UN GTR#13 IWG SGS meeting

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GTR#13 fire test in "bullet points" (shortened presentation)

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Bullet points

- GTR#13 “fire test” should **drop maximum temperature requirements** (similar to “engulfing fire test”!)?
- Tank should be tested **at least at real HRR/A** in automobile (gasoline fire scenario, HRR/A≥1MW/m^2) and probably lower HRR/A for other commodity scenario (HRR/A<1MW/m^2) fires?
- Re-establishment of engulfing fire **test without TPRD** to determine fire resistance rating (FRR) for first responders.
- **Burner design** with two simultaneous **thermal requirements**:
  - Minimum temperature in defined locations as it stands now, plus
  - Specific heat release rate, HRR/A, from a burner of area A.
- There are pipe burners with **diffusion combustion** (real case) that satisfies the thermal requirements (T and HRR/A). We could give an example but not “dictate” a design of a burner.
- Reaction of original tank to fires with different HRR/A: rupture.
- Reaction of explosion-free tank to fires with different HRR/A: leak.
- Conclusions

New term: “thermal requirements”

Remarks

- **Only temperature control** (without heat flux or correlated with the heat flux specific HRR/A) **is insufficient** to have test reproducibility in different labs. It must be complemented by control of specific heat release rate in a burner, **HRR/A**.
- Introduction of **thermal conditions** (minimum temperature and HRR/A) **control** is a right (scientifically based) way forward.
- **Maximum temperature requirements** in GTR#13 “fire test” (with localised and engulfing parts) **should be relaxed** as:
    - Required temperatures are below published data on flame temperature and thus **enforcing** labs **to use a weak fire** source (low HRR/A) generating potential safety issues.
    - Measured temperature is a function of thermocouple (TC) size and flame turbulence (flickering flame).
    - Flame temperature (measured by a thin TC in laminar flame) is a constant.
    - Cancelling maximum temperature requirement will simplify the fire test protocol (and its implementation in different labs).

HRR/A in automobile (gasoline) fires

Gasoline fires: published data (1976-2017)

- The automobile fire research over almost half a century demonstrates that HRR/A in **gasoline fires** is **1-2 MW/m²**:
  - On road: **HRR/A=2 MW/m²** *(A. Heselden, Proceedings of the 2nd International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, Cambridge, UK, 23-25 March 1976, pp. J1-1–J1-18).*
  - On road: **HRR/A=2 MW/m²** *(S. Liew, D. Deaves, Proceedings of the First International Conference on Safety in Road and Rail Tunnels, Basel, Switzerland, 23rd–25th November 1992, pp. 227–237).*
  - Pool fire equation by Babrauskas for gasoline spill: **HRR/A=2.2 MW/m²** *(V. Babrauskas, Heat release rates, The SFPE Handbook of Fire Protection Engineering, National Fire Protection Association, Quincy, MA, USA, 2002, 3-1–3-37).*
  - On concrete: **HRR/A=0.8-1.0 MW/m²** *(H. Ingason, Y.Z. Li, Fire Safety Journal, 91, 2017, 399–406).*
- GTR#20: Korean LPG burner with HRR/A=**0.8 MW/m²**.

Conclusion: to reflect reality the fire test must be carried out at least at HRR/A≥1 MW/m² (including localised part!)

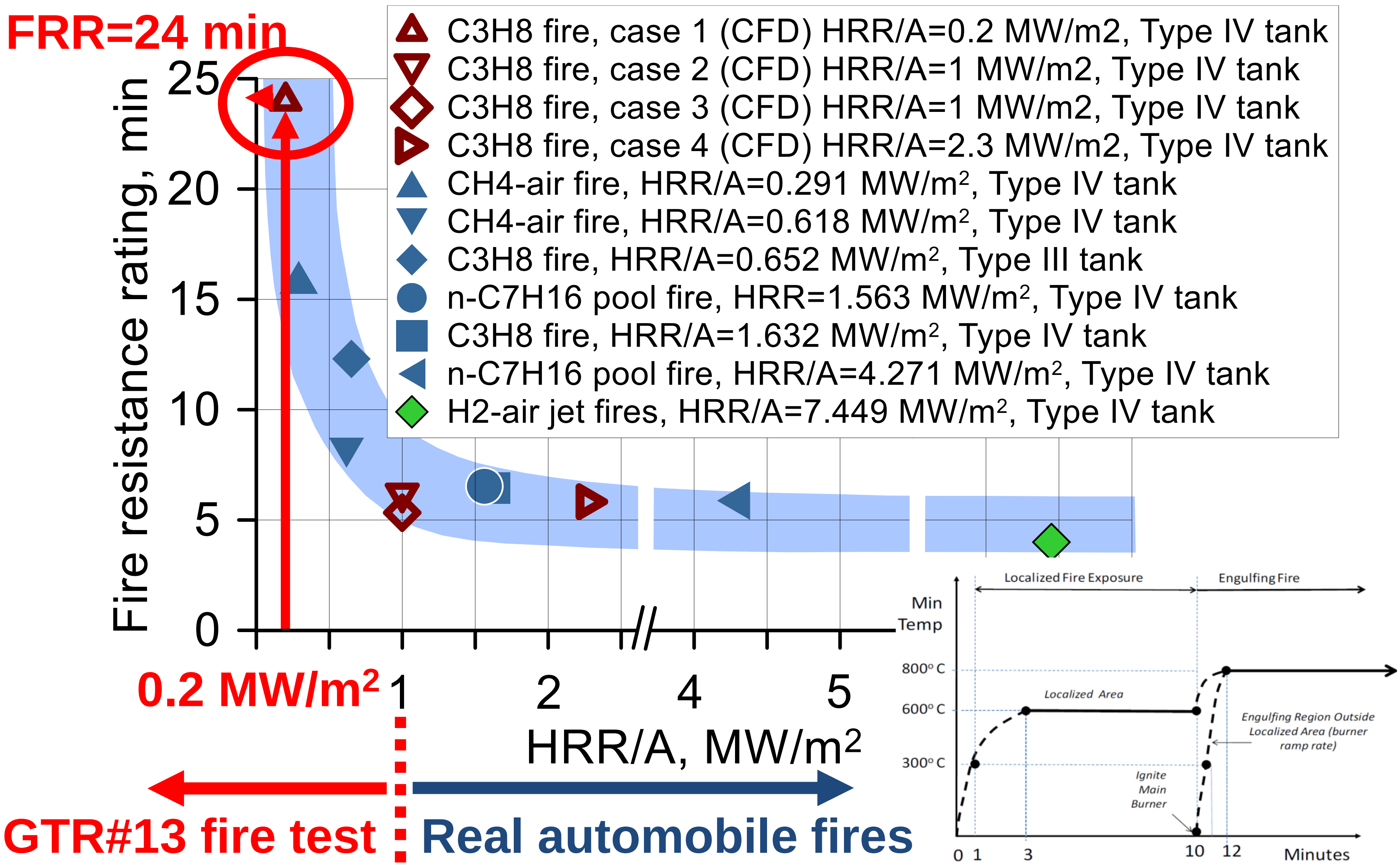
Tank should withstand any HRR/A fire

Remarks

- Real fires could have a range of thermal conditions affecting tank integrity.
- Typical fire scenario with gasoline fire (both localised and engulfing) is characterised by HRR/A=1-2 MW/m^2.
- Scenarios with fire between rear seats and smouldering fires could be characterised by smaller HRR/A<1 MW/m^2.
- Scenarios with hydrogen jet fires are characterised by higher HRR/A>1 MW/m^2.
- The only necessary regulation requirement can be: **tank should not explode at any fire conditions**.

