

Session Fourteen Introduction to functional safety standards in gas detection

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Objective:

The objective of this session is to create awareness on gas detection and the various technologies used in gas detection, including the role of gas detectors in risk reduction. Seminar covers gas dispersion & placement of sensors and the considerations that must be given while deciding sensor technology, sensor placement and maintenance of the detectors, with a life-cycle approach. We would also discuss the various standards applicable in the field of gas detection, functional safety applications, including standards applicable to plants & projects.

We would also look at the various traps & nuisance possible, due to incorrect use of standards, controller and the precautions that must be taken while using PLC's and the limitations of using PLC's for gas detection applications.

Introduction on the Presenter:-

- Instrumentation & Electronics Engineer with experience of over 16 yrs in the field of Fire & Gas Detection Systems, Personnel Protection & Rescue tools.
- Worked in the areas of Sales & Service, Product & Application Management and Marketing.
- Design & Engineering of standard & Functional safety F&G Systems & Sampling solutions.
- Project Management of Fire & Gas Systems including turnkey projects.

Gas Dispersion

Behaviour of gases can depend on various factors, including temperature, pressure, chemical & physical properties (including density), environment, ventilation, climate control etc.

Temperature:- colder gases tend to be denser/heavier than air and move down closer to the ground. Hot gases tend to rise, even when they are heavier than air, while light gases when cold will sink. Sources of heat (heaters or machinery generating heat) can also cause convection & movement of gas upwards.

Pressure:- Some gases when compressed turn to liquids and their vapours are heavier than air & drift downwards, while the lighter gases rise up & neutral gases follow the air movement. High pressure gas releases can also cause the release of gases to move horizontally from the point of leak, before it drifts up/down or straight.

Chemical & Physical properties can determine how the gas/vapour cloud can disperse. Some gases turn into liquids under pressure or when cooled or under both conditions. Large amount of gas/vapour cloud can be formed of gas when liquids evaporate and the amount of gas/vapour cloud depends on the physical properties of the gas. Chemical properties determine the Flammability of the substance, while Physical property determines the density and the state in which the substance normally exist (solid/liquid/gas) under normal atmospheric conditions.

Physical Properties:-

Color (vividness of visual appearance)

Odor (distinctive smell)

Conductivity (transmission of heat or electricity or sound)

Solubility (ability to be dissolved)

Density (the measure of the relative "heaviness" of objects with a constant volume)

Viscosity (resistance to flow - stickiness)

Compressibility (made more compact)

Freezing point (temperature below which a liquid turns into a solid)

Boiling point (temperature above which liquid turns into gas)

Melting point

Chemical Properties:-

Flammability (the ability to catch on fire)

Toxicity (the ability to be poisonous)

Radioactivity (giving off ionizing radiation)

Heat of combustion (amount of heat released when the substance is completely burned)

Reactivity with water (what happens when a substance reacts with water)

Reactivity with acids (what happens when a substance reacts with an acid)

Oxidation (the combination of a substance with oxygen)

Environment

Factors such as wind direction and its seasonal changes can affect gas dispersion and so can temperature affect generation of gases & vapours. In outdoor conditions, you may have factor in rain/flooding, while mounting sensors at very low levels.

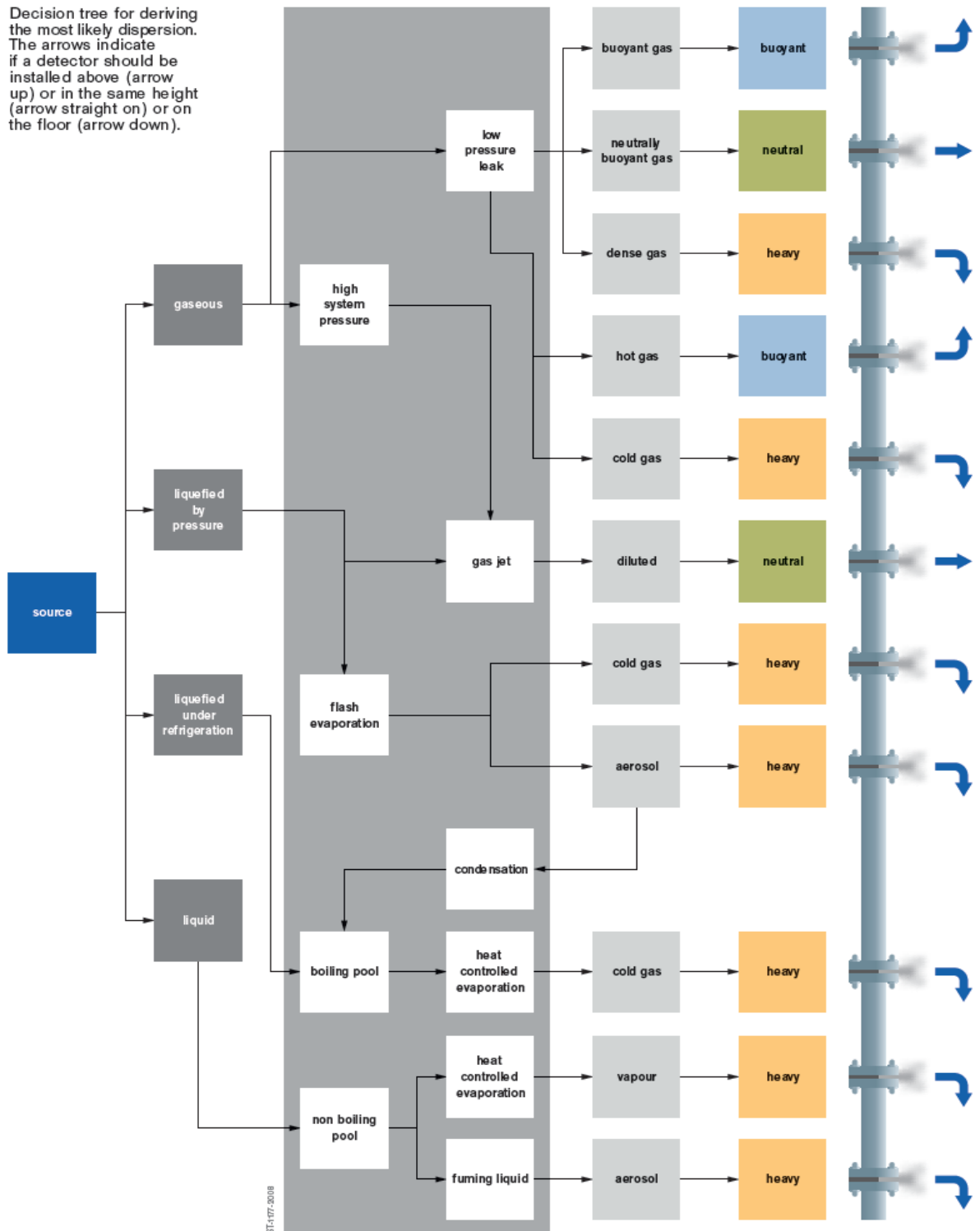
Ventilation:- Sources of ventilation (both inlet & exhaust) and position of ventilation can play a key role in the movement & build-up of gases/vapours, understanding of which is key for sensor placement in indoor applications.

