EXPLOSION RISK REDUCTION USING CFD

O. Talberg, GexCon AS, Norway
Ø. Strøm, GexCon AS, Norway
J.R. Bakke, GexCon AS, Norway

AUTHOR BIOGRAPHICAL NOTES

Ole Talberg graduated from the Offshore Technology department at the Stavanger University College (HiS) in 1996, where he studied offshore safety. After being employed at ABB Offshore Technology as an engineer, he joined GexCon in March 1998. At GexCon he has been working as a consultant, performing ventilation, dispersion and explosion analysis using the Computational Fluid Dynamics (CFD) program FLACS.

Øyvind Strøm graduated from the Offshore Technology department at the Stavanger University College (HiS) in 1996, where he studied offshore safety. After being employed at Halliburton AS as an engineer, he joined GexCon in January 1999. At GexCon he has been working as a consultant, performing ventilation, dispersion and explosion analysis using the Computational Fluid Dynamics (CFD) program FLACS.

Jan Roar Bakke has a PhD in applied mathematics (i.e. gas explosion modelling) from the University of Bergen in 1986. He has worked 12 years at Christian Michelsen Research (CMR) with gas explosion research, followed by 6 years in Statoil's Safety Technology department. Since November 1998 he has held the position of Technical Director in GexCon, a consultancy company owned by CMR. He is also Visiting Professor of Safety Technology at the Stavanger University College.

ABSTRACT

Explosion risk both onshore and offshore can be reduced or managed by applying a number of measures. In evaluating which measures to use it is necessary to be able to demonstrate which are most efficient and even more importantly which give the optimum combination of risk reduction and cost. It is also important to evaluate the effect of selected measures on other issues like fire risk and evacuation.

During the last few years’ explosion risk analysis methodology has developed rapidly, particularly with regard to including advanced CFD analyses in the methodology. Recent papers[1, 2] have focused on the development of the technology. The present paper, however, is an attempt to shift focus to the application side: How can the methods developed be used in an optimum way to reduce risk and save money?

Examples of measures that can be examined for their effect on explosion risk are:

- Optimisation of gas detector type, number and location (based on gas dispersion analyses)
- Reduction of confinement (incl. explosion vent panels)
- Platform orientation
- Change/reduction of module/room size
- Reduction/limitation of inventories (may be more important for fires)
- Layout optimisation

- Optimisation of water deluge system (nozzle type, number and location as well as water application rate)
- Initiation of water deluge on gas alarm
- Blowdown (more important for fires)
- Isolation of ignition sources
- Shutdown and segmentation of process systems (ESD)

Examples of applying the methodology to selected scenarios will be presented, together with a brief overview of the status of the technology development.

1 INTRODUCTION

Evaluating the effectiveness of different explosion risk reducing measures sets certain requirements to the methodology used for the evaluation of such measures. The methodology used must be able to give a good representation of the physics involved in ventilation, gas dispersion and explosion, but also include the important platform characteristics with respect to gas detection, shutdown- and isolation philosophy, mitigation measures, etc.

Simple approaches, that not fulfil these requirements, can give wrong answers and trends with respect to both the explosion risk level and the effectiveness of the measures evaluated.

2 STATUS OF TECHNOLOGY DEVELOPMENT

For a typical probabilistic explosion risk analysis, performed by GexCon, the main parts of such a study and the variables evaluated are listed in FIGURE 1.

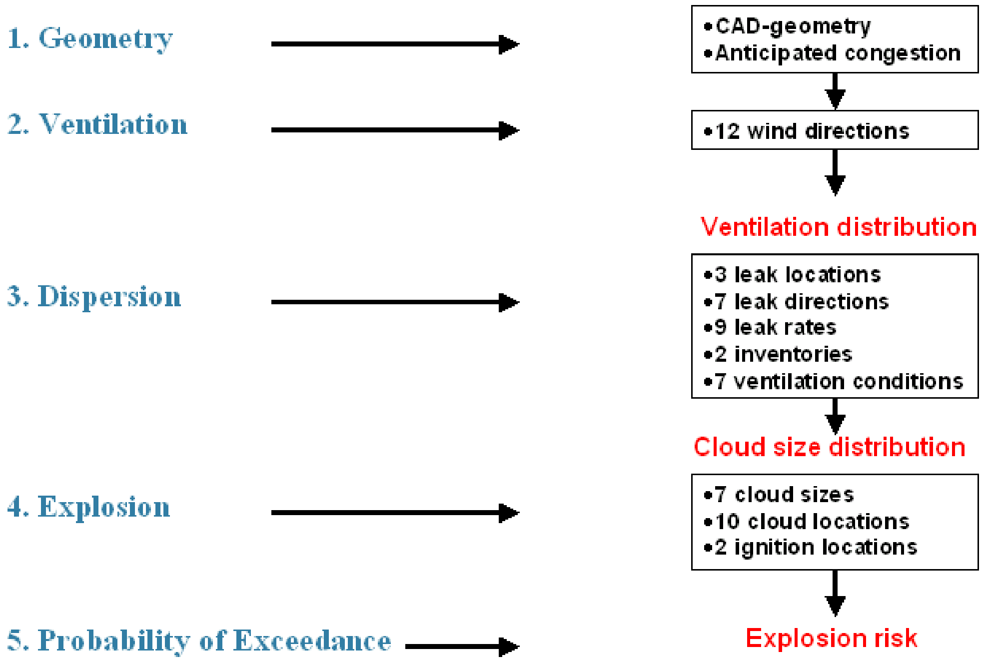

FIGURE 1 Main parts of a probabilistic explosion risk analysis

The CFD simulations performed in such an analysis are related to the ventilation, dispersion and explosion part. All of these simulations are performed with FLACS. All platform specific characteristics such as shutdown philosophy, isolation of equipment upon gas detection, blowdown, activation of deluge, etc, are implemented in the analysis.

