

CHAPTER 7

FIRE AND GAS DETECTION SYSTEMS

Lecture material for TTK 4175 Instrumentation Systems and Safety at the Department of Engineering Cybernetics, Norwegian University of Science and Technology (NTNU).

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The essence of fire and gas detection?

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7 Fire and gas detection systems

Fire and gas (F&G) detectors and systems are essential in many industrial facilities that handle flammable, explosive, or toxic substances. Many countries treat F&G systems as SIS systems, and functional safety requirements apply. This chapter provides an overview of detection principles, detector types, and the integration of detectors with F&G controllers. Detection of dust is not addressed here; however, some dust detection principles are discussed in Chapter 12 (ATEX and Ex).

7.1 Abbreviations

ESD	Emergency shutdown system
FD	Fire detector
F&G	Fire and gas system
GD	Gas detector
IR	Infrared
LEL	Lower explosion limit
SD	Smoke detector
UV	Ultraviolet

7.2 What to detect?

Fig. 1 illustrates the roles of F&G detectors: Toxic and flammable substances may generate gases detected by gas detectors (GD). If a flammable gas is ignited, it can cause a fast- or slow-developing fire or even an explosion. Flame detectors (FD) detect burning flames, while smoke detectors (SD) detect smoke particles. Not all fires will generate smoke.

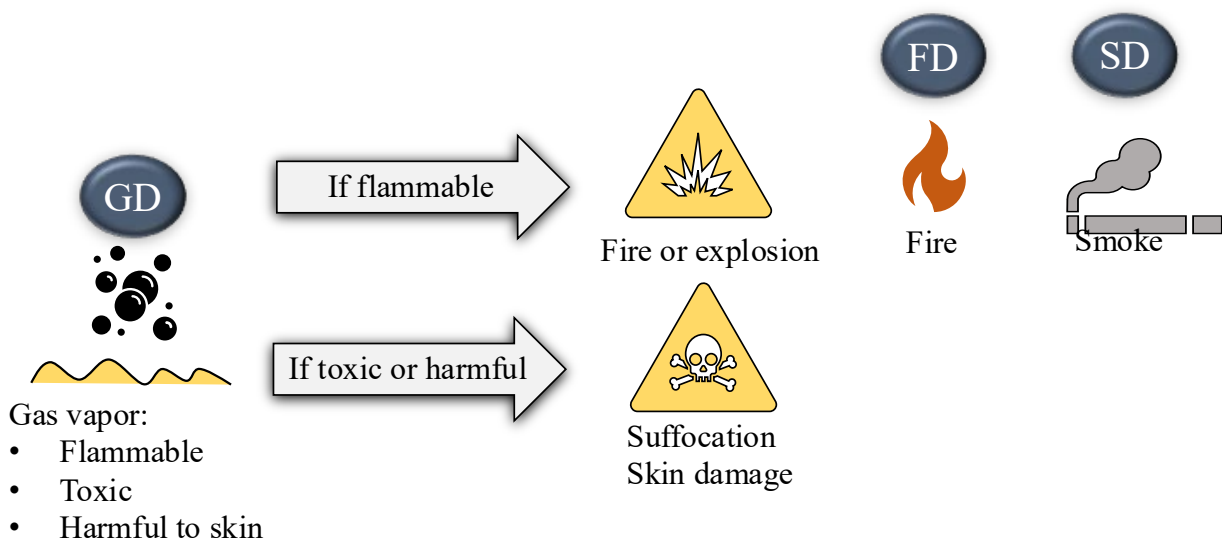
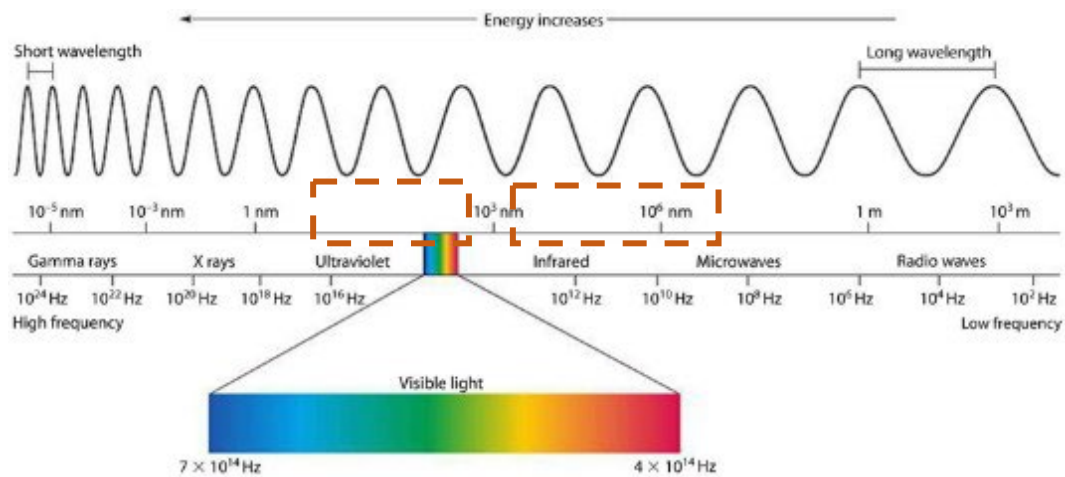


Fig. 1. What to detect with F&G detectors

Many gas and flame detectors rely on optical detection using light in the infrared (IR) and ultraviolet (UV) of the electromagnetic spectrum in Fig. 2. IR has longer wavelengths than visible light, while UV has shorter wavelengths.



IR: 700nm til 1 mm (0.7 μ m-10 μ m)

UV: 10nm til 400 nm

Fig. 2. The electromagnetic spectrum

7.3 Gas leakage detection

Gas detectors may be split into the following categories based on measuring principles:

- Optical gas detectors that are either implemented as point gas detectors or line gas (or open path) detectors
- Catalytic detectors, which are point detectors only
- Acoustic detectors, which are point detectors only

A point detector requires direct exposure to gases, i.e., the gas must flow to the detector's mounting location. In contrast, a line (or open-path) gas detector measures along a path between a sender and a receiver unit. The acoustic detector listens to sounds from gas leaks, which are outside what people can hear.

Gas detectors are expected to detect gas leaks and quickly notify controllers. Depending on the measured gas concentration, the controller may shut down the facility with all its consequences. It is, therefore, vital that the detector is reliable, meaning that it (ideally) has:

- (Ideally) no false alarms
- No complete breakdowns before exceeding the expected lifetime
- Minimal need for temporary outage due to maintenance and testing

Most detectors provide 4-20 mA, so the controller can compare the measured value with set points for alarm (only) and confirmed detection. The 4-20 mA signal is also highly reliable and fast. Most detectors have advanced microcontrollers running several diagnostic operations. Detectors have interfaces such as HART and Modbus to retrieve diagnostic information over Fieldbus and/or Industrial Ethernet. Calibration over the net or via a handheld device can also use the same interfaces.

General considerations about gases and gas detection:

The detection of gases can be relevant in two different contexts:

- Gas detection: Detection of gas leakages (before ignition)
- Fire detection: Detection of burning gases

For the detection of gas leakages, the following aspects are important:

- Hydrocarbon gas leakages:

- Generally sufficient time to isolate ignition sources in due time after receiving alarm and confirmed detection.
- Detection: Based on % of lower explosion limit
- CO₂: leakages:
 - Generally sufficient time to detect CO₂ gas to take necessary responsive actions
 - Detection: Based on particles per million in the air.
- H₂:
 - Self-ignites instantaneously after release if an explosive atmosphere is formed. It may even self-ignite in contact with particles in the air, such as snow, the duct from which it releases, and objects on the ground and in the surroundings (such as stones and gravel).
 - As the lower explosive limit (LEL) is at 4% and the upper explosive limit (UEL) is at 75% of the concentration in air, the continuous presence of mechanical or natural ventilation (for removing H₂ from an area) is more efficient than detection itself, depending on how fast a situation may escalate after ignition.

The correct location of leakage detectors is as (almost) important as the detector itself. Questions relevant to ask are, for example:

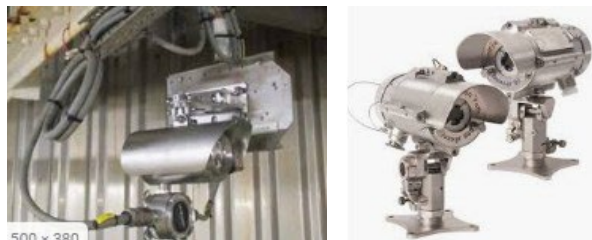
- Where are the gas leakages likely to occur?
- Is the gas lighter or heavier than air?
- Given the geometry of the area or room where leakages occur or can be reached by the gas cloud, where can gases accumulate?

7.3.1 Optical gas detection

Fig. 3 shows two typical optical gas detectors: a point gas detector (left) and a line gas detector with sender and receiver (right). The optical point gas detector has a chamber behind the black cover in front of the detector. Inside this chamber, the detector emits two or more IR (or UV) beams, some of which the gas will absorb and others that will not, serving as a reference.



Point gas detector



Line gas detector with sender and receiver

Fig. 3. Optical gas detectors

Different gases absorb different wavelengths and create the gases' footprints. An absorption spectrum shows the absorption intensity (peaks or curves) per wavelength (or frequency). Examples of absorption intensity for gases in the IR spectrum are shown in Fig. 4 (left side). The absorption coefficient – seen as the height of the peak – is a measure of the loss of intensity. The right side in Fig. 4 zooms in on the absorption spectrum for methane gas, one of the common explosive gases processed at petrochemical and petroleum plants. A similar absorption spectrum can also be found for gases exposed to UV light.

