HYCO Plant Gas Leak Detection And Response Practices

AIGA 110/20

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As part of a program of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has published AIGA 110, *HYCO Plant Gas Leak Detection and Response Practices*, jointly produced by members of the International Harmonization Council and originally published as CGA H-14 by Compressed Gases Association (CGA) as *HYCO Plant Gas Leak Detection and Response Practices.*

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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1 Introduction

HYCO plants are facilities that produce hydrogen, carbon monoxide, or mixtures thereof. These plants are typically operated with feed stocks such as natural gas, refinery off gas, naphtha, and other light hydrocarbons.

Gases from HYCO plants are flammable and can be toxic; therefore, appropriate leak prevention design, monitoring, and response practices shall be applied to ensure personnel and public safety. Leak detection is part of an overall system comprising design aspects, leak detection devices, operating practices, and the response to leak indications.

2 Scope

This publication applies to HYCO plants. Information in this publication may also be applied to facilities, such as trailer fill stations, cylinder fill stations, electrolytic production facilities, or vehicle fueling stations.

This publication covers methodologies for prevention of, detection of, and response to flammable and/or toxic gas leaks that occur within the fence line of these facilities. Typical leak detection technologies are discussed including personal monitoring, fixed monitoring, and specialized detectors for identifying leak location. This publication also addresses the specifics of gas leaks occurring at unmanned or remotely monitored sites.

The leaks discussed in this publication are due to a loss of containment in process piping and equipment. A loss of containment is an unexpected release of process fluid to the atmosphere. A leak of this type is typically through a failed sealing device (e.g., stem packing, flange gasket) or a failure of the pressure boundary (e.g., crack in a weld). Many jurisdictions use the concept of fugitive emissions for leaks that are too small to repair, which are not covered in any detail in this publication due to jurisdictional variances.

This publication does not cover leaks from transportation piping or components leading to flares or process vents. It does not address routine oxygen deficiency and enrichment as these are covered in other harmonized publications AIGA 009, Safety Training of Employees; AIGA 08, Hazards of Inert Gases and Oxygen Depletion, as well as in CGA SB-2, *Oxygen Deficient Atmospheres* [1, 2, 3].[1] It also does not address fire and smoke detection in buildings as these are covered in National Fire Protection Association (NFPA) standards and local building codes.

The reader should determine applicability for facilities other than those described in this publication or for leaks entering the facility from outside of the perimeter.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3.1.5 Can
Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Action level
Condition in which the atmosphere is outside the acceptable range and an operator shall take action to prevent the hazard from escalating.

3.2.2 Alarm level
Condition that results in a warning (alarm) indicating that the atmosphere is outside of the range of normal.

3.2.3 Cross header
Refractory lined pipe that connects the reformer outlet manifold to the inlet of the waste heat boiler.

NOTE—Also known as a transfer header.

3.2.4 Cross-sensitive
Situation in which a sensor designed for a particular target gas reacts to another gas as if that gas were the target (e.g., a carbon monoxide sensor that is cross-sensitive to hydrogen will interpret a hydrogen leak as carbon monoxide).

3.2.5 Fugitive emissions
Emissions that cannot reasonably pass through a stack, chimney, or vent or other functionally equivalent opening [4].

3.2.6 HYCO plant
Facilities which produce hydrogen, carbon monoxide, or mixtures thereof.

3.2.7 Immediately dangerous to life or health (IDLH)
Maximum concentration from which unprotected persons are able to escape within 30 minutes without escape-impairing symptoms or irreversible health effects.

3.2.8 Line stop
Plug that is installed in plant piping, typically while the plant is in operation.

3.2.9 Lower flammability limit (LFL)
Minimum concentration in air of a gas that would burn when ignited.

NOTE—Also known as the lower explosive limit (LEL).

3.2.10 Monitors

3.2.10.1 Fixed monitor
Detection device that is permanently mounted in one (fixed) location and that can be used for detection of one or more fires or gas leaks.

3.2.10.2 Personal monitor
Gas detection device that is worn by personnel or visitors at an operating facility and that transmits warnings via audible and visible signals, such as alarms and flashing lights, when dangerous levels of gas vapors are detected.

3.2.10.3 Portable monitor
Handheld gas detection device that transmits warnings via audible and visible signals, such as alarms and flashing lights, when dangerous levels of gas vapors are detected.

3.2.11 Permissible exposure limits (PEL)
8-hour time weighted average exposure set by the U.S. Occupational Safety and Health Administration (OSHA).

3.2.12 Reportable quantity (RQ)

Minimum amount of hazardous substance which, when known to have been discharged into the environment within a prescribed time limit, is required to be reported to the authority having jurisdiction.

NOTE—In the United States the prescribed time limit is 24 hours and reports are made to the National Response Center in Washington, DC.

3.2.13 Upper flammability limit (UFL)

Maximum concentration in air of a gas that would burn when ignited.

NOTE—Also known as upper explosive limit (UEL).

4 Safety considerations

A HYCO plant produces hydrogen and/or carbon monoxide as products. The feed stocks for a HYCO plant are a variety of light hydrocarbon gases or liquids and sometimes ammonia. These colorless gases or liquids can be flammable and/or toxic. Toxic and flammable gas detectors are commonly used throughout a HYCO plant to warn of potentially dangerous gas leaks or harmful exposure to personnel; they play a valuable role in risk mitigation. Selection of appropriate gas detectors will depend on the gas being detected. Table 1 identifies the key properties of some of the substances most commonly found in HYCO plants. The basic physical characteristics listed in the table affect sensor selection and placement, leak detection, and required personnel behavior in the area of the leak. The operator shall review the safety data sheet (SDS) to understand all of the hazards associated with a specific gas.

Diffusion governs the behavior of gases leaking into the atmosphere. Wind direction, turbulence, leak rate, and the temperature and specific gravity of the leaking gas all have an effect on how the vapor cloud moves away from the leak source. Sensor placement shall take all of these factors into account. In the case of an enclosed space such as a building, the impact of these parameters is obvious. However, some plant areas with limited ventilation can offer similar risk regarding a gas leak. The proximity to occupied buildings should be considered, for guidance see AIGA 093, *Guideline for the Location of Occupied Buildings in Industrial Gas Plants* [5].

