Digital stakeholders' workshop
HyTunnel-CS project
4-5 May 2020

Effect of hydrogen jet fire on a tunnel structure (CFD part)

D. Cirrone, V. Shentsov,
D. Makarov, V. Molkov
Ulster University

Introduction

Background. Numerical study performed by Sandia National Laboratories showed that the impingement on a tunnel ceiling of a hydrogen jet fire from a 70 MPa tank and release diameter 2.5 mm may lead to concrete spalling (Anleu et al., 2017).

Scenario. A hydrogen powered bus is involved in a accident in a tunnel, which causes the Thermally activated Pressure Relief Device (TPRD) on the storage tank to open. Released hydrogen ignites, producing a jet fire impinging on a tunnel false ceiling.

Aim of the study. CFD modelling of hydrogen jet fire focusing on:

- ❖ Assessment of the thermal load on a tunnel infrastructure.
- ❖ Assessment of hazards distances for people.

Release from a hydrogen bus

Definition of a scenario (1/2)

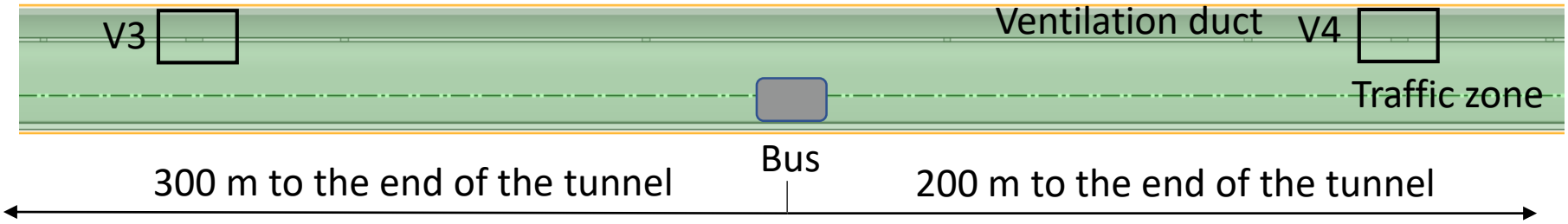
- The study considers a hydrogen powered bus with 4 storage tanks.
- Bus dimensions are 13.2x3.4x2.6 m.
- TPRD diameter on each storage tank is 5 mm.
- Hydrogen is released through the TPRD in upwards direction.
- Opening of one storage tank.

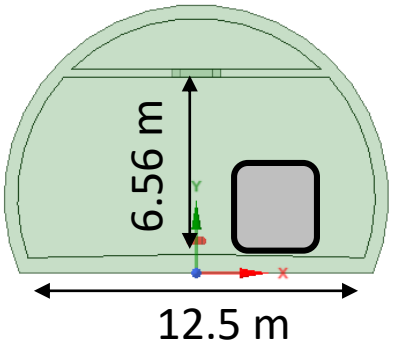
Storage of hydrogen	
N. of tanks	4
Pressure (at 288K)	350 bar
Tank volume	322 l
Mass of hydrogen	7.7 kg

Tunnel geometry

Definition of a scenario (2/2)

- A 500 m long tunnel is considered for the study.
- During fire the openings for fresh air injection are all closed.
- Five extraction vents (1.8x1.4m) are placed each 100 m along the tunnel. The ventilation system is not active for the release duration.
- The bus is located towards the centre of the tunnel.



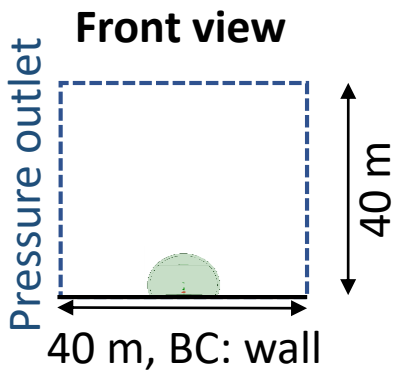


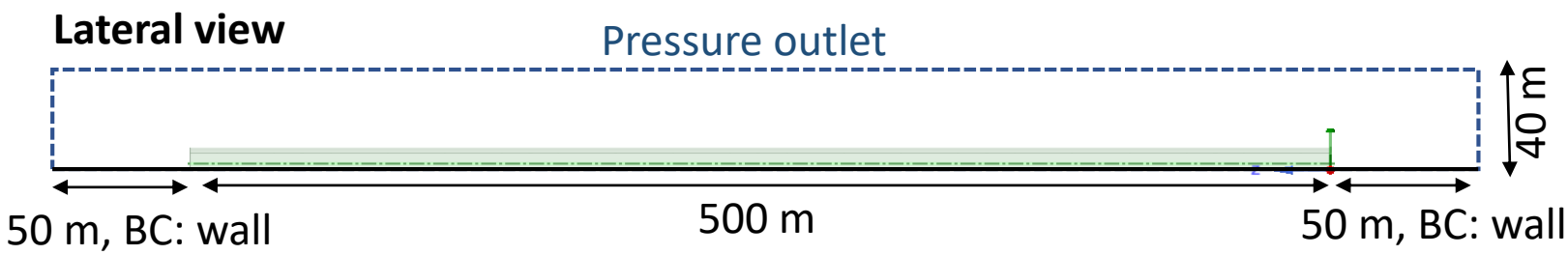
CFD model and numerical domain

Description and details (1/2)

