KEYS TO IMPROVING SAFETY IN CHEMICAL PROCESSES

EMERSON

Many facilities handle dangerous processes and products on a daily basis. Keeping everything under control demands well-trained people working with the best equipment.

Safety within chemical processing plants is truly a life-or-death issue for many companies due to the presence of toxic, flammable, and potentially explosive products. Even if the products themselves are fairly benign, steam, compressed air, high-voltage electric power, and combustion equipment can injure workers due to a malfunction or mistakes stemming from inadequate training. In addition to personnel injuries, safety incidents can damage equipment, cause releases with environmental impact, and damage a facility's relationship with its surrounding community.

Incident-related costs add up quickly as well. Medical and legal costs for injured workers, repair and replacement of damaged equipment, higher insurance rates, and fines from regulatory agencies are made worse by income loss from production interruptions. Less-tangible costs result from personnel problems as current and future hires are reluctant to work in what they perceive as a dangerous environment.

In many respects, the first line of defense for personnel safety is **the people themselves**, along with a **strong safety culture**. Plant personnel must have **sufficient training** to understand their environment, including the potential hazards presented by equipment, processes, and substances around them. This minimizes potential for injury. However, in most facilities, many potential hazards go far beyond what any individual can control, no matter how safe his or her actions.

A comprehensive safety solution calls for a broad approach built on a variety of technologies to identify potential hazards and detect when a problem may be developing. The system should take effective measures to correct or at least mitigate the situation, while warning workers that additional action may be necessary. Worker training is still critical, but comprehensive solutions acknowledge the limitations of human responsibility.

SAFETY LIFECYCLE

For process industries, designing safety systems is guided by two standards: IEC 61511 and IEC 61508. The former applies most directly to industrial process environments and outlines a series of steps, beginning with analysis of potential hazards to determine safety requirements for a safety instrumented system (SIS). Overall safety strategy uses layers of protection (Figure 1), to build responses proportional to the threat, increasing in severity based on threat escalation.

