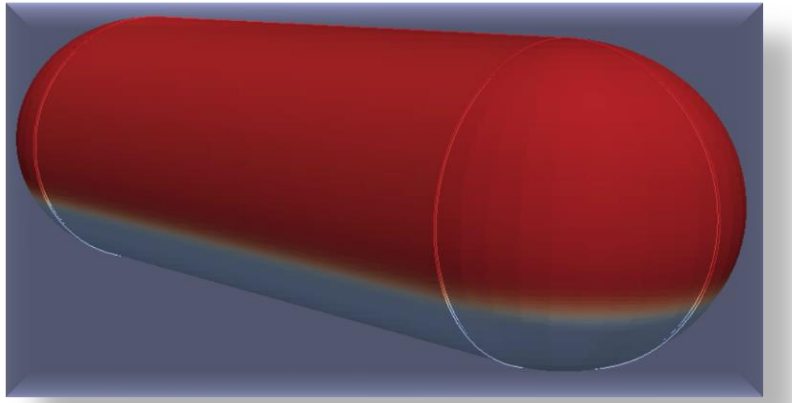
Model for the thermal response of Liquefied Petroleum Gas Tanks subjected to accidental heat input



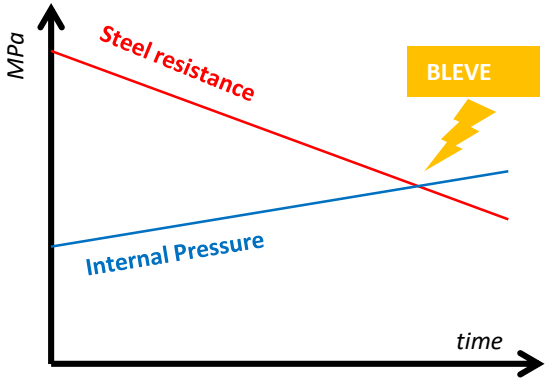
Etienne CATRY – Shihab Rahman
INERIS
Accidental Risk Division
BLEVE WG Madrid 10-2019
DRA-19-178007-07436A

INERIS
maîtriser le risque
pour un développement durable

Summary

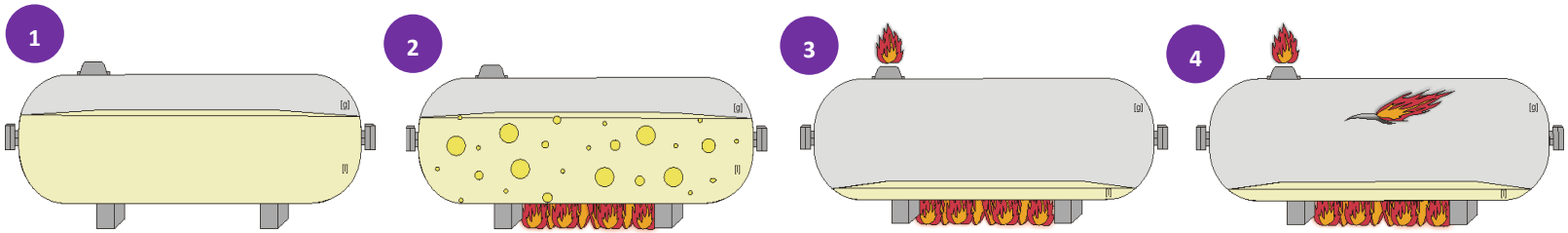
- Introduction
- INERIS model presentation
- Calculation on tanks subjected to specific fire scenario
  - Tyres fire
  - Pool fire
  - Cabin fire
  - Jet fire
- Summary of last years calculations
- Conclusion

Introduction – Context



Behaviour diagramm of the tank

BLEVE scenario



The tank is filled

Tank is located in fire
Boiled liquid

Pressure increases
Liquid level drops
Safety valve opens

Pressure continues to rise
Strength reduction of steel
Tank wall cracks

INERIS
maîtriser le risque
pour un développement durable

Methodological approach used for INERIS model

Calculation of fire devlopment
- Thermal load

Input
- Steel wall characteritics (diameter, thickness,…)
- Thermal protection (safety valve, coating)
- Lading characteristics (Level filling, Products)
- External thermal load characteristics

MECHANICAL MODEL ⟷ **THERMAL MODEL**

Failure Criterion : Loss of containment

Model Results
- ✓ Temperature distribution in the tank shell
- ✓ Temperature distribution in the lading
- ✓ Pression evolution
- ✓ Level filling evolution
- ✓ Stress cartography in the tank shell

✓Effective protection ← **No collapse**

Collapse → ✓Effectiveness of the measure depending on time to failure (to be defined by authorities)