A brief description of the main parts in the methodology is given in the sections below. A more detailed description can be found in the two previous papers[1, 2] produced by GexCon.

2.1 Ventilation

The purpose of the ventilation simulations is to calculate the internal ventilation distribution, with respect to internal flow direction and speed, for all combinations of external wind direction and -speed. When the internal ventilation distribution is established, a set of representative internal wind conditions are selected and used in the dispersion part of the analysis. A typical number of simulations to perform with FLACS are 12. Assumed that internal wind speed is scaleable with external wind speed, these 12 simulations produce the necessary data for all combinations of wind speed and direction. GexCon's experience is that this is a fair assumption, except for the cases when the wind is coming from a dead angle, as for example the same side of the platform as the Living Quarter is located.

2.2 Dispersion

The gas dispersion part of the analysis is the part with most variables to consider. The purpose with this part is to calculate an equivalent stoichiometric cloud size distribution, with associated frequencies of occurrence. This cloud size distribution is based on all combinations of variables listed in the dispersion part in FIGURE 1, and for this reason this part of the analysis is the most demanding part with respect to number of simulations to perform. Due to the fact that there is no simple relationship between changes in any of these variables and the corresponding cloud size distribution, the use of simple approaches for extrapolation of results are also very limited. A typical number of simulations to perform with FLACS, for one offshore module, may be in the range from 100 - 200. Using "Frozen cloud" and "Symmetry" approximations, the results from these FLACS simulations produce the cloud size distribution for several thousand different dispersion scenarios.

2.3 Explosion

In the explosion part of the study the explosion loads and impulses from the different cloud sizes are calculated. These loads together with the corresponding probability of occurrence give the necessary data to establish the probability of exceedance curve for explosion risk. A typical number of simulations to perform with FLACS, for one offshore module, may be in the range from 70 - 150.

2.4 Time Dependent Ignition Model

In general GexCon follows the recommendations given in the JIP report[3] from 1998 when calculating the ignition intensities to be used in the explosion risk analysis. This means that a time dependant ignition model is used. The time dependant ignition intensities are in turn coupled with the transient dispersion results from the FLACS dispersion simulations. The ignition sources are split into two main groups; continuous and discrete ignition sources.

These groups represents ignition sources such as; pumps, compressors, generators, electrical equipment, personnel and a source referred to as "other" in the JIP report[3]. The contribution to the overall ignition probability from continuous ignition sources is calculated based on the continuous ignition intensities and the additional volume of the module exposed to flammable gas for the first time. The contribution from the discrete ignition sources is calculated based on the discrete ignition intensities and total volume of flammable gas multiplied with the exposure time. This calculation is done for every second for all dispersion scenarios.

3 EXAMINED MEASURES

In the following sections a brief description of different measures and their influence on the explosion risk are described. These examples are results from recent probabilistic explosion risk analyses performed at GexCon.

3.1 Confinement

Many offshore modules, especially in the North Sea, are enclosed by a combination of louver and explosions relieve walls. The louver walls allow a certain amount of air to flow through the wall. The explosions relieve walls are normally closed, except for the situation when a gas explosion has occurred. These walls then open at a specified pressure, typically 50 mbar.

These louver and explosions relieve walls limit the amount of air to flow through the module. If these walls were removed, an increase in ventilation would be the result. This will also have an influence on the gas dispersion development. For explosions the absence of these walls is assumed to reduce the pressure build up inside the module.

3.1.1 Description of module

In the analysis referring to here, a comparison was made, between the explosion risk with and without these kinds of walls. The module considered was a 54-meter long wellhead module, with firewalls along the long sides and plated decks at the bottom and top of the module. The ends of the module had walls consisting of louver and explosions relieve panels. In FIGURE 2, a plot of the FLACS model can be seen.

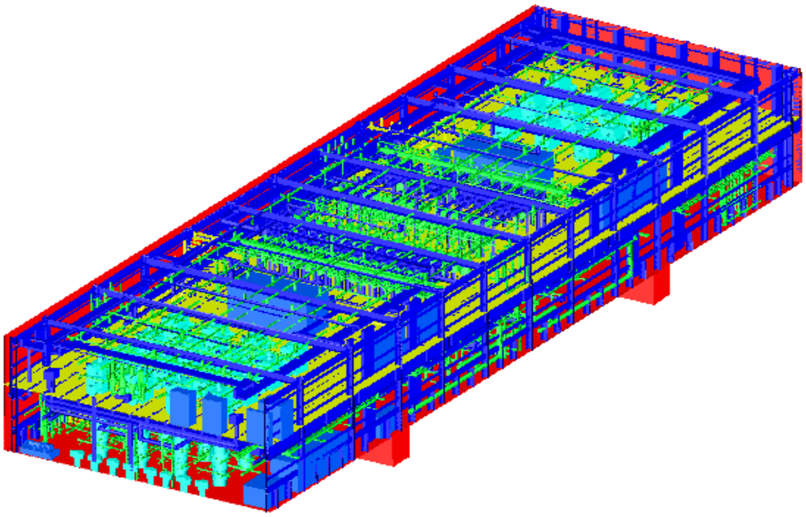

FIGURE 2 FLACS model of the module seen from southwest and above (upper deck and southern firewall is made invisible)

3.1.2 Effectiveness of removing walls

After the walls had been removed, the internal ventilation rate increased by 80% - 90%.

Based on the results from the gas dispersion simulations, a reduction of 8% - 85% was seen in the annual exposure time for the different cloud sizes in the stoichiometric cloud size distribution. The largest difference was seen for the largest clouds. This also meant that the frequencies for the different cloud sizes were reduced.

The overpressures from explosions were reduced by 7% after the walls at the end of the module were removed.

