Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces

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Report on the workshop of emergency services

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Summary

The D5.2 Report on the workshop of emergency services presents the results of the international workshop of emergency services which were raised by the project partners and the workshop attendants.

Originally the workshop was planned as “international workshop with participation of experts from fire services, police services and rescue services”. Due to COVID-19, the on-site event planned for May 2020 was not feasible. Instead, an international virtual workshop of emergency services was held in October 2020 as an online event.

The workshop counted 102 participants. These were actors of the projects HyTunnel-CS and HyResponder as well as first responders from fire services. Representatives also included operators of underground transport systems (UTS) as well as regulatory and safety authorities and e.g. manufacturers of hydrogen-powered vehicles.

The goals of the workshop were firstly to have a better common understanding of the tasks, options and also limitations of first responders, especially firefighters. Secondly, the workshop served to identify open questions, especially from firefighters, to the scientists involved in the project. Both goals were achieved by sharing knowledge on established operational firefighting tactics for UTS and by solving tabletop scenarios together.

It was not the intention of the workshop to formulate conclusive, generally valid recommendations for the management of incidents involving hydrogen-powered vehicles at this stage. This will only be possible after the issues raised in the workshop have been solved.

One of the main findings of the workshop was that technologies like TPRD-less tanks would significantly reduce or even eliminate many risks of hydrogen-powered vehicles. For many participants of the workshop this was a completely new perspective for the future. This gave the impression that in some cases problems were discussed which, thanks to innovative technology, could no longer pose serious problems. At the same time, it became clear that despite these innovative security technologies, specific hazards will remain.

This report therefore proposes that one of the next steps should be to clearly identify which hazards could be eliminated by the new technologies and which will remain. Only then will it be possible to review how the tactics and techniques recommended so far for dealing with incidents involving hydrogen-powered vehicles need to be adapted accordingly.

Regardless the prospect of significantly safer hydrogen vehicle technologies in the future, the workshop is of the opinion that most incidents involving hydrogen-powered vehicles can be handled in a similar way to conventional powered vehicles. However, there are some special properties of hydrogen-powered vehicles that have to be considered, e.g. how to detect and handle a hydrogen jet flame.

Therefore, the most important recommendation at this stage is to ensure that firefighters are informed about the involvement of hydrogen at an incident as early as possible.

As a further result of the workshop many detailed questions were identified and listed. The next step is to investigate which of these questions should be dealt with within the project and by whom.

Keywords

Hydrogen safety, first response, standard operation procedures, ventilation, tactics, strategies, Hy-Response, tabletop exercises, TPRD-less tanks, underground transport systems, angle of attack, put-stay.

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Nomenclature and abbreviations

CNG	Compressed Natural Gas
HPV	Hydrogen-Powered Vehicle
HY	Hydrogen
HY-SOP	Standard Operating Procedure for HY-incidents
LEL	Lower Explosive Limit
LPG	Liquefied Petroleum Gas
SCBA	Self-Contained Breathing Apparatus
SOG	Standard Operating Guidelines
SOP	Standard Operating Procedure
TPRD	Thermally activated Pressure Relief Device
UTS	Underground Transport System
VIN	Vehicle Identification Number

Definitions

Emergency Services: Organizations which ensure public security and safety by addressing emergency situations, in the HY-context mainly fire services.

First Response: First actions taken at an incident scene; in the HY-context mainly by police, ambulance services or fire services. First response by laymen is not discussed in the present report.

Incident is something that occurs casually in connection with something else.

Risk is the combination of the probability of an event and its consequence.

Standard Operating Procedures: step-by-step instruction to help perform complex operations.

List of figures

1. Introduction and scope

The HyResponse project developed recommendations for Standard Operating Procedures (SOP) for the intervention in case of incidents with hydrogen-powered vehicles. In the HyTunnel-CS project, the special features of tunnels and similar confined spaces must be considered additionally.

Both outdoors and in tunnels or underground car parks, for example, firefighters are faced with a fundamental problem: There is very little concrete experience to date in dealing with incidents involving hydrogen-powered vehicles. To develop suitable tactics and techniques, it is primarily necessary to draw on scientific and technical facts. From these facts, it can be derived how firefighters should best proceed in theory. A completely different question is how this theory can be put into practice.

For the development of tactics for rare incidents, the method of tabletop exercises has proven its worth. First, an initial scenario is defined to which actors react individually, thereby changing the scenario. This creates a new situation to which the actors react individually. If this is repeated several times, a unique chain of decisions is created, which leads to a certain result. If the actors make different decisions, this may lead to different results, but sometimes this may lead to identical results.

If defined scenarios are played through several times in this way, suitable and less suitable tactics gradually crystallize. This makes it possible to reduce the total number of possible tactics to a few, which in an emergency are very likely to be effective. Whether this is the case, however, only proves itself in practice.

This scenario technique is also ideal for identifying open questions of principle or insufficient experience. In the first tabletop exercises conducted by the International Fire Academy (IFA) on the subject, it became clear that there is no method of reliably determining that a hydrogen-powered vehicle is involved.

Also, it was recognized with the scenario technology that much information, which would be helpful for the evaluation of the concrete danger situation, will hardly be available in the initial phase of an operation.

The primary purpose of the international workshop for emergency services should therefore be to use the scenario technique to identify open questions and review existing and newly developed SOPs.

During the preparation of the workshop, however, a great need for mutual exchange of knowledge was identified. Many of the firefighters involved in the project are of course familiar with the essential properties of hydrogen and know how to handle it. However, very few of them are familiar with hydrogen-powered vehicles in detail.

Conversely, the scientists involved in the project naturally have an immense amount of knowledge about fire and explosion protection. However, most of them are not familiar with the practical work of firefighters, or at least not from their own experience.

Therefore, the workshop was designed in such a way that all participants can learn from each other.

Thereby it was shown that the term workshop alone can be understood very differently depending on the cultural area and field of work. For firefighters, a workshop is primarily an event in which several experts work together to clarify specific questions. In the field of science, a workshop is also understood as a course.

The project participants may perceive as an enrichment of their intercultural competence that it was possible to reconcile these apparent opposites by planning the workshop in such a way that both demands can be met. This should even prove to be a great benefit. The workshop also encouraged many participants to ask the seemingly "stupid questions". Of course, the "stupid questions" often turned out to be the most interesting ones. Thus, the workshop was able to contribute to deepening the exchange between theory-based science and the necessarily extremely practice-oriented emergency services.

This workshop was not expected to be able to finally clarify all open questions. Neither was there enough time for this, nor did the complexity of the topic allow for simple answers to all questions.

However, it became very clear that the practical possibilities of intervention depend to a large extent on the system-immanent safety of the hydrogen technology used in vehicles. This is particularly true for explosion hazards. The less likely hydrogen tanks are to burst and the lower the probability of an explosion in a tunnel or a confined space, the faster and more effectively firefighters will be able to successfully ward off the remaining hazards in any case.

The goals of the workshop were firstly to have a better common understanding of the tasks, options and also limitations of first responders, especially firefighters. Secondly, the workshop served to identify open questions, especially from firefighters, to the scientists involved in the project. Both goals were achieved by sharing knowledge on established operational firefighting tactics for UTS and by solving tabletop scenarios together.

In working through these scenarios, the following questions should and were then also discussed.

- What are the specific conditions for intervention in underground transportation systems?
- How do first responders get all relevant information needed?
- What are the possible actions taken by firefighters?
- Why is ventilation a very important factor?
- Who is responsible for which measures of response?
- What behaviour by persons involved must be taken into consideration?
- Which issues need further research?

2. Planning and conduct of the workshop

The hands-on workshop in Balsthal would have offered ideal conditions to experience the special world of intervention in tunnels and to discuss it intensively but due to COVID-19 this event was finally performed online. Information about the initial planning is available in the Annex I. Annex II presents the final agenda of the event.

Both can hardly be realized in an online meeting. To compensate for the limitation of sensory experiences, two measures were taken. Firstly, elaborate presentations with numerous pictures and graphics were produced to visualize all statements in the best possible way. Secondly, a completely new tool for tabletop exercises in video conferences was developed. Based on these optimized or newly developed tools, the goals for the workshop were sharpened and the agenda was developed.

2.1 Presentations

Presenters of IFA created presentations with many pictures and drawings to explain design and hazards of UTS and established tactics and techniques for interventions in UTS. Animated slides were created to visualize procedures.

