European Train the Trainer Programme for Responders

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)
Grant Agreement Number 875089

Deliverable D2.6
HyResponder Virtual Reality Training Materials

Lead authors: CRISE (Eric Maranne)
Contributing authors: ENSOSP (Franck Verriest), S Brennan (UU)

Version: 17-12-21
Delivery date for internal review: 10 March 2021
Due date: 28 02 2021
Dissemination level: PUBLIC

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Deliverable administration						
Work Package	WP2. Training Material Development					
N. and title	D2.6 HyResponder Virtual Reality Training Materials					
Type	Report					
Status	Draft/Working/**Released**	Due	14	Date	28/02/2021	
Means of verification	Uploaded to the participant portal.					
Comments	Delay as the requirements changed in January 2021 when it was agreed training in June 2021 would be delivered remotely					

Development and revision			
Version N.	Date	Authors	Description
210310	10 03 2021	Eric Maranne – Franck Verreist	1st document draft
210323	23 03 2021	L Xing, S Brennan	Minor amendments
210325	25 03 2021	S Brennan	Project coordinator approval
211130	30 11 2021	Eric Maranne	After review modifications on Chapter 6 on pandemic considerations
211216	16 12 2021	Eric Maranne	Inserted Chapter 7 for December hands on workshop
211217	17 12 2021	S Brennan	Coordinator approval and upload

Disclaimer

Acknowledgments

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 875089. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Summary

This deliverable outlines both the training materials developed for the Virtual Reality (VR) training sessions, and for the production of video documents to be included into the training kit for the 'train the trainers program'.

Partner CRISE is lead on the VR provision in HyResponder and thus this document describes the materials developed for CRISE systems. However, it should be noted that videos produced to inform training sequences are not system dependent.

The aim of this document is to provide information on:

- A presentation of VR training strategies that can be used by responder trainers to train responders, whilst these are described in terms of CRISE systems, the approach is not limited to these systems.
- 3D items designed to produce H2 and LH2 VR training scenarios (these items will be distributed to all CRISE systems users)
- Scenarios that have been developed in the frame of this project (will be available to CRISE systems users too)

Keywords

Hydrogen risk training, Virtual Reality, Hydrogen risk mitigation, First response, Hydrogen emergency handling, Hydrogen event response, preparedness

Table of contents

1. Figures and tables

2. Glossary

Term	Definition
VR	Virtual Reality
TTX	Table Top Exercise
Drills	Short and simple exercises
FE	Functional Exercises
FSE	Full scale Exercises
C3	Command, Control and Communication
PPE	Personal Protection Equipment
VR simulator	A set of VR computers aiming at sharing a situation from each user standpoint
VR Exercise	A solo or team exercise where trainees are to handle a shared VR event using their knowledge, virtual intervention equipment, PPE, and team C3
SOP	Standard Operating Procedures
ROE	Rules Of Engagement
EXCON	Exercise Control (instructor(s))
ICP	Incident Command Post
ERCC	Emergency Response Command and Control
EVE©	Enhanced Virtual Environments is CRISE VR framework used in HyResponder VR developments.

3. Training methodologies

It is envisaged that the methodologies presented in the following sections are portable across VR systems as it its recognized that the VR systems available may vary from one training institution to another. However, the role of CRISE within HyResponder is to lead delivery of VR training to the trainers who are trained within HyResponder, those trainers in turn introduce the training, but as with the operational training it is not expected that this is exactly replicated across all countries, rather that key elements are selected and integrated within existing training provisions. Thus, an emphasis is on CRISE software in later sections of this document when discussing the specific exercises. However, it should be emphasized that the pedagogy and the principles remain the same across platforms.

Experience gained in the pedagogic strategies successfully trialled during the HyResponse project (2013-2016) will be presented, alongside those additionally designed for HyResponder. We hope that the material will be portable on any system, and the described approaches are generic enough to be adapted by any training organization.

Illustrations and set up examples presented in this document are taken from the ENSOSP Virtual Reality training platform.

3.1 Pedagogic approach, from HyResponse to HyResponder : Andragogy

In HyResponse, the use of Andragogy and experience-based training is what governed the pedagogic choices and set ups.

According to Knowles (1984) there are four principles that are applied to adult learning:

1. Adults need to be involved in the planning and evaluation of their instruction.
2. Experience (including mistakes) provides the basis for learning activities.
3. Adults are most interested in learning subjects that have immediate relevance to their job or personal life.
4. Adult learning is problem-centred rather than content-oriented. (Kearsley, 2010)

Besides, the adult learner brings into the continuing educational arena a rich array of experiences that will affect their learning styles and assimilation of knowledge.

In the context of HyResponder, we favor this methodology, and, Virtual Reality Training systems enable to fulfill andragogy concerns.

We need to ensure trainers can deliver correct Hydrogen related events knowledge and know-how, both at a theoretical, technical, doctrinal and operational level.

We need to be sure the pedagogic concepts are well understood by the future trainers, so that they can get a good comprehension and appropriation of the methodology, and provided tools.

Reaching point 1 is an **organizational** matter, and the experience gained with HyResponse will be reproducible in HyResponder. The trainers trained through HyResponder's 'train the trainer' programme will be able to present to their organisations and trainees what was used in HyResponse, and summarized below.

HyResponder trainees obviously understood why the course is important to their learning and life situation, and they will be able to **apply the knowledge they will gain in their life situation**, so we may be confident in reaching point 3.

To reach points 2 and 4 illustrates the need to use VR based training. Hydrogen risk is a technological risk; hence it calls for **understanding**. Adult learners need to be **convinced** and technological elements are to be **proven** and exposed at the audience cognitive level. In this aspect, VR training is complementary to the lectures provided in the frame of the threefold training (educational, operational and virtual reality) delivered within the HyResponder project.

3.2 VR use in HyResponder andragogic approach

As noted, experience (including mistakes) provides the basis for learning activities (Point 2), this implies that instruction should be task-oriented instead of memorization -learning activities should be in the context of common tasks to be performed. In this context Virtual Reality will be used in HyResponder to provide this task orientation illustration to lectures, and will be used to provide experience acquisition through problem resolving approaches.
Using virtual reality technology (VR) enables assists in addressing several expectations in an andragogic context:

1. explanation and explicitness: the production of real-life foreseen problems relating to H2 wide use enables trainees to picture, and explicitly be exposed to why specific protocols, functions, operations, etc. are needed.

2. task orientation and interaction: VR is the perfect tool for this.

3. relevance and real/personal life relation will have to be designed through the

4. choice of environments, operational problems, and scenarios. This will be discussed in the next chapters.

5. the low cost of VR scenarios creation enables to provide a rich set of scenarios fitting the diversity of learners experience as extensively as possible.

6. VR may provide training schemes ranging from single user to full blown multi agency set ups, providing many inhibition avoidance strategies, and providing a fresh approach to learning that may overcome existing beliefs or reluctance.

VR may be used in different set ups, depending on what is expected. The approaches most successfully used in the HyResponse project and thus proposed for

HyResponder are discussed in the following sections.

Illustration / Orientation: VR will be used to illustrate theoretical lessons, in order to facilitate understanding of trainees, when they are presented with 'realistic looking' pictures in addition to curves, tables and equations (item number 4 in Knowles Andragogic principles).

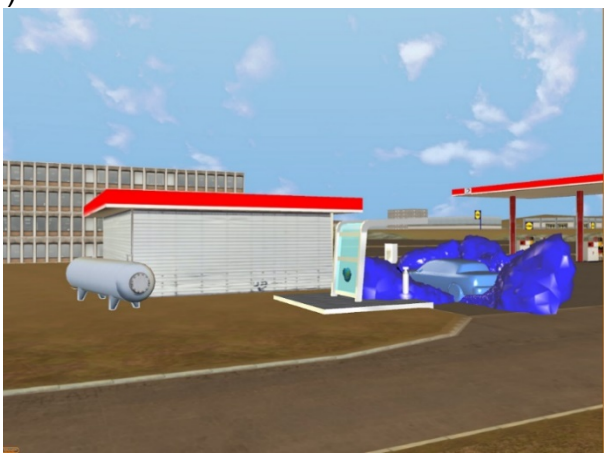

Figure 1 Illustration use of VR: representation of a leak (credit Ulster University)

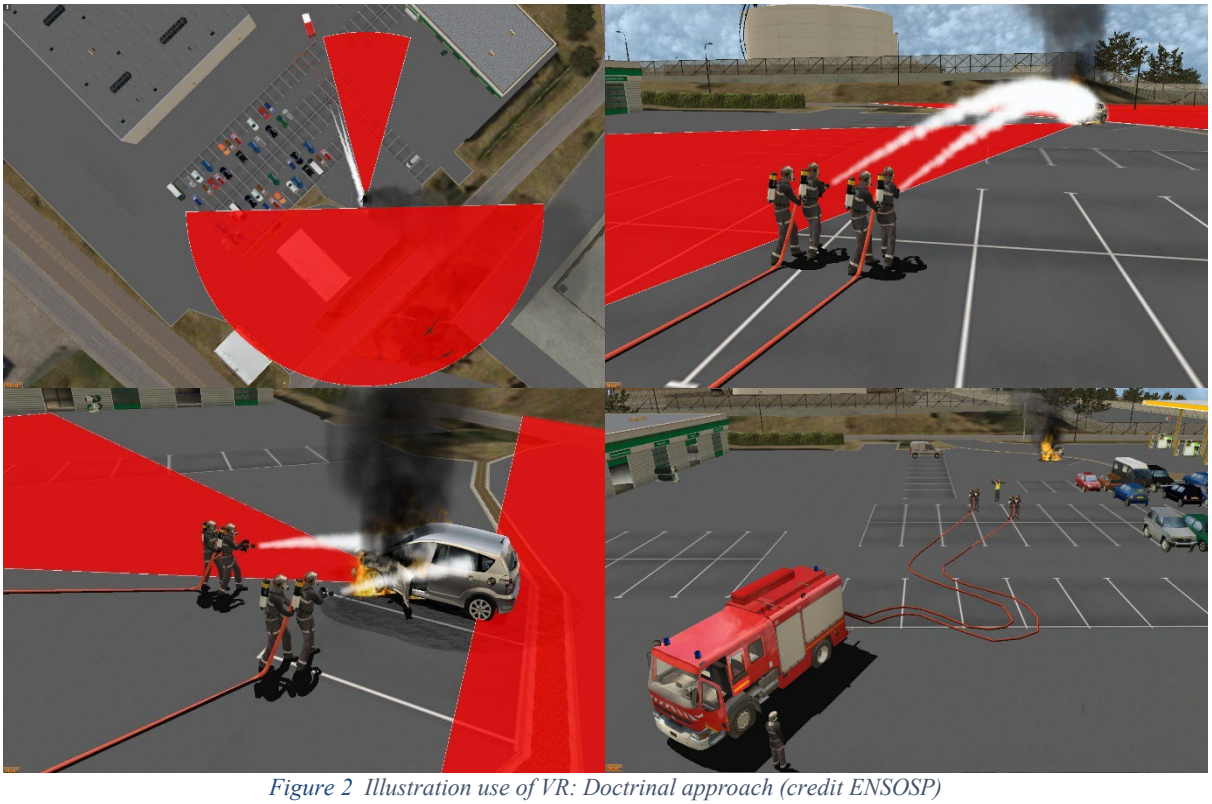

Figure 2 Illustration use of VR: Doctrinal approach (credit ENSOSP)

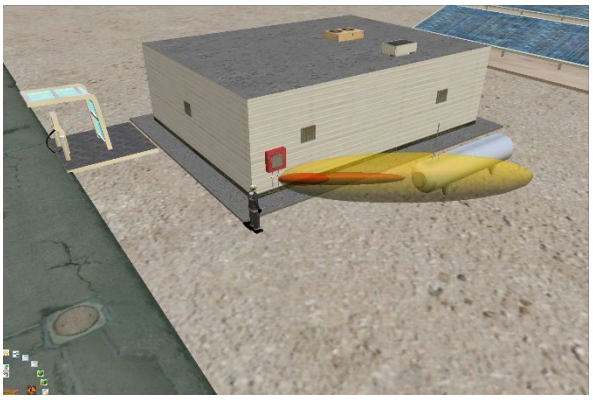

Figure 3 Illustration use of VR: Heat patterns

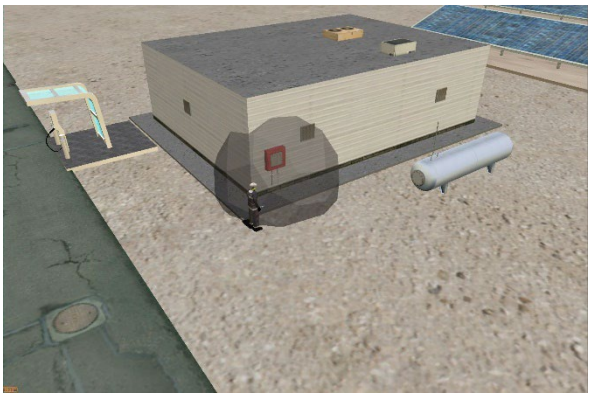

Figure 4 Illustration use of VR: Blast Zone Overpressure Danger

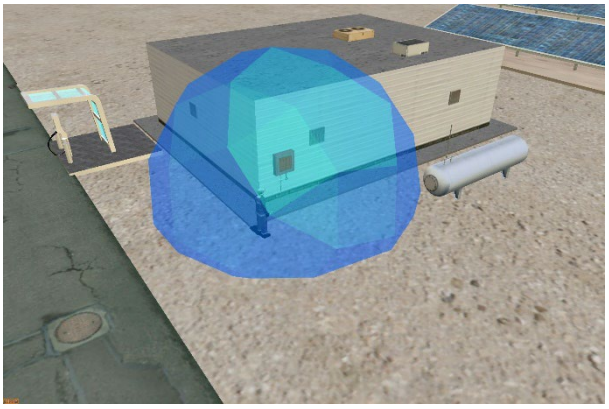

Figure 5 Illustration use of VR: Sound at 120 dB limit

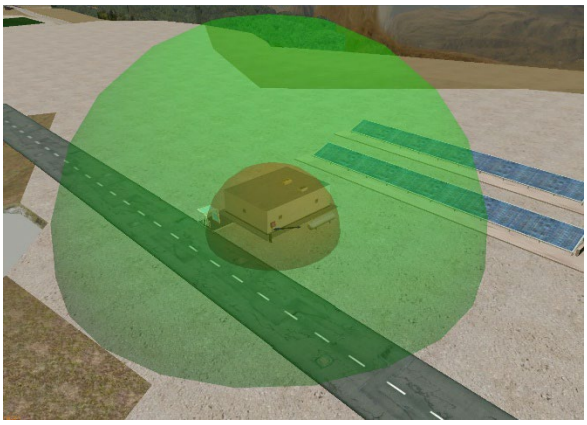

Figure 6 Illustration use of VR : Sound detection volume, and sound danger area.

