GTR#13 meeting

5-7 February 2019, Vancouver

Ulster University

GTR#13 engulfing and localised tests: further analysis

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Definitions

Heat release rate (HRR)	-	Heat release rate in a fire [kW] (can easily be measured by propane flow rate to a burner).
Specific heat release rate (HRR/A)	-	Heat release rate in a fire, HRR, divided by the area of fire source, A, [kW/m^2]
Heat flux, $\dot{q}''$	-	Heat flux on tank surface [kW/m^2] (not the same as HRR/A even dimension is the same!).
Fire resistance rating (FRR, required by first responders – EU HyResponse project)	-	Time from burner ignition until container rupture in a fire (without TPRD or failed TPRD or localised fire far from TPRD)

Part 1. Engulfing fire

GTR#13 temperature requirements
6.2.5.2. Engulfing fire test

GTR#13 fire test requirements:

"Within five minutes after the fire is ignited, an average flame **temperature of not less than 590°C** (as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval) **is attained and maintained for the duration of the test**."

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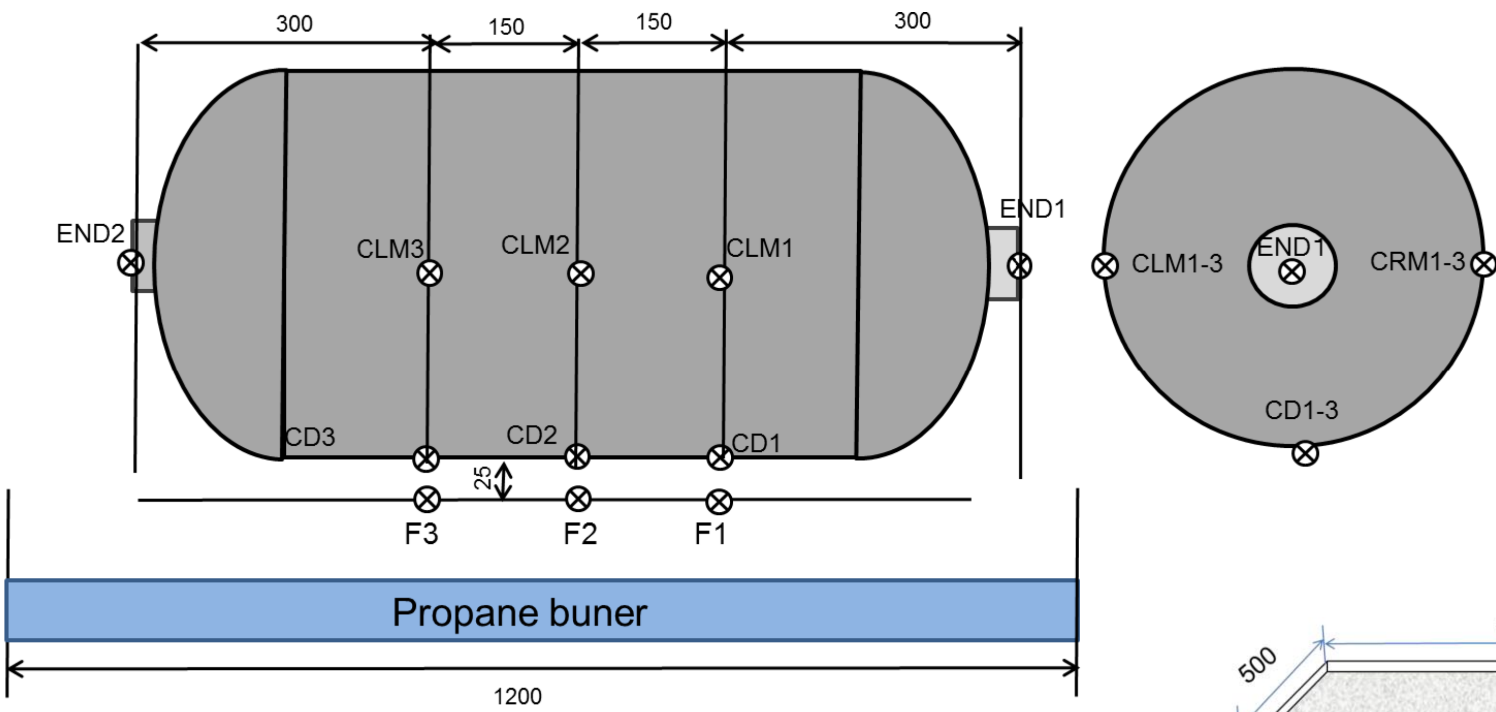
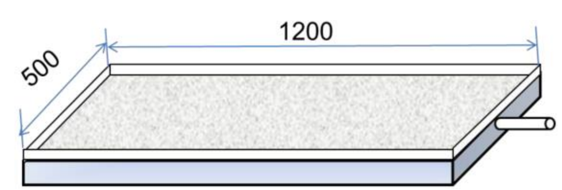
JARI test with blanket burner

Description

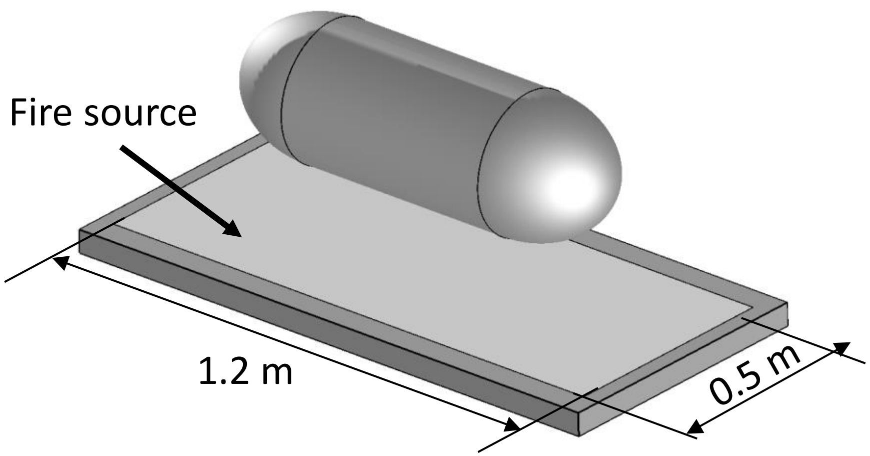
Propane (C_3H_8) flow rate $\dot{V}$=100 NL/min ($\dot{m}$=3 g/s), blanket burner of area A=0.6 m^2 with HRR=0.137 MW. Thus, specific heat release rate is **HRR/A=0.228 MW/m^2**.

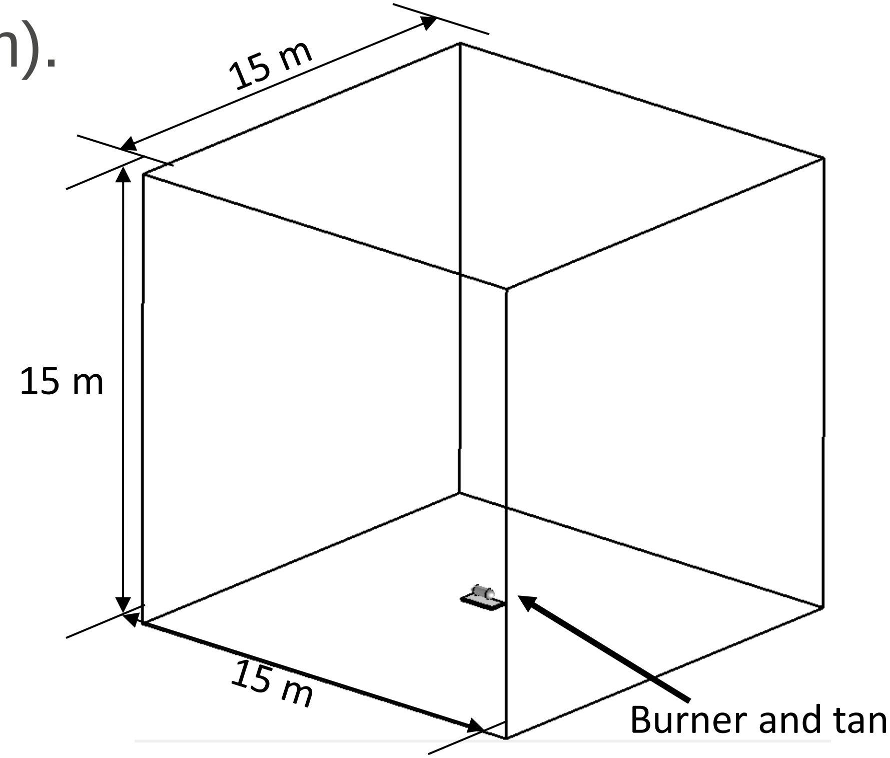




Ulster model (blanket burner test)

- Similar to JARI test the area of “blanket burner” is $A=0.6\ m^2$ (LxW=1.2x0.5 m). Velocity release: 3 mm/s.
- Burner is positioned 0.5 m above the ground.
- Large calculation domain: 15x15x15 m.
- Conjugate heat transfer from the fire to the Type 3 tank (LxD=0.9x0.3 m).

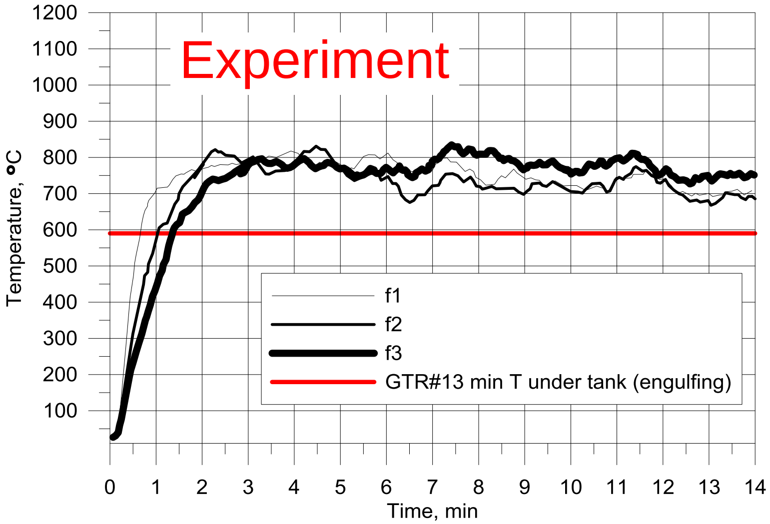


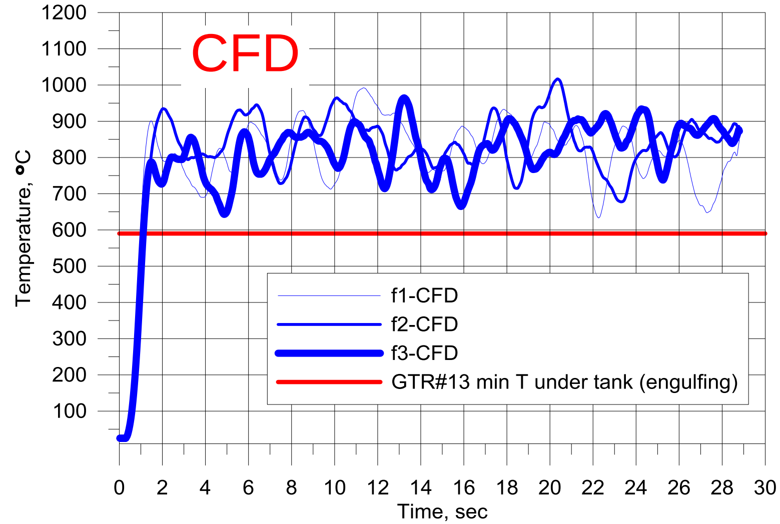


Blanket burner: HRR/A=0.228 MW/m^2

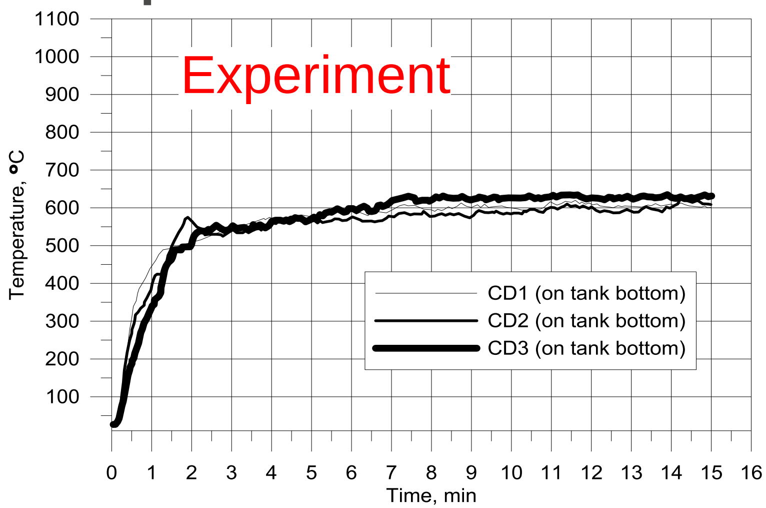
CFD model validation (1/2)

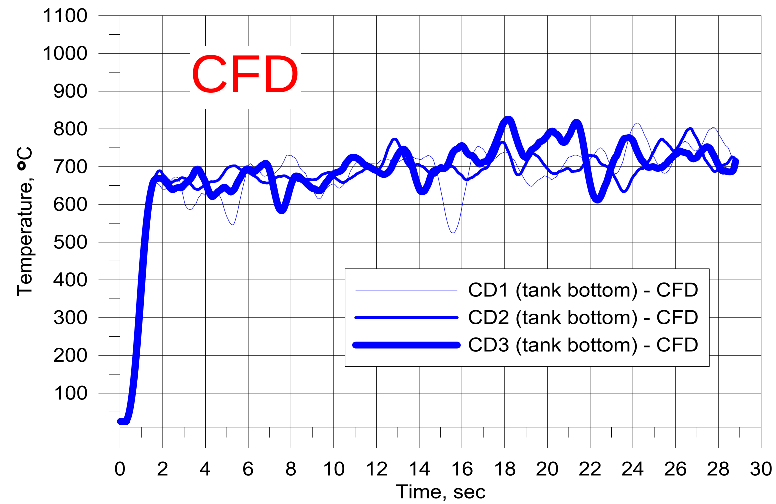
Temperature: 25 mm under tank bottom (GTR#13 compliant)





Temperature: tank bottom

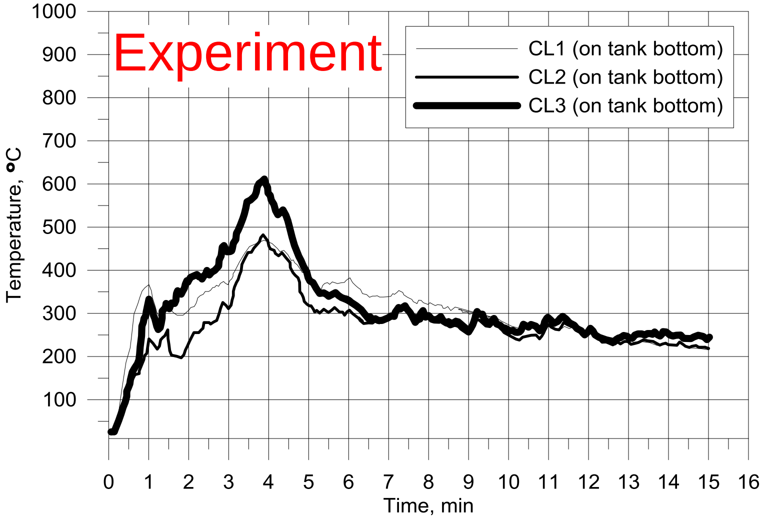


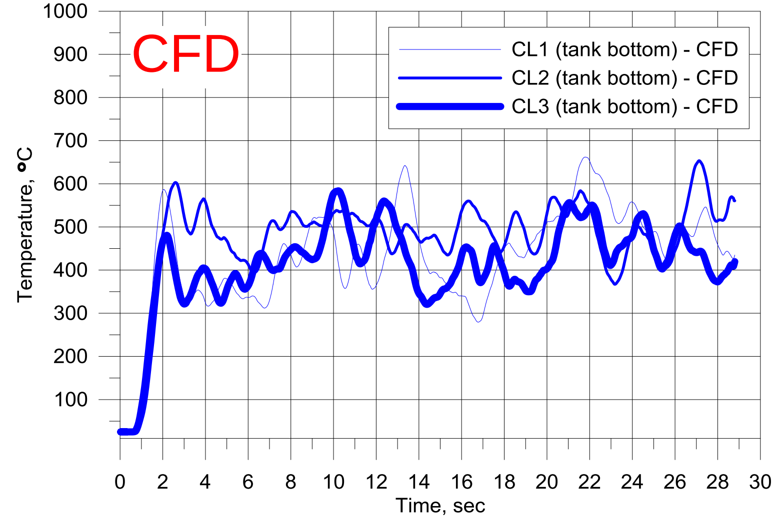


Blanket burner: HRR/A=0.228 MW/m^2

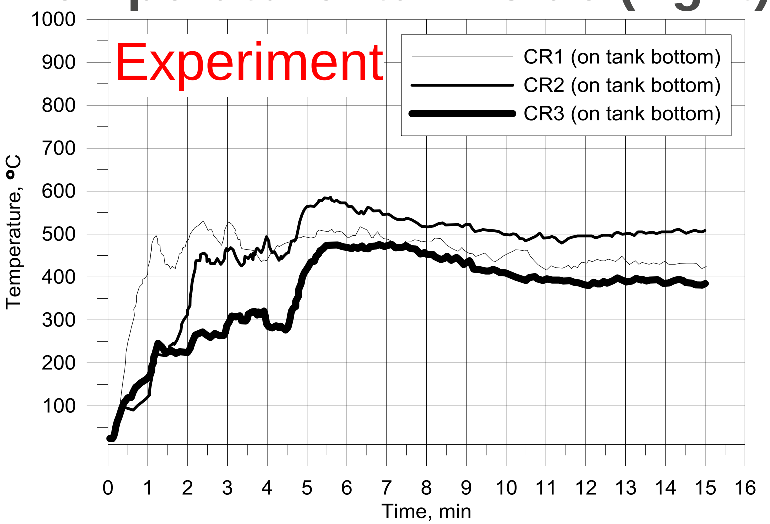
CFD model validation (2/2)

