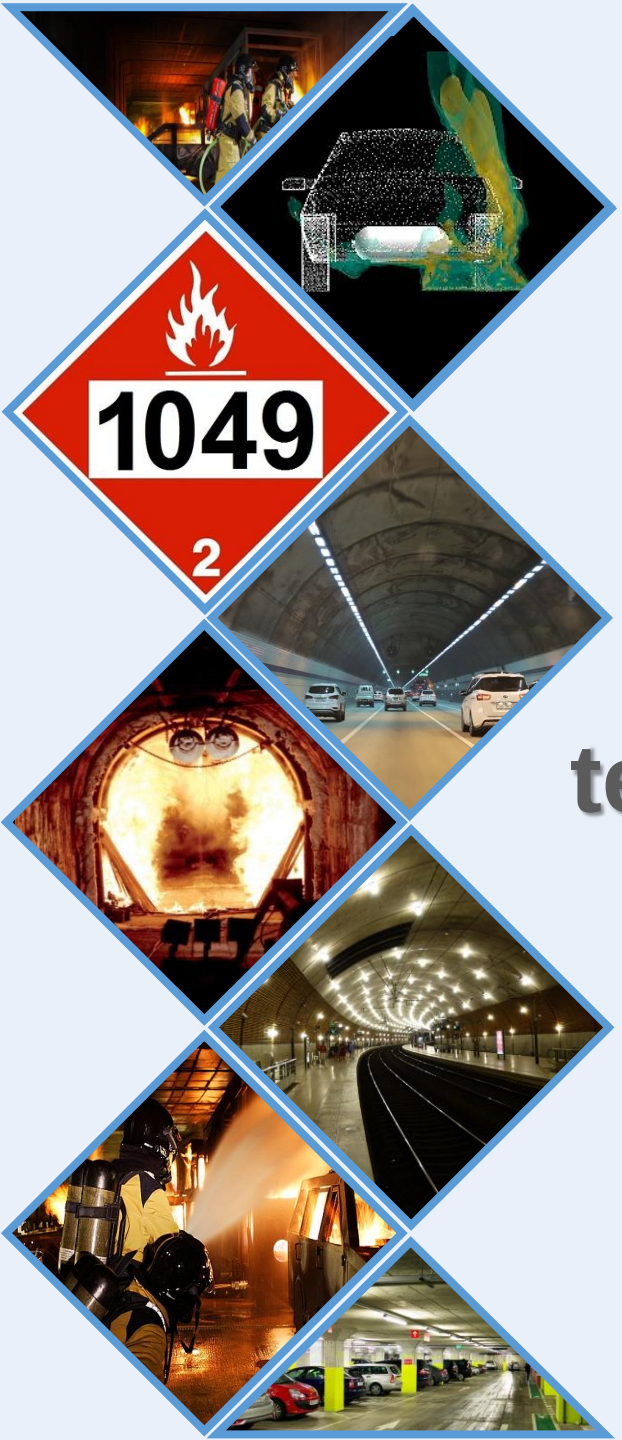



Dissemination Conference of HyTunnel-CS project
*"PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces"*
14-15 July 2022, Brussels

# Breakthrough safety technology of explosion free in a fire TPRD-less tank

Kashkarov S., Makarov D., Molkov V.

# Types of fires

## Battery fires

- “In January 2017 a NYC garbage truck was the source of a neighborhood surprise when a **Lithium ion battery exploded in the compactor of the truck**. Luckily no one was injured”
- “**Two airlines** have lost 747s **to lithium battery fires**. Each had over 50,000 batteries onboard and the source of ignition was traced to those containers”
- “In 2008, lithium-ion batteries being charged **ignited a blaze aboard a Navy SEAL mini-submarine** in Pearl Harbor”

*References:*

- *https://www.maritimeprofessional.com/news/lithium-battery-fires-threat-container-360275*
- *https://www.forbes.com/wheels/news/battery-car-fires/*
- *https://www.latimes.com/california/story/2019-12-15/lithium-ion-battery-fire-red-flags-coast-guard-conception*

# Types of fires

## Battery fires

Lithium ion batteries can catch fire if they were badly made or damaged, or if the software that controls the battery has been poorly designed.

# Types of fires

## Battery fires

- “34 people were killed in a fire aboard the dive boat Conception”
- “unsupervised charging of lithium-ion batteries and extensive use of power strips and extension cords”


*References:*

- *https://www.latimes.com/california/story/2019-12-15/lithium-ion-battery-fire-red-flags-coast-guard-conception*
- *https://www.businessinsider.com/us-coast-guard-issues-lithium-battery-warning-following-california-boat-fire-2019-9?r=US&IR=T*

# Types of fires

## Liquid fuel fires and their HRR/A

- Liquid fuel spill on concrete: HRR/A=0.8-1.0 MW/m$^2$
- On road liquid fuel spill: HRR/A=2 MW/m$^2$
- Pool fire equation by Babrauskas for gasoline spill: HRR/A=2.2 MW/m$^2$
- Gasoline/lube oil accidental leaks: 31% of fire and explosion accidents in maritime sector!


*References:*

- *Heselden, Proceedings of the 2nd International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, Cambridge, UK, 23-25.03.1976*
- *H. Ingason, Y.Z. Li, Fire Safety Journal, 91, 2017, 399–406*
- *Baalisampang, T., Abbassi, R., Garaniya, V., Khan, F., Dadashzadeh, M., 2018. Review and analysis of fire and explosion accidents in maritime transportation. Ocean Eng.*

# Types of fires

## Smouldering fires

CNG garbage trucks explosions in the USA:

- "…**natural-gas powered garbage truck began smouldering**… neighbour was recording just as the **truck exploded**",
- "…garbage truck exploded after catching fire … and **blasted a hole in the front of a nearby house**". "A total of **four houses were damaged** in the explosion".


*References:*

- https://www.today.com/video/caught-on-camera-natural-gas-powered-garbage-truck-explodes-609780803613
- https://www.nj.com/mercer/2016/01/garbage_truck_explosion_damages_hamilton_house.html

