Economic Commission for Europe

Inland Transport Committee

Working Party on the Transport of Dangerous Goods

Joint Meeting of the RID Committee of Experts and the
Working Party on the Transport of Dangerous Goods **18 February 2019**
Bern, 18-22 March 2019
Item 6 of the provisional agenda
Reports of informal working groups

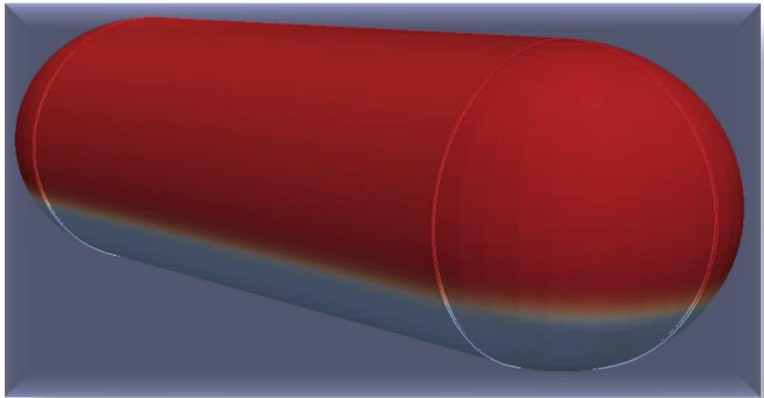
Report of the Informal Working Group on the reduction of the risk of a BLEVE

Transmitted by the Government of Spain on behalf of the Informal Working Group

Annex 4

Presentation of FEM calculations (INERIS, France)

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



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Accidental Risk Division

BLEVE WG Madrid 01-2019
DRA-19-178007-00231B

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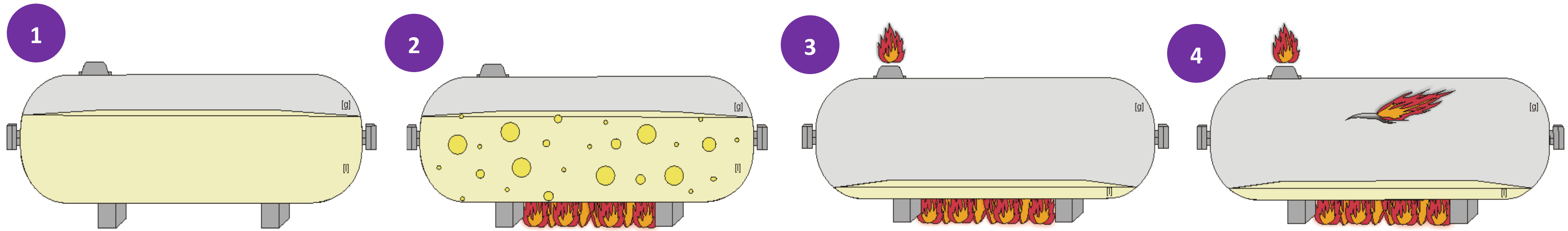
Summary

- Introduction – Context
- INERIS model presentation
- Summary of previous calculations
  - Tank subjected to full fire engulfment
  - Tank subjected to fire on lower part
  - Conclusion after 2018 WG
- Calculation on tanks subjected to specific fire scenario
  - Model presentation
  - Calculation assumptions
  - Calculation results
- Conclusion after specific fire scenario calculations

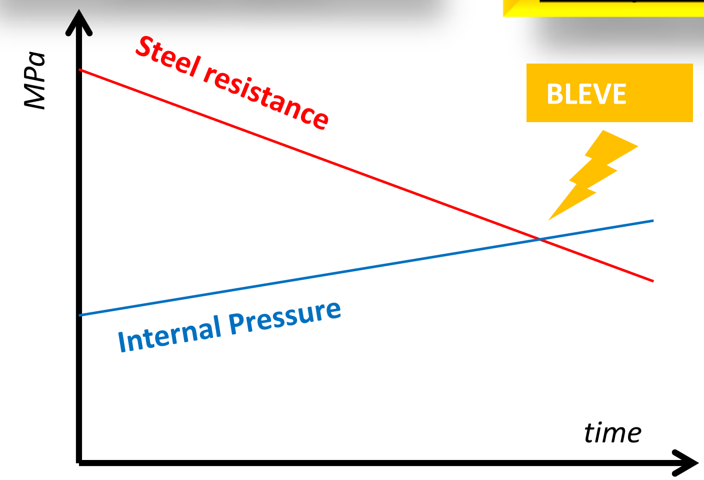
Reminder of previous work: reliability of the model demonstrated

- Previous work:
  - **development of a predictive tool** to study the behaviour of different configurations tanks
  - **demonstration of reliability of the model** by comparison with BAM experiments (2013)

BLEVE scenario



1. The tank is filled
2. Tank is located in fire
   Boiled liquid
3. Pressure increases
   Liquid level drops
   Safety valve opens
4. Pressure continues to rise
   Strength reduction of steel
   Tank wall cracks



Behaviour diagramm of the tank

Methodological approach used for INERIS model

Input

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

MECHANICAL MODEL | **THERMAL MODEL**

Model Results

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

Failure Criterion
:
Loss of containment

✓Effective protection ← **No collapse**

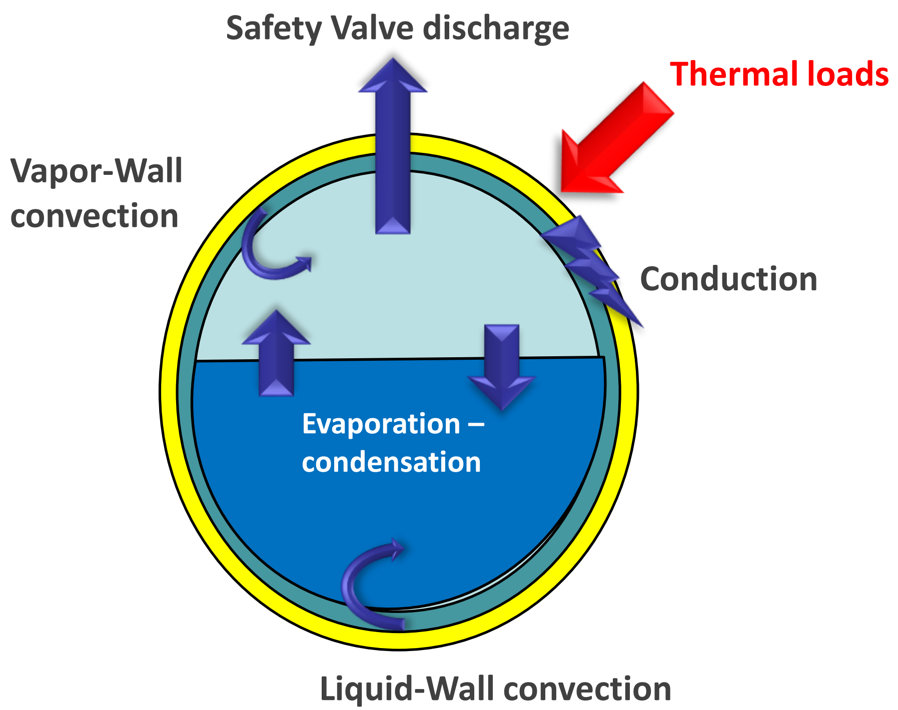
Collapse →

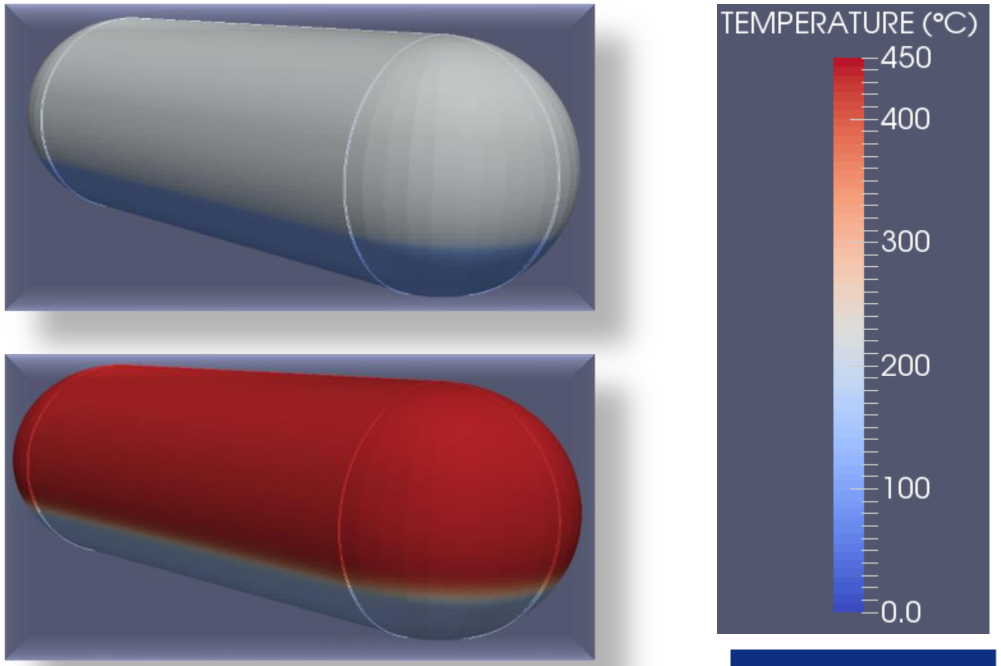
✓Effectiveness of the measure depending on time to failure (to be defined by authorities)

✓Non effective protection

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.