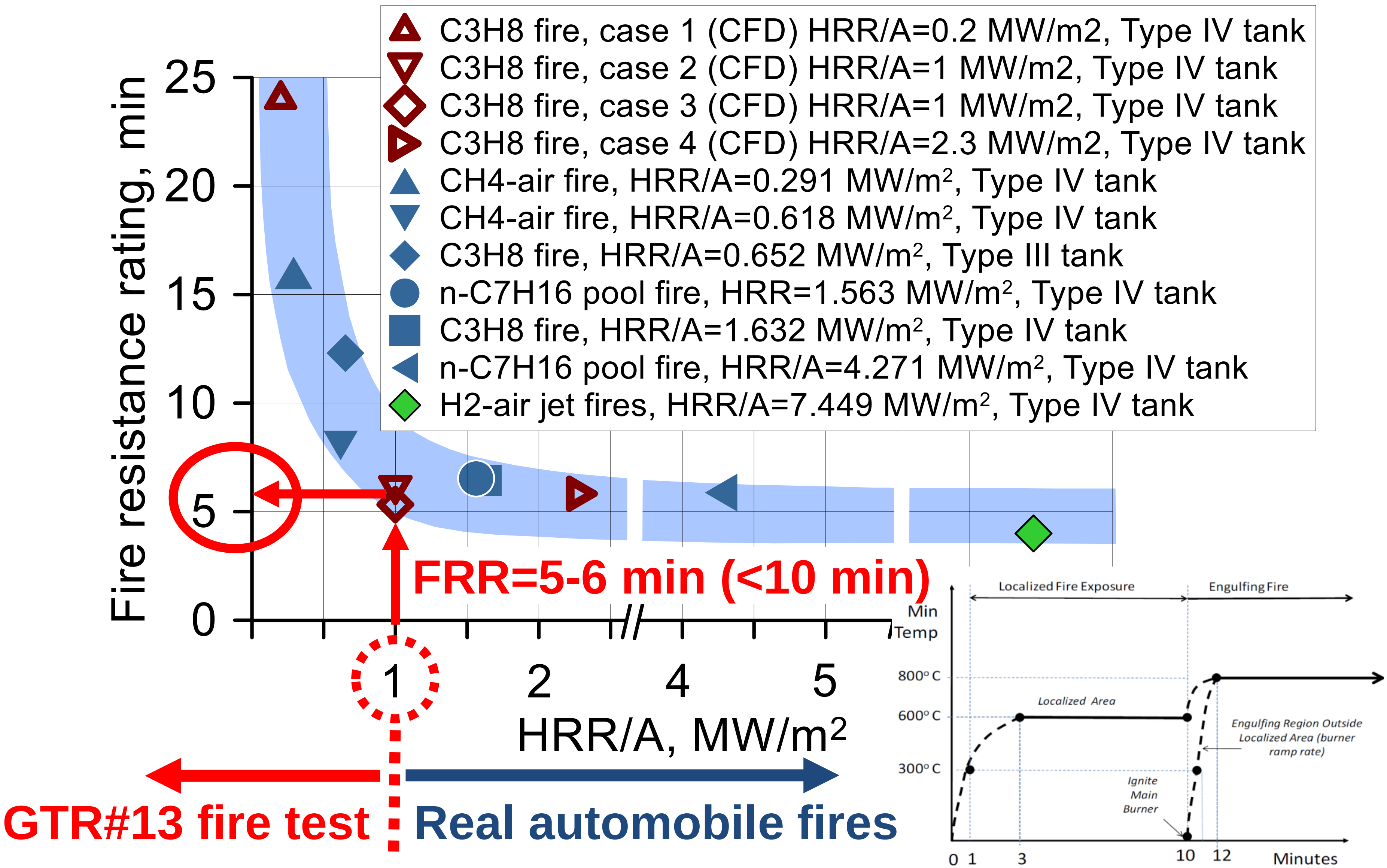
Fire test problem to avoid

"Use low HRR/A to pass localised part of test"



Fire test problem to avoid

Rupture at localised fire time at gasoline HRR/A



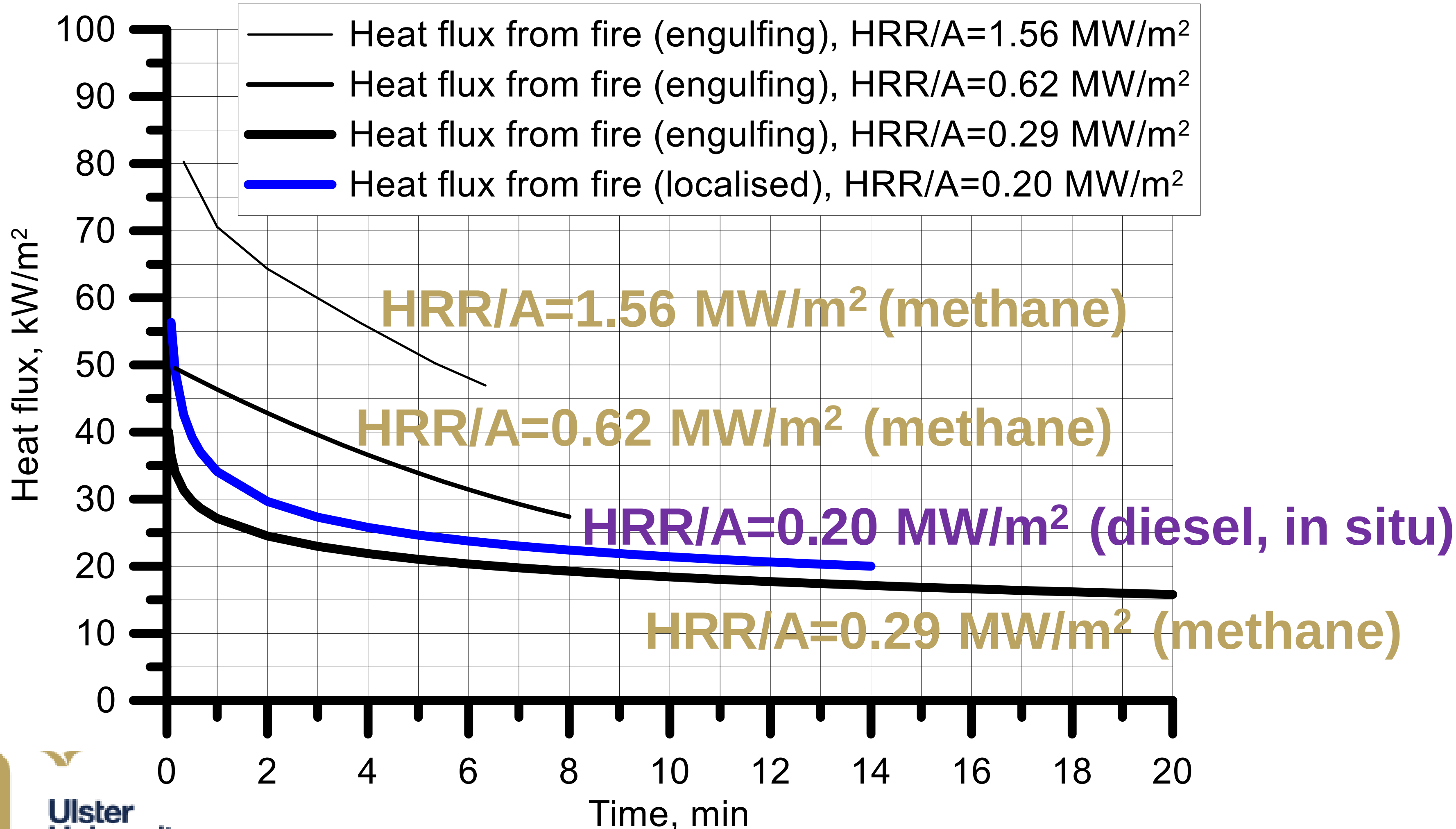
Only low HRR/A cannot be used alone

Remarks

- Literature review gives HRR/A=1-2 MW/m^2 in gasoline fires (applicable to both car and truck scenarios, localised and engulfing fire for scenarios with gasoline spill under vehicle).
- Tank+TPRD system must undergo “fire test” (localised and engulfing portions) at least at real conditions of HRR/A≥1 MW/m^2 (and any other conditions with reduced HRR/A, if needed, but seems highest HRR/A is sufficient).
- “Fire test” with only HRR/A below 1 MW/m^2 should be forbidden. It bears a life threat for use of vehicle in real life (even GTR#13 fire test would be passed!).
- HRR/A is a key parameter for fire test reproducibility. Easy to measure (only flow meter) compared to heat flux, $\dot{q}''$.
- HRR/A ≥1 MW/m^2 unambiguously defines FRR (parameter requested by firemen). Engulfing fire test without TPRD must be re-established and performed at HRR/A ≥1 MW/m^2.

Gasoline and smaller HRR/A fires

Heat flux $\dot{q}''$ changes in time



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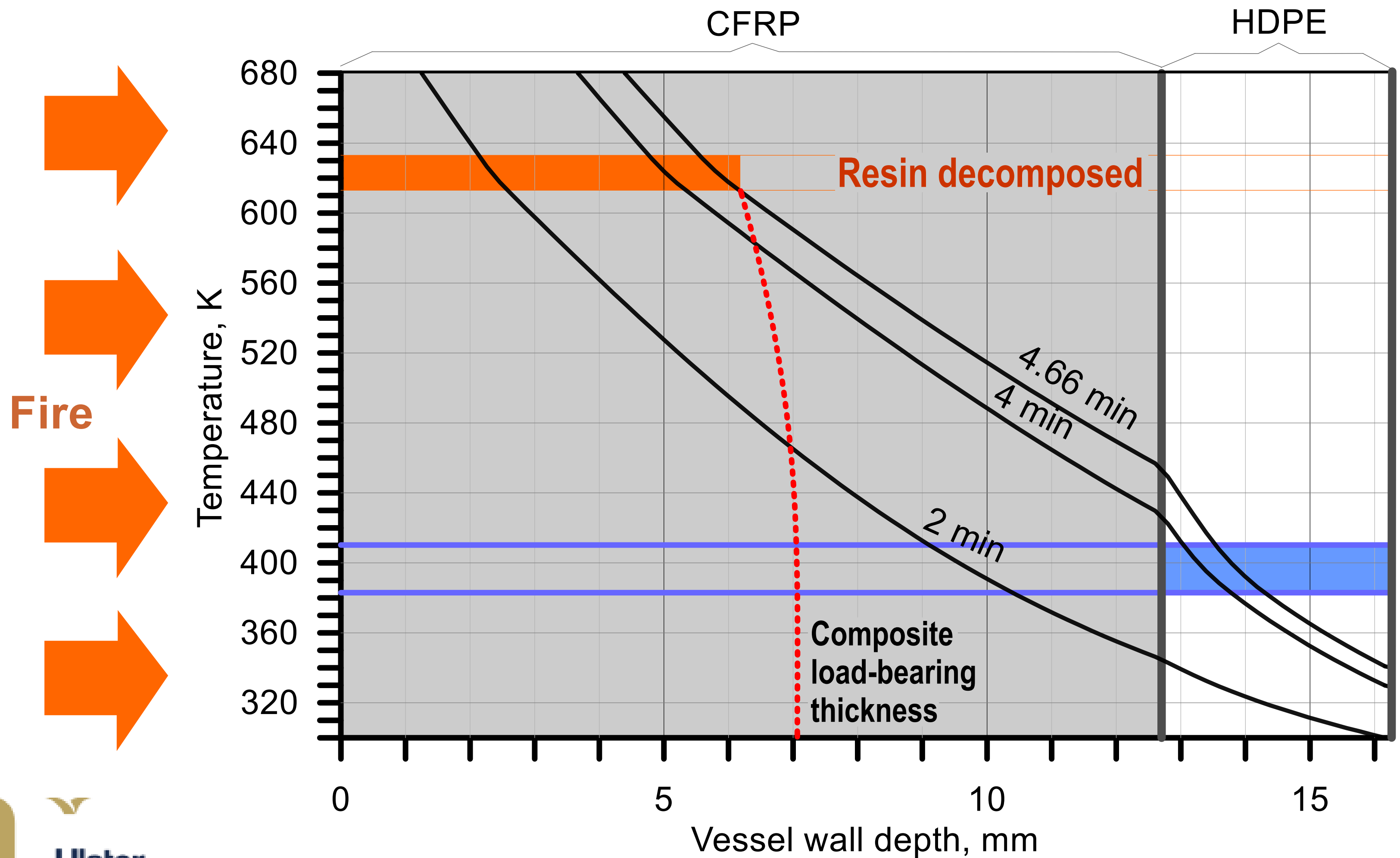
The higher HRR/A (constant) the higher heat flux to tank $\dot{q}''$ (yet decreasing)

