CFD AND VR FOR RISK COMMUNICATION AND SAFETY TRAINING

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ABSTRACT

There are new safety challenges with an increased use of hydrogen, e.g. that people may not see dangerous jet flames in case of an incident. Compared to conventional fuels, hydrogen has very different characteristics and physical properties, and is stored at very high pressure or at very low temperatures. Thus the nature of hazard scenarios will be very different. Consequence modelling of ventilation, releases, explosions and fires can be used to predict and thus understand hazards. In order to describe the detailed development of a hazard scenario and evaluate ways of mitigation, 3D Computational Fluid Dynamics (CFD) models will be required. Even with accurate modelling the communication of risk can be challenging. For this visualization in virtual reality (VR) may be of good help, in which the CFD model predictions are presented in a realistic 3D environment with the possibility to include sounds like noise from a high pressure release, explosion or fire. In cooperation with Statoil, Christian Michelsen Research (CMR) and GexCon have developed the VRSafety application. VRSafety can visualize simulation results from FLACS (and another CFD-tool KFX) in an immersive VR-lab or on a PC. VRSafety can further be used to interactively control and start new CFD-simulations during the sessions. The combination of accurate CFD-modelling, visualization and interactive use through VRSafety, represents a powerful toolbox for safety training and risk communication to first-responders, employees, media and other stakeholders. It can also be used for lessons learned sessions studying incidents and accidents, and to demonstrate what went wrong and how mitigation could have prevented accidents from happening. This paper will describe possibilities with VRSafety and give examples of use.

1.0 INTRODUCTION

CMR, which is the parent company of GexCon, has been developing concepts in the field of virtual reality (VR) since 1997. The first project, HydroVR [1], was developed to visualize 3D seismic data for well planning to facilitate and optimize oil production. The activity was funded by the Norwegian oil company, Norsk Hydro. The well planning process involves experts representing different disciplines, e.g. reservoir engineers, geologists, geophysicists and drilling engineers. Traditionally the work process is sequential, where the experts representing one discipline perform one stage in the process and handle the result over to the experts responsible for the next stage. Since each discipline has its own constraints and goals, which can conflict with those of other disciplines, traditional well planning would involve several iterations among the different competence teams before a solution meeting all the different constraints and goals could be reached. The use of VR in collaborative sessions where experts from different disciplines could work together and visualize their 3D calculations and iterate towards an approach, increased the understanding among the experts, shortened the decision process from weeks to days and led to improved decisions. In the Oseberg oil field, wells planned using VR had 20% more oil-filled sand than traditionally planned wells. At Troll field, errors in the geological model were discovered using VR, which led to a modified approach and an estimated increased production of more than half a million barrels. Remote collaboration was developed in 2002, so that participants from Houston, Bergen and an oilrig could meet and discuss in the same virtual environment. The concept was commercialized in 2000 as Inside Reality and was purchased and further developed by Schlumberger for oil exploration and production around the world.

The work within visualization continued into new areas. CMR developed a new platform for visualizing, FAVE (Framework Architecture for Virtual Environments), and based on this virtual reality was applied to new areas like medicine, urban planning and safety. In the area of safety, CMR initiated a cooperation with Norsk Hydro and Statoil (Now merged to Statoil) to develop VRSafety. One main functionality of VRSafety is 3D visualization of simulation results from the CFD-models FLACS (developed by GexCon) and KFX (Kameleon FireX developed by Comput-IT) in a virtual reality laboratory, see Figure 1, or a desktop computer. KFX is a CFD tool for fire predictions used by several oil and gas companies for consequence studies on oil platforms. Several other VR or visualization concepts exist in the field of safety, see e.g. [2] and [3]. In addition to the ability to visualize simulation results, there is another dimension to VRSafety as it can interactively operate the CFD software by modifying scenarios (e.g. add or remove a wall element, move ignition location for an explosion or release location during dispersion) and restart simulations. This latter functionality is useful for safety training sessions where a team may discuss possible improvements to current design, and quickly evaluate different options. This functionality can also be very useful if implemented e.g. in an emergency control center. Statoil has installed the VRSafety prototype at a number of their sites, and has used the tool in their safety training programme [4]. In 2008, Statoil and CMR entered a commercialization agreement for VRSafety, and VRSafety will be commercialized through GexCon.