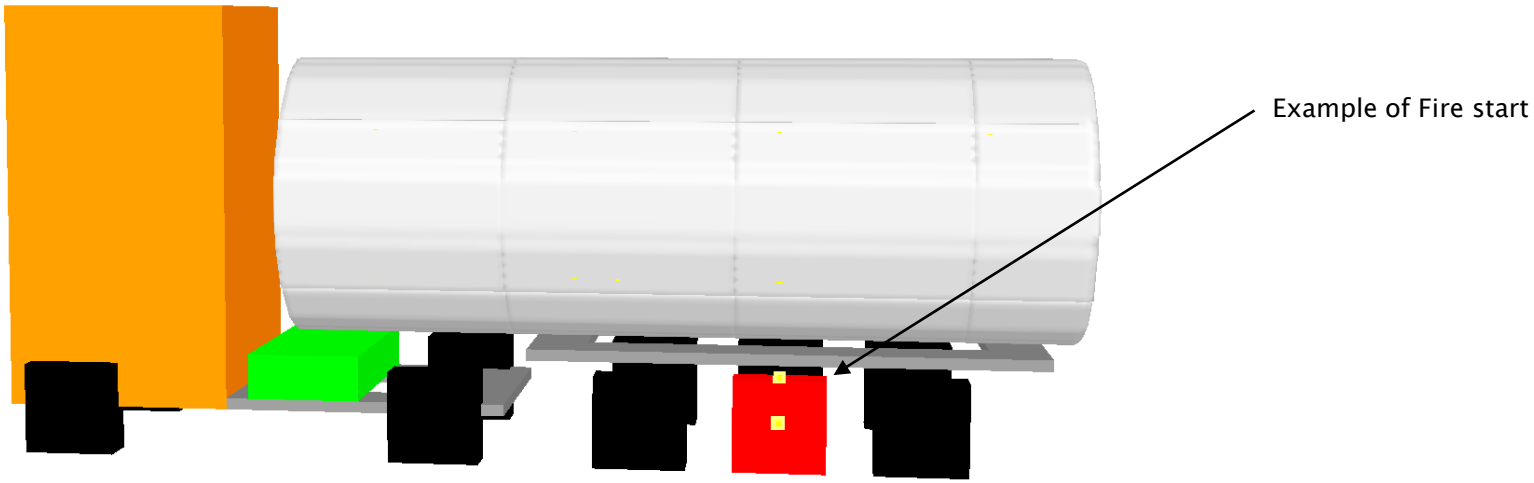
✓Non effective protection

INERIS
maîtriser le risque
pour un développement durable

Model presentation : Fire computation code : FDS (Fire Dynamics Simulator)

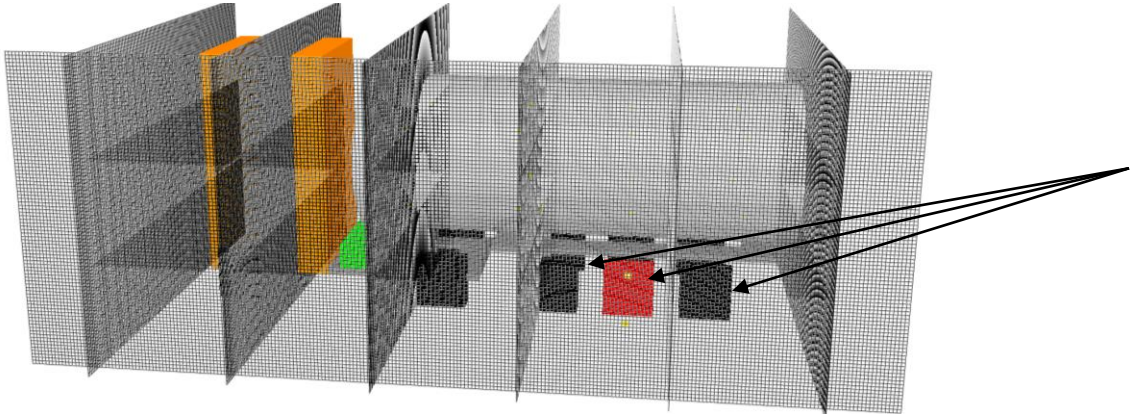
3D-calculations performed with FDS model developed by NIST solving physical quantities as functions of space and time:

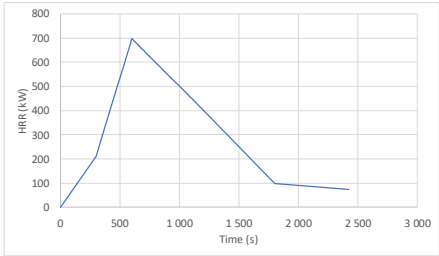
- CFD model of fire-driven fluid flow, relevant for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires
- Based on Large-Eddy-Simulation (LES) turbulence model
- Coded to allow massively-parallel computing on Superclusters



Model presentation : Fire computation code : FDS (Fire Dynamics Simulator)

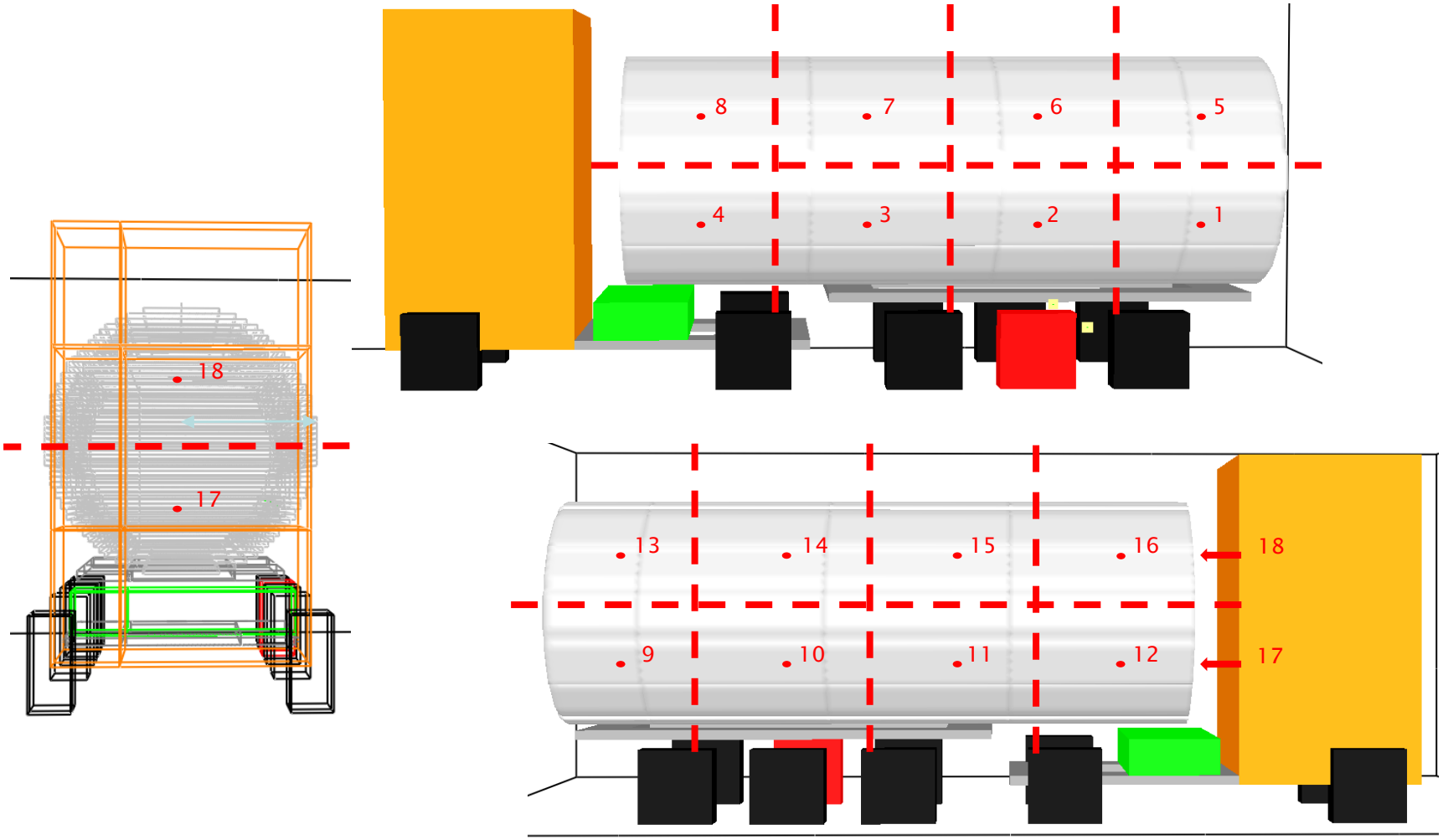
- General assumptions:
  - Truck dimensions : cabin (2m X 2m X 3.5m) ; tank (2.5m X 7 m) ; wheels (0.8 m X 0. 35 m)
  - Mesh size : 5 cm X 5 cm X 5 cm, 3 024 000 cells divided in 72 domains for parallel computing
  - Calculations performed on COBALT supercluster (1500 Tflops) of CCRT (Centre de Calcul Recherche et Technologie)
- Physics assumptions:
  - Prescribed heat release rate based on experiments for each combustible element. Max HRR for tyres : 700 kW ; for cabin : 20 MW ; for gasoline pool : 2400 kW/m²
  - Fire propagation criterion between each combustible elements : 12 kW/m²





