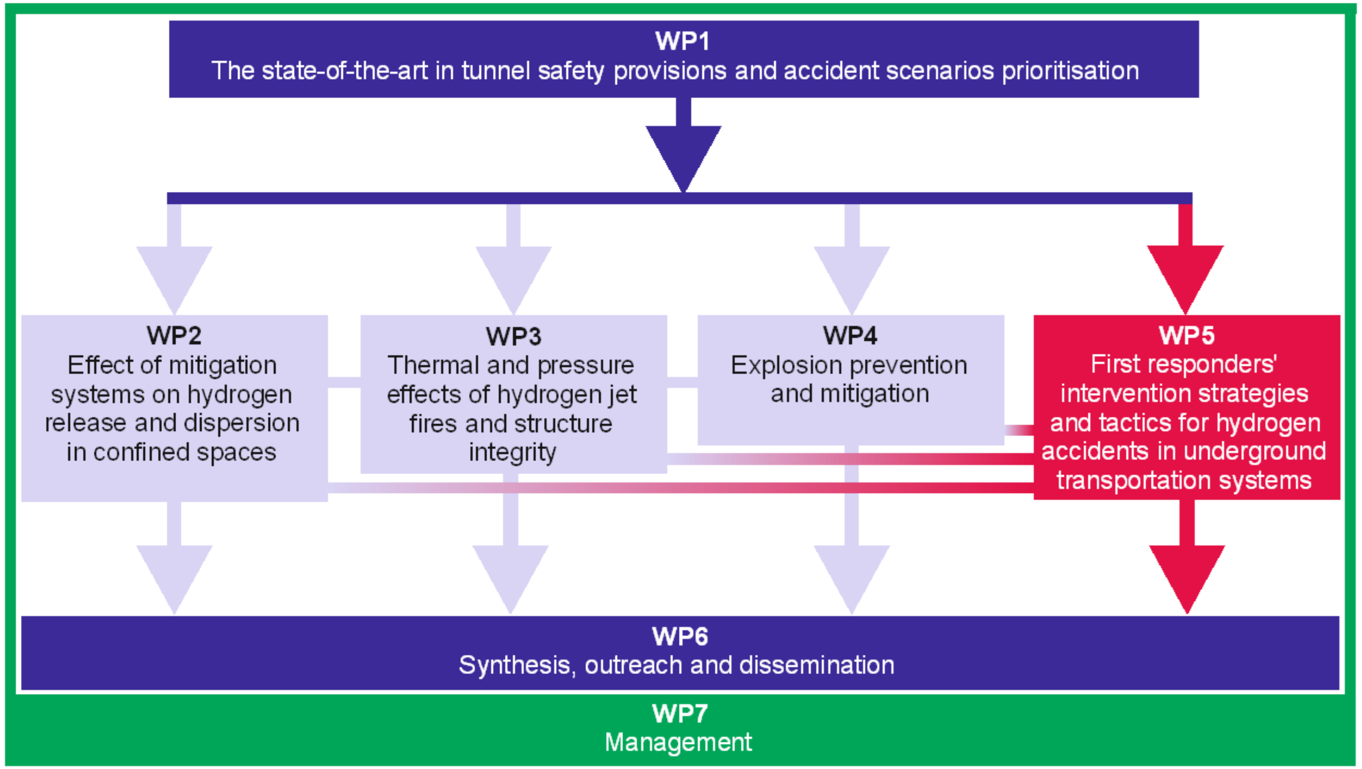
Project Summary (1/2)

HyTunnel-CS ambition, research approach (work plan), aim

Ambition: Allow hydrogen-powered vehicles enter underground traffic infrastructure.

Research approach: Consider hydrogen vehicle and underground traffic structure as a **single system** with integrated safety approach (using complementarities and synergies of theoretical, numerical and experimental studies).

Aim: Conduct PNR to close knowledge gaps and technological bottlenecks in the provision of safety in the use of hydrogen-powered vehicles in underground transportation systems.



Structure of work plan

Project Summary (2/2)

Main objectives

Main objectives of HyTunnel-CS:

- Generate **unique experimental data** regarding the interaction of hydrogen with underground infrastructure using the best European hydrogen safety research facilities including real tunnels.
- Create deeper knowledge of the relevant physics to underpin advanced hydrogen safety engineering and **develop innovative prevention and mitigation strategies.**
- Develop further existing and **new contemporary CFD and FE models**, **engineering correlations**, **hazard and risk assessment tools**; validate them against experimental data.
- Prepare harmonised recommendations for intervention strategies and tactics for first responders providing conditions for their life safety and property protection.
- Develop recommendations for inherently safer use of hydrogen vehicles in underground transportation systems.
- Produce commonly agreed, scientifically based recommendations for the update of relevant RCS.

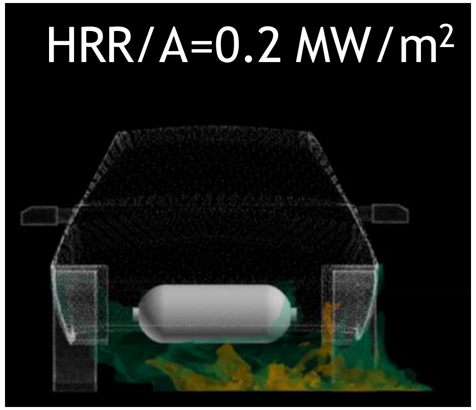
Project Progress (1/11)

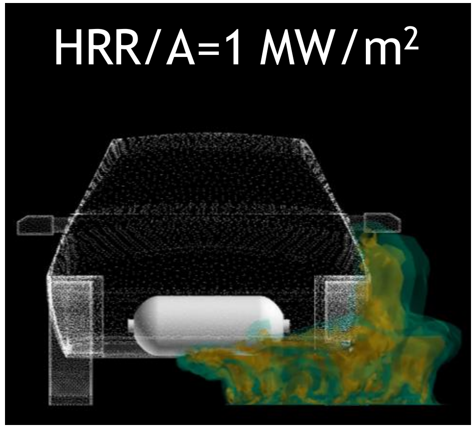
Innovative safety strategies and engineering tools

Tackling hazards of hydrogen vehicles protected by TPRD:

- We can now **design** any **tank-TPRD system to exclude tank rupture in fire of any intensity** (beyond reduced by GTR#13 localised fire intensity of **HRR/A=0.35 MW/m²**) and different TPRD response time.
- We can define **TPRD diameter** to exclude the pressure peaking phenomenon **(garages, in storage enclosures** on trains, ships, planes).
- We can design **TPRD parameters** to exclude flammable cloud and hot products at T>300ºC under the ceiling **to allow underground parking**.
- We can **reduce hazard distances** for hydrogen releases (the similarity law) and jet fires (the dimensionless flame correlation) at atmospheric and **cryogenic temperature** by proper TPRD design.
- We can **design** release system to **exclude** formation of flammable cloud that can deflagrate and transit to detonation (**DDT**) in an underground structure.

