HySafe Research Priorities Workshop

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Effect of heat release rate (HRR) in bonfire test on fire resistance rating (FRR)

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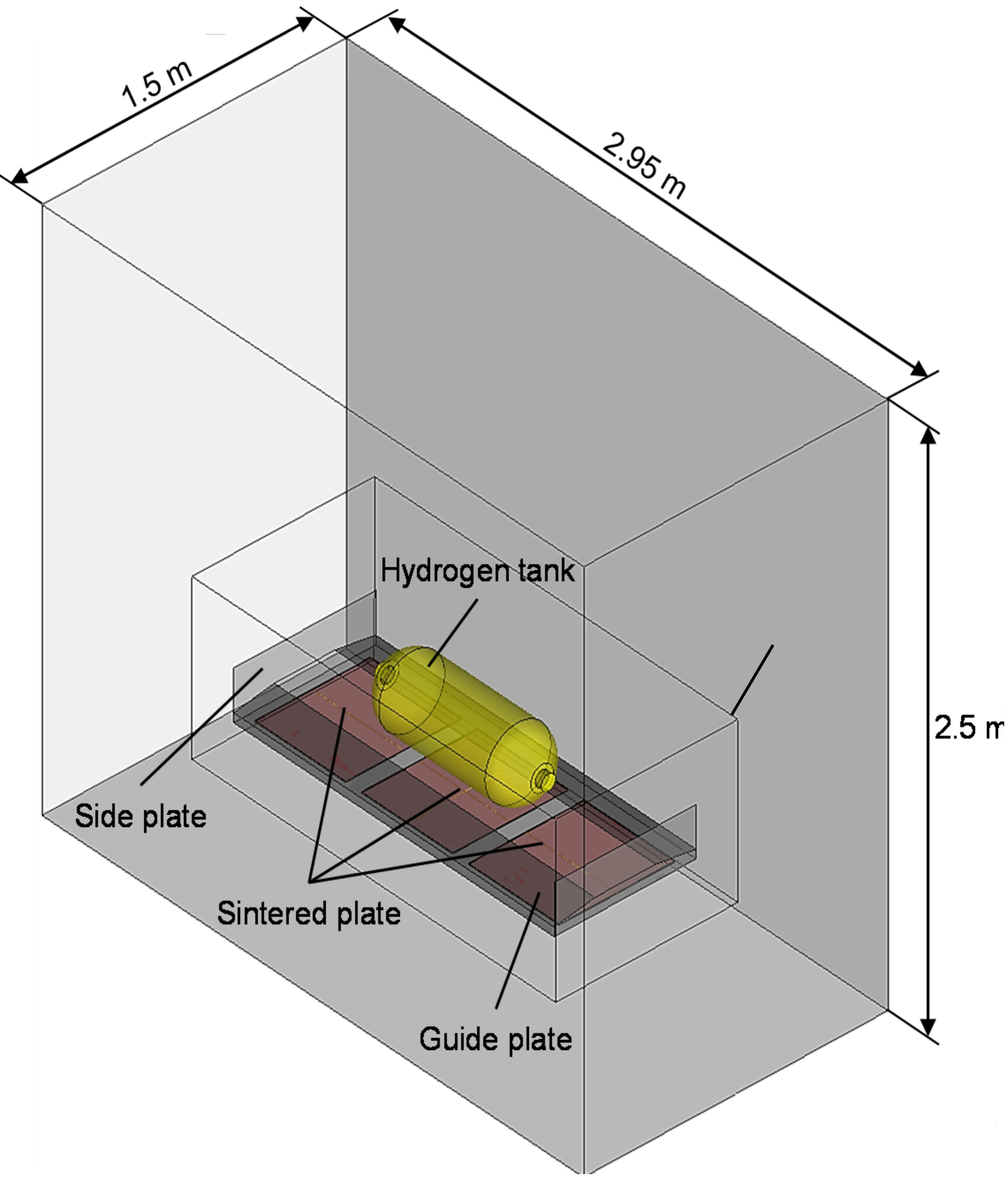
Outline

- ❖ Bonfire test in Global Technical Regulation (GTR) 2013
- ❖ Burner description
  - Geometry
  - Numerical mesh
- ❖ Criterion of bare hydrogen tank failure
- ❖ Effect of HRR on FRR of bare hydrogen tank
- ❖ Effect of resin glass transition temperature (T_g) on FRR
- ❖ Joint effect of HRR and resin T_g on FRR
- ❖ Suggestions to GTR 2013 change