Some rules of thumb for *when* IR and UV detectors are efficient, based on input from a fire and gas detector supplier, considering at what frequencies the detectors detect the gases within the IR and UV range:

- IR gas detectors: Are best suited for detecting flammable gases and other carbon-containing gases such as methane (CH₄), ethane (C₂H₆), propane (C₃H₈), CO, and CO₂. They are generally unsuited for detecting H₂, because hydrogen does not absorb infrared radiation as it has a homonuclear molecule with no dipole moment. A dipole moment means the molecule is slightly charged, causing it to vibrate, which is needed for it to be affected by IR light.
- UV gas detectors: Are generally less suited for gas leakage detection. However, they are suitable for detecting certain toxic gases, such as ammonia (NH₃) and hydrogen sulfide (H₂S), which absorb strongly in the usable UV range. CO₂ has no significant absorption in this range and therefore cannot be detected. The same applies to hydrocarbons and hydrogen (H₂), which are not effectively detected by UV unless they are burning (as in UV flame detectors). The reason is that their strongest absorption bands lie in the UV region (shorter than ~200 nm), where oxygen and nitrogen in air absorb strongly, preventing these wavelengths from propagating through air.

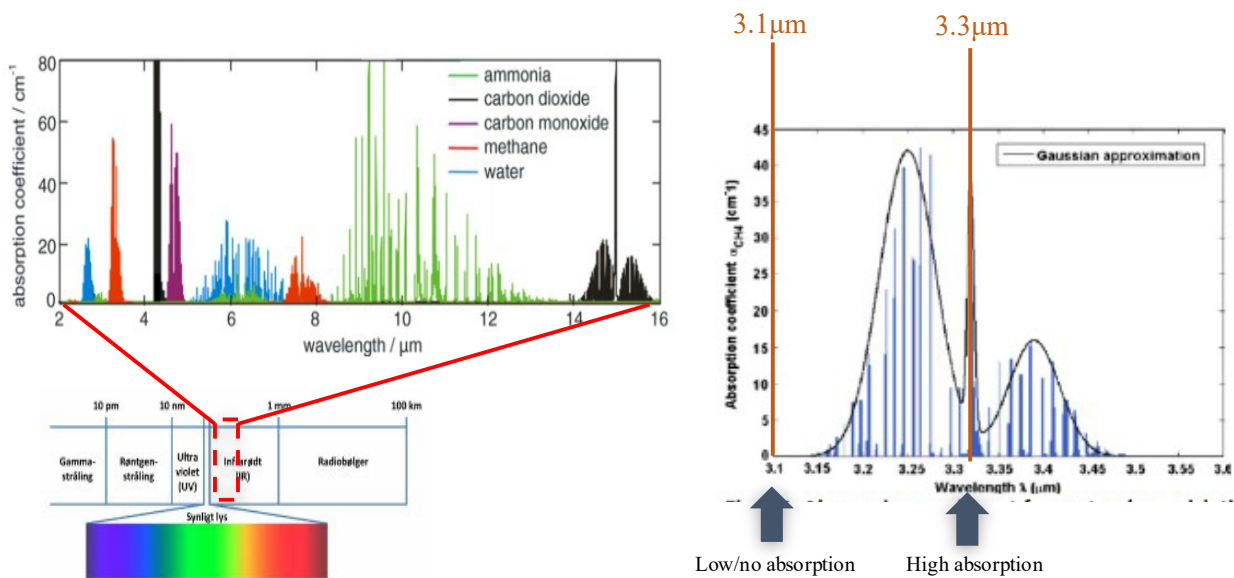


Fig. 4. Absorption spectrum for some gases in the IR light region

The process inside the point gas detector chamber can be as shown in Fig. 5. The reference and the detection beams are sent through a lens into the chamber that is filled if exposed to gases, and a mirror reflects the beam through the same lens to a measurement sensor. The reference beam has a wavelength where no absorption is expected, while the measurement beam has a wavelength that will be absorbed. The intensity of absorption is proportional to the concentration of the gas. Consider the methane gas absorption spectrum in Fig. 4. Here, the 3.1 μm wavelength can be the reference beam, while the 3.3 μm wavelength can be the detection beam.

The four beams provide capabilities to detect as well as diagnose several fault states, as illustrated in Tab. 1. The intensity in the reference and measurement beams is usually converted to a signal in the 4-20 mA range.

Tab. 1. Detector states

Measurement signal	Reference signal	Detector response
$I_m < I_{m,0}$	$I_r = I_{r,0}$	Gas detected. Concentration as % LEL is a function of the value of I_m .
$I_m < I_{m,0}$	$I_r < I_{r,0}$	Dirty optics (lens) or blockage of the beam. No gas present.
$I_m = I_{m,0}$	$I_r < I_{r,0}$	Failed detector. Unknown cause.
$I_m = I_{m,0}$	$I_r = I_{r,0}$	No gas and clean optics

Another way to illustrate the functioning principle of a point gas detector is shown in Fig. 7, also illustrating the detector responses with graphics.

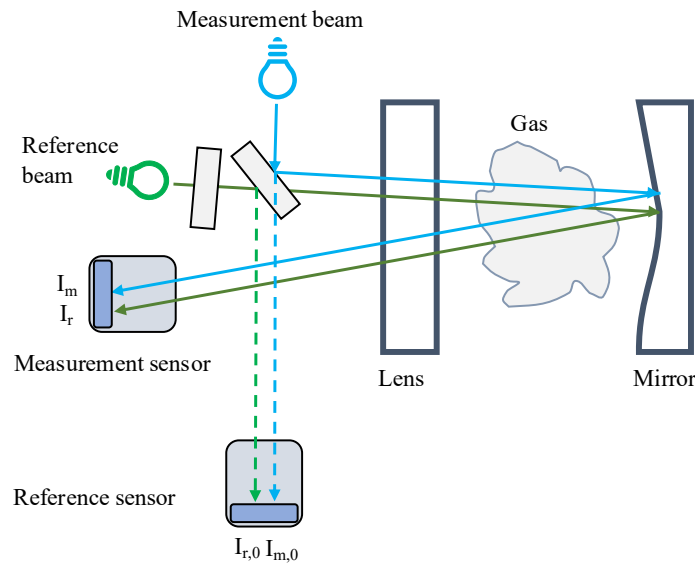


Fig. 5. Principle of optical point gas detectors

As shown in Tab. 1 and Fig. 7: If gas is present, the intensity of the measurement beam is reduced, leading to a reduction in the mA value correlated with the gas concentration.

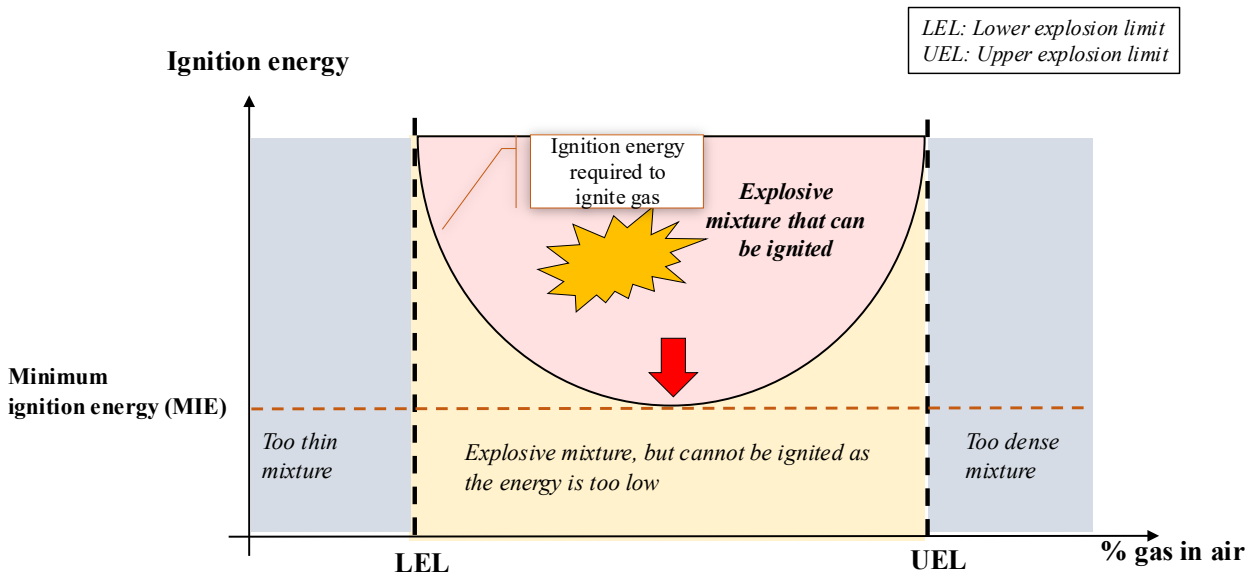


Fig. 6. Explanation of LEL, UEL, and MIE

The measured values for flammable/explosive gases are calibrated to detect the gas on a scale of 0 to 100% of the lower explosion limit (LEL).

LEL: The thinnest mixture of gas concentration in air that can be ignited

Fig. 6 explains LEL and related concepts:

- A gas concentration below LEL cannot be ignited regardless of the energy added. Similarly, there is an upper limit on gas concentration below which ignition cannot occur.

- The gas may be ignited between LEL and UEL, provided sufficient energy is added.
- The ignition energy as a function of the gas concentration is used to find the minimum ignition energy (MIE). To prevent gases from igniting, it is essential to ensure detection occurs before the LEL is reached.

