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Lead partner: UNIVERSITY of ULSTER (UU)
Name: **Li Zhiyong** ; Molkov Vladimir; Makarov Dmitriy; Tretsiakova-McNally Svetlana

Contributing partner(s): CRISIS SIMULATION ENGINEERING SARL CRISE (CRISE)
Name: Maranne Eric

Author printed in bold is the contact person for this document.

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This document provides hydrogen phenomena input for virtual reality training exercises. Generally, three typical categories of hydrogen hazardous phenomena are considered: (1) unignited/ignited free hydrogen jet release; (2) unignited/ignited jet release with impingement; (3) catastrophic rupture of tank in a fire. In virtual reality training, these hydrogen hazardous phenomena can be part of scenarios in different hydrogen facilities including but not limited to fuel cell vehicles, hydrogen refuelling stations, and other applications.

1 INPUT FOR UNIGNITED FREE JETS IN THE OPEN

The first chapter of this document provides hydrogen phenomena input for scenarios with unignited free jets. The deterministic separation (hazardous) distances for unignited hydrogen jets can be calculated using engineering tools developed by the Univrsity of Ulster and available for example through the Cyber-Laboratory (www.h2fc.eu). The time dependent data of free jet hydrogen concentrations can also be obtained using contemporary CFD tools, which can take into account real world accident scenarios such as hydrogen releases from the onboard storage on a bus roof. Two typical free jets are upward releases and horizontal releases. The upward release is a typical release direction from TPRD of hydrogen storages on the roof of a bus, and the horizontal release could occur when the bus turns over on its side in an accident.

1.1 Hydrogen phenomena input using engineering tools

1.1.1 Distances to different hydrogen concentrations for unignited free jets

Releases from high pressure hydrogen tanks are usually under-expanded jets rather than expanded jets. Fortunately, the similarity law [1] for axial concentration decay in round expanded jets was expanded and validated for under-expanded hydrogen jets [2]. The similarity law is applied as an engineering tool in this section to obtain hydrogen concentrations of free jets for virtual reality input. This engineering tool allows to obtain a distance from release point to specific hydrogen concentration for a given release pressure and leak diameter. It should be underlined that the similarity law is developed for momentum-dominated jets. It is known that momentum-dominated jets decay longer compared to buoyancy-controlled jets. Thus, the application of the similarity law to buoyancy-controlled jets would give a conservative estimate. Examples of calculation results for two possible scenarios for virtual reality input are given in Table 1 and Table 2 below. The tool is available at www.h2fc.eu and can be used by any stakeholder for calculation of deterministic separation distance for arbitrary storage pressure and release diameter.

Table 1 and table 2 only give the calculation results two specific release diameters. To make the input for virtual reality training more flexible, we develop simple correlations between distances and diameters and pressures, as listed in Table 3.

Table 1 Distance to different hydrogen concentrations of unignited releases (20 mm)
(Scenarios of full bore rupture of one inch pipe in hydrogen stationary facilities)

H_2 conc., v/v Pressure (bar)	4%	8%	11%	16%	29.5%
1000	200	96	68	44	20
875	189	91	64	42	19
700	172	82	58	38	18
438	140	67	48	31	14
350	127	61	43	28	13
200	100	48	34	22	10
100	74	36	25	16	8

Table 2 Distance to different hydrogen concentrations of unignited releases (4.2 mm)
(Scenarios of hydrogen releases from TPRD of onboard hydrogen storage)

H_2 v/v conc. Pressure(bar)	4%	8%	11%	16%	29.5%
875	40	19	13	9	4
700	36	17	12	8	4
438	29	14	10	7	3
350	27	13	9	6	3

Table 3 Simple correlations for virtual reality input - calculating distances of a given hydrogen concentrations for releases from different diameters

Hydrogen concentrations	Correlations for calculating distances to hydrogen concentrations
4%	Distance= diameter* 515.94*Pressure$^{0.4291}$ (R^2=0.9952)
8%	Distance= diameter* 247.98*Pressure$^{0.4291}$ (R^2=0.9952)
11%	Distance= diameter* 174.91*Pressure$^{0.4291}$ (R^2=0.9952)
16%	Distance= diameter* 114.01*Pressure$^{0.4291}$ (R^2=0.9952)
29.5%	Distance= diameter* 52.71*Pressure$^{0.4291}$ (R^2=0.9952)