Global Technical Regulation 2013

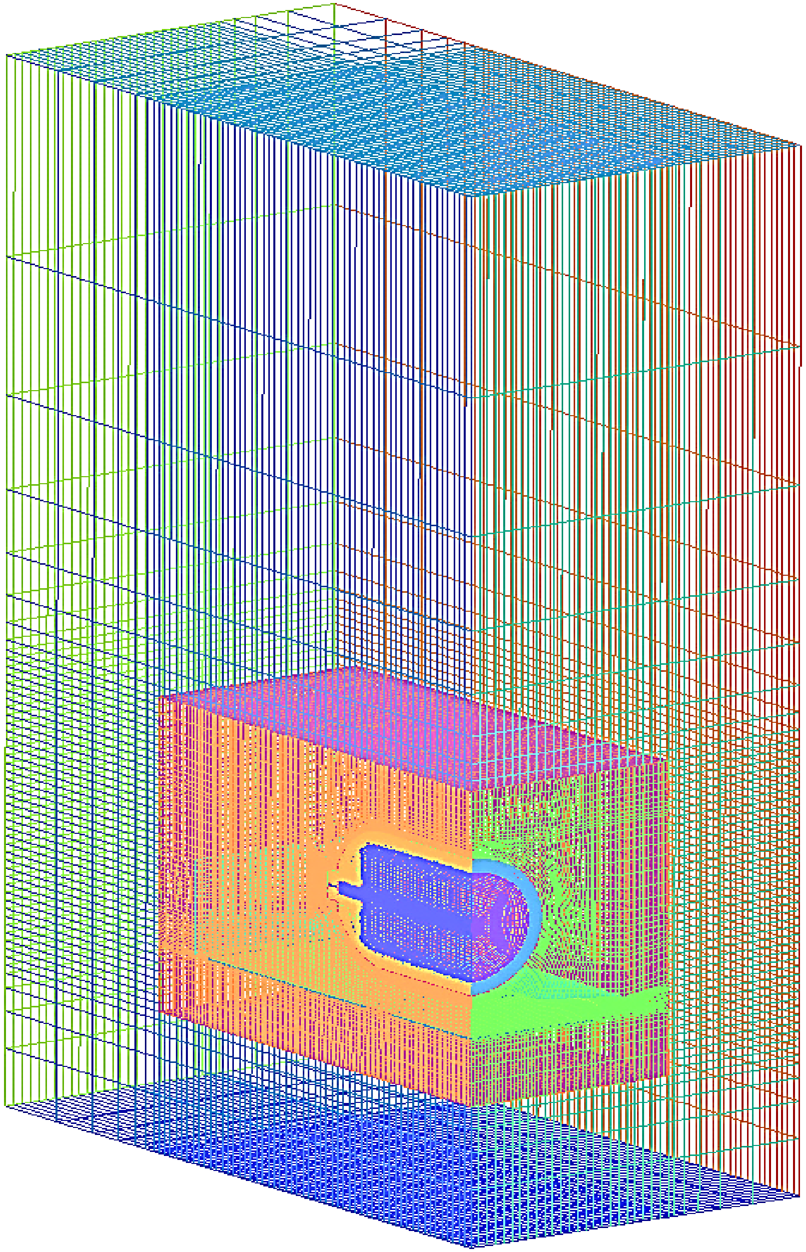
- **Engulfing fire test:**
- "Within five minutes after the fire is ignited, an average flame temperature of not less than 590ºC (as determined by the average of the two thermocouples recording the highest temperatures over 60 second interval) is attained and maintained for the duration of the test."
- Flame temperatures are measured by at least 3 TCs, 25 mm beneath the tank
- Distance between burner and the tank bottom is approximately 100 mm.
- "Uniform fire source of 1.65 m length provides direct flame impingement on the container surface **across its entire diameter".**
- Tank should vent through TPRD without burst.