Therefore, Optical gas detectors are calibrated from 0-100% LEL with pre-alarm and confirmed detection at, e.g., 10% LEL and 20% LEL.

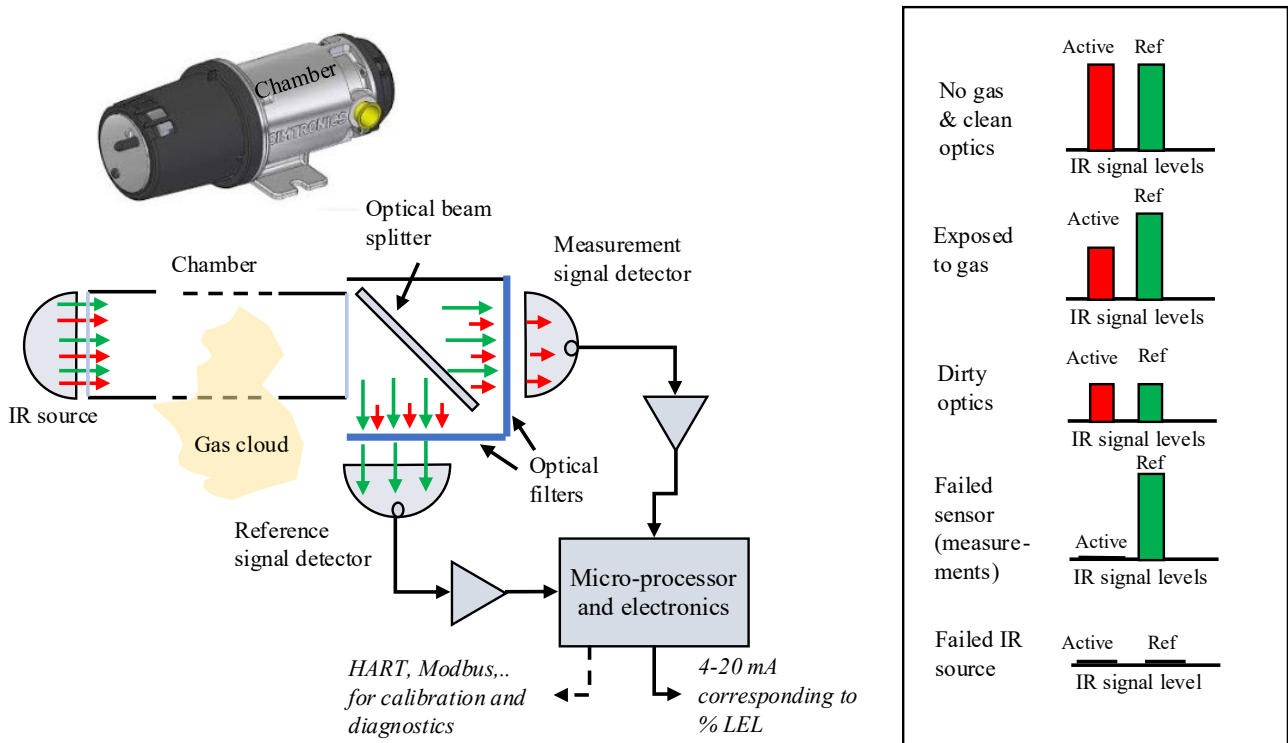


Fig. 7. Principle for optical gas detector with measurements and diagnostics

For other gases, non-explosive but toxic, measurements can be calibrated to units such as parts per million (ppm).

7.3.2 Detection of CO₂ leakage

IR detectors are best suited for CO₂ detection. As the normal concentration of CO₂ in air is low and the threshold for dangerous levels is similarly low, measuring particles per million gives better accuracy than measuring % in air. For example, 1% of CO₂ in the air corresponds to 10,000 ppm. Normal concentration is in the range of 400-1500 ppm (0.04% to 0.15%), depending on whether it is outdoor or indoor. Alarms are sometimes set at around 5000 ppm (0.5% CO₂) in the air. 4% CO₂ causes immediate danger to life and health. The webpage for the [Heimann sensor](#) provides a well-explained example of an IR detector for CO₂ with two IR light sources: one at a wavelength that does not absorb CO₂, and the other at a wavelength that does.

The optical line (or open path) gas detector sends one or more beams through open air between a sender and receiver, as shown in Fig. 8. At least one beam is for reference, and at least one is for measurement/detection. A laser, such as the high-precision type Enhanced Laser Diode Spectroscopy (ELDSTM), is often used to emit the light.

A line gas detector cannot directly measure gas concentration because the loss of intensity depends on both concentration and the distance it travels through the gas.

- In case of gas: Instead of measuring % LEL, the line gas detector measures LEL meter (LELm). This is a factory-calculated value within the 4-20 mA range that combines %LEL and the gas cloud's outreach (in meters).
- In case of non-explosive gases, like CO₂, ppm-m is measured instead of LELm.

Therefore, the same measured value can be obtained for a gas with a high LEL percentage and a short outreach as for a gas with a low LEL percentage and a longer outreach. For example, 10% LEL x 5 meters = 0.5 LELm; the same value would be obtained with 50% LEL x 1 meter = 0.5 LELm. Therefore, the same measurement value can be generated for a gas with a high percentage of LEL and short outreach as a gas with a low percentage of LEL and more extended outreach. For example, 10% LEL x 5 meters = 0.5 LELm; the same value would be obtained with 50% LEL x 1 meter = 0.5 LELm.

A point gas detector requires gas to enter its chamber. Therefore, point gas detectors must be placed close to potential leakage points, such as pipe flanges, connection points, or tank entry points. A line gas detector can cover several leakage points along a path, but the path must not be obstructed. If the path is obstructed, the receiver will raise an alarm, and the detector will not work until the blockage or out-of-position condition has been fixed.

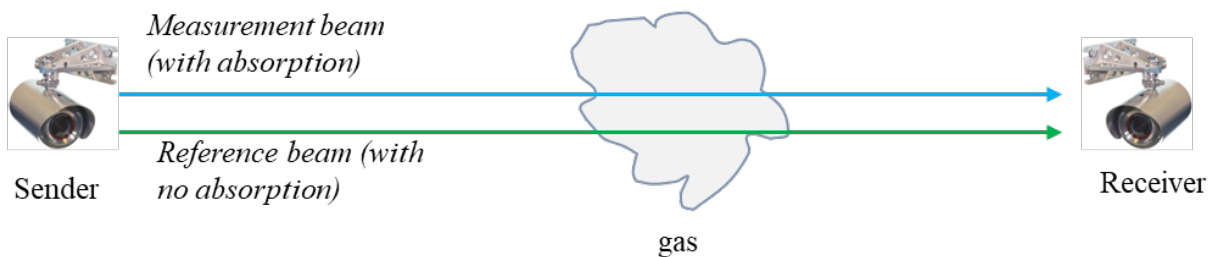


Fig. 8. Line (or open path) gas detector



You Tube video [1](#) and [2](#) explain line/open path gas detectors.

7.3.3 Catalytic gas detectors

Catalytic gas detectors are available only as point detectors and can detect flammable gases, including hydrogen and methane. The detection principle is based on a catalyst to generate an oxidation reaction when gas is present in the detector chamber, as shown Fig. 9.

When the gas is exposed to the catalyst, the temperature increases, resulting in higher resistance in the coil of the electrical circuit. The change in resistance is converted to a 4-20 mA signal correlated with gas concentration in the range of 100% LEL.

A drawback of catalytic detectors is their long response time, limited lifetime, and poor reliability. It is also necessary to perform the testing with specific test gas, and recalibration may be needed as often as every 3 months. In practice, this often means replacing the detectors. The current practice in Norway, based on national requirements like NORSOK S-001 (2021) is to select catalytic detectors when no other options are available. They have been mentioned as an option for H₂ detection; however, their efficiency depends on the

escalation potential, as the detector has a slow response time, and H₂ may self-ignite immediately after release.

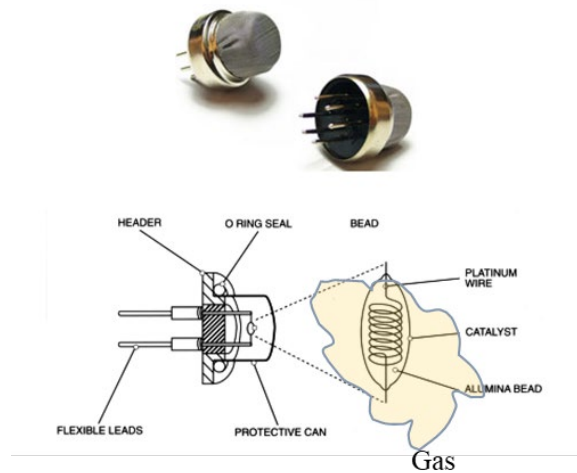


Fig. 9. Catalytic gas detector

An electrochemical gas detector is sometimes suggested as an alternative to catalytic detectors. It uses an electrode to create oxidation in contact with the target gas. The change in electrode properties (due to the chemical reaction) causes a change in the measured signal. Like catalytic gas detectors, the sensor must be calibrated to detect the specific gas. Both detector types can be calibrated to detect very low concentrations. For example, 1% LEL for H₂-gases is well below the % LEL. The leakage rate and accumulation time will decide if this is sufficient. However, it may be sufficient in battery rooms where leakages can be small and occur over time.

7.3.4 Acoustic gas detectors

Acoustic gas leak detectors, sometimes called ultrasonic detectors, detect leaks from pressurized gas systems by sensing the airborne ultrasound produced by gas escaping from the leak.