Attention shall be paid to the impact of the temperature of the fluid on vapor cloud behavior when assessing the hazards associated with a leak. Cryogenic gases or cryogenic liquid boil off that have specific gravities that are lighter than air can drop due to their low temperatures. Conversely, gases that have normal specific gravities that are heavier than air can rise when heated. A special case of high gas temperature is where a flammable gas mixture is greater than the autoignition temperature and can spontaneously ignite on contact with air. In this case the leak confirmation will often be the presence of a flame.

Unexpected behaviors can occur in the presence of wind or forced ventilation. Wind driven air flowing over an object such as a building or pipe rack can cause eddies downstream, which can form down drafts. These down drafts can cause gases whose normal specific gravity is lighter than air to fall.

Depending on the concentration of the flammable gas in air, the vapor cloud can ignite. Gases with a low threshold of ignition energy (e.g., hydrogen) can ignite due to static sparks generated by flow friction, which is accentuated by flow velocity. Vapor clouds ignited in an open area typically burn as a deflagration. However, if the vapor cloud is confined or is in a congested area, the deflagration can transition to detonation. This vapor cloud behavior shall be part of the risk assessment after the leak is confirmed.

When a gas is both toxic and flammable, the toxicity often dictates the behavior requirement in response to a leak. For example, in the case of carbon monoxide, the point at which the concentration is considered IDLH is approximately 1% of the LFL. The PEL is 0.02% of the LFL.

If a gas detector indicates that the concentration of a toxic gas is greater than the PEL, actions shall be taken to address the hazard before attempting to work in the area (e.g., increased ventilation, appropriate personal protective equipment [PPE], use of breathing air). It is important that the user of the gas detector be aware that the vapor cloud shape is typically irregular and that the concentration is not homogenous. PPE and other mitigations should be identified based on a hazard assessment.

Visitors to the site shall be informed of the hazards associated with any gases or liquids that could be present in the facility along with the appropriate response to any leaks that could occur. Visitor indoctrination shall include appropriate response to site alarms, which could be triggered in the event of a significant leak. Hazards associated with the materials on site shall also be covered.

Table 1—Key properties of common HYCO plant chemicals

Chemical	Typical location in plant	Fire/ Explosion	Toxic [1)]	Asphyxiant	Odor	Health impact	Heavier/ Lighter than air	LFL - UFL in air (vol %)
Ammonia (NH_3)	Product, refrigeration, NOx depletion in flue gas, process condensate, deaerator vent	Yes	Yes	Yes	Yes [2)]	Yes	Lighter	15.5 - 27.0
Amines	Carbon dioxide removal	Yes	Yes	Yes	Yes, fishy	Yes	Heavier	[3)]
Carbon dioxide (CO_2)	Product, syngas, carbon dioxide removal, PSA tail gas	No	Yes	Yes	No	Yes	Heavier	N/A
Carbon monoxide (CO)	Product, syngas, PSA tail gas, flue gas	Yes	Yes	Yes	No	Yes	Lighter [4)]	12.5 - 74.2
Hydrogen (H_2)	Product, syngas, PSA tail gas, hydrogenation of sulfur compounds in feed gases	Yes	No	Yes	No	No	Lighter	4.1 - 74.8
Hydrogen sulfide (H_2S)	Hydrocarbon feedstock, desulfurization, partial oxidation raw syngas	Yes	Yes	Yes	Yes, rotten eggs [2)]	Yes	Heavier	4.3 - 46.0
Natural gas (NG)	Feedstock, fuel	Yes	No	Yes	Yes, if odorized	Yes	Lighter	5.0 - 15.0 [5)]
Liquid petroleum gas (LPG)	Feedstock, fuel	Yes	No	Yes	Yes, if odorized	Yes	Lighter	2.1 - 9.5 [6)]
Methanol (CH_3OH)	Feedstock, syngas purification (Rectisol), product, process condensate, deaerator vent	Yes	Yes	Yes	Yes, alcohol	Yes	Lighter	6.7 - 36.0
Naphtha	Feedstock, fuel	Yes	Yes	Yes	Yes	Yes	Heavier	[7)]
Metal carbonyls	Desulfurizer, reformer, and other components	Yes	Yes	Yes	Yes, musty [2)]	Yes	Heavier	[8)]
Nitrogen (N_2)	Utility station, equipment purge, instrument gas, startup gas	No	No	Yes	No	No	Lighter [4)]	N/A
Oxygen (O_2)	POX feedstock	[9)]	No	No	No	No	Heavier [4)]	N/A
Refinery off gas (ROG)	Feedstock, fuel	Yes	Yes	Yes	Maybe	Yes	Lighter	[10)]
Sulfur dioxide (SO_2)	Flue gas (from fuels containing sulfur), waste gas from Rectisol unit	No	Yes	Yes	Yes, acidic [2)]	Yes	Heavier	N/A
Syngas	Product, intermediate from reforming/partial oxidation to purification steps (mixture of carbon monoxide, carbon dioxide, hydrogen, and methane)	Yes	Yes	Yes	No	Yes	Lighter	[11)]

Chemical	Typical location in plant	Fire/ Explosion	Toxic 1)	Asphyxiant	Odor	Health impact	Heavier/ Lighter than air	LFL - UFL in air (vol %)

1) Toxicity based on the National Institute for Occupational Health and Safety (NIOSH) criteria [6].

2) Odor is *not* a good indicator of concentration, as your olfactory cells quickly become saturated and you cannot smell it anymore. However, the odor of this gas should not be ignored, as it can be smelled at concentrations lower than most sensors can detect and is thus a leading indicator of a problem.

3) Refer to specific amine SDS.

4) Heavier if vapor cloud from liquid vaporization.

5) As methane. The presence of other hydrocarbon compounds can affect the LFL/UFL.

6) As propane. The presence of other hydrocarbon compounds can affect the LFL/UFL.

7) Plant specific, refer to naphtha specification.

8) Flammability varies based on metallic constituent.

9) Supports combustion.

10) Plant specific, refer to gas composition.

11) LFL/UFL will vary with composition.

