EUROPEAN HYDROGEN SAFETY TRAINING PLATFORM FOR FIRST RESPONDERS: HYRESPONSE PROJECT

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ABSTRACT

The paper presents HyResponse project i.e. a European Hydrogen Safety Training Platform that targets to train First responders to acquire professional knowledge and skills to contribute to FCH permitting process as approving authority. The threefold training program is described: educational training, operational-level training on mock-up real scale transport and hydrogen stationary installations, and innovative virtual training exercises reproducing entire accident scenarios. The paper highlights how the three pilot sessions for European First Responders in a face to face mode will be organized to get a feedback on the training program. The expected outputs are also presented i.e. the Emergency Response Guide and a public website including teaching material and online interactive virtual training.

1.0 INTRODUCTION

The first educational program dedicated to hydrogen safety for First Responders (FR) has been developed in USA under DoE funding[1]. This web-based awareness-level course has since been reinforced by operations-level training utilizing fuel cell vehicle and plan to enhance its content to reflect current larger early-market application for stationary power, portable power, auxiliary power units, and forklifts[2].

There are no similar activities in Europe at the moment. A comprehensive standardized hydrogen safety training program for emergency response personnel is needed on a European scale addressing key personnel involved in authorization and incident response.

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.

In addition to the consortium, an Advisory and Consultative Panel (ACP) will be established at the start of the project. The aim is to engage as many European stakeholders as possible to underpin the project outputs quality, its visibility, and facilitate dissemination process. For example, OEMS will advise on parameters of unscheduled leaks from their products (piping diameters, time of shut-down valves, etc.), and details of realistic accident scenarios. Fire brigades will be consulted on their experience with controlling accidents with CNG and LPG vehicles, relevant strategies and tactics. Travel and other costs for up to five active ACP's members are included in the ENSOSP's budget. The panel membership will be opened to practically all stakeholders in Europe including first responders, site operators, etc.

2.0 EMERGENCY SCENARIOS AND FIRST RESPONSE STRATEGIES

As a first step, the project aims to put together materials reflecting the knowledge on the potentially hazardous phenomena that may take place during accidents with FCH systems.

The targeted hydrogen applications include passenger vehicles, busses, forklifts, hydrogen vehicle refuelling, materials handling, decentralised hydrogen production, hydrogen storage (with or without coupling to renewable energy sources) and distribution systems, backup power generation, stationary fuel cells for combined production of heat and power (CHP).

In the technical and juridical frameworks related to safety studies, the elaboration of major hazard scenarios allows identification of the main accident scenarios that can occur on a FCH installation. State-of-the-art modelling tools will be applied to simulate accident dynamics and consequences. Organizational and technical measures to prevent and/or mitigate the consequences will be identified.

Based on the identification of typical scenarios and their potential consequences, First Responders and system developers will be able to work on emergency response plan and take appropriate decisions to tackle the developing dangerous situations. The strategy will be based on the severity of the consequences for each particular scenario and the possible means of intervention and prevention depending on the FCH system involved.

The identified intervention strategy and tactic will be then tested using the operational and virtual platforms. The feedback from these exercises tools will help to assess the efficiencies of the emergency plan and possible improvement will be identified before final validation. This is an iterative process as shown on the diagram below:

