FIRECOMP

Modelling the thermo-mechanical behaviour of high pressure vessel in composite materials when exposed to fire conditions

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PROJECT OVERVIEW

Project Information	
Call topic	SP1-JTI-FCH.2012.5.4 - Pre-normative research on fire safety of pressure vessels in composite materials
Grant agreement number	325329
Application area (FP7) or Pillar (Horizon 2020)	FP7
Start date	01/06/2013
End date	31/05/2016
Total budget (€)	3 543 498
FCH JU contribution (€)	1 877 552
Other contribution (€, source)	
Stage of implementation	100% project months elapsed vs total project duration, at date of November 1, 2016
Partners	**AIR LIQUIDE/HEXAGON/CNRS/INERIS/LMS SAMTECH/ University of Edinburgh/HSL/AYMING**

PROJECT SUMMARY

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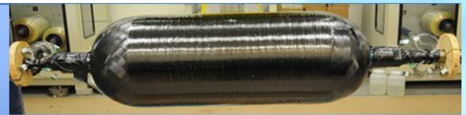
To exploit the benefits of hydrogen at large scale, in particular the storage of hydrogen must be secured.

Under normal working conditions a burst in service of a composite vessel is very unlikely, but when exposed to a fire the integrity of the composite material can be compromised and presents safety challenges.

=>The main objective of the FireComp project:



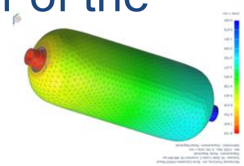
Better characterize the conditions that need to be achieved to avoid burst of composite vessels for CGH2 storage.

- To this aim, Experimental work to improve the understanding
  - heat transfer mechanisms
  - loss of strength

  of composite high-pressure vessels in fire conditions.

coupled with

Modelling of the thermo-mechanical behaviour of the vessels



- Both stationary and mobile applications considered : automotive application, transportable cylinders, bundles and tube trailers.

PROJECT PROGRESS/ACTIONS - Aspect 1

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Achievement to-date

% stage of implement.

HT and degrad. mechanisms

Loss of Strength

25% 50% 75% 100%

Thermo-mecanical model

Aspect addressed	Parameter (KPI)	Unit	SoA 2016	FCH JU Targets		
				Call topic	2017	2020
Model integrating the thermo-mechanical behaviour of the pressure vessel in fire conditions	Understanding of the heat transfer and degradation mechanisms	Na	Need to define interaction between flame/composite during typical fire, (exp. and modelling)	Model integrating the thermo-mechanical behavior of the pressure vessel in fire conditions	Specific technology assessment tailored	Innovative safety strategies and safety solutions
	Understanding of the loss of strength of the vessel	Na				
	Thermo mechanical model on lab scale	Na				

PROJECT PROGRESS/ACTIONS - Aspect 1

Conclusions and Future steps:

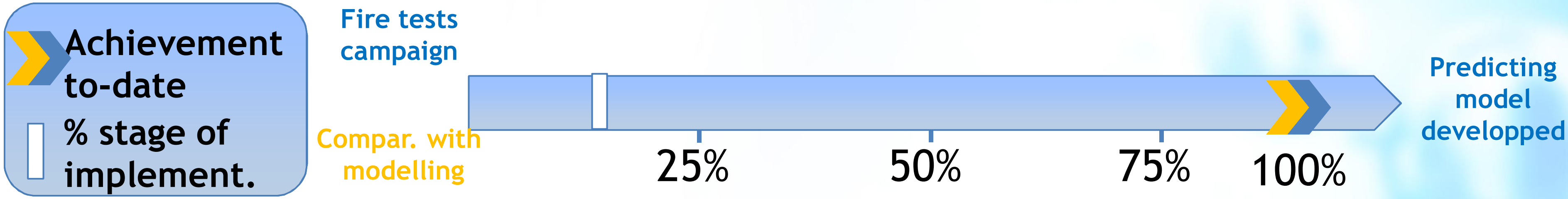
When degradation rate of a specific composite material is known, FireComp has demonstated that it is possible to determine the remaining performance of structural material by modelling and calibration.