This meant that both the probability for having an explosion and the consequences related to explosions were reduced after the walls had been removed. Both these effects are represented in the probability of exceedance curve. The exceedance curve for the northern firewall is shown in FIGURE 3.

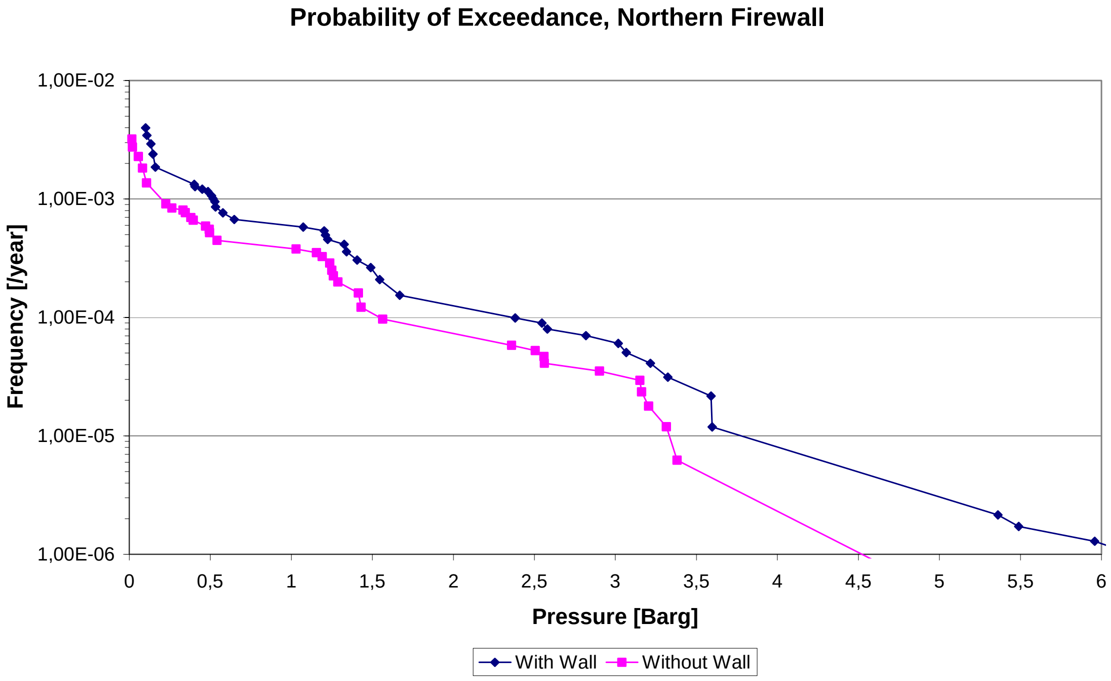

FIGURE 3 Probability of Exceedance, with and without walls at the end of the module

As the figure shows, a pressure reduction for the $1*10^{-4}$ pressure of approximately 0.8 barg is achieved when the two walls at each end of the module are removed.

3.2 Deluge

Many companies have decided to use deluge as a mitigation measure for explosions. The main reason for this is the significant effect deluge can have on explosions under certain circumstances. The overpressure can, under perfect circumstances, be reduced down to a tenth of its initial value. However, because deluge is activated upon detection, there still are some explosions that can occur before the water has been able to pass through the nozzles and before the deluge is effective inside the module. Compared to the removal of walls, deluge can only be regarded as a measure reducing consequences of gas explosions, not reducing the likelihood of these events.

3.2.1 Description of module

In the same module as described in previous chapter, also the effectiveness of deluge was investigated. This was done for both the situation when the walls at the end of the module were present and absent. In this analysis it was also taken into account that some explosions occur before the deluge is effective inside the module. I.e. combinations of “dry” and “wet” explosions are represented in the probability of exceedance curve. The water application rate for the deluge system in this module was 10 l/min/m^2 in some areas, and 20 l/min/m^2 in other areas.

3.2.2 Effectiveness of deluge, with walls

Comparing the overpressures from the explosion simulations performed with and without deluge, showed an increase in overpressures for the smallest cloud size (filling 5% of the module with stoichiometric gas) and a reduction for all other cloud sizes. The reduction was not as large as it has seen to be under other circumstances, on average less than 10% reduction in overpressure. In FIGURE 4 a plot showing the probability of exceedance curve for the northern firewall is shown.