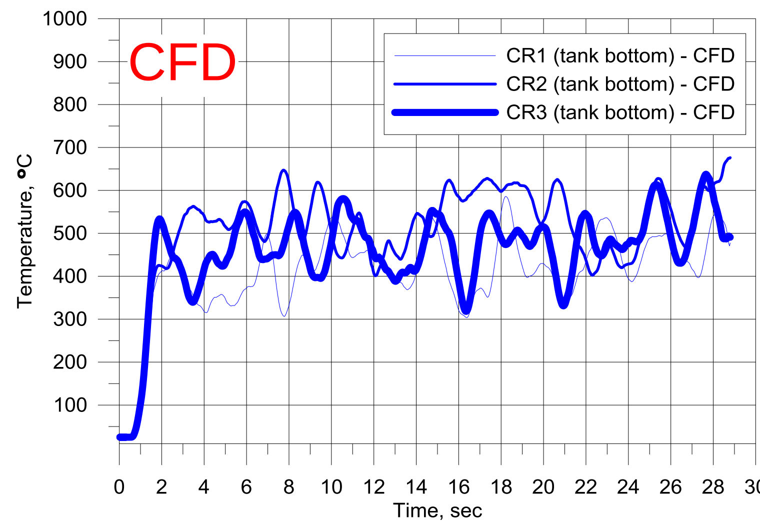
Temperature: tank side (left)





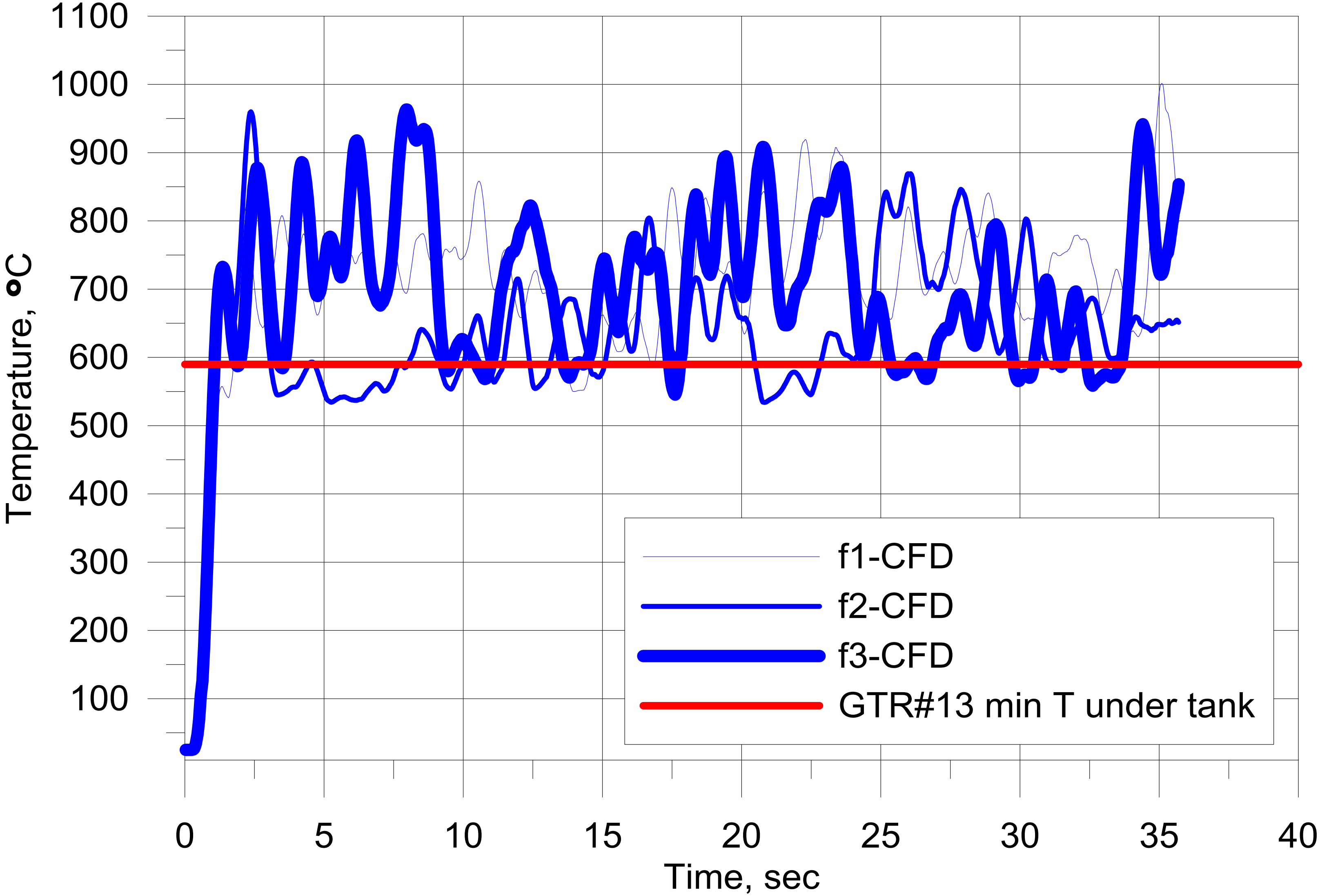
Temperature: tank side (right)





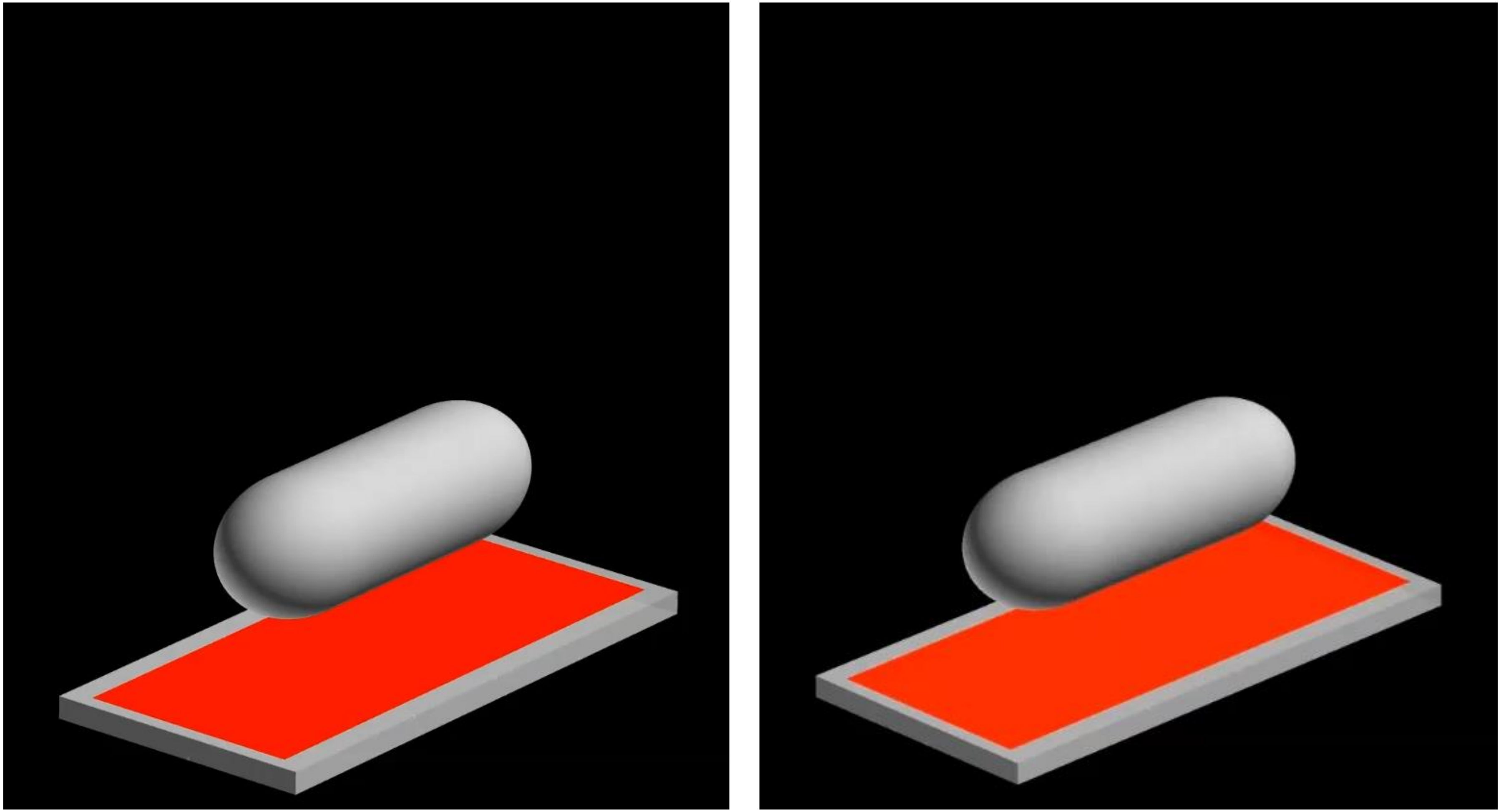
Blanket burner: HRR/A=1 MW/m²

Temperature under tank (GTR#13 compliant!)



Blanket burner: two different HRR/A

HRR/A=0.228 MW/m^2 | HRR/A=1 MW/m^2

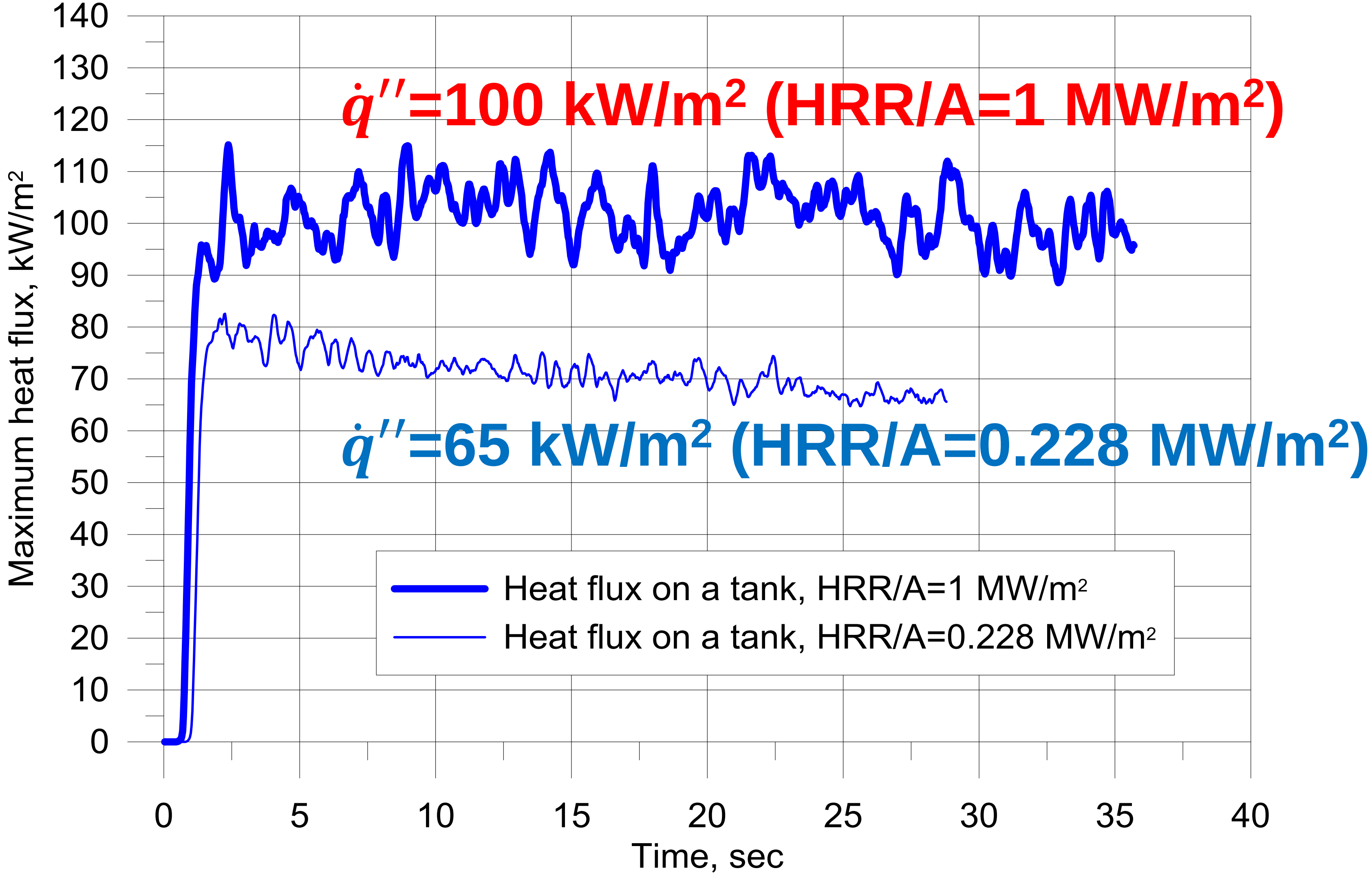


590°C (GTR#13 min required) | 1030°C | 1230 °C

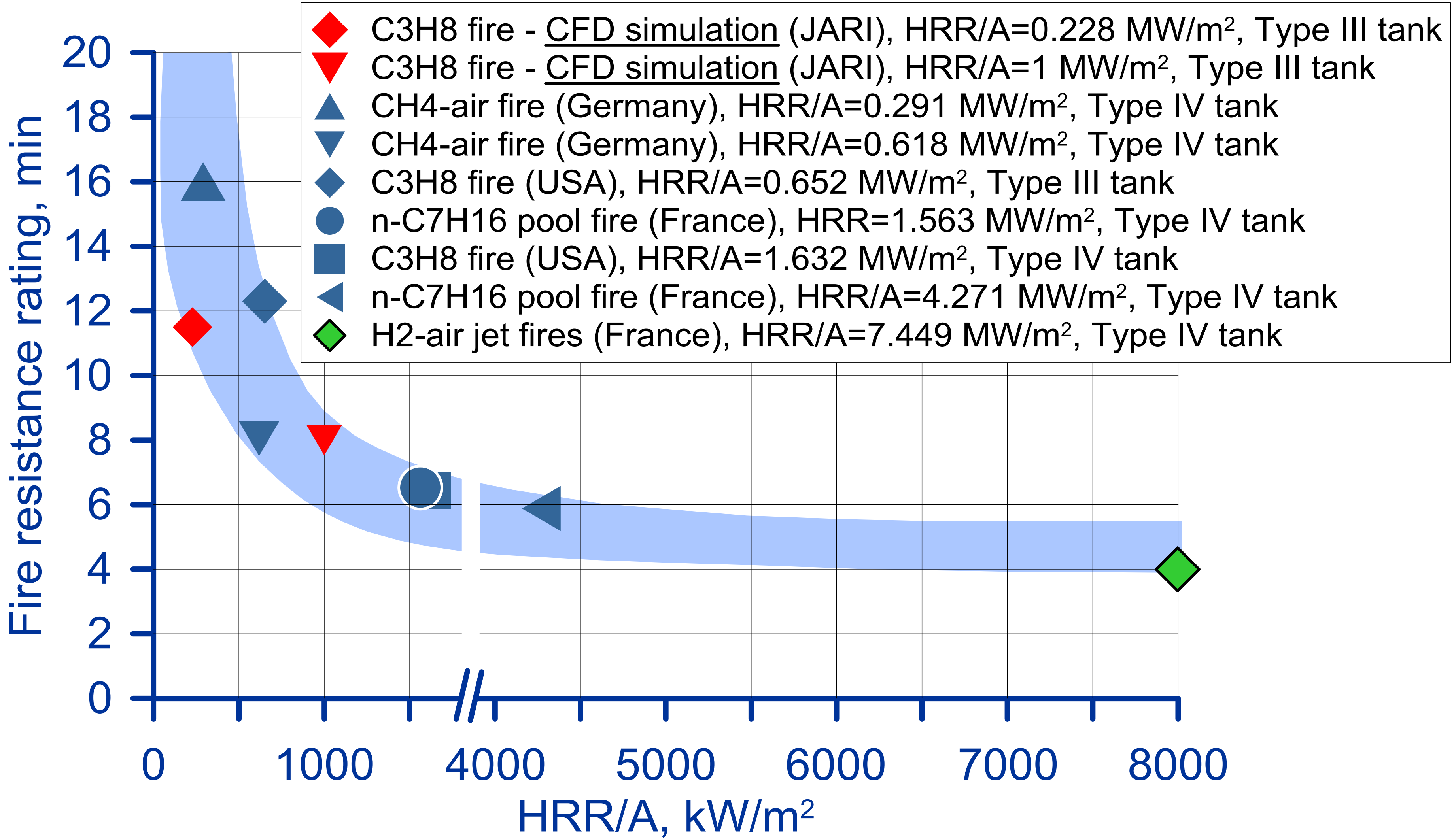
Blanket burner: $\dot{q}''$ depends on HRR/A