All of the above illustrations, and others are already available to support the HyResponder materials and lectures and are usable either by ENSOSP, and Ulster University to illustrate their lectures. In the frame of HyResponse, a specific VR package was installed and configured at UU to ensure compatibility with locally used CFD packages.

Constructive and explicit problem exposure was performed usually by a single instructor in a face to face or face to a homogeneous participants group situation.

Orientation exercises are designed to ‘guide’ the user towards a problem. This should be understood both as an explanation of ‘why’ it is necessary to train for H2 specifics, but, as well, as an orientation towards the different contents of the proposed training. We want the public to be self- directing into following the proposed lectures, so we need to provide orientation. Both the physical and virtual simulators will be used to expose, illustrate, anchor and enforce the lecture content and threefold training in HyResponder.

Illustration / Orientation items are to be used in the classroom. Typically, they are projected onto a screen, and any trainee may ask to visualize from another angle, and, eventually to perform a measure with any available sensing device available in the VR application. Sound can be rendered too.

We encourage trainers to use a VR package to produce such illustrations. VR allows the free choice of the point of view, and, if VR package enables trainees, to explore, hear, measure with sensor devices the 'reality' of the exposed issue.

Demonstration: VR is used to demonstrate theoretical or doctrinal approaches during lessons. Using table top exercises (TTX), it is possible to honour point 2 and 4 of andragogy principles: a TTX enables particpants to explore new doctrinal or operational approaches and validate the understanding of a chosen doctrine or operational tactics.

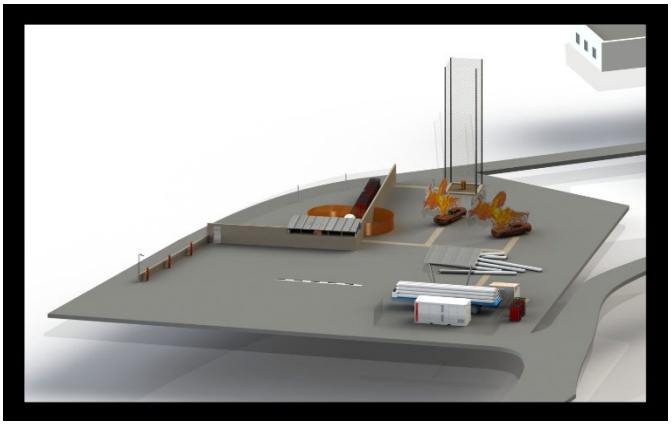

Figure 7 Demonstration use of VR: preparing real action on ENSOSP H2 Platform

Figure 8 Demonstration use of VR: TTX on bridge

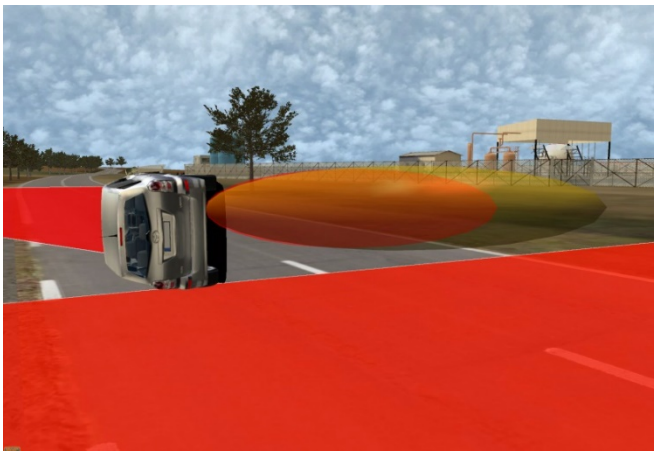

Figure 9 Demonstration use of VR: choosing the approach path

Figure 10 Demonstration use of VR: TTX on LH2 delivery

Demonstration scenarios will be available for CRISE system users. These scenarios are used in the classroom. While illustration/orientation does not ask trainees for any decision or SOP tactical choice, in this case, the problem must be tackled through with a class wide cooperation mechanism. This leads to what is called an inverted classroom, in which the trainer mostly orients, evaluates and enforces the explanation of the good or bad choices made by the team.

A TTX is a low-stress event to stimulate discussion of a simulated situation. Participants discuss issues in depth and make decisions using slow-paced problem-solving methods in contrast to the fast-paced, spontaneous decision making typical of actual or simulated emergency conditions. TTXs are designed as an early step along the way to functional and full-scale exercises. Constructive problem solving is the goal of such an exercise.

The scenario is generally invented and describes an event or emergency incident, bringing participants up to a simulated “present moment” in time. From there, a virtual simulator may be used to provide the realistic material and vision suitable to describe the subsequent interactive pacing of events decisions and effects. TTX shouldn’t be though as ‘real time’, some events may be accelerated if not conveying interest for the

discussion, others may be slowed down in order to expose inner mechanisms, or to simply provide enough time for discussion.

VR is used to provide the realistic material and vision suitable to expose the subsequent interactive pacing of events decisions and effects.

Constructive and interactive problem solving is usually performed by a single instructor facing a group of **heterogeneous** participants. This means that it is possible to mix different proficiency levels in the classroom, which enables each participant to expose theit own experience and all trainees will benefit of the exposure of the problem and its solutions, both proficient and less proficient.

Gaining experience: VR drills enable comprehension and practice to be gained by practicing numerous short exercises. VR enables trainees and teams to face many different configurations of the same event, and to gain experience on how to use SOPs, while keeping good situation awareness and control.

The main purpose of a drill is to use repetition to instruct thoroughly. Drills can be used to test personnel training, response time, interagency cooperation and resources, and workforce and equipment capabilities.

Another purpose of drills is to put trainees in very different operational environments, implying danger area assessment evaluation in a wide variety of situations. For each identified HyResponder category of concern (automotive, storage, distribution, production, ...), drills enable to test and improve threat assessment through a large number of slightly different exercises. (Automotive in open / underground car park, private garage, in tunnel, in city center, ...).

This enables to avoid 'task fixation blindness' by practicing situational awareness at an incident scene, including personnel, team, environment, resources and broad picture. *Drills ought to induce the importance of situational awareness, personal safety, and personal accountability at the incident scene.*

Drills optimally take place after orientation and demonstration; staff should have an understanding of the agency function that will be tested in the drill and be given an opportunity to ask questions. Operational procedures and safety precautions are reviewed before the drill begins.

Drill categories include but are not limited to reaction, notification, communication, command post, and evacuation. In most cases, a general briefing by the drill designer sets the scene and reviews the drill’s purpose and objectives.

A drill is usually focused on a segmented functional part of a protocol, like ‘immediate response’, or ‘operative answer’.

VR is used to provide shared operational exposure and understanding, to expose the interactive pacing of decisions, actions and effects, and to sustain the drill action with spontaneous or planned events.

A physical platform ought to also be used to perform some drills, when possible, but virtual reality will offer a much broader variety of incidents scenes and rehearsal capabilities and expands the physical platform experience. It is for this reason that it forms a core element of the threefold “train the trainer” HyResponder package.

Figure 11 Handling Drill example

Figure 12 Tunnel drill example

Figure 13 Underground Parking

Figure 14 Urban incident

Figure 15 Stationary example

Figure16 Dismantled trailer example

Figure 16 Remote power station

Figure 17 Hazmat

Figure 18 Fuel cell stationery

Figure 19 Liquid H2 trailer incident on rail crossing

Figure 20 Trailer refueling site

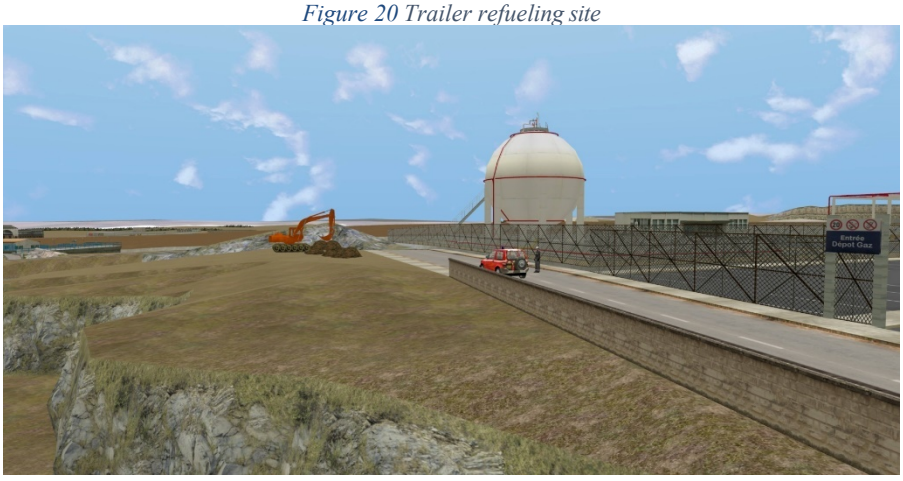

Figure 21 Liquid Hydrogen leak & pool in storage area.

Elaborating *beyond SOPs*: complex situations may put SOPs out of scope. For example, tunnel fires are often demanding to build up an adapted response that may or may not fit with standard procedures, but which should still comply with ROEs. Exploring these situations with trainees, enables to enforce their confidence in their newly acquired competences.

While simple drills ought to simple and straightforward, to gain SOP and ROE experience, it may be worth introducing more complex exercises, in order to prepare to FSE (Full Scale Exercises)

Figure 22 Beyond simple SOPs exercises : a complex incident in tunnel

Figure 23 Beyond simple SOPs exercises : a complex multi energies incident

Functional Exercises: The purpose of an FE is to test and evaluate the capabilities of an emergency response system, or parts of an emergency response system, interagency cooperation and resources.

Unlike Drills, an FE encompasses more complete system, mixing typically functional and commandment levels, over several first responders' types.

While in HyResponse we were training 'first responders', hence having to learn how to cope with the interaction of different organizations, agencies, like police, medics, etc., in HyResponder, this will be in charge of the national trainers, since the trainings will be done locally.

While the use of FE is slightly out of the scope of HyResponder, more focused on bringing tools to trainers to train first responders, these kinds of exercises are the next step for an emergency management organization to ensure and validate its preparedness as a whole response system, tightly coupled with other concerned organizations in management of a crisis. Typically, functional exercises may involve, besides first responders, one or more whole chain of commands, other organizations, like medics, police forces and other civil servants contributing to the crisis resolution resorption.

While almost any preceding scenario content may be used to train not only field responders but the command chain, some scenarios have been designed to fit more specifically this need.

Figure 24 Typical functional Exercise: numerous victims in a large incident, involving multi energy vehicles.