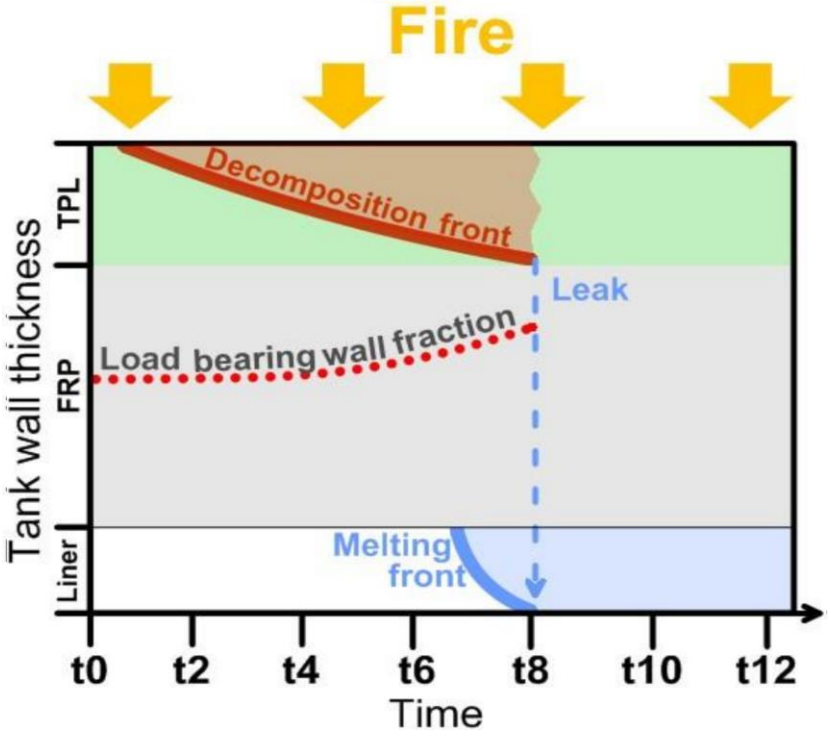
# Ulster's IP

V. Molkov, D. Makarov, S. Kashkarov.
European Application No 18706224.5
"Composite Vessel for Hydrogen Storage", 2019

# Explosion free in a fire TPRD-less tank

## Schematic description

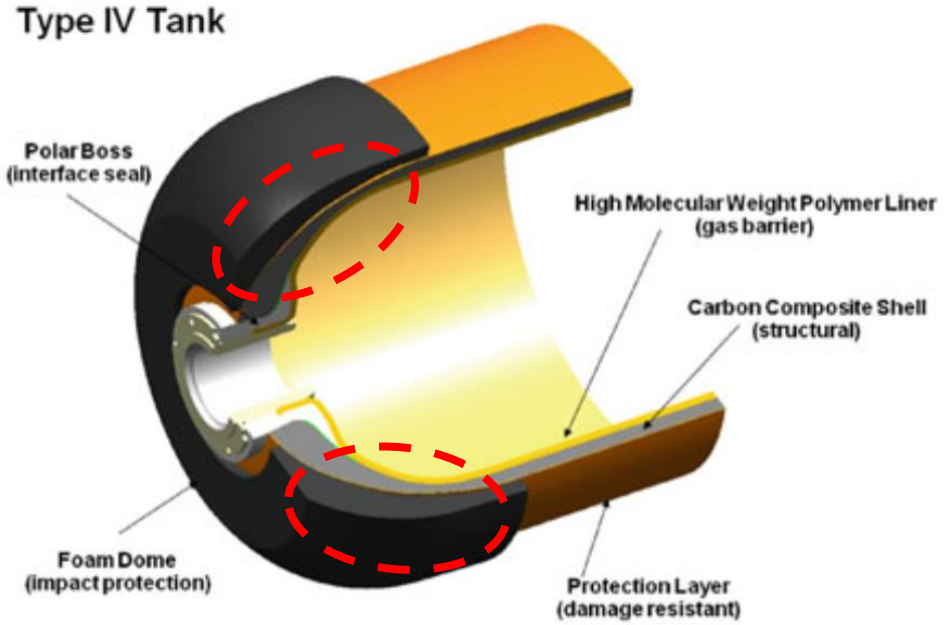
Explosion free in a fire tank: **no rupture**




A vessel comprises the load bearing fibre-reinforced polymer (FRP) layer, inner liner against gas permeation and outer thermal protection layer (TPL) that can be load bearing. Liner melts and the gas leaks through the wall before tank rupture.

# Fire resistance problem

## Thinner composite at domes

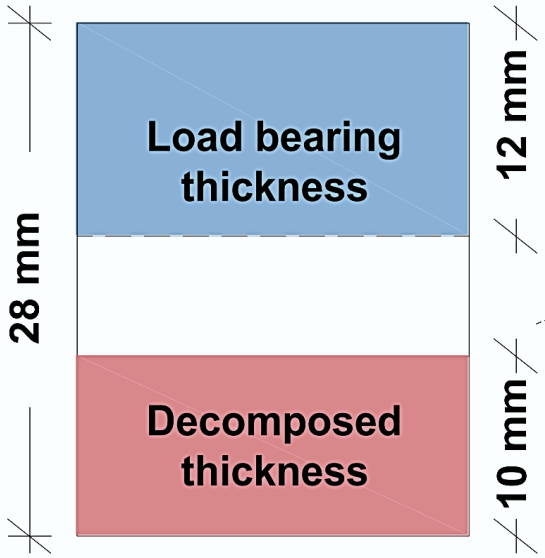




*References:*

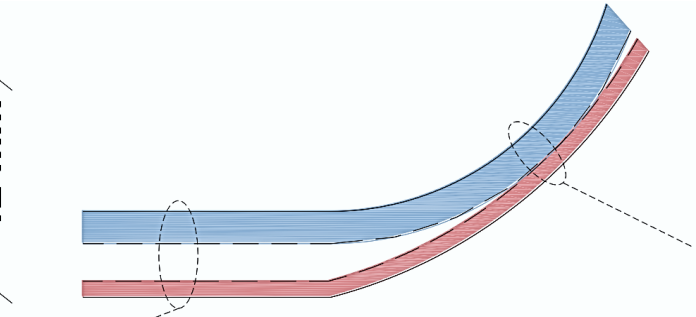

- *https://www.h2euro.org/whats-h2appening/hyundai-sees-green-future-in-hydrogen-powered-cars/attachment/hydrogen-tank-car/*
- *https://www.researchgate.net/publication/251104697_Hydrogen_Production_Storage_and_Fuel_Cells*