Reason of poor fire test reproducibility

GTR#13 temperature is satisfied but heat flux to tank ($\dot{q}''$) is different

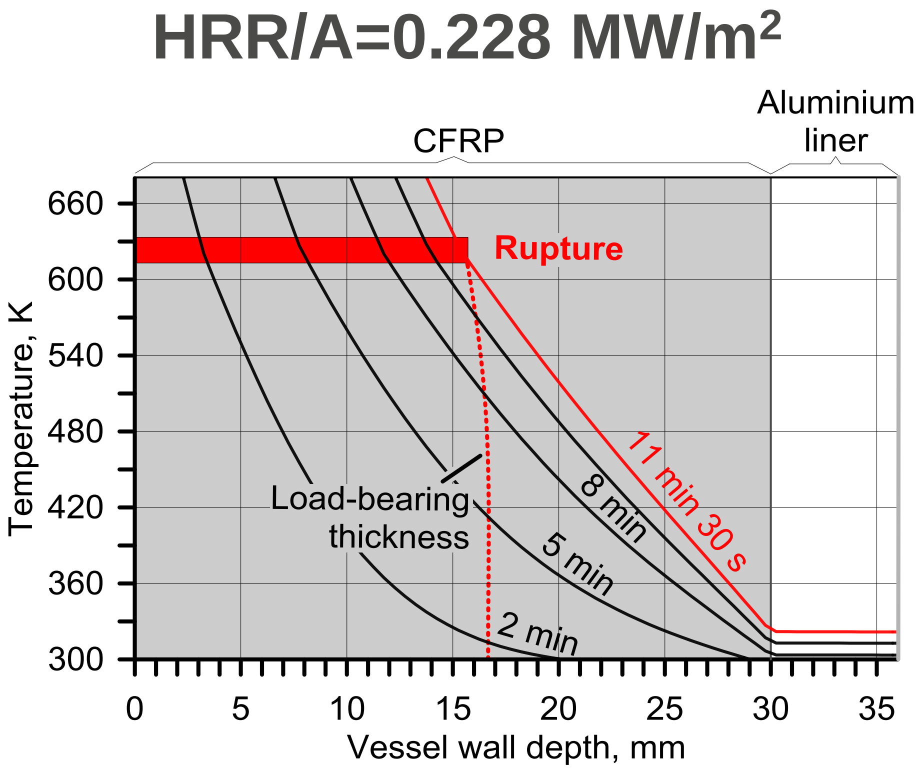


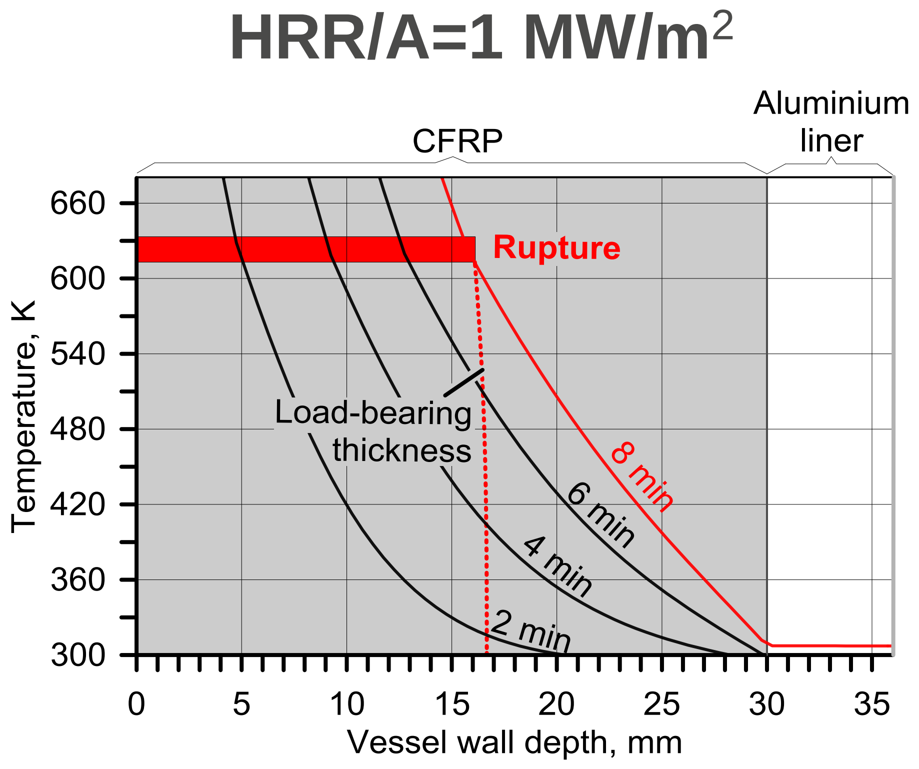
FRR dependence on HRR/A



Blanket burner: HRR/A defines FRR

700 bar Type 3 tank (0.9x0.3 m)





Difference in FRR is 44%:

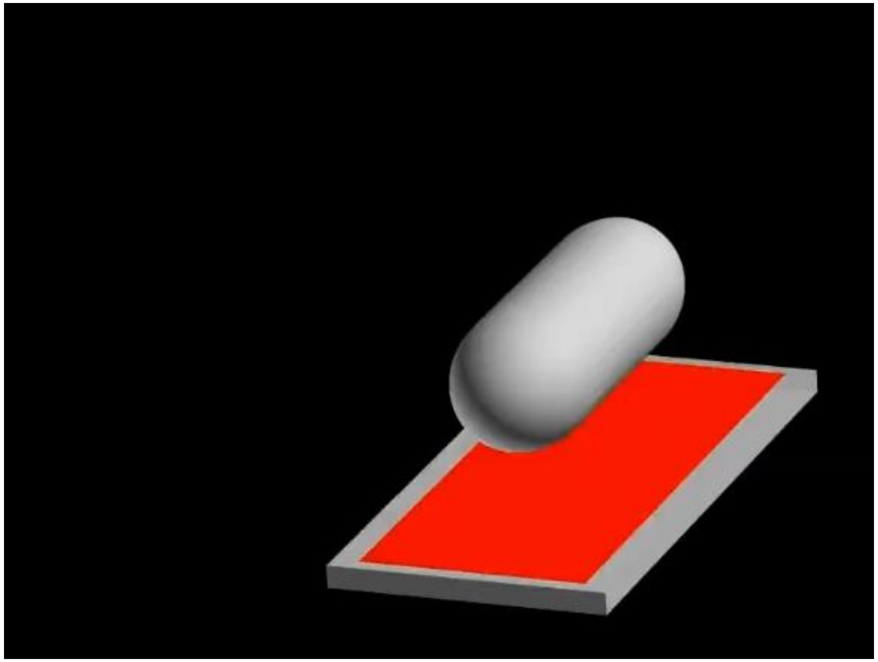
For HRR/A=0.228 MW/m^2 the FRR=11 min 30 s.

For HRR/A=1 MW/m^2 the FRR=8 min.

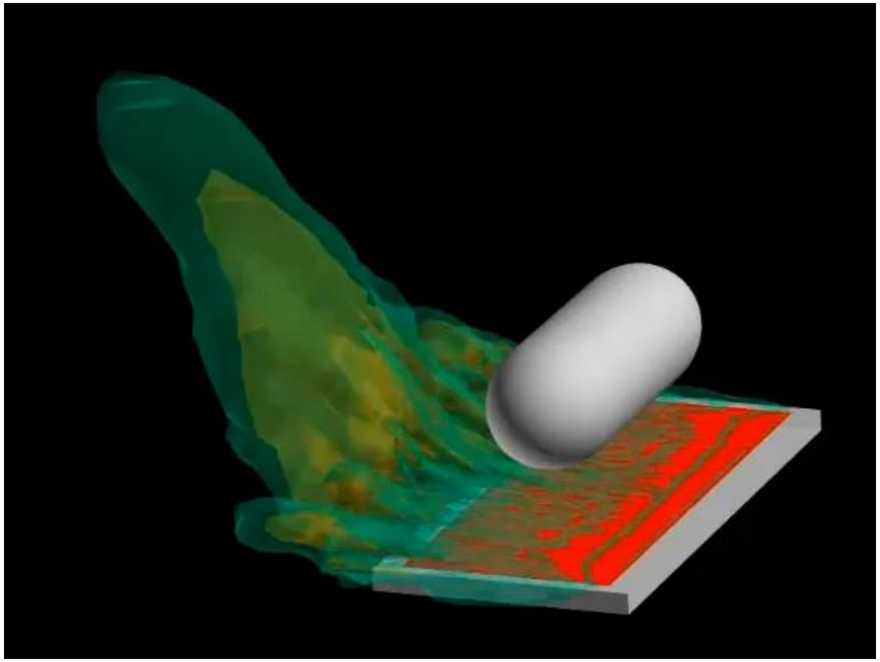
Blanket burner: wind effect (1.8 m/s)

Simulation video (temperature)

HRR/A=0.228 MW/m^2



HRR/A=1 MW/m^2



Temperatures:

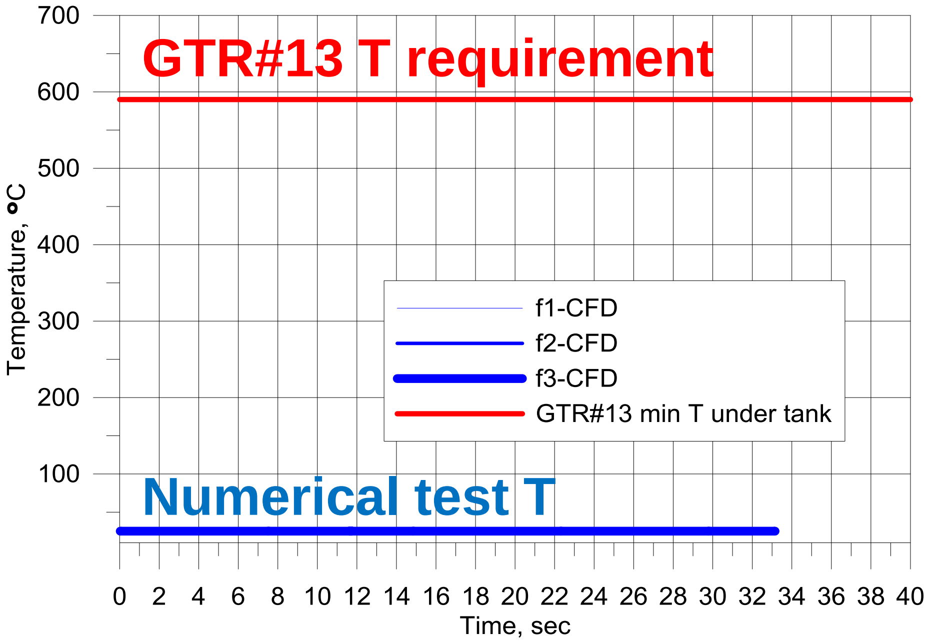
590°C (GTR#13 min required)

1030°C

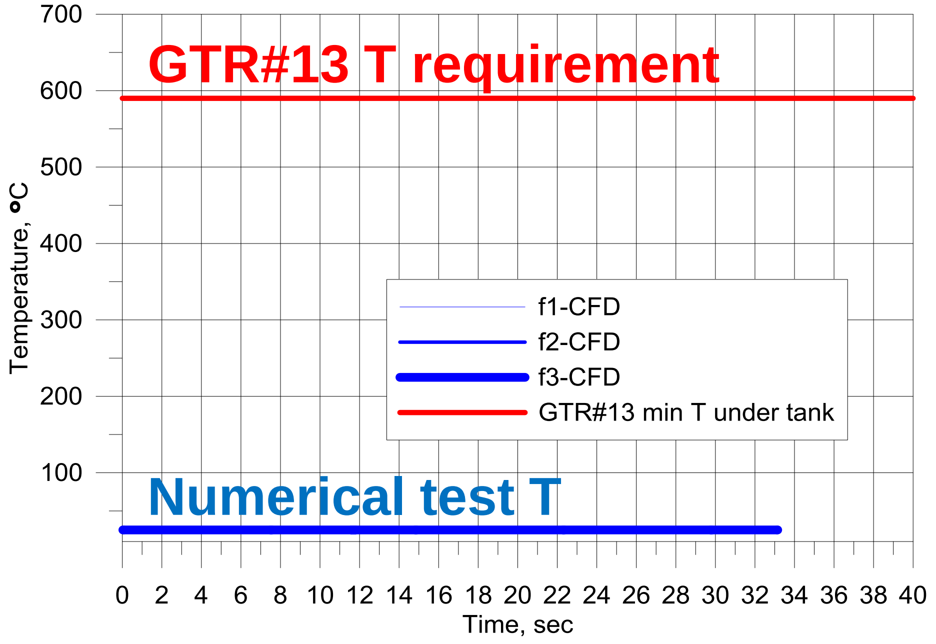
Blanket burner: wind effect (1.8 m/s)

Temperature under tank (GTR#13 non-compliant)

HRR/A=0.228 MW/m^2



HRR/A=1 MW/m^2



In wind conditions (<1.8> m/s, Buxton, UK) GTR#13 minimum temperature requirements **are not satisfied**: **temperatures under the tank are close to ambient 20°C!**

Intermediate remarks

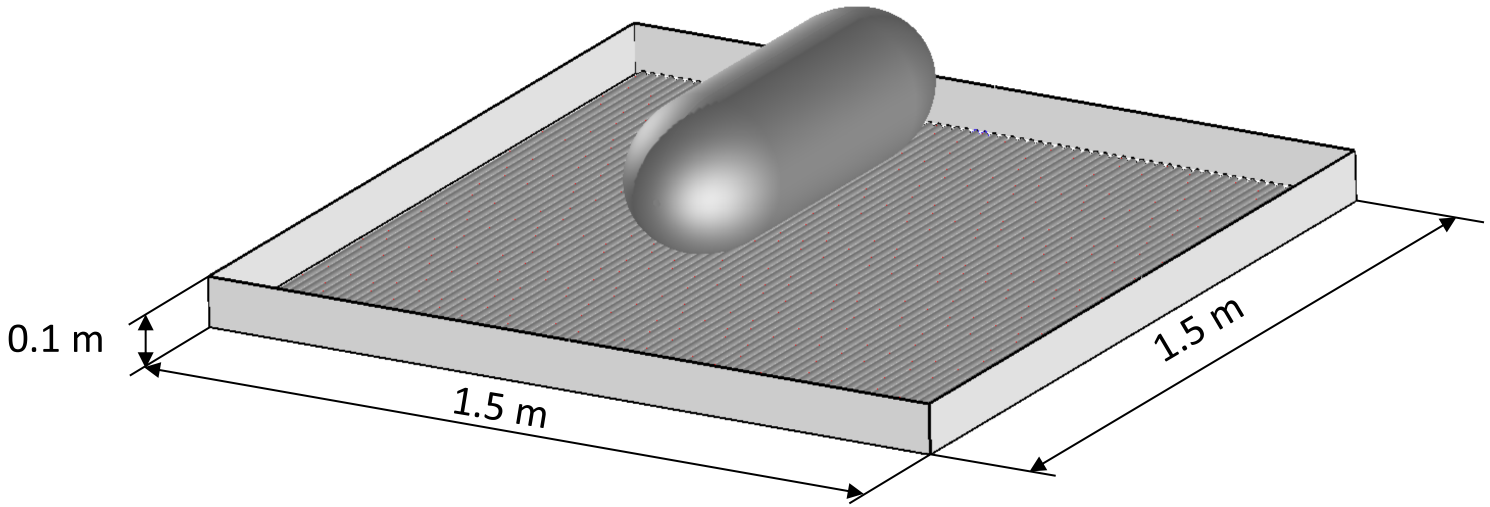
Blanket burner

- Heat flux to a tank in fire with blanket burner increases by about 50% (from $\dot{q}''$=65 kW/m^2 to $\dot{q}''$=100 kW/m^2) for the increase of HRR/A from 0.228 MW/m^2 to 1 MW/m^2. This resulted in FRR decrease by 44% from 11.5 min to 8 min (GTR#13 temperature requirements are reproduced in both cases!).
- For no wing conditions, the fire test reproducibility can be provided for HRR/A>1 MW/m^2 (as per "saturation graph").
- Blanket burner of investigated size 500x1200 mm performance in a wind of order 1.8 m/s is a concern. Only "no wind" facilities could use it to satisfy GTR#13 temperature requirements.
- A new "wind-resistant" blanket burner is needed (increased size?).