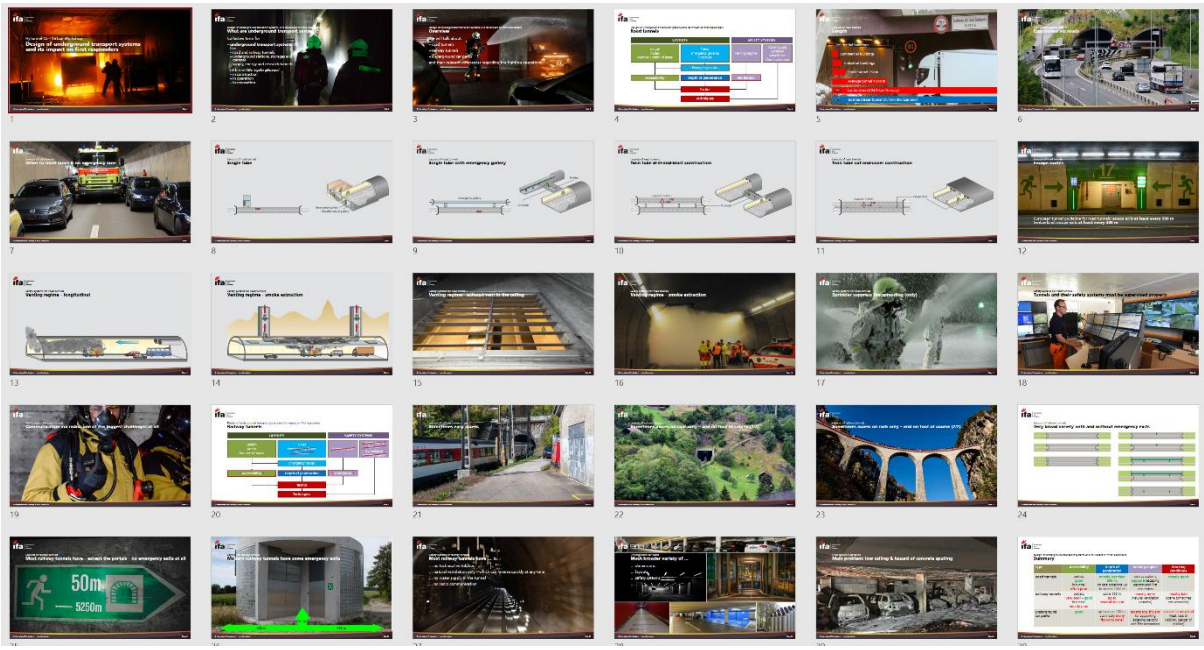

Figure 1: Example for presentations created for the virtual workshop

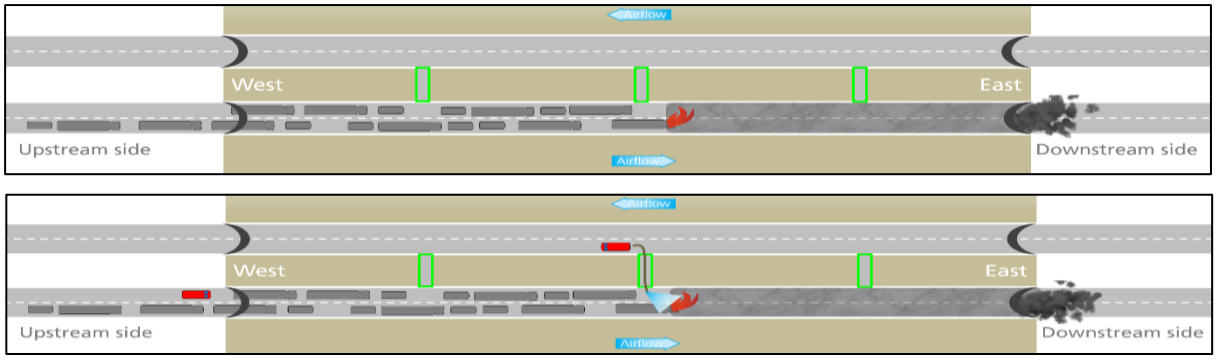

Figure 2: Example for animated slides

2.2 Virtual tactic simulator

Tabletop exercises are a well-established method for developing and train tactics. IFA uses special tables in which scenarios are projected from below onto a glass plate, which can be painted with felt pens.

Since firefighters are very familiar with tabletop exercises, this procedure itself did not have to be changed. But a way had to be found to show the scenarios online and change them interactively during the presentation. Therefore, the scenarios were modified first. Normally, for tabletop exercises toy cars are used. Emergency forces can be symbolized with game figures, among other things. For the online version, both were simply represented by moveable symbols.

Technically, the scenarios and the resources were drawn on PowerPoint slides. In order to be able to move them, however, working in editing mode and not in presentation mode is necessary. Finally, it was desired that the symbols be moved by all participants and that they be able to draw them into the scenarios.

For this purpose, various conference systems were tested that allow remote control by all participants by sharing their mouse and keyboard with the moderator. Of course, this only makes sense if only one or two participants intervene in the scenario at a time. During the tests, the GoToMeeting platform proved to be well suited for this purpose. In the previous tests as well as during the workshop, this remote control worked reliably.

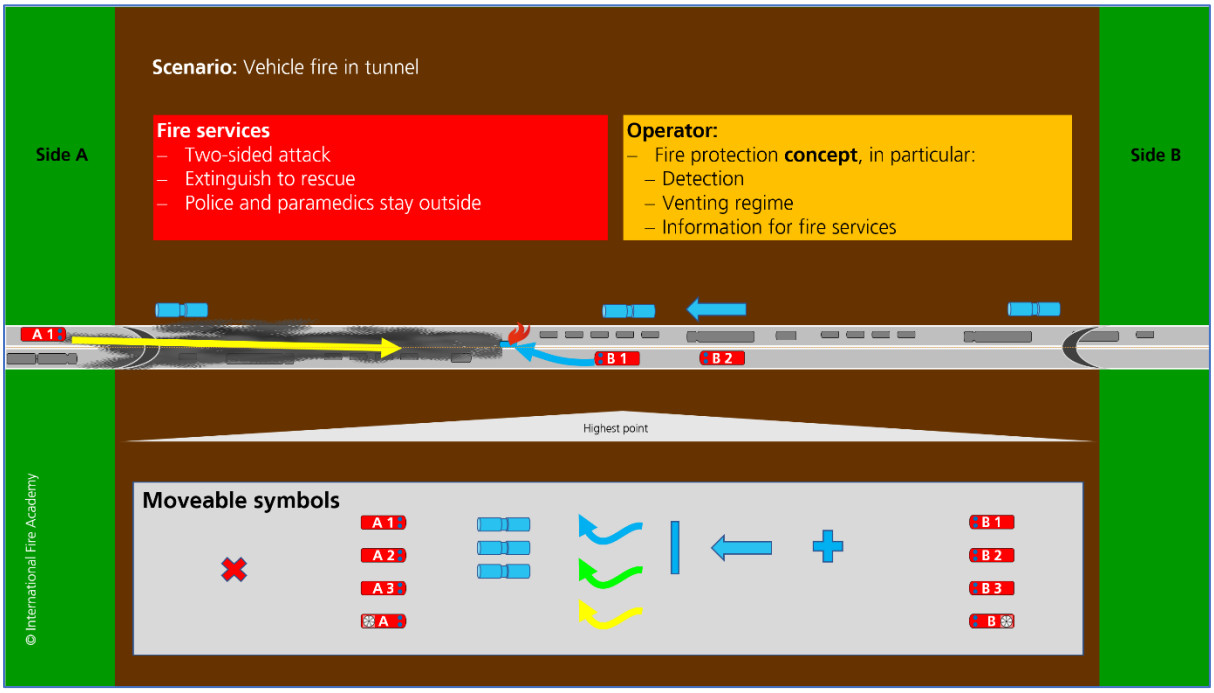

Figure 3: Example for a scenario from the virtual tactic simulator

2.2.1 Discussion between participants

One of the main goals of the workshop was to enable an intensive exchange between the participants. The meeting was online, so the general experience is much more difficult than in a physical meeting. Surveys and pre-tests shown that direct requests to speak in video conferences are rare, but the chat channel is used intensively. For this reason, an additional moderator was appointed to organize the chat channel and to filter out particularly exemplary questions and contributions from it and place them in the public oral discussion. Participants were encouraged to speak directly. This made it possible to make the discussion more lively than usual in videoconferences.

2.3 Invitation, registration, participants

IFA sends digital newsletters in German, French and English to a total of 2746 people. The newsletters were linked to a special IFA website where participants could register. Exactly 1000 of the sent newsletters were opened. 204 recipients used the link to the IFA's website.

The addressees were former course participants, visitors of the annual IFA International Commanders' Forum, as well as persons who had registered for the IFA's newsletter in the past years. These addressees are persons who are specifically interested in the topic of fire operations in UTS. It is not always known which organizations they belong to, especially since they often have given private email addresses. What is certain, however, is that the circle of users includes operators of UTS, supervisory authorities and security agencies. In addition, representatives of police forces and emergency services (paramedics) were invited to participate by e-mail. All recipients of e-mails and newsletters were asked to forward them to possibly interested colleagues. We know from correspondence that use was made of this option. However, it is not known how many other people were invited in this way.

In addition, a flyer was created by FHa to motivate those invited to participate in the workshop, and which was used for the dissemination of the event in LinkedIn and also in a specific newsletter prepared by the project and distributed to the contacts list.

Figure 4: Dissemination material used for the event

A total of 158 people registered for the free workshop. At the peak, 92 participants were in the forum at the same time.

The link to the GoToMeeting platform was sufficient for active participation in the workshop. Therefore, not all participants had registered before. Apparently, many people attended from their home office and used private e-mail addresses. For this reason, there is no complete overview of the organizations represented at the workshop.

However, it can be seen that nearly all of the above-mentioned areas were represented, especially operators of UTS and manufacturers of hydrogen-powered vehicles. The field of paramedics was indirectly represented since many of the participating fire services also operate paramedics.

It was not apparent whether police authorities were also represented. It can be assumed that this was rather not the case. This is because police forces have so far shown virtually no interest in the subject of hydrogen incidents. This is against the background that in most countries, technical emergency response is the sole responsibility of fire services.

3. Content of the workshop

In terms of content, six focal points were established for the workshop.

- Overview of the projects HyTunnel-CS and HyResponder
- Knowledge-sharing on interventions in UTS in general
- Interactive discussion of appropriate tactics for response to Hy-incidents in tunnels and similar confined spaces
- Exchange views on education and training for Hy-Response in tunnels and similar confined spaces
- Identify questions that need further scientific clarification.
- Synchronization with partner activities.

It would go too far here to reproduce the contents of all presentations completely. There would also be the danger of reproducing complex contexts incompletely or even incorrectly. Therefore, only those statements that seem relevant from the fire services point of view are summarized below. For this purpose, the initial slide as well as slides with summaries and conclusions are shown. Presentations can be downloaded here: https://hytunnel.net/?page_id=1168.

3.1 Overview of the projects HyTunnel-CS and HyResponder

HyTunnel-CS and Hy-Responder are independent but closely linked projects.

Dmitriy Makarov (UU) introduced the HyTunnel-CS project.

