



IA HySafe Research Priorities Workshop

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Simulation of hydrogen release from TPRD under the vehicle (W-i-P)

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Outline

- Vehicle parameters
- Validation of blowdown model
- Validation of volumetric source model
- Calculation domain and mesh
- Results and discussion
 - Blowdown of 171 L tank from TPRD
 - Unignited releases: envelope 4% (LFL) and 11% ("fire")
 - Ignited releases: flame (1300 C), "death" limit 309 C, and "no harm" limit 70 C

Mock vehicle parameters

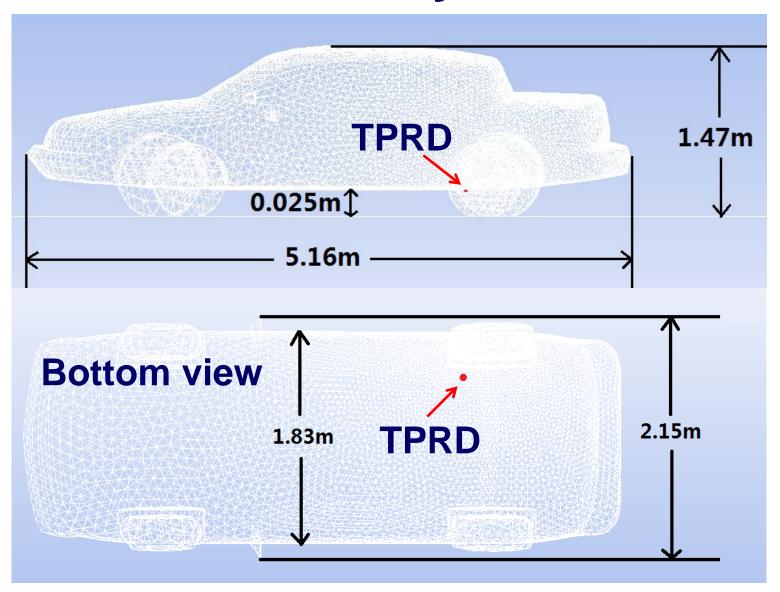
- **❖** The scenario is an accident that occurs in the open space
- The hydrogen tank is assumed to be full (conservative)

Honda FCX clarity	Parameters	Hydrogen tank Stores hydrogen 2 V Flow fuel cell stack Generates electricity	
Storage pressure [1]	35 MPa		
Storage volume [1]	171 L		
TPRD diameter	5.7 mm		
Storage temperature	20 °C		
Ambient pressure: 1 atm	1	Lithium-ion battery Stores electricity Power Drive Unit (PDU) Governs electical flow Electric drive motor Propels vehicle	

Air temperature: 20 °C

[1] 2009 Honda FCX Specifications. http://www.hondaclarity.org/.

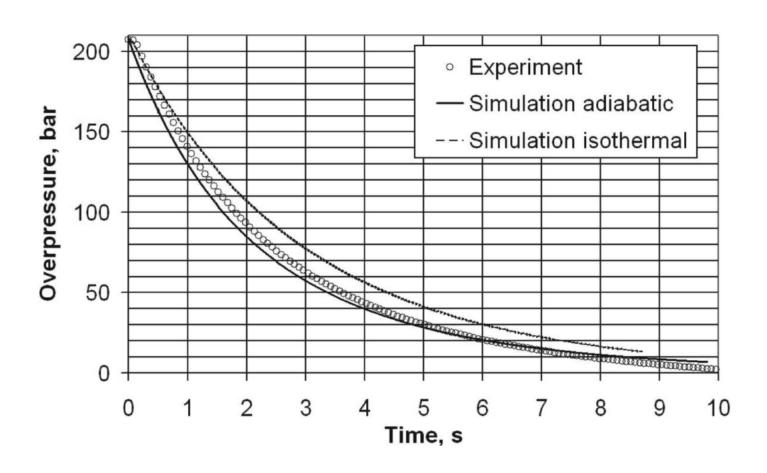
Release vertically downwards



TPRD (D=4.2 mm) location from the reference [2] Yohsuke, Tamura et al; IJHE, 39(2014) 6169-6175. (Note: D=5.7 mm in simulations).