Pipe burner (1/2)

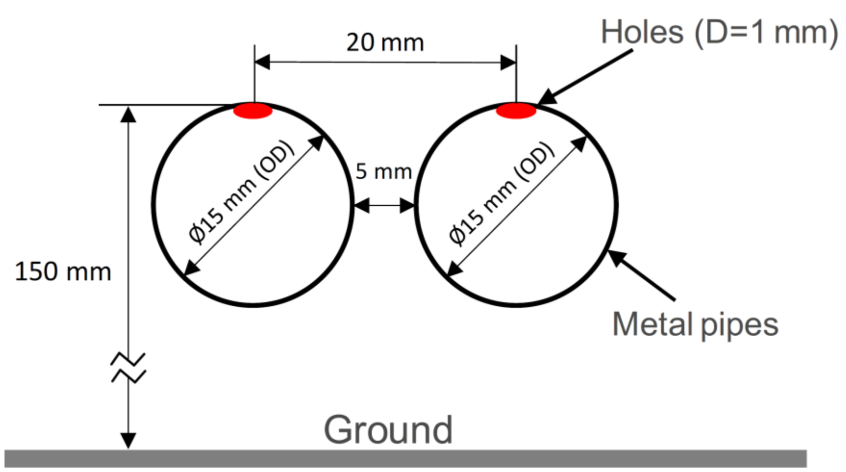
Two HRR/A cases (same as JARI burner)

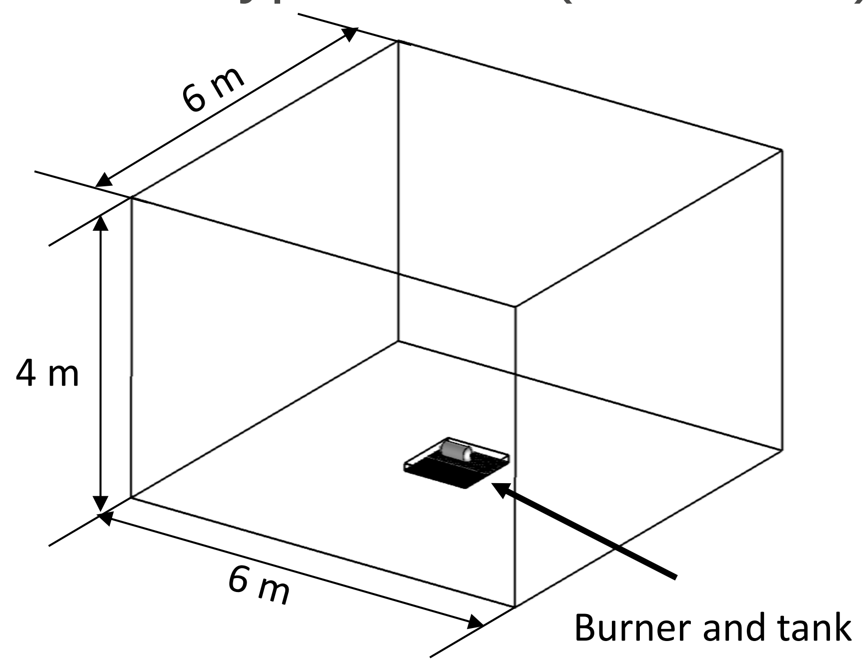
- **Case 1**: Propane ($C3H8$) flow rate $\dot{V}$=362.4 NL/min, $\dot{m}$=11.07 g/s. Pipe burner area 2.25 m^2, HRR=0.513 MW. Thus **HRR/A=0.228 MW/m^2**.
- **Case 2:** Propane ($C3H8$) flow rate $\dot{V}$=1589 NL/min, $\dot{m}$=48.54 g/s, HRR=2.25 MW. Thus **HRR/A=1 MW/m^2**.
- With and without wind (1.8 m/s) study.



Pipe burner (2/2)
Numerical details

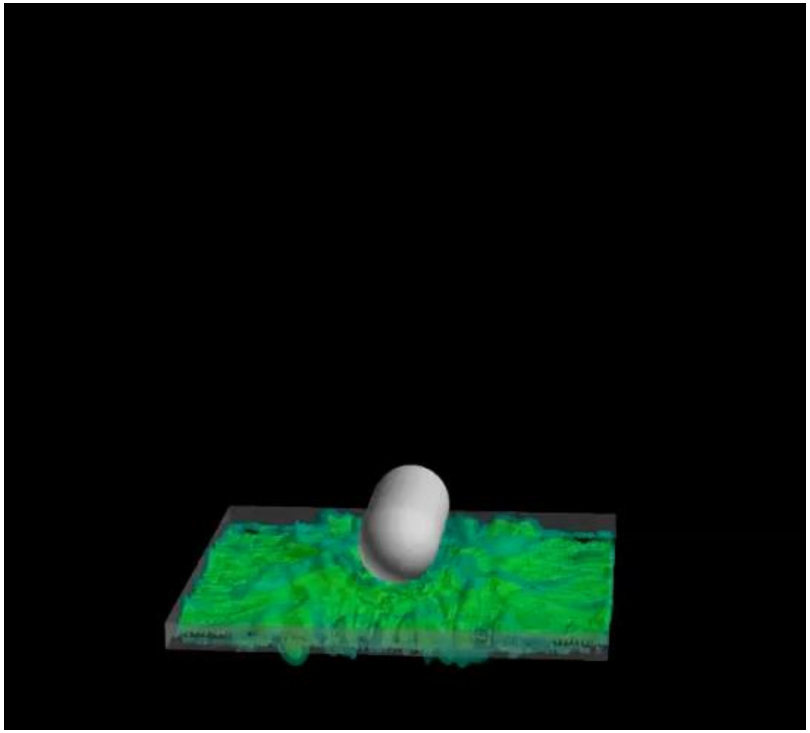
- 5600 holes spaced uniformly at 20 mm. Hole D=1 mm.
- Propane velocity: 1.2 m/s (HRR/A=0.228 MW/m^2) and 5.3 m/s (HRR/A=1 MW/m^2). Note: 3 mm/s in blanket burner.
- Burner positioned at 0.15 m above the ground.
- Calculation domain: 6x6x4 m.
- Conjugate heat transfer from fire to Type 3 tank (0.9x0.3 m).



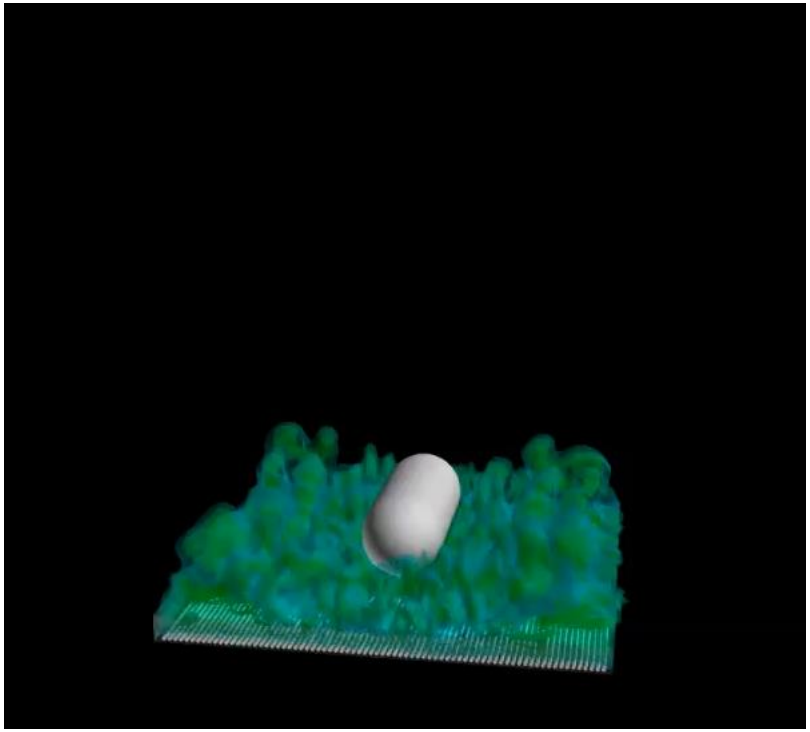


Pipe burner: no wind
Simulation video (temperature)

Case1: HRR/A=0.228 MW/m^2



Case 2: HRR/A=1 MW/m^2



Temperatures:

590°C (GTR#13 min required) 1030°C

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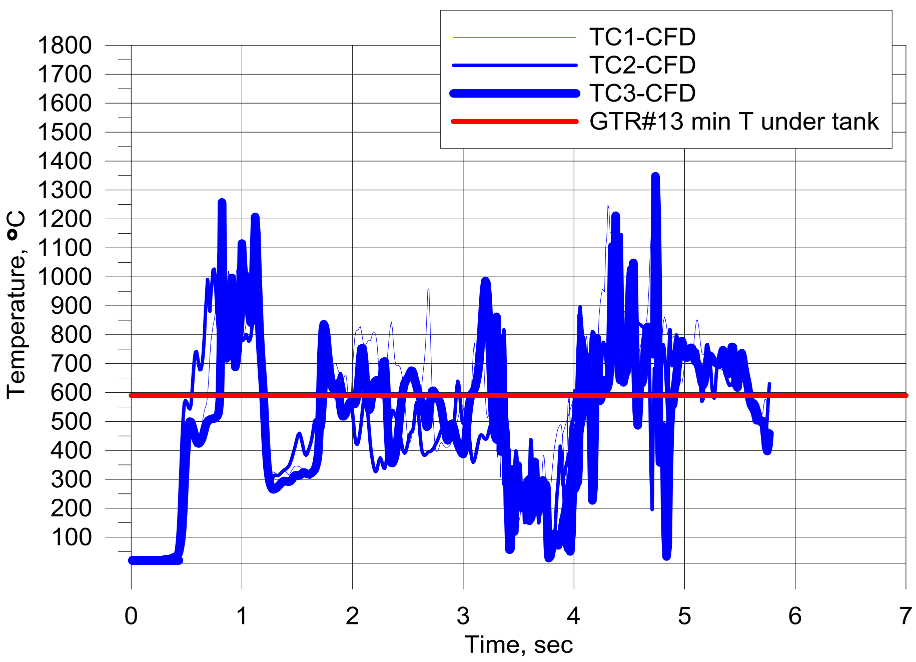
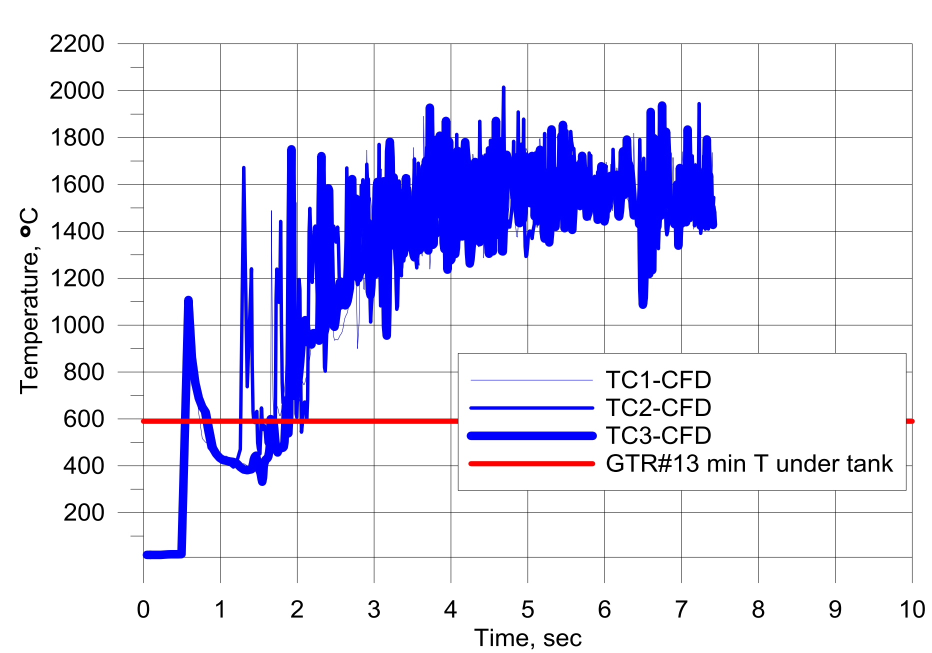
Pipe burner: no wind

Temperature under tank (simulation)

Case1: HRR/A=0.228 MW/m^2



Case 2: HRR/A=1 MW/m^2



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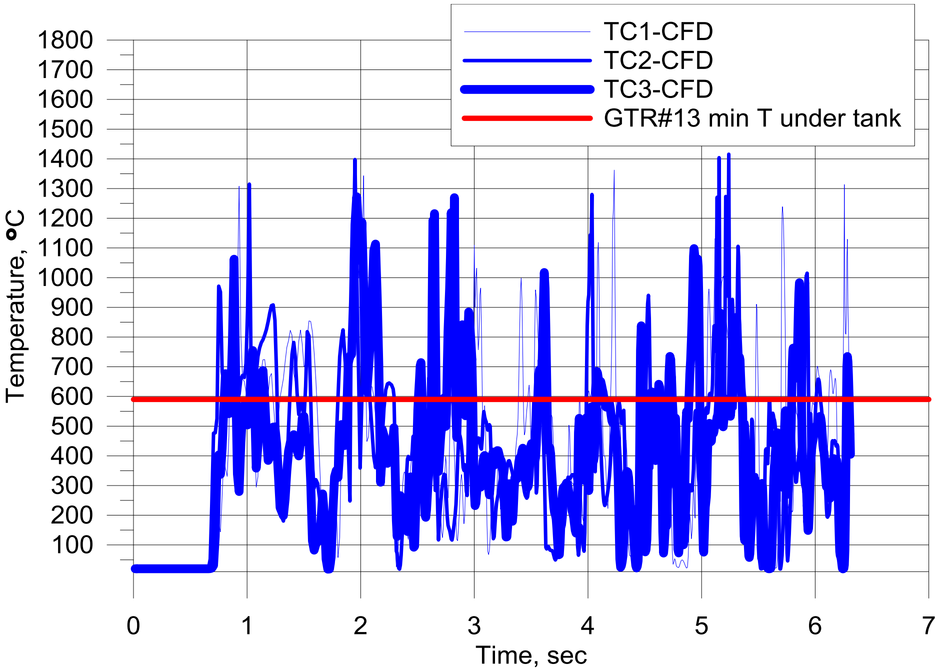
GTR#13 T requirements are satisfied for both HRR/A.

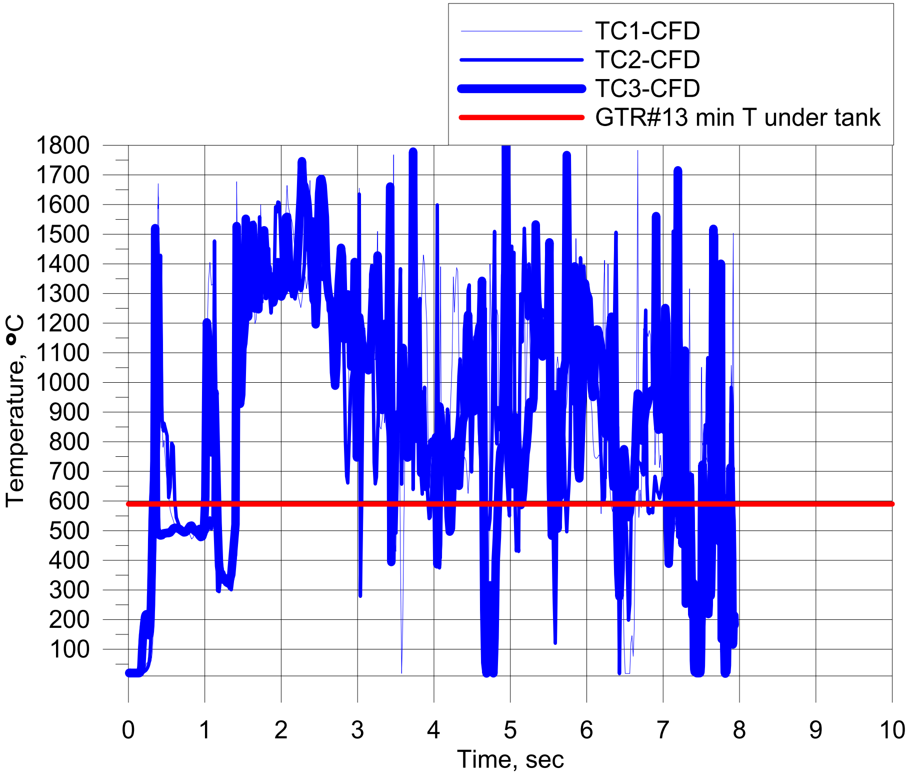
Pipe burner: wind effect (1.8 m/s)

Temperature under tank (simulation)

Case1: HRR/A=0.228 MW/m²



Case 2: HRR/A=1 MW/m²

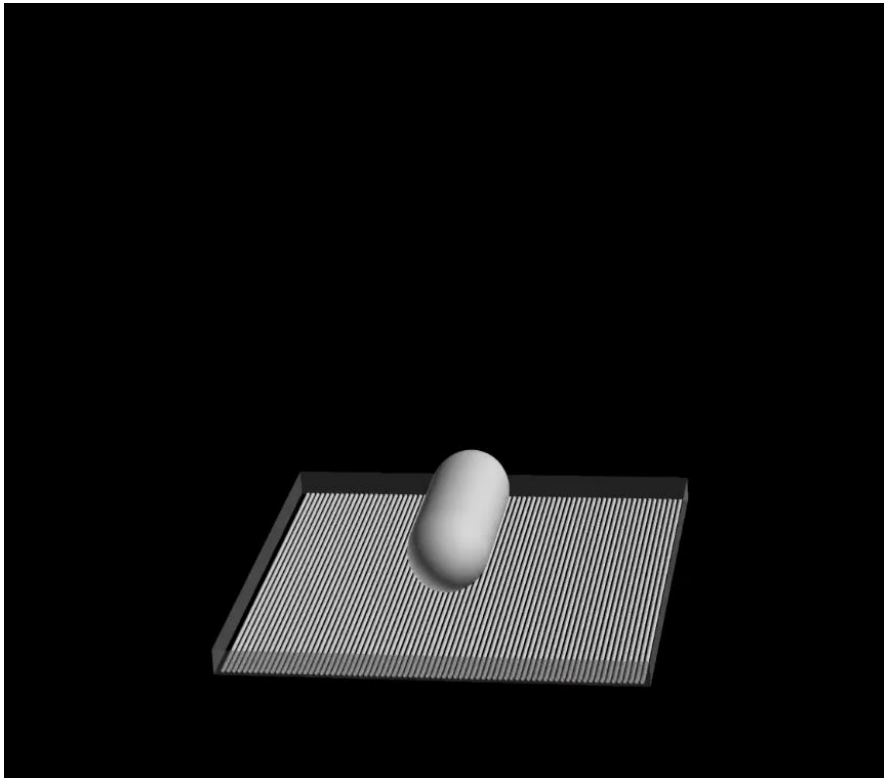


- **GTR#13 T are not always satisfied for HRR/A=0.228 MW/m2 (initial test stage).**
- **GTR#13 T are satisfied for HRR/A=1 MW/m² (concluded from initial test stage).**

