Laser-based gas detection technology and dispersion modeling used to eliminate false alarms and improve safety performance on Terra Nova FPSO

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Suncor Energy is the operator of the Terra Nova FPSO, which is located in the Grand Banks, off the East Coast of Canada. In 2010, a multi-disciplinary team was assembled to assess and upgrade the overall gas detection system on the FPSO. The team involved personnel from safety, risk analysis, operations, instrumentation and controls engineering. A detailed analysis of the facility, based on computational fluid dynamics (CFD) modeling, was performed. In aggregate, more than 1,400 gas leak scenarios were simulated and used in the evaluation, detector selection process, optimization and overall design of the upgrade to the gas detection system. Laser-based technology was selected to replace infrared gas detection technology after extensive testing in both onshore and offshore environments. By combining a quantitative gas dispersion study with the implementation of new technology, Terra Nova was able to achieve:

1. An elimination of false alarms
2. An increase in gas leak detection coverage
3. Earlier warning for preventative and remedial action
4. A reduction in maintenance requirement
5. A reduction in the exposure of operations personnel to hazardous locations and gases
6. An improvement in the reliability and robustness of the FPSO’s overall gas detection system.

The Terra Nova FPSO is a remote facility with limited egress. Therefore, any hazardous gas release in the facility requires complete production shutdown, blow down of available inventory and isolation of electrical equipment that is not Zone 1 rated. Prior to the upgrade, false alarms from gas detectors were resulting in prolonged outages, damage to process equipment and production deferments of approximately 50,000-100,000 barrels per year. The upgrade was able to address all of these problems. This paper describes the methodology that was applied and presents an overview of the results. Implementation of this retrofit and upgrade approach is expected to benefit numerous industrial facilities where the threat of a toxic or flammable gas leak exists.

Introduction and background

The Terra Nova oil field is situated in the Grand Banks, approximately 350 km (220 miles) east-southeast of the city of St. John's in the Canadian province of Newfoundland and Labrador. The field is the second largest producing oil field in East Coast Canada and is located in the Jeanne d'Arc basin (see figure 1). The total recoverable oil reserves in the field are estimated by the Canada-Newfoundland Labrador Offshore Petroleum Board (C-NLOPB) to be 419 million barrels. The owners of the Terra Nova field are: Suncor Energy (37.675%), ExxonMobil (19%), Statoil (15%), Husky Energy (13%), Murphy Oil (10.475%), Mosbacher Operating Ltd. (3.85%), and Chevron Canada (1%). Suncor Energy is the operator of the Terra Nova field.

Discovered in 1984, the field was the second to be developed off the coast of Newfoundland and Labrador. Production from the field began in 2002, through the use of a Floating, Production Storage and Offloading (FPSO) vessel. This was the first development in North America to use FPSO technology. One of the largest FPSO vessels ever built, the Terra Nova FPSO is 292.2 meters long and 45.5 meters wide, approximately the size of three football fields laid end to end. From the keel to the helideck, it stands more than 18 stories high (see figure 2). The Terra Nova FPSO can store 960,000 barrels of oil and accommodate up to 120 personnel while producing. Oil production wells are pre-drilled by a semi-submersible mobile offshore drilling unit. The wellheads and production manifolds are placed in “glory holes” (excavations in the seafloor) that protect the equipment from potential scouring by icebergs. A network of more than 40 kilometers of flexible flowlines is used to convey hydrocarbons to and from the wells. Produced gases are separated from the oil and re-injected into the reservoir for production support and possible future extraction. Crude oil is offloaded from the FPSO onto large shuttle tankers for shipment.

Environmental conditions and challenges

The Grand Banks region has a harsh environment, similar to that of the northern North Sea. The FPSO is situated in "iceberg alley" where large icebergs from Greenland and Ellesmere Island drift south with ocean currents. The Terra Nova FPSO is a double-hulled, ice-reinforced vessel, with five thrusters and a dynamic positioning system, which enables the FPSO to change to more favorable headings in high winds and storms. The cold Labrador Current from the north and the much warmer Gulf Stream from the south collide in this area to produce very challenging weather conditions (see figure 3). In June and July, the FPSO can be covered in thick fog 84% of the time and, with over 200 foggy days each year this is one of the foggiest places in the world. During the fall and winter, the Terra Nova FPSO can experience intense storms whereby wave heights exceed 25 meters and wind speeds exceed 100 knots. Snow squalls, freezing rain and freezing ocean spray occur frequently in the winter months.

Gas detection history

The original Terra Nova gas detection system was designed to utilize a combination of point detectors and line-of-sight (LOS) detectors based on infrared (IR) technology, with the bulk of coverage being provided by the LOS type. Since the facility first started production in 2002 there have been ongoing issues with the reliability of the LOS detectors. The most significant issue has been performance during adverse weather conditions. During periods of fog or snow many detectors would report a blocked beam fault condition and, depending on the situation, some would falsely detect gas. As a result, Suncor would frequently be forced to assign technicians to clean the lenses and return the units to service. Simultaneously, operations staff would also place inhibits on many detectors to prevent inadvertent plant trips. In any zone, once a threshold of 50% of detectors requiring inhibits had been crossed, temporary portable detectors were deployed and operating personnel would need to be present more frequently in the affected areas to monitor for gas releases.

As the Terra Nova FPSO is a remote facility with limited egress, any gas release in the facility requires a complete production shutdown, blow down of available inventory and isolation of electrical equipment that is not Zone 1 rated. To achieve this, the FPSO was designed with multiple fire and gas detection zones. Each of the zones utilizes one of two voting methodologies depending on coverage and detectable gas cloud size. The first and most widely used method is 1oo2D. This method is a typical 2ooN voting system with the addition of diagnostic coverage, which simply means than any detector that is in fault counts as a vote. For example, a zone with 5 detectors would require 2oo5 for executive action to occur. If one detector enters into a fault condition the zone then becomes 1oo4. The second methodology is 1ooN. This voting methodology is limited to the main vessel deck area of the FPSO and was selected due to the low number of detectors, the confinement in the area and the need to detect small clouds. Many of the false plant trips have occurred due to detectors in the 1ooN zones.

Advent of sour gas

By 2010 parts of the Terra Nova field were beginning to produce hydrogen sulfide (H_2S) in the well fluids. As toxic gases were not expected in the original Terra Nova design, the fixed gas detection system did not incorporate dedicated H_2S detection. Based on the need to upgrade the gas detection system to detect H_2S and the LOS detector performance issues, several projects were initiated. The first initiative was to build a gas dispersion model for the Terra Nova FPSO and use this analysis to complete a comprehensive gas detection evaluation and optimization study. In parallel, Suncor began to investigate and trial various gas detection technologies that could address the problems with the existing system and detect both flammable and toxic gas releases.

Evaluation of the gas detection system

Detailed analysis based on computational fluid dynamics (CFD) modeling was performed for the Terra Nova FPSO by GexCon. The overall objective of the analysis was to test and optimize system performance and suggest improvements for the existing system and detector layout. The process included:

1. Accurately representing ventilation conditions across all process modules
2. Simulating a range of realistic gas leak cases
3. Simulating explosions to establish dangerous cloud sizes for each module
4. Suggesting and benchmarking a range of detector designs and layouts for each module
5. Arriving at a recommended optimum system for each module, accounting for limitations on number and type of detectors, input / output limitations, and voting schemes
6. Ensuring sufficient performance for both toxic and hydrocarbon gas detection

In aggregate, more than 1,400 gas leak scenarios were simulated and used in the evaluation, optimization, detector selection and overall design of the upgrade to the gas detection system.