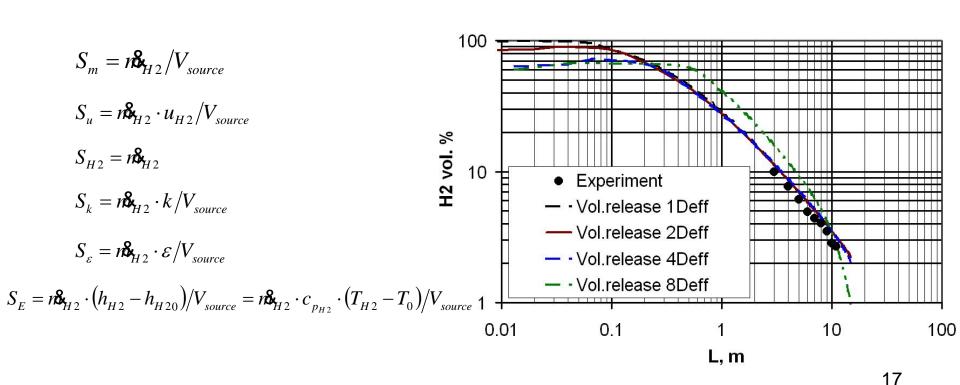
Blowdown model validation

Under-expanded jet theory is applied for non-ideal gas release (blowdown) from a vessel [3]



Volumetric source model validation

Notional nozzle diameter changes during blowdown. Volumetric source model is applied (equations for source terms are below). If volumetric source diameter is up to 4 times of the notional nozzle diameter then concentration decay in under-expanded jet is reproduced accurately. Validation against HSL experimental data [4]: quasi steady-state release from storage at p=100 bar ($T=14^{\circ}$ C) through a 3 mm diameter orifice



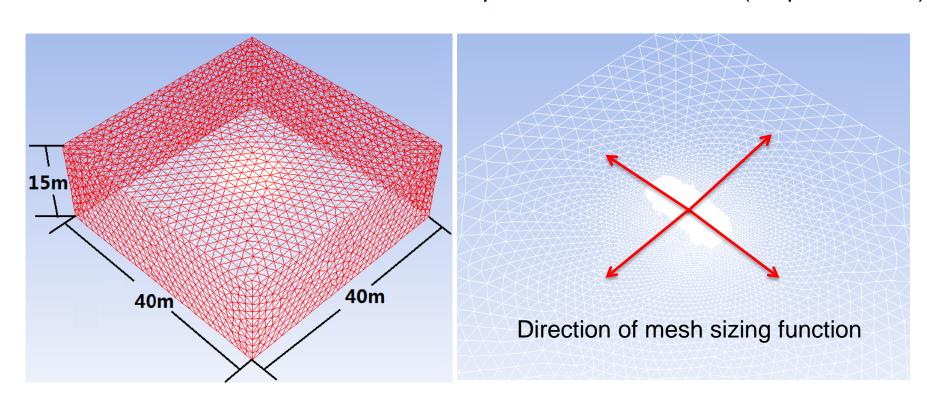
[4] Roberts P.T et al, Proc. of Hazards XIX Conference, 28-30 March 2006, Manchester, UK

Calculation domain and mesh

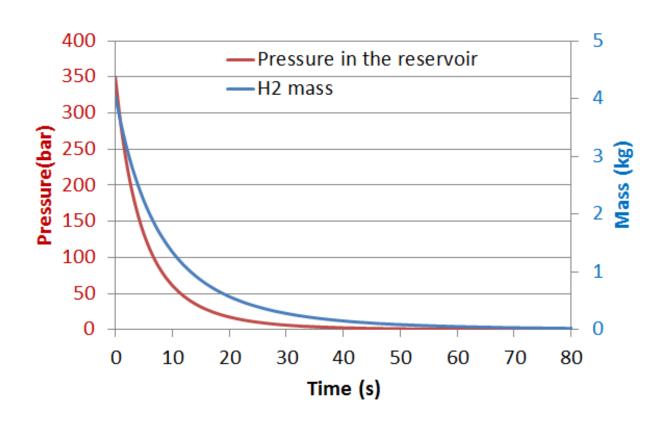
Minimum CV volume: 878 mm³ Total number of CVs: 188,788

Maximum CV volume: 1.31 m³

Computation time: a week (48 processors)