Gasoline HRR/A fire: RUPTURE!

HRR/A=1.56 MW/m^2 (rupture at 4.66 min)



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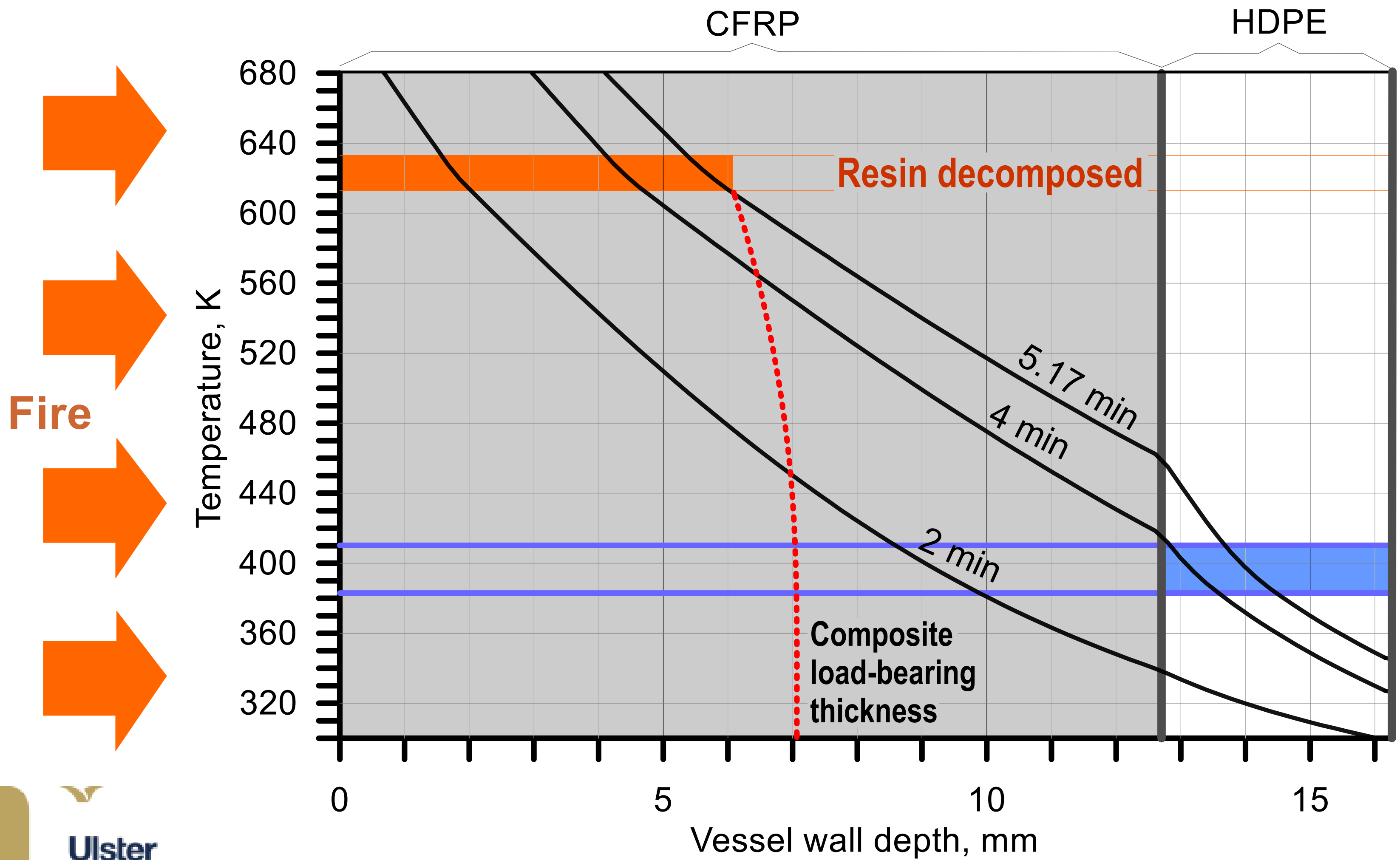
Medium HRR/A fire: RUPTURE!

HRR/A=0.62 MW/m^2 (rupture at 5.17 min)



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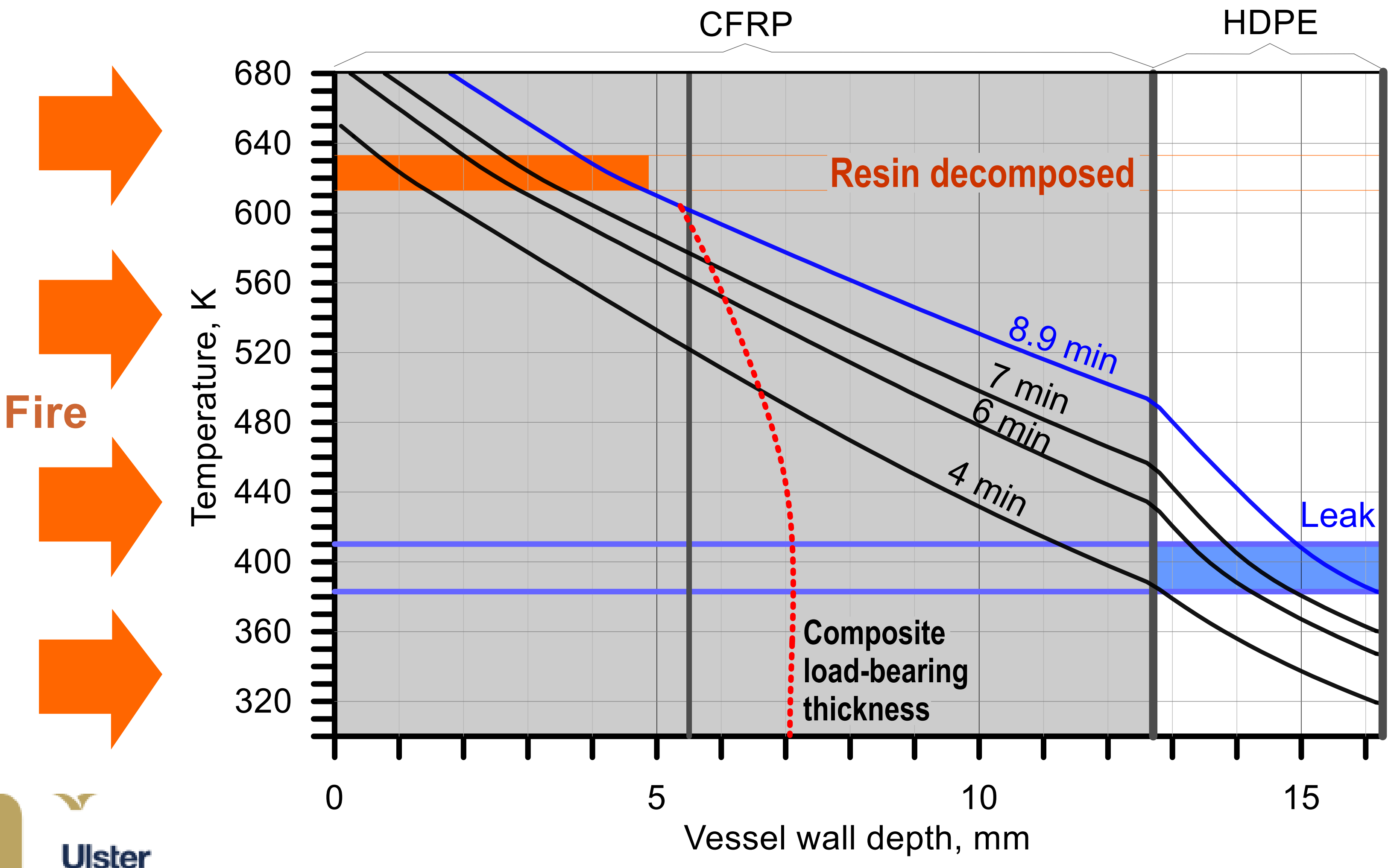
Small HRR/A fire: LEAK!