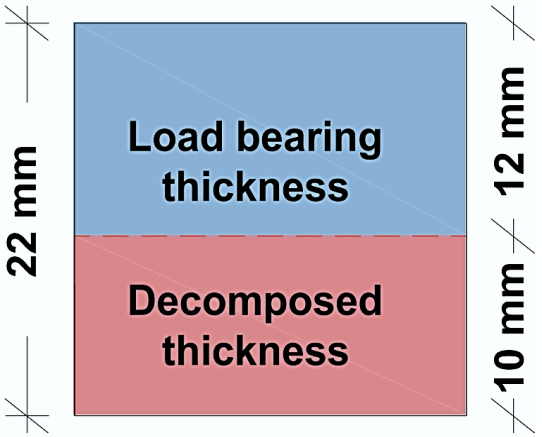
# Fire resistance problem

## Thinner composite at domes




**Wall cylindrical section:** no rupture after 10 mm is decomposed






**Wall dome section:** rupture after 10 mm is decomposed

# The first set of prototypes

# The first set of prototypes

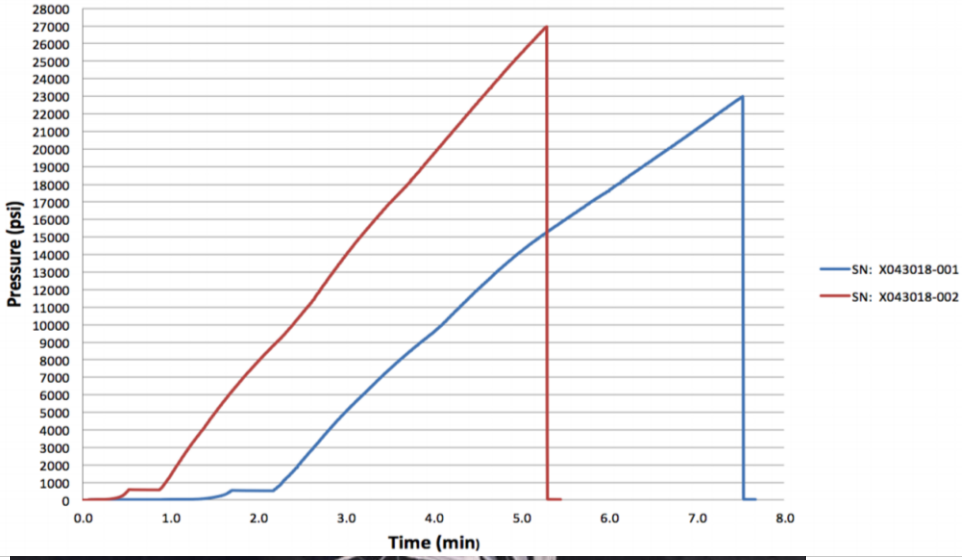
## Features and characteristics targeted

- Tank V=7.5 L, NWP=700 bar
- Technology validation: explosion free in a fire behaviour (without TPRD)
- Fire HRR/A=1 MW/m$^2$, which is comparable with gasoline-diesel fires
- Designs and testing glass fibre reinforced polymer as the thermal protection layer, with increased wall thickness