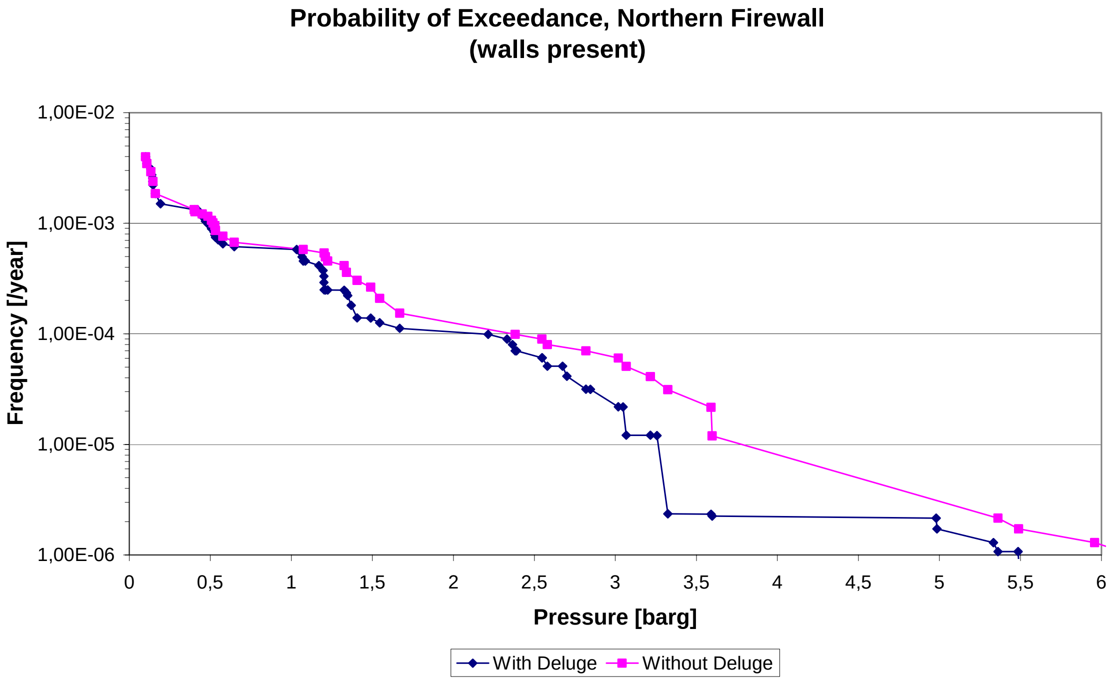

FIGURE 4 Probability of Exceedance, with and without deluge (walls present)

The reason for the low effectiveness of deluge is assumed to be a consequence of the high level of confinement in the module and for this reason also a reduced water droplet break up capability.

3.2.3 Effectiveness of deluge, without walls

Reducing the module confinement, by removing walls, can increase the explosion wind inside the module and hence allow an even better break up of the water droplets from the deluge system. The results from the explosion simulations without the walls at the end of the module showed an even better mitigation effect compared to the situation when the walls were present. An average decrease in overpressure of approximately 30% was achieved. In FIGURE 5 a plot with the probability of exceedance curve for the northern firewall is presented, for the case when the walls at the end are removed.

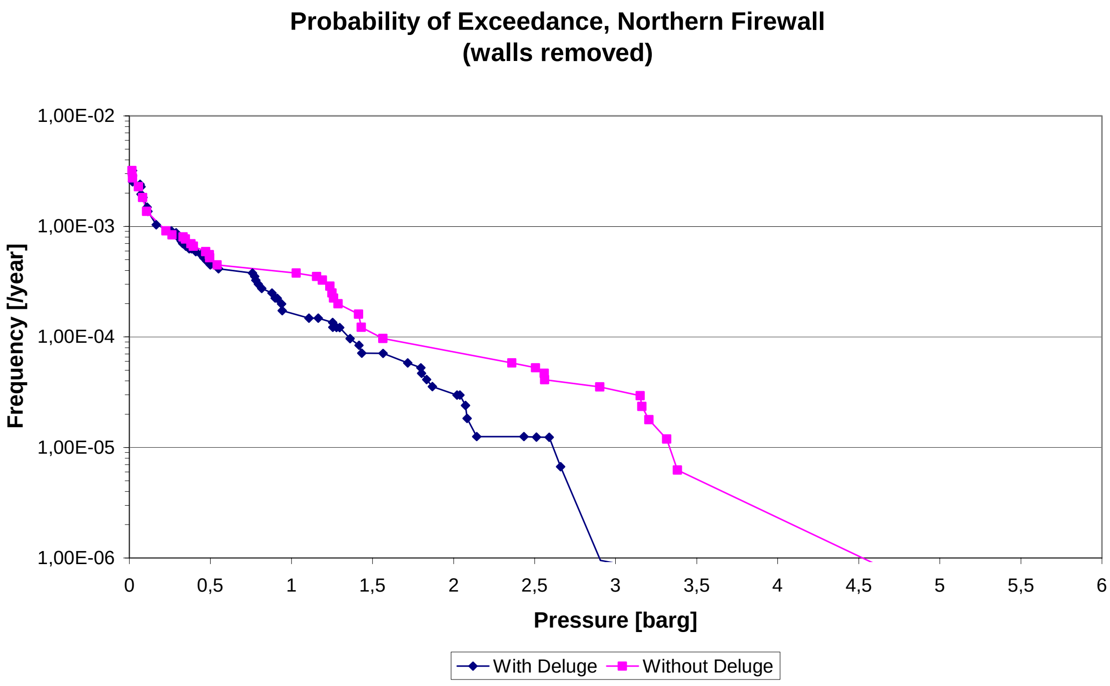

FIGURE 5 Probability of Exceedance, with and without deluge (walls removed)

A final comparison of the boundary situations was also made: Between the situation where the walls are present and deluge is not used as a mitigation measure, and the situation where the walls are removed and deluge is activated upon the detection. This comparison is visualised in FIGURE 6, and clearly shows that the combination of these two measures has a significant effect.

