Hazards31

Addressing the unique challenges of hydrogen gas detection in 3D Fire & Gas Mapping

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Presentation Agenda

- Introduction
- Presentation Objective
- Hydrogen vs Hydrocarbon
- Risk Based Assessment Methodology
- General Data and Assumptions
- Case Study
- Results and Discussions
- Conclusions and Recommendations

Introduction

- The positioning Flammable Gas Detectors plays a key role in protecting facilities against escalation events from explosions. The ultimate function of the FGD is to detect this particular gas before it reaches a defined target gas cloud volume. The efficiency of this system depends on the’ position and the layout density.
- The two major approaches being currently practiced are the performance-based gas detection mapping methodologies: Geographic approach and Risk-based mapping.
- The risk-based approach uses historical leak frequencies and consequence analysis, and ignition probability models to quantify the risk from escalation scenarios.

Introduction

- Although significant progress`has been made in gas detectors layout design and optimization, the focus has majorly been on process installations with hydrocarbon services.
- This presentation focuses on the newly emerging hydrogen industries, where currently, there is no existing definitive industrial standards to guide the design engineers on gas detectors layout for installations handling mostly hydrogen.

Presentation Objective

- This presentation will summarise the challenges of hydrogen gas detection in 3D Fire & Gas Mapping when compared to conventional hydrocarbon gas detection.
- Propose means to determine the detection criteria for facilities handling hydrogen gases using risk-based methodology.
- Important factors differentiating hydrocarbon releases and hydrogen releases such as ignition probability, frequency analysis, target gas cloud, and flammable gas dispersion properties will be detailed.

Hydrogen vs Hydrocarbon

- Huge demand to decarbonise heavy industries including the oil and gas sectors.

- Hydrogen is flammable and explosive over a very wide range of concentrations: (4%–75%) in air and (15%–59%) at a standard atmospheric temperature.

- It is odourless, colourless, very buoyant and very diffusive and can potentially accumulate at high points.

BLACK HYDROGEN: Black coal gasification – High CO_2 emissions

BROWN HYDROGEN: Brown coal gasification - High CO_2 emissions

GREY HYDROGEN: produced from fossil fuels (i.e. from methane using steam methane reforming (SMR) – less CO2 emissions

PURPLE/ PINK HYDROGEN: From nuclear power – no CO_2 emissions but not renewable source

YELLOW HYDROGEN: Mixed origin (e.g. electricity from grid) – definition varies

BLUE HYDROGEN: Grey hydrogen with carbon capture and storage [CCS]. CCS capture efficiencies expected to reach 85-95%. CH4 emissions from supply system

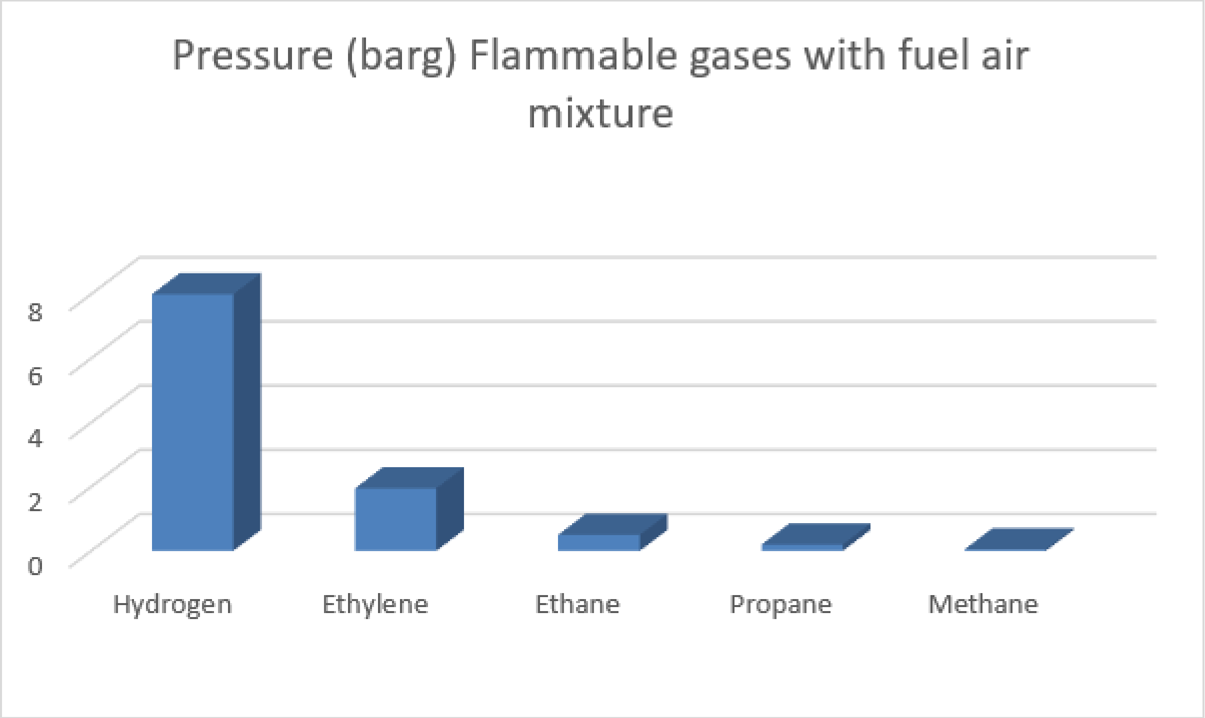
TURQUOISE HYDROGEN: Uses natural gas as feedstock but using pyrolysis to produce carbon black as a by-product