# The first set of prototypes

## Hydro-testing

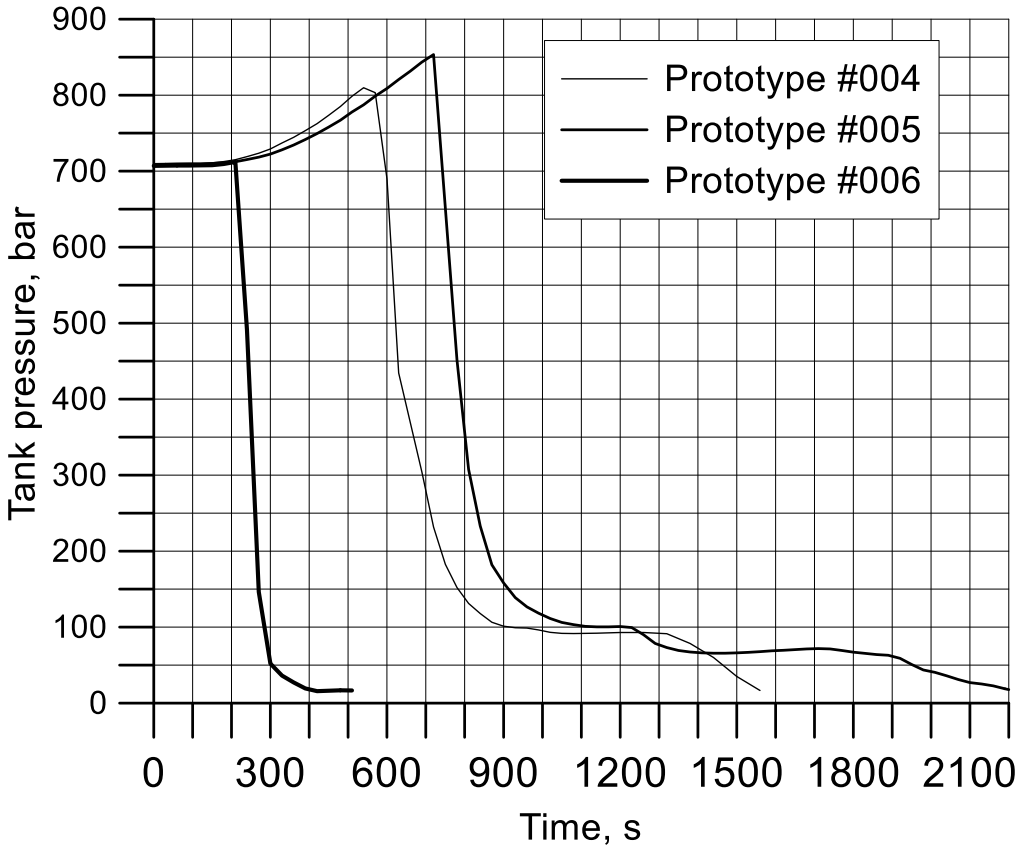
Burst pressure ratios 2.26~2.66

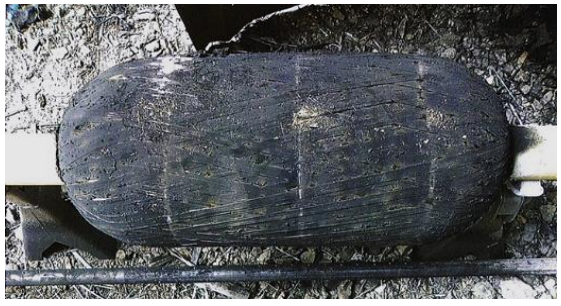




# The first set of prototypes

## Fire testing: all cylinders leaked (no rupture)



# The second set of prototypes

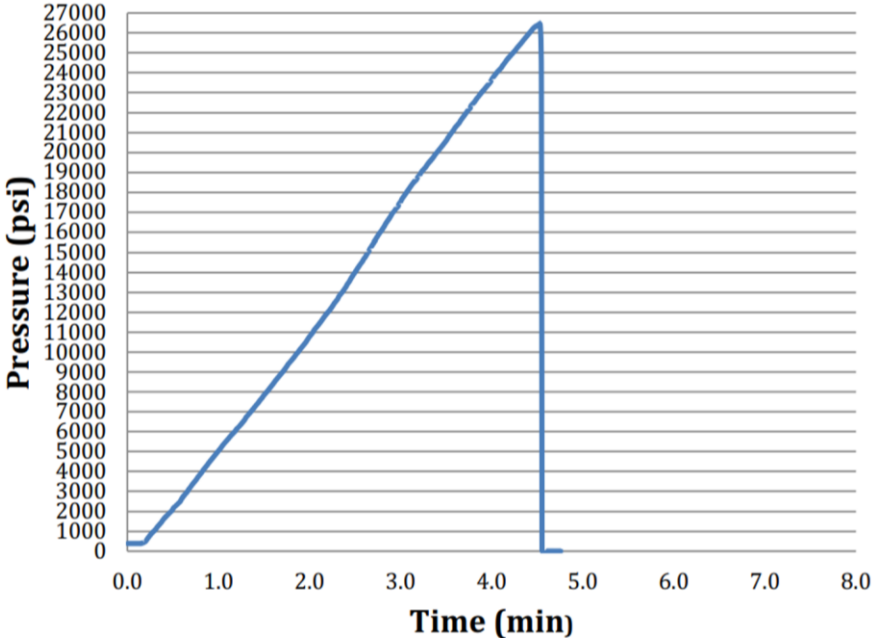
# The second set of prototypes

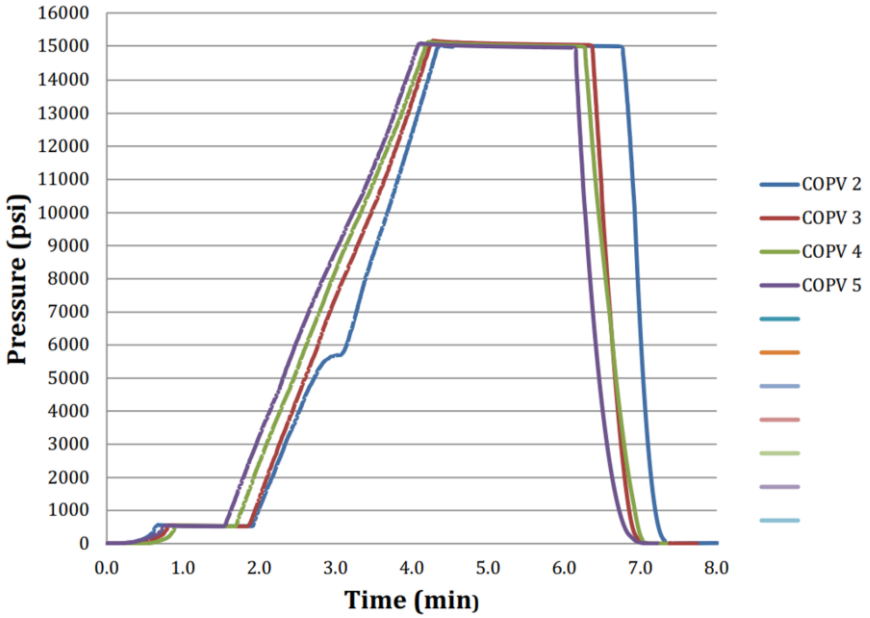
## Features and characteristics targeted

- Tank V=7.5 L, NWP=700 bar
- Technology validation: explosion free in a fire behaviour (without TPRD)
- Fire HRR/A=1 MW/m$^2$, which is comparable with gasoline-diesel fires
- Designs optimisation to original wall thickness
- Use of other composite not susceptible to acid influence