Figure 25 *Example of a full Functional exercise setup*

4. Physical and software setups

4.1 Architectures used in HyResponse:

4.1.1 Basic face-to-face training (whole group split in 6 teams – 6 instructors)

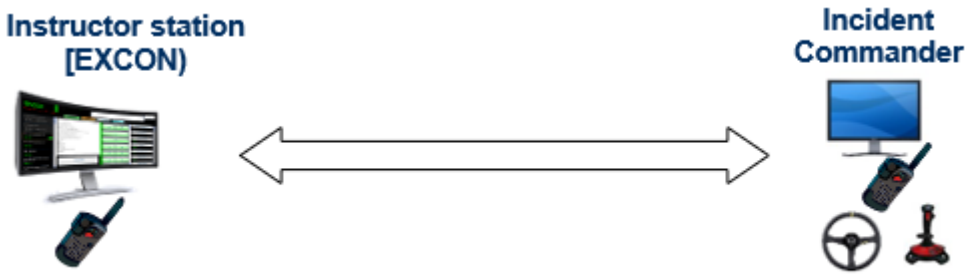

Figure 26 Simple face to face set up

4.1.2 Comprehensive configuration for Final functional exercise (Group split in 3 teams)

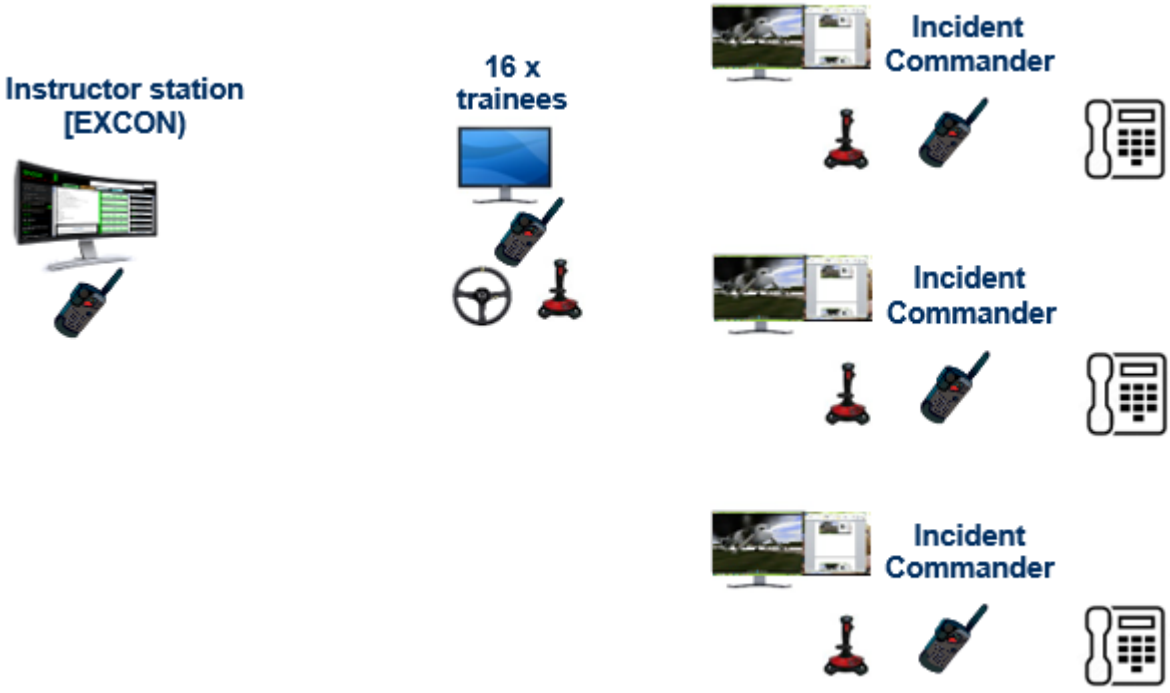

Figure 27 Functional exercise set up

4.2 Proposed organisation of training for HyResponder:

4.2.1 For Classroom and TTX:

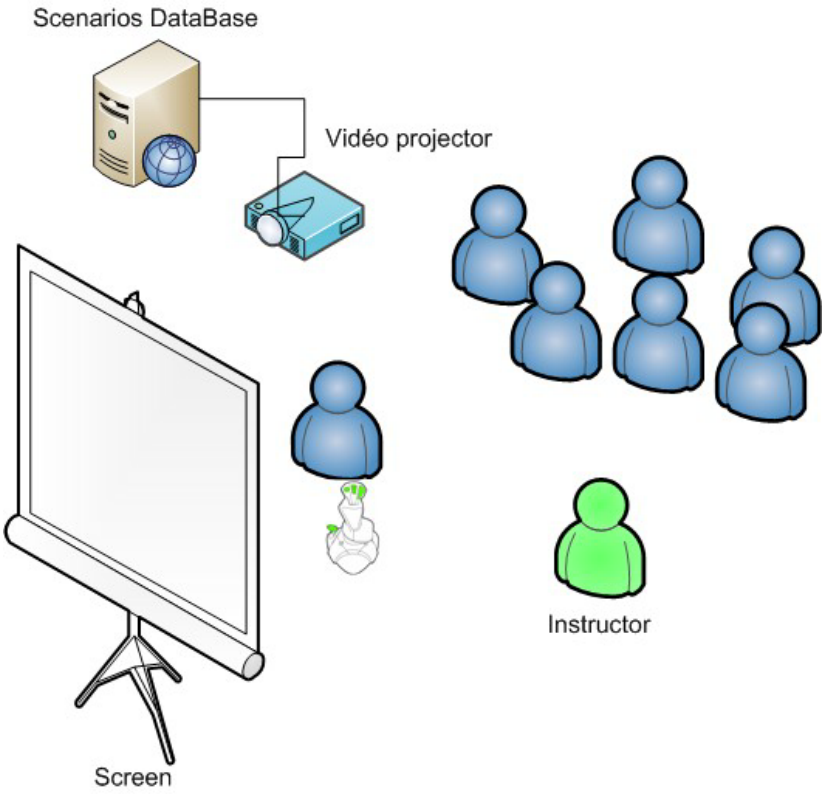

Figure 28 TTX : Classroom set up

The easiest setup. The instructor may direct the 'show' himself, or let the control to the users, if interaction is expected. For TTX, trial and error process are supported by either backtracking or simply trying something else upon instructor choice.

Figure 29 Classroom TTX exercise

4.2.2 Drills:

Two setups are possible for drills:. In a single user case, the trainee tries to complete his task on his own. This is suitable for simple drills, and, eventually, the screen may be replaced by VR Googles for more immersion

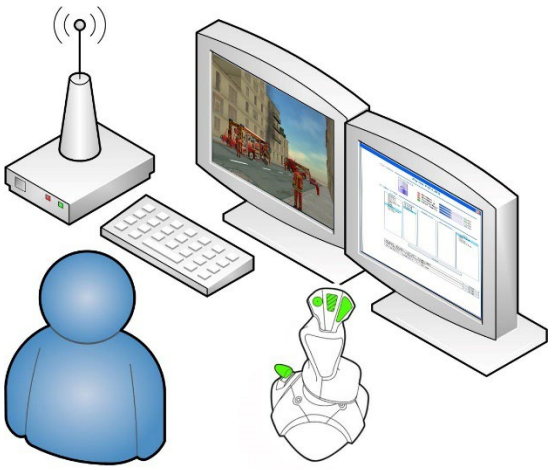

Figure 30 Drill set up

.

Figure 31 Simple Drill setup (Abu Dhabi 2019)

Figure 32 Simple Drill immersive (first on scene training SDIS04 2019)

Or Student vs Instructor set up:

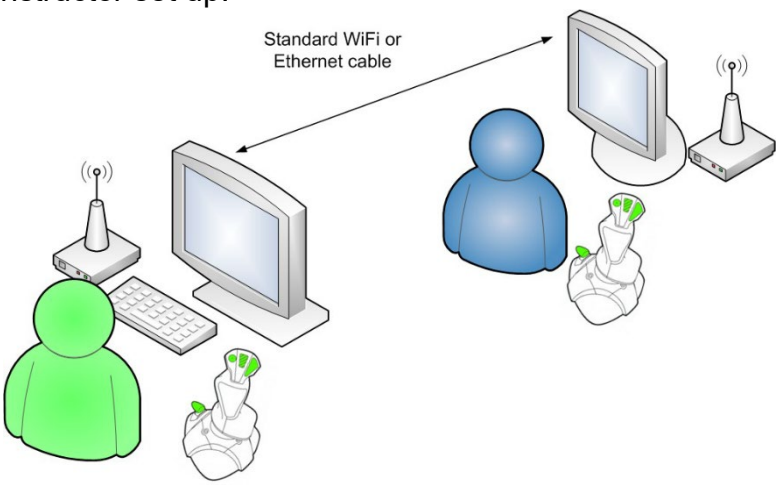

Figure 33 Student vs instructor

The main interest of this setup is that it enables the trainer to adapt to the trainee, and work on more complex drills, in which there may be several paths to resolve the issue.

Of course, it takes more instructor time.

Figure 34 Drill example 2ith different hardware setups (BMP 2020, ENSOSP 2020, Fujian-China 2019)

Figure 35 Trainee and Instructor Qualifiant Drill (Chevron Texaco 2019)

4.2.3 Functional exercises or team-based drills:

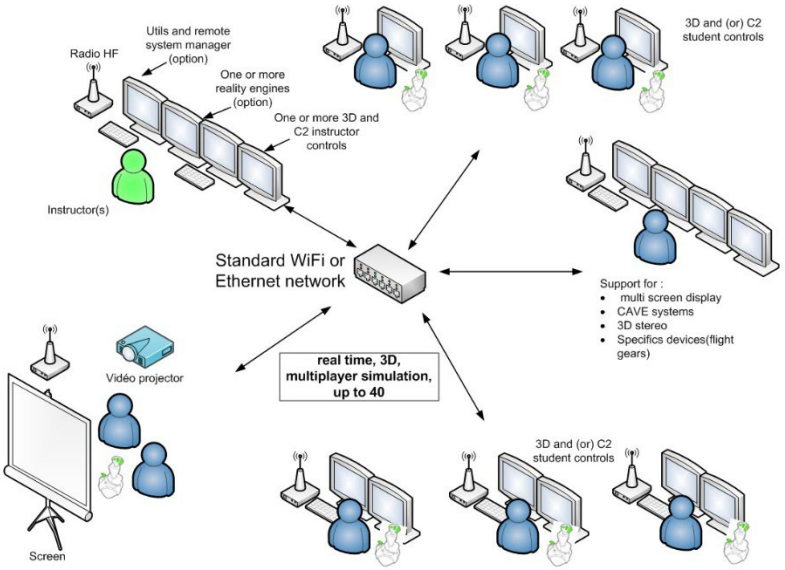

Figure 36 Team based set up

In this set up, any number of participants may cooperate in resolving the incident. Can be limited to a truck crew, to an intervention squad of a few trucks, or be scaled to the entire chain of command with several organization. The largest training to date in ENSOSP involved 60 persons together.

Figure 37 Control room for Full Functional Exercises (BMP 2016)

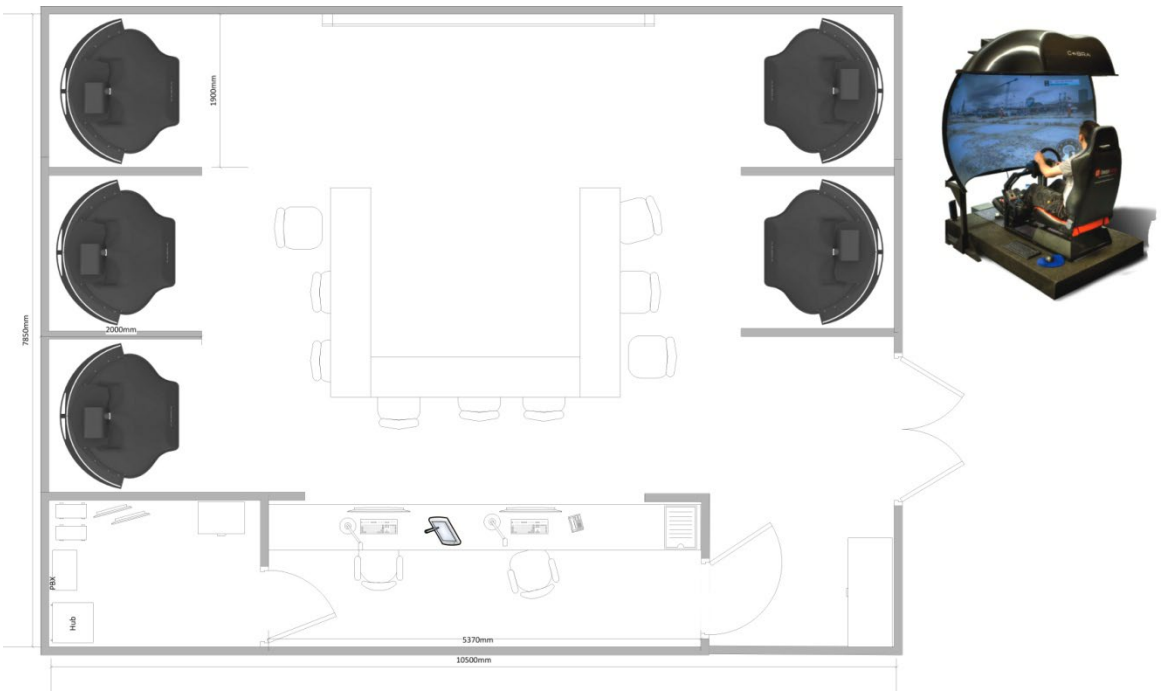

Figure 38 Example of immersive display design

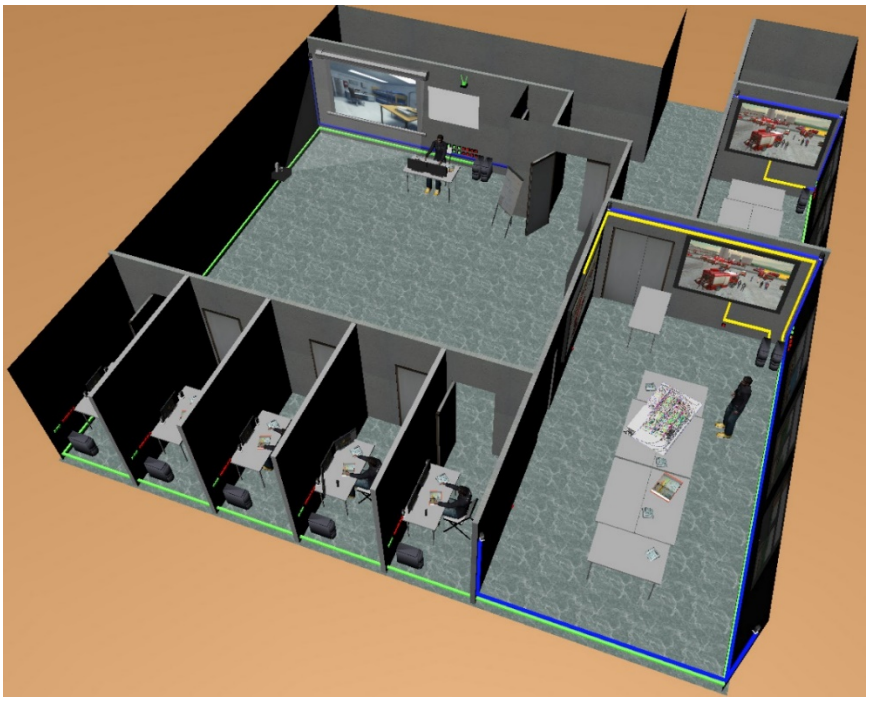

Figure 39 Examples of Functional simulation (including EXCON, ICP, ERCC and first responders)

Figure 40 Another example of functional simulation set up

4.3 Software used

In ENSOSP, the Virtual Reality Training center generalized to many trainings. The following software are used:

4.3.1 A 3D immersive environment,

Of course, this is the base for VR Training:

Figure 41 EVE 3D example (copyright CRISE)