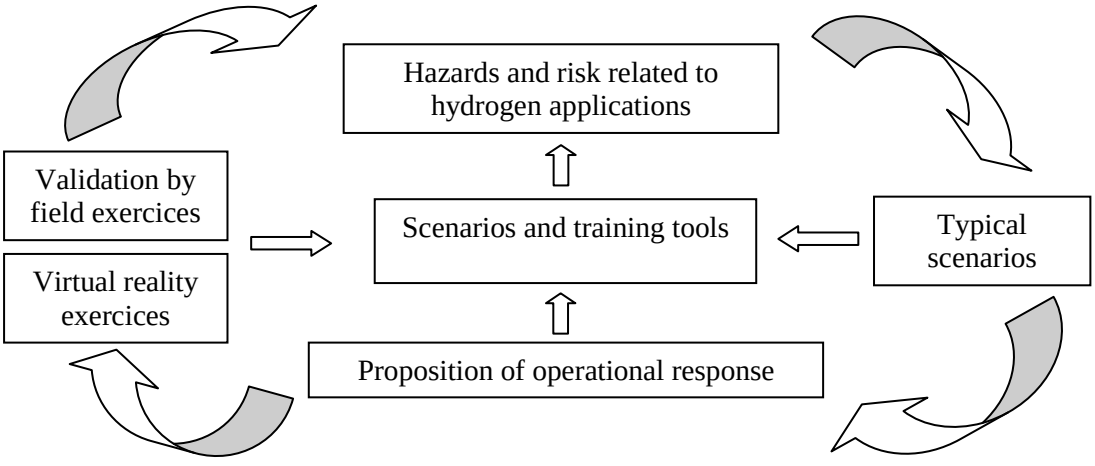

Figure 1. Iterative process for improved intervention strategy and tactic.

2.0 EDUCATIONAL TRAINING

2.1 Curriculum development

The development of educational materials on basics of hydrogen safety, on regulations, codes and standards, and on the intervention strategy and tactic, will be based on an International Curriculum on hydrogen safety training for First Responders that will be delivered at the early stage of the project.

The International Curriculum will contain but not limited to the following information: aim and objectives of the educational training, target audience and their prerequisites necessary for the understanding of the material, table of content on basics of hydrogen safety, on regulations, codes and standards, and on the intervention strategy and tactic, envisaged content of chapters and sections, references and sources, expected duration of delivery of each section during the pilot sessions, etc.

2.2 Basics of hydrogen safety for First Responders

The educational materials developed will provide the state-of-the-art in hydrogen safety knowledge to ensure that First Responders fully apprehend the specificities of hydrogen as an energy carrier during its production, transport, delivery and use.

It will include latest up-to-date scientific and engineering knowledge on hydrogen safety relevant to First Responders. The educational training will include but not limited to the following themes: basic properties and behaviour of hydrogen (physical properties, combustion properties, comparison of hydrogen with other conventional fuels), hydrogen releases (permeation leak, compressed hydrogen leaks, cryogenic leaks, etc), ignition of hydrogen-oxidizer mixtures, hydrogen flames (microflames and jet fires), hydrogen dispersion in confined environments, combustion of flammable hydrogen-oxidizer mixtures (explosions and blast waves), compatibility of hydrogen with different materials, overview of hydrogen and fuel cell applications (stationary applications, transport applications, portable applications), mitigation techniques (detection, pressure relief devices (PRD), vent stacks, venting of deflagration, natural and forced ventilation, barriers, etc.), overview of accidents, etc.

When available and relevant, lessons learnt from hydrogen accidents and intervention practice, etc. from hydrogen accidents, including those involving First Responders, will be included into educational materials using available resources e.g. HySafe[3] and US DoE databases[4] on hydrogen accidents.

Small demonstrations of hydrogen releases and jet fires conducted on the operational training facility will be presented to trainees to illustrate the course and experience specificities of hydrogen: odourless, colourless, invisible flame, etc.

The educational material will be made available to the public through the project's website in its final version. In addition, an interactive online training course will be developed on the project's website, and will include videos of demonstrations and experiments, photos, links to other website and other sources of information, etc. Materials will be available for translation into different European languages but the consortium will not be responsible for this activity.

2.3 Regulations, codes and standards requirements to FCH systems relevant to First Responders, intervention strategies and tactic

The aim of this task is to analyse the hydrogen safety approaches and requirements defined in RCS related to FCH systems, including those needed for their approval, and relevant to First Responders (assessment of accident scheme, decision making, intervention, etc.).

When available and relevant, lessons learnt from existing resources (i.e. HyFACTS training material) could be used to deliver some chapters on Regulations, Codes and Standards.

Training materials will present the safety requirements of RCS for FCH systems, in order to provide First Responders with a clear picture of mitigation technologies and safety measures that should be in place, when reaching the scene of an incident/accident: safety distances, detection

systems, vent stacks, emergency shutdown devices, etc.

As per call requirement, the training will also serve First Responders assessing the compliance with RCS, facilitating the permitting process of FCH systems or technologies. Educational training will address the involvement of First Responders into FCH permitting process, the RCS requirements to FCH systems relevant to First Responders, and the safety strategies and tactic for operation of First Responders at the accident scene. The training on RCS will be disseminated into the teaching material used in face-to-face mode and it will also be prepared in a format suitable for integration into the online training course on the HyResponse website.