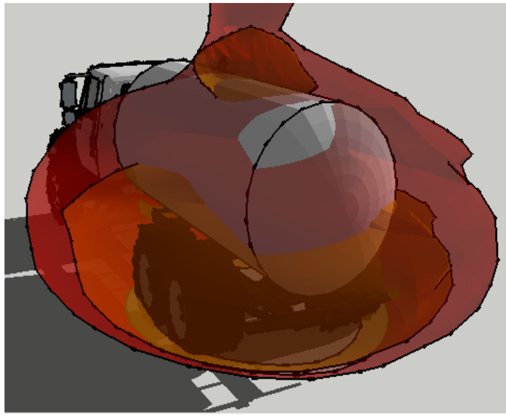


Thermal transfers in LPG tanks under thermal loads

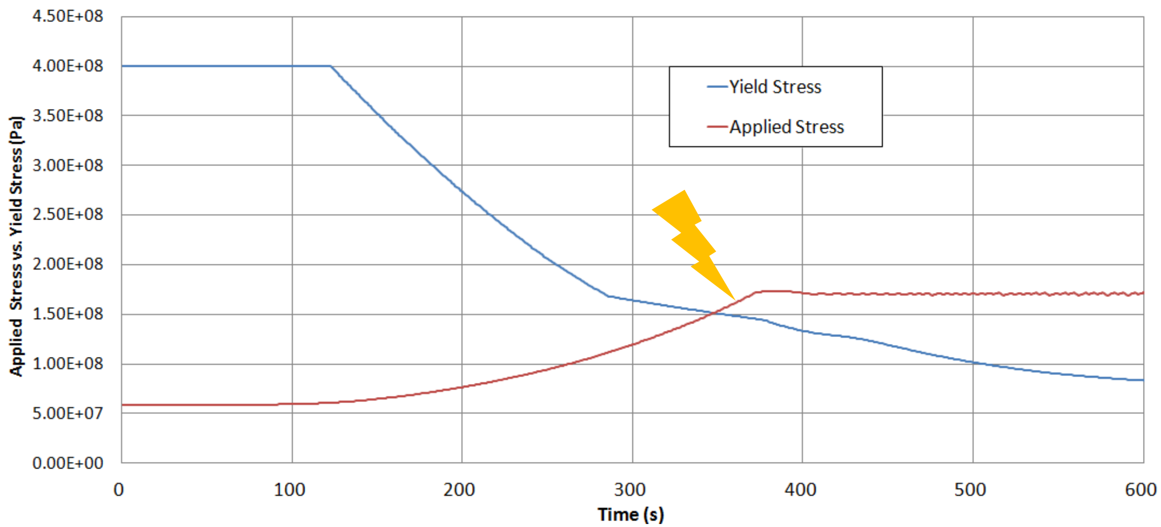
Evaluation of a valve efficiency - Calculation results

- Reminder: these results have been presented at RID ADR Joint meeting 03-2017
- Common PRV considered (diameter 2'' and $P_{opening}$ 16.5 bar) on LPG tank: volume $31 m^3$, filling rate 50%
- Thermal loading : full fire engulfment

=> **Safety valve is not efficient in that case**



Full fire engulfment



*Results considering **a common safety valve** : risk of BLEVE*

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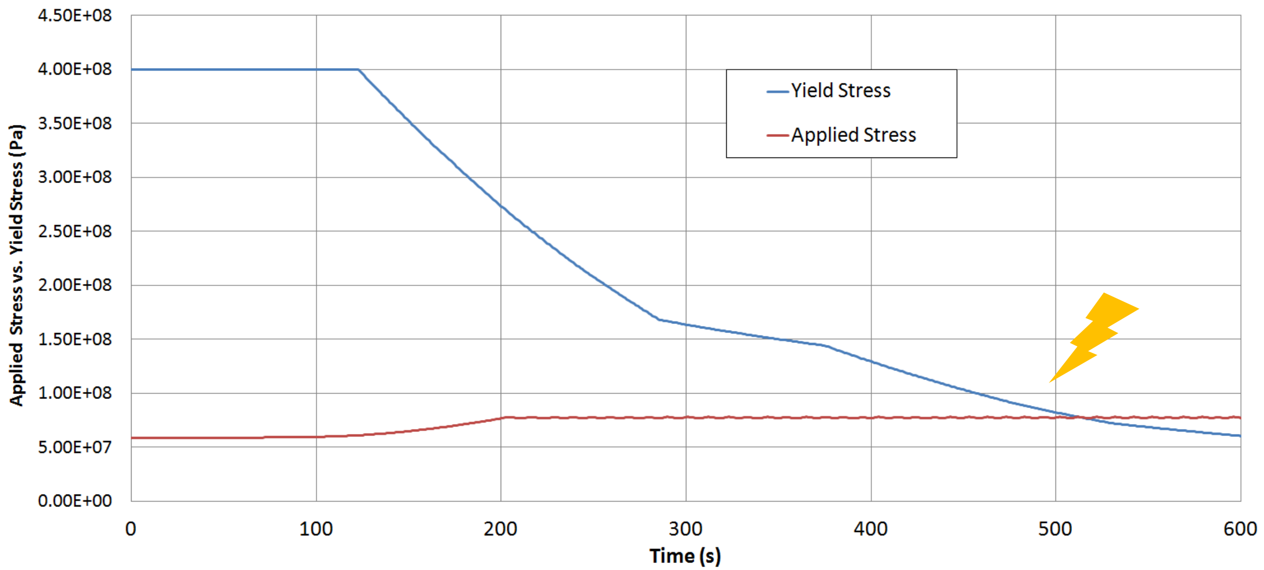
Evaluation of a valve efficiency - Calculation results

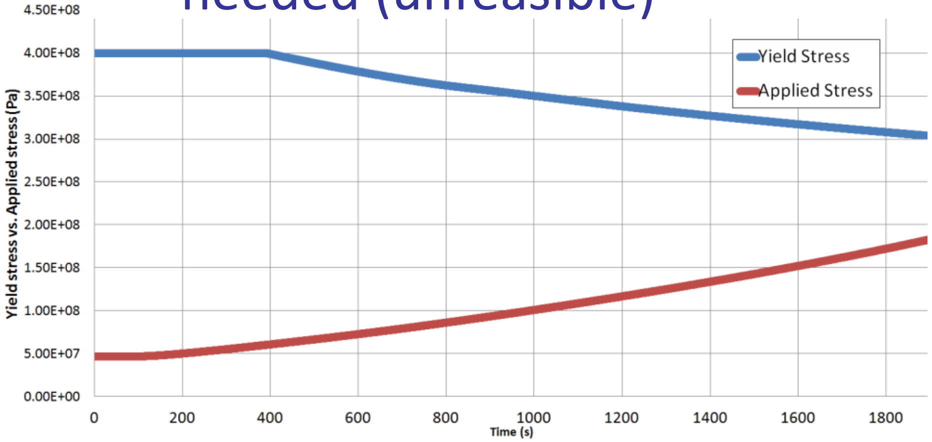
- Test of an ideal safety valve on the same tank with the same thermal loading
- This safety valve set to low pressure (8 bar) is not efficient:
  - A very low applied stress is observed as expected
  - Failure is due to a sharp fall of Yield stress of steel
  - This result can be generalized to all filling rate



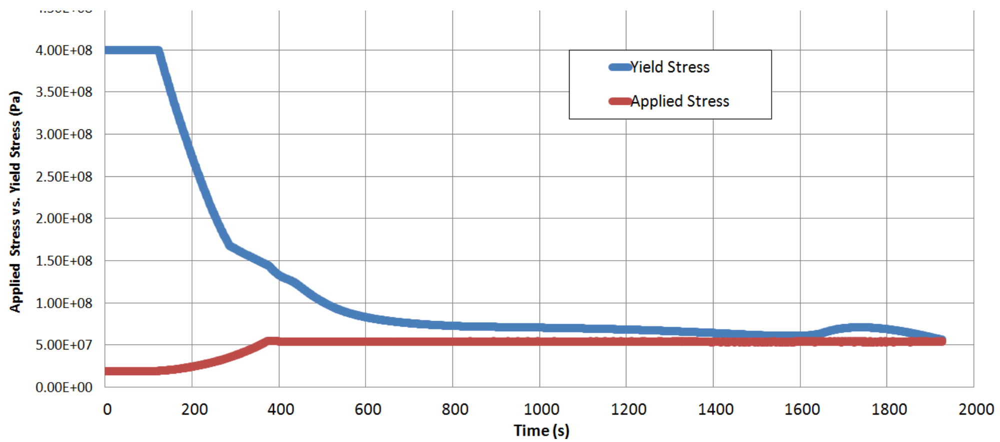
Results considering ***an ideal safety valve (set to 8 bar)*** *:* ***risk of BLEVE due to sharp fall of Yield stress of steel***

Evaluation of thermal coating and increased steel thickness - Calculation results

- 2 other protections are tested : thermal coating or increasing steel thickness of shell to 3 cm
- Thermal coating can avoid or delay BLEVE but several issues are raised concerning use on trucks:
  - no retrofit about ageing
  - behaviour with vibrations
  - behaviour with various climatic conditions
  - etc…
- Increasing steel thickness of shell is efficient to avoid BLEVE, but 3 cm thick shell are needed (unfeasible)



*Results considering **a thermal coating** : no risk of BLEVE*



*Results considering **a 3 cm thick shell** : no risk of BLEVE*

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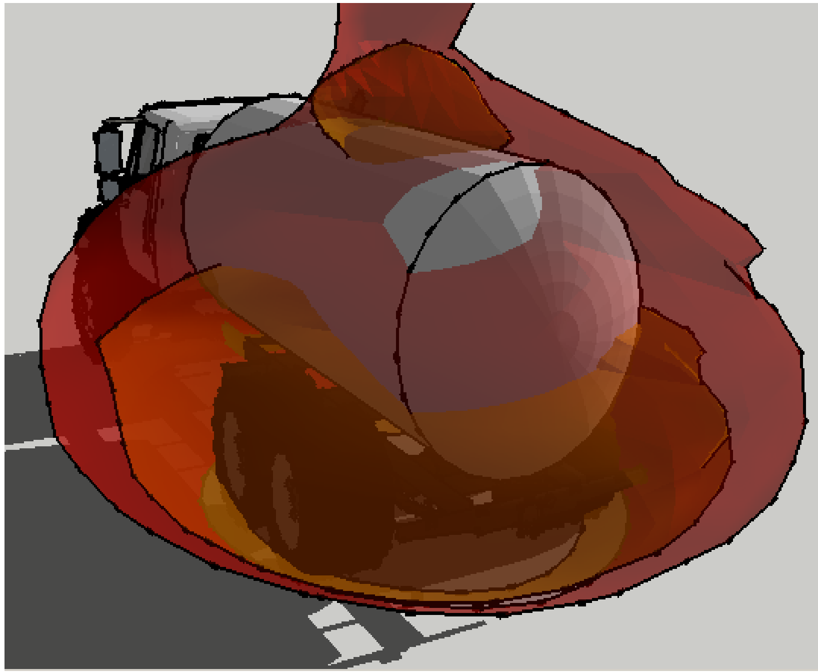
Conclusion on the PRV/thermal coating efficiency (RID ADR Joint meeting 03-2017)

- Valves are not efficient for some scenarios (ex: full fire engulfment)
- Other protections (thermal coating or increasing of shell thickness) may delay/avoid BLEVE but may present issues (ageing, cost, etc…)