GREEN HYDROGEN: Hydrogen produced from renewable energy through electrolysis

Hydrogen vs Hydrocarbon

- Hydrogen is more easily ignited and therefore has a higher ignition probability in the event if there is a release.
- The minimum ignition energy is 0.02mJ, when compared to 0.3mJ for methane.
- In the presence of congestion, a higher overpressure is expected from a hydrogen cloud, when compared to an equivalent volume of hydrocarbon. This is due to the higher laminar burning velocity.
- The frequency of leaks can be impacted by hydrogen inventory, with concern on material selection, and the impact of hydrogen embrittlement

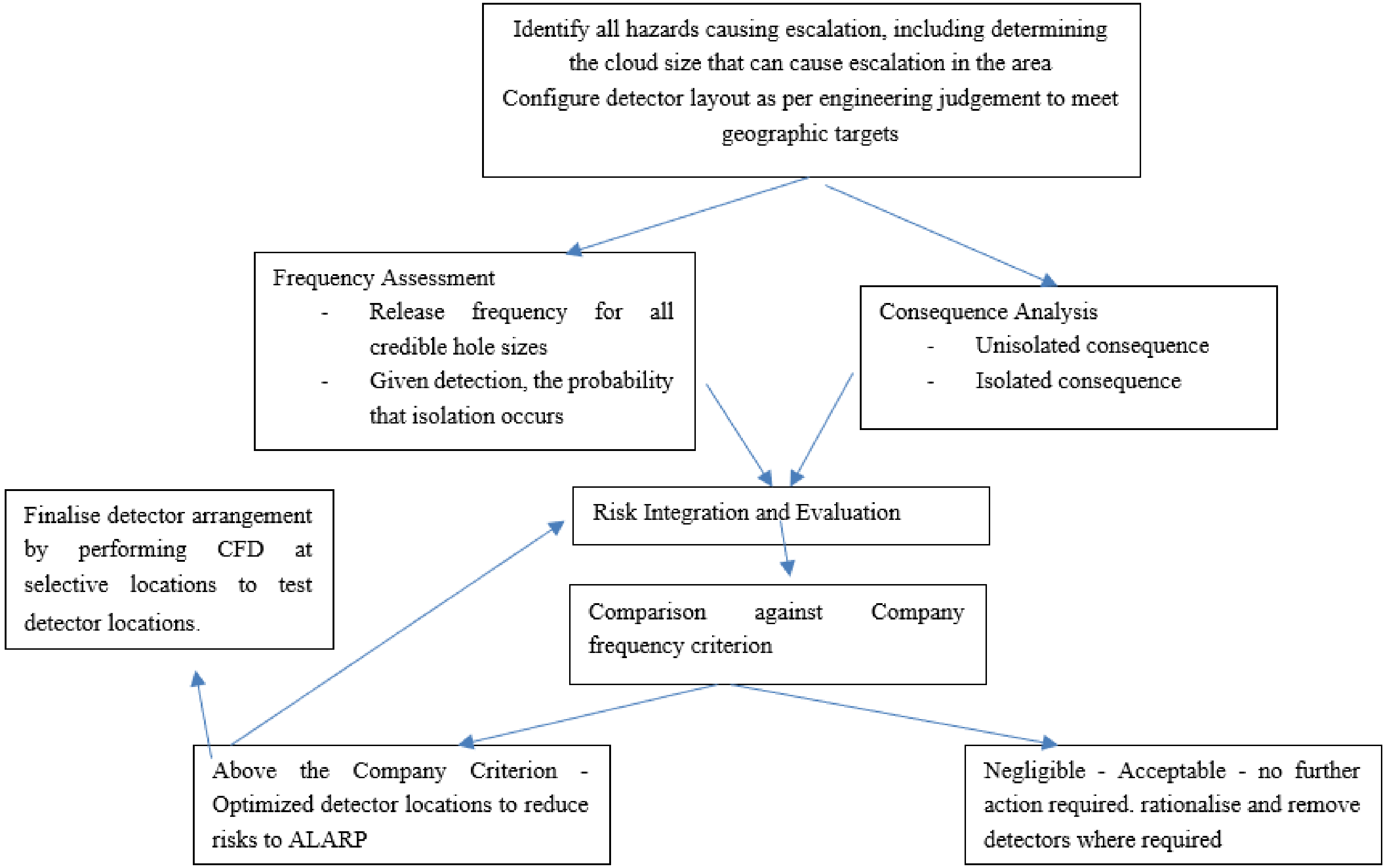
Comparison of explosion pressure for various stoichiometric fuel-air