2.4 Teaching materials for First Responders intervention strategy and tactic

Teaching materials (case studies) will be developed to train First Responders, prior to the operational and virtual trainings, with FCH systems, their safety features, their potential hazards, the related typical risk scenarios and the intervention strategy and tactic to tackle developing disaster. Teaching materials form the fundamental knowledge basis on which First Responders will lean on to prepare operational and virtual training exercises.

The teaching material will contain:

- Description of typical FCH systems, their safety concept and safety features and customized using VR tool for pedagogic purposes;
- Description of accident scenario(s) related to each selected FCH will be used to identify and select sequence of events during an accident with high consequences, and highest probability to occur. e.g. First Responders operations to extricate people from damaged hydrogen vehicle during traffic accident, etc.;
- Modelling of major hazard scenarios using state-of-the-art tools such as CFD tools to help First Responders to visualize hydrogen behaviour and consequences;
- Pedagogic explanation on the response and intervention strategy and tactic identified for each accident scenario within the case study. VR tool will be used to generate animation films in order to explain accident scenarios and show adequate response strategies.

The teaching materials will be available in its final version to all stakeholders at the end of the project in word document support and will also be prepared in the format suitable to the online training course on the HyResponse website with for example 3D interactive FCH systems, animation films explaining identified scenarios and adequate response strategies.

3.0 OPERATIONAL HYDROGEN TRAINING PLATFORM

3.1 Operational hydrogen training facility

A pilot operational hydrogen training facilities for the European Hydrogen Safety Training Platform (EHSTP) will be built to train First Responders, test and validate emergency response procedures relevant to FCH systems and infrastructures accident scenarios.

The operational hydrogen training facility will allow First Responders to visualize hydrogen applications, put into practice what they have learnt during class, simulate interventions, test and implement operational response strategies identified for selected scenarios. The operational hydrogen training facility will also allow First Responders to discover and observe phenomena related to the behaviour of hydrogen in a real incident and / or accident scene. The challenge is to create a dynamic accidental environment as real as possible while guarantying safety of First Responders.

The operational training will be realized on the existing technical platform at ENSOSP (French Academy for Fire, Rescue and Civil Protection Officers) site. This state-of-the-art educational and technical tool dedicated for emergency response training contains four fire and rescue stations with 64 fire engines, a control room and several small platforms over an area of 23 ha where more than 300 intervention scenarios can be tested. The existing platform includes in particular an urban area,

a main road and a motorway, a villa and a building (5 levels - 4 flours).

Full scale training exercises will take place on the existing highway and road portions for car accident scene and potentially residential area. To complete the range of training exercises, it is planned to build a hydrogen-dedicated training facility that will include a mock-up hydrogen refuelling station, hydrogen passenger vehicle, a hydrogen-based energy storage system coupled with photovoltaic panels installed on the roof of an adjacent building.