Turbulence	Realizable κ-ε (Shih et al.,1995)
Combustion	Eddy Dissipation Concept (Magnussen, 1981): 9 species and 18-step chemical reactions from Peters and Rogg's kinetic mechanism (1993)
Radiation	Discrete Ordinates model (Murthy et al., 1998)

Numerical domain includes the entire 500 m long tunnel and a portion of open atmosphere (blue dashed lines).

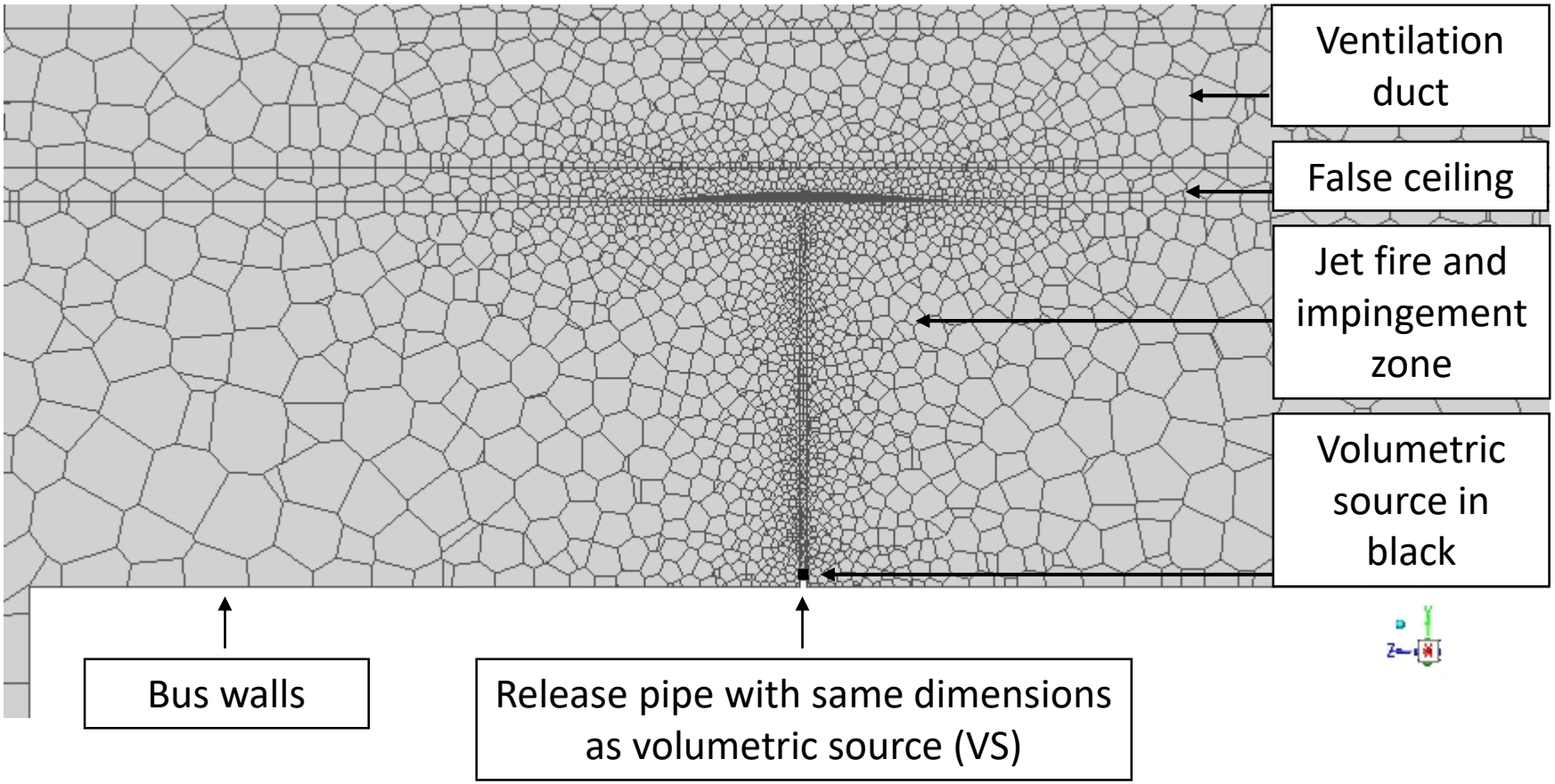




Numerical grid

Description and details (2/2)