The CFD model FLACS was chosen in the present study because it allows (1) the simulation of the relevant toxic and flammable gaseous releases, (2) the modeling of the detailed geometry within the facility, (3) the simulation of both natural and forced ventilation within the facility, (4) the evaluation of gas concentration measured by line and point detectors, (5) the evaluation of danger potential for the dispersion cloud, and (6) the ability to perform parametric sensitivity and optimization studies. The geometry of the Terra Nova FPSO was based on a computer-aided design (CAD) model. In order to produce reliable results from the simulation, it was of great importance that the geometry model be sufficiently accurate. Obstructions will restrict the air flow and result in reduced ventilation rates, diversion of flow, or both. Having a geometry model with representative congestion and confinement characteristics assures the reliability of both the ventilation and dispersion simulations.

Gas dispersion simulations

In order to assess the performance of the gas detection system (GDS) with regards to safety, the following criteria were used:

1. A confirmed gas alarm must be triggered before a leak reaches a hazardous level. This hazardous level occurs when the cloud of gas from the release becomes larger than the ‘dimensioning cloud size’. This dimensioning cloud size is the smallest flammable cloud, which, if ignited, could break through walls or decks or otherwise cause escalation and is determined by performing explosion simulations for a range of cloud sizes. As an example, the V30 module covers the entire main deck of the FPSO. Explosion simulations were performed to identify the size of cloud that could exceed the design strength of the main barriers. The congested and confined nature of the V30 area meant that relatively small flammable gas clouds could threaten the integrity of the deck, resulting in a dimensioning cloud size of $88m^3$. The dimensioning cloud sizes for other main areas and modules (refer to figure 4) of the FPSO were determined as follows:
    - Turret Area (T06) – $1,585m^3$

- Water Injection Module (M02) – 604m^3
- Separation and High Power Compression Module (M03) – 556m^3
- Produced Water / Glycol Module (M04) – 406m^3
- Separation and Low Power Compression Module (M05) – 332m^3
- Power Generation Module (M09) – 695m^3

2. Low alarm must be triggered for any leak scenario where the volume with an H_2S concentration above 10ppm exceeds 100m^3.
3. Low alarm must be triggered within 30 seconds for any leak scenario where the volume with an H_2S concentration above 100ppm exceeds 10m^3. The concentration level of 100ppm was selected because it is defined as being Immediately Dangerous to Life and Health (IDLH) by the US National Institute for Occupational Safety and Health.

Beyond these three key criteria, it was decided that the system should be optimized to give an alarm as early as possible. Judging performance by time to detection alone would miss the spatial extent of the gas cloud.

The quantitative evaluation of the GDS in the process modules was based on testing the performance for a large set of realistic gas leak scenarios. This means that ventilation conditions and gas leak properties had to be modeled as accurately as possible. The local ventilation conditions were critical in understanding the formation and migration of flammable or toxic gas clouds. The ventilation conditions were determined by the wind speed and direction, the heading of the FPSO, large-scale effects from modules and buildings upwind and downwind of the area of interest, as well as smaller-scale effects from buildings, walls, equipment and piping inside the area of interest itself. An aerial view of the entire FLACS model of the FPSO is shown in figure 5.

Gas detector technology selection

Since it commenced operation in 2002, the Terra Nova FPSO has relied primarily on LOS detection. Therefore, Suncor's preferred option was to determine if LOS technology existed that could replace its existing detectors and provide coverage for both flammable and toxic gas leaks. This would minimize structural modifications required to mount new units, avoid having to run new cables and trays, thereby minimizing construction time and cost. An extensive search eventually led the Suncor team to lab test, field trial and ultimately select the Enhanced Laser Diode Spectroscopy (ELDS™) technology. This technology, developed by Senscient, had the capability of combining toxic and flammable gas detection in a single LOS detector whilst significantly improving the performance and reliability of the FPSO's overall gas detection system.

In February 2011, a trial ELDS™ unit was acquired and subjected to qualification testing at the Terra Nova onshore distributed control system (DCS) simulator. Over a period of two weeks, stringent performance tests were conducted on the device, under a variety of conditions that were known to generate problems for the existing IR detectors. The test results are summarized below.

Test Description	Result
Simulated fog using water mist	No issue with performance
Direct water spray on the device lenses	No issue with performance
Plastic of various types placed in the beam path	No issue with performance
Snow placed over the lens (approx. 1 inch thick)	No issue with performance

Using a transmitter-receiver configuration, ELDS™ systems detect and measure gas concentrations at specific target gas absorption wavelengths over distances of up to 200 meters (see figures 6 and 7). The transmitter utilizes a highly reliable, solid-state laser diode sources similar to those used in demanding telecommunications applications to generate a laser beam. The receiver measures absorbance changes when a combustible or toxic gas passes through the laser beam. One of the key techniques that enables ELDS™ to detect small fractional absorbances and eliminate false alarms is Harmonic Fingerprinting. A Harmonic Fingerprint is a specific set of harmonic components introduced by target gas absorption where the relative amplitudes and phases of the components are known and specific to the target gas absorption line that is being scanned (see figure 8 for an example).

Using a small retained sample of target gas inside the transmitter, the temperature and wavelength modulation currents applied to the transmitter's laser diodes are actively controlled to lock the lasers such that absorption by target gas produces specific Harmonic Fingerprints. The relative amplitudes and phases of the harmonic components in a Harmonic Fingerprint are so specific and unique that only absorption by the specified target gas produces a signal with the desired Harmonic Fingerprint. Noise, absorption by atmospheric gases and coherent interference effects never produce signals with the Harmonic Fingerprint, enabling an ELDS™ based gas detector to eliminate false alarms (see figure 9). In addition to maintaining a Harmonic Fingerprint lock, the gas reference cell enables remote, on command, electronic functional testing of the gas detector either locally or from the control room under any condition. In the test, the Transmitter simulates a predefined quantity of target gas by directing the laser beam through the reference cell as seen in figure 12. ELDS™ units are programmed to conduct a validity test every 24 hours. The results of detector functionality testing are gathered and logged automatically. The presence of a gas reference cell is an innovation that improves reliability and reduces maintenance, which eliminates the need for technicians to carry cylinders of hazardous gases through the FPSO in order to test gas detectors.

Optimization of the gas detection system

In order to verify and optimize the performance of the GDS in each module, a diverse and challenging set of leak scenarios was needed. Leak positions were selected that resulted in flammable and toxic clouds in all parts of the module, so that the entire GDS could be evaluated quantitatively. Leak rates that yielded challenging clouds were chosen, i.e. large enough to be dangerous, but small enough to be difficult to detect (see figure 10 for an example). The gas detectors on the vessel are logically split into fire zones. Where 1oo2D or 2ooN voting is used, both contributing detectors must be in the same fire zone in order for the alarm to be triggered. This voting logic was fully implemented in the CFD testing of detector layouts. Though the fire zone splits are mostly by location, in some cases, detectors located physically close to each other are logically placed in different fire zones.

For every module, detection results were summarized and presented as graphs showing cloud size at detection for simulated scenarios. This format shows the performance of a GDS at a glance, but requires a closer description. Figure 11 shows an example graph prepared for detection of hydrocarbon gas clouds. Detected scenarios are ordered by cloud size at detection (increasing order). Undetected scenarios are shown after the detected scenarios, in descending order by maximum cloud size. To discern between detected and undetected scenarios, the latter are shown with negative values (i.e. the lower the value, the larger the undetected cloud). Also shown are the threshold values – the dimensioning cloud size for hydrocarbon detection, $100m^3$ or $10m^3$ for H_2S detection (these threshold values correspond to the three criteria listed previously). A curve that dips below the lower red line represents undetected scenarios over the threshold size, which means the GDS does not satisfy the detection criterion. A curve that crosses the upper red line represents scenarios that are detected, but only after the cloud reaches threshold size. For hydrocarbon detection, this means the GDS does not satisfy the detection criterion, while the H_2S detection criteria are not directly tied to cloud size at detection.