In real world conditions, a hydrogen release from the tank is not a steady state release but a blow-down process with pressure decay in the reservoir until it is empty. Therefore, the distance to a given concentration will decrease with the pressure decrease in the tank during the blowdown. To reflect the dynamic distances to a given concentration during a tank blowdown, the equation of pressure decay versus time (Table 4) should be added to the correlations in Table 3. Then, a simple equation in the form of "Distance=f (time)" will be obtained. This simple equation can be directly applied as an input for virtual reality. The blowdown dynamics for tank of arbitrary volume, storage pressure, and lead diameter can be calculated using the corresponding tool developed at University of Ulster and available at www.h2fc.eu.

Table 4 Example of pressure decay during a tank blowdown

Tank Pressure (bar)	Tank volume (m^3)	Release diameter (mm)	Pressure decay versus time (Pressure in bar and T refers to time in seconds)
350	1.12	4.2	Pressure = $9\times10^{-14}\times T^6 - 2\times10^{-10}\times T^5 + 2\times10^{-7}\times T^4 - 1\times10^{-4}\times T^3 + 0.0312\times T^2 - 4.748\times T + 337.72$ (R^2 = 0.9992)

1.1.2 Example of scenario with input for virtual reality: free jet from a bus roof

The accident is assumed to be an unintended hydrogen release from the onboard hydrogen storage on the roof of a bus. The bus is at an opening parking place. Inside the parking place, there are others buses and an office kiosk; outside the parking place, there are roads, vehicles on the roads, hospitals and commercial buildings. The scenario can include accidents that occur in the open and the hydrogen tank is assumed to be at full for the reason of conservatism. The fuel cell bus parameters are selected from Toyota fuel cell bus [3]. The hydrogen tank onboard is at pressure of 350 bar with seven cylinders and a volume of 160 L each. The thermally activated pressure relief devices (TPRDs) are assumed to be on the roof of the bus and the orifice diameter is 4.2 mm directed upwards. The ambient pressure and temperature are assumed to be of 1 atm and of 20 °C.

By combining the equations of table 3 and table 4, we will get the following hydrogen concentration equations that reflect the dynamics of the blowdown process:

Distance of 4% hydrogen concentration = $2.17*(9\times10^{-14}\times T^6 - 2\times10^{-10}\times T^5 + 2\times10^{-7}\times T^4 - 1\times10^{-4}\times T^3 + 0.0312\times T^2 - 4.748\times T + 337.72)^{0.4291}$

Distance of 11% hydrogen concentration = $0.74*(9\times10^{-14}\times T^6 - 2\times10^{-10}\times T^5 + 2\times10^{-7}\times T^4 - 1\times10^{-4}\times T^3 + 0.0312\times T^2 - 4.748\times T + 337.72)^{0.4291}$

Distance of 29.5% hydrogen concentration =$0.22 *(9\times10^{-14}\times T^6 - 2\times10^{-10}\times T^5 + 2\times10^{-7}\times T^4 - 1\times10^{-4}\times T^3 + 0.0312\times T^2 - 4.748\times T + 337.72)^{0.4291}$

(T refers to Time in seconds, $0<T< 480$s, hydrogen blow down ends within 480 s.)

In virtual reality training, to use three transparent colours will show the three distances mentioned above. CRISE generate a preliminary sketch to show the three transparent distances, as shown in figure 1 below.