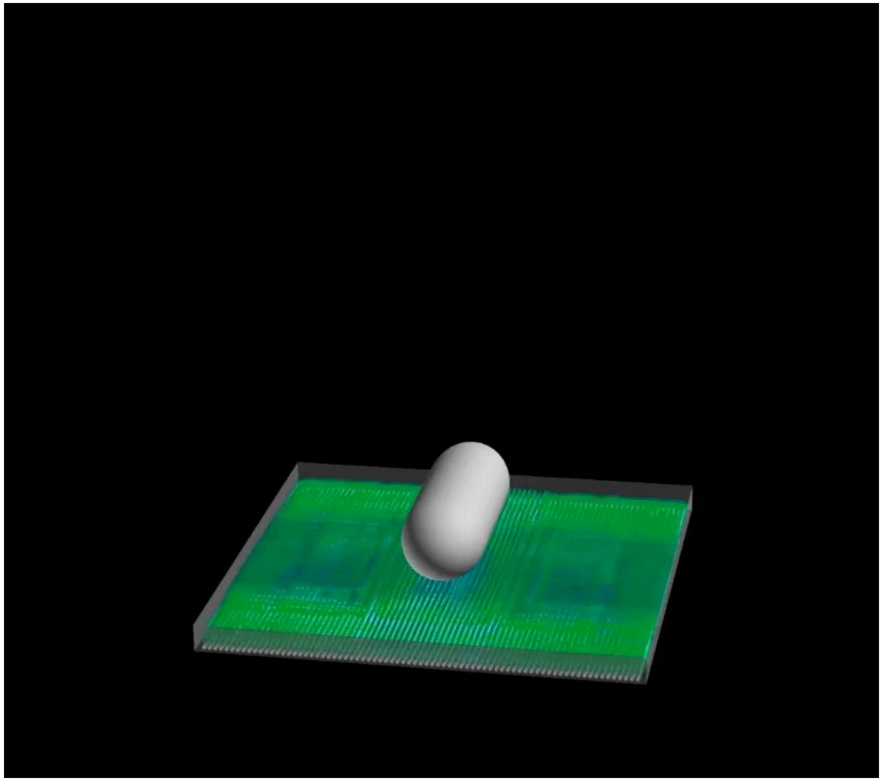
Pipe burner: wind effect (1.8 m/s)

Simulation video (temperature)

Case1: HRR/A=0.228 MW/m^2



Case 2: HRR/A=1 MW/m^2



Temperatures:

590°C (GTR#13 min required)

1030°C

Intermediate remarks (engulfing test)
Pipe burner

- With no wind, the engulfing fire test with the pipe burner satisfies GTR#13 minimum temperatures at HRR/A=0.228 MW/m^2 and 1 MW/m^2 (similar to blanket burner).
- In wind conditions, the pipe burner reproduces GTR#13 minimum temperatures with HRR/A=1 MW/m^2 and not always reproduces temperatures with HRR/A=0.228 MW/m^2.
- Pipe burner is more “wind resistant” compared to blanket burner (flow velocities 1200 mm/s and 3 mm/s respectively!).
- The improve fire test reproducibility the use of pipe burner with HRR/A>1 MW/m^2 can be recommended (in addition to the temperature requirements).

Concluding remarks
Engulfing test

- Engulfing fire test must include determination of a tank FRR (time to rupture of tank without TPRD in a fire) as required by first responders in EU HyResponse project.
- Investigated pipe burner performs more “wind resistant” compared to investigated blanket burner.
- “Wind resistant” burner should be designed and used for different wind conditions (only 1.8 m/s is investigated here) to satisfy GTR#13 minimum temperature requirements for engulfing fire test.
- New requirement should be introduced to the temperature control in GTR#13 fire test protocol: HRR/A>1 MW/m2 should be provided by burner.

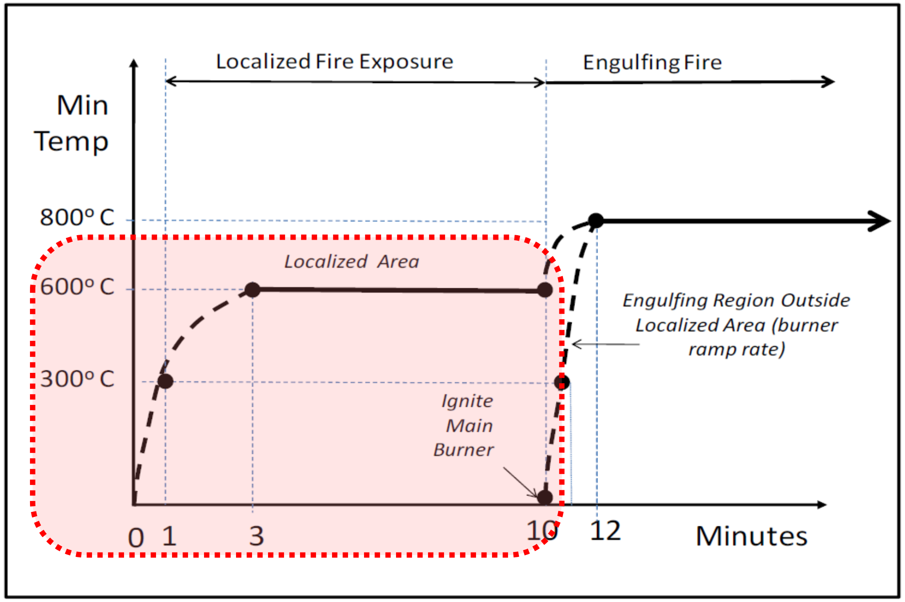
Part 2. Localised in-situ fire

GTR#13 temperature requirements

6.2.5.1. Fire test (localised + engulfing)

Localised portion of the fire test:

"…the temperature of the thermocouples in the localized fire area has increased continuously to at least 300 °C within 1 minute of ignition, to at least 600 °C within 3 minutes of ignition, and a **temperature of at least 600 °C is maintained** for the next 7 minutes …"



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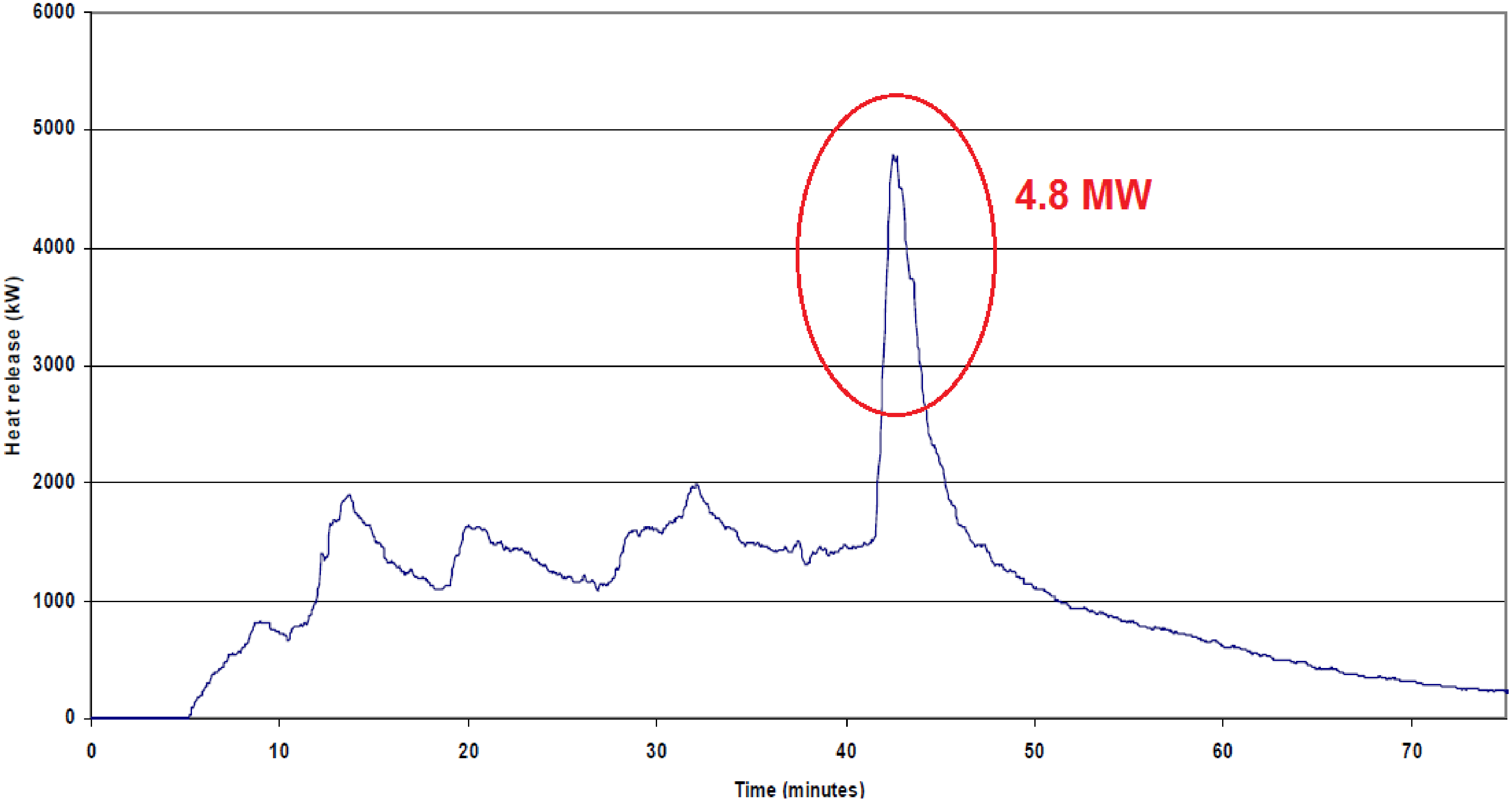
Reference 1: fuel spill during car fire

Increase of HRR by (4.8 MW -2 MW)=2.8 MW

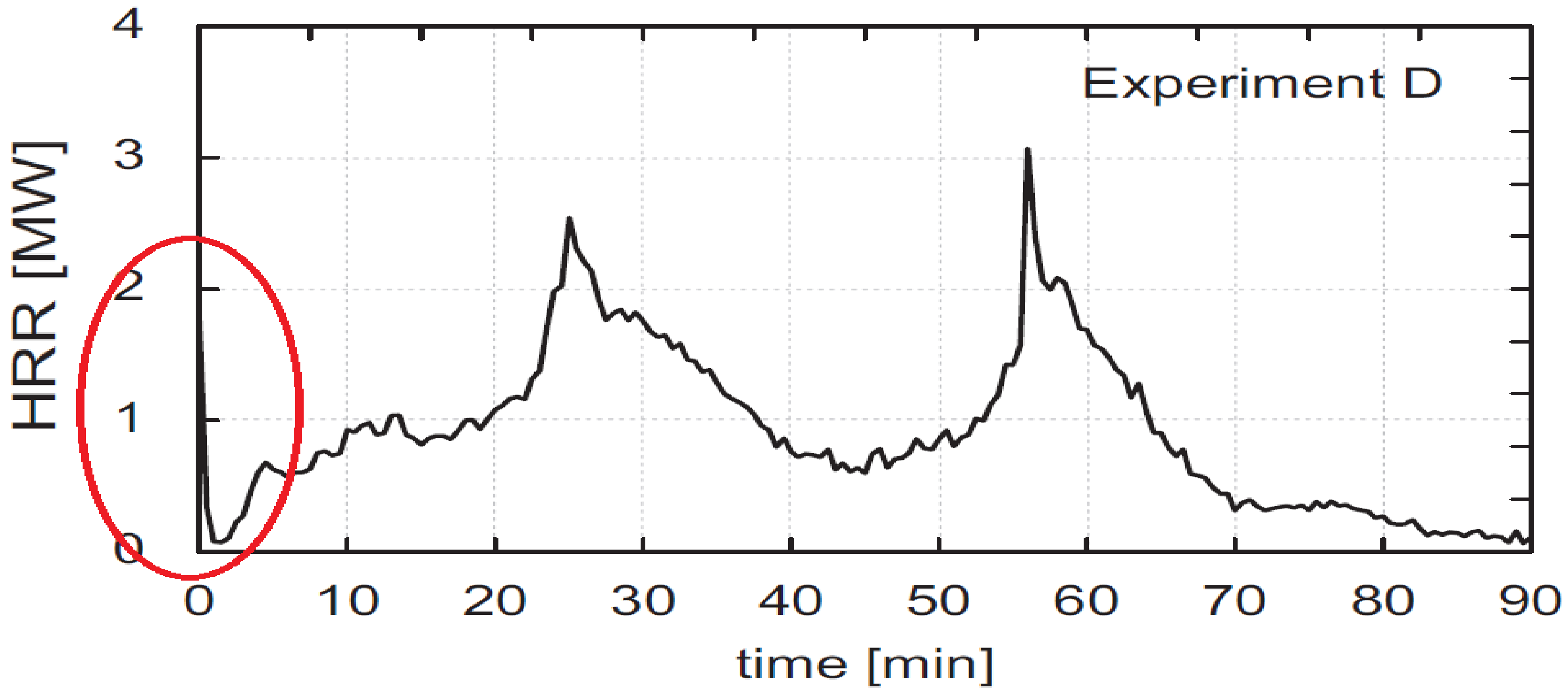


“The 4.8 MW peak is associated with a spillage of fuel”.

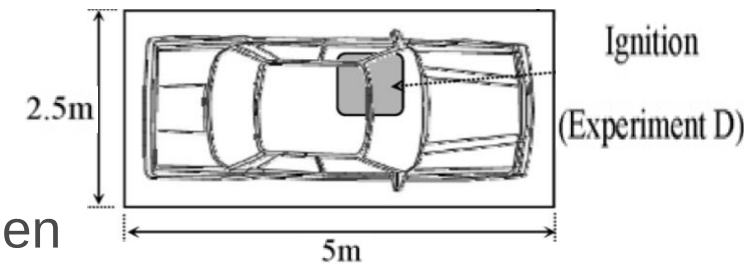
Source: Fire spread in car parks, BD2552, BRE, Department for Communities and Local Government, 2010.

Reference 2: fuel spill in a car

HRR about 1.7 MW from the gasoline fire start



The HRR was more than 1.7MW immediately after ignition of gasoline spill inside a car for about 2-3 min then combustion inside the car was suppressed quickly due to the lack of oxygen (it would give 3.4 MW/m^2 for 0.5 m^2 spill).



Source: K. Okamoto et al., Burning behaviour of sedan passenger cars, Fire Safety Journal, 44, 2009.