# The second set of prototypes

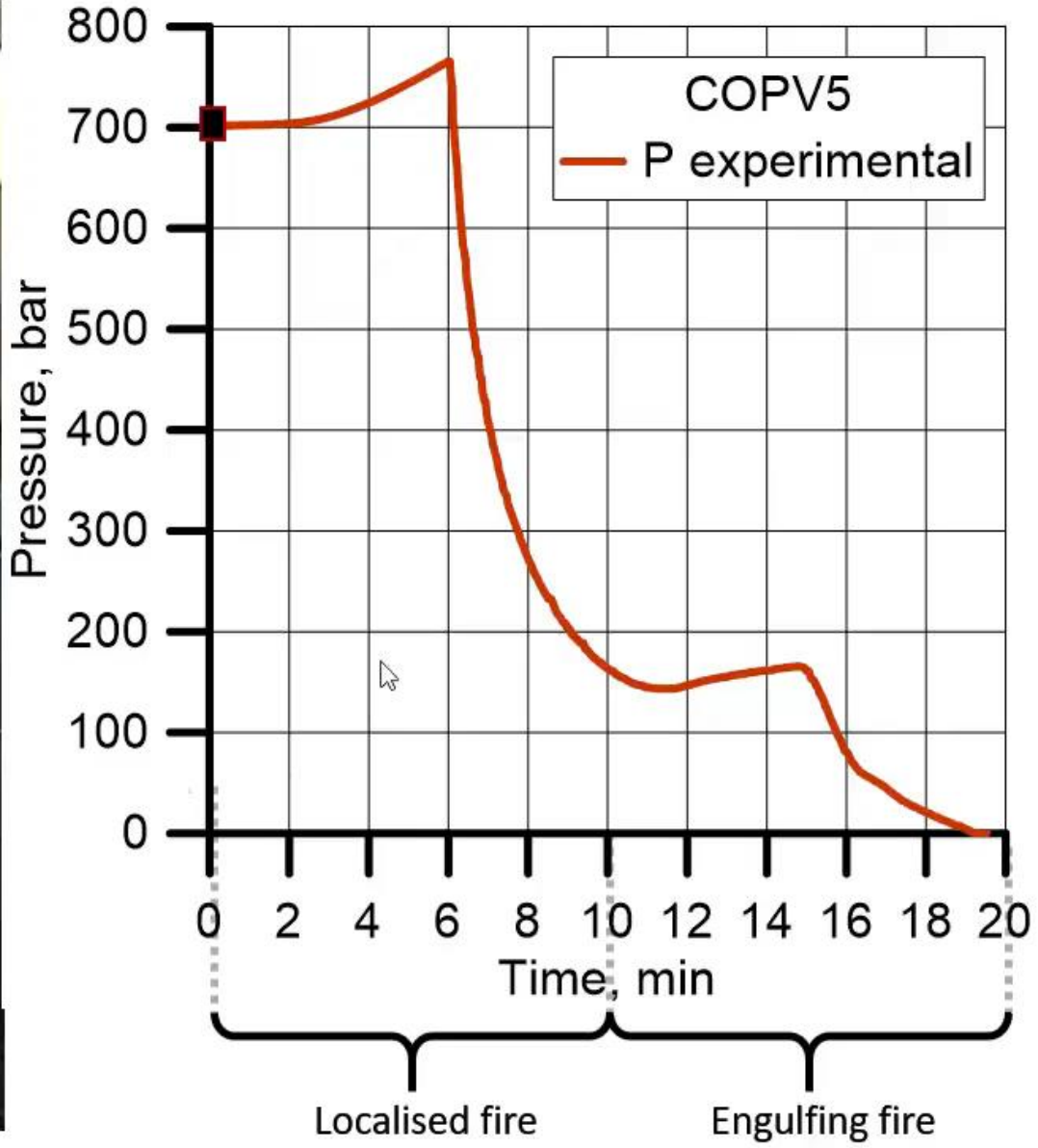
## Hydro-testing




Burst pressure ratio 2.61

# 2nd prototype in fire (HRR/A=1 MW/m$^2$)

# The third set of prototypes

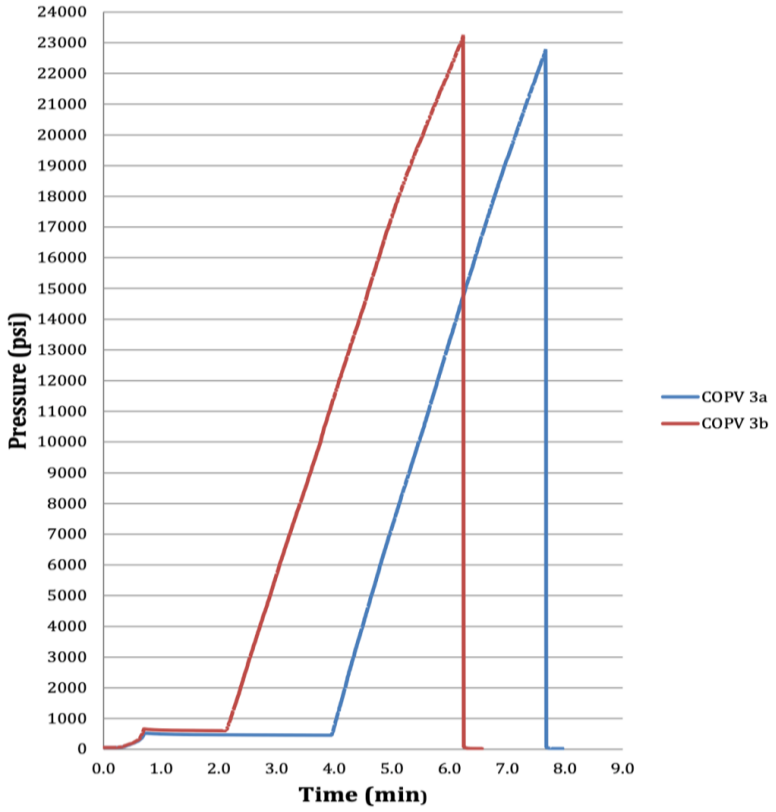
# The third set of prototypes

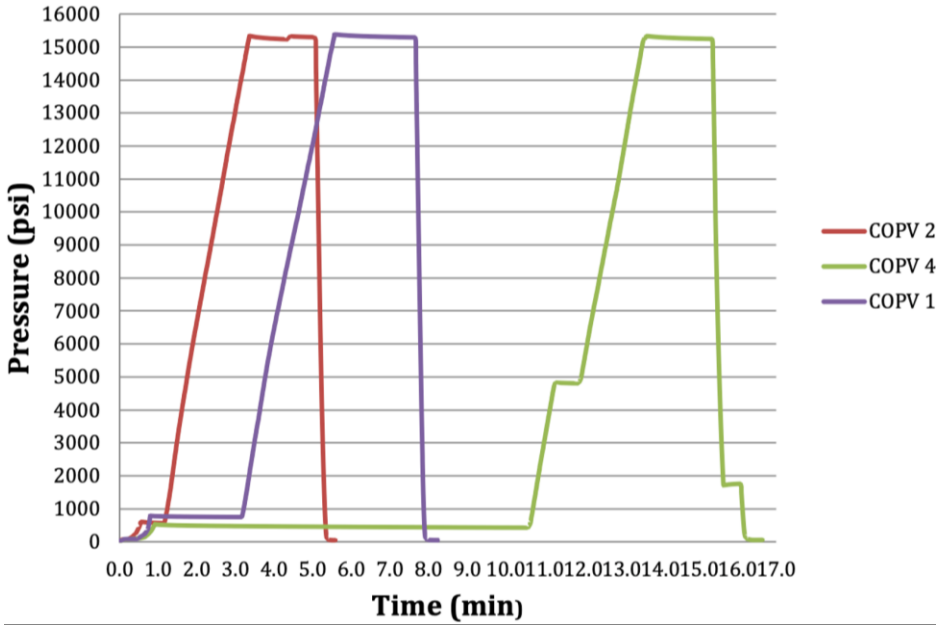
## Features and characteristics targeted

- Tank V=7.5 L, NWP=700 bar
- Technology validation: explosion free in a fire behaviour (without TPRD)
- Fire HRR/A=1 MW/m$^2$, which is comparable with gasoline-diesel fires
- Safe blow-down even when the fire is extinguished
- Leak in a fire and safe blow-down demonstrated with different liner polymers