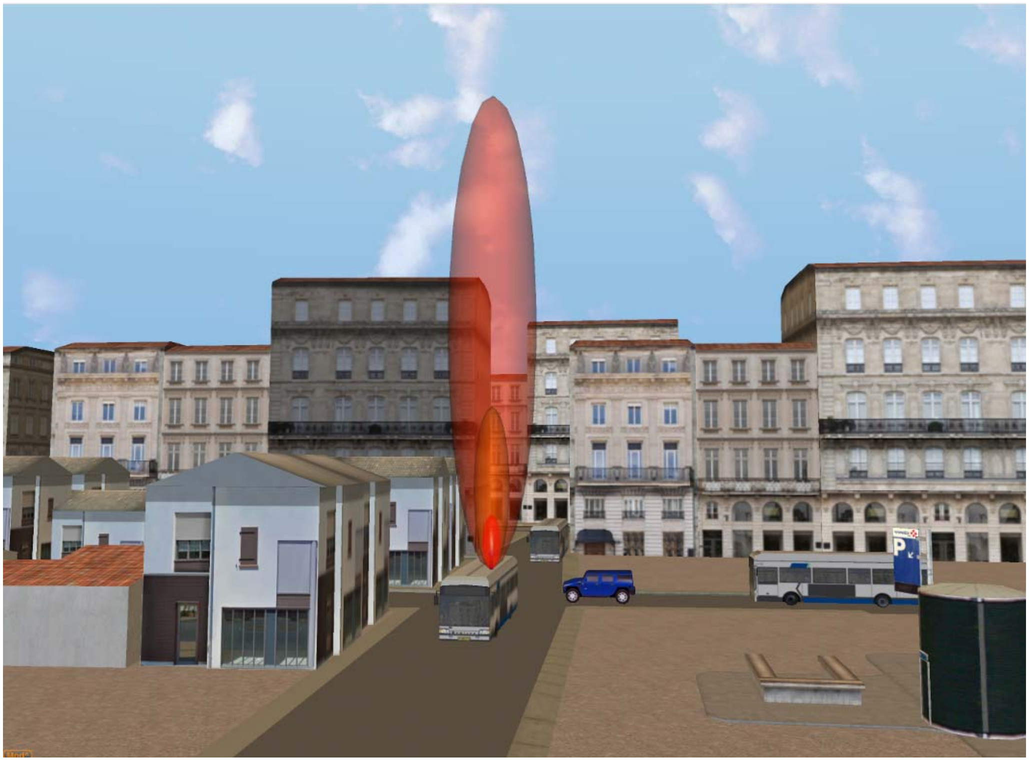

Figure 1 Example of the three transparent colours to show different hydrogen concentrations in virtual reality by CRISE

Fire brigade fights with the fire from a distance outside the 11% hydrogen concentration envelope (corresponds to jet fire length, see [2]). The tank will empty within 8 min. Therefore, the total duration of the virtual reality training scenario will be no longer than 10 min.

1.2 Hydrogen phenomena input for unignited jets using CFD tools

1.2.1 Dynamics of hydrogen flammable envelope during tank blowdown

Hydrogen release from a tank at high-pressure of either 350 bar or 700 bar is in the form of under-expanded jet, i.e. the pressure at actual nozzle exit is above atmospheric pressure. The CFD calculation of this expansion with resolution of complex shock wave structure from the nozzle exit to the Mach disk and flow beyond would require intensive computations and significant resources. In many practical situations, it is not necessary to fully resolve these shock structures if the main safety concerns are not in the near field around the nozzle. For the assessment of a deterministic separation distance for hydrogen releases, the far field parameters are the major concern. Therefore, it is convenient for our case to substitute the under-expanded jet with an expanded jet by applying the notional nozzle model that was introduced and widely validated against published experiments by Molkov et al. [4].

During the tank blowdown, the size of notional nozzle exit diameter will decrease with the decay of pressure in the reservoir. It would be difficult to change the effective diameter in CFD transient calculation by rebuilding the mesh at each time step. Instead, the hydrogen mass flow is treated as a volumetric source in the form of hydrogen mass, momentum, turbulence parameters, and total energy equations to avoid numerical simulations based on changing with time effective diameter. In this approach the release “effective volume” is constant, but the volumetric sources in the equations are changing to reflect changing parameters at the notional nozzle exit. This approach was validated against experimental data [5] of hydrogen releases through a 3 mm diameter orifice. The results reveal that if volumetric source size is smaller than 4 times of the notional nozzle exit diameter then concentration decay in under-expanded jet is reproduced accurately in the far field.

By using the volumetric source model, CFD simulation can produce the transit hydrogen concentration distribution data that can be used as a virtual reality training input. All CFD calculation results related to selected scenarios by the consortium for different hydrogen applications will be transfer by partner UU to partner CRISE to produce virtual reality movies/animation.

1.2.2 Example of scenario input for virtual reality: attached jet from a bus

This accident is assumed to be a hydrogen releases from the onboard storage on the bus roof which is attached to the ground (assuming the bus is turned on its side during the accident on the motorway). The tank is assumed to be fully filled by hydrogen for the reason of conservatism. The fuel cell bus parameters are selected from Toyota Fuel cell bus [3]. The hydrogen tank onboard is at pressure of 350 bar with seven cylinders and a volume of 160 L each. The TPRDs are assumed to be of 4.2 mm. The ambient pressure and temperature are assumed to be of 1 atm and of 20 °C as in previous example.