2.0 DESCRIPTION OF VRSAFETY

The development of VRSafety started in 2003, with funding from Statoil and Norsk Hydro (now merged to Statoil) as well as the Norwegian Research Council. GexCon and Comput-IT have contributed to optimize application specific features for FLACS and KFX.

Some of the main features of the VRSafety application are [5]:

- A run-time interface between the simulator codes (FLACS & KFX) and the VR-application
- Interactive online viewing, animation and control of fire and explosion simulations while they run
- Several simulations can run simultaneously, and the user can easily switch between them
- Playback of previously calculated simulation results
- A range of visualization tools can be combined, including probes, slices, and volume visualization
- Sessions, representing sequences of instructions to VRSafety, can be stored and used for playback of user interactions
- The look and behavior of the VR-application can be controlled through XML scripting
- Special effects like local sound sources (noise from gas leak or ambulance) can make scenarios very realistic

3.0 POSSIBLE POTENTIAL APPLICATION AREAS:

There are many possible application areas for the VRSafety-tool. So far VRSafety has mainly been applied to safety training and risk communication, but it would also be a useful tool integrated in an emergency response control center. These different application areas will be described below.

3.1 Safety Training

This is currently a main application area for VRSafety. Very few workers or emergency first responders will ever get in the middle of a major accident/incident, and it is even less likely this will happen twice, so they can benefit from their experience from the first incident. Still, to be prepared if a potential major incident should happen, we would like the involved workers or first responders to understand the risk and act in the best possible way. Using VRSafety it is possible to simulate possible emergency scenarios in a realistic way with sounds and 3D visual impression. In this way, workers and first-responders can learn how an incident may develop, e.g. how quickly hot and toxic gases from a fire may spread, and also understand the importance of rapid evacuation to safe areas in the case of a flammable gas release. It would also be possible to practice evacuation in a setting with noise and poor visibility due to smoke. In a training session the instructor can typically show the group some pre-simulated cases, from which the students can learn important aspects of the physics in connection to dispersion, fire and explosion. During such an exercise, possible actions can also be demonstrated e.g. activation of deluge, closing or opening doors, what escape route to follow and more. While it may be impossible to run away from an explosion, it will also be of value to understand the potential forces from a gas explosion, so that workers understand when to evacuate instead of risking their life staying near the evolving incident.

3.2 Risk communication

Safety studies are frequently performed in industry, often to conform with regulations or standards. There are numerous situations where recommendations from safety studies can be difficult to communicate properly to the involved parties. This can be workers, who are the ones risking their lives, but still do not understand or accept the reasoning behind a safety measure (this could e.g. be a decision to tear down weather protection walls on an offshore platform to improve natural ventilation, or to activate water deluge at significant gas detection). It could also be senior management who are the ones to take the investment decision for a proposed safety measures. There are often several disciplines and many considerations involved in a decision. A meeting with different teams included (safety, working environment, engineering and finance) where the challenge is presented clearly and the best possible solution is found (e.g. how to modify walls to get a significant improvement of ventilation, while at the same time keeping worker's environment acceptable) is generally required. In other situations there may be a need to communicate unacceptable risks to top management in a convincing way, so that proper attention is given to the issue. Finally, there are also a number of situations where a company and authorities want to locate an industrial facility, like an LNG receiving terminal, a facility handling toxic gases, or a hydrogen refueling station, and people living near the site are against the development due to fear of risks. In many cases these risks are highly exaggerated, possibly due to over-simplified analyses which do not take mitigation measures and presence of buildings and protection walls into account. With a proper CFD-study of release scenarios, VRSafety could be used to demonstrate how various mitigation measures, facility layout and surrounding buildings, would ensure safety for the neighbours of the plant, or trigger alarms in due time for evacuation.

