Benefits and Hidden Dangers in the Application of ISA TR84.00.07 in the Petrochemical Industry

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INTRODUCTION

With the increase in prevalence of Fire and Gas detection technology in the Petrochemical Industry, deciding on where to locate these detectors based on the hazard they are intended to mitigate has become far more open to scrutiny. As a result, different methodologies on how to 'map' detector layouts have emerged in the last decade. Fire and Gas Mapping however has been applied by some for over 30 years and is not as new an application as some would suggest.

To emphasise the dangers of fire and gas hazards specific to the process industry, there are many potential forms in which a fire or gas release can impact on an asset. Certain applications can present the potential for a gas jet/ liquid spray fire where pressures exist in the stream; also a possibility are flash fires/ fireballs, Boiling Liquid Expanding Vapour Explosion (BLEVE) and hydrocarbon/ chemical pool fires. Gas releases can present an explosion hazard in congested areas, a hazard to adjacent areas through migration, as well as providing the potential for toxic gases within any given stream. It is therefore critical that an appropriate methodology and knowledge base is applied to detect the potential fire or gas release at an acceptable stage along the event timeline. The application of available technology must be chosen wisely as each detection technology will respond differently to each potential hazard. The limitations of each technology must be noted and accounted for within the design, and the methodology must be clear enough to allow this. It is all too apparent the potential for disaster present within the industry if inappropriate design of fire or gas detection is applied.

As the process industry moves towards the reduction of the potential for 'fail to danger' in safety related systems (with an increase in the prevalence of IEC 61508 and IEC 61511), it is of great concern that designs of fire and gas detection technologies (whether one feels this can be classed as a Safety Instrumented System [SIS] or not) applied today still provide this potential, and of greater concern, these drawbacks may never be accounted for in design.
In this paper, the guidance within ISA TR84.00.07 [1] in particular shall be reviewed with respect to fire and gas detection design in the process industry.

Also to be discussed are the certain areas where no available alternatives exist in detecting the hazard in question, where special provisions in design must be included and validated by competent professionals in the field of fire and gas detection. These are cases where the designer must accept drawbacks of the technology available. This alludes to a philosophical and practice question; does a completed F&G Mapping model equate to an adequate demonstration of competence? This paper will evaluate the current methods of dealing with such a scenario, question whether there are dangers associated with putting too much emphasis on the results of the software applied (and how it’s applied) during the mapping stage of the design, and highlight the dangers of not applying validation mapping tools at all.

PURPOSE OF DETECTION

In order to effectively account for the factors discussed, we must apply a method of design which shall account for the hazards, and sufficiently display that the appreciation for the hazards has been met with adequate design. One such method is through the assignment of performance targets and is generally the most widely applied method of designing F&G, and is alluded to in ISA TR84.00.07.

The method of setting fire and gas detection performance targets serves several purposes:

- The performance targets formally record the Operator's expectations of the system. For this the Specifier needs to be able to discuss hazards in terms of the damage they can cause (type of fire, time to escalation, tolerable levels of damage, etc.);
- The method then has to communicate the required system performance and philosophy to the system designers. This should be done in terms which can be related to the layout, quantities and types of detectors, and to the system controls and outputs;
- Lastly, the method should provide a clear set of criteria against which the design can be reviewed.
- This methodology requires that the Specifier determines for each area of a site:
    - "What are the consequences we are trying to prevent?”
    - "What hazards can lead to those consequences in this area?”
    - "What are we expecting fire or gas detection to do which will give us confidence that we can prevent these consequences?"

This approach (which should draw on data from sources including the operator experience) will define the minimum size and nature of the hazard the system is intended to detect and mitigate.

FIRE DETECTION IN PROCESS AREAS

PRACTICAL APPLICATION OF OPTICAL FLAME DETECTION

In external environments where hydrocarbon hazards exist, the industry standard form of fire detection is typically optical based flame detection. So why use optical based flame detection in these environments? As one can imagine, the open based designs of most oil and gas structures can expose personnel to extremely harsh, unpredictable conditions. For this very reason, it is entirely unacceptable to rely upon standard smoke/ heat detection within one of these highly hazardous areas to detect a fire, even if the detection target is a fire of significant Radiant Heat Output (RHO). As the role of fire detection is to mitigate an incident before it becomes a Major Accident Hazard (MAH), designing to wait until enough heat is generated from a potential fire to activate, for example, a heat detector located on the ceiling of a 10m high process module is simply unacceptable.

From this we can conclude that a detection technology which can detect a flame before getting to this level is the requirement. This then leads us onto specifying fire sizes which one would aim to detect. As the detection objective is to mitigate the hazard, we must ensure two important factors are met. One is that our target fire size is small enough that it will allow either manual or automatic control actions to be undertaken in a safe and successful manor before the ‘potential fire size’ is realised, and furthermore that appropriate executive actions are present in the area. For this to happen we must ensure that an accurate fire size is specified both for alarm (where the fire can be dealt with manually), and for control actions (where the fire in the area, and the hazards that area poses, are great enough that we can no longer rely on an operator to activate the protection, before a MAH is realised).

This brings us to the guidance within ISA TR84.00.07. As a performance based document, the guidance regarding optical flame detection is intentionally open ended providing the engineer options. While this is important to be retained, without any over encompassing F&G design specification of minimum requirement, compliance may be achieved with ISA TR84.00.07 but the design may still be inadequate for that particular region/ hazard. This therefore traps the designer in a loop that 1) there are no specific international or regional standards which provide enough information to design an appropriate system; 2) the appropriate guidance document (ISA TR84.00.07) which does reference F&G is intentionally vague and therefore difficult to fully design from, if the user does not have previous experience in design. This document contains a natural assumption that it is applied by ‘competent’ F&G professionals[1]; and 3) it will be very difficult/ impossible to create a document which bridges this gap.

1 It is important to note that ‘competent’ is a very difficult quality to demonstrate. Naturally with performance based design, we can see significantly varying degrees of competency, and also cross field competency issues. An example of this is an expert in computational fluid dynamics (CFD) designing a F&G system under ISA TR84.00.07. The individual will no doubt be very competent within the field of CFD, however if that individual has no direct F&G experience, the design may be seriously lacking in several crucial areas. This is an issue experienced in commercial fire engineering and is expertly evaluated by Michael Woodrow, Luke Bisby and Jose L. Torero of Edinburgh University [13] and certainly applies to safety design in the process sector.