EXAMPLE OF SIMULATIONS

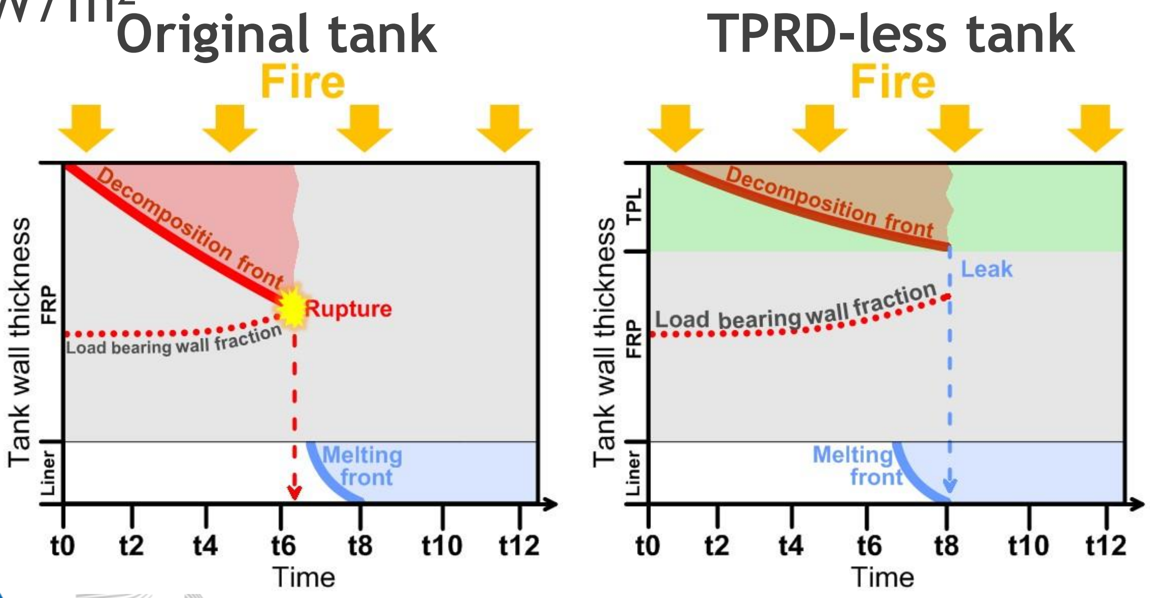




Project Progress (2/11)

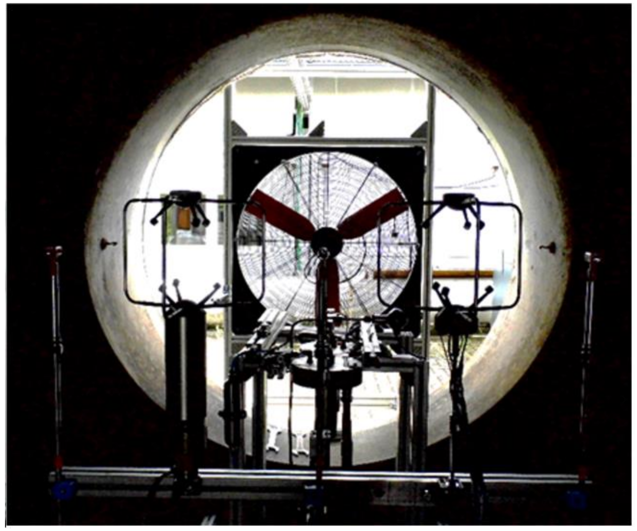
Breakthrough safety technology (background IP)

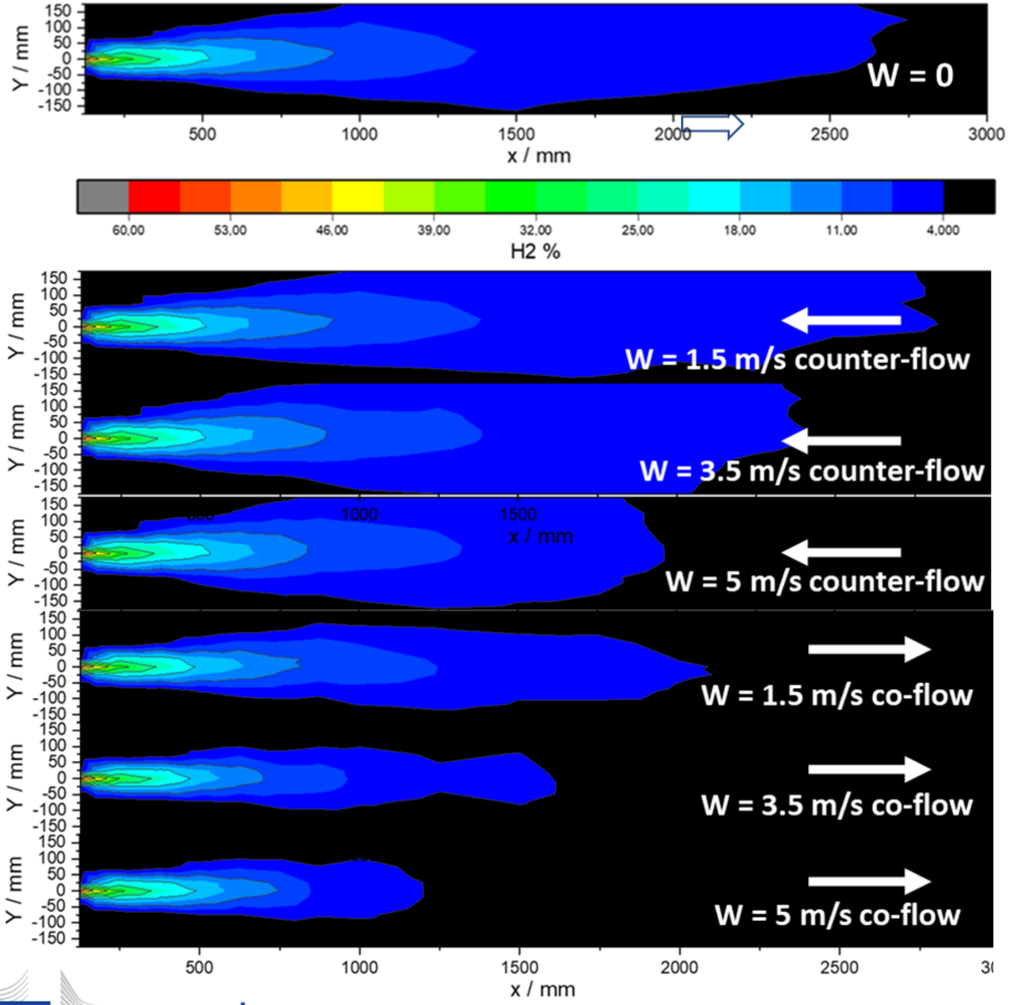
- Explosion free in a fire self-venting tanks are **successfully tested** (microleaks-no-burst, μLNB, safety technology).
- **Allows** hydrogen-powered vehicles enter and park in **any confined space**.
- **Excludes tank rupture** (tested at realistic fire with HRR/A=1 MW/m², i.e. beyond HRR/A=0.20 MW/m² (localised) and 0.76 MW/m² (engulfing) GTR#13 fire test:
  - No blast wave!
  - No fireball!
  - No projectiles!
  - No long flames (microflames)!
  - No formation of flammable cloud!
  - No pressure peaking phenomenon!
  - No life and property loss!



