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European Emergency Response Guide

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V1	29/04/2015	Elaboration of this document (ToC)	
V2	26/11/2015	Comments on the ToC (Basics of hydrogen are added based on Description of Work)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir; Makarov Dmitriy
V3	08/12/2015	Draft of UU contributions (draft of hydrogen basics of emergency respond guide for fuel cell vehicles)	Li Zhiyong; Tretsiakova-McNally Svetlana
V4	16/12/2015	Revision of UU contributions (add terms and definitions in a form of glossary)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir
V5	22/12/2015	Revision of UU contributions (reorganize the emergency response guide for fuel cell vehicles)	Li Zhiyong; Molkov Vladimir
V6	18/02/2016	Revision of UU contributions (more emergency response info from credible sources is added)	Li Zhiyong
V7	26/02/2016	Revision of UU contributions (revision based on the UU team discussion of both scientific and technical issues)	Li Zhiyong; Tretsiakova-McNally Svetlana; Molkov Vladimir; Makarov Dmitriy
V8	27/02/2016	Revision of UU contribution	Molkov Vladimir
V 9	29/02/2016	Revision of UU contribution	Svetlana Tretsiakova-McNally, Li Zhiyong
V10	31/10/2016	ENSOSP Contribution	Sebastien BERTAU

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Introduction

This Emergency Response Guide on hydrogen and fuel cell applications for First Responders is produced by the HyResponse consortium in line with the Work Package 6 (WP6) of the Description of Work (DoW). This guide is intended to be used by emergency response personnel, both by front-liners and commanders, from the moment they have received an emergency call until the overhaul. It is expected that this guide will support the decision-making personnel, who already have knowledge of emergency response operations and procedures.

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EMERGENCY REPONSE GUIDE

ON HYDROGEN AND FUEL CELL APPLICATIONS

Version #1.0/2016 October 31st

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Introduction

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This guide is intended to be used by emergency response personnel, both by front-liners and commanders, from the moment they have received an emergency call until the overhaul. It is expected that this guide will support the decision-making personnel, who already have knowledge of emergency response operations and procedures.

For more information about Hyresponse project, please visit our web site www.hyresponse.eu.

If you have any comments and/or questions about this Emergency Response Guide, please email to*:* *specialized.training@ensosp.fr* .

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PART 1 HYDROGEN, APPLICATIONS AND ASSOCIATED RISKS

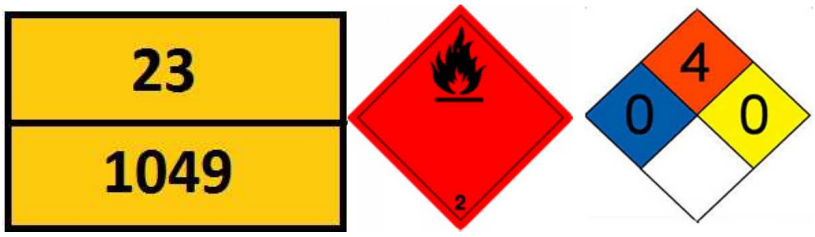
1. GAZEOUS HYDROGEN

1.1. Identification:

Figure 1 Bundle V18

Figure 2 Bottle 50 liters

1.2. ADR, IMDG, IATA



NAME : Hydrogen (En); Hydrogène (Fr); Dihydrogène (Fr) ; Wasserstoff (D); Hidrógeno (Sp); Idrogeno (It)

Chemical Abstracts Service (CAS) No :	1333-74-0
EC number :	215-605-7
EC index number :	001-001-00-9
Chemical formula :	H_2 ; H—H
Molar mass :	2 $g.mol^{-1}$
SDS NUMBER :	SDS-067A-CLP (air liquide)

1.3. Classification, Labelling and Packaging (CLP)

H220 - Extremely flammable gas.

H280 - Contains gas under pressure; may explode if heated.

P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely.

P381 - Eliminate all ignition sources if safe to do so.

P403 - Store in a well-ventilated place.

P410+P403 - Protect from sunlight. Store in a well-ventilated place.

1.4. Operational relevant features:

Colour :	Colourless.
Odours:	Odourless.
Melting point:	-259 °C (solid to liquid)
Boiling point:	-253 °C (liquid to gas)
Auto-ignition temperature:	560 °C
Flammability range:	4 - 77 vol % in air
Detonability range	11 - 59 vol. % [1] in air
Relative density, hydrogen/air:	0.07/1
Relative density, air/hydrogen:	14.28/1
Solubility in water:	1.6 mg/l
Ignition energy	0.017 mJ

At standard conditions of temperature and pressure STP (273.15 K-0 °C/101.325 kPa -1bar), Hydrogen :

- Is GAZEOUS
- goes UP due to its very low relative density/Air
- Mixes very quickly with the atmosphere where it is released
- Has a wide flammability range
- Can be ignited by one of the lowest gas ignition energies (eg. static electricity, rubbing, shocks, heat…)
- Spontaneous ignition of a sudden release is possible

If the release is the result of a leak of liquid Hydrogen, the extremely cold temperature of the gas can lead the hydrogen cloud to flow horizontally or downwards after immediate release. The condensation of atmospheric humidity can make the cloud visible for a moment even if hydrogen itself is invisible.

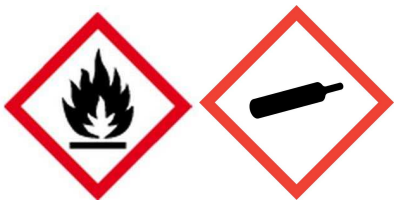
[1](Alcock et al., 2001)

2. LIQUID HYDROGEN

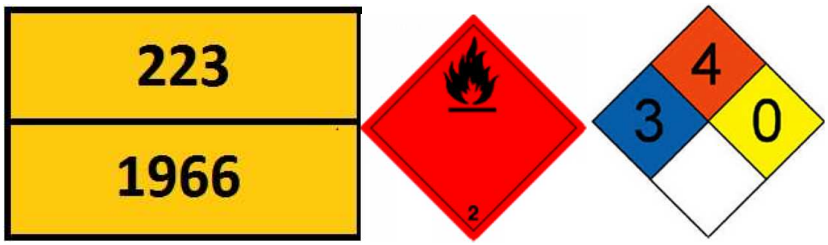
2.1. Identification:

Figure 3 Cryogenic Hydrogen truck. Source Air Liquide Image Bank

2.2. Danger



2.3. ADR, IMDG, IATA



NAME :	Liquid Hydrogen (En); Hydrogène liquid (Fr);
Chemical Abstracts Service (CAS) No :	1333-74-0
EC number :	215-605-7
EC index number :	001-001-00-9
Chemical formula :	H_2 ; H—H
Molar mass :	2 $g.mol^{-1}$
SDS NUMBER :	SDS-067R-CLP (air liquide)

2.4. Classification, Labelling and Packaging (CLP)

H220 - Extremely flammable gas.

H281 - Contains refrigerated gas; may cause cryogenic burns or injury

P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely.

P381 - Eliminate all ignition sources if safe to do so.

P336 - Thaw frosted parts with lukewarm water. Do not rub affected area.

P315 - Get immediate medical advice/attention.

P403 - Store in a well-ventilated place.

P410 - Protect from sunlight.

2.5. Operational relevant features:

Color:	Colorless.
Odors:	Odorless.
Melting point:	-259 °C (solid to liquid)
Boiling point:	-253 °C (liquid to gas)
Auto-ignition temperature:	560 °C
Flammability range:	4 - 77 vol % in air
Detonability range	11 - 59 vol. % [2] in air
Relative density, hydrogen/air (gas):	0.07/1
Relative density, air/hydrogen (Gas):	14.28/1
Volumetric ratio of LH_2 to GH_2	**1: 848**
LH_2 density (at NBP)	70.78 kg/m^3
Solubility in water:	1.6 mg/l
Ignition energy	0.017 mJ

At standard conditions of temperature and pressure STP (273.15 K-0 °C/101.325 kPa -1bar), Hydrogen :

- Is GAZEOUS
- goes UP due to its very low relative density/Air
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- Has a wide flammability range
- Can be ignited by one of the lowest gas ignition energies (eg. static electricity, rubbing, shocks, heat…)
- Spontaneous ignition of a sudden release is possible

[2](Alcock et al., 2001)

LIQUID HYDROGEN

If the release is the result of a leak of liquid Hydrogen, the extremely cold temperature of the gas can lead the hydrogen cloud to flow horizontally or downwards after immediate release. The condensation of atmospheric humidity can make the cloud visible for a moment even if hydrogen itself is invisible.

Due to the volumetric ratio of LH2 to GH2 (1:848), the vaporization of LH2 in a closed vessel will lead to a violent increase of pressure.

3. HYDROGEN DANGERS

Hydrogen is an odourless, colourless, tasteless, non-toxic, non-corrosive, but highly flammable gas. It can be stored in a gaseous phase at ambient temperature by high pressure compression or in a liquid phase by cryogenic liquefaction. Hydrogen dangers are associated with its chemical and physical properties.

3.1. Asphyxiation

Hydrogen, when released in enclosed/confined areas, can replace oxygen in the atmosphere and then cause asphyxiation by anoxia. The effects begin if oxygen content in the air is below 18%. (normal oxygen level in the air is 20-21%).

3.2. Pressure

Gaseous hydrogen is stored in tanks, pressurised up to 700 bar. The rupture of tanks or flexible tubes under pressure may cause major injuries.

The liquid to gas phase change causes the occupied volume to increase from 1 to 845. Consequently the pressure in a confined space will increase extremely quickly.

3.3. Noise

Due to the high pressure needed for storage (350-700 bar), a gaseous hydrogen leak produces a noise that can reach 130-140dB. (first ear damages occur above 90dB and pain limit starts at 120 dB).

3.4. Embrittlement

Hydrogen is the smallest molecule of all known elements. The interaction of hydrogen with the containment material lattice can cause a loss of structural strength and lead to tanks and pipes embrittlement causing their eventual rupture.

3.5. Cryogenics

At ambient pressure, liquid hydrogen must be kept a 20.3°K (-252.85°C/-423.13ºF). This is extremely low temperatures. Direct skin contact with liquid or cold gaseous hydrogen causes instantaneous cold burns.

3.6. Combustion

Hydrogen is highly flammable and explosive. The flammability range in air is 4-75% [% v/v] and the minimum ignition energy is 0.02 mJ. Hydrogen has a wider detonability range compared to other fuels. The widest detonability range of hydrogen in air 11-59 vol. % is recommended by Alcock et al., 2001.Hydrogen burns with pale-blue flames and emits neither visible light in day time or smoke unless some materials or particles are entrained and burned along with the combustible mixture. In the air, the hydrogen flame is only visible on 30% of its length. Compared to hydrocarbons, hydrogen flames

radiate significantly less heat. Thus, a human physical feel of this heat does not occur until direct contact is made with the flame. A hydrogen fire may remain undetected and will propagate in spite of any direct monitoring by people in the areas where hydrogen can leak, spill or accumulate and form potentially combustible mixtures.

4. SPECIFIC TOOLS

4.1. Thermal Imaging Equipment

The first responders can use a thermal imaging device to make the hydrogen flame in the air visible as shown on Figure 2.

Figure 4: H2 tank fire (700b) ensosp 2014

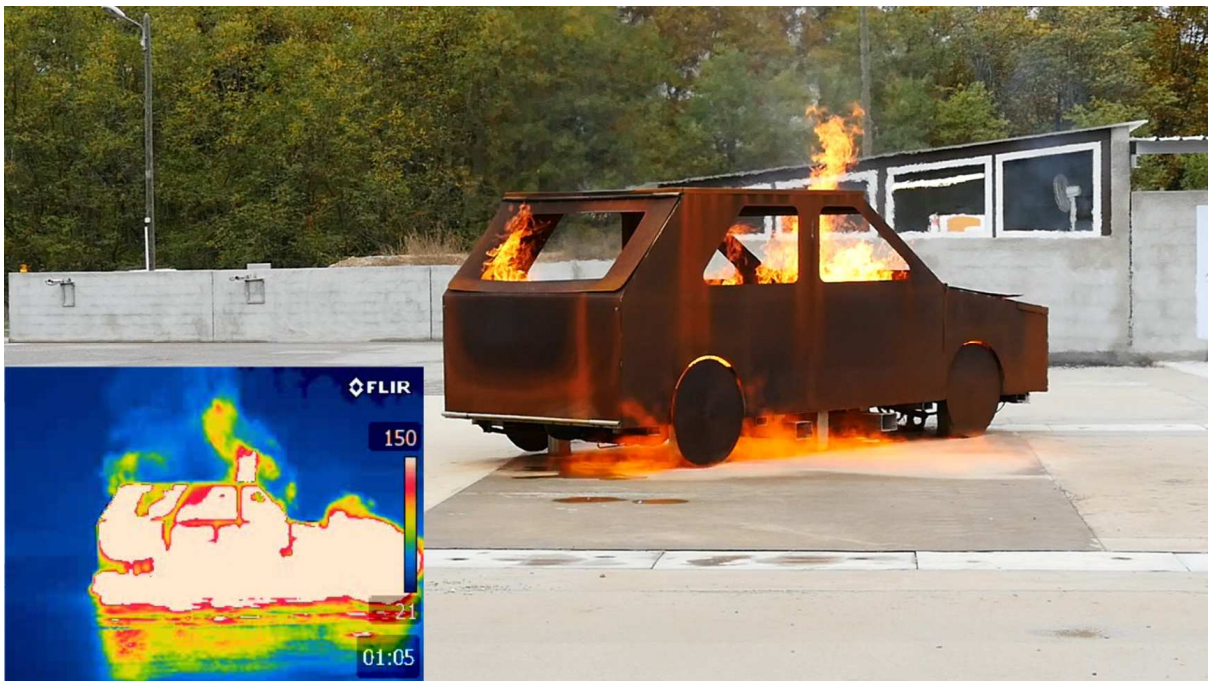


Figure 5 Hydrogen Flame under a mock up H2 Car (Ensosp 2016)

Figure 6 H2 horizontal flame on ENSOSP operational platform (only visible with thermal imaging device)

A laser thermometer can also be used to identify safely high or low temperature items.

4.2. Single-gas monitor

Single-gas or multi=gas monitor continuously displays gas concentrations in the atmosphere. It can be used to monitor O_2 and H_2 levels. Such equipment is useful for first responders to assess the threat zone and create or refine the danger area.

Mind that a catalytic detector for other flammable gases can detect the presence of hydrogen, but the concentration on display will not be reliable.

5. FUEL CELL

5.1. Principle

The fuel cell is an electrochemical generator which produces electricity, heat and water (pure), from a fuel (hydrogen) and a combustive (oxygen which can be pure or resulting from the ambient air).

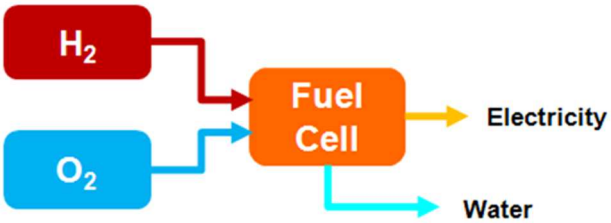


Figure 7 principle of fuel cell

- PROTON EXCHANGE MEMBRANE FUEL CELL

- At the anode, the hydrogen H_2 molecules are dissociated in H^+ protons and electrons e- under the effect of a catalyst: $H_2 \rightarrow 2H^+ + 2\ e^-$,

These protons are led to cathode through the membranes and the electrons pass through the external electrical circuit.

- At the cathode, the oxygen O_2 molecules are recombined with the protons and the electrons to form water: $½\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$.

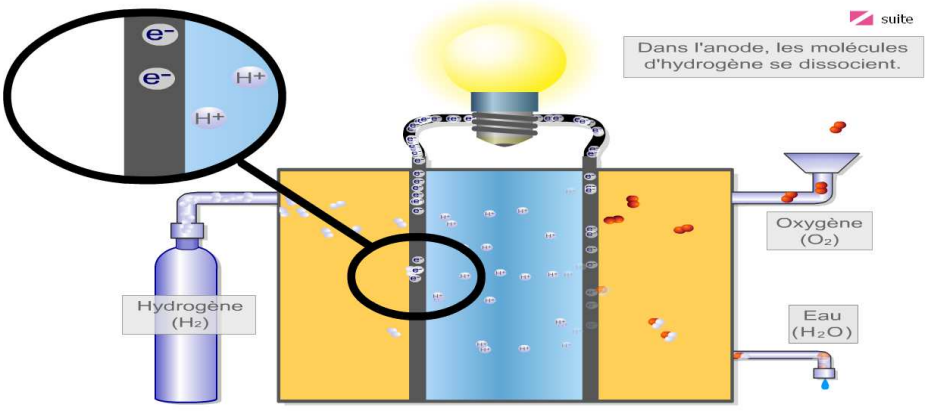


Figure 8 Schematic principle of fuel cell functioning

In a practical way, the electrodes (anode and cathode) and the membrane are associated to form a Membrane Electrode Assembly called MEA.

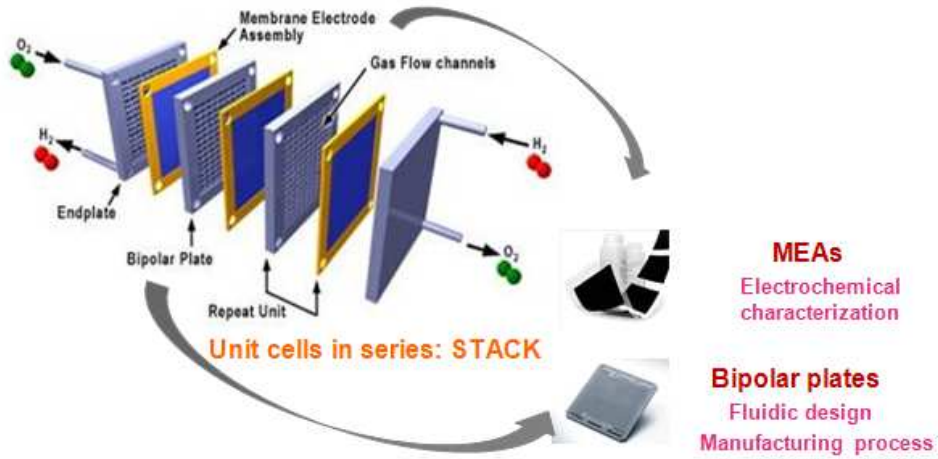


Figure 9 Membrane Electrode Assembly (MEA)

Figure 10 Fuel cell backup power coupled to the IP Energy data center

5.2. Main risks associated with fuel cells:

High voltage equipment

Flammable gas (hydrogen) under pressure

Equipment under pressure.

Possible indoor gases accumulation

6. ELECTROLYSER

6.1. Principle

An electrolyser produces Hydrogen and oxygen from water and electricity.

Figure 11 principle of electrolyser

6.2. Proton exchange Membrane ELECTROLYSER

PEM Electrolyser converts electrical energy into chemical energy and can be seen as the opposite device of the Fuel Cell Conversion takes place in two rooms which are separated by a Proton Exchange Membrane (PEM). By application of a continuous tension, water is dissociated out of hydrogen (H_2) at the negative pole and oxygen (O_2) at the positive pole.