Four localised fires under a vehicle

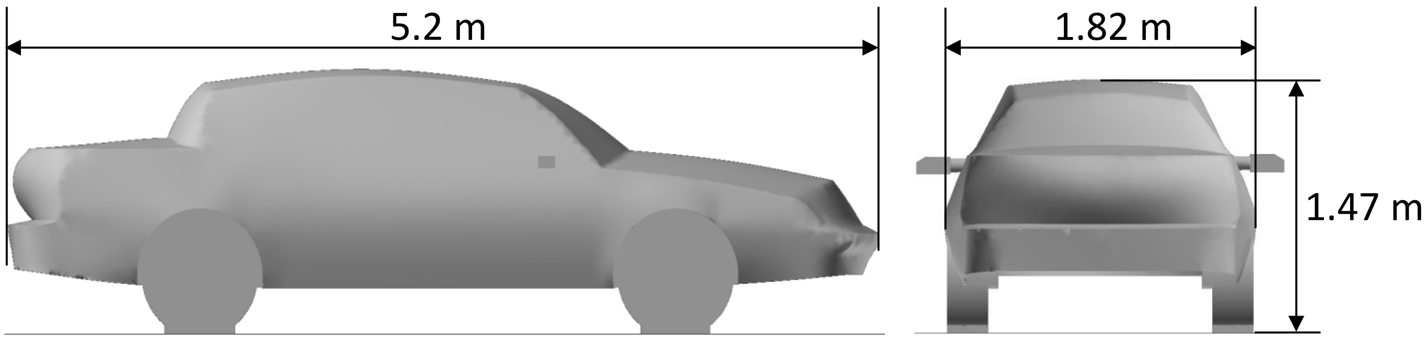
Range: A=0.2-1.9 m^2, HRR/A=0.2-2.3 MW/m^2

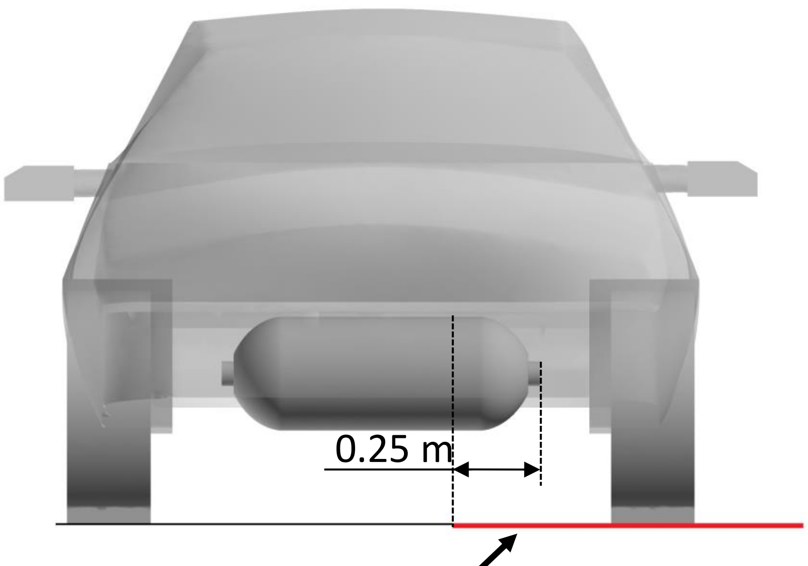
- **Case 1:** *surrogate fuel*, C3H8 equivalent $\dot{m}$=8.2 g/s. Burner A=1.9 m^2, HRR=0.38 MW: **HRR/A=0.2 MW/m^2**.
- **Case 2:** *surrogate fuel*, C3H8 $\dot{m}$=41 g/s. Burner **A=1.9 m^2**, HRR=1.9 MW: **HRR/A=1 MW/m^2**.
- **Case 3:** *diesel* $\dot{m}$=4.72 g/s(*), C3H8 $\dot{m}$=4.31 g/s. Burner **A=0.2 m^2**, HRR=0.2 MW: **HRR/A=1 MW/m^2**.
- **Case 4:** *diesel* $\dot{m}$=103 g/s(*), C3H8 $\dot{m}$=94.5 g/s. Burner A=1.9 m^2, HRR= 4.38 MW: **HRR/A=2.3 MW/m^2**.

(*) **Obtained using** D. Drysdale, An introduction to fire dynamics, 3rd ed., 2011.

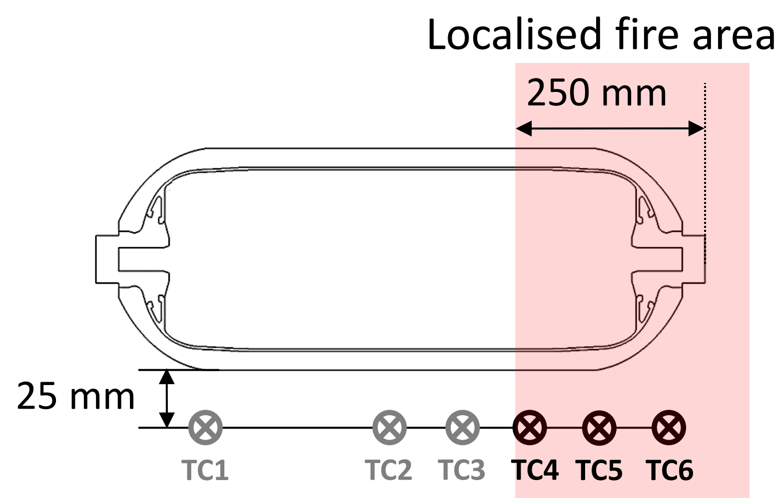
Four localised fires under a car

Car and tank geometry, TCs and fire location





Fire source (No.1, No.2) covers localised area of tank 0.25 m

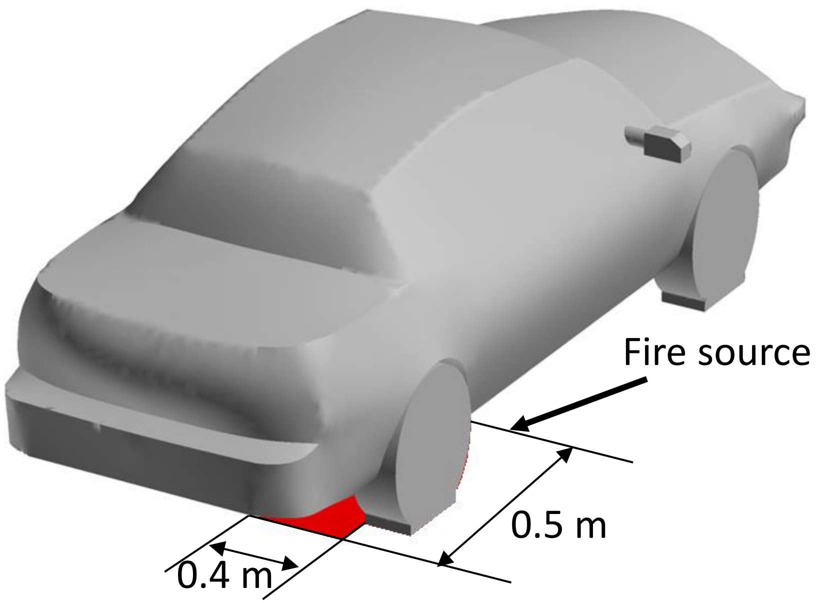


Conjugate heat transfer from fire to 700 bar Type 4 tank (LxD=0.91x0.325 m).

Localised fire: diesel fire with A=0.2 m^2

Case 3

- Fire area A=0.2 m^2 (fire source of area No.1), diesel $\dot{m}$=4.72 g/s.
- Total HRR=0.2 MW;
- Hence, **HRR/A=1 MW/m^2**.



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Source: D. Drysdale, An introduction to fire dynamics, 3rd ed., 2011.

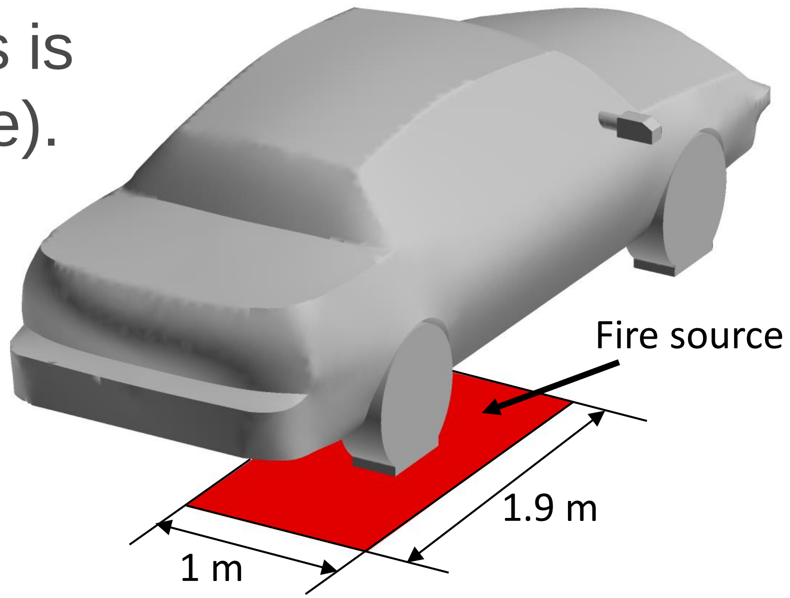
Localised fire: diesel fire with A=1.9 m^2

Case 4

For pool fire of about 1-2 m (localised fire) the fuel burning rate can be taken as quasi-steady value (literature sources).

- Burning rate of diesel for such fire sizes is $\dot{V}$=3.9 mm/min.
- This is equivalent to $\dot{m}_A$=54.08 g/m^2/s.
- Fire area A=1.9 m^2 (fire source of area No.2), $\dot{m}$=103 g/s.
- Total HRR=4.38 MW;
- Thus **HRR/A=2.3 MW/m^2** (this is close to References 1-2 above).

Source: D. Drysdale, An introduction to fire dynamics, 3rd ed., 2011.



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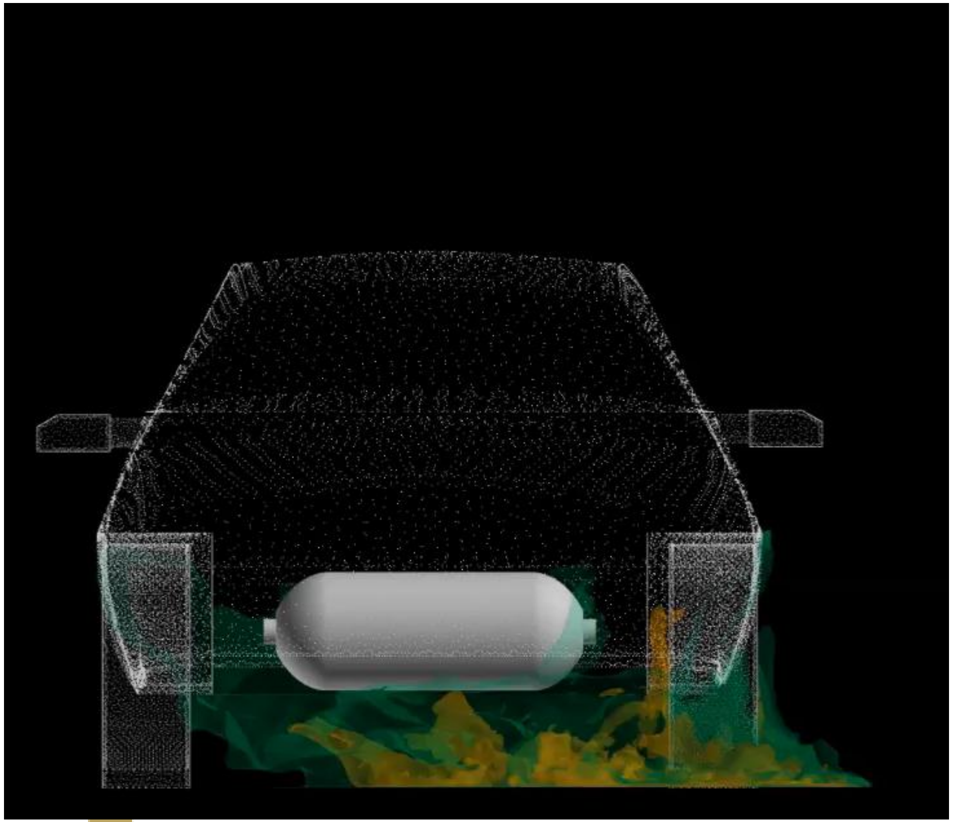
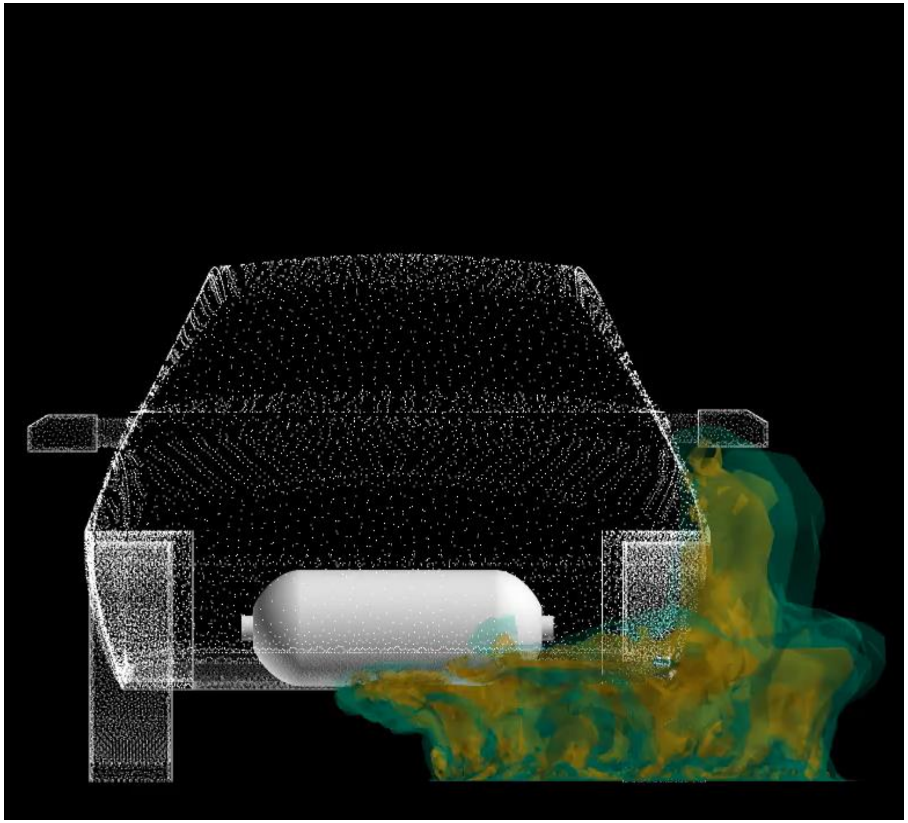
In-situ fire dynamics: cases 1 and 2
Video

Case 1: HRR/A=0.2 MW/m^2



Case 2: HRR/A=1 MW/m^2



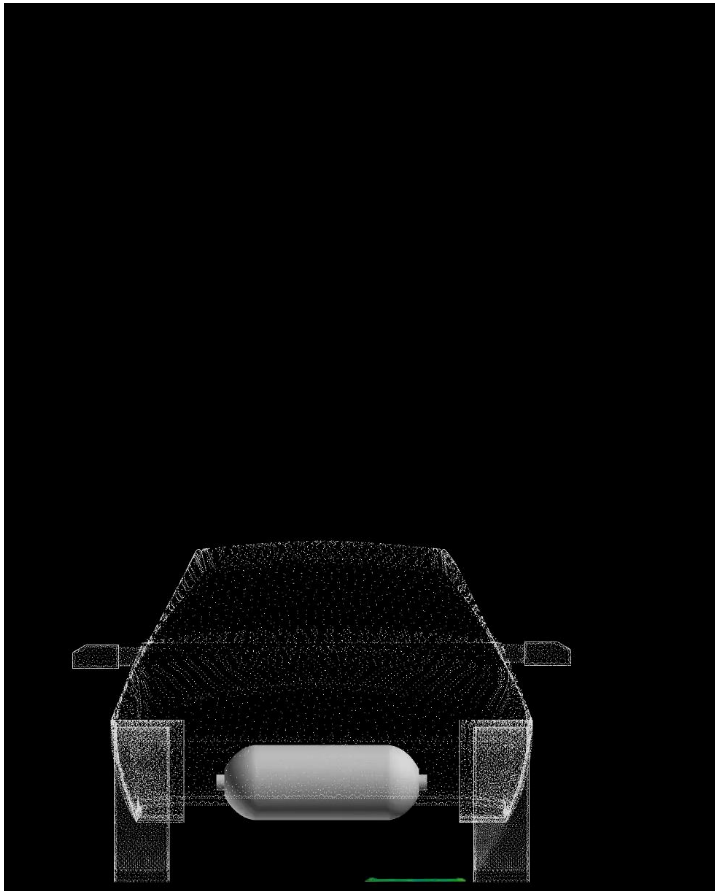
600°C (GTR#13 min required)