Degradation speed is mostly depending on resin behavior and type of fire

If resin and fire exposure is unchanged, the degradation of the composite material will be about the same and independent of the diameter of the cylinder (mostly driven by degradation of the resin) and independent of the length of the cylinder.
The structural lay up (fiber orientation) might influence marginally on the degradation rate, and not more than what can be adjusted for by a correction factor or within the safety margin defined.
If a specific composite material behavior in fire is known, the needs for performing fire test of composite cylinders are substantially reduced.

No need for new fire test if valve or Pressure Relief System is modified, as long as the new Pressure Relief System match the performance of the composite material in fire.

PROJECT PROGRESS/ACTIONS - Aspect 2



Aspect addressed	Parameter (KPI)	Unit	SoA 2016	FCH JU Targets		
				Call topic	2017	2020
Experimental validation of the model and validation of the model	Definition of the test matrix and tests conditions	Na	Predictibility of numerical tools not sufficient, need of thermo-mechanical one, no clear definition of a breach criteria	Experimental validation of the predicting model	Develop predicting model	Innovative safety strategies and safety solutions
	Realization experimental test campaign at full scale	Na				
	Comparison predicting model with exp. Results at full scale	Na				

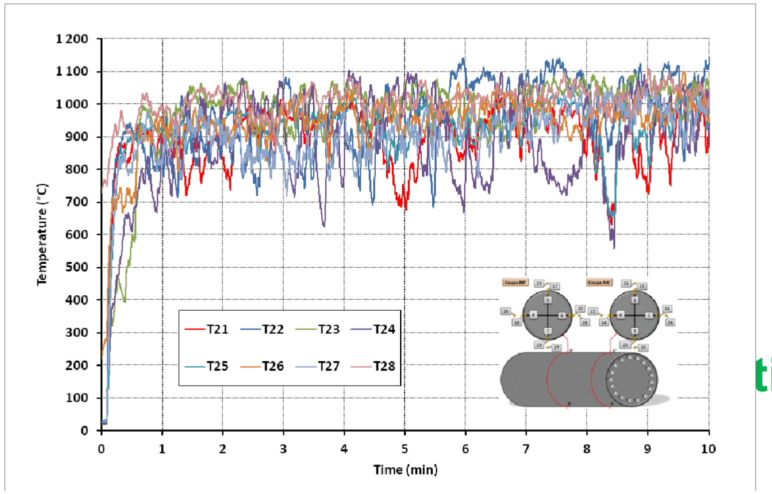
PROJECT PROGRESS/ACTIONS - Aspect 2

According to the fire scenarios study performed in WP2, the cylinder should be submitted to an **engulfing bonfire test**.

The cylinder can be pressurised with **helium** or **nitrogen** instead of hydrogen.

All fire setups (pool fire, gas burners) are acceptable as long as they produce a satisfying heat flux – see next slide for **fire calibration**. An alternative setup using a gas burner is proposed in FireComp WP5.

If the cylinder is too big for an engulfing fire (*e.g.* length > 1.5 m), a **partial exposition is possible as long as at least one of the domes is completely engulfed by the fire**.



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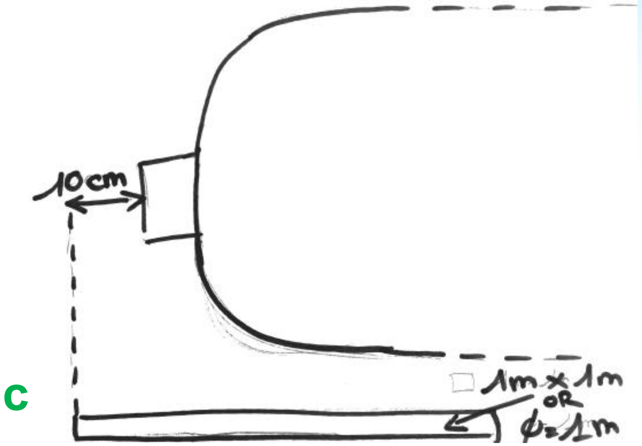

How to get information on the cylinder's performance?