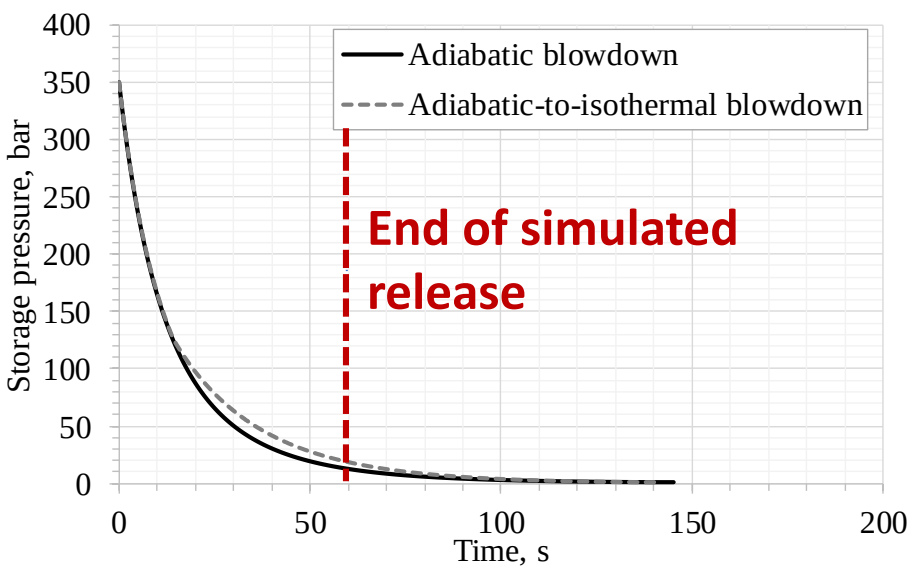
❖ Polyhedral mesh with 688200 CVs

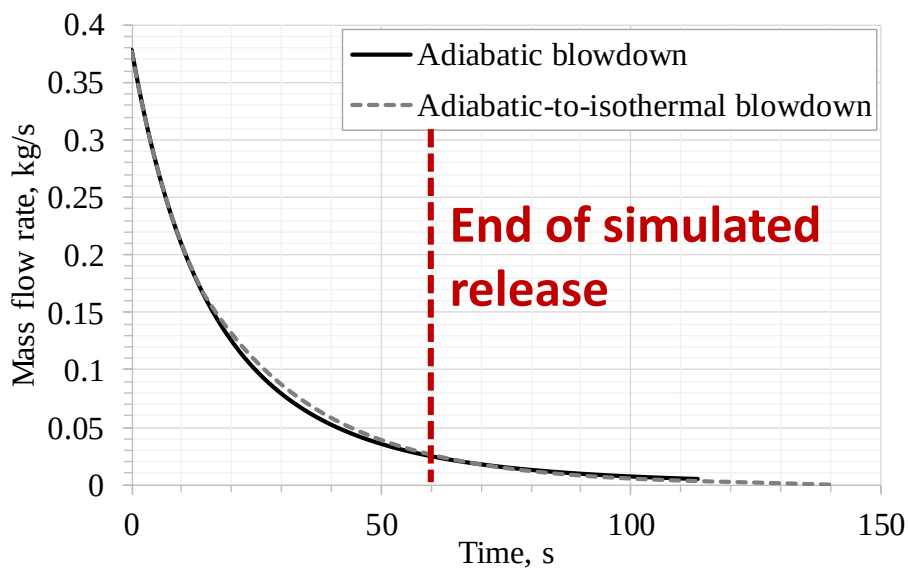


Tank blowdown dynamics

Problem formulation

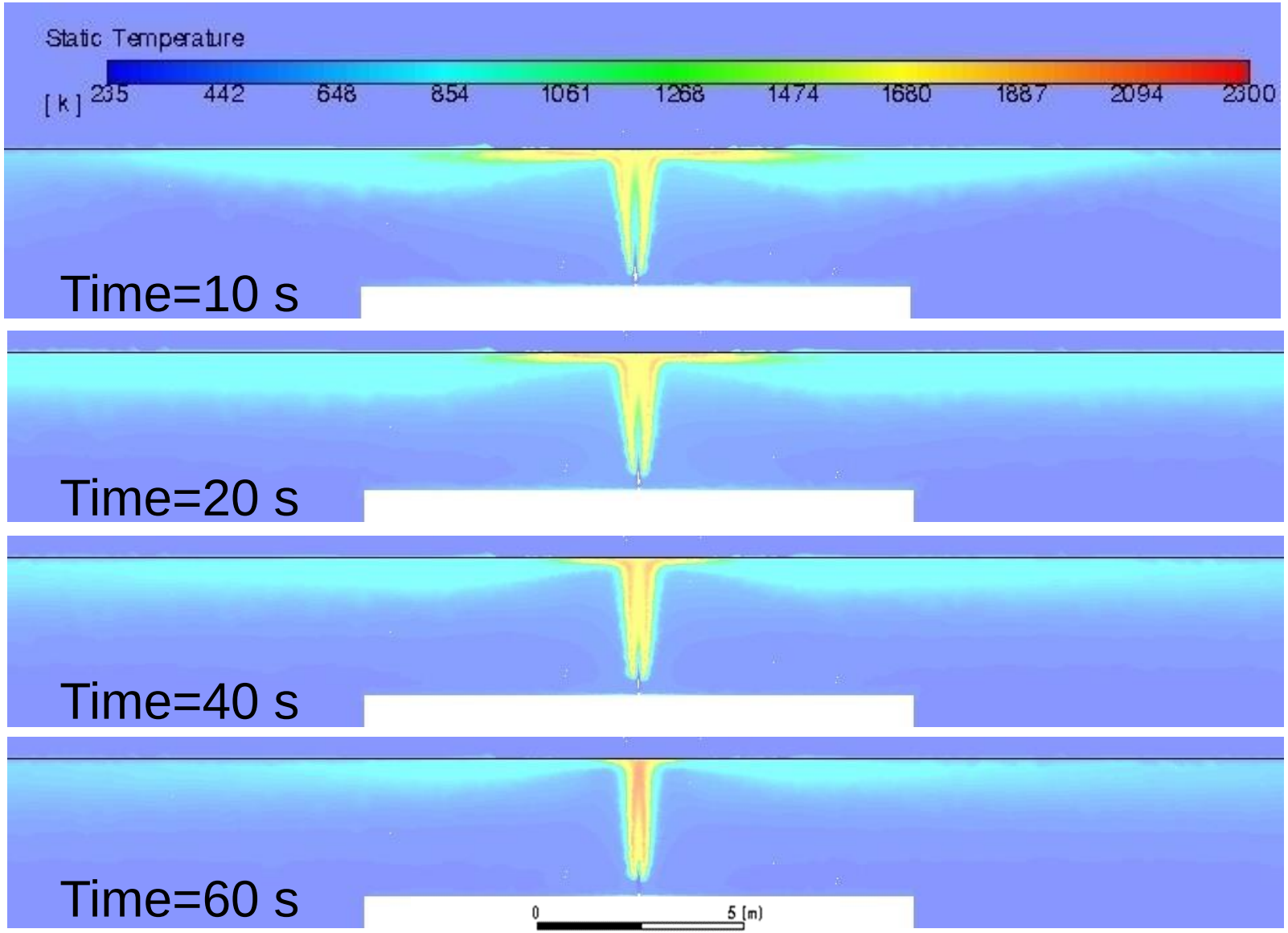
- The Ulster notional nozzle approach is applied to simulate the under-expanded jet properties dynamics during the tank blowdown through implementation of a **volumetric source**.
- The adiabatic-to-isothermal (215K) blowdown formulation is selected to model the release.