1030°C

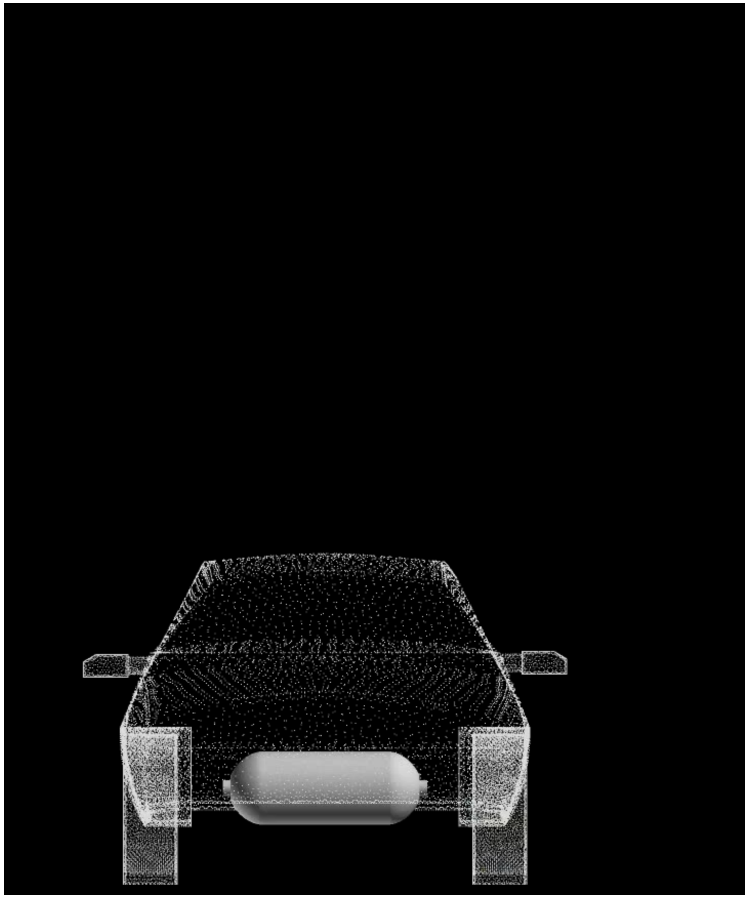
In-situ fire dynamics: cases 3 and 4

Video

Case 3: HRR/A=1 MW/m^2



Case 4: HRR/A=2.3 MW/m^2



600°C (GTR#13 min required)   1030°C

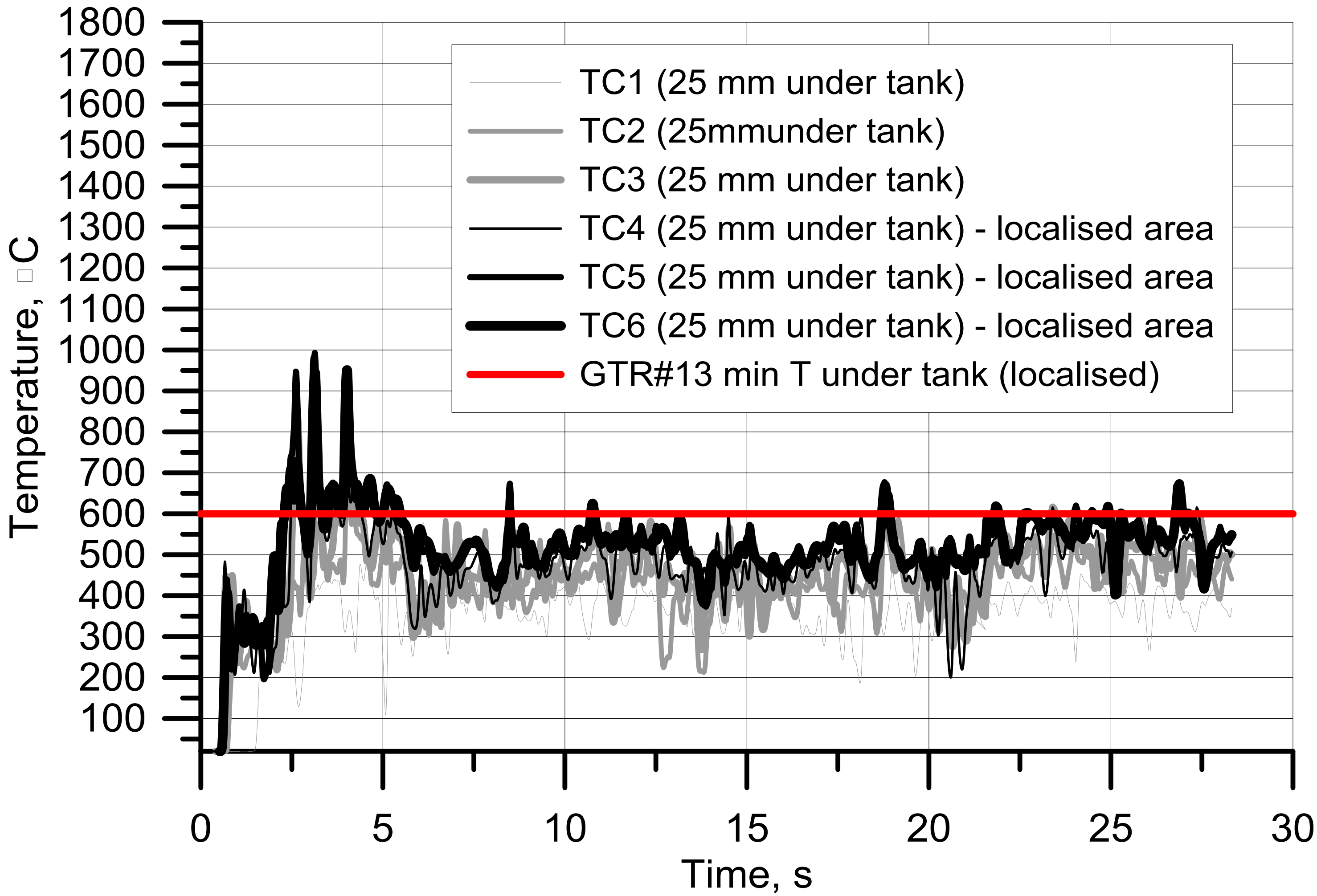
Four localised fires under a car

Questions to answer

- Would the range of localised fires with different specific heat release rate, HRR/A, from 0.2 MW/m^2 to 2.3 MW/m^2 provide agreements with GTR#13 temperature requirements?
- How different will be heat flux to a tank from a fire for different HRR/A?
- If GTR#13 fire test temperature requirements are fulfilled, but the heat flux to the tank is different – would this affect the fire resistance rating (FRR) of a tank (time to rupture of a tank without or failed to be initiated TPRD, e.g. being blocked during accident)?

In-situ fire: HRR/A=0.2 MW/m²

Temperature under tank (simulations): Case1

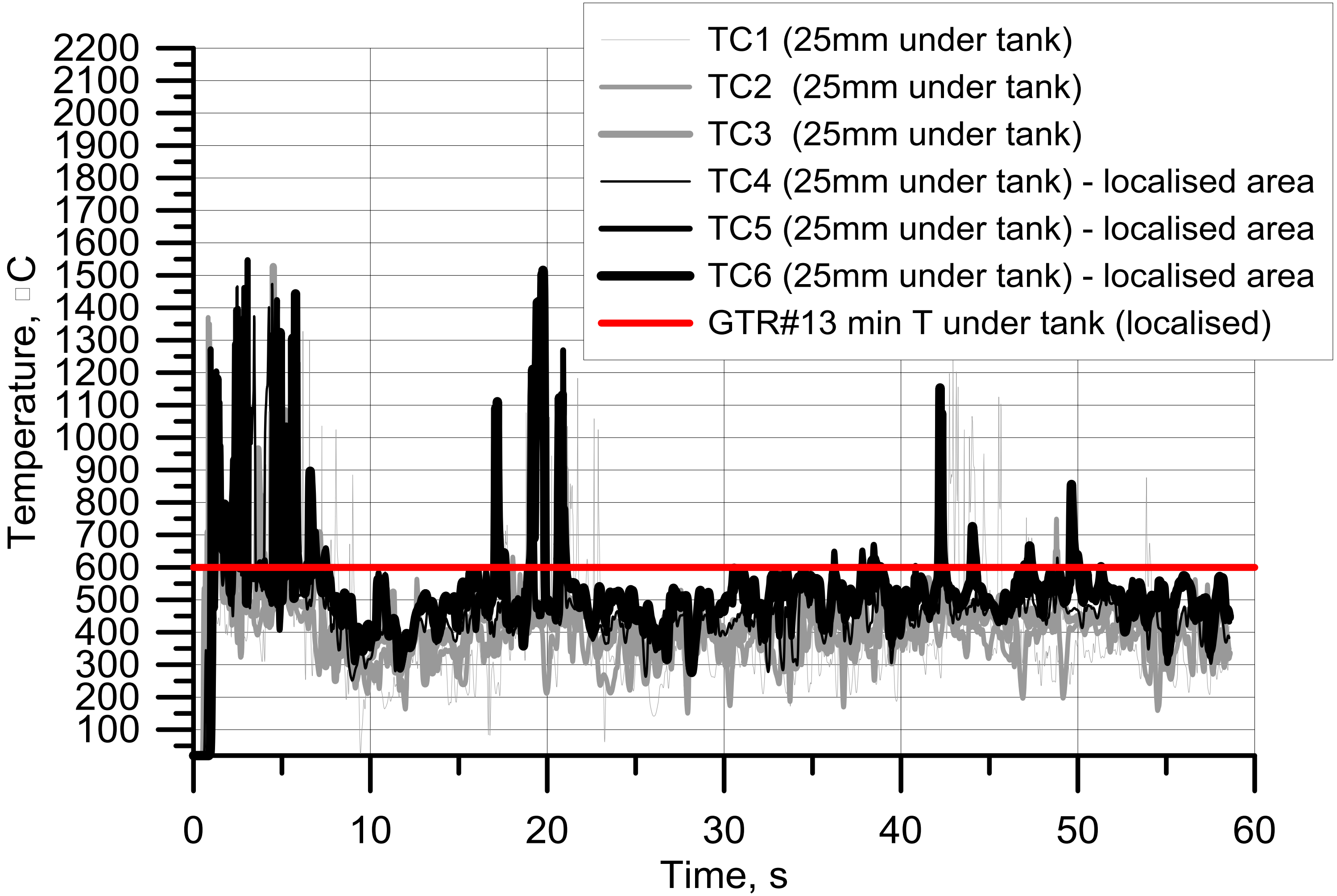


GTR#13 minimum T requirements are not satisfied for in-situ test (!)

FRR of the tank for HRR/A= 0.2 MW/m² (surrogate fuel) is 24 min.

In-situ fire: HRR/A=1 MW/m^2

Temperature under tank (simulations): Case 2

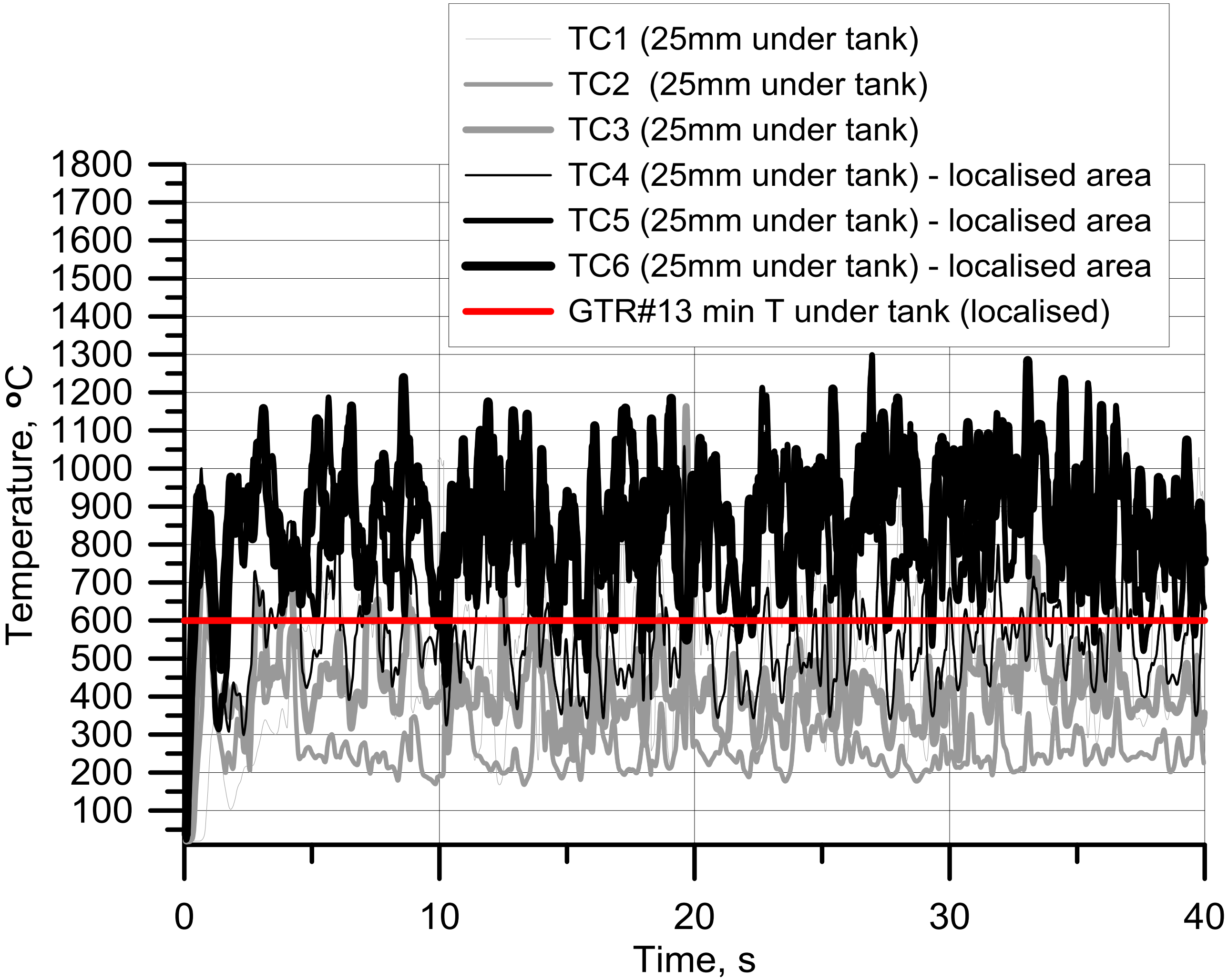


GTR#13 min T requirements are not always satisfied (A=1.9 m^2).

FRR of the tank for this HRR/A=1 MW/m^2 (surrogate fuel) is 6 min.

In-situ fire: HRR/A=1 MW/m²

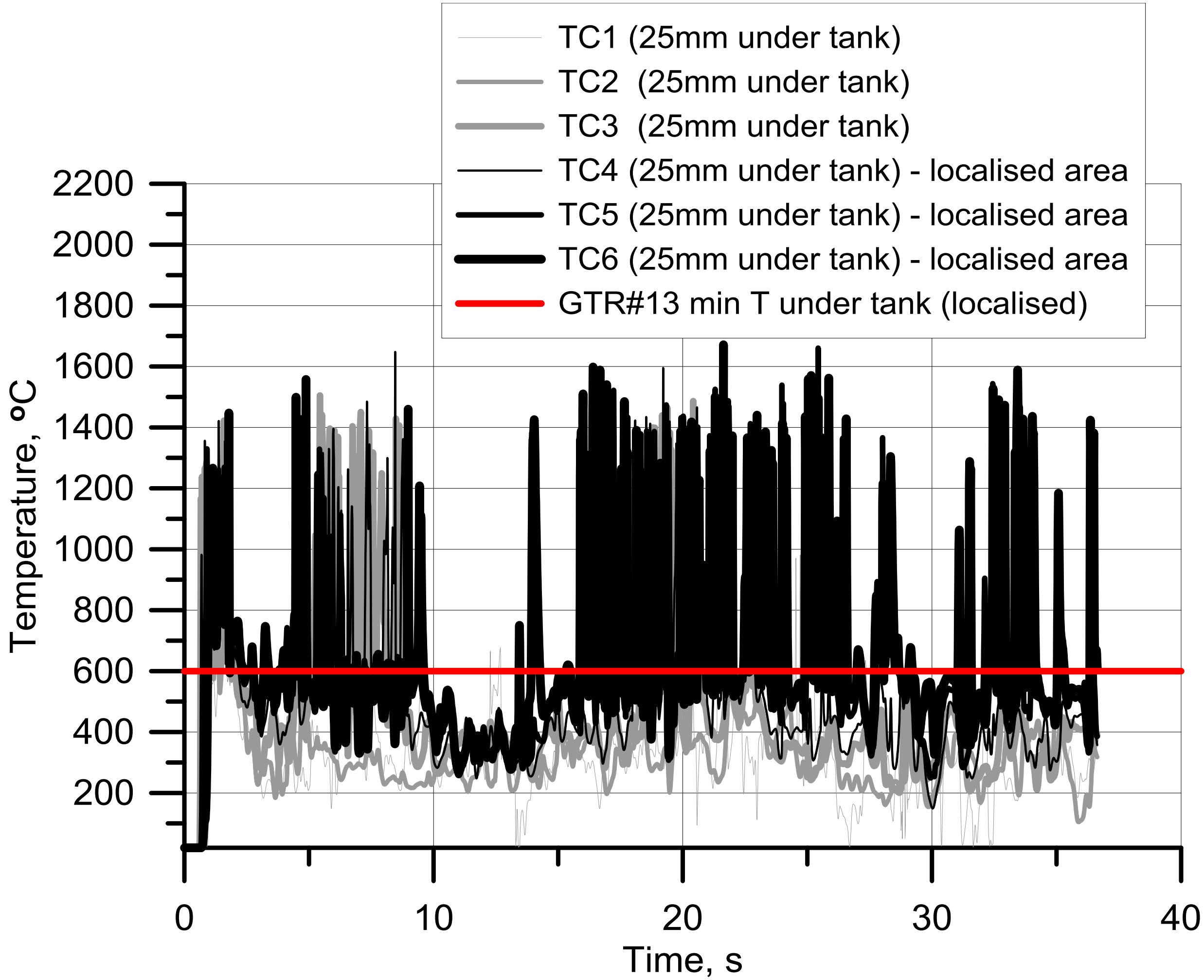
Temperature under tank (simulations): Case 3



GTR#13 minimum T requirements are satisfied (A=0.2 m^2).
FRR of the tank for this HRR/A (diesel) is 5 min 20 s.