Presenting results for the entire FPSO would be an extremely lengthy endeavor, well beyond the scope and space limitations of this paper. Instead, it is possible to illustrate the methodology and results by focusing on one module. The M02 module, comprising of the water injecting area, can be considered as such an example. Explosion simulations were performed to identify the size of cloud that could exceed the design strength of the main barriers and this analysis resulted in a dimensioning cloud size of 604m3. Gas dispersion simulations were then performed with a range of different release locations. The majority of the releases were placed on the process deck as this area contains most of the potential leak sources. The confinement and flow pattern in this area generated a wide range of cloud shapes. In aggregate, 253 gas dispersion simulations were performed for module M02. Following this, two optimization rounds were performed in an iterative manner. The first round was used to test the sensitivity of the system. The second run focused on finding the optimal layout. Figure 12 shows performance graphs for several tested GDS solutions in the water injection area (module M02).

- The original GDS (black curve titled “BC”) has the worst performance, signified by the early drop-off (signifying many scenarios are undetected) and the deep trough (showing that the undetected scenarios are relatively large).
- The first attempted improvement was simply to combine voting across fire zones. The grey-blue “Combined Firezones” shows a slight improvement – a lower peak, and slightly later drop-off signifying a few more scenarios are detected. Both this and the BC curve dip below the lower red line, and thus do not satisfy the performance criterion.
- Next, the effect of the planned transition to laser-based LOS technology, combined with the aforementioned combined voting was evaluated. The green “Combined Senscient” has a much later drop-off, detecting many scenarios that are not detected by the two previous curves. However, it crosses the upper red line where those curves did not. This may seem counter-intuitive, but is actually a sign of improved performance. Some scenarios that were previously undetected are detected, even though the detection occurs after the cloud has reached a large size. While this represents an improvement over not detecting these scenarios, this curve still does not satisfy the criterion.
- Further, several alternative layouts with additional detectors were evaluated. The brown “L2 Senscient” curve shows further improvement, with a lower peak, later drop-off and shallower trough. As it crosses both of the red lines, it is still not in compliance with the performance criterion.
- Finally, another tested GDS, the blue “L3 Senscient” shows the best performance of these curves. While it still has a drop-off (signifying undetected scenarios), the undetected scenarios are smaller than the dimensioning size.

The GDS solution illustrated by the blue curve entitled “L3 Senscient” was selected for implementation. With this solution, all gas leak scenarios bigger than 604m^3 (the dimensioning cloud size for module M02) are detected before reaching that size. The curve does not cross any of the red lines and satisfies the criterion for hydrocarbon detection.

Implementation of the retrofit and upgrade

Once onshore testing was completed, a dual Methane-H_2S ELDS^{TM} detector was installed on the Terra Nova FPSO, in May 2011, in place of an existing IR LOS device that was known to cause issues in the past. The distance between the transmitter (Tx) and receiver (Rx) for this installation was approximately 34m. During a trial period that lasted approximately 24 months, the ELDS^{TM} detector performed very well, with zero spurious trips. The only issue identified was a loose mounting bracket that resulted in misalignment, a problem that was easy to identify and resolve. Following the successful offshore trial, a decision was made by Suncor to replace all existing IR LOS gas detectors on the Terra Nova FPSO with the ELDS^{TM} technology. In aggregate, 141 IR LOS detectors were slated for replacement. A recommendation from the study by GexCon added another 17 ELDS^{TM} detectors to provide for additional coverage. Therefore, the overall retrofit and upgrade plan called for the decommissioning or 141 IR LOS and the installation of 158 ELDS^{TM} detectors.

Retrofitting the FPSO while it was on location, in full operation, required significant planning. A thorough work package was developed which provided a plan for the decommissioning of the existing IR detectors, installation of the new ELDS^{TM} detectors and training of personnel. Change out of the LOS detectors commenced in 2013. As of July 2014, 78 of 158 ELDS^{TM} detectors have been installed, with the remaining devices scheduled to be changed through the remainder of 2014 and 2015.

Results and discussion

The performance of the upgraded system has been exceptional. Prior to the upgrade, the Terra Nova FPSO experienced 3-5 plant trips, more than 100,000 fault indications and 20-25 unrevealed failures per year. Data from the Terra Nova data historian, maintenance management system and lost production tracking register was analyzed to quantify this performance. The sections below summarize the improvement in performance to date.

Impact on safety performance

A review of the maintenance management system showed that there was an average of 21 unrevealed gas detector failures per year from 2009 to 2013. The signal these IR devices were sending to the control system indicated full health, however, they failed to respond to a function check. The ELDS^{TM} detectors address this problem by completing a daily diagnostic check and signaling a fault if there is an issue. As of July 31, 2014, Terra Nova had not recorded a single unrevealed failure with the laser-based gas detectors. Startup and shutdown of a facility introduce risks that are not present when a plant is in steady state operations. By reducing the number of spurious trips, the time spent in startup or shutdown modes is reduced, thereby decreasing the risk to the facility.

The laser-based sensors installed on the Terra Nova FPSO have a minimum detection threshold that is much lower than the older IR-based detectors. Instead of a hydrocarbon detection threshold of 1 LELm / 2.5 LELm (low / high alarm), the laser-based detectors can be set to a threshold of 0.2 LELm/1 LELm (low / high alarm), without experiencing any drifting and related spurious alarms. The effect of this five-fold increase in sensitivity is that the detectable volume of any gas cloud is larger. Figure 14 shows two plots of the same simulated gas leak. The red zone is flammable gas, whereas the yellow zone represents detectable volume with a sensitivity of 10% LEL and 50% LEL, respectively for the top and bottom plots. Increasing the sensitivity of detectors increases the detectable volume and makes it more likely that any given detector will be exposed to detectable gas before the flammable volume reaches a dangerous size (see figure 15). Furthermore, the H_2S content on Terra Nova means even small leaks can be hazardous, thus increased sensitivity is an important tool to ensure worker safety.

In some areas of the FPSO, detectors that were physically close belonged to different fire zones. Since voting is done on a per-fire zone basis, this organization could lead to cases where several detectors must be exposed before a confirmed alarm is achieved. Results obtained from the gas dispersion model showed that, for some modules, combining voting across neighboring fire zones significantly improved detection performance even in the absence of any other improvement. For example, in modules M03, M04 and M05, voting across the fire zones in each module is being combined and this increases the percentage of scenarios detected before reaching dangerous size to 100% from 98%, 99% and 91%, respectively.

A comprehensive dispersion analysis based on worst case H_2S concentrations in the production stream was performed for the entire FPSO. This study revealed that hazardous levels of H_2S could occur in the port half of module M04, the area of the process facility where regeneration of glycol and treatment of gas and produced water takes place. For other areas of the FPSO, results obtained from the gas dispersion modelling demonstrated that the H_2S concentrations were low and thus detection was adequately ensured via the optimized hydrocarbon GDS. Consequently, a dedicated H_2S detection system was developed and installed in the M04 module utilizing laser-based LOS devices. The installed system satisfied the performance criteria for H_2S detection.