Climate Control

Heating in indoor applications can cause convection, and thus affect gas dispersion & placement of sensors.

Gas Dispersion

Decision tree for deriving the most likely dispersion. The arrows indicate if a detector should be installed above (arrow up) or in the same height (arrow straight on) or on the floor (arrow down).



Sensor Technologies & Principle of Operation

Infra-Red based Flammable gas detection sensors:-

When substances contain both carbon (C) and hydrogen atoms (H), i.e. hydrocarbons, their C-H bonds can briefly absorb part of the infrared light radiation. This slightly weakens the intensity of the emitted light. Light-sensitive pyro-detectors are able to measure this weakening, and can calculate a signal on this basis which serves as a reliable indicator if a gas concentration is present.

Catalytic Sensor :-

Catalytic sensors consist of two small beads (pellets). The pellistor without the catalyst (compensator) is used to measure the ambient temperature, while the pellistor with the catalyst (detector) is used to measure the ambient temperature plus heat of combustion, where the difference between the two signals – is a measure of the gas concentration – and is generated electrically.

Electro-Chemical Sensors:-

Electro-chemical sensors contain electrolytes which react with specific target gases. The chemical reaction produces electrons (electric current), and the number of electrons produced is proportional to the concentration of the target gas present. The current produced can be measured and useful signal in mA be generated by the electronics.

Acoustic Sensors:-

Acoustic sensors are high precision microphones that listen to ultrasound waves which are generated by high pressure leaks that is in-audible to human ears. Low pressure leaks cannot generate ultrasound waves. Acoustic sensors are not gas specific and may respond to any source of noise that generates ultrasound waves. Noise mapping of the facility must be done to determine placement of the sensors. Advantage of Acoustic detector is that, they are independent of the wind direction, which is a major factor for other sensor technologies. Acoustic detectors can be used to compliment traditional gas detectors with an additional mode of detection, where very small leaks from high pressure sources could be detected, which otherwise may not be detectable with traditional gas detector.

UV & IR Flame Detectors:-

When flammable substances burn, most of them produce CO₂ and Water. The UV & IR based detectors emit UV or IR or both or multiple wavelengths of IR (triple IR) radiations that are absorbed by CO₂ or water. Absorption of these radiations due to CO₂ & Water is interested as fire. Radiation based detectors are the most economical, however have some limitations, due to UV & IR radiations being present in Atmosphere naturally.

Visual (CCTV) Flame detectors:-

This technology is used only in Draeger Flame 3000 & 5000. The visual flame detectors were developed to overcome the limitations of the radiation based detectors. In these flame detectors, a camera takes multiple pictures per second in the near infra-red spectrum; the pictures are stitched up to form videos. The videos are then compared for flame pattern movement, which are built into the detectors algorithm. These detectors have much superior performance when compared to

radiation based detectors and are not susceptible to false alarms due to elements (UV & IR radiation) being present in nature.

Risk Reduction & Role of gas detectors

Plant Safety is a result of good plant design and instrumentation, as well as the competence of the plant operators. There are several ways to achieve risk reduction, and steps are always taken to prevent any possible scenario for the leak or build-up of flammable & toxic substances using process control equipment. Additional steps can be taken to reduce risk through modification of the design, placement of the ventilation ducts, ventilation rate etc. Gas detector may also be used as one of the methods to achieve some risk reduction to tolerable levels by itself or in combination with others mentioned above.