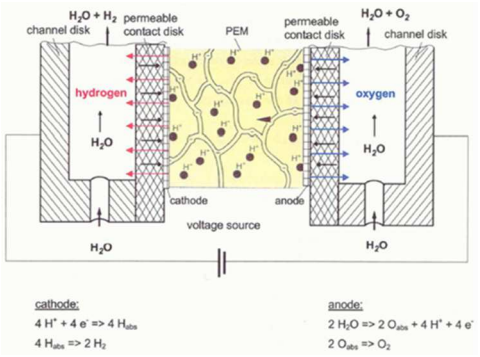


Figure 12 PEM Principle

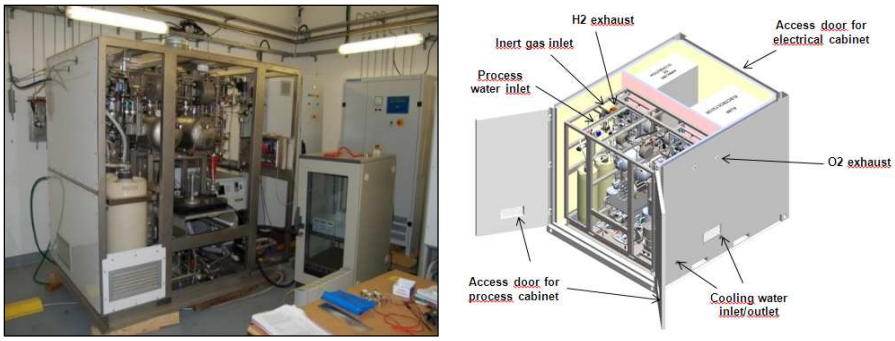


Figure 13 Technical specification and picture of AREVA Energy storage New Stack PEMFC generation

6.3. Alkaline Electrolyser

Alkaline electrolyser is characterized by having 2 electrodes immersed in a liquid alkaline electrolyte composed with a caustic potash (potassium hydroxide or KOH) solution at a level of 25% at 80°C up to 40% at 160°C. The 2 electrodes are separated by a diaphragm. This diaphragm has 2 functions: first to keep the product gases (namely hydrogen and oxygen) apart from another and secondly to be permeable to the hydroxide ions (OH-) and water molecules.

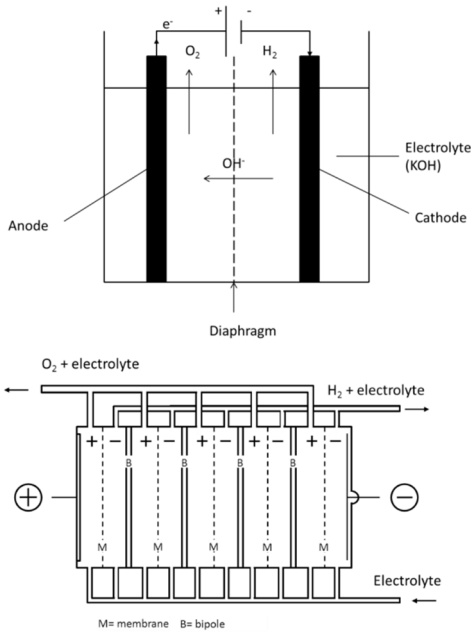


Figure 14 principle of alkaline electrolyser

<u>At the anode</u>: $2\ OH^- \rightarrow \frac{1}{2}\ O_2 + H_2O + 2\ e^-$

<u>At the cathode</u>: $2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$

<u>Total reaction</u>: $H_2O \rightarrow H_2 + \frac{1}{2}\ O_2$

Figure 15 Alkaline electrolyser IHT type S-556, 760 Nm3/h and 30 bars

6.4. Main Risks associated with electrolysers:

High voltage equipement

Flammable gas (hydrogen) under pressure

Comburent gas (oxygen) under pressure

Alkali solution at high temperature

Equipment under pressure.

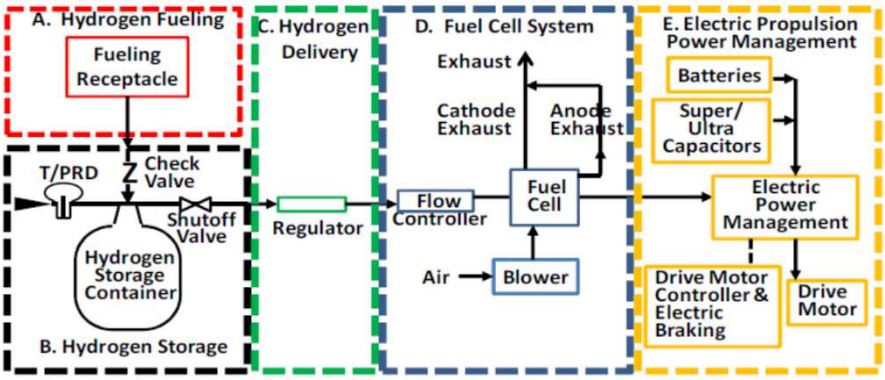
Possible indoor gases accumulation

7. FUEL CELL VEHICLES

7.1. Principle

A hydrogen vehicle is an electrical vehicle (E) combined with a Hydrogen fuel cell system (A-B-C-D).

The fuel cell is supplied with Hydrogen and oxygen (from the ambient air) and produces the electricity necessary to charge batteries and operate electrical motors.



7.2. Types of FUEL CELL vehicles

Several types of vehicles can be powered by hydrogen. Most common are cars, buses and forklifts. Prototypes exits for bikes and motorbikes.

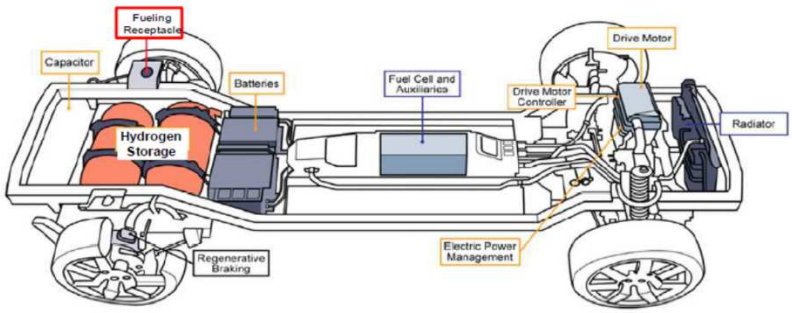
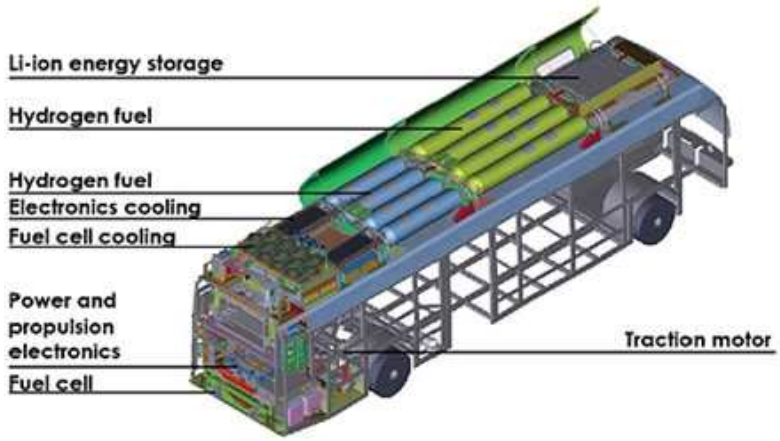


Figure 16 From Draft global technical regulation on Hydrogen Fuelled vehicle. Economic and social Council, United Nations, 2012

Fuel cell car principle



Fuel cell bus principle

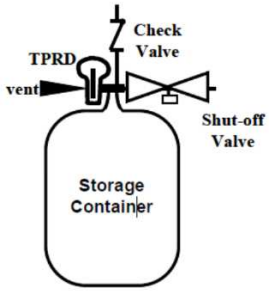
7.3. Hydrogen onboard the fuel cell vehicles

7.3.1. Hydrogen storage

Hydrogen is stored under pressure in tanks onboard the vehicle. The pressure in tanks can be 350b for buses to 700bars for cars.

The main danger of those tanks is the increase of temperature that could cause an increase of pressure and lead to the rupture of the envelope.

So, to prevent the rupture due to increase of pressure, each tank is equipped with a **Thermal Pressure Relief Device (TPRD).** This TPRD is designed to open when the surrounding temperature reaches 110°C (230°F), and vent the hydrogen in the atmosphere.



the vent line is on the roof for the buses, on the side for forklifts, and can be on the roof for car but more frequently between rear tyres oriented towards the back of the vehicle.

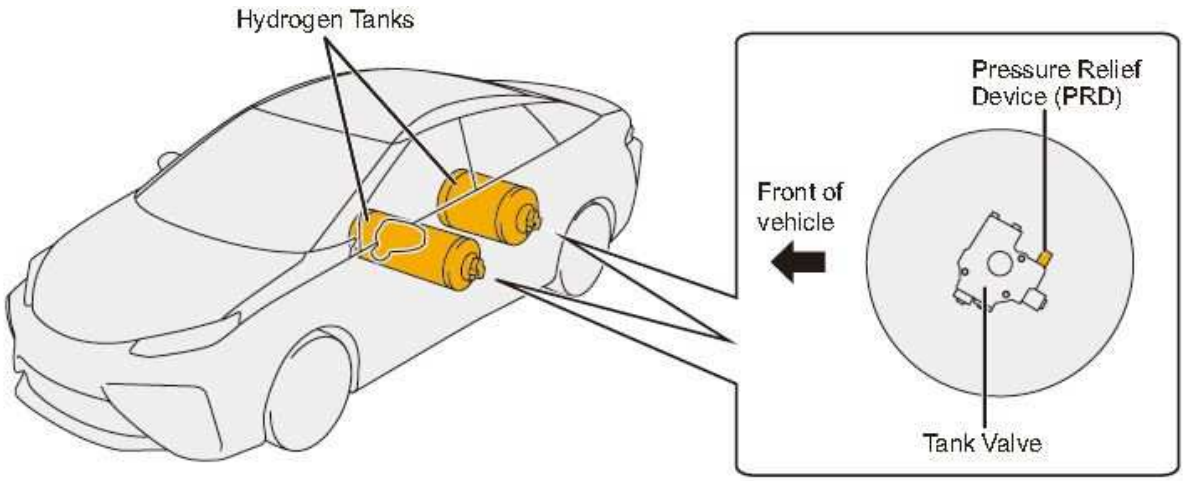


Figure 17 TPRD location (Toyota Emergency response guide)

7.3.2. Refueling

Hydrogen tank are filled in refueling stations through a specific filling hole.

Toyota Mirai Filling hole.

7.4. Risk associated with Fuel Cell Vehicles

Fuel Cell vehicle are also **electrical vehicle**, so the associated risks are:

In case of malfunction, fire and/or road traffic accident, extrication activities:

Risk	Origin	situation
Electrocution	Batteries Super-capacitors	Electrical Shock due to Malfunction, Fire, accident, extrication
Burns	Metal alloys combustion	Projections of molten metal du to Use of an unsuitable agent (water) to extinguish such fire
Violent inextinguishable fire	Batteries	Batteries runaway when involved in fire
Poisoning	Toxicity of Batteries Electrolyte leakage	fire or containment failure (accident)

But the specificity of using Hydrogen adds several risks

Risk	Origin	situation
asphyxiation	Hydrogen (simple asphyxiator)	Unignited Hydrogen leak in confined space
burns	Invisible H2 flame	Vehicle Fire AND activation of TPRD
Shock wave	bursting of H2 tank	Vehicle Fire AND failure of the TPRD/envelope failure
Shock wave & heat wave	Explosion of H2 cloud (UVCE)	H2 leak and Ignition source

7.5. Identification of Fuel Cell Vehicles

*

Figure 18 H2 Label

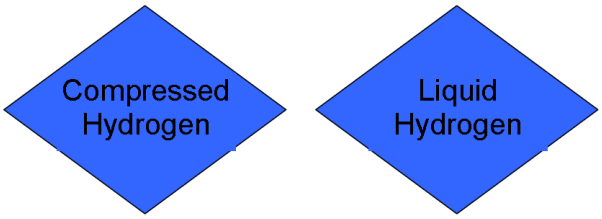


Figure 19 Blues diamonds (US)

Figure 20 badge on the vehicle (Ix35 Toyota emergency response guide)

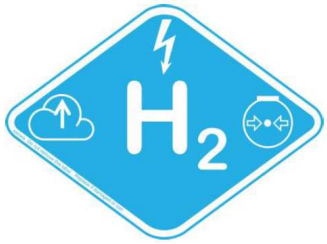


Figure 21 Label proposed by CTIF to ISO (project)

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8. REFUELING STATION

8.1. Principle

The main function of the refueling station is to fill with gaseous hydrogen the tanks of vehicles (forklift truck, bus, car) powered by fuel cells. The gaseous hydrogen, contained initially in a storage at a pressure of 200 bar, is compressed in the HP storage. During the filling, the tank is filled by a balancing of the pressure.

The pressure in HP storage is between 450 bar for forklift truck and bus and 1000 bar for car.

The pressure in vehicle tank is between 350 bar for forklift truck and bus and 700 bar for car.

To fill as fast as possible a car, hydrogen could be cool during filling by cryogenic liquid nitrogen storage or a cold unit.

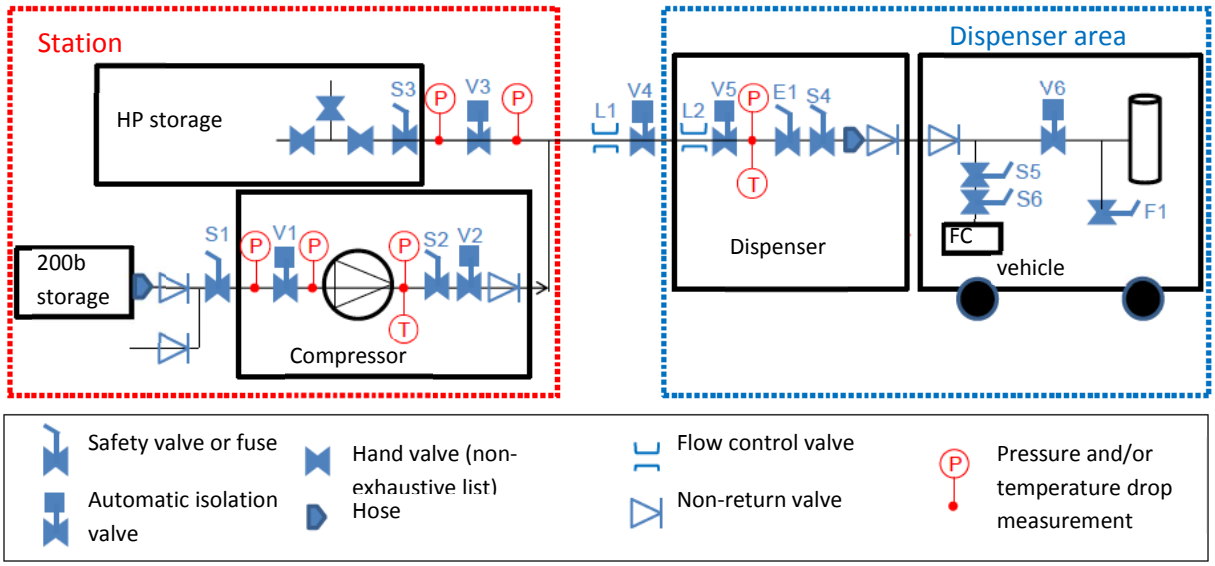

Figure 8-1: diagram of the installation

The dispenser could be located in the dedicated building or outdoor

8.2. Examples of refuelling stations

Figure 2 refueling station (air liquide Germany)r

Figure 3 refueling station (vattenfall Hamburg)

Figure 4 forklift dispenser air liquide

Figure 5 dispenser 350 bar (vattenfall-hamburg)

Figure 6Figure 24 dispenser 700 bar (vattenfall-hamburg

Figure 7 Indoor refuelling station for forklifts (dispenser) ©Air Liquide-2014

Figure 8 refueling station-low pressure storage 200bar

Figure 9 refueling station high pressure storage 1000bar

Figure 10 refueling station ESD away from dispenser (Hamburgp airport)

8.3. Risks associated with refuelling stations

Electrical equipment

Flammable gas (hydrogen) under pressure

Equipment under pressure.

Possible indoor gases accumulation

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PART 2 EMERGENCY RESPONSE

9. NOMOGRAMS

1.1. How to use the nomograms

The aim of those nomograms is to define safety distances depending

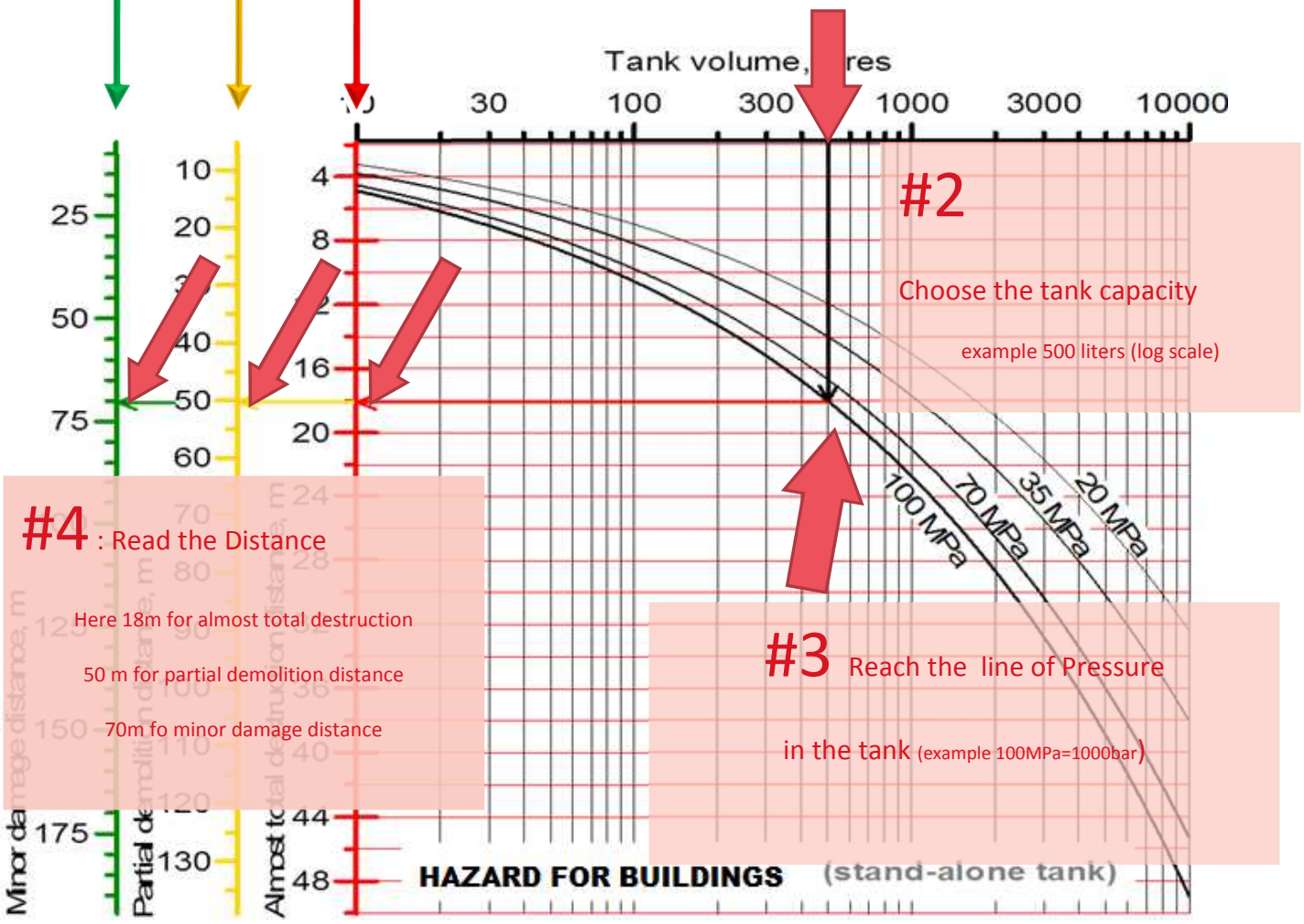
- The pressure of a hydrogen tank
- The volume of the tank