Impact on maintenance and offshore operations

A review of performance data from the Terra Nova data historian shows dramatic improvement over the IR devices in spurious trip avoidance. The key metric reviewed was the number of faults / blocked beam indications. Performance data was reviewed from January to December of 2011 for the IR-based detectors as the FPSO was off station for maintenance for portions of 2012 and 2013. Data from June 2013 to June 2014 was used to capture the performance of detectors that had been changed to laser-based systems. As the number of devices and time in service for the two groups is not equal, a metric of 'fault rate per detector day in service' is used for comparison purposes (total faults / sum of days in service). A summary of the data is provided below.

	Faults (total)	Faults / Day
Infrared (IR) LOS Detectors	206,323	3.82
Laser (ELDS^{TM}) LOS Detectors	1,899	0.14

It should be noted that in both cases there were a large number of faults attributed to detectors chattering in and out of a fault condition. The table above includes all faults regardless of the cause. In the case of the laser-based detectors 1,561 of the 1,899 faults were attributed to two detectors that had alignment issues over several days before being corrected. Outside of these two detectors, the fault rate per detector was approximately 0.025 faults per detector per day and the vast majority were due to alignment issues. For the IR detectors, one device accounted for nearly half of the faults. This IR device had a failed source that resulted in a chattering fault for a six-month period while waiting on parts for replacement. Overall, the fault rate, not counting the problem detector, was significantly higher for IR than for ELDS^{TM}, with 1.1 faults per detector per day with the majority due to weather, dirty optics and alignment.

With such a significant decrease in the number of faults, the requirement for technician response and troubleshooting has been drastically reduced. From 2009 to 2013, an average of 234 maintenance work orders per year was generated, relating to IR LOS detectors being in fault. Note that this number does not include the significant number of maintenance call outs during conditions of limited visibility (rain, fog, mist and snow) to clean detectors as these calls are not tracked. From June 2013 to July 2014, there were only 13 maintenance work orders created relating to issues with laser-based devices.

Impact on production

Historically, the Terra Nova FPSO has experienced three to four production trips per year due to false gas detection. These trips have resulted in production deferments of approximately 50,000-100,000 barrels per year. During a trip initiated by gas detection, emergency shutdown valves are closed quickly, equipment is tripped and gas inventory is sent to the flare system. Shutting down the plant in this manner has potential damaging effects on plant equipment such as generators and gas compressors. The FPSO experienced damage to process equipment during emergency shutdowns several times prior to the installation of the laser-based gas detectors, resulting in prolonged outages and significant repair costs. Conversely, there has not been a single instance of false gas detection with the laser-based gas detection technology.

Conclusion

This paper presents the methodology that Suncor adopted to tackle problems that were impacting safety, maintenance and production operations. The advent of sour gas in the production fluid stream and detector failures, in particular the problem of false alarms due to adverse weather, were the catalyst for an extensive overhaul and upgrade of the gas detection system on the Terra Nova FPSO. A detector optimization study based on computational fluid dynamics, combined with the installation of advanced laser-based gas detection technology, has solved these problems and resulted in a significant improvement in safety, reliability and process uptime. Implementation of this approach is expected to benefit numerous industrial facilities where the threat of a toxic or flammable gas leak exists.

References

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2. Haugen, E. D., Costello, J. P., Wilcox, L. B., Albrechtsons, E., & Kelly, I. (2007, January 1). Reservoir Management Challenges of the Terra Nova Offshore Field: Lessons Learned After 5 Years of Production. Society of Petroleum Engineers. doi:10.2118/109587-MS

Figure 1. Location of the Terra Nova field in the Jeanne d'Arc basin.

Figure 2. The Terra Nova FPSO.

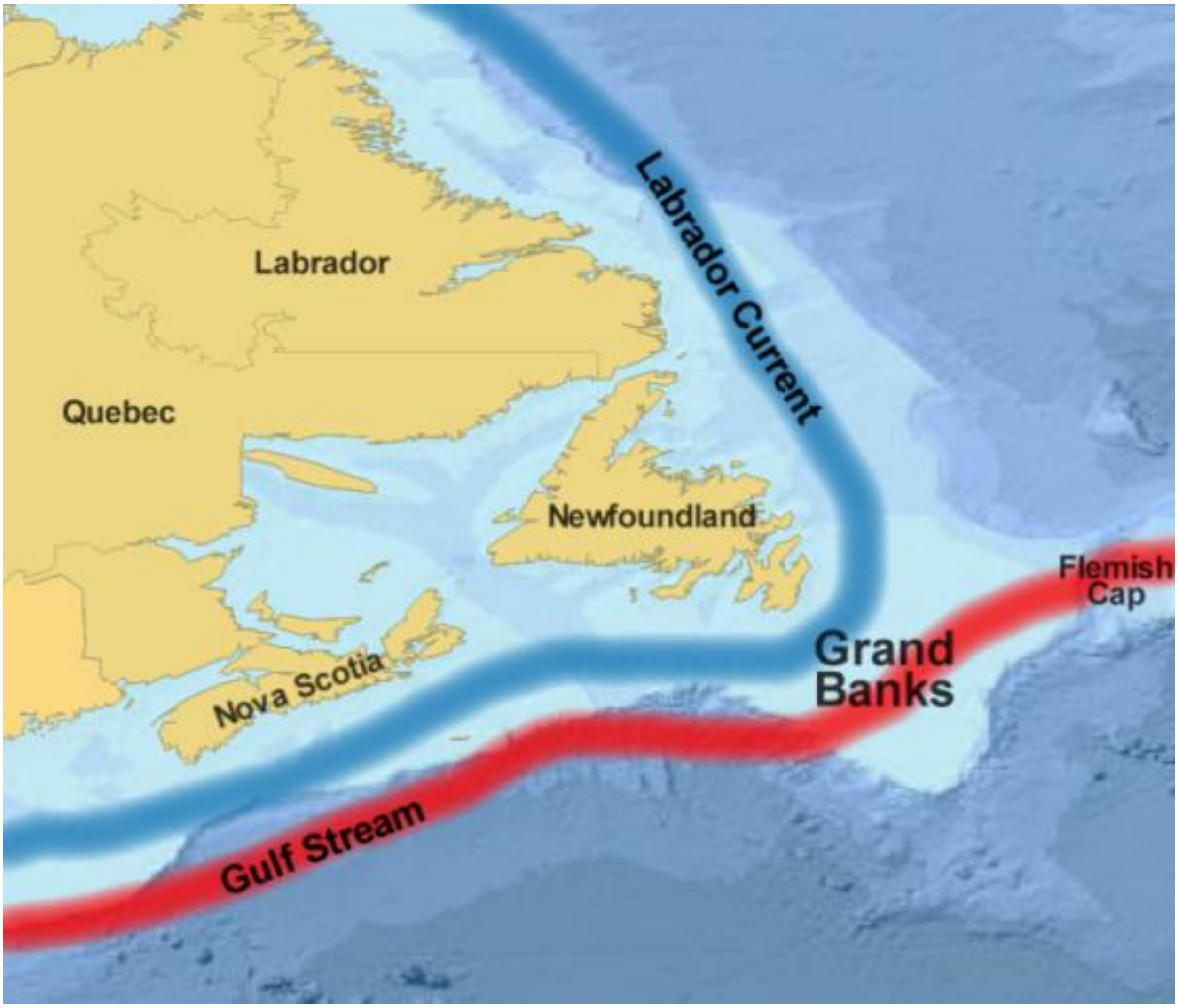

Figure 3. The cold Labrador Current from the north and the much warmer Gulf Stream from the south collide in the Grand Banks to produce very challenging weather conditions.