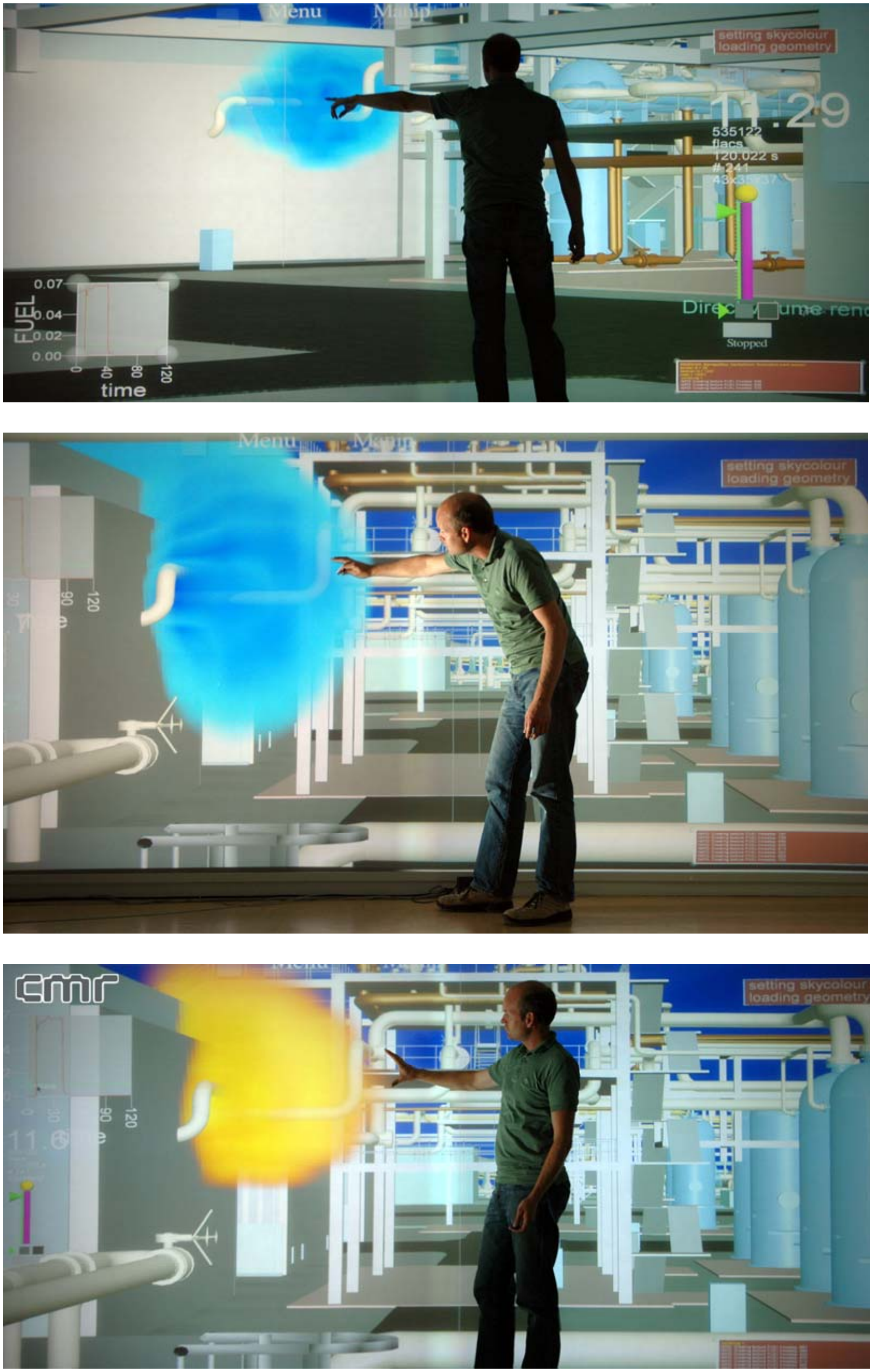

Figure 1 Examples of using VRSafety in an immersive display environment

3.3 Understanding the accident

While good safety work should limit the risks for accident, they still happen from time to time. In most situations, whether for legal reasons or for organizational training, there is a wish to learn what went wrong, to understand the physics involved properly, and also to evaluate what could have led to a further escalation of the incident. CFD simulations with properly validated models and virtual reality are excellent tools to investigate and illustrate an accident or incident. It can then be communicated what went wrong, which safety barriers failed, and how design or mitigation systems can be modified to prevent this or similar incidents from recurrence. Possible audiences would both be workers, neighbours, management, authorities, news media or the courts during a potential legal case.