When gas-detection systems are being used as risk-reduction systems, you should be fully aware of the safety functions and the system requirements with respect to safety integrity.

How is risk defined?

Risk can be explained as the combination of two variables:

P - The probability or frequency of an unwelcome (or undesirable) event, and

C - The consequence of, or damage caused by, this event.

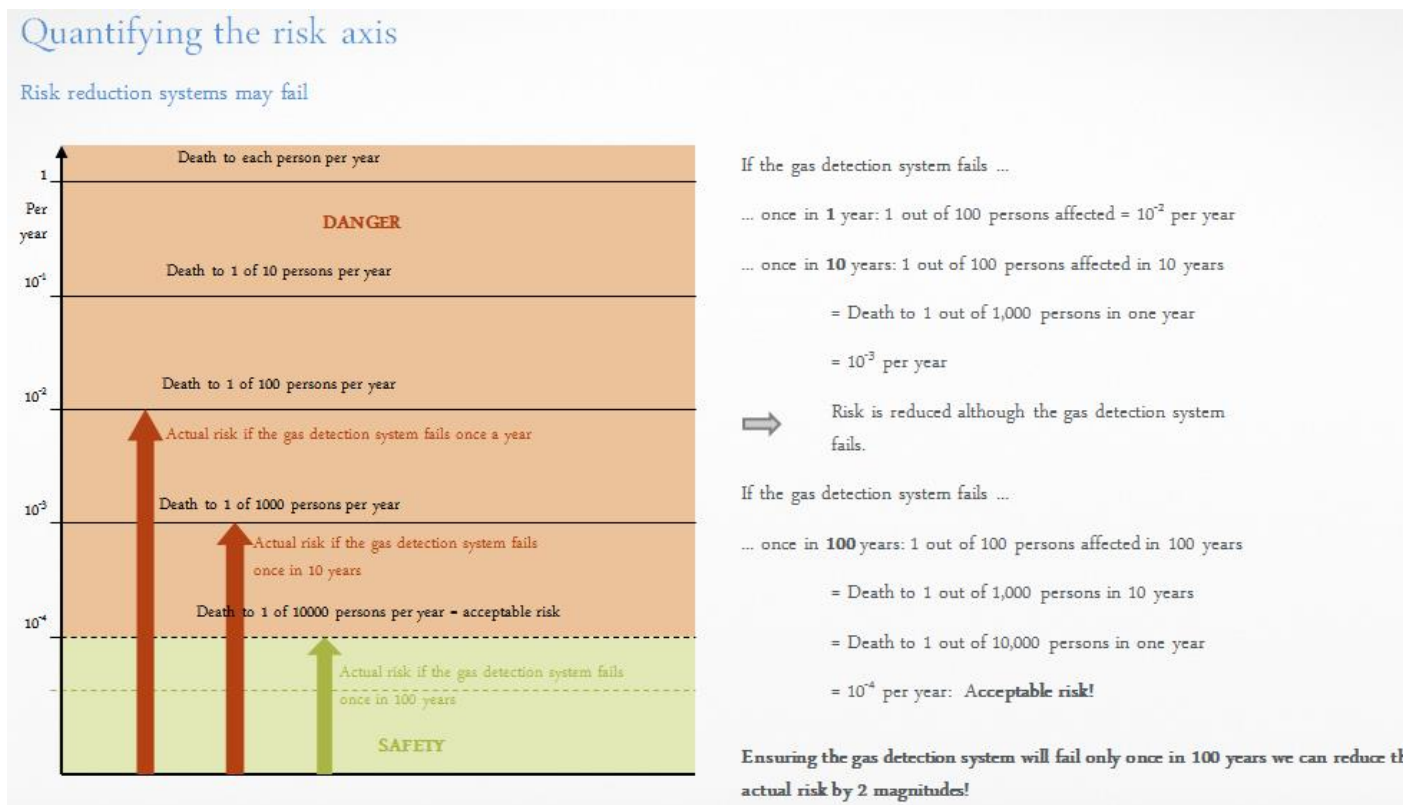
So, a simplified formula for risk is: Risk = Probability x Consequence - in other words, $R = P \times C$.



Let's start by assuming the consequence (C) of a hazard is the death of one person. Let us also assume that the probability (P) of this one death occurring in a given year

is 1 in 10,000. We can then say the risk is quantified as “1 person out of 10,000 is killed per year,” which is 0.0001, or 10^{-4} , cases of death per year.

The risk of 10^{-4} cases of death per year is commonly assumed as the norm, and therefore is classed as the acceptable risk level. We can thus arrive at a definition of safety as a situation where the actual risk is lower than the acceptable risk. Conversely, we can define danger as a situation where the actual risk is higher than the acceptable risk.



Let us first quantify the vertical axis of risk.

The horizontal acceptable risk line represents the risk that 1 out of 10,000 persons is killed per year; the lines above stand for 1 out of 1,000 persons, 1 out of 100, 1 out of 10, and the top line even characterizes the hazardous situation that 1 out of 1 person is killed per year. Remember that we are dealing with statistical values that are mean values per year.