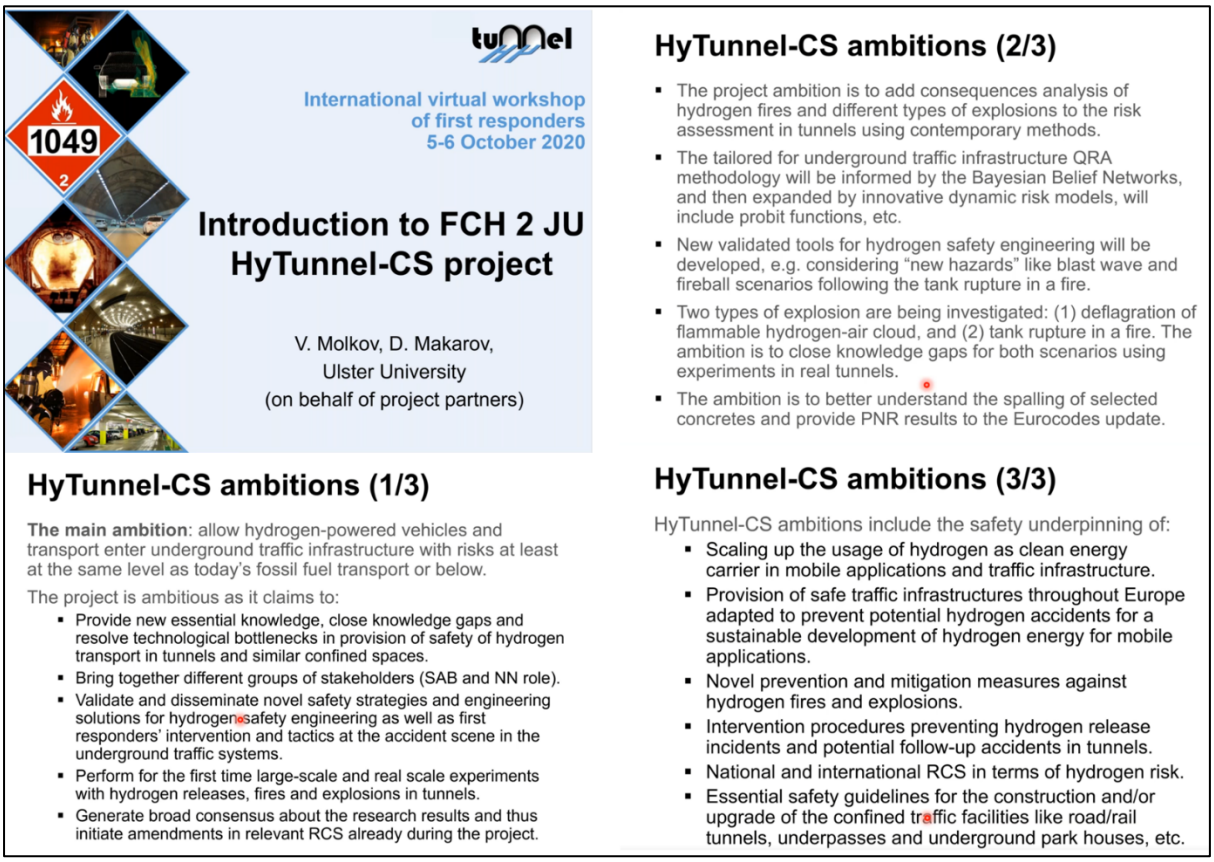

Figure 5: Ambitions of the HyTunnel-Cs project

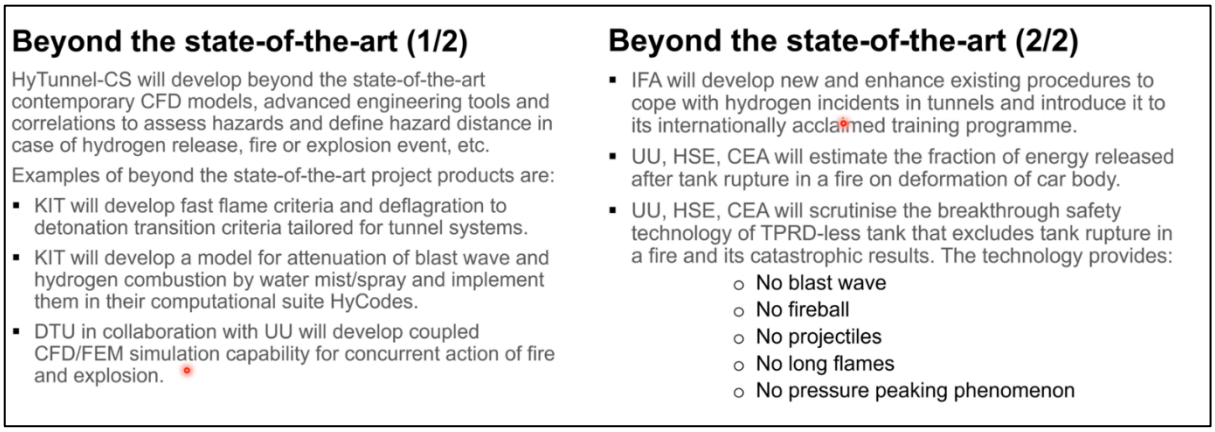

Figure 6: Objectives of the HyTunnel-CS project

Sile Brennan (UU) introduce to the HyResponder project.

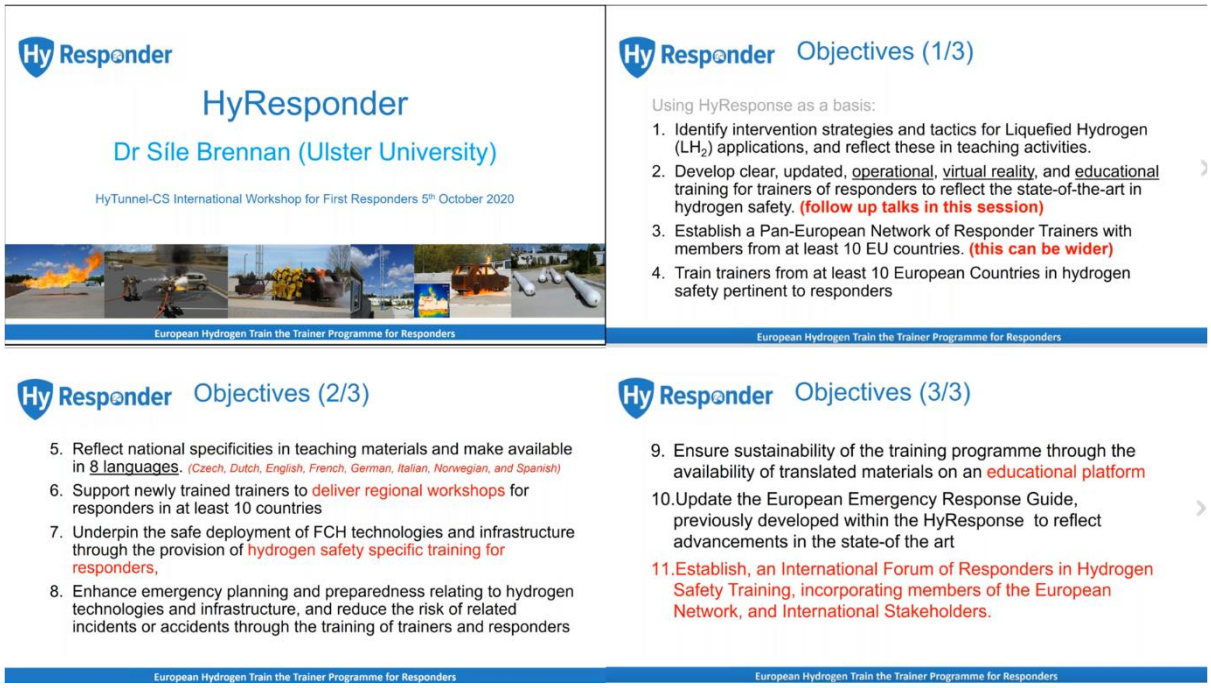

Figure 7: Objectives of the HyResponder project

3.2 Examples for research done in HyTunnel-CS project

To give an insight into the research methods and an impression of the possible results, four examples from the current project work were presented.

3.2.1 Dmitriy Makarov: Similarity law and exclusion of flammable cloud formation

Dmitriy Makarov explained the meaning of TPRD-diameters for release consequences.

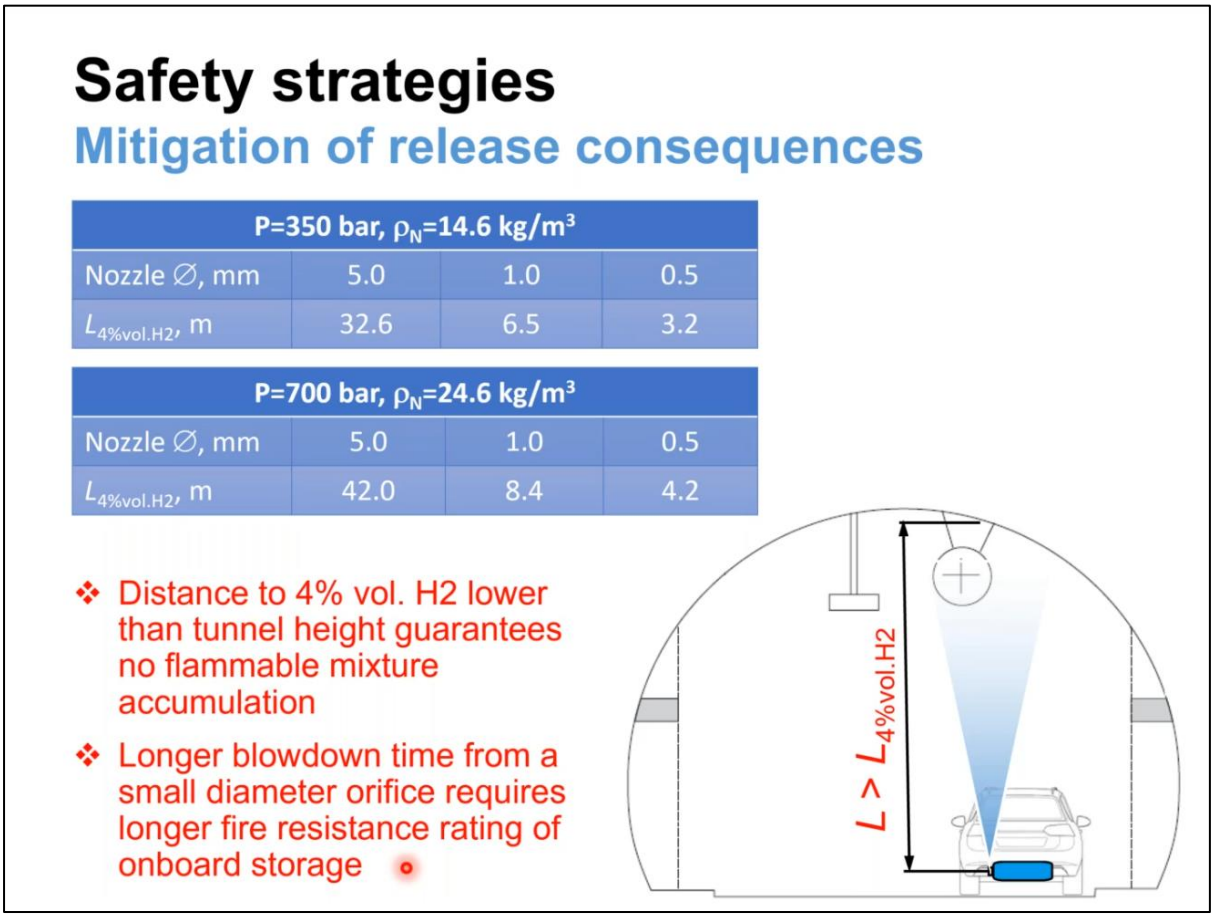

Figure 8: Example for safety strategies regarding TPRD-diameters

3.2.2 Ilias Tolias, NCSRD: Effect on tunnel slope on hydrogen dispersion in an accident

Ilias Tolias (NCSRD) discussed the effect of tunnel slope on hydrogen dispersion in an accident.