As the ‘grey area’ of F&G has been around for decades, some major operators have generated their own in house method of designing F&G. Therefore, in order to generate an independent F&G design document today, many of these companies would have to be told they have been doing it ‘incorrectly’ which could be unacceptable to many - also where no undetected major incident has happened, who is to say the design has any shortcomings? Therefore to generate this document, representatives from these operators must be involved and therein lays the problem. With all these parties included, any resulting design guidance document simply will not have specific and direct guidance. For example if one operator uses ‘Effective Viewing Distance’ to assess flame detection coverage and another uses Radiant Heat Output (RHO) with differing values (despite these methodologies having a direct relationship), a consensus will not be made to the exact characteristic to be employed and we end up back at the start with non-specific, open ended guidance. When this document is then applied in a review, and RHO is selected by the designer in order to comply, this can then be queried by the operator and no specific reference can be given from where the values come from - unless working for a major operator who has a F&G design technical practice which can be explicitly referenced.

Weighing up all of these factors leads to a very ambiguous compliance requirement. The potential for over complication of the more straight forward and well understood areas of F&G design to gain some form of commercial edge from consultants can become prevalent, along with the cover up of lesser understood, more complex principles with an aesthetically pleasing output to distract the reader. This is something which unfortunately the ISA TR84.00.07 document has given rise to, with very little guidance on which method is best applied to a specific application.

In theory designing for compliance with a specified document can be straightforward; however there are a number of underlying issues which can catch out the designer if he/she is not experienced in the field of fire and gas detection. Mapping the area using a 3rd party software while applying no F&G engineering principals, or designing the F&G system by hand with no software assistance, can have very costly consequences (for both business and personnel). One of these issues is that of the effectiveness of the detector – how do we interpret the detector manufacturer when they specify the capabilities of their product?

It is important not to misinterpret this. The manufacturer of the detector is not misleading the client into the capabilities of the detector. With reference to flame detectors, the detectors have to be capable of detecting the fuels specified within their manuals at the specified distances if they are to achieve certification from an approved body (e.g. Factory Mutual). What the designer must be aware of is the effect the environment will have on these detection characteristics.

The environment in which these optical flame detectors are to be applied can be harsh, variable, and unpredictable to say the least. It is important to note then that there is no difference in the devices which are installed in the frozen wilderness of the Alaskan Prudhoe Bay, to the bleak Saharan desert of Algeria. Occasionally we have sites which experience both extremes, for example the Baku Tbilisi Ceyhan (BTC) pipeline pumping stations, which in some months of the year can resemble a desert environment and, in the winter, can resemble the landscape of the Arctic.

We also have constantly changing environments day to day in areas like the North Sea where it is not uncommon to have heavy fog in the morning followed only a couple of hours later by clear skies, calm seas and bright sunlight. This is evident in the following figures which show a comparison of summer and winter conditions in Aberdeen, Scotland for example.

Figure 1: Site in summer

Figure 2: Site in winter

As most of the flame detectors present on the market are attempting to detect similar forms of radiation emitted from those present in our everyday environment, this can give rise to the potential for false alarm, or desensitisation to these stimuli. An obvious example of this would be the largest fire in our solar system, the sun. When a flame detector is designed to detect radiation from a fire, the sun can have an interesting impact on what we achieve from our flame detectors. This is one of the most fundamental issues when relating to flame detection design, and one which has very little coverage within ISA TR 84.00.07. The effects of the environment on the application of optical based flame detectors is an issue which ISA TR 84.00.07 must be updated to specifically address.

For further information on flame detection technologies see ‘Desensitisation of Optical Flame Detection in Harsh External Environments’ [2].

FLAME DETECTION PERFORMANCE TARGETS

Where the need for fire detection has been identified, the required performance of the fire detection system can be specified considering the predicted fires and the consequence of those fires. The performance specification (Grading) defines flame detector viewing distance thresholds for alarm and action(s).

The base area (e.g. pan size) of a fire is not a good measure of the damage a fire can do. A small propane torch flame, for example, can be much more aggressive than a larger diffusion flame. For this reason, for hydrocarbon risks, we can define a fire hazard by its Radiant Heat Output (RHO) specified in kW. RHO gives a good indication of the potential damage and the probability that it will escalate or cause loss. Some form of variation of RHO is the most common target when looking at flame detection, for example the ‘effective viewing distance’ (often referred to as ‘D’) can be traced back to the RHO methodology.

The typical fire sizes used in design are generally smaller than those associated with escalation, for example one should not design based on the fire sizes stated in a Control of Major Accident Hazards (COMAH) document. This may be the worst case scenario fire size with respect to damage which can be caused, but it is not the worst case scenario fire with respect to detection. If the fire detection system is designed with this large fire size as the target, we can reasonably assume that all fire sizes up to the worst case may not be detected.

Table 1: Potential Offshore Hydrocarbon Risk Area Grades and associated Fire Sizes

Grade	Fire Size (RHO) Alarm	Fire Size (RHO) Control Action
High	10kW	10kW
Medium	10kW	50kW
Low	100kW	250kW
Special	Special - to be defined if none of the above is suitable.	Special - to be defined if none of the above is suitable.

ISA TR84.00.07 discusses differing ways to assign performance targets including one such method allowing the application of functional safety principles to F&G detection design. It is widely accepted that F&G detection be treated in an alternate way and performance targets be assigned in a different manner. In order to ensure the system is adequate (in more than just a pass/fail percentage of acceptable coverage of an area as a typical SIS would be reviewed), there are far more variable and unpredictable elements of the design which should go hand in hand with the mapping of the area. One area with 70% coverage from the detection system can actually have more appropriate coverage than an area with 90% coverage, dependent upon the specifics of that area (e.g. what the hazards are and where the blockages are located). This Semi-Qualitative option is available in ISA TR 84.00.07 should the designer prefer this application. The danger is in those designing F&G from a predominantly instrumentation based background who apply only SIL related principles of design in the evaluation of a F&G system (purely due to familiarity and experience in this field), without understanding the full strengths and limitations of each approach, which fail to be fully detailed within the document.

FLAME DETECTOR MAPPING

In order to ensure a facility is adequately covered based upon the hazards and the associated risk, the area can be mapped to ensure the given target fire sizes are adequately detectable, as is recommended in ISA TR 84.00.07.

Flame detection mapping software provides a percentage coverage of each analysed area, and is a useful tool in determining whether the operator’s F&G philosophy is adhered to, and can be a useful tool in demonstrating compliance with many pieces of guidance relating to F&G mapping, including ISA TR84.00.07, along with optimising the F&G layouts.