Let us assume that if the gas-detection system fails, the actual risk rises to 1 out of 100 persons per year.

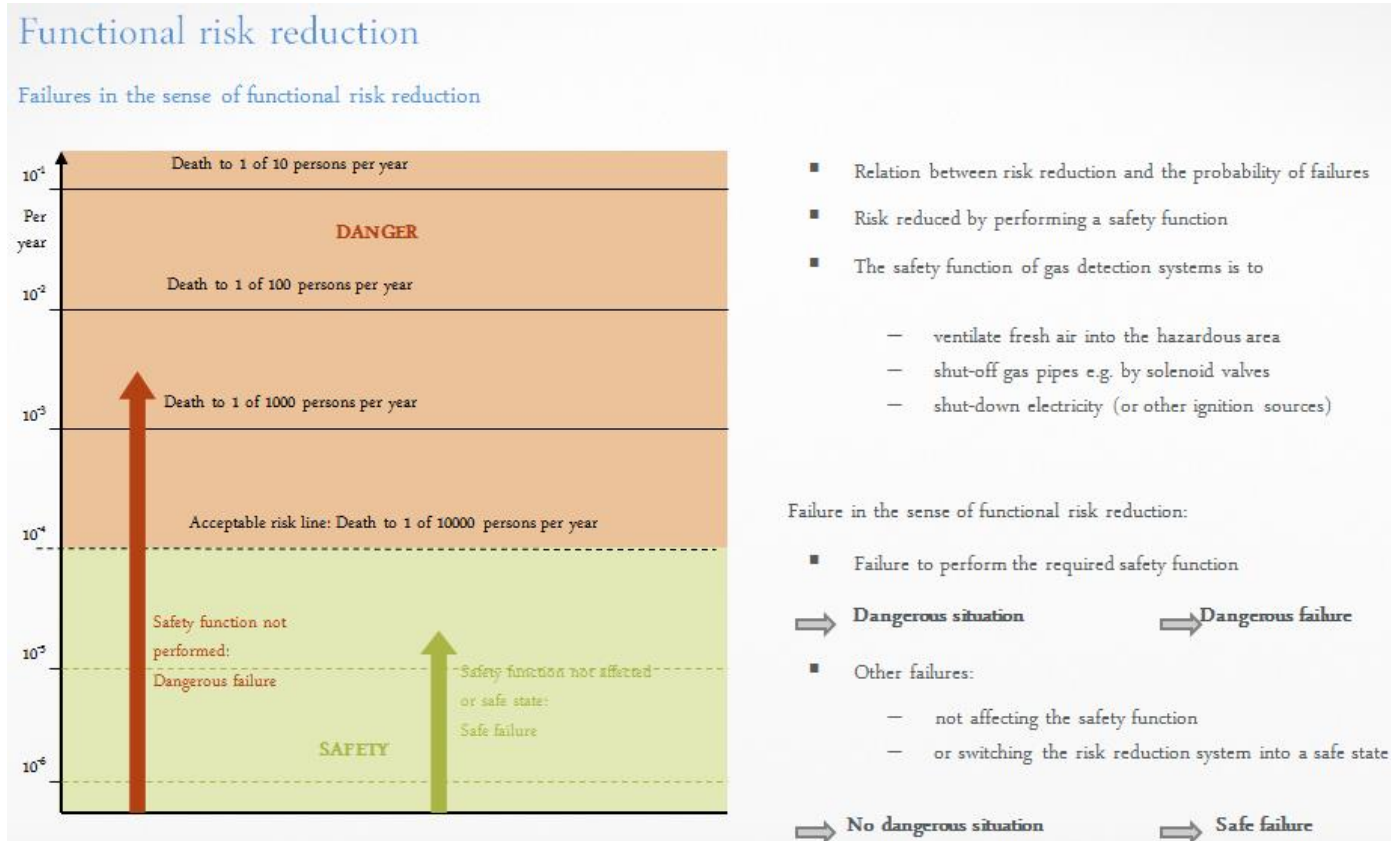
So, if it fails once a year, then 1 out of 100 persons is affected; the risk is then 10^{-2} per year.

If, however, it fails once in ten years, then 1 out of 100 persons in ten years is affected, which is equivalent to one out of 1,000 persons in one year; the actual risk is thus reduced to 10^{-3} per year.

* It is important to realize that in this case, the risk is reduced even though the gas-detection system fails.

Now, if the gas-detection system fails once in 100 years, then 1 out of 100 persons in 100 years is affected; this equals 1 out of 1,000 persons in ten years or one out of 10,000 persons per year. The resulting risk is 10^{-4} per year, which we have already learned is the level of the acceptable risk.

This is a very important result: If it is ensured that the gas-detection system fails only once in 100 years, we can reduce the actual risk by two magnitudes!



We've learned that there is a relationship between risk reduction and the probability of failure of the risk-reduction system. Now, what does the term "fail" mean when applied to risk reduction?

Risk-reduction systems need to perform a well-defined safety function – this is their purpose.

For example, a gas-detection system's safety function is to:

- ventilate fresh air into the hazardous area,
- shut off gas pipes (for example, using solenoid valves), and
- shut down electricity (or other ignition sources).