HRR/A=0.29 MW/m^2 (leak at 8.9 min)



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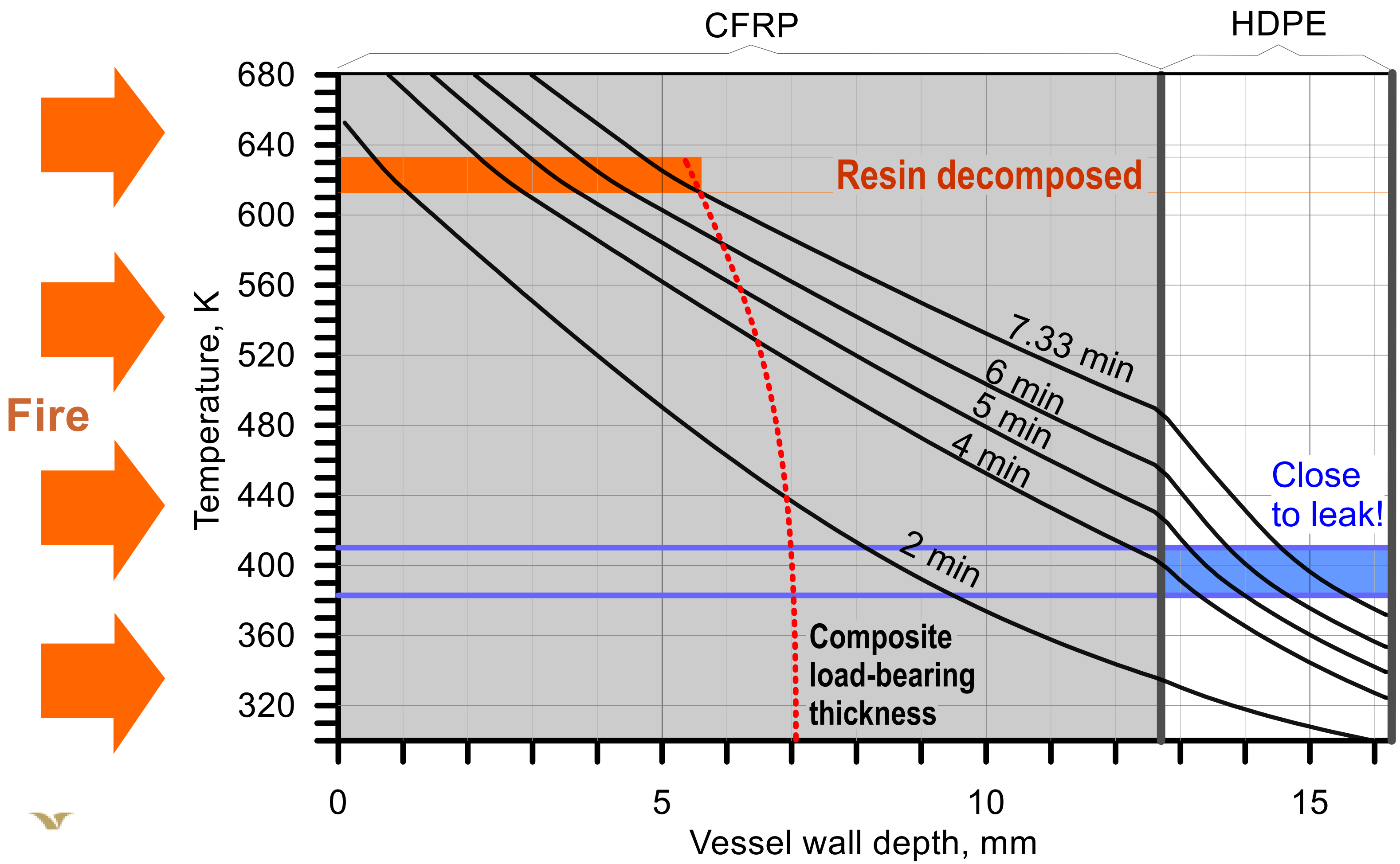
Even smaller HRR/A fire: RUPTURE

Diesel localised HRR/A=0.2 MW/m² (at 7.33 min)



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Original tank in different HRR/A fires

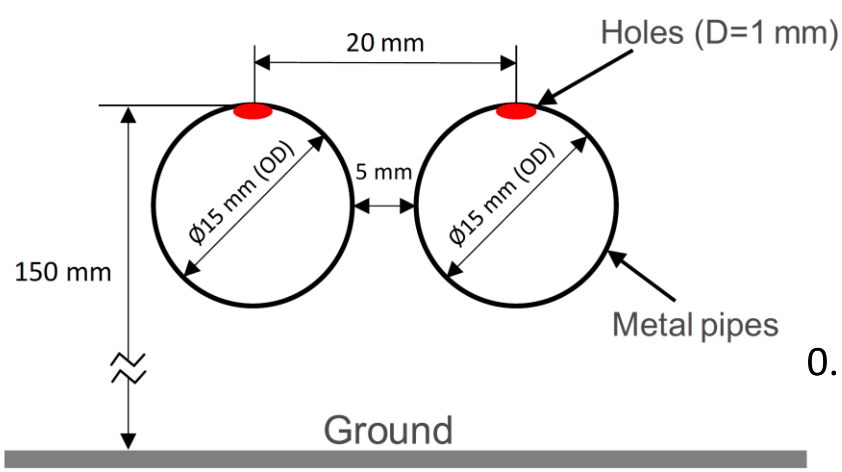
Remarks on performance in fires

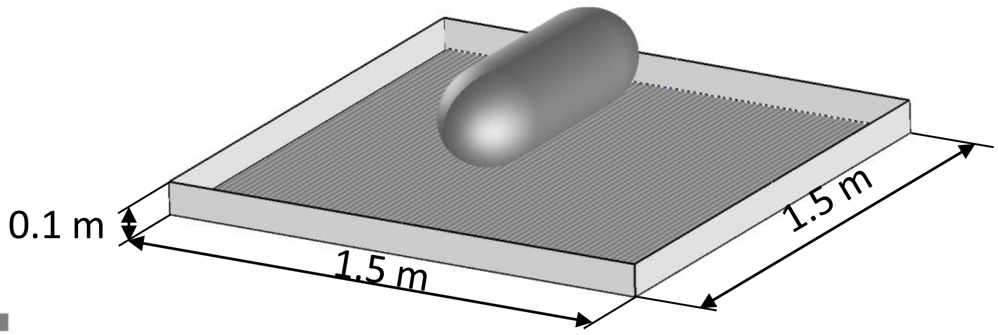
- **Non-protected** original composite tank of volume 7.5 L and NWP=70 MPa (no TPRD) **ruptures** in fires with high **HRR/A=0.20-1.56 MW/m²** in numerical tests.
- Thus, **testing at only higher HRR/A** could be sufficient (to save on fire test cost).
- The higher is specific heat release rate in a fire, HRR/A (constant in time), the higher is heat flux to the tank, $\dot{q}''$ (decreasing in time). Temperature control **cannot help** here!
- Localised **in-situ** diesel fire with HRR/A=0.20 MW/m² generates somewhat higher maximum heat flux to tank surface, $\dot{q}''$, compared to engulfing stand-alone methane fire with HRR/A=0.29 MW/m². The deviation is due to the difference of testing stand-alone and in-situ tank.

Example of satisfying GTR pipe burner

Details

- 5600 holes spaced uniformly at 20 mm. Hole D=1 mm.
- Propane injection velocities: 5.3 m/s (HRR/A=1 MW/m^2), 1.2 m/s (HRR/A=0.228 MW/m^2).
- Burner 1.5x1.5 m positioned at 0.15 m above the ground.
- Calculation domain: 6x6x4 m.
- Conjugate heat transfer to Type 3 tank (0.9x0.3 m).