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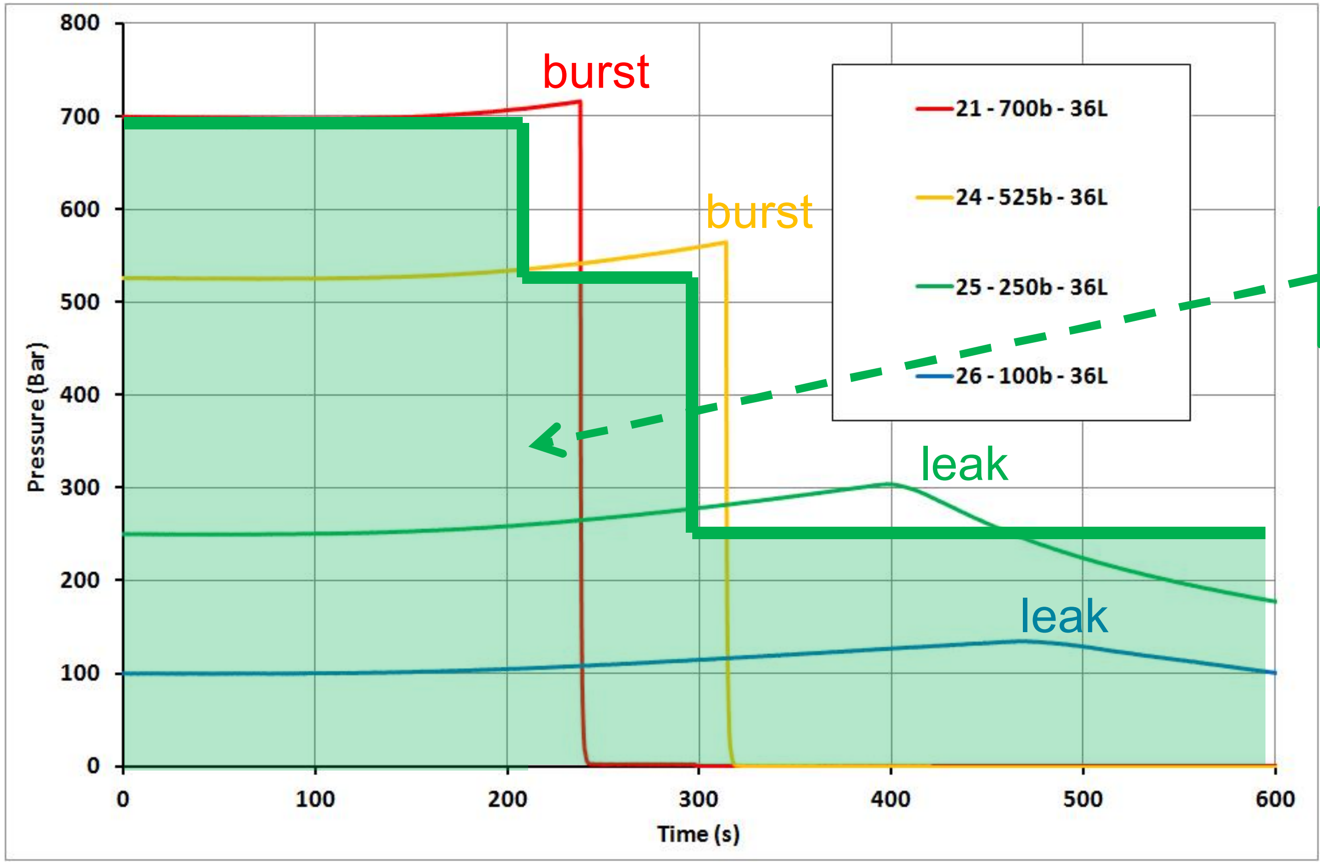
The goal is to obtain a **safe relief curve**:
Area of the pressure vs. time in fire graph for which there is **no burst of the cylinder**

Example: bonfire tests results from WP5 – Hexagon 36 L cylinders



Safe pressure zone

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

PROJECT PROGRESS/ACTIONS - Aspect 3

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Achievement to-date

% stage of implement.

Risk method

RCS mapping

25% 50% 75% 100%

Guidelines

RCS recomm.