The term "failure" in the sense of functional risk reduction means:

Any failure that can inhibit the risk-reduction system's performance of its required safety function. A failure of this nature will cause a dangerous situation; therefore, these types of failures are called dangerous failures.

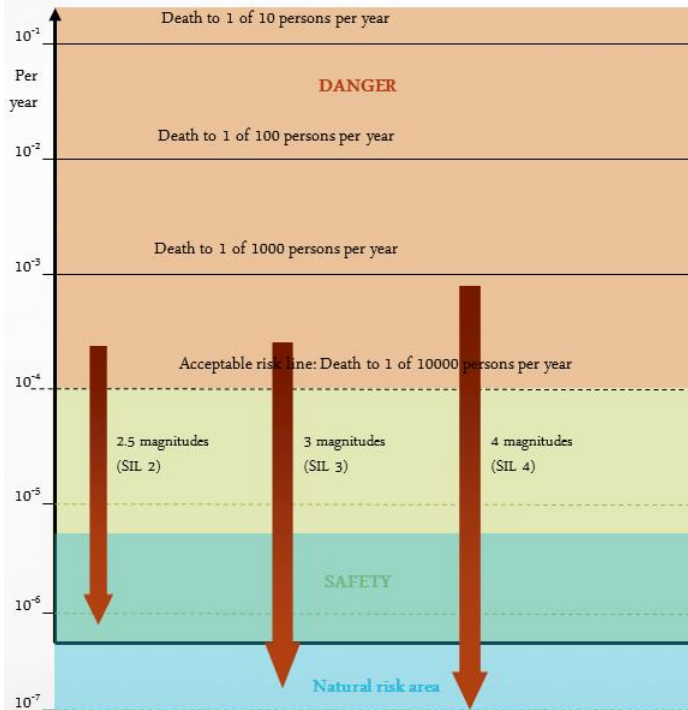
Any other failure within the risk-reduction system

- that does not affect the safety function,

- or enables the risk reduction system to switch into a defined safe state, does not cause dangerous situations. These types of failures are called safe failures.

SIL – Safety Integrity Level

Low risk and high safety integrity levels are not consistent



Risk reduction by	Safety function may fail less than ...	Safety Integrity Level
1 magnitude	... once in 10 years	SIL 1
2 magnitudes	... once in 100 years	SIL 2
3 magnitudes	... once in 1000 years	SIL 3
4 magnitudes	... once in 10000 years	SIL 4

The higher the SIL the greater the risk reduction?

Low risk and high SIL:

No!

- risk is lower than the natural risk
 - killed by lightning strike: $R = 10^{-6}$ per year in Germany
 - low risk system: $R = 2 \cdot 10^{-4}$ per year
- ⇒ acc. to SIL 3: $R = 2 \cdot 10^{-7}$ per year or less

It is meaningless to ask for high SIL in case of low risk!

Although it is highly recommended that gas-detection systems not be used for risk reductions of the magnitude SIL 4, to complete the table we can conclude: To reduce the risk by four magnitudes, the gas-detection system is allowed only one dangerous failure in 10,000 years. This means that the gas-detection system's safety function must not fail to function within a 10,000-year period; or, to put it another way, may fail to perform its safety function less often than once in 10,000 years. This is the definition of Safety Integrity Level 4, often expressed as SIL 4.