This detection method is omnidirectional (meaning that many aspects are included), functional in extreme weather conditions, and ideal for quickly detecting leaks from valves and flanges in complex pipelines, both onshore and offshore. One important aspect is that the detector is not affected by wind that can move the gas cloud away, as shown in Fig. 10.



Fig. 10. Functioning of an ultrasonic gas detector

The main advantage of ultrasonic gas leak detectors is that they do not need to wait for gas to accumulate, making it explosive. Instead, they respond instantly and will detect a 0,1 kg/sec gas leak up to 28 meters. Therefore, setting a 10-second delay in the safety system is mentioned as a common practice. Compared with IR and UV detectors, an acoustic detector cannot distinguish one gas leakage from the other based on the gas's properties.

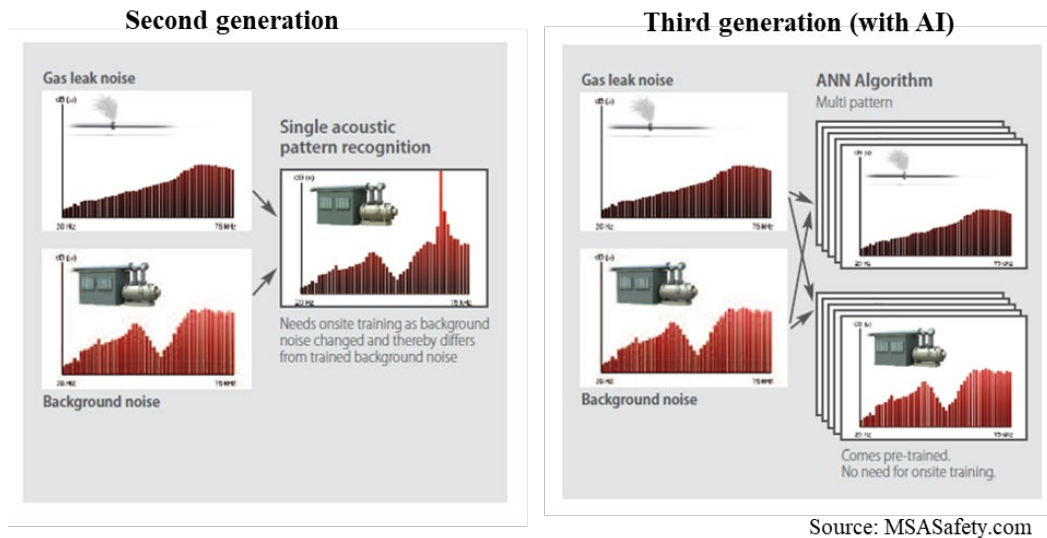


Fig. 11. Examples of acoustic detection principles for detector Observer-i (MSASafety.com)

Fig. 11 shows two examples of acoustic detection principles for the Observer-I detector from MSA Safety. The second generation uses on-site acoustic pattern recognition to distinguish leakage noise from background noise at the plant. The third generation applies artificial neural networks (ANNs), a method within AI, to automatically learn, without on-site training, what the leakage noise and background noise are.

According to the company's webpage, this specific detector can cover up to 28 meters at all background noise levels.

Several gases are listed as applicable targets for acoustic leakages. However, efficient detection relies on “noisy” release, so the detectors are most efficient for high-speed leakages. The detector is not suitable for detecting silent gas leaks, for example, when the gas flow through the leakage point is very slow, or the gas is diffusing into an area where it accumulates.

A variant of acoustic detectors, referred to as photoacoustic CO₂ sensors, is mentioned in the context of CO₂ detection, even though non-dispersive infrared detectors are most commonly used. The sensors are very small, and the most common applications seem to be indoor, in workshops, air conditioners, heat and ventilation systems, and smart home devices. Automotive (presumably inside the car) and smart agriculture are also mentioned as application areas. The detection principle seems to involve (i) generating pressure waves from pulsed IR light that, because of the absorbed energy from CO₂ molecules, and (ii) microphones that detect the sound altitude of the pressure waves corresponding to the CO₂ contraction.

7.3.5 Combining detectors

Fig. 12 gives an example of how the ability of detectors is affected by wind direction in a process plant. The example shows one line (open path) and two-point gas detectors. The leakage sources that could generate a gas cloud are marked.

With wind direction No. 1 and both detectors (point and gas) of type IR (or UV, depending on the type of gas to be detected), it is not likely that the gas leakage will be detected as the cloud is pushed away from the detectors. However, if the point gas detector is an acoustic detector, it detects the sound of the leakage at the

point of leakage regardless of where the cloud moves afterward. With wind direction No 2, we can assume that the IR (or UV) detector would be exposed.

When deciding which detectors to use, it is vital to combine detectors of several types. IR (or UV) detectors may be placed close to leakage points, opposite the area's dominant wind directions. In cases where the facility is rebuilt, for example, with new equipment added, it is essential to check whether the equipment's location can redirect the wind compared to the initial assumptions.

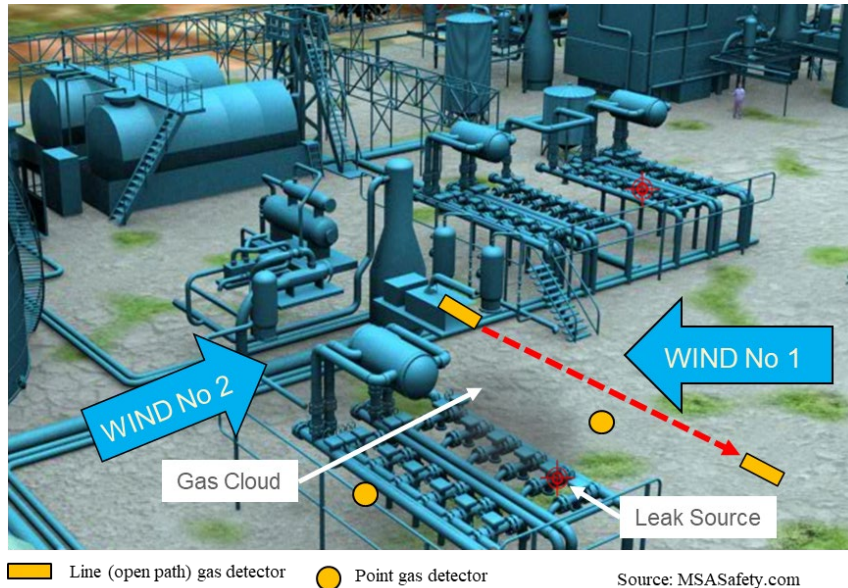


Fig. 12. Combining different detector types

Another way to illustrate the role of gas detectors is by using an event tree that shows the stages following a gas leakage, as shown in Fig. 13.

EVENT TREE FOR GAS RELEASES								
Gas release	Immediate ignition	Vapor cloud forms and ignites	Liquid rainout & ignition	Explosion occurs	Toxic chemicals	Outcome		
○	Yes					Jet fire		
				Yes		Vapor cloud explosion		
	No	Yes			No		Flash fire	
				Yes			Pool fire	
		No				Yes		Toxic exposure
							No	
Acoustic detector		IR point or open path detector			UV point or open path detector, alt. catalytic			

Adapted from MSASafety.com

Fig. 13. Event tree for gas release

An acoustic gas detector may provide the fastest detection of a gas leakage, as it does not need to wait to be directly exposed to the gas cloud. An immediate ignition of the gas cloud can result in a jet fire that must be detected by fire detectors (out of scope of this example). If there is no ignition, the cloud may build up. If the wind direction is not moving the cloud away, the gas could be detected by point-and/or open-path detectors, most likely IR detectors. Depending on whether the gas cloud is ignited, the result may be a vapor-cloud explosion, flash fire, or pool fire. The nature of these types of fires is not covered here.

If the gas is toxic, it is most likely not detected by the IR detector types, nor is it flammable (so, therefore, not ignited), and here, UV detectors would be needed to detect the release.

7.3.6 Alarm and detection levels

NORSOK S-001 (2021) The Norwegian guideline on technical safety for the oil and gas sector provides examples of %LEL levels for pre-alarm and confirmed detection. Confirmed gas detection triggers an automatic shutdown at the plant, isolates ignition sources, and activates fire water pumps. At the same time, an alarm is followed up by an inspection in the area. There may be almost no time between an alarm and a confirmed detection for fast-escalating gas leaks. Some examples of setpoints for alarms and confirmed detection in NORSOK S-001 are:

- Detection of hydrocarbon gases in air intakes (e.g., into buildings, into containers with rotating equipment):
 - Low alarm: 10% LEL point gas and detection distance x 10% if ≤ 1 LELm for open path /line gas detectors
 - High alarm (confirmed detection): 30% LEL for point gas and detection distance x 30% LEL if ≤ 2 LELm for open path/line gas detectors
- Detection of hydrocarbon gases in the process area:
 - Low alarm: 20% LEL point gas and detection distance x 10% if ≤ 1 LELm for open path /line gas detectors
 - High alarm (confirmed detection): 30% LEL for point gas and detection distance x 30% LEL if ≤ 2 LELm for open path/line gas detectors

For toxic gases such as CO₂ and CO, the measurement is expressed in parts per million (ppm), since these gases are not necessarily explosive.

- Toxic gases:
 - Low-level alarm: ≤ 5 ppm
 - High-level alarm: ≤ 50 ppm
- CO₂:
 - Low-level alarm: ≤ 5000 ppm
 - High-level alarm: $\leq 15\ 000$ ppm
- CO:
 - Low-level alarm: ≤ 100 ppm
 - High-level alarm: ≤ 600 ppm

There are many more details and some nuances of these requirements in NORSOK S-001 (2021), and the examples shown are primarily intended to illustrate how the requirements are formulated and at what level setpoints are given.