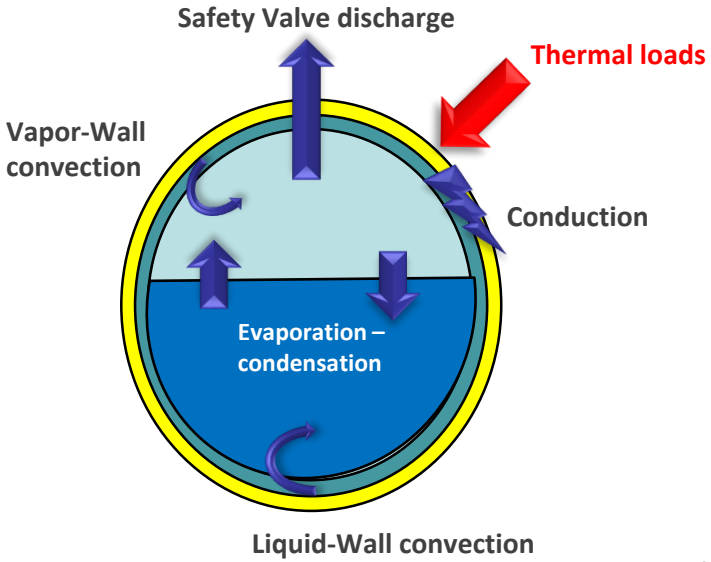
INERIS
maîtriser le risque
pour un développement durable

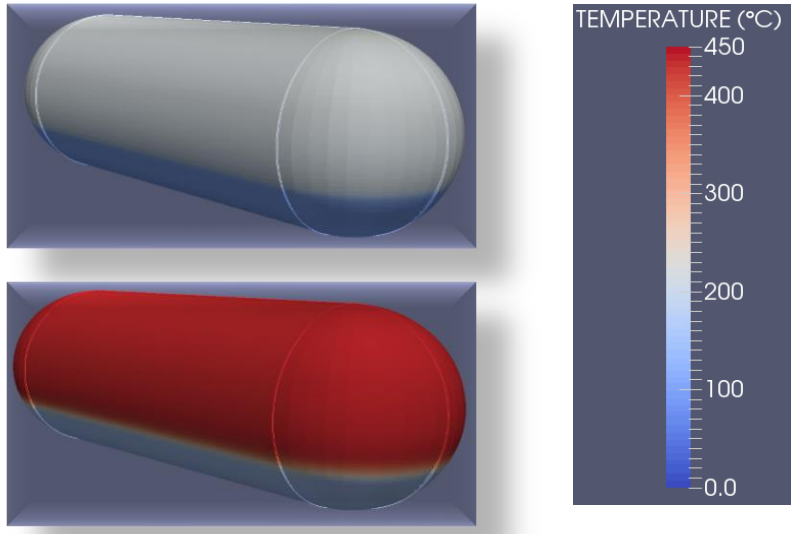
Positions of numerical sensors for BLEVE calculation



Description

- Models characteristics
  - Finite elements model for the tank shell (insulation + steel wall)
  - Analytical approach with a 2 phase model for the content. This model provides relevant results for tanks with a maximum capacity as used in transport (up to 100 - 150 m^3). This approach is widely used in industry (ex : Vessfire software developed by Petrell As)
  - **Objective**: To predict the temperature (for both phases) and pressure evolution of tanks (with or without coatings) when submitted to heat input.