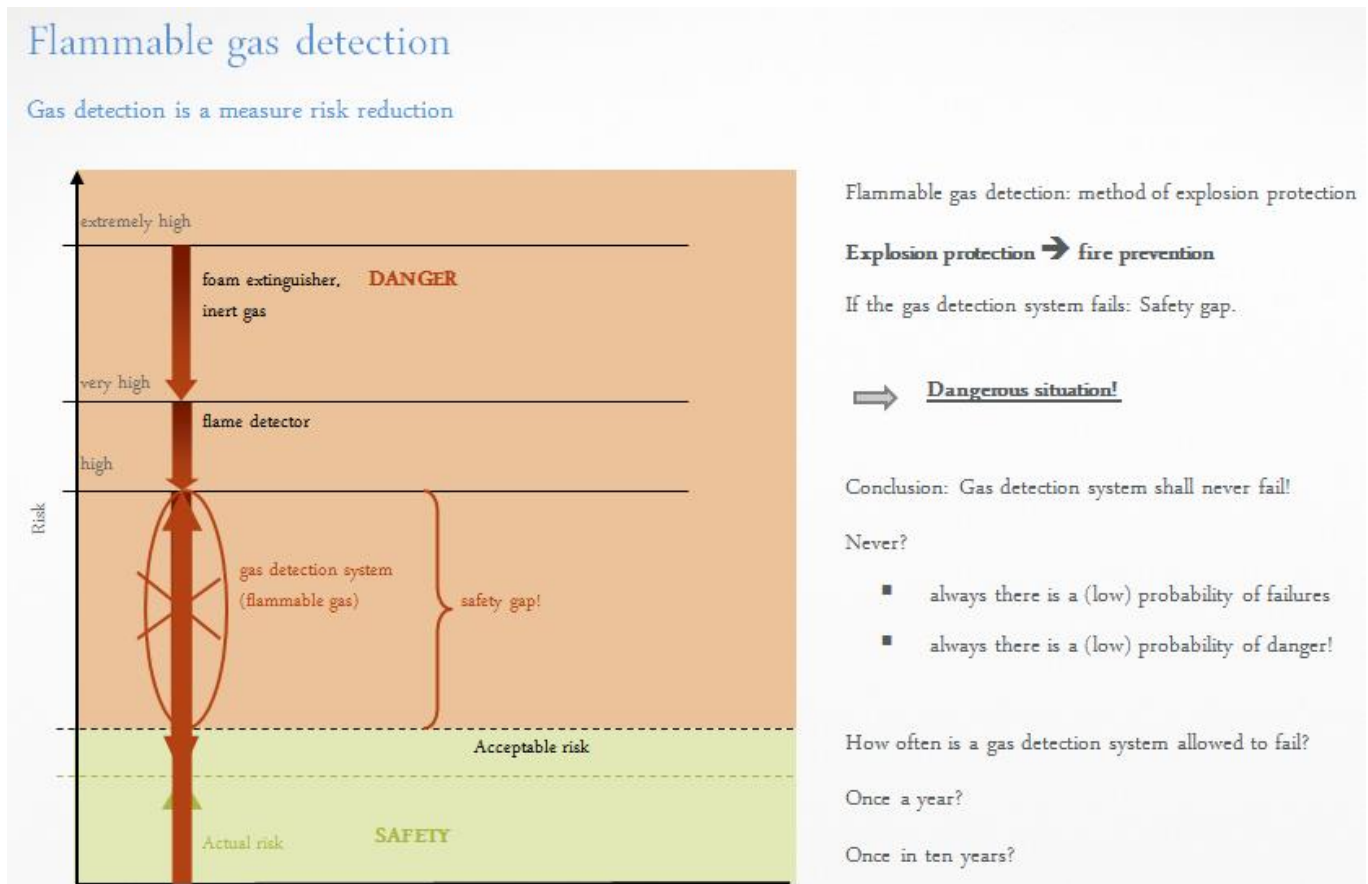
Sometimes, the meaning of SIL-level is misunderstood.

For example, "the higher the SIL number, the better."

But take a look at the risk-reduction arrows to see why this is meaningless:

If the initial risk is low, higher SIL values would reduce the risk far below the natural risk, which is commonly assumed to be below 10^{-5} per year.

E.g.:-



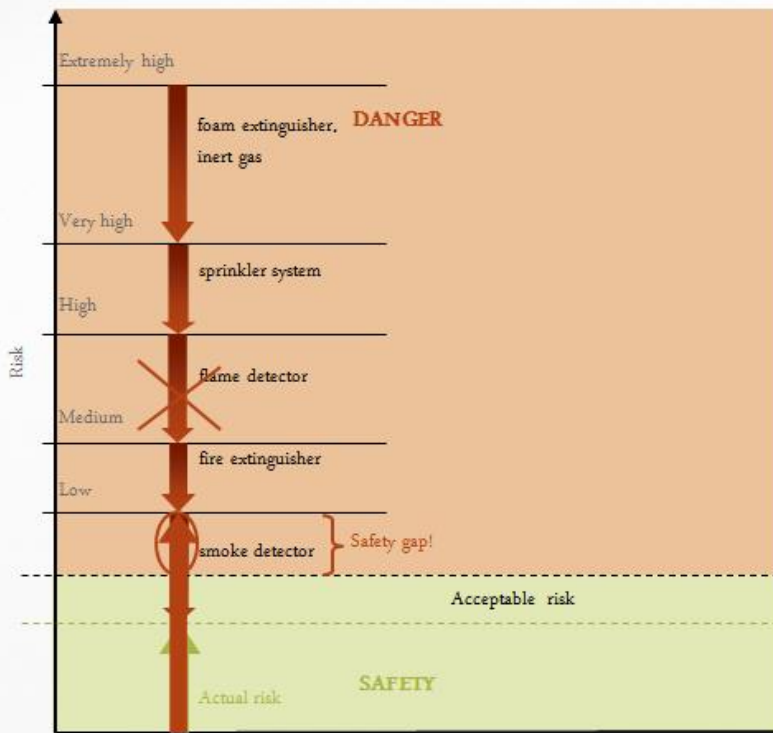
When flammable gases are in use or flammable liquids are stored, the primary way to reduce risk is to detect leaks or spillage in order to avoid a possible fire or explosion. Explosion protection, of course, goes hand in hand with fire prevention.

Gas-detection systems reduce risk. However, if the gas-detection system fails, its risk-reduction function, naturally, is no longer available, thus resulting in a safety gap - a dangerous situation. We might argue that a gas-detection system, if well maintained, should never fail. We all know, however, that it is not possible to claim zero failures, therefore “never” does not exist.

There is always a probability of failure, and so there is always a probability that dangerous situations might occur. Since there is always a probability of system failure, we have to ask: “How often is a gas-detection system allowed to fail - once a year? Once in ten years?” ...and so on.

Risk reduction by fire protection

Risk reduction by several different measures



One risk reduction measure (e.g. flame detector) fails:

- Risk increases!
- Safety gap results!
- Risk is higher than acceptable!

⇒ Dangerous situation!



Let's use the same graph to illustrate some risk-reduction measures as they apply to fire protection.