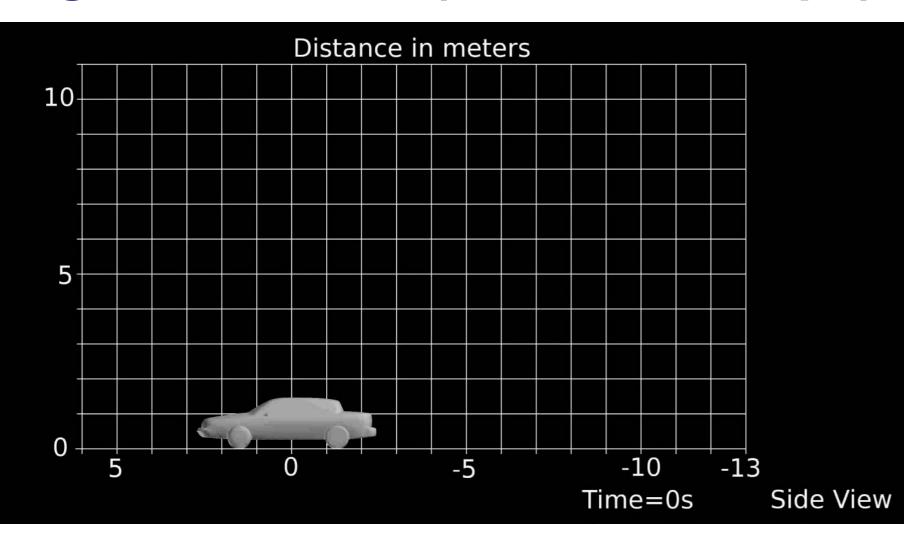


Blowdown of 170 L tank (5.7 mm "TPRD")

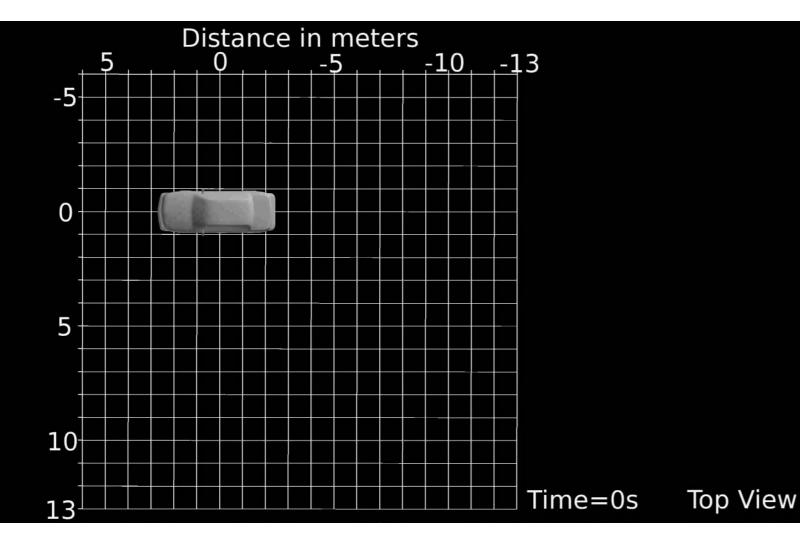


Changing mass flow rate and velocity (including due to adiabatic expansion) from the blowdown model (<u>www.h2fc.eu</u>) are used in source terms of the "volumetric source" model. ¹⁹

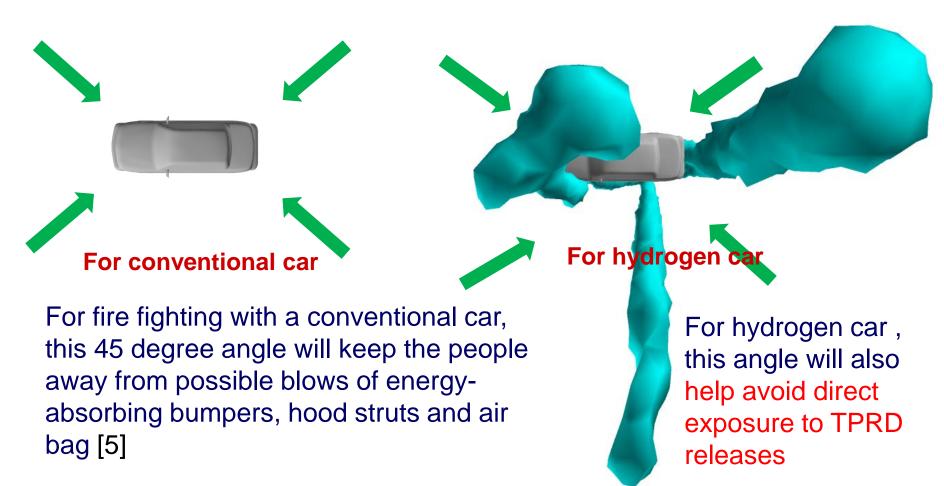
Unignited release (4% v/v envelope)



