EUROPEAN HYDROGEN SAFETY TRAINING PROGRAMME FOR FIRST RESPONDERS: HYRESPONSE OUTCOMES AND PERSPECTIVES

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ABSTRACT

The paper presents the outcomes of the HyResponse project i.e. the European Hydrogen Safety Training Programme for first responders. The threefold training is described: the content of the educational training is presented, the operational training platform and its mock-up real scale transport and hydrogen stationary installations are detailed, and the innovative virtual tools and training exercises are highlighted. The paper underlines the outcomes the three pilot sessions as well as the Emergency Response Guide available on the HyResponse's public website. The next steps for widespread dissemination into the community are discussed.

1.0 INTRODUCTION

HyResponse is a 3 years "Coordination and Support Action (CSA)" project funded in 2013 by the FCH JU for a total contribution of 1 858 572 €. This project aims to support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to First Responders, including fire, law enforcement, and emergency medical personnel) and site operators, who must know how to respond to potential incidents. Their understanding can also facilitate local approval of hydrogen projects.

The project is coordinated by the French Academy for Fire, Rescue and Civil Protection Officers (ENSOSP). Other partners of the consortium include in particular Air Liquide, the University of Ulster (UU), FAST/EHA (European Hydrogen Association), CCS Global group, CRIsis Simulation Engineering (CRISE) and AREVA Stockage d'Energie.

2.0 EDUCATIONAL TRAINING

2.1 International Curriculum on hydrogen safety training for First Responders (FRs)

The International Curriculum on hydrogen safety training is a foundation of educational training programme for First Responders. It is a basis for the development of teaching materials in: basics of hydrogen safety; regulations, codes and standards and intervention strategies and tactics. The international curriculum can be found on HyResponse's website [1].

2.2 Basics on hydrogen safety for First Responders

The educational materials developed provide the state-of-the-art in hydrogen safety science and engineering and develop science-informed training materials dedicated to FRs. It includes in particular 11 detailled lectures i.e. introduction to hydrogen and FC applications, hydrogen properties relevant to safety, safety of hydrogen storage, harm criteria for people and environment, damage criteria for structures and equipment, unignited hydrogen releases, their prevention and mitigation, sources of hydrogen ignition and prevention measures, hydrogen fires, dealing with hydrogen explosions, hazards of hydrogen use indoors. The lectures are available on HyResponse's website [1].

2.3 Regulation, Codes and Standards (RCS) materials for First Responders

The educational materials (i.e. lecture) on RCS for First Responders aim to provide First Responders with the updated RCS knowledge. The lecture is based on the review of the existing RCS in hydrogen and incorporates the latest state of the art to date in RCS status. The materials provide First Responders with the RCS knowledge of hydrogen production, storage, transportation, delivery and uses in the modern world. The lectures are available on HyResponse's website [1].

2.4 Intervention strategy and tactics for assessing accident scene status and decision making

Case studies related to FC stationary installations, hydrogen refuelling stations and storage installations, and FC vehicles have been developed to prepare First Responders prior to the operational and virtual trainings. For each FCH installation, feedbacks and lessons learned, hazardous phenomena, detailed scenarios using fault/event tree analysis accounting for positives or negative impact of the tactic conducted by the First Responders have been detailed. Pedagogic explanation on intervention strategy and tactics has been developed for each accident scenario within the case study. The case studies are available on HyResponse's website [1].

3.0 OPERATIONAL HYDROGEN TRAINING PLATFORM

3.1 Operational hydrogen training facility

An operational hydrogen training facilities has been built to train First Responders, test and validate emergency response procedures relevant to FCH systems and infrastructures accident scenarios. The finalized operational platform from different views is on the Figure 1:

Figure 1. Photos of ENSOSP's operational training facilities.

The operational platform is composed of a technical platform and six exercises areas.

3.2 Technical platform

The overall technical platform, the pilot room and control command are presented respectively on the Figures 2 and 3 below.

