HyApproval

WP2 – Handbook Compilation

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APPENDIX V

WP4 Consequence Assessment Summary Report

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1. Summary

This report summarizes the numerical investigations of accident scenarios that were performed by partners CEA, ENI, FZK, JRC and NCSRD within work package 4 (Safety Work Package) of HyApproval.

Given the large number of partners involved in the consequence assessment simulations special care was taken to present the results in a uniform and coordinated way, in order to facilitate the subsequent step of the Quantitative Risk Assessment activity (QRA) held within HyApproval.

The report is structured based on the various scenarios identified for investigation. For each scenario the effects of various parameters are discussed, where this was possible.

Since one of the requirements in order to publish papers in scientific journals is that the research results can not be published before, quantitative results have not been included in this public version of the report. Therefore the report contains mainly a qualitative description of the results. When the process of publishing in scientific journals is finished, a new version of the report will be released and it will contain all the relevant quantitative results.

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2. Introduction

Within the framework of WP4 partners CEA, ENI, FZK, JRC and NCSRD have performed consequence assessments of the H2 accidental release scenarios identified earlier in the project through scenario selection workshops, see HyApproval deliverables D4.6 and D11/12. Accident scenarios with compressed hydrogen gas (CGH2) and liquid hydrogen (LH2) have been considered.

The scenarios analyzed were the following:

- D4, CGH2 dispenser hose rupture
- DL8, LH2 dispenser hose rupture
- T1, CGH2 trailer hose disconnection during refilling
- TL1, LH2 trailer hose disconnection during refilling
- S8, Burst of one hydrogen storage tank at 70MPa storage pressure.
- PR1, Rupture of NG feed line inside the production container (h2 production from steam reforming of NG).

The consequence assessment was performed employing mainly the CFD methodology. A simpler integral modelling tool was applied in the last two scenarios.

Table 1 below summarizes the simulation work performed by each partner involved. Table 2 shows the applied computational tool for each case. Deliverable 4.6 includes information on the validation status of the various simulation tools.

Pre-existing experimental information from HSL-SHELL (Shirvill and Roberts, 2006) (Shirvill et al., 2007), related to CGH2 releases in a modelled Hydrogen Refuelling Station was also used in the analysis for comparison against the calculated results.

Detailed description of the modelling work performed by each partner can be found in the partners' individual reports, see CEA (Beccantini et al., 2007) (Perret at al., 2007), ENI (Podenzani, 2007), FZK (Kotchourko et al., 2007), JRC (Baraldi et al., 2007) and NCSRD (Papanikolaou and Venetsanos, 2007).

The purpose of the present report is to summarize the main findings of the consequence assessment and perform an evaluation of the effects of various parameters on the computed results. From the calculated results the following "risk assessment" information was mainly considered:

- Hydrogen mass in the flammable cloud (4-75% hydrogen)
- Flammable cloud volume,
- Maximum horizontal distance of the LFL cloud (4% h2) from release source
- Maximum vertical distance of the LFL cloud from release source
- Maximum overpressure as function of horizontal distance from ignition source

From the various parameters affecting the results the following were considered, based on Table 1.

- Atmospheric conditions (D5 wind at different wind directions or stagnant conditions)
- Mitigation (present or not)

- Different partner/simulation tool

Table 1: Performed Simulations Matrix

<table>
<tr><th>Scenario</th><th>Layout</th><th>Mitigation</th><th>Atmospheric conditions</th><th>CFD Dispersion</th><th>CFD Combustion</th><th>Integral code</th></tr>
<tr><td rowspan="4">D4-35 Mpa</td><td rowspan="10">SHELL simplified</td><td rowspan="2">No</td><td>Stagnant</td><td>ENI</td><td></td><td></td></tr>
<tr><td>D5</td><td>ENI</td><td></td><td></td></tr>
<tr><td rowspan="2">Yes</td><td>Stagnant</td><td>ENI, FZK,</td><td>FZK</td><td></td></tr>
<tr><td>D5</td><td>ENI, CEA-6</td><td>CEA</td><td></td></tr>
<tr><td rowspan="3">D4-70 Mpa</td><td>No</td><td>D5</td><td>CEA-6</td><td></td><td></td></tr>
<tr><td rowspan="2">Yes</td><td>Stagnant</td><td>CEA-6</td><td></td><td></td></tr>
<tr><td>D5</td><td>CEA-6, CEA-11</td><td></td><td></td></tr>
<tr><td>D4-Premixed</td><td>No</td><td>Stagnant</td><td></td><td>FZK</td><td></td></tr>
<tr><td rowspan="2">DL8</td><td>No</td><td rowspan="2">Stagnant, D5 West, East, North, South</td><td>NCSRD</td><td>JRC</td><td></td></tr>
<tr><td>Yes</td><td></td><td>JRC</td><td></td></tr>
<tr><td rowspan="2">T1</td><td rowspan="2">Air Liquide, Luxemburg</td><td rowspan="2">No</td><td>Stagnant</td><td>ENI, FZK</td><td>FZK</td><td></td></tr>
<tr><td>D6</td><td>ENI</td><td></td><td></td></tr>
<tr><td rowspan="2">TL1</td><td rowspan="2">SHELL Washington DC</td><td>No</td><td rowspan="2">D5 West, East, North, South</td><td>NCSRD</td><td>JRC</td><td></td></tr>
<tr><td>Yes</td><td></td><td>JRC</td><td></td></tr>
<tr><td>S8-70 Mpa</td><td>50 and 90 lt tank</td><td></td><td></td><td></td><td></td><td>CEA</td></tr>
<tr><td>PR1</td><td></td><td></td><td></td><td></td><td></td><td>CEA</td></tr>
</table>

Table 2: Applied simulation tools

Partner	CFD Dispersion	CFD Combustion	1-d code
CEA	FLUENT	CAST3M	SPHERE 1D
ENI	FLUENT		
FZK	GASFLOW-II	COM3D	
NCSRD	ADREA-HF		
JRC		REACFLOW	

3. Scenario D4

Scenario D4 considers gaseous hydrogen release after CGH2 dispenser hose rupture.