# The third set of prototypes

## Hydro-testing

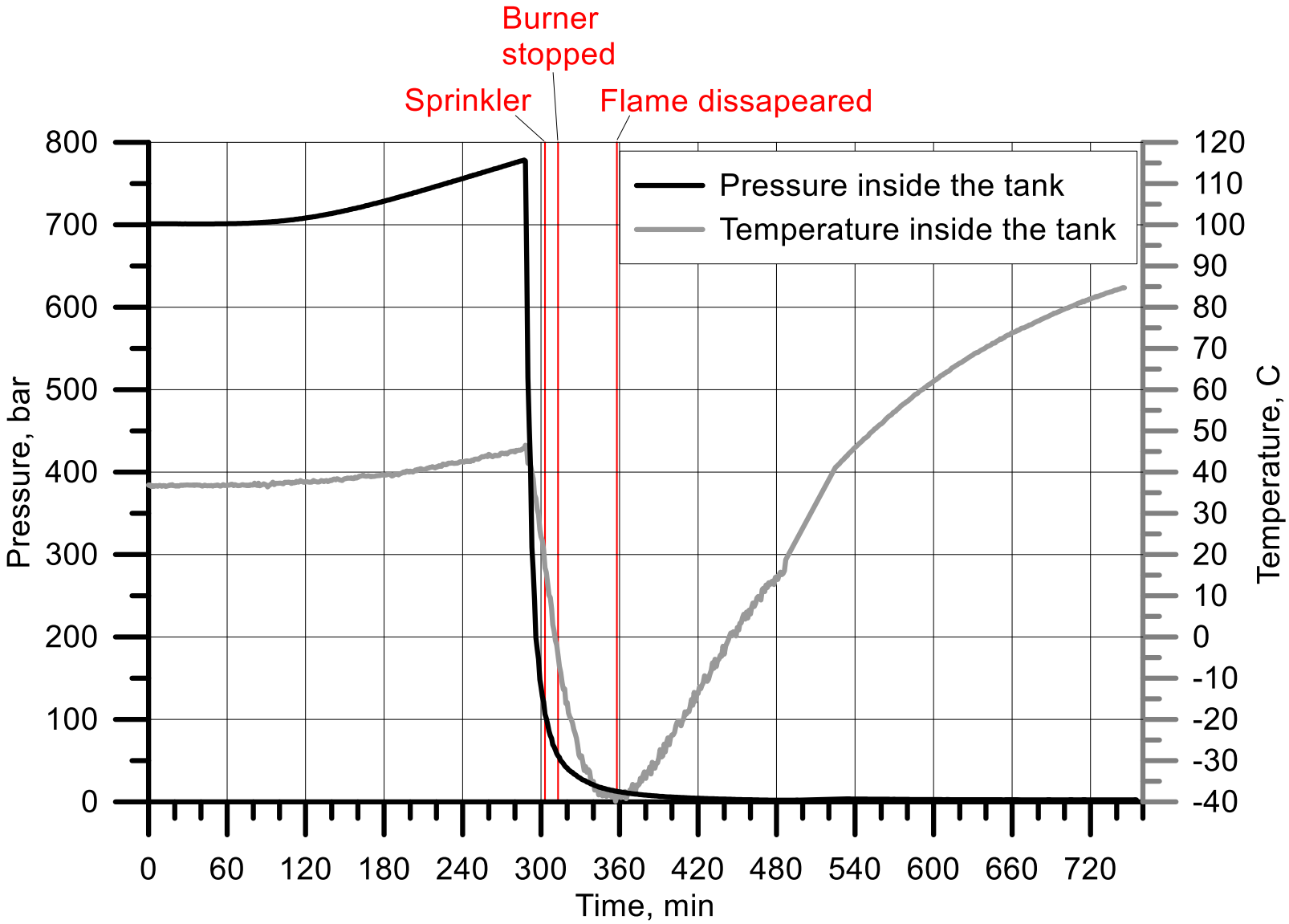



Burst pressure ratio 2.25~2.26

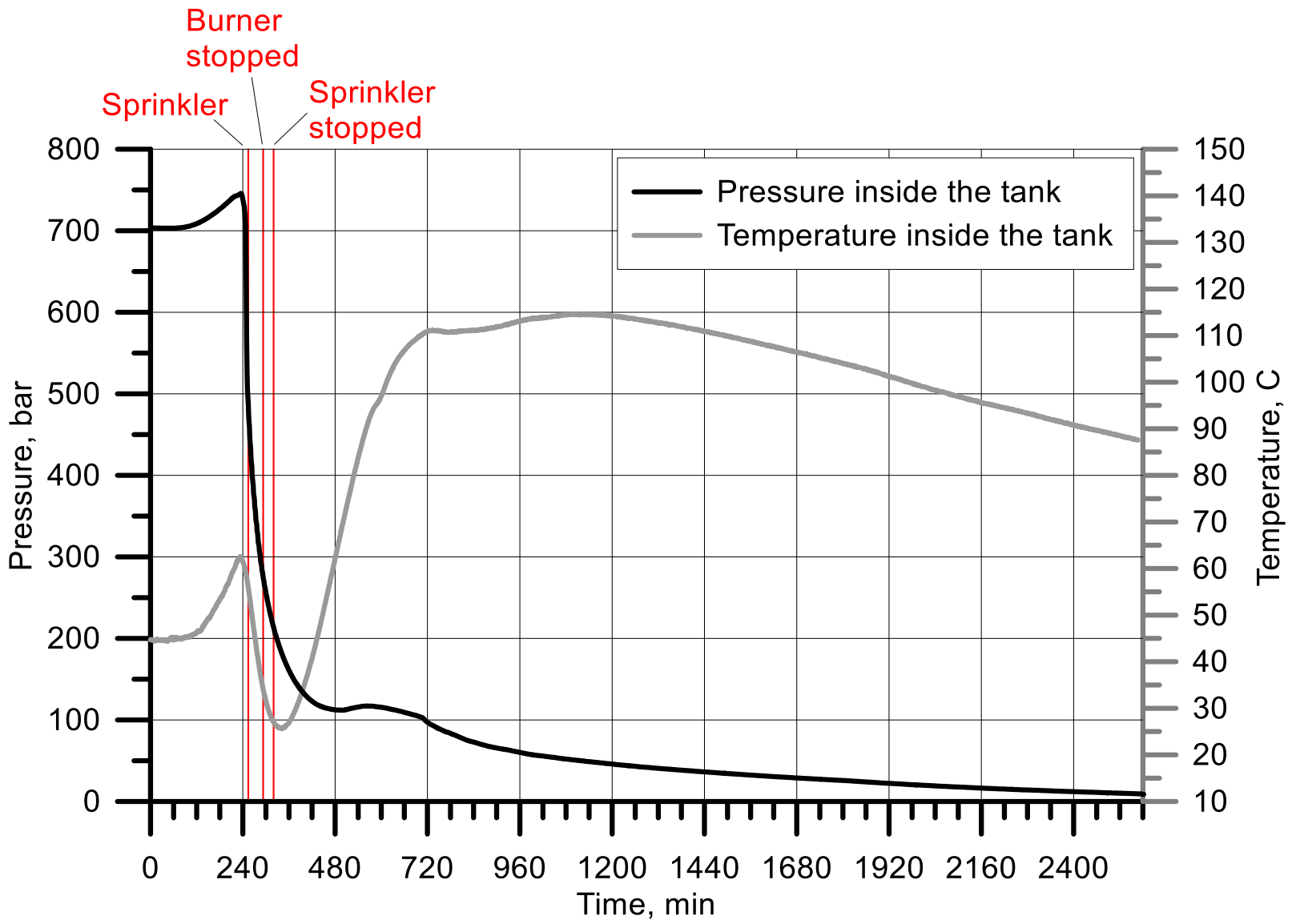
# The third set of prototypes

## Fire testing: Prototype#1 - leaked (no rupture)



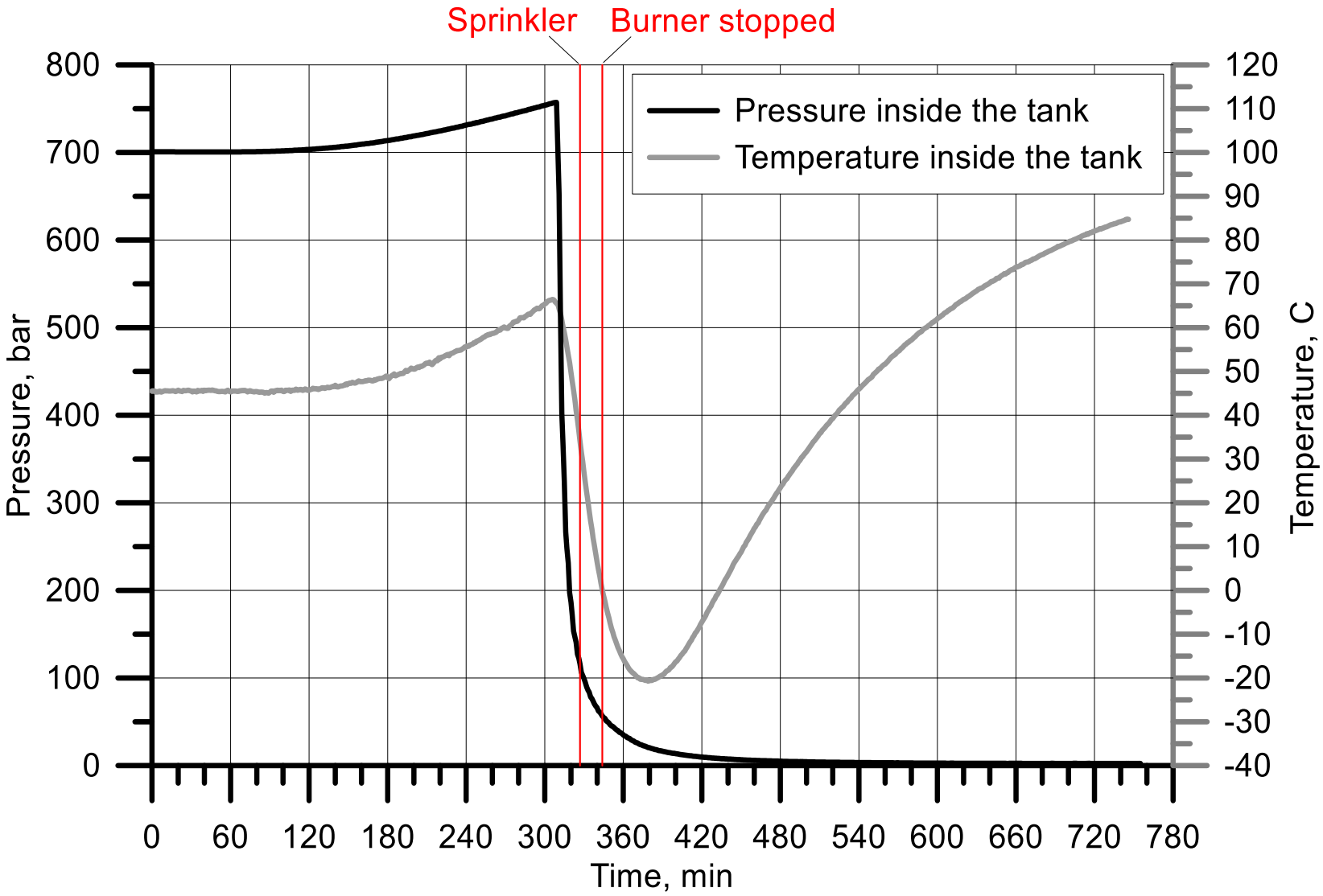
# The third set of prototypes

## Fire testing: Prototype#2 - leaked (no rupture)



# The third set of prototypes

## Fire testing: Prototype#3 - leaked (no rupture)



# The third set of prototypes