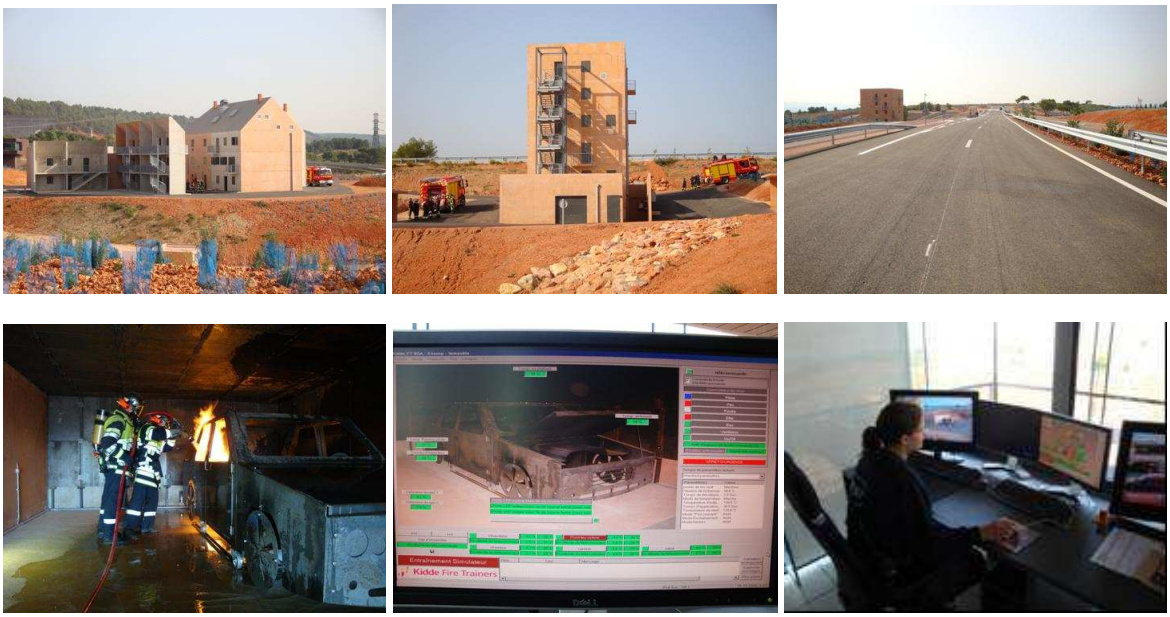

Figure 2. Photos of ENSOSP's operational training facilities.

The operational hydrogen training facility will allow testing the emergency response procedures identified. Based on the operational training exercises, the efficiency of the operational response plan will be assessed, improved and validated in an iterative way to finally converge on an Emergency Response Guide for First Responders (see § 5.2).

A very schematic, rough and simplified proposition of the operational hydrogen training facility is shown below.

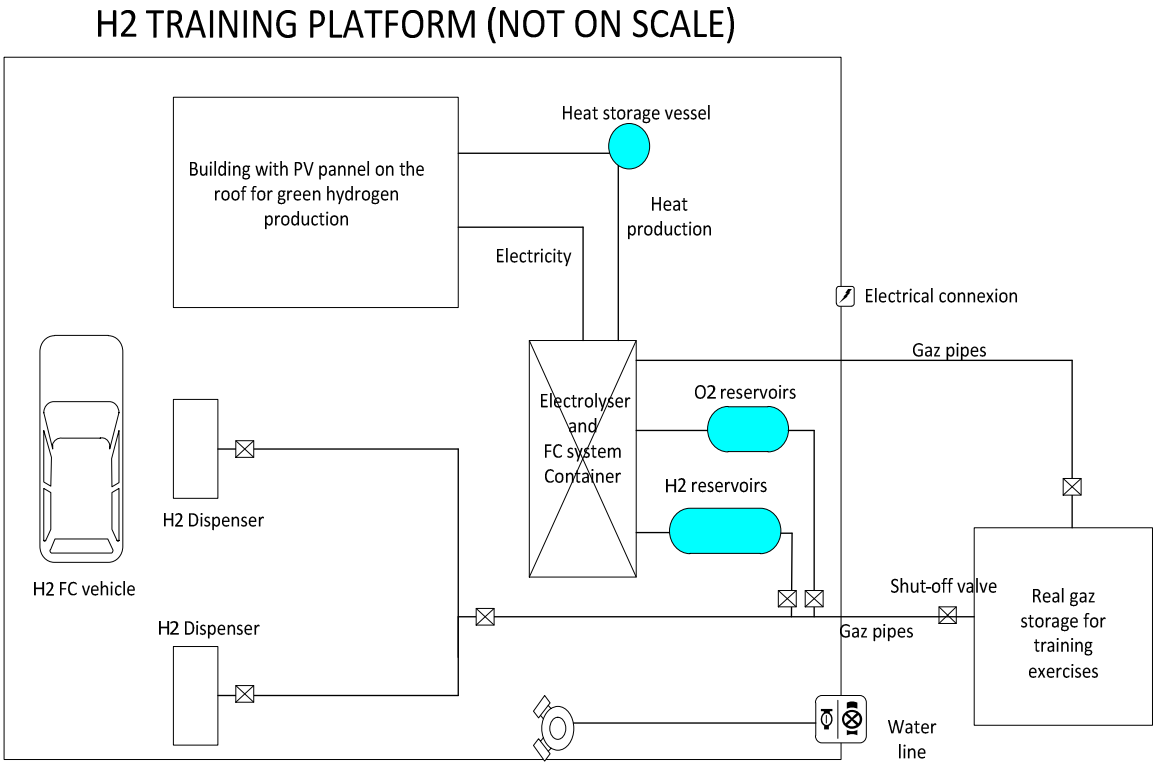

Figure 3. Simplified sketch of the operational hydrogen training facility.