Risk Based Assessment Methodology

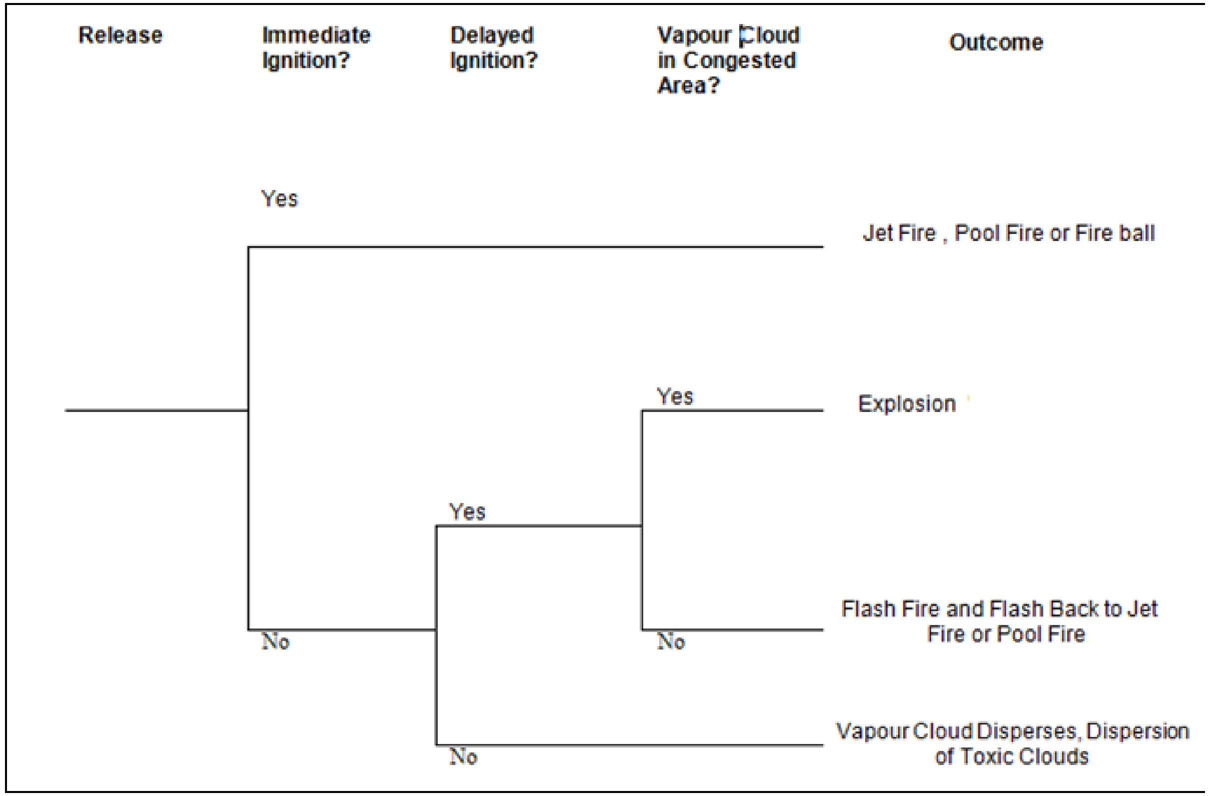
- For the case study, only flammable gas hazards which can escalate to secondary events were considered, although the same principles could be applied to fire detection.

Figure 3 Risk Based Gas Detector Mapping Methodology



Risk Based Assessment Methodology

- Event tree highlights the potential consequences of hydrocarbon releases.
- Probabilities are assigned to each branch in the event tree. The frequency of each outcome event is then determined by multiplying the initiating event frequency by the probabilities along that branch of the event tree.
- Risks relative to the locations of equipment and fire and gas detection, results are provided over the facility plot plans.



Risk Based Assessment Methodology

1. Perform Unmitigated Risk Assessment

- Establish the average frequency of overpressure scenario within the escalation sensitive area
- Areas where the risk exceeds 1E-4 events / year require that the gas detection is optimised.

2. Perform Mitigated Risk Assessment

- The frequency of the hazard scenario - with consideration of the benefit of a gas detection system
- The frequency of the escalation scenario while **considering isolation** was included in plotting the risk contour.