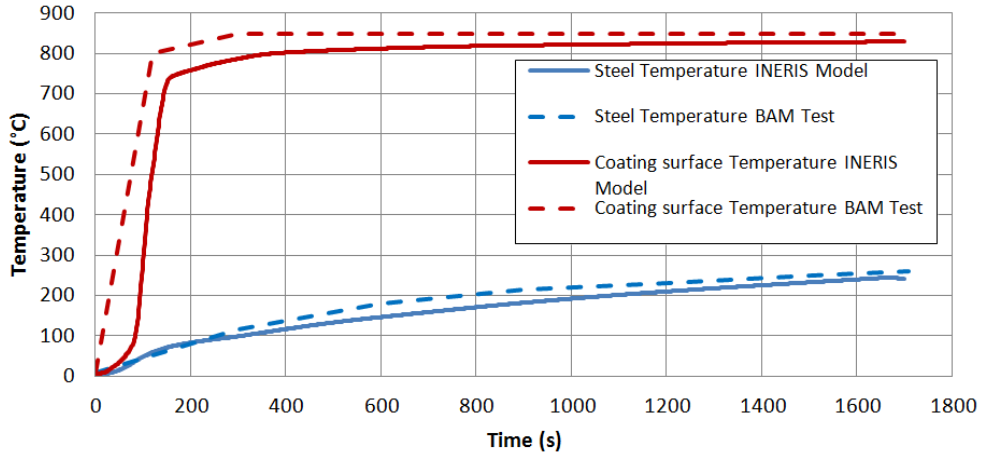
Thermal transfers in LPG tanks under thermal loads

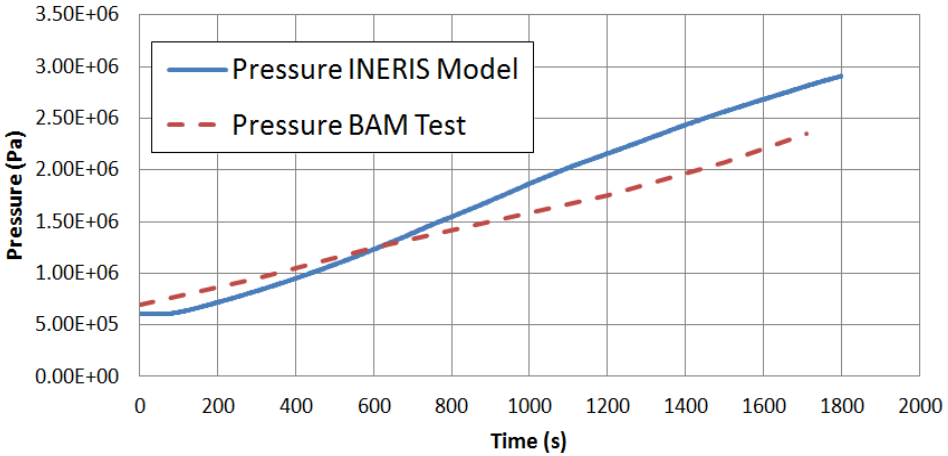
INERIS
maîtriser le risque
pour un développement durable

Validation – comparison with experiments

- Example: BAM test carried out in the frameworks of the Working Group dedicated to “BLEVE reduction” in 2013
  - Very good reliability

View of the tank after the test

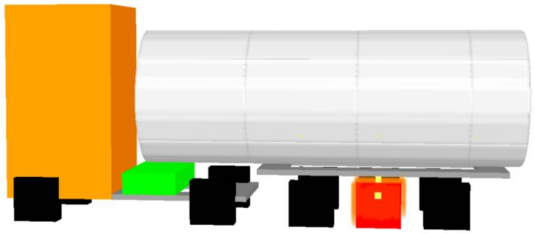




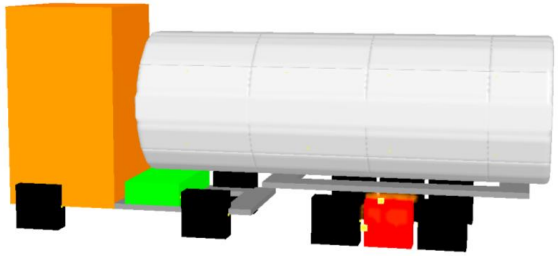
INERIS
maîtriser le risque
pour un développement durable

Fire locations of interest

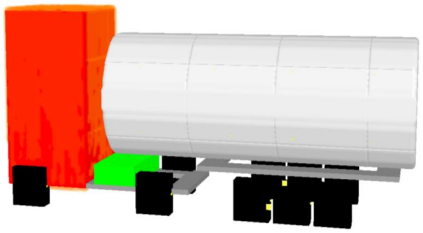
- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% / 50% / 10% filling rate



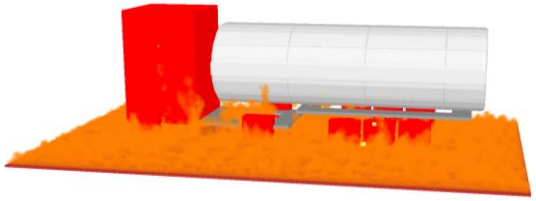
Tyre fire (no propagation)



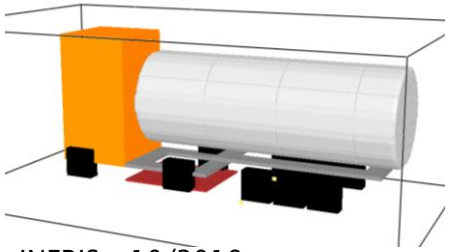
Tyre fire (propagation)

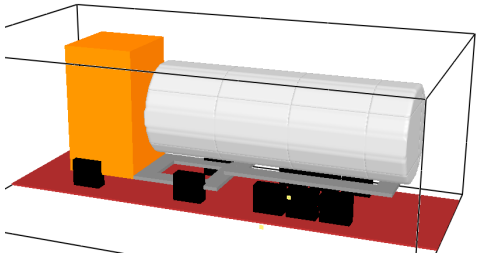


Cabin fire (no propagation)



Pool fire (different gasoline spill sizes)