5 Monitoring

5.1 Guidelines

Monitors or detectors are devices used to measure a gas concentration or to identify the presence of a potentially dangerous condition. They are made up of one or more sensors and an electronics package that interprets the sensor signal. There may be an array of detectors that comprise a monitoring system. The device or system then conveys the information to an operator through a display or through audible and/or visual alarms. The sensor is the actual device that detects the condition of interest by measuring a physical characteristic, for example, results of a chemical reaction, change in temperature, presence of smoke, change in radiant energy, and flammability.

Types of gas detection equipment include personal monitors for personal protection, portable monitors for establishing hot work permit zones or leak characterization, and fixed monitors for plant early warning systems (fire or gas). The following are general guidelines for the use of gas detection equipment:

- Personal monitors should be fastened to clothing near the breathing zone. They only indicate that the area is safe to enter or that an area is becoming unsafe and evacuation is required. Personal monitors shall not be used for leak characterization. Personal monitors do not identify the type or size of the leak;
- Sensors to detect gases that are lighter than air should be placed above potential leak sources and sensors to detect gases that are heavier than air should be placed below potential leak sources;
- Radiant energy fire sensors shall have a clear line of sight (light path) to potential fire zone. If any ultraviolet or infrared light (such as sunlight, welding, etc.) strikes the sensor either directly or by reflection, it can result in a false alarm;
- Convective energy sensors (temperature) or smoke detectors should be placed above the potential fire zone;
- Electrochemical gas sensors are a consumable and can be cross-sensitive to more than one type of gas. This cross-sensitivity is listed in the manufacturer's data sheet and shall be taken into account. Until proven otherwise, assume the most hazardous gas is present. Use of this type of sensor for leak characterization will quickly wear out the sensor. They shall be replaced when exhausted and their active life depends on exposure level to the gas of interest. An electrochemical sensor becomes a small battery when exposed to the gas to which it is sensitive;
- Monitoring systems require periodic testing. Systems typically have a "test" button to ensure audible and visible warning elements operate properly. Testing should include exposing the sensor to the condition or gas of interest. The test gas should provide a sufficient concentration to trigger the alarm condition;
- The operator shall be trained and qualified to identify false alarm conditions and take appropriate actions to real conditions; and

- An operator can use their senses (sight, hearing, and smell) to detect leaks before they will show up on fixed monitoring systems. The sense of smell shall not be used as the only sensing method, but an alert operator who reports “smelling something odd” can provide a valuable early warning. Some gases can be detected by smell prior to being identified by a gas monitor; however, olfactory cells can become saturated and can no longer detect the smell.

Note: Gases Like CO, H2 or CO2 cannot be sensed by smell.

5.2 Sensor types

Different types of detectors or monitors are used in HYCO facilities and they contain one or more sensors. Multiple sensing technologies can be available for detecting a specific gas or condition. Some of the more common sensor technologies utilized in these detectors are summarized in the following sections.

Exposure limits will vary based on the flammability or toxicity of the component being detected. Specific exposure limits will vary with the country/region of the facility. The exposure limits and/or the flammability limits of a component shall be taken into account when determining the alarm set points of a monitor. For more information on typical exposure limits for U.S. facilities, see NIOSH and OSHA [6, 7].

5.2.1 Electrochemical carbon monoxide sensor

This sensor is predominately specific to carbon monoxide (1 ppm indicated is 1 ppm actual), but can be cross-sensitive to hydrogen or other gases. Cross-sensitive gases can read higher or lower value concentration of that gas. The user shall check the manufacturer’s data sheet for cross-sensitivities and their magnitude. Any reading shall be assumed to be carbon monoxide until positively proven otherwise.

The toxicity level of carbon monoxide is more important than the flammability of carbon monoxide. An LFL detector is useless for identifying safe levels of carbon monoxide because 1% LFL is 1250 ppm, which is significantly greater than any published exposure limit.

5.2.2 Electrochemical oxygen sensor

This sensor is predominately specific to oxygen (20% indicated is 20% actual), but can be cross-sensitive to other gases, and the manufacturer’s data sheet should be consulted for details. Many oxygen detectors use the atmosphere as the bump check/calibration source. If the detector uses ambient air as its calibration gas, make sure the atmosphere you are standing in is 21% oxygen. It is recommended to go outside upwind of process to make the check. Units have been miscalibrated in areas contaminated with excess nitrogen. If the oxygen sensor reads greater than 21% when outside, double check the calibration.

The high alarm point for oxygen indicates an oxygen-enriched atmosphere where fuels can ignite easily and burn extraordinarily well. A human being can breathe this atmosphere without noticeable symptoms. The low alarm condition for oxygen indicates an oxygen-deficient atmosphere. The effect on the human body is as if the individual were standing at high altitude; their breathing rate can be higher to the point of distress. Fuels will still burn under these conditions.

5.2.3 Electrochemical hydrogen sulfide sensor

This sensor is predominately specific to hydrogen sulfide (1 ppm indicated is 1 ppm actual) but can be cross-sensitive to other gases, and the manufacturer’s data sheet should be consulted for details. Hydrogen sulfide is a gas that is colorless, extremely toxic, and flammable. The gas smells like rotten eggs. It is 1.21 times heavier than air and thus collects in low places. Smell is *not* a good indicator of concentration, as olfactory cells quickly become saturated and can no longer detect the smell. However, the smell of this gas should not be ignored, as it can be smelled at concentrations less than the sensor lower detectable limit, providing a leading indicator of a problem.

The toxicity level of hydrogen sulfide is more important than the flammability of hydrogen sulfide. An LFL meter is useless for detecting hydrogen sulfide as 1% LFL is 400 ppm, which is significantly greater than any published exposure limit.

5.2.4 Lower flammability limit sensor (electrochemical or controlled combustion)

This sensor is non-specific and looks for flammability of the surrounding atmosphere or gas mixture being sampled. LFL sensors are typically calibrated with methane (CH_4), therefore, the LFL indicated can vary from the actual LFL for a different gas. For example, the LFL of methane is 5% in air and the LFL for hydrogen is 4% in air, which causes the sensor to read 20% less for a hydrogen in air atmosphere (i.e., 10% LFL reading is actually 12.5% LFL).