Full fire engulfment

Calculation assumptions

- Calculations led on tanks with safety valve only and subjected to a smaller size fire (localized on lower part of tank)
- New calculations are therefore led considering a smaller size fire scenario with the following conservative parameters:
  - Pool fire on lower part of tank
  - Fire reaches immediately intense burning on the entire length of the truck and has an infinite duration (a real fire can have a duration of 3 hours, and an intense burning of 30 minutes)

Large fire localized on lower half of tank
- Conservative hypothesis-

Summary of previous calculations - Calculation on tanks subjected to fire on lower part

Calculation assumptions and results

- Characteristics of the LPG tanks:
  - Volume: 31 m^3
  - Common PRV – pressure relief valve- (diameter: 2’’ & $P_{opening}$: 16.5 bar)
- 3 scenarios are calculated for 4 filling rates and 5 flame temperature (great influence on results)
- Conclusion : a LPG tank exposed to fire a lower temperature (a radiative heat flux from a 500°C flame) applied on lower part is able to survive when equipped with valve

<table>
<tr><th>Initial filling rate \ Flame temperature</th><th>900 °C</th><th>800 °C</th><th>700 °C</th><th>600 °C</th><th>500 °C</th></tr>
<tr><td>10%</td><td><400s</td><td>460s</td><td>680s</td><td>960s</td><td>>2400</td></tr>
<tr><td>30%</td><td>400s</td><td>530s</td><td>810s</td><td>>2400</td><td>>2400</td></tr>
<tr><td>50%</td><td>1200s</td><td colspan="4" rowspan="2">>2400s</td></tr>
<tr><td>85%</td><td>>2400s</td></tr>
</table>

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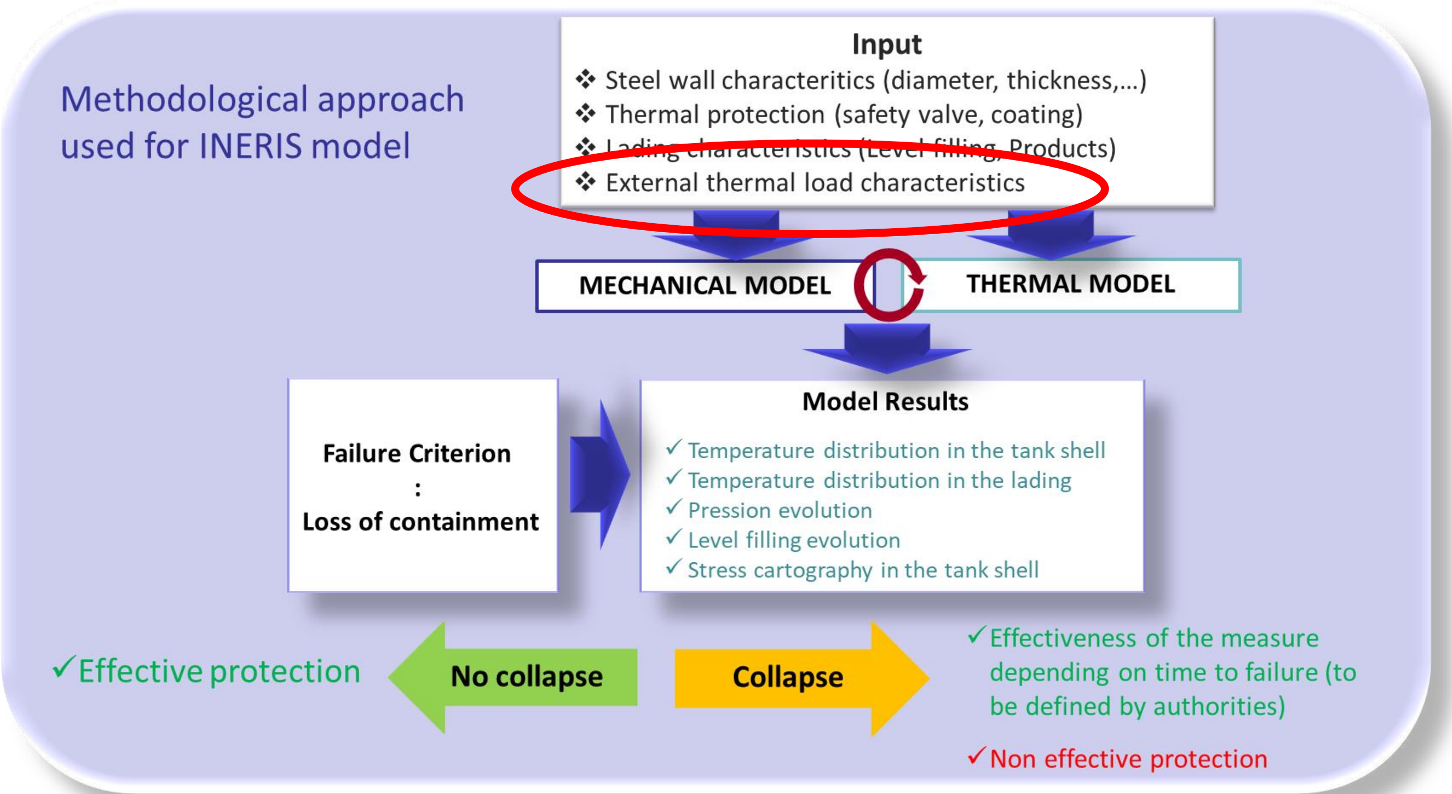
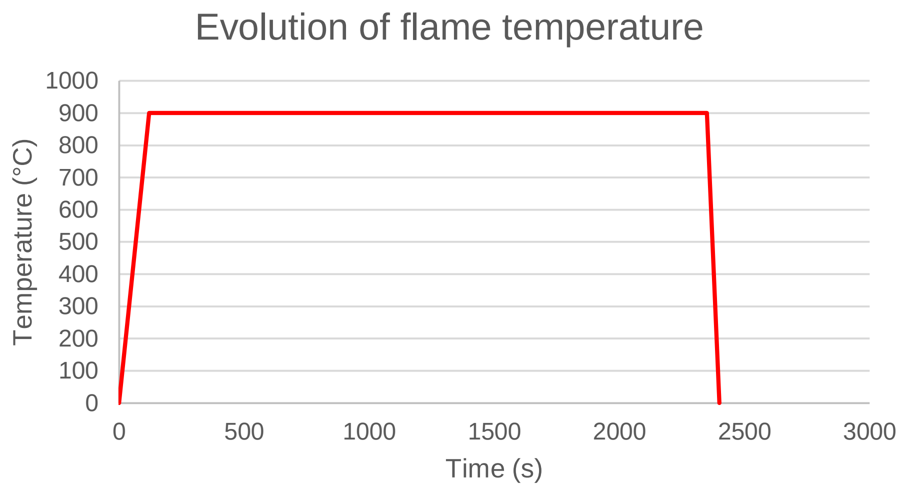
Model presentation

- Model improvement : inclusion of real heat transfer phenomena (radiation/convection) for some specific fire scenario:
  - tyre fire (no propagation)
  - tyre fire (with propagation)
  - fire from the fuel tank
  - fire from the cabin



Model presentation

- Radiative flux was previously characterized by:
  - Flame temperature
  - Duration



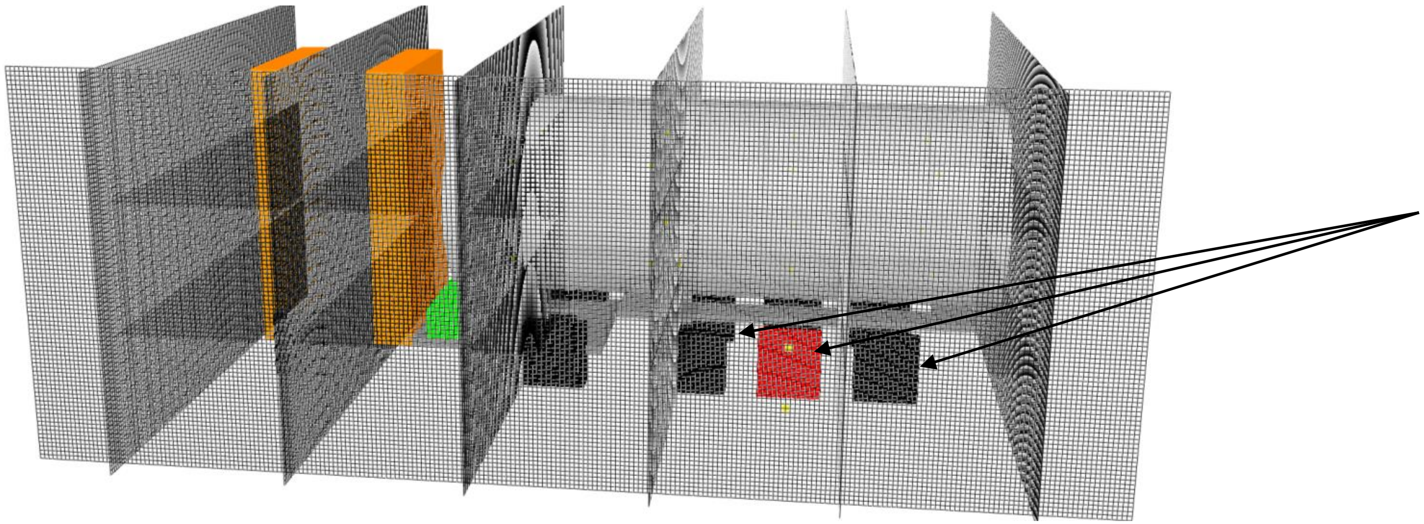
- Heat flux applied is now characterized by
  - First calculation with the FDS software
  - Heat flux calculated (convection and radiation) are applied on LPG tank considering a space discretization

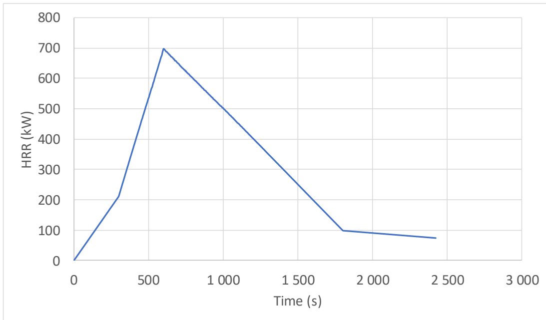
Model presentation : Fire computation code : FDS (Fire Dynamics Simulator)

- 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
  - Fire propagation criterion between each combustible elements : 12 kW/m²