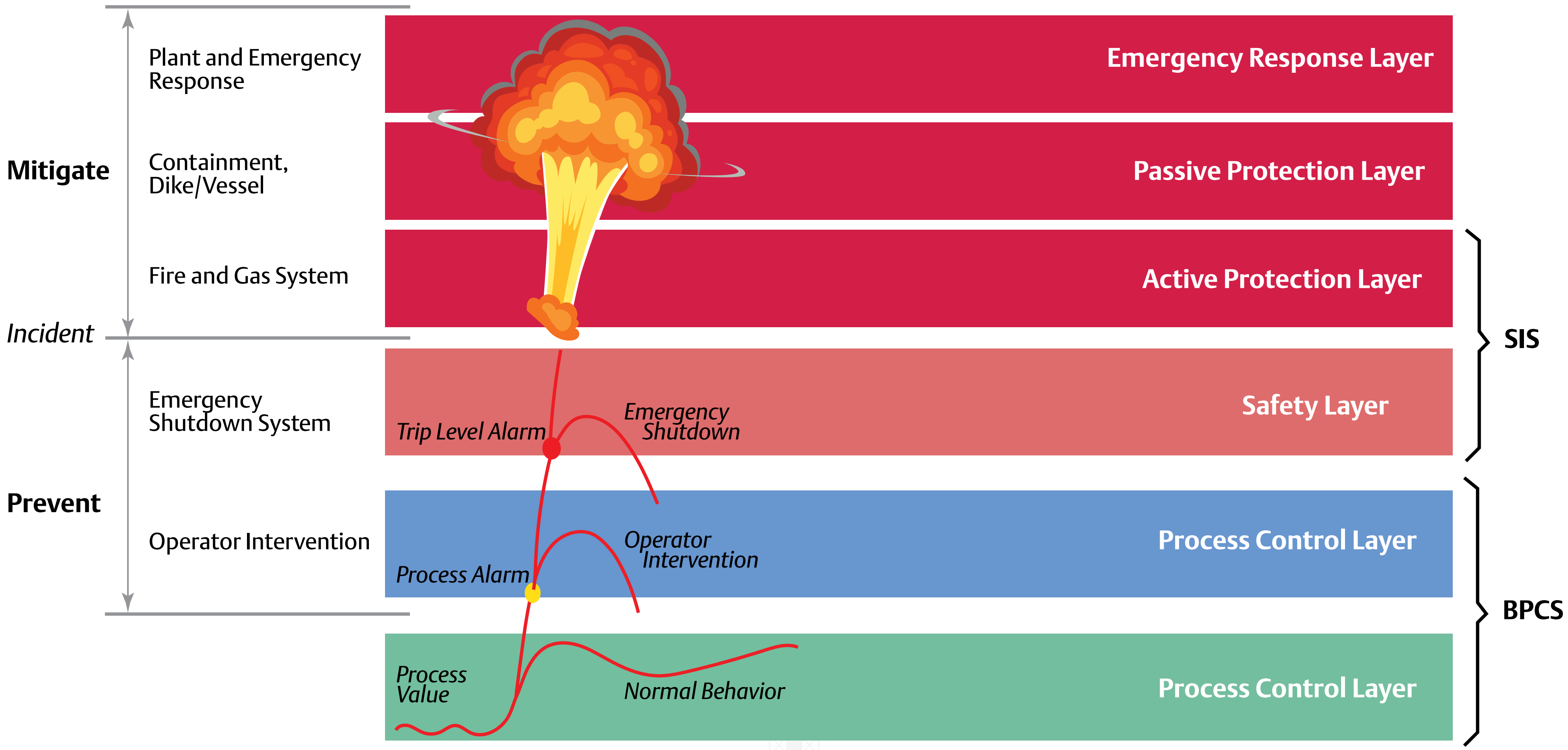

Figure 1: Comprehensive safety systems use layers of protection proportional to the threat's severity, to avoid needlessly disruptive responses.

It is important to view safety holistically, but this can be overwhelming. One practical approach keeps the full scope in mind but divides the solution into more manageable parts. For purposes of this eBook, we will examine three areas:

- Occupational safety—emphasizing the interaction of people with the processes and equipment
- Process safety—concentrating on what goes on within the vessels and piping
- Containment safety—sound process piping and vessels, along with safe storage of feedstocks and finished products.

In some respects, these are distinct, but they also overlap, as we will show. Safety goals within a facility must address all three since any one can be the root cause of an incident. For example:

- A facility might have a very thorough training program for occupational safety to avoid accidents and injuries, while having an outdated and poorly maintained SIS, capable of allowing a process upset to escalate into a fire or chemical release.
- Dependence on operator rounds and poor accessibility to critical equipment can put people at risk, rather than automating such tasks.
- Poor maintenance of vessels and piping can allow corrosion to cause leaks or major containment failures, even with an effective process control system in place.

The lesson is that no aspect of safety can be ignored if a facility is to be considered safe, defined as having hazards managed well enough to create an environment with tolerable risk. Employees must believe they will be going home at the end of the shift without experiencing an incident or injury. Let's look at how this can become an everyday experience.

1 UNDERSTANDING FUNCTIONAL SAFETY

UNDERSTANDING FUNCTIONAL SAFETY

Before examining the three areas, we will review basic functional safety concepts, and how safety systems work. A fundamental concept relates to safety instrumented functions (SIF) which have as their objective to take a specified action during a hazardous condition. A SIF has three components: sensors, logic solver, and final elements.

A sensor or instrument serving as a detector is the first element of a SIF. For example, a pressure instrument installed on a reactor sends its data to a logic solver which reads and processes the data and sends a specific command to a final control element (FCE). In this case, it might activate a valve to release pressure. It probably also sends a signal to the control room to alert operators of the situation, and an alarm may be triggered.

The SIF elements must have no other duties. The sensor must not be part of the basic process control system (BPCS) and the FCE must only relate to the safety function. A SIF cannot have another function that might put it into conflict with its primary duty.

SIFs are implemented in SISs, which execute dozens and even hundreds of independent SIFs. Functionally, each individual SIF must be independent, but that doesn't mean they can't communicate with each other to reinforce safety efforts (Figure 2). Large-scale SIS deployments benefit from distributed architectures.

Figure 2: The DeltaV™ Smart Logic Solver provides flexibility for safety instrumented systems with scalability from 12 to 30,000 configurable I/O.

A SIF that malfunctions and launches a potentially disruptive action when there is no actual threat, can be very disruptive to production and even cause a process interruption. To minimize this possibility without sacrificing protection, highly critical SIFs can use multiple sensors to measure the same variable, arranged in a voting scheme.

The most common voting scheme is two-out-of-three (2oo3) where three sensors are installed in the same location. A single sensor reporting a problem can't trip the function, so this avoids a disruption caused by a single malfunction. Any two of the three sensors must report the same problem simultaneously for the function to trip. To avoid complex installations, some instruments are configured as multiple units (Figure 3) with a set of fully independent transmitters specifically for this purpose.

Figure 3: Flow meters, such as the Rosemount™ 8800 Quad Vortex Flow Meter, provide the ultimate redundant flow measurement solution to guard against spurious trips using 2oo3 voting, plus a fourth integrated transmitter for process control.

SAFETY CERTIFIED DEVICES

There is a wide category of components (Figure 4) certified for SIS applications. Sensors, instruments, controllers, valves, and others can be purchased with such designations, often including a safety integrity level (SIL) number. Across all of Emerson's products—including instrumentation, controllers, valves, and software—the collection of safety certified products is the largest in the industry, providing a good source of information to begin a new project or upgrade.

Figure 4: Emerson offers the broadest range of safety certified equipment, including instruments, controllers, and valves.

The concept underlying safety certified devices is not that they can't fail. Safety engineers know that anything can fail, but for safety applications, it is important to know how something might fail, along with its probability of failing. To earn a safety certification, a device is subjected to a battery of tests listed in safety standard IEC 61508 to determine the probability of failure on demand (PFD). Such tests are performed by a specialized agency, independent of the manufacturer.

Certification means the testing agency is convinced that the PFD when the instrument must handle an actual problem is low enough that the instrument can be part of a SIS, while providing a reliable layer of protection for the plant. The PFD rating places it into a SIL category, usually either SIL 2 or SIL 3, which must match the criticality of the application.