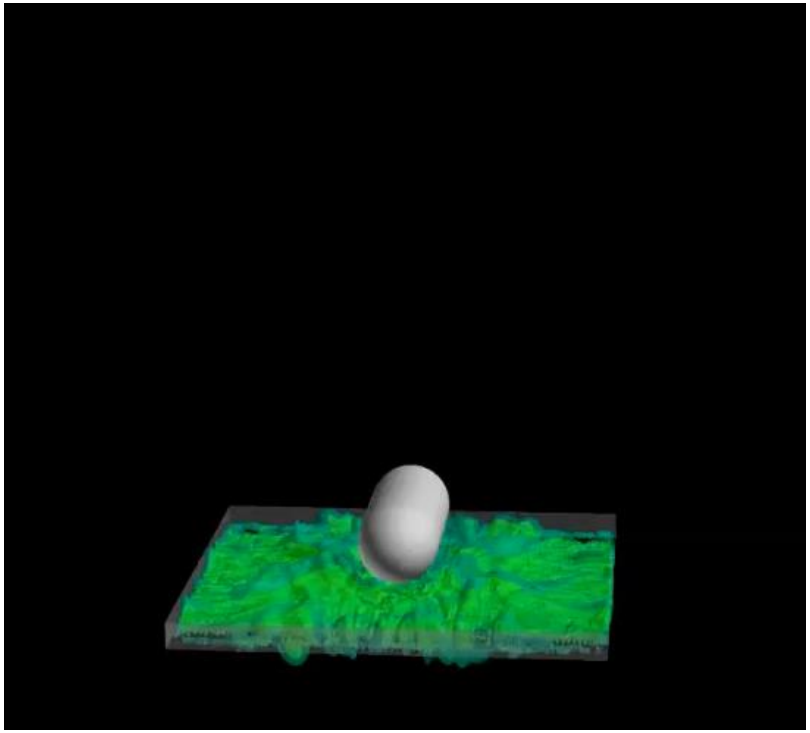




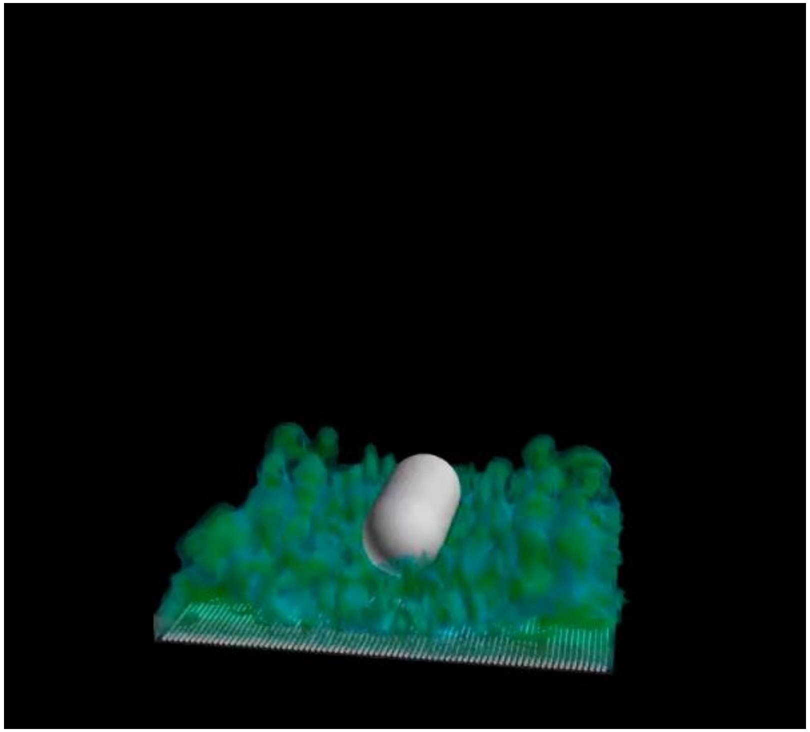
The pipe burner: no wind

Temperature iso-surfaces

Low HRR/A=0.228 MW/m^2



Real HRR/A=1 MW/m^2



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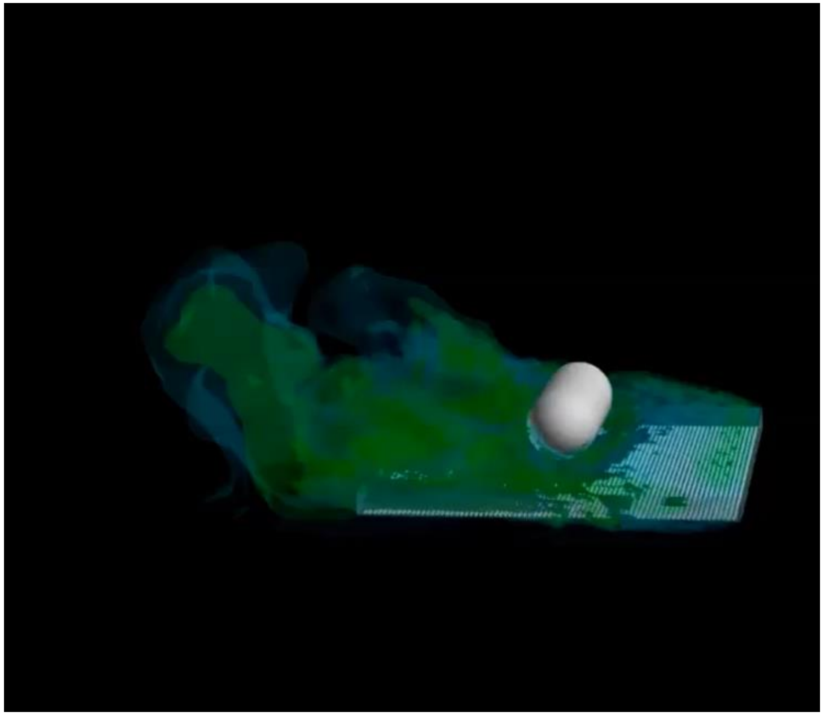
Temperatures:

590°C (GTR#13 min required)   1030°C

The pipe burner: wind 5 m/s and 10 m/s

Temperature iso-surfaces

Wind 2: 5 m/s



Wind 3: 10 m/s

Temperatures:

590°C (GTR#13 min required)   1030°C

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The pipe burner prototype in wind

Remarks on performance in different wind

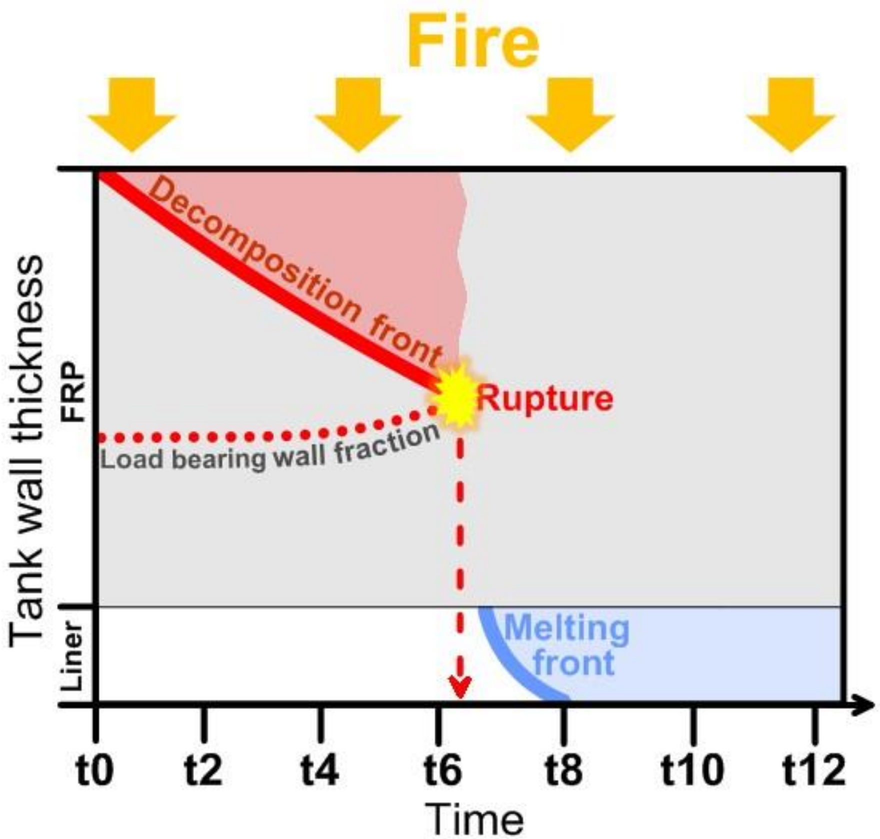
- The **pipe burner prototype** (1.5x1.5 m) reproduces GTR#13 minimum temperatures requirements with HRR/A=1 MW/m^2 and wind **up to 5 m/s** (“gentle breeze”) for tank size up to 0.9x0.3 m.
- Controlling value of HRR/A relaxes any limitation of burner size. The burner simply must comply with minimum temperature requirements (the wider the burner the higher is wind velocity at which T min requirements will be satisfied).
- The use of lower HRR/A in fire test would probably require reduction of minimum temperature requirements (“or use of premixed or partially-premixed burners”). This to be studied further (could be ignored now).