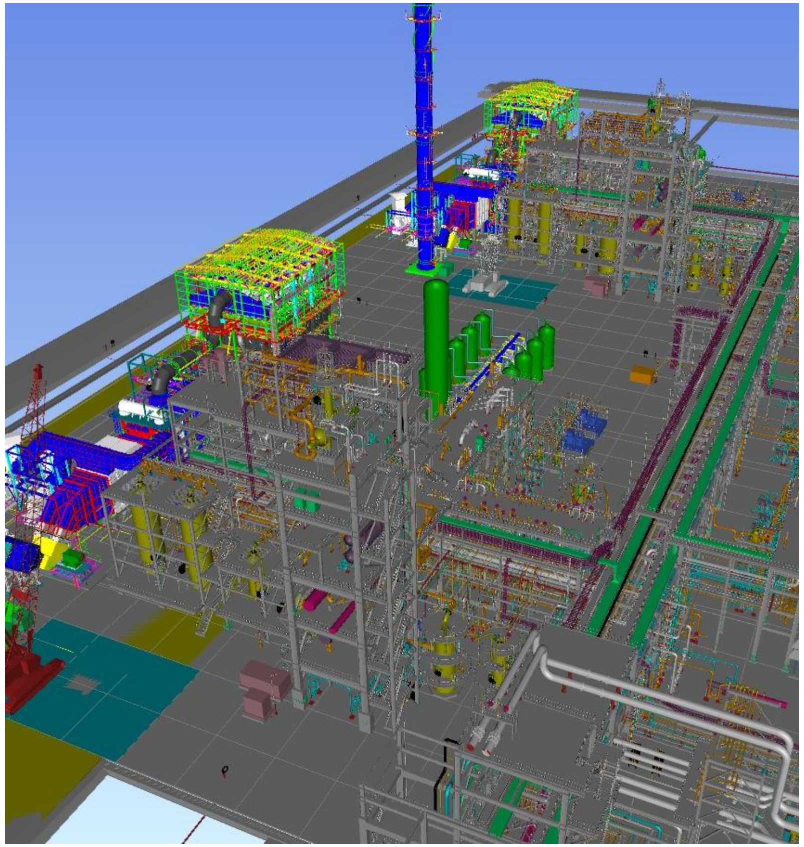
Risk Based Assessment Methodology

3. Perform Optimised Mitigated Risk Assessment

- Following review of the unmitigated and mitigated risk assessment detector locations were optimised to the provided coverage and help mitigate those risks to acceptable levels.

The frequencies and consequences results were combined using the in-house risk integration software, **MES 3D F&G Mapping tool AMNIS and QRA tool MERIT** to generate risk contours.

Case Study: Process Description



3D Model Overview of the Hydrogen process

- The case study consists of a hydrogen plant with a start-up system, which consisted of a start-up interchanger and an electrical heater.
- The equipment was used for catalyst reduction of the pre-reformer and was used with nitrogen and hydrogen.

Case Study: Process Description

- The flammable gas detection requirements for the plant are described in Table 1 below.

Hazard	Type of Detector	Detection Target / Spacing Criteria	Geographic Detection Coverage Target	Voting	Set Points	Assessments
Flammable Gas	Point IR (Hydrocarbon) Point Catalytic (Hydrogen)	Flammable Gas Scenarios Leading to Explosions Hazards as per CFD Analysis	80% 1ooN	1ooN	20% and 50% LFL	Flammable Gas Assessment

Assumptions

The objective of the gas detection system was to provide early warning to personnel of potential LOC events that could cause escalation.

Gas detection systems were provided to perform three main functions:

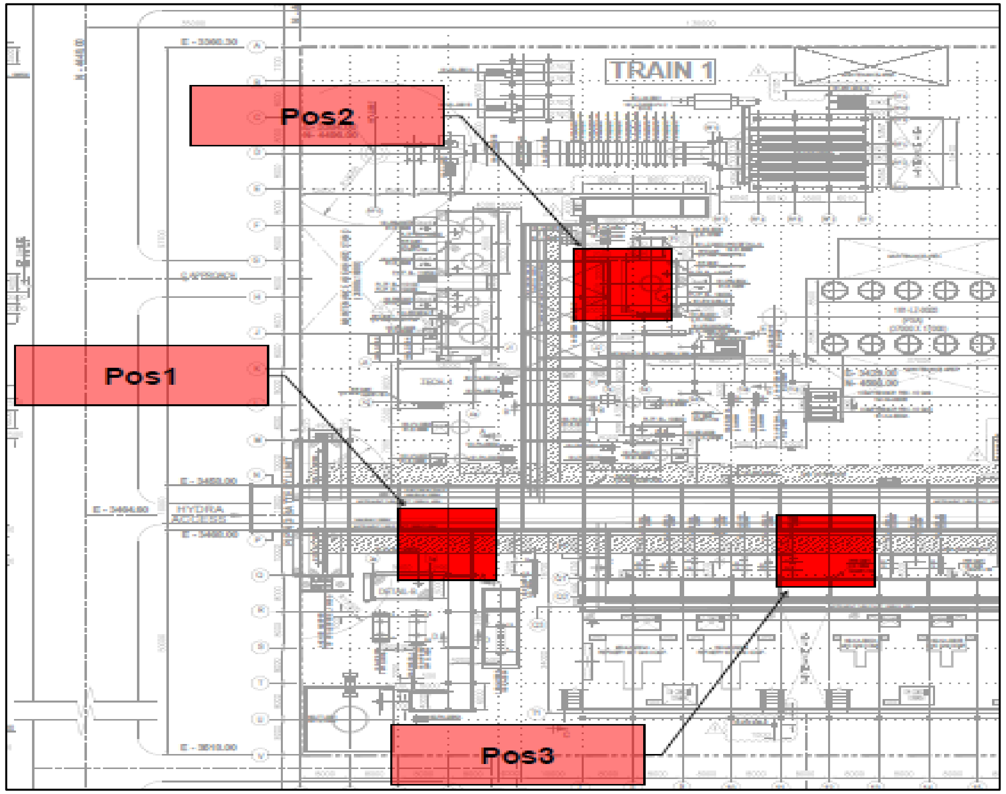
- Detect – monitor for potentially hazardous releases / accumulation of explosive gases;
- Alarm – initiate alerts to response personnel allowing appropriate action to be taken; and
- Protect – drive actions that effectively reduce escalation and/or minimise loss.

Gas detection systems in this study was configured to ensure that detection probability was within acceptable bounds.

Target Gas Cloud Determination

- As per OTO (1993) report, and typical industry practice, overpressures above 150mbar were considered to be capable of causing escalation. The aim was to detect only clouds that are capable of causing escalation i.e. smaller gas clouds were not targeted.
- As per the CFD modelling, based on the congestion of the area and three representative locations a hydrogen gas cloud with a radius of 6.3 m could cause escalation.
- Very small leaks which are likely to have a higher frequency of release (low risk of escalation – removed from model) are discounted from the risk assessment.