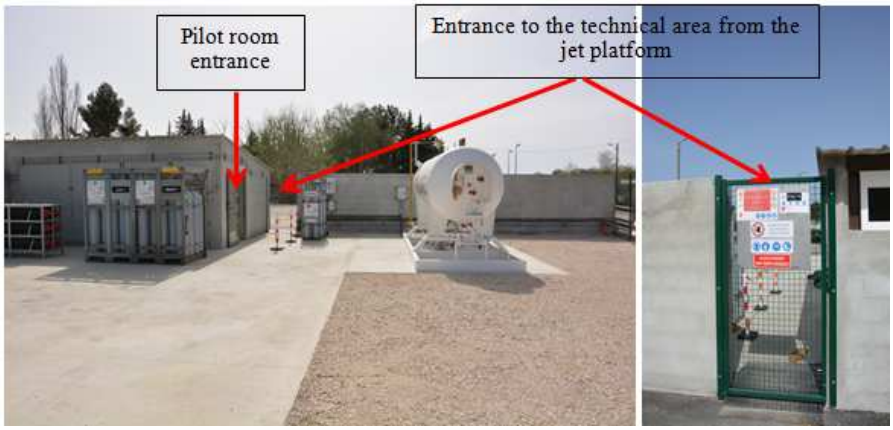

Figure 2. Technical area of the HyResponse's training platform.

Figure 3. Pilot room and its pilot console.

The technical hydrogen and nitrogen storage area is on the Figure 4.

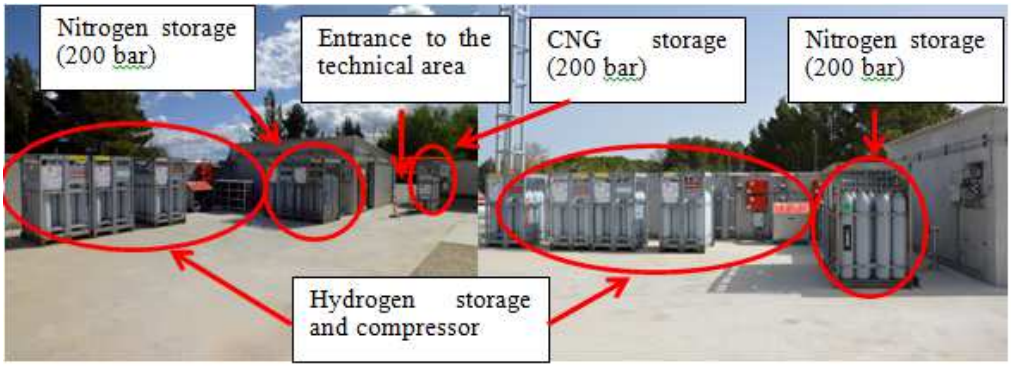

Figure 4. Hydrogen and nitrogen storage area of the technical platform.

The hydrogen 700 bar compressor and 700 bar storage are shown on the Figure 5 below.

Figure 5. Hydrogen 700 bar compressor and 700 bar storage of the technical platform.

The Figure 6 shows the LPG storage and the technical installation for the explosion platform (right).

Figure 6. LPG storage (left) and technical installation for the explosion platform (right).

3.2 Jet fire platform

The jet fire platform is able to reproduce:

- LPG jet fires at 20 bar
- CNG jet fires at 200 bar
- H2 jet fires at 700, 350 and 200 bar with 2 ignition sources (close to the release point and away from the release point)

The operational jet fire and its technical area are presented on the Figure 7.

Figure 7. Operational jet fire platform (left) and its technical area protected behind the wall (right).

The Figure 8 below show the hydrogen and LPG jet fire release nozzles and their ignition sources.

Figure 8. Hydrogen (left) and LPG (right) jet fire release nozzles and their ignition sources.

The Figure 9 shows a 20 bar LPG jet fire (left) and a 200 bar hydrogen jet fire visualized with the thermal camera (right):

Figure 9. 20 bar LPG (left) and 200 bar hydrogen jet fires (right).

3.3 700 bar hydrogen car and alternative energy car (LPG, H2, CNG, battery)

The operational platform is composed of two mock cars i.e. a 700 bar hydrogen car and an alternative energy car able to reproduce fires from different fuels and energies i.e. LPG (20 bar), CNG (200 bar), H2 (350 bar) and Battery fire. The Figure 10 shows a hydrogen flame under a mock up H2 car.