Hydrogen safety breakthrough: explosion-free in a fire tanks (polymer liner: HDPE, PA…)

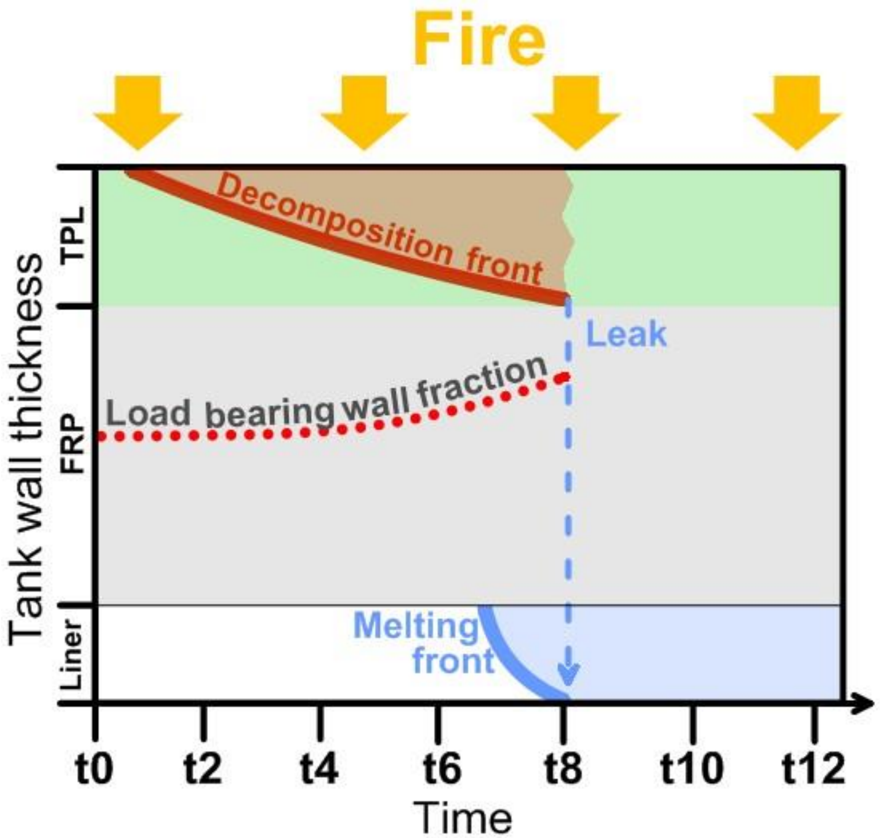
Explosion-free in a fire tank: concept

Original (left) and explosion-free (right) tank

Original tank: **rupture**



Explosion-free in a fire tank: **no rupture!**



First prototypes
Characteristics

- Tank V=7.5 L, NWP=700 bar.
- Materials of first LNB tank prototype: CFRP + GFRP.
- Burst test: safety factor 2.65.
- **Wall thickness increase**: from 12.7 mm increase by 11-14 mm (not suitable for automotive applications).
- **Tank mass increase**: from original 6.04 kg by more than twice (not suitable for automotive applications).

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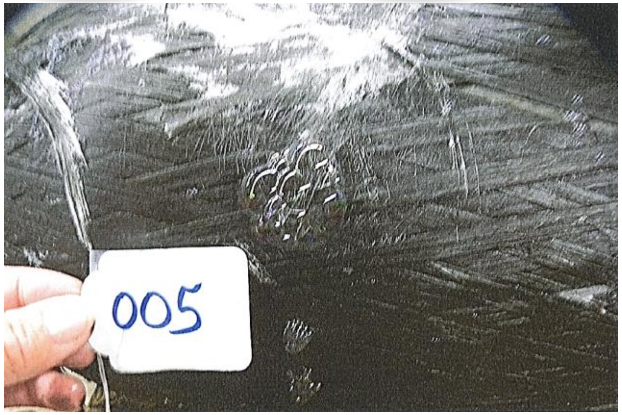
First prototypes: concept validation

Tanks' parameters

Tank ID	OD of liner, mm	OD of tank, mm	FRP#1 thickness, mm	FRP#2 thickness, mm	"Additional" wall thickness, mm	Mass increase, kg
#004	160.9	207.7	11.43	12	10.73	6.43
#005	160.9	215	9.3	17.7	14.3	8.61

Test results: leak-no-burst!

Tank ID	Charge pressure, bar	Vent pressure, bar	Leak starts	Leak duration
#004	700	812.4	9m 27s	16m 29s
#005	700	854.5	12m 23s	14m 37s



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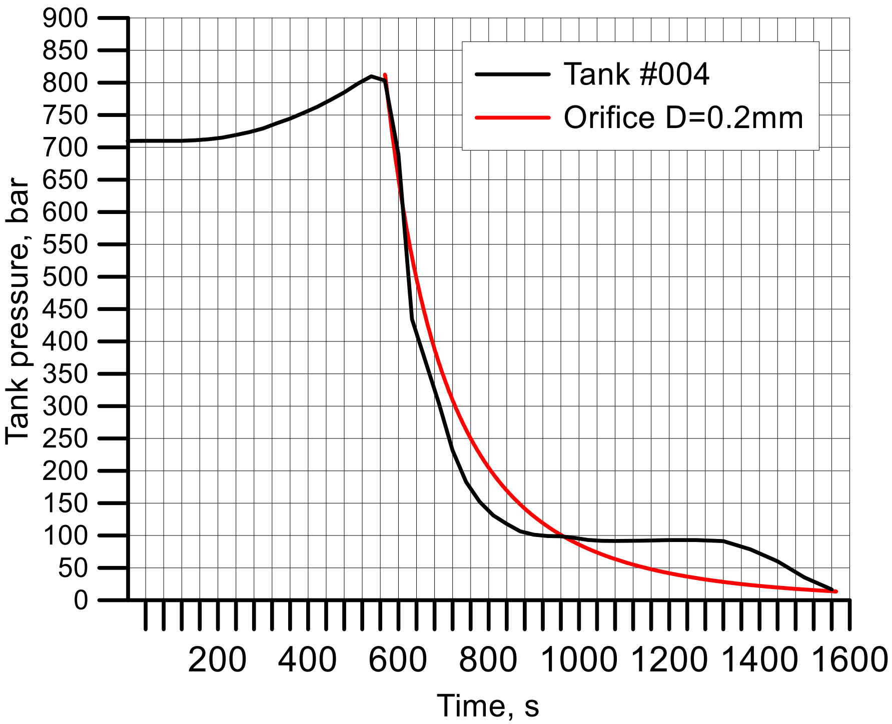
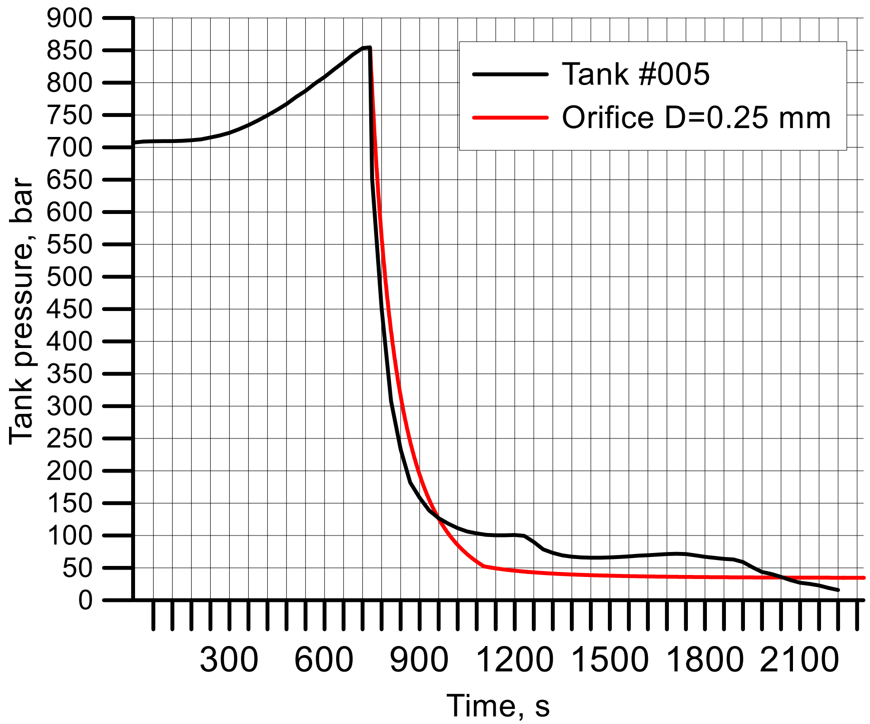
First prototype: insignificant leak

Equivalent leak diameter D=0.20-0.25 mm





Conclusion from first prototypes testing:

1. The concept works.
2. Toyota suggested to demonstrate that explosion-free in a fire tank can have the same wall thickness as original tank and be explosion-free in a fire.

Second prototype
The same wall thickness

- Tank V=7.5 L, NWP=700 bar.
- Materials of LNB tank: CFRP1 (first layer) + CFRP2 (TPL).
- Burst test: safety factor 2.61.
- **Wall thickness: no increase!**
- **Tank mass increase**: by only 0.56 kg (from original 6.04 kg).

