



European Train the Trainer Programme for Responders

Lecture 6

Harm criteria for people and property

LEVEL I

Firefighter

The information contained in this lecture is targeted at the level of **Firefighter** and above.

This topic is also available at level II, III and IV

This lecture is part of a training material package with materials at levels I – IV :

This lecture is part of a training material package with materials at levels I – IV :
Firefighter, crew commander, incident commander and specialist officer. Please see the lecture introduction regarding competence and learning expectations

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FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Lecture 6: Harm criteria for people and property

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FUEL CELLS AND HYDROGEN
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Summary

This lecture provides responders with valuable information on the impact of hydrogen leaks, fires and explosions on the health and environment of humans. It also considers the damage to structures and equipment caused by hydrogen fires and overpressure events.

Keywords

Hydrogen accident, thermal radiation, overpressure, harm criteria, personal protective equipment

Table of contents

Summary	3
Keywords	3
Table of contents	4
1. Target audience	Error! Bookmark not defined.
1.1 Roll description: Specialist.....	Error! Bookmark not defined.
1.2 Competence level: Specialist	Error! Bookmark not defined.
1.3 Prior learning: Specialist	Error! Bookmark not defined.
2. Introduction and objectives.....	5
2. Main definitions.....	6
3. Health hazards of hydrogen releases	7
3.1 Gaseous hydrogen	8
3.2 Liquefied hydrogen	8
4. Harmful effects of hydrogen combustion on humans.....	9
4.1 Effect of air temperature	9
4.2 Effect of direct contact with hydrogen flames	9
4.3 Effect of radiant heat flux from hydrogen fires.....	9
4.4 Effect of overpressure on people.....	10
5. Damage to structures, equipment and environment caused by hydrogen fires	Error! Bookmark not defined.
6. Impact of overpressure on structures and equipment	Error! Bookmark not defined.
7. Summary of acceptance criteria for life and property	Error! Bookmark not defined.
8. Labelling of hydrogen systems	10
9. Personal protective equipment	12
10. Impact on the environment	14
Acknowledgement.....	14
References	14

Lecture 6: Harm criteria for people and property

1. Target audience

The information contained in this lecture is targeted at LEVEL 1: Firefighter. Lectures are also available at levels II, III and IV: crew commander, incident commander and specialist officer.

The role description, competence level and learning expectations assumed at crew commander level are described below.

1.1 Roll description: Firefighter

A firefighter is responsible and expected to be capable of carrying out operations safely in personnel protective equipment including breathing apparatus using equipment provided, like vehicles, ladders, hose, extinguishers, communication and rescue tools, under any climatic conditions in areas and to emergency situations which can be reasonably anticipated as requiring a response.

1.2 Competence level: Firefighter

Trained in the safe and correct use of PPE, BA and other equipment which it is expected they will operate first responders must be supported by appropriate knowledge and practice. Behaviours that will keep them and other colleagues safe should be described by Standard Operating Procedures (SOP). Practiced ability to dynamically assess risk to self and others safety is required.

1.3 Prior learning: Firefighter

EQF 2 Basic factual knowledge of a field of work or study. Basic cognitive and practical skills required to use relevant information in order to carry out tasks and to solve routine problems using simple rules and tools. Work or study under supervision with some autonomy.

2. Introduction and objectives

The primary concern of hydrogen safety is the protection of life and property. Thus, it is important to establish the criteria for operators, users, members of the public, as well as for Responders, who may be affected by the consequences of an incident or accident on a FCH system or infrastructure. The acceptance criteria for customers and personnel involved in the operation, inspection and maintenance of FCH facilities and infrastructure will be similar, whilst for the general public, who happened to be in a vicinity of an incident/accident, the approach should be more conservative. According to British Standard BS 7974 (2004) fire fighters are considered as a separate category of those affected. They are not present at FCH facility when incident/accident occurred and often arrive to the scene when conditions are the most hazardous and they must carry out their professional duties. They are vulnerable to the possible collapse of the buildings/structures and the consequences of the blast wave. Also, because they are equipped with special personal protective equipment (PPE) they can withstand higher levels of thermal radiation and temperatures as well as asphyxiating and toxic atmospheres. In addition, the location of a person within the FCH infrastructure at the time of an incident/accident is very important. Indeed, the effects of hydrogen incident/accident can be