Geometry and calculation domain



Experimental facility (KIT)

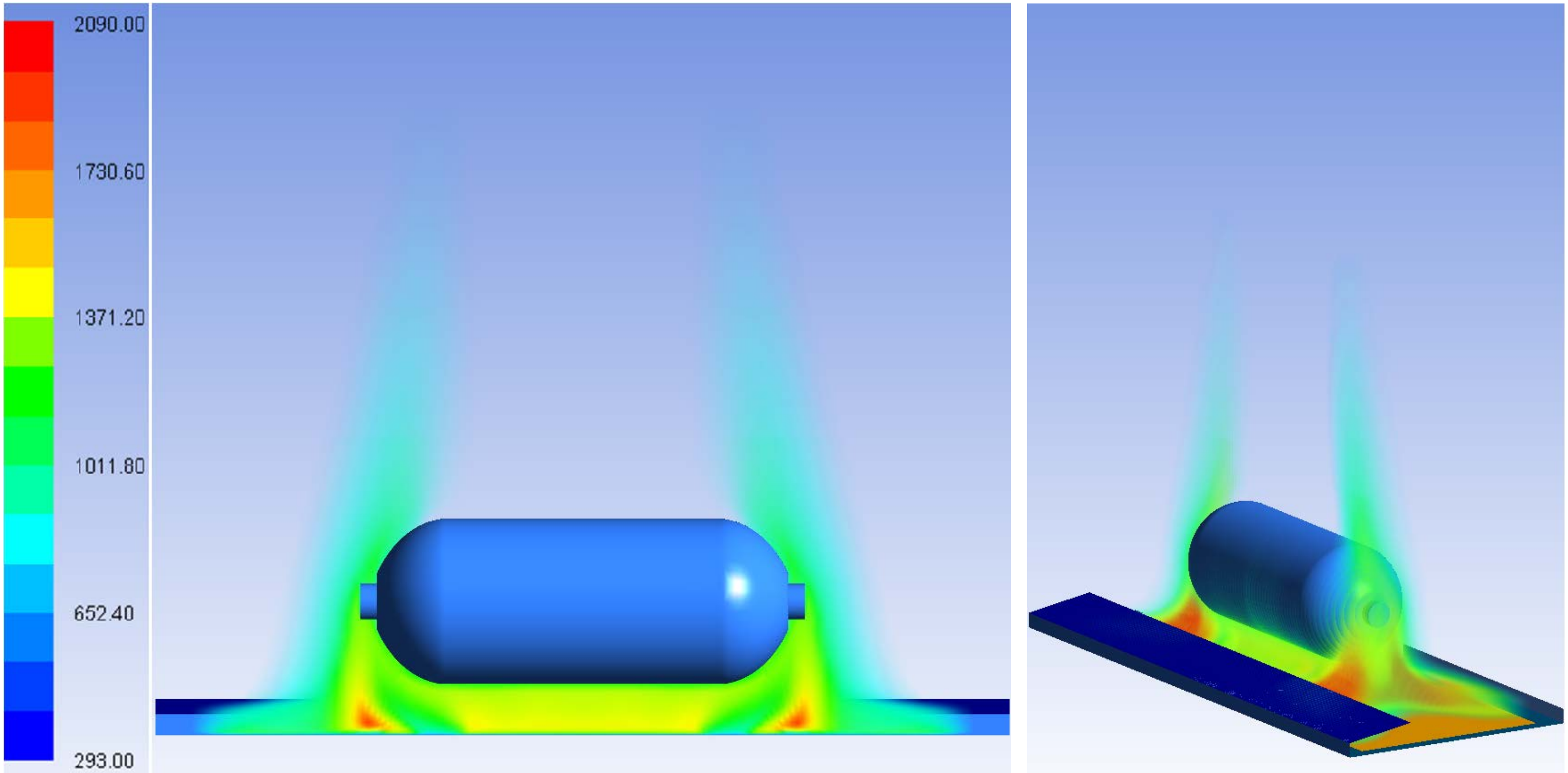
Numerical mesh

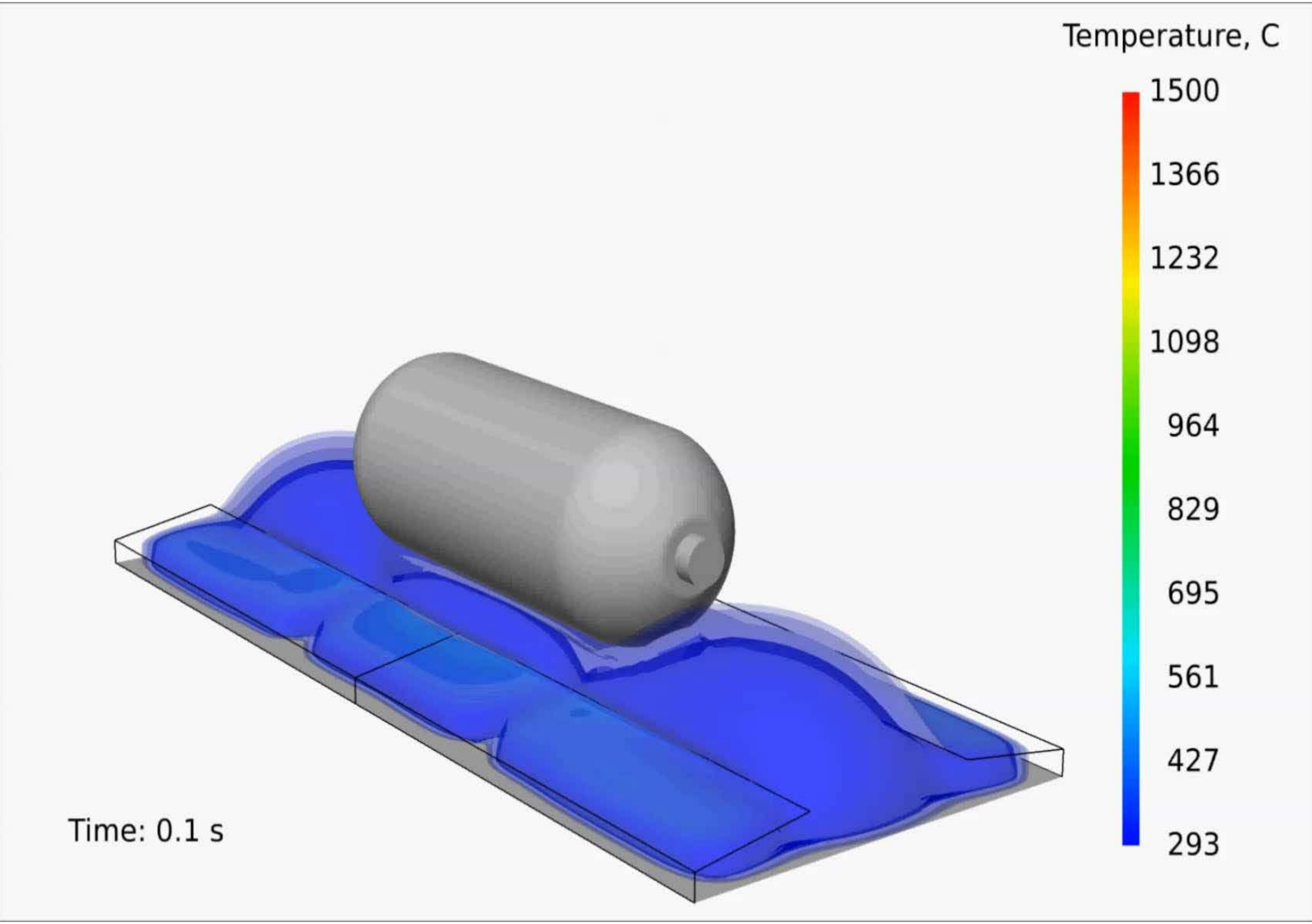


- Geometry is based on bonfire test design by KIT
- Number of CVs: 300k (reduced by using mesh interfaces feature of ICEM)
- Dimensions L×W×H = 1475×750×2500 mm
- Burner's dimensions (3 sintered plates) 1660×570 mm

Premixed methane-air bonfire

- Bonfire HRR as low as **78 kW (see next slide with simulations movie)** satisfies the requirements of GTR 2013: lower temperature limit of 590^{o}C is exceeded in 5 min (simulated T=800-1100^{o}C)!
- HRRs in USA tests by Weyandt (2005-2006) are **265-370 kW…**




Temperature, C
1500
1366
1232
1098
964
829
695
561
427
293
Time: 0.1 s

The composite tank failure criterion

- Normal Working Pressure (NWP) is at least 2.25 times less than Minimum Burst Pressure, following EU Regulations 2010

- In the assumption that internal tank pressure does not increase during bonfire, the failure happens at 1/2.25 = 0.44 of the wall thickness

- When the resin T_g front propagates through CFRP and passes 0.56 of the wall thickness (and only remaining 0.44 wall thickness fraction is load bearing), the wall looses its strength to withstand internal pressure and fails