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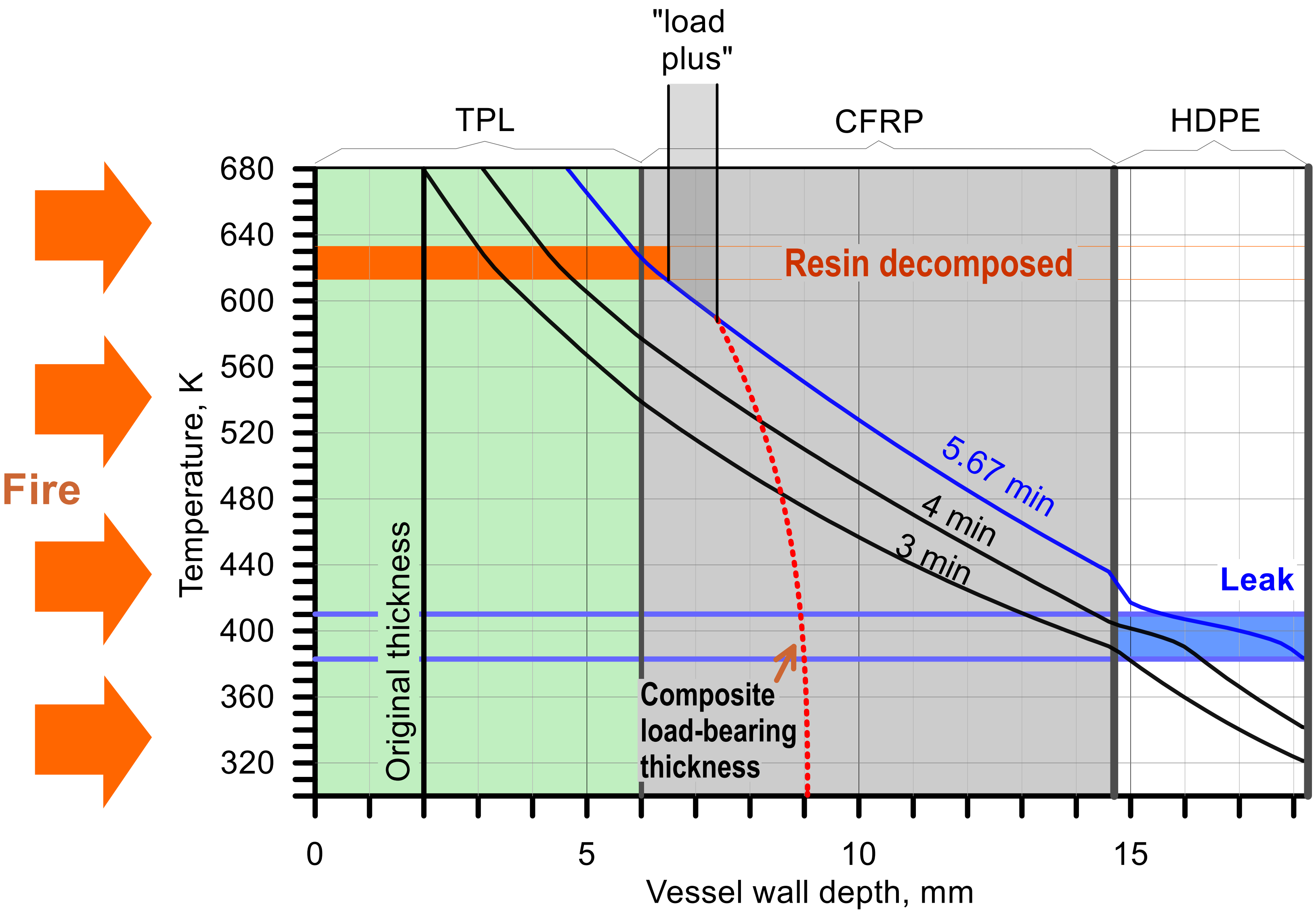
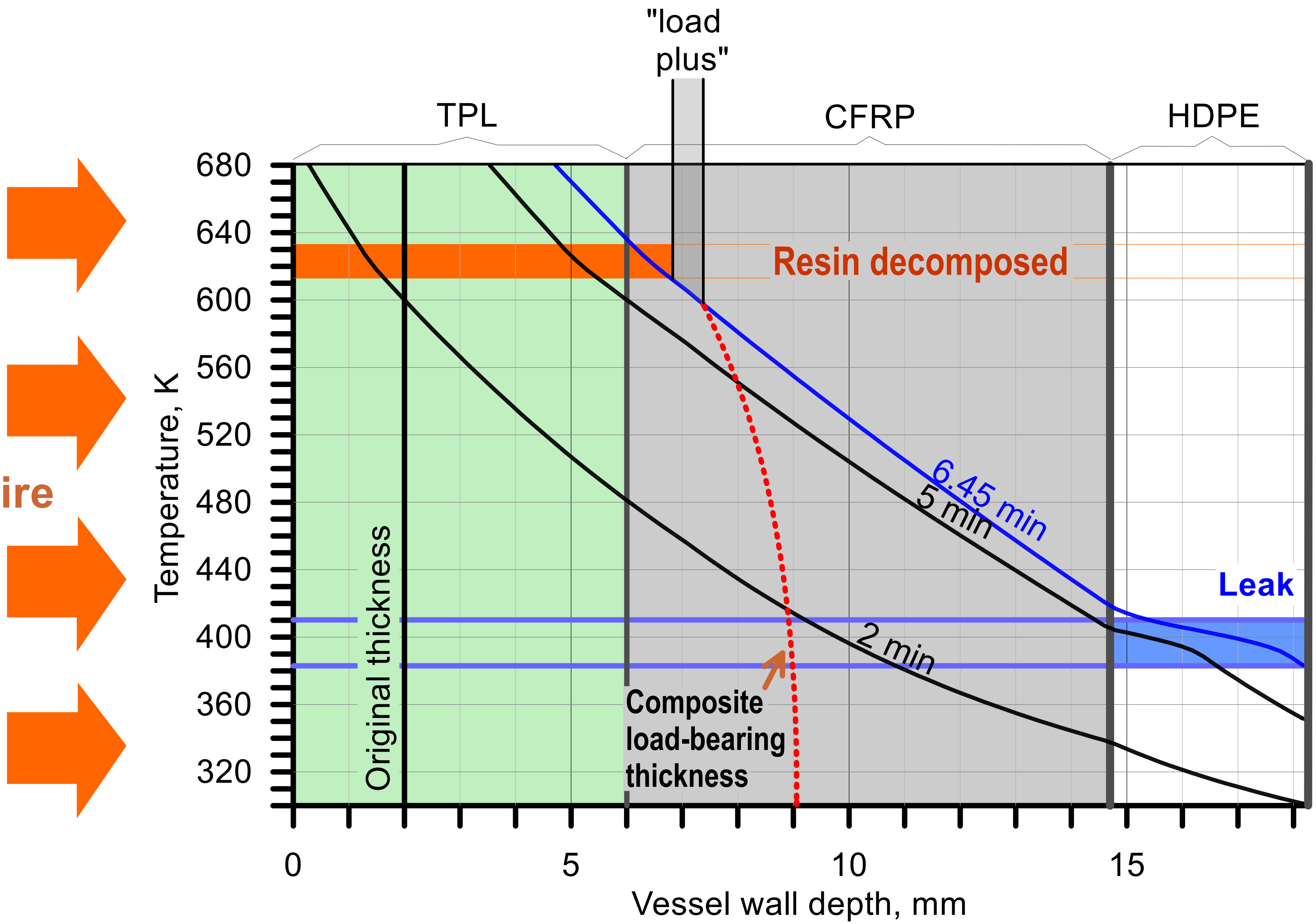
Second prototype (numerical): Leak!

Gasoline HRR/A=1.56 MW/m² (leak at 5.67 min)



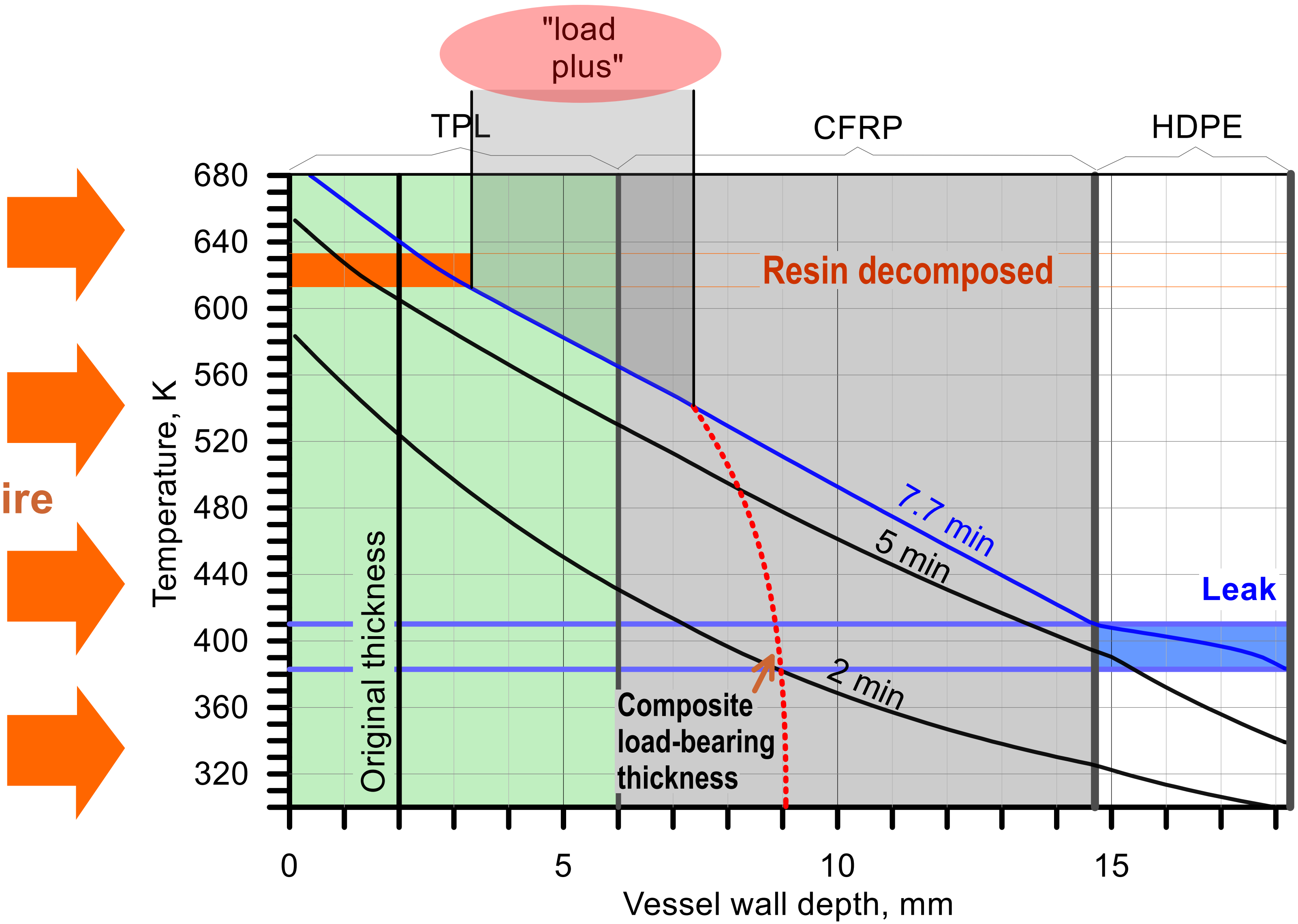
Second prototype: Leak!

