Enjeux, attentes et travaux d'Air Liquide sur le comportement au feu des réservoirs composites

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1

Composite pressure vessels @Air Liquide

AL in the hydrogen value chain

Distribution

Transport

Storage

Production

Applications & Customers

AL in the hydrogen value chain

Composite cylinders as **customer's storage to be filled**

Distribution

Transport

Composite cylinders for **AL supply chain operations**

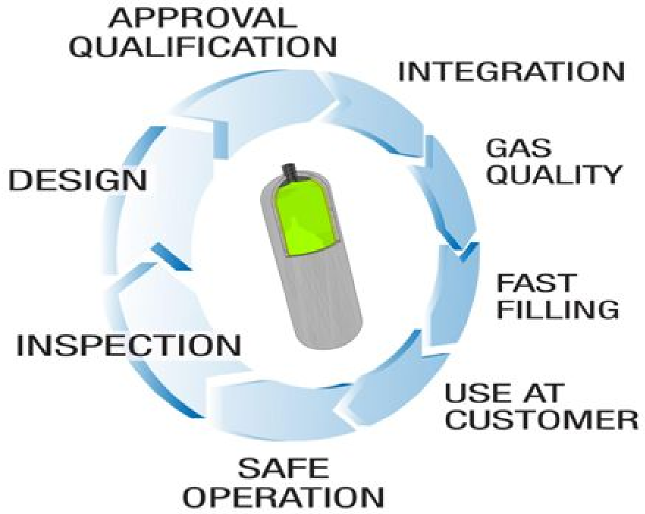
Storage

Production

Applications & Customers

R&D activity in composite pressure vessels

R&D knowledge covering **all aspects of cylinder's lifetime within AL operations**
Targeting a **safe & efficient use** of composite cylinders



Ensure **structural integrity** of vessels through their lifetime, beyond existing standards

Assess the **consequences** of accidental events and **mitigate** the industrial risk

Reduce the total cost of safely operating
composite pressure vessels
through better understanding

Air Liquide

Fire risk with composite cylinders

In fire, burst due to
Inner pressure increase

→

In fire, burst due to
Material degradation

- **Shorter time to burst**
- **High energy content**
- **No pressure increase**

↓

Need to adapt fire strategy

⇒ fireCOMP

2

FireCOMP project and results

2013 - 2016 FCH JU funding

A EUROPEAN PROJECT SUPPORTED THROUGH THE SEVENTH FRAMEWORK PROGRAMME FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT

New Energy World JU
fuel cells & hydrogen for sustainability

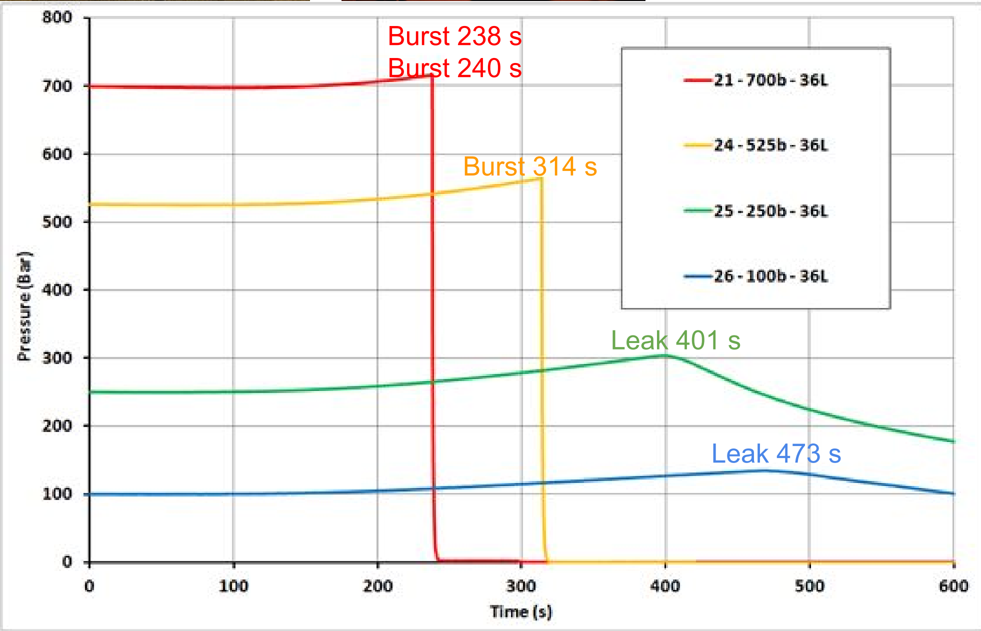
fireCOMP

Pre-normative research on fire safety of composite pressure vessels

- **Risk analysis**
  - Identification and quantification of fire scenarios depending on applications
  - Comparison with metallic cylinders
- **Experimental work**
  - Heat transfer, thermal degradation & loss of strength
  - Material (lab) & cylinder (full) scale
  - Bonfire tests matrix based on relevant scenarios
- **Modelling**
  - Thermo-mechanical behaviour of the vessels
  - Model validated by full scale fire tests