Lecture 6: Harm criteria for people and property

immediate and will impact people differently, depending on their proximity to the source of harm. People located indoors are more likely to be affected by the blast wave compared to those positioned outdoors.

It is beyond the scope of the HyResponder project to provide harmonized harm criteria or threshold values to characterise the potential impacts of hazardous phenomena. Any interested stakeholders should utilise the standards applicable to their own country.

By the end of this lecture Responders will be able to:

- Describe main health hazards associated with the unignited releases, physical explosion (compressed vessel rupture), fires, deflagrations and detonations of gaseous and liquefied hydrogen;
- Define harmful effects related to unignited hydrogen releases in confined spaces:
 - the noise level;
 - effect of hydrogen temperature;
 - effect of overpressure in case of pressure peaking phenomenon.
- Define the harmful effects of hydrogen combustion on humans:
 - effect of combustion atmosphere temperature;
 - exposure to radiant heat flux;
 - effect of overpressure.
- Appreciate the principles and implementation of framework of harm criteria for people and environment, damage criteria for structures and equipment:
 - air temperature;
 - thermal dose;
 - heat flux;
 - overpressure, etc.
- Specify dangerous and Lethal Dose, 50% (LD50) thermal dose levels;
- Distinguish between direct and indirect harmful effects of overpressure on humans;
- Relate in particular the damages to structures, equipment, and environment caused by hydrogen fires/blast waves to the levels of radiant heat flux and overpressure;
- Recognise labelling systems for gaseous and liquefied hydrogen storage on hydrogen and fuel cell applications;
- List the items of personal protective equipment that should be used not only by First Responders but also by the personnel working at a FCH facility;
- Outline the impact of hydrogen on the environment.

3. Main definitions

It is important for Responders to be able to evaluate an impact of hydrogen incidents/accidents on life safety and loss control. Several methods are available to define and assess the consequences of an incident/accident depending on its severity, exposure, duration and the

Lecture 6: Harm criteria for people and property

target under consideration (i.e. public, occupants, structures, buildings, equipment, etc.). There are some useful definitions used in the current and future lectures.

Acceptance criteria are the terms of reference, against which safe design of a FCH facility/infrastructure is assessed [1].

Incapacitation is a condition, under which humans do not function adequately and unable to escape untenable conditions [2].

Occupants are people present within the boundaries of a FCH facility/infrastructure including personnel involved in its operation and maintenance as well as the customers/visitors [1].

Place of safety is a predetermined place inside or outside an FCH facility/infrastructure, in which persons are not in immediate danger from the effect of hydrogen release, fire or explosion [1].

Public are people present outside the boundaries of an FCH facility/infrastructure.

Sensitive area is the establishment, infrastructure or equipment containing inventories of dangerous substances that can become a source of harm when targeted by a hydrogen incident/accident [1].

Survivability is the maximum exposure that may be received with a negligible statistical probability of fatality/damage and without impairment of an individual's ability to escape [1].

Tenability is the maximum exposure to hazards from a hydrogen incident/accident that can be tolerated without violating safety goals [1].

Threshold is the maximum intensity or dose for a given hazard that corresponds to a specific physiological (for humans) or structural (for structures and equipment) response [1].