Project Progress (3/11)

Example (WP2): mechanical ventilation and hazard distances





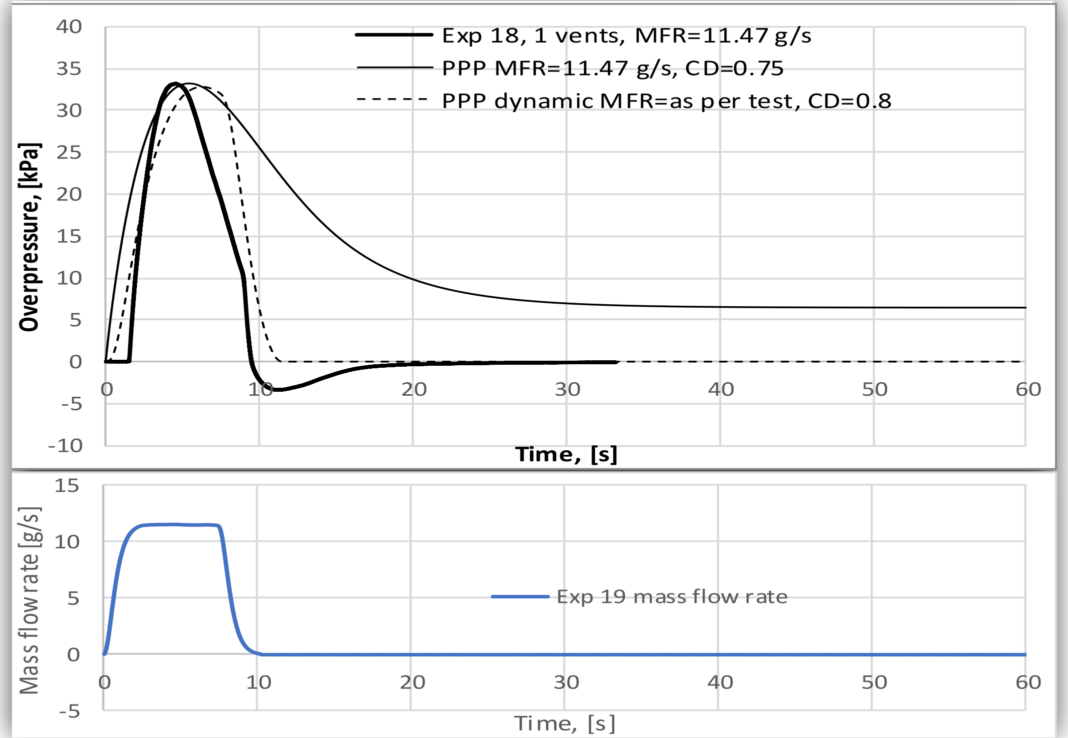
Mechanical ventilation promotes hydrogen mixing for both co- and counter-flow ventilation directions (reduction of hazard distance defined by LFL) for “small” hydrogen releases, e.g. ∅1 mm, $\dot{m}$=5 g/s.

Project Progress (4/11)

Example (WP2-3): unique for H2 pressure peaking phenomenon

- Storage enclosure 14.9 m^3.
- Mass flow rate up to 11.7 g/s.

- Validated engineering tools (reduced and CFD).
- Figure: thick solid line – test, dashed line – simulations for experimental mass flow rate.



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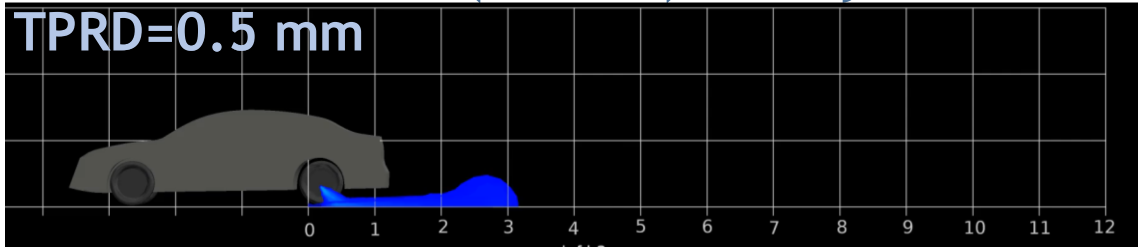
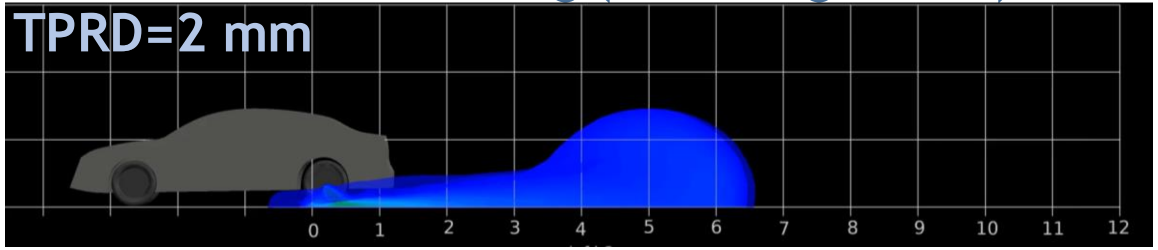
Project Progress (5/11)

Example (WP2-3): TPRD parameters for underground parking

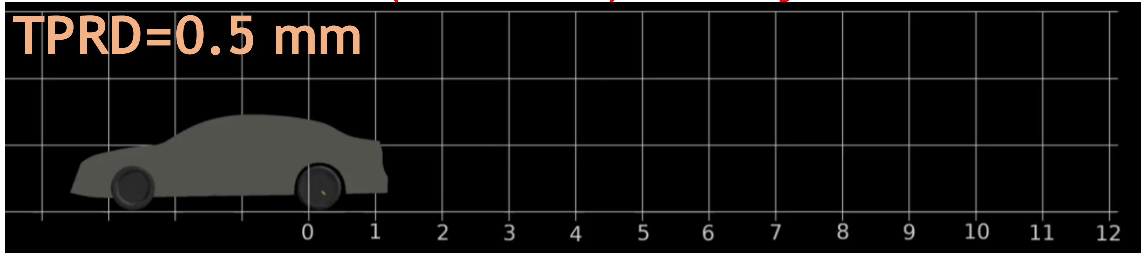
Reduced models are not capable to represent car parks with multiple ventilation openings and downward ignited releases. Example of CFD study for underground parking (23.5x3x45 m): ceiling height 2.1-3.0 m, TPRD=0.5-2.0 mm, tank (62.4 L NWP=70 MPa), angle 45º ("optimum"), ACH=0-10.

