

Performance analysis
Sour gas detection around wellhead area (WHP#1 1.0%+H2S 88.0%CH4)
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Performance analysis
 Common detector types

EVENT TREE FOR GAS RELEASE

Gas Release	Immediate Ignition	Vapor Cloud Forms & Ignites	Liquid Rainout & Ignition	Explosion Occurs	Toxic Chemical	Outcome
UGLD	Yes (MSIR UVIR)	Yes				Jet Fire
	No	Yes (MSIR UVIR)		Yes		Vapor Cloud Explosion
ULTRASONIC GAS DETECTION	Yes (MSIR UVIR)	Yes		No		Flash Fire
		No	Yes (MSIR UVIR)			Pool Fire
	No	Yes (OPGD PGD)		Yes		Toxic Exposure
		No	Yes (OPGD PGD)		No	

Risk escalation, time

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Performance analysis
 The importance of early detection

Early detection and mitigation help limit growth of gas clouds with dangerous concentrations, hence reduce the consequences of gas releases.

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Performance analysis
 Detection coverage is the most significant influence on FGS effectiveness

Hazard scenario	Detection coverage	FGS availability	Mitigation eff.	Likelihood	Additional remarks
1	0.50	0.9998	0.99	0.495	$F_{unmitigated} = 1.0E-04$ per year
	0.50	0.0002	0.01	0.005	Detection coverage = 0.50
				0.500	$PF_{D1} = 1.0E-04$ $PF_{D2} = 1.0E-05$ $PF_{D3} = 1.0E-04$ FGS unavailability = 0.0002 FGS availability = 0.9998

FGS effectiveness = Detection coverage X FGS availability X Mitigation effectiveness = 0.495

Unmitigated risk = $F_{unmitigated} \times (1 - \text{FGS effectiveness}) = 5.1E-05$ per year

$RRF = 1 / (1 - \text{FGS effectiveness}) = 2.0$ times

Mitigation effectiveness = 0.99

Ref.: TR84.00.07-2018

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Performance analysis
 Risk reduction with FGS

Increasing individual risks and societal concerns

- Unacceptable region: Initial RR (Risk without FGS)
- After initial FGS implementation: RR improvement (Basic detection coverage)
- After gas mapping*: RR improvement (Improvement of detection coverage, Optimization of detector quantities, Quantification of detection coverage and residual risk)
- With utilization of better gas detection technology: Final RR (Higher detection and alarming probabilities, Greater certainty of instrument functional and safety integrity)
- Negligible risk

* Gas mapping result is highly dependent on the assumptions made for release and site conditions.

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Performance analysis
 Achieving an effective FGS while minimizing costs is an engineering challenge

CAPEX: Detector Quantity, System Hardware, Cabling & Installation

OPEX: Periodic Maintenance, Calibration Gas, Sensor & Hardware Replacements

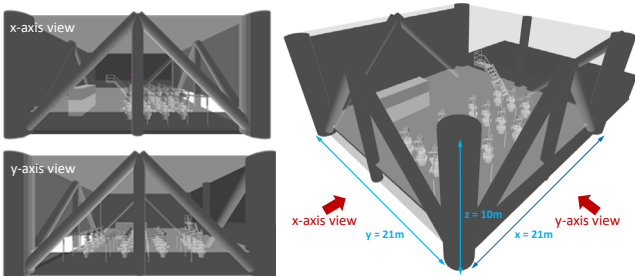
EFFECTIVE FGS: HIGH DETECTION PROBABILITY (Detection Coverage, Measurement Sensitivity, Environmental Influence), HIGH FUNCTIONAL & SAFETY INTEGRITY (Sensor Technology, Transmitter Hardware Design, Diagnostic Coverage, Autonomous Self-Checks & Adjustments)


COST OF OWNERSHIP: IDEALLY (up arrow), EFFECTIVE FGS: IDEALLY (down arrow)

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Performance analysis

Case study model





1. Performance targets

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Performance analysis

Zone grading to set performance targets



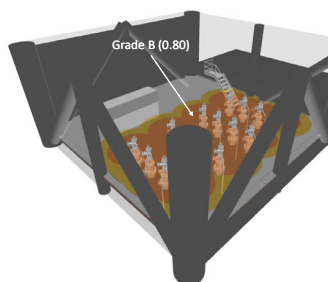
Zone	Scenario ID	Likelihood adjustments				Likelihood factor	Consequence adjustments				Graded Hazards		
		Base score	Occupancy	Ignition environment	Entry or immediate ignition		Base score	Potential pressure	Flammable environment	H2S toxicity	Hazards ranking	Grade	
1	Wellhead gas release	1.0	-1.0	-0.5	-2.0	-2.0	3.0	1.5	0.0	0.0	4.5	2.5	B
						-0.5					4.5	4.0	B
					0.0						4.5	4.5	B

The derived performance target for both flammable gas detection and toxic gas detection is ≥80%.