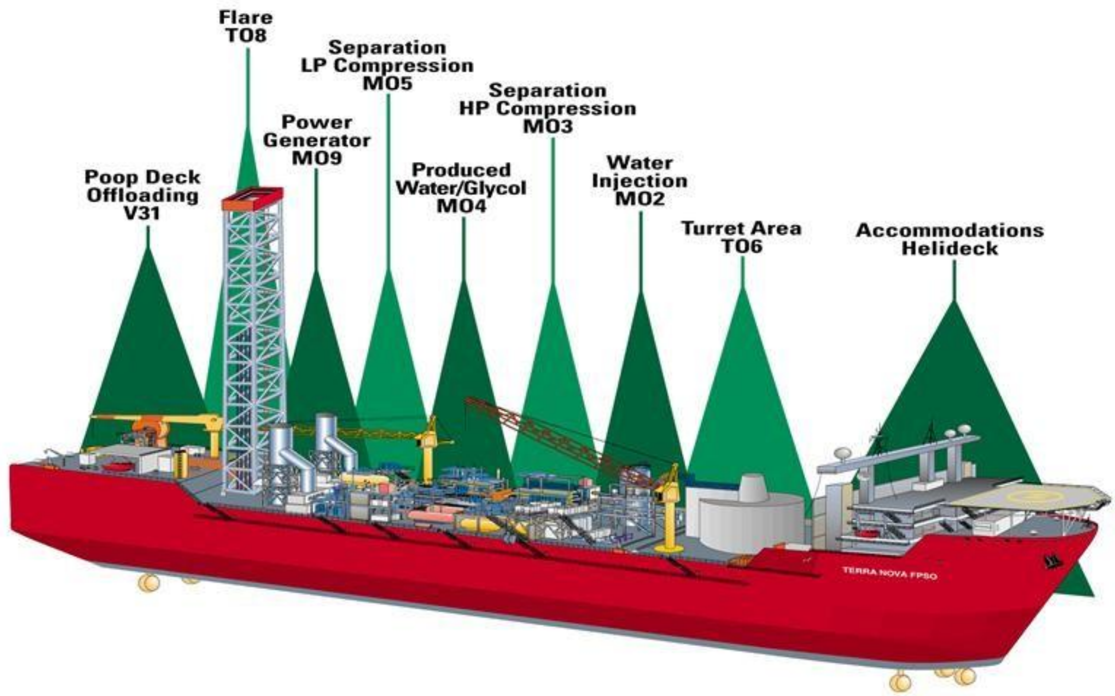

Figure 4. A graphical illustration of the Terra Nova FPSO that indicates key areas / modules.

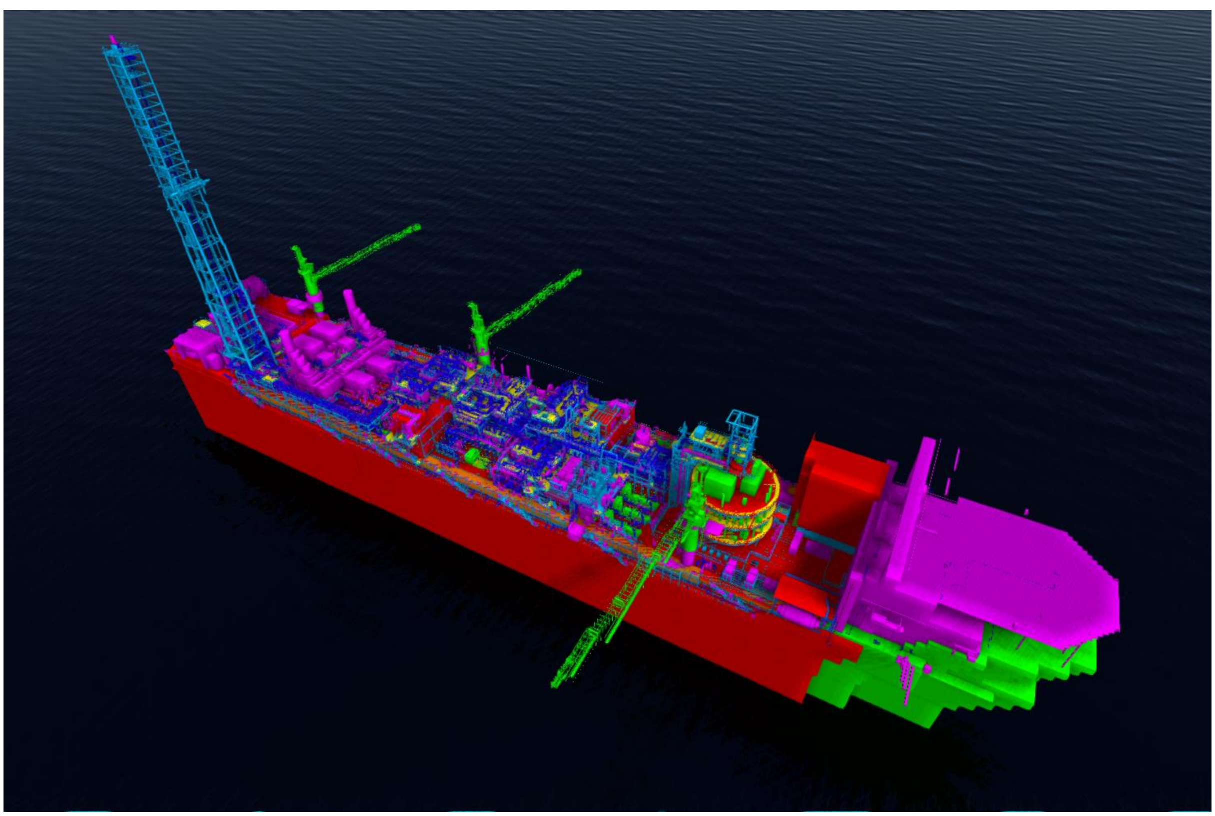

Figure 5. A graphical illustration of the FLACS geometry model of the Terra Nova FPSO.

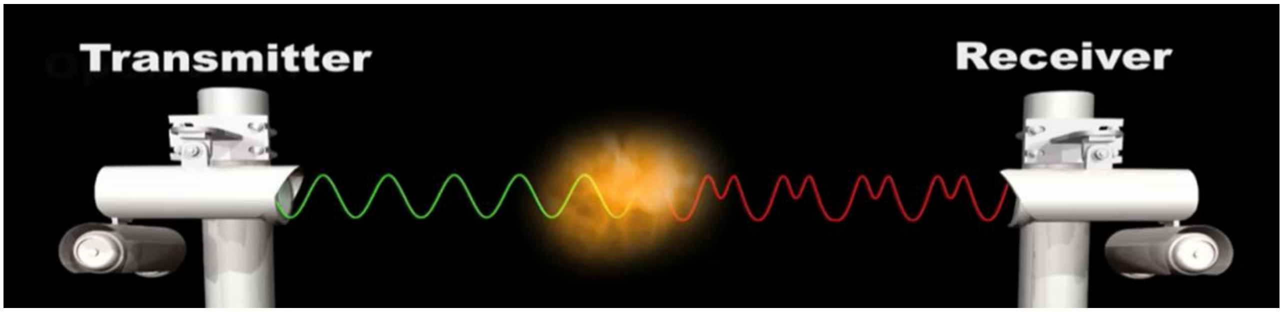

Figure 6. ELDS™ systems use a transmitter-receiver configuration to detect and measure gas concentrations at specific target gas absorption wavelengths over distances of up to 200 meters

Figure 7. ELDS™ systems installed in field operations.