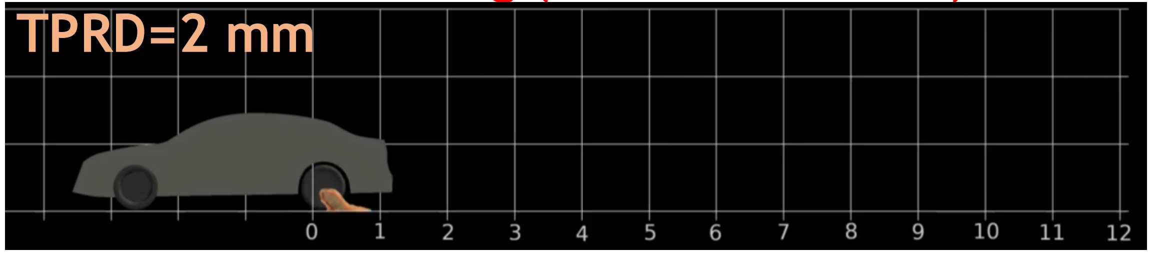
Release from TPRD (LFL=4%). Safety criterion: no cloud under the ceiling (no deflagration!).





Fire from TPRD (T>300ºC). Safety criterion: T<300ºC under the ceiling (ventilation ducts).



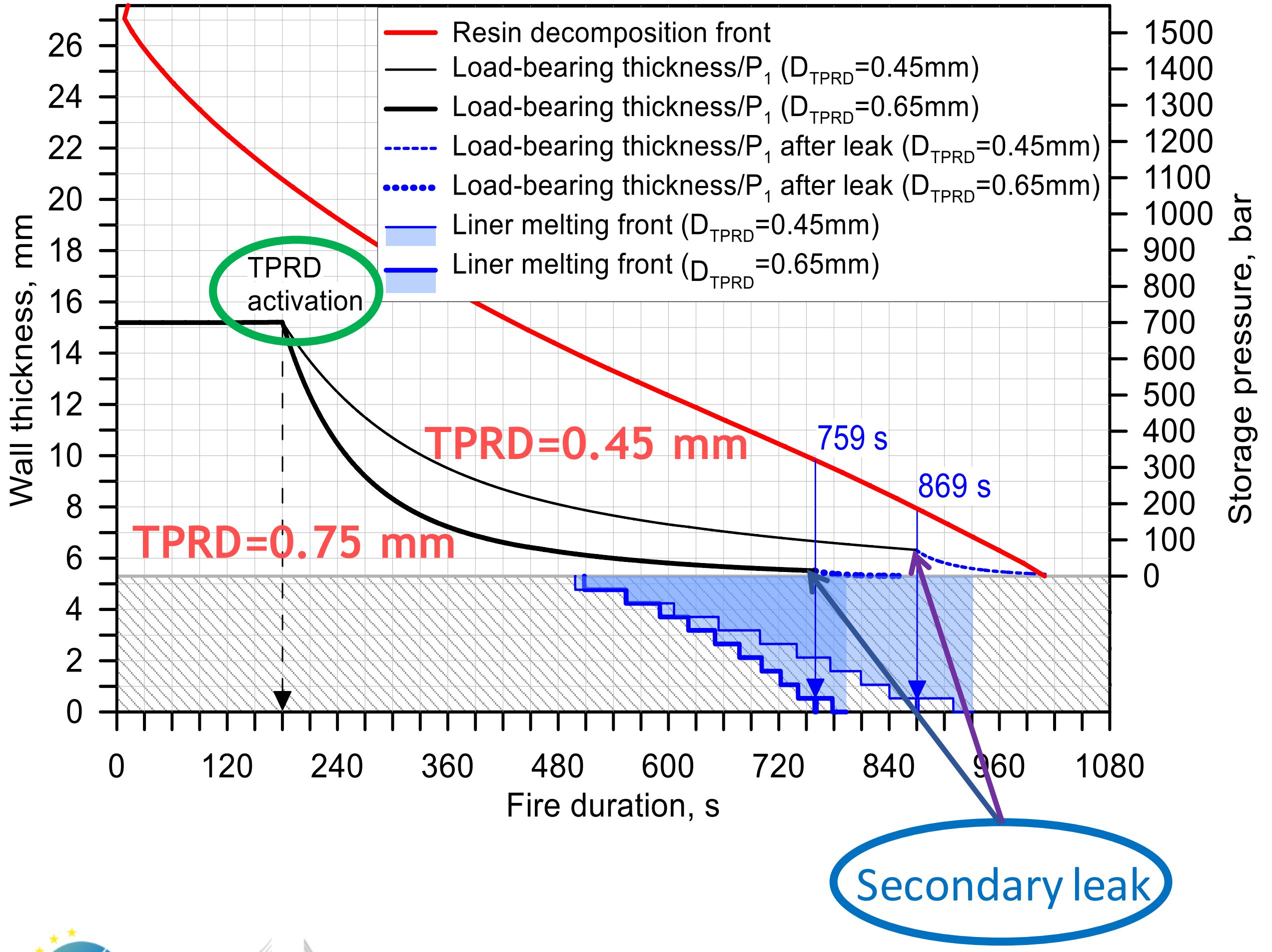


Will TPRD=0.5 mm exclude rupture?

Project Progress (6/11)

Example (WP4): new model for tank-TPRD system design

- **Tank:** 70 MPa, 36 litres, type IV (HDPE)
- **Gasoline fire:** HRR/A=1 MW/m^2.
- **TPRD response time:** 3 min.
- **Question:**
  What TPRD diameter would exclude:
  (a) tank rupture,
  (b) the pressure peaking phenomenon,
  (c) formation of flammable cloud under the underground parking ceiling
  (d) formation of products with T>300ºC under the ceiling of underground parking.
- **Answer:**
  for selected tank parameters (!) it is
  TPRD=0.45 mm (36 L tank)
  TPRD=0.75 mm (244 L tank)