Aspect addressed	Parameter (KPI)	Unit	SoA 2016	FCH JU Targets		
				Call topic	2017	2020
Proposed approach for standardization - Recommendations for implementation in international standards	Current fire approach for cylinders, RCS mapping and define risk methodology approach	Na	Discrepancies between standards, need for fire testing each time there is a change of tank, PRD, or major component.	Proposed approach for standard. - Recommendations for international standards	Compare policy and tech. Options Including altern. and competing tech. Dissem. prog. results include towards RCS	Assess against benchmark results
	RCS recommendations and guidelines: Propose a set of test to be performed (the vessel alone, and devices) Propose to review referenced goal of standard (obtain safe pressure relief curves instead of just resist 2 min)	Na				Best practices and guidelines for various FCH appli . Allow deployments

PROJECT PROGRESS/ACTIONS - Aspect 2

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- If a reliable pressure relief system is used, **composite cylinders have demonstrated equal or better behaviour in fire** comparable to metallic ones.

- **Fire scenarios might include both engulfing and localised fires**, which should be taken into account in any risk analysis. A well designed fire detection and pressure release system can protect the composite cylinders against both types of fire.

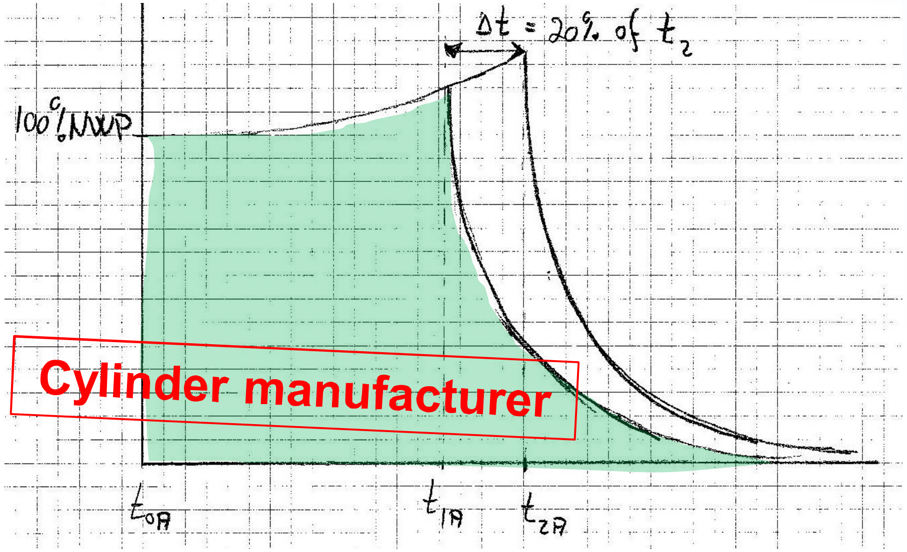
- A way of protecting the cylinder against punctual jet fires should also be used.

- Whatever measures taken to protect the composite cylinder in a fire, a **pressure relief system is needed for all types of fires.**

- The **performance of the cylinder alone** (without any protections) should be assessed in order to provide information to the integrator.

- Separate test/documentations of pressure release systems is needed, independent of cylinder geometry. Responsibility for use of adequate pressure release systems in any application can only be by the assembler/end-user. **System assembler should design and test his safety devices**

Determination of safety strategies



Design of the protective devices, for example:
Frames can be used to delay the time to burst
Position, number, orientation, diameter of the pressure relief pipes

?

?

?

Assembler / End-user

SYNERGIES WITH OTHER PROJECTS AND PROGRAMMES

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Interactions with projects funded under EU programmes (max. 5)	
HyCOMP	Useful to build the knowledge and the state of the art.
DELIVERHY:	Useful to build the knowledge and the state of the art.
Hypactor	Useful to build the knowledge and the state of the art. Exp. Tests done contribute to confirm the knowledge of the composite behaviour (useful for modelling).

Interactions with national and international-level projects and initiatives (max. 5)	
SUPERGEN -Integrated safety strategies for onboard H2 storage	EPSRC ref EP/K021109/1, face to face meetings, Exchanges and expert networking on modelling and composite behavior.
Warwick Fire	http://www.warwick.ac.uk/warwickfire, share of modelling practices
H2E –Horizon Hydrogene energie (BPI)	knowledge acquired in this project allows critical to advance in the definition of the bonfire experimental set-up and the questions on protections sizing strategies

DISSEMINATION ACTIVITIES

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Public deliverables

- D6-1-Website regularly updated
- D6.4- Transcription of project results into safety guidelines
- D6-5- Recommendation for RCS
- D6-6-Current fire approach for cylinders, RCS mapping and project expected outcomes