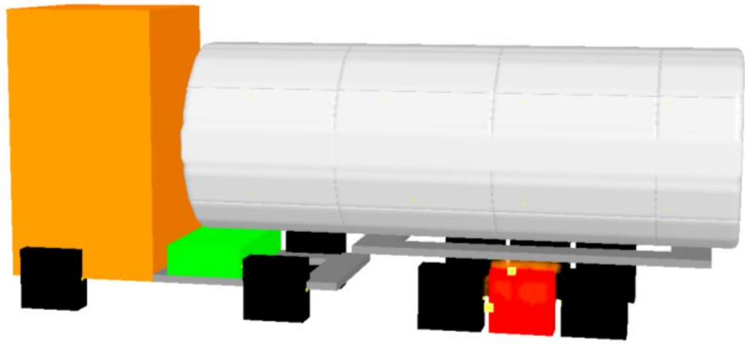


Positions of numerical sensors for BLEVE calculation

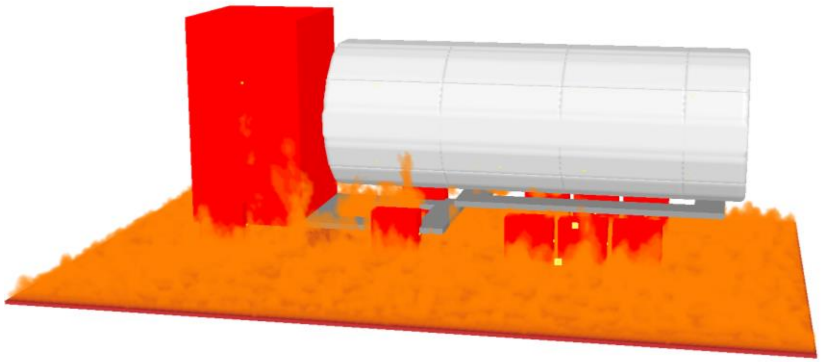
Fire locations of interest

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

Tyre fire (no propagation)



Tyre fire (propagation)

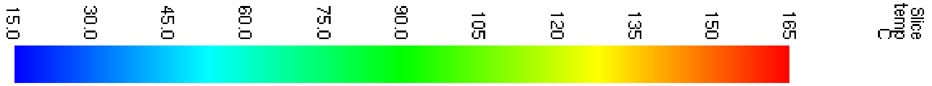


Pool fire

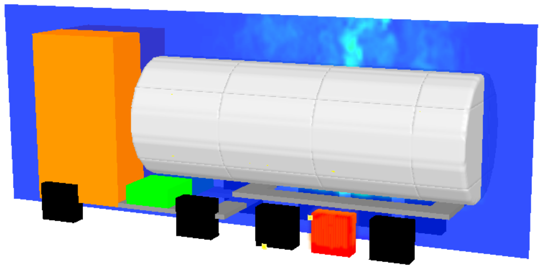
Cabin fire (no propagation)

Calculation results: fire start on tyre (no propagation)

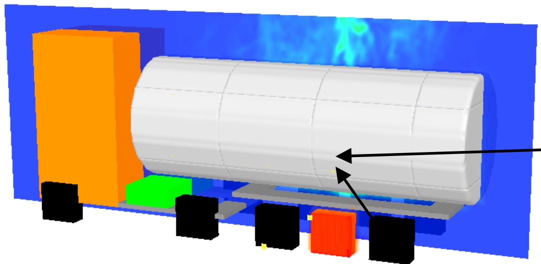
- Modeling of a no propagation tyre fire – only 1 tyre burning
- Many unsteady physical quantities available for input to BLEVE calculation : steel temperature, heat fluxes (convective, radiative, net) at different points of the tank



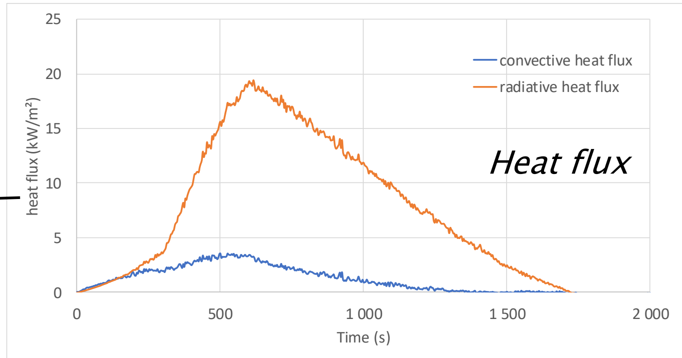
Heat release **evolves with time**

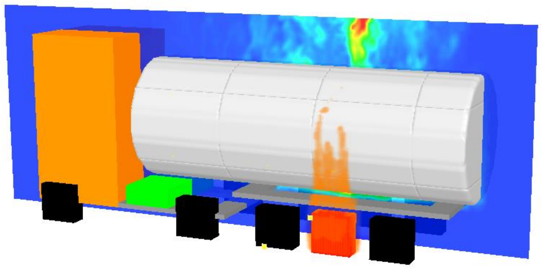


T=3 min

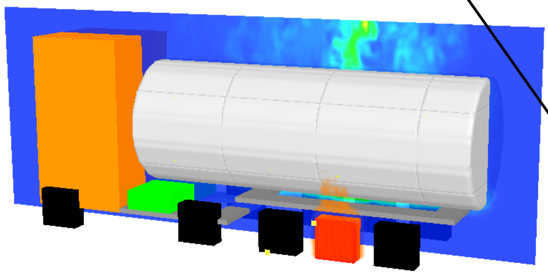


T=5 min

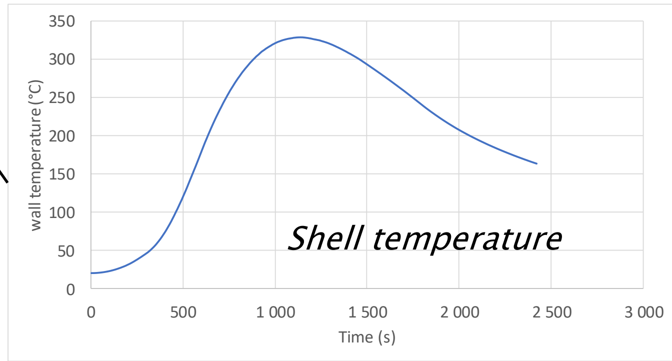




T=10 min

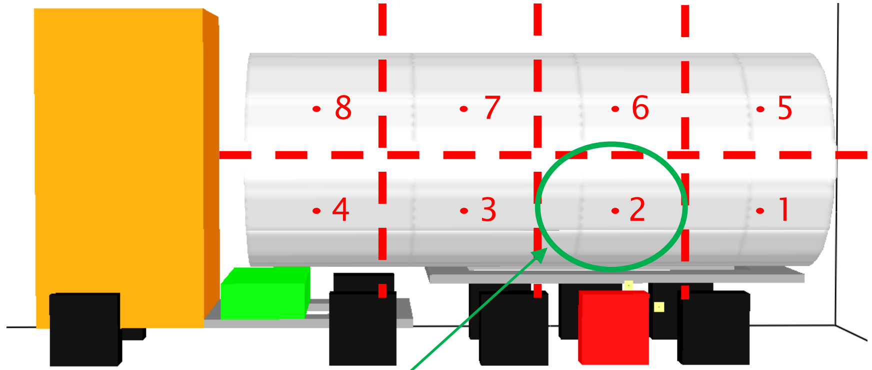


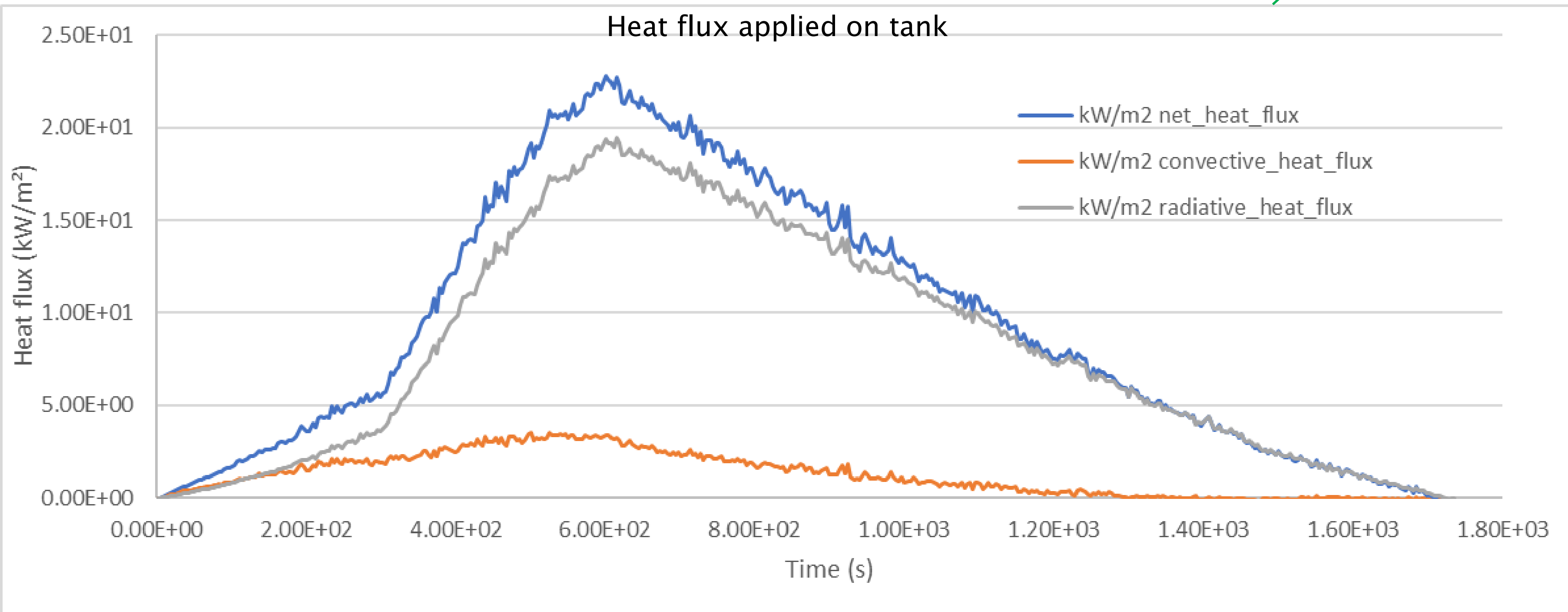
T=20 min



Calculation results: fire start on tyre (no propagation)