Unignited release (4% v/v envelope)



Firefighter intervention (TPRD open)



[5] Corbett, G (Ed) (2009). Fire Engineering's Handbook for Firefighter I and II.

But what if the TPRD not open?

Firefighter intervention (TPRD not open)

An experiment carried out in USA [6] on 88 L type 3 tank

at 31.8 MPa mounted under sports utility vehicle recorded that catastrophic rupture of a tank occurred after about12 minutes of fire initiation. This led to formation of a fireball with diameter reaching 24 m.

Detailed report of this experiment [7] states that the vehicle ("projectile") was moved 22 m from its initial position FORWARD LEFT (tank was in the rear).

Therefore the conclusion is not approach car from the front as for conventional cars

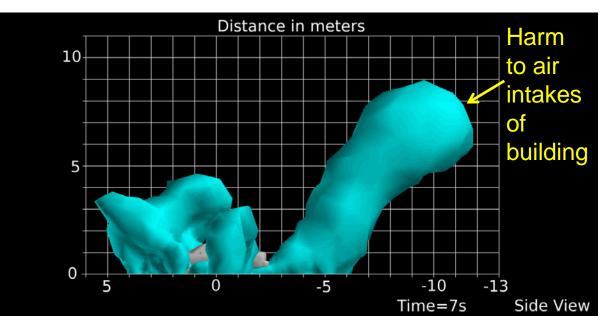


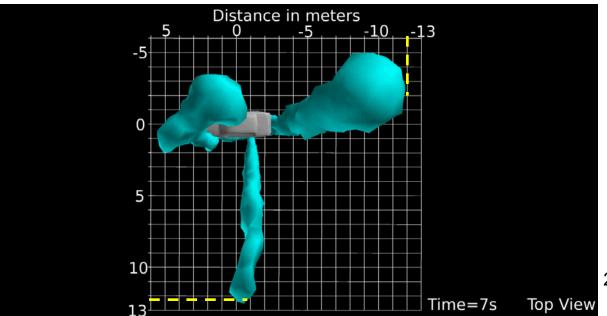
[6] Zalosh, R. Proceedings on the 5th Seminar on Fire and Explosion Hazard, Edinburgh, UK, 23-27 April 2007, pp. 2154-2161.

[7] Weyandt, N. Vehicle bonfire to induce catastrophic failure of a 5000-psig hydrogen cylinder installed on a typical SUV, Motor Vehicle Fire Research Institute(2006)