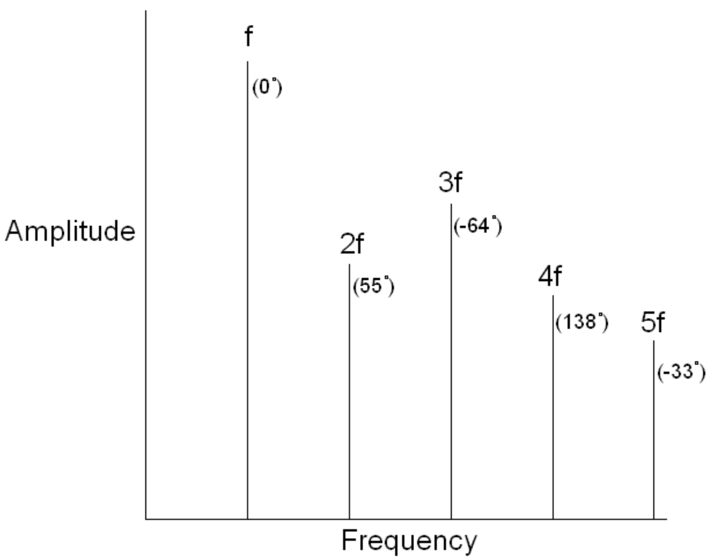

Figure 8. Harmonic Fingerprint produced by scanning a H_2S absorption line at 1589.97nm.

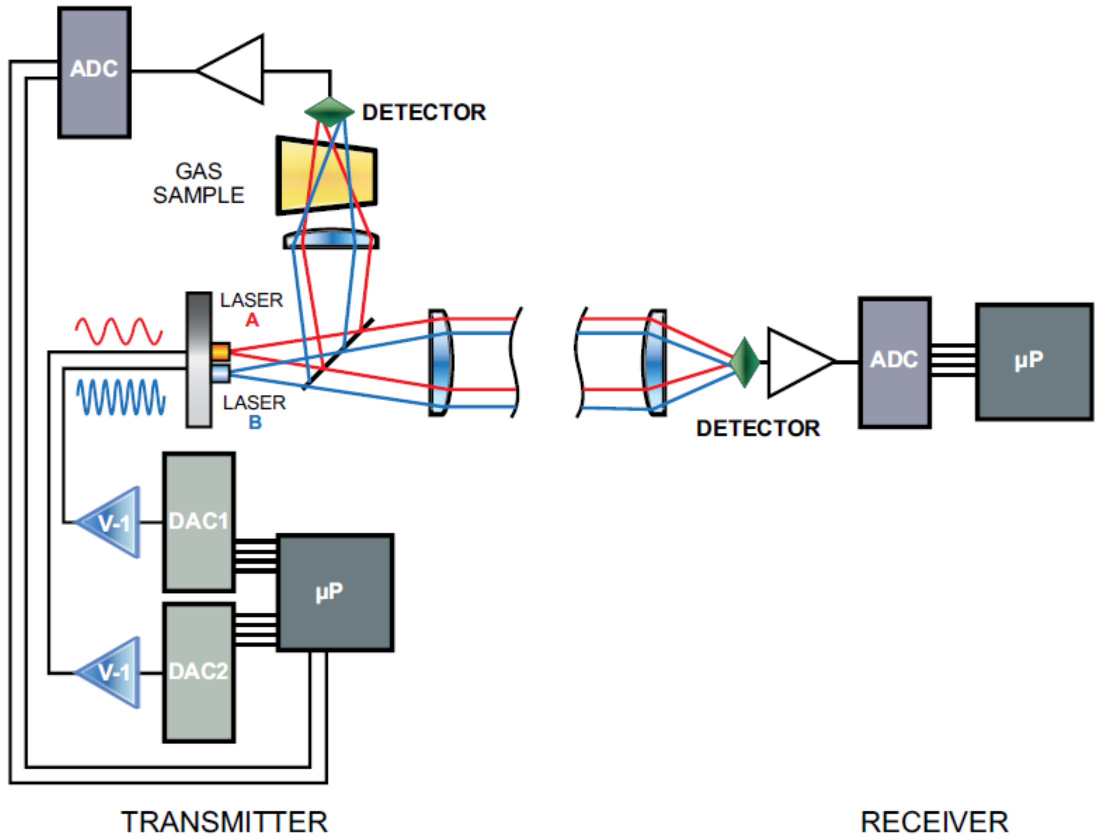

Figure 9. The transmitter unit sends up to two beams of modulated laser radiation through an open path which is to be monitored for the presence of the target gases. The transmitter unit uses its target gas sample to maintain Harmonic Fingerprint lock of its laser diode(s), and in so doing ensures that any absorption of its output beam by target gases in the monitored path will introduce a Harmonic Fingerprint onto the beam. The receiver unit analyses the detected signal, looking for the Harmonic Fingerprint(s) which it knows will be produced by target gases in the monitored path. The receiver unit measures the amplitude of any Harmonic Fingerprint components in the signal reaching it to determine how much, if any, target gas there is in the monitored path and sends a signal to the control system.