Refer to appendix 3 for complete instruction about the use of nomograms.

harm to humans from a rupture of a STAND-ALONE tank in a fire

#1 select the overpresure of burst for a STAND ALONE tank

Damage	Overpressure, kPa
Minor damage of the house (chosen as "minor damage")	4.8
Partial demolition of the house-remains inhabitable (chosen as "partial demolition")	6.9
Almost total destruction of the house (chosen as "almost total destruction")	34.5-48.3



#2 Choose the tank capacity

example 500 liters (log scale)

#3 Reach the line of Pressure in the tank (example 100MPa=1000bar)

#4 : Read the Distance

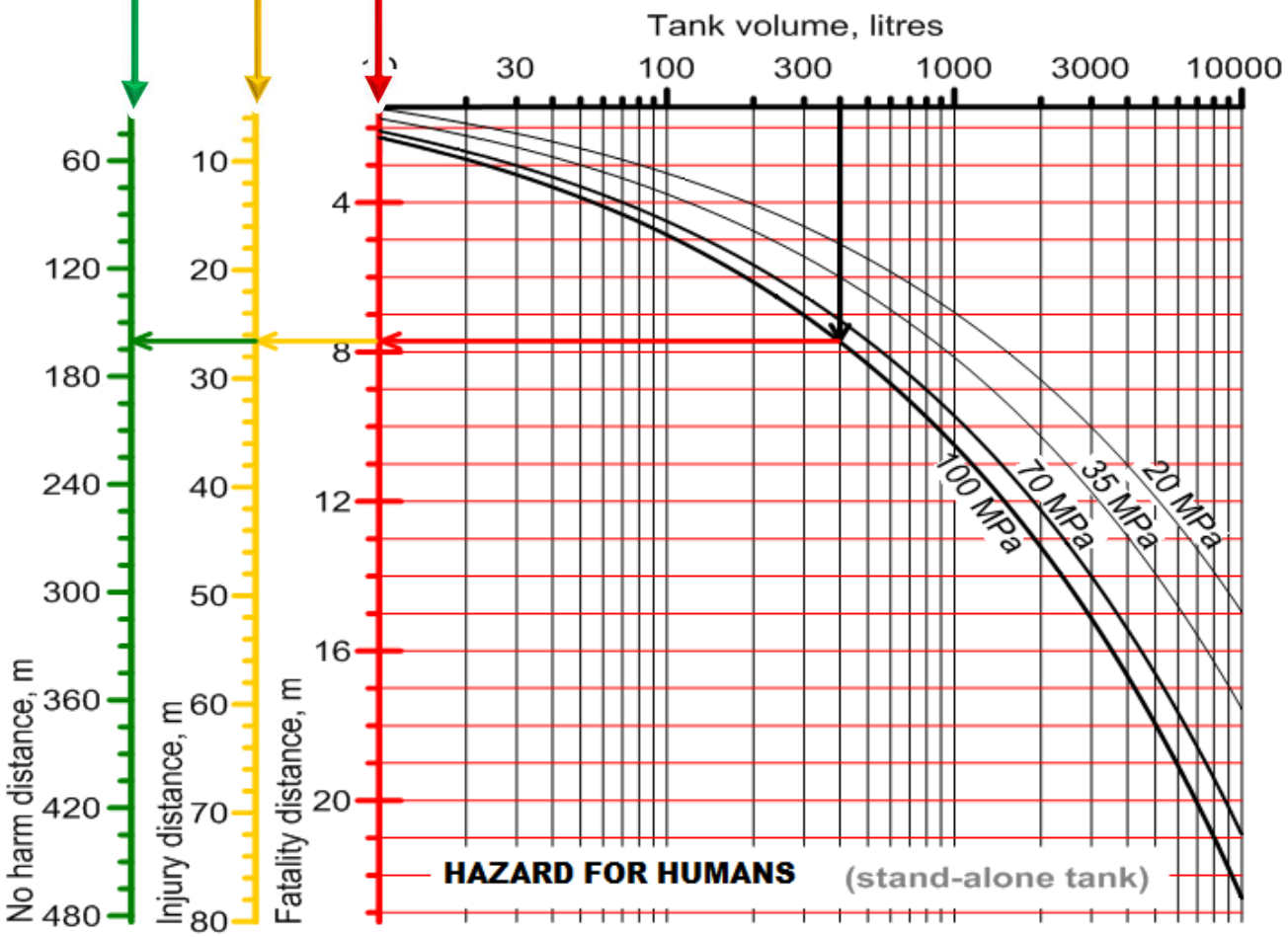
Here 18m for almost total destruction

50 m for partial demolition distance

70m fo minor damage distance

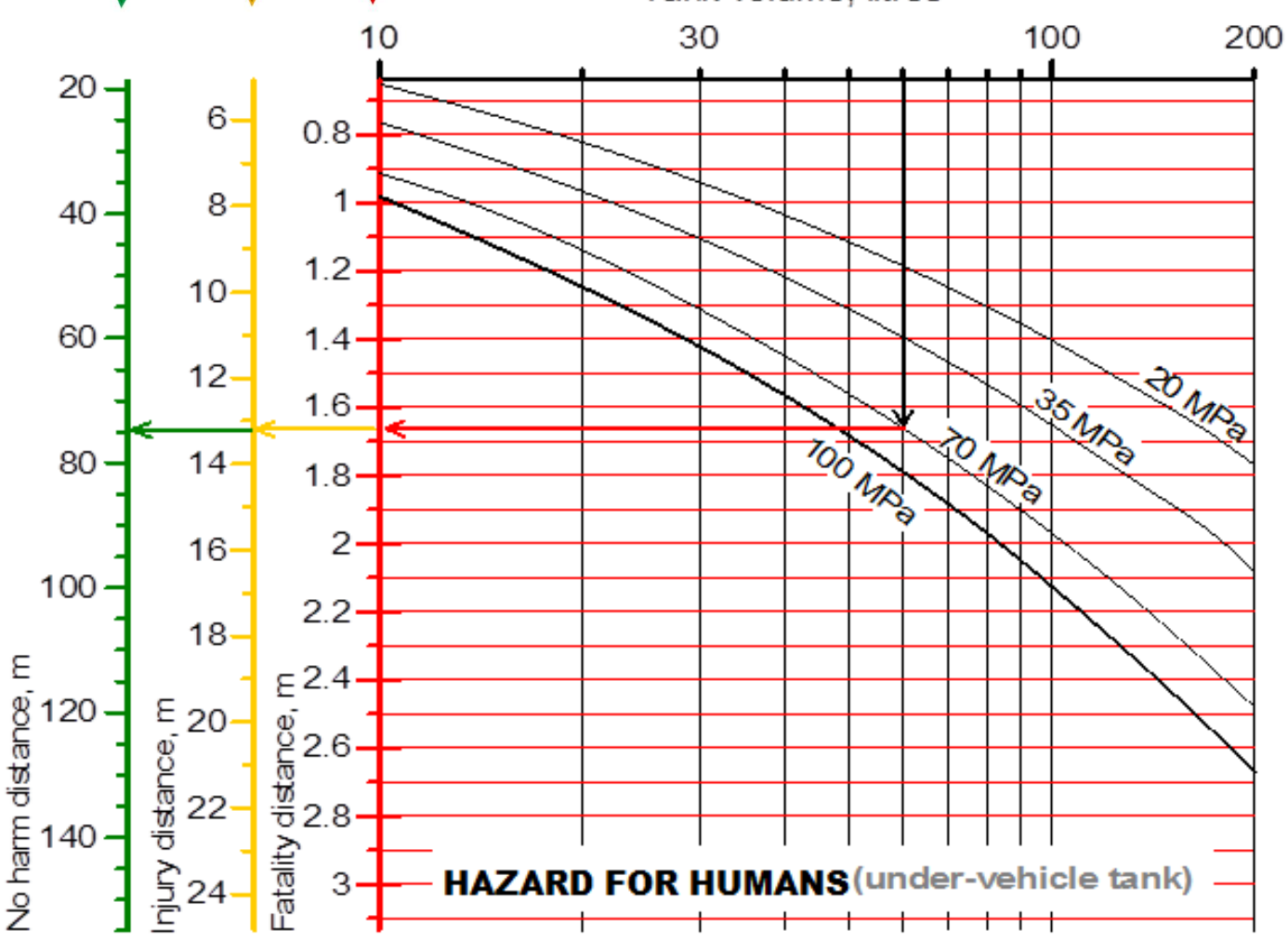
10. Harm to humans from a rupture of a STAND-ALONE tank in a fire

Harm criteria (selected thresholds)	Overpressure, kPa
Temporary threshold shift (Baker, 1983): "no harm" hazard distance (evacuation perimeter)	1.35
1% eardrum rupture probability (Mannan, 2005): "injury" distance	16.5
1% fatality probability due to lung haemorrhage (Mannan, 2005): "fatality" hazard distance	100



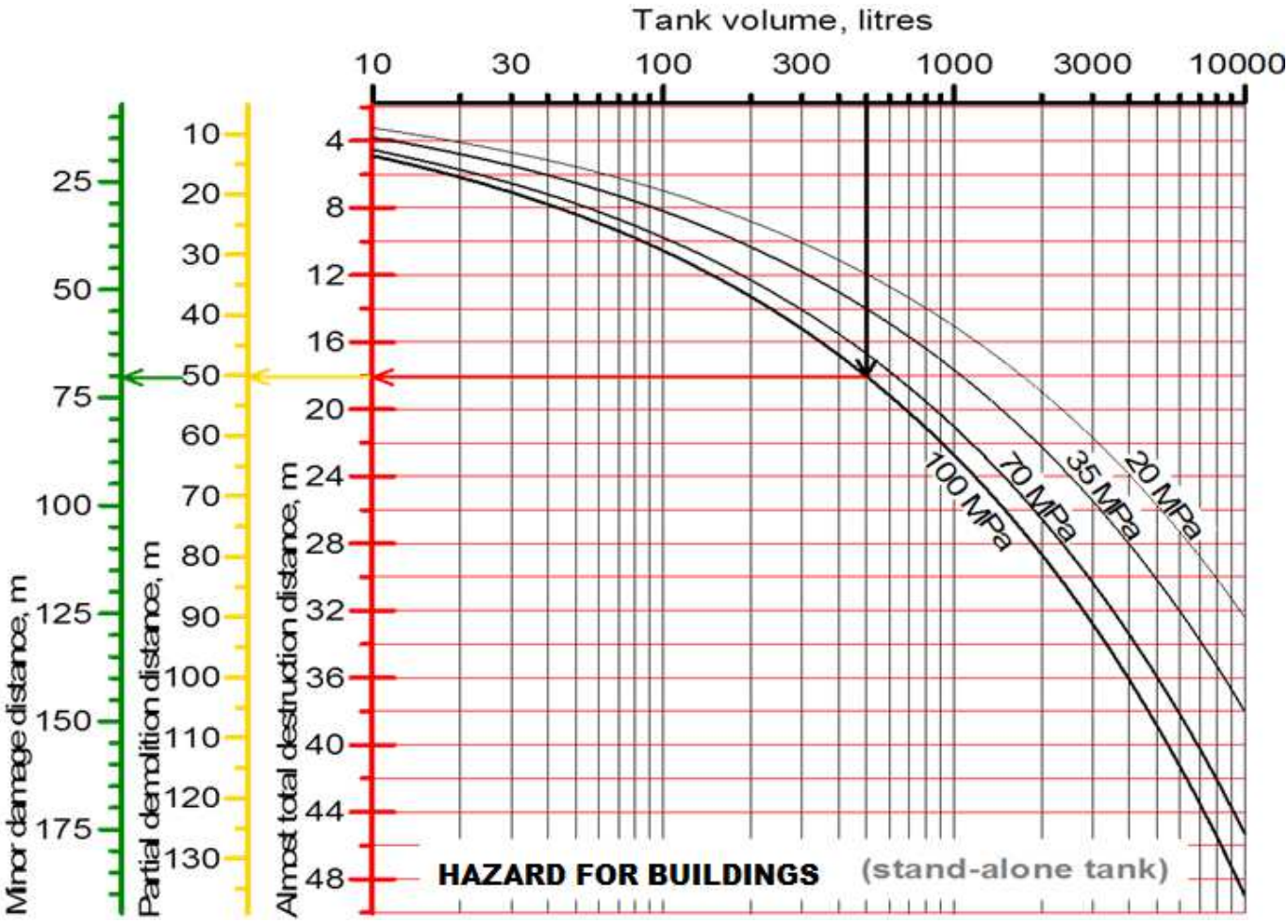
11. Harm to humans from a rupture of an UNDER-VEHICLE tank in a fire

Harm criteria (selected thresholds)	Overpressure, kPa
Temporary threshold shift (Baker, 1983): "no harm" hazard distance (evacuation perimeter)	1.35
1% eardrum rupture probability (Mannan, 2005): "injury" distance	16.5
1% fatality probability due to lung haemorrhage (Mannan, 2005): "fatality" hazard distance	100



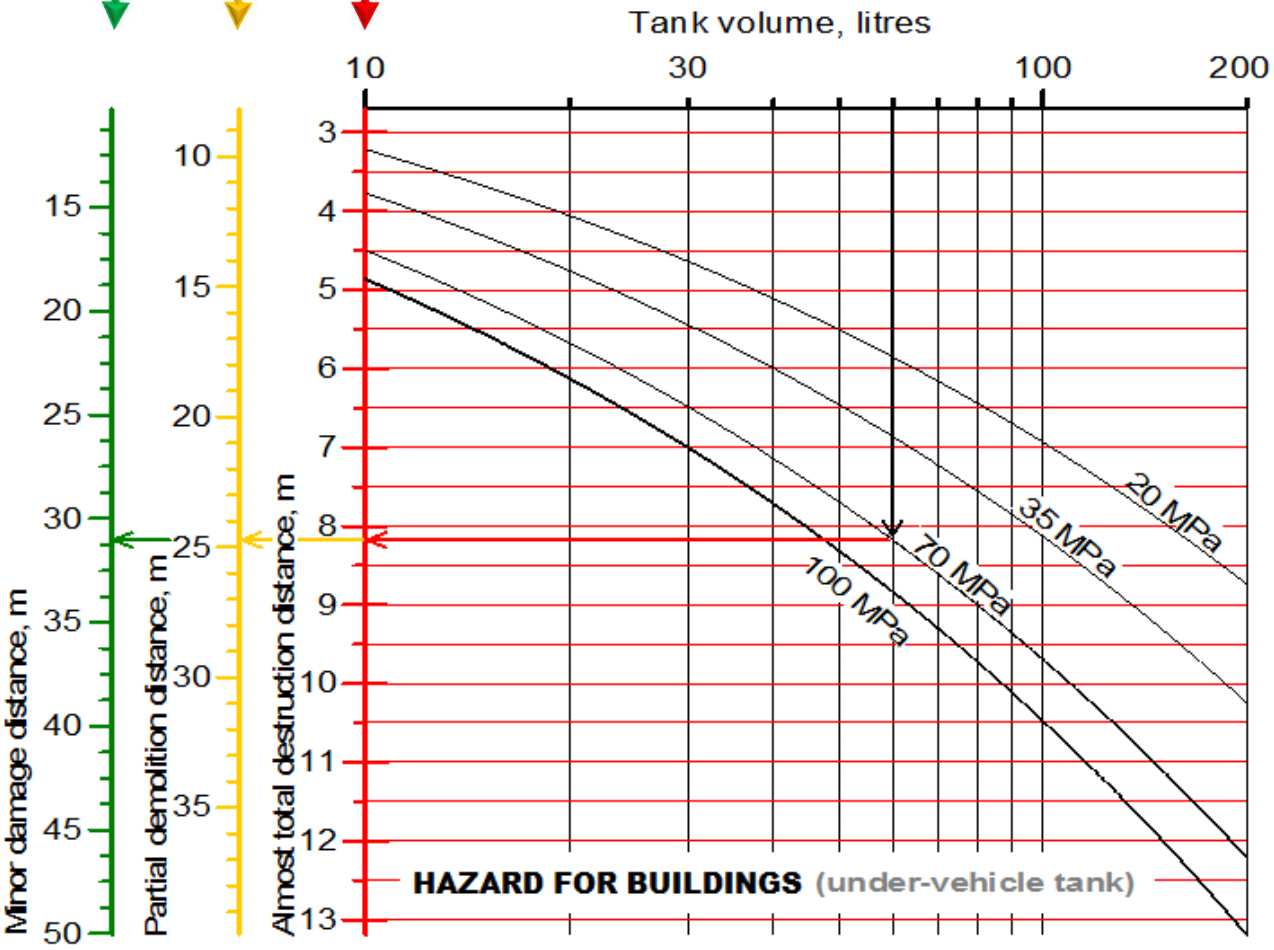
12. Damage to buildings from a rupture of a stand-alone tank in a fire

Damage	Overpressure, kPa
Minor damage of the house (chosen as “minor damage”)	4.8
Partial demolition of the house-remains inhabitable (chosen as “partial demolition”)	6.9
Almost total destruction of the house (chosen as “almost total destruction”)	34.5-48.3



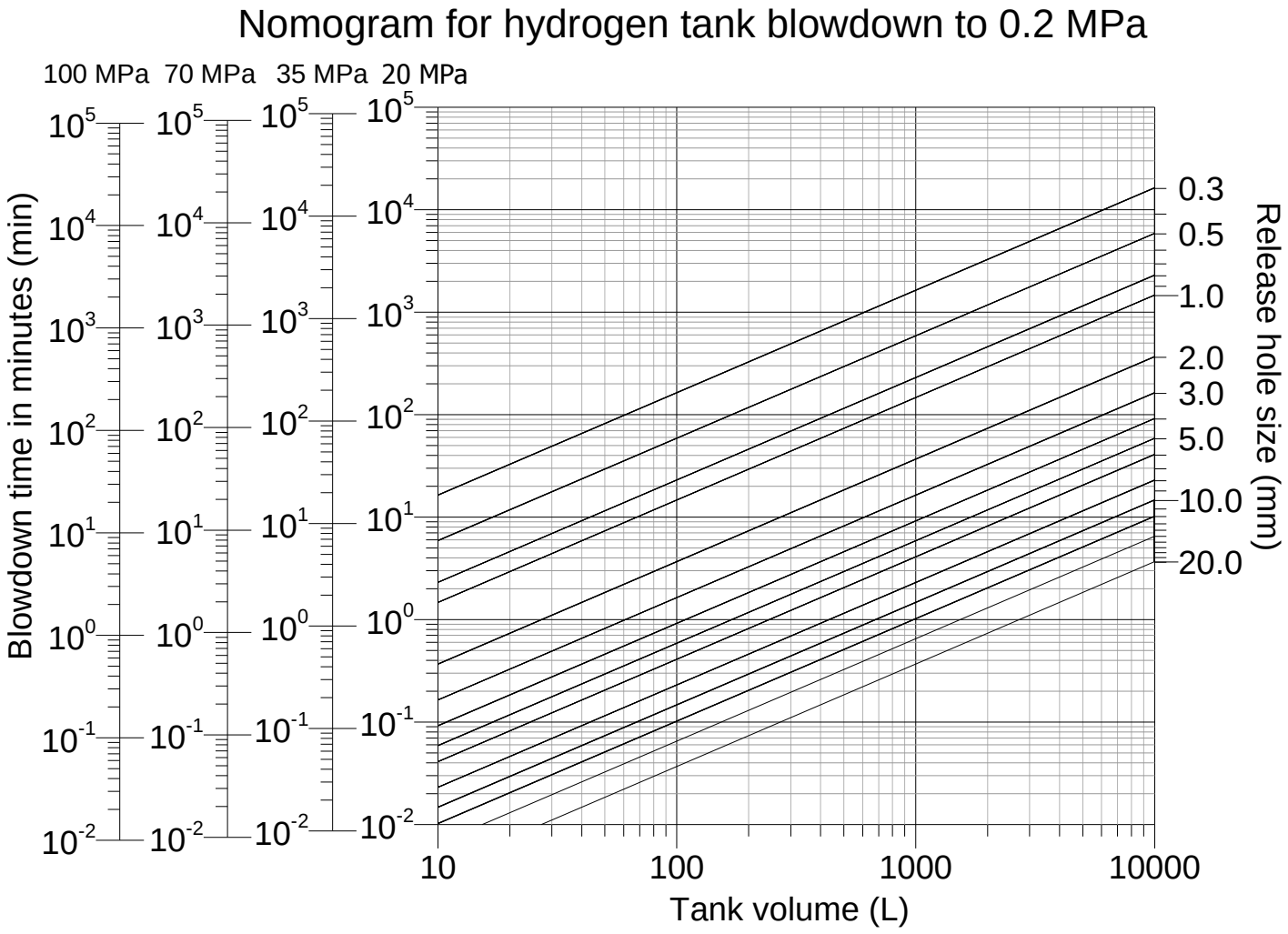
13. Damage to buildings from a rupture of an under-vehicle tank in a fire

Damage	Overpressure, kPa
Minor damage of the house (chosen as “minor damage”)	4.8
Partial demolition of the house-remains inhabitable (chosen as “partial demolition”)	6.9
Almost total destruction of the house (chosen as “almost total destruction”)	34.5-48.3



14. Blowdown time

This nomogram gives an evaluation of the blowdown time of a tank depending the volume, the pressure and the size of the release hole.