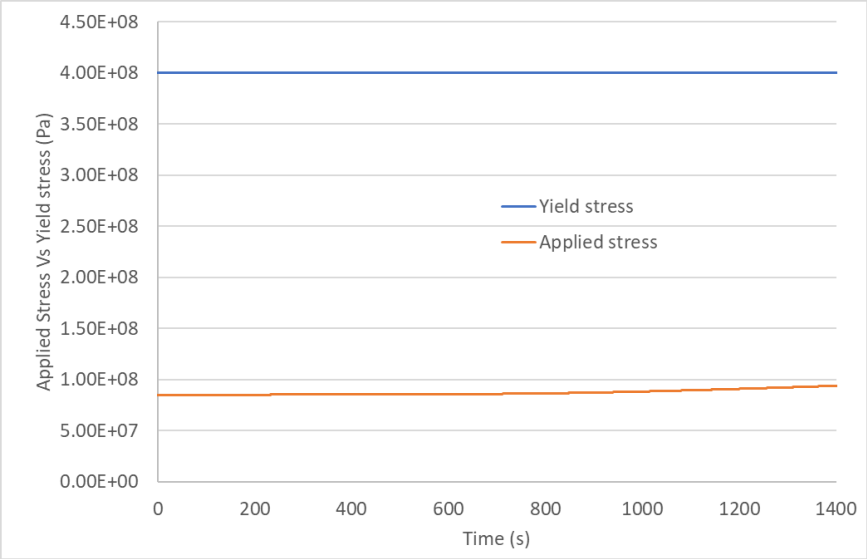


Jet fire
(simplified analysis)

Calculation results: fire start on tyre (no propagation)

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 50% / 10% filling rate

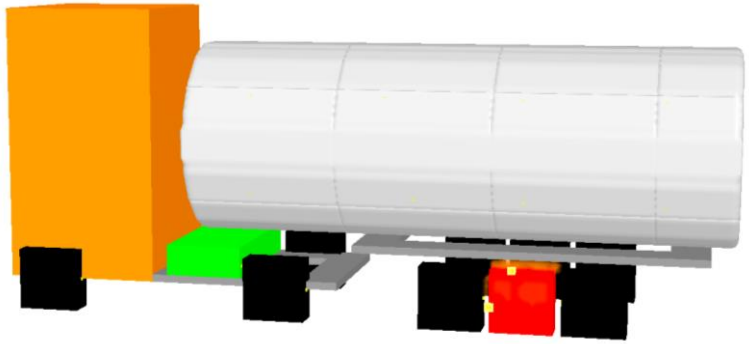
No risk of BLEVE for 50% / 10% filling rate



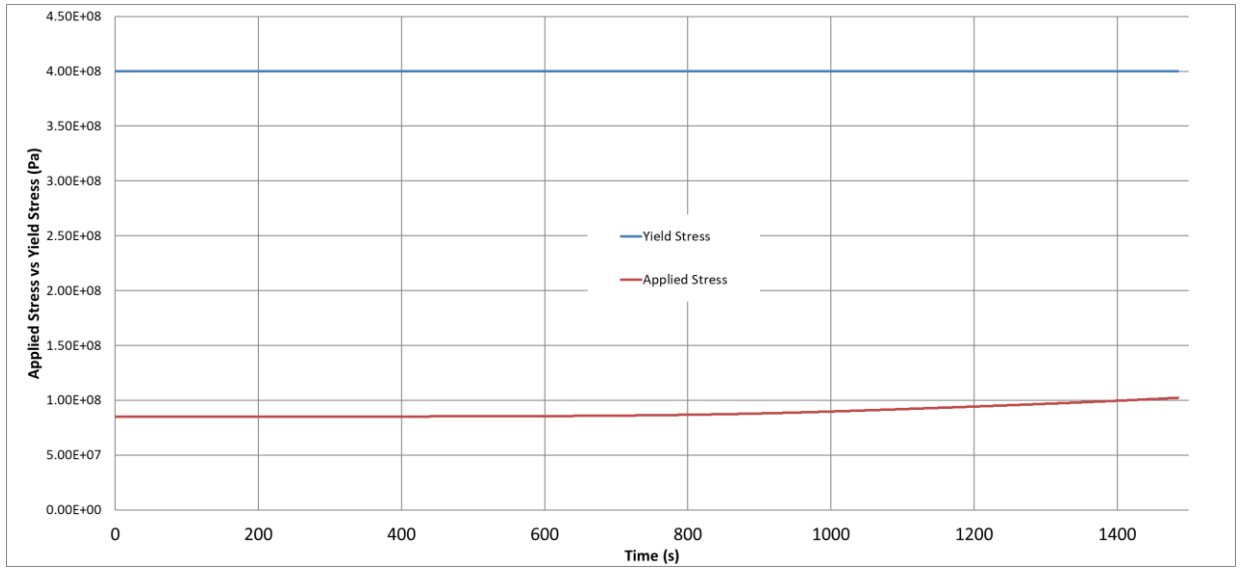
Calculation results: fire start on tyre (propagation to other tyres)

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 50% / 10% filling rate

No risk of BLEVE for 50% / 10% filling rate



Tyre fire (propagation)