Because the LFL measurement is based on a flammable gas in an air atmosphere of nominal composition (21% oxygen), an oxygen-deficient atmosphere can affect the reading. It is essential to ensure an appropriate oxygen concentration, especially if sampled remotely through tubing.

When using nitrogen or another nonflammable gas to purge a piece of equipment containing a flammable gas out-of-service, a typical LFL detector can give a misleading reading. This is particularly true if the detector is held directly in or samples directly from the vent stream, as there is no oxygen in the vented gas. The detector shall be used so that there is a sufficient admixture of air. The air will dilute the sample, but a suitably conservative LFL will account for the disparity.

LFL detectors should not be used as the primary means of detecting gases that have an exposure limit that is less than the LFL of the gas (e.g., carbon monoxide, hydrogen sulfide), as the LFL detector will not detect the presence of the gas until it is greater than the exposure limit.

5.2.5 Solid state gas sensor

This sensor is a semiconductor device that employs a molecular filter that only allows a specific molecule to reach the sensing surface. The signal strength varies based on the gas molecule presence at the sensing interface. There are solid state sensors specific to hydrogen that are not appreciably cross-sensitive to carbon monoxide, however, the lack of cross-sensitivity should be confirmed by the end user. These sensors may be used to confirm that a leak is hydrogen, while a cross-sensitive meter cannot be used.

5.2.6 Flame (fire) sensors

There are three basic types of sensors used for detecting fire or flame: thermal, smoke, and radiant energy. There are subtypes of each and they are summarized in the following paragraphs.

Thermal sensors measure temperature by some means (bimetallic strip, fusible link, or some electronic device [resistance temperature detector (RTD) or thermocouple]). Upon detection of an elevated temperature, these devices may take direct action (for example, activate a switch contact [trip a circuit or shut down a unit] or open a water valve [sprinkler]) and/or may send an alarm to the local control system and/or a signal to a fire protection panel.

Smoke detectors come in two varieties: ionization and photoelectric. Ionization smoke alarms can quickly detect the small amounts of smoke produced by flaming fires. Photoelectric smoke detectors typically respond faster to a fire in its early smoldering stage. Many building fire detection systems have detectors that contain both types of sensors. Smoke detectors are typically not used in outdoor process areas but are used in buildings in a process area.

Infrared or ultra violet sensors are examples of radiant energy sensors that detect radiation given off by a flame. These sensors require a direct line of sight to the fire location; therefore, in a crowded process area, many sensors are required to have adequate coverage. Different gases have different light emission spectra and sensor sensitivity shall be matched to process gas composition. It is easy to end up with a false indication due to sun light. Radiant energy detectors often have both UV & IR sensors tuned for a particular process to minimize false alarms.

5.3 Monitoring and alarms

Detectors produce a signal indicating presence of a condition (e.g., fire or smoke) or concentration of the gas of interest. Each detector will have at least one alarm/action set point with prescribed operator actions.

Detector signals can be managed on one or more monitoring systems including but not limited to the following:

- Local panel—Alarms locally by sound and light (e.g., a door into an analyzer shelter);
- Plant control distributed control system (DCS)—Trending of detection signals, with alarming and annunciation in the control room; or
- Fire and gas detection system panel—A system separate from the plant control DCS. Annunciates at a master panel in a suitable location such as a control room.

Signals can be reported to the plant control DCS in addition to a local panel or fire detection panel.

Alarms typically generate a visual and audible indication. A bright strobe light annunciator may be used in high ambient noise areas. For alarms annunciated in the plant control system, appropriate alarm management techniques should be employed to ensure that the alarms can quickly be identified and be acted upon by the plant operator. This may include plant overview graphics with gas detector locations being shown along with appropriate alarm grouping with prioritization.

Gas detector systems are subject to producing false alarms. Selection and placement of these sensors shall be carefully assessed in order to avoid repetitive false activation of an alarm that would cause plant personnel to ignore or suppress the alarm. Alarms should be configured such that they cannot be permanently inhibited. In order to avoid false activation of remedial actions, some systems require operator intervention to take action such as shutting down unit and activating suppression system.

Action level alarms may be used to shut down equipment, turn off electrical power, or automatically activate deluge/sprinkler systems or gas fire suppression systems such as carbon dioxide or HFC-227ea. These actions may be automatic or initiated by an operator. Alarm and action level set points may differ depending on whether the facility is manned or unmanned. A risk assessment, taking response times into account, should be used to determine what set points and actions are required. Procedures covering leak detection and response shall be developed for each process unit.

6 Leak detection

In order to detect a leak there shall be a sensor in a location near enough to the source. Installing a set of fixed monitors around a potential leak location is one method of assisting in the detection of leaks. Table 2 summarizes many of the locations and detector types that should be evaluated in terms of fixed monitors. Operating experience suggests that these areas have a higher probability of leak occurrence, although the likelihood of leaks can be reduced by taking measures during the design of the plant, see Section 8. The monitoring described in Table 2 or additional monitoring can be necessary due to local or national regulations. If a potential leak location is in an enclosure or building, existing standards specify fixed monitoring requirements (NFPA 70, *National Electric Code*®; IEC 60079-10-1, *Explosive Atmospheres*–Part 10-1: Classification of areas–Explosive gas atmospheres) [8, 9].

Table 2—Guidance for placement of fixed monitors

Operating area	Typical location of fixed monitor	Detectors for consideration					
		CO	O_2	Flame	LFL	NH_3	H_2S
Analyzer rooms (inside)	• Air inlet and outlet duct of room/building	Yes [1)]	Yes	No	Yes	No	No
Carbon monoxide buffer tank	• Immediate area above valves/flanges • Above evaporator bundle if atmospheric	Yes	No	No	No	No	No
Carbon monoxide turbine/compressor	• Air inlet and outlet duct of room/building • Immediate area above machinery	Yes	Yes [2)]	No	No	No	No
Carbon dioxide compressor [3)]—building (if closed shelter/machine house)	• Air inlet and outlet duct of room/building • Immediate area above machinery	No	Yes [2)]	No	Yes [4)]	No	No
Coldbox	• Immediate area above valves/flanges and box purge outlet	Yes	No	No	Yes	No	No