7.4 Fire detection

A fire is usually, but not always, visible to the human eye, such as when burning methanol and hydrogen. One of the phenomena used to detect a fire is IR or UV radiation; in this case, we refer to the detectors as flame detectors. The other phenomenon is to detect smoke if the fire generates it. Smoke can be volatile particles, such as carbon and ashes, or non-volatile substances, such as visible smoke and gases like CO, CO₂, and water vapor.

Like gas detectors, most detectors provide 4-20 mA so that the controller can compare the measured value with set points for alarm (only) and confirmed detection. The fieldbus and/or Industrial Ethernet communication

interface, such as HART or Modbus, may be used to retrieve diagnostic information and calibrate. Since detectors are part of safety instrumented systems (SIS), they must be SIL certified.

7.4.1 Flame detectors (UV and IR)

All fires produce UV radiation from gases generated in the fire, and its intensity (or energy level) and wavelengths depend on which gases are generated. Some gases, including the ones generated, also generate radiation in the IR range, as illustrated in Fig. 14.

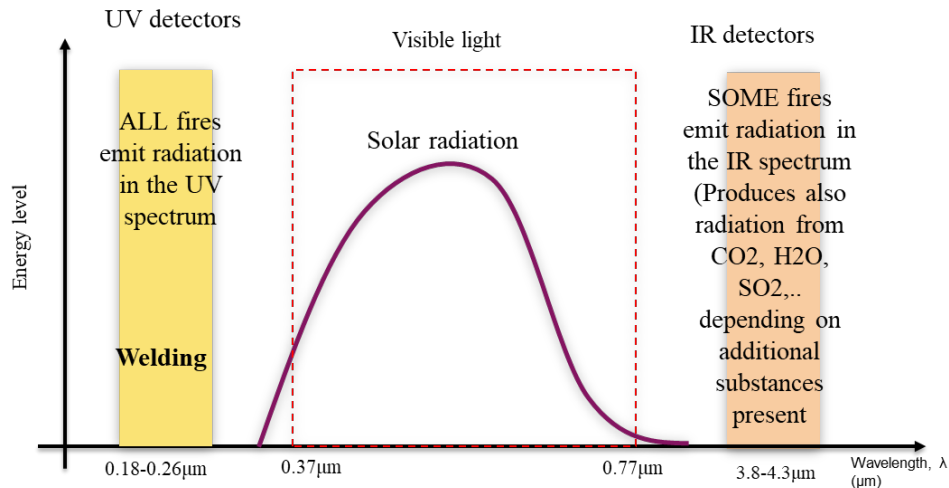
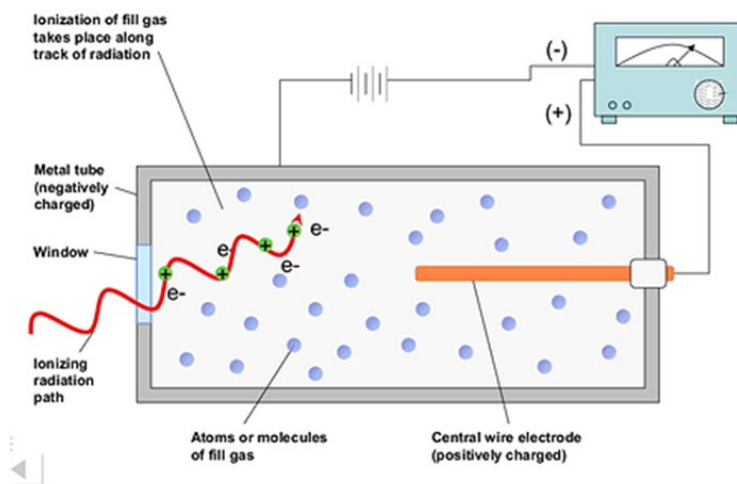


Fig. 14. Radiation spectrum

Some gases also generate radiation in the IR zone, such as:

- CO₂, CO
- Water vapor (H₂O)
- Sometimes also: SO₂ (sulfur dioxide) and NH₃ (ammonia), depending on the presence of additional substances



Source: <https://forumautomation.com/t/basics-of-geiger-muller-counter/2923>

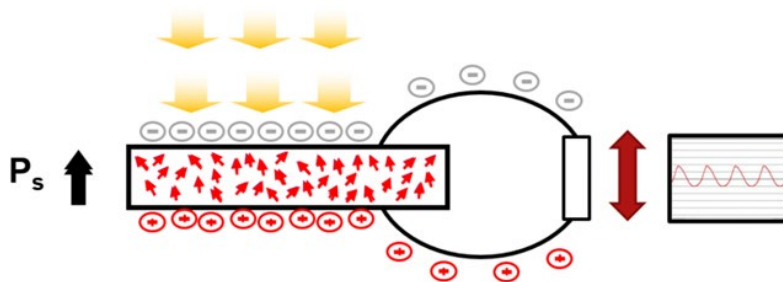
Fig. 15. Geiger-Muller detector (UV)

Radiation comes from both visible and invisible fires. Different gases emit radiation at different wavelengths and intensities, and a flame detector measures these parameters and compares them with the gases' fingerprints.

Flame detectors, however, cannot determine the composition of gases. The intensity and wavelengths are used to determine, with a high degree of certainty, whether a fire is present and, in some cases, its distance.

Flame detectors are based on two principles: UV detectors measure the intensity of UV radiation, and IR detectors measure the intensity of IR radiation. The UV detection principle may use the energy of the radiation to initiate a reaction inside a Geiger-Muller phototube, which generates a power pulse signal whose frequency is measured. The frequency increases with the increased intensity of the radiation, as shown in Fig. 15.

The tube is filled with an inert gas such as Helium or Argon. A high voltage is passed through the tube wall and the central electrode wire, and the current is measured. When the inert gas is exposed to radiation, the tube chamber becomes conductive, generating a voltage pulse with an amplitude proportional to the radiation intensity.



Source: <https://pyreos.com/core-technology/>

Fig. 16. Pyroelectrical sensor (IR)

One example of the IR detection principle is using a pyroelectric sensor that checks the presence of flutter and the corresponding radiation wavelengths. Another principle, shown in Fig. 16 uses the intensity of the fire to produce a potential difference across a crystal, which is converted into a sinusoidal electrical signal with a given amplitude and frequency.

The UV and IR flame detectors have their advantages and disadvantages, which are summarized in Tab. 2.

Tab. 2. Comparison of IR and UV flame detectors

Type	Advantages	Disadvantages
UV	<ul style="list-style-type: none"> • Fast detection (<25ms) • Reacts to all types of fires (burning liquids, gases, solids, sulfur, hydrogen) • Does not respond to direct or reflected sunlight 	<ul style="list-style-type: none"> • Cannot detect in case of contamination (oil, dirt, ice) on the lens • Prone to false alarms in case of: <ul style="list-style-type: none"> ○ Welding and radioactive radiation ○ Lightning, flashlight ○ Many substances, including gases, mist, and smoke, naturally absorb UV radiation and reduce radiation and radiation intensity
IR	<ul style="list-style-type: none"> • Can detect most hydrocarbon fires • Detects even with steam and dust present • Does not respond to welding • Not sensitive to sunlight • Requires less maintenance than UV detectors 	<ul style="list-style-type: none"> • Slower detection than UV (3-5 sec) • Some more restrictions on detection capability: <ul style="list-style-type: none"> ○ Sensitivity influenced by ambient temperature (less sensitive at high temperatures) ○ Less suited to detect fires of, for example, pure hydrogen (H₂) and ammonia (NH₃) fires (unless in combination UV). For H₂ gases, it is mentioned that the problem relates to the nature of the IR radiation (minimal heat radiant) and

		wavelength outside typical IR detector calibration) <ul style="list-style-type: none"> ○ High-pressure fires characterized by having no flickering are not detected (as opposed to “ordinary” fires).
Both	<ul style="list-style-type: none"> • Does not respond to sunlight (UV is a bit less sensitive than IR) 	

7.4.2 Smoke detection

Smoke can be defined as a visible suspension of carbon or other particles in air, typically one emitted from a burning substance. Two properties of smoke are of particular interest:

- Density of particles
- Particle size

The type of burning substance, the temperature, and the time elapsed influence the particle size. For example, particles from a propane fire can be around 0.005 μm, while those from a smoldering fire in a bed mattress (“skum-madrass”) can be around 5 μm.

Higher temperatures shrink particles, but over time they agglomerate into larger particles.

There are two commonly used smoke detection principles:

- Optical (using the IR range)
- Ionization

The expected particle size is important when choosing between the two detection principles. Fig. 17 illustrates that optical detectors are suitable for particles larger than a specific size, whereas ionic detectors can detect smaller particles.

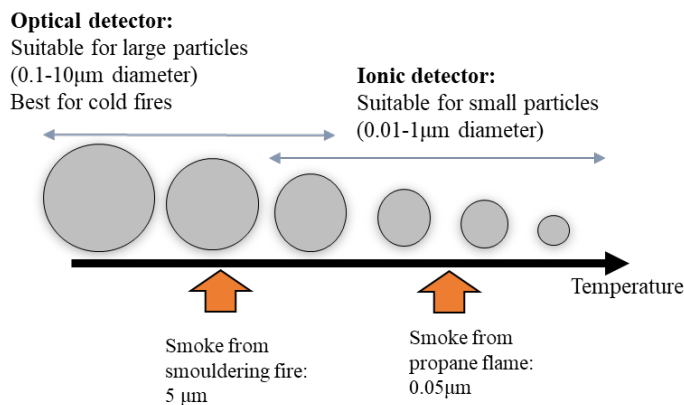


Fig. 17. Particle size vs smoke detection principle

7.4.2.1 Optical smoke detectors

Optical smoke detectors use IR light to illuminate the smoke, or more precisely, the smoke particles. The commonly used wavelength for IR light is 0.85-0.95 μm to avoid interference from other light sources in the surroundings. Only particles above this diameter can be detected. Optical detectors are, therefore, less useful for high-temperature fires (where particles are smaller) and in the early stage of a fire when particles have not yet agglomerated.