The mapping software is only a small portion of a review of the flame detection however. Often a great deal of weight is placed on the mapping software as this provides the outputs in a review. While this is very important, of greater importance is the knowledge and certified competence of the designer regarding flame detection devices and their applicability to the proposed environment and hazards.

The guidance in ISA TR84.00.07 recommends that fire detection mapping may be carried out to ensure the design is adequate but few expanding details are provided. While mapping has been around for decades and has been applied by many of the major oil and gas operators, this was the first time an independent guidance document had included this as a recommendation. This signified a noteworthy step forward for F&G design and has increased the market for F&G designers significantly. While this is good for the industry, there are a number of recorded instances where a heavy reliance simply on mapping software has been utilised in design, and the fundamental aspects of good practice have been secondary, resulting in costly errors in design.

The following figures show a simple example Flame Detection Assessment.

Figure 3:3D Assessment Micropack Test Ground

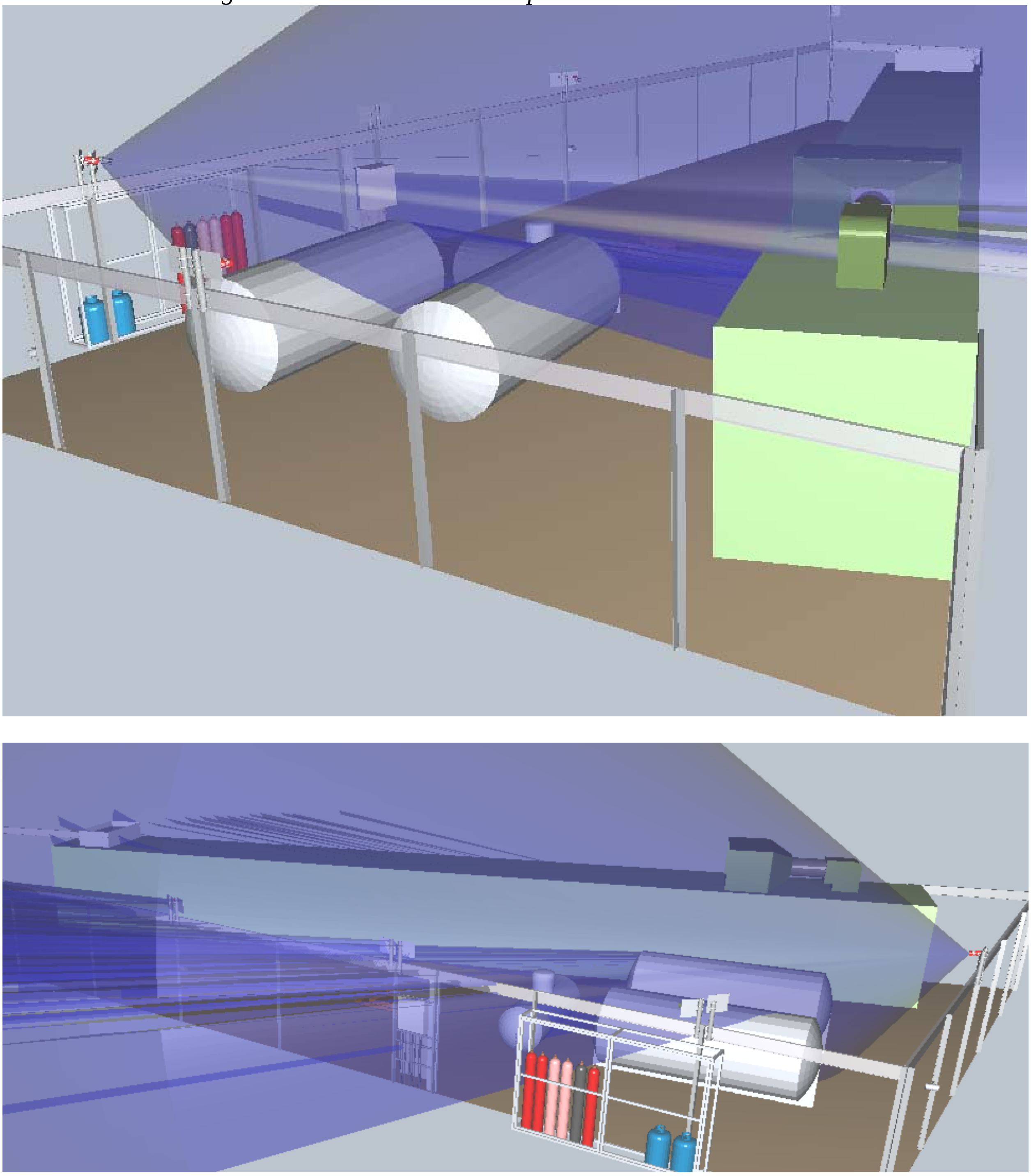
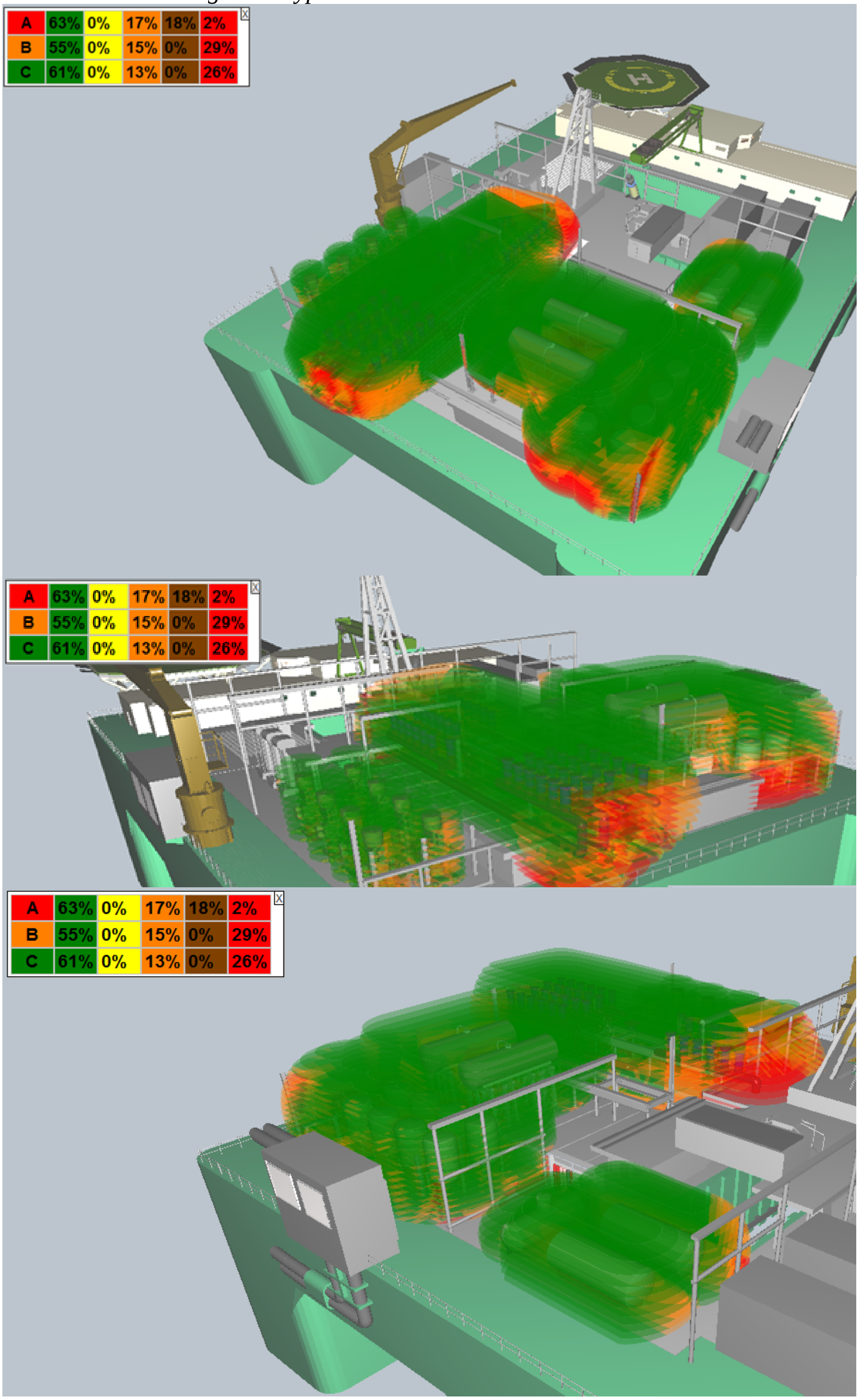