Representative Cloud Position to Determine Overpressure



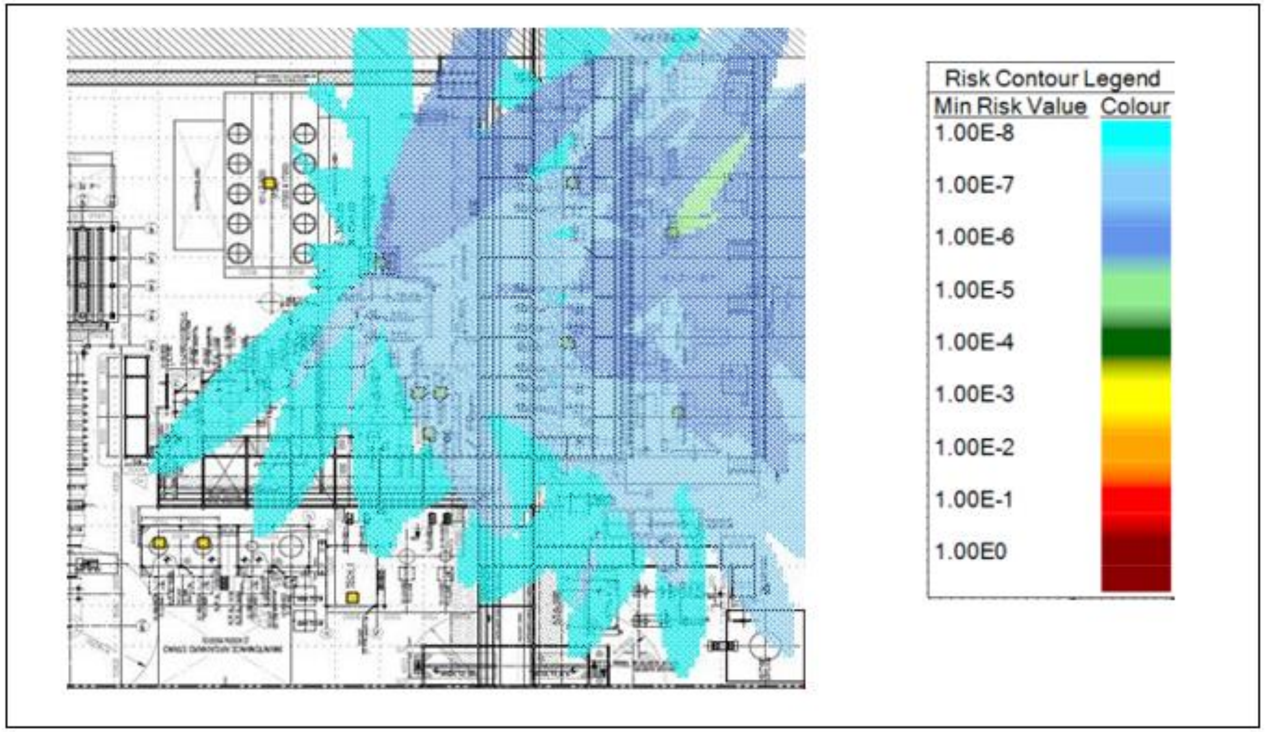
Target Gas Cloud Comparison

- Equivalent gas size volume for hydrocarbon releases are much larger than hydrogen releases
- Gas detection requirements for hydrogen streams are typically more onerous.
- Target cloud size is highly dependent on the congestion in the area.

Cloud Position	Hydrogen Cloud		Hydrocarbon Cloud (Methane)	
	Stoichiometric Cloud Volume (m3) for 150 mbarg	Equivalent Sphere Radius (m) for 150 mbarg	Stoichiometric Cloud Volume (m3) for 150 mbarg	Equivalent Sphere Radius (m) for 150 mbarg
01	130	6	>4000	>20
02	180	7	>4000	>20
03	880	12	>4000	>20

Results and Discussions – Unmitigated Risk

- The unmitigated escalation risk contour represents the predicted frequency of explosions from clouds capable of causing escalation to the surrounding equipment in the facility.
- Using the quantitative risk assessment methodology, leak frequencies and consequences were integrated to generate the risk contours.
- For this case, the escalation risk did not exceed 1.0E-04 events /year. Therefore, sensitive equipment is unlikely to be impacted at above the target risk.