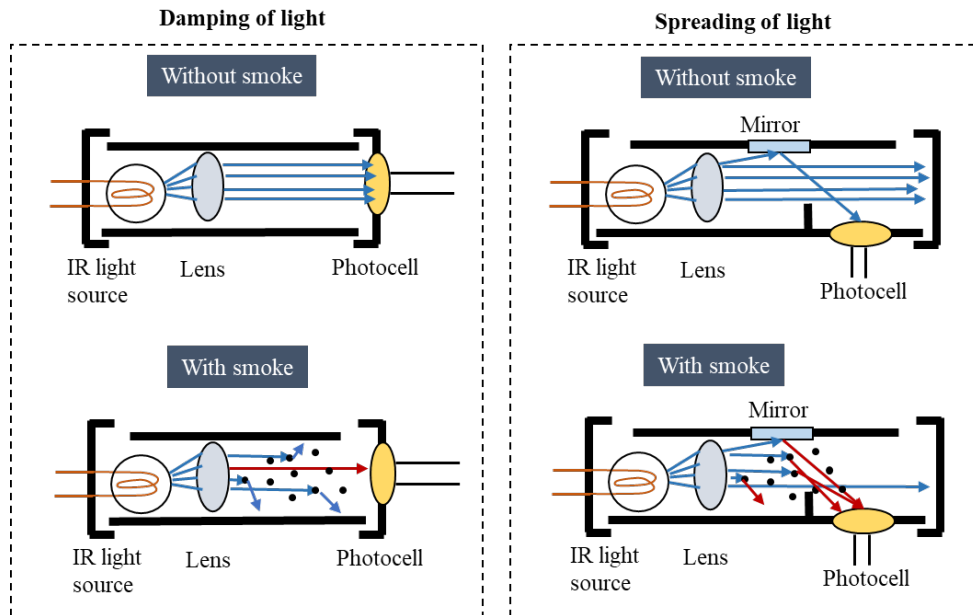


Fig. 18. Principles of optical smoke detectors

The smoke must enter a chamber, like a point gas detector, to be detected. The intensity of the IR light is measured by a photocell after the IR beam has passed through the smoke. The two principles of detection are:

- Damping of IR beams: The intensity of IR light measured at the photocell decreases when smoke is present
- Spreading of IR beams: The intensity of IR light measured at the photocell increases

The two principles are shown in Fig. 18. With the damping of IR light, fewer beams will reach the photocell with smoke particles in the chamber. When the IR beam hits the smoke particles, they leave the original path. According to the principle of spreading, the photocell receives only the IR beams reflected by the mirror. With smoke in the chamber, more beams will reach the photocell because they collide with smoke particles.

The principle of damping of light has the following advantages:

- High sensitivity. Even small concentrations of smoke particles will lead to a loss of intensity at the photocell.
- Simple principle suitable for clean areas, like equipment rooms, inside panels

The spreading principle is more robust than the damping principle, as the photocell continues to measure the same relative changes in light intensity even if the lens and the mirror have been contaminated.

Both types of detectors have the following common weaknesses:

- It can give a false alarm if vapor enters the chambers, as the vapor can lead to the same distortion of the IR beams.
- Are sensitive to high air velocity, as smoke particles may be prevented from entering the chamber.
- Dirt and dust can give false alarms or indicate that the detector is no longer working.

7.4.2.2 Ionization smoke detectors

Ionization detectors are suitable for detecting smaller smoke particles. Smaller particles are common in fast-burning, high-energy fires. A radioactive source sends high-energy alpha particles (helium nuclei) and beta particles (electrons) into a chamber. The particles generate an electrical field that can be measured, as shown in Fig. 19. When smoke enters the chamber, the particles attract the ions, reducing the measured current. The amount of reduced current correlates with the smoke concentration.

A reference chamber not exposed to smoke is added in series with the measurement chamber to remove sources of faults. Unfortunately, vapor from showering may, analogously to smoke particles, absorb ions and cause a false detection.

Like optical detectors, ionization detectors may operate less effectively when the surrounding air velocity is high. Therefore, placing detectors near a ventilation inlet or outlet is not recommended. Ionization detectors used to be the most common type of detector in homes, but now optical detectors are usually preferred.

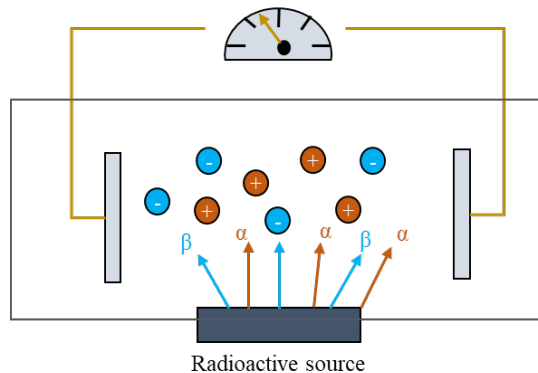


Fig. 19. Ionization detector principle

7.4.2.3 Comparison of optical and ionization detectors

The two smoke detection principles are summarized in Tab. 3, focusing on the situations where the detectors are best suited.

Tab. 3. Summary of properties of optical and ionization detectors

Optical detectors	Respond quickly to smoldering fires, as such fires have low energy but generate larger particles	Respond late to open flames with rapid temperature increase and smoke generation due to too small particles. The response takes place when particles have agglomerated into a sufficient size.
Ionization detectors	Able to detect open flames with smoke that consists of tiny particles	Will respond late to smoldering fires, most likely when the situation has developed into an open fire. Sensitive to vapor from showering, which can result in false alarms.

Optical detectors were once a bit more costly than ionization detectors, but a search for their purchase costs does not reveal any systematic trend. Some ionization detectors seem more expensive than some optical detectors, and vice versa.

7.4.2.4 Multi-sensor smoke detector

A multi-sensor smoke detector combines multiple detection principles to detect a wider range of smoke characteristics. A multi-sensor may combine the following detection principles:

- Optical & ionization & heat sensor
- Optical & gas detector for CO & heat sensor
- Optical & heat sensor

A heat sensor is not sensitive to smoke but to high temperatures and can replace the ionization detection principle. A disadvantage of the heat sensor is that it can detect internal fault states less effectively than the ionization detection principle.

7.4.2.5 Early-warning smoke detectors

A special type of smoke detector is the early-warning detector. In some areas, such as electrical equipment rooms or offices, it is vital to be notified of any condition, such as a sparkover or damaged electrical equipment,

that could lead to a fire. A low concentration of smoke may be generated with low energy before escalating into a fire. An early-warning detector uses the aspiration principle to suck air inside electrical panels or in a room into an optical smoke detector via dedicated tubes/pipes. The principle is shown in Fig. 20.

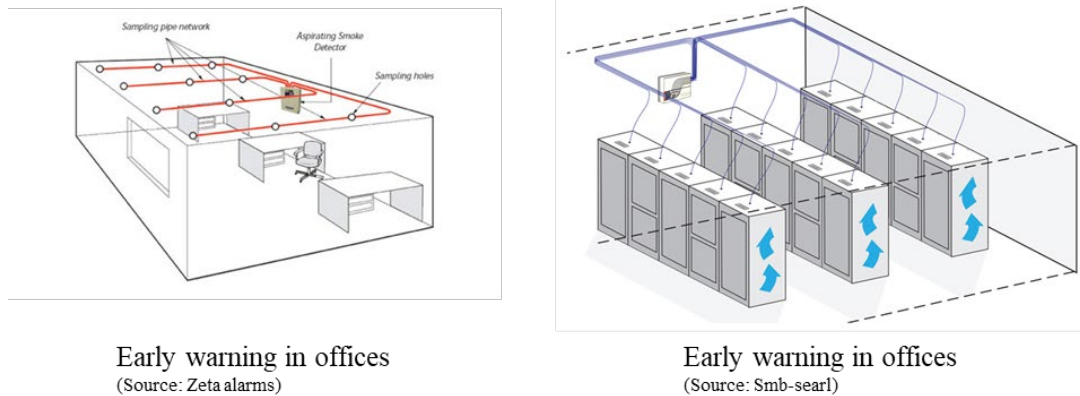


Fig. 20. Early warning detectors based on aspiration

Some smoke detectors without aspiration are also called early-warning detectors if they claim high sensitivity to one of the two types of smoke: high-energy/small-particle or low-energy/large-particle. In practice, their ability to respond early depends on where they are positioned relative to the smoke's origin.

7.4.3 Heat detectors

Heat detectors are sometimes used in addition to optical smoke detectors in areas where high-temperature fires can be expected. The advantage of these detectors over ionization detectors is their lack of sensitivity to atmospheres that can be misinterpreted as smoke, such as gases, vapor, and dust. The detector relies on a simple design principle using a bimetal-type switch and an electrical circuit, as shown in Fig. 21.