4. Health hazards of hydrogen releases

Hydrogen gas is lighter than air and that is why it rises quickly and can be diluted rapidly in air during unwanted releases in an open environment. If accidental release occurs in a confined space/indoors it can harm humans by asphyxiation. In addition, hydrogen releases in the confined spaces pose dangers of explosions. Hydrogen-air mixtures are flammable due to the wide flammability range, from 4 to 75 vol. % of hydrogen. When released in air and in the presence of ignition source hydrogen will combust, producing water and heat. The probability of hydrogen being ignited following its release is very high as it has low minimum ignition energy: even static electricity discharge is sufficient to ignite hydrogen. For responders, using protective clothing to avoid static electricity discharge is not needed because static electricity discharge is sufficient to ignite hydrogen in rare cases. In case of fires, hydrogen flame is almost invisible in daylight and its temperature can reach 2000 °C. Although hydrogen flame radiates little compared to a hydrocarbon one, there is a risk for Responders to walk into the flame..

Lecture 6: Harm criteria for people and property

4.1 Gaseous hydrogen

Hydrogen gas is odourless, colourless and tasteless gas, undetectable by human senses. The use of odorants (e.g. mercaptans) in storage vessels is not possible as they can poison fuel cells. Hydrogen is not a carcinogenic substance. Hydrogen is not expected to cause mutagenicity¹, teratogenicity², embryotoxicity³ or reproductive toxicity. There is no evidence of adverse effects on skin or eyes exposed to hydrogen atmospheres. However, high pressure hydrogen jets may cut bare skin [3]. Hydrogen cannot be ingested. However, inhaled hydrogen can result in a formation of a flammable mixture within the human's lungs.

Similar to other gases, an increase in hydrogen concentration leads to a reduction of oxygen levels in air, which in turn may lead to *asphyxiation*. Hydrogen is classified as a simple *asphyxiant*; it has no threshold limit value (TLV) [4]. High concentrations of hydrogen in air, in fully/partially confined spaces, lead to formation of *oxygen-deficient atmospheres*. Individuals exposed to/breathing such atmospheres may experience the following symptoms: headaches, dizziness, drowsiness, unconsciousness, nausea, vomiting, depression of all the senses, etc. An affected person may have a blue coloured skin, and under some circumstances, a death may occur. If hydrogen is inhaled and the above symptoms are observed the person should be moved to fresh air; oxygen should be given if breathing is laboured, or artificial respiration should be supplied if the person is not breathing.

4.2 Liquefied hydrogen

Liquefied hydrogen is stored/used at extremely low temperatures due to its low boiling point (-253 °C). Health hazards associated with the release of liquefied hydrogen are outlined below.

- Contact with liquid hydrogen or its splashes on the skin or in the eyes can cause serious cold burns by *frostbite or hypothermia*.
- *Cryogenic burns* can also result from contact of unprotected parts of human body with either cold fluids or cold surfaces.
- Inhalation of cold hydrogen vapours may cause *respiratory discomfort* and can result in *asphyxiation*.
- Direct physical contact with LH₂, cold vapours or cold equipment can cause serious *tissue damage*. Momentary contact with a small amount of the liquid may not pose as great a danger of a burn because a protective film of evaporating gaseous hydrogen may

¹ The induction of permanent transmissible changes in the amount or structure of the genetic material of cells or organisms.

² Birth defects via a toxic effect on an embryo or foetus.

³ Toxic effects on the embryo of a substance that crosses the placental barrier.

Lecture 6: Harm criteria for people and property

form. Danger of freezing occurs when large amounts are spilled, and exposure is extensive⁴.

- Personnel should not touch cold metal parts and they should wear *protective clothing*. They also need to protect the affected area with a loose cover.
- *Cardiac malfunctions* are likely when the internal body temperature drops to 27°C or lower, and death may result when the internal body temperature drops lower than 15°C [5].
- *Asphyxiation* is also possible if liquefied hydrogen released and vaporised indoors.

5. Harmful effects of hydrogen combustion on humans

An inhalation of combustion products originated from conventional fuels is one of the major causes of an injury and a primary consequence of a fire. It is considered less serious in the case of hydrogen because the sole combustion product is water vapour (non-toxic, non-poisonous). However, secondary fires can produce smoke or other combustion products that present a health hazard.