3.1 Jet 35MPa

3.1.1 Scenario description

It was decided to use a model layout based on the HSL-Shell jet release experiments (Shirvill and Roberts, 2006) (Shirvill et al., 2007). The refuelling station was represented by a dummy vehicle, two dispensers and a confining wall. The two dispensers had dimensions 0.6 m × 0.9 m × 2.1 m and the wall had dimensions 0.6 m × 5.4 m × 4.5 m. The dimensions of the vehicle are shown in Figure 1, while Figure 2 shows the refuelling station model used in the experiments. Figure 3 shows the component relative positions.

The release position (marked R1 in Figure 4) is located in the middle between the dispenser and the vehicle at 1.2 m height from ground. The release direction is vertically downwards.

Figure 4 shows the pressure sensor and ignition positions for the jet release scenarios D4-35MPa and D4-70MPa.

In the HSL-Shell experiment RC08 a hydrogen mass of 0.59g was released in 0.7s.

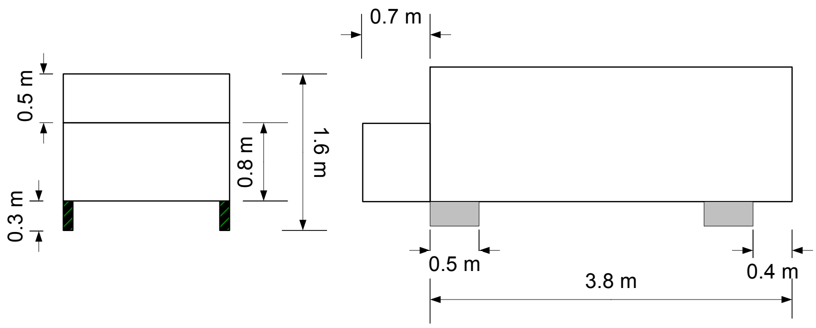

Figure 1: Model vehicle used in Shell experiments (Shirvill et al., 2007).

Figure 2: The refuelling station model used in the jet release experiments (comparison with real car) (Shirvill et al., 2007).

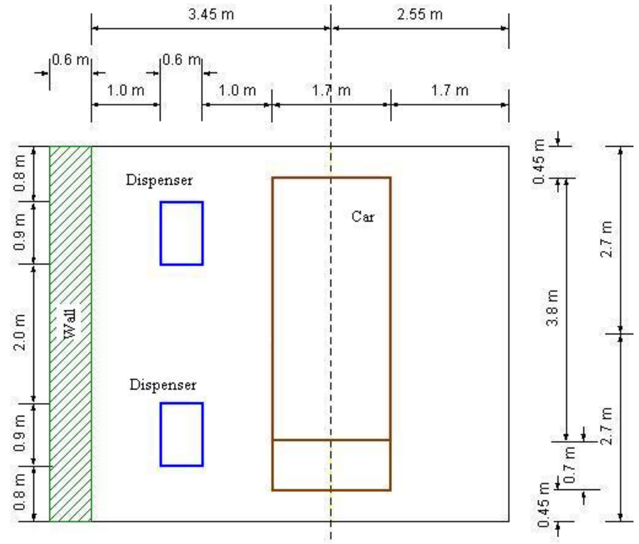

Figure 3: Geometrical dimensions(Shirvill et al., 2007).

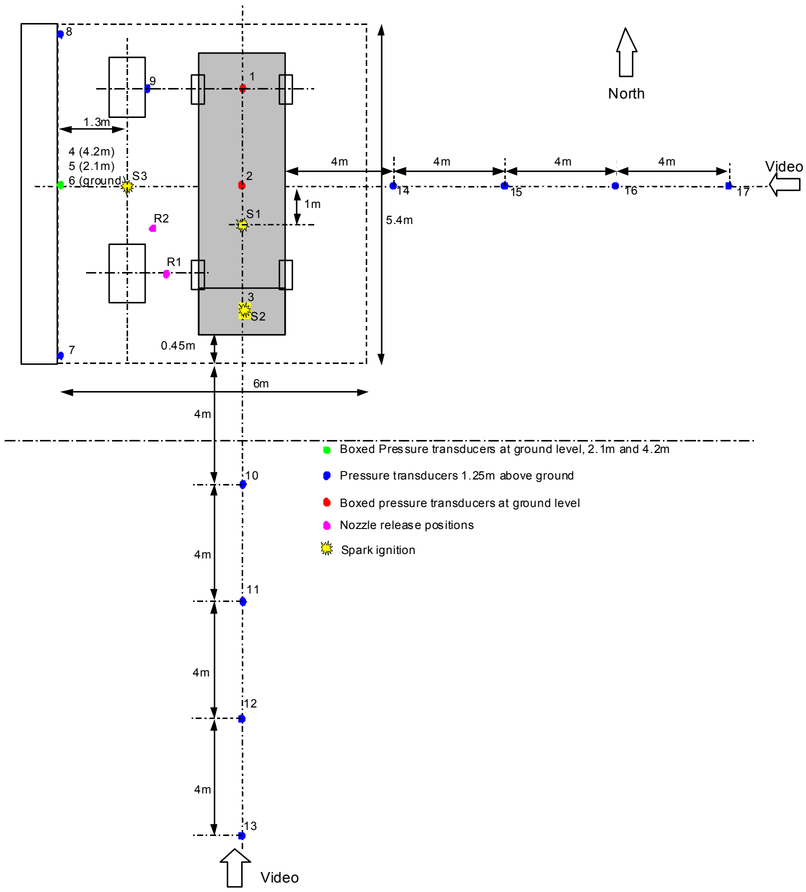

Figure 4: Pressure sensor and ignition positions for jet release scenarios (Shirvill et al., 2007).

3.1.2 Results and discussion

Focus is given first on the ENI results. For the mitigated case the effect of the wind is very limited. For the non-mitigated case the flammable cloud volume and the h2 mass contained within it are significantly reduced under the presence of D5 wind as compared to stagnant conditions. Flammable cloud volume and flammable H2 mass is higher for the mitigated case. This occurs because of the assumed higher h2 release mass flow rate for the mitigated case (0.86 kg/s) as compared to the non-mitigated case (0.1 kg/s).