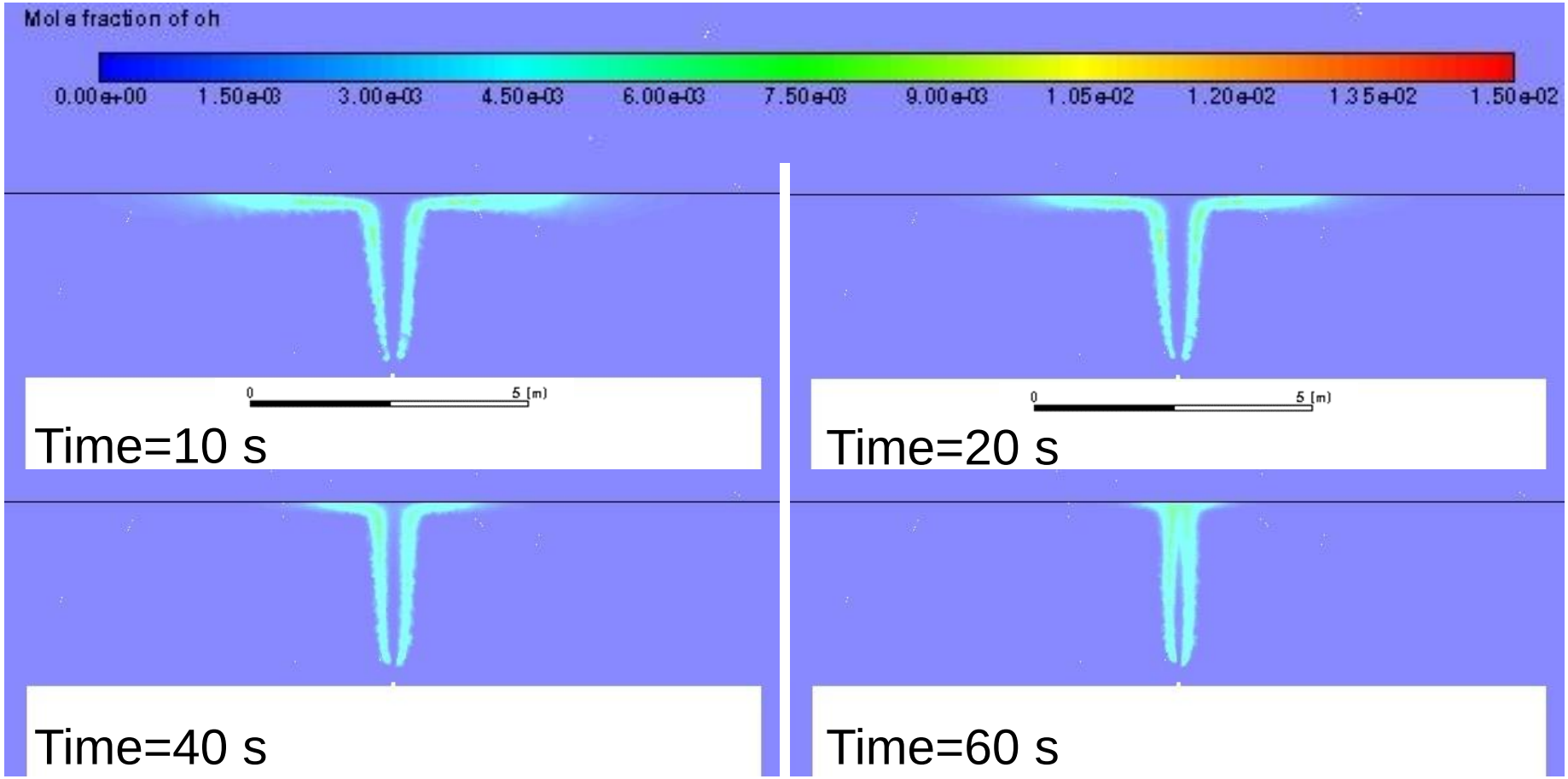
Temperature dynamics

Simulation results



OH mole fraction dynamics

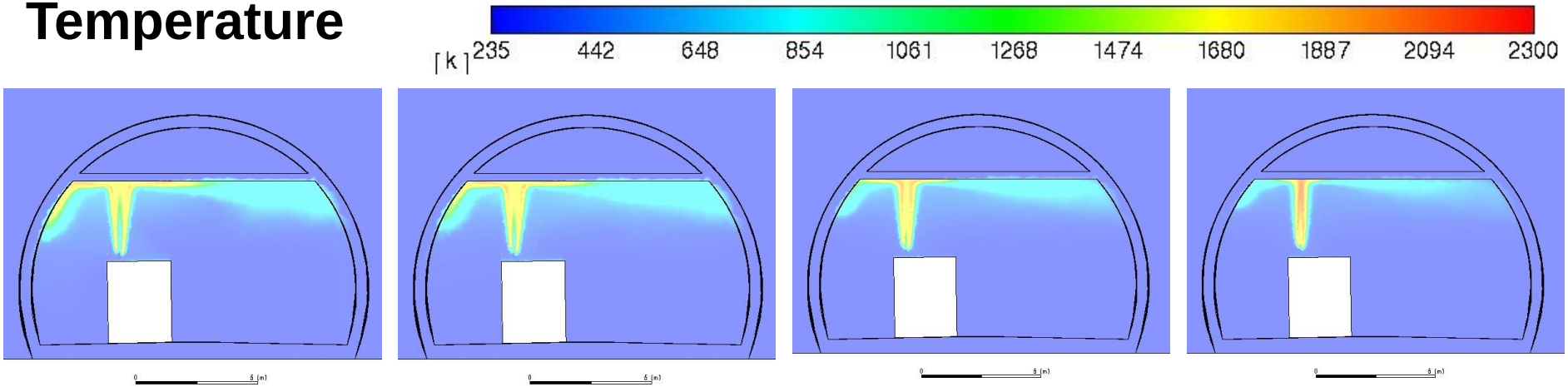
Simulation results



T and OH mole fraction dynamics

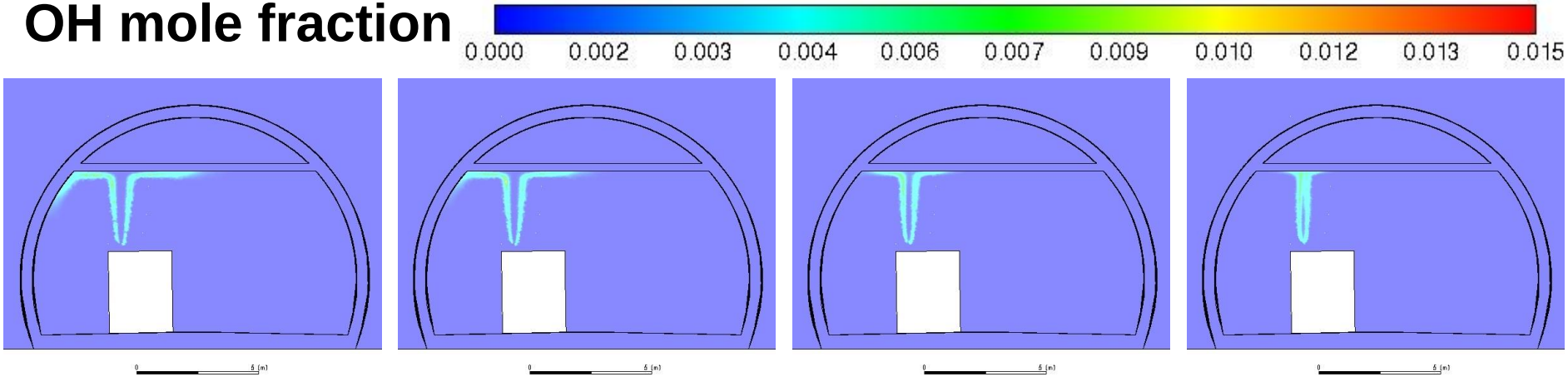
Distributions on tunnel cross section

Temperature



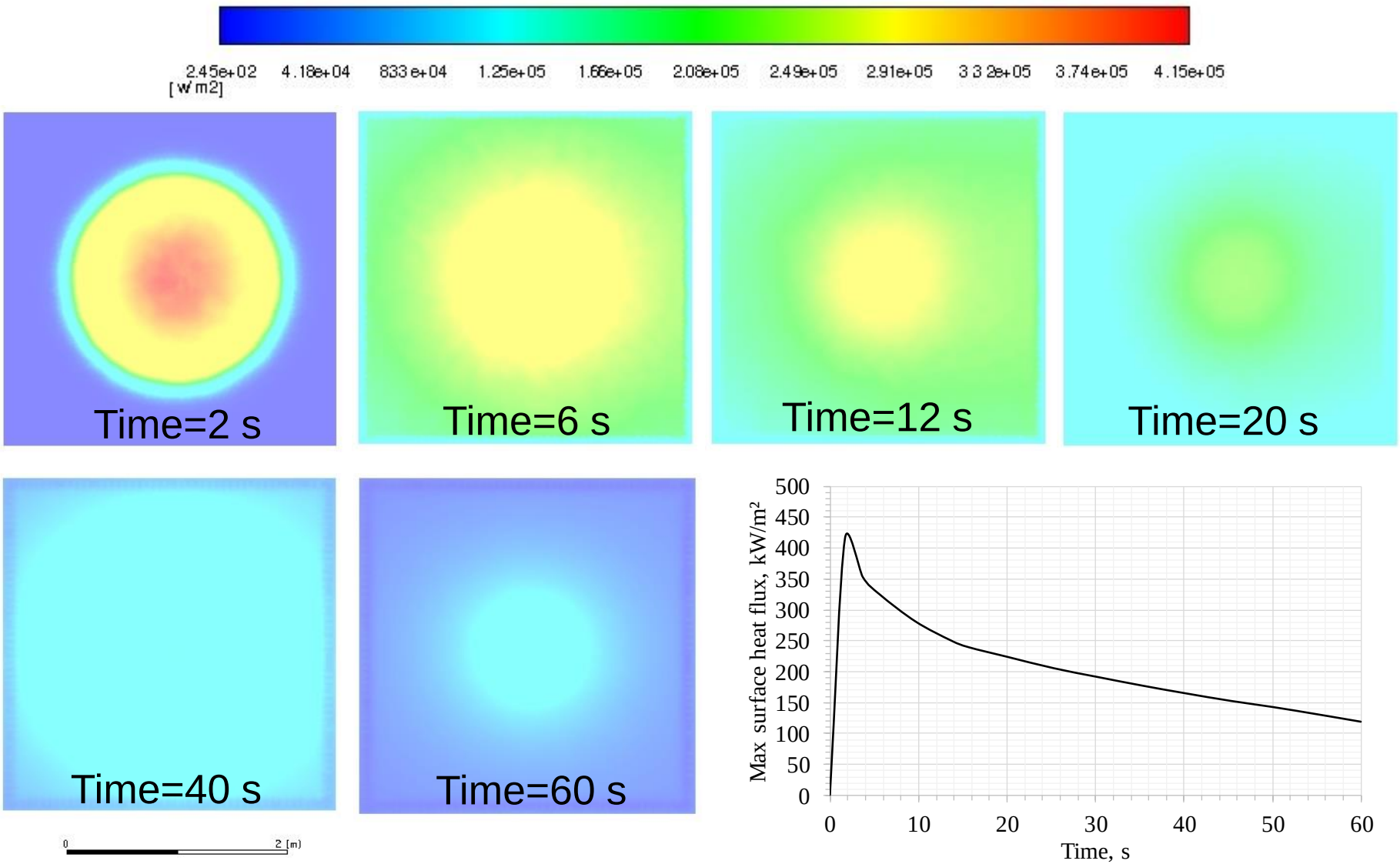