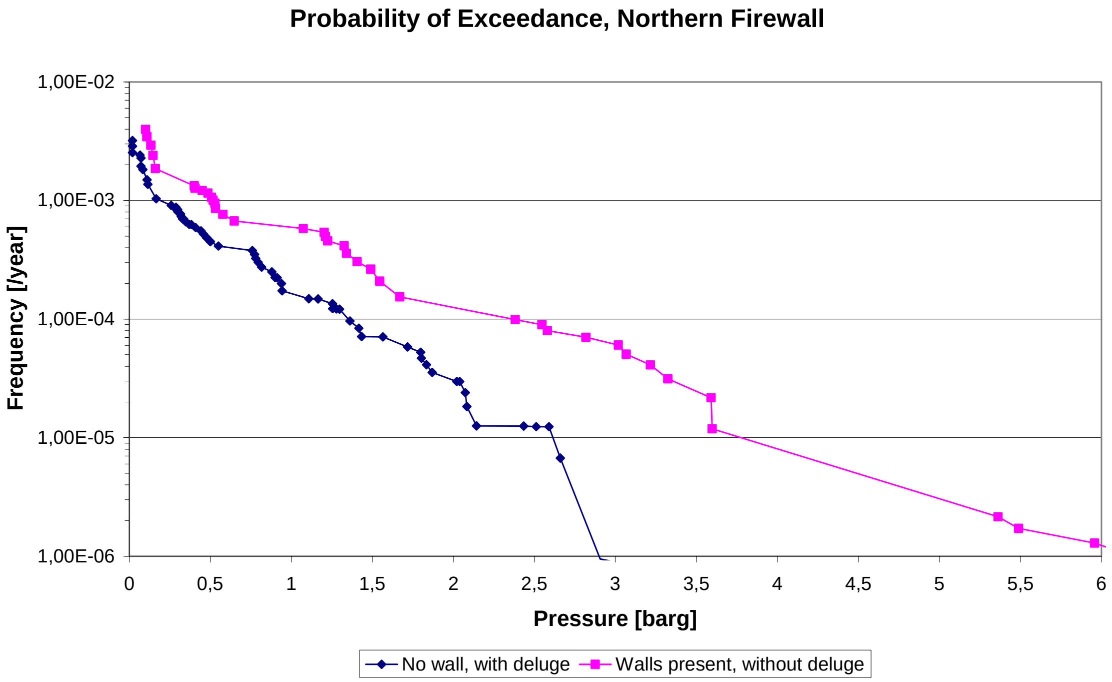

FIGURE 6 Probability of Exceedance, “no wall and deluge” vs. “wall and no deluge”

3.3 Module size

The effect, on the explosion risk, of dividing one large process area into three smaller areas by introducing additional blast walls has been evaluated for a specific geometry. The effect on the explosion risk was quantified using the GexCon probabilistic gas explosion risk analysis methodology. It is not straight forward to do a quantitative estimate of the effect on the explosion risk, as the introduction of additional blast walls will have both positive and negative effects on both the ventilation conditions, the gas dispersion conditions and the explosion conditions. Possible effects area qualitatively described in Table 1.

Ventilation	Dispersion	Explosion
+ No positive effects on ventilation are expected. ÷ General ventilation in the process area is expected to be reduced significantly. This reduces the dilution dispersed gas.	+ The new walls split the process area into 3 smaller areas. This reduces the maximum theoretical gas cloud possible to get within the area. ÷ More gas could get accumulated in any of the three “sub-areas” as the new walls will not let the gas escape as efficiently as in the base case.	+ Smaller areas give a shorter maximum flame travel distance. This will reduce turbulence generation and hence the overpressures. ÷ Confinement is increased, this will increase the overpressure compared to an equal gas cloud in the base case geometry. ÷ As more walls are introduced, it is more likely that ignition will occur close to a wall. This is likely to increase the overpressure.

TABLE 1 Possible effects of introducing additional blast walls

3.3.1 Description of module

A schematic figure of the geometry is shown in Figure 7.

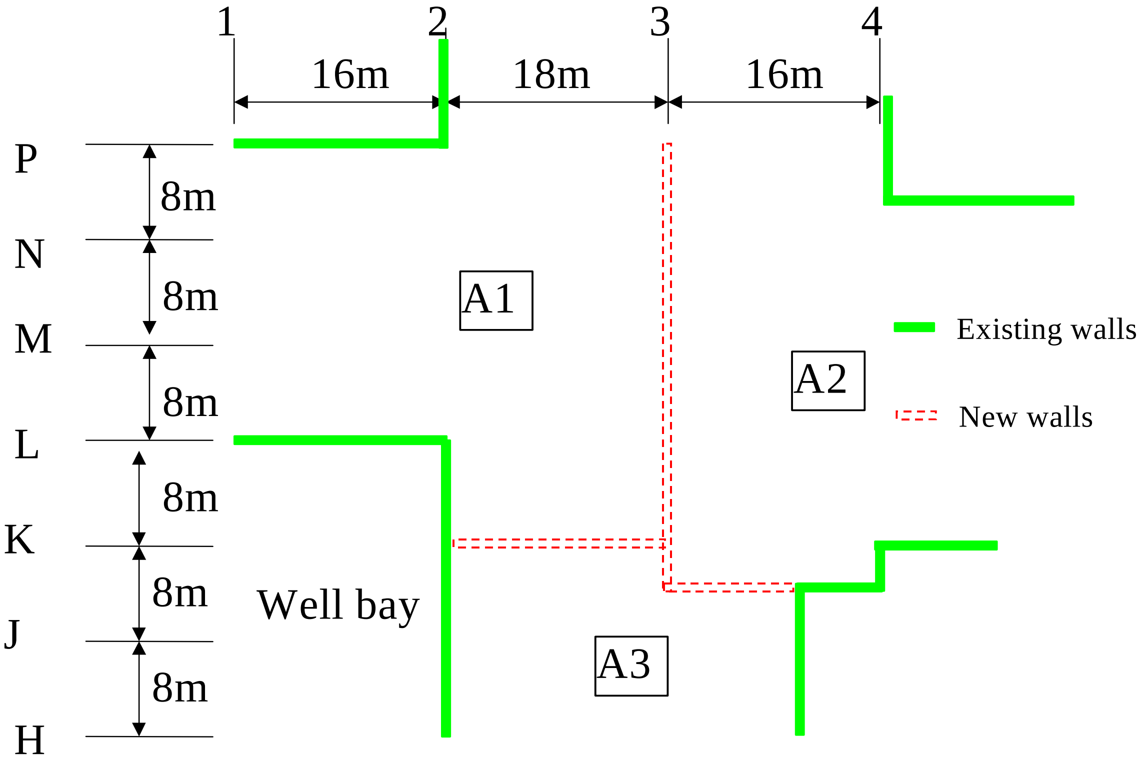

FIGURE 7 Schematic figure of the geometry

As can be seen from Figure 7 the the additional blast walls divided the process area into three smaller areas; A1, A2 and A3. The analysis was limited to area A1 only.