Results of fire tests on Hexagon 36 L type IV vessels without any protection

- **Two failure modes**
  - Burst when initial pressure 525 or 700 bar
  - Leak when initial pressure 100 or 250 bar
- **Cylinders equipped with thermocouples**
  - Wound inside the composite
  - Slightly decrease the time to burst
  - Allowed checking the heat transfer model
- **Good reproducibility**
  - Two vessels @700 bar burst at rsp. 238 s and 240 s
  - Temperature evolutions inside composite thickness are similar



Modelling approach in the project

UEdin / CNRS
Thermal properties decomposition model

CNRS
Mechanical properties

INERIS
Experimental data on bonfire

⇩

Siemens
Continuum Damage Mechanics
3D simulation

+ : Potentially any fire case
- : Heavier computation

CNRS
Progressive Failure Analysis
Axisymmetry simulation

+ : Short computation time
- : Only engulfing fires

Calibration at sample scale (samples cut from large vessels)

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Validation at vessel scale (prediction of INERIS tests results)

Mechanical degradation in range 20°C – 150°C

experimental data obtained at sample scale

Effect of combustion (charring kinetics)

controlled by temperature, no explicit modelling

Thermal expansion

Deactivated

Thermal properties of composite

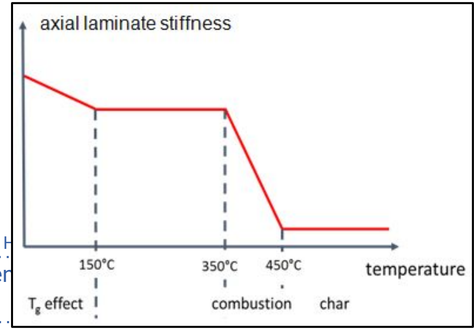
data (k and Cp) from UEdin

Emissivity

ε = 0.91 (from LEMTA)

Convection

SIEMENS: yes
CNRS: no



Failure criteria

Burst

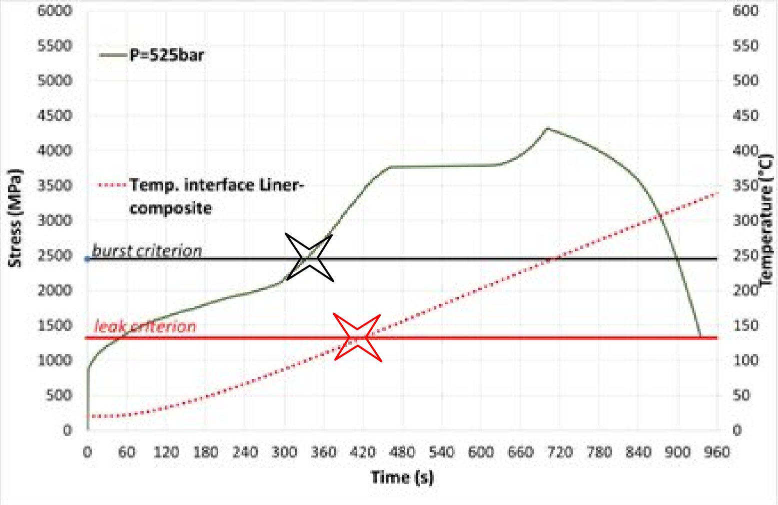
One composite layer is stressed above its rupture stress

It was found that the burst is very quick after a first layer fails

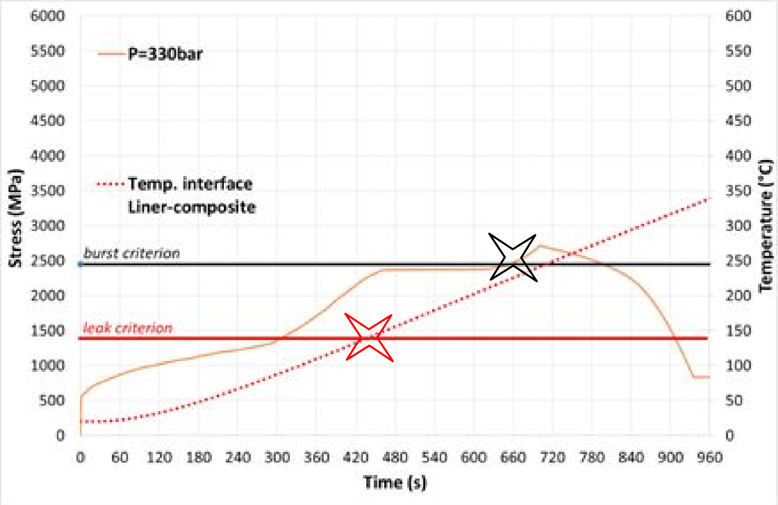
Leak

Temperature at liner / composite interface reaches melting temperature of HDPE (135 °C)