To ensure that the equipment supporting a SIF actually works, safety standards require periodically putting the equipment through its paces. These verifications are called proof tests, and the frequency of a proof test for a specific SIF is determined by a statistical calculation related to its SIL rating.

Proof-testing involves simulating conditions that cause the SIF to respond, without doing anything actually unsafe. In the case of a SIF where it is necessary to simulate a high-pressure incident, the pressure instrument might be isolated from the process and connected to a compressed air line to push it past the limit and make sure the system responds correctly. Naturally, performing such a test can disrupt production.

The proof-testing process is particularly important if it is the only mechanism to determine the condition of equipment tied to a SIF. However, advanced diagnostics (Figure 5), can tell operators much about the condition of an instrument or smart valve actuator, and how it's operating. This diagnostic information often can be used to extend the time between tests, and/or reduce the most disruptive parts of the test.

Figure 5: The Rosemount 5900 Radar Level Gauge can be proof-tested safely and remotely from the control room using Rosemount TankMaster™ Inventory Management Software that allows an operator to perform one or several proof-tests. Following a guided process, proof-testing can be done in less than five minutes, and afterwards an automatic report is generated which specifies the details of the test and confirms success.

Where an instrument or valve actuator supporting a SIF has few or no diagnostic capabilities, proof-testing procedures will likely call for a disruptive approach, which is resource-intensive and disruptive to production. Instruments with advanced diagnostics for SIFs can reduce production disruptions associated with proof-testing procedures, with no negative impacts to safety.

2 | OCCUPATIONAL SAFETY

OCCUPATIONAL SAFETY

Occupational safety is primarily concerned with keeping humans safe in the plant environment. Naturally, all safety systems protect people, but these are less focused on equipment and processes.

Many aspects of occupational safety have nothing to do with systems. Safety begins with effective training for new hires as well as veterans, with “safety moments” often included in company meetings to reinforce safety culture. Requirements for proper use of personal protective equipment (PPE) is part of training in any plant and governed by the immediate hazards present.

Training is critical because people are often the cause of incidents. Consequently, managers look for ways to keep people out of the plant as much as possible. They automate procedures (Figure 6) that would have called for manual rounds to avoid this potential source of incidents and worker exposure.

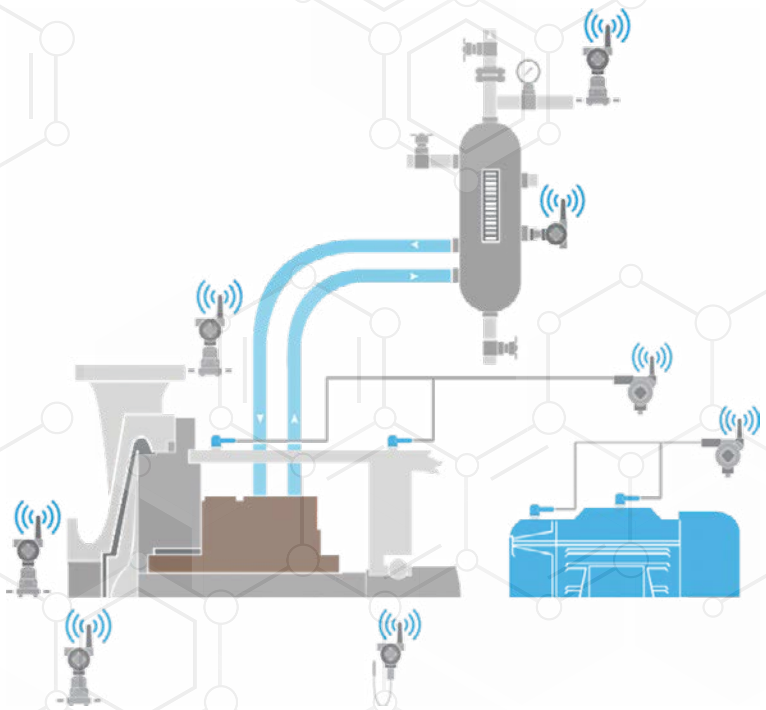

Figure 6: Adding vibration and bearing temperature sensors that communicate via WirelessHART® to a pump installation collects critical data continuously, while greatly reducing the need for manual inspections.

Examples include:

- Installing analyzers at strategic locations to replace manual sample collection
- Mounting vibration sensors on pump or compressor installations to replace routine maintenance inspections
- Placing toxic or combustible gas detectors in areas where hazardous gases could affect workers’ health
- Deploying *Wireless*HART networks to support wireless sensors in locations that are not practical or cost-effective to wire.

LOCATION MONITORING

There are situations where sending operators and maintenance technicians into the plant is unavoidable. A key element in protecting those people is simply knowing where they are in the plant, and if they might be in trouble. Many plant managers want just such a mechanism, but implementing this type of system, usually using Wi-Fi, is complex and expensive.