Figure 4:Typical 3D Flame Detection Assessment



The most important points to note in Flame Detection Mapping are: always account for blockages and shadowing; and understand the design aspects other than just percentage coverage of the area, while also ensuring that multiple differing target fire sizes can all be analysed in a single assessment, as this is mainstay in most of the widely applied F&G design guidance documents, including ISA TR84.00.07. Should each different grade need to be assessed individually, a holistic approach cannot be analysed.

Something which is limited in ISA TR 84.00.07 is how critical the selection of mapping tools can be. It is crucial to ensure the software tool being applied will comply with the basis of design (i.e. operator specific engineering technical practice), and ISA TR 84.00.07 itself. The science behind fire dynamics and gas cloud behaviour/ fluid dynamics is complex in nature, but does not appear to carry the same weight as other engineering disciplines. If one were to design a structure for an offshore jacket, a competent structural engineer would be approached. That group would then apply any software tools which would have been developed alongside other competent structural groups and validated to ensure adequacy. Why therefore should the design of a safety system for the mitigation of the phenomena of flame spread and gas accumulation be carried out by anyone other than a qualified and experienced fire safety professional? It is therefore of pivotal importance that if a tool is to be used in the design of a F&G system, the tool itself must be designed by those with extensive experience in the field of fire and gas detection.

This also highlights the requirement for those applying the software tool to demonstrate an adequate level of competence, as would be the case in most other professional industries.

FLAMMABLE GAS DETECTION: HAZARDOUS AREAS

PRACTICAL APPLICATION OF FLAMMABLE GAS DETECTORS

The main point to note regarding flammable gas detection is that it is virtually impossible to detect all leaks. It is also important to note that the fundamental principle of process area gas detection is not to detect leaks, but to detect clouds. It is therefore imperative that only those clouds which would be of concern become the target. In the past, locating flammable gas detection next to the leak source was commonplace, however it soon became apparent that even when the slightest increase in pressure is present, locating detectors close to those leak points becomes detrimental to detection reliability, and alternative measures must be sought. This can however still be seen to be practiced at the time of writing in some regions of the world.

As with flame detection, the technological advancements of gas detection became a necessity as the failures of each technology became apparent. Initially the industry applied catalytic bead detectors which relied on the gas being burned within the detector, which subsequently produced a gas reading equivalent to the LEL/ LFL within the environment. The application of these detectors was fraught with issues as noted below:

- The catalyst could become poisoned (leading to unrevealed failure).
- Sintered disks could become blocked (leading to unrevealed failure).
- Sensors could 'drift' and require regular calibration.
- Exposure to high concentrations of gas would damage the sensor and impair performance.

In addition to the disadvantages listed above, catalytic gas detectors would have poor response times. Previous tests concluded that the response time of catalytic gas detection is approx. 30s.

As the industry moved away from Catalytic detectors for general hydrocarbon detection, IR detectors soon took their place. Infrared gas detectors provide a fail-safe indication of the presence of potentially explosive atmospheres, with some operators in Norway going as far as to state the current generation of IR point can be installed and will never require maintenance - only reviewed in the event of a fault. These devices offer the benefit of being free from contamination/ poisoning.

The drawbacks which are still encountered however include the fact that, as previously stated, they cannot respond to the presence of specialised gases like Hydrogen, and can only be used to infer toxic detection under very specific conditions. Related to this, these devices do not respond well to multiple gases potentially being present - care must always be taken to ensure the reading is never an under-estimation of the flammable atmosphere present. It is important to note here that this is the kind of information a F&G Mapping software cannot provide, and where competent professionals within the industry should be consulted. It also reflects an area under represented within ISA TR 84.00.07.

GAS DETECTION PERFORMANCE TARGETS

After the Piper Alpha accident in 1988, it became apparent that there was a significant body of academic knowledge relating to the behaviour of hydrocarbon gas 'explosions' in congested process plant, however this was kept mainly within academia and the information was not shared to those practicing fire and gas review work in the North Sea.

In order to change this, UK HSE conducted a literature review and released the guidance design document OTO 93 002 [3].