Operating area	Typical location of fixed monitor	Detectors for consideration					
		CO	O_2	Flame	LFL	NH_3	H_2S
Cooling tower	• Cooling water return line or tower exhaust	Maybe 1)	No	No	Maybe	No	No
Feedgas compressor	• Air inlet and outlet duct of room/building • Immediate area above machinery	No	Yes 2)	Yes	Yes	No	No
Hydrogen compressor	• Air inlet and outlet duct of room/building • Immediate area above machinery	No	No	Yes	Yes	No	No
Startup compressor circulating nitrogen—building (if closed shelter/machine house)	• Air inlet and outlet duct of room/building • Immediate area above machinery	No	Yes	No	Yes 4)	No	No
Hydrogen trailer filling	• Immediate area above valves and flanges at (automatic) control station	No	No	Yes	Yes	No	No
Membrane units 5)	• Immediate area above valves/flanges	Yes 1)	No	No	Yes	No	No
Methane pumps	• Immediate area above pump housing/valves/flanges	No	No	No	Yes	No	No
POX reactor	• Immediate area above valves/flanges	Yes	No	Yes	Yes	No	No
Rectisol units	• Immediate area above valves/flanges	Yes 1)	No	No	Yes	No	Yes 6)
Refrigeration units (propylene, ammonia)	• Immediate area above compressor/valves/flanges	No	No	No	Yes 7)	Yes 7)	No
Cross header/syngas cooler/shift reactor	• Immediate area above/close to main flanges	Yes	No	Yes	No	No	No
Syngas purification—amine wash	• Immediate area above valves/flanges	Yes	No	No	No	No	Yes 6)
Syngas purification—syngas drier	• Immediate area above valves/flanges	Yes 1)	No	No	Yes	No	No
Hydrogen purification—PSA unit	• Immediate area above valves/flanges • Perimeter of the PSA valve skid	Yes	No	No	Yes	No	Yes
Vents to atmosphere 8)	• Immediate vicinity of vent, considering main wind direction, skid layout, etc.	Yes	No	No	No	No	No
Liquid hydrocarbon/ hydrogen storage	• Surrounding area	No	No	Yes	Yes	No	No
Ammonia storage	• Surrounding area	No	No	No	No	Yes 7)	No
Waste water sump	• Inside sump	No	No	No	Yes	No	No

NOTE—This table is not intended to be an all-inclusive list.

1) If carbon monoxide risk is present.

2) Only if within a building and nitrogen is used for startup.

3) Monitoring *shall* be by carbon dioxide detector.

4) This sensor type should be considered in this location if there is a potential for flammable gas to exist in the gas being compressed or in the surrounding area.

5) Applies to syngas, carbon monoxide, hydrogen membrane units.

6) Only for plants with sulfur containing feed with total sulfur levels > 10 ppm (or sulfur dosing) and respective sulfur treatment unit (Claus, Rectisol, etc.), also hydrogen cyanide if risk is present, and only in high risk areas of the plant based on plant assessment.

7) Only for plants with this refrigerant/process fluid.

8) Such as on deaerator or deaerator clean vent if syngas/carbon monoxide can be released in case of tube rupture or gas breakthrough. Not process vent.

Potential leaks can be identified by either an operator on rounds using their senses or by a fixed monitor, however the initial indication might not be sufficient to determine the leak location.

For partially manned or unmanned sites, which may be remotely monitored or operated, additional fixed monitors and/or different types of monitors can be required based on a facility hazard assessment. In this situation, a mixture of monitor types such as LFL detectors and flame detectors can be required to improve probability of leak indication. Additionally, this type of site should be covered by visible light cameras. Thermal imaging cameras should be considered if a significant risk of fire is present.

Any indication shall be assessed and confirmed as either a leak or a false indication, and any indication of a leak shall be treated as such until proven otherwise. If a personal monitor alarms when an individual enters an area, individual(s) should exit the area by retracing their entry path. If a personal monitor alarms after an individual is already in an area, individual(s) should exit the area by walking cross-wind until the reading is less than the alarm level.

Depending on the situation, different approaches may be taken to confirming whether or not a leak exists, but the assessment typically consists of taking corroborating observations with additional people or sensors.

For example:

- Operator hears an unusual hissing sound (indication) and confirms a leak by observing a flame or a steam plume at a flange joint (assessment/confirmation); or

- Carbon monoxide area monitor goes into alarm (indication) and operator proves the area monitor reading is false using a portable monitor (assessment/negative confirmation).

If a leak is confirmed, the next step is to determine the perimeter of the vapor cloud which will give an indication of the location of the source. The size of the perimeter also gives an indication of the leak rate, which also typically identifies the major constituents of the cloud.

A personal monitor should not be used to determine the leak location or to further characterize the leak. A portable monitor with pump and wand is used while walking toward the leak to identify the constituents and perimeter of the leak. It is good practice to approach the leak from an upwind direction, walking in an arcing pattern with successively smaller arcs, as the leak source is initially unknown. Appropriate PPE is required to perform this action. For example, if the leak is carbon monoxide, a search for the location of the leak should not be undertaken without additional personnel with self-contained breathing apparatus (SCBA).

The response to the confirmed leak shall be based on the leak characteristics identified. See Section 7.

The identification of the material leaking and the size of the leak is the most important aspect of leak detection and in determining the appropriate response.

6.1 Leak detection during maintenance

The impact of potential process leaks on any maintenance activity shall be assessed prior to performing maintenance and actions, such as conducting additional monitoring, shall be undertaken to mitigate any risk posed. Leaks that have minimal process or personnel impact during normal operation can have more significant impact when performing maintenance near an operating unit or on a system connected to an operating unit. When using a grinder, for instance, sparks from the tool can travel a significant distance and could result in ignition of a flammable gas leak.

Maintenance activities that can be adversely impacted by the presence of a flammable or toxic gas leak include:

- hot work (welding, grinding, use of electrical tools, etc.);

- entry into a confined space (vessel entry, cleaning a sump, etc.); and

- leak repair or mitigation (installing a leak clamp).

For hot work while the plant and plant equipment are in operation, specific atmospheric monitoring of the surrounding area is required to ensure that no hazardous atmosphere exists before or during the planned hot work. For confined space entry work, typical confined space entry procedures shall be followed; but additional monitoring can be required if there is the potential for a flammable or toxic leak to impact the confined space. Care shall be taken to ensure that any monitors used are compatible with the atmosphere being tested, for example, the monitor can operate in an inert atmosphere and does not require oxygen to operate.