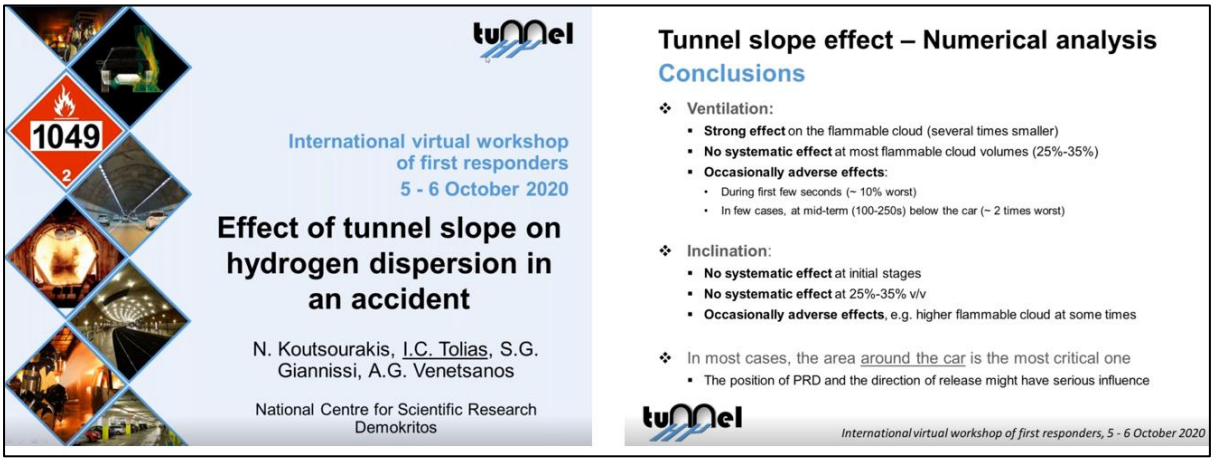

Figure 9: Effect of tunnel slope on hydrogen dispersion in an accident

3.2.3 Wulme Dery, UU: Correlation of blast wave attenuation in a tunnel

Wulme Dery (UU) introduced in the complex of blast wave attenuation.

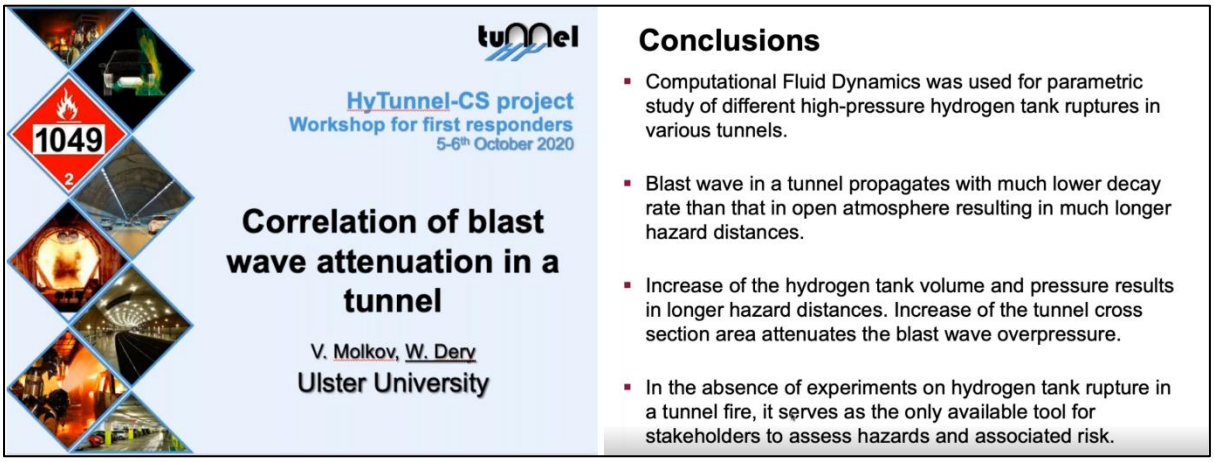

Figure 10: Correlation of blast wave attenuation in a tunnel

3.2.4 Sergei Kashkarov, UU: Safety technology to prevent hydrogen tank rupture

Sergei Kashkarov (UU) presented a new leak-no-burst-technology invented by UU which would allow to build tanks which cannot rupture in case of fire. This would significantly reduce the risks for first responders.

Figure 11: Safety technology to prevent hydrogen tank rupture

3.2.5 Conclusions

In the concluding discussion of this part of the workshop it became clear that incidents involving hydrogen-powered vehicles will not be without danger in the future either. However, technologies are available that can significantly reduce the hazards.

3.3 Knowledge-sharing on interventions in underground transport systems in general

Urs Kummer, Clemens Pessel and Christian Brauner (all IFA) introduced to the basics of firefighting in road and railway tunnels and similar confined spaces.

Only the central statements are presented and summarized. The conditions for interventions are mainly defined by the design of an UTS as shown for road tunnels in Figure 12 and for railway tunnels in Figure 13.

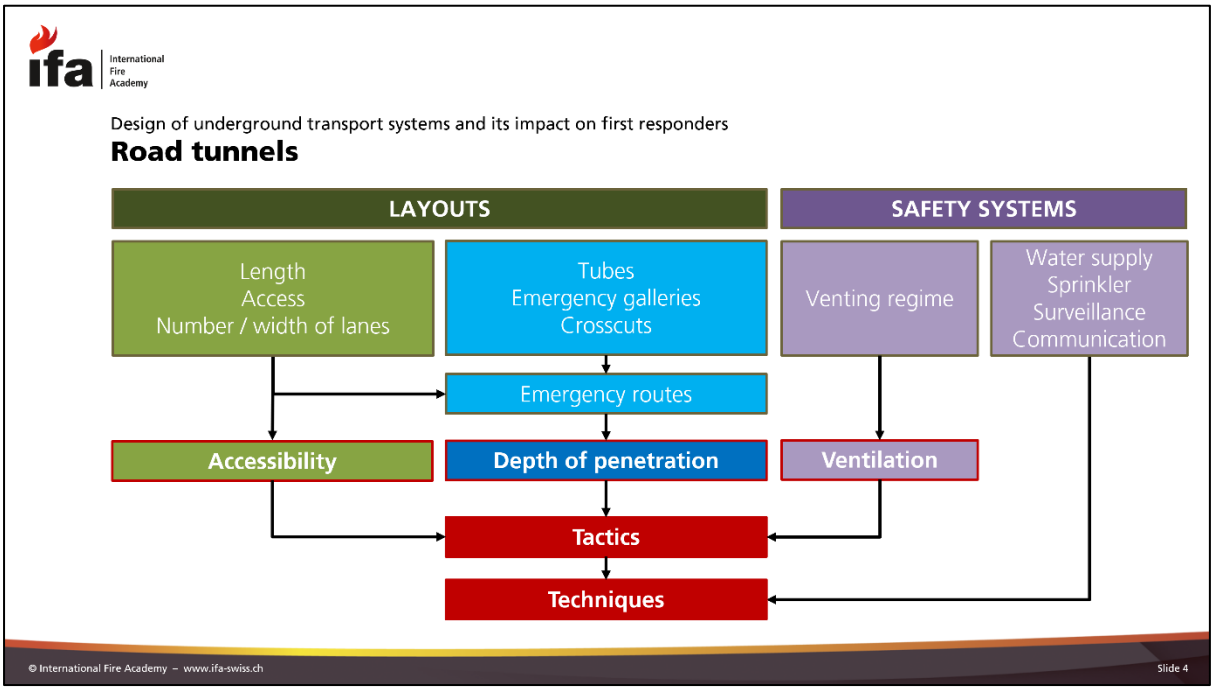

Figure 12: Impact of design of road tunnels

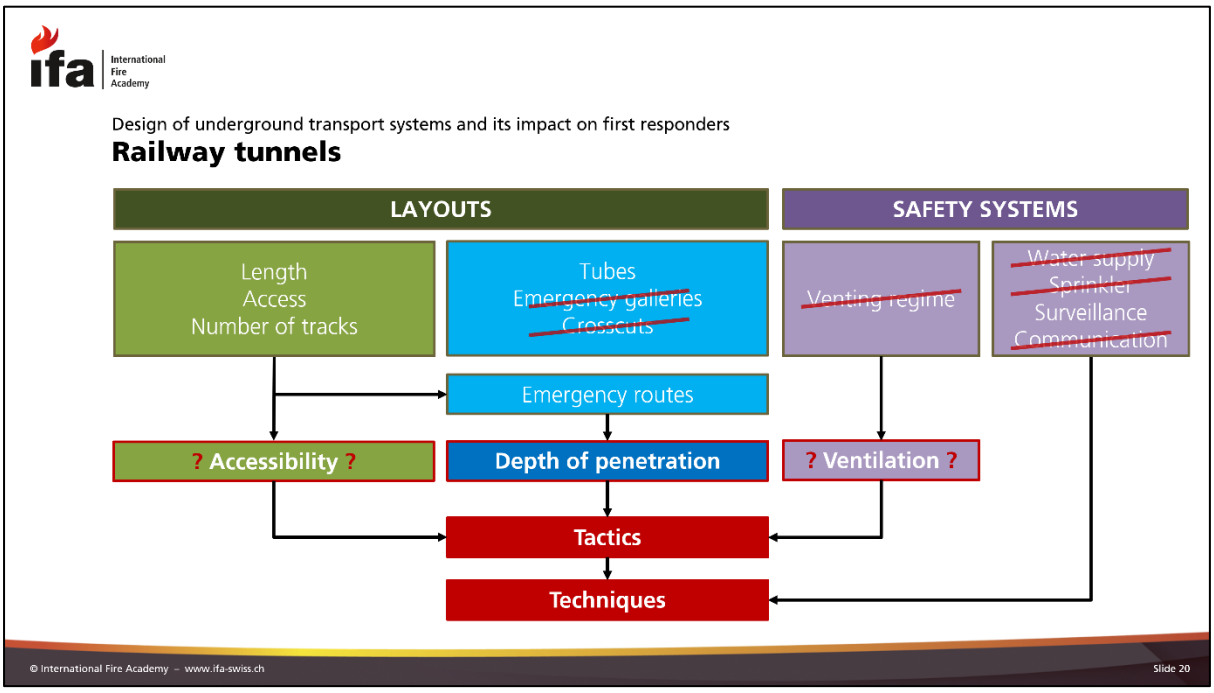

Figure 13: Impact of design of railway tunnels

The most important parameters for interventions in UTS are the accessibility, the depth of penetration and the venting regime.

The importance of accessibility is self-explaining. Firefighters must be able to reach any area in the UTS quickly to intervene successfully. Most road tunnels provide a good access. Many railway tunnels are not easy to access by road vehicles.