15. STRATEGY

15.1. Strategy Definition

Build an incident settlement strategy is answering the question:

"Which goal does the organization want to reach?"

Answering this question defines the general goal of the fire and rescue services.

Their three main goals are always the same all over the world:

N°1: Protect human life

N°2: Protect property

N°3: Protect environment

Inside a society, Strategy is a stable notion decided at a political level, according to the risk sociological acceptance. Choosing a strategy to deal with a type of incident is tightly linked with the "Stakes assessment" notion.

15.2. Stakes assessment

The three mains goals (protection of life, property and environment) must be pursued in the safest manner allowed by each unique incident situation stakes assessment. The authority in charge must take only the appropriate risks considering the salvable lives, salvable possessions and environmental situation balanced out with the available rescue forces at the moment he takes his operational decisions.

Nevertheless, the rescue of human lives overrides all other considerations.

So strategies can be divided in two main orientations:

High stake level situations: If nothing is done the incident will lead in a short time to the certain death of human(s), major infrastructure destructions and/or irreversible environmental effects.

Low stake level situations: The incidental situation will lead within a longer amount of time to minor effects on humans, infrastructures and/or reversible effects on environment.

16. TACTICS

16.1. Tactic definition

Using a defined tactic is the direct consequence of the chosen strategy. As the strategy is the answer to the question "Which goal do I want to reach?" a tactic is the answer to the question:

"How will I reach this goal (in the safest manner)?

Tactics is a variable concept decided at an operational level, according to the situation available at the present moment and in a near future.

For a defined situation type, it is possible to plan tactic as a step- by- step procedure that describes the actions of a first responders team. However, from the general rules, the incident commander has always the opportunity and the duty to use the appropriate behaviour for each incident because each incident is unique.

16.2. The danger process theory

The danger process theory (Perilhon, 2007) was developed to describe the ways a danger source affects a target through a danger flux.

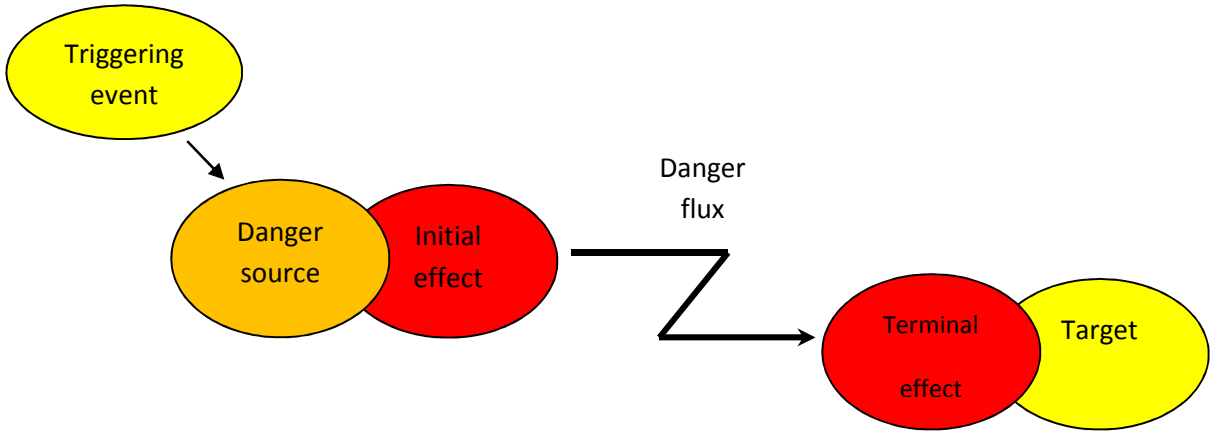


Figure 32 dangers process

During an incident and when the fire service is called, the triggering event has already occurred. So, to suppress the effect on targets, fire services can act:

- On danger sources, thus preventing the initial effects to happen
- On danger flux, preventing the terminal effects to exist
- On targets, preventing the effects to reach the targets.

16.3. Offensive and defensive tactics

Two main types of tactics are usually in use: offensive and defensive.

Offensive tactic: (or acting on danger sources)

This tactic aims to act very quickly on the origin of the incident to prevent it to produce its effects.

Advantages: rapid settlement of the incident, a little area is concerned; the required amount of personnel and equipment is limited

Drawbacks: risky for firefighters, one shot is available

Defensive tactic: (or acting on danger flux and targets)

This tactic aims to act on the closest area of the incident preventing those effects from reaching an area which was not concerned beforehand

Advantages: safer for crews

Drawbacks: it needs more preparedness, the settlement of the incident takes a long time, and the area finally concerned by the incident is wider. Hydrogen specificties in emergency situations

17. EMERGENCY CALL MANAGEMENT

The incident begins when the emergency call arrives to the control room. People who call the emergency services are usually over-excited or terrorised. Despite this, essential information must be gathered:

- Type of incident (electrical malfunction, gas leak, explosion, fire, etc.)
- Location of the incident

Number of persons killed, injured or threatened by the incident
With that information, the emergency answering service can select the nearest available emergency equipment and provide useful advice to the person who called:

As an example, if the emergency call concerns an FC vehicle involved in a fire in, the street the following steps must be considered:

- Look for identification graphics placed on the exterior or interior of the vehicle to establish that FC or hydrogen is involved
- Make sure all the passengers can escape from the vehicle
- Turn-off the ignition key
- Provide first aid to the casualties in a safe area
- Try to extinguish the fire with a fire extinguisher if the fire is small
- Keep the members of general public away from the burning vehicle before the fire services arrive

Before leaving the fire station, the incident commander must choose a safe route to arrive at the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

18. FIRE AND RESCUE OPERATIONAL SEQUENCE

Every fire and rescue operation follows the same "step-by-step" sequence on the incident field. Please note that those steps can be realised simultaneously, according to the real situation.

1. RECOGNITION
2. RESCUE
3. PREPAREDNESS
4. INCIDENT SETTLEMENT
5. PROTECTION
6. CLEAR OUT
7. OVERHAUL

18.1. Recognition

This step aims at collecting every available piece of information on the incident field in order to size up the scene. The incident commander will look for the following information:
What happened and what is happening?
Are there casualties or people threatened by the situation?
Was a fire dart seen? Was a loud hissing sound heard?
What are the resources of the place?
To do so, he will set a large circle around the scene. If the scene takes place in a building, the recognition also includes the floors under and above the incident area.

The recognition a danger area is defined, taking into account the reality of the known risks. The incident commander is at this moment able to decide the safest way to deal with the situation, enounce the objectives and choose the angles of attack.

18.2. Rescue

If a casualty is identified and located, rescue operations are launched immediately even if recognition is not complete. Casualties are taken out of the danger area and led to the first aid paramedics teams. As said before the rescue of human lives overrides all other considerations.

18.3. Preparedness

During this step, the crew will prepare the needed tools and accessories required to deal with the situation (for example, hose lines, hydrants, thermal imaging devices, gas detectors, etc.). The tools and accessories used are function of the incident situation.

18.4. Incident settlement

Considering the available information, the incident commander will, at this step, decide whether to use an offensive or a defensive tactic.

1st example:

An FCH car is burning on a small road in the countryside. The driver is safe and out of the danger area.
A large flame is visible with the thermal imaging device and a loud hissing sound is heard.
Analysis: the TPRD of H2 tank is opened and in a very short time the ignited leak will blowdown. Nothing is threatened by the flame.

Tactical choice:
Use a defensive tactic: close the road in both directions, wait for the blowdown of the tank while preparing the hose lines and then extinguish the car fire, using the electrical car fire procedures.

2nd example:
An FCH car is burning in a crowded street, close to a 10 storey building, no sound is heard, and the fire began 2 minutes ago.

Tactical choice:
Use an offensive tactic: close the road in both directions, prevent anybody from approaching less than 100 meters from the car, stretch two hose lines and attack immediately the car fire simultaneously with two teams, from safe angles (see below) before TPRD opens. Keep cooling the tanks, after the fire is put out.

18.5. Protection

The “protection” step aims to avoid destructions caused by the incident (the fire) or by what was used to extinguish it (the water).
As an example, if the fire occurs in a bus parking lot, the buses closest to the fire are protected using water jet curtains, and those which are a little bit further can simply be driven away from the incident area.
In the buildings and the industrial plants, the effects of the water or foam sprays can also be destructive. The incident commander must use the only necessary amount of water or foam. During this step, shoring-up can also be necessary.

18.6. Clear out

At the end of a fire, it is important to clear out the incident scene, remove and sprinkle all burnt pieces of material to be sure that no ignited materials remain underneath.

18.7. Overhaul

After the end of extinguishing operations and the incident settlement, the first responders must not leave the fire ground too early.
The temperature decrease of the burnt tank must regularly be checked.
An overhaul of the fire ground must be steadily done, until any risk still exists.

18.8. Incident tactics for FCH applications

18.8.1. Type of incidental situations

The situations encountered with FCH application are very various. They can be classified in 5 main situations:

1 RESCUE on a FCH application
2 IGNITED HYDROGEN LEAK
3 UNIGNITED HYDROGEN LEAK
4 FIRE on a FCH application
5 FIRE THREATENING FCH application

The 5 following tables (extracted and translated form the French guidelines) explain the operational sequences on how to deal with the related situations.

18.9. Rescue

Situations covered by this sequence are:

- Injured person in a FCH application.
- Asphyxiation caused by an H2 leak in a confined space.
- Electrocution.
- Burns caused by a hydrogen leak.

The indicative step-by-step sequence is listed below.

Table 1 Operational sequence for RESCUE on a FCH application

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident; - Take into account the risk of explosion of hydrogen in confined spaces; - Take into account the risk of anoxia in confined spaces.
	Prohibit	- Prohibit the progress downwind. It is imperative to establish an exclusion zone of 50 m; - Prohibit the use of electrical or electronic devices in the non ATEX exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building
RESCUE	Act Isolate	**In case of hydrogen leak in confined spaces:** - Wear a self-contained breathing apparatus; - Remove the affected casualty outside the exclusion zone. **If risk of electrified or electrocuted victim** - Use the electro-rescue equipment to remove the victim - Avoid contact of the first responders with electrical elements;
PREPAREDNESS/ INCIDENT SETTLEMENT		- Confirm or refine the exclusion zone (50 m); - Conduct surveys using an explosimeter (from top to bottom of the installation or storage facility)
PROTECTION		**-Actions to prevent a risk of anoxia:** • Close the hydrogen supply valves • Ventilate the area by promoting the natural drawing (do not use electrical and thermal fans) **Action on the electrical risk:** Press the emergency stop button of the installation (delay of 20 minutes with the presence of residual current)
CLEAR OUT OVERHAUL		The monitoring phase ceases as soon as the oxygen level in the room is normal (about 20 vol. %) Repeatedly check: • hydrogen presence in the atmosphere • the electrical system is secure and supported by a technician

18.10. Electrical Fire

Situation covered by this sequence is a Fire on the electrical components of a FCH application.

Table 2 Operational sequence for FIRE on the electrical components of a FCH application

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident ; - Take into account the "low voltage" hazards
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building;
RESCUE	Act Isolate	- In case of hydrogen in confined spaces: • Wear a breathing apparatus; • Remove the affected person outside the exclusion zone. - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim • Avoid contact of the first responders with electrical elements
PREPAREDNESS/ INCIDENT SETTLEMENT		- Confirm or refine exclusion zone (50 m) (based on the sound of a leak under pressure, readings of explosimeter, etc.); - Proceed to the extinction of the flame based on its virulence: • With a powder or CO2 fire extinguisher at a distance more than > 1m • With variable flow-rate nozzles in, spray attack pulse at a distance of more than 3m
PROTECTION		- Operate the emergency stop punch installation (20 minutes from time with the presence of a residual current); - Take into account the flow of water during the timeout shutdown phase of the installation (electrical hazard); - Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT OVERHAUL		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage ; - The monitoring phase ends when it is found that the actions aimed at extinguishing measures proved effective.

18.11. External Fire

The situation covered by this sequence is a Fire threatening a FCH application or H2 storage

Table 3 Operational sequence for a FIRE THREATENING a FCH application or H2 storage

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident; - Take into account the risk of explosion of a hydrogen tanks under fire, with projectiles travelling several tens of meters for bottles and several hundred for trailers.
	Prohibit	- Prohibit the progress downwind and imperative to establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.).
	Inspect	- Operate the external power cuts of the building;
RESCUE	Act Isolate	- In case of hydrogen in confined spaces: • Wear a breathing apparatus; • Remove the affected person/victim outside the exclusion zone; - If risk of electrified or electrocuted victim: • Use the electro-rescue equipment to remove the victim; • Avoid contact with electrical stakeholder bodies.
PREPAREDNESS/ INCIDENT SETTLEMENT		- Confirm or refine the exclusion zone (tanks or installation directly threatened by the flames); - Proceed with the extinction of fires - Provide preventive cooling of the facilities and hydrogen storage in the following ways: • Establishment of a “peacock tail “type nozzle; • Direct attack spread water jet on the hydrogen tanks using with variable flow-rate nozzles spear 250 l/min minimum (avoid directing the jets on pipes) • Establishment of spread water jet for the protection of sensitive point (power Bay ....)
PROTECTION		Operate the emergency stop punch installation (20 minutes from time with the presence of a residual current); - Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT OVERHAUL		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage;-The monitoring phase ends when it is found that • the actions aimed at extinguishing proved effective. • the water spread on the hydrogen tanks do not evaporate on contact with surfaces

18.12. Ignited H2 leak

The situation covered by this sequence is an ignited H2 leak

Table 4 Operational sequence for an IGNITED HYDROGEN LEAK

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details of the incident; - Take into account the dispersion of H_2 in premises before the ignition (possibility of UVCE unconfined vapour cloud explosion).
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.). - Prohibit the extinguishment of the hydrogen flames. - Prohibit the actions on the electrical system of the facility in case of hydrogen leak.
	Inspect	- Operate the external power cuts of the building; - Confirm the presence of an ignited leak and its length using thermal camera (hardly visible flame in its entirety, in the day light); - Pay attention to the significantly loud sound of an ignite gas leak.
RESCUE	Act Isolate	**- In case of hydrogen in confined spaces:** • Wear a breathing apparatus; • Remove the affected person(s) outside the exclusion zone. **- If risk of electrified or electrocuted victim:** • Use the electro-rescue equipment to remove the victim; • Avoid contact with electrical stakeholder bodies.
PREPAREDNESS/ INCIDENT SETTLEMENT		- Refine the exclusion area (explosimeter measurements, information on the nature of the incident ...); - Set up water curtains to prevent a fire spread; - If necessary, provide preventive cooling on hydrogen storage and facilities nearby.
PROTECTION		- Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
CLEAR OUT OVERHAUL		- Look for high temperature points on hydrogen storage using thermal imaging device on hydrogen storage; - Conduct surveys of explosimeter in confined spaces prioritizing high points; - Press the emergency stop button of the installation (delay of 20 minutes with the presence of a residual current).

18.13. Unignited H2 leak

The situation covered by this sequence is an unignited H2 leak

Table 5 Operational sequence for an unignited Hydrogen leak

Steps	Actions	Goals
RECOGNITION	Identify	- Contact the safety manager of the installation for the details on the incident; - Take into account the risk of explosion.
	Prohibit	- Prohibit downwind progression and imperatively establish an exclusion zone of 50 m; - Prohibit the use of non ATEX electrical or electronic devices in the exclusion zone (cell phones, radios, etc.). - Prohibit the actions on the electrical system of the facility in case of hydrogen leak.
	Inspect	- Operate the external power cuts of the building
RESCUE		- In case of hydrogen in confined spaces: • Wear a breathing apparatus • Remove the affected person (s) outside the exclusion zone - If risk of electrified or electrocuted victim • Use the electro-rescue equipment to remove the victim • Avoid contact with electrical stakeholder bodies
PREPAREDNESS/ INCIDENT SETTLEMENT	Act Isolate	- Refine the security area based explosimeter measurements (from top to bottom of the installation); - Close hydrogen supply valves; - Ventilate premises facilitating natural drawing (opening existing outlets).
PROTECTION		
CLEAR OUT OVERHAUL		- The monitoring phase ends when there is no risk of explosion in a secure area (complete emptying of the tank or draining in open air in a secure area monitored by the operator, efficient ventilation of the premises.) - Press the electrical emergency shutdown device of the installation (delay of 20 minutes with the presence of a residual current)

Note: the action on the emergency stop punch during the overhaul phase, clears electric ignition sources, intrinsic with the installation.

19. HYRESPONSE FIRST RESPONDERS TEAM AND EQUIPMENT

All the firefighting equipment used in HyResponse program must be in accordance with the following document:

"Catalogue des Normes Applicables aux Sapeurs-Pompiers et à la Sécurité civile Direction Générale de la Sécurité Civile et de la Gestion des Crises Sous-direction des ressources, des compétences et de la doctrine d'emploi Bureau de la Formation, des Techniques et des Équipements, Version Éditée le 27 août 2014 » and following.

19.1. The team

The typical fire equipment used in HyResponse training has the following crew:

- Equipment Chief (first incident commander)
- Driver/pump operator
- Team leader 1
- First responder 1
- Team leader 2
- First responder 2

Each first responder must wear a complete fire gear composed in particular of the following elements:

Helmet with face shield, hood, turnout coat, turnout pants, and fire fighter boots and gloves. All protective clothing must be worn as a complete set.

Use of self-contained breathing apparatus is also mandatory.

19.2. The fire equipment

The vehicle used in HyResponse is the French Pump (fourgon pompe tonne). It has the characteristics specified in the European standard EN 1846-1/2/3 and to the French standard NFS 61-515. In order to tackle H2 fires, additional tools are required:

- Polyvalent flammable gas detector
- H2 detector
- Thermal camera

19.3. Specific tactics sheets proposed for selected applications

Taking into account the existing knowledge about hydrogen application fires, HyResponse project propose the following "Tactical sheets".