Conferences/Workshops

- 1 organised by the project
- 26 in which the project has participated (but not organised)

Social media

Only on website

- **Publications and proceedings:** 18
- Determination of the tensile residual properties of a wound carbon/epoxy composite first exposed to fire, Journal of composite materials, 2106
- Simulation of Burst of hyperbaric hydrogen tanks in fire conditions, 17th ECCM, 2016

Patents: no

-

HORIZONTAL ACTIVITIES

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Training and education

- Some partners are directly members of University and PhD. students contribute also.
- INERIS and HSL have in their own missions to provide information to train potential users from industry and national regulation. Air Liquide and LMS SAMTECH participate to educational trainings.

Safety, Regulations codes and standards

- Hexagon very involved in the WG targeted for project recommendations (ISO TC58-SC3 and ISO 197).
- Air Liquide as composite cylinder user also part of these RCS discussions
- Joint recommendations about fire testing submitted to ISO groups

Public awareness

- Works performed within the project are sensible for public awareness.
- INERIS and HSL are mandated by their country to provide the right level of information for end users.
- RCS recommendations will also be public on the web site

Thank You!

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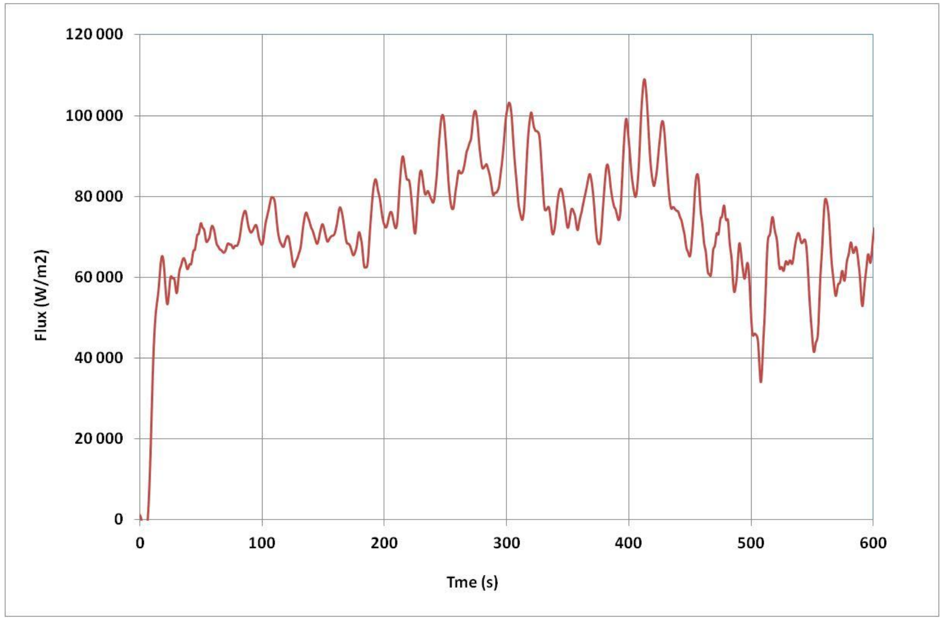
Calibration of thermal aggression

Fire should be calibrated to ensure a satisfying thermal aggression.

This can be done by **exposing a metallic mock-up** to the fire setup and record its **internal temperature increase**.