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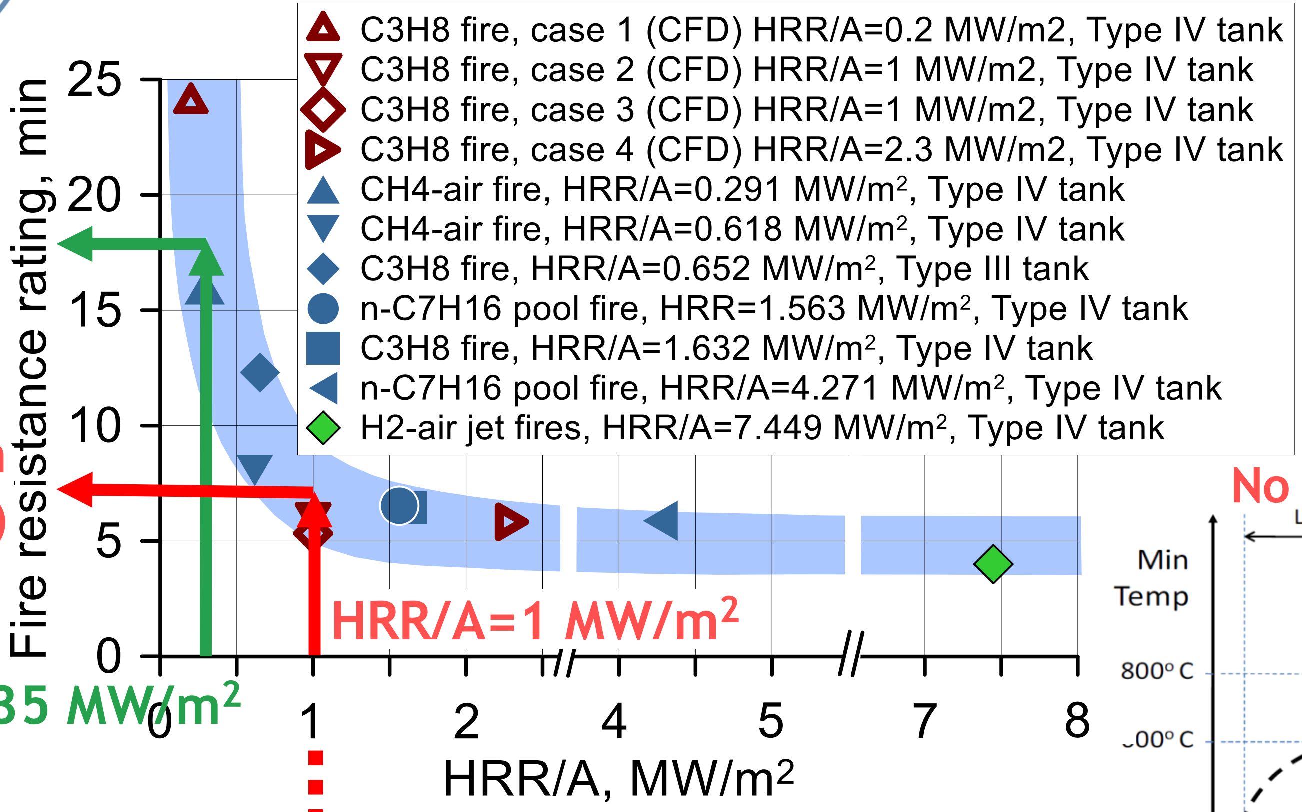
Project Progress (7/11)

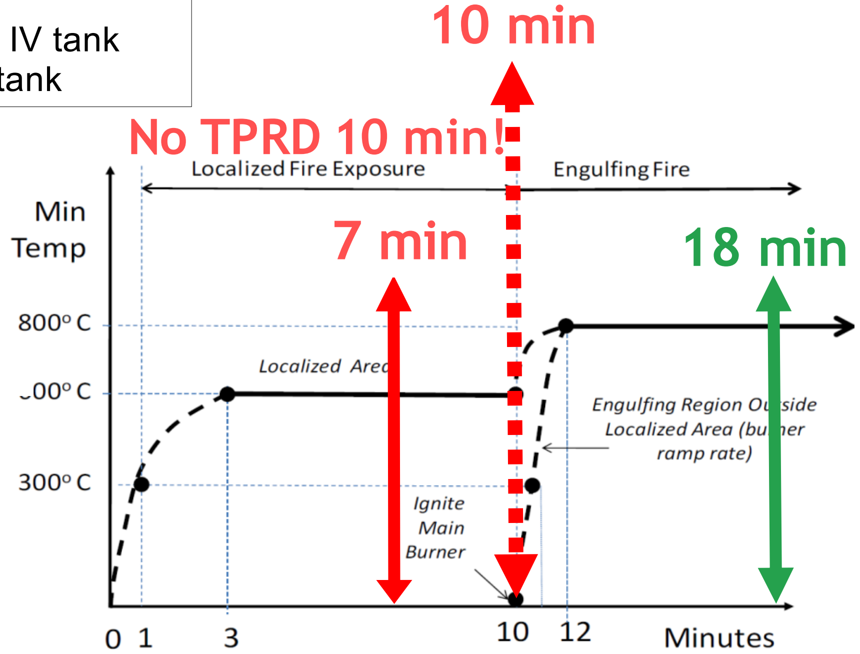
Example (WP4): proposal to amend GTR#13 fire test protocol

Rupture in 18 min (if TPRD fail), leak

Rupture in 7 min (no TPRD 10 min)



HRR/A=0.35 MW/m²



GTR#13 fire test

Real gasoline fires

Tank must survive any fire!