The aim of a flammable gas detection system is to detect the presence of flammable gas accumulations which are of sufficient size that, if ideally ignited, could cause damage through the effects of explosion. One of the primary methodologies adopted for detecting gas release is through application of a target gas cloud size. The size of gas accumulation requiring detection is usually based on the volume of the area and the levels of confinement and congestion throughout. This approach is essentially drawn from the UK HSE publication OTO 93-002 which presents data on the overpressures associated with a range of ignited gas accumulations. In summary the report concludes that a 6 metre cloud of stoichiometrically mixed methane will not, if ignited efficiently in an area with a blockage ratio of 0.3 – 0.4, produce flame speeds greater than 100m/sec or 125m/sec respectively. These flame speeds are associated with overpressures of less than 150mBar, a widely accepted minimum threshold for pressure–induced damage. Increased congestion or blockage ratios in an area are likely to decrease the cloud size required to achieve a damaging overpressure.
This approach has more recently been reviewed by the Institute of Chemical Engineers (IChemE) [4] in light of the more sophisticated methods of reviewing gas cloud behaviour, and as such has generally been accepted by most operators, who now adopt a spacing philosophy behind their gas detection design. These two methodologies (spacing vs target gas cloud) are not to be confused as using the same design criteria, however, as is often the case.

While the objective, experiment-based 5m rule was generally adopted, and is still regarded as a major step forward, it did contain gaps associated with design of flammable gas detection in petrochemical installations. These included air intakes to hazardous areas; 'unconfined' areas of plant; and area perimeter detection. These issues were only addressed by individual operator guidance documents, 3rd party F&G specialists, and more recently ISA TR84.00.07.

In conclusion to this form of performance target, this method has be applied in many sites worldwide, and is generally accepted by certifying and legislative bodies as an acceptable level of gas detection design.

The target gas cloud methodology provides a robust design principal, but further review is required. Also missing from the review were such areas of a significantly higher degree of congestion where explosion overpressures can be achieved from clouds smaller than 5m in diameter. Methods such as using Computational Fluid Dynamics (CFD) tools to analyse the effects of blockage and the subsequent potential for explosion overpressure for specific sites may have a place within practicing gas detection design specialists, but a robust guidance on how to do this appropriately is yet to be produced.

VOLUMETRIC VS SCENARION MODELLING - DOES ISA TR84.00.07/ CURRENT LITERATURE DO ENOUGH TO *OBJECTIVELY* DIFFERENTIATE BETWEEN THESE METHODS?

All computational modelling of a physical environment and events requires a compromise between accuracy, usability and more recently, aesthetics.
The spherical gas cloud model is very simple to specify and use. Those who do not fully understand the method and its application, however, can presume it will produce pessimistic assessments of a gas detection system's performance, and therefore assume it will result in some very onerous requirements of the system. When this method is fully understood and applied (depending upon the application), an engineered and optimised approach can be achieved which has been proven to reduce detector numbers from a scenario based approach, while providing a much safer system in the protection against explosive overpressures upon ignition of gas clouds.

It is true that if a scenario based approach is taken, and a limited number of representative scenarios are run (even up to 500,000 scenarios could still be classed as limited), this approach can show that detector numbers can be removed, but what is failed to be specified is how many scenarios can be claimed to be sufficient. To an extreme extent, if one scenario is run, then detection can be placed where the leak is 'likely' to travel. This is obviously not acceptable, but the detector numbers would be significantly reduced. Does this automatically mean that scenario based mapping will allow detector numbers to be optimised in most/ all cases? The argument appears at the point of how many scenarios we claim to be a sufficient number. For most open based facilities, if an acceptable number of scenarios are run, the user will generally find that the gas can accumulate at any point, and a volumetric approach should be taken anyway, leading the designer to ask why, in such a standard application, one would use the time and money in applying a scenario based analysis?

This is not to say the scenario based approach has no place in gas detection design, it most certainly does. It is widely accepted by academics involved in the practice of gas detector placement, however, that this method should be reserved for specialised cases such as turbine/ internal enclosures, where the environmental conditions at the time of release can be far more accurately programmed. For further reading on this see Evaluation of Computational Fluid Dynamics vs Target Gas Cloud for Indoor Gas Detection Design [5].

Bringing the discussion back to the guidance within ISA TR 84.00.07, there is very little by way of discussion on these issues such that the designer can be fully aware of which method to apply in any given application. When we also look at what little literature is available on the subject, it is clear that little has been written by those conversant with the application of gas detection technologies in the process industries, as much of the comparisons are heavily weighted towards tests favourable to the scenario based method. Benavides-Serrano, for example, 2015 [6] analyses the detection response to specific scenario based leaks, rather than clouds which would actually be required to result in control action. This shows that these comparisons often lack credibility by comparing apples to oranges. Much of the literature available, also incorrectly reflects a suitable volumetric gas detection design, instead applying a 5m grid of point gas detectors, which results in a number of detectors no performance based volumetric detection design should result in. The issue here is that in comparing the two methodologies to examine which methodology optimises the system more effectively, the volumetric approach is automatically at a disadvantage as it is unfairly represented by not applying performance based principals, or the detection technology available in the market today to optimise the detection layouts. This will be discussed in greater length in the following section.

This can ultimately result in the designer opting to apply a methodology not suited to their application, resulting in a significantly extended review period (such as when using scenario based gas mapping in a standard process site), resulting in a greater number of detectors than required (as the target becomes ‘leaks’ rather than clouds).

When applying a scenario based approach, it is also crucial to apply suitable software. This is widely accepted to be the application of adequately validated Computational Fluid Dynamics (CFD) tools, and that application of 2D consequence modelling tools are simply unacceptable in representing the complex nature of fluid dynamics, and the problem to be solved in scenario based mapping. Within the process industries there are many CFD models applied, all with varying degrees of validation. Regardless of the package applied, it is vital to be aware that there are a number of constraints within which these models operate, and it is crucial that any CFD model applied must have adequate validation for the problem in which it is being used to solve. This is not to say these models are not appropriate when applied correctly, but in a similar situation to a F&G mapping tool (and in fact even more so), simply having access to a CFD modelling tool does not qualify one to adequately analyse the complex nature of the phenomena it graphically represents.

MISREPRESENTATION OF VOLUMETRIC COVERAGE

We often see comparative analysis of the target gas cloud method vs scenario based/ CFD analysis which grossly misrepresents a performance based geographical approach. An example of this is in ‘Performance Based Gas Detection: Geographic Vs Scenario Based Approaches using CFD’ [8] whereby an area is specified a target 5m diameter cloud size, with only point gas detectors applied. This results in a detection layout that no performance based geographical approach would recommend. This layout can be optimised by applying widely available gas detection technologies not addressed in the paper, and a performance based approach to the target cloud can also be applied (i.e. not simply applying 5m as the cloud size, but determining what cloud presents the explosion overpressure within the area).
Other misrepresentation of this methodology include ‘Performance-Based Gas Detection System Design Using Computational Fluid Dynamics (CFD) Modeling of Gas Dispersion’ [8], and ‘A Quantitative Assessment on the Placement Practices of Gas Detectors’ [6]. These papers both fall under the issue of misunderstanding the basis of the OTO objective. Within Reference 9, the conclusion based on geographic coverage results in a large number of point gas detectors. The scenario based approach results in a small reduction of point detectors. The issue is that a performance based, geographical approach, would apply a maximum of 4 OPGDs to this area, potentially only 3. This is approximately 10% of the total number of

detector initially used to demonstrate geographical mapping, and is also before optimising the target gas cloud size.