Furthermore, small demonstrators of hydrogen releases, fire, explosions will be built in this task in order to illustrate educational training class. These small demonstrators will be set on the ENSOSP's educational platform. The goal of these demonstrations is to train First Responders to apprehend intervention on a hydrogen facility and identify warning signs:

- As hydrogen is colourless and odourless, non-reacting leaks can be identified by the sound of high-pressure gas escaping,
- Hydrogen burns with a pale blue flame that is nearly invisible in daylight and produces no smoke. A hydrogen fire will be performed and trainees will be able to visualize the flame by the use of thermal imaging or adjunction of particle into the fire,
- These small demonstrations will be recorded to be included as videos into the online training course available on the project dedicated website.

The didactic FC system BAHIA[5] developed by AREVA Stockage d'Energie will also be used to illustrate, teach and train First Responders regarding fuel cell technologies. BAHIA FC system integrates a PEM (Proton Exchange Membrane) stack rated between 500W to 1kW electrical power and 500W to 1KW thermal power. Thanks to the various functions of its integrated software, Bahia FC system will enable First Responders to simulate different practical works through realistic applications such as backup power system application and coupling with renewable energies applications.

3.2 Elaboration of multi-level operational training exercises

The operational training scenarios will be elaborated based on the identified scenarios and will also contribute to finalize the specifications of the operational hydrogen training facility.

The pedagogic approach consists of dividing the operational exercises into three levels i.e. "Discovery level", "Advanced level", and "Expert level" in order to reflect the increase of the trainee's skill requirements. For each level, several scenarios will be described for all the stationary

and transport applications.

An assessment sheet will be created for the instructors to check and validate the achievement of trainee's skills and knowledge during the exercises.

4.0 VIRTUAL REALITY TRAINING PLATFORM

4.1 3D Virtual Reality Serious Game exercises

Virtual Reality (VR) is an artificial environment that is created with software and presented to the user in such a way that the user suspends belief and accepts it as a real environment. On a computer, virtual reality is primarily experienced through two of the five senses: sight and sound. The major interest to use VR comes from the possibility to recreate totally different situations from one to another, and this, without presenting any risk for First Responders.

CRISE has developed a 3D VR Serious Game software that enables life sized training for crisis preparedness, commandment, and emergency help, in ideal pedagogical environment, in safe conditions and at low cost.

In France, fire-fighters use virtual reality to train their teams in virtual environments to face specific risks such as radiological, nuclear or chemical in an interactive use and in real time for different sites such as classified SEVESO (chemical risk), port, airports… International training sessions have been held between French, US and Australian fire fighters for HRO and doctrine comparison studies, international training sessions are regularly held for practicing international cooperation, typically like wildfires going to/from France to Spain or Italy. On these aspects, the VR simulator and the experience of CRISE, will be valuable to fulfil the objective of the project to train simultaneously first-responders from different European countries.

Figure 4. Snapshots of 3D Virtual Reality Serious Game training at ENSOSP's virtual facility.

Virtual training exercises will be elaborated and will aim at completing the multi-level operational training exercises. For each particular exercise, the whole scenarios will be described in detailed flowcharts taking into account the development of a hydrogen accident/incident, its consequences, and how it will evolve depending on the actions of the First Responders during the virtual training.

An assessment sheet will be created for the instructors to check and validate the achievement of trainee's skills and knowledge during the exercises.

4.2 Hydrogen virtual training platforms

The VR training exercises will be performed on the hydrogen VR training platform. 3D representations of each FCH system and infrastructures including passenger vehicles, buses, forklift, refuelling station, decentralised hydrogen production, storage and distribution systems, backup power generation, stationary fuel cells for combined production of heat and power (CHP) will be created. All the modelled FCH systems and infrastructures will be integrated within the virtual department of ENSOSP (EVE urban, port and industrial site).

