EXPLOSION RISK ASSESSMENT USING FLACS

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AUTHOR BIOGRAPHICAL NOTES

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ABSTRACT

Explosion assessment has in the past often been based on generating information on consequences of identified worst case scenarios. Recent full-scale explosion tests, as well as the application of Computational Fluid Dynamics (CFD) tools for explosion modelling, have demonstrated that worst case design is unrealistic.

A probabilistic explosion assessment takes into account the probability for establishing gas clouds. Due to limitations in computer speed and capacity, this has previously been done by

- Simulating a very high number of scenarios using simple models, or
- Performing a low number of CFD simulations and extrapolating the results

Neither of these approaches is considered satisfactory. Even if these studies are performed in a responsible way, very conservative estimates for the risk as well as wrong trends with regard to sensitivity studies can be expected.

At GexCon and CMR work has been carried out in order to improve the probabilistic methodology. A minimum of 75-100 CFD-simulations using FLACS are performed in the base case study (15 ventilation / 30 dispersion / 30 explosion), in order to establish a reasonable explosion risk. A highest possible accuracy/consistency is the aim, where required input to the study is wind data, exact geometry, leak and ignition frequencies. A study would consist of:

=> CFD-ventilation simulations to establish a ventilation rate distribution
=> CFD-dispersion simulations to establish gas cloud size distribution
=> CFD-explosion study to establish probability of exceedance curves
=> Structural assessment (not described in the present paper)

A major advantage with the methodology is the reduction of conservatism compared to current practise.

The objective of this paper is to present the proposed methodology, giving anonymized examples from case studies.

1.0 INTRODUCTION

Throughout the later years there has been many different ways to quantify the risk from gas explosions, where the overall aim is to identify the “correct” risk level. Because of uncertainties in methodologies, models, data sources, etc., it has also been common practice to add an amount of conservatism in order not to underestimate the risk.

The result from the recent full-scale experiments revealed that very high explosion loads could be expected in congested offshore modules. This meant that the geometry of modules or installations that were supposed to be used in explosion risk analyses would have to be reproduced with a fine degree of detail. When this was done, the explosion loads from the simulated worst case scenarios also became very high. Designing offshore installations to withstand the estimated loads from current worst case scenarios became very expensive, unrealistic and often impossible.

The main idea behind the methodology described in this paper is to bring more accurate CFD-calculations into Quantitative Risk Analysis (QRA) in a consistent way and to obtain a reduction of conservatism compared to current practise.

Another important issue is that advanced QRA-methods might get very complicated. This in addition to commercial confidentiality concerns may push them into being “black box” methods. The input and the outcome are available, but intermediate results and dependencies are less visible. In order to evaluate the performance of a method for quality assurance, and also to facilitate the search for the most cost effective risk reduction measures, full insight into the intermediate results could be of great importance. One of the strengths with the proposed methodology is full transparency of intermediate results and considerations. Thus users get a better understanding. Because also “critical voices” can more easily see problems with this approach than for “black box” methods, this is believed to accelerate the development into an even better methodology.

2.0 DESCRIPTION OF THE PROPOSED QRA-METHOD

In November 1998 GexCon was invited to perform an explosion risk analysis on a future offshore platform with one wellhead and one process module. A major problem with the planned offshore assembling of the platform was the weight of the modules. This meant that if it was possible to obtain lower design loads and lower weight by being less conservative, this was preferable. To achieve this, GexCon proposed to perform a significantly more thorough explosion risk analysis compared to current practice. It is the methodology performed in this project that is described in this chapter. Although the analysis was performed for the wellhead and process area, only the results from the wellhead area is presented.

2.1 Geometry

The detailed representation of the geometry is one of the most important issues that have to be established before simulations can be performed. Because all equipment present will influence the explosion development, and to some extent also the dispersion, even minor details should be included if the information is available. The particular areas where gas and explosion analyses are carried out must be modelled with high accuracy. In adjacent areas influencing the ventilation minor equipment can be ignored if necessary. In early design stages, where no accurate descriptions of the geometry exist, particular techniques are applied estimating the final expected object distribution. Inserting the "anticipated" congestion where equipment density is otherwise expected to be too low does this. Experiences from several offshore projects using such early design techniques are convincing.