It is noted that some in the petrochemical industry are moving towards a scenario based approach with the intention of reducing the overall detector counts, however this example shows that in fact an even further optimised design can be achieved using geographic based coverage, while also providing an auditable system that will not have a significantly different detection layout depending upon who has carried out the analysis. This can be seen in The Benefits of Using CFD for Designing Gas Detection Systems [9], when the different detection layouts are analysed based on the scenario based approach.

While some may apply scenario based design with the aim of reducing detector numbers, others claim this can improve the detection performance over the geographic design. There appears to be no baseline from which to measure this against, and again there is a flaw in the data set used in this analysis. There is an inherent assumption in this argument that the recommendations of the OTO were actually applied in industry.

Taking a walk across the vast majority of offshore installations or congested onshore petrochemical sites will very quickly highlight that the majority of sites barely took note of the OTO recommendation, and as such gas detectors are still located at locations where gas will ‘likely’ migrate to. Therefore the argument that there are still a significant number of undetected releases despite the OTO recommendations, is not an adequate critique of the suitability of the methodology as, for the most part, it is simply not followed. An interesting area of future research would be the analysis of significant undetected gas releases on sites which follow the target gas cloud principle vs. those where the detection configuration was based on likely gas migration.

This also begins to show the issue related to competency in carrying out the analysis. Naturally with performance based design, we can see significantly varying degrees of competency, and also cross field competency issues. An example of this is an expert in computational fluid dynamics (CFD) designing a F&G system under ISA TR84.00.07. The individual will no doubt be very competent within the field of CFD, however if that individual has no direct F&G experience, the design may be seriously lacking in several crucial areas. The same can also be said vice versa. This is by no small measure highlighted by the misunderstanding and misrepresentation of the geographical approach which can be widely seen today.

Benavides-Serrano, 2015, represents a rare published work directly comparing the accepted industry approach of volumetric with other approaches. Multiple comparative approaches for locating gas detectors were evaluated:

1. Random placement of detectors
2. Volumetric approach (5m-target)
3. An optimised leak detection approach (optimising by distance to leak source)
4. Two scenario-based approaches (accounting for a range of dispersion simulation data)

5. A stochastic programming formulation – accounting for a range of dispersion simulation data and utilising a numerical optimisation procedure (including detector availability/voting variables).

The paper demonstrates the potential improvement in terms of detector numbers and time-to-detection possible with such advanced probability and optimisation sub-models. It is simultaneously demonstrated that the performance of such detection arrangements is a function of the scope of leak scenarios modelled where a decrease in performance was recorded when a detector arrangement based upon a randomly selected 75% of total leak scenarios was then tested against the remaining 25% of simulated leak scenarios.

Of great concern however is the result that the volumetric approach performed poorly and in some cases was the worst, of all trialled approaches. A typical criticism of the volumetric approach is the high I/O associated with adding enough detectors to cover an entire area despite varying levels of hazard/ risk that may be exhibited throughout that area. It may be intuitive therefore to consider that the volumetric approach would perform well, in terms of time-to-detection, but at the cost of the onerous number of units required. The surprisingly low detection rate of the volumetric approach however might be traced to, not only a validation method weighted towards leak detection methodologies (not cloud detection like the geographical approach), but also the elevation of implementation of the 5m grid within the simulations. For the volumetric approach detectors were located at the ceiling elevation in modules between 7m and 12.5m in height. In practice, a volumetric gas detector layout would be poorly designed if it were generically located at 12.5m elevation in a typical process module due to the reliance on transport of the gas to such an elevation due to natural buoyancy or momentum from a pressurised leak. For buoyant-in-air leaks typical industry practice would be to locate a layer of detectors a few metres (depending upon local conditions) above the main potential leak point elevation, adding further detectors above if the specific local hazards are deemed to require it. Previous research also shows that the molecular weight of the material release has little bearing on the behaviour of the gas, and that the conditions of release are the primary driver of such an incident (JIP 2000 [10]).

Subsequently only point gas detectors are considered so the potential cost-saving and performance-enhancing benefits of open-path gas detectors (OPGDs) are not included in this study, along with applying a performance based approach that perhaps the 5m grid is too stringent and in this particular occasion perhaps a larger diameter gas cloud, with dilute factor accommodated, may be more appropriate. It is therefore highly conceivable that when applying good engineering practice with understanding of the principals behind its application, the 25 point detectors represented in the analysis could be reduced down to 5 detectors (as a maximum), with a vastly improved detection performance through appropriate detector positioning.

Of great further interest would be the repetition of this analysis with a volumetric layout positioned at a reasonable elevation within the context of the module and local structures, and in relation to specific hazards. Visualisation of the proprietary modules and details of the location and elevation of the most successful optimised layouts, along with a breakdown of locations/directions/pressure range of simulated leaks would complement this work and give beneficial further context to the reader.

Also worth noting is that the comparison of scenario based gas detector placement with the volumetric approach. This could be analysed as comparing apples to oranges due to the fact the volumetric approach is design to detect clouds large enough to present an explosion hazard (as is the intention of gas detection application). The application of scenario based modelling is to detect leaks through analysing the predicted fields of movement of a selection of release scenarios. This scenario based approach could be argued to result in excessive detector numbers in the areas where the leak is likely to propagate, with significant gaps in areas where explosive overpressures could credibly accumulate, which have not been examined in that particular group of scenarios.

This form of analysis has not yet been carried out by any comparative research of the current gas detection methodologies i.e. analyse the effectiveness of a scenario based gas detection design to detect clouds across the facility which would result in an explosion overpressure. It is evident that when the validation is being carried out to compare the two methodologies, validation of the system as a gas leak detection system is often applied, which is ultimately favourable to the scenario based method, and isn't applicable in analysing the performance of the system as intended. This is, however, only true when looking at flammable gas detection in open based petrochemical applications. For specialised areas, or where the hazard permits, the application of a gas leak system may be more appropriate, whereby validation of the design techniques may want to analyse how successful the system is as a leak detection system.