New location-monitoring technology, enabled by *Wireless*HART, supports location monitoring at a much more reasonable cost, and with simpler implementation. Location calculations use information provided by a *Wireless*HART device called a Location Anchor. These anchors communicate with each other and *Wireless*HART gateways, in a similar way as conventional *Wireless*HART instrument transmitters (Figure 7). However, anchors communicate with Location Tags worn by each worker, helping to determine where each worker is located.

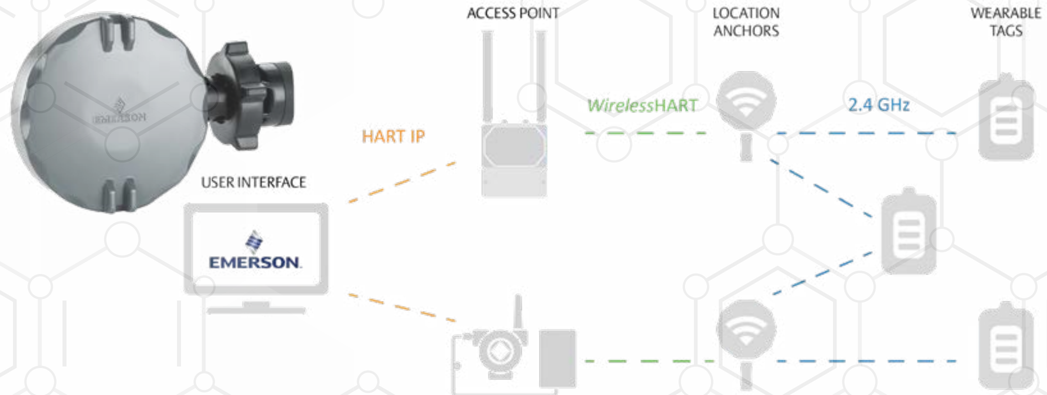

Figure 7: Emerson’s Location Monitoring solution extends WirelessHART networks to read individual wearable Location Tags.

Location Anchors are small, light, and self-powered. They are less expensive than systems utilizing industrialized Wi-Fi access points, and their Class 1/Div 1, Zone 0 rating allows them to be deployed throughout chemical plant environments. Rechargeable tags (Figure 8) worn by each worker communicate with the anchors, and the anchors communicate with each other and the gateways or access points. This approach is easily scalable to accommodate the number of employees in a given plant, plus it provides an exceptionally high level of flexibility to achieve the required coverage and resulting overall worker safety.

Figure 8: Wearable Location Tags automatically detect a person's whereabouts and send signals to fixed Location Anchors for relevant-time updates.

Location software (Figure 9) supports safety functions:

- Geofencing indicates if individuals have moved into areas where they should not be due to presence of a hazard or lack of training.
- Safety mustering lets first responders know which people have moved to the correct safe areas during a drill or incident.
- Safety alerting allows a worker who is injured, in an unsafe situation, or a witness to an incident to press the user-assistance button on the Location Tag to indicate an emergency in progress and the location.

Figure 9: The Plantweb™ Insight Location application provides visualization for raw location data.

SAFETY SHOWER AND EYEWASH STATIONS

Mishaps in a plant may result in a worker being splashed or sprayed by hazardous chemicals. To minimize potential injury, plants have safety shower and eyewash stations, but they are not always monitored. A worker needing attention may have to call for help on the plant radio or hope to be spotted by a colleague. With a simple *Wireless*HART valve monitoring device (Figure 10), any activation immediately reports the situation and location to the control room, and to first responders in the plant.

Figure 10: Adding a Rosemount 702 Wireless Discrete Transmitter can tell the control room which safety shower or eyewash station has been activated.

Wireless instrumentation and accompanying apps simplify the installation, configuration, and maintenance of equipment monitoring systems. These systems can be brought online at a fraction of the cost of traditional wired transmitters and complex enterprise-wide analysis software.

3 PROCESS SAFETY

PROCESS SAFETY

Process safety is the most complex given the number of possible hazards and potential for damage from incidents. Dozens and even hundreds of individual SIFs must be coordinated to provide the necessary layers of protection, calling for comprehensive systems.

Yet, in many respects, the most critical systems in a plant or process unit are an effective distributed control systems (DCS) combined with reliable SISs. If the process has sound control strategy built using modern hardware and software (Figure 11), and if it is supported by adequate instrumentation, it will be able to keep the process stable, even in the face of potential upsets and feedstock inconsistencies. In the event the DCS cannot control the process, the SIS will take the process to a safe state. Tight integration between DCS and SIS provides multiple benefits through the lifecycle of the systems. Proper integration between DCS and SIS does not compromise the independence of the two layers of protection.