The CEA results have been obtained for the mitigated case with D5 wind assuming a mass flow rate of 0.611 kg/s and a release period of 0.7 s. This flow rate corresponds to a release diameter of 6mm in contrast to the HSL-Shell tests were the diameter was 8mm. Despite the difference in release conditions the CEA results are compared against the corresponding ENI results. As expected the predicted flammable cloud volume and flammable h2 mass are higher for the ENI results because of the higher mass flow rate. CEA dispersion calculations were continued way past the end of release period (first 0.7 s). Although the max flammable h2 mass is reached at the end of the release period, maximum flammable cloud volume is reached later.

The FZK results have been obtained for the mitigated case with stagnant conditions assuming a mass flow rate of 0.1 kg/s and a release period of 0.7 s. This release rate is significantly lower than the one used by CEA and ENI for the mitigated case.

CEA performed also combustion calculations for the mitigated case with D5 wind. Ignition position was assumed at the engine bay of the car. (marked as S2 in Figure 4).

The above CEA combustion results can be compared to the FZK combustion results (with same ignition location), despite the different atmospheric conditions assumed based on the fact as shown by ENI results above that for the mitigated case the presence of wind plays minor role. Such a comparison reveals much lower predicted maximum overpressure for FZK compared to CEA. Again this can be partly explained, since in the FZK case the released hydrogen was only 0.07 kg compared to 0.43 kg for CEA.

The above discussion shows that although the initial intention was to simulate the same scenarios and to perform partners' inter-comparisons, in practice different release assumptions were used by the various partners. As a result differences were observed in the various predictions.

For future similar activities it is strongly recommended to have very carefully agreed initial and boundary conditions to permit useful partner/code inter-comparisons.

3.2 Jet 70 MPa

3.2.1 Scenario description

Layout, release location and direction were the same as in the previous case, i.e. jet release at 35 MPa.

3.2.2 Results and discussion

CFD calculations for this case were performed only by CEA.

CEA assumed an exit diameter of 6 mm for cars and 11 mm for busses. Calculated hydrogen mass flow rates were 1.222 and 4.108 kg/s respectively corresponding to a storage pressure of 70 MPa. For the mitigated case a release period of 0.7s was assumed as in the previous 35 MPa case.

The calculations show that the mitigation is very effective in the present situation as the non-mitigated case reaches approximately 8 times larger flammable h2 mass and 10 times larger LFL cloud volume than the mitigated case.

The effects of the atmospheric conditions for the mitigated scenario D5 have been evaluated, by comparing the wind and stagnant conditions. It has been found out that during the release period flammable h2 mass and LFL cloud volume are practically not affected by the atmospheric conditions. A similar observation was made above when considering the ENI results for 35 MPa jet. After the end of the release the presence of the wind plays an important role: the flammable h2 mass and LFL cloud volume values with wind are lower than in the stagnant case. This can be attributed to wind induced enhancement of mixing of hydrogen with ambient air. On the other hand it can be observed that the horizontal distance of LFL cloud from source is larger with wind than without. This of course is because wind enhances transport of the flammable cloud horizontally along the wind direction while without wind the LFL cloud tend to rise mainly due to buoyancy.

The effects of tank pressure and leak diameter have been investigated for the mitigated case with D5 wind. The effect of tank pressure includes comparison to the CEA 35 MPa jet results. It has been observed that both an increase in leak diameter and an increase in tank pressure lead to higher values for flammable h2 mass and LFL cloud volume. This can be attributed of course to the fact that both an increase in the leak diameter and an increase in the tank pressure both lead to an increase in the hydrogen release mass flow rate.

3.3 Premixed

3.3.1 Scenario description

The layout is based on the HSL-Shell tests (Shirvill et al., 2007). In the present case the refuelling station rig was surrounded by a 5.4 m x 6.0 m x 2.5 m frame. The top, sides of the frame and the outside of the wall were covered with a thin (23 µm) plastic film. A photograph of the rig with the plastic film in position is illustrated in Figure 5.

A total amount of 1.847 kg of h2 was homogeneously mixed with air at stoichiometric concentration inside the space surrounded by the plastic film. Ignition position was assumed at the engine bay of the car (marked as h2refuel03 in Figure 5).

Figure 5: Layout based on the HSL-Shell experiments (Shirvill et al., 2007)

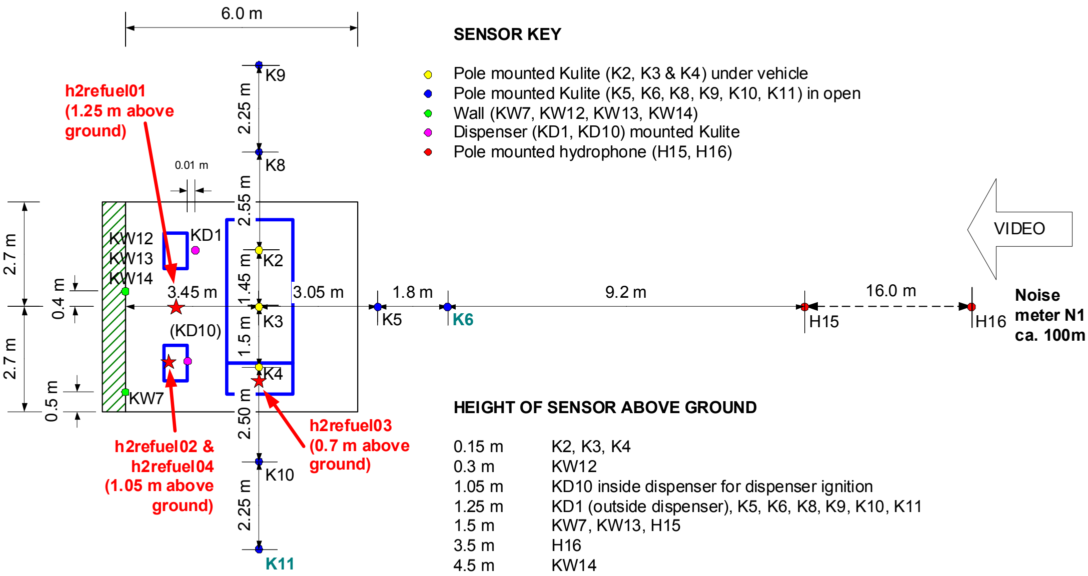

Figure 6: Pressure sensor and ignition positions for the HSL-Shell experiments (Shirvill et al., 2007).