Grade	Ranking	Recommended fire detection coverage	Ranking	Recommended flammable gas detection coverage	Ranking	Recommended toxic gas detection coverage
*	≥7.0	0.9 (Additional risk analysis required)	≥7.0	0.9 (Additional risk analysis required)	≥7.5	0.9 (Additional risk analysis required)
A	5.0 to <7.0	0.9 (based on a 10kW/m ² incipient stage fire)	5.0 to <7.0	0.9 (for detecting a 5m diameter spherical gas cloud)	5.5 to <7.5	0.9 (for detecting small releases of life threatening toxic gas hazards)
B	2.0 to <5.0	0.8 (based on a 50kW/m ² incipient stage fire)	2.0 to <5.0	0.8 (for detecting a 5m diameter spherical gas cloud)	3.5 to <5.5	0.8 (for detecting small releases of injury level toxic gas hazards)
C	0.5 to <2.0	0.6 (based on a 100kW/m ² incipient stage fire)	0.5 to <2.0	0.6 (for detecting a 10m diameter spherical gas cloud)	1.5 to <3.5	0.6 (for detecting large releases of injury level toxic gas hazards)
No FGS	<0.5	No detection is required	<0.5	No detection is required	<1.5	No detection is required

Performance analysis

Zone grading & performance targets



Typical grading definition

Grade	Definition
A	Hydrocarbon processing, with high exposure
B	Hydrocarbon processing, with moderate exposure
C	Hydrocarbon processing, with low exposure
No FGS	Risk is tolerable without benefit of FGS

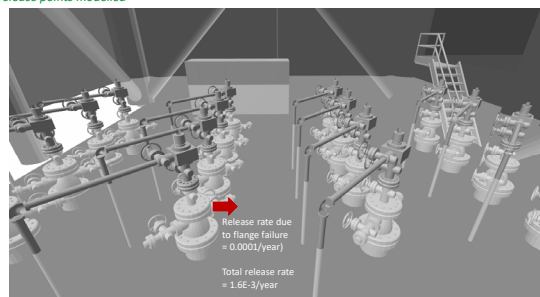
Typical FGS performance targets

Grade	Detector coverage	FGS safety availability
A	0.90	0.95
B	0.80	0.90
C	0.60	0.90

2. Consequence modelling

Performance analysis

Gas release points modelled



Performance analysis

Gas composition used in dispersion model



Components		Properties
Available Components	Selected Components	Show Mass Amount
Component	Component	Molar Amount
1,2-PROPYLENE OXIDE	METHANE	88
1,3-BUTADIENE	ETHANE	15.5
1-BUTENE	PROPANE	2.5
ACETONE	N-BUTANE	1
ACROLEIN	HYDROGEN SULFIDE	1
ACRYLAMIDE		
ACRYLONITRILE		
AIR		
AMMONIA		
BENZENE		
BENZYL CHLORIDE		
CARBON DIOXIDE		
CARBON DISULFIDE		
CARBON MONOXIDE		
CHLORINE		
DICHLOROMETHANE		
DIMETHYLAMINE		
ETHANOL		

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Performance analysis

Input parameters used in dispersion model



Group	Field	Value	Units
Material	Material	Sour gas mixture, WHP#1	
	Specify volume inventory?	No	
	Mass inventory	500	kg
	Volume inventory	12.2689	m3
	Material to track	1. Hydrogen Sulfide 2. Methane	
Phase	Specified condition	Pressure/temperature	
	Temperature	35	degC
	Pressure (gauge)	50	bar
	Fluid state	Vapor	
	Liquid mole fraction	0	fraction

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Discharge Results (after atmospheric expansion)



Path	Scenario	Weather	Mass flow rate (kg/s)	Temperature (degC)	Liquid mass fraction in material (fraction)	Droplet diameter (µm)	Expanded diameter (m)	Velocity (m/s)	Release duration (s)
Pressurized release of sour gas	Leak 5mm	Category 2/B	0.165	-100.744	0	0	0.015647	653.12	3021.79
	Leak 10mm	Category 2/B	0.662	-100.744	0	0	0.0312941	653.12	755.447

HSE Hydrocarbon release classification system:

Release Classification	Definition	Criteria	
		Either	Or
Minor	Potential to cause serious injury to personnel in the immediate vicinity, but no potential to escalate or cause multiple fatalities	<1 kg released	<0.1 kg/s release rate and duration <2 min
Significant	Potential to cause serious injury or fatality to personnel within the local area and to escalate within that local area	release rates between 0.1 to 1 kg/s lasting 2 to 5 min	
Major	Potential to quickly impact out of the local area causing serious injury or fatalities	>300 kg released	>1kg/s release rate and duration >5 min

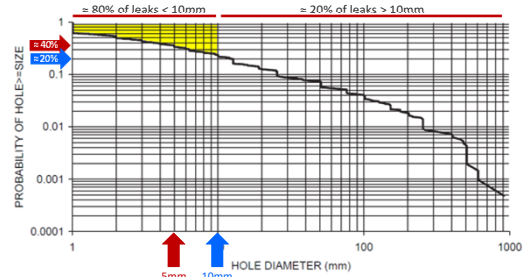
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Performance analysis

Leak hole size for assessment



Reference: Leak frequencies from the hydrocarbon release database (Symposium Series No. 151, 2006, IChemE)

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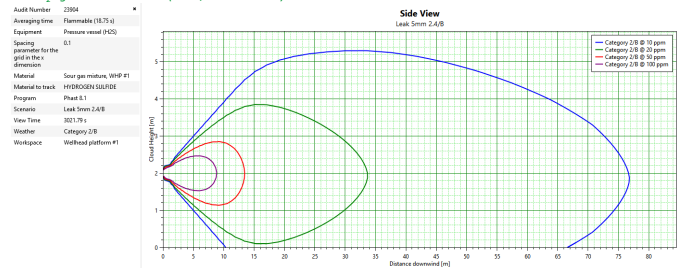
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2.1 Dispersion plume 1.0% H2S 88.0% CH4 (5mm leak hole)