MISCONCEPTION OF OTO COMPLIANCE OFFSHORE

At the time of publishing, the results of Kelsey, 2002, [11] were compared to the offshore statistics from 1992-1999. The JIP release data previously discussed is biased toward larger release rates (commonly 10kg/s, to align with one definition of a major leak), where 70% of simulated releases were defined as major releases, while only 9% of reported offshore releases were classified as major. As it happens however the numbers are well aligned. Major gas releases offshore (1992-1999) totalled n=49 and the simulated major releases constituted n=45, so these groups are actually quite comparable. The Table below outlines these comparisons as well as results data organised by leak classification:

Leak Distribution		
Type	**Offshore**	**Simulated**
Major	9% (n=49)	70% (n=45)
Significant	67% (n=354)	30% (n=19)
Minor	23% (n=137)	N/A
Detection Performance		
Type	**Offshore**	**Simulated**
Major	61%	97%
Significant	60%	97%
Minor	67%	N/A
Total	62%	97%

It was demonstrated that the 5m-spacing model had an excellent detection rate, averaging 97% (of 64 cases) for major and significant releases compared to 62% (of 540 cases) detection success from the 1992-1999 offshore statistics. The Table above breaks these numbers down by release category and it is clear that the 5m-spaced grid outperforms for both large and significant release rates compared to the actual detection success rate offshore. No minor release rates were simulated. 3% of simulated releases were not detected due to a lack of buoyancy following horizontal releases which did not rise to the elevation of the lowest detectors (3.9m) and small releases which did not result in flammable gas clouds corresponding with the low gas detector alarm set-point (20% LEL). These minor releases are the kind of releases which may be detected by scenario based detection layouts, however it is possible these would then not perform as adequately for the larger, momentum driven releases.

Direct comparison of the simulated data with the offshore statistics requires the assumption that all offshore installations have utilised a 5m-spacing volumetric approach as per the simulations. This is underlined by Kelsey, 2005, [12] where the HSE build upon the results from Kelsey, 2002, and investigate further optimisation of the 5m-spaced arrangement. One possibility attributing to the offshore detection results is that the environmental conditions offshore are typically more severe than in the simulated tests thus reducing detection performance of the offshore systems. Having visited numerous North Sea installations, the author is aware that just as there are areas of each platform exposed to high wind flow rates, there are many areas well protected from high flow rates due to the layout of the platform, the result of which is variable depending upon the direction of the wind on a given day. In any case, an average detection rate of 62% by dedicated, fixed gas detection systems in high consequence sites should not be considered adequate.

GAS DETECTOR MAPPING

The gas detection assessment software would typically provide a three dimensional assessment of the volume under review and present the coverage data in elevation ‘slices’. The gas hazard as described in OTO 93 002 was represented in the initial programs by a 5m diameter ‘hard-edged’ sphere of stoichiometric gas/air mix (to this day this is still commonly applied by operators in the petrochemical industry). It was recognised from the outset that such sharp transitions from gas to fresh air were clearly unrealistic (except in some special cases involving very low pressure, cold and ‘heavy’ vapours). In the absence of any data, however, which could realistically be classed as practical, there was no alternative and this conservative approach has been used extensively to assess the adequacy of flammable gas detection arrangements.
As one of many projects initiated in the aftermath of the Piper Alpha accident, a Joint Industry Project was conducted in order to establish the ‘true’ behaviour of flammable gas releases in confined process areas. Part of the data gathered during these tests included behaviour of the initial gas cloud measured by a local three dimensional array of gas detectors.

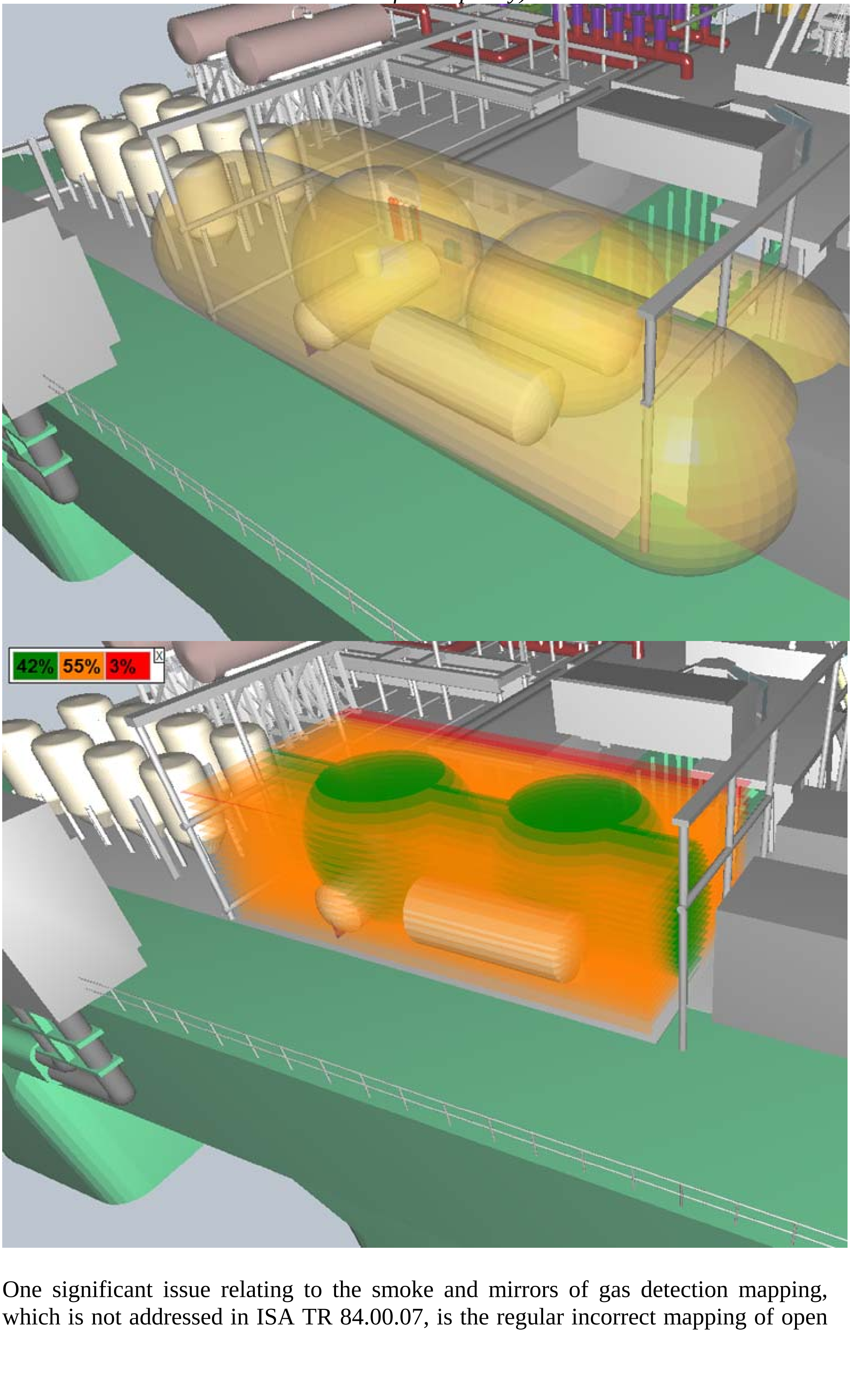
When this was reviewed, this showed (unsurprisingly) that the ‘core’ of flammable gas was surrounded by a diffuse layer, the concentration of which fell as the distance increased from the source concentration (nominally 200% LEL) to a final value of 0% gas in air.