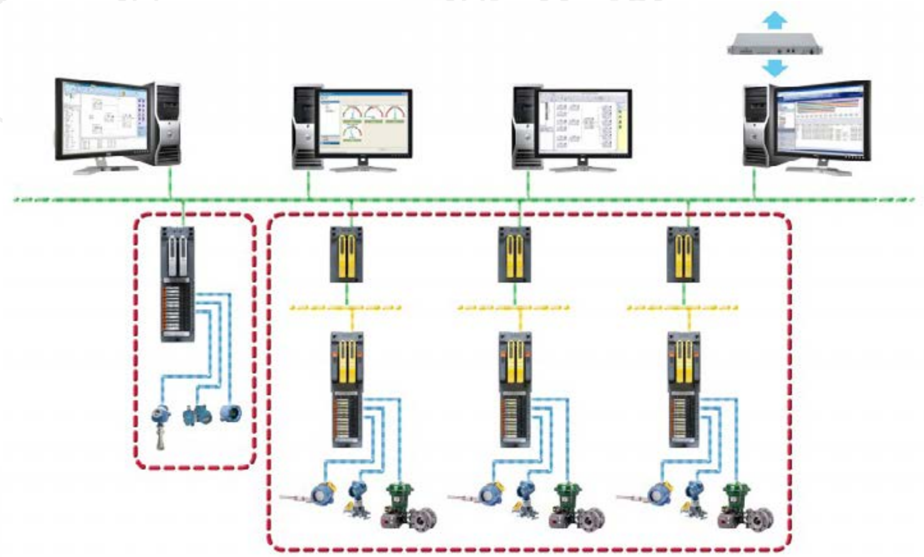

Figure 11: An effective Integrated Control and Safety System, such as the DeltaV Control System, combined with traditional and WirelessHART instrumentation and field devices, will provide dependable and stable production.

When well-trained operators have deep visibility into process conditions, and are assisted by carefully managed alarms, they can deal with abnormal situations before they escalate into incidents. Under these conditions, an effective SIS remains critically important, but it will have little to do.

On the other hand, a poorly controlled process will be unstable and generate too many demands for the SIS.

Cybersecurity is a critical aspect of automation systems since a malicious attacker can exploit a vulnerability to find a way to either disrupt the process or create a hazardous condition. Today's automation system architectures, such as DeltaV 14, DeltaV SIS, and *Wireless*HART, have many built-in protections, but companies still must be aware of potential threats, and tighten up work practices to minimize vulnerabilities.

DIAGNOSTICS DETECT PROBLEMS

Advanced instruments used for SIFs can recognize a variety of equipment and process problems. For example, the Rosemount 3051S with Advanced Diagnostics (Figure 12) can detect unusual conditions early and send messages to operators of an abnormal condition developing. This can happen without interfering with the basic safety function. If the diagnostics are fully enabled to take advantage of their capabilities, reliability and maintenance technicians can fix these undetected failures before they escalate to the point of creating a false trip.

Figure 12: Safety-certified transmitters have the same Advanced Diagnostics as their conventional counterparts.

A safety-certified Rosemount 3051S with Advanced Diagnostics can recognize and report:

- Changes in the process noise signature that could be indicative of an issue, such as furnace flame instability or pump cavitation
- Plugged impulse lines or other process connection issues
- Water in the transmitter housing
- Wiring damage or corroded terminals
- Poor power quality or improper grounding.

Rosemount Magnetic Flow Meters and Micro Motion™ ELITE™ Coriolis Flow Meters (Figure 13) are available with Smart Meter Verification, a specialized set of diagnostics that monitor the entire flow meter's performance and integrity continuously while the process is running. This meter diagnostic software provides information in real-time to ensure flow measurement accuracy and when it is time to schedule calibration. When combined with a digital control network, this diagnostic tool can eliminate the need for scheduled visits to the field, and it can extend testing intervals.

Figure 13: Smart Meter Verification is a specialized set of diagnostics that monitor the entire flow meter's performance and integrity continuously.

All these diagnostic capabilities can indicate something might be wrong with the process or the specific SIF. Some, if left unaddressed, could result in a false system trip. This shows how advanced diagnostics provide a double benefit, improving availability by reducing the potential for a false trip while simultaneously providing insight into equipment condition and even process changes. Taking advantage of the advanced diagnostics is only possible if the SIS can process the diagnostic information. A legacy SIS may only process the 4-20 mA signal, while DeltaV SIS can utilize the advanced diagnostics. For example, DeltaV SIS can recognize a malfunctioning device and remove it from the voting architecture.

MINIMIZING HAZARDS

As mentioned earlier, effective automation minimizes manual processes, such as operator rounds to gather data or perform inspections. This serves two important functions, overlapping with occupational safety:

- Operators spend less time in the plant where there is opportunity for exposure to hazards
- Automated data gathering is more effective because it can be continuous and avoids human errors.

A prime example of this concept is continuous monitoring of pressure relief valves (PRVs) and steam traps using an acoustic monitor (Figure 14).