## Fire extinction does not stop hydrogen leak

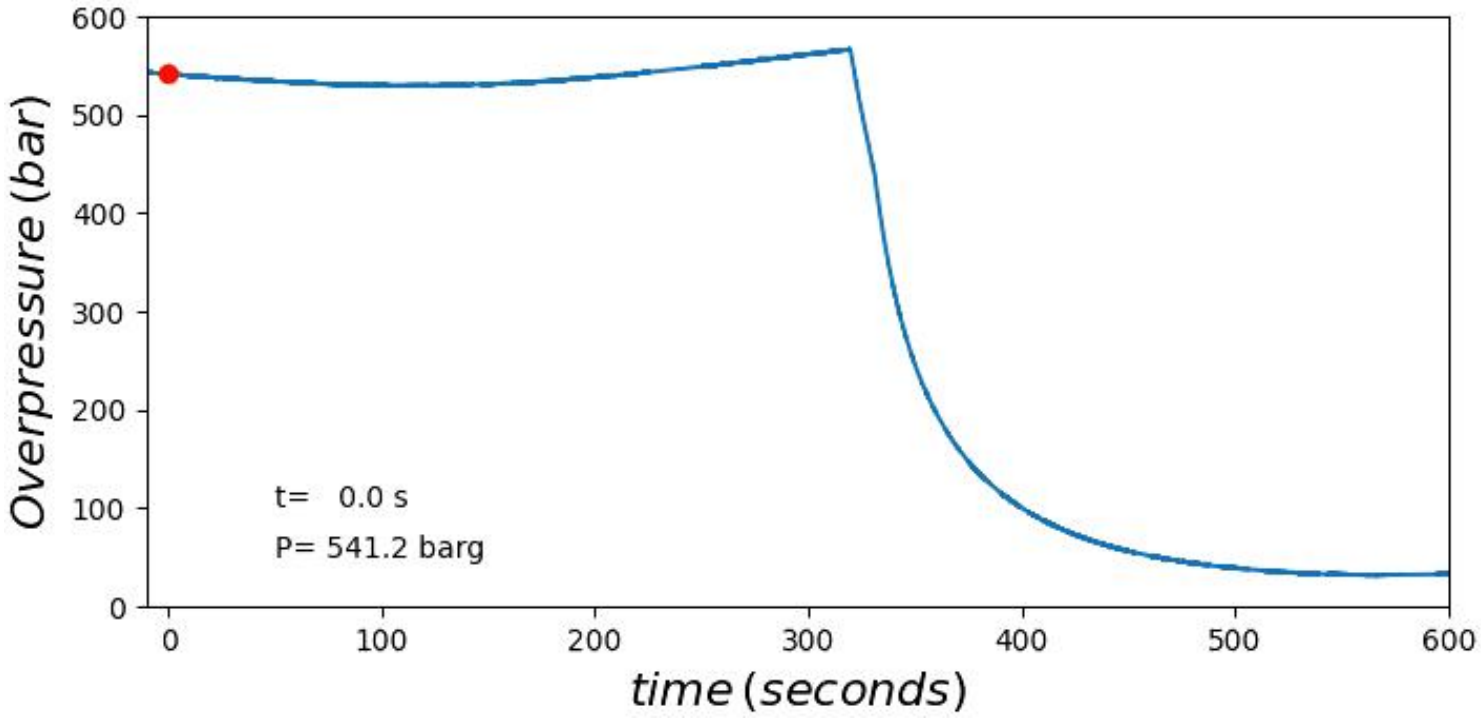
# The fourth set of prototypes

# The fourth set of prototypes

## Features and characteristics targeted

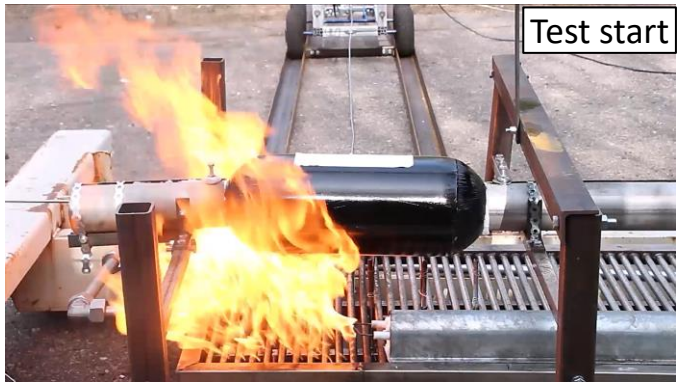
- Effect of fibre in a composite on hydrogen flame length (regulated limit 0.5 m)
- Decay of hydrogen concentration in the vicinity of the tank wall after fire extinction
- Reproducibility of technology performance in different testing laboratories