5.1 Effect of air temperature

During hydrogen fire the surrounding air is heated up significantly and this can affect people located nearby. Direct contact with combusting hydrogen or hot post-flame gases resulting from combustion of hydrogen will cause severe *thermal burns*. An increase in air temperature can cause difficulty breathing or respiratory tract burns. High temperature may also lead to a collapse.

5.2 Effect of direct contact with hydrogen flames

The hydrogen flame impact on humans is similar to one by the flames of other common fuels. Direct contact with combusting hydrogen or hot post-flame gases resulting from combustion of hydrogen will cause severe burns [11].

5.3 Effect of radiant heat flux from hydrogen fires

A hydrogen flame radiates significantly less heat compared to hydrocarbon one and is practically invisible in a broad daylight. The maximum wavelength of its emission is about 311 nm, which is near ultraviolet (UV) part of radiation spectrum [11]. This means that people located near a hydrogen flame might not sense its proximity until they are in contact with it [11]. Without suitable detection equipment, the first indication of a small flame is likely to be a “hissing” noise of the gas escaping through an orifice and perhaps appearance “heat ripples” [11].

⁴ Effect of liquid nitrogen:

<https://www.youtube.com/watch?v=F9dhZJQk80A&feature=youtu.be&t=291>

Lecture 6: Harm criteria for people and property

Please note that a hydrogen flame radiates minimum of infrared radiation and virtually no visible radiation.

For people who are not in direct contact with hydrogen flames, there is a potential of being exposed to high radiation heat fluxes for time sufficient to result in first-, second- or third-degree burns.

5.4 Effect of overpressure on people

One of the important indirect effects of overpressure results from flying fragments (aka missiles or projectiles). The level of injury will depend on the size and the weight of fragments, the impact velocity and the location of the impact on a human body [12]. The velocity of missile acceleration is the main factor causing injury. The probability of a penetration wound increases with the increase of velocity, particularly for small size missiles such as glass fragments.

6. Labelling of hydrogen systems

The pictograms for commercial transport of hydrogen are shown in Figure 1, in which “1049” denotes gaseous hydrogen, while “1966” denotes liquid hydrogen [13].

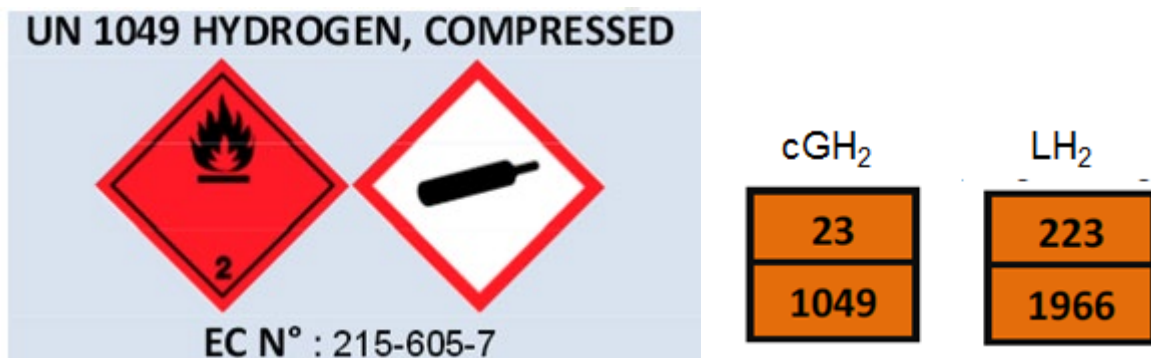


Figure 1. Examples of pictograms used for hydrogen transportation.

For FC vehicles EU regulation, No. 406/2010 recommends using green diamonds in white frames with words ‘H2 GAS’ or ‘LIQUID H2’ written in white letters [14].