"*The International Fire Academy defines penetration depth in general as the distance from the safe area of a facility to the working area of the firefighters. Great depths of penetration are understood as distances over 80 m. This definition is based on following considerations: penetration depths of about 70 m are familiar to most firefighters and therefore manageable.*

With greater depth the physical stress grows disproportionately with every metre, especially when people have to be transported. Furthermore, all operations are extended in time. It takes some time until reconnaissance information is available, also searching areas and vehicles requires more time. With increasing depth of penetration, the strength of a firefighter decreases and with it his performance. The distance of 80 m was chosen for practical reasons: it is four times the length of a fire hose and can be remembered easily. Therefore, from this consideration it is recommended that fire services penetrate depths of at least 80 m in hands-on tunnel drills; so that participants can experience first-hand, what great depth of penetration means for them."[1]

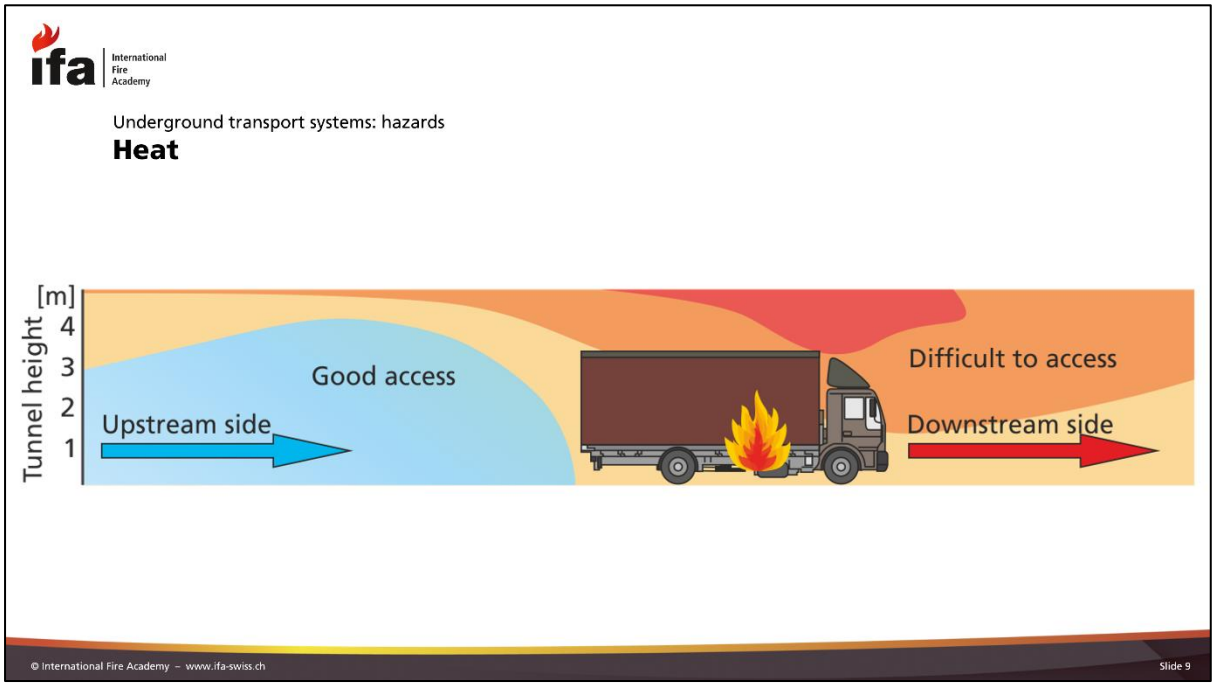

Figure 14: Upstream side and downstream side

When a vehicle fire in a tunnel is ventilated, an upstream side and a downstream side are formed as shown in Figure 14. The upstream side provides very good working conditions for the firefighters. On the downstream side, the temperatures can be unbearably high, and the smoke can be so thick that the firefighters can hardly make any headway. Therefore, the ventilation regime is of crucial importance. In most road tunnels it is ensured that the stationary ventilation

[1] IFA, 2016

systems generate a stable direction of air flow. Many railway tunnels do not have ventilation systems. Therefore, a sudden flow reversal is possible at any time. The firefighters try to prevent this by using mobile ventilators.

In underground car park the height of the ceiling is one of the most important parameters. As ceilings are low there will be great heat near the floor. The heat load on the operating forces can be very high or even unbearable. Therefore, they will try to reduce heat and smoke by using mobile fans.

Figure 15 gives an overview of the conditions for intervention in different types of UTS. As shown, there are many differences. Hence there is no such thing as “the tunnel”. Although there are some basic tactics the applied procedures must be specific for the single UTS and the given potential of the emergency services involved.

ifa International Fire Academy

Design of underground transport systems and its impact on first responders

Summary

Type	Accessibility	Depth of penetration	Venting regime	Working conditions
Road tunnels	portals: **good** in tunnel: **often poor**	**mostly less than 500 m**, on rare occasions up to several 1000 m	various systems; **supports** escaping persons and first responders	**mostly good**
Railway tunnels	portals: **very poor - good** in tunnel: **mostly poor**	some 100 m **up to several 1000 m**	**mostly none** (natural ventilation unstable)	**mostly bad** (scene sometimes not accessible)
Underground car parks	**good**	up to some 100 m, but mostly **many floors to cover**	**mostly insufficient** for supporting escaping persons and first responders	sometimes **very bad** (heat, lack of visibility, danger of spalling)

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Figure 15: Conditions for intervention in different types of UTS

As with all fires, the greatest danger to people in UTS is smoke. Although firefighters can protect themselves well with self-contained breathing apparatus. In dense smoke, however, they make very slow progress and would need a very long time to find and rescue people in the smoke. The basic tactic for firefighting in tunnels is therefore to extinguish the fire as quickly as possible and thus stop smoke production. This is the quickest way to significantly improve the conditions for both self-rescue and external rescue.

This tactic can be applied very well because the working conditions for the firefighters on the upstream side are relatively good. This results in the tactic of "extinguish to rescue". The faster the fire is extinguished, the faster the smoked areas can be searched and the greater the chance of rescuing people from smoke hazards in time.

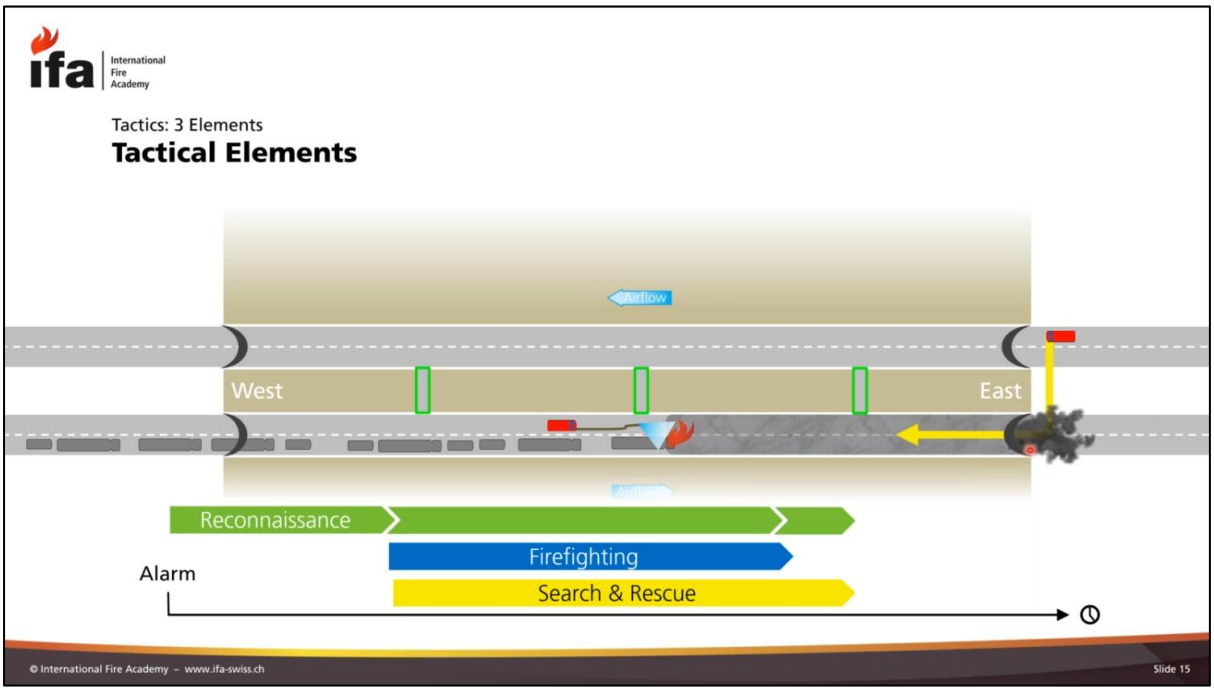

Figure 16: Tactical elements

3.4 Interactive discussion of appropriate tactics for response to Hy-incidents in tunnels and similar confined spaces

An essential characteristic of the scenario technique is that the participants associate different further questions with the situation presented in each case and the reactions to it and bring these into the discussion on an ad hoc basis. All topics that had to be considered according to the task definition were addressed across all scenarios and discussions. However, the extent to which these issues were addressed varied greatly. It also lies in the nature of the technical scenarios that the participants get bogged down in some of the detailed questions.

Therefore, the chronological course of the discussion is not described in the following. Instead, the results of the discussion have been summarized in blocks that inevitably overlap in part.

3.4.1 Vehicle Identification Numbers (VIN)

Prior to the workshop, it had already been recognized that one of the biggest problems of the intervention was to be able to identify with certainty that a hydrogen-powered vehicle is involved in the event. It is true that hydrogen-powered vehicles are often clearly marked as such. However, it cannot be guaranteed that this marking can be recognized under all circumstances. In addition, from the point of view of firefighters, it would be helpful if they could also recognize from the outside whether hydrogen-powered vehicles are in a tunnel or in an underground or multi-storey parking lot. Ideally, information about the exact number and location should even be available. Without the information that a hydrogen-powered vehicle is involved, all recommendations for a hydrogen-specific approach made little sense.

Tom van Esbroek, (SFPI), gave a detailed introduction to this problem and presented possible solutions, such as those pursued by CTIF. The goal of using the Vehicle Identification Number (VIN) to obtain information was met with great interest and general approval. Every vehicle

has such a VIN, which can also be used to clearly identify the type of fuel. Ideally, this VIN would be transmitted electronically from the damaged vehicle to the fire service or could be read out by the firefighters. From a technical point of view, this procedure would already be feasible today.