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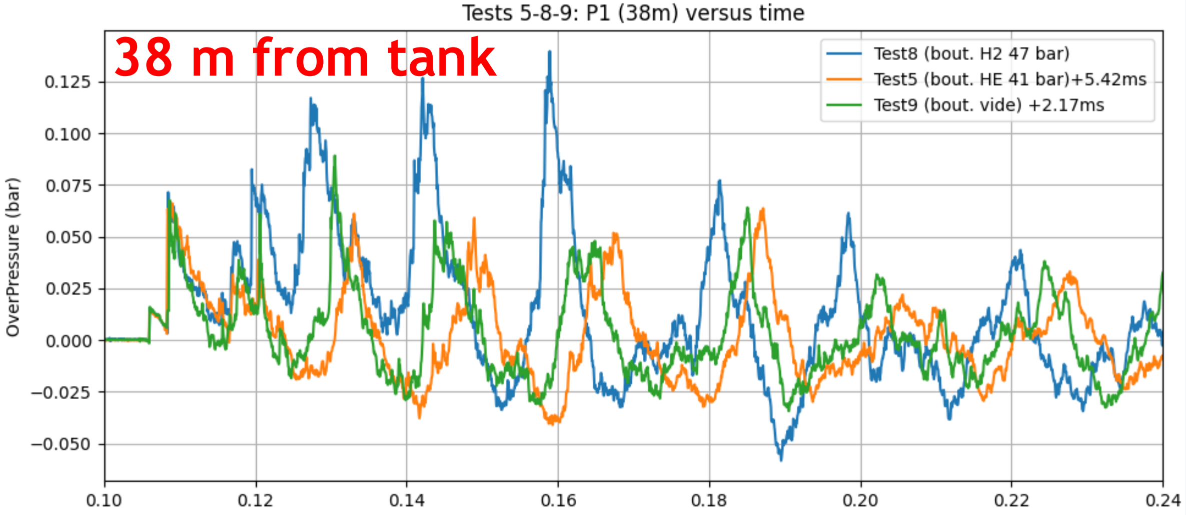
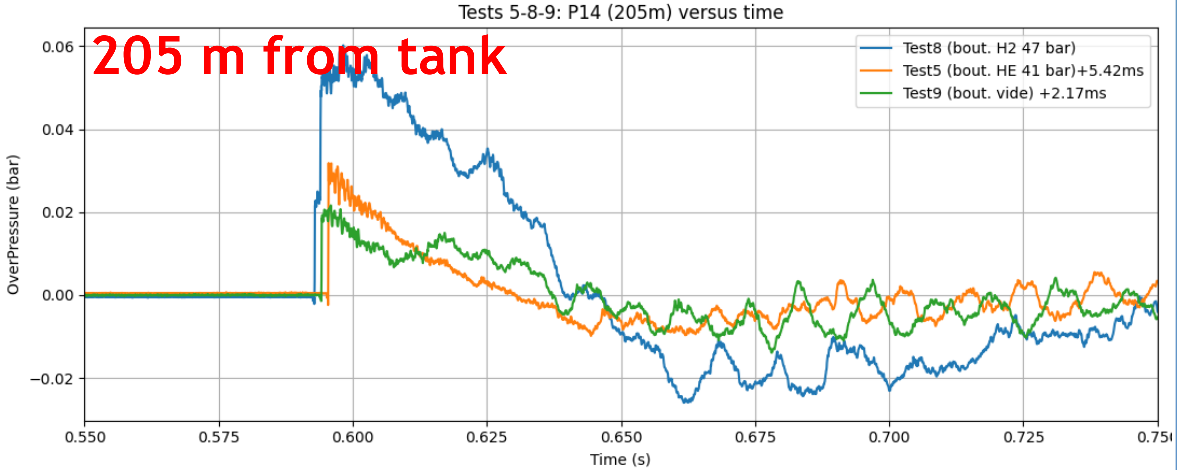
Project Progress (8/11)