Given the h2 mass involved and the stoichiometric conditions, this case was characterized as a non-mitigated one. This case was modelled by FZK.

3.4 Conclusions

The calculations show that the accident consequences in case D4-70 are potentially more severe that in case D4-35.

Simulations demonstrate how a jet release from a hose for busses is more severe than a release from a hose for cars both in term of maximum flammable mass and in term of maximum distance of the LFL cloud.

Regarding the effect of mitigation, the 70 MPa results show that mitigation significantly limited the amount of flammable h2 mass by almost one order of magnitude.

Regarding the wind effects it has been found that for the mitigated scenarios the wind plays a role only after the end of the release (after 0.7 s), while for the non-mitigated scenarios it plays a role at times not very close to the start of the release. The presence of wind in general has been found to enhance mixing and lead e.g. to lower flammable h2 masses but at the same time increase horizontal distance of LFL cloud from source due to transport of the LFL cloud along the wind direction.

4. Scenario DL8

Scenario DL8 represents liquid H_2 release caused by a hose break during refuelling.

4.1 Scenario description

The release position is located in the middle between the dispenser and the vehicle at a 1.2 m height. The release direction is vertically downwards.

The assumed nozzle exit conditions are listed in Table 3. The table shows mitigated and non-mitigated conditions. In the mitigated case a shut off valve is assumed to be activated 5 seconds after the start of release. In the non-mitigated case it is assumed that the shut off valve is not activated so that the release is continuously fed from the buffer tank located before the dispenser. In both cases the flow rate was assumed constant and approximately equal to the one that exists under normal refuelling conditions (the flow rate forced by the pumping system).

With the estimated flow rate the amount of LH2 released after 5 seconds would be 267 g. This mass is assumed to be inside the hose and dispenser piping before the release starts. For the non-mitigated cases a release time of 100 seconds was simulated.

The release was modelled as an area source (8 mm diameter) with inflow boundary conditions as given in Table 3.

No specific CFD simulations were performed to investigate the dilution of the H2-air cloud after 5 seconds in case of the mitigated scenarios, as the maximum H2 flammable mass and volume occurred at 5 seconds. The results at 5 seconds of each non-mitigated CFD run were considered as the mitigated calculation results.

Table 3: Release conditions for scenario DL8

Exit Conditions	Non mitigated	Mitigated
Diameter	8 mm (id)	8 mm (id)
Exit void fraction	All liquid (void =0)	All liquid (void =0)
Exit pressure	101325 Pa	101325 Pa
Saturation temperature at ambient pressure	20.4 K	20.4 K
Density	70.8 kg/m3	70.8 kg/m3
Velocity	15 m/s	15 m/s
Mass flow rate (constant)	0.0534 kg/s	0.0534 kg/s
Volumetric flow rate (constant)	0.7542 lt/s	0.7542 lt/s
Release duration	100 seconds	5 seconds

4.2 Results and discussion

Dispersion results have been obtained by partner NCSRD for five different atmospheric conditions (stagnant, D5 West wind direction, D5 East, D5 North and D5 South). For the mitigated cases simulations for the period after the release were not performed based on the fact that (from experience) maximum flammable mass occurs at most at the end of the release.

Non-mitigated dispersion results show that absence of wind results in higher maximum flammable mass and maximum flammable mixture volume compared to the examined D5 wind cases. This is attributed to the lower mixing under stagnant conditions.

Non-mitigated dispersion results also show that from the 4 wind directions considered D5 North results in the worst consequences as far as maximum horizontal distance of LFL cloud from source is concerned. This is due to obstacles affecting dispersion (blocking the extension of the cloud) in the other wind direction cases as shown in (Papanikolaou and Venetsanos, 2007). The extension of the LFL cloud in the wind direction was also observed in the D4 scenario.

It should also be mentioned that although case D5 North presents the higher horizontal distance of LFL cloud from source and higher flammable mixture volume, case D5 West presents the higher flammable H2 mass. This affects the combustion results.

From the non-mitigated combustion results, it can be observed that the maximum overpressures are obtained under D5 West wind conditions. It is interesting to note that although having much higher flammable masses the stagnant case produced overpressure results lower than in case D5-West. Additionally overpressures for case D5-West are significantly higher than for the other three wind directions, although for case D5-North flammable h2 mass is relatively close to that for case D5-West. Both of these phenomena can be attributed to the effect of confinement enhancing flame acceleration for case D5-West.

The mitigated dispersion results show that atmospheric conditions play a significant role. This behaviour is different from what it has been observed for the mitigated scenario D4 where the atmospheric conditions do not play a role. The different behaviour can be explained by considering the release time: the assumed mitigation time of 5 seconds is large enough compared to the 0.7 s assumed for the mitigated scenario D4. The time scale of the release should be large enough to allow the atmospheric conditions to play a role. This role is similar to what was described above for the non-mitigated cases.

The mitigated combustion results show that the worst overpressures are also produced for the D5-West wind case.

The combustion calculations show that mitigation measure is effective by reducing the max overpressures, especially for the more severe cases such as the D5-West and the stagnant.

4.3 Conclusions

Regarding the effect of mitigation, the results show that mitigation significantly limited the amount of flammable h2 mass by a factor 7. The maximum overpressures were reduced by factor of 2 .

Regarding the effects of wind on dispersion it has been verified (as in scenario D4) that wind results in lower flammable h2 mass and flammable air-h2 mixture volumes, due to enhanced mixing and higher horizontal distances of LFL cloud from source due to transport along the wind direction.

Regarding the effects of confinement on combustion it has been shown that higher overpressures are obtained for case D5-West where wind direction results in blocking the flammable cloud within the obstructions.

5. Scenario TL1

Scenario TL1 concerns LH_2 leakage, due to trailer hose disconnection during refilling.