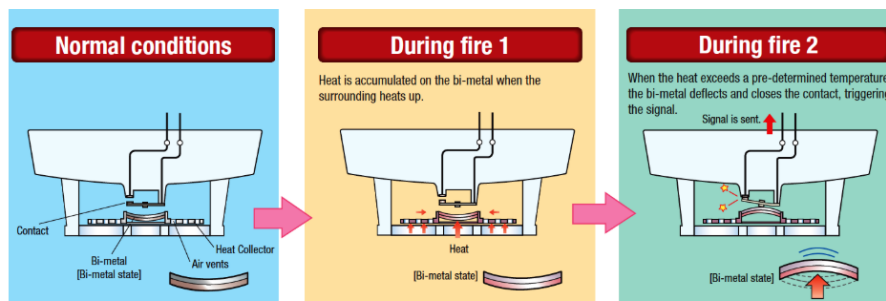


Image Courtesy : Hochiki

Fig. 21. Working principle of a heat detector

The electrical circuit is open under normal conditions (no high temperature), so the connected controller measures no current. When the detector is exposed to a temperature above a specific setpoint, the bimetal piece bends, closing the circuit switch and causing the controller to interpret the current as a confirmed fire.

Compared to ionization detectors, the time to detect high-temperature fires may be longer. In addition, a broken bimetal, a broken switch, or damaged circuit wires cannot be detected before the detectors are subjected to a function test or until a real fire occurs.

7.5 Location of fire and gas detectors

While level, pressure, flow, and temperature transmitters are continuously exposed to their measured media, it is more challenging to determine the optimal location for fire or gas detectors. The detectors need to provide coverage over larger areas, both indoor and outdoor, with potentially many locations where gas leaks or fires

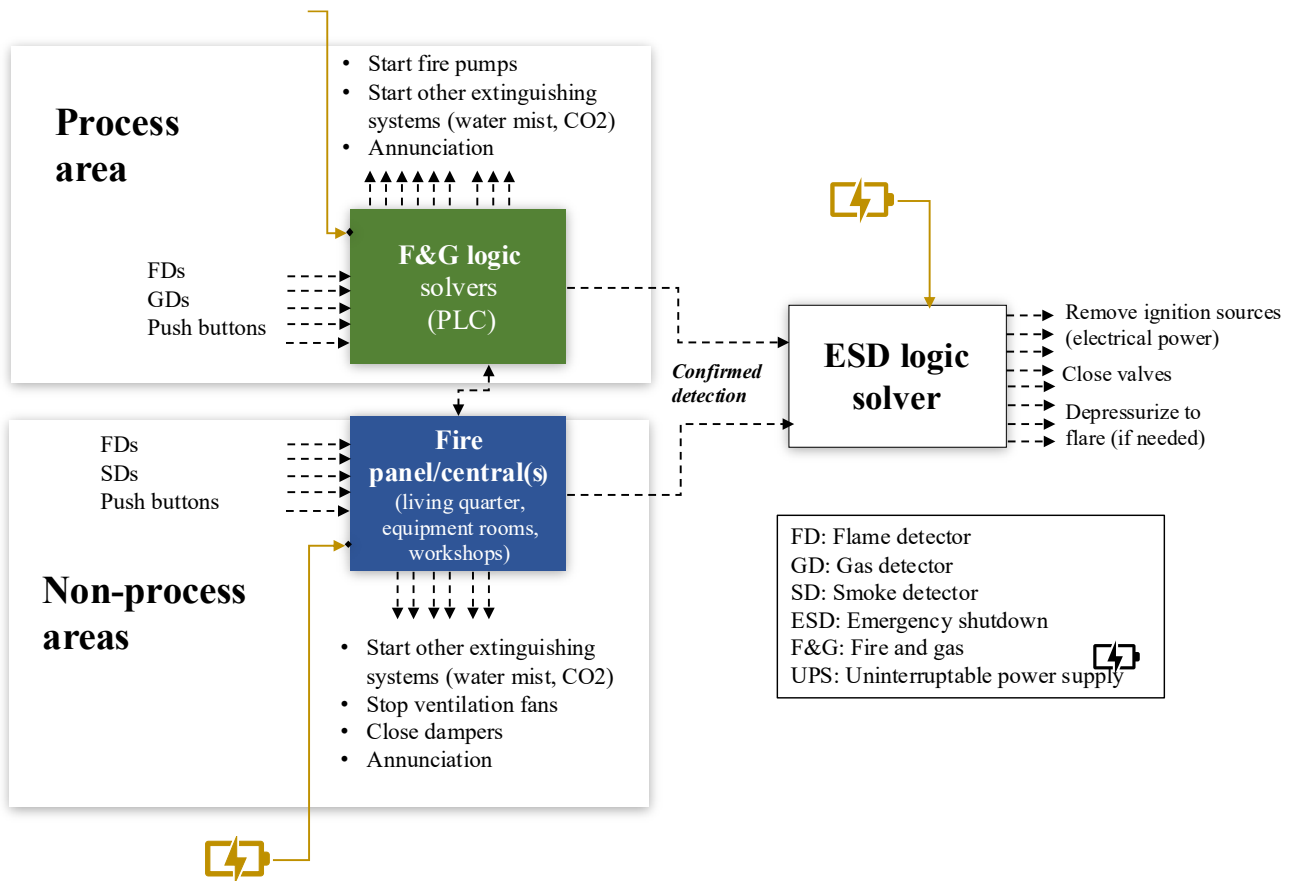


Fig. 23. F&G detection vs ESD system

7.6 Physical integration with controllers

Fire and gas detection systems may be split into two types:

- F&G detection system for process areas, focusing on flame and gas detection and extinguishing, dimensioned to manage such risks.
- F&G detection in buildings, here referred to as non-process areas, focuses on smoke and flame detection, extinguishing, and limiting further escalation by operation of ventilation fans and fire dampers. Buildings may include living quarters, kitchen areas, restrooms, the control room, workshops, and equipment rooms housing cabinets and panels.

When a fire or gas leak has been detected, it is important to ensure that the flow and storage of hazardous materials and fluids are secured, and that electrical equipment that does not need to be powered is isolated to prevent ignition and further escalation. The F&G controller and fire panel may, therefore, send a message to the emergency shutdown system, which will take further action for additional risk-reducing (mitigative) tasks.

In principle, the interaction between ESD and F&G logic solvers is as shown in Fig. 23. It may be noted that the power supply to F&G and the ESD system is secured by an uninterruptible power supply (UPS), as the ESD system cuts off the main power supply and, at some point, also the emergency generator. Diesel generators with sufficient fuel storage can provide power to water pumps for several hours.

7.6.1 F&G detection and interface to ESD system

A way to integrate F&G detection with the emergency shutdown (ESD) hierarchy is specified in NORSOK S-001 (2021), supported by the illustration in Fig. 23. Three F&G detection functions are identified here:

- Confirmed gas in a non-hazardous area, meaning gas is detected in areas that should not be exposed to gases, such as living quarters, workshops, and equipment rooms.
- Confirmed fire in a hazardous (i.e., Ex-zone) area, meaning fire is detected in the process area where equipment contains flammable substances.
- Confirmed fire or gas detection in the wellhead or riser area, meaning fire or gas is detected in areas where the amounts of contained gases operate at high pressures (as for the wellhead area) or in areas with large volumes of gases (as with the riser area, where all pipelines enter and exit the facility).

NORSOK S-001 (2021) explains the meaning of “confirmed” in more detail with values expressed in %LEL.

Most flame and gas detectors provide measurements of 4-20mA and can, therefore, be interfaced to all PLC and DCS systems via analog input cards. Smoke detectors often rely on continuous measurements, which can be transferred via a digital protocol developed by fire panel manufacturers. There are also examples of wireless gas detectors that rely on digital communication, but these detectors are often supplementary to existing wired detectors.

The ESD hierarchy identifies relationships between F&G detection systems and ESD system functions. To enhance the reliability of this relationship, all signals between the ESD and the F&G system are either hardwired or transmitted via functional safe communication (black-channel type).