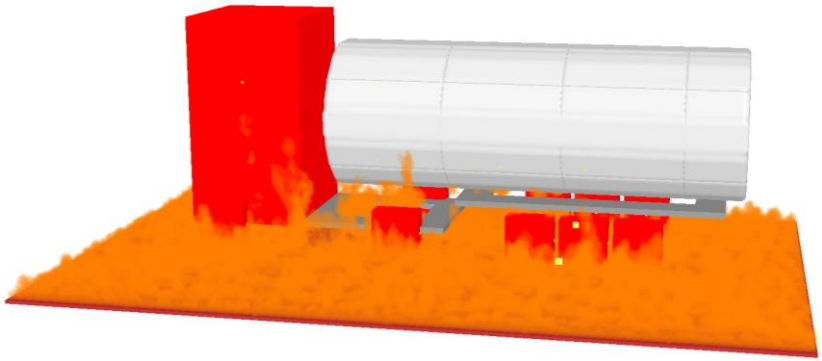


INERIS
maîtriser le risque
pour un développement durable

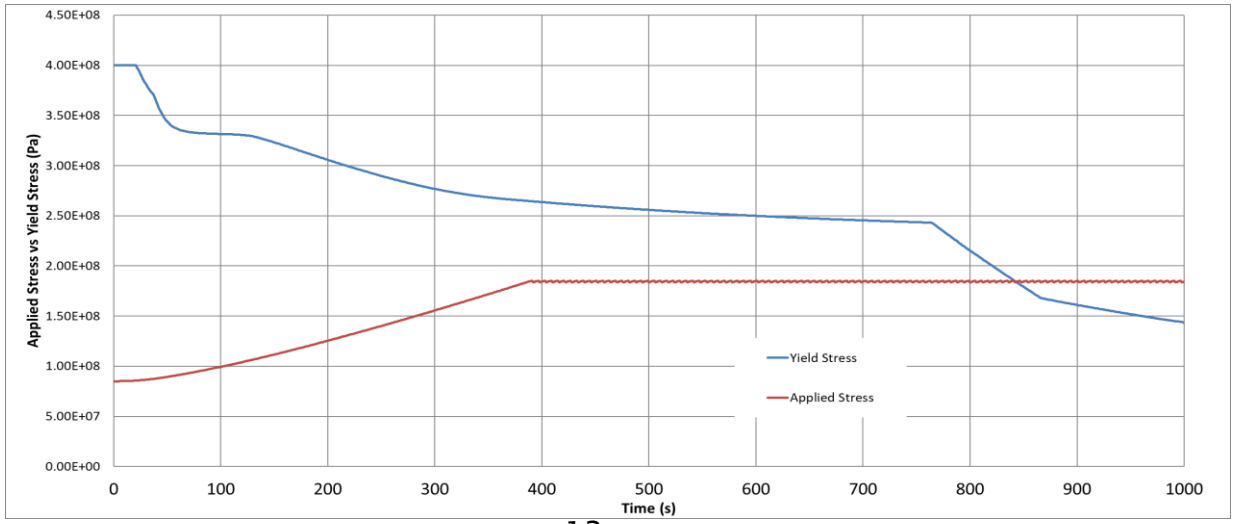
Calculation results: pool fire from the fuel tank, with propagation to tyres and cabin

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% / 50% / 10% filling rate
- 50 m^2 pool fire / 3 min duration (500 l gasoline)

Filling rate	BLEVE Time
10%	15 min
50%	15 min
80%	20 min



Pool fire

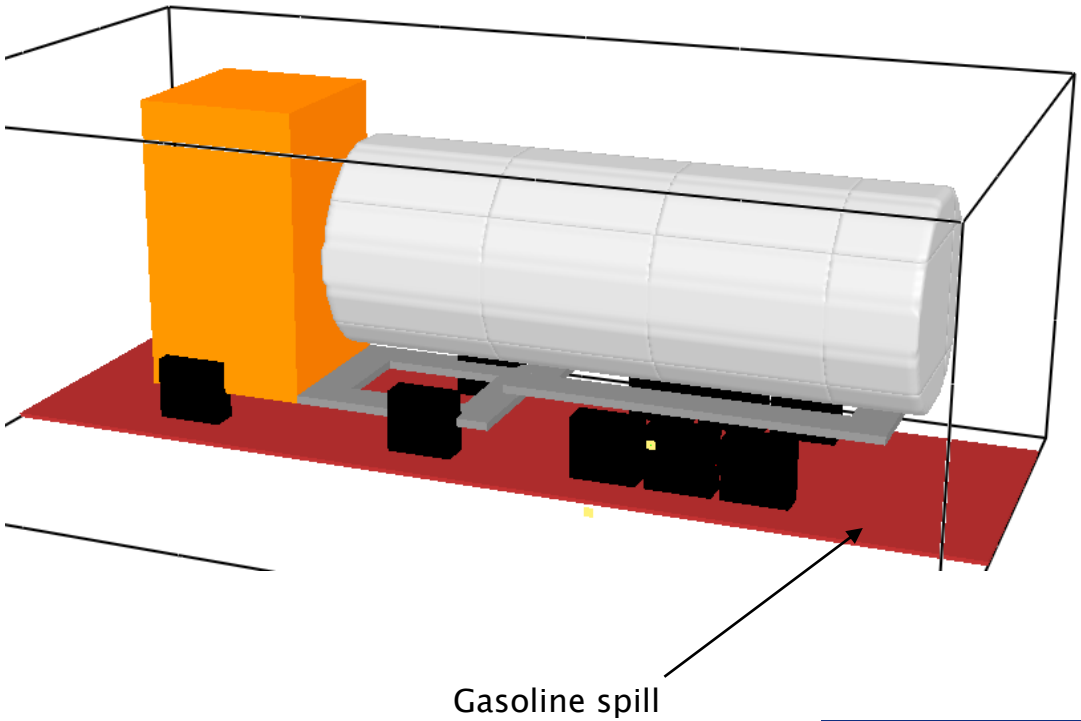


INERIS
maîtriser le risque
pour un développement durable

Calculation results: pool fire from the fuel tank, 25 m² pool fire with no propagation to tyres and cabin

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% / 50% / 10% filling rate
- 25 m² pool fire / 5 min duration (500 l gasoline)

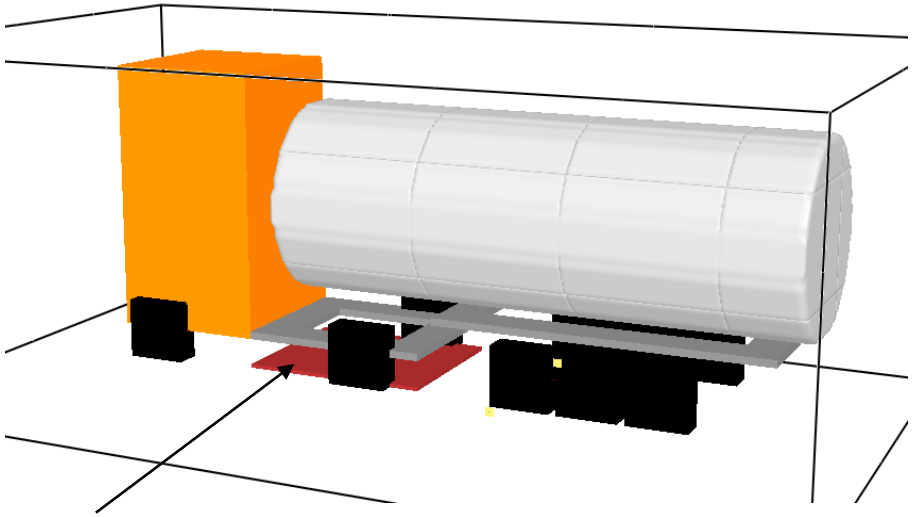
Filling rate	BLEVE Time
10%	No BLEVE
50%	No BLEVE
80%	No BLEVE