Simplified criterion, not verified - out of the scope of the project



Initial pressure **525 bar** => **burst** occurs first



Initial pressure **330 bar** => **leak** occurs first

Results of the heat transfer model

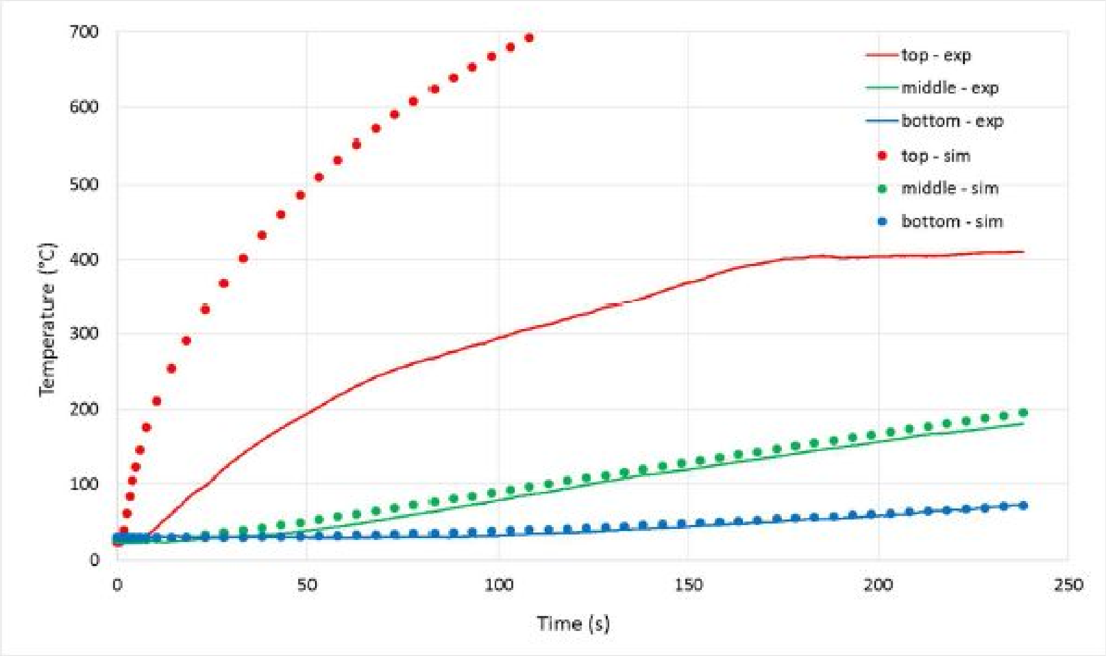
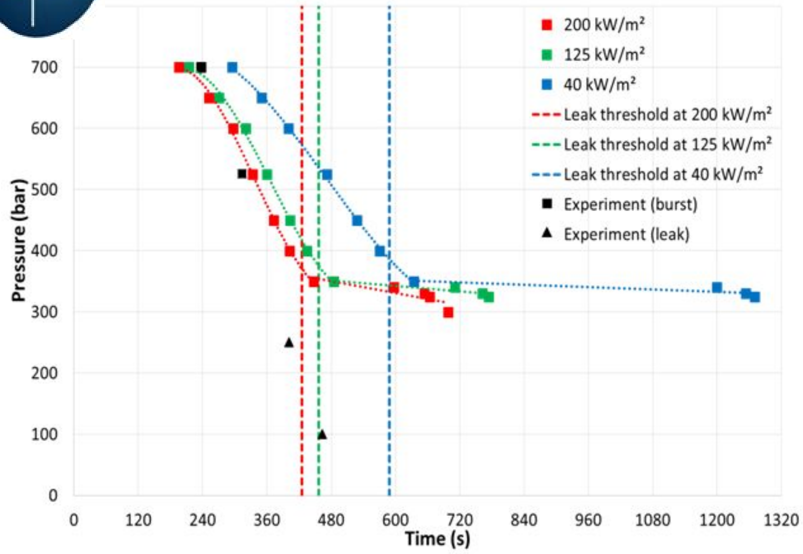
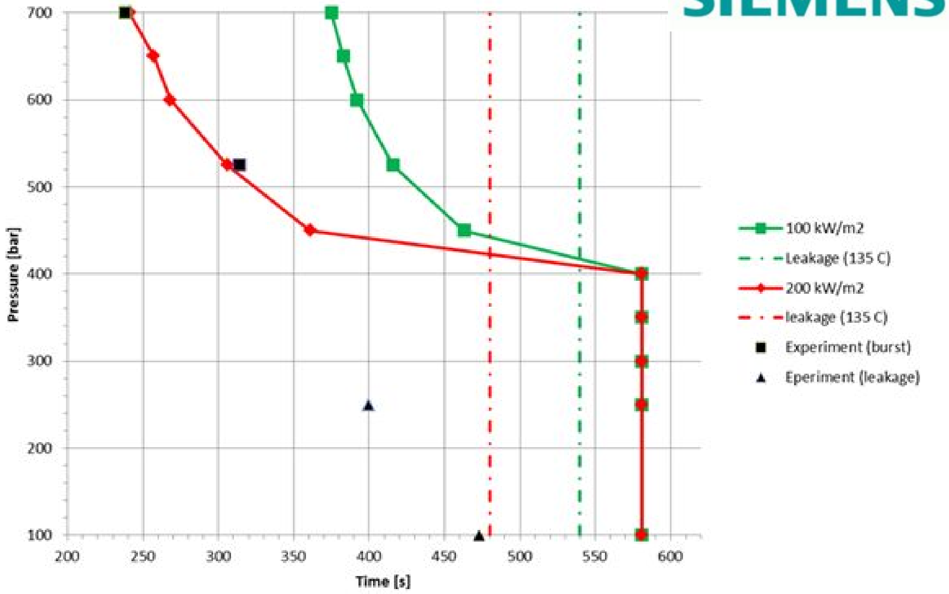