Example (WP4): blast wave strength and hydrogen combustion

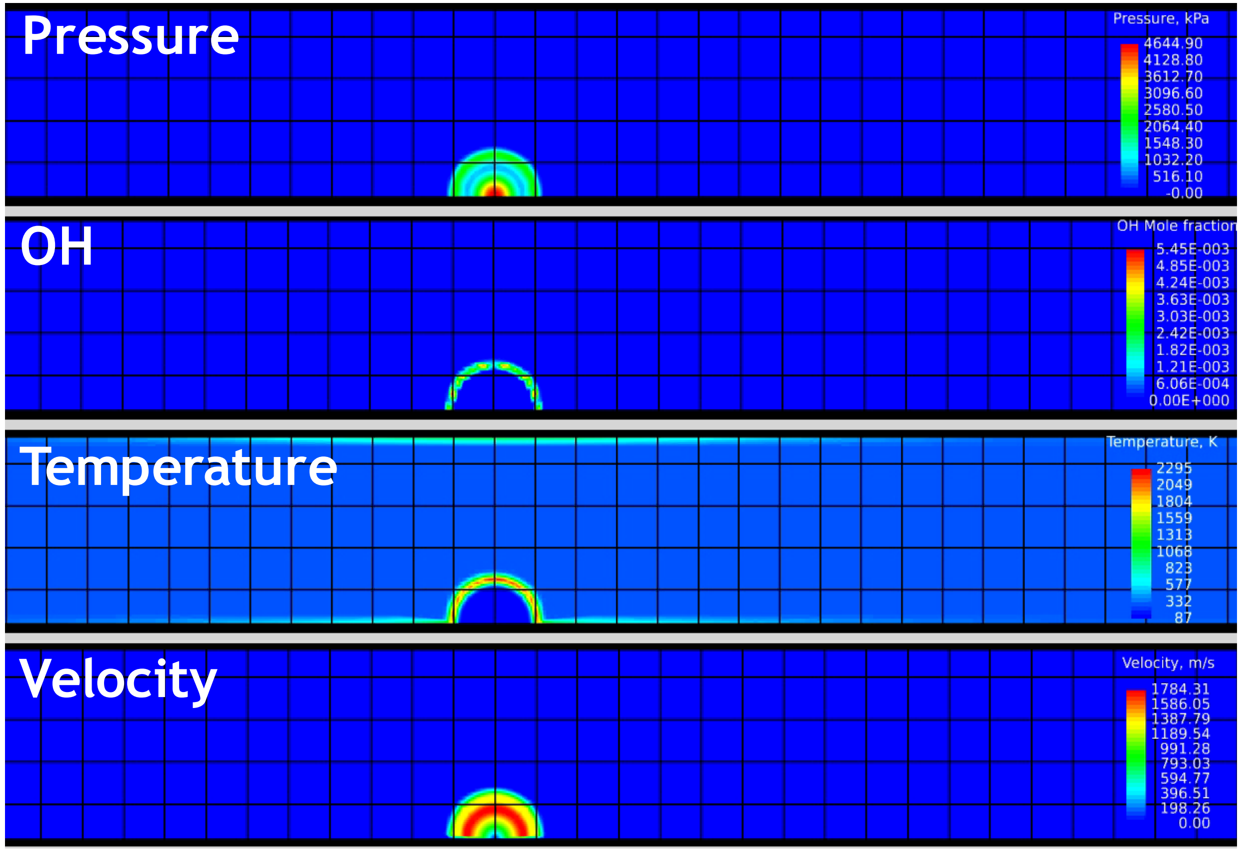


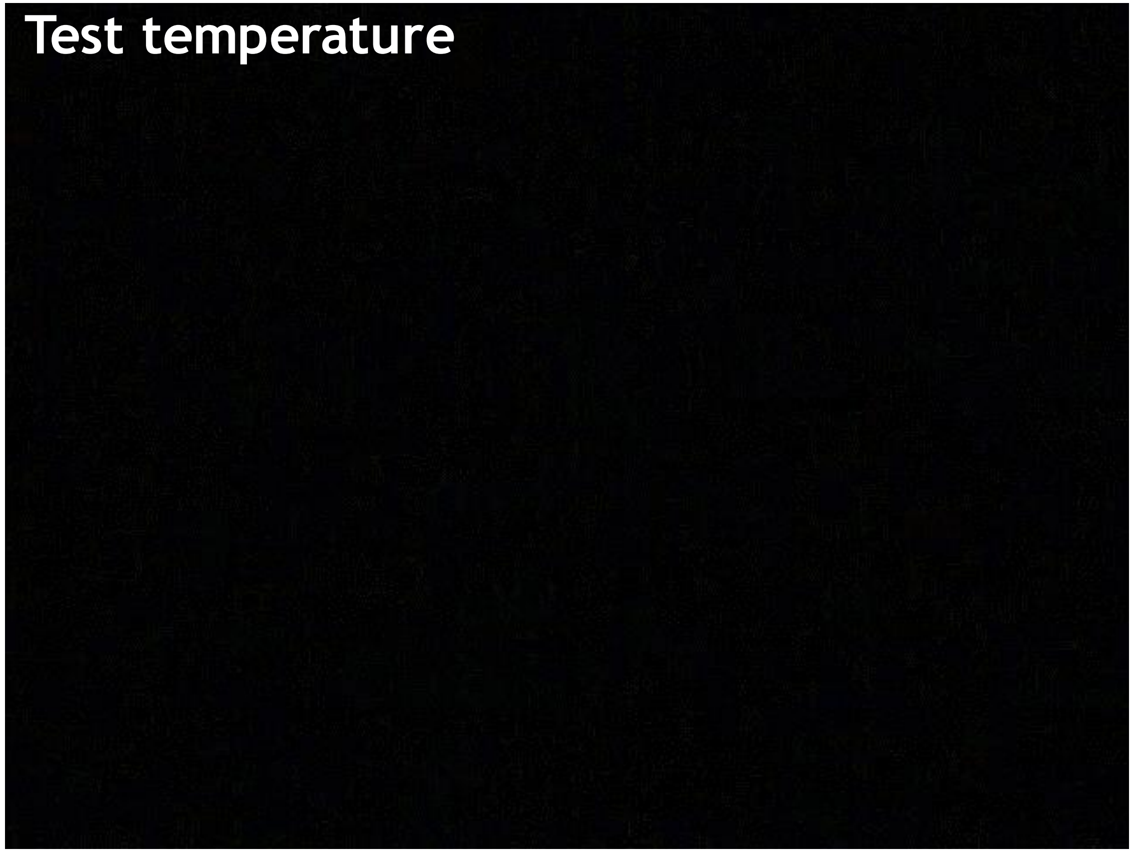


- Three cases: GH2, GHe, Detonation belt alone.
- Similar overpressure: GHe and Detonation Belt.
- Significant contribution of chemical energy from GH2 combustion to blast wave.

Project Progress (9/11)

Example (WP4): CFD prediction of fireball is validated by test

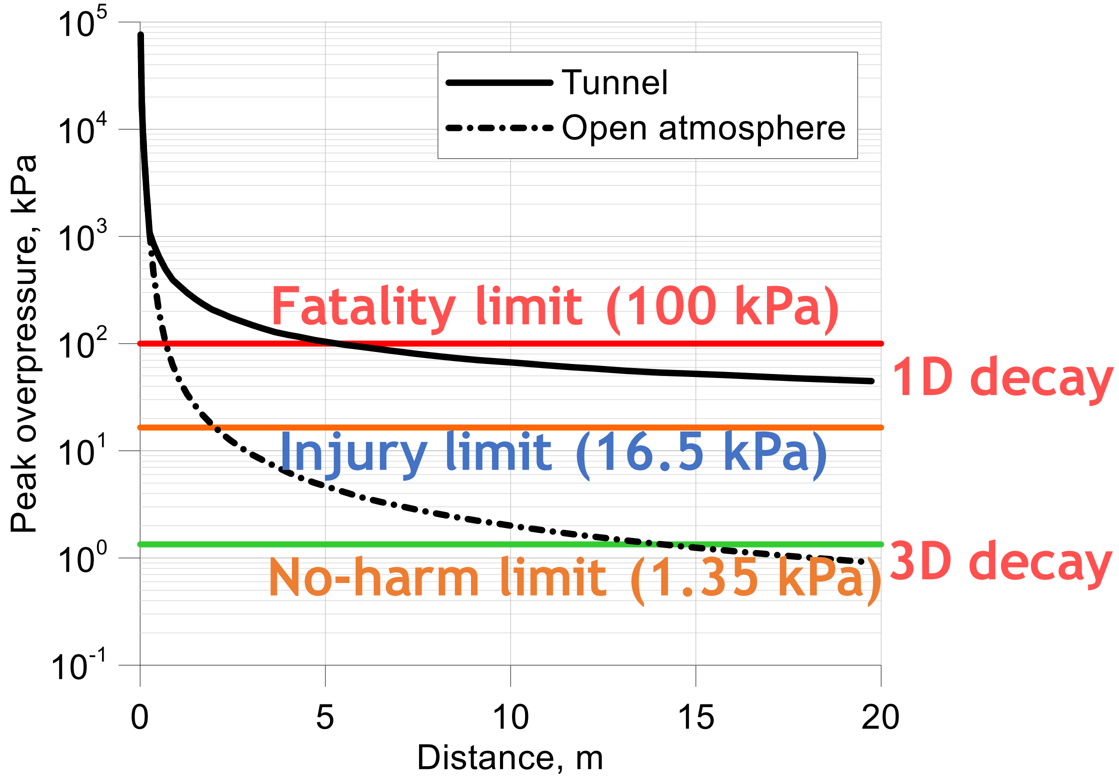




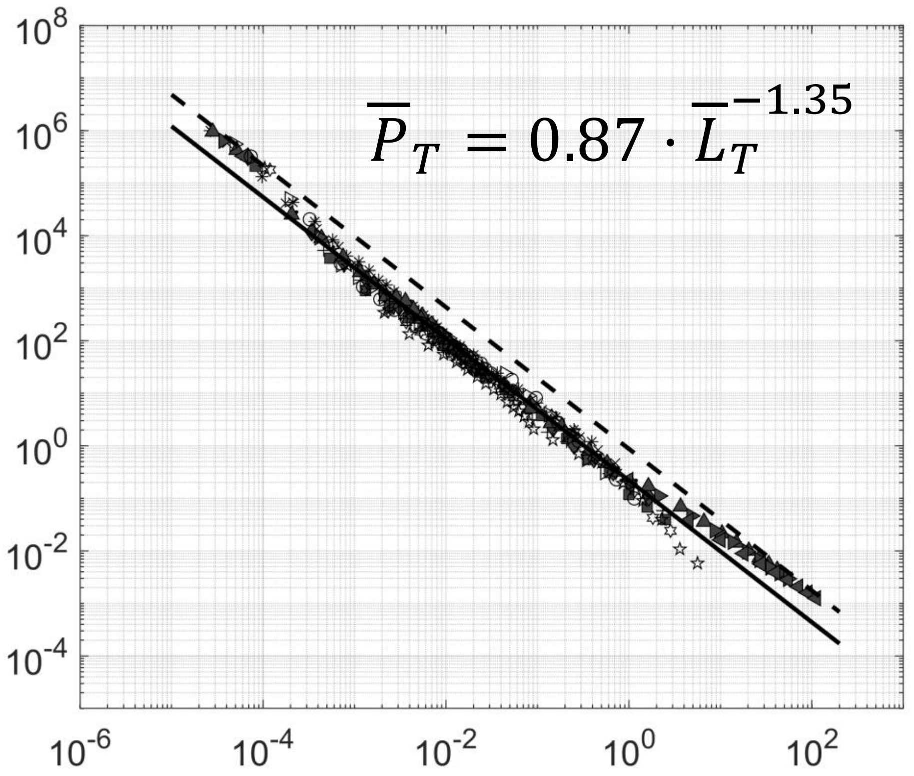
This is initial stage (later fireball propagates at speed of 25 m/s (!) along a tunnel behind the blast).