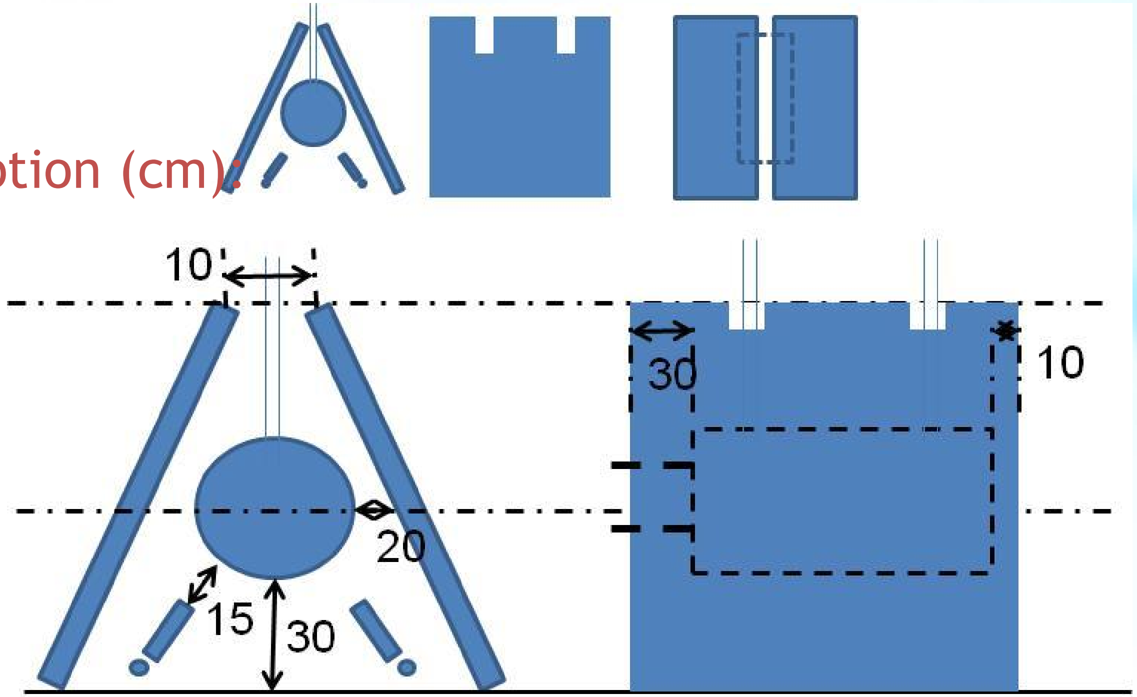
The **net heat flux** absorbed by the metallic tube can then be calculated (see appendix for the calculation).

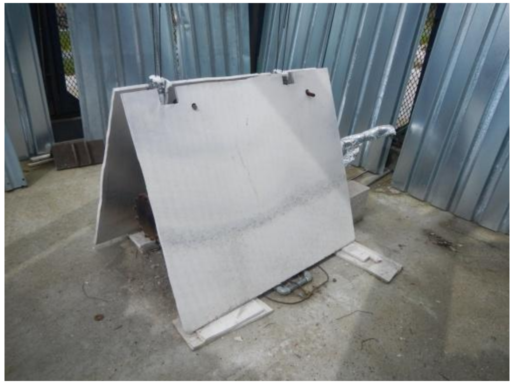
It should be stay between 60 and 100 kW/m² with an average value of 80 kW/m².



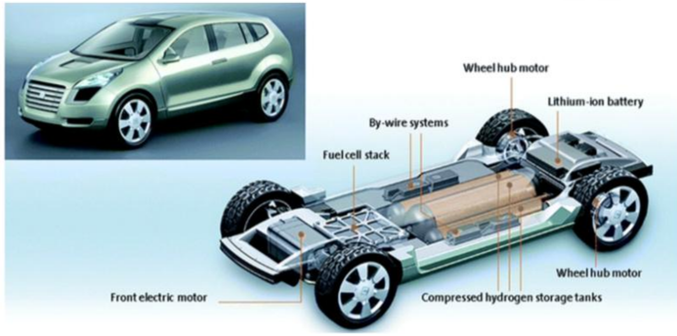
Example of FireComp fire setup

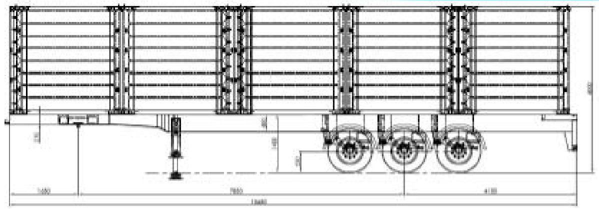
– Cover description (cm):