Figure 18: Comparison experiment / simulation of the temperature evolution (incident flux 100 kW/m^2)

Predictions of both models





Both models proved able to accurately **predict the time to burst** and capture the **transition between burst and leak** failure modes

3

FireCOMP recommendations and example of application

Methodology proposed for fire testing

Current practice is to test both cylinder and TPRD simultaneously and **regardless of their integration** in a structure.

FireComp project aimed at understanding the behaviour of a composite pressure vessel in fire. Hence it is proposed, when qualifying a cylinder, to focus on getting information on what the cylinder can endure.

The proposed methodology is to separate

1 Performance of the cylinder alone

Fire test without protection in order to establish a **pressure relief curve** = "safe" pressure vs. time zone in a fire

By **cylinder manufacturer**, during **qualification** process

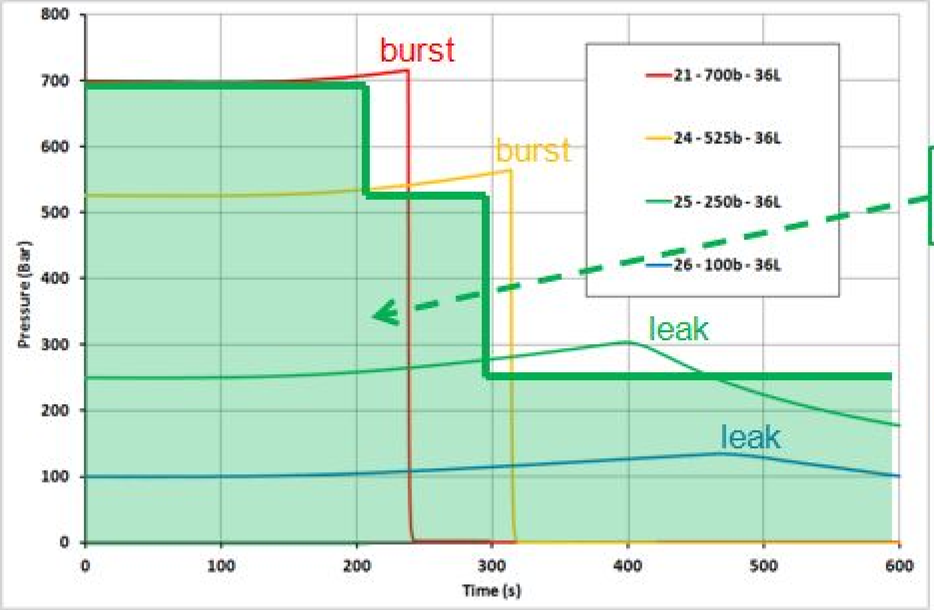
2 Safety of the complete structure

(e.g. Bundles, trailers, cars,...)

With a safety **strategy depending on the risk analysis** for the application; possibly including metallic frames, protections, fire detectors, pressure relief system...