- Analysis of heat flux applied on point 2
  - Convective/Radiative flux are in the same proportions up to 5 minutes
  - After 5 minutes convective flux can be considered as negligible compared to radiative flux





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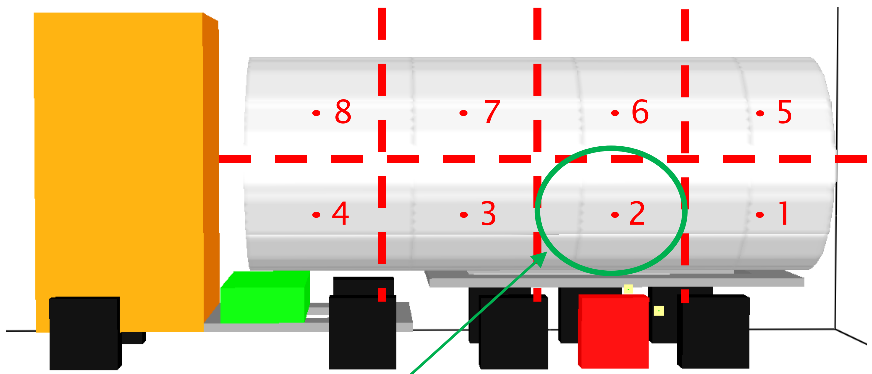
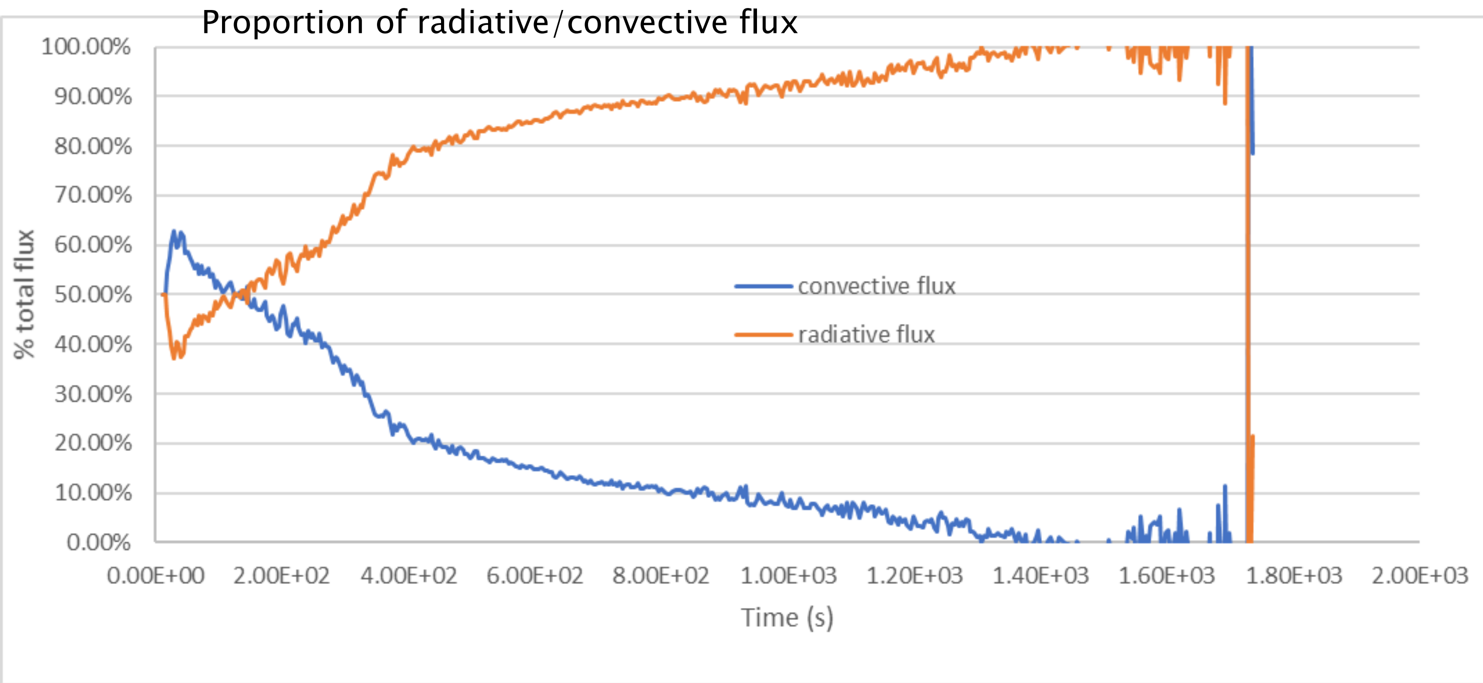
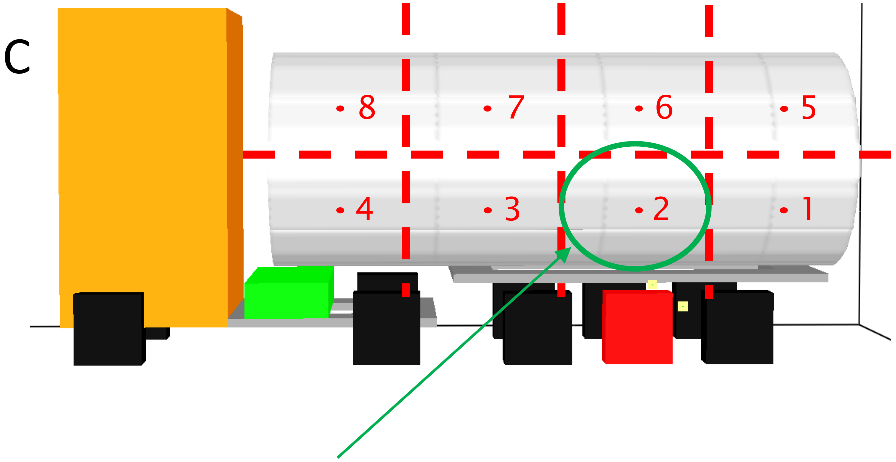
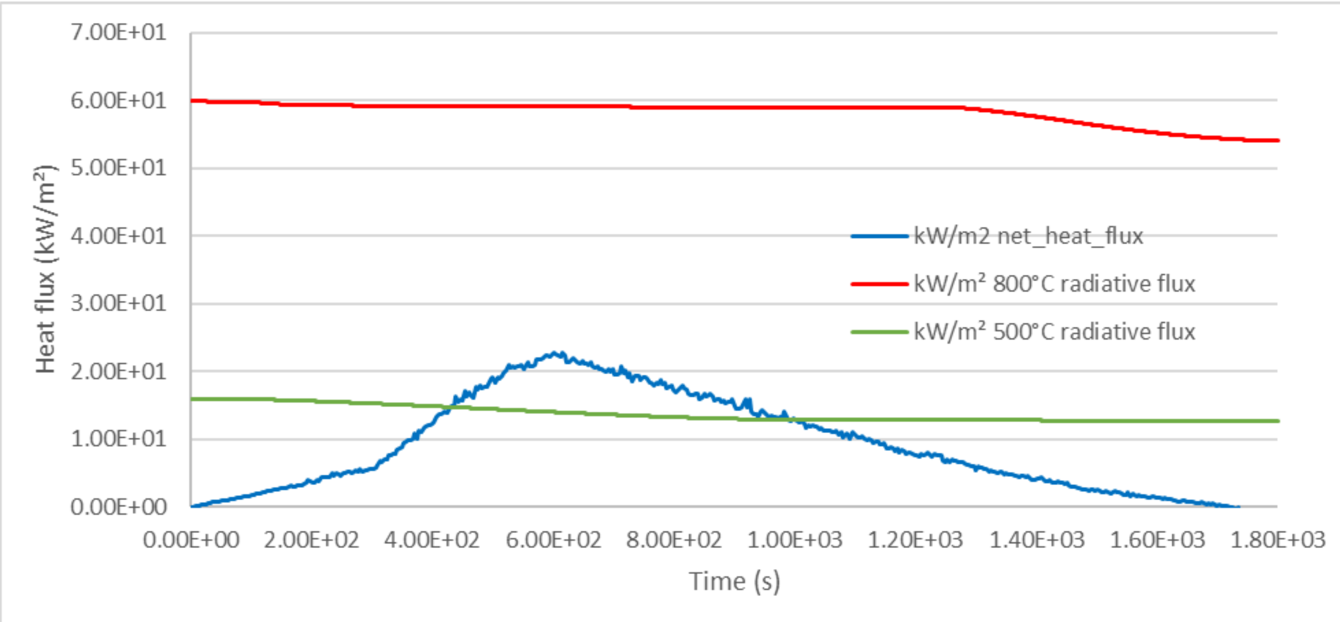




Calculation results: fire start on tyre (no propagation)

- Comparison with previous calculation
  - Order of magnitude of flux similar to a 500°C radiant flame (see slide 11)
  - But with a shorter duration