Calculation results: fire from the fuel tank, localized pool fire

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% / 50% / 10% filling rate
- 3 m^2 pool fire / 45 min duration (500 l gasoline)
- Major contribution of duration

Filling rate	BLEVE Time
10%	20 min
50%	25 min
80%	No BLEVE



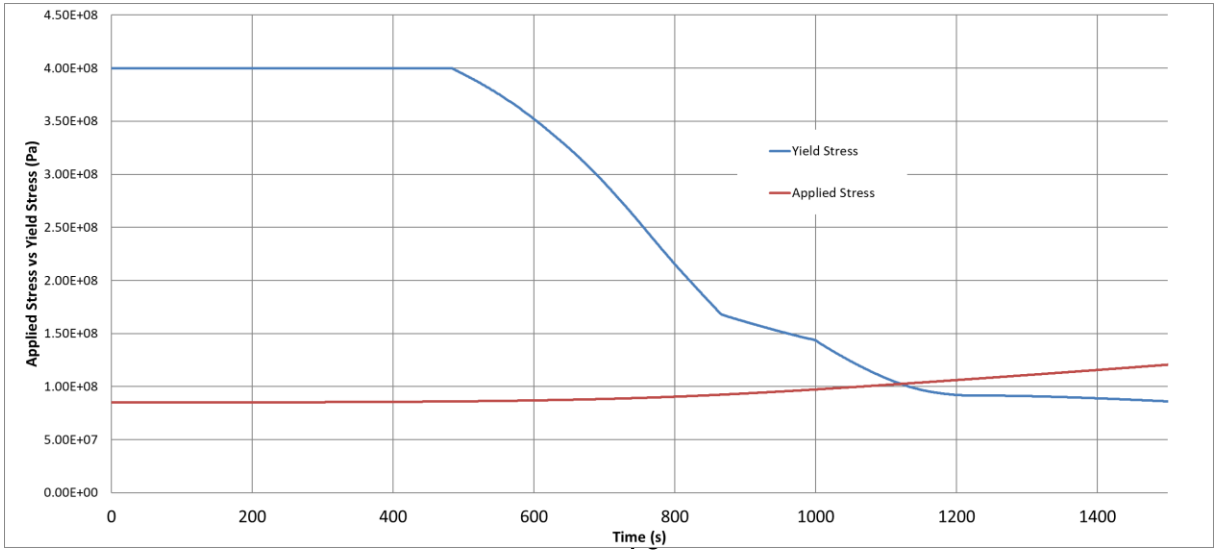
Gasoline spill

Calculation results: fire from the cabin with no propagation

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% / 50% / 10% filling rate

Filling rate	BLEVE Time
10%	18 min
50%	18 min
80%	18 min

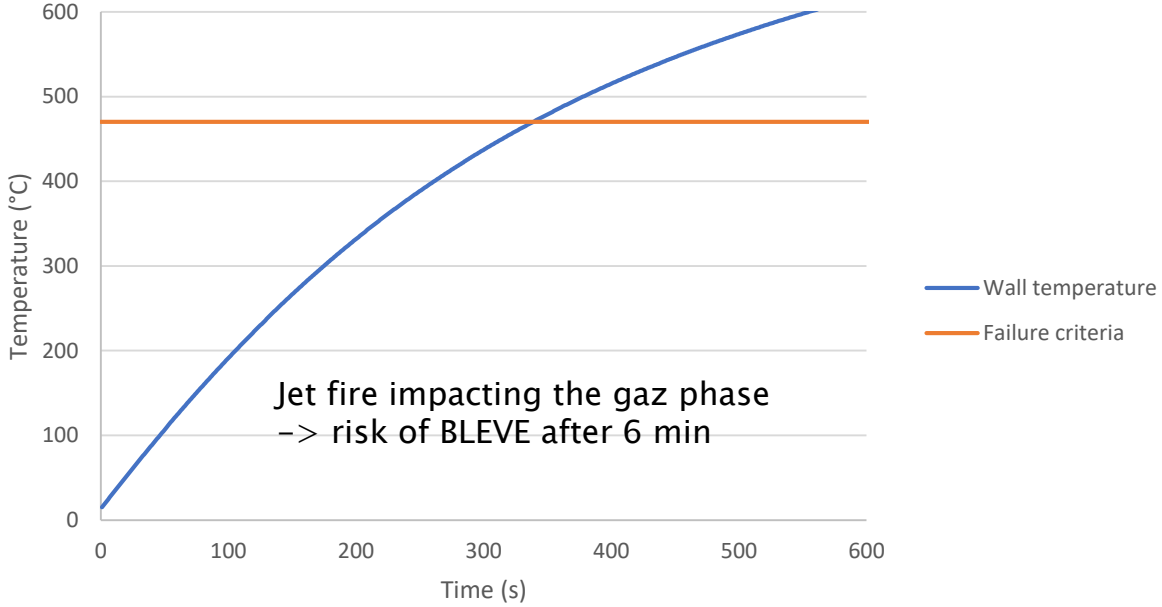
Cabin fire (no propagation)