Further study confirmed that it was reasonable (indeed conservative) to assume that the idealized hard sphere was surrounded by a shell of gas of no less than 20% LFL at a distance of 5m from the edge of the 'hard' sphere. This was then used to improve the performance of (particularly open path) gas detection systems.

This approach – the assumption of a diffuse cloud of dilute gas surrounding the core hazard - was incorporated into some F&G Mapping software, but must be applied with care. When applied in an external environment with lower set points than the specified 20%LEL, these dispersion principals can become meaningless, and will typically result in an inadequate system which can result in significant potential for undetected gas clouds providing the conditions for explosion overpressures well in excess of 150mBar. Engineering judgment must always be applied when using this model to ensure this does not happen.

For all of the factors discussed above, we can conclude there is far more to account for than simply mapping the area, and the adage of claiming "the area has been mapped and can therefore be considered compliant and safe" has significant dangers associated.

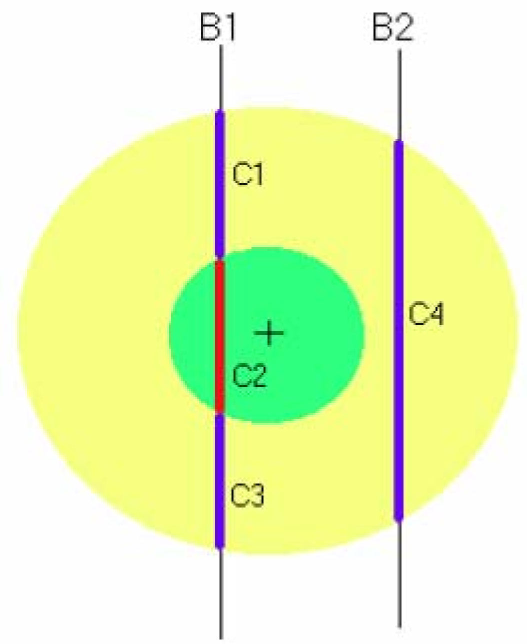
Figure 5: Typical Simple 3D Gas Detection Assessment (Beam Attenuation model inhibited for simplicity)



One significant issue relating to the smoke and mirrors of gas detection mapping, which is not addressed in ISA TR 84.00.07, is the regular incorrect mapping of open path detection systems. In order to accurately map the coverage of these devices, one must understand the detection principles of the technology.

Where the target gas cloud method is selected, we often see open paths showing a simple cylinder of coverage. This is inaccurate of the detection capability of this technology. This method of coverage is suitable for point gas detectors where the target gas cloud will intersect with the point device, providing a gas reading for that point. For an open path device, however, there must be a given concentration of gas across a given length of that beam in order to result in detection.

Figure 6: Beam Attenuation Principles (Beam detectors B1 and 2 with different readings provided by concentrations C1-4)



While this is detail you would not typically expect to find in a performance based guidance document, it shows the potential for inaccurate mapping to be carried out when following ISA TR 84.00.07 and using some commercially available tools. This is of particular concern when, at the time of writing, this is rarely accounted for within mapping software.

CONCLUSIONS

One of the most important factors in the review of F&G systems is to ensure that the implementation of an appropriate methodology based on the application is addressed. There are real dangers in not applying F&G detection adequately and this must be addressed when the methodology is initially determined.

Many operators have their own guidance documents with respect to F&G Mapping, and where these are specified it is important to not only comply with these, but also to have an appreciation of the practical implications of the design, which may not be explicitly reference within the guidance document. One such example is within the ISA TR84.00.07 which provides two different methods of detection design: Geographical and Scenario based.

The issue with ISA TR 84.00.07 is that there is very little guidance for the designer as to which method is more suited to any specific application, and as a result of this we may see unnecessary time and effort being placed on fairly standard applications, and ending up with an excessive number of detectors; or conversely spending too little analysis time in a complex, specialised application, and not placing a sufficient number of detectors in the volume.

ISA TR84.00.07 provides the appropriate starting point of a design basis and intentionally allows the user to apply differing methodologies. This may, however, give rise to those not familiar with F&G design applying an inappropriate methodology based on, for example, a simplified version of mapping which is more easily comprehended but may not be appropriate in the given circumstance; or designers trying to force a methodology which works for other safety systems with which they are more familiar, then justifying this as compliance with an international guidance document.

It is also clear that where any comparative studies have been carried out reviewing the two methods specified in ISA TR 84.00.07, these typically do not adequately represent a well-designed performance based geographic approach, particularly with respect to gas detection design. Such studies will advise that when using volumetric detection, a point gas detector is the only available technology and that a detector will be required every 5m, on a grid based layout. This is either through a lack of understanding of the purpose of the methodology and how it can be used to optimise the system (and also a misunderstanding of what gas detection is intended to do), or worse, it is a misrepresentation of the target gas cloud methodology to imply the optimisation potential of a scenario based approach.

It is also clear that in these comparative studies, scenario based modelling is used to validate a layout generated using a scenario based method. This method cannot be used to validate a volumetric based layout as the volumetric detection layout is intended to ensure dangerous clouds do not remain undetected, whereas scenario based mapping is primarily for the detection of likely leak migrations of gas. Were a validation of where dangerous clouds remain undetected be carried out to compare the two methods, the effectiveness of the volumetric based design would be expected to far out perform that of a scenario based design, however this also would be an unfair comparison.

Whichever methodology is applied using the guidance within ISA TR84.00.07, it is crucial that parties involved on both sides of the project (designers and implementers) are happy with the methodology at kick off, are fully aware of the strengths and limitations of the selected methodology, and work together to ensure the resulting design is appropriate for the specific application.

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