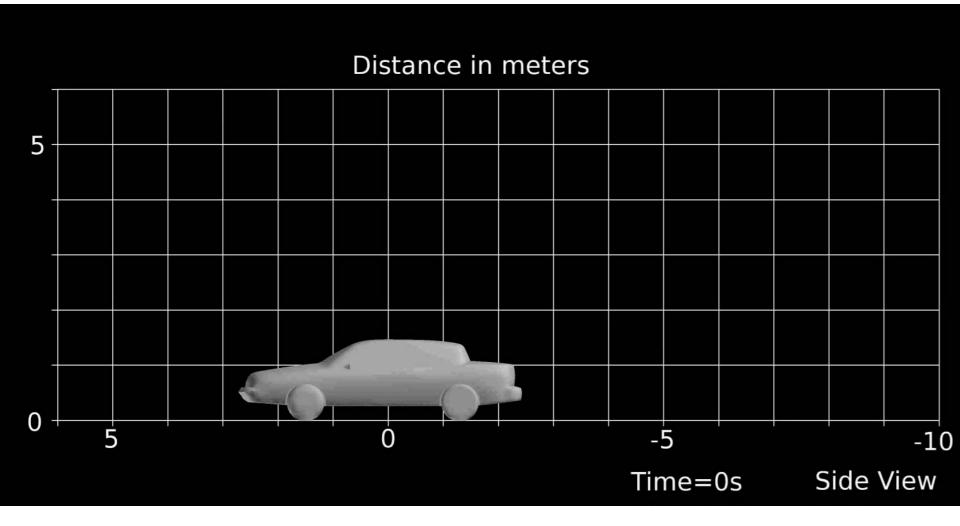
Largest size of flammable envelope

Deterministic separation distances for air intakes of buildings should at least 13 m (largest envelop is at about 7 seconds)

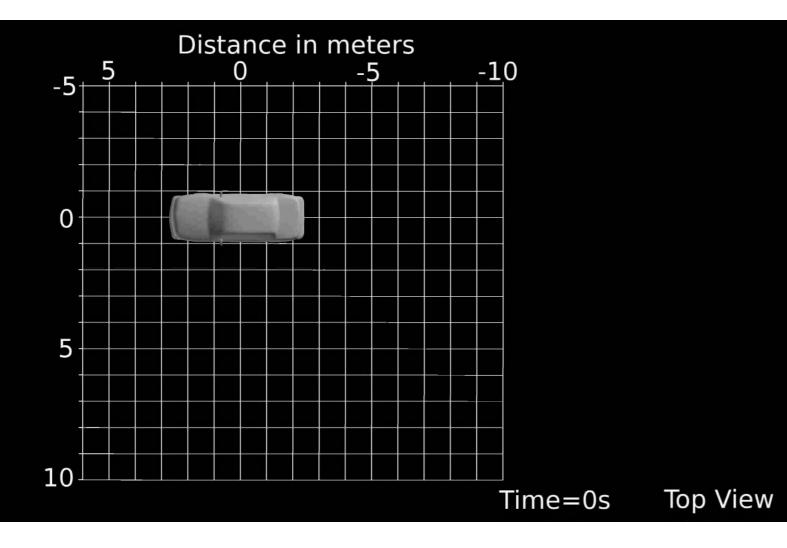




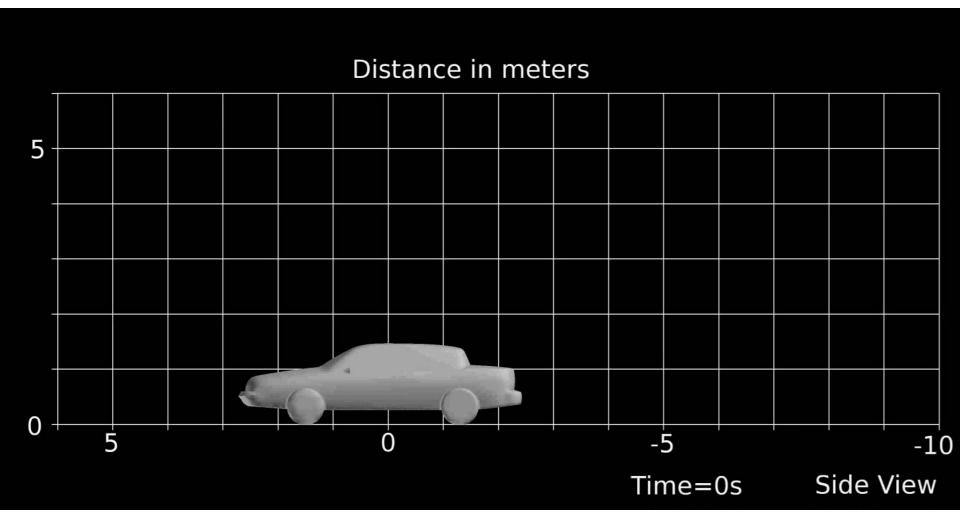
Unignited release (11% v/v envelope)