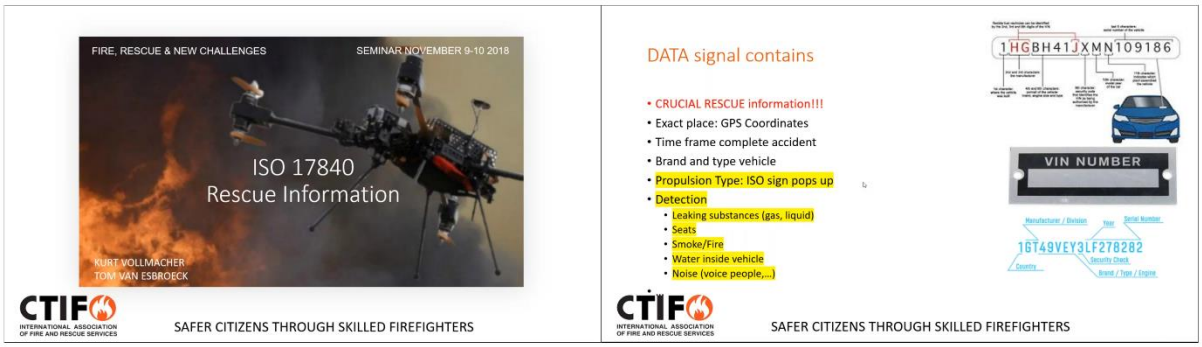

Figure 17: Vehicle Identification Numbers (VIN)

3.4.2 “Let-it-burn” tactic

Until now, the general rule for gas fires has been to let them burn down in a controlled manner. This is also expressly recommended by manufacturers of hydrogen-powered vehicles. Fire services practice this tactic by protecting the surroundings of the burning vehicle until the gas storage of the vehicle has burnt off.

In the discussion of various scenarios, this approach was questioned in principle. The technologies aimed at in the HyTunnel-CS project, or some of which have already been developed, would make it possible to tackle fires of hydrogen-powered vehicles in exactly the same way as in the case of fossil fuels.

Regarding the tactic "extinguish-to-rescue" this would be of great advantage. After all, even in the event of a fire in a hydrogen-powered vehicle, large quantities of smoke can be produced simply by the plastic bodywork and tires, which pose a considerable danger to tunnel users. Therefore, it would also be expedient to extinguish the fire completely as quickly as possible and thus improve the conditions for self-rescue and external rescue. If, on the other hand, the "Let-it-burn” tactic is followed, the smoke would last much longer and would also be considerably higher overall.

In the discussion it became clear that a distinction must be made between the fire of the vehicle itself and the burning of the hydrogen flowing out of the tank. This combustion takes place in a long jet flame, which, according to the experience of participants, is practically impossible to extinguish by using firefighting hose nozzles.

Against this background, the dominant view is to extinguish the vehicle and protect the surroundings, without extinguishing the gas fire.

It would be very helpful to gain more experience to how long the controlled burn-off will take. Nomograms are available from the HyResponse project. However, these can only be used if both the actual tank content and the exact time of the start of the fire are known, which is hardly to be expected under operating conditions.

In the further course of the project it should be estimated at which point in time of the course of the fire firefighters will approximately arrive and which fire duration they then must expect. In practice, it could turn out that the hydrogen is usually already completely burned by the time the firefighters arrive and "only" a conventional vehicle fire has to be fought.

Another suggestion from the discussion: Some electric vehicles are designed in such a way that in the event of a fire, part of their cover melts away to create a clear path for the extinguishing water. This could also be helpful for hydrogen vehicles and should be researched.

3.4.3 Ventilation

Practically in all fires, smoke is the greatest danger to people. In addition, the smoke, which is often in itself combustible, brings the greatest heat load for the firefighters. Therefore, it is standard practice to push or suck smoke and heat out of the building by using stationary or mobile fans.

There is a broad consensus that in case of hydrogen incidents, suction should generally not be used because the fans are usually not explosion-proof. However, positive pressure ventilation seems to be unproblematic regarding hydrogen. This means that positive pressure ventilation can also be used in the event of incidents involving hydrogen-powered vehicles, especially if these vehicles are equipped with the desired optimized safety technologies.

It is still unclear how released hydrogen affects smoke extraction in tunnels. This requires further clarification.

3.4.4 Stay-put-advice

In the event of a building fire, under certain conditions it may be necessary to leave people in safe rooms instead of trying to rescue them through the smoke, for example the staircase. This tactic is known as stay-put-advice. It has proven its worth in many cases but has been the subject of controversy since the fire at Grenfell Tower in London in June 2017.

In the workshop, a case study of the Bürgerwald-Tunnel in the south of Germany showed that this tactic can also be useful for vehicle fires in tunnels. In the specific case, a passenger car had caught fire within the tunnel. A total of 19 vehicles were enclosed in thick smoke. Eleven people escaped through the smoke, some of whom suffered severe smoke injuries. A not exactly known number of people remained in their vehicles after they had been instructed by the firefighters to stay-put. The incident commander had decided to leave the persons in their vehicles because he assessed that the vehicle would be extinguished within a few minutes due to the specific situation.

Against the background of this case study, it was suggested that the "stay-put" procedure should be examined more closely as a possible option in the further course of the project. It should

also be investigated whether staying in the vehicle can also provide a certain degree of protection against explosion hazards. However, it should be considered that evacuation is the standard procedure for fires in the European road tunnel guideline at the moment.

3.4.5 Safety distances

So far, firefighters have been trained to maintain large safety distances in the event of hydrogen incidents. These vary considerably depending on nation and regulations. What they all have in common is that they keep firefighters at such a distance that they cannot fight fires from hydrogen-powered vehicles in the same way as they can with conventional powered vehicles. This is because the distance between the firefighters and the burning vehicle is regularly less than one meter during extinguishing. Moreover, to extinguish fires effectively, it is even necessary and therefore common practice to open vehicle doors or hoods to be able to reach all areas inside the vehicle with water.

Against this background, two questions arise for the further course of the project. On the one hand, in coordination with the HyResponder project, it must be discussed how effective firefighting can be achieved even from greater distances from the vehicle. On the other hand, the general and very far-reaching question arises whether and to what extent the required safety distances can be reduced by using the safety technologies for hydrogen vehicles that are being targeted or have already been developed. Especially considering the confinement of UTS like tunnels and underground car parks.

3.4.6 Angle of attack

An important finding of the HyResponse project was that fires in hydrogen-powered vehicles should only be tackled from the side of the vehicle and not from the rear or front. This is to prevent firefighters from being hit by the hydrogen jet flame. However, as the scenario in Figure 18 shows, this will not be possible in all cases. If a vehicle stands between two other vehicles as shown here, it can practically only be approached from the rear.

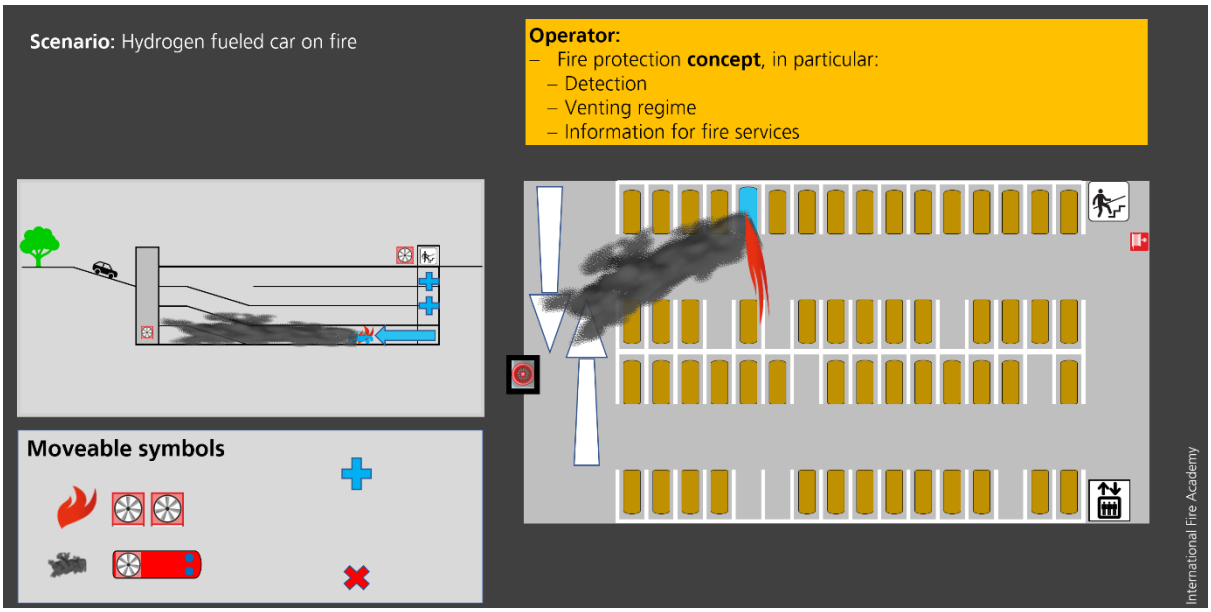

Figure 18: Scenario with limited access possibilities

This problem has been recognized for some time now and is a topic of the HyResponse project. In the project HyTunnel-CS, however, all expected situations are to be recorded systematically in which an optimal angle of attack is not practicable. In addition, ideas are to be developed as to whether and how this problem could be solved with new types of extinguishing tools.

3.4.7 Responsibilities

There was a broad consensus on the distribution of responsibilities between fire services and UTS operators:

In principle, it should be up to the operators to provide the fire services with information on whether and if so, how many hydrogen-powered vehicles are involved and what type of vehicles are involved. One probable solution is using the VIN as described in section 3.4.1. It is also seen as the responsibility of the operators to design stationary ventilation systems "hydrogen-compatible" and to control them accordingly in the event of an incident. This includes the use of mobile fans from fire services. As already mentioned elsewhere, fundamental questions still need to be clarified in this regard, especially in the case of ventilation systems with smoke extraction.

The question of whether released hydrogen in tunnels and, for example, underground car parks should be automatically detected is still open. If so, this would also be the responsibility of the operators, more details on this topic follow in the following section.

Vehicle recovery is not seen as a standard task of fire services. This should be done by towing companies, for example, which should have the appropriate specialists at their disposal.

3.4.8 Detection and measurements

The detection of hydrogen should be done by the operators of the UTS. This is also with the aim of informing the emergency services as early as possible that hydrogen is involved.

In all scenarios it was taken for granted that the emergency personnel is equipped with gas detectors and immediately withdraw when an acute danger of explosion is detected. In most cases the emergency services will only be able to measure the concentration of flammable gases in the air at individual points. It is impossible to obtain a reliable picture of the spread of a gas cloud by taking several measurements at different locations simply because the situation changes constantly during the measurements.

Only specialist can take qualified and highly reliable measurements. These specialists are provided by the fire service but are not available at every station, therefore arrive at the scene of the emergency only long after the first responders have arrived. It is the task of the first responder to request the specialists and not to carry out such measurements.

Against this background, the topic of measurements (except for using gas detectors) was considered of secondary importance for first responders.

3.4.9 Unignited release of hydrogen

The question of how to proceed when hydrogen is released but not ignited proved to be very difficult to answer.