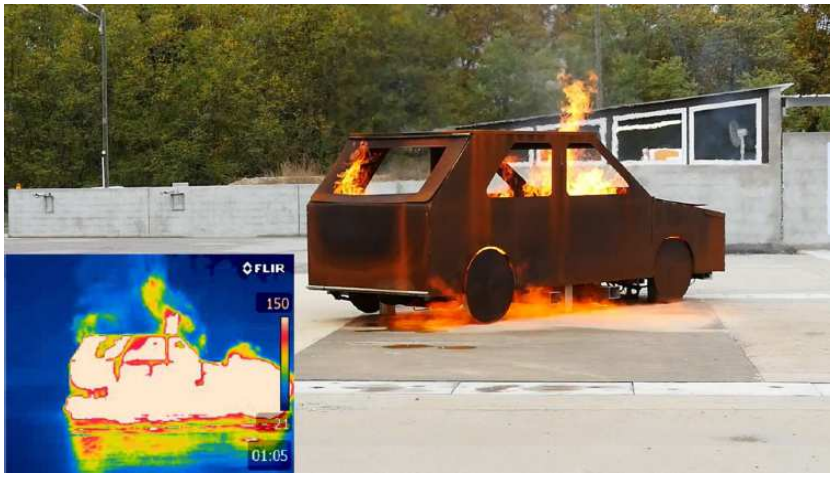

Figure 10. 700 bar hydrogen jet fire at the back of the mock-up car.

3.4 Explosion platform

The explosion platform is able to reproduce explosions of hydrogen and methane mixtures at different concentrations:

- H2: 4%, 10%, 15%, 20%, 30%, 50% (vol.)
- CH4: 4%, 9%, 12%, 15% (vol.)

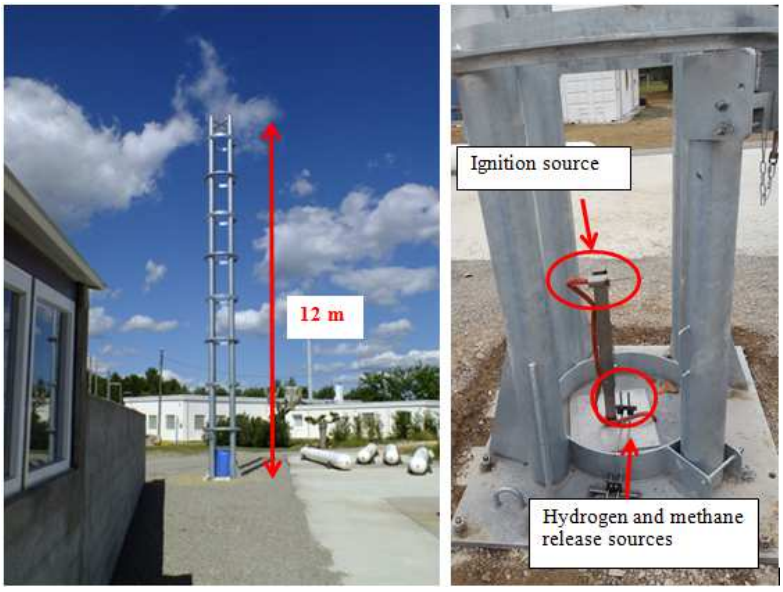

Figure 11. Explosion platform.

3.5 Dismantled H2 tube trailer

The dismantled H2 tube trailer platform is presented on the Figure 12. The 200 bar hydrogen release source from the tube trailer as well as the ignition source can be seen on the middle photo. The visualisation of a 200 bar impinging hydrogen jet fire released from the tube trailer using the thermal camera is seen on the right.

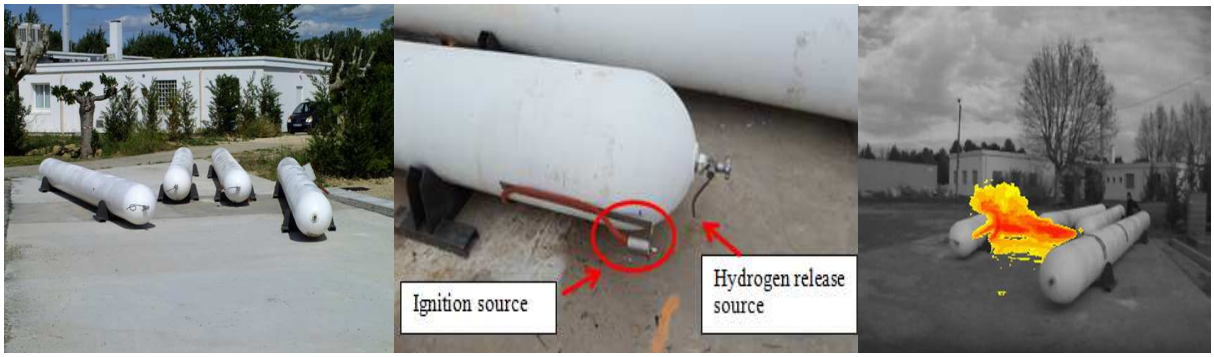

Figure 12. Dismantled H2 tube trailer training platform.