For each selected application (Car, bus, forklift, trailer, refuelling station, Stationary power generation unit (SPGS), Hydrogen-based energy storage system (H2ESS)), we propose a tactical approach for 4 incidents:

- No leak, no fire,
- H2 leak,
- Fire,
- External fire threatening the application

For each situation we propose a step- by- step sequence, information about safety points and indicative safety distances **in case of a failure of the pressure release devices and to prevent the public from the effects of the explosion of the tanks.**

Important Notice: Mind that those distances are INDICATIVE. The incident commander must enlarge or reduce the safety perimeter taking into account the reality of the situation and especially the capacities of H2 (or O2) tanks involved.

Refer to section “how to use nomograms”

20. FUEL CELL VEHICLES

20.1. No leak, no fire

FC CAR/FC FORKLIFT/FC BUS		
Tactic n° 1	NO LEAK, NO FIRE (technical alarm, work accident, road trafic accident)	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:
- assure the precise incident location
- are there any person involved in the incident?
- type of vehicle concerned
- what happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:
- wind direction
- wind speed

ITINERARY

choose a safe itinerary:
- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:
- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

Fuel cell vehicles
No leak no fire

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident, away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o Which type of vehicleis involved?

o What has happened?

o Is someone injured? Threatened? Trapped inside?

o Has a leak occured? Is a leak still occuring?

o Is a part of the vehicle damaged?

Check energies present in the vehicle involved (tank type, pressures, capacities, refuelling hole type, vehicle registration papers, etc)

Vehicle identification:

FC car may be recognised by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3)

Operate H2 detector

RESCUE

Engage rescue as a conventional accident

Rescue of humans override all other considerations.

EXPOSURE PROTECTION

• Use only necessary personnel

• Open the doors and hoods (if present)

• Set the hand- brake on

• Wedge the vehicle.

• Turn off the ignition key

• Press the fuel cell emergency shutdown device (for buses and forklifts)

For buses, the emergency shutdown device is generaly located near the driver seat, on the left-hand side and another is on a fuel cell in "engine" compartment, located at the back of the bus.

Fuel cell vehicles
No leak no fire

• If it is not possible to reach the ignition key, remove all the fuses in the fuse boxes and then, cut the negative low voltage battery cable (12 or 24V).

• Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.
• Check if high temperature points exist on the vehicle (more than 150°C/302°F).
• Stretch a fire hoseline to protect the action of teams.

INCIDENT TREATMENT

If no H2 leak and no sign of fire is detected:
• Engage incident settlement following manufacturers of Emergency Response Guides and rescue sheets.

DO NOT:
• cut or crush H2 lines
• cut or crush High Voltage Lines (orange-coloured)
• damagehydrogen tank
• damage traction Battery Stack

If a H2 leak is detected, apply tactic n°2 "H2 LEAK WITHOUT FIRE"

OVERHAUL

• after a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorized personnels (idealy by the vehicle manufacturer)

20.2. Leak without fire

FC CAR/FC FORKLIFT/FC BUS		
Tactic n° 2	H2 LEAK WITHOUT FIRE	
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location,
- type of vehicle concerned,
- what happened.

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction,
- wind speed.

ITINERARY:

choose a safe itinerary:

- do not cross an eventual explosive gas cloud,
- do not reach scene from bellow,
- anticipate the need of a hydrant.

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,
- H2 detector,
- O2 detector,
- Thermal imaging camera.

Fuel cell vehicles
FIRE

ARRIVAL ON SCENE

ARRIVAL:

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident. away from a possible ignited flammable leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA:

For a CAR and FORKLIFT: Set up a safety area for the public beyond a radius of 100 meters (110 yd)

• For a BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA:

ENGAGE THE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

• answer the following questions:

o Which type of vehicle is involved?

o What happened?

o Has a loud hissing sound being hared before the FR arrive?

Vehicle identification:

H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3)

Confirm the safety area with the H2 detector .

If H2 is detected, refine the safety area.

Check if high temperature points exist on the vehicle (more than 150°C/302°F).

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the gas leak:

• Team 1: extract the victim(s) from the danger zone by any possible means.

• Team 2: stretch a fire hoseline to protect the action of the Team 1 in case of an ignition of the cloud.

Fuel cell vehicles
FIRE

Evacuate the passengers in the opposite direction of the wind.

EXPOSURE PROTECTION

- Use only necessary personnel.
- Evacuate adjacent buildings.
- If the vehicle is in a building, prevent H2 accumulation by operating wide ventilation of the building.
- Open the doors and hoods (if present).
- Set the hand-brake.
- Wedge the vehicle.
- Turn off the ignition key.
- Press the fuel cell emergency shutdown device (buses and forklift)

For Buses, an Emergency shutdown device is generaly located near the driver seat, on the left-hand side and another is on fuel cell in "engine" compartment, located at the back of the bus.

- Do not operate any other electrical breaker to avoid creation of electrical spark.
- Repeatedly check H2 presence in the atmosphere.
- Refine safety area.
- Check if high temperature points exist on the vehicle (more than 150°C/302°F).

INCIDENT TREATMENT

- If H2 leak continues after the protection step , close H2 valve as close as possible of the H2 tank.
    - If it is not possible to reach a H2 valve, allow H2 to leak safely until the tank is empty.

OVERHAUL

- After a last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorized personnels (idealy by manufacturer).

20.3. Fire

	FC CAR/FC FORKLIFT/FC BUS	
Tactic n° 3	FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:
- assure the precise incident location
- type of vehicle concerned
- what happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:
- wind direction
- wind speed

ITINERARY
choose a safe itinerary:
- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:
- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL:
- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment 50 meters (55 yd) before the incident, away from a possible ignited flammable leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA
- CAR and FORKLIFT: Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yd)
- Ensure that unauthorized/untrained personnel do not enter the hazardous area.

Fuel cell vehicles
FIRE

SIZE UP THE SCENE
IF A PERSON IS INSIDE THE HAZARDOUS AREA : ENGAGE RESCUE OPERATIONS • answer the following questions: o Is someone threatened by the fire? Where? o How many vehicles are involved in the fire? o How many of these vehicles are powered by H2 or by another compressed flammable gas? o Has a loud hissing sound being heared before the FR arrive? Did the TPRD activate? Is the flame produced? Vehicle identification: H2 car may be identified by FCHV Fuel Cell Hybrid Vehicle graphics (figure 3).
RESCUE
Rescue of humans override all other considerations. If a human is threatened or concerned by the Fire : • Team 1: extract the victim(s) from the danger zone by any possible means (figure 10) • Team 2: stretch a fire hoseline to protect the action of the Team 1 to evacuate the passengers in the opposite direction of the wind.
EXPOSURE PROTECTION
• Use only necessary personnel • Evacuate adjacent buildings • Prevent the fire from spreading to a uninvolved vehicle(s) or building(s) • Move ajacent non involved vehicles by any way possible (driving, towing, pushing, etc) • If the vehicle is in a building, prevent combustion gases and H2 accumulation by operating wide ventilation of the building. If possible and safe: • Open the doors and hoods (if present) • Set the hand-brake on • Wedge the vehicle • Turn off the ignition key • Press the fuel cell emergency shutdown device (buses and forklifts) For Buses, an Emergency shutdown device is generaly located near the driver seat on left side and another is on fuel cell in "engine" compartment, located at the back of the bus • Repeatedly check H2 presence in the atmosphere. • Refine safety area. • Repeatedly check H2 tanks temperature with thermal imaging device.
INCIDENT TREATMENT
In case of High stake level situation : Operate an offensive Fire attack: (figures 8-9)

each Team prepare 80 m of hoselines directly connected to the fire equipment pump (figure 4)
• Team 1: aims to cool the H2 tank. Thisprevents the Thermal Pressure Release Device to operate.
• Team 2: aims to extiguish the vehicle fire.
The teams avoid passing through danger angles. (figures 5-6-7)
Mind that violent reactions are possible between water and burning materials
as soon as possible, wedge the vehicle.
Mind that water will be polluted during extinction (especialy if battery is damaged.)
operate its containement.
In there is no identified stake:
evaluate the opportunity to let the vehicle burn safely.

OVERHAUL

• Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
• After the last H2 atmospheric control, make sure that the vehicle or the wreckage is evacuated by authorized personnels (idealy by the manufacturer).

20.4. External Fire threatening the application

FC CAR/FC FORKLIFT/FC BUS		
Tactic n° 4	EXTERNAL FIRE THREATENING THE APPLICATION	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:
- assure the precise incident location
- are there any person involved in the incident?
- type of vehicle concerned
- what happend?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:
- wind direction
- wind speed

ITINERARY
choose a safe itinerary :
- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:
- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :
- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment 50 meters (55 yd) before the incident away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA
- CAR and FORKLIFT Set up a safety area for the public beyond a radius of 100 meters (110 yd)
- BUS: Set up a safety area for the public beyond a radius of 200 meters (220 yd)

Fuel cell vehicles
External fire

• Ensure that unauthorized/untrained personnel do not enter the hazardous area
SIZE UP THE SCENE
• Answer the following questions: • What is burning? • What's the fire Strength? • What's the distance between the Fire and the FC Vehicle? o Is someone injured, threatened or trapped inside? o Has a hydrogen leak occured? Is a leak still continuing?
RESCUE
Rescue of humans override all other considerations. If a human is threatened or concerned by the Fire : • Team 1: extract the victim(s) from the danger zone by any possible means • Team 2: stretch a fire hoseline to protect the action of the Team 1 evacuate the passengers in the opposite direction of the wind
EXPOSURE PROTECTION
• Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle.
INCIDENT TREATMENT
Operate a defensive Fire attack: each team prepare 80 m of hoselines directly connected to the fire equipment pump. • Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the FCH vehicle. • Team 2: Put out the fire with water, foam or powder depending what is burning. If putting fire out is not possible, or if not enough personnel is available, attempt to move the FCH vehicle by any way possible (driving, towing, pushing…) away from the radiant effect of the fire.
OVERHAUL

Figure 12 Offensive fire attack preparedness (connected to hydrant if available)©crise-2015

Figure 13 (In red) forbidden angles for reaching a FCH car in fire on wheels. ©crise-2015

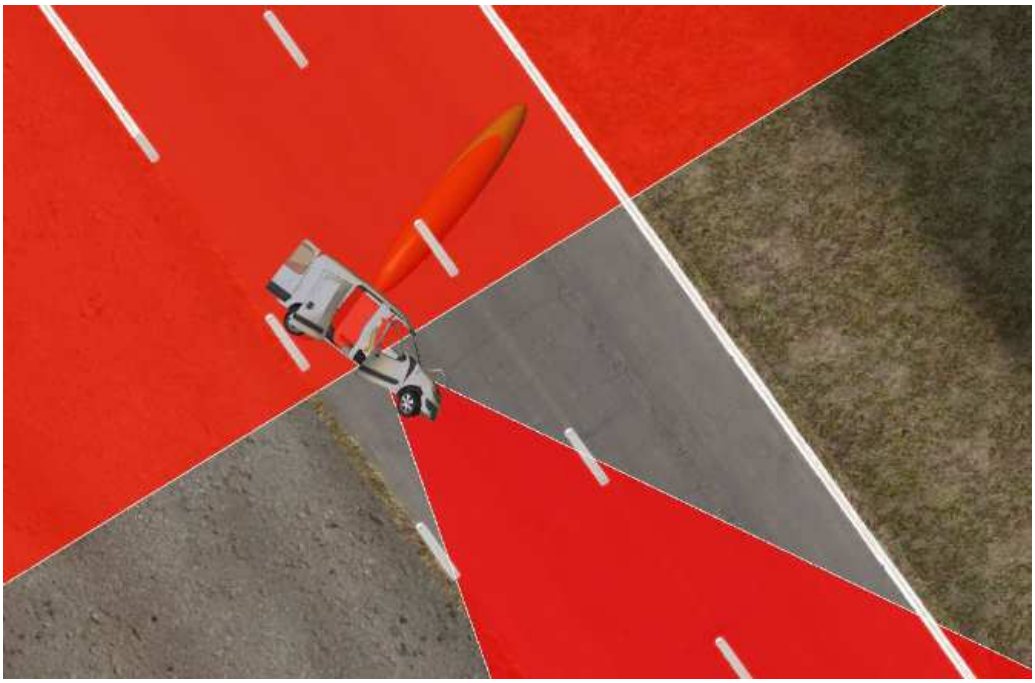


Figure 14 (In red) forbidden angles for reaching a FCH car in fire on the side (TPRD located in the roof) ©crise-2015

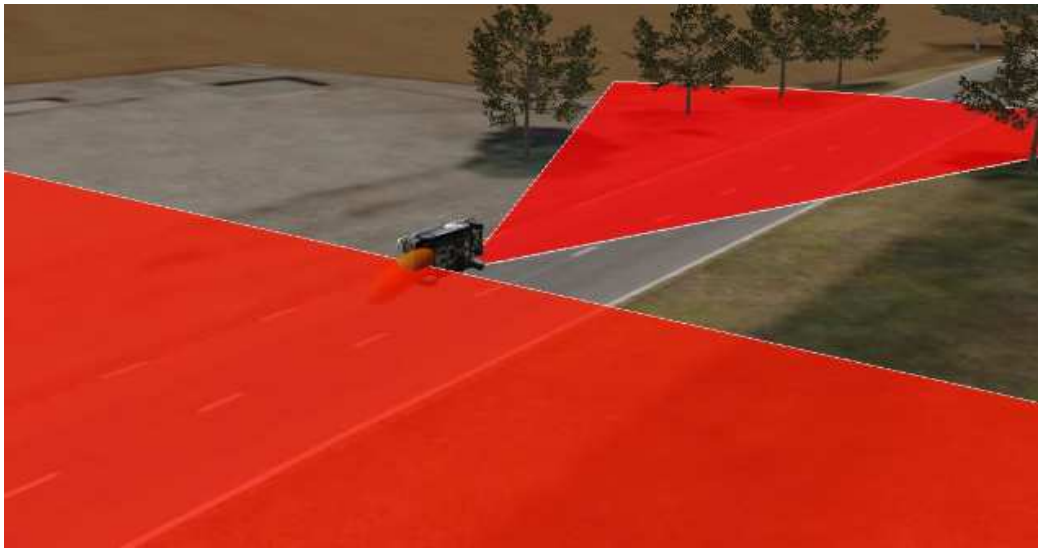


Figure 15 (In red) forbidden angles for reaching a FCH car in fire on the side (TPRD located between the rear wheels with an angle of 45°)©crise-2015

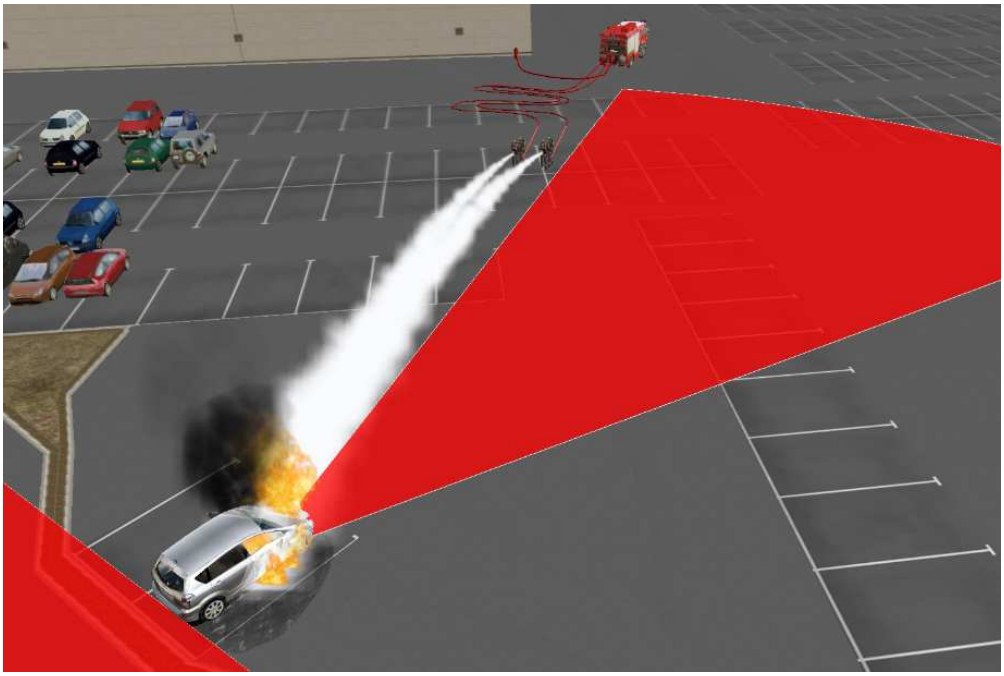


Figure 16 Offensive fire attack with two teams (1st phase) ©crise-2015

Figure 17 Offensive fire attack with two teams (2nd phase) ©crise-2015

Figure 18 Rescue near a FCH car on fire. ©crise-2015

Figure 19 Forklift H2 release vent (on each side) ©Air Liquide-2014

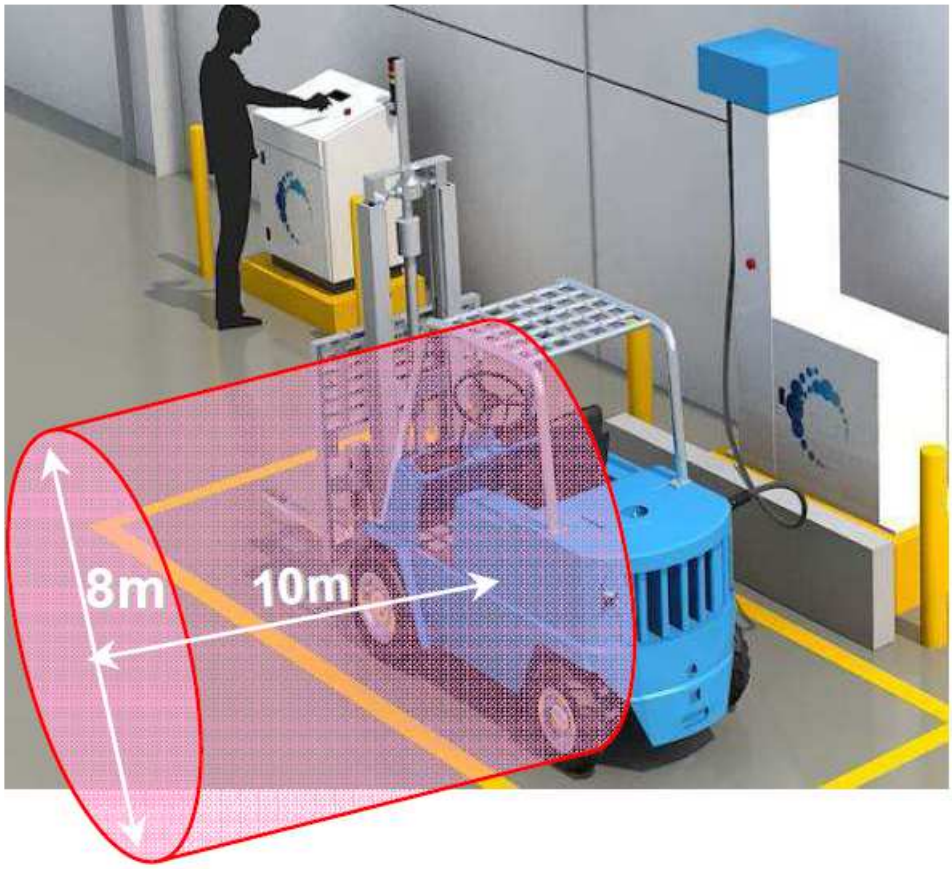


Figure 20 gaseous Danger zone for a forklift during a TPRD H2 release (on each side during 1 minute) ©Air Liquide-2014

Figure 21 Fire threatening the forklifts©crise-2015

Table 6 Concentrations of hydrogen in air depending on distance to the leak (m)

Pressure in hydrogen storage tank, MPa	TPRD orifice diameter, mm	Distances to 4 vol %, m	Distance to 8 vol %, m
35	2	15	7
35	3	23	11
35	4	31	15
35	5	38	18
35	6	46	22
70	2	20	10
70	3	30	14
70	4	40	19
70	5	50	24
70	6	60	29

Table 7 Flame lengths and separation distances for jet fires from on-board hydrogen tanks

Pressure in storage tank, MPa	TPRD orifice, mm	Flame length, m	SD (no harm), m	SD (pain threshold), m	SD (3rd degree burn), m
35	2	5	18	16	10
35	3	8	27	23	16
35	4	10	36	26	18
35	5	13	46	39	26
35	6	16	55	47	31
70	2	7	23	20	13
70	3	10	35	30	20
70	4	13	46	40	27
70	5	17	58	50	33
70	6	20	70	60	40

21. H2 TRAILER

21.1. No leak, No Fire

H2 trailer		
Tactic n° 5	NO LEAK NO FIRE (technical alarm, work accident, road trafic accident)	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:
- assure the precise incident location
- are there any person involved in the incident?
- type of trailer concerned? Size, cargo?is if full or empty?
- is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:
- wind direction
- wind speed

ITINERARY
choose a safe itinerary :
- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:
- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :
- Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.
- Stop the fire equipment 50 meters (55 yd) before the incident
- away from a possible ignited flammable liquid leak progression.
- Engage the pump and connect the fire equipment to a hydrant.