On the one hand, it such an event is considered as being very rare in connection with hydrogen-powered vehicles. On the other hand, it was argued that serious accidents could lead to the destruction of the tank or other hydrogen propulsion system components. But then, it was also argued, that hydrogen will always ignite.

Since the discussion revealed a clear discomfort on the part of the firefighters regarding a possible release of hydrogen without ignition, the question should be investigated in more detail in the further course of the project.

It might be helpful here to compare the probability of such an incident with the probabilities of other critical incidents.

It could also be helpful to anticipate the temporal course of the event. It is possible that the release of non-ignited hydrogen is not a problem for firefighters simply because the release and dilution of the hydrogen usually occurs well before the firefighters arrive at the scene.

3.4.10 Not yet considered topis

In the discussion, it is pointed out that many topics have not yet been considered or have not been sufficiently considered. These are listed below.

- Buses and lorries are a major topic, especially since they will be first types of commonly used hydrogen-powered vehicles in the near future.
- The HyTunnel-CS project will provide new safety technologies for hydrogen-powered vehicles. This may simplify the incident management of the fire services considerably. But even then, there will still be older hydrogen-powered vehicles on the road, which could possibly be associated with high explosion risks. This problem should also be investigated in the further course of the project.

3.5 Exchange of views on education and training

Christian Brauner (IFA) gave a brief overview of the training requirements and framework.

If intervention in the event of an incident involving hydrogen-powered vehicles is to be carried out as quickly as possible, the firefighters stationed nearest to the incident will be deployed. Once hydrogen vehicles are in general use, this means that all firefighters can be confronted with incidents involving hydrogen-powered vehicles. This in turn means that all firefighters must be trained accordingly.

However, there is not unlimited time available for this training. It will also not be possible to provide all firefighters with all the necessary knowledge to assess hydrogen hazards and for them to develop countermeasures on their own. Rather, the extensive knowledge must be reduced to a few and as simple as possible SOPs. These can then be taught by multipliers; whose training is the subject of the HyResponse project.

Laurent Lecompte presented the training platform operated by the ENSOSP, which will be used, among other things, to further optimize the content of the multiplier training.

Figure 19: Training platform operated by ENSOSP

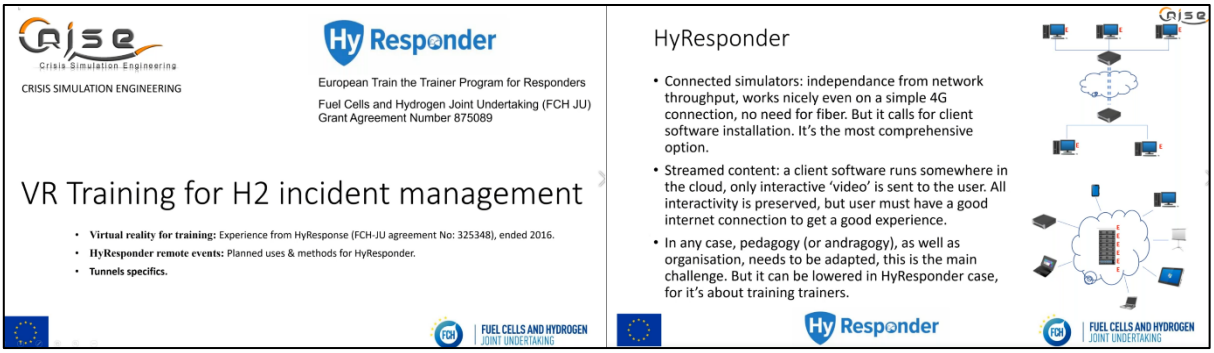

Figure 20: Virtual Reality Training for hydrogen incident management

Eric Maranne, (CRISE), demonstrated the norm high potential of virtual reality for firefighter training. In the further development within the HyResponder project, two possibilities appear particularly attractive:

- Firstly, virtual reality scenarios can be varied much more easily than it is possible with hands-on training facilities. In principle, every imaginable situation can be represented.
- Secondly, practically any number of fire services can be involved by networking the virtual reality platforms accordingly. Thus, the individual effort of each fire service for the development of an own training can be reduced considerably.

The fact that virtual reality can bring enormous progress in education has been confirmed by all sides. Regardless of the training formats, however, a great challenge remains. Despite all the common features, fire services already differ on a national level. They are organized differently. In detail, they have different responsibilities. They use different training practices. Their time budgets for training vary greatly. There are also very big differences in the technical equipment.

Therefore, it does not seem possible or reasonable to develop SOPs that are equally suitable for all fire services in Europe. Rather, on the one hand, scientific and technical facts that are universally valid must be conveyed. On the other hand, however, the fire services must be given building blocks from which they can develop their own SOPs that meet their specific needs and possibilities.

For the near future, a wide range of approaches can be expected. But the more hydrogen-powered vehicles are put into operation, the more incidents with their involvement will occur. Then the fire services will be able to gain more and more practical experience. It remains to be seen which of the tactics and techniques developed will be best suited to the harsh conditions of firefighting operations. Then it will be helpful to make the gained knowledge available on a broad European level at the latest.

Gerhard Schöpf, (LFS Tirol), presented another European development project. SAFEINTUNNELS aims to develop standardized recommendations for the initial and continuing training of firefighters and other emergency services for operations in railway tunnels.

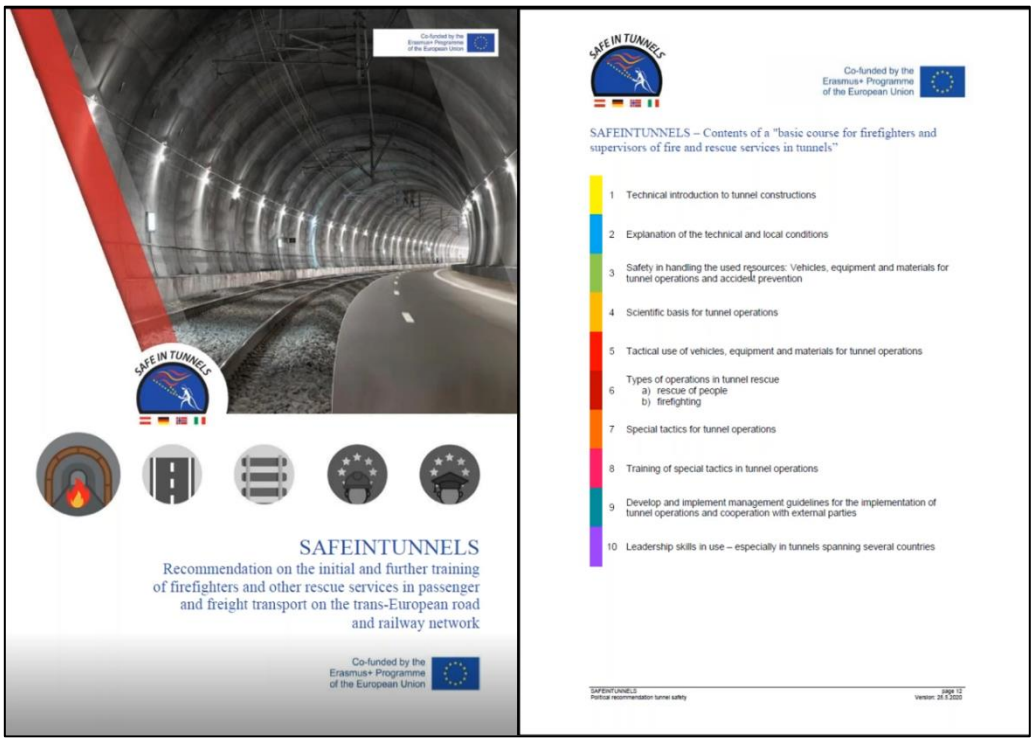

Figure 21: SAFEINTUNNELS project

4. Conclusions of the workshop

General conclusions are:

- Technologies like TPRD-less tanks would significantly reduce or even eliminate many risks of hydrogen-powered vehicles.
- Regardless the prospect of significantly safer hydrogen vehicle technologies in the future most incidents involving hydrogen-powered vehicles can be handled in a similar way to conventional powered vehicles.
- However, there are some special properties of hydrogen-powered vehicles that have to be considered, e.g. how to detect and handle a hydrogen jet flame.

Questions that need further scientific clarification.

- What hazards would remain if safe technologies such as TPRD-less tanks were used or the size of the TRPD outlets were optimized?
- Will firefighters be able to tell at the scene whether hydrogen-powered vehicle technologies are safe or less safe?
- How to deal with hydrogen vehicles that do not comply with what will be the standard in the future?
- How long does it take at most until all the hydrogen in a tank of a passenger car, a bus, a lorry, or a locomotive is burned-off?
- Is it planned to equip hydrogen vehicles with covers that melt in case of fire and give firefighters better access to the hydrogen tank?
- How does non-combusted released hydrogen affect the ventilation systems of tunnels and, for example, underground car parks; especially extraction systems?
- In which cases could the “stay-put” procedure be successful?
- Are safety distances affected if safer hydrogen-powered vehicle technologies find general application?
- Could it make sense to develop new extinguishing tools, such as monitors that could be pushed under a burning vehicle that spray upwards?
- How to deal with the risk of hydrogen being released without ignition?
- Will it be necessary to equip UTS with appropriate hydrogen detection if hydrogen vehicles become widely available? If so, are there any ideas how the operators of UTS will copes?

Annex I

From the initial planning to the virtual workshop

This section documents the development of the workshop from the first ideas to the virtual workshop.

Originally, paramedics and police officers were to be invited to the workshop in addition to firefighters. However, it soon became apparent that these two target groups have so far shown little interest in the topic of incidents involving hydrogen-powered vehicles.

The reasons for this are simple and understandable. In case of fire operations in UTS, the emergency personnel must wear breathing protection. In most countries only firefighters are trained to use self-contained positive pressure breathing apparatus (SCBA). Therefore, first response to hydrogen incidents is normally only done by firefighters.

Figure 22: Firefighters with Self Contained Breathing Apparatus (SCBA)

Paramedics and police patrols remain outside the buildings in case of fires in UTS. Therefore, their tasks in incidents involving hydrogen-powered vehicles will be the same as they are in incidents involving conventionally powered vehicles. Consequently, there is no special training need for paramedics and police officers. This explains the low interest of these target groups in the workshop or the HyTunnel-CS project.

Only the issue of safety distances is likely to be of great importance to the police. After all, it will be the task of the police to evacuate people from the endangered areas. Here however the police forces will follow the recommendations and defaults of the fire services.

Firefighters are the most important target group for both the workshop and the HyTunnel-CS project. However, first responders can also be employees of a UTS operator, for example. In

order not to exclude any group of people, it was therefore decided to refer to first responders in the future. First responder then means persons with specialized training who arrive first at the scene of an incident. In practice this can be paramedics, police officers, firefighters, or members of other rescue services. In some context first responders can be law enforcement officers as well.