4.3.2 A scenario management support tool:

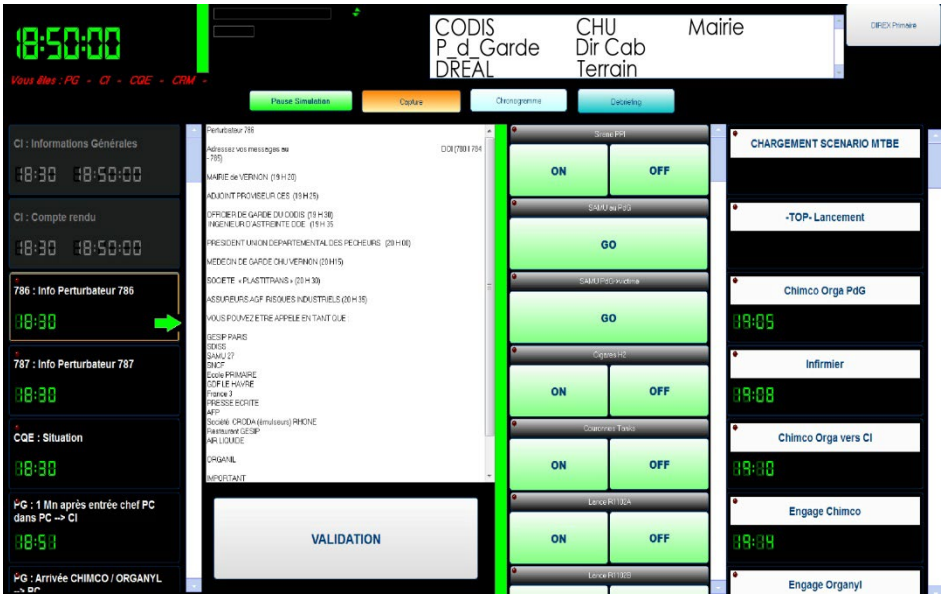

Figure 42 Anim, a scenario management system (copyright Crise)

Such device, running on a tablet PC for example enables the instructor to get rid of technical manipulations when controlling an exercise. The complete simulation can be controlled with pushbuttons, and helper text is provided to the instructor to not forget important items. Ideally this scenario management system is contextualized with through the actions of the trainees’ as the scenario progresses, and / or trainees awareness (did they see the victim, or do they wear PPI, etc…). This type of software enables to alleviate technical manipulations from instructor mind, but it provides strong guides to the instructor himself: the trainer manager is sure that the scenario is evolving as planned or designed by the expert, no shortcuts or approximation can be possible. Besides, this kind of software enables to qualify, since the happening of events is reproductible, and a quantitative assessment of trainee work can be provided, based on resolution path, relative to best path, and time spent.

4.3.3 Debriefing tool:

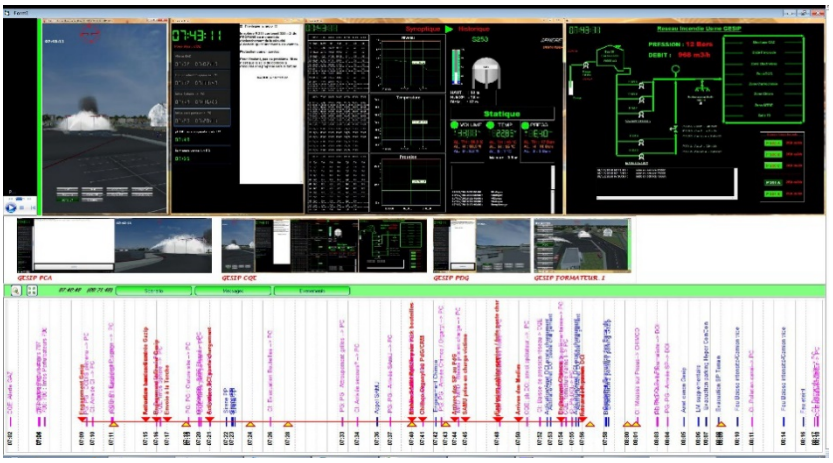

Figure 43 Debriefing (copyright CRISE)

Either simple debriefing for drills or more complex debriefing for full scale functional exercises, the debriefing tools should enable to trace the timeline of actions performed, radio communications, and instructor on time observations. The possibility to replay an exercise up to a critical or bad choice point in time and restart the exercise from there is appreciable, while re-loading the trainees' screens at some point in time, in 3D, so that it's possible to review the event from another point of view is a very good option.

5. The material developed for HyResponder

Crise's simulation framework (EVE) allows the user to easily create their own scenarios. So, although many scenarios are available (HyResponder scenarios are adding to existing scenarios developed within HyResponse), we included in EVE object library all the new objects.

This means that all EVE users can now either provided scenarios, or create their own. This is important, since all provided scenarios are created on our generic environment (shared by all our users). A user will be able to reproduce or easily create new scenarios on their own territory, so to match a real installation … or a planned one, and train specifically on this equipment in its 'real' surrounding, which is very important for our customers.

This enables to shift from 'initial education' to H2 risk handling to 'hands on training' to enforce preparedness on real assets incidents.

5.1 Sources for measurement devices and visualisation

5.1.1 Leak Source for pressurized H2

In the 3d simulation, it's necessary to simulate a source, so that measurement devices can 'sense' a concentration, or temperature change.

The H2 source is an object that is placed, in the 3D, at the emission point of H2. It can be a leak or, in the case of LH2 a pool.

The new enhanced Leak source, proposes the following capabilities:

- 3 parts decomposed sound (begin – sustain- end of leak)
- Added deflagration sound.
- Preset to 10 minutes leak, tunable from short burst (1 second) to continuous
- Flame either invisible or tinted (exposing external compound burning in flame)
- Temperature / Infrared visible, with calibration for mostly horizontal or vertical oriented leak.

Infrared camera visualization:

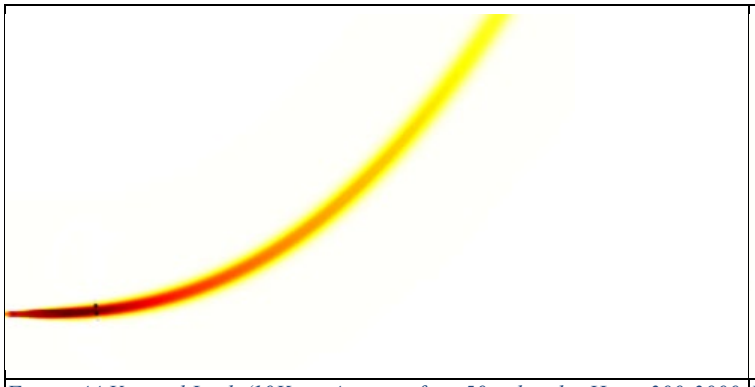

Figure 44 Vertical Leak (10Kpsi, 4 mm orifice, 50 m height, Heat: 300-3000 °K)

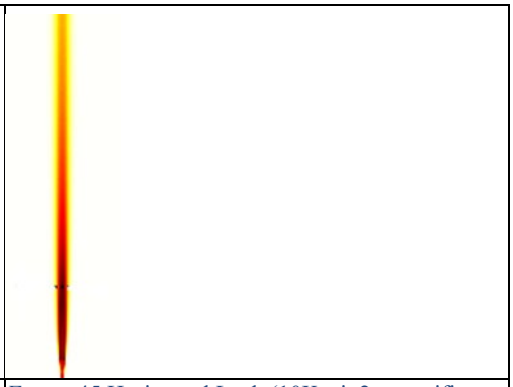

Figure 45 Horizontal Leak (10Kpsi, 2mm orifice, 35m length, Heat: 30-3000°K)

The H2 leak source has been greatly enhanced in comparison with HyResponse.

5.1.2 Source for unlit H2 or LH2 pool

For unlit source or LH2 pool source, a concentration distribution can be specified.

It can be tailored for indoor use (maximum concentration in a room staged as a function of height: the greater the height, the higher the concentration), or as an outdoor source: maximum concentration on leak point or across all pool surface, with rapidly fading concentration downwind at constant height. A simple Gaussian dispersion model of light gas has been used:

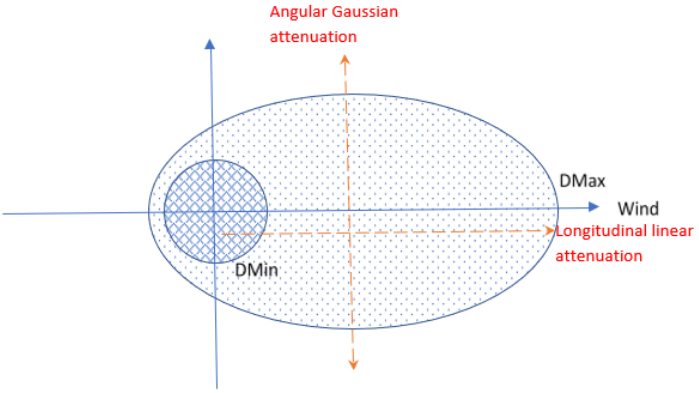

Figure 46 Simple Gaussian dispersion model (shown in horizontal plane)

If wind speed is null, the result is the following (Fig. 41) at ground height: (note that the back of the truck has a maximum concentration too, because of accumulation under

the truck)

.

Figure 47 Dispersion model a round pool colorized for visibility: Max concentration on pool (red) rapidly decreasing (No Wind),

If wind speed gets higher, the result becomes that shown in the Figure below

Figure 48 Dispersion model a round pool colorized for visibility: Max concentration on pool (red) rapidly decreasing (black is undetectable) (Wind 30 km/h),

As we can see, the concentration is rapidly decreasing in both cases, with pool surface keeping the maximum concentration, rapidly dispersed by wind.

For an unlit Pressurized H2 leak, the dispersion model gives the following pattern (leak below measurement height)

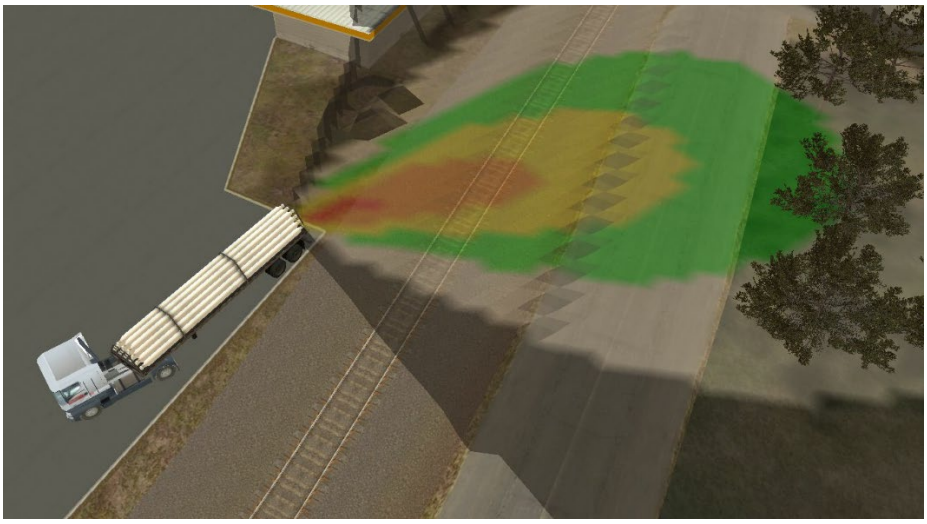

Figure 49 Dispersion model (false colorization as a function of concentration), unlit.

Since the simulation is not designed to replace a CFD package, this only is an approximation of course. Here, the results presented are calculated with standard parameters, but these parameters can be tweaked by the instructor or scenario designer.

The main interest here is that the concentrations are calculated in ***full 3D, and in real time***, so they will update immediately to any change of weather conditions or source change.

This source provides a lot of possibilities for automatic sensing in the VR and provides great flexibility in the frame of HyResponder.

5.2 Measurement devices

In HyResponse, the explosimeter reading was set, on demand, by the instructor determining concentration reading or explosimeter alarm, depending on evaluated location of sensor bearer.

For HyResponder, thanks to the sources presented in preceding paragraph, the measurement devices readings are automatic (though they still can be filled by hand or set faulty if desired). The automated measurement devices which are available are described in the following sections:

5.2.1 Probe

Probe is a simple sensor device that will enable scenario designers or instructor to visualize H2 or O2 concentration value at any point or to visualize the emission pattern around it.

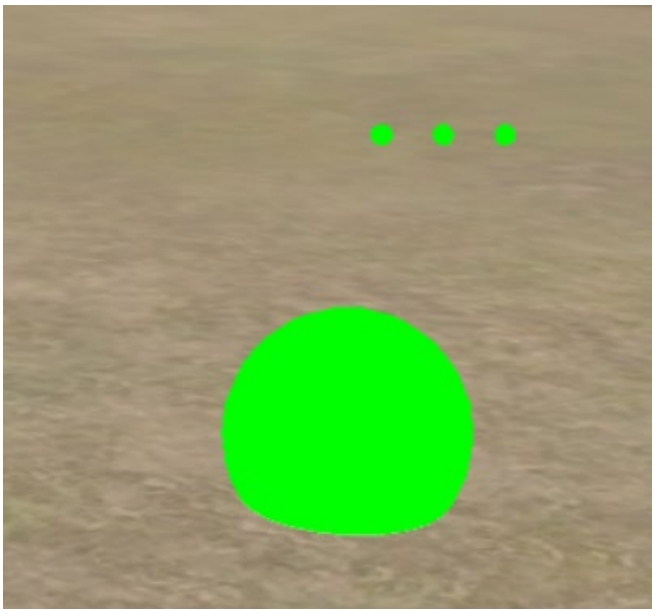

Figure 50 Chem Probe (EXCON visualisation)

The basic shape of a probe is very visible since it’s designed as a tool for scenario creation or animation. It’s not designed to be used by trainees.