Performance analysis

H₂S gas threat zone size (5mm, 50bar release)



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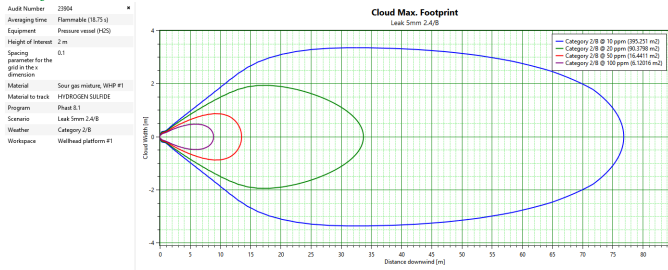
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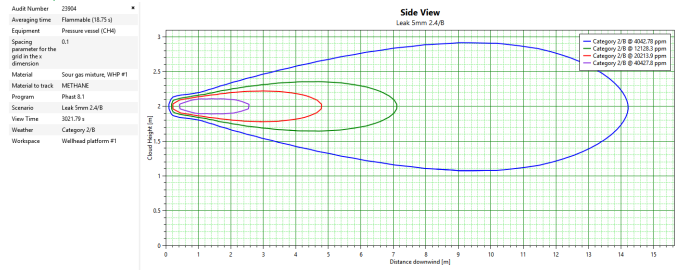
Performance analysis

H₂S gas threat zone size (5mm, 50bar release)



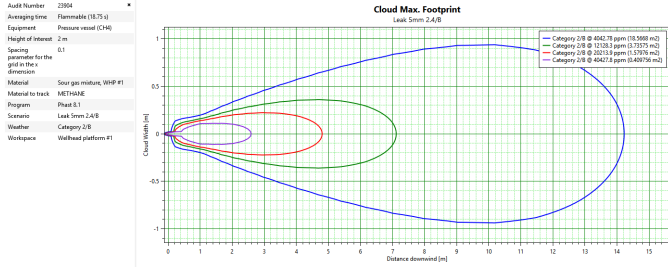
Performance analysis

CH₄ gas threat zone size (5mm, 50bar release)



Performance analysis

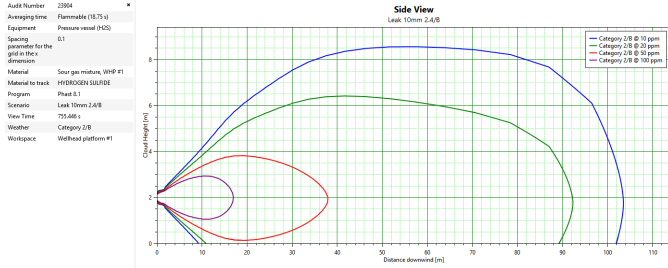
CH₄ gas threat zone size (5mm, 50bar release)



2.2 Dispersion plume 1.0% H₂S 88.0% CH₄
(10mm leak hole)

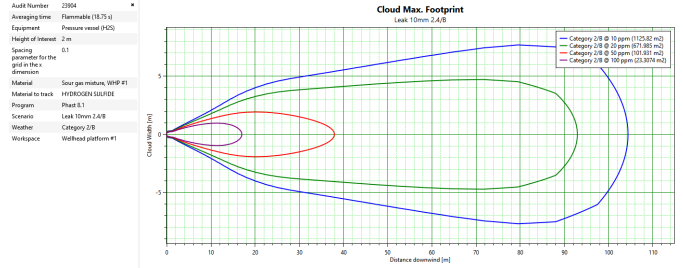
Performance analysis

H₂S gas threat zone size (10mm, 50bar release)



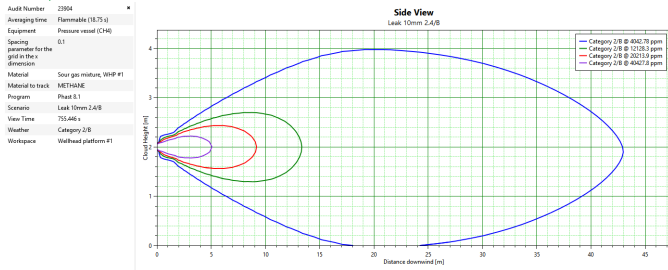
Performance analysis

H₂S gas threat zone size (10mm, 50bar release)



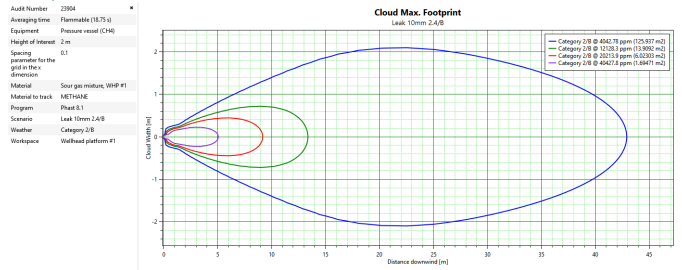
Performance analysis

CH₄ gas threat zone size (10mm, 50bar release)



Performance analysis

CH₄ gas threat zone size (10mm, 50bar release)



3. Detector selections



Performance analysis

Boundary gas detection



"Open-path detectors are the **only practical option** for boundary monitoring."