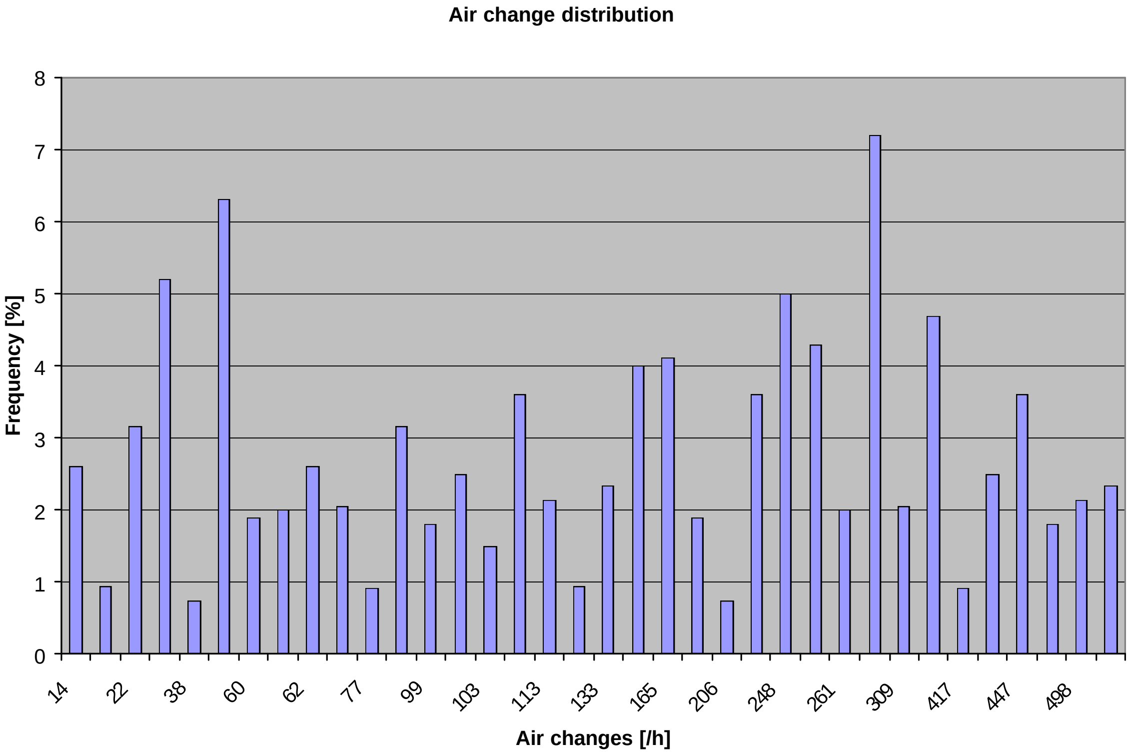
Because the platform in this project was in the early design phase, the geometry of the platform was represented both by existing geometry information converted from Computer Aided Design (CAD) geometry and by inserting "anticipated" congestion where equipment density otherwise was expected to be too low. This was done in a consistent manner and in close co-operation with the design team.

2.2 Ventilation

The objective with the ventilation simulations was to identify a few representative wind conditions that could be used in the dispersion simulations.

After initial hazard identification, to decide from where gas could be assumed to migrate into the area considered, a ventilation study was carried out. Ventilation simulations with an average wind speed from 12 different sectors were carried out. For the areas studied, an air change rate per unit wind speed was found for each of the 12 wind sectors. Using the conversion factors from wind speed to air change rates, the wind direction/speed probability tables were converted into a probability distribution for air changes, see FIGURE 1.

FIGURE 1 Air change distribution from the ventilation simulations



The air changes were then sorted into 3 different categories with their respective frequencies in such a way that a low ventilation (with a frequency of 27.68%), medium ventilation (with a frequency of 52.11%) and strong ventilation regime (with a frequency of 20.21%), was established. These 3 ventilation conditions were used in the dispersion simulations.

In order to represent the 3 ventilation conditions in such a way that their estimated air changes was reproduced, one wind direction and speed was chosen for each of them. In the selection of such, combinations with a high external wind direction frequency, typical internal ventilation patterns and wind from different directions was preferred.

2.3 Dispersion

The main objective with the dispersion simulations was to produce a basis for a representative cloud size distribution for the different module areas. These representative cloud sizes would be used in the explosion simulations.