3.6 Mock-up dispenser

The Figure 13 shows the mock-up dispenser of the refuelling station. 200 bar nitrogen leaks are released at the dispenser.

Figure 13. Mock-up hydrogen dispenser at the refuelling station training platform.

3.7 Mock-up Fuel Cell and Electrolyser containerised system

The Figure 14 show the fuel cell/electrolyser platform and mock up storage (left) during a simulated fire in the Fuel Cell container (right).

Figure 14. Mock-up Fuel Cell and Electrolyser training platform.

4.0 VIRTUAL REALITY TRAINING PLATFORM

Pedagogic concepts for developing HyResponse VR training

The pedagogic concept based on which has been developed HyResponse's VR training is andragogy. Andragogy, as known as 'adults oriented pedagogy' implies a more self directing learner, less didactic and more hands on approaches, real life application focused and based on previous and acquired experience.

Using virtual reality technology (VR) enables to help answering to several expectations:

- explanation and explicitness: the production of real life foreseen problematic of H2 wide use enables to picture, and explicitly expose why specific protocols, functions, operations, etc. are needed
- task orientation and interaction: VR is the perfect tool for this.
- relevance and real/personal life relation will have to be designed through the choice of environments, operational problem, and scenarios.
- the low cost of VR scenarios creation enables to provide a rich set of scenarios fitting learners experience diversity as extensively as possible.
- VR may provide training schemes ranging from single user to full blown multi agency set ups, providing many inhibition avoidance strategies, and provides a fresh approach to learning that may overcome existing beliefs or reluctance.

VR tool has been used in many different ways during HyResponse project. First of all, it has been used in classroom to present the full scale operational platform and also used to brief the trainees regarding the safety rules to be respected when on the operational platform.

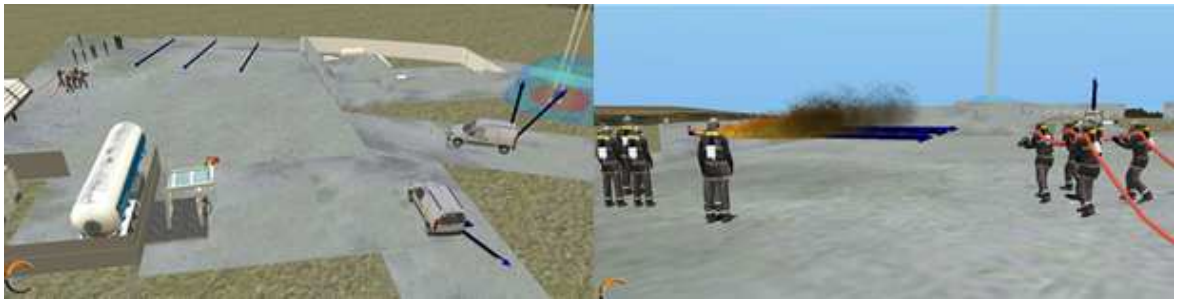

Figure 15. VR operational platform (left) and safety rules briefing prior to training (right).

VR has also been used to illustrate, visualize and understand physics and chemistry such as sound, blast overpressure, separation distance, heat patterns, as shown on the Figure 16 below:

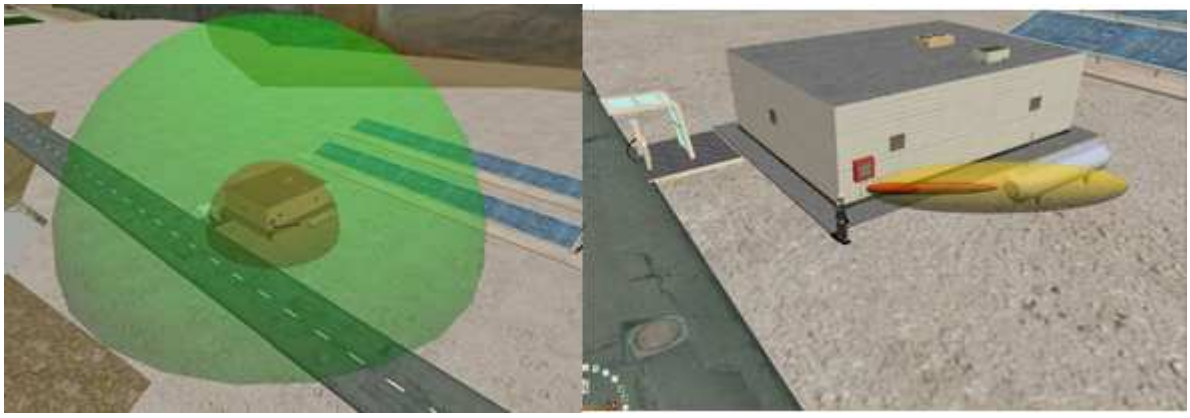

Figure 16. Visualisation of blast overpressure distances (left) and jet thermal effects (right).