Reference: Fixed flammable gas detector systems on offshore installations: optimization and assessment of effectiveness (HSEUK Research Report RR1123 2017)



Performance analysis

Open area gas detection



"Dispersion in open areas resulting from momentum, evaporation or a combination of both may be subject to mixing from collisions and wind turbulence. For open areas, open-path gas detectors are generally better than point detectors. They increase the probability of detection, i.e. have high coverage, and produce path-integrated concentration measurements (i.e. measurement units of LFL-m) which is a better measure of risk for dispersed clouds. They also, crucially, offer the benefits of detecting gas anywhere along the line-of-sight, rather than relying on air movement to carry the gas cloud to the detector, as with point gas detectors."

Reference: Fixed flammable gas detector systems on offshore installations: optimization and assessment of effectiveness (HSEUK Research Report RR1123 2017)



Performance analysis

Improving probability of detection with acoustic leak detectors



"Increasing the detection rate of leaks could be improved by networking the flammable gas detectors and acoustic (also known as ultrasonic) leak detectors and applying detection algorithms to the gas/leak detection system in addition to the use of a basic (e.g. low and high) alarm threshold on individual detectors."

Reference: Fixed flammable gas detector systems on offshore installations: optimization and assessment of effectiveness (HSEUK Research Report RR1123 2017)



Performance analysis

Combining detector types in protection layers



Effective in detecting	Detector type		
	UGLD	OPGD	PGD
Gas leaks	✓✓		
Dispersing plumes		✓✓	✓
Gas accumulations		✓	✓✓

In line with HSE's RR1123 recommendations, MSA advocates the application of different detection types in protection layers where ever possible.

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4. Gas detection coverage assessment

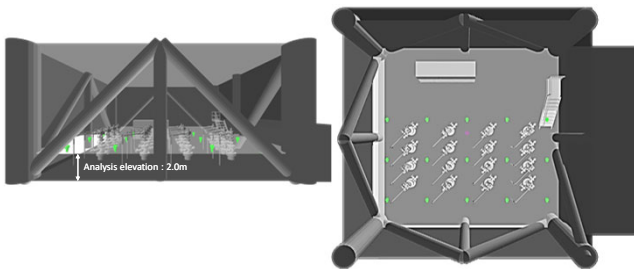
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Performance analysis

Point detector mounting and layout



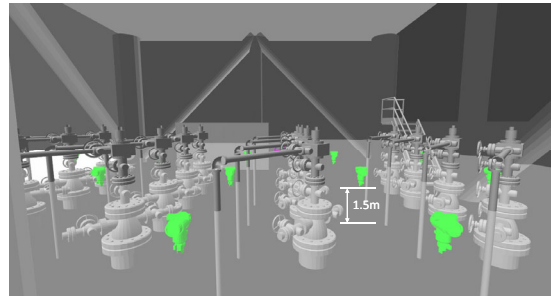
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Point detector mounting and layout



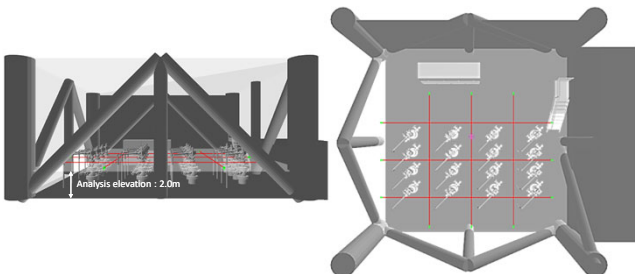
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Performance analysis

Open-path detector mounting and layout



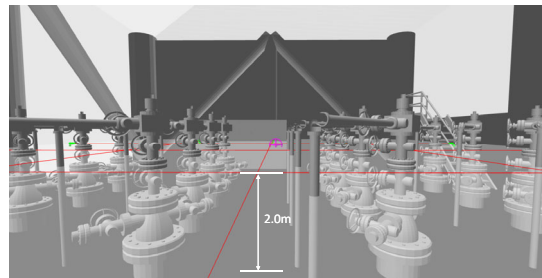
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Open-path detector layout and mounting



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Performance analysis

Alarm thresholds applied in assessments



CH ₄ gas detector	Measuring range	Alarm threshold for 10%LFL plume	Alarm threshold for 30%LFL plume
PGD-F	0 - 1LFL	0.1LFL	0.3LFL
ELDS-F	0 - 1LFL.m	0.2LFL.m (minimum alarm threshold)	
OPGD-F	0 - 5LFL.m	1.0LFL.m (minimum alarm threshold)	

H ₂ S Gas detector	Measuring range	Alarm threshold for 10ppm plume	Alarm threshold for 20ppm plume
PGD-T	0 - 100ppm	10ppm	20ppm
ELDS-T	0 - 250ppm.m	75ppm.m (minimum alarm threshold)	

Performance analysis

Geographic coverage vs. Scenario coverage



Parameter considered?	Geographic	Scenario
Wind direction changes	No	Yes
Wind speed	No	Yes
Release directions	No	Yes
Rate of release / gas cloud size (L x W)	No	Yes
Concentration of gas cloud	No	Yes
Detectable concentration by detector	No	Yes
Percentage of release scenarios covered	No	Yes
Release frequency	No	Yes
Alarm threshold	No	Yes
Relative height of detector	Yes	Yes
Critical cloud size	Yes	No
Percentage of graded area covered	Yes	No