From a dispersion simulation the gas clouds reactivity is one important factor that was decided to use. From a typical dispersion simulation the total amount of gas (Total), the amount of flammable gas (LFL:UFL) and the equivalent amount of stoichiometric gas (Er.fac) is given for a predefined area, which in this case was the entire wellhead module. The example given in FIGURE 2 gives a stoichiometric gas cloud of 150 kg.

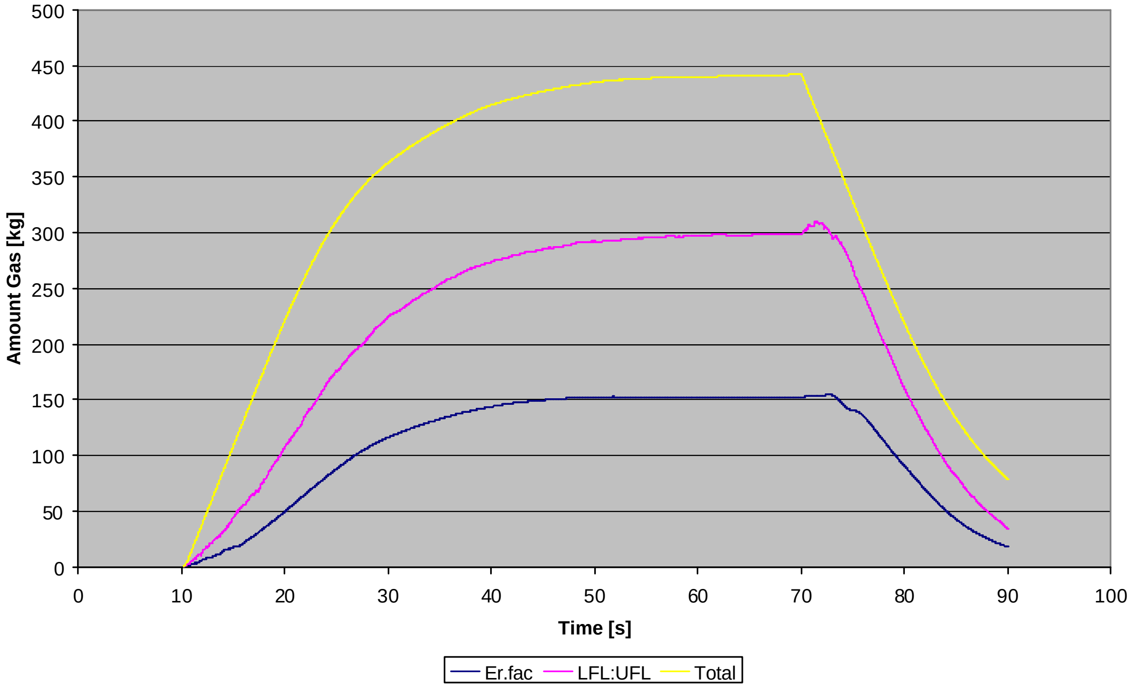


FIGURE 2 Amount of gas inside a predefined area, during a dispersion simulation

For the leak and dispersion study the number of parameters to vary were significantly higher compared to the ventilation study (leak locations, - rates, - directions and different wind conditions). Because it was unrealistic to simulate all possible combinations of these variables with CFD, a selection of what to simulate with CFD had to be made.

It is often hard to tell exactly where a leak will take place. Since a choice was already made with regard to wind conditions (wind directions are not properly distributed, ventilation rates are), it was decided to stick to one fixed centrally placed leak location. It was thus implicitly assumed that getting a good estimate for the gas cloud size and composition was more important than the exact gas cloud location. Instead of using only 3 leak rates, which has been common practice, it was assumed that at least 5 leak rates would be necessary to get a proper representation of the possible cloud size distribution. A leak can have an infinite number of leak directions, which all of them were assumed could give very different dispersion results. Because of this it was decided to include 6 perpendicular directions (west, east, north, south, up and down).

With 5 leak rates, 3 wind conditions and 6 leak directions (west, east, north, south, up and down), TABLE 1 illustrates the scenarios for the leak location in the wellhead module (90 scenarios). It was assumed sufficient to simulate 25 of the 90 scenarios with FLACS. These are in TABLE 1 written in the shaded cells, and are located in the area from the lower left corner of the table to the higher right corner. These leak scenarios were most likely to generate large stoichiometric gas clouds. Release scenarios above the area were assumed to give gas clouds with low gas mixture due to high ventilation and low releases. Gas releases below the area were assumed to give very rich gas clouds due to low ventilation and large releases. The equivalent stoichiometric cloud sizes from the simulations listed in TABLE 1 are given in kg.