5.1 Scenario description

The SHELL hydrogen refuelling station located in Washington DC was selected for the simulations (see Figure 7 and Figure 8). The required geometrical information was provided by SHELL. The LH2 truck-trailer was included in the simulations. The geometrical data used to reproduce the LH_2 truck-trailer were provided by Linde. The modelled site geometry is shown in Figure 8.

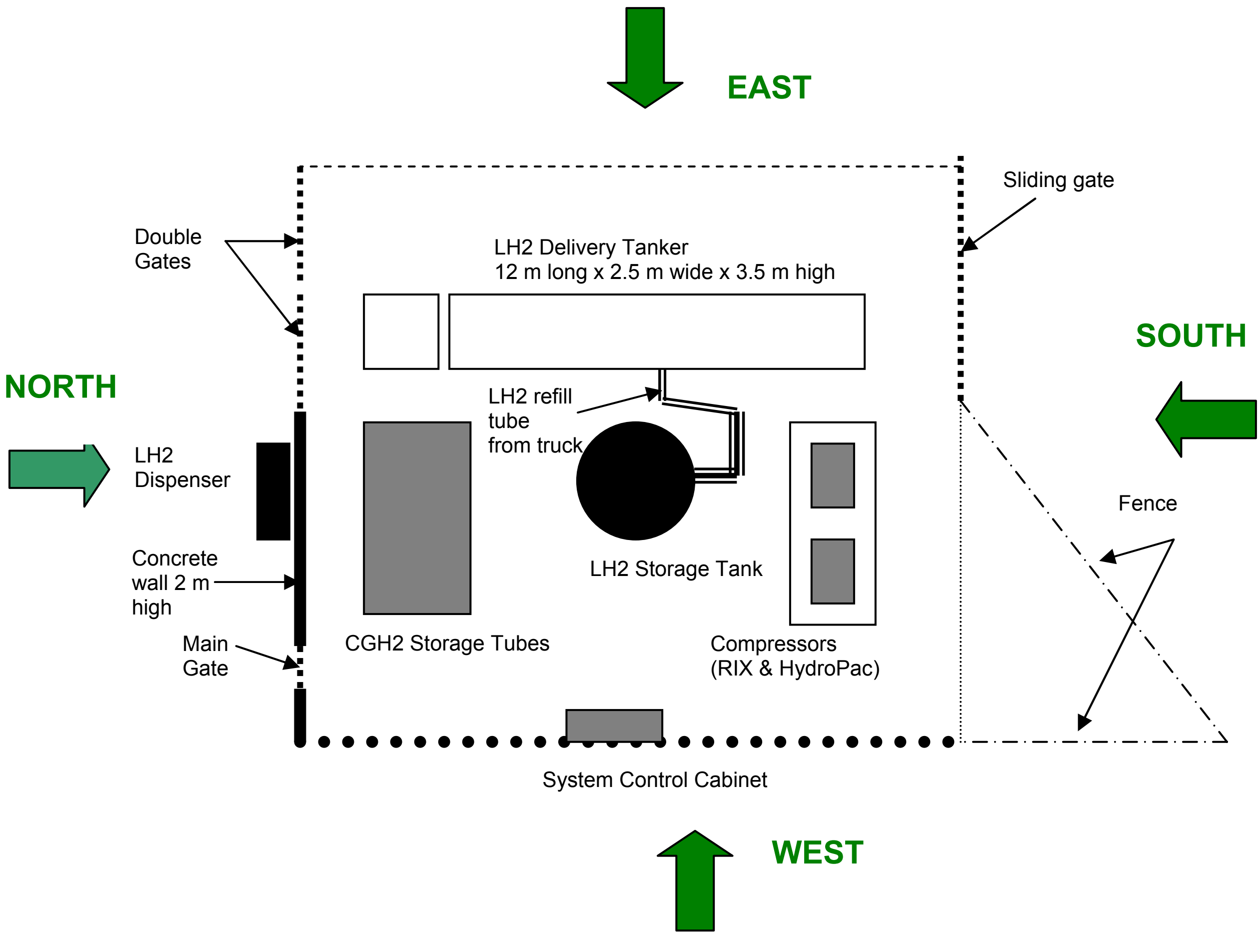

Figure 7: Sketch of simplified layout for liquid hydrogen storage / transport area based on Washington HRS. The green arrows identify the wind direction.