The main steps in the development of symbols for formal hazard identification are presented in Figures 2 and 3. These colours are also used in Rescue Information and to colour vehicle components (Rescue Sheets).

Lecture 6: Harm criteria for people and property

GREY	DIESEL
RED	GASOLINE
GREEN	GAS
WHITE	CRYOGEN LNG
BLUE	HYDROGEN
ORANGE	HIGH VOLTAGE

SYMBOLS














- 1) FIRST ENERGY SOURCE:    CNG LNG LPG
- 2) SECOND ENERGY SOURCE:    
- 3) DENSITY COMPARED TO AIR:   
- 4) STORED AGREGATE STATE:   



Figure 2. Colours and symbols suggested by CTIF for the development of standardized signs

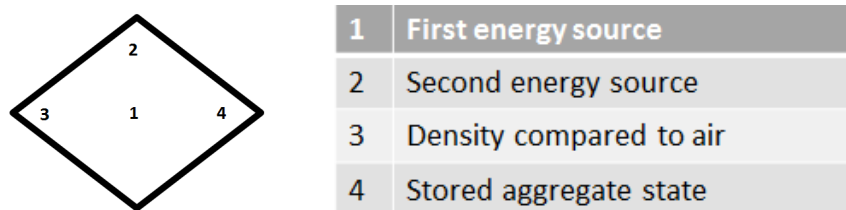


Figure 3. A diamond shape suggested by CTIF for identification of vehicle hazards [15]

Figure 4 shows the most recent version of a label for FC vehicle indicating two main energy sources: hydrogen (in the centre) and electricity in the top corner. Symbol in the left corner indicates that the first energy source (i.e. hydrogen) is lighter than air; the symbol in the right corner indicates that this is compressed gas. ISO 17840-4 provides responders with valuable information regarding dangers, which is visible from a long distance.

Lecture 6: Harm criteria for people and property



Figure 4. A symbol developed by CTIF for FC vehicle powered by compressed gaseous hydrogen [15]

The examples of symbols suggested by CTIF for other types of vehicles, traditional and hybrid ones are shown on Figure 5.

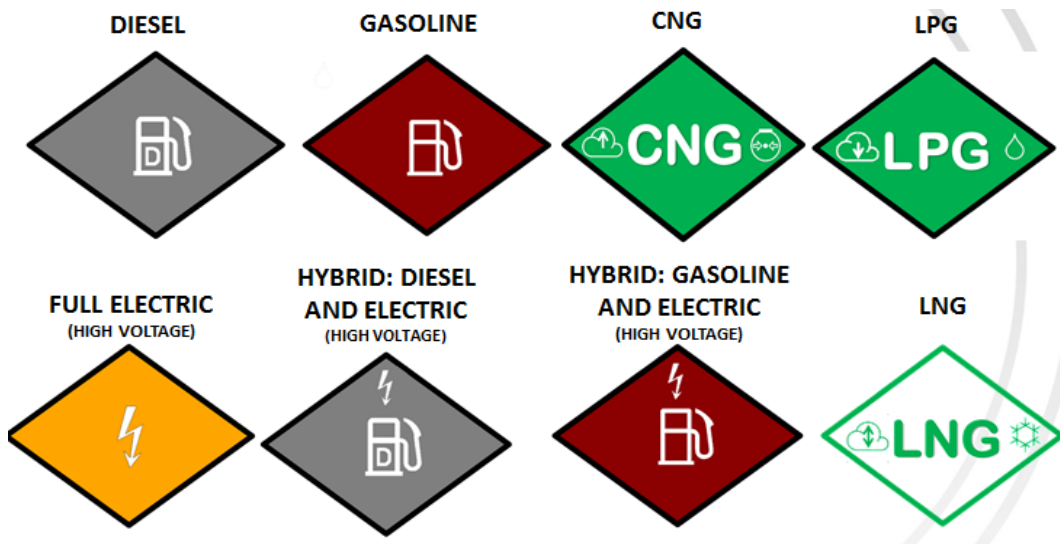


Figure 5. Symbols developed by CTIF for different types of vehicle fuels/energies [15]



Figure 6. Formal methods identification used in the US [13]

7. Personal protective equipment

Two main EU standards should be mentioned with regards to performance requirements of firefighting PPE. The (NF) EN 469:2006-02 [16] contains requirements for protective clothing for firefighters, and (NF) EN 136: 1998 [17] – those for respiratory protective devices.