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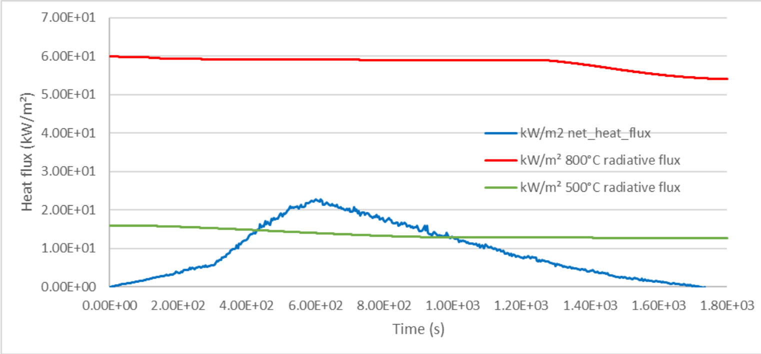
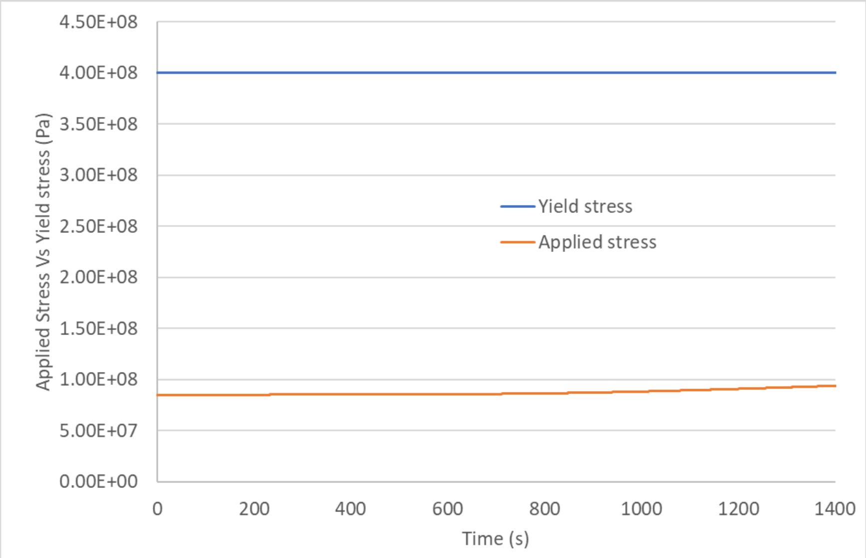
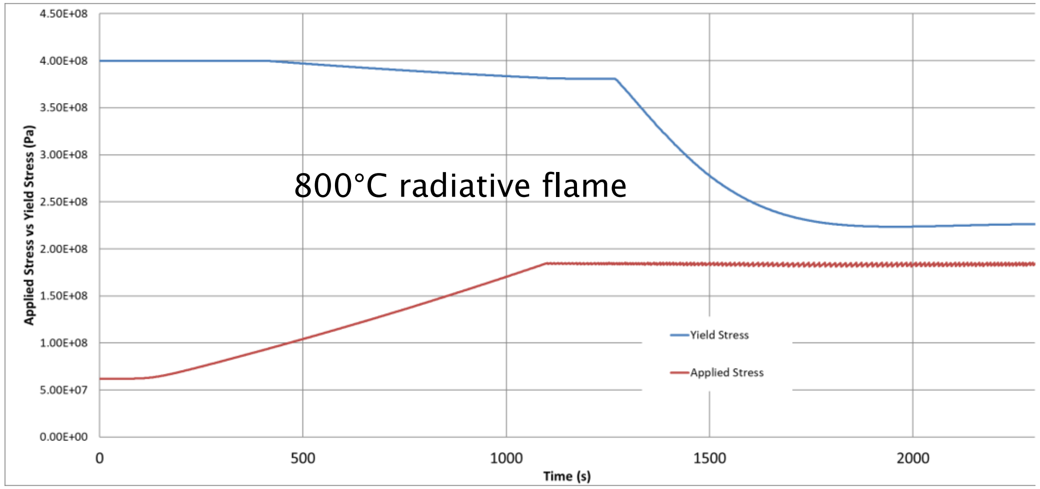
Calculation results: fire start on tyre (no propagation)

- Results: **No risk of BLEVE for a tyre fire with no propagation** in this case



Tyre fire with no propagation





- Comparison with previous calculation
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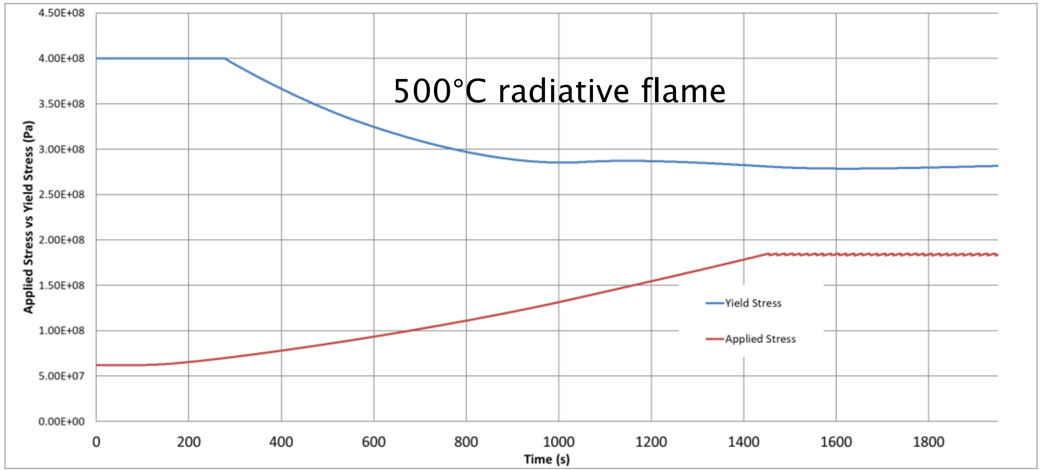
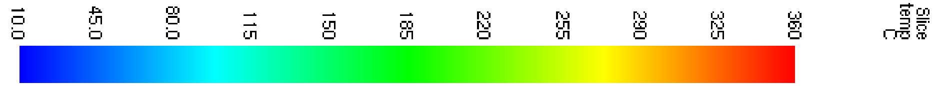


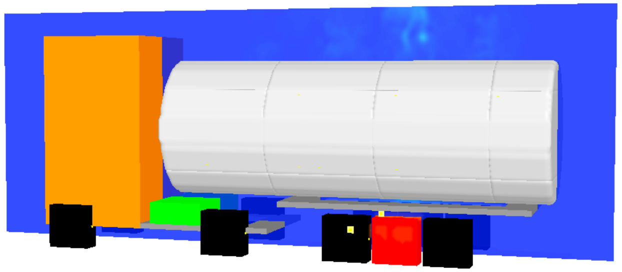
Calculation on tanks subjected to specific fire scenario

Calculation results: fire start on tyre (propagation)

- Many unsteady physical quantities available for input to BLEVE calculation : steel temperature, heat fluxes (convective, radiative, net) at different points of the tank



Heat release **evolves with time**



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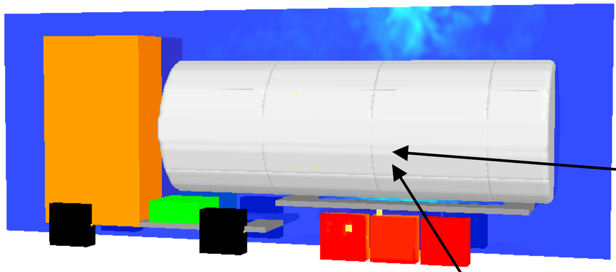
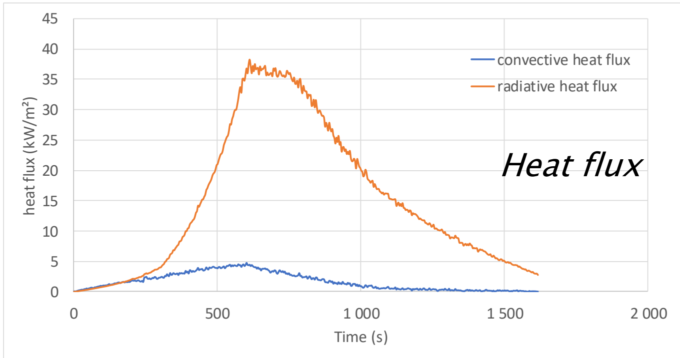
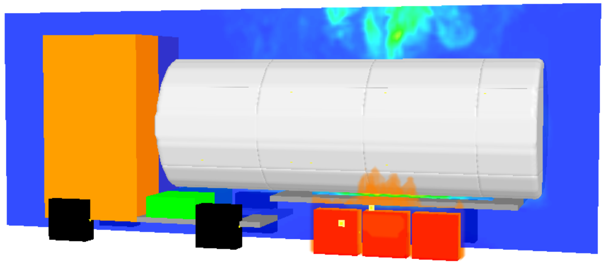


T=5 min





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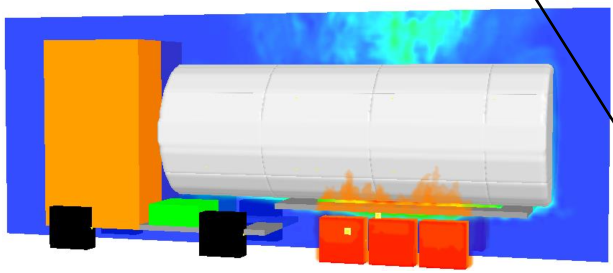
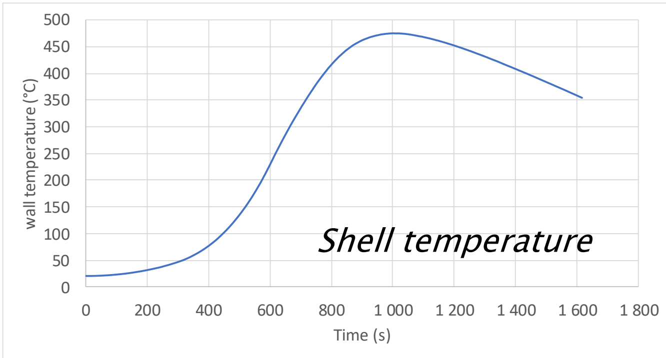
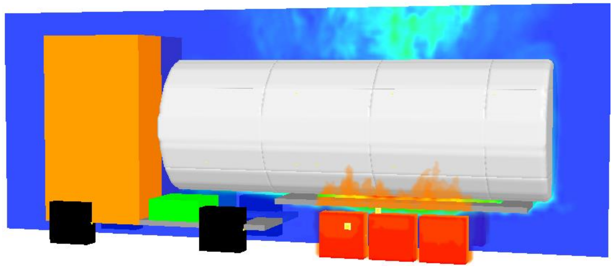