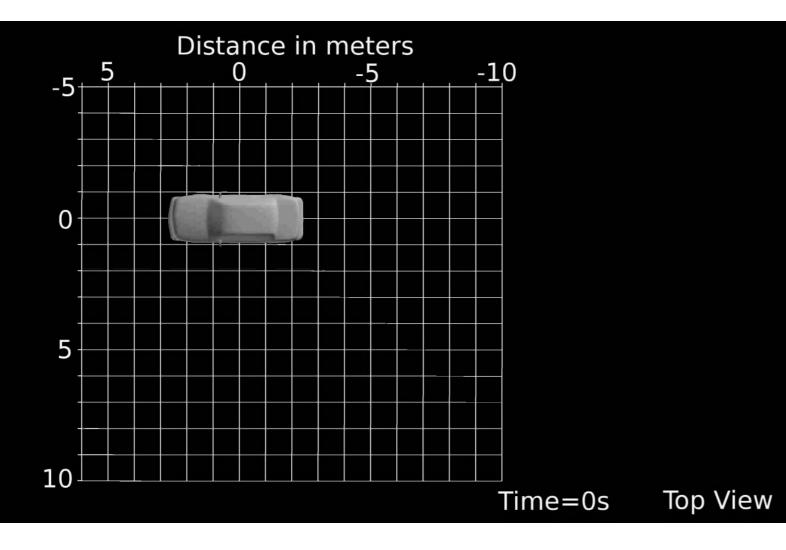
Unignited release (11% v/v envelope)