Lecture 6: Harm criteria for people and property

Personnel performing operations at a hydrogen facility or system can reduce the possible consequences of a hazard by using appropriate protective equipment. Some of the conditions, for which personnel should be protected, including exposure to cryogenic temperatures, flame temperatures, thermal radiation from a hydrogen flame, and oxygen-deficient atmospheres of hydrogen or inert purge gases such as nitrogen and helium. The nature of the work determines which kind of PPE should be used. Some general guidelines for PPE were provided in ISO 15196 [11]. These guidelines do not include PPE that should be considered when involved in other activities such as working on electrical circuits or performing a cleaning or decontamination operation [11]. Necessary or mandatory parts of PPE must be selected on the basis of the conditions on-site.

- Eye protection should be worn if appropriate (e.g. a complete face shield should be worn when connecting and disconnecting lines or components or goggles during handling of LH₂).
- Properly insulated gloves should be worn when handling anything that comes in contact with LH₂ or cold GH₂. The gloves should fit loosely, remove easily, and not have large cuffs.
- Full-length trousers, preferably without cuffs, should be worn with the legs kept on the outside of boots or work shoes.
- Closed-toe shoes should be worn (open or porous shoes should not be worn).
- Clothing made of ordinary cotton, flame-retardant cotton or antistatic material should be worn. Avoid wearing clothing made of nylon or other synthetics, silk or wool because these materials can produce static electricity charges that can ignite flammable mixtures. Synthetic material (clothing) can melt and stick to the flesh, causing greater burn damage. Any clothing sprayed or splashed with hydrogen should be removed until they are completely free of hydrogen gas.
- Gauntlet gloves, tight clothing, or clothing that holds or traps (pockets) liquid against the body should be avoided.
- Hearing protection should be worn if the hydrogen facility or system involves equipment that creates loud noise.
- Hard hats/helmets should be worn if the hydrogen facility or system involves any danger from falling objects.
- Self-contained breathing equipment should be worn when working in a confined space that may have an oxygen-deficient atmosphere.
- Portable hydrogen- and fire-detection equipment should be used to warn of hydrogen leaks and fires.
- Thermal cameras and unmanned hose or monitor nozzle should be used by firemen.

Lecture 6: Harm criteria for people and property

- Personnel should ground themselves before touching or using a tool on a hydrogen system if any hydrogen is suspected to be in the area.

8. Impact on the environment

Hydrogen will not contaminate groundwater (it is a gas under normal atmospheric conditions), nor will a release of hydrogen contribute to atmospheric pollution. Hydrogen is found in terrestrial atmosphere at concentration of 0.5 ppm (parts per million) from ground level to 60 km altitude [1]. The sources of hydrogen emissions described by Schultz [18] include:

- Incomplete combustion of fossil fuels and biomass (40%),
- Atmospheric petrochemical oxidation of methane and non-methane hydrocarbons (50%),
- Emissions from volcanoes, oceans and nitrogen-fixing legumes (10%).

75% of hydrogen emissions are removed from atmosphere by dry deposition on soils while the remaining 25% are removed through oxidation in atmosphere [18].

Hydrogen when used as a fuel does not create "fumes or "smoke". A FC vehicle has zero exhaust pipe emissions [19].

Acknowledgement

The HyResponse project is acknowledged as the materials presented here are extended based on the original HyResponse lectures.

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Lecture 6: Harm criteria for people and property

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