A fuel cell bus hits the road barrier on a motor way and turns over on its side. Horizontal release from the bus roof results in an attached jet during the tank blowdown. By using the volumetric source model, CFD simulations are being performed to understand the transit hydrogen concentration distribution data that can be used in the virtual reality training input. CFD calculation results will be transfer to CRISE to produce virtual reality movies/animation in due course.

2 IGNITED FREE JET IN THE OPEN

The second chapter of this document will provide hydrogen phenomena input of free jet fires. The deterministic separation distances for free hydrogen jet fires will be obtained using engineering tools. The time-dependant data of flame envelopes and other temperature envelopes during tank blowdown will be obtained using CFD simulations, which are focused at real world accident scenarios such as hydrogen jet fire release from the onboard storage on a bus roof. Two typical jet fires will be considered including upward jet fires and horizontal jet fires. The upward jet fire is a typical release direction from TPRD of hydrogen storages on the roof of a bus, and the horizontal jet fire could occur when the bus turns over on its side in an accident.

2.1 Hydrogen phenomena input for jet fires using engineering tools

2.1.1 Hydrogen flame length and temperature harm distances for jet fires

Hydrogen flame length model and correlation is described by Molkov & Saffers, 2013 [6]. The correlation is applied to calculate the flame length for virtual reality input. This model utilizes the dimensionless flame length of hydrogen reacting leaks including both expanded and under-expanded (sonic and supersonic) jet fires. This method is applied as an engineering tool in this section to obtain hydrogen flame length of jet fire and three deterministic separation distances relevant to jet fire (see Table 5) for virtual reality input. This engineering tool allows us to obtain separation distances to different harm criteria at a given release pressure and leak diameter. The harm criteria are taken from the book [2]. Calculation results for two typical scenarios for virtual reality input are given in Table 5 and Table 6 below.

Table 5. Deterministic separation distances of jet fire (20 mm) in meters
(Scenarios of full bore rupture of one inch pipe in hydrogen stationary facilities)

Harm criteria / Pressure (bar)	Flame length	"Death" limit 309 °C	"Pain" threshold 115 °C	"No harm" limit 70 °C
1000	76	152	228	266
875	72	144	216	252
700	66	132	197	230
438	55	109	164	191
350	50	100	150	175
200	40	80	120	140
100	30	60	91	106

Table 6. Distance to different hydrogen concentrations of unignited releases (4.2 mm) in meters (Scenarios of hydrogen releases from TPRD of onboard hydrogen storage)

Harm criteria / Pressure(bar)	Flame length	"Death" limit 309 °C	"Pain" threshold 115 °C	"No harm" limit 70 °C
875	15	30	45	53
700	14	28	41	48
438	11	23	34	40
350	10	21	31	37

Table 5 and table 6 give only calculation results for two specific release diameters. To make the input for virtual reality training more flexible, we develop simple correlations between distances and diameters and pressures, as listed in Table 7. Alternatively, engineering tool for calculation of deterministic separation distances available at www.h2fc.eu can be applied.

For blowdown process in real world conditions, the equation of pressure decay versus time (Table 4) should be added to the correlations in Table 7. Then a simple equation in the form of "Distance=f (time)" will be obtained. This simple equation can be directly applied as an input for virtual reality.

Table 7. Simple correlations for virtual reality input: calculating deterministic separation distances of jet fires for different release diameters

Hydrogen criteria	Correlations for calculating harm distances to jet fires
Flame length	Distance= diameter* 239.42*Pressure$^{0.40}$ (R^2=1.00)
“Death” limit - 309 °C	Distance= diameter* 478.84*Pressure$^{0.40}$ (R^2=1.00)
“Pain” threshold - 115 °C	Distance= diameter* 718.26*Pressure$^{0.40}$ (R^2=1.00)
“No harm” limit - 70 °C	Distance= diameter* 837.97*Pressure$^{0.40}$ (R^2=1.00)