If the risk is low, such as in residential areas, the installation of smoke detectors may be sufficient to reduce the risk of fire to an acceptable level.

If the risk is medium or high, it may be sufficient to make available the well-known red fire extinguisher; however, additional risk-reduction devices, such as flame detectors, sprinkler systems, automatic foam extinguishers or inert gas deluge systems, contribute further to overall risk reduction, and thus to safety.

If, however, even one of these measures should fail (for example, the flame detector), the risk increases to above the green safety area; therefore, it is no longer considered safe, and we have a so-called safety gap. The actual risk is now higher than the acceptable risk, which results in a dangerous situation.

Fire & Gas detection standard Applicable in functional Safety, Plants & Projects

Major objective of IEC 61508 is to develop Application or Industry specific standards, and hence the developments of Application specific standards for Fire & Gas detection with a lifecycle approach in mind. Fire & Gas detection system have unique requirements which differ from other applications, equipment & standards.

Standards as applied currently in projects:-

Currently in most projects the fire & gas detection is packaged under the process control standard and this is not the ideal. Issues with combining gas detection with Process control may cause the following issues.

- Spurious alarms
- Incorrect information (negative signal/maintenance signal/under range/Beam Block/Over range/short circuit)

Fault causing false gas alarms (maintenance/testing) or water ingress causing gas alarms in IR detectors due to IR absorption of water.

Additional standards have been developed for the performance requirement of gas detectors used in functional safety application that has a function of risk reduction. **E.g.** Need for diagnostic signals (drift/beam-block/warning/maintenance) and fault signals below 4mA and over range & over current fault above 20mA and the special need to properly recognise them, to prevent false alarms. Built in fault tolerance due to short circuit using a rate a rise algorithm (fault should not cause a false gas alarm). Performance approvals for the gas detector to detect the target gas in a functional safety application.

There are mainly two functional safety Standards that apply to gas detection, they are IEC 60079-29-3 and EN 50402. **EN50402** applies only to manufacturers of gas detection equipment and provides information on design, and of manufacture detectors and R&D to operate under FSM.

IEC 60079-29-3: Explosive atmospheres - Part 29-3: Gas detectors - IEC 60079-29-3:2014 gives guidance for the design and implementation of a fixed gas detection system, including associated and/or peripheral gas detection equipment, for the detection of flammable gases/vapours and oxygen when used in a safety-related application in accordance with IEC 61508 and IEC 61511. This International standard also applies to the detection of toxic gases. Other parts of this international standard and pertinent local, national and international standards separately specify the performance requirements of a gas detector and a gas detection control unit (logic solver). These standards are commonly known as Metrological Performance Standards and are concerned with the accuracy of the measured value, the overall system performance, but not the device or system integrity with respect to the safety function. This international standard applies to the integrity of the safety function.

EN 60000 series standards are generally technically equivalent to IEC 60000 series. For EN 60079 series standards, the main difference is the addition of ATEX marking. EN 50000 series standards are not directly based on IEC documents and may not have an international equivalent (E.g. EN 50495 Safety Systems for ATEX) Dual certification to IEC 60079 series and EN 60079 series is common practice.

IEC 60880 - Provides requirements for the software of computer-based instrumentation and control (I&C) systems of nuclear power plants performing functions of safety category A as defined by IEC 61226

IEC 60079 Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen

IEC 60079-29-2 gives guidance on, and recommended practice for, the selection, installation, safe use and maintenance of electrically operated group II apparatus intended for use in industrial and commercial safety applications for the detection and measurement of flammable gases complying with the requirements of IEC 60079-29-1.

Interpretation of Standards

Three key elements of FSM:-

1. Procedures which are transparent, traceable, independent and repeatable to ensure that any phase of the safety life cycle is performed correctly and is fully auditable.
2. Competency management is in place to ensure the right people are employed and used for the right functions at the right time.
3. A Company culture which encourages honesty, trustworthiness, openness and professionalism to ensure that any functional safety project phase is executed correctly.

Concerns with using PLC for gas detection Applications:-

PLC's are not delivered with Performance approvals from manufacturers or independently certified by third parties.

All the special requirements of Gas detection may not be known to a programmer.

IEC 61508 Part 1, Clause 6 and Annex B (Competence)

- All persons, including management, shall be competent to discharge their responsibilities.
- Training, knowledge and experience should be assessed in relation to the particular application or responsibility.
- Engineering knowledge of the application and technology.
- Safety knowledge of the application.
- The training, experience and qualifications of all persons shall be documented.

Importance of Performance Approval

Device approval such as Ex approvals or functional safety approvals under IEC 60079-29-3 or IEC 61508 is not a guarantee for the sensor to perform a safety function of risk reduction, if the sensor is exposed to the target gas (Flammable/oxygen/Toxic). These approvals are not related to the ability of the sensor to detect the specific target gas which is part of the safety function.

All products used in functional safety application must be performance tested for measurement accuracy by independent third parties, so that the intended safety function is performed, so as to meet the required level of risk reduction. IEC 60079-29-1 details the Performance requirements of detectors for flammable gases.