3.3.2 Effect of dividing process area

Based on the results from the ventilation simulations the ventilation of area A1 is better than in the base case for some wind directions, and worse for other wind directions. In general the additional blastwalls increased the availability of the highest ventilation rates, but reduced the availability of the lowest ventilation rates.

The "worst" dispersion simulation in area A1 caused a gas cloud equivalent to (with respect to size and reactivity) a stoichiometric gas cloud of about 3900 m3. The "worst" dispersion simulation in the base case geometry caused a gas cloud equivalent to (with respect to size and reactivity) a stoichiometric gas cloud of about 4800 m3. Total open volume of area A1 is about 15500 m3, and total open volume of the entire process area is about 20700 m3. This means that the largest equivalent stoichiometric gas clouds from the dispersion simulations in area A1 fills about 25% of this area, and the largest equivalent stoichiometric gas clouds from the dispersion simulations in the base case geometry fills about 23% of this area (entire process area). From the results it is clear that, at least for area A1, the additional blastwalls does not reduce the relative cloud sizes compared to the simulations in the base case geometry.

The explosion simulations showed that the pressure, from gas clouds containing about the same amount of gas, is significantly higher in A1 than in the Base Case geometry.

Based on the results from the ventilation, dispersion and explosion simulations a probability of exceedance curve was produced for area A1. Since the sensitivity study was limited to looking at the effect for area A1 only, the overall effect would have to be estimated based on the results from the A1 simulations. The project assumed that the effect for areas A2 and A3 would be similar as for area A1. About 1/3 of the leak frequency was associated with equipment located in area A1. Based on these two assumptions the overall effect on the explosion risk was expected to be about 2.5 times higher than the A1 results indicated. The A1 exceedance curve was then compared to the exceedance curve from the Base Case simulations as shown in Figure 8. The third curve in Figure 8 illustrates the project's estimate of the effect on the overall explosion risk based on the new layout.

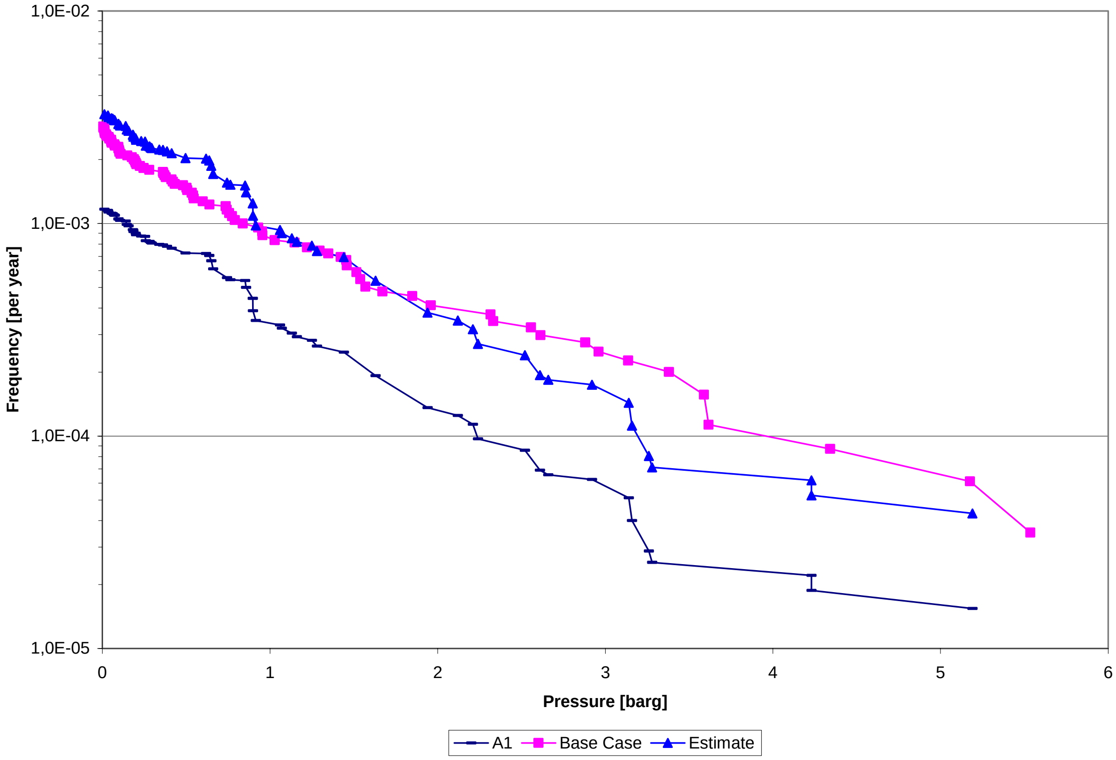

FIGURE 8 A1, Base Case and estimated total exceedance curve for the cellar deck

3.4 Isolation of ignition sources and ESD

Isolation of ignition sources together with shutdown and segmentation of process systems are both important risk reduction measures implemented on most offshore facilities operating today. This section of the paper will illustrate how the risk reduction effect of these measures are quantified in the GexCon methodology for performing gas explosion risk analysis. This will be done by looking at a study recently performed for a process module on a platform located in the North Sea.