Ignited release (EBU): 1300 C flame

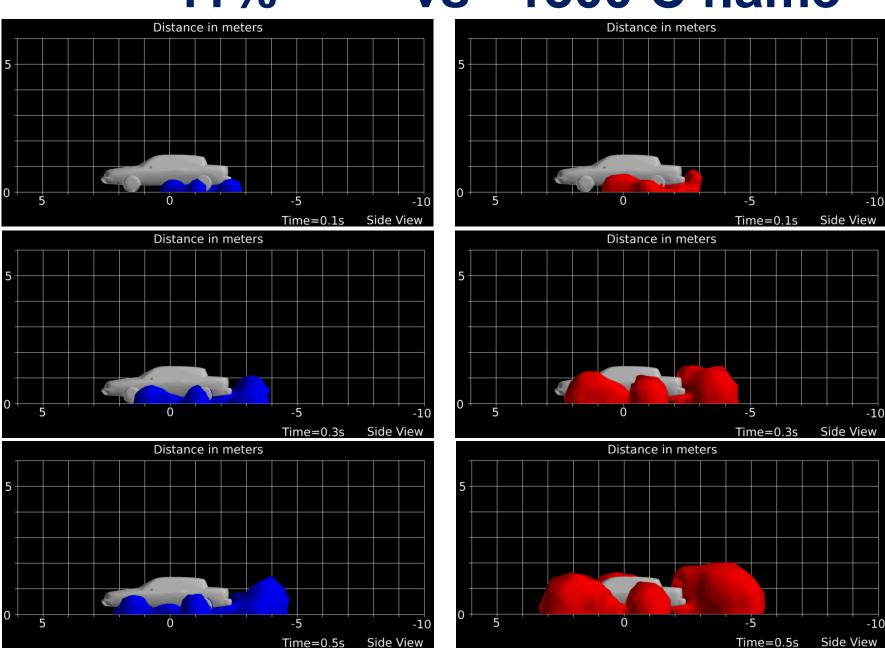


Ignited release (EBU): 1300 C flame



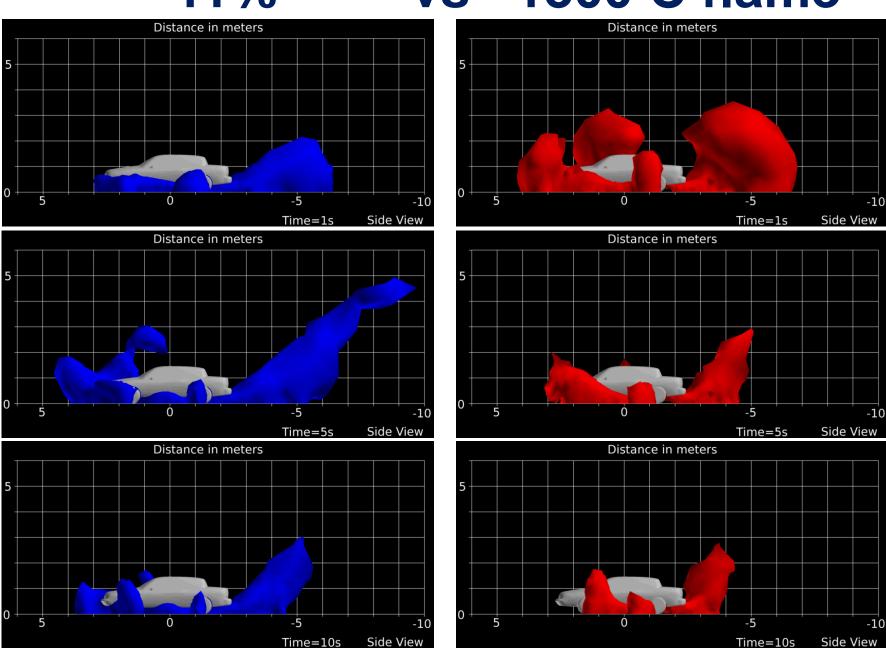
11%

vs 1300 C flame

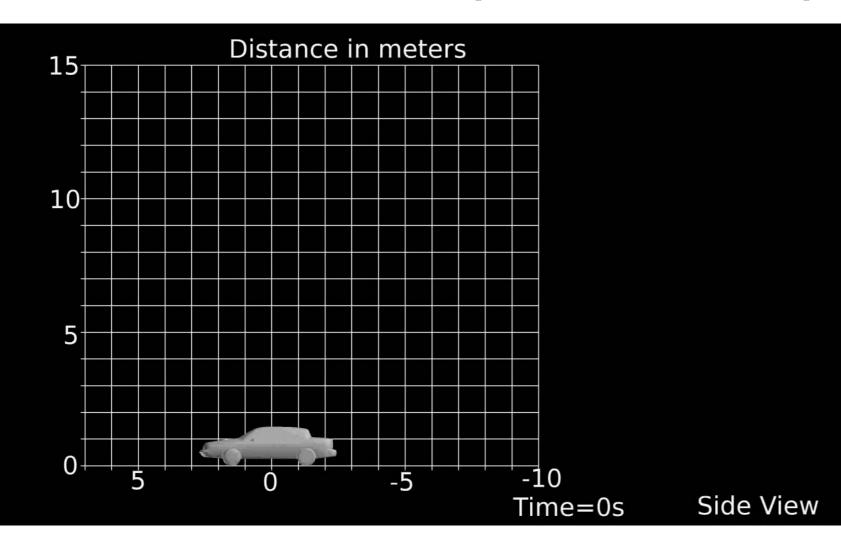


11%

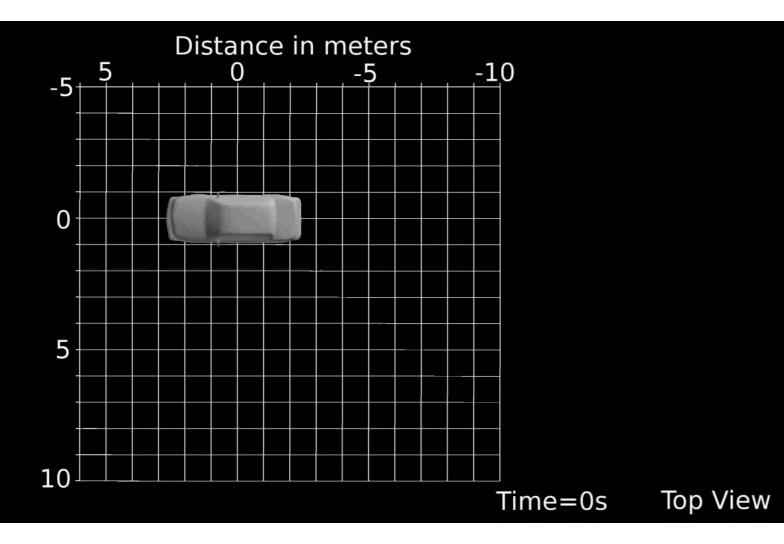
vs 1300 C flame



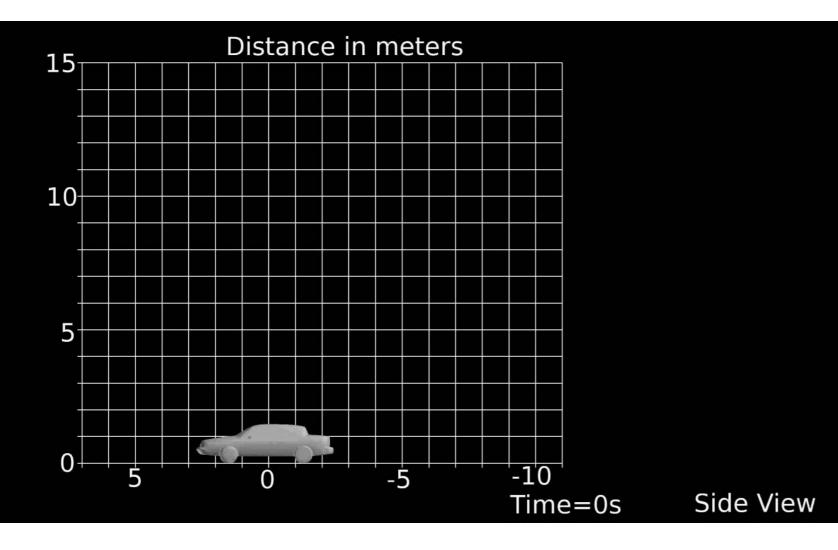
Ignited release: 309 C ("death" limit)



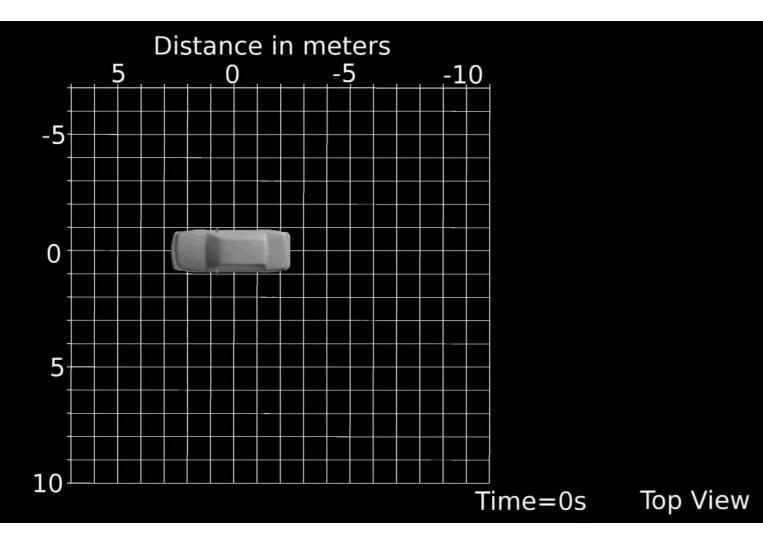
Ignited release: 309 C ("death" limit)



Ignited release: 70 C (no harm)

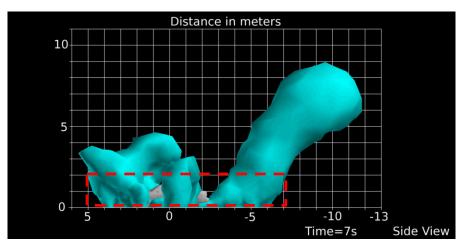


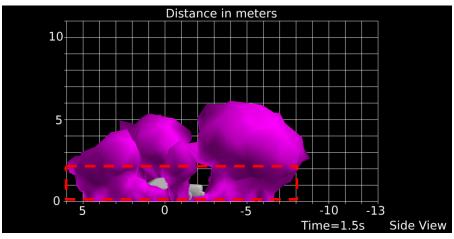
Ignited release: 70 C (no harm)



Which separation is longer?

- ❖ For free jets deterministic separation for 4% v/v for unignited release is **practically equal** to the "death" limit for fire from the same source (two other separation distances for fire, i.e. "pain" and "no harm" are longer).
- Simulations confirmed that deterministic separation from unignited release (4% v/v) is **close** to separation from fire ("death" limit of 309 C).





4% (unignited)

309 C (ignited)



Acknowledgment to FCH JU for funding this study within the HyResponse project (<u>www.hyresponse.eu</u>)

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, <u>www.bookboon.com</u>, October 2012)