Figure 5. Virtual refuelling station and Fire Trucks developed for ENSOSP.

4.3 Hydrogen phenomena input for virtual training exercises

CRISE already developed external models for chemical risks, including fire heat and atmospheric releases (heavy gas models), but need to be extended to hydrogen.

The simulator tool will allow reproducing realistic hazardous phenomena such as hydrogen release, fire or explosion and their potential developments into domino scenarios in the simulated environment. For example, simulation allows a trainee to calculate jet flame length as a function of storage pressure and orifice diameter, the radiative power of the flame, the overpressure and blast decay created by a hydrogen deflagration and/or detonation, the dispersion and concentration of hydrogen released from high pressure storage, etc.

Domino effects will be anticipated by using data on the impact of radiation and overpressure on structural elements, equipment, vehicles, etc. Generated heat radiation, overpressure and oxygen depletion will impact victims and fire fighters, depending on their location, their clothing and their personal protective equipment.

Other information might include, for example, the sound pitch and volume of high pressure hydrogen release, so that acoustic renderer may calculate sound reproduction on users from their location. The hydrogen concentration decay will be used to impact portable measuring equipment carried by trainees during the VR trainings.

Behaviour, representation and timelines will be reproduced, as well as countermeasure effects, like the activation of emergency shutdown, the closing of a valve, the effect of water spray on fire, etc.

5.0 PILOT TRAINING SESSIONS

5.1 European First Responder training sessions

Three training sessions will be organised during the project in face to face mode on the EHSTP at the ENSOSP facility the last year (2016) of the project to develop, test and get a feedback on the educational, practical and virtual trainings. A three months interval is foreseen between each training session in order to allow modifications and continuous improvements.

The training sessions “Hydrogen safety and Emergency Response Training for First Responders”

will be three folds i.e. educational training class, operational exercises and virtual training exercises. During the whole training week, educational part will preferably be taught in the morning, while virtual and operational exercises will be performed in the afternoon.

Information about the training sessions will be available on the HyResponse website. A list gathering the contact details of the European First Responders involved in current or future hydrogen projects in Europe e.g. Large-scale demonstration of road vehicles and refuelling infrastructure IV (Topic n°1 of the Annual Implementation plan 2011) will be collected by FAST/EHA partner. Based on this contact list, HyResponse project aims to select and train a total of at least 50 First Responders for testing the full training sessions. All expenses including transport, accommodation, food, etc. will be fully reimbursed for all the trainees for the five-day training.

An educational training briefcase will be delivered to each trainee at the end of the session and may be revised after each session based on lessons learnt, exchanges of feedback and best practices. It is envisaged that educational materials, delivered during these pan-European training sessions, will be used to develop and deliver training sessions at local level with use of language different from English, although the consortium will not be responsible for any translations.

Members of the consortium will take part in the training as organizers and instructors to deliver the educational content during the class, the operational exercises and virtual reality training sessions.

The feed-back from trainees on technical and organisational aspects of the training sessions will be gathered and analysed and used to improve the content, format and delivery channels.

5.2 European Emergency Response Guide

There is a need for a global emergency response guide specific to hydrogen fuel cells and technologies, that must include the most relevant accidental scenarios first responders may encounter and the appropriate intervention strategies.

Intervention strategy and tactic identified to tackle accidental situations will be applied and evaluated during exercises on the operational hydrogen training facility and on the virtual training tools. The final updated intervention strategy and tactic will be compiled in an Emergency Response Guide dedicated to First Responders. The document will be based on the experience and knowledge of the members of the consortium, the Advisory Panel, and will take into account feedback of trainees after the three training sessions to adjust the strategy and tactic.

The Emergency Response Guide will extract key information developed in the teaching materials on the basics of hydrogen and on the most relevant RCS. The content will then describe, per HFC system, the most appropriate strategies and tactic to tackle an incident/accident involving hydrogen. It will describe the relevant actions to perform by First Responders and the ones to avoid, in order to ensure the protection of life, property and the environment, and to prevent any dangerous escalation in the development of the accident/incident. The guide will be illustrated with figures developed during the project (pictures of numerical simulations, graphical representations, 3D representations of HFC systems, etc.).