Medium HRR/A=0.62 MW/m² (leak at 6.45 min)



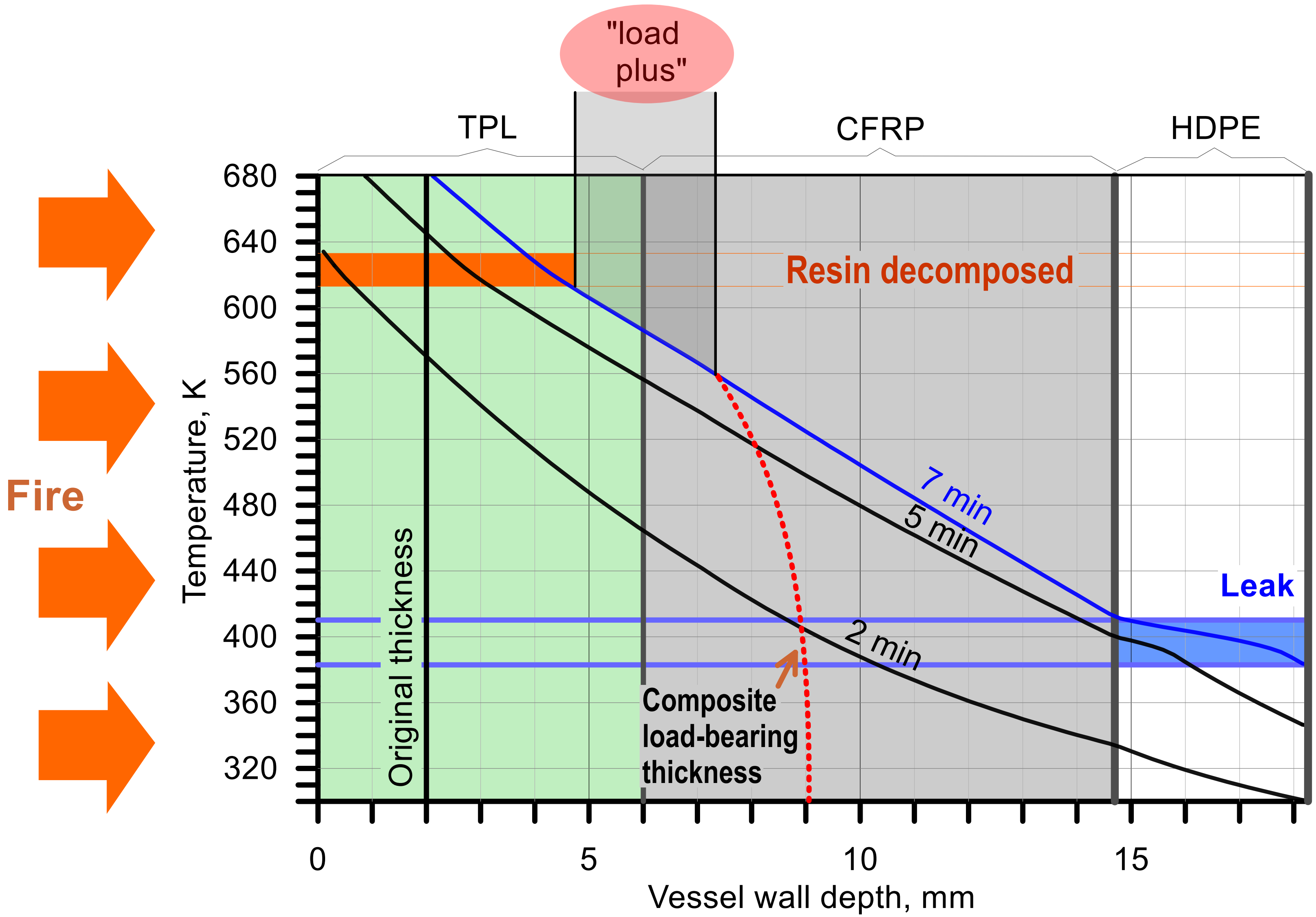
Second prototype: Leak!

Small HRR/A=0.29 MW/m^2 (leak at 7.7 min)



Second prototype: Leak!

Diesel localised in-situ 0.2 MW/m^2 (at 7 min)



Explosion-free in a fire tanks

Second prototype testing

OD of liner, mm	OD of tank, mm	FRP#1 thickness, mm	FRP#2 thickness, mm	“Additional” wall thickness, mm	Mass increase, kg
1670.7	186.1	7.2	5.5	0	0.56

VIDEO

Explosion-free in a fire tank of original wall thickness

Explosion-free in a fire tanks

Concluding remarks (1/2)

- Explosion-free in a fire tanks leak in the whole range of fires HRR/A=0.20-1.56 MW/m^2 (CFD tests). TPRD of D~<0.5 mm still can be used (the pressure peaking phenomenon!).
- Explosion-free in a fire safety technology has larger safety margin (“load plus”) for lower HRR/A. Thus, fire testing should be focused on scenarios with higher HRR/A.
- The devastating consequences and associated risks of hydrogen vehicles are eliminated with the use of explosion-free in a fire tanks:
    - No blast wave!
    - No fireball!
    - No projectiles (car will not fly 22 m as in Weyandt test)!
    - No long flames (TPRD=3 mm would give up to 9 m flame)!
    - No pressure peaking phenomenon (leak D<0.5 mm)!

Explosion-free in a fire tanks
Concluding remarks (2/2)

- Explosion-free in a fire tank closes safety issues of any hydrogen vehicle in confined spaces like:
  - Garages
  - Tunnels
  - Underground parking
  - “Isolated” marine and aviation applications, etc.
- Testing confirmed that the customers could have hydrogen vehicles with explosion-free in a fire onboard storage tanks (this would indeed provide level of risk below of fossil fuels cars).

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Final concluding remarks (1/3)

- **Only temperature control is insufficient** to have test reproducibility in different testing laboratories around the globe. It must be complemented by **control of specific heat release rate in a fire source (burner) HRR/A**.
- **Maximum temperature requirements** in “fire test” (with localised and engulfing parts) **should be relaxed.**
- **Tank must withstand any fire condition without explosion.** Tank must undergo fire test at gasoline spill fire scenarios with HRR/A=1-2 MW/m^2 and, if needed, at smaller HRR/A, e.g. for scenario of localised fire between rear seats, smouldering fire scenario and similar scenarios (if this indeed reflects the reality). However, if a tank withstands severe fire conditions no need to test at lower HRR/A.

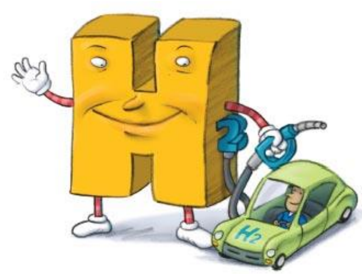
Final concluding remarks (2/3)

- Fire resistance rating, FRR, is a function of specific heat release rate, HRR/A. Lowering HRR/A cannot be used to pass “fire test”, which must include localised part of fire test with HRR/A=1-2 MW/m^2 (gasoline spill fire scenario).
- Engulfing fire test without TPRD must be re-established.
- Heat flux $\dot{q}''$ changes in time (measurements and 3D simulations) for fire source with constant HRR/A.
- **HRR/A** is easy to measure parameter (flow meter) compared to measurement of heat flux to tank $\dot{q}''$. HRR/A correlates with $\dot{q}''$.
- **Original** composite tank of volume about 7.2 L and NWP=70 MPa (no TPRD) **ruptured** in all numerical fire tests with **HRR/A in the range 0.20-1.56 MW/m^2**.
- **Explosion-free in a fire tank didn’t rupture** in all tests at the same HRR/A range.
- GTR#13 text should include “TPRD and **other proven means**”.

Final concluding remarks (3/3)

- GTR#13 could give an example of a burner design but **should not prescribe** a burner design. Diffusion combustion burner is preferable to closer reflect the reality.
- Burner should provide **thermal conditions** (minimum T plus HRR/A). Burner length **1.65 m** must be **relaxed**.
- The **pipe burner prototype** (1.5x1.5 m) reproduces GTR#13 minimum temperatures requirements with **HRR/A=1 MW/m^2** and wind velocity up to and **5 m/s**.
- GTR#13 text is amended to account for the **pressure peaking phenomenon** (following requirements of ISO 19882 “Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers”).

THANK YOU



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