By cylinder **end-user**, when designing a fire safety **strategy at structure level**

Safe pressure relief curve

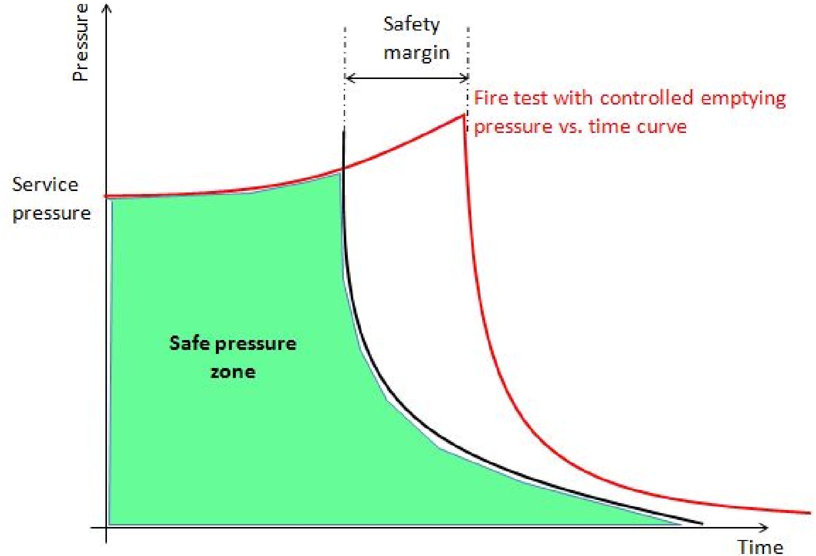


Safe pressure zone

The pressure relief system shall be designed for pressure to always be in this area in case of fire

Safe pressure relief curve

Possibly determined using only one tank...



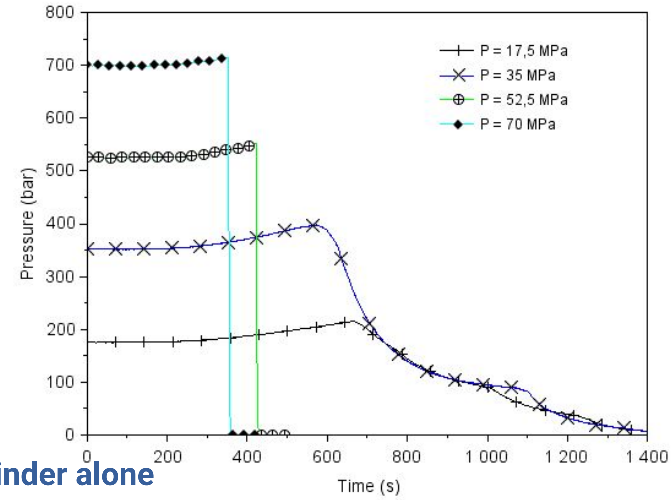
...or numerically predicted using models developed in the project

Information can be found in the following paper and its references:
D. Halm, F. Fouillen, E. Lainé, M. Gueguen, D. Bertheau, T. van Eekelen, Composite pressure vessels for hydrogen storage in fire conditions: Fire tests and burst simulation, *International Journal of Hydrogen Energy · July 2017 · DOI:10.1016/j.ijhydene.2017.06.088*

Example of application AL hydrogen bundle

High pressure bundle

- 4 * 143 L @700 bar
- Safety distance for 50 mbar overpressure in case of burst: 34 m => not acceptable for this application



Fire tests on cylinder alone

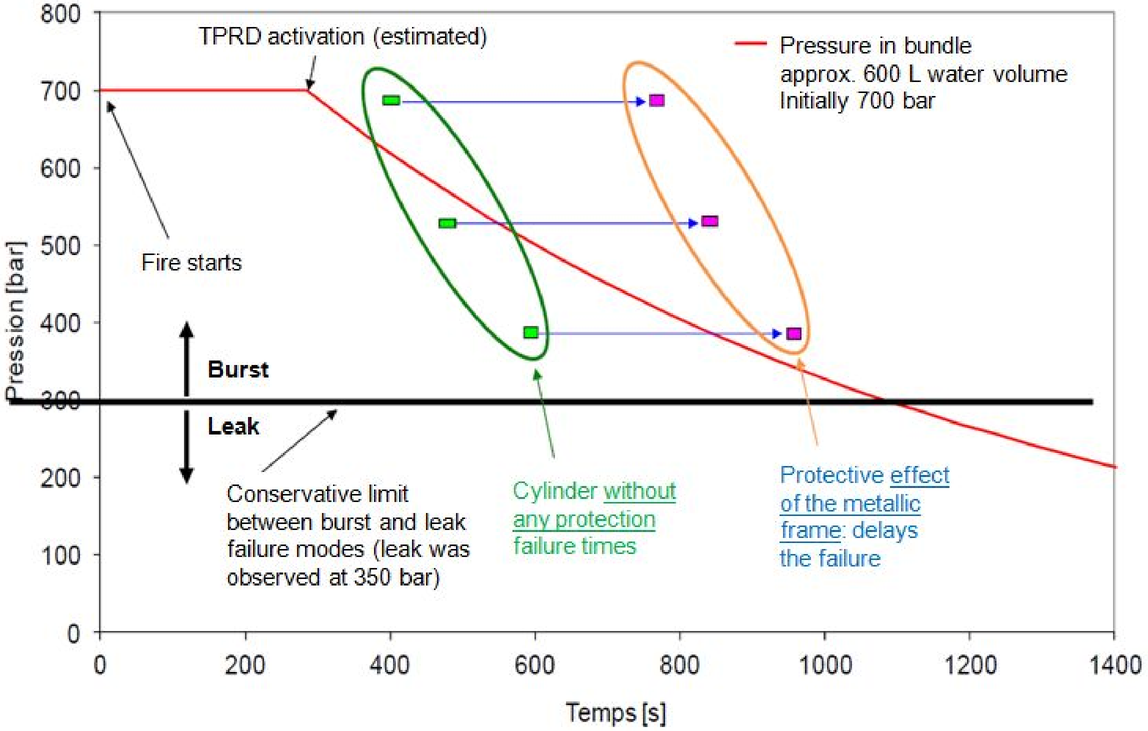
- Measure of the time to burst / leak
- Too short time for an acceptable flame length if ignited release => metallic frame to delay the fire