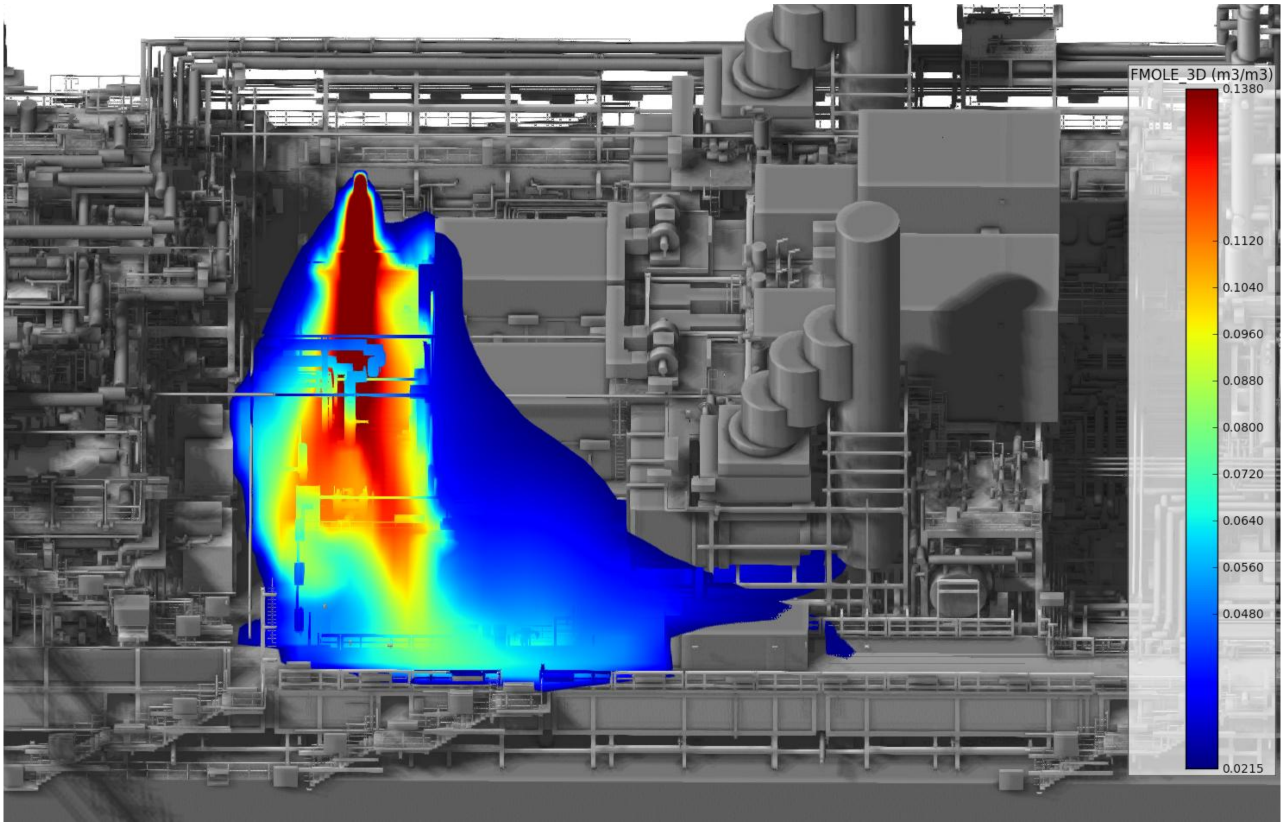

Figure 10. Illustration of a gas release simulation resulting in a hazardous flammable cloud scenario (1,250m^3) in the power generation module (M09). The dimensioning cloud sizes for this modules 695m^3. Concentration contours from 50% LEL (lower explosive limit) depicted in deep blue, to UEL (upper explosive limit) depicted in dark red, are shown.

Dimensioning cloud size

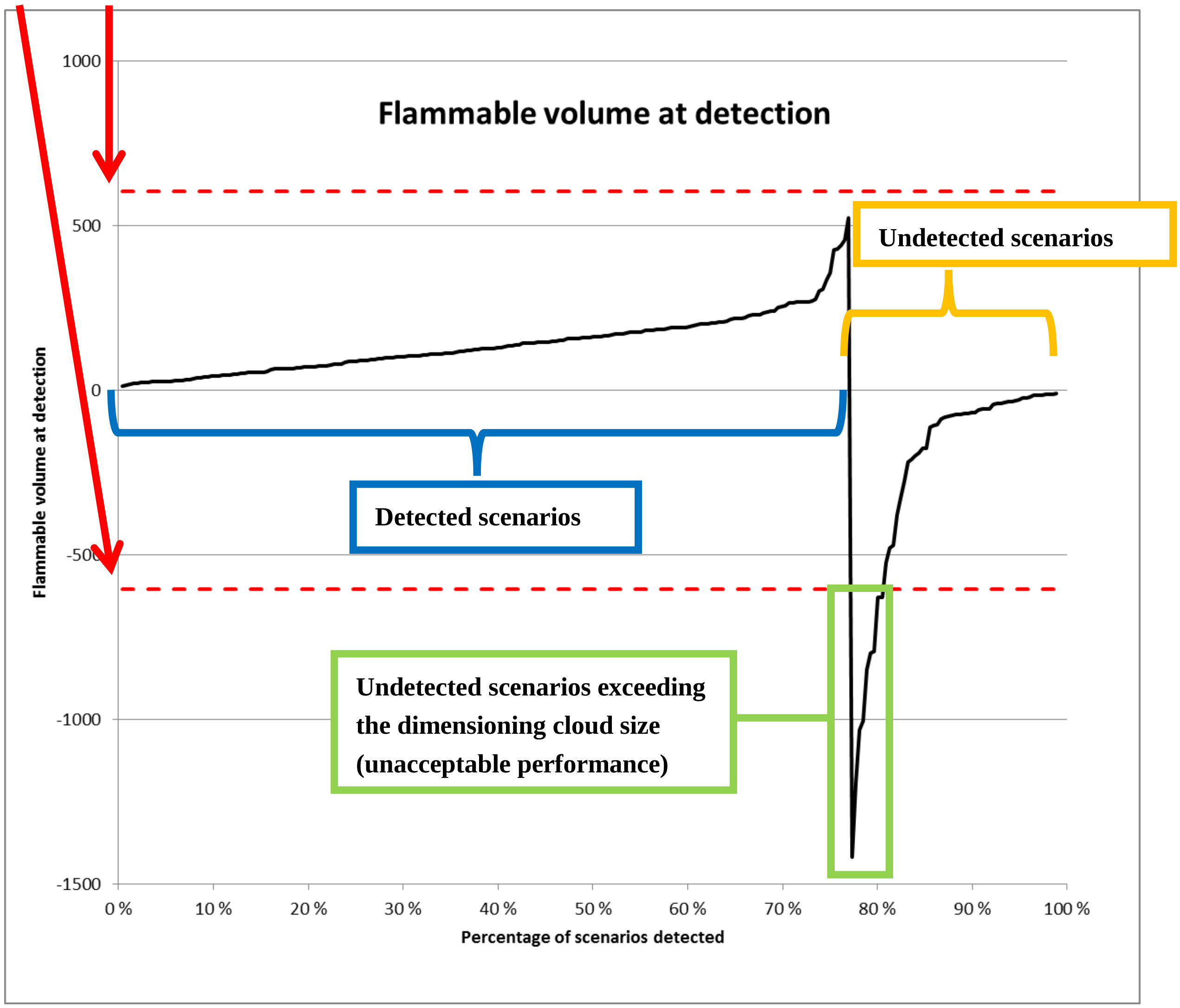

Figure 11. This is a sample graph that depicts important parts of cloud size at detection. A curve which dips below the lower red line represents undetected scenarios over the threshold size, which means the GDS does not satisfy the performance criterion. If the curve crosses the upper red line, this represents scenarios which are detected, but after the cloud reaches threshold size.