Time=10 s Time=20 s Time=40 s Time=60 s

OH mole fraction



Thermal load on tunnel structure

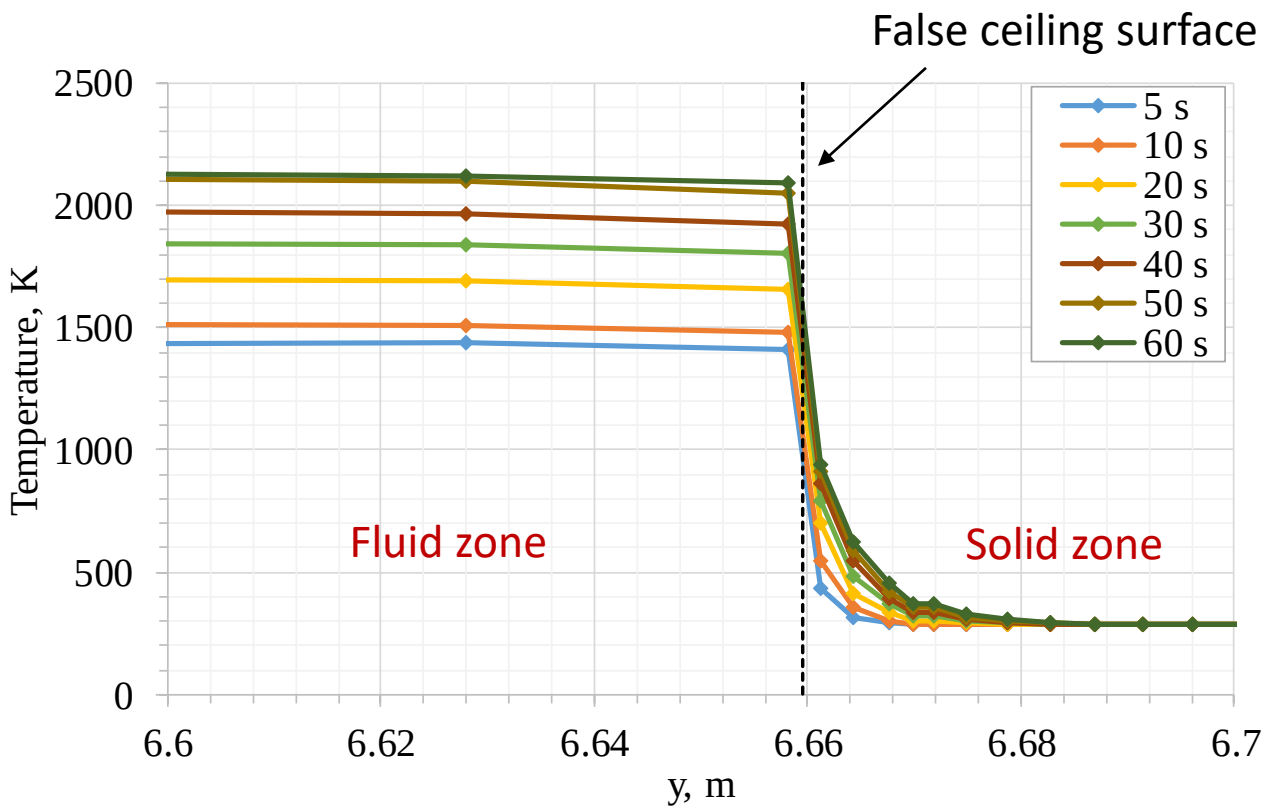
Total surface heat flux on false ceiling



Temperature dynamics

Distribution within the false ceiling

❖ Temperature distribution along the jet fire axis in proximity to and across the tunnel false ceiling.