3.4.1 Description of module

For the particular module looked at in this study, the following ignition intensities were calculated based on the procedure recommended in the JIP report[3]:

Discrete		Adjustment Factors for Ignition Source Categories						# items or sq. meter		Adjust	DISCRETE
	Gas		Age	Maintenance	Manning	Technology	Overall		Module		Total
Pump	1.20E-07							Pump	0	0.612	0.00E+00
Compressor	2.70E-06							Compressor	0	0.612	0.00E+00
Generator	6.20E-06	Rotating machinery	0.9	0.85	1	0.8	0.612	Generator	0	0.612	0.00E+00
Electrical eq. *	3.40E-08	Electrical eq.	0.9	0.9	1	0.6	0.486	Electrical eq. *	2148	0.486	3.55E-05
Other *	8.40E-09	Other	0.9	0.9	1	0.8	0.648	Other *	2148	0.648	1.17E-05
Personnel *	2.80E-08	Personnel	1	0.95	0.6	1	0.57	Personnel *	2148	0.57	3.43E-05
* per m2 exposed to gas										**SUM**	**8.15E-05**

Continous		Adjustment Factors for Ignition Source Categories						# items or sq. meter		Adjust	Continous
	Gas		Age	Maintenance	Manning	Technology	Overall		Module		Total
Hot work (# hours pr. 365*24h)	4.57E-02							Hot work		0.100	4.57E-03
Pump	6.40E-05							Pump	0	0.612	0.00E+00
Compressor	1.50E-03							Compressor	0	0.612	0.00E+00
Generator	3.50E-03	Rotating machinery	0.9	0.85	1	0.8	0.612	Generator	0	0.612	0.00E+00
Electrical eq. *	3.30E-06	Electrical eq.	0.9	0.9	1	0.6	0.486	Electrical eq. *	2148	0.486	3.44E-03
Other *	1.40E-05	Other	0.9	0.9	1	0.8	0.648	Other *	2148	0.648	1.95E-02
Personnel *	5.50E-06	Personnel	1	0.95	0.6	1	0.57	Personnel *	2148	0.57	6.73E-03
* per m2 exposed to gas										**SUM**	**3.42E-02**

FIGURE 9 Discrete and continuous ignition intensities calculated for the example study

For a platform with no automatic actions upon gas detection (or no gas detection system at all), the ignition intensities would be constant until manual intervention takes place. For a platform with automatic actions upon gas detection, for example disconnection of electrical equipment when 20% LEL is detected, the ignition intensities would be reduced. These two different cases will be further described in the following two sub-sections. Finally the resulting exceedance curves for the two cases are compared.

In the example study manual intervention was defined as manual (remotely from the CCR) disconnection of potential ignition sources, and manual activation of the platform ESD system. It was assumed that the disconnection of ignition sources would be initiated 5 minutes after detection of gas in the module. ESD was assumed to be effective 5 minutes after the leak had started. The resulting exceedance curve is shown in Figure 12.

For the particular module looked at in this study, several automatic actions would take place upon detection of 20% LEL and 60% LEL. A delay time of 20 seconds after detection of the different LEL levels was also defined before automatic actions related to ignition sources would be completed. ESD was assumed to be effective 60 seconds after a gas leak had occurred. Both these assumptions were taken from the existing QRA for the platform. Based on these criteria the reduction factors for the different ignition intensities were defined as shown in Figures 10 and 11. In these two figures it is important to notice that the x-values (time) used are for illustration only. These values will in reality be unique for each dispersion scenario.