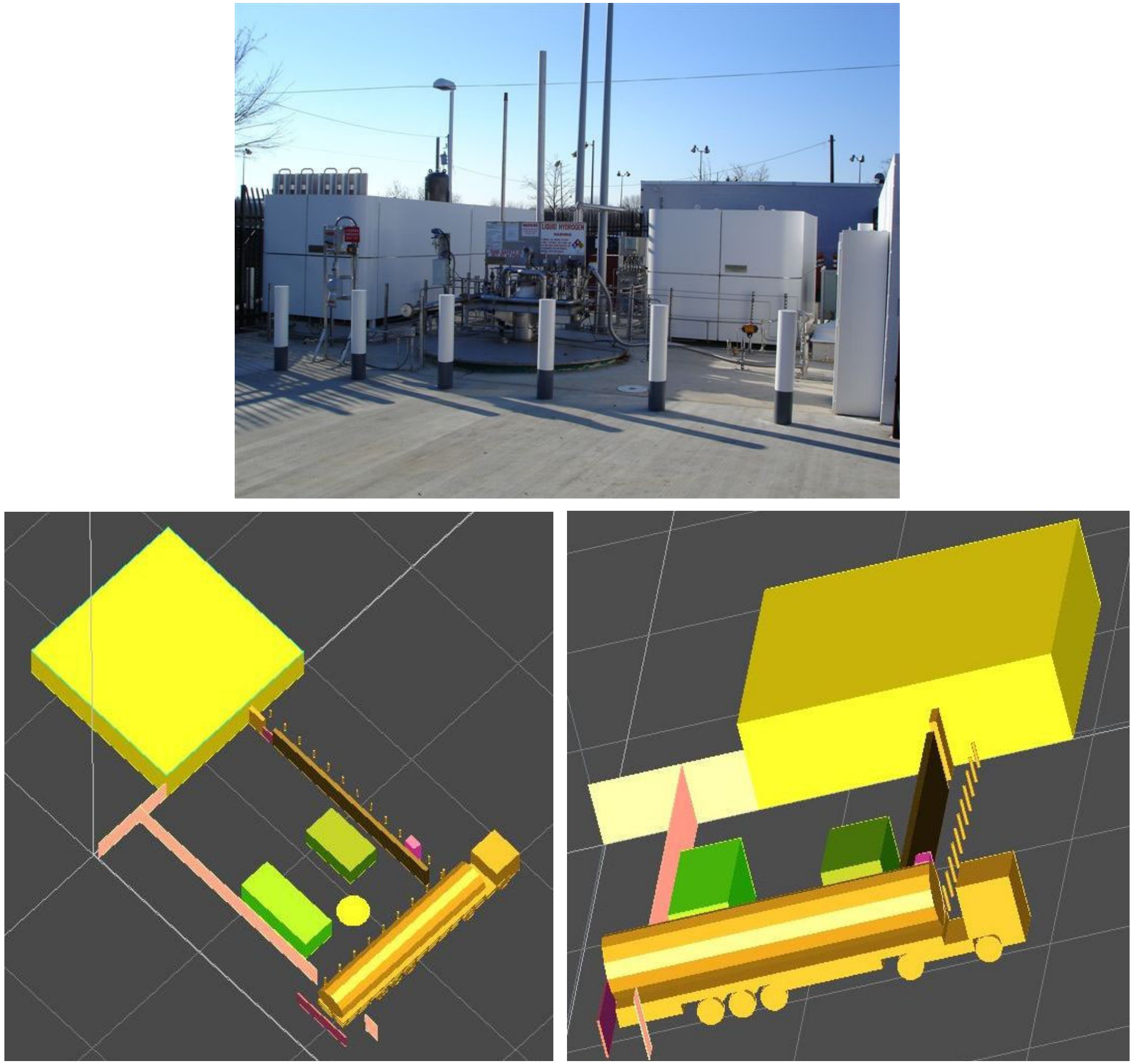

Figure 8: Top: Photo of the Washington DC HRS. Bottom: Aspects of the modelled site geometry

The release position is shown in Figure 9. It is located close to the truck-trailer and bollards at a 0.5m height. Its direction is assumed to be vertically downwards.

The assumed nozzle exit conditions are described in Table 4 for mitigated and non mitigated case. For both cases the discharge flow rate was assumed constant and equal to 25 kg LH2/min (as provided by pumping system). For the mitigated case it was assumed that the time period required for the excess flow valves or the pressure sensing devices to shut down the system is approximately 4 minutes. During this period with the above flow rate an amount of 100 kg LH2 will be released. For the non mitigated case, the H_2 released mass was assumed 1000kg, i.e. ten times as much as in the mitigated case. This represent approximately half the contents of a full truck-trailer (the total mass of an LH2 trailer is approximately $30m^3$ x $70\ kg/m^3$= 2100 kg).

Given the above, scenario TL1 is expected to be far more dangerous than scenario DL8.

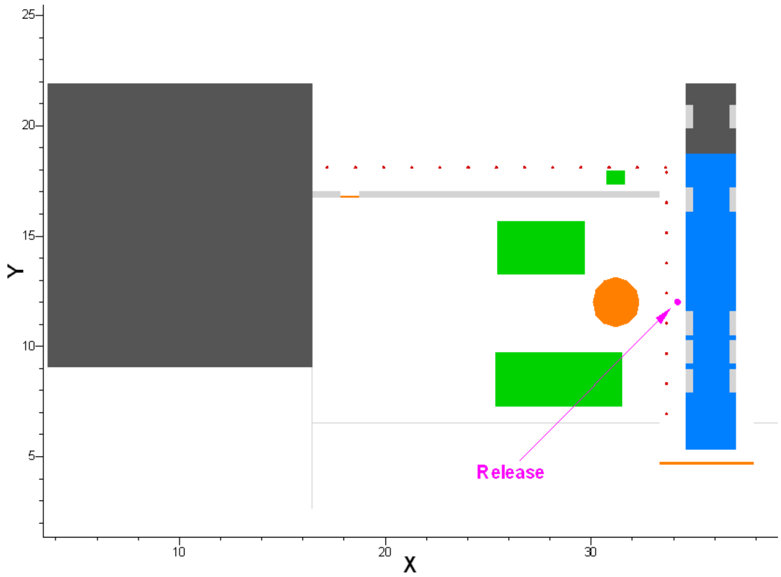

Figure 9: Release Position

For the mitigated cases the dilution of the hydrogen-air cloud after 240s was not simulated, since the maximum H_2 flammable masses and volumes occurred at 240s or earlier.

Table 4: Release conditions for scenario TL1

Exit conditions	**Non mitigated**	**Mitigated**
Exit diameter (mm)	22.5	22.5
H2 Mass flow rate (kg/s)	0.417	0.417
Release duration (s)	2400	240
Released H2 mass (kg)	1000	100
Exit temperature (K)	20.4	20.4
Exit pressure (Pa)	101325	101325
Exit void fraction	All liquid (void=0)	All liquid (void=0)
Exit density (kg/m3)	70.8	70.8
Exit velocity (m/s)	14.8	14.8
Exit area (m2)	3.976e-4	3.976e-4

5.2 Results and discussion

Dispersion results have been obtained by partner NCSRD for four different wind directions (D5 West wind direction, D5 East, D5 North and D5 South). The effect of atmospheric conditions on h2 dispersion characteristics have been investigated both for the non-mitigated release and for the mitigated. For the mitigated cases simulations for the period after the release were not performed based on the fact that (from experience) maximum flammable mass occurs at most at the end of the release.

Non-mitigated dispersion results show that from the 4 wind directions considered case D5 East results in the worst consequences as far as maximum flammable h2 mass, maximum flammable mixture volume as well as maximum horizontal distance of LFL cloud from source. Case D5 South on the other hand presents the lowest values of the above parameters.

Non-mitigated combustion results show that maximum overpressures are obtained for case D5 South, for which the smallest flammable masses were observed. This can be attributed to obstacle effects enhancing flame acceleration and eventually predicted overpressures. Blocking of the flammable cloud within the obstructions for case D5 South as compared to case D5 East can be seen in (Papanikolaou and Venetsanos, 2007).