3.4 Emergency Control Center

The risk for terrorist attacks has been increasing in the recent years, and places like transportation hubs (subways, car tunnels, airports, etc.), shopping malls, tall buildings or stadiums may be particularly exposed. Increasing population density around chemical facilities handling or storing toxic substances, combined with a lower general acceptance for 3rd party risk, is also a concern for authorities and major companies. For many of these situations centralized emergency control centers exist, so that in the event of an accident/incident at one particular location this can be monitored and appropriate action can be taken. Such an action will usually involve some kind of alarms, evacuation guidance and more, but will in some cases also involve active actions like the initiation of emergency ventilation, or water mitigation. If observation systems (e.g. gas or smoke detectors) combined with knowledge about ventilation systems or meteorological observations can be combined, and a number of fast CFD scenarios can be started with the aim to simulate the ongoing incident, this would give very interesting possibilities with regard to decision support. When simulations much faster than real-time can be performed, the system can predict how the scenario will develop into the future, evaluate different mitigation options (e.g. ventilation), and decide what actions to take and where to evacuate people. GexCon demonstrated the potential for such fast simulations with neutral tracer gas in Manhattan [6, 7], see also example in Figure 2. Such a concept should also be interesting for large petrochemical companies in urban areas, where a number of potential accident scenarios may have been pre-simulated, and the VRSafety model may visualize the most relevant scenarios (wind direction, release location and size) and give valuable decision support during incidents. Common for all the above scenarios is that simpler consequence models than CFD may give very misleading predictions as these can not take into account the effect of geometry.

4.0 WHY USE VIRTUAL REALITY FOR HYDROGEN

There are several reasons to apply a tool like VRSafety for hydrogen. Some of these are discussed in the following:

1. Hydrogen is different from other gases, and few people have experience with it

Compared to petrol, LPG and CNG, hydrogen is extremely buoyant, has a very wide flammable range, is extremely reactive in a wide concentration range, and is more likely to ignite during release. Unlike for petrol, LPG and CNG, very few people have experience using hydrogen in daily life. For this reason it should be valuable to develop virtual reality based safety training sessions showing simulation results with reliable and validated CFD-software. Primary targets for the sessions would be workers at hydrogen facilities as well as first responders.

2. Hydrogen releases as well as flames may be invisible

A high pressure release of hydrogen will generate a loud sound, but the gas will not be visible. If the release ignites, there may be an explosion as well as a following jet-fire, but still the flames will often be invisible. This may represent a safety challenge as people scared by the sound may get hurt by running into open flames during escape. By simulating a range of release and fire scenarios with a validated CFD-tool, VRSafety visualization could be a powerful way to teach workers and first-responders about expected flame-lengths and shapes, so they may better understand the hazards in connection to such scenarios.