T=15 min

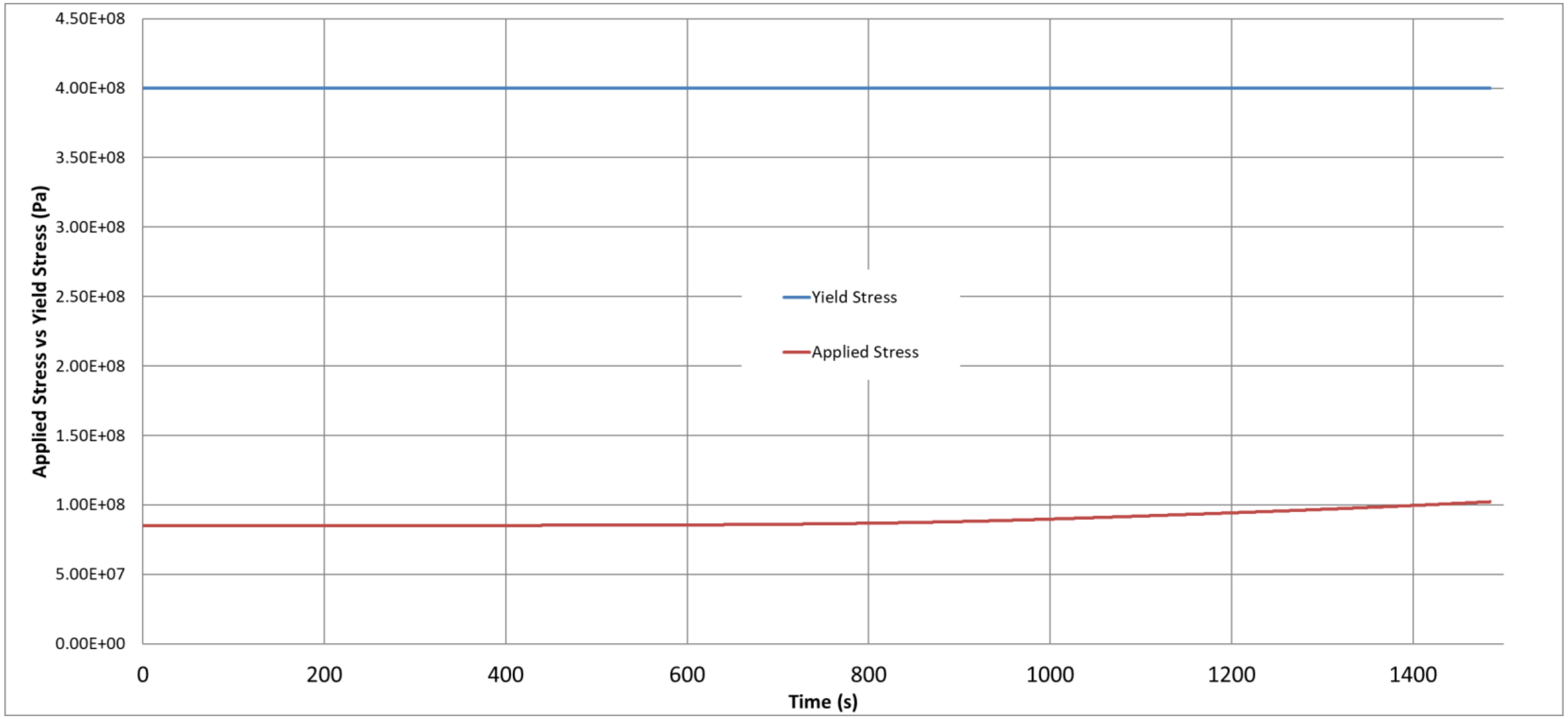


Calculation results: fire start on tyre (propagation)

- No risk of BLEVE for a tyre fire **with propagation**



Tyre fire with propagation



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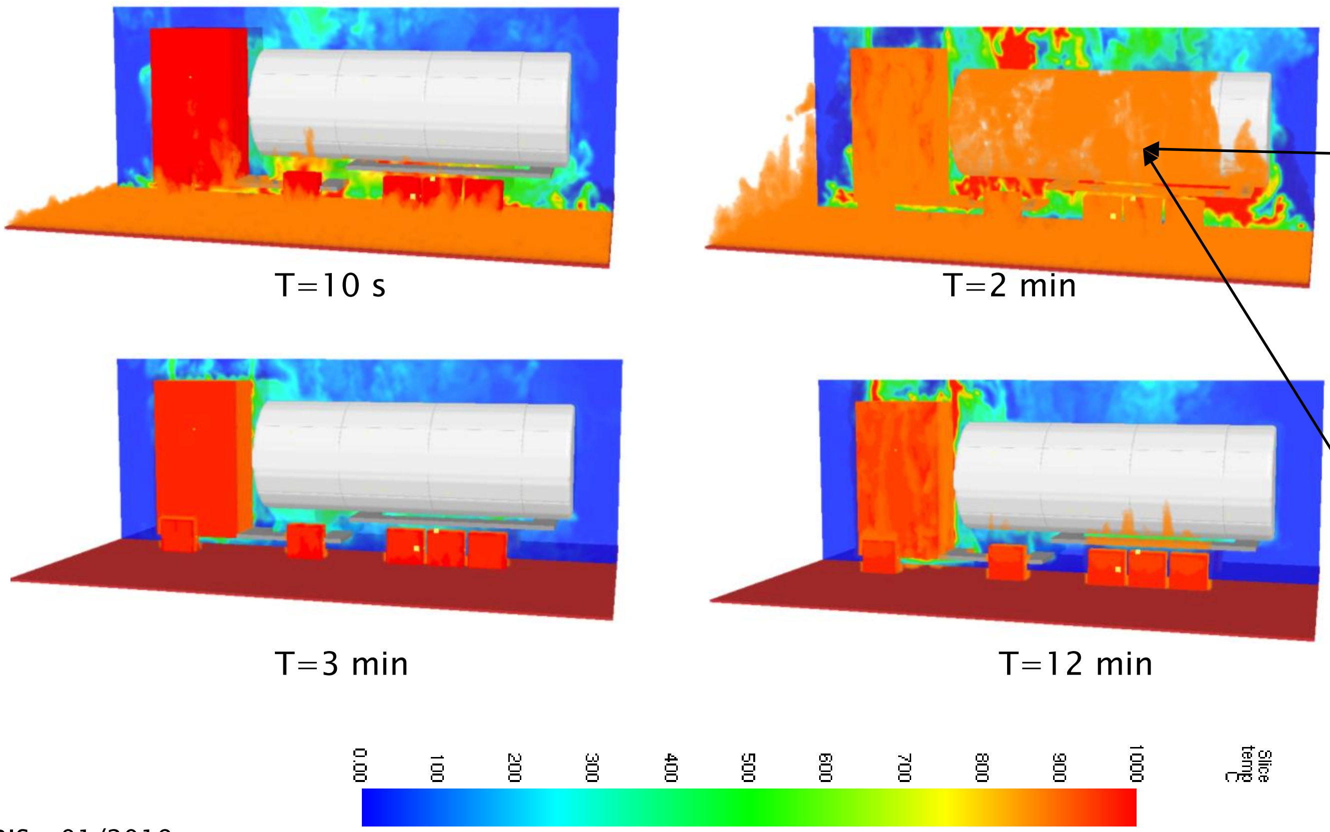
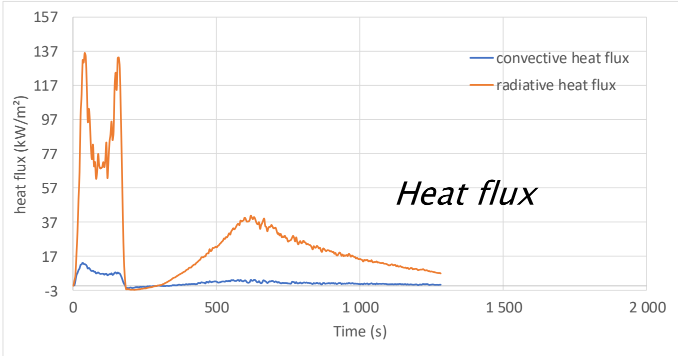
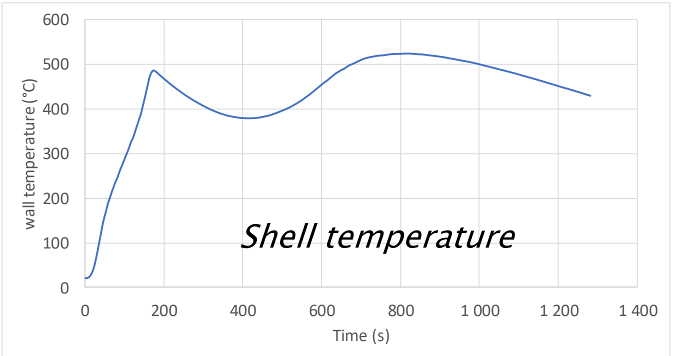
Calculation results: fire from the fuel tank, with propagation

- Fire start on 500 L gasoline spill of 6 mm height (84 m²)
- Many unsteady physical quantities available for input to BLEVE calculation : steel temperature, heat fluxes (convective, radiative, net) at different points of the tank

Heat release **evolves with time**

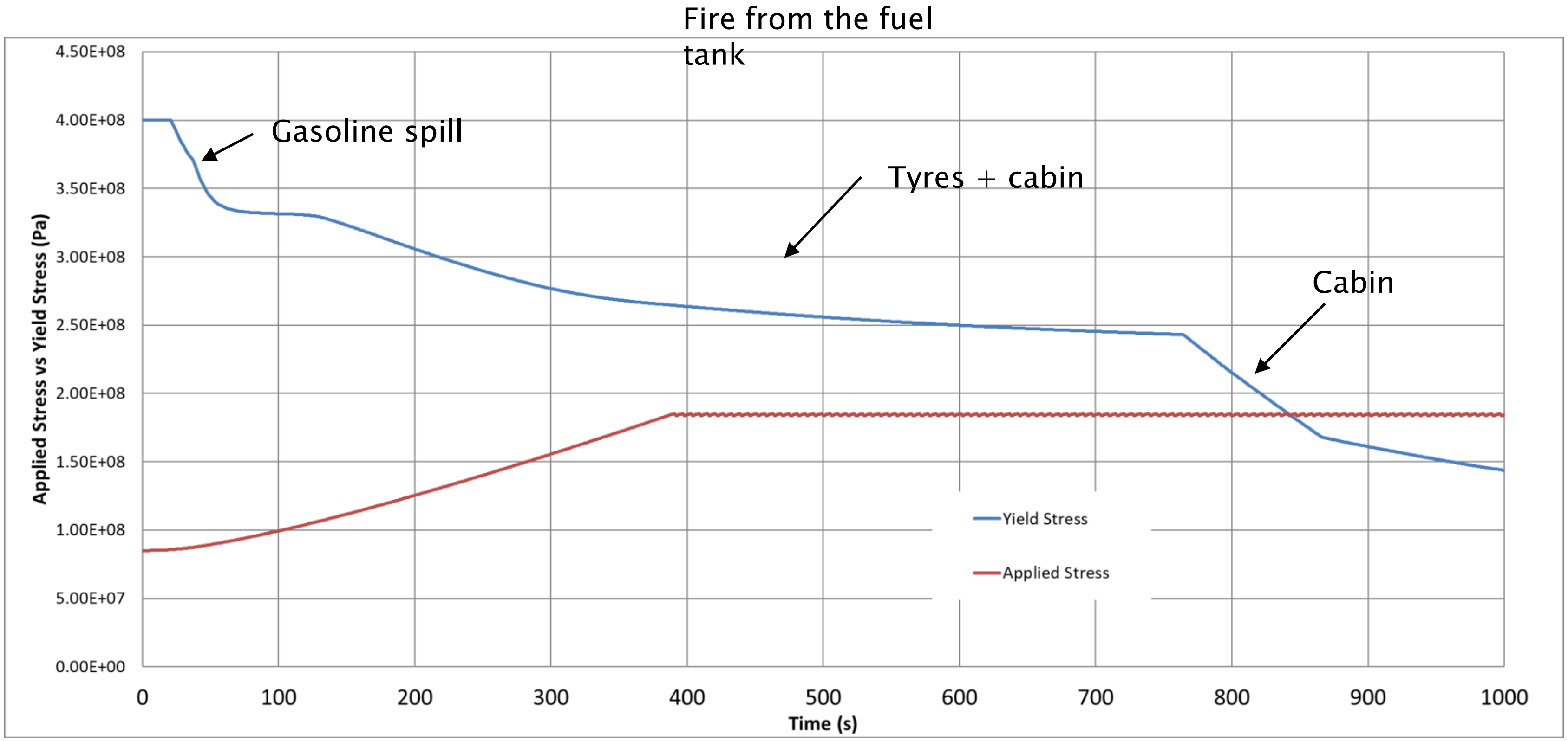






Calculation results: fire from the fuel tank, with propagation

- Risk of BLEVE after 15 minutes
- Safety valve does not prevent risk of BLEVE for this scenario