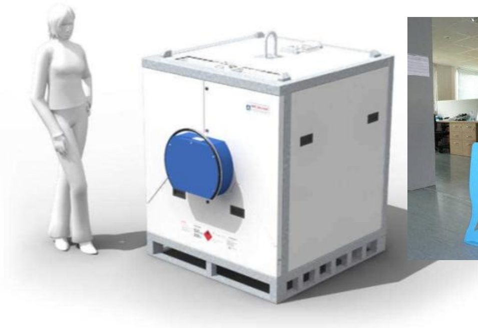


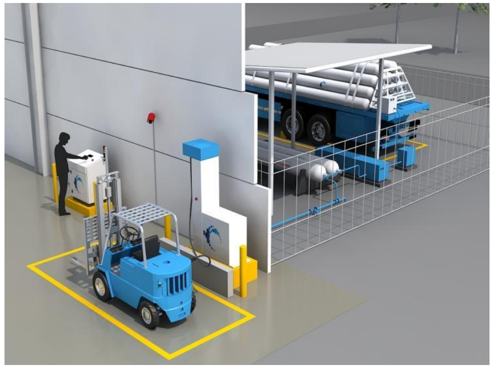


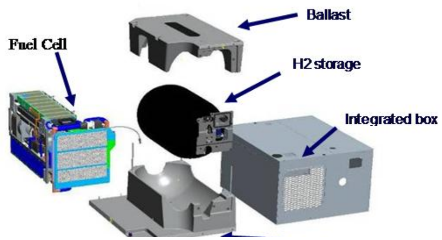
Firecomp Hydrogen systems



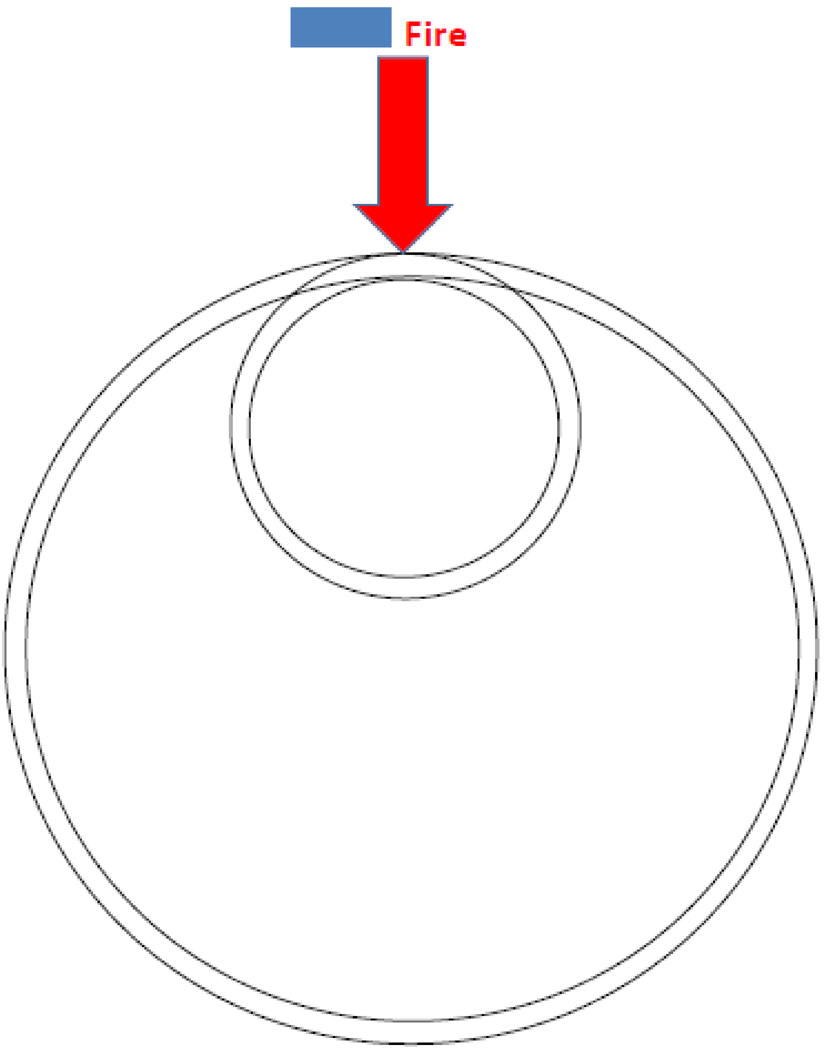








Direct extrapolation from smaller cylinder



Particular case

Small and large diameter cylinders
Different service pressure
Same composite material (CF & Resin)
Same wall thickness
Same safety factor

If the **winding sequence is comparable** (*i.e.* the mechanical load through the thickness is the same for both cylinders)

Then the safe relief curve will be the same for both cylinders.