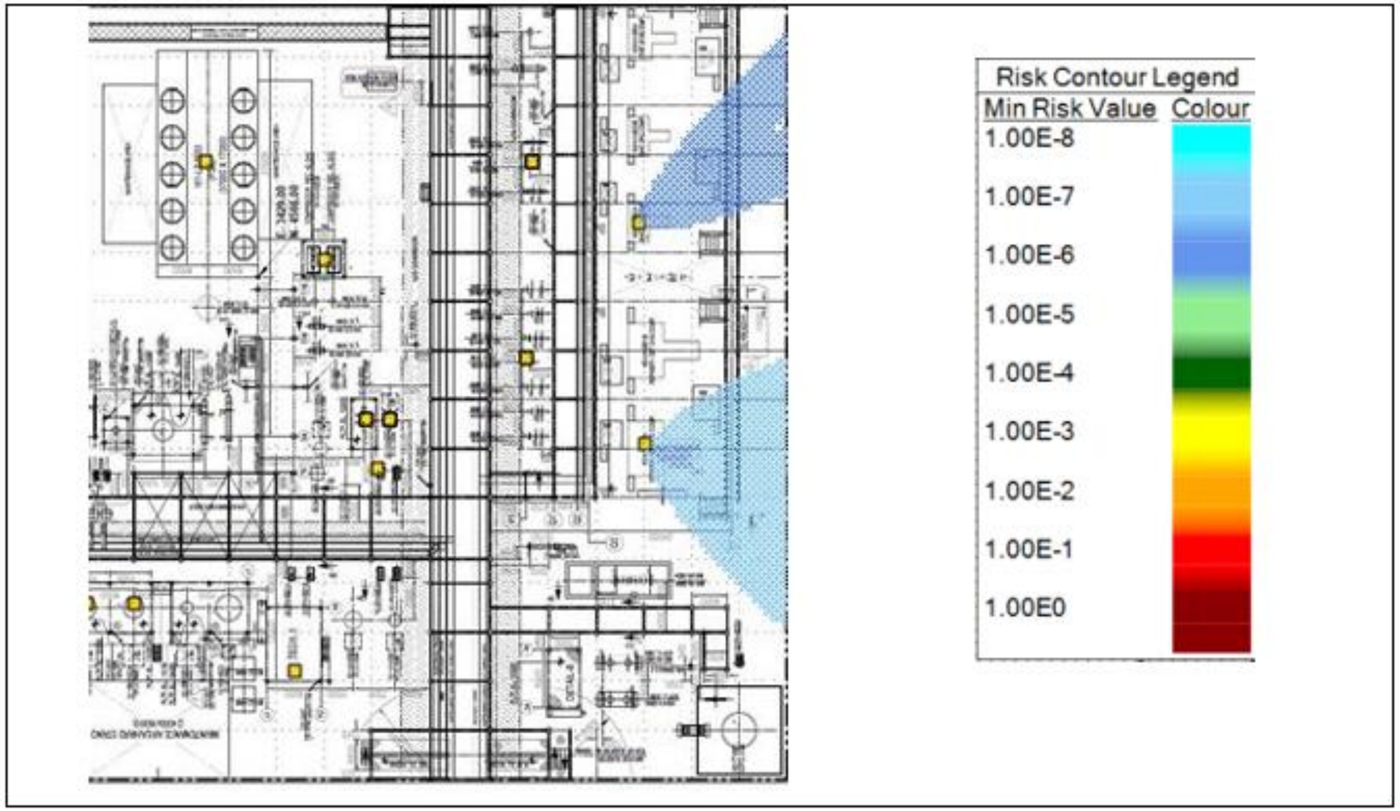


Results and Discussions(Mitigated Risk)

MES

- The mitigated risk contour represents risk from undetected scenarios that are capable to cause escalation due to explosion.
- The risk from these scenarios was significantly less than the unmitigated contours and **highlights the effectiveness of the detector locations in terms of providing early detection of potential escalation events.**
- The are no areas above the 1E-04 events /year target. However, additional risk reduction was required to ensure detection within the compressor shelter.

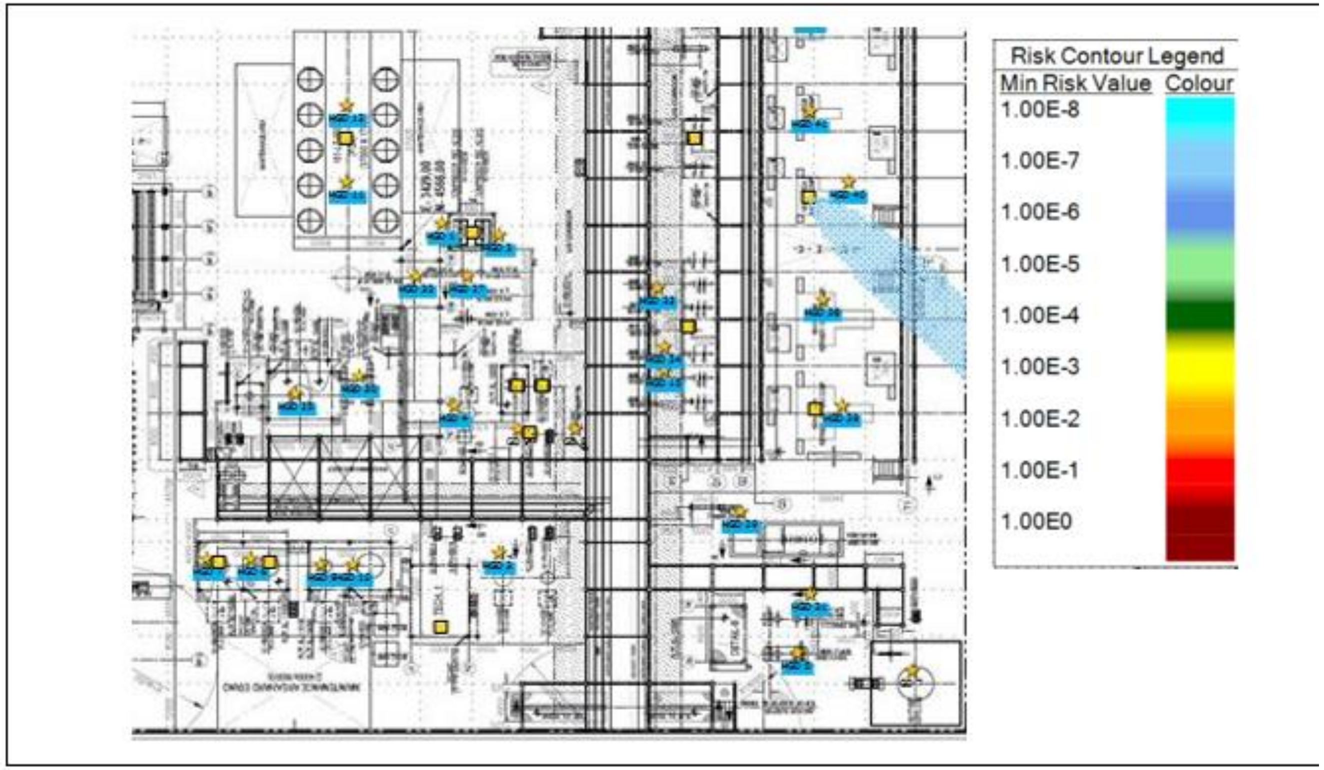
Figure 9 Flammable Gas Detection Assessment: Mitigated Risk