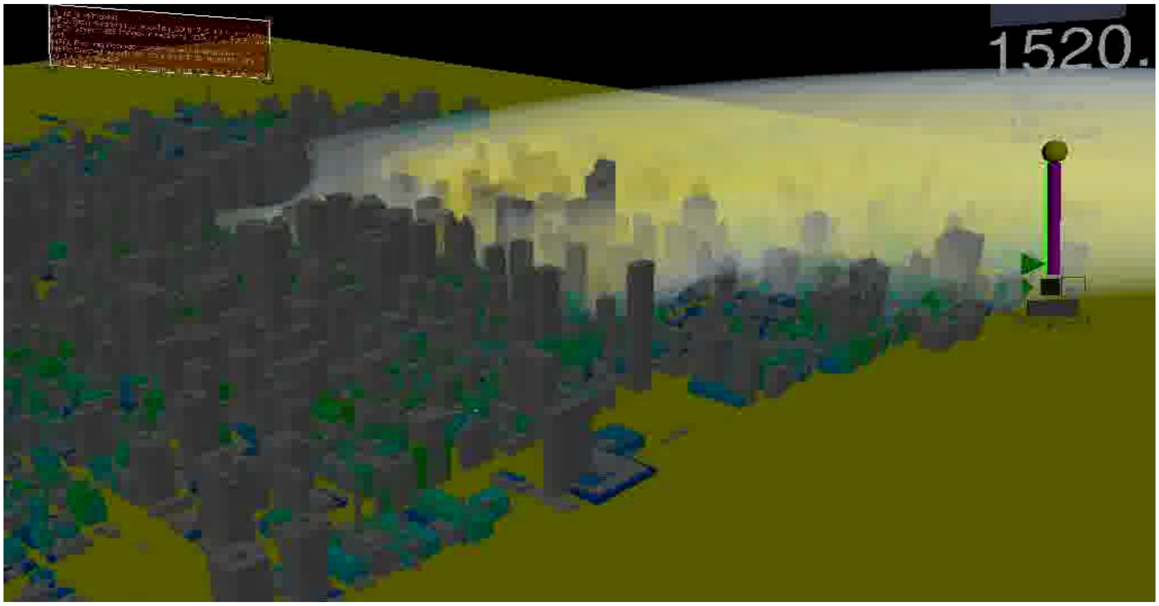

Figure 2 The realistic visualization and interactive operation of CFD-tools should make VRSafety an interesting tool to apply in emergency response control rooms. Above a gas dispersion scenario in Midtown Manhattan with is simulated, view from East River (UN Headquarters are seen centrally in the lower part of the picture)). With pre-simulated wind-scenarios from relevant wind directions faster than real-time dispersion simulations can be started based sensor observations.

3. Experience handling low probability incidents, escalation prevention and mitigation

Many hydrogen incidents have potential to develop into severe accidents. For indoor incidents, hydrogen accumulation must be avoided, and during an incident it could be critical to activate additional ventilation (passive or active) to hazardous gas build-up. For outdoor incidents, e.g. high pressure releases at a refueling station, it may be important to prevent that gas jet will enter highly congested vegetation (trees and bushes) or stacks of commercial goods, as this can generate very high explosion pressures, and potentially a DDT (deflagration-to-detonation-transition) if the gas jet is ignited. VRSafety combined with validated CFD-models, are powerful to illustrate how a hazard may develop and can therefore be used to teach how to mitigate and limit the risks from low probability incidents which could escalate into high consequence events.

4. Risk communication, teach 3rd party neighbours and users

Many people will be skeptical to new technology and be against facilities in their neighbourhood (e.g. NIMBY = Not In My Back-Yard). Potential users of the new technology may also hesitate due to lack of understanding. Proper CFD-simulations and use of VRSafety could visualize potential accident scenarios and demonstrate how e.g. hydrogen buoyancy, or implemented mitigation measures (e.g. protection walls) would ensure tolerable risk from potential hydrogen incidents for neighbours and customers at the facility. The simulation of potential incidents will usually be more informative and much cheaper than experiments

5. Revisit accidents and what could have happened

To improve safety within an industry it is of paramount importance to report incidents and accidents, including near misses, and also to do the best possible job understanding the incidents. As hydrogen characteristics are somewhat different from other commonly used fuels, well validated CFD-models should be used to get a realistic picture of what did and could have happened. VRSafety will be a good tool to visualize the CFD modelling in a realistic way, including potential escalation scenarios, and also to show the effect of mitigation measures, implemented or possible new, to prevent or reduce the severity of the incident. Organizations like the US Chemical Safety Board (www.csb.gov) has its mission to investigate and document accidents in the process industry, and will in most cases produce a lessons learnt video. BP's Process Safety Series (http://www.icheme.org/bpsafetyseries) also deliver lessons learned videos. Sometimes animations showing physical processes leading to the accidents are pure illustrative video-animations made by the artists rather than CFD-modelling of the incidents, which could give the viewers misleading information about the cause and origin of the incidents.