2.1.2 Example of scenario input for virtual reality: free jet fire from bus roof

Fires in buses are not uncommon. At least 1 in every 100 will have a fire or an overheating event during their lifetime [7]. Fire on a bus will be able to trigger thermally-activated pressure relief devices (TPRD) of hydrogen storages, possibly one by one during the spread of fire. Here, an accident is assumed to be a hydrogen jet fire from the onboard storage on the roof of a bus. Bus is at an opening parking place. Inside the parking place, there are others buses and an office kiosk; outside the parking place, there are roads, vehicles on the roads, hospitals and commercial buildings. The group of scenarios are accidents that occur in the open and the hydrogen tank is assumed to be at full for the reason of conservatism. The fuel cell bus parameters are selected from Toyota Fuel cell bus [3]. The hydrogen tank onboard is at pressure of 350 bar with seven cylinders and a volume of 160 L each. The TPRDs are assumed to be on the roof of the bus and the orifice diameter is 4.2 mm. The ambient pressure and temperature are assumed to be of 1 atm and of 20 °C.

An example of accident progression for virtual reality input can be:

1. At 0 min, a bus is on fire. Fire starts from the passenger compartment. And fire spreads from the rear to the front.

2. At 5 min, an emergency call is received and fire brigade is sent out.

3. At 15 min, firemen arrive at the accident scene and try to put out the fire. In the meantime, the fire spreads to the roof of the bus and triggers the TPRD.

4. Firemen fight with the fire from a safe angle away from the jet fire direction.

Combining the equations of table 7 and table 4, we will get the following hydrogen flame length equations that reflect the dynamics of the blowdown process:

Flame length distance= 1.01*Pressure$^{0.40}$

“Pain” threshold = 3.02*Pressure$^{0.40}$

“No harm” limit = 3.52*Pressure$^{0.40}$

(T refers to Time in seconds, 0<T< 480s, hydrogen blow down ends within 480 s.)

In virtual reality training, it is intended to use three transparent colours to show the three determinseparation distances mentioned above.

Fire brigade fights with the fire from a safe angle away from the jet fire direction. The tank will empty within 8 min. Therefore, the total duration of the virtual reality training scenario will be no longer than 25 min.

CRISE generate a preliminary sketch for the above scenario of a bus turning over on its side on road environment, as shown in figure 1 below.

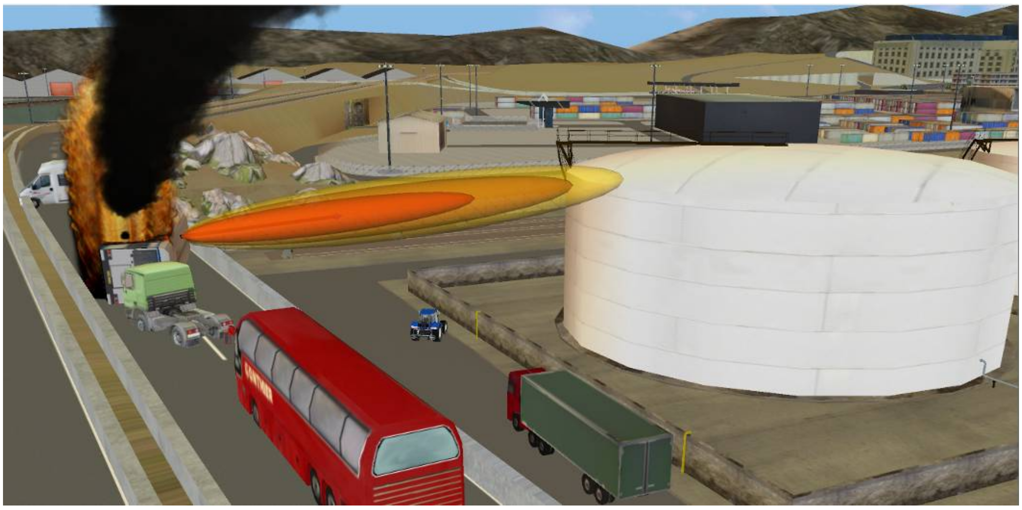

Figure 2 Example of bus turning over on its side on road environment

2.2 Hydrogen phenomena input for jet fires using CFD tools

2.2.1 Hydrogen flame and other temperatures envelopes during tank blowdown

The volumetric source model that described in section 1.2.1 will also be applied here. For combustion simulations, the eddy-dissipation model is applied. It is a turbulence-chemistry interaction model based on the work of Magnussen and Hjertager [8]. In this model, reaction rates are assumed to be controlled by the turbulence, so expensive Arrhenius chemical kinetic calculations can be avoided. The model is computationally comparatively cheap and effective for one or two step heat-release mechanisms such as hydrogen combustion.