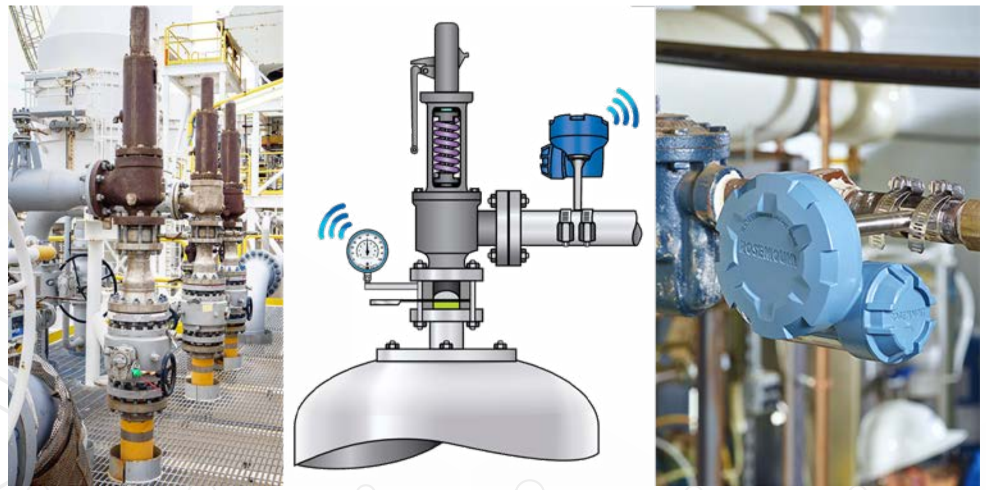

Figure 14: Rosemount 708 Wireless Acoustic Transmitters mount on piping adjacent to PRVs and steam traps to detect if they are functioning correctly or might be leaking. They are self-powered and send data via WirelessHART, so there is no need for any wiring.

PRVs are critical safety equipment, but create operational problems due to a tendency to remain partially unsealed after a release event. This permits simmering, a slow leakage of process fluid into the collection system. Leakage can also interfere with their ability to open correctly during an incident, while wasting energy, and increasing emissions. Such problems are often difficult to diagnose due to PRV inaccessibility, calling for scaffolding and putting workers into potentially unsafe situations to evaluate their condition manually.

Steam traps are subject to frequent malfunctions in many environments, wasting product and energy. There is also potential for safety-related incidents caused by condensate backing into the steam lines, resulting in piping ruptures and other equipment damage due to water hammer effects.

Replacing dangerous manual inspection rounds with acoustic monitors provides continuous data while allowing operators to perform higher level tasks.

4 CONTAINMENT SAFETY

CONTAINMENT SAFETY

Chemical plants generally have tanks on site to hold various liquid products, such as feedstocks, intermediates, and final products. Some may be dangerously toxic or flammable, so it is important to ensure tanks can't be overfilled, or have releases caused by leaks or inadvertent valve openings.

As a case in point, in January 2014, residents in a southeastern U.S. state noticed a strange odor from their drinking water and called local authorities. The odor was caused by 4-methylcyclohexylmethanol leaking from a nearby chemical storage facility. The chemical was running out of a one-inch hole in the bottom of a 40,000-gallon tank. Approximately 7,500 gallons escaped and affected the water supply to 300,000 local residents.

Containment incidents must be prevented by effective safety automation:

- Appropriately selected level instruments and an effective SIS can stop operators from overfilling a tank.
- An effective level instrument and SIS can recognize when the contents in a tank decrease with no corresponding process reason but is instead caused by a leak.
- Automated valves tied to a control program to set up valve lineups during liquid transfers avoid spills caused by incorrect procedures.