Initially the workshop was planned to be held in May 2020 in Balsthal. Due to COVID-19 and the massive travel restrictions this was not possible. Therefore, the workshop was postponed to October 2020 and completely reorganised as a virtual workshop. As preparation for the workshop in Balstahl IFA had collected open questions from firefighters. These questions had been structured as shown in Figure 23. The goal was set to clarify all open questions.

Expected results from workshop: all questionmarks cleared

Situation Information available	**Occurrence possible and not to rule out (Yes) or unlikely or even impossible (No)** (if "Yes" then quantify duration in average)							**Possible procedures**
	Vehicle fire	**Sudden HY-release**	**Sudden HY jet flame**	**Sudden burst of HY tank**	**Explosion of HY cloud in the open**	**Explosion in building-system**	**Explosion in tunnel system**	
Vehicle is not deformed "Something wrong" No HY phenomena reported	**Yes**	Average duration of release?	Average duration of HY fire?	?	No?	No?	No?	- self protection - permanent reconnaissance - (crash) rescue - secure site - block entrances - close tubes - protect ventilation outlets - cordon off - order evacuation - support evacuation - cool vehicle - cool surroundings - cool underbody - let HY-flame burn - fight vehicle fire but no HY fire - confine - ventilate - remove HY vehicle - conduct salvage - supporting procedures like water supply
HY release from vehicle reported No fire	**Yes**	No?	X	?	After what time No?	Yes? For how long?	Yes? For how long?	
Vehicle is deformed, No fire No release reported	**Yes**	Average duration of release?	Average duration of HY fire?	?	Only if release happens	?	?	
Vehicle fire No release or jet flame detectable or reported	already given	Average duration of release?	Average duration of HY fire?	No, due to valves?	No?	?	?	
HY fire spreads within vehicle	**sure**	Average duration of release?	already given	No, due to valves?	No?	No?	No?	
Fire outside HY vehicle; HY vehicle itself intact	**Yes**	No?	No?	No?	Not as long HY vehicle not heated up	?	?	
Tank has burst w/ or w/o fire	**Yes**	No	already given	already given	already done	already done	already done	
Vehicle fire has been extinguished without HY release	**re-ignition**	?	?	?	?	Cooling time?	Cooling time?	
?								

Figure 23: Open questions

The workshop was subdivided into 9 sessions. Some of these sessions should addressed all participants. For other sessions, the participants should be split into smaller working groups. The concept is shown in Figure 24.

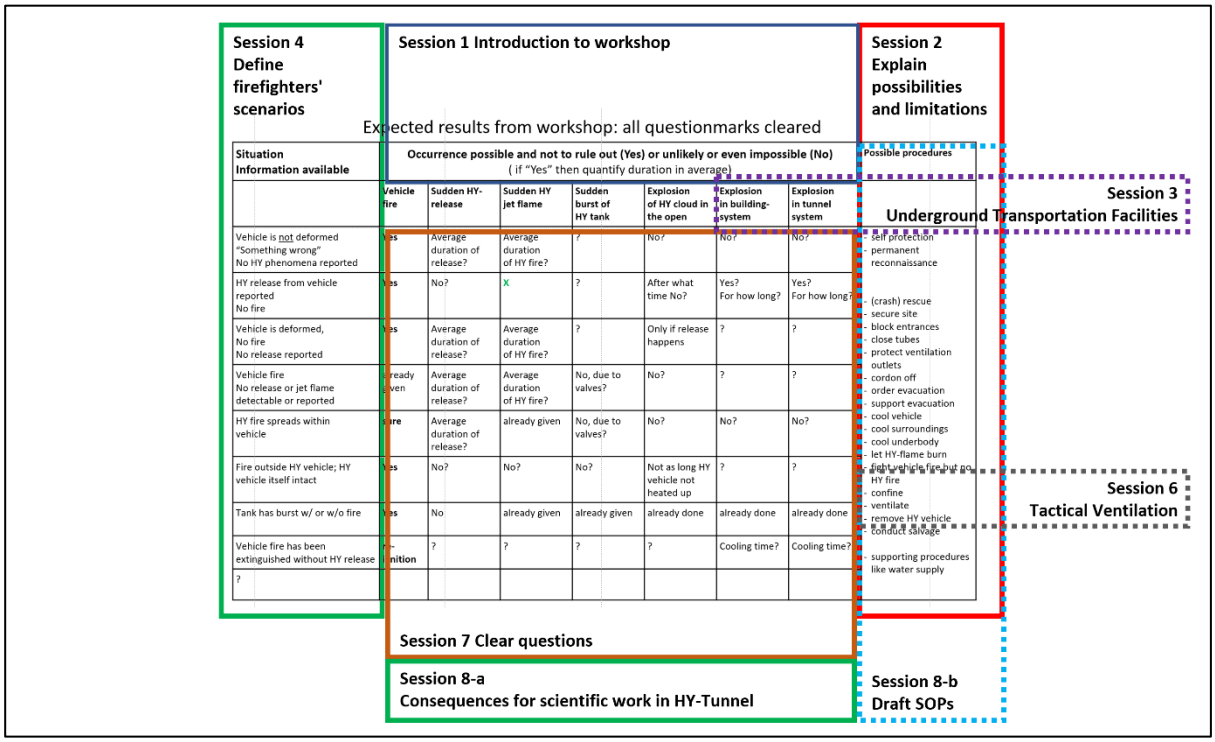

Figure 24: Sessions

Based on this structure the agenda for the workshop was initially planned to be as shown in Figure 25.

Draft Agenda

International Workshop for Firefighters in Balsthal

Thursday, 07.05.2020

Time	Duration	Session	Topics	Form of knowledge exchange	Location	Lead
9:30	00:30		Welcome, organizational issues	Particpants address	Auditorium	uk
10:00	00:30	1	Briefing	Lecture	Auditorium	cb
10:30	01:00	2	Possibilities and limitations of	Lecture	Auditorium	cb
11:30	00:30		Break / equip / proceed to tunnel			
12:00	01:00	3	Underground Transportation Facilities	Onsite-inspection	Training tunnel road and railway	cb, mn, cp
13:00	01:00		Lunch		Canteen	
14:00	01:30	4	Define firefighters scenarios	Debate	Auditorium	cb
15:30	00:15		Minibreak/ equip / proceed to tunnel			mn
15:45	01:30	5	Firefighting in tunnels Firefighters' tools and equipment	Live presentation Hands-on-exprience	Training tunnel road / 114	db
17:15	00:15	6.1	Tactical ventilation	Lecture	Car park	cb
17:30	00:45	6.2	Large ventilator	Demonstration	Car park / training tunnel road	mn
18:15	00:15		Proceed to auditorium			
18:30	00:30		Debriefing	Discussion	Auditorium	uk
19:00			Dinner			

Friday, 08.05.2020

Time	Duration		Topics	Form of knowledge exchange	Location	Lead
8:15	00:15		Briefing	Lecture	Auditorium	cb
8:30	02:00	7	Clear questions in working groups	Work in groups	3 classrooms + Classroom 10	tbd
10:30	00:30		Break		Canteen	
11:00	01:00	7	Common decision on answers to give	Debate	Auditorium	cb
12:00	01:00		Lunch		Canteen	
13:00	02:30	8-a	Consequences for scientific work	Discussion	Auditorium or classrooms	tbd
		8-b	SOPs draft	Tactical discussion	Tactical Centre	cb
15:30	00:30		Break		Canteen	
16:00	00:30	8	Results from 8-a	Presentation	Auditorium	cb
16:30	01:00		Results from 8-b	Debate	Auditorium	cb
17:30	00:30		Summary, conclusions, outlook	Particpants address	Auditorium	tbd
18:00			Ending and Good Bye			uk

Figure 25: Agenda for the planned and cancelled workshop in Balsthal

Annex II

Agenda of the virtual workshop on 5th and 6th October 2020.

BST	Day 1	
13:00-13:15	**Welcome to the workshop** Goals, procedures and organization of the workshop; rules for video conference	U. Kummer, IFA
13:15-14:30	**–Introduction to FCH 2 JU HyTunnel-CS project** Pre-normative research contribution to hy-accident response - Similarity law and exclusion of flammable cloud formation - Effect of tunnel slope on hydrogen dispersion in an accident - Correlation of blast wave attenuation in a tunnel - Safety technology to prevent hydrogen tank rupture - Concluding remarks and questions	D. Makarov, UU D. Makarov, UU A. Venetsanos, NCSRD W. Dery, UU S. Kashkarov, UU D. Makarov, UU
14:30-15:00	**Design of underground transport systems and its impact on first responders** Presentations and discussion: types of design and ventilation systems; varieties and dimensions	U. Kummer, IFA
15:00-15:20	*Break*	
15:20-15:45	**Underground transport systems and confined spaces: hazards** Presentation and discussion: extremely large fire compartments > long emergency routes > great depth of penetration; smoke, heat, structural collapse; hazard of explosion	C. Brauner, IFA
15:45-16:15	**Underground transport systems and confined spaces: tactics** Presentation and discussion: extinguish to rescue and the two-sided attack; reconnaissance – firefighting – search and rescue; tactical ventilation.	C. Pessel, IFA
16:15-16:30	**Framework for education** Different countries, different tasks, different expectations on curricula, intensity and time budgets for education and training	C. Brauner, IFA
16:30-17:00	*Break*	
17:00-17:30	**Vehicle Identification Numbers (VIN)** Presentation and discussion: to respond you need to know what you are dealing with. The VIN could tell you all you need to know.	T. Van Esbroek, SPFI
17:30-18:30	**HyResponder project** - Overview and current status of FCH 2 JU HyResponder project - Virtual reality for training - HyResponder remote events	S. Brennan, UU L. Lecomte, ENSOSP E. Maranne, CRISE
18:30-19:00	**Final discussion and closure of Day 1**	D. Makarov, UU
	Day 2	
08:30-08:45	**Introduction: Rules for tabletop exercises**	C. Brauner, IFA
08:45-10:15	**Tunnel scenarios** One Tube, single Tube, different types of ventilation	C. Brauner and C. Pessel, IFA
10:15-10:45	*Break*	
10:45-12:15	**Car park scenarios**	C. Brauner and

	Single car garage; parking garage, underground parking garage	C. Pessel, IFA
12:15-12:45	**Concluding round-table discussion** Define consent and dissent as well as questions to be answered	C. Brauner and C. Pessel, IFA
12:45-12:55	**Next steps in PNR project HyTunnel-CS to assist intervention strategies and tactics**	D. Makarov, UU
12:55-13:00	**Wrap-up and closure of the workshop**	C. Brauner, IFA