By using the volumetric source model and eddy dissipation model, CFD simulation can produce the transit temperature distribution data that can be used in virtual reality training input. CFD calculation results will be transfer to CRISE to produce virtual reality movies. CFD movies will be available at the HyResponse website http://www.hyresponse.eu

2.2.2 Example of input for virtual reality: attached jet fire from bus roof

The accident is assumed to be a hydrogen free jet fire from the onboard storage on the roof of a bus. The bus parameters and environment are the same as in previous example 2.1.2.

The accident occurs on a motor way. There are other vehicles on the road and warehouses at the on the roadside. The accident progressions for the virtual reality input are listed below:

1. At 0 min, a fuel cell bus hit the road barrier on a motor way and turns on its side.
2. At 15 seconds, bus is on fire. Fire starts from the rear and spread toward the front.
3. At 5 min, an emergency call is received and fire brigade is sent out.
4. At 15 min, fire men arrive at the accident scene and try to put out the fire.
5. At 20 min, Firemen failed to extinguish fire before TPRD opens. Horizontal hydrogen jet fire is created.

By using the volumetric source model and eddy-dissipation model, CFD simulation can produce the transit temperature distribution data that can be used in virtual reality training input. The tank will be empty within 8 min. Therefore, the total duration of the virtual reality training scenario will be no longer than 30 min.

3 UNIGNITED HYDROGEN JET IMPINGEMENT

The third section of this document provides hydrogen phenomena input for jet impingement taken into account two real word scenarios including (1) TPRD downward unignited releases and hydrogen jet fire at realistic conditions of release under a fuel cell vehicle as per European Regulations 2010); (2) TPRD upward releases from a bus in a tunnel. Thus, both the open space and confined space scenarios are addressed.

3.1 Hydrogen phenomena input for downward releases under the car

3.1.1 Hydrogen flammable envelope during tank blowdown

The volumetric source model that described in section 1.2.1 will be applied here to calculate impinging jets in hydrogen releases from vehicles. Unlike free jet calculation that use the standard k-ε model, for jet impingement here the shear-stress transport (SST) k-ω model is applied in turbulence calculation as this model allows for a more accurate near wall treatment compared to the standard k-ε model. The SST k-ω model was developed by Menter [9] to effectively blend the robust and accurate formulation of the k-ω model in the near-wall region with the freestream independence of the k-ε model in the far field.

The flammable concentration envelop will include 4% by volume (lower flammability limit) and 11% (corresponds to averaged flame tip location) for setting separation parameters for both general public and first responders. The transient hydrogen concentration data from CFD calculation will be transfer to CRISE to produce virtual reality movies/animation using scales and timing from CFD movies

3.1.2 Example of input for virtual reality: TRPD downward release under car in the open

The car accident occurs in the open and the hydrogen tank is assumed to be at full for the reason of conservatism. The fuel cell car parameters are selected from Honda FCX Specifications [9]. The hydrogen tank onboard is at pressure of 350 bar with a volume of 171 L. The estimated driving range is about 240 miles (386 km). The TPRD is assumed to be located near the rear wheel under the vehicle, and its orifice diameter is 4.2 mm, according to Tamura et al. [10]. The ambient pressure and temperature are assumed to be of 1 atm and of 20°C.

The accident is assumed to be a fuel cell car collision with a bus in a city environment. The bus is "fine" after collision but the car releases hydrogen due to the collision accidently triggered the pressure relief device of the onboard storage. The unignited release of hydrogen will create a flammable cloud that has a potential to harm people and property as well, e.g. by creation of flammable atmosphere inside the building nearby. A snapshot of the hydrogen flame input obtained from CFD calculation for virtual reality training is shown in Figure 3 below.