Prior to real exercises, tactical and operational representations were discussed using VR environment. The red zone indicates the dangerous areas where the first responders should not go.

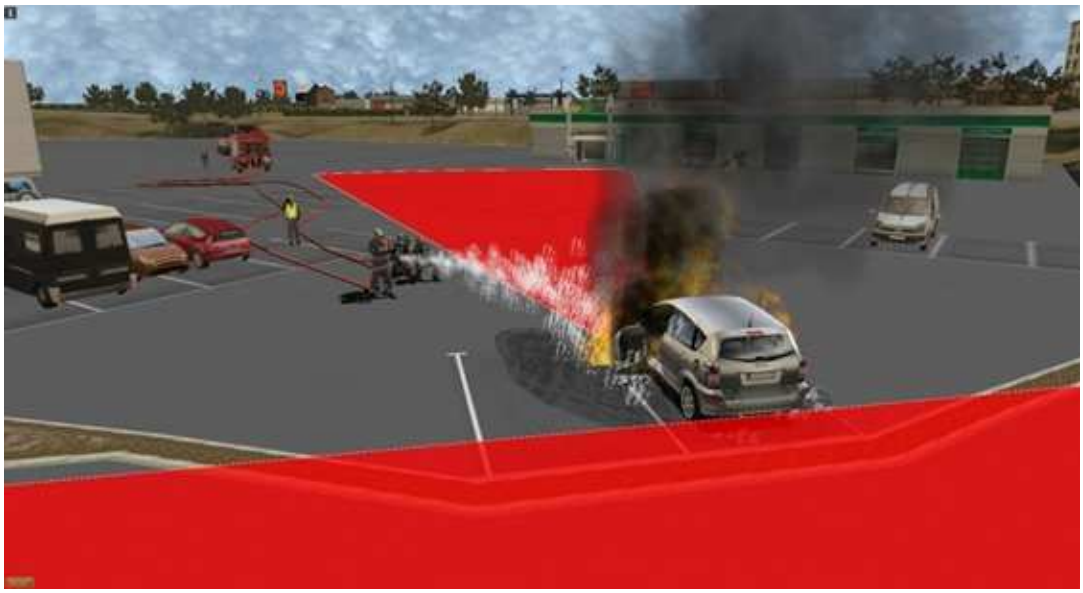

Figure 17. Visualisation of blast overpressure distances (left) and jet thermal effects (right).

Several exercises have been organized during the training sessions where different applications in different environment were represented: isolated bus, warehouse, stationary application, hydrogen storage facility, city bus accident scene, car accident at refuelling station. For each exercise, a group of trainees were asked to provide an assessment of the situation, describe the stake assessment and explain the strategy and the tactics they would undertake to tackle the situation.

Figure 18. Isolated bus (top left), warehouse (top right), stationary application (bottom left) and city bus accident (bottom right) VR exercise situations.

At the end of each training session, a trans-border VR exercise was played to test the coordination between two countries. First responders but also command officers took part in the scenario and a media report had to be prepared by each team at the end of the exercise.

Figure 19. Trans-border road accident VR exercise.

5.0 FACE-TO-FACE TRAINING SESSIONS

The training session programme consists of a mix between educational lectures (light blue), case studies and intervention strategies and tactics (pink), operational training exercises (orange) and virtual reality exercises (green), as shown on the Table 1 below.

Table 1. Training session programme.

	Monday	Tuesday	Wednesday	Thusday	Friday
8h00-9h45	FCH application and safety	Safety of storage	Harm and damage criteria	Hazards of H2 use indoors	Ignition sources and prevention
	Hydrogen properties	Methodology and response guide	Unignited H2 releases and their mitigation	Dealing with hydrogen explosions	Motorway accident involving a H2 trailer and hazmat truck
10h15-12h00	H2 fires	FC vehicles (car, bus, forlift, etc.)	Refuelling stations, storage and FC systems	Stationary and mobile applications	
	RCS for First Responders				
12h00-14h00	Lunch				
14h00-15h30	VR tour for presentation of the operational platform	Multi-vehicle accident - FC car in a fire	H2 leak at a refuelling station	Multi-vehicle accident - H2 jet fire from H2 trailer	
	CNG and H2 explosions at various concentrations	Multi-vehicle accident – CNG/LPG car in a fire	FC system default - H2 leak	H2 leak from storage – urban refuelling station	
16h00-17h30	H2, CNG, LPG jet fires	FC bus in a fire on a small road	FC car in a fire at a refuelling station	Urban accident - FC bus in a fire - urban environment	
	Firefighting exercises	Forklift in a fire inside a warehouse	H2 jet fire from industrial storage	Fire in an industrial environment with FC system	
17h30-18h00	Debrief	Debrief	Debrief	Debrief	