Line break operations, such as opening of flange connections, are a form of maintenance that can be impacted by leaks within the process such as a valve leaking into the line being maintained. This can result in the release of toxic or flammable gas to the atmosphere during the maintenance activity. Residual pressure in the line that is being opened can result in the release of process gas to atmosphere. Monitoring shall be employed during line break operations to mitigate risk to personnel from a flammable or toxic gas release. Other safety precautions and PPE shall be based on a risk assessment of the activity. For maintenance activities within regularly occupied enclosures (e.g., analyzer maintenance) where a risk of a flammable and/or toxic atmosphere entering or being created exists, additional safeguards shall be applied. These safeguards are fixed monitors with audible and visual indication to alert personnel of gas release. The monitors shall be suitable for the gases that can be present, either from the process, utilities, or off-site locations.

6.2 Leak scenarios

It is not possible to list/discuss all possible leak scenarios here. However, examples for the most common experienced leak points include:

- Valves—stem packing leaks, especially on high cyclic duty valves or cryogenic valves;
- Flanges—thermal cycling or vibrations or pressure cycling can cause leakages; or
- Fans, compressors, blowers, pumps, shaft seals, stuffing boxes, bearings, etc.

These equipment leak locations should be assessed relative to the operating areas and potential detectors listed in Table 2, and the appropriate sensor type selected from 5.2.

In particular, these potential leak points and surrounding areas shall be searched for leaks prior to conducting hot work. This search shall include the immediate work area and a sufficiently large perimeter to preclude inadvertent ignition of a flammable leak. Many incidents have occurred during hot work execution that resulted from an inadequate search for flammable leaks.

It is important to take into account the effect that temperature has on the leaking fluid (see Section 4). In the case of a flammable leak source with temperature greater than the autoignition temperature, a flame sensor is required, see 5.2.6.

7 Leak assessment and response

Once a leak has been confirmed, the response to the leak—whether monitoring, repair, or shutdown of the facility—shall be decided. Care shall be taken when working around a leak, as leak mitigation or repair can escalate into an emergency situation if the wrong actions are taken. For example, see CSB Regulatory Report *Chevron Richmond Refinery Pipe Rupture*, 2012-03-I-CA January 2015 [10].

Emergency planning and response to leaks shall be part of the site's emergency response plan. This plan shall include, at a minimum, the following elements:

- Plant-wide alarm notification protocol with required action by site employees;
- Emergency response and control procedures;
- Procedures for emergency shutdown of operations;
- Internal and external emergency contact information; and
- Required authority and regulating agency notification requirements and timing based on the regulations for the site.

Employees and contractors working on the site shall be trained on the site's emergency response plan. Periodic emergency response drills with first responders are recommended.

7.1 Initial leak response

The first step on confirmation of a leak is an initial assessment of the potential risks associated with the leak. This shall be completed as quickly as possible to help determine the response protocol. Response to a leak will vary based on its potential consequences and severity. Initial actions may include any of the following (in order of increasing leak severity):

- Assess resources needed (operators, technicians, maintenance, etc.) to eliminate the leak and mitigate any consequences;
- Increase operator rounds in the area of the leak(s) to monitor the leak detection perimeter;
- Increase facility-wide notification at the initial event and later during shift change;
- Impose restricted access around the leak area with a visual indication (barricades, chains, signs) on areas that require permit access to enter;
- Shut down and depressurize equipment to eliminate leak risks;
- Issue shelter in place alert until the outside areas can be made safe to enter; and
- Activate emergency response with site evacuation and potential for an offsite evacuation zone.

When assessing and responding to a leak, it is critical to limit access to the leak location to essential personnel. Allowing nonessential people into an area around a leak puts more individuals at risk.

7.2 Leak estimation and characterization

The data and information gathered during the leak detection phase, outlined in Section 6, may be used to estimate the amount of released material and the area of impact. An estimate of the amount of material released and the duration of the leak can be required for compliance with environmental regulations and for subsequent submittal to the local authorities.

Characterization of the release requires identification of the composition, temperature, and operating pressure of the leaking fluid. The leak location shall also be determined to properly characterize the release. The level of physical confinement (e.g., structures, equipment, walls) and the wind speed and direction at the source of the leak are required to properly estimate the consequence of the release. The leak rate can be estimated through a mass balance analysis of process data, a pressure drop calculation (this method requires a value for the leak opening size or area), or through evaluation of atmospheric sampling data with dispersion analysis.

There are many tools and methods that may be used to estimate the consequence of a leak. Dispersion evaluation tools such as ALOHA® and Det Norske Veritas Process Hazard Analysis Software Tool (DNV PHAST) may be used to determine the area of impact of the release. ALOHA® and DNV PHAST tools require prior knowledge and experience to use. Less sophisticated tools may also be used to estimate the area of impact. For flammable gas leaks, the potential for jet fire, flash fire, or vapor cloud explosion can be determined along with the area of impact. For toxic leaks, lethality charts can be developed given an estimated leak rate, ambient temperature, and wind speed and direction. In addition, an estimated crack or hole size can be estimated based on the observed concentration in the area around the leak. If the leak poses a significant safety hazard based on the initial evaluation, immediate actions shall be taken to manage or eliminate the hazard.

7.3 Subsequent leak response

Once a leak has been detected, verified, and initially assessed, the appropriate response actions shall be taken. Where possible and practical, the leaking system should be isolated and depressurized to facilitate the leak repair. If isolation is not possible or practical, the appropriate actions to be taken depend on a number of factors. The primary factors to consider include:

- Severity of the leak as characterized by the leak rate and hazards (flammability, toxicity, pressure, and temperature) of the leaking fluid;

- Potential negative impact of leak repair on the integrity of the equipment (e.g., weight of a clamp causing excess pipe stress, injection of sealant causing excess bolt stress);
- Potential negative impact of process fluid on the integrity of the equipment used for the leak repair (e.g., process fluid is corrosive and can limit life of clamp);
- Risk of damage to surrounding piping, insulation, bolting, and equipment due to exposure to process fluid;
- Incompatibility of leaking process fluid with its surroundings such as flammable gases migrating to nonclassified equipment area;
- Risk to personnel, both the current risk and the risk associated with any repair attempt;
- Possible effect of the leak on the environment or populace;
- Inventory of the contained fluid;
- Location of the leak (e.g., accessibility, proximity to other hazards);
- Mechanical condition of the leak source (e.g., corroded, fractured) and whether the leak is likely to get larger; and
- Stability of the leak due to fluid characteristics (potential of the leak rate to increase).