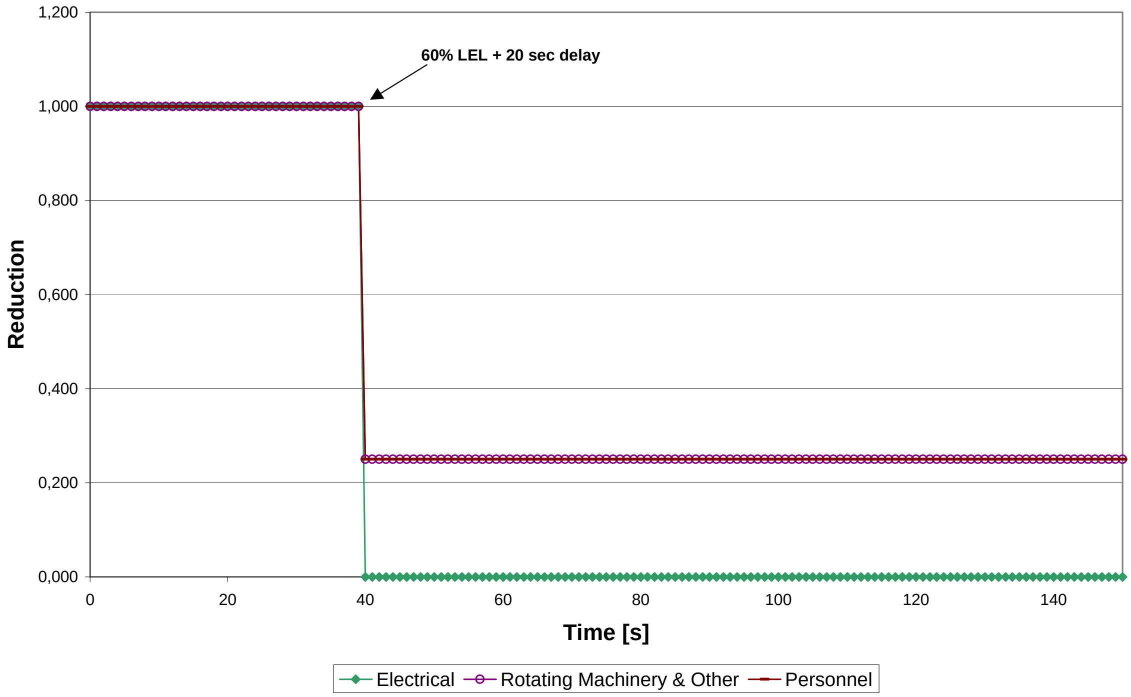

FIGURE 10 Reduction factors for the discrete ignition intensities

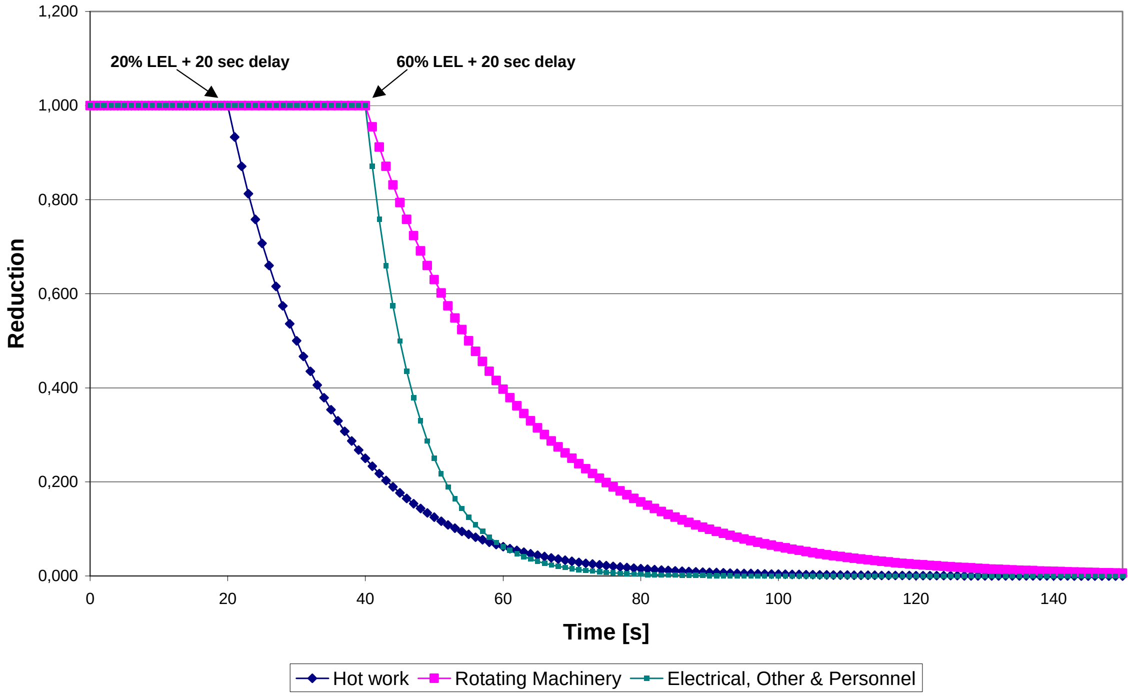

FIGURE 11 Reduction factors for the continuous ignition intensities

3.4.2 Effect of isolation and ESD

Figure 12 shows the resulting exceedance curves for the two different cases.

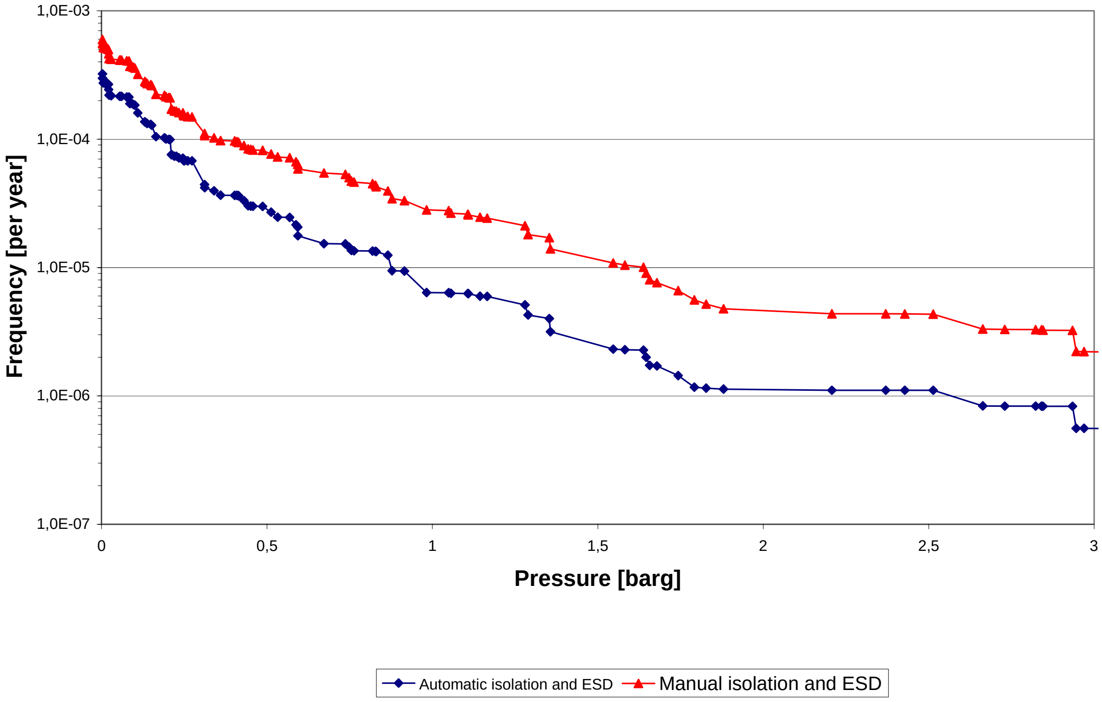

FIGURE 12 Exceedance curves for manual and automatic intervention upon gas detection

As figure 12 shows, automatic actions upon gas detection gave a significant explosion risk reduction in the current study. If the delay time before manual intervention takes place is more than the assumed 5 minutes, the difference between the two cases would increase.

4 CONCLUSIONS AND RECOMMENDATIONS

The examples presented in this paper shows that the explosion risk methodology used by GexCon can be a useful tool to quantify the effects of risk reduction measures. This is important when it comes to selecting the most cost effective risk reducing measure to be implemented. It is also important when designing risk reduction measures and systems like explosion panels, deluge systems, blastwalls and shutdown systems. The methodology makes it possible to quantify the effect from different design options for these systems, and hence makes it possible to optimise the systems for the specific module.

It is important to note that the results shown for the different examples in this paper cannot be directly applied to other installations.

5 REFERENCES

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