5.0 EXAMPLE CASES RELEVANT FOR HYDROGEN:

5.1 Release in a garage (CEA Garage Experiments with Helium):

To obtain a better understanding of safety issues with regard to hydrogen releases from cars in a garage, the French Atomic Energy Commission (CEA)performed a test series Garage [8] with helium releases in a garage sized enclosure. In the different tests release rate as well as ventilation conditions were varied. In Figure 3 a screen-shot from VRSafety from the simulation of CEA Garage test 5 is shown, with a release rate around 0.05 g/s from the middle of the floor. The geometry has been made with similar textures/colours as found in the test geometry. It can be seen how gas concentrations are visualized with different partially transparent colours. Measurement sensors (probes) have also been defined inside VRSafety and the transient helium concentration is reported at these locations. In this experiment, efforts were done to seal the building properly to avoid leaks of gas from the enclosure. If the gas had been hydrogen, and not helium, and the leak rate had been higher, potentially hazardous gas clouds would develop. One simple measure to mitigate this risk would be to make some passive vent openings near the ceiling, so that buoyant hydrogen gas (or helium in this experiment) would escape instead of accumulating.

In a VRSafety training session or design meeting the instructor/group leader could show the participants the base case design scenario with dangerous accumulation of gas. Thereafter, the group could discuss possible venting configurations, combining practical design aspects and costs with knowledge about hydrogen behaviour/safety, and decide number of vents, their size and location. Thereafter the instructor could restart the simulation with the new vent openings defined, and the group could study how well the selected vent configuration prevented build-up of flammable gas. If necessary, a couple of different choices could be studied to find the optimal solution. This type of simulations can be performed very efficiently with FLACS, using a non-compressible solver and parallel processing, close to real time performance can be obtained. Thus, within minutes it will be possible to evaluate if the selected vent solution can prevent gas build-up from a given release size or not.

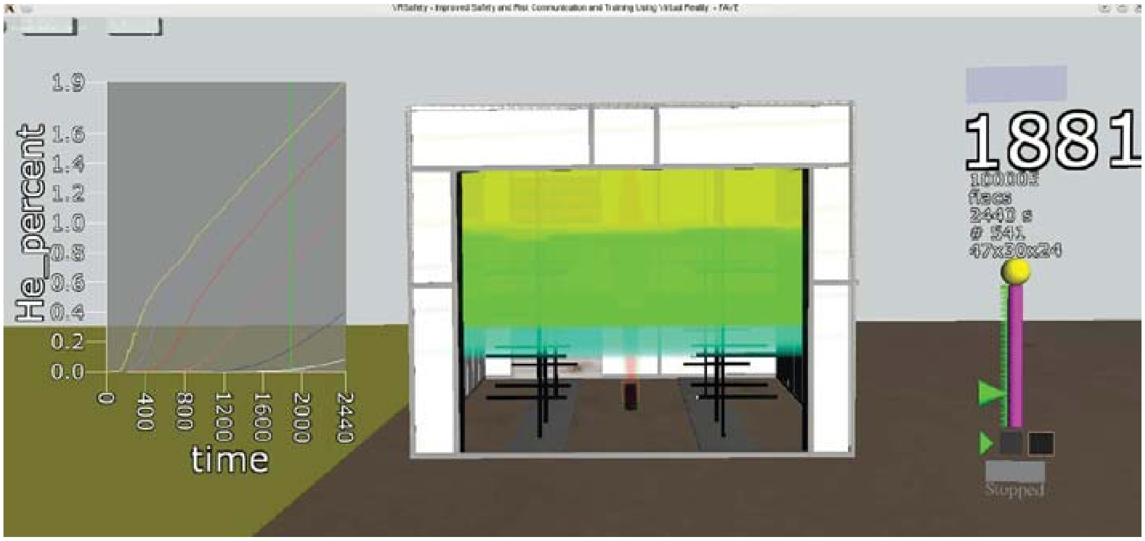

Figure 3 VRSafety visualization of dispersion simulation (CEA Garage test 5, 0.05 g/s He injected into a garage sized enclosure). The gas is released centrally on the floor (see red plume from black cylinder) and the different colours show gas concentrations. To the right the progress bar can be seen, illustrating that this is a FLACS simulation 1881s after start of the release. To the left gas concentrations at 6 sensors can be seen, the green vertical line shows the current time in the animation.