H2 trailer
No leak no fire

SAFETY AREA
- Set up a safety area for the public beyond a radius of 50 meters (55 yd)
- Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

- BY QUESTIONNING THE WITNESSES AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :
  - o Which Type is the involved vehicle?
  - o what has happened?
  - o Is someone injured? Threatened?
  - o Has a leak occured? Is a leak still occuring?
  - o Is a part of the truck damaged?
  - o Is the trailer dismanteled?
- Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers...)
- does a flammable liquid leak exists?
- operate H2 detector

RESCUE

engage rescue as a conventional accident
Rescue of humans override all other considerations.

EXPOSURE PROTECTION

- Use only necessary personnel
- set parking brake
- wedge the vehicle.
- Turn off the ignition key

- Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.
- Check if high temperature points exist on the vehicle (more than 150°C/302°F)
- stretch a fire hoseline to protect the action of other teams

INCIDENT TREATMENT

- check and close every H2 valve on the trailer.
- If no H2 leak and no sign of fire is detected :

engage incident settlement following usual road trafic accident and extrication guidelines.

DO NOT:
- cut or crush H2 lines
- damage H2 tanks

If the trailer is dimanteled, inspect individualy each cylinder
contact the transport company hotline to evacuate safely the cylinders

H2 trailer
No leak no fire

OVERHAUL
• after a last H2 atmospheric control, Make sure that the vehicle or the wreckage and the cargo is evacuated by authorized personnels (idealy transport company)

21.2. H2 leak, No fire

	H2 trailer	
Tactic n° 6	H2 LEAK WITHOUT FIRE	
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- what happend?
- are there any person involved in the incident?
- type of trailer concerned? Size, cargo?is if full or empty?
- is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident (figure 15)

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 100 meters (110 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :

ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS:

o Which Type is the involved vehicle? (Figure 22)

o what happened?

o Is the trailer dismanteled?

o Has a loud hissing sound been eared before the FR arrive?

Confirm the safety area with the H2 detector . If H2 is detected, refine the safety area

Check if high temperature points exist on the vehicle (more than 150°C/302°F)

RESCUE

H2 trailer
H2 leak without fire

Rescue of humans override all other considerations.

If a human is threatened or concerned by the gas leak :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1 in case of an ignition of the cloud

EXPOSURE PROTECTION

• Use only necessary personnel

• set parking brake

• wedge the vehicle.

• Turn off the ignition key

• Check if high temperature points exist on the vehicle (more than 150°C/302°F)

• stretch a fire hoseline to protect the action of other teams

INCIDENT TREATMENT

• listen to abnormal noises

• Repeatedly check H2 presence in the atmosphere.

• check and close every H2 valve on the trailer.(figures 16-17-18-19-20)

If there is no means for preventing H2 leak, and no identified stake

evaluate the opportunity to let the vehicle leak safely.

OVERHAUL

• after a last H2 atmospheric control, Make sure that the vehicle or the wreckage and the cargo is evacuated by authorized personnels (idealy transport company)

21.3. Fire

H2 trailer		
Tactic n° 7	FIRE	
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- what happend?
- type of trailer concerned? Size, cargo?is if full or empty?
- is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :

ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

BY QUESTIONNING THE WITNESSES (DRIVER) AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS:

• Which Type is the involved vehicle?

• what happened?

• Is the trailer dismanteled?

• is a cylinder involved in fire?

check the fire scene with the thermal imaging camera:

H2 trailer
FIRE

• is a cylinder provide a ignited H2 leak?

• is a cylinder impinged by a flame dart?

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the gas leak :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

EXPOSURE PROTECTION

• evacuate adjacent buildings

• Prevent the fire from spreading to a uninvolved vehicle(s) or building(s)

• move ajacent non involved vehicles by any way possible (driving, towing, pushing…)

INCIDENT TREATMENT

In case of High stake level situation :

operate an offensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

• Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks

• Team 2: aims to extiguish the vehicle fire. Mind that foam can be used to extinguish the truck (tractor) while water is used to cool the trailer tanks. Make sure not to flush foam with water.

THE INCIDENT COMMANDER WILL EVALUATE THE OPORTUNITY AND THE SEQUENCE ORDER TO CLOSE LEAKING TANKS AS SOON THEY ARE NO MORE SUBMITTED TO A PRESSURE INCREASE;

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

Previosly, the incident commander must have took appropriate actions to prevent pressure increase in the tanks and checked the efficiency.

Mind that violent reactions are possible between water and burning materials

as soon as possible, wedge the vehicle.

Mind that water will be polluted during extinction

operate its containement.

In there is no identified stake:

evaluate the opportunity to let the vehicle burn safely.

Mind that a cylinder or a bottle is not equiped with pressure release device and will explose if submited to a pressure increase.

OVERHAUL

• Cool the wreckage as soon as no heat point is detected by the thermal imaging device.

• after a last H2 atmospheric control, Make sure that the vehicle or the wreckage is evacuated by authorized personnels idealy transport company)

21.4. External fire threatening the application

H2 trailer		
Tactic n° 8	EXTERNAL FIRE THREATENING THE APPLICATION	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- what happend?
- type of trailer concerned? Size, cargo?is if full or empty?
- is the cargo dismanteled?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,

H2 trailer
External Fiire

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• answer the following questions:

• What is burning?

• What's the fire Strength?

• What's the distance between the Fire and the H2 trailer?

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the Fire :

• Team 1 : extract the victim(s) from the danger zone by any possible means

H2 trailer
External Fiire

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate the passengers in the opposite direction of the wind

EXPOSURE PROTECTION

• Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the H2 trailer.

INCIDENT TREATMENT

Operate an defensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

• Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the H2 trailer.

• Team 2 : Put out the fire with water, foam or powder depending what is burning.

If putting fire out is not possible, move the H2 trailer by any way possible (driving, towing, ...) away from the radiant effect of the fire

Mind that a cylinder or a bottle is not equiped with pressure release device and will explose if submited to a pressure increase.

OVERHAUL

• Check temperature on the H2 trailer with thermal imaging device.

• after a last H2 atmospheric control, Make sure that the vehicle or the wreckage is evacuated by authorized personnels idealy transport company)

Figure 22 H2 Trailer©Air Liquide-2014

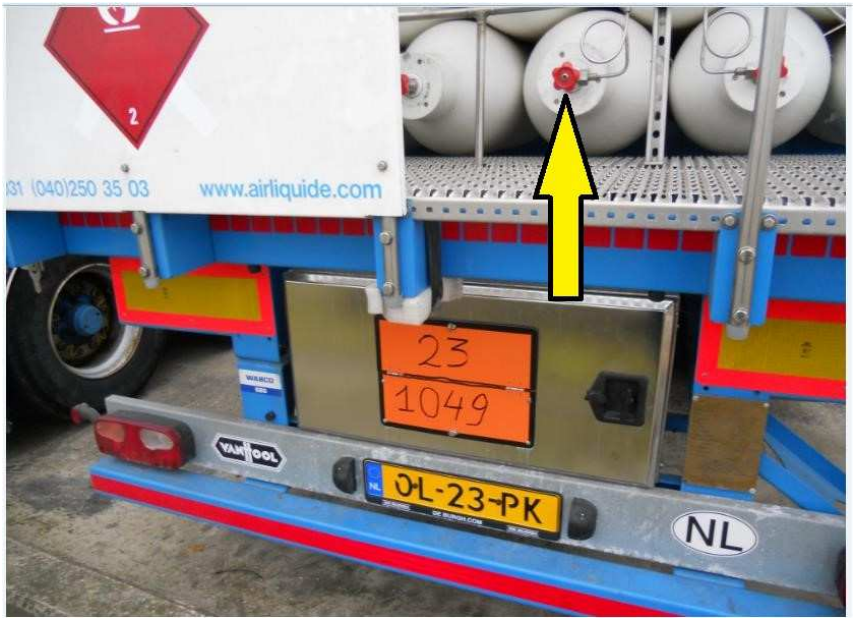


Figure 23 Individual cylinder valve on a H2 trailer. ©Air Liquide-2014

Figure 24 H2 trailer with vertical bottles racks. © Areva/ENSOSP 2015

Figure 25 H2 bottles rack © Areva/ENSOSP 2015

Figure 26 Trailer Main H2 valve (outside view) © Areva/ENSOSP 2015

Figure 27 Trailer Main H2 valve (inside view) © Areva/ENSOSP 2015

Figure 28 Valves on a H2 bottles Rack © Areva/ENSOSP 2015

22. REFUELING STATION

22.1. No leak, No Fire

REFUELLING STATION		
Tactic n° 9	NO LEAK NO FIRE (technical alarm, work accident, road trafic accident)	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

Refueling station
H2 leak without fire

• Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

o Is a vehicle connected to the refueling sation? (if yes, apply FCH vehicle related tactic)

Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers...)

operate H2 detector

where emergency shutdown devices of the refuelling station activated?

RESCUE

engage rescue as a conventional accident

Rescue of humans override all other considerations.

EXPOSURE PROTECTION

• Use only necessary personnel

• Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.

• stretch a fire hoseline to protect the action of teams

push Emergency shutdown devices

if the dispenser if physcaly damaged, close the valves between the storage area and the dispenser.

INCIDENT TREATMENT

If no H2 leak and no sign of fire is detected :

• engage incident settlement with conventional techniques.

If a FCH vehicle is connected to the refueling station, disconnect it and move it away.

if a H2 trailer is connected to the refueling sation storage, close the valves between the trailer and the storage and apply simultaneaously the tactic related to trailers

DO NOT:

• cut or crush H2 lines

• cut or crush High Voltage Lines (orange)

• damage H2 tank

OVERHAUL

• after a last H2 atmospheric control,

Make sure that the refuelling station will be checked be authorized personnels before restart.

22.2. H2 leak without fire

	REFUELLING STATION	
Tactic n° 10	H2 LEAK WITHOUT FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,
- H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 100 meters (110 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :

ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

Has a loud hissing sound been eared before the FR arrive?

o Is a vehicle connected to the refueling sation? (if yes, apply related tactic)

Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers...)

operate H2 detector

where emergency shutdown devices of the refuelling station activated?

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the gas leak :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1 in case of an ignition of the cloud

evacuate the persons in the opposite direction of the wind

EXPOSURE PROTECTION

• Use only necessary personnel

• Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.

• stretch a fire hoseline to protect the action of teams

push Emergency shutdown devices

if the dispenser if physcaly damaged, close the valves between the storage area and the dispenser.

INCIDENT TREATMENT

close the valves between the dispenser annd the h2 storage

If a FCH vehicle is connected to the refueling station, disconnect it and move it away.

if a H2 trailer is connected to the refueling station storage, close the valves between the trailer and the storage and apply simultaneaously the tactic related to trailers

Prevent H2 to accumulate in enclosed premises

DO NOT:

• cut or crush H2 lines

• cut or crush High Voltage Lines

Refueling station
H2 leak without fire

• damage H2 tank
OVERHAUL
• after a last H2 atmospheric control, Make sure that before restart, the refuelling station will be checked be authorized personnels and the malfuction and damages repaired.

22.3. Fire

	REFUELLING STATION	
Tactic n° 11	FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,
- H2 detector
- O2 detector
- Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

Refueling station
FIRE

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

IF A PERSON IS INSIDE THE HAZARDOUS AREA :

ENGAGE RESCUE OPERATIONS

IF NO ONE IS INSIDE THE HAZARDOUS AREA:

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE REFUELLING STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

Has a loud hissing sound been eared before the FR arrive?

o Is a vehicle connected to the refueling sation? (if yes, apply related tactic)

Check energies present in the involved vehicle (tank type, refueling hole type, vehicle registration papers...)

operate H2 detector

where emergency shutdown devices of the refuelling station activated?

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the Fire :

Refueling station
FIRE

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate the passengers in the opposite direction of the wind

EXPOSURE PROTECTION

• evacuate adjacent buildings

• Prevent the fire from spreading to a uninvolved vehicle(s) or building(s)

• move ajacent non involved vehicles by any way possible (driving, towing, pushing…)

Push Emergency shutdown devices on the dispenser and the storage.

close the valves between the storage area and the dispenser.

INCIDENT TREATMENT

two cases are possible:

The fire concerns the dispenser area.

Push Emergency shutdown devices

prevent the fire to spread to a uninvoved part of the refuelling station with water spray curtains.

put the fire out.

the fire concerns the storage area.(High stake level situation)

Push Emergency shutdown devices

prevent the fire to spread to a uninvoved part of the refuelling station with water spray curtains.

put the fire out.

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

Previously, the incident commander must have took appropriate actions to prevent pressure increase in the tanks and checked the efficiency.

Refueling station
FIRE

Operate an offensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

• Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks

• Team 2: aims to extiguish the fire.

Mind that H2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.

Mind that violent reactions are possible between water and burning materials

Mind that water will be polluted during extinction

operate its containement.

OVERHAUL

• Cool the wreckage as soon as no heat point is detected by the thermal imaging device.

• Repeatedly check H2 presence in the atmosphere.

22.4. External fire threatening the application

	REFUELLING STATION	
Tactic n° 12	EXTERNAL FIRE THREATENING THE APPLICATION	
AT THE FIRE STATION		

TAKE USEFUL information ABOUT THE INCIDENT:

- assure the precise incident location
- are there any person involved in the incident?
- are there any vehicle involved in the incident?
- what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

- wind direction
- wind speed

ITINERARY

choose a safe itinerary :

- do not cross an eventual explosive gas cloud
- do not reach scene from bellow
- anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

- Gaseous hydrocarbons dectector,
- H2 detector

Refueling station
External fire

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE STATION AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o witch part of the application is concerned by the incident? (dispenser, storage, electrical equipment...)

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

• What is burning?

• What's the fire Strength?

• What's the distance between the Fire and the refuelling station?

The station manager is able to provide accurate informations

RESCUE

Refueling station
External fire

Rescue of humans override all other considerations.

If a human is threatened or concerned by the Fire :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate people in the opposite direction of the wind

EXPOSURE PROTECTION

• Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and the reffuelling station.

INCIDENT TREATMENT

Operate an defensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

• Team 1: Attenuate the radiant heat by providing a water spray curtain between the fire and therefuelling station.

• Team 2 : Put out the fire with water, foam or powder depending what is burning.

Mind that a refuelling station storage ist equiped with pressure release device . A H2 leak may occur if the storage is submitted to a high temperature flux.

OVERHAUL

• Cool the wreckage as soon as no heat point is detected by the thermal imaging device.

• Repeatedly check H2 presence in the atmosphere

23. STATIONARY POWER GENERATION UNIT

23.1. No leak, No Fire

	Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)	
Tactic n° 13	NO LEAK NO FIRE (technical alarm)	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

• assure the precise incident location and the concerned power

• is this stationary power generation unit kwown by the fire service?

• Does a firefighting plan exists? take it in the fire equipment and read it on the road.

witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

• are there any person involved in the incident?

• what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

• wind direction

• wind speed

ITINERARY

choose a safe itinerary :

• do not cross an eventual explosive gas cloud

• do not reach scene from bellow

• anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

• Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident .

If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

if H2/O2 storage is concerned:

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

• Set up a safety area for the public beyond a radius of twice the height of the wind turbine ..

if fuel cell or electrical devices is concerned:

• Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?Which ones?

is the system delivering electricity?

Is a technician present on the plant area?

look for the mergency fire and rescue plan.

locate precisely dangerous areas, Emergency shutdown devices, valves,

evaluate the amount of compressed gases present in the tanks.

RESCUE

engage rescue as a conventional accident

Rescue of humans override all other considerations.

To reach safely a casualty, it is necessary sure that he's not already submited to an electrical current.

Push Emergency shutdown devices, take fallen cables away with appropriate elctrical gloves...(figure 23)

EXPOSURE PROTECTION

Push Emergency shutdown devices of the concerned aera

As it is possible:

Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storages (each one from the others).

Check and note every ESD or valve turned off on the emergency plan.(figures 24-25-26-27)

• Repeatedly check H2 presence in the atmosphere. If H2 is detected apply H2 leak tactic.

Stationary power generation unit
No leak no fire

INCIDENT TREATMENT
If no H2 leak and no sign of fire is detected : • engage incident settlement. DO NOT: • cut or crush H2/O2 lines • cut or crush High Voltage Lines (orange) • damage H2/O2 tank If a H2 leak is detected, apply tactic n°2 "H2 LEAK WITHOUT FIRE" Mind that Photovoltaic panels still produce high voltage electricity when exposed to daylight.
OVERHAUL
• after a last H2 atmospheric control, Make sure that the application will be checked be authorized personnels before restart.

23.2. H2 Leak without fire

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 14	H2 LEAK WITHOUT FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

• assure the precise incident location and the concerned power

• is this stationary power generation unit kwown by the fire service?

• Does a firefighting plan exists? take it in the fire equipment and read it on the road.

witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

• are there any person involved in the incident?

• what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

• wind direction

• wind speed

ITINERARY

choose a safe itinerary :

• do not cross an eventual explosive gas cloud

• do not reach scene from bellow

• anticipate the need of a hydrant

Stationary power generation unit H2 leak without fire

TAKE FOLLOWING TOOLS:

• Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident .

If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

if H2/O2 storage is concerned:

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

• Set up a safety area for the public beyond a radius of twice the height of the wind turbine .

if fuel cell or electrical devices is concerned:

• Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

Stationary power generation unit H2 leak without fire

SIZE UP THE SCENE
• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS : o what has happened? o witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, ...) o Is someone injured? Threatened? o Has a leak occured? Is a leak still occuring? is the system delivering electricity? Is a technician present on the plant area? look for the mergency fire and rescue plan. locate precisely dangerous areas, Emergency shutdown devices, valves, evaluate the amount of compressed gases present in the tanks.
RESCUE
Rescue of humans override all other considerations. If a human is threatened or concerned by the Fire : • Team 1 : extract the victim(s) from the danger zone by any possible means • Team 2 : stretch a fire hoseline to protect the action of the Team 1 evacuate the passengers in the opposite direction of the wind
EXPOSURE PROTECTION
note that a SPGU is supposed to produce electricity as soon as it is no longer supplied by the electrical network. So it is necessary to stop the electrical production of the SPGU before any other action by Pushing Emergency shutdown devices. As it is possible: Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storages (each one from the others). Check and note every ESD or valve turned off on the emergency plan. • Repeatedly check H2 presence in the atmosphere.