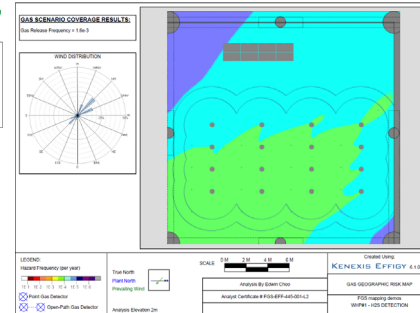
4.1.1 H₂S gas detection coverage assessment (5mm leak, 10ppm plume)



Performance analysis

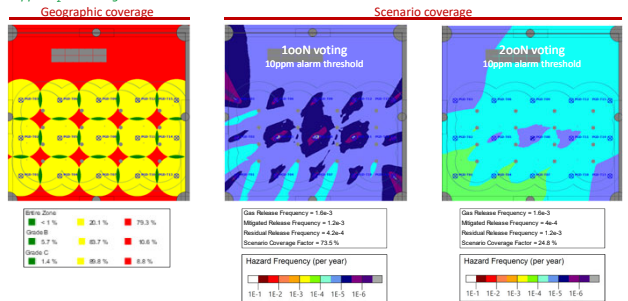
Unmitigated risk map

- Scenario:
- 5mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 10ppm H₂S plume



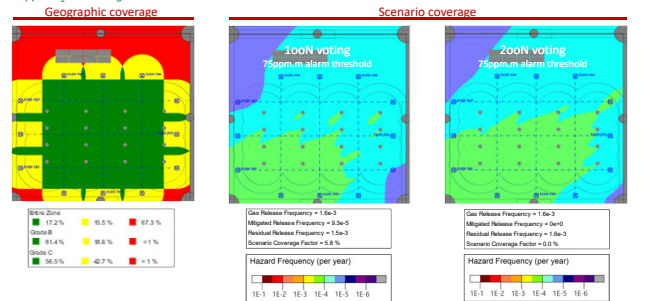
Performance analysis

10ppm H₂S alarming with PGD-T



Performance analysis

10ppm H₂S alarming with ELDS-T



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4.1.2 H₂S gas detection coverage assessment (5mm leak, 20ppm plume)

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Performance analysis
Unmitigated risk map

Scenario:

- 5mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 20ppm H₂S plume

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Performance analysis
20ppm H₂S alarming with PGD-T

Geographic coverage

Scenario coverage

100N voting
20ppm alarm threshold

Gas Release Frequency = 1.6e-3
Mitigated Release Frequency = 1.7e-3
Residual Release Frequency = 4.8e-4
Scenario Coverage Factor = 69.8 %

Hazard Frequency (per year)

200N voting
20ppm alarm threshold

Gas Release Frequency = 1.6e-3
Mitigated Release Frequency = 3.5e-4
Residual Release Frequency = 1.2e-3
Scenario Coverage Factor = 21.6 %

Hazard Frequency (per year)

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Performance analysis
20ppm H₂S alarming with ELDS-T

Geographic coverage

Scenario coverage

100N voting
75ppm.m alarm threshold

Gas Release Frequency = 1.6e-3
Mitigated Release Frequency = 5e-4
Residual Release Frequency = 1.1e-3
Scenario Coverage Factor = 31.5 %

Hazard Frequency (per year)

200N voting
75ppm.m alarm threshold

Gas Release Frequency = 1.6e-3
Mitigated Release Frequency = 5.7e-5
Residual Release Frequency = 1.6e-3
Scenario Coverage Factor = 3.8 %

Hazard Frequency (per year)

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4.1.3 H₂S gas detection coverage assessment (10mm leak, 10ppm plume)

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Performance analysis
Unmitigated risk map

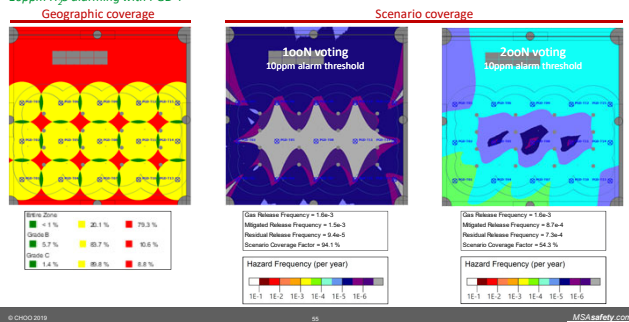
Scenario:

- 10mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 10ppm H₂S plume

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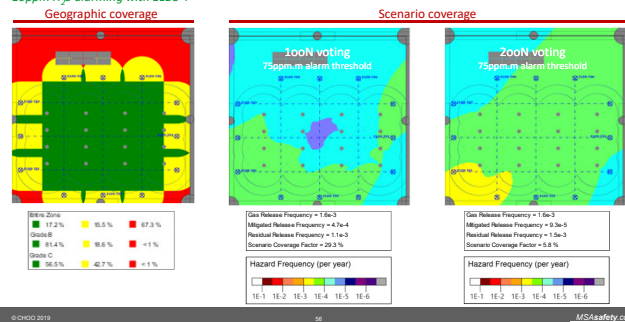
Performance analysis