In-situ fire: HRR/A=2.3 MW/m^2

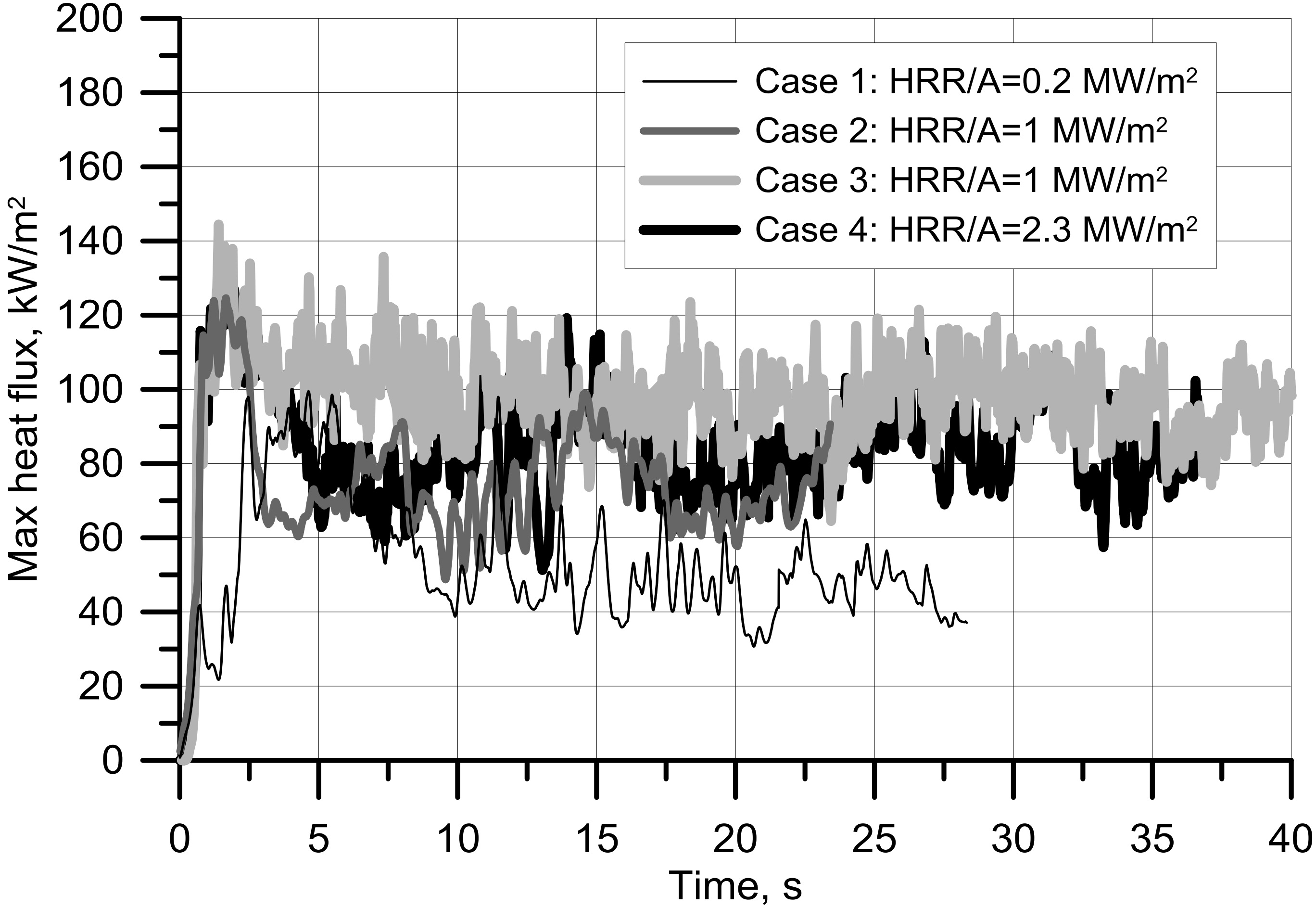
Temperature under tank (simulations): Case 4



GTR#13 minimum T requirements are satisfied.
FRR of the tank for this HRR/A (diesel) is 5 min 50 s.

Heat flux to tank in four in-situ fires

Cases 1-4



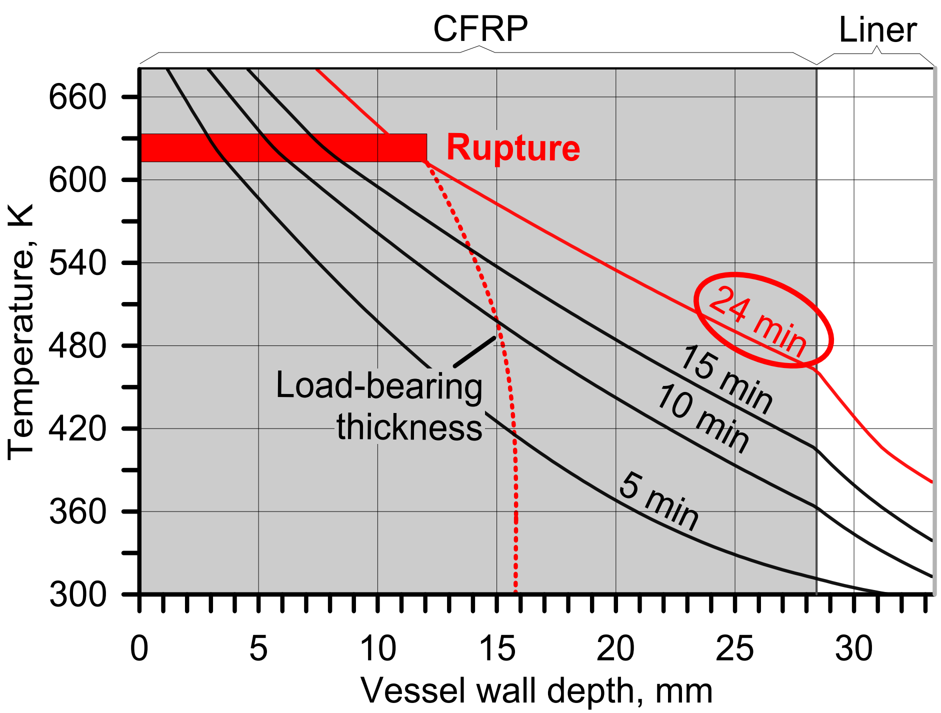
Heat flux to the tank is similar for Cases 2-4: HRR/A≥1 MW/m^2.

Heat flux for Case 1 with HRR/A=0.2 MW/m^2 is noticeably less.

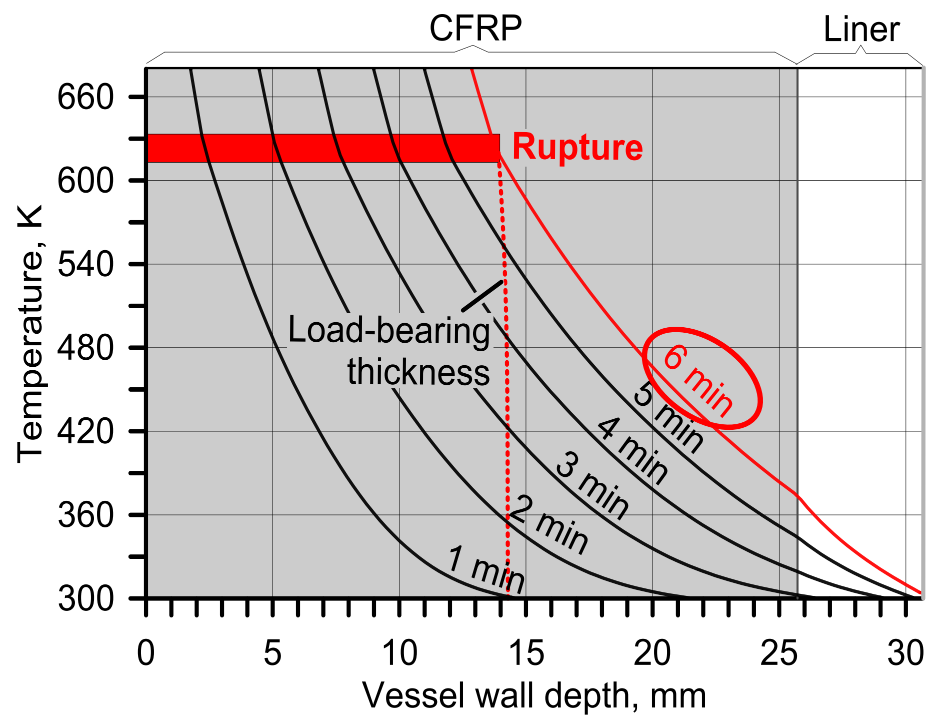
Localised fire under a car: FRR (1/2)

700 bar, Type 4 tank (0.91x0.325 m)

Case1: HRR/A=0.2 MW/m^2



Case2: HRR/A=1 MW/m^2



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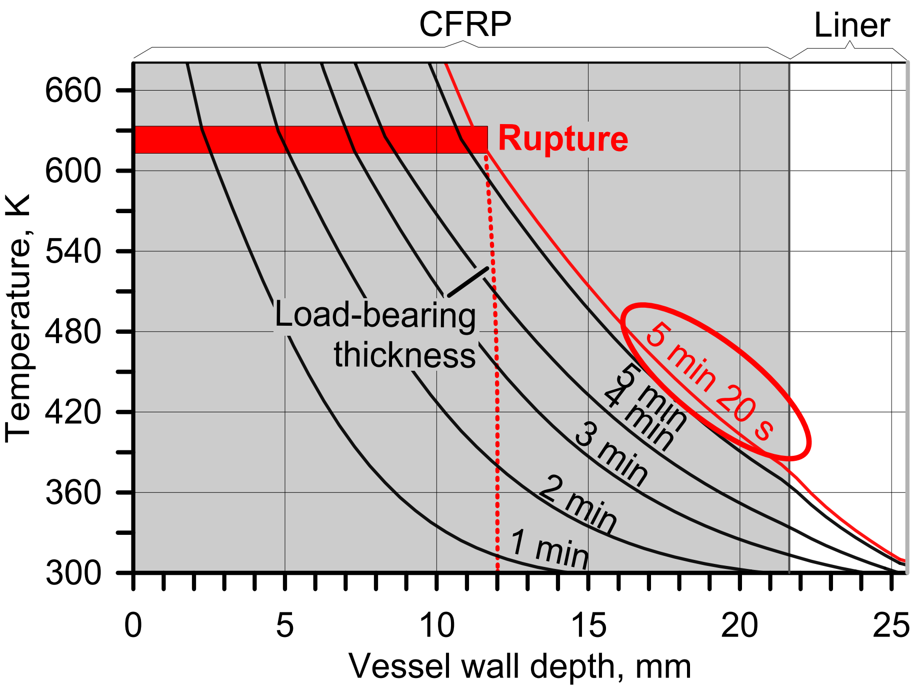
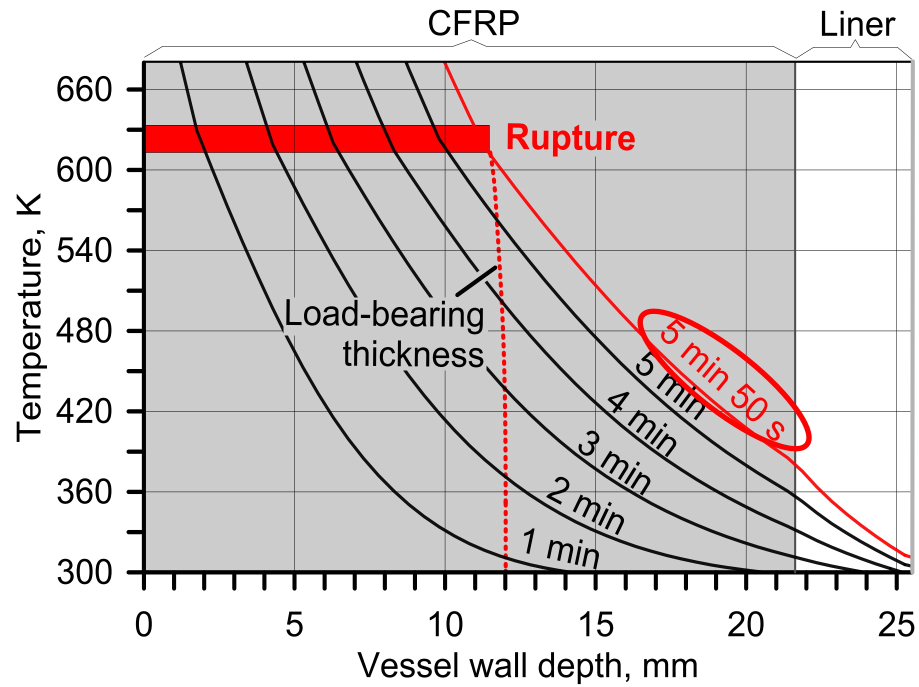
Localised fire under a car: FRR (2/2)

700 bar, Type 4 tank (0.91x0.325 m)

Case 3: HRR/A=1 MW/m^2



Case 4: HRR/A=2.3 MW/m^2



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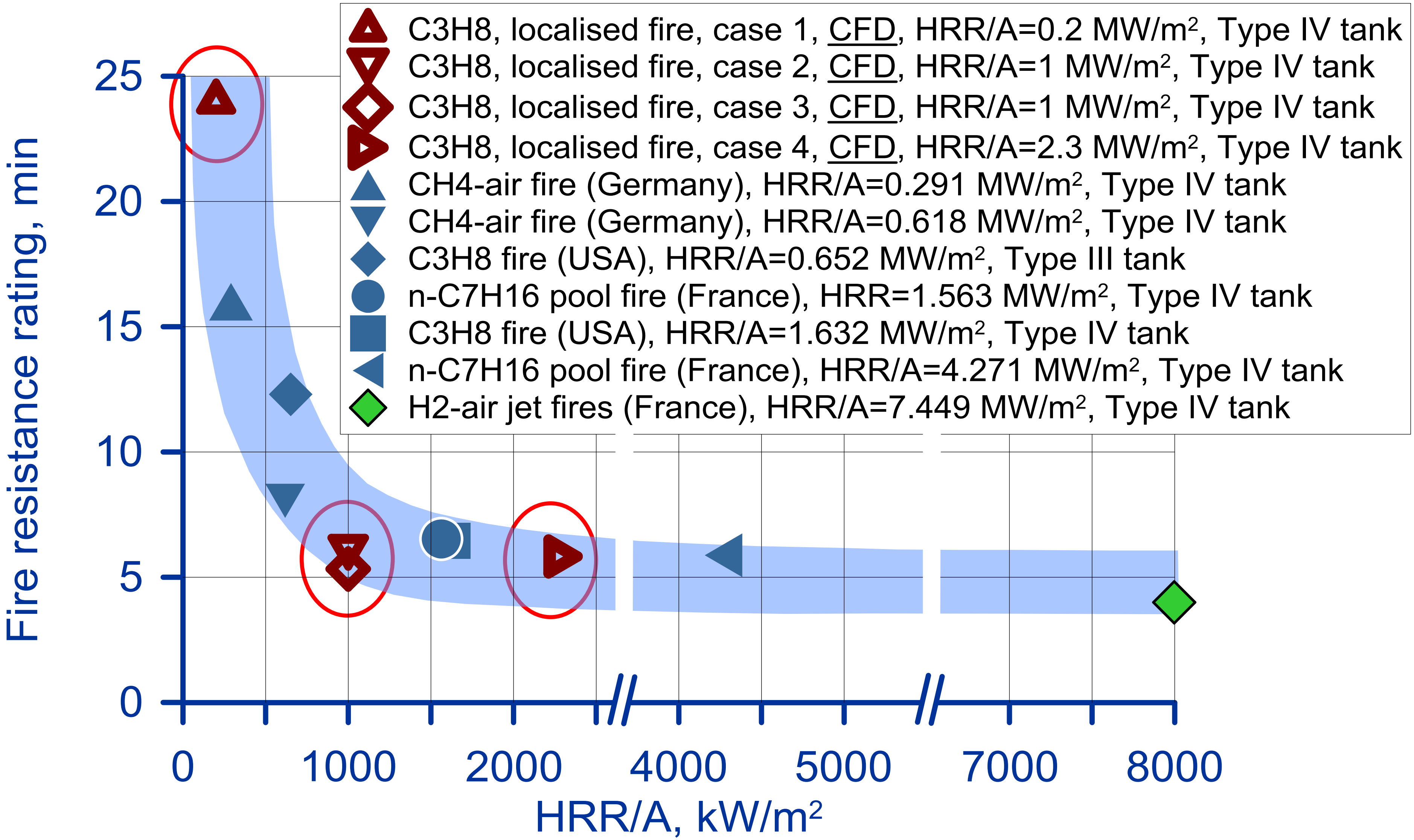
FRR dependence on HRR/A



Saturation of FRR with HRR/A after 1 MW/m²

Three in-situ fire questions answered

- Would the range of localised fires with different specific heat release rate, HRR/A, from 0.2 MW/m^2 to 2.3 MW/m^2 provide agreement with GTR#13 temperature requirements? **Answer: No!**
- How different will be heat flux to a tank from a fire for different HRR/A? **Answer: $\dot{q}''$=50 kW/m^2 (HRR/A=0.2 MW/m^2); $\dot{q}''$=90 kW/m^2 (HRR/A>1 MW/m^2)**
- If GTR#13 fire test temperature requirements are fulfilled, but the heat flux to the tank is different – would this affect the fire resistance rating (FRR) of a tank (time to rupture of a tank without or failed to be initiated TPRD, e.g. being blocked during accident)? **Answer: Yes! For HRR/A=0.2 MW/m^2, FRR=19 min. For HRR/A=1.0-2.3 MW/m^2, FRR=5.3-6.0 min**

Concluding remarks
Localised test

- Carried out research demonstrated that in-situ localised fire test is more appropriate for assessment of TPRD performance.
- GTR#13 localised fire test minimum temperature requirements cannot be realised for in-situ fire test with HRR/A<1 MW/m^2.
- GTR#13 localised fire test minimum temperature requirements must be added by a requirement of HRR/A>1 MW/m^2 in a burner.
- Similar to engulfing fire, the increase of HRR/A in localised fire resulted in the increase of heat flux to a tank and the decrease of FRR (with clear “saturation” of FRR at HRR/A>1 MW/m^2).
- FRR in localised fire (time to rupture on tank without TPRD in a fire) obey the same “saturation curve” as FRR in engulfing fire.
- FRR should be included into GTR#13 fire test protocols to inform responders to develop intervention strategies and tactics.

THANK YOU

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