Fire tests with the frame

To assess the delay provided

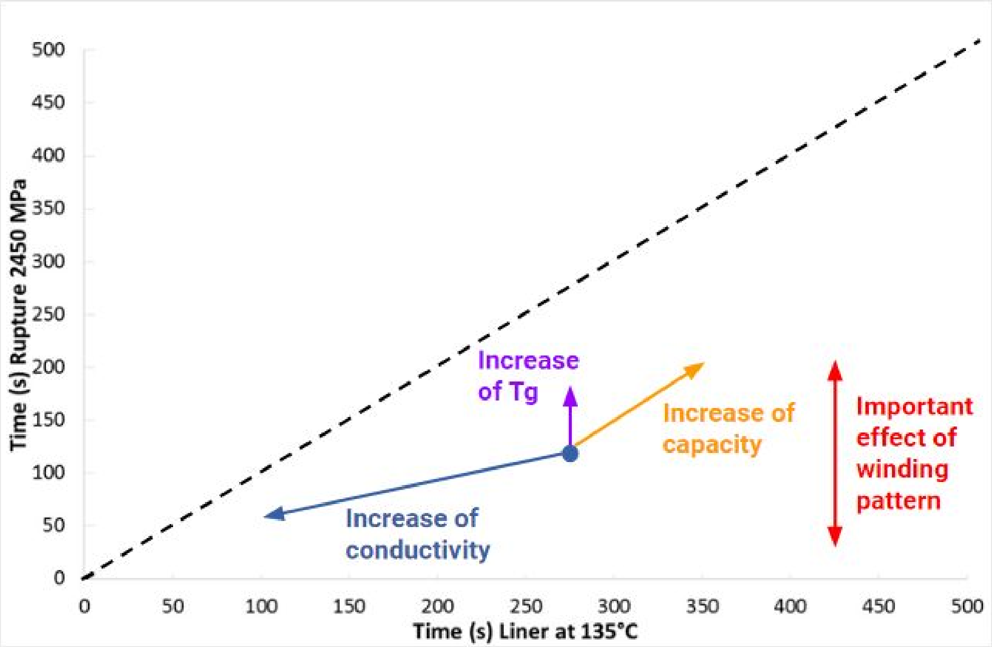
The frame also makes the **fire detection** by TPRD more reliable and protects vs. **local fires**

Summary of the fire safety strategy for the bundle



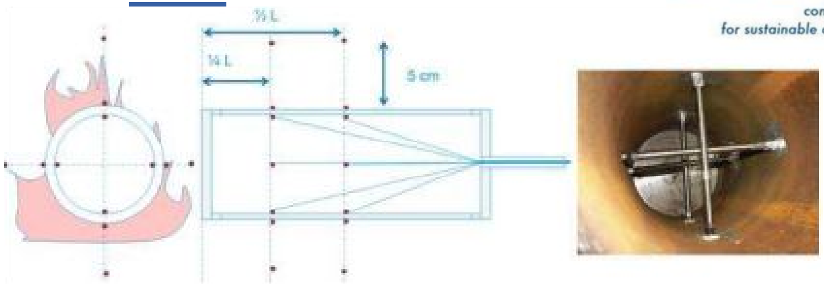
Future paths of research ?

- **Fire detection capacity**
  - Improved TPRD fire detection capacity for large cylinders
  - Smart cylinders with embedded fire detection
- **New materials**
  - Behaviour of thermoplastic cylinders in fire
- **Leak-no-burst designs**
  - Materials & cylinder design to favor leak even at MAWP



Thank you for your attention.