Probe enables to visualize its surrounding concentration fields:

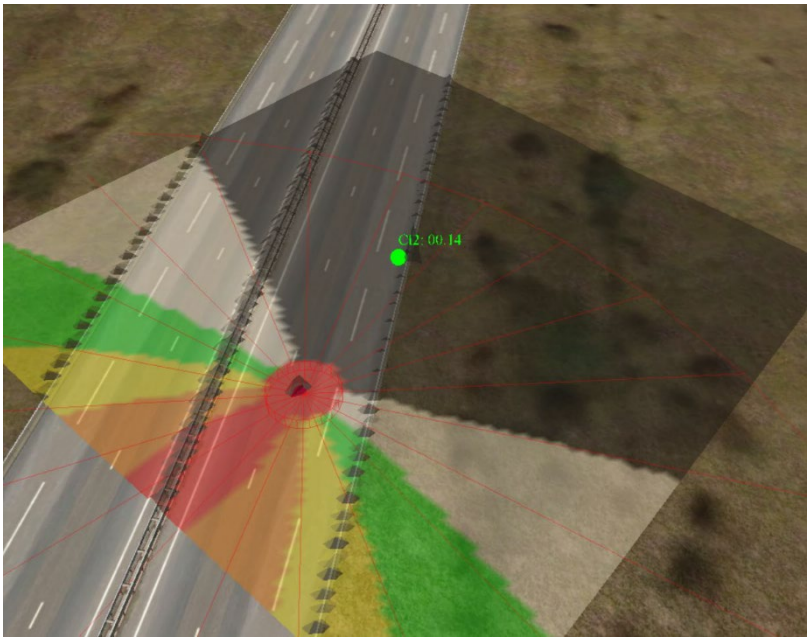

Figure 51 Instructor probe: it visualizes the concentration field on the instructor screen, invisible for trainees

5.2.2 CHEMPRO Gas identification,

A simple chemical sensor device is an object that can be ‘taken’ and used by an avatar: a trainee with an avatar can ‘left click’ and ‘take the object, then activate it in its objects list.

Once activated, the device will show up in the user interface, fully functional. The values and icons are automatically updated when the trainee moves.

Figure 52 Automated CHEMPRO sensor

5.2.3 EXTREME GAS ALERT - MINIRAE 3000 - QUATTRO Gas Alert – Mx21

Extreme GasAlert is a single channel electrochemical gas-detector.

Quattro Gas Alert is a quad channels explosimeter ('H2Sppm', 'COppm','O2perc' and 'LELperc').

MiniRae is a single channel gas Detector (COV).

MX21 is a selectable quad channel detector.

Figure 53 Automated Gas Sensors, explosimeters

5.2.4 GM700 Non-Contact Thermometer Laser Temperature Gun Infrared Thermometer -50° to 700° Celsius

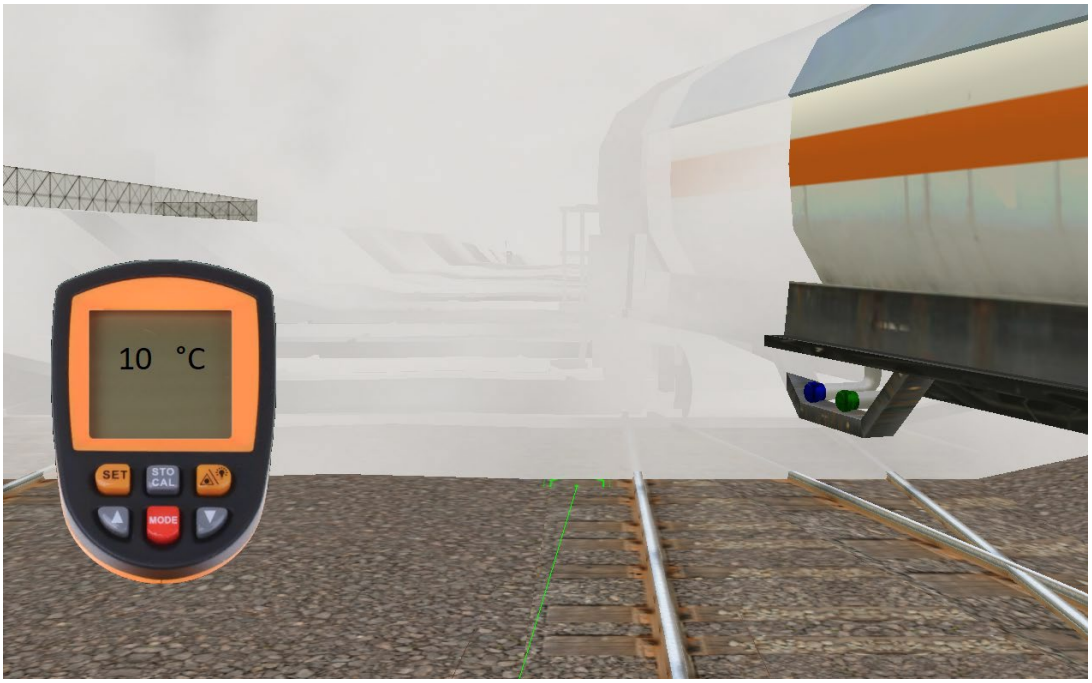

Figure 54 GM700 Non-contact Infrared thermometer

The laser pointer can be operated with the trainee’s mouse. Temperature reading is automated too. The temperature reading is bound to the area the laser pointer is pointing to.

5.2.5 Conclusion on Sources and Sensors

The ability for the trainees to visualize infrared information, and to be able to choose and use a wide range of gas detectors, explosimeters, and thermal measurements is a big improvement from HyResponse. Since the sensor readings are automated, real time, and embedded into the scenario**, it opens the way to newer set ups, including ‘solo’ exercises**.

From the scenario creator, and instructor point of views, the animation charge consisting in evaluating local gas concentration (H2, O2) is greatly reduced, enabling to concentrate on training itself.

None of these sensors can be carried by a Drone/UAV/UGV. If necessary, a sensor can be attached to any of robotic vehicles available in EVE©. All sensors provide true 3D capabilities.

5.3 H2 / LH2 related assets

5.3.1 Storage

Many assets were developed for HyResponse:

- Liquefied hydrogen trailer
- Hydrogen bus
- Combined heat and power installation
- Hydrogen delivery trailer
- Dismantled trailer
- Containerized hydrogen installation
- Hydrogen production and storage site (cigars and bottles storage)
- Multiple car crash on motorway
- Remote power backup installation
- Hydrogen car in a tunnel
- Hydrogen delivery pipe

For HyResponder, the storage has been diversified, to include representations of LH2 storages.

- Cigars
- Spheres and Spheroids,
- Above or underground cryogenic tanks

A spheroid is shown below.

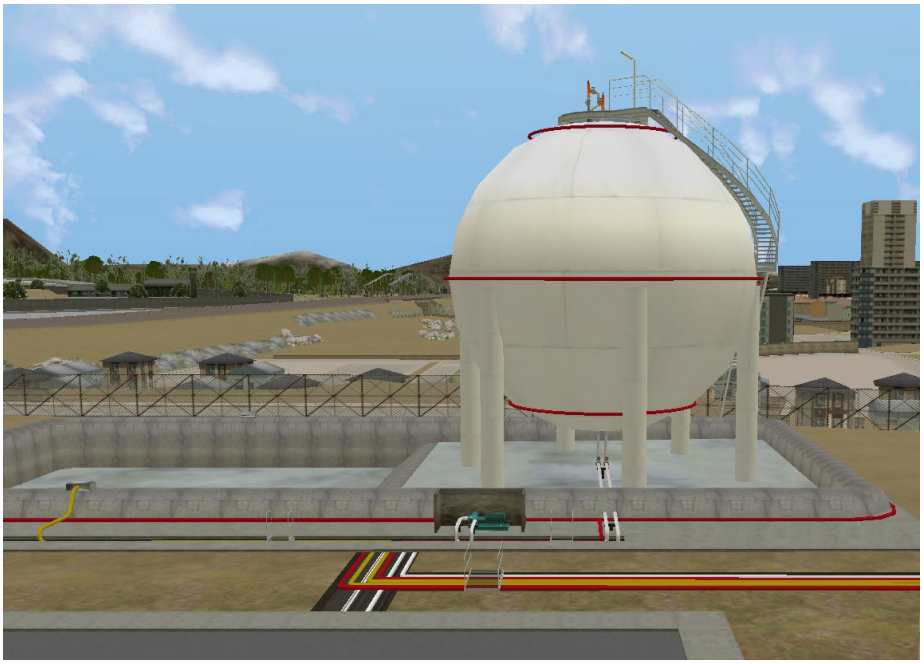

Figure 55 Spheroid vessel

A new storage geometry creation tool, developed in EVE© is able to create any spheroid given height, minimum, maximum diameters and height above ground.

If height above ground is bigger than half heigh, then the spheroid is placed on feet above the ground, if not, the spheroid is partially or totally buried.
In any case, the access stairways are automatically generated, as well as pressure relief valves (yellow on top), lights, piping in and out, and ready to work fire defenses, like foam and mostly, for H2, sprinklers. These can be triggered by scenario, by instructor during an exercise, or by triggering site alarms.

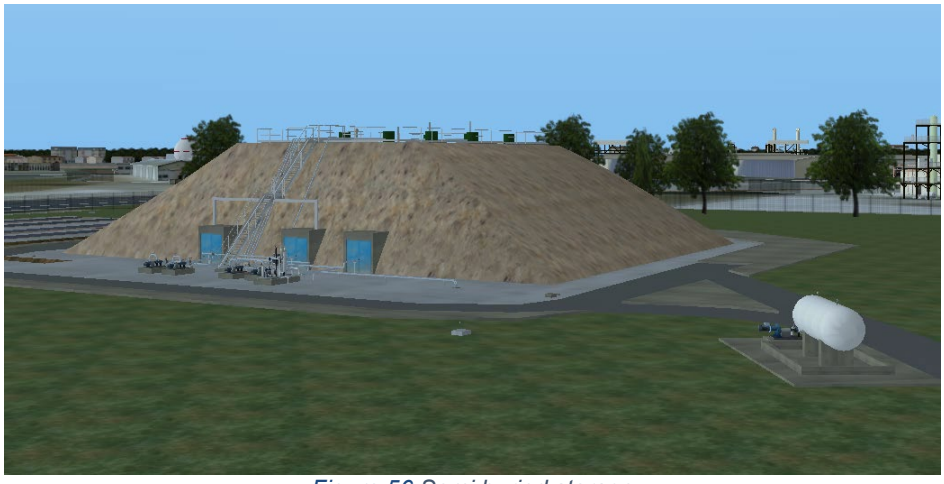

Figure 56 Semi buried storage

These new storage objects enable to expand already existing Hydrogen production and storage site with new storage options.

5.3.2 Mobility:

New H2 powered city bus is available:

Figure 57 H2 city bus

A new H2 train is available (Alstom).

Figure H2 train

Plane provision:

Although not requested during HyResponder, more mobility assets can be made available for specific training, like Airbus or Boeing plane equipped with H2 powered APUs. Indeed as of November 2021: ENSOSP is likely to use this capability to train airport firefighters specifically to H2 safety on tarmac.

Figure 58 Plane object for eventual airplane/airport H2 training

5.4 Scenarios

New scenarios to complete HyResponse scenarios are focused on LH2, either on storage leak, transportation and mobility.

All assets are available and ready for HyResponder's users of EVE©. ENSOSP will be the first to receive new assets and scenarios, in order to be able to release HyResponder videos and training kits.

5.4.1 HyResponse scenarios and upgrade:

HyResponse already existing scenarios cover:

- Liquefied hydrogen trailer
- Hydrogen bus
- Combined heat and power installation
- Hydrogen delivery pipe
- Hydrogen delivery trailer
- Dismantled trailer
- Containerized hydrogen installation
- Hydrogen production and storage site
- Multiple car crash on motorway
- Remote power backup installation
- Hydrogen car in a tunnel

All existing HyResponse scenarios can be utilized together with new assets developed for HyResponder: Sources (jet, dispersion, thermal) and measurement tools.

5.4.2 New HyResponder scenarios:

Scenarios with liquid hydrogen jet and rainout forming a LH_2 pool that causes vaporization and cryogenic cloud formation are now available:

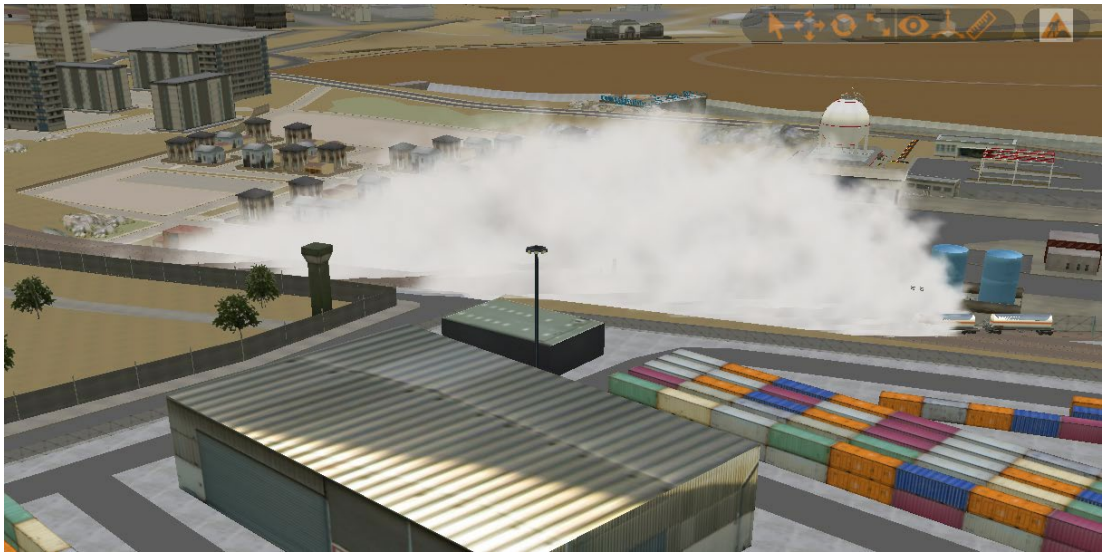

Figure 59 LH2 wagon delivery incident.