Credit:
CEA colleagues

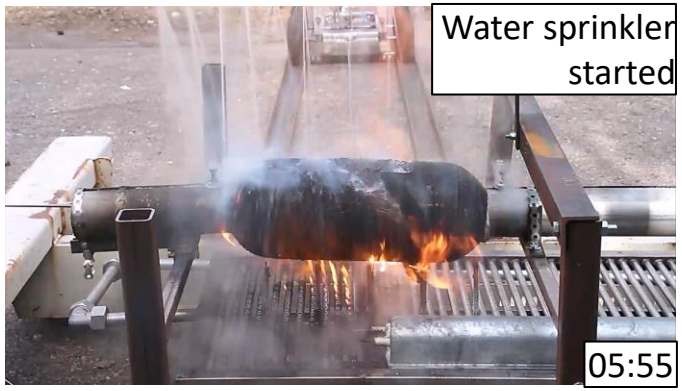


# The fifth set of prototypes

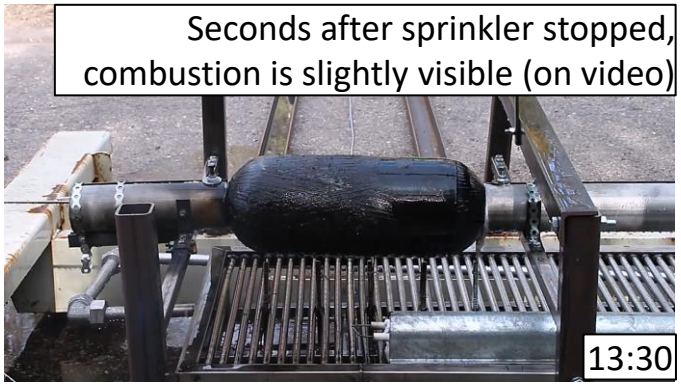
# The fifth set of prototypes





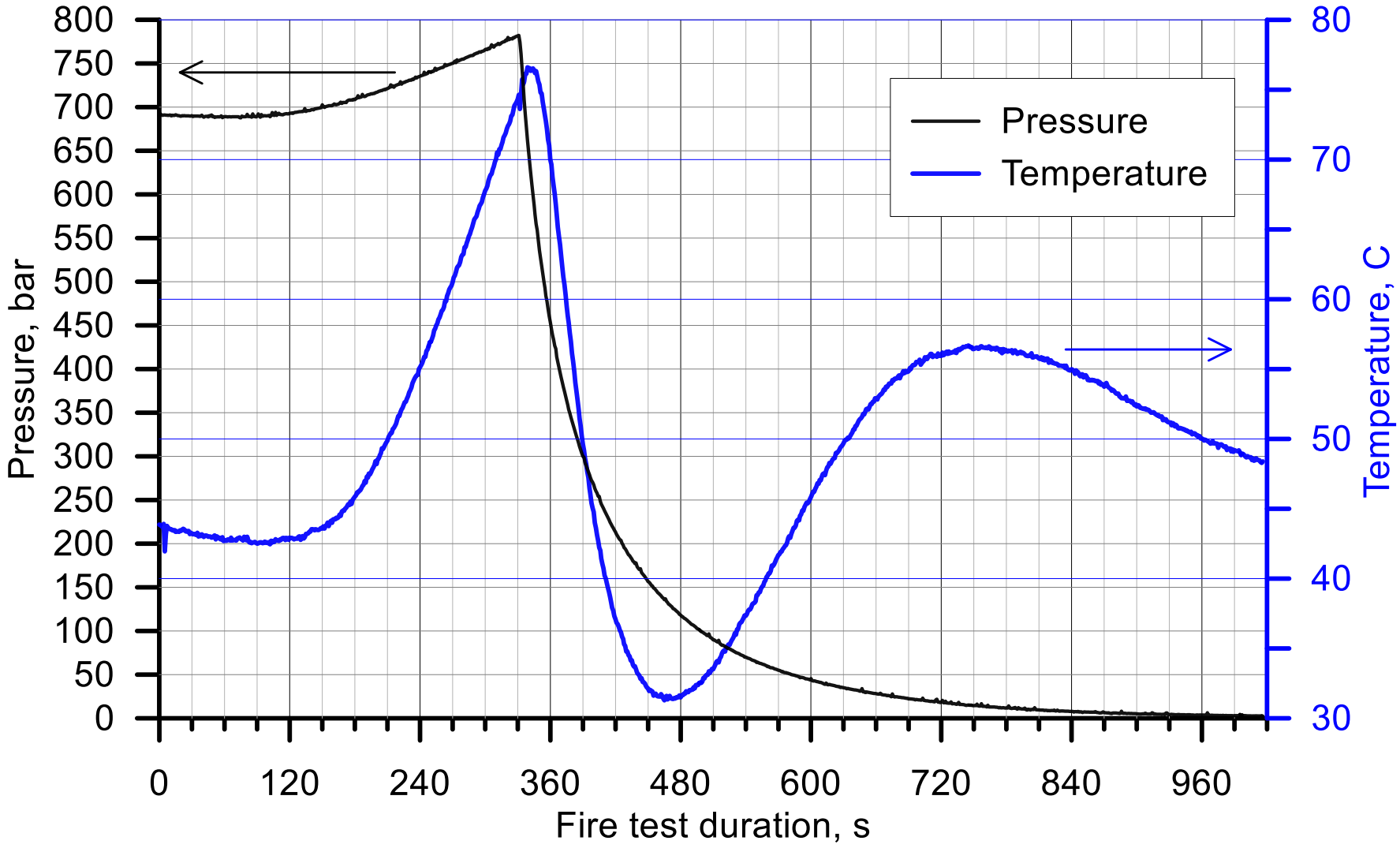





Credit:
USN colleagues

# The fifth set of prototypes

## Pressure and temperature reading



# Innovative TPRD-less tank technology

## Unprecedented level of safety

- **No devastating consequences of tank rupture in a fire:**
  - ✓ ***No blast wave***
  - ✓ ***No fireball***
  - ✓ ***No projectiles***
  - ✓ ***No pressure peaking phenomenon***
  - ✓ ***No long flames***
  - ✓ ***No loss of life and property due to tank rupture***
- Tank is explosion free in a fire at any SoC up to 100%.
- TPRD-less tank withstands any fire, including a localised fire!
- Standard tank-TPRD system will not withstand localised fire. It will rupture if TPRD is blocked from a fire, if response time of TPRD is comparatively large

# Innovative TPRD-less tank technology

## Conclusions

- There is no additional size and cost of the explosion free in a fire self venting container, to follow the request of OEMs

- Testing of these tanks confirmed that the fire extinction does not interrupt hydrogen release, i.e. ***firefighters can conduct their interventions at accident scenes as before***

# Acknowledgements

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 826193. The JU receives support from the European Union's Horizon 2020 research and innovation programme and United Kingdom, Germany, Greece, Denmark, Spain, Italy, Netherlands, Belgium, France, Norway, Switzerland.