INERIS
maîtriser le risque
pour un développement durable

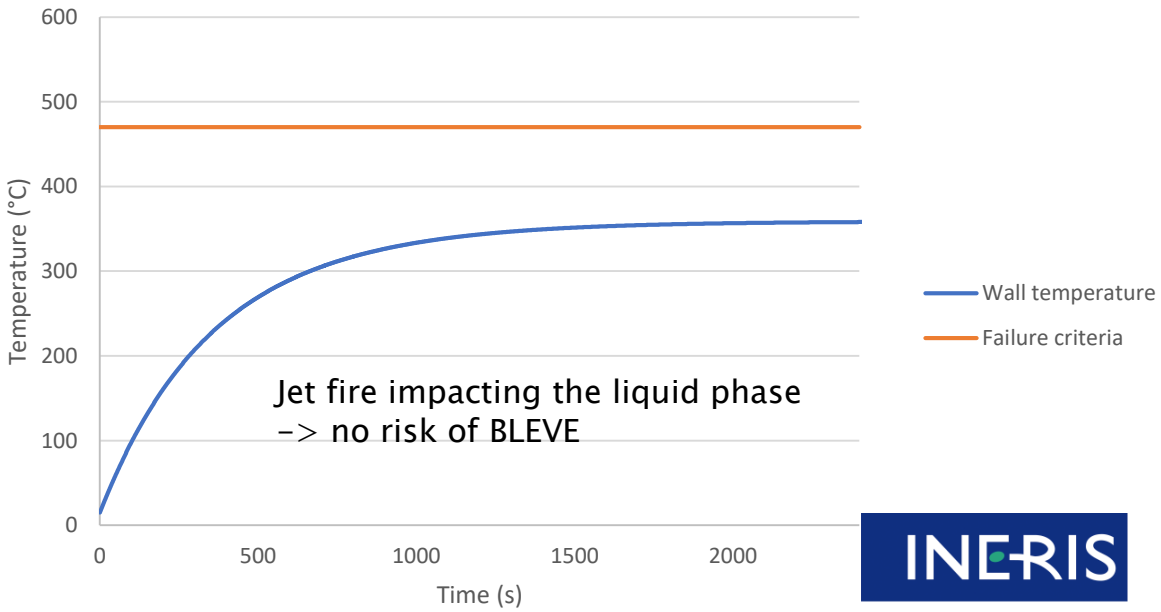
Calculation results: jet fire

- Simplified analysis (1D approach):
  - Localized load
  - No influence of the heating of lading
  - No pressure increase
  - Wall temperature is the only criteria



- Risk of BLEVE for tank subjected to jet fire

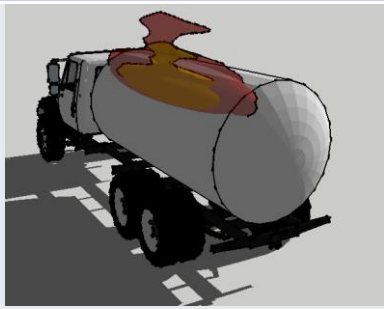
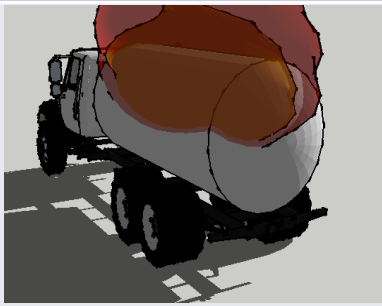
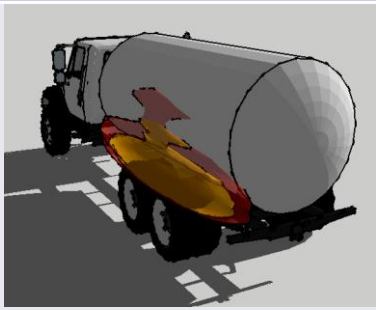
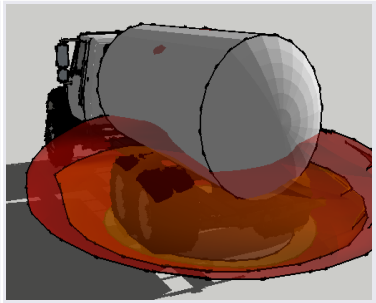
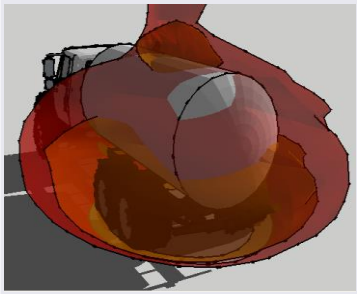
- **For a long duration jet fire or large heated area, influence of pressure increase have to be considered**



Summary of last years calculations

Tank subjected to generic fires

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)

Calculation Number	1	2	3	4	5
Fire scenarios	Small Fire on gas phase 	Large Fire on gas phase 	Small Fire on liquid phase 	Large Fire on liquid phase (Ex. Pool fire) 	Full Fire engulfment (Ex. Pool fire) 
BLEVE time with PRV (min)	9,2	6,6	>60	37,2	5,8
BLEVE time without PRV (min)	9,2	6,6	>60	26,7	5,8

Tank subjected to generic fire on lower part

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 85% to 10% filling rate
  - 500°C to 900°C flame temperature

Initial filling rate \ Flame temperature	900 °C	800 °C	700 °C	600 °C	500 °C
10%	<400s	460s	680s	960s	>2400
30%	400s	530s	810s	>2400	>2400
50%	1200s	>2400s			
85%	>2400s				

INERIS
maîtriser le risque
pour un développement durable

Summary of last years calculations

Tank subjected to specific fire scenario

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2'' & $P_{opening}$: 16.5 bar)
  - 80% to 10% filling rate

Scenario	BLEVE time		
	10 % filing rate	50% filing rate	80% filing rate
Tyre fire	No BLEVE	No BLEVE	No BLEVE
Large pool fire (50 m² / no propagation / fire duration 3 min)	No BLEVE	No BLEVE	No BLEVE
Medium pool fire (25 m² / no propagation / fire duration 5 min)	No BLEVE	No BLEVE	No BLEVE
Small pool fire (3 m² / no propagation / fire duration 45 min)	20 min	25 min	No BLEVE
Large pool fire with propagation to tyres and cabin	20 min	15 min	15 min
Cabin fire	18 min	18 min	18 min
Jet fire (simplified analysis – 1D approach)	Fire on gaz phase : 6 min		Fire on liquid phase : no BLEVE (depend of time)

Conclusion

- As a conclusion, it seems necessary to specifically deal with :
  - Fire from the engine, to prevent cabin fire
  - Fire from the fuel tank, to prevent :
    - Pool fire with long time combustion (small size pool fire)
    - Propagation from pool fire to cabin fire
  - Fire from tyres to prevent propagation to fuel tank / cabin
- Future work:
  - To be discussed