Calibration of thermal aggression



Thermocouples inside and around steel cylinder

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The evolution of the **gas temperature** inside the metallic cylinder allows determining the **net heat flux** it absorbed

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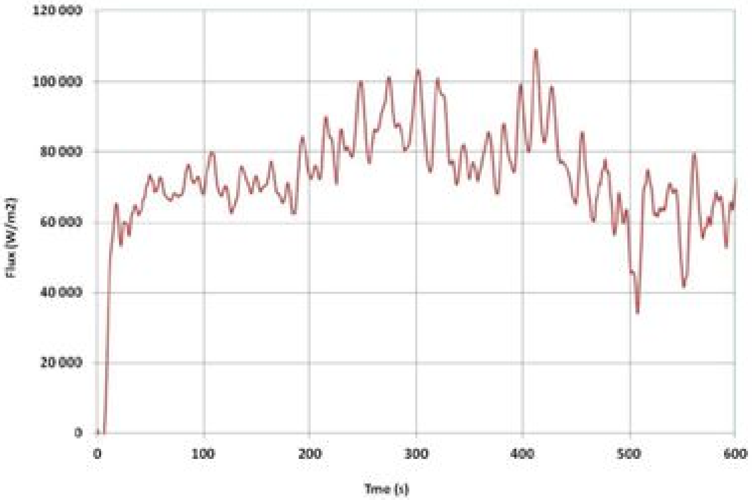
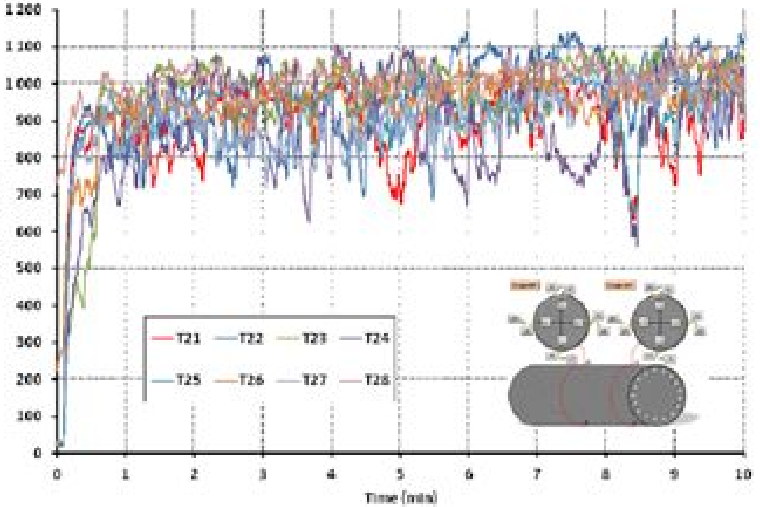
Calibration of heat flux and temperature

Net heat flux absorbed by the metallic cylinder

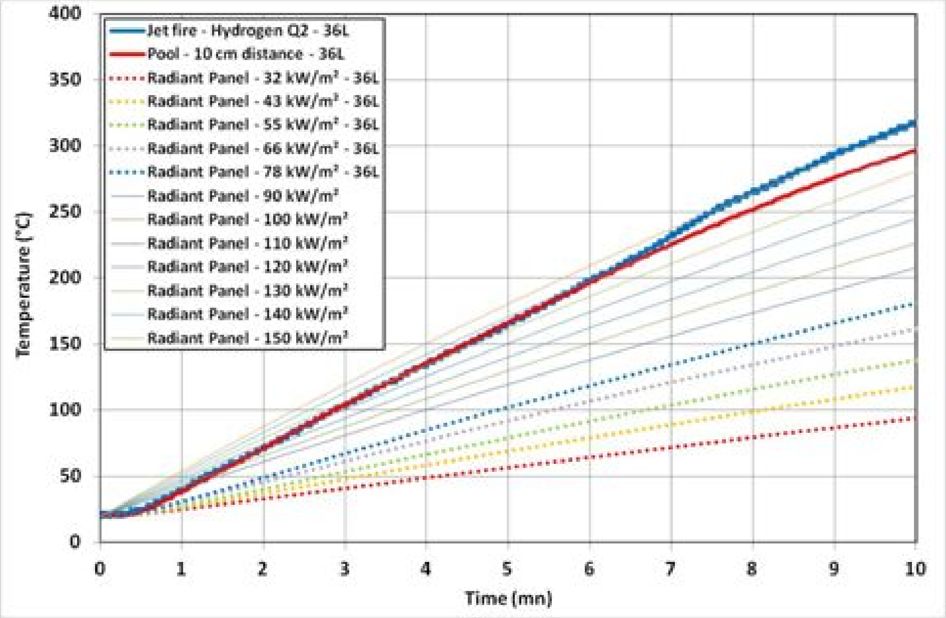
Average **90 kW/m2** between 200 s and 400 s