Resin glass transition temperature

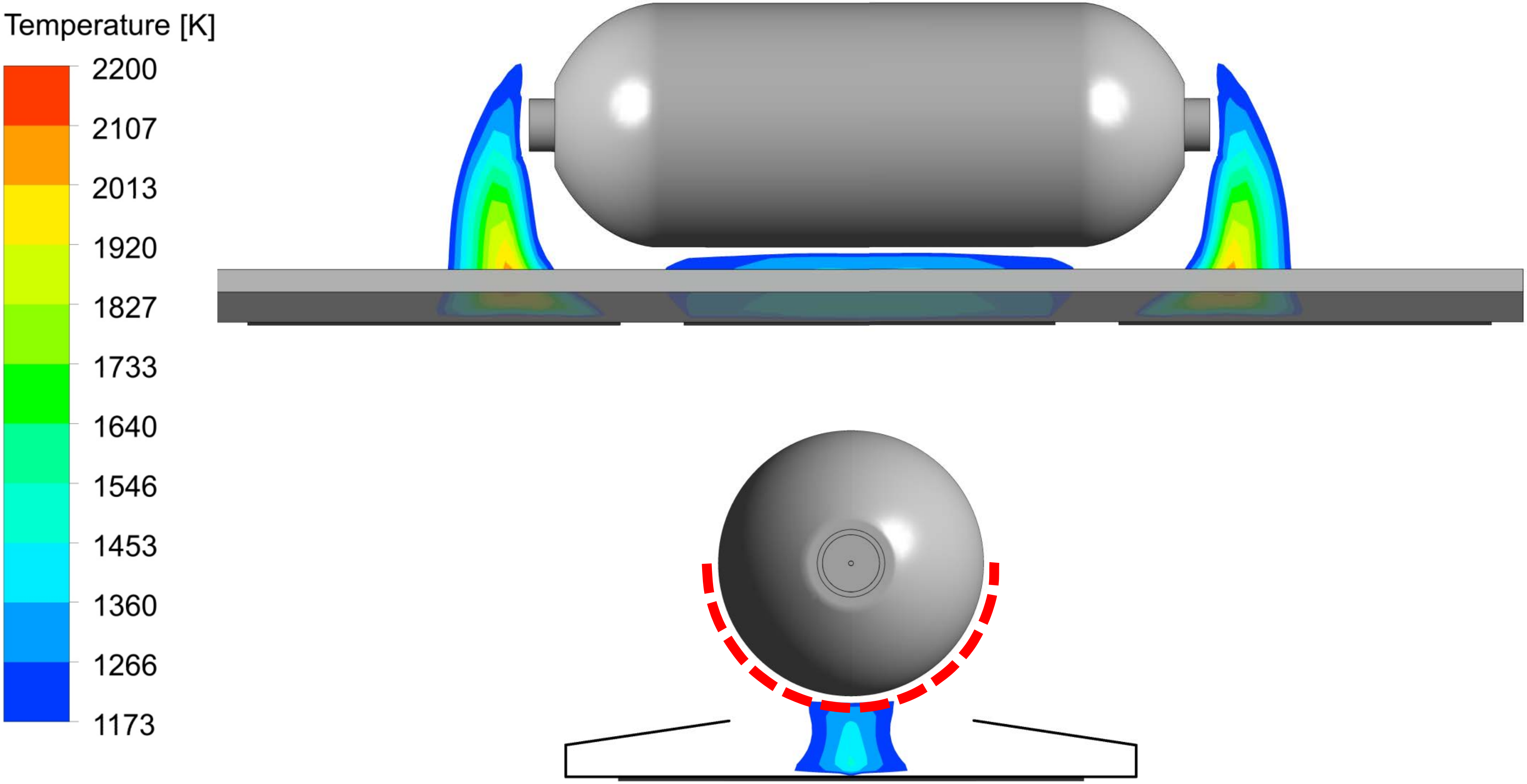
Resin with GTT=130ºC

Resin with GTT=170ºC

Fire resistance
<u>4 min</u>

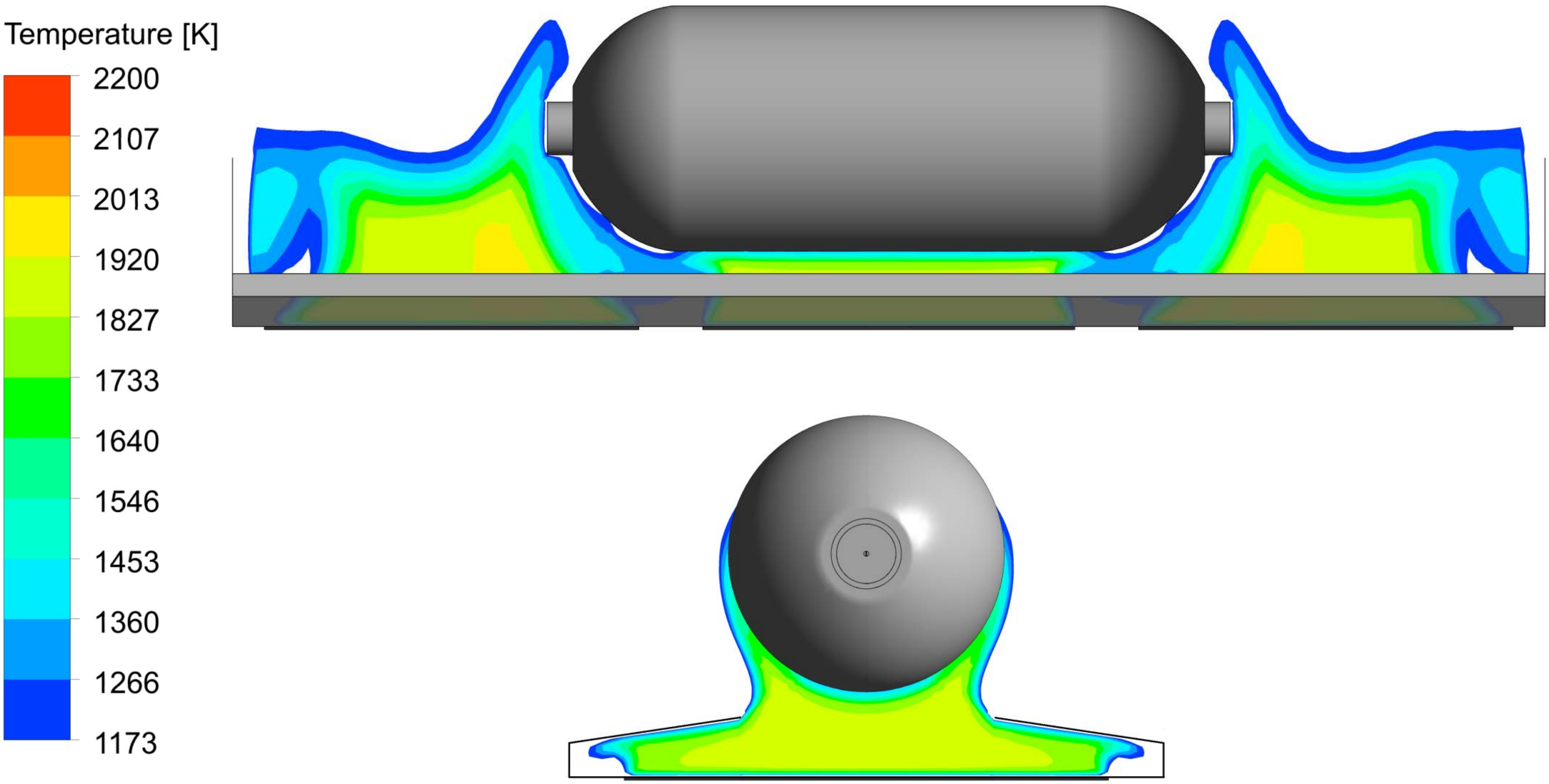
Fire resistance
<u>7 min</u>

Fire test with HRR=78 kW



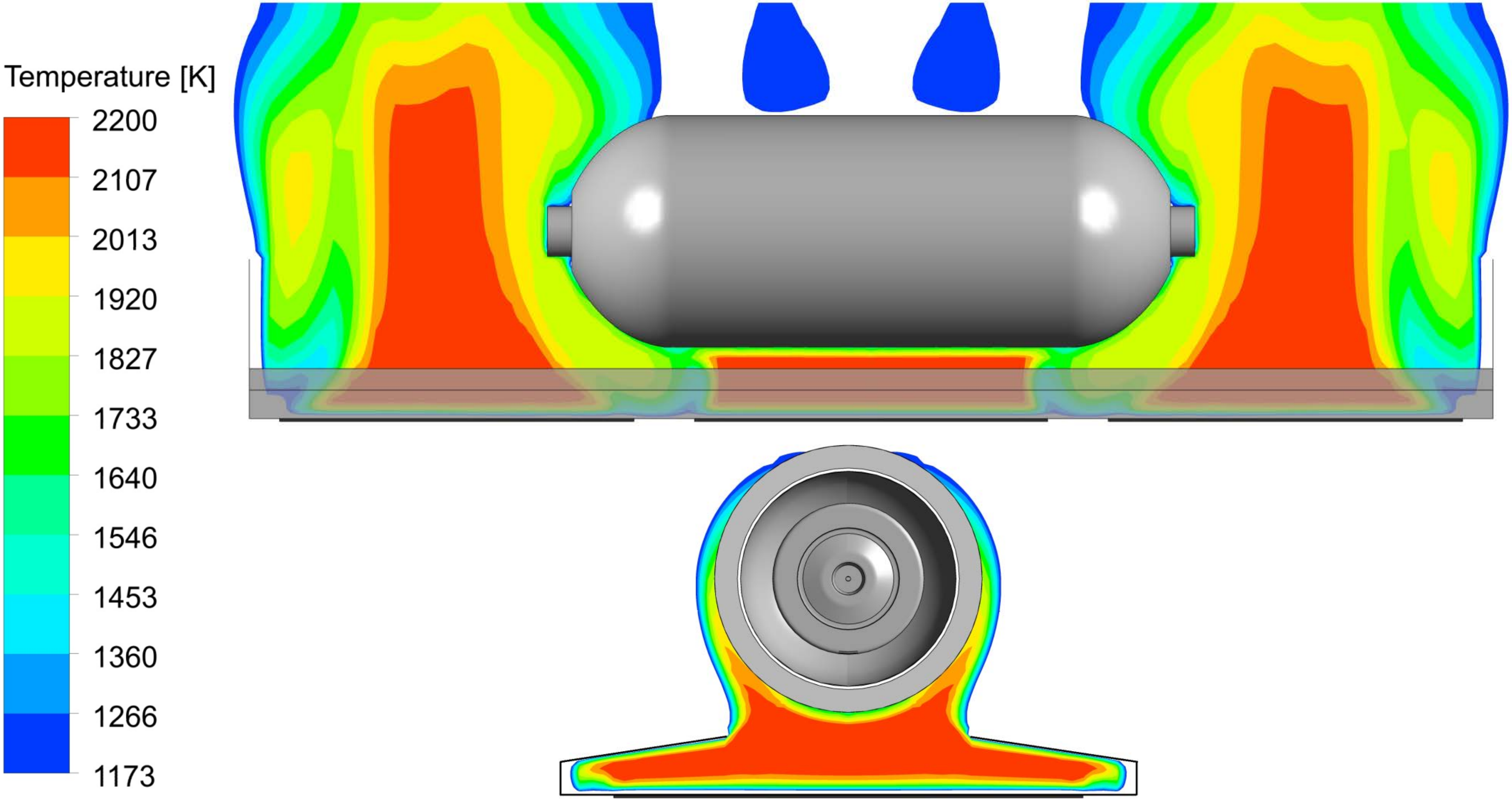
GRT 2013 requirement “flame impingement on the container surface across its entire diameter” **is not satisfied (even simulated T=800-1100ºC is above 590ºC)!**

Fire test with HRR=167 kW



GRT 2013 requirement "flame impingement on the container surface across its entire diameter" **is satisfied (simulated T=1000-1550°C is above 590°C)!**

Fire test with HRR=350 kW



GRT 2013 requirement “flame impingement on the container surface across its entire diameter” **is satisfied (simulated T=1450-1900^{o}C is above 590^{o}C)!**