The mitigated dispersion results show a trend similar to the non-mitigated case with case D5 East presenting the worst consequences.

Similarly mitigated combustion results show that maximum overpressures are again for case D5 South.

The role of mitigation in this scenario is found to be questionable. Although maximum flammable cloud sizes were slightly reduced by mitigation, maximum overpressures were on the contrary slightly increased. This suggests that there is a clear need to reduce the release duration at times much lower than the 240 s assumed in the analysis.

5.3 Conclusions

Regarding the efficiency of the assumed mitigation in this scenario, this has been found to be questionable. Although maximum flammable cloud sizes are slightly reduced by mitigation, maximum overpressures are on the contrary slightly increased. This suggests that there is a clear need to reduce the release duration at times much lower than the 240 s assumed in the analysis.

Regarding the effects of confinement on combustion it has been shown that although maximum flammable h2 mass has been observed for case D5 East, maximum overpressures have been obtained for case D5 South, for which case blocking of the cloud within the obstructions is more pronounced.

6. Scenario T1

Scenario T1 concerns CGH2 leakage, due to trailer hose disconnection during refilling.

6.1 Scenario description

For scenario T1, the refuelling station geometry is based on the H_2 Refuelling Station situated at Luxembourg.

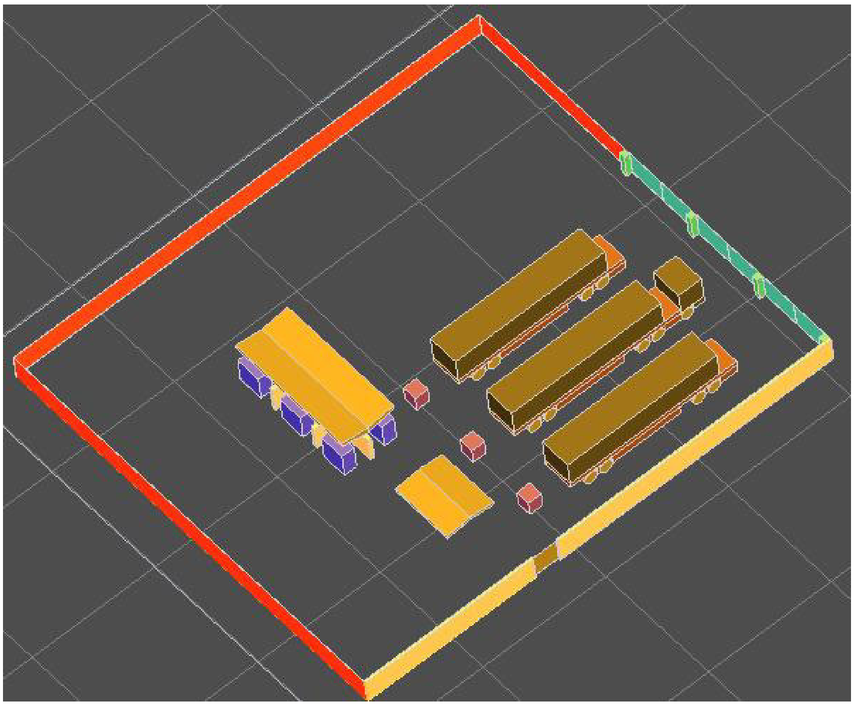

Figure 10: CGH2 Refuelling Station Side View (Luxembourg refuelling station)

The truck in the middle is assumed to be refilling the station. The hydrogen hose is assumed connected at the middle of the back side of the truck at a height of 1.5m. The hose is assumed to be accidentally disconnected from the truck. The hose diameter (ID) is 12.5 mm. The release is assumed to be directed horizontally, hitting the trailer unloading station located behind the truck (red box in Figure 10). The entire amount of hydrogen stored on the trailer (250 kg at pressure 20MPa) is assumed to be released in the non-mitigated scenario.

Based on the above information release calculations were performed by partner NCSRD using the GAJET integral tool to calculated the release exit conditions. The calculated h2 mass flow rate used as input (boundary condition) for the subsequent dispersion calculations is shown in Figure 11.

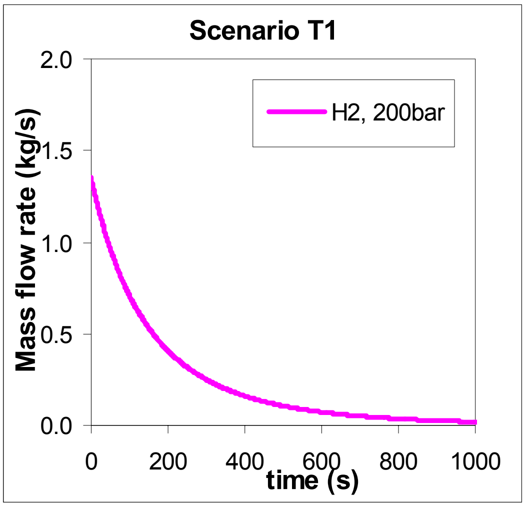

Figure 11: Hydrogen source based on NCSRD simulation

6.2 Results and discussion

Only the non-mitigated scenario was considered by the partners in this case.

Partner ENI performed dispersion simulations with and without wind. D5 wind condition was assumed with wind direction along the X axis (perpendicular to the trailers).

From the analysis of the calculations, it has been found that the maximum distance of LFL cloud from source along the X axis is increased under the presence of wind, as expected. Additionally maximum vertical distance of LFL cloud from source is higher under stagnant conditions as also expected due to buoyancy. It can also be observed that under stagnant conditions maximum flammable h2 mass as well as maximum flammable mixture volume are generally higher.

The abovementioned effects of the wind on the dispersion characteristics are consistent with similar findings from the other scenarios considered in this analysis.

Partner FZK performed both dispersion and combustion simulations for this scenario. Stagnant wind conditions were assumed. The maximum value of the predicted flammable h2 mass as function of time differs from the value of the ENI computations. This difference remains to be explained.

FZK investigated the potential of the h2-air mixture to the energetic regimes of deflagration using σ- and 7λ-criteria. More information on this approach can be found in Breitung et al. (2001). The potential for strong FA remains almost constant during all time of the modelling.