Hazard distances by temperature

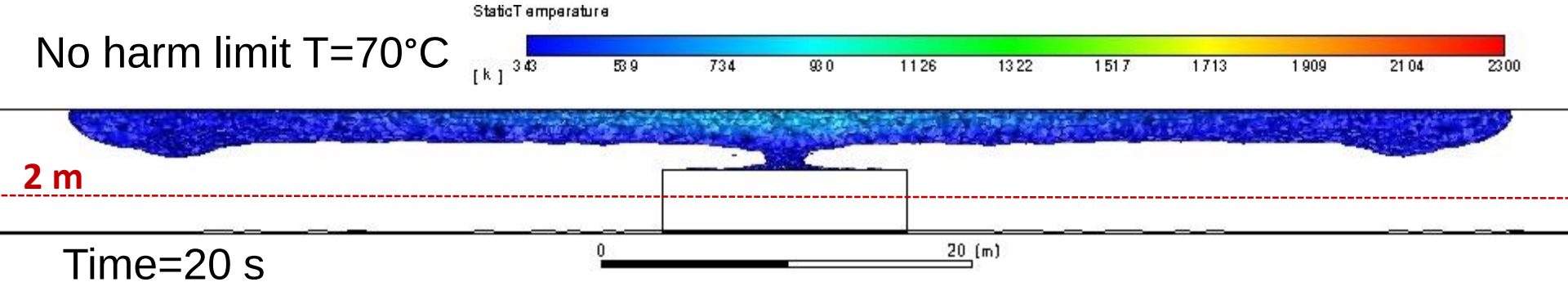
Simulation results

Harm criteria for people:

- ❖ “No harm” limit: 70°C for any exposure duration;
- ❖ “Pain” limit: 115°C for 5 minutes exposure;
- ❖ “Death” limit: 309°C, third degree burns for 20 s exposure.