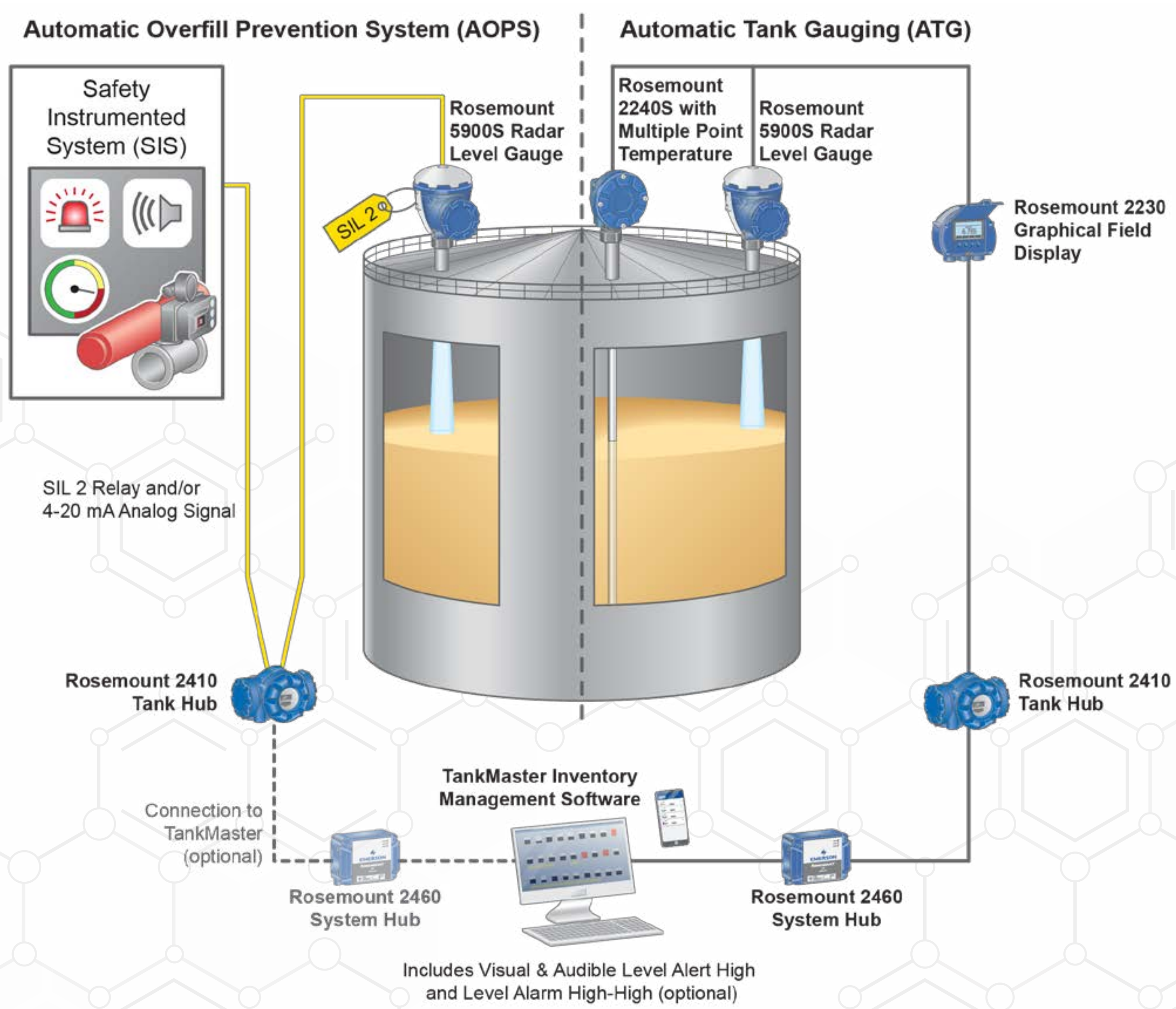

Figure 15: The ATG and AOPS exist side-by-side but separately so they can function independently. Rosemount 5900S Radar Level Gauge is available in conventional and SIL-rated versions for these types of applications.

While catastrophic events understandably get attention, smaller incidents are common, but these can be prevented. Safety certified level instruments (Figure 15) are very accurate and monitor their respective tanks continuously, watching for unexplained changes. They can support SIFs designed to shut down filling actions before tanks reach their limit and detect minute changes in level resulting from leaks. These protect workers, the surrounding community, and the plant itself from potential disasters.

Leaks can also be recognized by gas detectors that detect escaping hydrocarbon gases or toxic gases such as hydrogen sulfide. Selecting the right gas detectors naturally depends on the types of feedstock and final product manufactured at the site.

CONTAINMENT SAFETY

Gas detectors take two forms (Figure 16), fixed point detectors and open path. Fixed point detectors can monitor critical areas such as valve clusters, while open path gas detection is typically used to monitor perimeters around tanks.

Figure 16: Fixed point combustible and toxic gas detectors use multiple sensor technologies, such as infrared, catalytic bead and electrochemical. The Net Safety Millennium II series (left) can detect all flammable gases and common toxic gases. Rosemount 935/936 Open Path Combustible and Toxic Gas Detectors (right) use infrared and ultraviolet technology to detect hydrocarbon and toxic gases, including methane, propane, ethylene, hydrogen sulfide and ammonia.

Many sites also deploy flame detectors (Figure 17) to cover areas where a process leak may find a source of ignition. Flame detectors generally activate alarms but may also trigger fire suppression equipment to douse strategic areas in foam.

Figure 17: Rosemount 975 Multi-Spectrum Ultraviolet & Infrared Flame Detectors respond to the specific wavelengths of light produced by a variety of burning fuels.

DETECTING LOSS OF CONTAINMENT BEFORE IT OCCURS

While some incidents are caused by human error, corrosion is also a root cause for safety and maintenance issues. Industrial accidents are often related to uncontrolled or unexpected corrosion. By monitoring corrosion, the elevated risk and damage are detected long before loss of containment, which improves operational safety for the plant, personnel, and the environment. Since corrosion attacks from the inside, it is difficult to spot by visual inspection, but it can be detected in two ways.

First, conditions capable of causing corrosion can be detected via an electrical resistance (ER) probe inserted into a pipe or vessel wall (Figure 18). This can warn operators when it is necessary to change some process variable, or add an inhibitor, to slow corrosion. Historized data can also be analyzed to calculate how much damage may have been done over a critical period.

Figure 18: The Roxar™ Retrievable ER Probe monitors internal corrosion in common environments such as chemicals, oil, gas, and water. It provides sensitive and fast responses to corrosion change.

Second, it is possible to monitor pipe and vessel wall thickness using ultrasonic sensors (Figure 19). These clamp on at strategic points, such as a pipe elbow, and send data via *Wireless*HART to a central collection and analysis platform. They measure the wall thickness continuously and can detect changes as small as 2.5 microns. Over time, it is possible to recognize periods when metal loss was particularly aggressive.

Figure 19: Rosemount Wireless Permasense Corrosion and Erosion Monitoring Systems measure wall thickness continuously so maintenance can determine when pipe must be replaced.

A data-driven corrosion and integrity management program will ensure that asset conditions are known. As a result, the timing and scope of maintenance and repair strategies can be optimized to avoid unplanned outages or safety issues.