6.3 Conclusions

Both ENI and FZK performed dispersion calculations for the T1 non-mitigated scenario. FZK carried out also combustion calculations. In addition FZK investigated the potential of the h2-air mixture to the energetic regimes of deflagration using σ- and 7λ-criteria. The potential for strong FA remains almost constant during all time of the modelling.

7. Scenario S8

7.1 Scenario description

Burst of a hydrogen storage tank at 70MPa storage pressure. Two tank volumes were considered 50 and 90 lt.

7.2 Results and discussion

Simulations were performed by CEA using the integral tool SPHERE 1D simulating spherical expansion from 70 MPa.

No mitigation of any kind was assumed.

Predicted maximum overpressures are compared against three threshold values (5 kPa, 7 kPa and 15 kPa). 7 kPa (1 psi) is a threshold values used by US DOE (Roberts and Crowley, 2004) representing an overpressure at which glasses can be broken. 15 kPa can cause the rupture of tympanic membrane. 5 KPa is a threshold value recommended by CEA authority for computing the safety distance for general public, in the design of a Gas Cooled Reactor used for the production of hydrogen.

For a 90 litres tank, the distance to window breakage threshold (5kPa) is 5 m larger than for a 50 litres tank. Moreover for a 90 litres tank the distance to the tympanic membrane threshold (15 kPa) is 2 m larger than for a 50 litres tank.

7.3 Conclusions

For a 90 litres tank, the distance to window breakage threshold (5kPa) is 5 m larger than for a 50 litres tank. Moreover for a 90 litres tank the distance to the tympanic membrane threshold (15 kPa) is 2 m larger than for a 50 litres tank.

8. Scenario PR1

8.1 Scenario description

Rupture of NG feed line inside the production container (h2 production from steam reforming of NG). In case 1 the container has a very large mechanical resistance (of 10 bars). In case 2 the container has a very low mechanical resistance or has by design relief panels preventing any pressure increase.

8.2 Results and discussion

Also for this scenario, predicted maximum overpressures are compared against three threshold values (5 kPa, 7 kPa and 15 kPa). 7 kPa (1 psi) is a threshold values used by US DOE (Roberts and Crowley, 2004) representing an overpressure at which glasses can be broken. 15 kPa can cause the rupture of tympanic membrane. 5 KPa is a threshold value recommended by CEA authority for computing the safety distance for general public, in the design of a Gas Cooled Reactor used for the production of hydrogen.

For a container with very large mechanical resistance, a value of 50 kPa is attained at 20m distance.

For a container with very large mechanical resistance, the distance to window breakage threshold (5kPa) is above 90 m and the distance to the tympanic membrane threshold (15 kPa) is above 40 m.

For a container with very low mechanical resistance or relief panels by design preventing any pressure increase, there would be no significant over pressure.

8.3 Conclusions

For a container with very large mechanical resistance, the distance to window breakage threshold (5kPa) is above 90 m and the distance to the tympanic membrane threshold (15 kPa) is above 40 m.

For a container with very low mechanical resistance or relief panels by design preventing any pressure increase, there would be no significant over pressure.

9. Overall Conclusions

Scenario D4: CGH2 dispenser hose rupture.

- The calculations showed that the accident consequences in case D4-70 are potentially more severe that in case D4-35.
- The simulations demonstrated how a jet release from a hose for busses is more severe than a release from a hose for cars both in term of maximum flammable mass and in term of maximum distance of the LFL cloud.
- Regarding the effect of mitigation, the 70 MPa results showed that mitigation significantly limited the amount of flammable h2 mass by almost one order of magnitude.
- Regarding the wind effects it was found that for the mitigated scenarios the wind plays a role only after the end of the release (after 0.7 s), while for the non-mitigated scenarios it plays a role at times not very close to the start of the release. The presence of wind in general was found to enhance mixing and lead e.g. to lower flammable h2 masses but at the same time increase horizontal distance of LFL cloud from source due to transport of the LFL cloud along the wind direction.

Scenario DL8: LH2 dispenser hose rupture.

- Regarding the effect of mitigation, the results showed that mitigation significantly limited the amount of flammable h2 mass by a factor 7. The maximum overpressures were reduced by factor of 2.
- Regarding the effects of wind on dispersion it was verified (as in scenario D4) that wind results in lower flammable h2 mass and flammable air-h2 mixture volumes, due to enhanced mixing and higher horizontal distances of LFL cloud from source due to transport along the wind direction.
- Regarding the effects of confinement on combustion it was shown that higher overpressures are obtained for case D5-West where wind direction results in blocking the flammable cloud within the obstructions.

Scenario T1: CGH2 trailer hose disconnection during refilling.

- FZK investigated the potential of the h2-air mixture to the energetic regimes of deflagration using σ- and 7λ-criteria. The potential for strong FA remains almost constant during all time of the modelling.

Scenario TL1: LH2 trailer hose disconnection during refilling.

- Regarding the efficiency of the assumed mitigation in this scenario, this was found to be questionable. Although maximum flammable cloud sizes were slightly reduced by mitigation, maximum overpressures were on the contrary slightly increased. This suggests that there is a clear need to reduce the release duration at times much lower than the 240 s assumed in the analysis.

- Regarding the effects of confinement on combustion it was shown that although maximum flammable h2 mass was observed for case D5 East, maximum overpressures were obtained for case D5 South, for which case blocking of the cloud within the obstructions is more pronounced.

Scenario S8: burst of one hydrogen storage tank at 70MPa storage pressure.

- For a 90 litres tank, the distance to window breakage threshold (5kPa) is 5 m larger than for a 50 litres tank. Moreover for a 90 litres tank the distance to the tympanic membrane threshold (15 kPa) is 2 m larger than for a 50 litres tank.

Scenario PR1: rupture of NG feed line inside the production container (h2 production from steam reforming of NG).

- For a container with very large mechanical resistance, the distance to window breakage threshold (5kPa) is above 90 m and the distance to the tympanic membrane threshold (15 kPa) is above 40 m.
- For a container with very low mechanical resistance or relief panels by design preventing any pressure increase, there would be no significant over pressure.

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