Harmful thresholds <u>are not reached</u> at height = 2 m and 0.5 m.
Ventilation system is not active!

No harm limit T=70°C



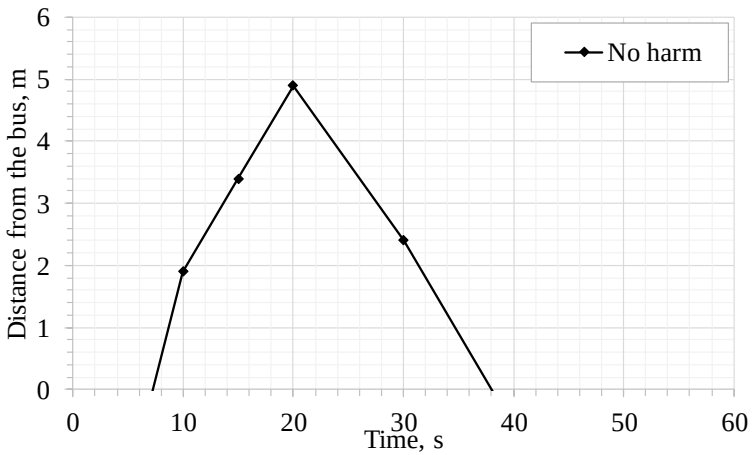
Time=20 s

Hazard distances by thermal radiation

Simulation results

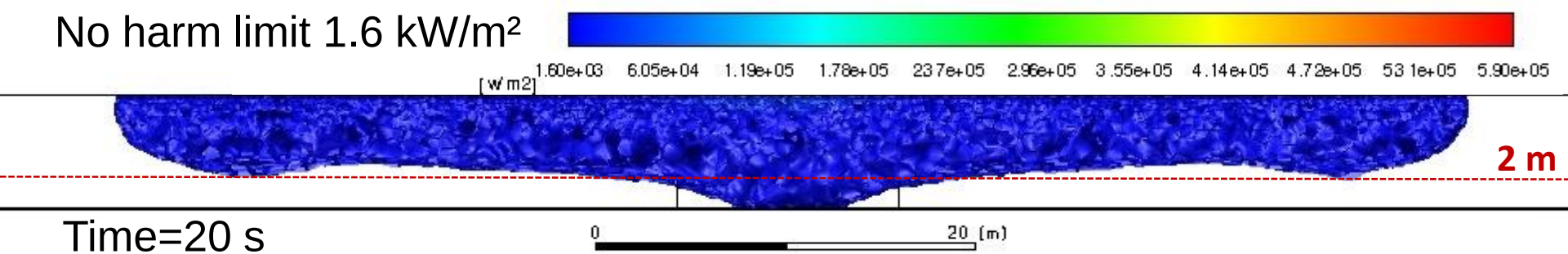
Radiation intensity trend close to the tunnel side wall (height = 2 m)

Thermal radiation intensity, kW/m²	Damage
1.6	No harm for long exposures
4	First degree burn
9.5	Second degree burn after 20 s
25	100% lethality in 1 min



No harm threshold <u>is reached</u> at height = 2 m and 0.5 m.
Ventilation system is not active!

No harm limit 1.6 kW/m²



Time=20 s

Concluding remarks

…and future works

- The study presented the CFD modelling of a jet fire from a storage tank of a hydrogen powered bus in a tunnel.
- The high temperature zone following the jet fire is concentrated in close proximity of the ceiling and moves along it.
- No harmful temperatures are reached at an height equal to 2 m for a 60 s release duration.
- The maximum no harm distance by thermal radiation at height = 2 m is reached at 5 m from the bus at time 20 s.
- Research will be extended to the opening of the remaining three storage tanks on the hydrogen powered bus, with inclusion of ventilation system activation 2 min after the accident time.
- CFD results will be used in FEM modelling for a comprehensive assessment of the tunnel structure response to the jet fire.

Acknowledgements

The authors are grateful to J. Sancho Cebrian and J. Ignacio Abad (IDOM) for their great support and advice for the scenario formulation.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 826193. The JU receives support from the European Union's Horizon 2020 research and innovation programme and United Kingdom, Germany, Greece, Denmark, Spain, Italy, Netherlands, Belgium, France, Norway, Switzerland.