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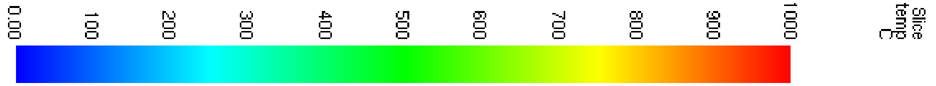
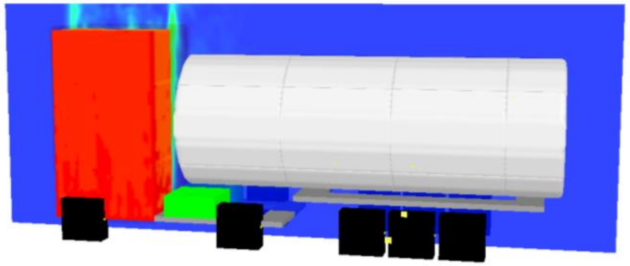
Calculation results: fire from the cabin with no propagation

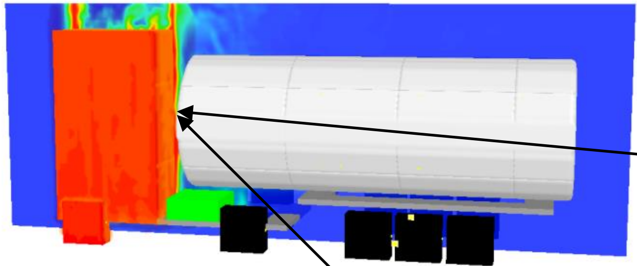
- Many unsteady physical quantities available for input to BLEVE calculation : steel temperature, heat fluxes (convective, radiative, net) at different points of the tank



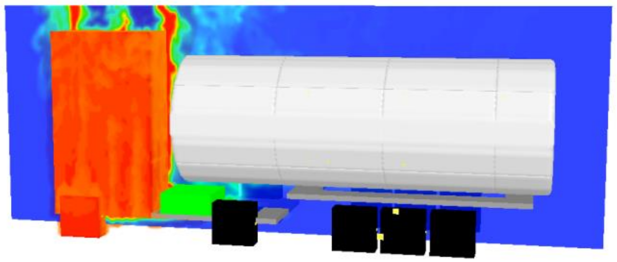
Heat release **evolves with time**



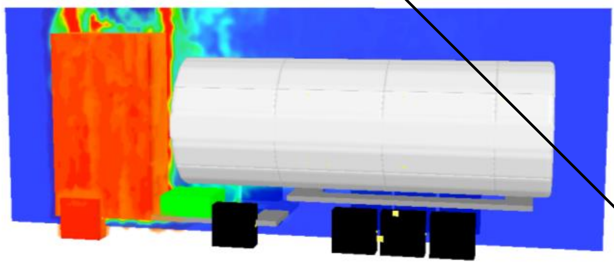
T=1 min



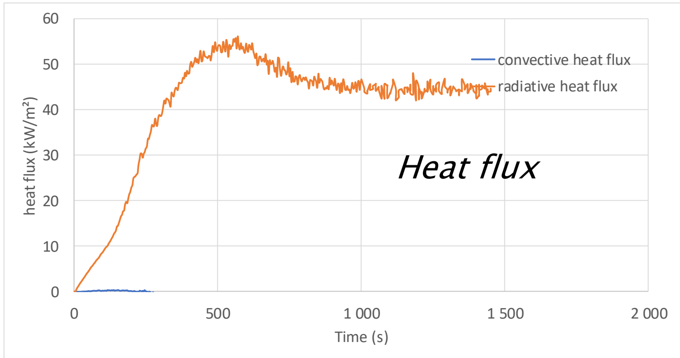
T=5 min

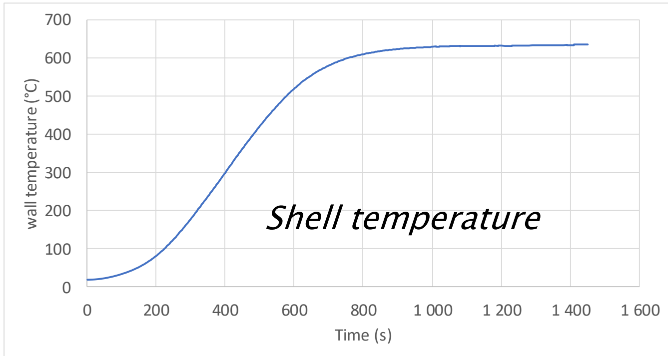


T=15 min



T=20 min

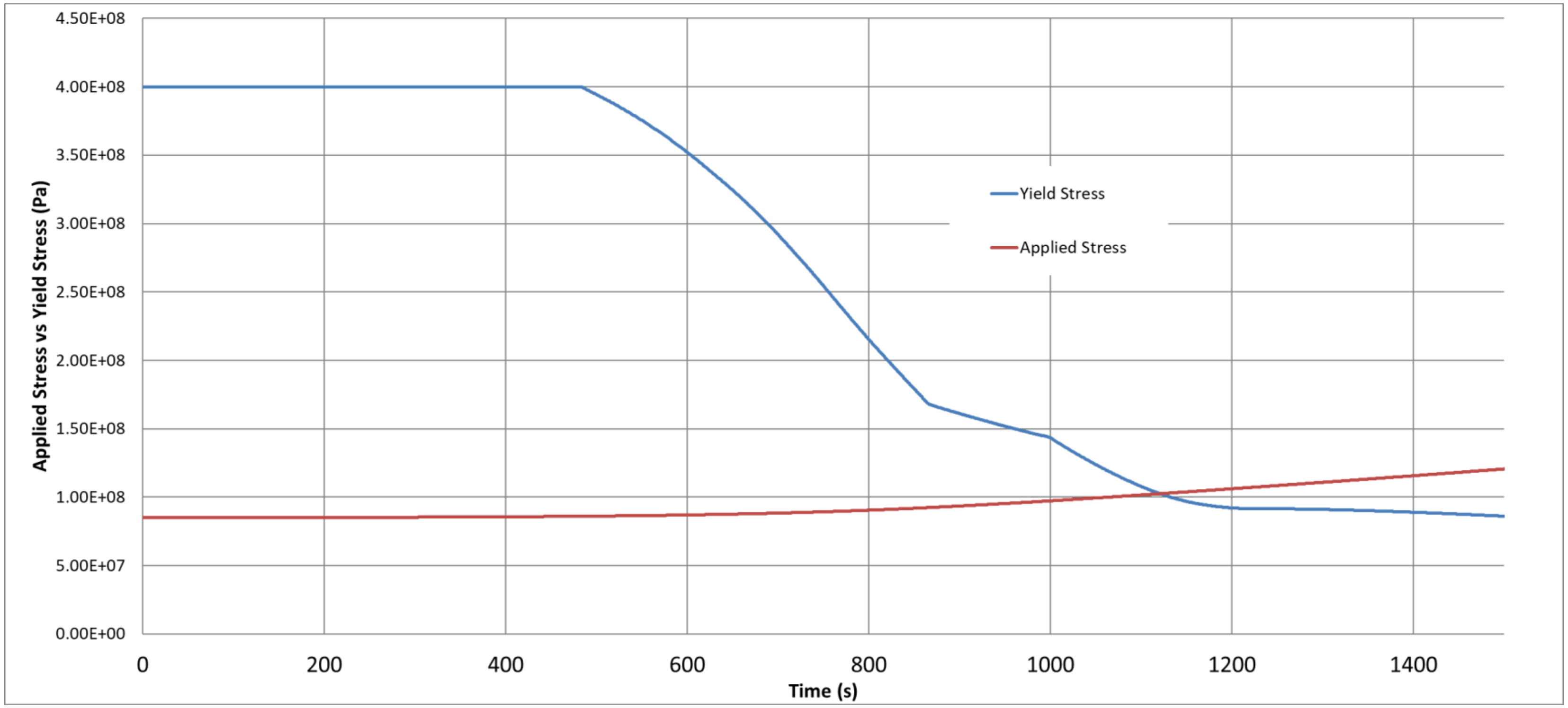




Calculation results: fire from the cabin with no propagation

- Risk of BLEVE after 18 minutes
- Safety valve does not prevent risk of BLEVE for this scenario

Fire from cabin



- Conclusion :
  - Calculations have been conducted for tank (31m3, Common PRV – pressure relief valve- diameter: 2’’ & Popening: 16.5 bar, 50% filling rate) subjected to some specific scenario:
    - No risk of BLEVE for a tyre fire (with propagation to other tyres or not)
    - Risk of BLEVE for a fuel tank fire (pool fire with propagation to tyres and cabin)
    - Risk of BLEVE for a cabin fire (with no propagation)
  - It seems important to avoid propagation, especially to the cabin
- Future work:
  - Continue calculation for different specific fire scenario :
    - External fire coming from a different transport unit
  - Modelling of damages caused by an accident in coating (small sized, scratches?)
  - Study for some case thank containing one or two other gases with similar properties: ammonia, chlorine for example
  - Assess how protecting equipments (on wheels, fuel tanks, engine, cabin…) may allow to keep flame temperature under the safe value. Starting to study Local protection of load from tyres and axles for example by steel plates
  - This will allow to assess the efficiency of safety valves in terms of risk reduction