Figure 60 LH2 leak & pool at storage

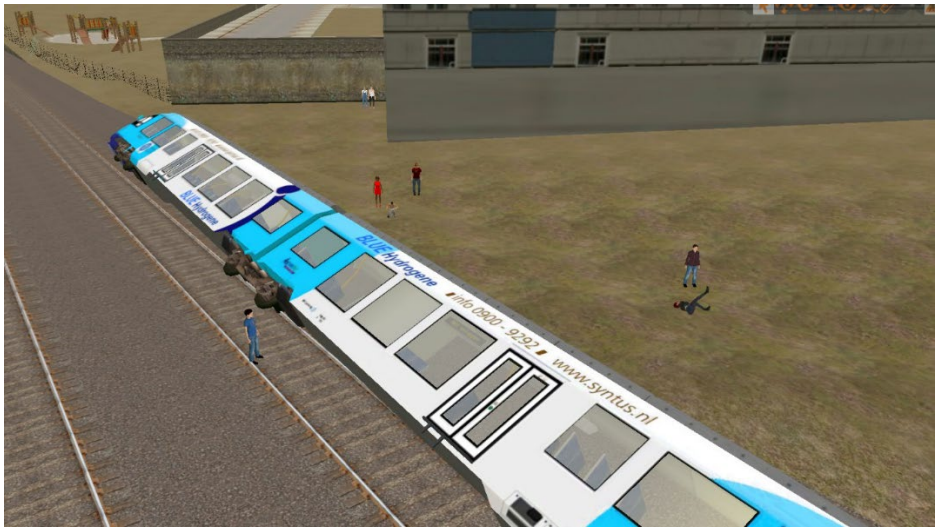

Figure 61 H2 Train incident Scenario 1

Figure 62 H2 train: fire at station

6. Organisation proposal for ENSOSP Workshop and Pedagogic kit

6.1 Replanning of training sessions due to COVID pandemic

The original proposed use of the VR tools had been designed around three goals:

1. Train the trainers to H2 response on VR setup of ENSOSP
2. Produce training material that can be used at national 'train the trainers' worshops in the project scope
3. Produce training material that may be used by national responders trainings 'out of the project' frame

During preparation of the project proposal, back in 2019, pandemic was inexistent, and not identified as a threat for the project.

However, even at project proposal elaboration, it has been planned that:

- Goal 1 would serve to accustom trainers to H2 risk, and to 'advertise' ENSOSP VR training infrastructure, in the same vein as project advertises ENSOSP H2 real fire platform. Indeed, ENSOSP (a non profit organization), would be in position to offer both real and VR trainings platform. Both platforms thought as a unique and valuable European asset for H2 training.
- Goal 2 would not take for granted the availability of VR rig at national levels, so, produced material would be in form of videos. Trainers are quite used to use this type of media, and it doesn't impact on the cost or set up of a training.
- Goal 3 would use the same kind of material, for the same reasons.

Early in 2020, it appeared that COVID was likely to prevent the organization that was planned and proposed. It was clear that ENSOSP workshop would not be able to take place face to face in summer 2021 as planned and that trainers would have to rely on lectures to get acquainted with H2. Besides both the Real Fire Platform and VR platform would be out of reach for them.

Whilst CRISE, made a proposal to use VR distance training. this required significant additional budget outside the scope of the project. Different schemes were evaluated. Using VR over internet implies to use specific network infrastructures, and to develop content specifically. The proposed budget was 25 k€ overshoot from our initial budget in order to design a cloud based exercises servers, that could have been used not only for 'ENSOSP workshop', but for national and 'out of project' trainings (Goals 1 to 3). Cloud management could be held by ENSOSP (a non profit organization), without CRISE intervention after the original set up.

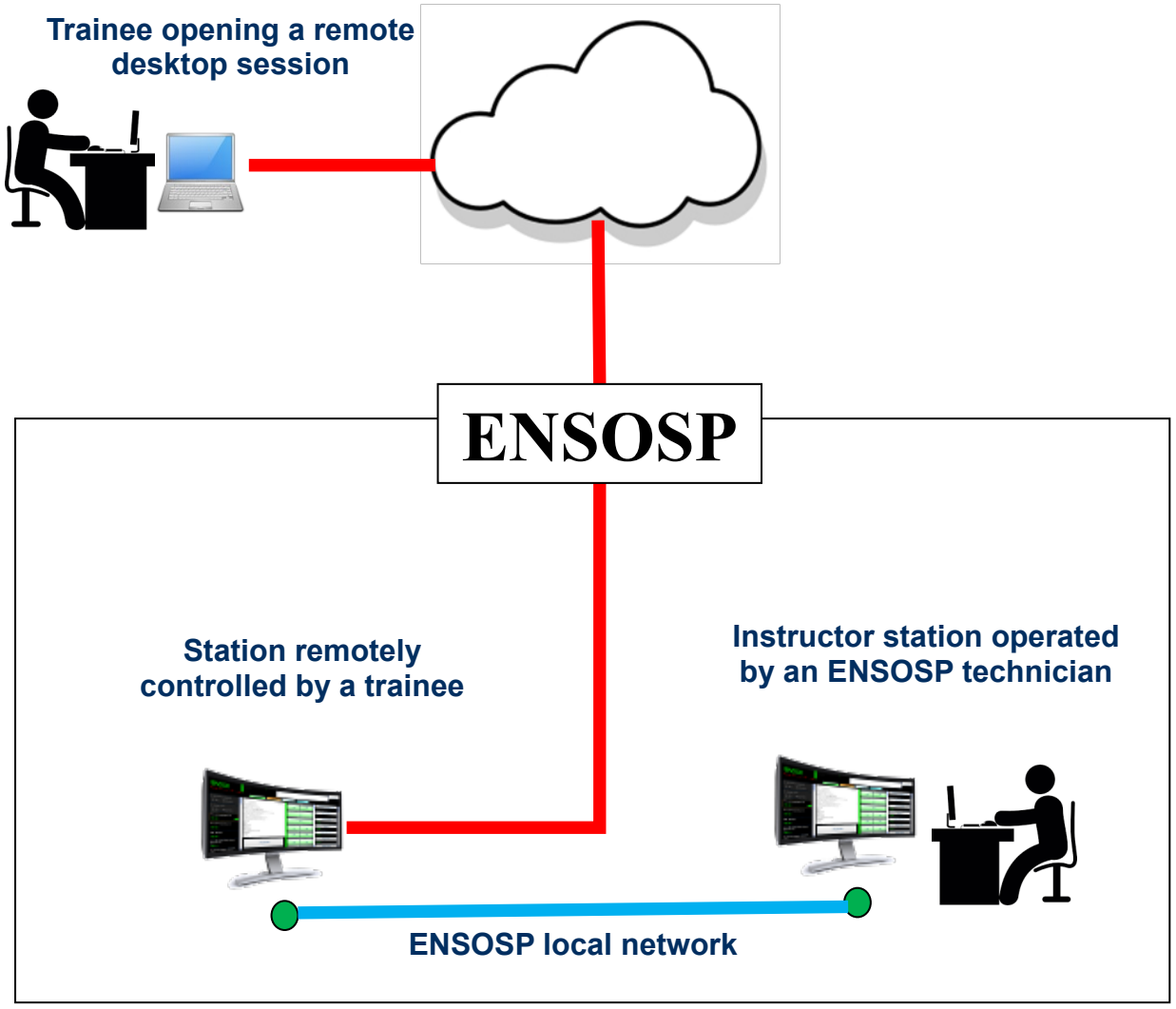

Figure 63 ENSOSP Infrastructure hosted Web distance training proposal (April 16 2019)

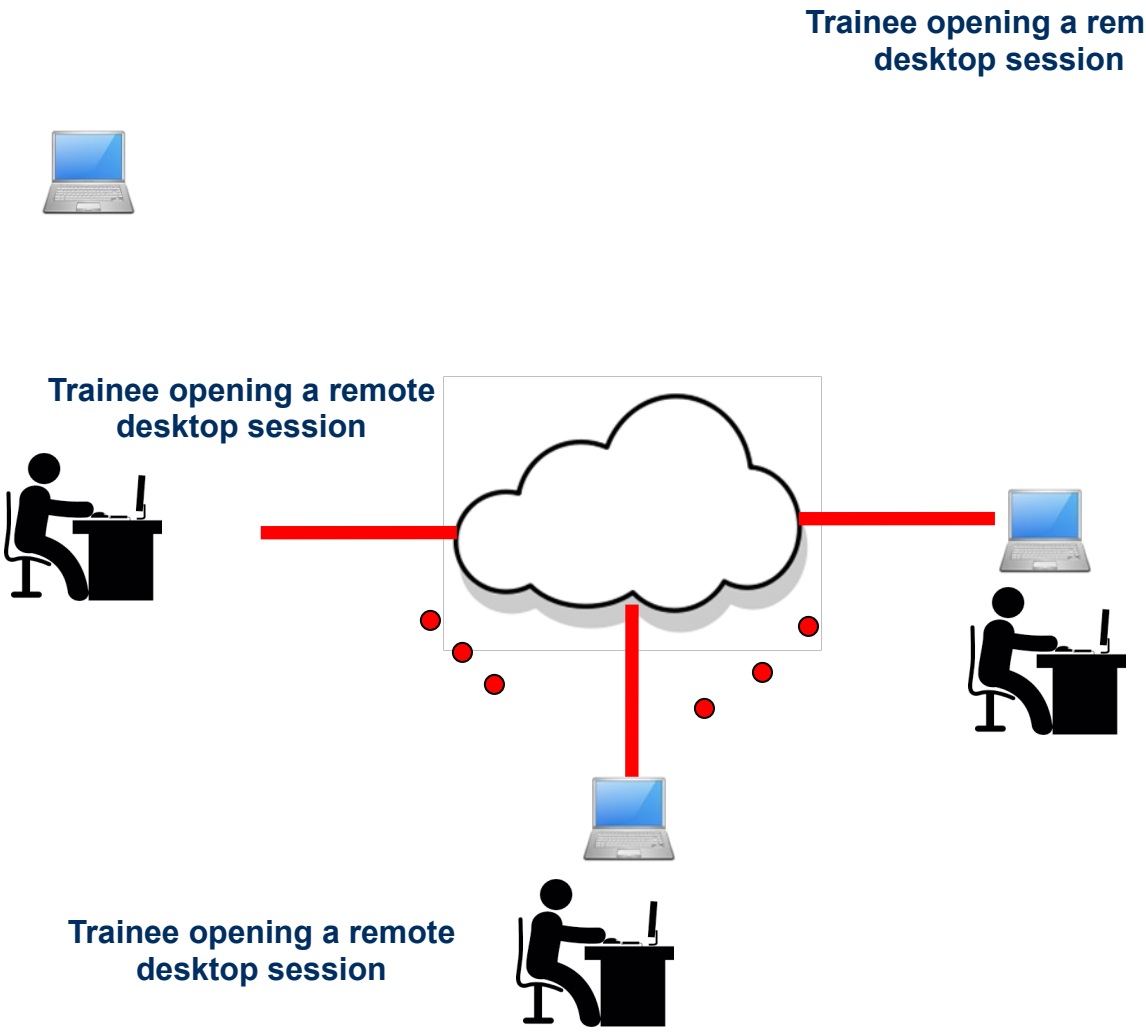

Figure 64 Full web proposal (April 16 2019)

Note that both proposals enabled the trainees to use *any* computer at their location to experience free immersive team based VR since all real time 3D computation is done either on ENSOSP hosted computers or on a cloud service (SAAS).

However, due to the additional budget involved, this proposal was not pursued. However, it is worth noting for organizations with their own training budget resources. This is in a similar vein to organizations having operational training on site.

Using the produced videos elaborated for ‘Goal 2 and 3’ during ENSOSP workshop, so that trainers could at least perform some exercises involving ‘live’ H2, even from distance. A new pedagogic set up has been imagined so as to enable ‘international mixed teams’ to elaborate an operational response from the video, and expose to other participants their operational ideas. Synchronized with the EERG presentations by ENSOSP, and with ENSOSP trainers managing the exercises. Whilst it is acknowledged that this is not an immersive VR experience nor an optimal VR pedagogic set up, it is a workaround within the constraints of the pandemic.

After this first distant workshop, another workshop has been planned in December. This new workshop, unplanned in the original proposal, would enable international trainers to use both the real H2 Fire platform at ENSOSP, and the VR infrastructure at ENSOSP.
The idea is that trainers may experience H2 incidents on the real fire platform, and experience a response build up on the VR platform.

The implications, for CRISE are the development of a new set of exercises, not to train the trainers to H2, the main item of ‘goal 1’, but to train the trainers to train trainees to H2 risks.

The trainees experienced distance led exercises, and is, during this second unplanned workshop, will experience immersive VR. This follows both main item of goal 1, and secondary items: more polish would be given to H2 operational response, through new exercises, and further possibilities offered by ENSOSP (a non profit organization) to train to H2 risk would be exposed.

So, as far as CRISE is concerned, this is a significant increase in workload within the scope of the original budget (two VR workshops in place of one, and two sets of exercises and pedagogic set ups creations).

6.2 Commercial use of produced materials

It has always been planned to make the training material freely available to responders, and it will be uploaded to project website.
Originally, it was planned to record the VR exercises on the ENSOSP workshop too, but, unfortunately, the workshop has been distant

When it comes to VR materials themselves, the situation is more complex and should be considered from different angles:

1. The raw materials themselves. Basically the 3D objects themselves: trailers, clouds, measurement devices, etc
2. The platform itself: a set of computers sharing a multi user immersive VR system with functionalities exposed in the document.
3. The pedagogic set up: that’s what VR users experience is important. A tool is only a tool. Knowing when and how to use it is certainly the most important.