10ppm H₂S alarming with PGD-T



Performance analysis

10ppm H₂S alarming with ELDS-T



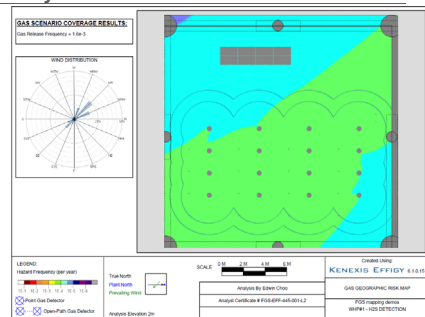
4.1.4 H₂S gas detection coverage assessment (10mm leak, 20ppm plume)

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Performance analysis

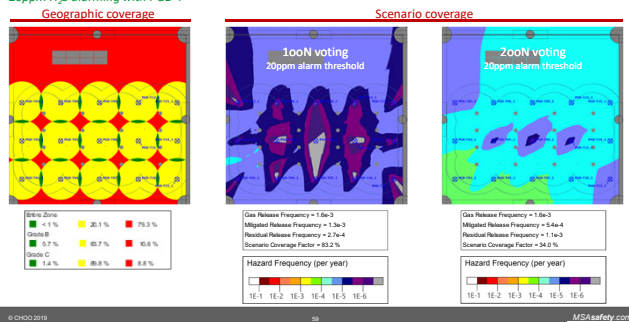
Unmitigated risk map

- 10mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 20ppm H₂S plume



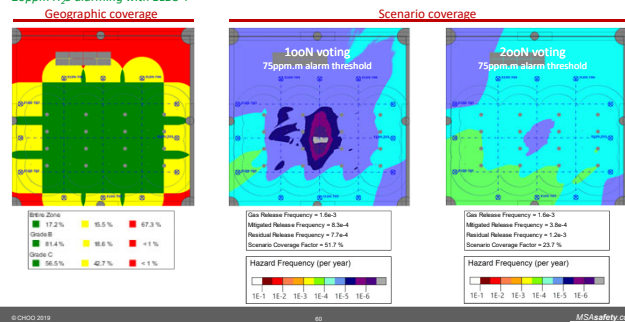
Performance analysis

20ppm H₂S alarming with PGD-T



Performance analysis

20ppm H₂S alarming with ELDS-T



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4.1.5 H₂S gas detection coverage assessment (Summary)

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Performance analysis

H₂S detection probability summary

Sour gas composition	Solution (Setpoint)	Quantity	Leak size	100N alarming		200N alarming	
				Geographic	Scenario	Geographic	Scenario
				1%H ₂ S	PGD-T (20ppm)	15	5mm
88.0%CH ₄ @50barg	PGD-T (10ppm)	15	10mm	89%	83%	6%	34%
			5mm	89%	74%	6%	25%
	ELDS-T (75ppm.m) ¹	06	10mm	89%	94%	6%	54%
			5mm	100%	32%	81%	4%
ELDS-T (75ppm.m) ²	06	10mm	100%	52%	81%	24%	
		5mm	100%	5%	81%	0%	
			10mm	100%	29%	81%	6%

¹Alarming probability calculations assume a homogeneous 20ppm plume. ²Alarming probability calculations assume a homogeneous 10ppm plume

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4.2.1 CH₄ gas detection coverage assessment (5mm, 10%LFL plume)

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Performance analysis

Unmitigated risk map

Scenario:

- 5mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 10%LFL CH₄ plume

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Performance analysis

10%LFL CH₄ alarming with PGD-F

Geographic coverage

10%LFL CH₄ alarming with PGD-F

Scenario coverage

100N voting
10%LFL alarm threshold

Scenario coverage

200N voting
10%LFL alarm threshold

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0.2LFLm CH₄ alarming with ELDS-F

Geographic coverage

0.2LFLm CH₄ alarming with ELDS-F

Scenario coverage

100N voting
0.2LFLm alarm threshold

Scenario coverage

200N voting
0.2LFLm alarm threshold

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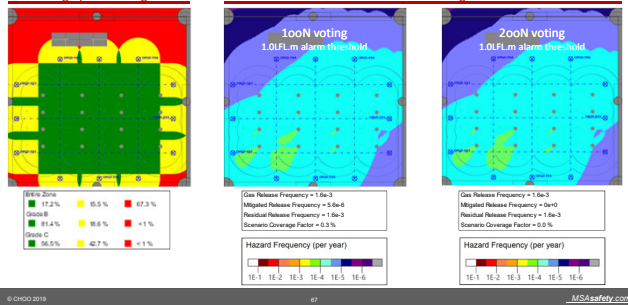
Performance analysis

1.0LFLm CH₄ alarming with OPGD-F



Geographic coverage

Scenario coverage



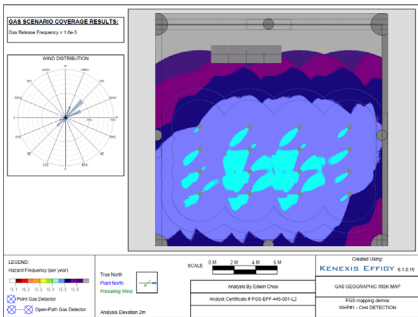
4.2.2 CH₄ gas detection coverage assessment (5mm, 30%LFL plume)