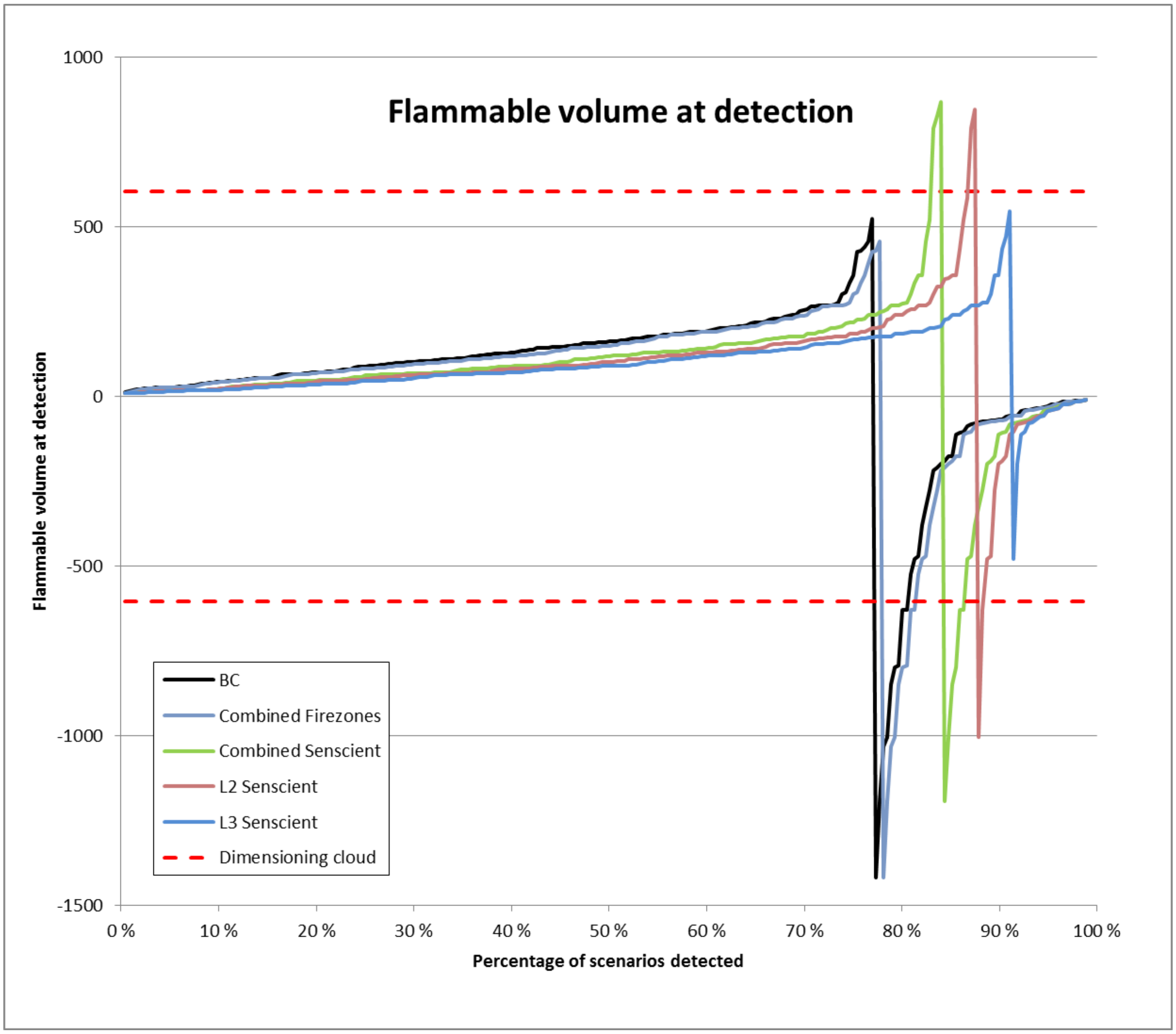

Figure 12. Gas detection simulations and optimization results for module M02 (water injection area). The GDS solution illustrated by the blue curve entitled "L3 Senscient" was selected for implementation. With this solution, all gas leak scenarios bigger than $604m^3$ (the dimensioning cloud size for module M02) are detected before reaching that size. The curve does not cross any of the red lines and satisfies the criterion for hydrocarbon detection.

Figure 13. An ELDS™ transmitter unit installed on the main deck of the Terra Nova FPSO.

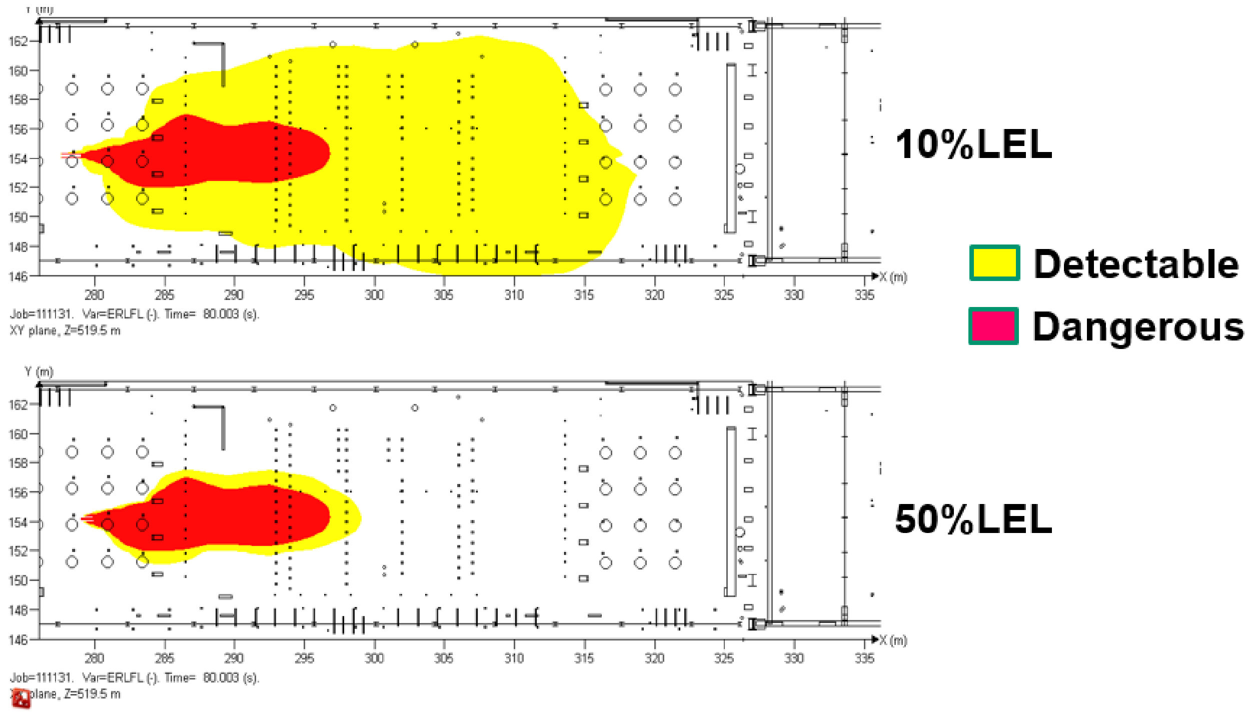

Figure 14. Flammable and detectable volume for a simulated gas leak scenario for two different detection thresholds.

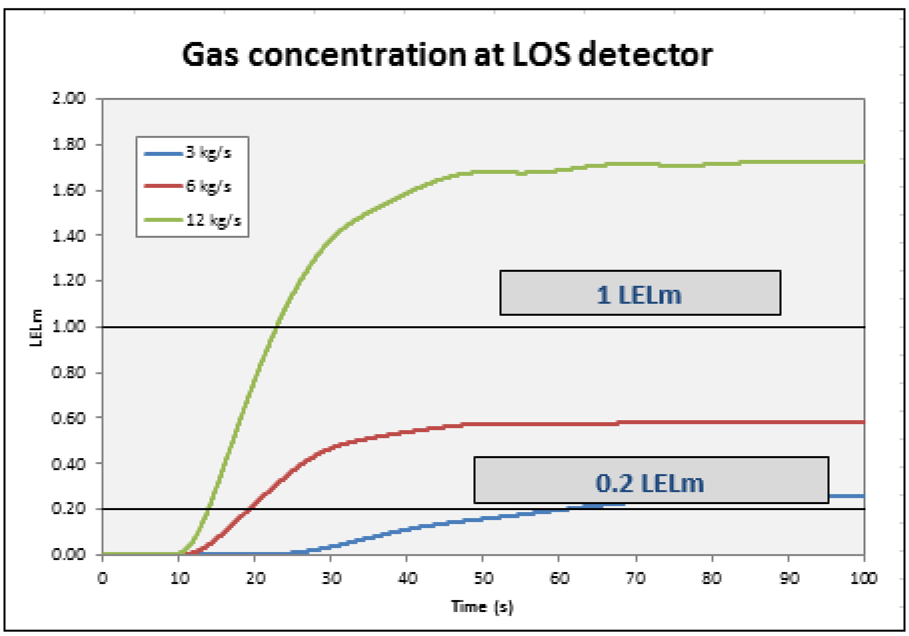

Figure 15. This graph shows the response of an LOS detector to several simulated gas leak scenarios (only leak rate is varied between these scenarios). For the 12 kg/s leak, the difference between a 1 LELm and a 0.2 LELm threshold is a difference in detection time of 5-10 seconds. For the 6 and 3 kg/s leaks, however, a detector with a 1 LELm threshold will not give alarm even as the cloud reaches steady state.