Effect of HRR on FRR

Example of CFRP with resin T_g=170°C

HRR	Fire resistance rating
78 kW	37 min
167 kW	9.7 min
350 kW	6 min

FRR is a function of HRR in a bonfire test

GTR 2013 to be changed to include **an agreed HRR**

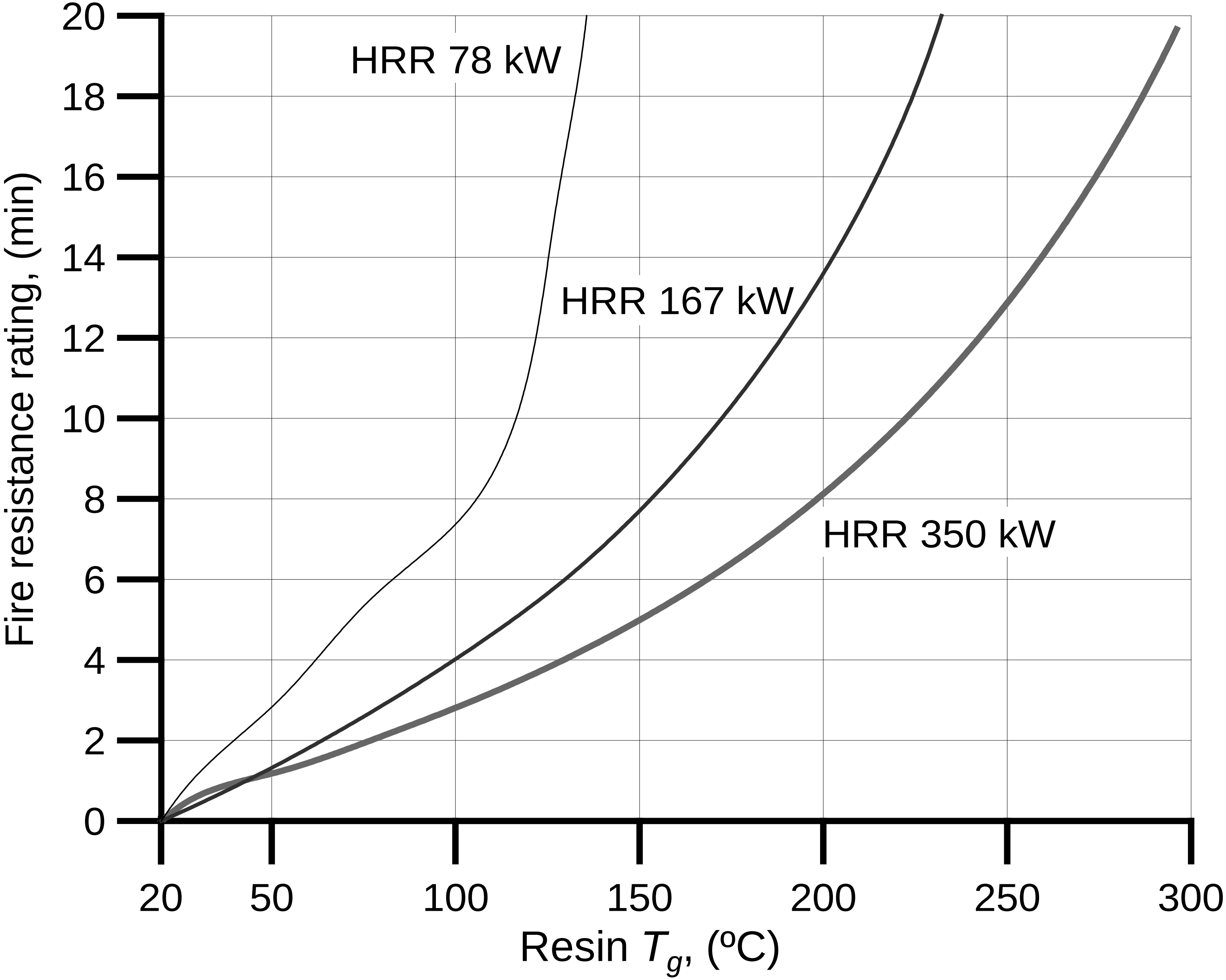
Effect of resin T_g

Example of bonfire test with HRR=350 kW

Resin T_g	Fire resistance rating
95° C	2.6 min
170° C	6 min
225° C	10 min

Information for tank manufacturers:
Resin with higher T_g increases FRR!

Effect of HRR and resin T_g on FRR



Concluding remarks

Suggestions for GTR 2013 change:

- ❖ **GTR should introduce the fire test without TPRD to reflect interests of first responders. FRR in the fire test without TPRD should be specified in the documentation on storage tank**

- ❖ **HRR (not only temperature!) has to be agreed and specified in the fire test protocol:**

  - UU research: FRR depends on the fire HRR, specification of temperatures of the flame is insufficient and provides ambiguous assessment of the hydrogen storage FRR.

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MSc in Hydrogen Safety Engineering (distance learning course):
http://www.ulster.ac.uk/elearning/programmes/view/course/10139

Fundamentals of Hydrogen Safety Engineering (free eBook, http://bookboon.com, search "hydrogen", available since October 2012)