Stationary power generation unit H2 leak without fire

INCIDENT TREATMENT
If no H2 leak and no sign of fire is detected : • engage incident settlement. DO NOT: • cut or crush H2/O2 lines • cut or crush High Voltage Lines (orange) • damage H2/O2 tank Fire services are not supposed to open the Fuel Cell comparment. Locate precisely the H2 leak if located in an building, operate a wide ventilation of all concerned premises. according to information provided by the emegency plans and the validation of the thechnicans (if available), close appropriate valves, ESD... • Repeatedly check H2 presence in the atmosphere. Mind that Photovoltaic panels still produce high voltage electricity when exposed to daylight. Mind that H2 and O2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.(figures 31-32)
OVERHAUL
• after a last H2 atmospheric control, Make sure that the application will be checked be authorized personnels before restart.

23.3. Fire

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 15	FIRE	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

• assure the precise incident location and the concerned power

• is this stationary power generation unit kwown by the fire service?

• Does a firefighting plan exists? take it in the fire equipment and read it on the road.

witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

• are there any person involved in the incident?

• what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

• wind direction

• wind speed

ITINERARY

choose a safe itinerary :

• do not cross an eventual explosive gas cloud

• do not reach scene from bellow

• anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

• Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident .

If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

if H2/O2 storage is concerned:

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

• Set up a safety area for the public beyond a radius of twice the height of the wind turbine .

if fuel cell or electrical devices is concerned:

• Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?Which ones?

is the system delivering electricity?

Is a technician present on the plant area?

look for the mergency fire and rescue plan.

locate precisely dangerous areas, Emergency shutdown devices, valves,

evaluate the amount of compressed gases present in the tanks.

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the Fire :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate the passengers in the opposite direction of the wind

EXPOSURE PROTECTION

• evacuate adjacent buildings

• Prevent the fire from spreading to uninvolved buildings

note that a SPGU is supposed to produce electricity as soon as it is no longer sullpied by the electrical network.

So it is necessary to stop the electrical production of the SPGU before any other action by Pushing Emergency shutdown devices.

As it is possible:

Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storages (each one from the others).(figure 33)

Check and note every ESD or valve turned off on the emergency plan.

• Repeatedly check H2 presence in the atmosphere.

INCIDENT TREATMENT

3 cases are possible:

The fire concerns the photovoltaic panels or wind turbine area.

Push Emergency shutdown devices

prevent the fire to spread to a uninvolved part of the plant with water spray curtains.

put the fire out.

the fire concerns the Fuel cell Compartment.

Push Emergency shutdown devices

prevent the fire to spread to a uninvolved part of the plant with water spray curtains.

do not open the FC comparment.

the fire concerns the storage area.(High stake level situation)

Push Emergency shutdown devices

prevent the fire to spread to a uninvolved part of the plant with water spray curtains.

put the fire out with an offensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

- Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks
- Team 2: aims to extiguish the fire.

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

Previosly, the incident commander must have took appropriate actions to prevent pressure increase in the tanks and checked the efficiency.

Mind that H2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.

Stationary power generation unit FIRE

Mind that violent reactions are possible between water and burning materials

Mind that water will be polluted during extinction

operate its containement.

In there is no identified stake:

evaluate the opportunity to let the fire burn safely.

OVERHAUL

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- Repeatedly check H2 presence in the atmosphere.

23.4. External Fire threatening the application

Stationary power generation unit (SPGU) Hydrogen-based energy storage system (H2ESS)		
Tactic n° 16	EXTERNAL FIRE THREATENING THE APPLICATION	

AT THE FIRE STATION

TAKE USEFUL information ABOUT THE INCIDENT:

• assure the precise incident location and the concerned power

• is this stationary power generation unit kwown by the fire service?

• Does a firefighting plan exists? take it in the fire equipment and read it on the road.

witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

• are there any person involved in the incident?

• what happened?

TAKE USEFUL INFORMATION ABOUT THE METEOROLOGICAL SITUATION:

• wind direction

• wind speed

ITINERARY

choose a safe itinerary :

• do not cross an eventual explosive gas cloud

• do not reach scene from bellow

• anticipate the need of a hydrant

TAKE FOLLOWING TOOLS:

• Gaseous hydrocarbons dectector,

• H2 detector

• O2 detector

• Thermal imaging camera

ARRIVAL ON SCENE

ARRIVAL :

• Choose a safe way to get to the incident ground, preventing the fire equipment to cross a flammable gas cloud, and make sure to arrive upwind.

• Stop the fire equipment 50 meters (55 yd) before the incident .

If a wind turbine is concerned, stop at a distance of twice the height of the wind turbine

• away from a possible ignited flammable liquid leak progression.

• Engage the pump and connect the fire equipment to a hydrant.

SAFETY AREA

if H2/O2 storage is concerned:

• Set up a safety area for the public beyond a radius of 500 meters (550 yd)

if a wind turbine is concerned:

• Set up a safety area for the public beyond a radius of twice the height of the wind turbine .

if fuel cell or electrical devices is concerned:

• Set up a safety area for the public beyond a radius of 50 meters (55 yd)

• Ensure that unauthorized/untrained personnel do not enter the hazardous area

SIZE UP THE SCENE

• BY QUESTIONNING THE WITNESSES, TECHNICAL STAFF OF THE SPGU/H2ESS AND OBSERVATION, ANSWER THE FOLLOWING QUESTIONS :

o what has happened?

o witch part of the application is concerned by the incident? (Fuel cell, H2/O2 storage, photovoltaic panels, wind tubine...)

o Is someone injured? Threatened?

o Has a leak occured? Is a leak still occuring?

is the system delivering electricity?

Is a technician present on the plant area?

look for the mergency fire and rescue plan.

locate precisely dangerous areas, Emergency shutdown devices, valves,

evaluate the amount of compressed gases present in the tanks.

RESCUE

Rescue of humans override all other considerations.

If a human is threatened or concerned by the Fire :

• Team 1 : extract the victim(s) from the danger zone by any possible means

• Team 2 : stretch a fire hoseline to protect the action of the Team 1

evacuate the passengers in the opposite direction of the wind

EXPOSURE PROTECTION

• evacuate adjacent buildings

• Prevent the fire from spreading to uninvolved buildings

note that a SPGU is supposed to produce electricity as soon as it is no longer sullpied by the electrical network.

So it is necessary to stop the electrical production of the SPGU before any other action by Pushing Emergency shutdown devices.

Stationary power generation unit External Fire

As it is possible:

Isolate (pressure, gas supply, electricity) energy production unit, fuel cell and storages (each one from the others).

Check and note every ESD or valve turned off on the emergency plan.

• Repeatedly check H2 presence in the atmosphere.

INCIDENT TREATMENT

2 cases are possible:

The fire threats the Fuel cell Compartment, the photovoltaic panels or wind turbine area.

Push Emergency shutdown devices

prevent the fire to spread to a uninvolved part of the plant with water spray curtains.

put the fire out.

do not open the FC comparment.

the fire concerns the storage area.(High stake level situation)

Push Emergency shutdown devices

prevent the fire to spread to a uninvolved part of the plant with water spray curtains.

put the fire out with an offensive Fire attack:

each Team prepare 80 m of hoselines directly connected to the fire equipment pump

• Team 1: aims to cool the H2 tank to prevent pressure increase in the tanks

• Team 2: aims to extiguish the fire.

if the fire concerns an ignited H2 leak, the only safe way to put out the fire is to close the appropriate valve.

Previosly, the incident commander must have took appropriate actions to prevent pressure increase in the tank an checked the efficiency.

Stationary power generation unit External Fire

Mind that H2 storages are equiped with Pressure release devices that may open and close several times depending the pressure inside the tank.

Mind that violent reactions are possible between water and burning materials

Mind that water will be polluted during extinction

operate its containement.

In there is no identified stake:

evaluate the opportunity to let the fire burn safely.

OVERHAUL

- Cool the wreckage as soon as no heat point is detected by the thermal imaging device.
- Repeatedly check H2 presence in the atmosphere.

Stationary power generation unit External Fire

Figure 29 Main electrical Emergency ShutDown © Areva/ENSOSP 2015

Figure 30 Example of emergency plan (1) ©areva

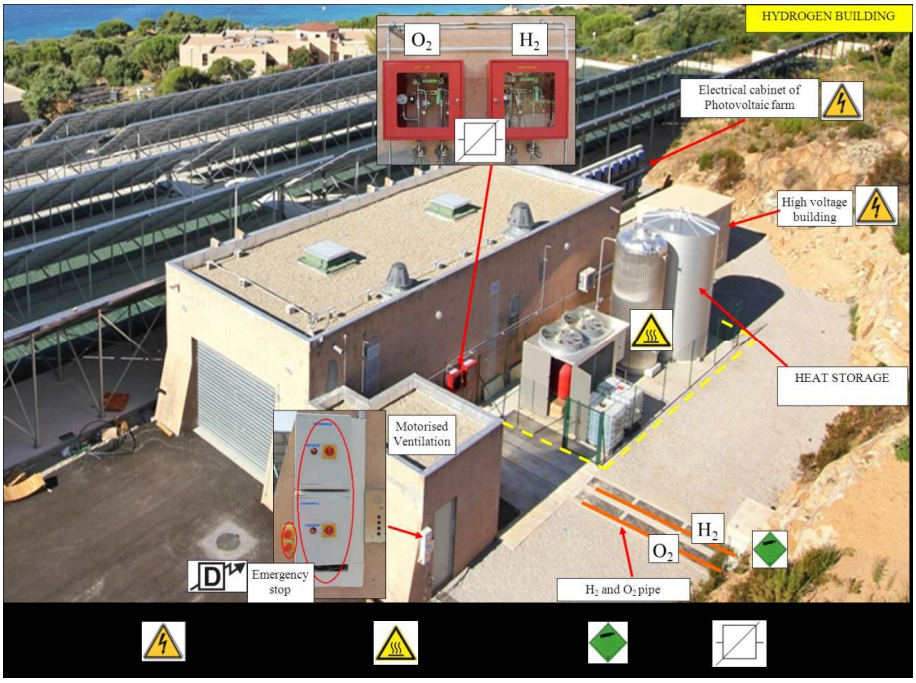


Figure 31 Example of emergency plan (2) ©areva

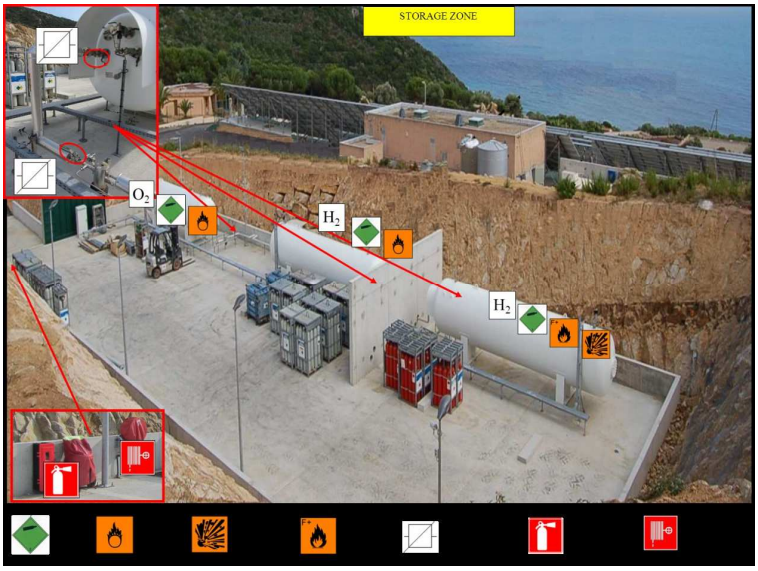


Figure 32 Example of emergency plan (3) ©areva

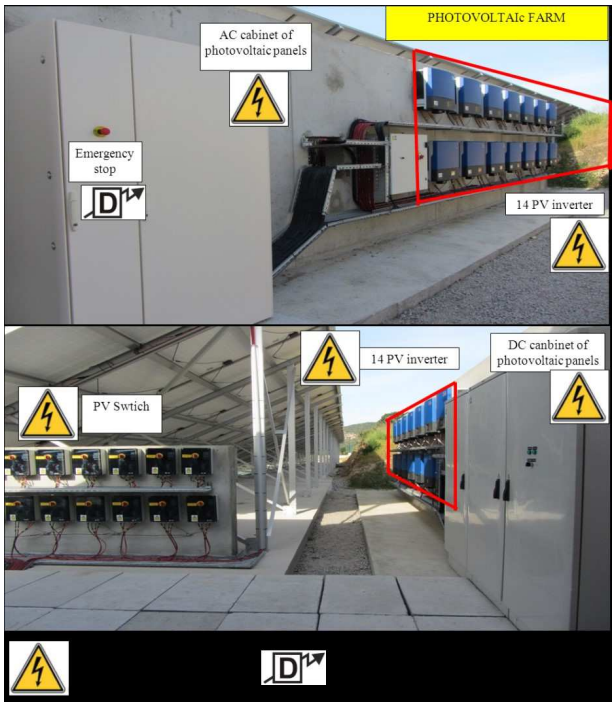


Figure 33 Example of emergency plan (4) ©areva

Figure 34 Areva backup System global view ©AREVA/Ensosp 2015

Figure 35 Areva backup System (fuel cell compartment) ©AREVA/Ensosp 2015

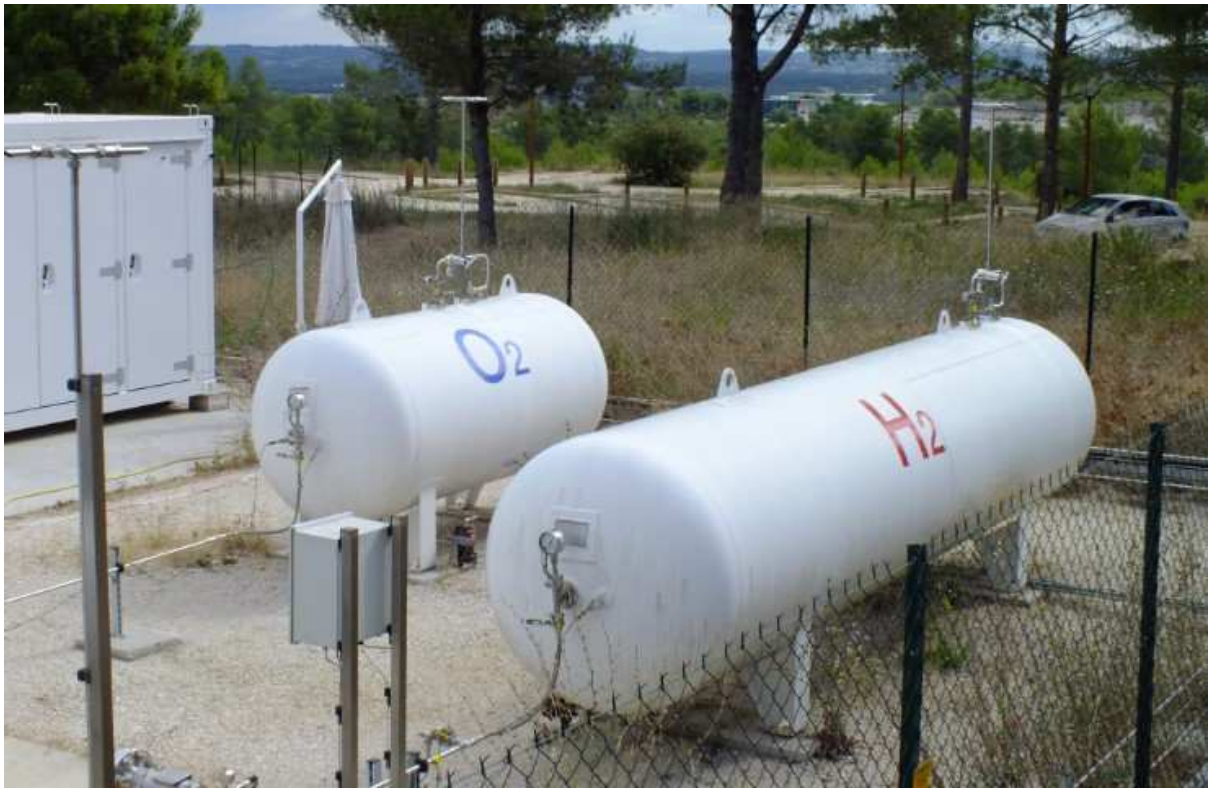


Figure 36 Areva backup System (H2 and O2 storages) ©AREVA/Ensosp 2015

Figure 37 Areva backup System (pressure release devices) ©AREVA/Ensosp 2015

Figure 38 Areva backup System (pressure release device detail) ©AREVA/Ensosp 2015

Figure 39 Figure 35Areva backup System (H2 and O2 network detail with valves) ©AREVA/Ensosp 2015

Figure 40 Emergency shutdown and h2/o2 valves on a areva greenbox ©AREVA/Ensosp 2015

Appendices (UU)

Appendix 1. Informative hazard distances for non-reacting hydrogen jets

The nomogram for graphical evaluation of hydrogen concentration decay in momentum-dominated hydrogen jet based on the similarity law and the under-expanded jet theory without losses is shown in Figure A1.1 [5]. The nomogram consists of four main graphs entitled: “Volumetric to mass fraction”, “The similarity law”, “Choose leak diameter”, and “Choose density in the nozzle exit”, and one additional graph “Calculate density in the nozzle exit by storage tank pressure and temperature” (based on calculations by the under-expanded jet theory without losses).

The use of the nomogram for the calculation of the distance from the nozzle (for example 1 mm in diameter) to the 4 vol. % of hydrogen in air (blue-coloured dash line) along the axis of the release from a storage tank at a pressure of 70 MPa and temperature 300 K is demonstrated below.

1. Draw the vertical line downward from the point on the horizontal axis “Hydrogen volumetric fraction”, corresponding to the concentration of interest (4 vol. % or 0.04), until the intersection with the line of the graph “Volumetric to mass fraction” (left-hand, top corner on Figure A1.1).
2. Draw the horizontal line from this intersection point to the intersection with the similarity law line on the right-hand top corner graph “The similarity law” (Figure A1.1).
3. Draw the vertical line downward from the intersection point obtained on “The similarity law” graph until the intersection with line corresponding to 1 mm diameter on the graph “Choose leak diameter” (Figure 1). Please note that there are eight lines on the “Choose leak diameter” graph, which correspond to the following leak diameters (from top to bottom): 15 mm, 10 mm, 5 mm, 3 mm, 2 mm, 1 mm, 0.5 mm, 0.1 mm). These figures are shown at the right side of the graph.
4. Calculate the density using the additional graph “Calculate density in the nozzle exit by storage tank pressure and temperature” located at the bottom of the nomogram using given pressure (70 MPa) on the ordinate axis and a line corresponding to the chosen temperature (300 K). This is shown by two thick grey arrows on the “Calculate density in the nozzle exit by storage tank pressure and temperature” graph. The density calculated graphically at the nozzle exit for 70 MPa and 300 K is about 23 kg/m^3.
5. Draw the horizontal line from the intersection point on “1 mm” line obtained of the “Choose leak diameter” graph to the left-hand graph entitled “Choose density in the nozzle exit” until the intersection with an imaginary line corresponding to 23 kg/m^3 (located between two lines, 20 kg/m^3 and 50 kg/m^3, shown on the graph). Please note that there are five lines at the graph corresponding to the densities of 1 kg/m^3, 3 kg/m^3, 10 kg/m^3, 20 kg/m^3, and 50 kg/m^3 from top to bottom, respectively. These values are shown at the left side of the graph.