5.2 Explosion in a refueling station (Shell Benchmark scenario)

The second example is a simulation of an explosion test scenario in a mock-up hydrogen refueling station [9]. A stoichiometric gas cloud filling the entire station area (highly unrealistic) was exploded, and this test was also used as a CFD-modelling benchmark within the HySafe project [10]. In Figure 4 screen-shots from a FLACS simulation (ignition location different from experiment) are shown in VRSafety 60 ms and 90 ms after time of ignition, showing the explosion progress (flame and unburnt gas). Pressure traces recorded at two probes (small white spheres) can also be seen.

In a VRSafety training session the instructor would discuss with the students what ignition locations would generate the highest overpressures at locations like the protection wall or under the vehicle. After a discussion one or two suggestions can be evaluated within the VRSafety session by simply moving the ignition location and restarting the simulation. Within a few minutes the explosion simulation with FLACS is near completion (see example in Figure 5) and the group can discuss to what extent the new ignition location created higher explosion pressures.

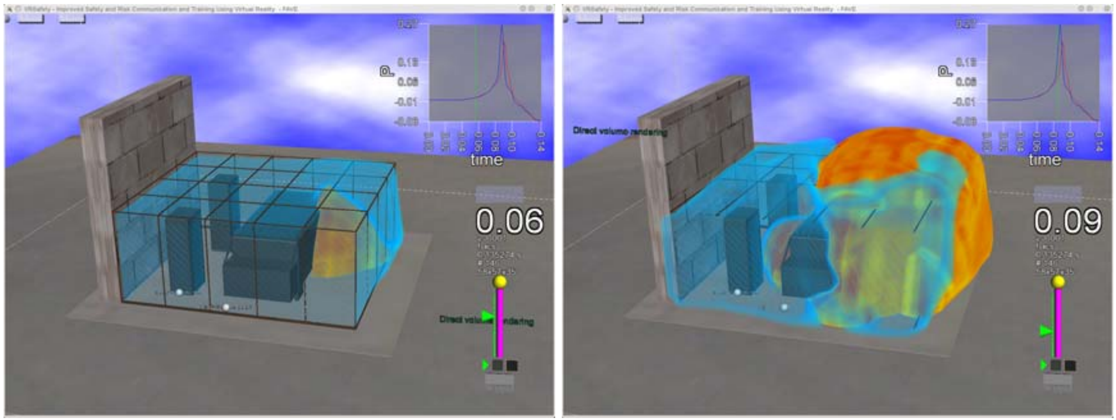

Figure 4 VRSafety visualization of explosion in a mock-up hydrogen refueling station, ignition point is chosen on the left-rear corner of the car and pictures after 60 and 90 ms are shown. Both the flame and the unburnt gas cloud (semi-transparent blue) are visualized, and transient explosion pressure is shown at two chosen locations (white probes).