6.0 RECOMMENDATIONS AND DISSEMINATION STRATEGY

6.1 HyResponse web-site and online training course

To allow effective communications of project results and training material to First Responders throughout the EU, a website dedicated to educational and training programmes on hydrogen safety for First Responders will be developed during the project.

This website will have a public area with:

- Information about the project,

- Links to partners' websites, hydrogen and fuel cell associations, relevant projects, Hydrogen Incident/Accident Database and other databases, hydrogen safety resources available to public, etc.,

- Announcement and information on training sessions,

- Access to educational teaching materials developed during the project,

- An online interactive training course containing synthesised educational teaching materials, case studies, videos of small hydrogen releases and explosions to illustrate hydrogen hazards, videos of operational training sessions to demonstrate first response strategy and information related to the trainings conducted on the virtual training tool,

- Access to the final version of public deliverables,

- Possibility to contact the consortium via an online form.

Virtual Reality tools as a support for the online training will be integrated. In particular, 3D representations of each hydrogen application will be customized to allow online operational functionalities interaction. For awareness and understanding enforcement, the models will be modified in order to exhibit more 'How does it work' or 'Why is it dangerous', or 'What are the safe operation conditions', etc. by providing specific 3D highlights, animations or any other visualisation technique. Animation films may be produced from the scenarios showing adequate response strategies.

6.2 Recommendations for RCS to the international standardization bodies

RCS issues including those needed for the approval of hydrogen systems and their installation from HyResponse findings will be identified. RCS findings will be summarized to extract gaps and improvements to make recommendations at the international level.

6.3 Recommendations on future research topics to be addressed

During the development and dissemination of educational, operational and virtual trainings dedicated to First Responders, the consortium might face knowledge gaps that would require further research on hydrogen safety. Questions might also arise from professionals outside the consortium during the dissemination process: it is expected to receive questions or comments via the project's website, during conferences or representations, during the Workshop on Hydrogen Safety or by the Advisory Panel.

Hydrogen safety research topics on education and science will be identified and formulated for further proposals.

6.4 Workshop on Hydrogen Safety for First Responders

A two days seminar is planned to be organized at the end of the project to disseminate the main results and recommendations of the project, present the training material and exchange experiences with programs in other countries. The session will include keynote speakers from DOE, Fire Departments in the US and gather feedback related to FR trainings and identify potential collaboration between EU and North America. The seminar will include a demonstration of the virtual reality training tool and break-out session will address specific topics as future research topics.

Permanent sessions for FR to allow exchanges of experiences and updates will be negotiated to suitable international hydrogen event.

6.0 CONCLUSIONS

The HyResponse project targets to create a European Hydrogen Safety Training Platform (EHSTP). This training platform will develop a tool box for European First Responders to help them assessing status and decision making not only for the implementation of a new hydrogen project but also on the emergency response level in case of incident/accident on site. Existing Fire Fighter pedagogic training approach will be followed to train First Responders on all safety aspects in dealing with not only transport but also stationary hydrogen applications. The training will be 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, thereby testing the whole chain of command and communication between all members of the First Responders team.

To develop, test, and get a feedback on the educational, practical and virtual training, three pilot sessions will be organized for European First Responders in a face to face mode, each of one week duration. In the framework of HyResponse, it is scheduled to train at least 50 fire fighters involved in hydrogen projects in Europe. Emergency response strategies identified to tackle accidental situations will be tested on the operational and virtual platforms and be finalized in an Emergency Response Guide dedicated to First Responders. When necessary, knowledge gaps on hydrogen safety requiring further research will be addressed and recommendations for RCS with regards to the integration of means of emergency response in systems and installations will be formulated.

A website will be created as to support the wide dissemination of knowledge into the First Responders community. The website will have a public access to the teaching materials developed during the project, an online interactive virtual training, the final version of the European Emergency Response Guide and links to European First Responders community to hydrogen and fuel cells related information. Hydrogen safety research topics on education and science will be identified and formulated for further proposals. A two days seminar is planned to be organized at the end of the project to disseminate the main results and recommendations of the project, present the training material and exchange experiences with programs in other countries.

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