Smaller high pressure cylinders can be used for characterization of larger diameter lower pressure cylinders and visa versa

Numerical simulation

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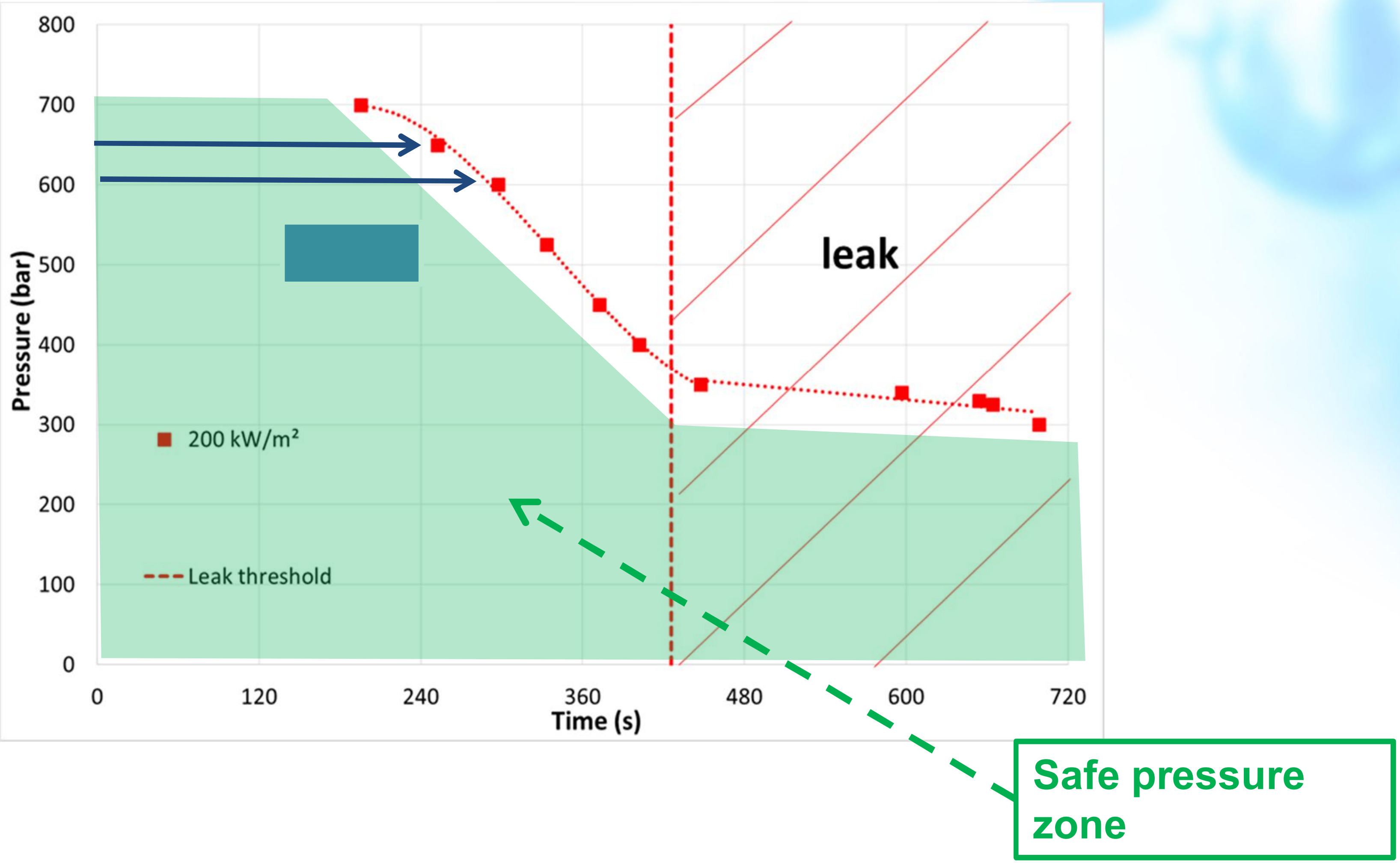
Numerically determined pressure relief curve for HEX 36 L – CNRS model



Numerical simulation

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Numerically determined pressure relief curve for HEX 36 L – SIEMENS model