Evaluation of these factors can lead to the conclusion that immediate shutdown of the facility is required to maintain safety.

The composition of the leak requires particular consideration when determining the actions to be taken in response to a leak. When dealing with a syngas or carbon monoxide leak, for example, the toxicity of the gas is often a more significant concern in terms of the safety of personnel and the surrounding populace than the flammability of the gas. The situation is complicated by the fact that many gas analyzers are cross-sensitive for hydrogen and carbon monoxide (i.e., hydrogen is reported as carbon monoxide). The size of the leak envelope shall be based on the most restrictive component in terms of PEL. The most restrictive component shall also be considered when determining the appropriate personal protective equipment to be used in assessing or repairing (if applicable) the leak. For example, the use of breathing air can be required when dealing with a carbon monoxide leak, while the same might not apply to a similarly sized hydrogen leak.

When assessing the actions to be taken in response to a leak, local or national regulations shall also be considered. There may be local or country-specific regulations that require additional reporting or additional actions if the amount of gas released exceeds region-specific threshold values (RQ). These threshold values are typically set on a component basis. On a national level in the United States, the U.S. Environmental Protection Agency's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), requires such reporting for hazardous chemicals in Section 103(f)(2) [11]. For more information on reporting, see 7.5.

In most instances, the repair of cryogenic leaks should not be attempted while the source of the leak is under pressure. For noncryogenic leaks, online repair may be possible depending on the assessment of the leak and the leak repair method. In other cases, shutdown of the plant may be warranted. Depending on the possible impact of the leak on the plant or surrounding areas, this may include activation of the site emergency response plan.

If online leak repair will not be attempted, standard maintenance and repair procedures shall be followed once the plant is shut down and/or the source of the leak has been isolated and depressurized.

If online leak repair will be performed, then one of the methods described in 7.4 may be appropriate. Before and during the repair, the situation shall be monitored to confirm that the leak does not escalate. If the leak escalates, different actions can be required up to and including immediate shutdown of the facility.

7.4 Online leak repair

Online leak repairs shall be reviewed and approved by appropriate management personnel at the facility. The more complex online leak repair methods are typically executed by a specialist contractor company, who can provide guidance on which repair methods are applicable in a given situation. Specialized PPE can be required to work in the area around the leak.

There are various methods for repairing leaks depending on the source or cause of the leak. If a system is altered from the original design to affect a leak repair, the management of change process shall be followed to ensure that the modification is executed safely and does not have any unintended consequences that affect the safety, operability, or reliability of the facility. The management of change process shall take into account any jurisdictional requirements (e.g., associated with the pressure boundary of a clamp). Any of the following repairs, with the exception of bolt tightening, shall be considered temporary and should be reversed at the next maintenance outage. The process fluid can cause degradation of these components and sealant injection can lead to failure.

The following sections are not meant to provide comprehensive information and instruction on leak repair, but only to introduce some of the typical repair methods and key considerations for their use. More information can be found in American Petroleum Institute (API) 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems* [12].

7.4.1 Bolt tightening

Tightening of valve packing bolts, based on valve manufacturers' recommendations, can eliminate valve stem packing leaks. Tightening of flange bolts can eliminate a flange leak and can be done if the flange gasket(s) is intact and if the bolts have not already been tightened beyond their allowable limit. Bolt tightening is often conducted by the site maintenance personnel or a general maintenance contractor. It is important that maintenance personnel are trained and follow the proper bolt tightening procedure.

Tightening of flange bolts is most often required following a maintenance outage when the plant equipment is first brought up to operating temperature and pressure. As the plant is heated up, bolts expand differently than equipment flanges. This can lead to leaks if the proper bolt tightening procedure is not followed. The greater care that is taken to ensure that bolts are tightened to the equipment or piping specifications, the less likely that leaks are identified on startup. On larger flanges, bolt tensioning can provide greater assurance of a leak-tight joint.

7.4.2 Sealant injection into packing gland

If a valve packing leak is not eliminated by tightening the valve packing bolts, it may be eliminated by injecting sealant into the valve gland. In this method, a hole is drilled and tapped in the valve for installation of an injection adapter. A hole is then drilled through the adapter into the valve stuffing box, and sealant is injected into the valve glands through the adaptor. The sealant takes the place of the original packing material, so the valve remains operational. This type of repair is typically executed by a specialist contractor.

7.4.3 Composite repair

This repair method uses a fiber material and a curable resin to form a composite wrap to provide a secondary pressure boundary. The pressure rating is adjusted by the number of layers of fiber. The temperature rating is primarily due to the resin. Choice of resin and fiber is based on the process fluid. This repair method is used mostly in low pressure, low temperature applications and is typically executed by a specialist contractor. The risk assessment of the repair method shall take into account that the life of the resin is dependent on temperature.

7.4.4 Wire wrap with sealant injection

For flange leaks that are not eliminated by tightening the flange bolts, another possible repair option is a wire wrap with sealant injection. With this method, the space between the flanges (over the bolts) is "wrapped" with wire to form a non-air tight seal. Sealant is then injected into the space between the wire wrap and the flange gaskets to eliminate the leak. Sealant injection puts extra stress on the bolts. If the bolts are compromised, this repair method shall not be used. This type of repair is typically executed by a specialist contractor.

7.4.5 Bolted/welded clamp with sealant injection

In this repair method, a premanufactured or custom fabricated clamp is used to enclose the defective component or leaking area (e.g., pipe, valve, or flange). The clamp is typically built in two pieces and is welded or bolted around the leaking component. Two types of designs are possible. In the simpler design case, the void area between the leaking component and the clamp is filled with sealant. In this design, the entire pipe/component surface within the clamp is exposed to the injection pressure of the sealant. With the other clamp design, the clamp itself is configured with seals at the half joint and at each bore where the seal meets the component surface. In this design, only short sections of the equipment/piping are exposed to the sealant injection pressure. The design of the equipment exposed to the additional sealant injection pressure should be assessed to determine whether the equipment is suitable for the additional pressure. This type of repair is typically executed by a specialist contractor.