Leak rate >	**0.7 kg/s**		**3.4 kg/s**		**10.3 kg/s**		**31.3 kg/s**		**324.9 kg/s**	
	Dir.	Size	Dir.	Size	Dir.	Size	Dir.	Size	Dir.	Size
	(-X)	20	(-X)	20	(-X)	30	(-X)	38	(-X)	58
High ventilation	(+X)	20	(+X)	20	(+X)	39	(+X)	39	(+X)	97
428.7 ACH	(+Y)	20	(+Y)	20	(-Y)	31	(-Y)	131	(-Y)	160
Frequency	(-Y)	20	(-Y)	20	(+Y)	20	(+Y)	20	(+Y)	39
20.21%	(+Z)	20	(+Z)	20	(+Z)	39	(+Z)	39	(+Z)	97
	(-Z)	20	(-Z)	20	(-Z)	39	(-Z)	39	(-Z)	97
	(-X)	20	(-X)	15	(-X)	60	(-X)	70	(-X)	39
Medium ventilation	(+X)	20	(+X)	20	(+X)	97	(+X)	97	(+X)	39
185.5 ACH	(+Y)	20	(+Y)	9	(+Y)	140	(+Y)	123	(+Y)	31
Frequency	(-Y)	20	(-Y)	20	(-Y)	97	(-Y)	97	(-Y)	39
52.11%	(+Z)	20	(+Z)	20	(+Z)	77	(+Z)	97	(+Z)	39
	(-Z)	20	(-Z)	20	(-Z)	44	(-Z)	97	(-Z)	39
	(-X)	0.4	(-X)	210	(-X)	100	(-X)	50	(-X)	97
Low ventilation	(+X)	20	(+X)	212	(+X)	97	(+X)	97	(+X)	97
41.5 ACH	(+Y)	20	(+Y)	50	(+Y)	150	(+Y)	115	(+Y)	150
Frequency	(-Y)	20	(-Y)	97	(-Y)	97	(-Y)	97	(-Y)	97
27.68%	(+Z)	20	(+Z)	130	(+Z)	97	(+Z)	97	(+Z)	97
	(-Z)	20	(-Z)	155	(-Z)	97	(-Z)	97	(-Z)	97

TABLE 1 Stoichiometric gas cloud sizes (kg) from the different scenarios in the wellhead module

Based on the results from the 25 dispersion simulations a stoichiometric cloud size distribution was established, ranging from the smallest to the largest cloud size. This cloud size distribution was split into 5 different gas cloud categories depending on the amount of gas near stoichiometric mixture (Er.fac). The cloud size distribution is presented in TABLE 2. Note that the largest stoichiometric gas cloud size only fills 55% of the wellhead module.

The 65 of the 90 dispersion scenarios not simulated were estimated based on the results from the scenarios that had been simulated and conservative assumptions based on previous experience with dispersion simulations. Their equivalent stoichiometric gas cloud sizes are in TABLE 1 written in blue text and normal style. The estimated amounts of stoichiometric gas for these scenarios were taken from the final cloud size distribution in TABLE 2. The largest cloud size in each cloud size interval in TABLE 2 was the value represented in TABLE 1.

Cloud Size (% of module)	0 – 5	5 – 10	10 – 25	25 – 40	40 – 55
Cloud Size in kg	0-20	20-39	39-97	97-155	155-212
Ignition Frequency	$1.2*10^{-4}$	$1.1*10^{-5}$	$3.3*10^{-5}$	$1.8*10^{-5}$	$8.1*10^{-6}$

TABLE 2 Stoichiometric cloud size distribution, wellhead module

Finally the ignition frequencies for each of the 5 different cloud sizes was calculated. In lack of a time dependent ignition model, this was done by multiplying the ignition frequency for a flammable gas cloud filling the entire module, with the volume of flammable gas from the largest gas cloud in each cloud size category compared to the volume of the module. This meant that if the ignition frequency for a flammable gas cloud filling the entire module was 1, and the amount of flammable gas from the largest gas cloud was filling half of the module, the ignition frequency for the gas clouds represented in this category would be 0.5. The calculated frequencies are presented in TABLE 2.