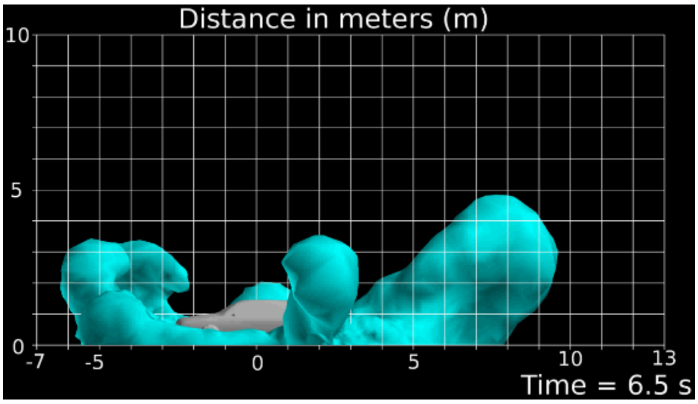

Figure 3 Snapshot of 4% v/v hydrogen concentration envelope for 4.2 mm release from 350 bar, 171L tank

By applying the above CFD results into virtual reality platform, CRISE is able to generate virtual reality training animation, as shown in figure 4 below.

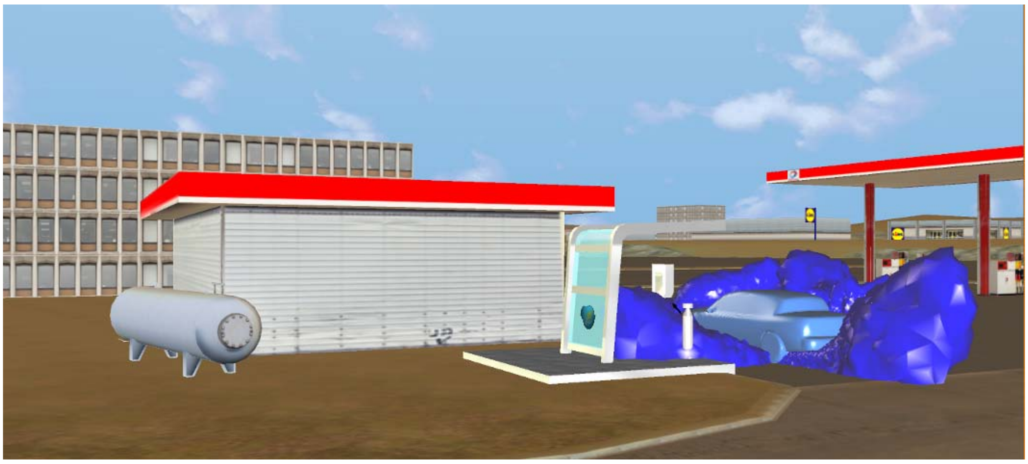

Figure 4 Example of virtual reality animation by applying CFD results

3.2 Hydrogen phenomena input for upward releases from bus roof in tunnel

3.2.1 Hydrogen flammable envelope during tank blowdown

The same method as described in section 3.1 is applied here to produce the hydrogen flammable envelope during the tank blowdown. Details have been described in previous sections.

3.2.2 Example of input for virtual reality: TPRD upward release in the tunnel

The bus with the same parameters as described in section 1.2 is used in tunnel release simulations. The transit hydrogen concentration data generated from CFD calculation will be transfer to CRISE to produce virtual reality movies/animation.

CRISE generated an example of the tunnel environment for the accident scenario, as shown in figure 5 below:

Figure 5 Example of the tunnel environment for the vehicle accident

4 IGNITED HYDROGEN JET IMPINGEMENT

4.1 Hydrogen phenomena input for downward jet fire under the car

4.1.1 Hydrogen flame and temperatures envelopes during tank blowdown

The harm criteria for temperature are taken from the book [2]. The volumetric source model that described in section 1.2.1 will be applied here to calculate jet impingement. As described in section 3.1, for jet impingement shear-stress transport (SST) k-ω model is applied in turbulence calculation as this model allows for a more accurate near wall treatment than the standard k-ε model. For combustion calculation, the eddy-dissipation model is applied, as described in the 2.2.1 of this document.

The transient hydrogen temperature data from CFD calculation will be transfer to CRISE to produce virtual reality movies/animation.

4.1.2 Example of input for virtual reality: TPRD downward jet fire under car in the open

The scenarios are accidents that occur in the open when a fuel cell car hit a bus in a city environment. The hydrogen tank is assumed to be at full for the reason of conservatism. The fuel cell car parameters are selected from Honda FCX Specifications [9]. The hydrogen tank onboard is at pressure of 350 bar with a volume of 171 L. The estimated driving range is about 240 miles (386 km). The TPRD is assumed to be located near the rear wheel under the vehicle, and its orifice diameter is 4.2 mm, according to Tamura et al. [10]. The ambient pressure and temperature are assumed to be of 1 atm and of 20°C.