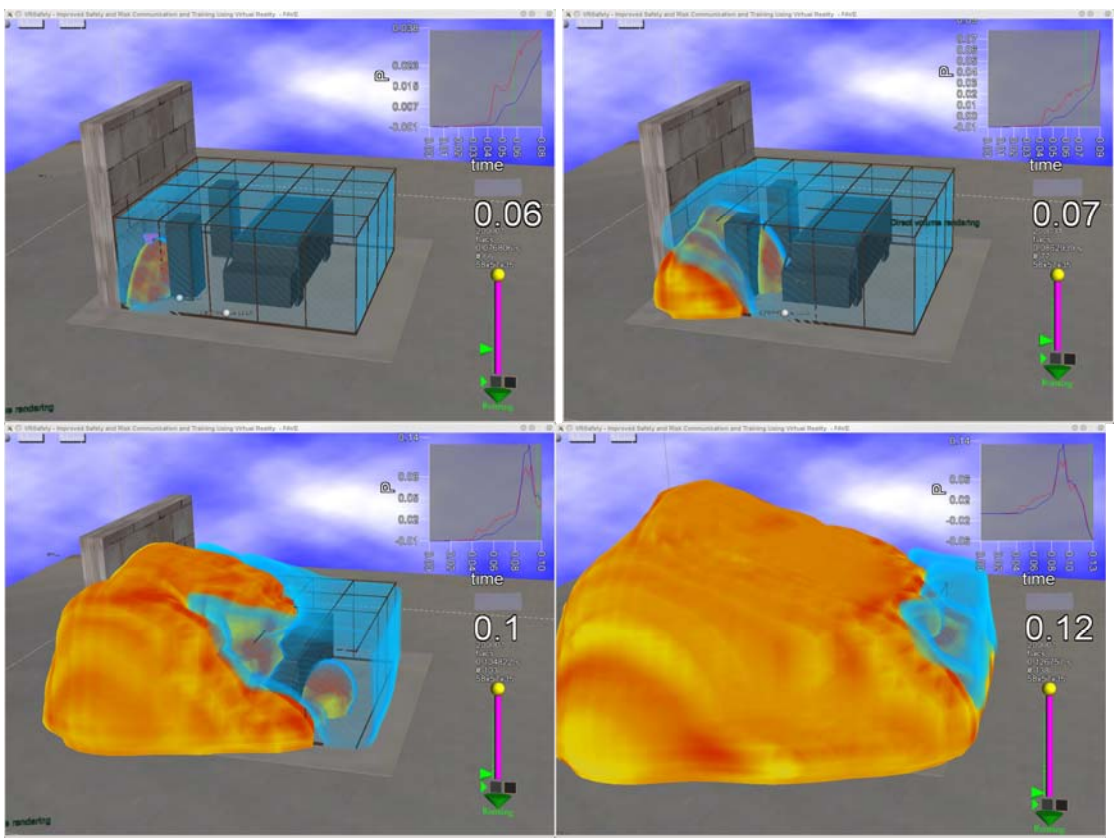

Figure 5 One of the possibilities unique for VRSafety is the interactive simulation with FLACS during a session. The above pictures show how ignition point is moved to the lower left corner of the enclosure and a new explosion simulation is started. The total simulation time is around 5 minutes, which can be shortened using the parallel version of FLACS.

Such interactive sessions are useful for teaching purposes, as the students will have to use their knowledge and explosion understanding proposing solutions to the exercise, and will thereafter get the correct answer (verdict?) within minutes. The exercise could be expanded further to look into potential mitigation measures, e.g. layout modifications, so that the group could discuss and evaluate what can be done to limit the risk.

The above examples were chosen among HySafe CFD benchmark exercises, but could have been any, more realistic, facility handling hydrogen.

6.0 PLANNED IMPROVEMENTS

There is an ongoing process to further develop the user interfaces of VRSafety to simplify use. At the same time, it is important that VRSafety becomes compatible with the latest FLACS versions, which includes parallel computing and non-compressible solver for faster calculations. A porting to Windows (Linux is currently the only platform) may also be undertaken. It is also planned to further lift the current prototype version of VRSafety to become a commercial prototype available to be leased by end users by 2012. GexCon and CMR will also be looking for cooperation partners in the process of commercializing VRSafety.

7.0 CONCLUSIONS

VRSafety is an existing prototype tool for visualization of results and interactive use of FLACS and KFX CFD simulation tools. As discussed in this article, there are numerous possible application areas. Statoil has sponsored the development of VRSafety, and has been using the tool for in-house safety training. A main strength of VRSafety compared with other visualization packages, is that the validated CFD tools FLACS and KFX can be used for simulations interactively in the sessions.

8.0 ACKNOWLEDGEMENTS

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