Explosive atmospheres – IEC 60079 Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases

IEC 60079-29-1 Specifies general requirements for construction, testing and performance, and describes the test methods that apply to portable, transportable and fixed apparatus for the detection and measurement of flammable gas or vapour concentrations with air. The apparatus, or parts thereof, are intended for use in potentially explosive atmospheres and in mines susceptible to firedamp

Explosive atmospheres – IEC 60079 Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen

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Types of Gas detection Systems Application (Safety function /Standard Gas detection)

There are several types of gas detection system, they include

- Standard gas detection system (warnings/alarms)
- Protection system
- Mitigation system
- Gas detection system operating in parallel to SIS

Gas detection systems can operate in low or high demand mode

Low Demand Mode: Most case of gas detection applications are low demand mode, and the sensor is normally operating under ambient conditions and only expected to perform its function (standard or safety) when exposed to such a condition as a gaseous environment.

High Demand Mode: The detector

High Demand Mode versus Low Demand Mode

High Demand Mode

- An error in the SIF has a direct influence on the process
- The process is in danger if the safety instrumented function fails.

Low Demand Mode

- An error in the safety instrumented function has no direct influence in the process.
- The process is in danger if the safety instrumented function fails AND the request occurs.

Special Applications in Gas detection

Gas detection at heights:-

When installing gas detectors at heights or inside ducts or under the ceiling or roof spaces, careful thought must be given to detector selection. Clear understanding must be reached on maintenance requirements (e.g. proof testing/bump testing/calibration) which are routinely carried out. If not well thought off, it could lead to inability to perform timely maintenance and cost over runs due to requirements of

special needs (scaffolding / cherry picker/ height safety equipment and permits etc.). Cost of scaffoldings can be extremely exorbitant in some locations, and if detector selection made with features for remote testing, there is huge savings in cost as well as increased safety (risk associated with height safety can be reduced/eliminated).

Gas detection at Depths or confined spaces:-

When detectors are installed in low lying areas (sumps/tanks/well-heads) or within tank bund walls which can be subject to flooding, selection of detectors must be made with the understanding that these areas can be subject to flooding and the associated consequences (faulty/permanent damage/replacements). Select detectors that can be subject to temporary/permanent immersion and can also withstand hosing for cleaning. Selecting detectors with remote test/maintenance features will also avoid need for confined space entry permits and cost associated with second person etc.

Leak detection:-

When selecting detectors for leak detection, ensure they are capable of detecting gases at very low levels. The lowest detection limit for the sensors must be obtained from the manufacturer. Lowest alarm set-point must be closer to twice the lowest detection limit to avoid spurious alarms from affecting operations.

Gas detection in inline Applications:-

When detectors are used in inline gas sampling systems, extra attention must be given to ensure the gas is flowing through the sensors and warning alarms are raised if the flow is affected. Depending on sensor technology, care must be taken to address issue of water & humidity. IR sensors may generate fault or momentarily give gas alarm if water is present in the measuring chamber. Electro-chemical sensors on the contrary require some humidity to operate normally for the designed life time. If sample conditioning system are used, provisions must be made to drain the water using solenoid valves, auto float drain or continuous condensate extracting systems.

Use of Gas detection Accessories:-

Ensure that gas detectors are fitted with all the necessary accessories as may be required for the smooth functioning of the gas detectors. When adding accessories in functional safety application, please check if a delay in speed of response would the safety function. Most accessories would have additional delays associated with it. (e.g. Splash-guard, insect-guard, hydrophobic filter) and must be understood by all persons concerned. Any accessory used for calibration (calibration adapter, flow cell, process adapter) in a functional safety application must also be performance approved.

Why use of PLC may generate trouble?

PLC's can cause trouble with respect to

- Total cost (cost of product + programing + independent verifications + Specialist for modification)
- SAFETY - risk if the programming is incorrect
- Production Loss – if programing is incomplete or incorrect, this could lead to spurious alarms & trips that may affect production.

- life time availability and support (support is very limited to specialist programmers)
- Since PLC's do not have local displays, it requires additional HMI, also to be programmed and does not have performance approval (as required under the standards).

Why PLC's are used?

- Customer use PLC's widely for process control applications and feel comfortable
- Superficially cheaper when evaluating hardware costs. (programming/modification etc. are not always considered)
- The application dictates that a PLC is more suitable
- Larger choice of input and output styles e.g. RTD, Pulse etc

Advantages with dedicated Gas detection Controllers:-

- Gas detection companies offer their own control systems which meet the demands of the gas detection standards and their own transmitters.
- Most controllers are also capable of accepting fire detectors and other inputs such as ESD or Push-buttons.
- There is no programming involved and is not available.
- Only alarms/set point can be adjustable and this requires minimal training.
- Training of maintenance team is much easier for the complete system.
- Product successions are much more smoother to implement.
- Support is available from a single vendor for the detectors, controllers & associated field devices.

Gas detection Systems – Main questions to be answered?

Which substances need to be detected?

What kind of technology is necessary or required?

How many transmitters do we need?

Where to put the transmitters?

What happens in case of an alarm?

What kind of alarming is required?

Installation related questions:-

Is the detector installed in a Hazardous Area?

What method of Ex-protection must be used?

Type of cable to be used (instrumentation/IS/SWA)

Type of glands & blanking plugs

Do cable trays exist? If so, does space exist for more cables? Are the cables allowed to be on the same tray?