6. Draw the vertical line downward from the intersection point with the imaginary line corresponding to 23 kg/m^3 to the intersection with the abscissa axis 'Distance to concentration of interest' on the "Choose density in the nozzle exit" graph. Thus, the calculated graphically distance from the nozzle exit to hydrogen concentration of 4% by volume is about 7.7 m.

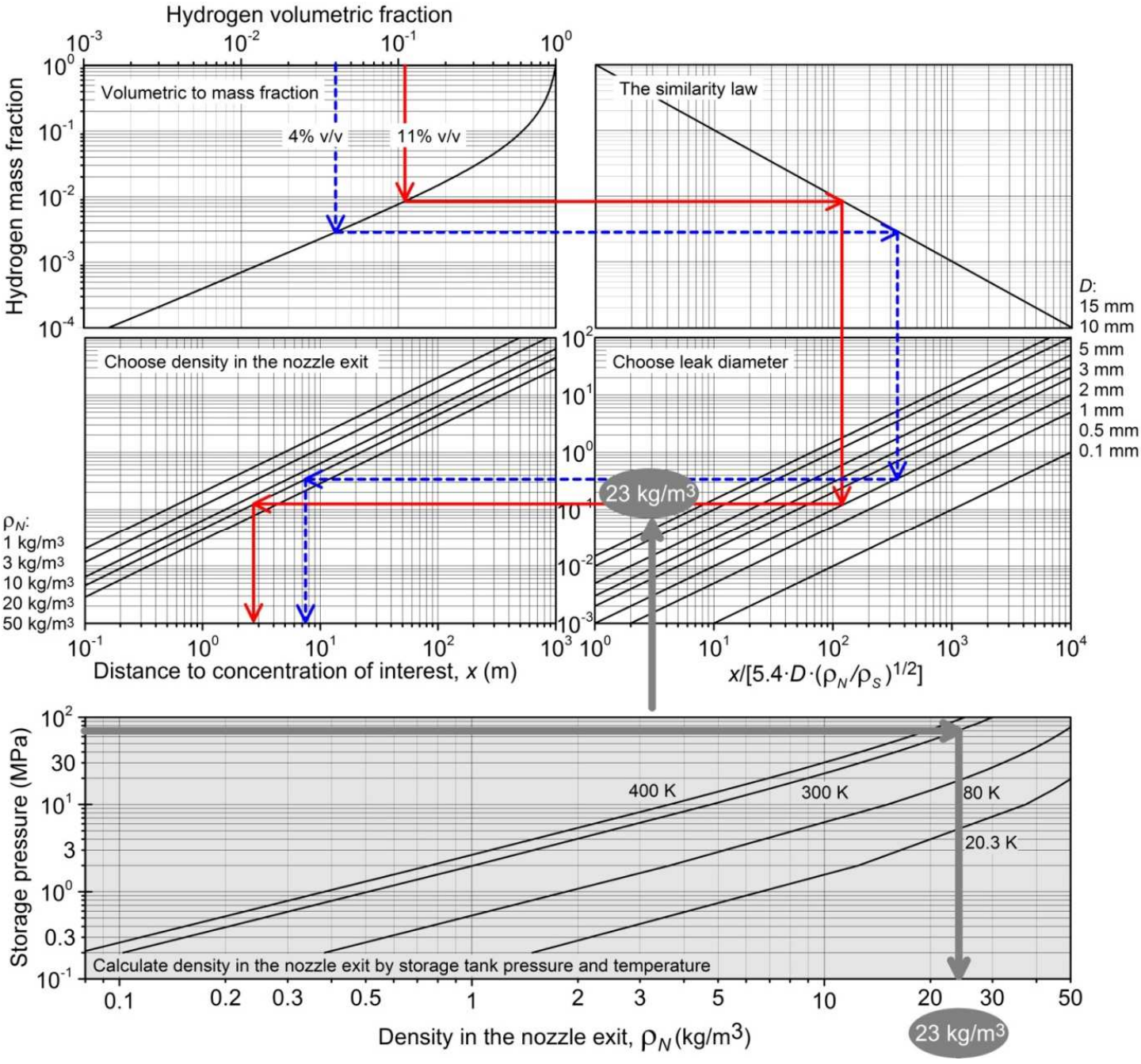


Figure A1.1. The nomogram for concentration decay calculation in unignited jets [5].

The use of the equation (2) for the similarity law with more accurate value of hydrogen density at the nozzle calculated by the under-expanded jet theory (23.95 kg/m^3) and air density of 1.205 kg/m^3 (NTP) gives a distance of 8.36 m for 4 vol. % of hydrogen in air. The error of graphical calculations is at the acceptable level and below 10% [5].

Appendix 2. Informative hazard distances for hydrogen jet fires

The parameters needed to predict the flame length using the nomogram in Figure A2.1 [5] are those at the actual nozzle exit only. This means that calculation of flow parameters at the notional nozzle exit is not required.

The dimensionless flame length, L_F/d increases for laminar and transitional to turbulent regime flames (traditional buoyancy-controlled jet flame regime), then it is practically constant for transitional and fully developed turbulent expanded flames (traditional momentum-dominated jet flame regime) and finally it increases again for under-expanded jets (under-expanded momentum-dominated jet flame regime). To use the last part of the curve, the application of the under-expanded jet model is required.

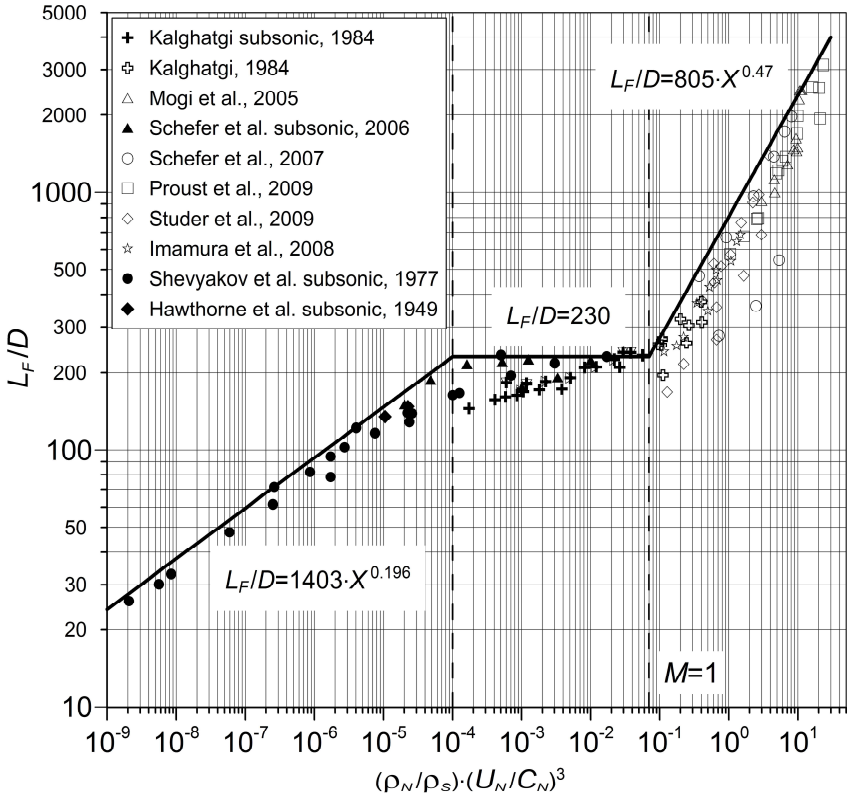


Figure A2.1. The dimensionless correlation for the flame length [5].

In Figure A2.1:

Y-axis: L_f/d_n where L_f - flame length, m; d_n – real nozzle diameter, m.

X-axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ where

- ρ_N - the density at the nozzle exit, can be found for under-expanded jets using the under-expanded-jet theory [5] or lower graph in the nomogram in Figure A1.1; and for expanded jets is equal to 0.0838 kg/m^3 at NTP,

- Iρ_S – the density of the surrounding air, equal to 1.205 kg/m^3 for air at NTP,
- C_N - the speed of sound in hydrogen at the nozzle exit parameters, U_N - the velocity of the hydrogen at the jet exit, $U_N = C_N$ for sonic and supersonic jets. For subsonic jets:

$$U_N = \sqrt{2\frac{\Delta P}{\rho}}$$

The three hazard distances for jet fire are defined as follows (:

- "no harm": 70 °C for any duration (this hazard distance equal to 3.5 times the flame length $x=3.5\ L_f$);
- "pain" limit: 115 °C for 5 min exposure (this hazard distance equal to 3 times the flame length; $x=3L_f$);
- "fatality" limit: 309 °C, third degree burns for 20 seconds exposure (this hazard distance equal to 2 times the flame length $x=2L_f$).

Appendix 3. Informative hazard distances for catastrophic rupture of high pressure hydrogen tank in a fire

The methodology [22] allows determine hazard distances for humans and buildings from a rupture of high-pressure hydrogen tank in a fire (either stand-alone tank or onboard tank). The methodology was applied to build the nomograms for graphical finding hazard distances from stand-alone (Figure A3.1) and under-vehicle (Figure A3.2) tank rupture in a fire.

The temporary loss of hearing described by Baker et al. [23] that occurs at overpressure above 1.35 kPa and impulses above 1 Pa·s will be considered as a threshold for "No harm" to humans. The thresholds for "injury" and "fatality" for humans and the thresholds for buildings were adopted from Mannan [24] are represented in Table 8 and 2.

Table 8. Thresholds of overpressures for humans harm (outdoors)

Effect	Overpressure, kPa
1% probability of eardrum rupture (chosen as "injury")	16.5
1% probability of fatality-lung haemorrhage (chosen as "fatality")	100

Table 9. Thresholds of overpressure for buildings damage

Damage	Overpressure, kPa
Minor damage of the house [3] (chosen as "minor damage")	4.8
Partial demolition of the house-remains inhabitable [3](chosen as "partial demolition")	6.9
Almost total destruction of the house [3] (chosen as "almost total destruction")	34.5-48.3

The harm criteria for humans and buildings described above are used further in the nomograms for determination of the hazard distances from a rupture of stand-alone and under-vehicle high-pressure hydrogen tanks of different volume with different pressure.

RUPTURE OF A STAND-ALONE TANK IN A FIRE

Figure A3.41 represents two nomograms allowing to find the hazard distances from a stand-alone tank rupture in a fire to humans (of different severity, i.e. "no harm", "injury" and "fatality") and to buildings (of different damage, i.e. "minor damage", "partial demolition" and "almost total destruction").

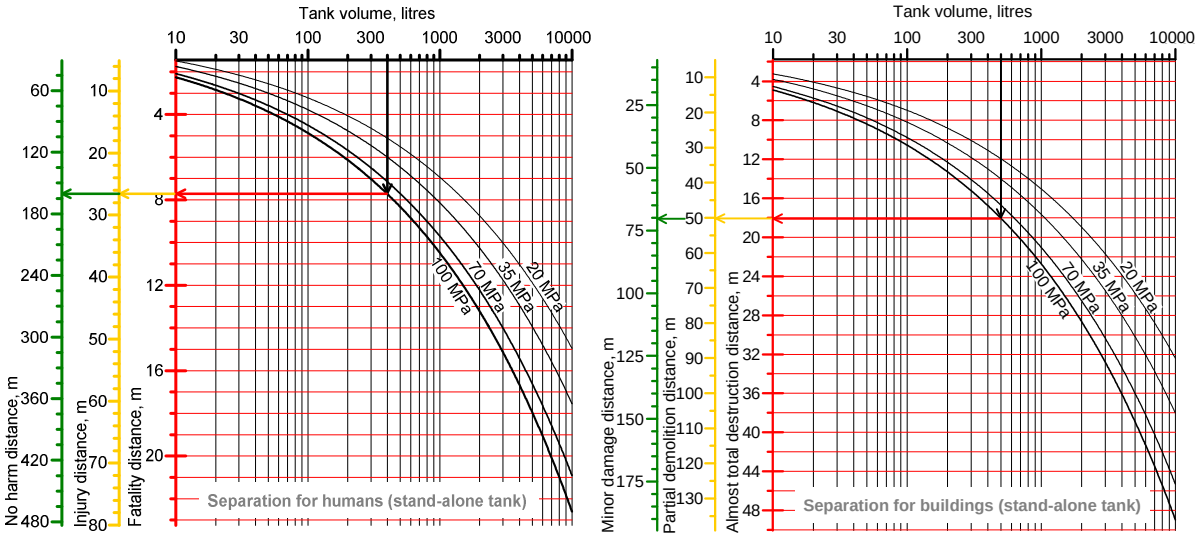


Figure A3.41. Nomograms for determination of hazard distances from stand-alone tank rupture: distances to humans (left) and distances to buildings (right).

One may use the nomogram as follows. For instance, in Figure A3.41 (left) let us choose the hydrogen tank volume of 500 L and internal tank pressure (see the curves) of 100 MPa (shown with black arrow). Then, for finding the “fatality” distance, the horizontal line is simply drawn towards the axes on the left (shown with red arrow). The first red axis gives the “fatality” distance (7.7 m). To find “injury” and “no harm” distances, the line should be simply extended to the yellow and green axes respectively. For the case under consideration the injury distance is 26.5 m and no harm distance is 160 m.

RUPTURE OF AN UNDER-VEHICLE TANK IN A FIRE

Figure A3.42 depicts two nomograms used for determination of hazard distances for under-vehicle tank rupture in a fire.

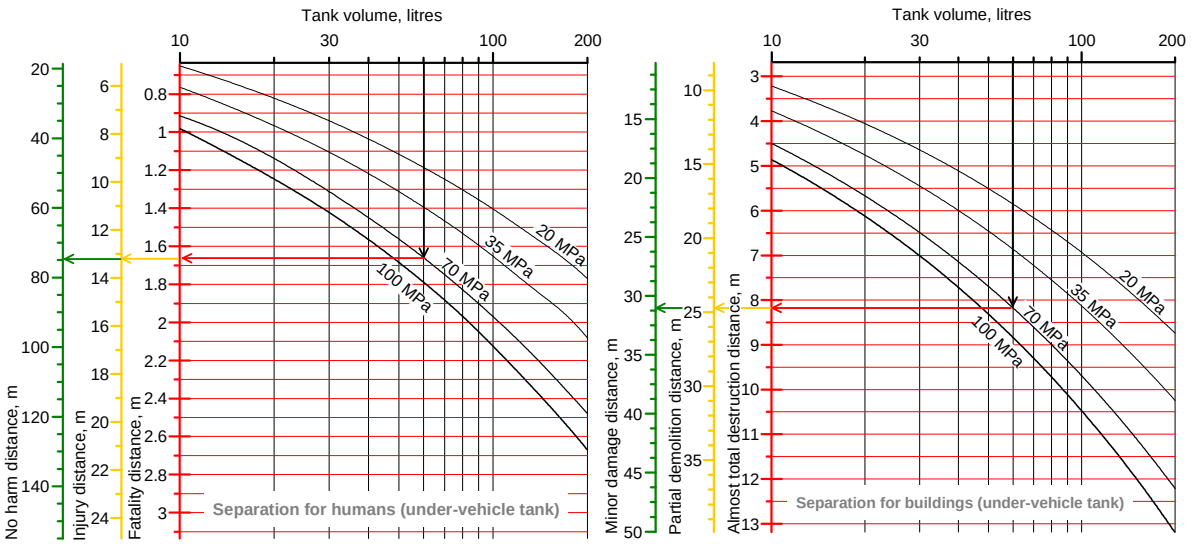


Figure A3.42. Nomograms for determination of hazard distances from under-vehicle tank rupture: distances to humans (left) and distances to buildings (right).

Glossary

Accident is an unforeseen and unplanned event or circumstance [5].

Acceptance criteria are terms of reference against which the performance of a design is assessed [5].

Blowdown is a process where the storage pressure decreases with time during a leak [5].

Consequences are expected effects from the realisation of the hazard and severity, usually measured in terms of life safety exposure, property damage and environmental impact [5].

Deflagration and **detonation** are propagation of a combustion zone at a velocity that is respectively less than and greater than the speed of sound in the unreacted mixture [5].

Deterministic study is a methodology, based on physical relationships derived from scientific theories and empirical results that, for a given set of initial conditions, will always produce the same outcome [5].

Emergency shutdown are control system actions, based on process parameters, taken to stop the fuel cell power system and all its reactions immediately to avoid equipment damage and/or personnel hazards [25].

First responder is an employee of an emergency service (e.g. fire-fighters, police, medical personnel), who is likely to arrive first to/assess a scene of an accident/incident.

Forced ventilation is a movement of air and its replacement with fresh air by mechanical means [5].

Flammability range is the range of concentrations between the lower and the upper flammability limits [5].

Fuel Cell (FC) is an electrochemical generator that produces electricity by the conversion of chemical energy into electrical. In the case of a hydrogen-fed FC, oxygen and hydrogen are combined to produce electricity, heat and water. FC is made of two electrodes (positive (cathode) and negative (anode)) immersed in an electrolyte solution, which provides a transfer of the ions in both directions, while a corresponding flow of electrons in an external circuit provides electricity [26].

Incident is something that occurs casually in connection with something else [5].

Lower flammability limit (LFL) is the lowest concentration and the **upper flammability limit** (UFL) is the highest concentration of a combustible substance in a gaseous oxidizer that will propagate a flame [5].

Natural ventilation is a movement of air and its replacement with fresh air due to the effects of wind and/or temperature gradients [25].

Minimum Ignition Energy (MIE) of flammable gases and vapours is the minimum value of the electric energy, stored in the discharge circuit with as small a loss in the leads as possible, which (upon discharge across a spark gap) just ignites the quiescent mixture in the most ignitable composition [5].

Normal Temperature and Pressure (NTP) conditions are: temperature 293.15 K and pressure 101.325 kPa.

Pressure Relief Device (PRD) is a safety device that protects against a failure of a storage vessel by releasing some or the entire tank content in the event of high temperatures, high pressures or a combination of both [1].

Probabilistic study is a systematic development of numerical estimates of the expected frequency and/or consequence of potential accidents [5]**.**

Reforming is a process of producing a hydrogen-rich gas mixture from a raw fuel for eventual use in a fuel cell [25].

Risk is a combination of the probability of an event and its consequence [5]**.**

Scenario is a set of circumstances, chosen as an example that defines the development of accident [5]**.**

Hazard distance is a distance from the (source of) hazard to a determined (by physical or numerical modelling, or by a regulation) physical effect value (normally, thermal or pressure) that may lead to a harm condition (ranging from “no harm” to “max harm”) to people, equipment or environment [ISO19880-1].

Strategy is a stable notion decided at a political level, according to the risk sociological acceptance. Choosing a strategy to deal with a type of incident is tightly linked with the “Stakes assessment” notion [27].

Tactic is a variable concept decided at an operational level, according to the situation available at the present moment and in a near future [27].

Thermally Activated Pressure Relief Device (TPRD) provides a controlled release of the GH_2 from a high pressure storage container before its walls are weakened by high temperatures, leading to a catastrophic rupture [1].

Under-expanded jet is a jet with a pressure at the nozzle exit which is above atmospheric pressure [5]**.**

Water electrolysis is a process, in which water is split into hydrogen and oxygen using electrical energy [26].

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