For CRISE, as stated in the proposal, it’s clear that all our clients will be given free access to the assets developed for HyResponder. This means almost 20 training centers in France, in several European states, in Africa, Americas and Asia, notably in Taiwan (one Taiwanese client came for HyResponse), and in China (Crise was meant to train bus conductors and first responders for H2 risk before Olympic games).

But, since different VR packages exist on the market, we tried to explain, in this document the best way to use VR, to cover points 2 and 3.
Point 1 is more problematic, since different 3D formats exist. Many converters exist to chanje the 3D format of objects. But, more important, CRISE is the only VR systems

providers using a free, public, open standard for our 3D assets. This group of standard is called VRML/X3D.
More precisely:

- ISO/IEC 19775-1
- ISO/IEC 19775-2
- ISO/IEC 19776-1
- ISO/IEC 19776-2
- ISO/IEC 19776-3
- ISO/IEC 19777-1

The consortium behind this standard is Web3D: “Founded in 1997, we are an International, non-profit, member-funded, industry standards development organization. We develop and maintain royalty-free ISO standards for web-based 3D graphics. Our standard X3D (Extensible 3D) originated from VRML and is available in XML, Compressed Binary, and classic VRML formats. X3D is open, royalty free, extensible, interoperable, and runs on all platforms including desktops, tablets, and phones. Our members are from business, academia, government and the military.”

Almost all 3D modellers on the market can open these 3D assets, or, if not, dozens of file format converters enable any other VR system vendor to use the assets produced under the project frame.

Our two international main competitors are using closed proprietary format, derived from game engines. It is not possible to design interoperable material or scenarios. It can only be their responsibility to make the effort, since, to my knowledge, they are not offering materials or scenarios creation capabilities to their competitors … , and even not to their clients.
CRISE is the only VR system provider encouraging it’s clients to create, share, materials, scenarios and pedagogic setups, on a free basis. Any client of CRISE may share and use any other client scenarios. None of our competitors is offering this kind of capability.

So, CRISE, even if a profit-based SME, has taken great care to produce, with this project, and HyResponse before, a solution that enables any actor on the market to enhance it’s capabilities to H2 operational response training.
Necessarily, the virtual training is mostly centred on one only commercial solution, but CRISE makes it’s best to open this deadlock as much as possible.

We can not do more on interoperability with other products. We share our 3D assets, we share the pedagogic setups that can be used, and are providing more than enough explanations and illustrations in this document to allow anyone to get some VR training material up and running without our package.

The only immediate way to open all the scenarios and capabilities to ‘any’ user through a non-profit organization would have been to port the solution to a cloud based system (an interactive web application) under management of ENSOSP or another training entity, but this solution is outside the project budget…

But, nevertheless, note that the training is available to any number of fee-paying participants, since the training can be offered by ENSOSP on a non-profit making, which, already, greatly impact the effectiveness of this project.

6.3 Organisation

AS mentioned due to the COVID pandemic, it was not possible to deliver a face to face workshop in June 2021 at ENSOSP premises in Aix En Provence.

It was decided, to replace this workshop with a ‘remote workshop’ held on a remote conferencing platform (Microsoft teams).

A thorough VR distant training was not possible as it was never foreseen that training would be delivered remotely within a pandemic!.

This does however fit with the choice of providing videos in place of VR access to the trained trainers’ pedagogic kit.

Hence, to replace the VR sessions that could have been experienced on ENSOSP in house infrastructure, it was proposed that videos were shared by all trainees during the June 2021 workshop. While it is far from being optimal for a VR training experience, it’ll enable trainees to minimally practice the proposed exercises, even in an isolated, remote way, develop their ‘first actions’ ideas and tactical planning.

These first actions and tactical planning as imagined by each remote isolated trainee, will then be discussed/corrected on the main training support application (Microsoft Teams).

If ENSOSP network bandwidths and availability permits it, we may isolate several small remote groups, that could experience remote VR in a ‘cozier’ way, means that the single interaction device (the mouse) will be shared by a lesser number of dispersed remote trainees. And if, by change, some trainees may group as teams in remote locations, it’ll be easier for them to agree on interaction.

For the ENSOSP workshop in June, we propose to compose, each day a set of scenarios harmonized with lectures of the day and Real Training Area operations demonstrations.

For each exercise, the initial conditions will be displayed on the VR shared screen / video, this environment will be presented by instructor.

Along this scheme, we will be able to practice H2 related operational experiencing, even if conditions are tedious.

Intelligence/Understanding/Awareness/Protection

- Information gathering
- Interpretation (each trainee apart, or by groups if some can gather remotely, or as a whole in the Conferencing application)
- Develop Situational awareness (again, either isolated, by group or as a whole, as decided / possible)
- Risk evaluation

Analysis, Decision and planning: (POST)

- Set **P**riorities (and isolate immediate reactions)
- Define **O**bjectives
- Develop **S**trategies
- Elaborate **T**actics.

When returning to main conference platform (Teams), then, some more actions will be performed, such as

- Elaborating a common representation of the event,
- Accounting,
- Reporting (for first on scene mostly)

Most of the on-field commandment schemes can be experienced, without imposing a common operational reasoning doctrine/organization, but that would still allow to compare national/cultural based approaches.

This approach, although non ideal, would fit a train the trainers' approach, and will expose the necessary steps that will be proposed to the trainers for performing their own national trainings.

Besides a three-day training, if possible, will be held physically (not remote) in ENSOSP in December 2021, and then real action on training platform, and virtual action in VR will be possible.

6.2 Proposed Scenarios:

During the workshop, the following scenarios will be used for VR training:

- Vehicle incident 1
- Vehicle incident 2 (in tunnel)
- Bus on fire
- Dispenser fire
- Fuel cell application
- Dismantled (gas) trailer
- LH2 sphere storage leak
- LH2 trailer incident

These incidents will be simple, without external complication (though an area analysis is always necessary, and it'll be enforced of course), so that discussions focus on the

expected operational choices rather than secondary problematics).

For each scenario, a video will be designed for embedding in the training kit that’ll be given to train the trainers’ trainees. Here again, the final trainees will be spectators rather than actors, so we suggest that some VR support be found for national trainings.

7. Preparation for follow up workshop

A supplementary workshop was planned to replace the ‘hands on’ part of the training that the original June workshop didn’t allow. This was scheduled for December 2021 but due to Omicron was further postponed to 2022.So, in this workshop, the sessions are organized to be interleaved between the Real H2 platform and VR platform.

On the real platform side, the June 2021 workshop did not allow any exercise to take place, so, no fundamental change has to be applied to original planning of exercises and organization.

On the other hand, concerning VR, some exercises were executed, to some extent during the June 2021 workshop.
The June 2021 exercises, conducted through videos, enabled trainers to introduce themselves to H2 risk related mitigation and decision making, but did not allow the trainers neither to experience Virtual Reality interaction, nor to be trained to use such tools for their trainings.

The set of exercises used in June 2021 had been designed as to be easily handled through videos and simplified to link with the daily lecture themes: the process was more on introducing the trainers themselves to H2 specifics, with VR informed activities in the afternoons.

The decision was taken, for the follow up workshop, to capitalize on the June workshop and thus to prepare more complex exercises. This will enable future trainers to explore more thoroughly the use of VR and will enable them to use the developed scenarios to train beyond first responders toward officers.

The material developed here, like that for the June 2021 workshop will be usable on CRISE VR systems, or will be suitable to produce videos by ENSOSP for amending the training kit or will be exported to other VR training systems. As explained before, the formats used by CRISE are conforming an open, public, free IEEE norm, so anyone, including CRISE competitors, is able to reuse it.

ENSOSP, a non-profit organization, will be able to use them to train anyone, and our clients will all be able to use these materials on their systems, and this includes many European training centers, some in the US and in Asia.

Organisation of the exercises

While, in June, a kind of video based team TTX paradox has been used, the decision has been taken, this time, to be more open on any other type of setup.

The idea, during each time lot, is to break the group into 4 to 8 subgroups (depending on attendees numbers).
Each subgroup will then be split in two: one part acting as trainees, the other acting as trainers.
On next time slot, of course, trainees and trainers would exchange their roles.

This enables, under ENSOSP supervision, to experience both sides, and more, to explore any training paradox, from drill to TTX, from face to face to full functional setup.

We think that this approach will enable trainers to gain experience as **trainers** for H2, and to turn Covid related reorganization as a positive asset to go further than originally expected in the project.

The exercises construction

There are two types of ‘exercises’: some with a predefined scenario, and some with ‘potential events’ that will be decided by the ‘trainers group’ and elaborated on the spot in real time. So, on the next screenshots, one may find a simple environment, and an incident elaborated from this environment. Many possibilities are offered for each environment, we will give an example each time, but the designed environments have been designed with easy on spot retargeting.

This approach allows for maximum flexibility on exercise type, exercise difficulty, and exercise organization.
Besides, depending on groups, different responding team structure, different number or type of trucks, etc. can be used *during the exercise* to fit with any country organization. Even if not every truck of any country has been modeled, many truck *types*already exist, and may cover almost any non exotic type of response group. Truck equipment and number of responders can be set on the spot too.

Of course this can’t be packed into a pedagogic kit as designed for this project. Only videos can be produced, and this can be done ‘on demand’ by ENSOSP, and captures will be done during the workshop and made available on the HyResponder e-Platform

The exercises

Airport Infrastructure with bus station in car park

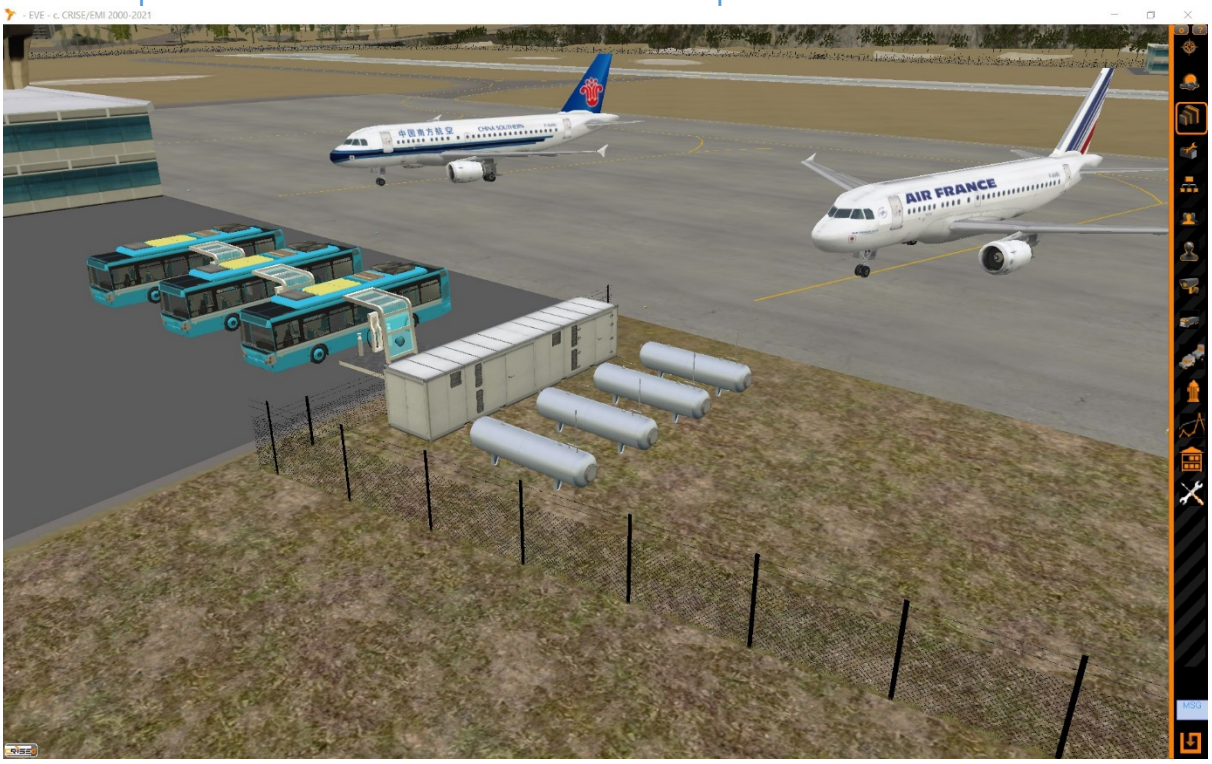

Figure 65 Airport Infrastructure with Bus station

Many exercises are possible here, ranging from bus leak, fire, or plane APU fire, H2 airport vehicle or mobile power unit fire. Besides many complications may be foreseen, by populating the car park or tarmac with cars or airplanes, or helicopters, catering

equipment or people. Even a crash at a Bus Station can be ‘played’ or simulated

Figure 66 Exercise example on Bus station leak

In this example, the exercise designer decided to reduce the airplane number, have the airplane evacuated (look at the slide emergency exits at back of plane), during a bus station leak. Leak sound and Alarm sound are available, ready to use, in the scenario.

Energy autonomous site

Figure 67 Energy autonomous site

On this site, very simple or very complex scenarios can be designed. H2 forklift and forklift distribution inside the warehouse, H2 Hydrolyser and Fuel cell containers can be concerned (leak, fire), storage of H2, or H2/O2 can be impacted, as well as electrical equipment. Warehouse contents can be set up on the spot, more or less flammable, solar roof is a complexification element.

Figure 68 Energy Autonomous site example

In this case, the exercise designer has removed many solar panels from the roof, in order to simplify the handling of a warehouse fire. Forklifts are visible outside the warehouse. The view here is from the other side of warehouse, equipped in the same way as front, but with smaller room for placing extinction equipment, that will be closer to H2 storage during extinction. Simply choosing the side of the warehouse to place an incident, dramatically changes operation conditions.