CONTAINMENT SAFETY

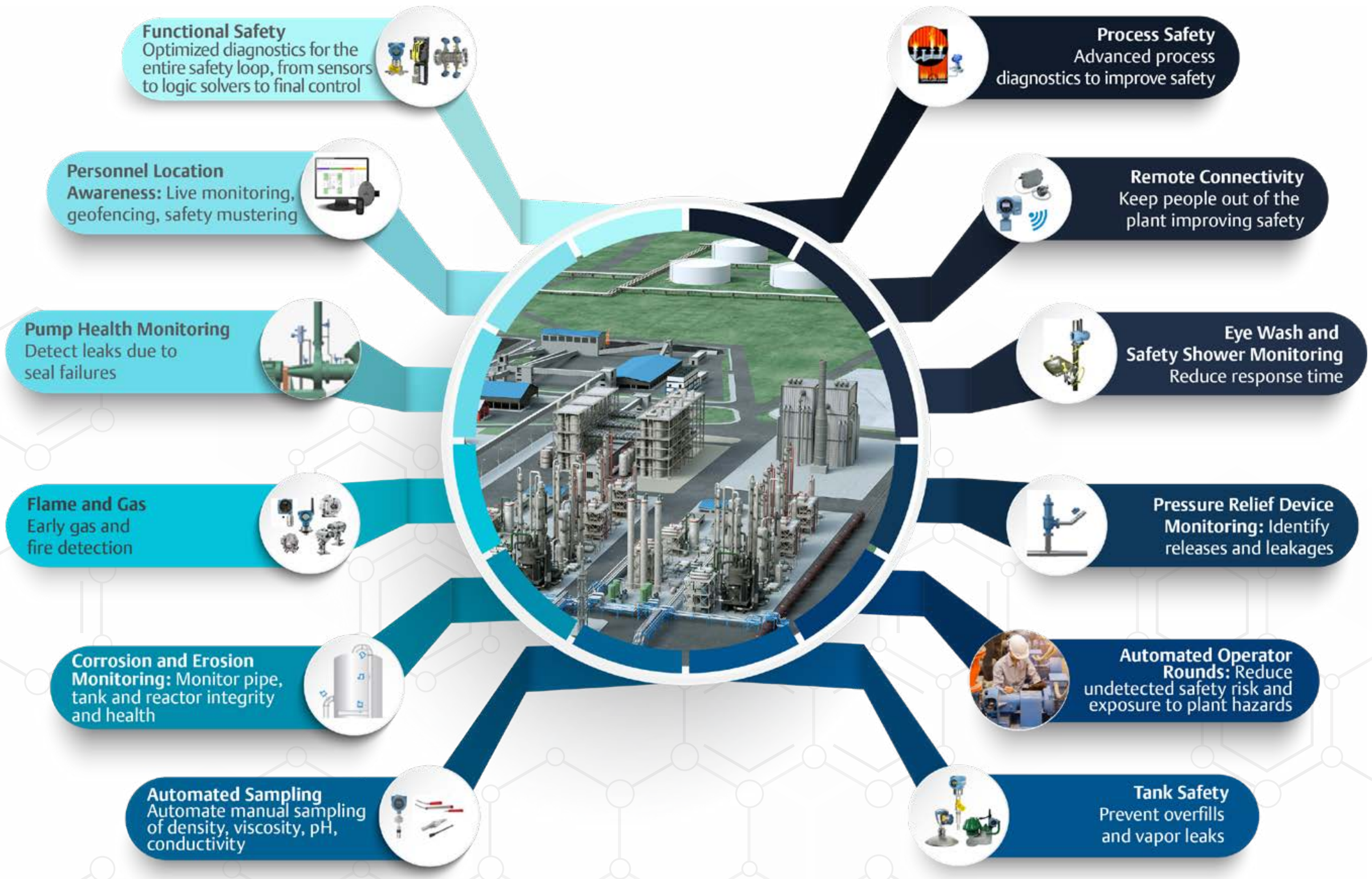

Figure 20: Emerson has a comprehensive set of technologies and services to provide early detection and avoidance of potential safety incidents and to mitigate the consequences.

- *Prevent fires, explosions, and other process incidents with our modern SIS*
- *Meet SIL requirements with our portfolio of safety certified devices*
- *Avoid leaks, spills, and releases with tank management solutions and corrosion monitoring*
- *Improve personnel safety and reduce emergency response time throughout the facility.*

ELEMENTS FILLING A LARGER STRATEGY

All the individual topics discussed so far must come together to create a coordinated strategy to link all the protective layers in all the areas. Safety takes many forms (Figure 20), and Emerson has the widest range of products in the industry.

The selection of various functional safety devices and how they are integrated to provide occupational, process, and containment safety through larger safety systems must be analyzed, planned, and maintained carefully by experts. Preserving a facility's ability to operate while avoiding safety and environmental incidents calls for the right strategy, equipment, proof-testing, and personnel training. Emerson can provide assistance in all these areas, starting with walkdowns and recommendations, and continuing with a complete array of required products.

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