7.4.6 Welded enclosure

A welded enclosure is a configuration similar to a bolted clamp. In this repair method, an enclosure is seal welded to the piping on either side of the leak source. The enclosure is vented through a valve during welding. When the welding is completed, the valve is closed and the leak is contained. This type of repair is typically executed by a specialist contractor.

7.4.7 Line stop (STOPPLE®)

If it is not possible to enclose the leaking component with a clamp or other device, isolating the component is another method to eliminate the source of the leak. Isolation can be achieved by installing a line stop in the piping upstream of the leaking component. A split tee fitting (with a flanged connection on top) is seal welded around the pipe that is to be plugged. A full bore equalization valve is mounted on the flanged tee connection, and a special machine is mounted on top of the valve and used to cut a hole in the pipe. A plug is installed through the hole and expanded or rotated to seal the pipe. The integrity, design, and operating conditions of the piping subject to the hot tap procedure should be assessed to determine if the method can be applied. This type of repair is typically executed by a specialist contractor.

7.5 Environmental considerations

Environmental legislation can prescribe what actions shall be taken in response to leaks, even if the leaks do not pose a safety or operational hazard. Many jurisdictions have fugitive emissions legislation that prescribes monitoring to identify and track small leaks within the facility (e.g., at bleeds or vents). This requirement is typically captured in the facility's air permit. Fugitive emissions legislation typically requires that the total amount of emissions of each component from all fugitive emissions leak sources within the facility be estimated and reported on an aggregate basis.

If the total quantity of a component released within a noted time period (typically 24 hours) exceeds a prescribed limit, additional environmental reporting requirements can apply. Once the RQ is exceeded for a given component, national legislation requires immediate reporting. The list of hazardous substances can vary by jurisdiction, and both local and national regulations shall be followed. As of 2016, neither hydrogen nor carbon monoxide had a RQ limit per EPA CERCLA regulations [11].

8 Operational and design recommendations to avoid potential leaks

The following are examples of specific actions that may be taken during the plant design phase to reduce the likelihood of leaks developing within the facility.

Hydrogen and other components which can be present in the process fluid are associated with a variety of degradation mechanisms; therefore, proper metallurgy selection and construction methods are important to avoid leaks in piping or vessels.

Flangeless wafer style valves that are sandwiched between pipe flanges and that have long bolts can be problematic (e.g., bolts exposed to fire and thermal stress in the event of a leak, non-concentric gasket installation). Since flange connections are potential leak points, using welded connections in place of flange connections is one means to reduce the likelihood that leaks develop. Threaded connections in flammable or toxic service should be minimized because they are potential leak points. Small bore piping in reciprocating compressor service is susceptible to premature failure due to vibration. These lines should be minimized or properly braced.

Using valves that are specifically designed to reduce or eliminate leaks to atmosphere. Valves that comply with ISO 15848, *Industrial Valves – Measurement, Test, and Qualification Procedures for Fugitive Emissions* utilize sealing components that meet stringent guidelines for leak rates [13]. The valve stem sealing component may be a fugitive emissions rated valve stem packing, or it may be a metal bellows seal incorporated into the valve design, with packing seals used as a secondary seal measure. The correct valve selection will be based on the design and operating conditions of the valve (temperature, pressure, composition, frequency of valve operation, etc.) as well as any local and national regulations regarding fugitive emissions for the fluid being processed.

Even if the plant is designed to minimize leak formation, proper installation or reassembly following maintenance is required. When assembling flanged connections, correct alignment is crucial, and excessive mechanical force to bring components into alignment is not allowed. Because parts wear and might need to be refurbished or replaced, inspection and maintenance are required to minimize the potential for leaks.

Following plant construction or maintenance, the plant shall be confirmed to be "technically tight." For new plants, this generally consists of a pressure test to confirm that the equipment meets the design intent. For repair work, this may consist of a pressure test or other form of non-destructive testing, or an in-service leak check. At a minimum, an in-service leak check should be performed following any maintenance outage.

9 References

Unless otherwise specified, the latest edition shall apply.

[1] AIGA 009, *Safety Training of Employees,* Asia Industrial Gases Association. www.asiaiga.org

[2] AIGA 08, *Hazards of Inert Gases and Oxygen Depletion,* Asia Industrial Gases Association.www.asiaiga.org

[3] CGA SB-2, *Oxygen-Deficient Atmospheres,* Compressed Gas Association, Inc. www.cganet.com

[4] *Code of Federal Regulations*, Title 40 (Protection of Environment), U.S. Government Printing Office. www.gpo.gov

[5] AIGA 093, *Guideline for the Location of Occupied Buildings in Industrial Gas Plants,* Asia Industrial Gases Association, www.asiaiga.org

[6] *Pocket Guide to Chemical Hazards*, National Institute for Occupational Safety and Health, Center for Disease Control and Prevention. www.cdc.gov/niosh.

[7] *Code of Federal Regulations,* Title 29 (Labor) Parts 1900-1910, U.S. Government Printing Office. www.gpo.gov

[8] NFPA 70, *National Electric Code®*, National Fire Protection Association. www.nfpa.org.

[9] IEC 60079-10-1*, Explosive Atmospheres*—Part 10-1: Classification of areas— Explosive gas atmospheres, International Electrotechnical Commission. www.ansi.org

[10] CSB report 2012-03-I-CA January 2015, *Final Investigation Report, Chevron Richmond Refinery Pipe Rupture and Fire,* U.S. Chemical Safety and Hazard Investigation Board. www.csb.gov

[11] *Comprehensive Environmental Response, Compensation, and Liability Act*, Section 103(f)(2), U.S. Environmental Protection Agency. www.epa.gov

[12] API 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems,* American Petroleum Institute. www.api.org

[13] ISO 15848, *Industrial valves – Measurement, test, and qualification procedures for fugitive emissions*, American National Standards Institute. www.ansi.org