H2 Dispenser

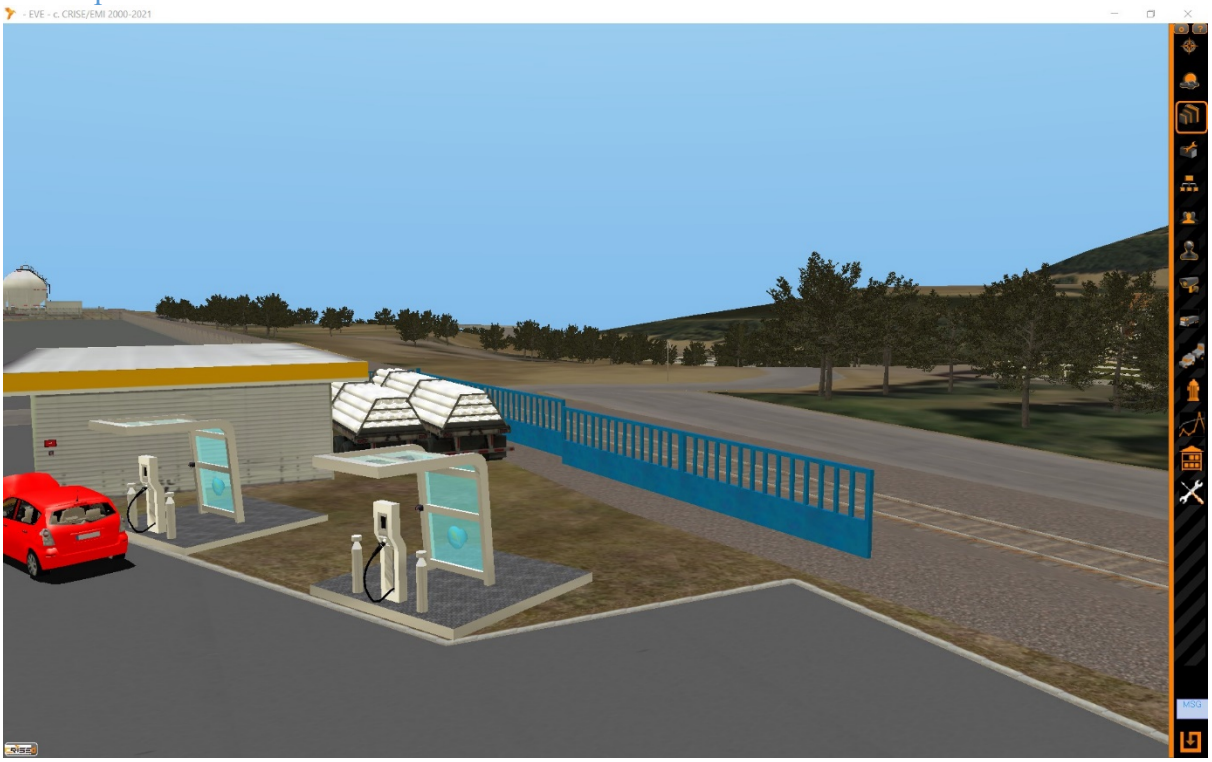

Figure 69 H2 Dispenser

A classic H2 dispenser, with trailer storage (may leak or burn), station (may burn), and dispensers ‘leak or burn, and car (same thing).

Figure 70 H2 dispenser example

Here, the designer choses a ’simple’ vehicle fire.

H2 train scene

Figure 71 H2 train scene

A simple train exercice. Train may burn (from bogies, or in car, or on top) or leak, and can be moved along the railway to be placed near or far from a road crossing, a tunnel, near an industrial site, etc.

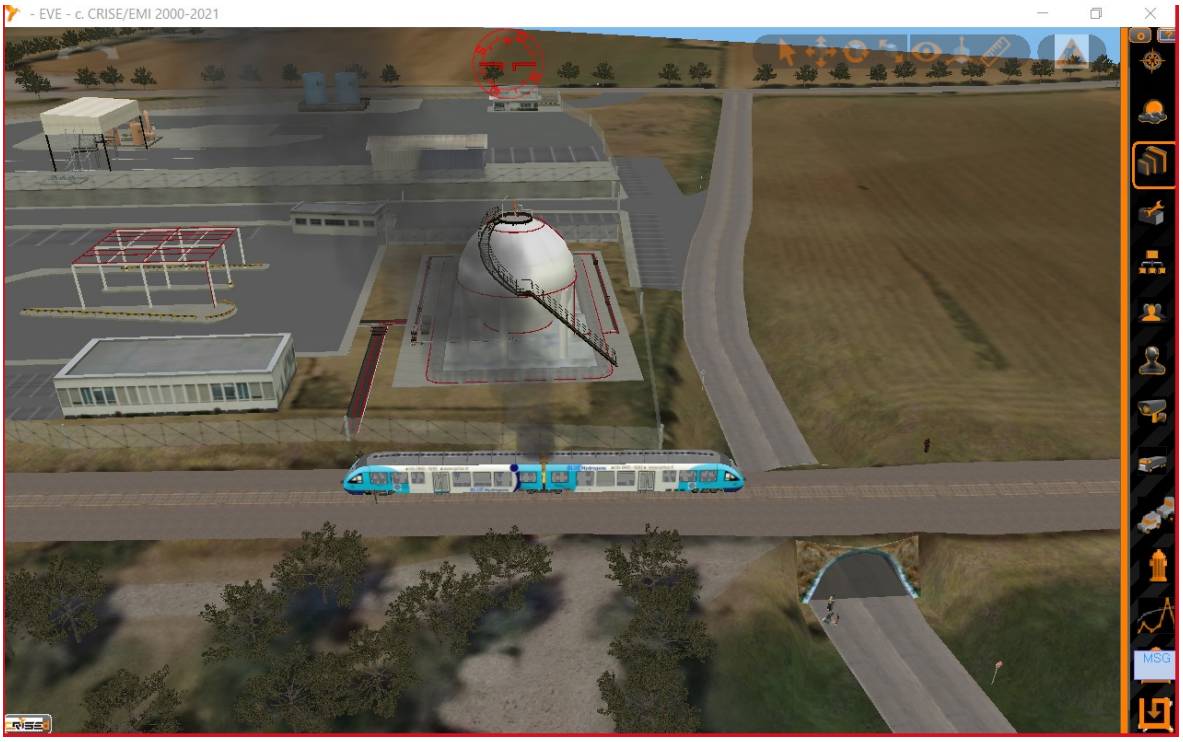

Figure 72 Train fire example

Here, the designer placed the train further from the road, and closer to an industrial site

Industrial installation

Figure 73 Industrial installation

A classic power plant inside an industrial environment.

Figure 74 Industrial installation example.

Here, a simple electric fire on electric facilities.

LH2 storage

Figure 75 LH2 Storage

LH2 storage. It may mostly leak. Wind force and direction, and eventual people or cars or trucks may complexify.

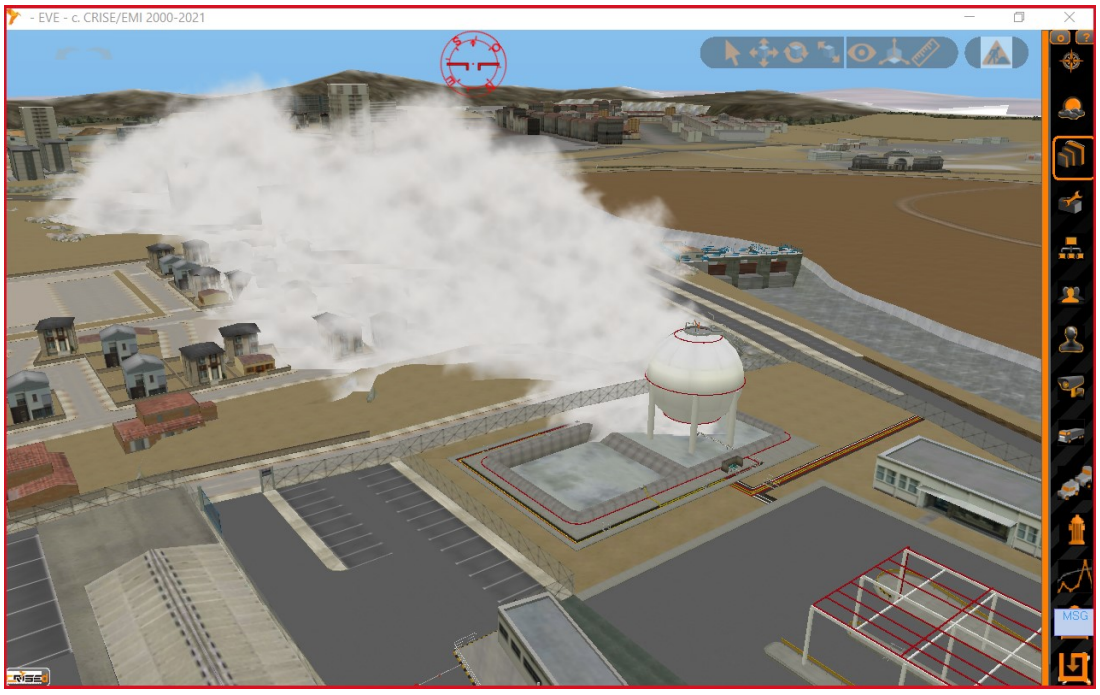

Figure 76 H2 storage leak

Here, a strong leak towards the city has been created.

Trailer

Figure 77 The trailer

The trailer can be placed in many preconfigured places, and many complicating factors can be included.

Figure 78 Dismantled trailer example

A dismantled trailer under a passageway. Victim in the car.

LH2 Trailer

Figure 79 LH2 Trailer

The LH2 trailer can be placed in several preconfigured places, for example as in Figures 80

and 81.

Figure 80 Lh2 trailer incident on rail bypass

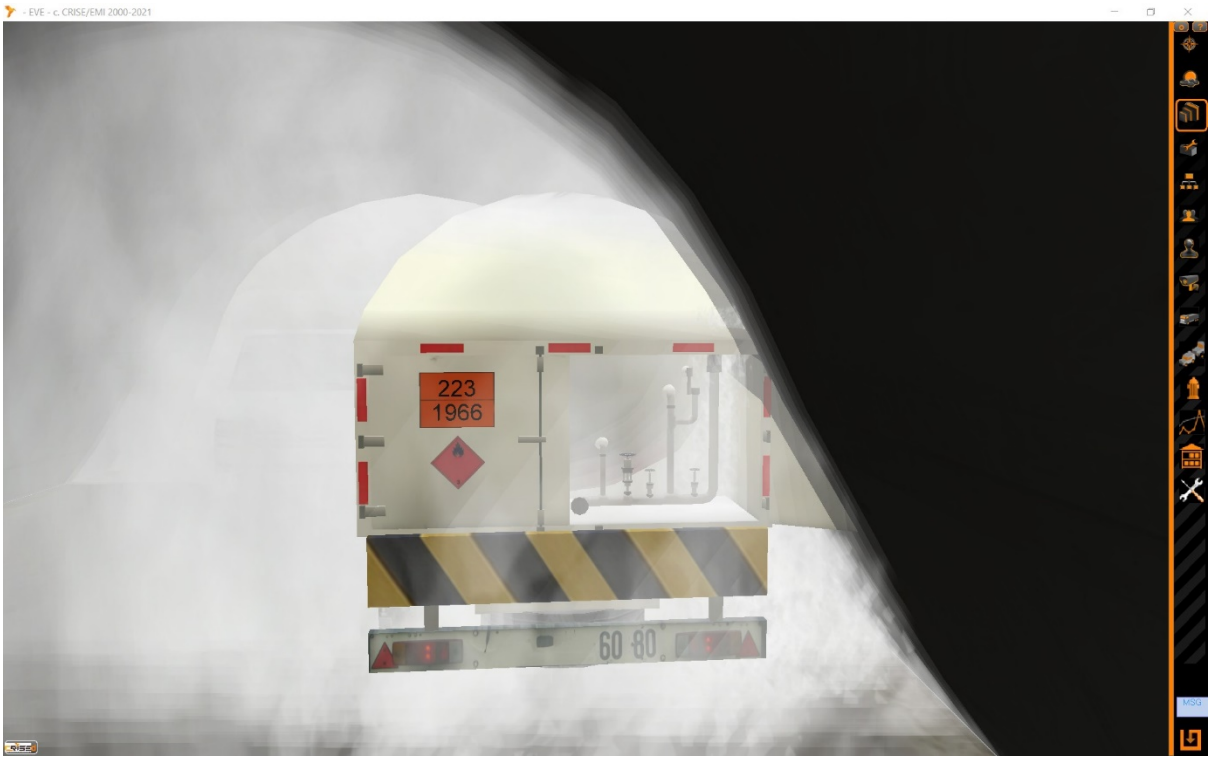

Figure 81 LH2 trailer incident

Here, it’s possible to complexify the incident with trapped, accidented car(s) or victims.

Conclusion

Many possibilities are offered by all these scenarios, there are multiple possible configurations and variations.
All scenarios have been designed with ease of change, either to design easy or very complex incidents, with a high variety of options to add complexity, so that many training configurations can be adapted to the exact needs of trainers.

All these scenarios are available on the ENSOSP set up, for the follow on workshop, and afterwards for any other training.

Note: At review date, the December workshop is postponed to a further date.

8. References:

Kearsley, G. (2010). Andragogy (M.Knowles). The theory Into practice database Retrieved from http://tip.psychology.org

Knowles, Malcolm S. Andragogy in Action. San Francisco: Jossey-Bass, 1984.

Tretsiakova-McNally S, Maranne E, Verbecke F., Molkov V., Mixed e-learning and virtual reality pedagogical approach for innovative hydrogen safety training of first responders, International Journal of Hydrogen Energy, Volume 42, Issue 11, 16 March 2017, Pages 7504- 7512