Results and Discussions

Optimised Design

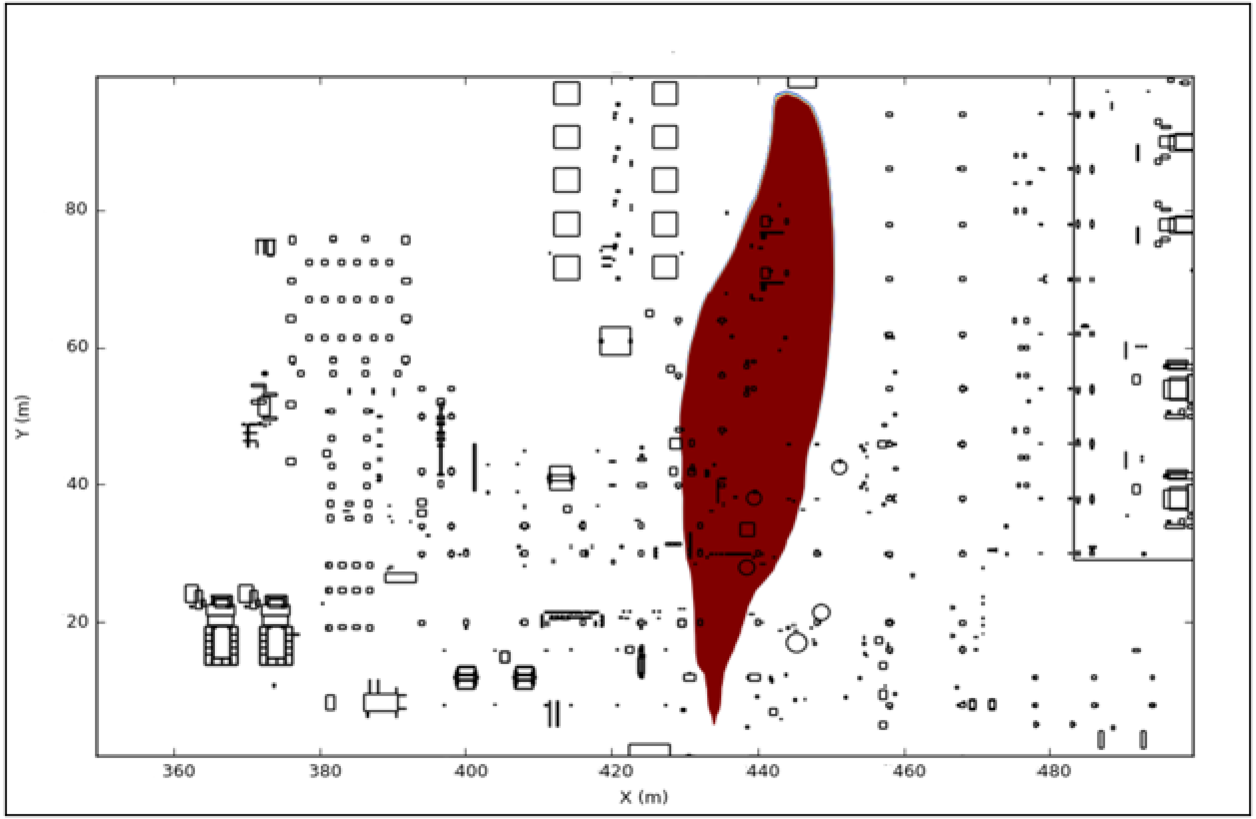
- The design was optimised based on the mitigated risk contours i.e. considering detection.
- Iterative steps were taken in placing the detectors to fully optimise the locations and minimise the risk as indicated in the Figure
- It can be seen that risks from undetected scenarios are significantly reduced below 1E-04/yr and are therefore considered ALARP.



Results and Discussions

Optimised Design

- The detection coverage achieved was 99% which is higher than the detection target of 90% with 1ooN voting.
- Selective additional CFD runs were then conducted to verify the detector locations against simulated cases (Figure 11)



Conclusion and Recommendations

- A hydrogen gas cloud with a radius of 6.3 **meters** was able to cause the escalation due to explosion. Comparing to hydrocarbon, equivalent gas size volume for hydrocarbon releases in the same area would be as large as **20 meters**.
- Hydrogen is more likely to ignite, therefore high risk when compared to hydrocarbon

There are a few recommendations can be drawn from this study.

- The dispersion analysis used to generate the risk contour was conducted using a simplistic model (2D model). Such models are not be able to cater for obstructions. However, risk modelling using only the CFD methodology is likely to take long time to obtain the same number of scenarios as with the simplistic 2D models.
- CFD for a limited number of cases is open to error as it solely based on the judgement of the engineer to pick selected cases. Therefore, considering currently existing computing capabilities, a risk contour based on the 2D modelling is considered approriate, this is also inline with current risk analysis practice when calculating individual risk to personnel.