Performance analysis

Unmitigated risk map



- Scenario:
- 5mm leak hole
- 2.0m release height
- 2.4m/s B wind
- 30%LFL CH₄ plume



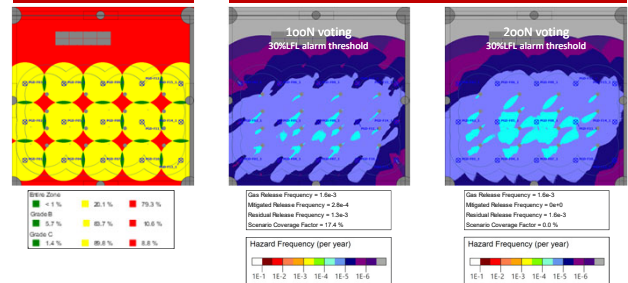
Performance analysis

30%LFL CH₄ alarming with PGD-F



Geographic coverage

Scenario coverage



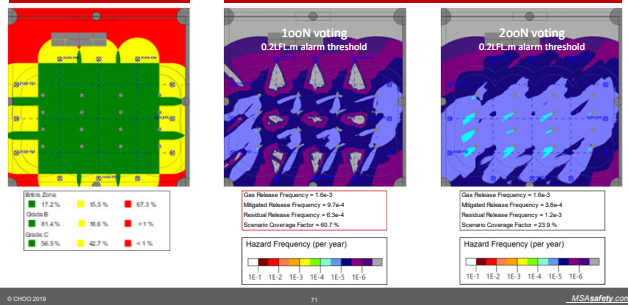
Performance analysis

0.2LFL CH₄ alarming with ELDS-F



Geographic coverage

Scenario coverage



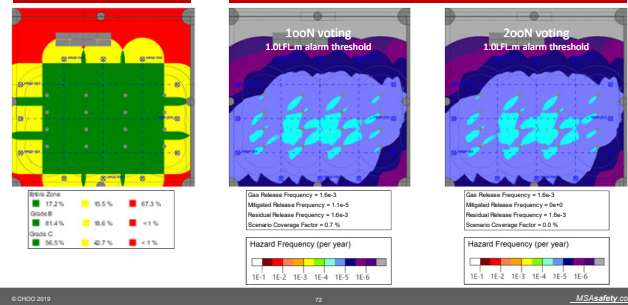
Performance analysis

1.0LFLm CH₄ alarming with OPGD-F



Geographic coverage

Scenario coverage



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4.2.3 CH₄ gas detection coverage assessment (10mm, 10%LFL plume)

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Performance analysis

Unmitigated risk map

Scenario:

- 10mm leak hole
- 2.0m release height
- 2.4m/s 8 wind
- 10%LFL CH₄ plume

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Performance analysis

10%LFL CH₄ alarming with PGD-F

Geographic coverage

Scenario coverage

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0.2LFL CH₄ alarming with ELDS-F

Geographic coverage

Scenario coverage

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1.0LFLm CH₄ alarming with OPGD-F

Geographic coverage

Scenario coverage

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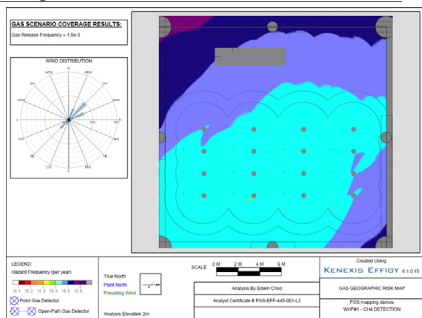
4.2.4 CH₄ gas detection coverage assessment (10mm, 30%LFL plume)

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Performance analysis

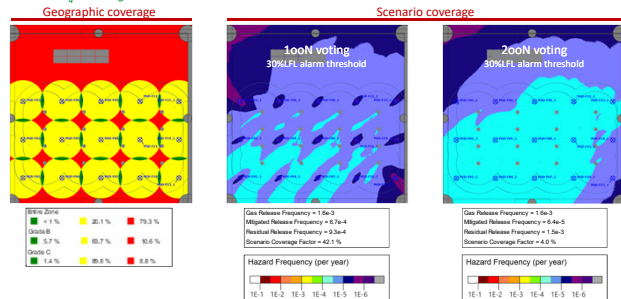
Unmitigated risk map

- Scenario:
- 10mm leak hole
 - 2.0m release height
 - 2.4m/s B wind
 - 30%LFL CH₄ plume