Project Progress (10/11)

Example (WP4): blast wave decay in tunnel (after tank rupture)



$$\bar{P}_T = \frac{\Delta P}{P_0} \cdot \frac{1}{\bar{L}_T}$$



$$\bar{L}_T = \frac{P_0 L A}{E \cdot AR^{0.5}} \left(\frac{fL}{D_T}\right)$$

Hydrogen tank rupture in a tunnel can not be accepted and **must** be prevented. How?

Project Progress (11/11)

Example (WP4): explosion free in fire self-venting TPRD-less tank (shared with other projects background IP)

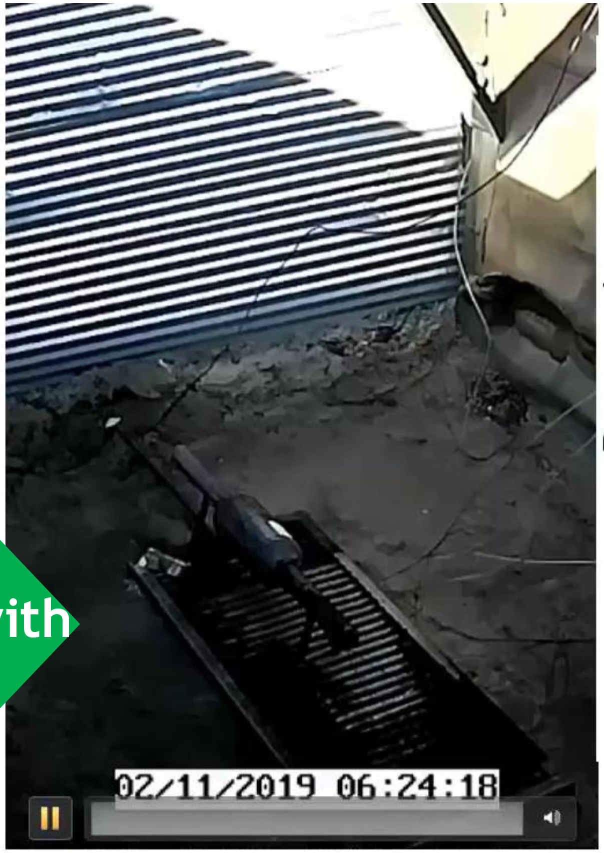
More tests to be performed and reported:

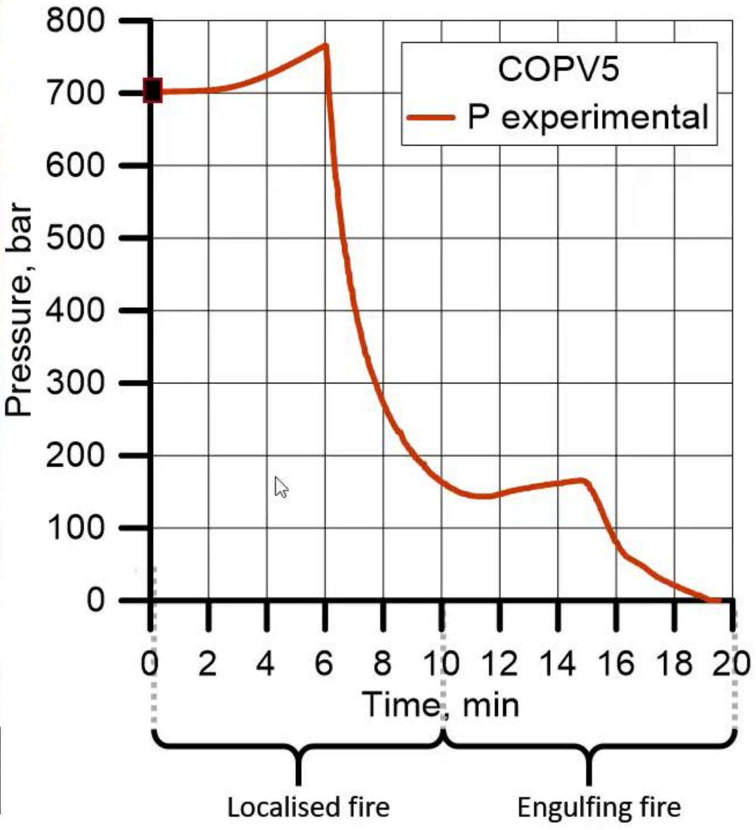
- CEA (pooling vehicle out of "spill fire")
- HSE (reaction to hydrogen jet flame)
- USN (decay of hydrogen concentration from microleaks after fire extinction).

Tank rupture

under vehicle (USA)

No tank rupture, no consequences with self-venting tank





Expected impact of PNR HyTunnel-CS

- **Stakeholders, including OEMs:**
  Recommendations for inherently safer use of hydrogen vehicles in underground transportation systems, including new engineering tools for e-Laboratory of Hydrogen Safety
- **First responders:**
  Harmonised recommendations for intervention strategies and tactics for first responders providing conditions for their life safety and property protection
- **Industry (HE and beyond):**
  Recommendations for the update of relevant RCS, including through partner NEN (secretariate of CEN/CENELEC/JTC6)
- **Research, including academia (HER and beyond):**
  Closed knowledge gaps, addressed technological bottlenecks, shared beyond the state-of-the-art in hydrogen safety

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- France,
- Norway,
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Thank you!

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HyTunnel-CS partners	
UU - University of Ulster, UK (coordinator)	IFA - International Fire Academy, Switzerland
KIT - Karlsruher Institut fuer Technologie, Germany	URS - Universita Degli Studi Di Roma La Sapienza, Italy
NCSRD - National Center for Scientific Research "Demokritos", Greece	NEN - Stichting Nederlands Normalisatie – Instituut, Netherlands
USN - Hogskolen I Sorost-Norge, Norway	SPFI - Service Public Federal Interieur, Belgium
HSE - Health and Safety Executive, UK	CEA - Commissariat A L Energie Atomique Et Aux Energies Alternatives, France
DTU - Danmarks Tekniske Universitet, Denmark	PS - Pro-Science - Gesellschaft Fur Wissenschaftliche Und Technische Dienstleistungen Mbh, Germany
FHa - Fundacion Para El Desarrollo De Las Nuevas Tecnologias Del Hidrogeno En Aragon, Spain	

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