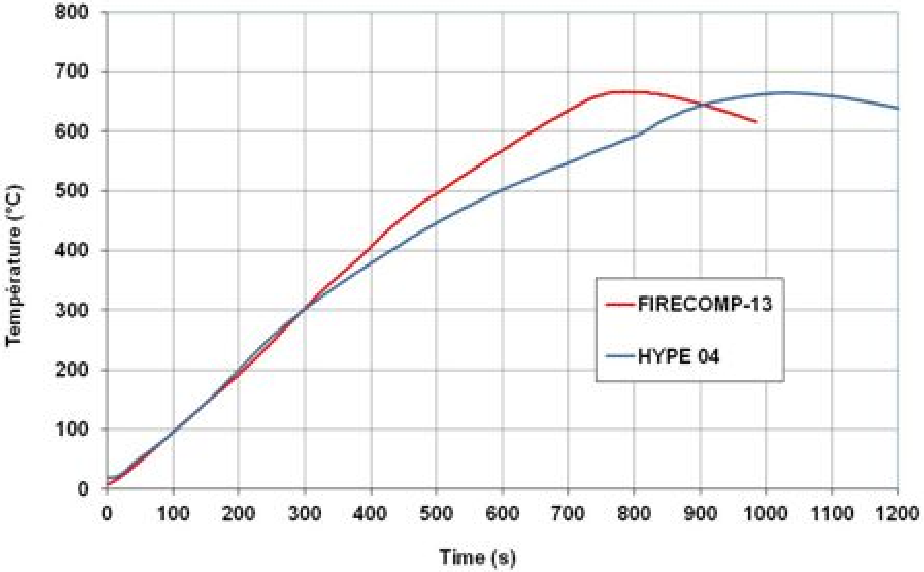
Temperatures recorded at 5 cm outside of the cylinder display a good homogeneity and fluctuate between **800°C and 1000°C**



Calibration of thermal aggression H_2 burners vs. pool fire



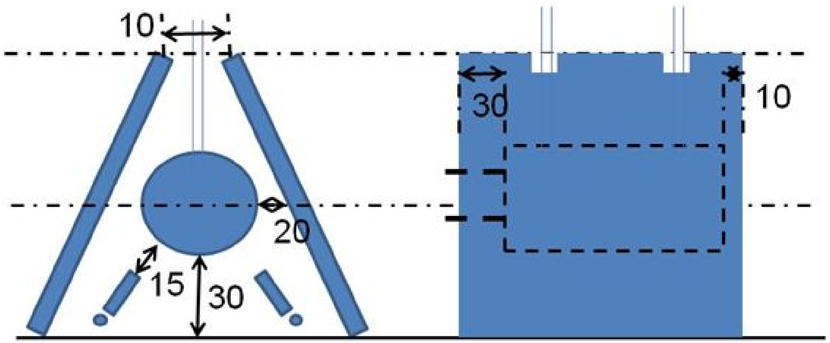
For 36 L cylinders, the injection flow rates retained allow to reach the **same temperatures as with classical pool fire**

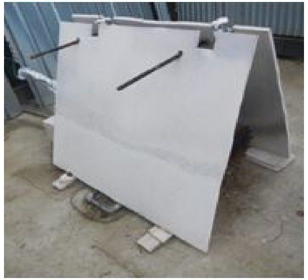


With results that **meet bonfires performed in the past**

Fire test setup @INERIS

controlling risks for sustainable development

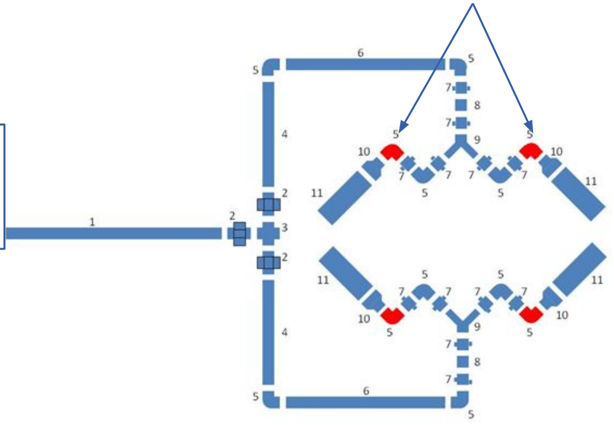




Hydrogen gas burners

4 burners, with each
1,5 g/s hydrogen
0,5 g/s oxygen

Oxygen alimentation points



- Hydrogen gas fire is a realistic scenario
- Gas fires are easier to calibrate and more reproducible than pool bonfire
- Calibration tests performed on steel cylinders to optimise:
  - The confinement
  - The needed hydrogen flow rate
  - The oxygen injection
- Complete definition regardless of the cylinder size