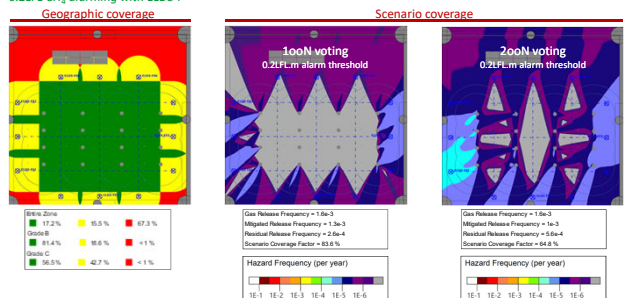
Performance analysis

30%LFL CH₄ alarming with PGD-F



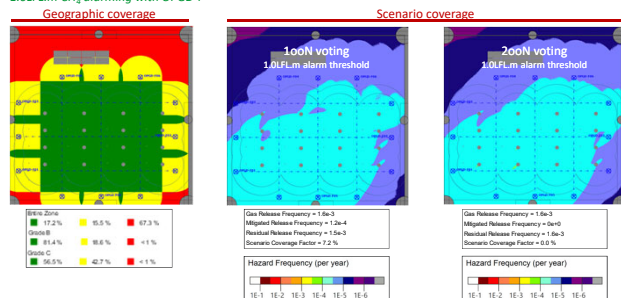
Performance analysis

0.2LFL CH₄ alarming with ELDS-F



Performance analysis

1.0LFLm CH₄ alarming with OPGD-F



4.2.5 CH₄ gas detection coverage assessment (Summary)

Performance analysis

CH₄ detection probability summary

Sour gas composition	Solution (Setpoint)	Quantity	Leak size	100N alarming		200N alarming	
				Geographic	Scenario	Geographic	Scenario
1%H ₂ S 88.0%CH ₄ @50barg	PGD-F (30%LFL)	15	5mm	89%	17%	6%	0%
			10mm	89%	42%	6%	4%
	PGD-F (10%LFL)	15	5mm	89%	52%	6%	7%
			10mm	89%	65%	6%	18%
	ELDS-F (0.2LFL.m) ¹	06	5mm	100%	61%	81%	24%
			10mm	100%	84%	81%	65%
	ELDS-F (0.2LFL.m) ²	06	5mm	100%	46%	81%	10%
			10mm	100%	63%	81%	41%
	OPGD-F (1.0LFL.m) ¹	06	5mm	100%	1%	81%	0%
			10mm	100%	7%	81%	0%
	OPGD-F (1.0LFL.m) ²	06	5mm	100%	0%	81%	0%
			10mm	100%	1%	81%	0%

¹Alarming probability calculations assume a homogeneous 30%LFL plume. ²Alarming probability calculations assume a homogeneous 10%LFL plume.

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4.3 Supplementary protection layer with UGLD

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Performance analysis

Supplementing point detectors with UGLD

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Supplementing point detectors with UGLD

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Supplementing open-path detectors with UGLD

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Performance analysis

Enhancing probability of 2ooN alarming with UGLD

7% 2ooN probability → 53% 2ooN probability

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Performance analysis

Improving probability of 2ooN alarming with UGLD

Solution	Alarm threshold	Quantity	Leak size	Probability of alarming		
				1ooN	2ooN w/o UGLD	2ooN w/ UGLD
PGD-F	30%LFL	15	5mm	17%	0%	16%
PGD-F	10%LFL	15	5mm	52%	7%	53%
ELDS-F	0.2LFL.m	06	5mm	61%	24%	68%
OPGD-F	1.0LFL.m	06	5mm	1%	0%	1%

Probability improvement

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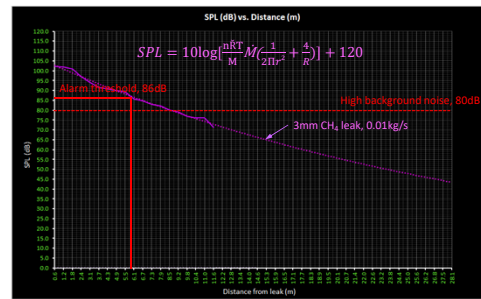
Performance analysis

The advantage of UGLD over conventional gas detectors



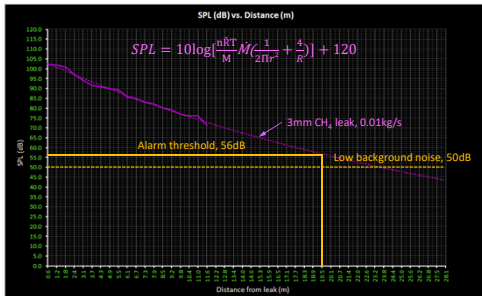
Performance analysis

Conventional UGLD – High noise areas



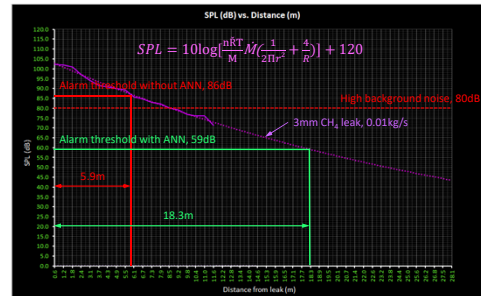
Performance analysis

Conventional UGLD – Low noise areas



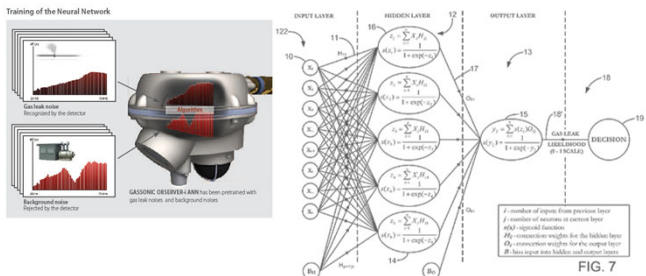
Performance analysis

ANN gas leak recognition allows larger coverage zone in high background noise areas



Performance analysis

UGLD with ANN can discriminate between real gas leak noise and background noise



Performance analysis

ANN gas leak recognition increases the probability of alarming in high background noise areas