CRISE generated an example of the city environment for the accident scenario, as shown in figure 6 below:

Figure 6 Example of the city environment for the vehicle accident

One route of the accident progression for the virtual reality input is listed below:

1. At 0 min, a fuel cell hydrogen car hit a conventional bus.

2. At 15 seconds, car is on fire. Fire starts from the front of the vehicle and propagates to the rear of the vehicle gradually.

3. At 5 min, an emergency call is received and fire brigade is sent out.

4. At 15 min, firemen arrive at the accident scene and are trying to put out the fire. Firemen fight with the fire from the 45 degree of rear side of the car.

5. At 25 min firemen successful extinguish fire and everything is fine, or firemen fail to extinguish fire and at 30 min and TPRD opens to releases hydrogen fire. A snapshot of the hydrogen flame input obtained from CFD calculation for virtual reality training is shown in figure 2 below. This CFD results is already available from Ulster and has been submitted to International Conference on Hydrogen Safety [11].

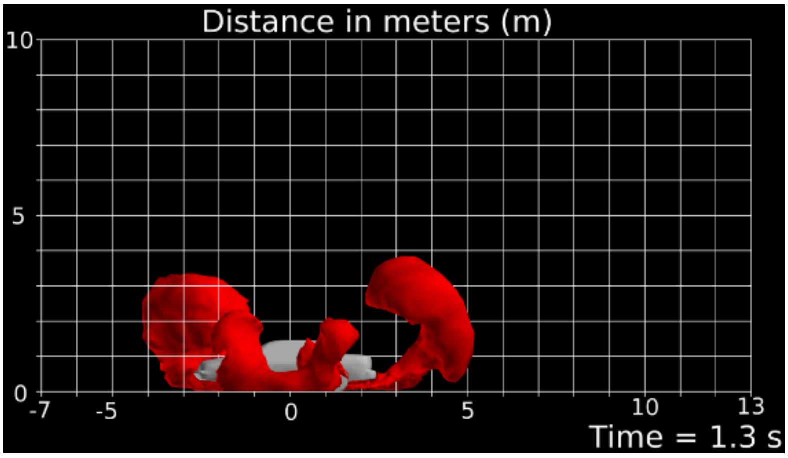

Figure 7 Snapshot of 1300 C hydrogen flame for 4.2 mm release from 350 bar, 171L tank

4.2 Hydrogen phenomena input for upward jet fire from bus roof in tunnel

4.2.1 Hydrogen flame and temperatures envelopes during tank blowdown

The same method as described in section 4.1 is applied here to produce the hydrogen flammable envelope during the tank blow down. Details have been described in previous sections.

4.2.2 Example of input for virtual reality: TPRD upward jet fire in the tunnel

The same typical bus and parameters as described in section 2.2 are applied in the tunnel release simulations. The transit hydrogen concentration data generated from CFD calculation will be transfer to CRISE to produce virtual reality movies/animation.

5 CATASTROPHIC RUPTURE OF HYDROGEN TANK IN A FIRE

5.1 Hydrogen phenomena input for catastrophic rupture of hydrogen tank

Catastrophic rupture of a hydrogen tank is a small probability event as TPRD is designed to prevent such catastrophic failure. However, there is a chance to have the catastrophic rupture if TPRD is blocked during accident or it is failed to be initiated or the fire is affecting high-pressure tank far from the TPRD. HySAFER has been developed a new a predictive model for calculation of deterministic separation distances defined by parameters of a blast wave generated by a high-pressure gas storage tank rupture in a fire [12]. The input of blast wave for virtual reality training will be obtained by the application of this model. Examples of input of separation distances for blast waves in virtual reality training are shown in Table 8.

Table 8. Example of input of separation distances (m) for blast waves for the virtual reality training scenarios

Tank parameters	**Fatality**	**Injury**	**No harm**
700 bar, 12L	1	7.5	35
700 bar, 33L	1.4	11	57
350 bar, 170 L	2	16	90
1000 bar, 10 m^3	23	78	470

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