2.4 Explosion

The objective with the explosion simulations was to produce the explosion loads that were to be used as input when the “probability of exceedance” curves should be calculated.

For the explosion risk assessment, simulations with the stoichometric cloud sizes given in TABLE 2 were carried out. 4 explosion simulations were carried out for each of the 5 stoichiometric gas cloud sizes, making a total of 20 explosion simulations. For all simulations pressure was monitored on smaller sub-panels of all solid decks and walls in the module.

Because only 3 different wind directions were included in the dispersion simulations, it was acknowledged that the locations of the gas clouds could be different if it had been used more or other wind directions. For this reason each gas cloud size was tried to be located conservatively in the 4 corners of the wellhead module, with an assumed worst case ignition location. The frequency for each gas cloud location was given by the frequency for a wind from the opposite direction, e.g. gas clouds located in north-east were represented by the frequency for wind from south-west, etc.

The results from the explosion simulations were presented as cumulative pressure exceedance curves for each solid wall and deck in the wellhead module. In addition one exceedance curve for the entire wellhead module was calculated, see FIGURE 3. The curve noted “Wall” in FIGURE 3 represents the specific wall or deck monitoring the highest overpressure from each of the 20 gas clouds. The curve noted “Panel” gives the same information for the smaller sub-panels of all solid decks and walls in the module, hence this is an exceedance curve represented by the local overpressures.

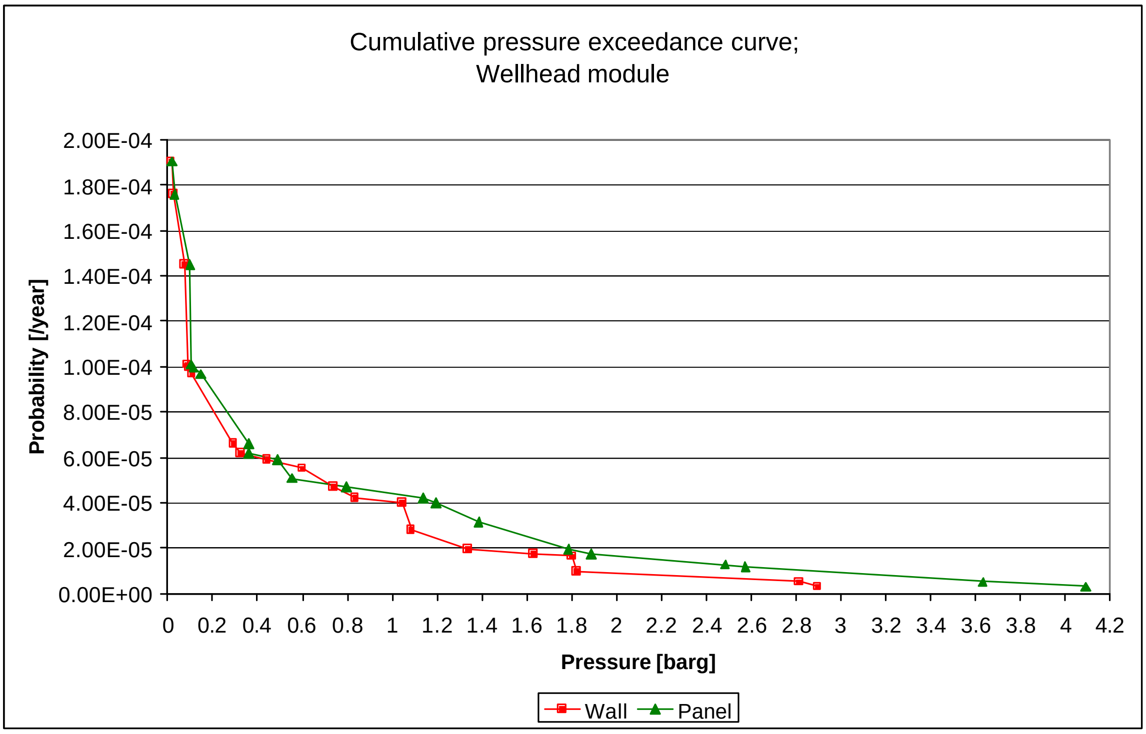


FIGURE 3 Cumulative pressure exceedance curve for the Wellhead module

3.0 LESSONS LEARNT

3.1 Validation of FLACS

The core area of FLACS is vapour cloud explosion calculations, and this is also the best validated application of the simulator. Ventilation and dispersion have received less attention, but various studies have been and are being performed.