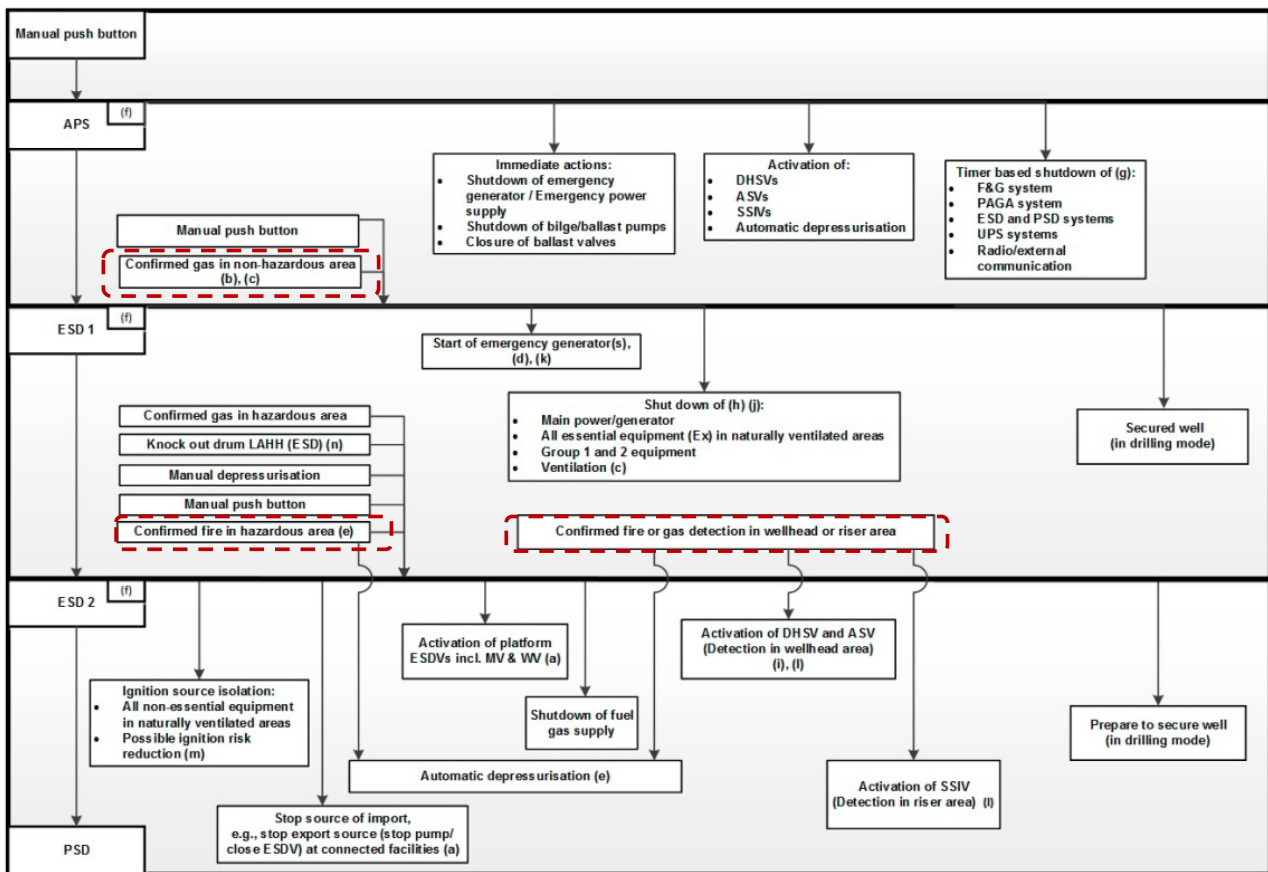


Fig. 24. ESD hierarchy (NORSOK S-001)

7.6.2 Fire panels/centrals

A plant often has a dedicated fire central or panel to detect fires in areas outside the process and utility areas, such as living quarters (including kitchens, canteens, cabins, etc.), equipment rooms, and workshops. Fire centrals are specialized logic solvers designed primarily for interfacing with smoke detectors. They possess

advanced diagnostic capabilities, combining continuous measurements within the detector with digital communication to transmit values.

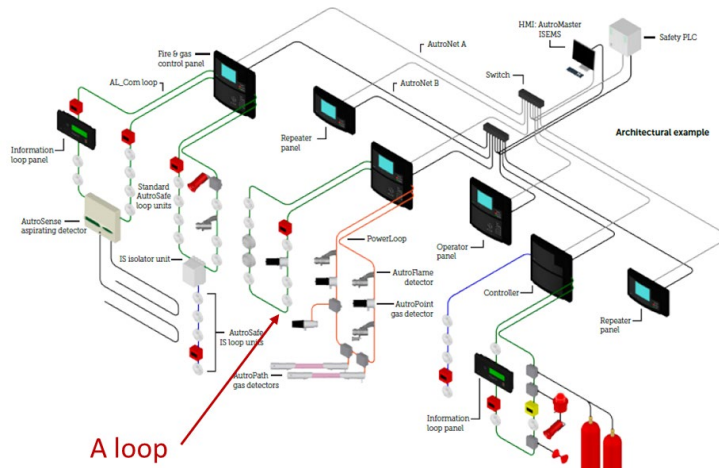
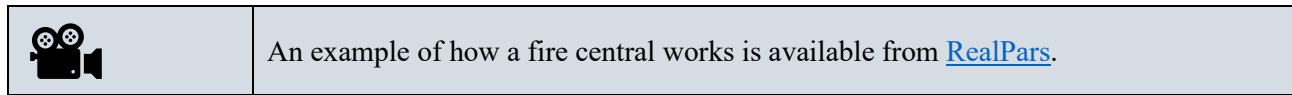


Fig. 25. An example of a fire central architecture with connected loops (Autronica)

Autronica is one of the providers of fire panels. It applies the Autronica loop communication protocol (AL_com and AutoFieldBus) to communicate with detectors connected to the ring-type network shown in Fig. 25. The communication protocol combines digital communication and power supply over a single cable. As illustrated, manual call points and various types of detectors can be added to the loop if they have the necessary communication interfaces. All detectors are addressable, meaning their addresses are included in the information about the measured value. It is also possible to send information to specific detectors.

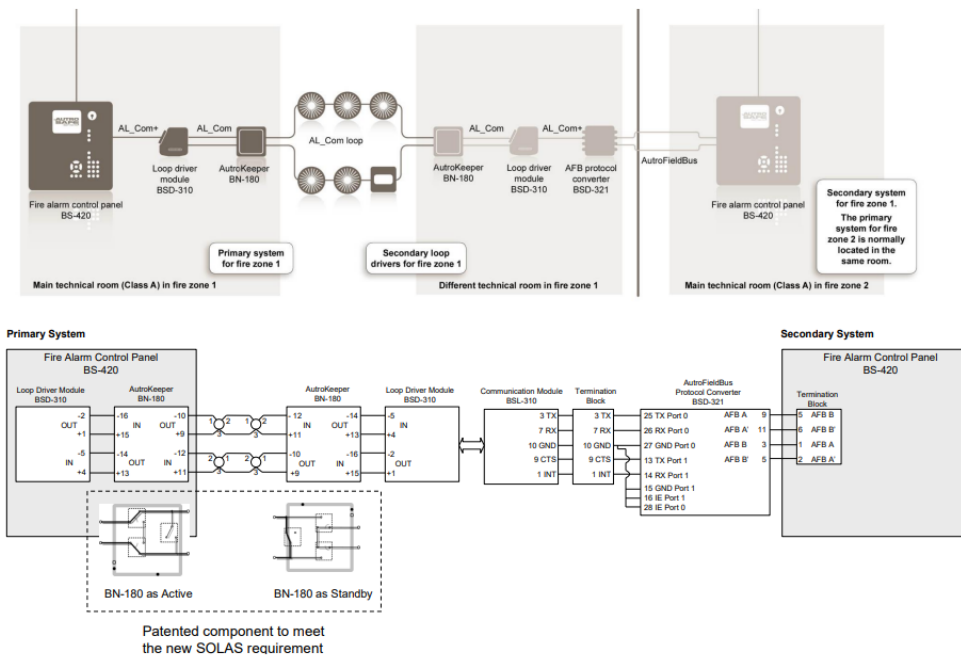


Fig. 26. AutoSafe connection diagram (AutoSafe installation guide)

An installation guide for AutoSafe Fire Central from Autronica explains some of the details of how the devices are connected using AL_com and AutoFieldBus, as shown in Fig. 26.

The Safety of Life at Sea (SOLAS) regulation requires that each detection loop be connected to two independent fire centrals, ensuring that detection capability remains intact even if one fire central becomes unavailable. The fire centers must be in different fire-separated zones. In the upper part of the illustration, we see that one fire central connects to the loop using AL_Com+ and AL_Com. AL_Com is the communication protocol used between the devices connected in the loop and the loop driver, and AL_Com+ is the protocol used between the fire central controller and the module stack. The second fire central (right side) connects to the loop with AutoFieldBus. This detail is not explained, but it is assumed that this protocol is suitable to apply when AL_Com loop drivers are located some distance from the fire central controller.

AutoSafe fire central systems include the product SelfVerify, which allows regular self-tests of the detectors. The self-test simulates a detection situation, and the fire central checks the results. The self-test also reports the detector's sensitivity and notifies you if it is outside the specifications.



To see how self-verify functions, see the following [video on YouTube](#)

7.7 Selection of regulations and standards

The design of fire and gas detectors often relies on the following standards:

- EN 50402 (2017): A European standard on requirements for the design of electrical apparatus for detecting and measuring combustible or toxic gases, vapors, or oxygen. Requirements on the functional safety of gas detection systems.
- ISO 13702 (2015): An international standard for the design of control and mitigation measures to avoid fires and explosions on offshore production facilities.
- National Fire Protection Association (NFPA) standards that cover several standards on design requirements for fire and gas detection and extinguishing systems, for example NFPA 72 (2022)

Not all countries define F&G systems as SIS. However, many F&G detector and controller manufacturers adopt functional safety standards, such as IEC 61508, as best practices in their product development, and many end-users use the same equipment, for example, in accordance with IEC 61511. Therefore, many providers of F&G detectors, fire centrals, and controllers offer safety integrity level (SIL) certification for their products in accordance with IEC 61508.

National (Norwegian) guidelines and standards that apply either directly or indirectly to F&G detection systems are:

- Offshore Norway GL 070 (2026) on the application of IEC 61508 and IEC 61511, which provide SIL requirements to F&G detection systems for the petroleum sector

Regulatory requirements of importance related to this sector are:

- Norwegian regulation for prevention of fire that applies to buildings (<https://lovdata.no/forskrift/2015-12-17-1710>)
- Norwegian regulation about safety measures for fire and explosion protection for mobile (offshore) facilities (<https://lovdata.no/forskrift/1984-01-31-227>)
- Norwegian regulation about fire protection measures onboard ships (<https://lovdata.no/forskrift/2014-07-01-1099>)
- Ocean industry Authority Regulation (HAVTIL) § 32 (<https://www.havtil.no/en/regulations/all-acts/the-facilities-regulations3/V/32/>)

7.8 Bibliography

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