3 training sessions were organized during the last year of the project:

- 71 trainees from 15 countries including Germany, Austria, Belgium, Croatia, Spain, USA, France, Italy, Norway, Netherland, Poland, Portugal, UK, Sweden, Czeck Republic
- 21 observers from 10 countries including Germany, Belgium, Denmark, Spain, France, Netherland, Portugal USA, Japan, Taïwan
- 15 instructors or lecturers (partners and experts)

As shown on the graph below, the overall training programme received most of the time good or even excellent comments.

Figure 20. Feedbacks from HyResponse's training session.

6.0 EMERGENCY RESPONSE GUIDE

An important outcome of the project is the European Emergency Response guide, publically available on HyResponse website [1]. This Emergency Response Guide has been produced by the HyResponse consortium and got inspired by other two key French documents [2, 3].
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.
"Tactical sheets" are proposed in the Emergency Response Guide. For each selected application (Car, bus, forklift, trailer, refuelling station, stationary power generation unit, hydrogen-based energy storage system), a tactical approach has been proposed to deal with for 4 incidents i.e. no leak/no fire, H2 leak, Fire, External fire threatening the application.
For each situation, it is proposed to follow a step- by- step sequence i.e. recognition, rescue, preparedness, incident settlement, protection, clear out, overhaul. For each step, key questions and information are proposed to tackle the incident/accidental scene.
The following conclusions can be drawn regarding hydrogen intervention strategies and tactics:

- Standard operation procedures on hydrogen application incidents are a combination of the procedures dedicated to flammable gases incidents and the procedure dedicated to electricity powered applications
- A stake assessment allows reducing the firefighter and public exposure as low as possible
- An improvement of knowledge in hydrogen behaviour allows a relevant stake assessment and the choice of an appropriate tactic

7.0 NEXT STEP

Pursue Hydrogen safety trainings for first responders
Based HyResponse project, ENSOSP currently proposes a training course for fuel cell and hydrogen community stakeholders and emergency services. The course lasts for 4,5 days and takes place at ENSOSP in Aix en Provence. Trainings can be taught in French or English. More information can be obtained in [4,5].

European "Train the trainer" programme for first and second responders and hazmat officer instructors
The success of the HyResponse project has paved the way to the next development stage, i.e. the foundation for the "Train the trainer" programme to further develop and empower relevant international, national and regional efforts and collaboration. This European "Train the trainer" programme would aim at educating a cohort of first and second responders and hazmat officer instructors, who would be empowered and responsible ambassadors to establish national hydrogen safety training programs using their own country's language, regulations, practices, etc. The coherent national training programmes would be built on the beyond the state-of-the-art knowledge gathered during HyResponse and afterwards, and exploit the outcomes of the HyResponse project, including unique facilities of the operational training platform and the novel virtual reality training.

8.0 CONCLUSIONS

In the frame of HyResponse project, a comprehensive training for First Responders dealing with FCH transport and stationary applications has been developed. The training is threefold: educational training including hydrogen hazard and risks from hydrogen applications, operational-level training on mock-up real scale transport and hydrogen stationary installations, and innovative virtual training exercises reproducing entire accident scenarios.

Three pilot sessions have been organized and have gathered more than 71 trainees from 15 countries, 21 observers from 10 countries and 15 instructors or lecturers. Emergency response strategies

identified to tackle accidental situations have been tested on the operational and virtual platforms. A European Emergency Response Guide dedicated to First Responders has been developed.

HyResponse website gathers all the information, teaching materials, photos, movies and the European Emergency Response Guide developed in the frame of the project and is freely accessible to support the wide dissemination of knowledge into the First Responders community. ENSOSP pursues the hydrogen safety training activity for first responders by offering a training course. It is proposed to widespread massively HyResponse outcomes by addressing a European "Train the trainer" programme for first and second responders and hazmat officer instructors, responsible to establish national hydrogen safety training programs using their own country's language.

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