The first part of the QRA-study is the ventilation assessment. On a few occasions, offshore ventilation measurements have been performed and results compared to FLACS simulations, both by CMR and independently by external FLACS users. These studies generally showed that the deviation between measurements and FLACS was on average low, typically of the order of 10% despite variations in external wind and uncertainty doing the measurements. Also wind tunnel experiments with a small-scale version of the platform were available in one case, these results also corresponded well with the simulations. Significantly larger differences were seen when comparing with general purpose CFD-tools not taking geometry details sufficiently into account. Here the ventilation rate was overpredicted.

For dispersion studies geometry details are even more important, and FLACS should benefit from the geometry handling, compared to other CFD-tool. To generate validation data for FLACS with regard to dispersion in highly congested geometries, 18 experiments were carried out at CMR a year ago (Hansen 1998). Methane leaks of different size (rate decaying from 0.16 kg/s or 0.5 kg/s), different momentum (sonic or low momentum), and at different locations were leaking into the CMR 50 m^3 congested module, which was exposed to wind fields of 0, 0.5 or 1.0 m/s. Gas concentrations were monitored at 10 different locations during the dispersion. From low momentum leak scenarios, a much lower mixing is seen and the concentration gradients got stronger. This is often seen in congested geometries. Studying the different scenarios, FLACS generally reproduced the gas concentrations with reasonable accuracy, even between ‘identical’ experiments a certain variation was seen.

From the studies mentioned, it is concluded that both dispersion and ventilation in congested geometries are modelled with good accuracy. Simpler dispersion models will often neither account for leak locations nor momentum of leak (rate is given). The experiments performed showed very significant changes in gas dispersion changing one of these parameters.

3.2 The methodology

Using the methodology, a range of non-optimal choices will have to be made, since it is not possible to simulate an infinite number of scenarios. It is believed that most of the choices made in the analysis presented in this paper were reasonable. A couple of modifications to the methodology are suggested in the sections below.

3.2.1 Ventilation

The ventilation study gives a good picture of the ventilation conditions, giving an air change rate distribution. Instead of only splitting the distribution into 3 ventilation conditions, adding a fourth ventilation condition could be preferable. This condition would represent the days with very low ventilation rates, hence the ventilation conditions would consist of a LowLow, Low, Medium and High ventilation condition.

3.2.2 Dispersion

For the dispersion studies again a limited number of scenarios will be selected. If the leak probability distribution is close to uniform, one or a few leak locations is assumed to be acceptable. Resent studies performed at GexCon indicate that it is more conservative to have one centrally placed leak location compared to having several locations, although this must be verified by more studies.

Choosing at least 5 different leak sizes in several directions gives a much better picture of the possible gas cloud sizes than a lower number of leak rates. Since some of the leaks are assumed to loose momentum, also including a low momentum leak would be preferable. The fraction of low momentum leaks will have to be assumed.

One critical step in the procedure is taking a gas cloud distribution into equivalent exploding gas clouds. It has been shown that the methods used will generally give pressures of similar strength for the equivalent quiescent gas clouds as for the non-homogeneous clouds subject to initial turbulence. However, the duration of the equivalent gas cloud explosions may be shorter than for the non-homogeneous ones, giving a different structural impact. This has yet to be studied in detail.

3.2.3 Explosion

Including a time dependent ignition model is one of the most important proposed changes to the methodology presented in this paper. A time dependent ignition model is assumed to reduce the amount of conservatism even further and also give important information to the operator regarding how the gas detection and shut down philosophy should be set up.

4.0 CONCLUSIONS AND RECCOMMENDATIONS

The methodology presented in this paper is assumed to reduce conservatism and hence the recommended design loads. Another major advantage is the visualization of all risk contributors through the entire analysis. Because the information from the study presented in this paper also can be used in wind chill and gas detector studies, these can easily be performed in the same analysis without making the amount of work significantly larger.

The Quantitative Explosion Risk Assessment concept presented is still under development, and will probably have weaknesses compared to other QRA-tools used in explosion studies. But due to vastly better modelling of physical mechanisms, the concept also has significant strengths. It will not be difficult to point at inconsistencies in major QRA-tools handling dispersion/explosion safety. It is believed that faster computers and better understanding and modelling of the physics will lead QRA-methodology in the direction presented in this paper.