Handbook – Process safety for HC leak prevention

FOREWORD

Preventing hydrocarbon (HC) leaks plays an important part in avoiding major accidents. Norwegian Oil and Gas has developed a handbook on process safety for HC leak prevention. The purpose of this publication is to apply process safety principles to work on hydrocarbon systems. The handbook describes practical measures and systems which should be in place. It also goes into more detail on important information about the hazards posed by hydrocarbons and about systems for detecting and measuring HC leaks.

The manager for HSE and standardisation is responsible for the handbook.

This handbook replaces the handbook for process safety established in 2017. The change of title has been made to underline that the handbook is directed at preventing HC leaks.

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1 INTRODUCTION

1.1 Purpose

Norwegian Oil and Gas has developed a handbook on process safety for HC leak prevention. Its purpose is to help prevent such incidents, which plays an important part in avoiding major accidents. Process safety is a broad concept which covers all phases of the life cycle on an offshore facility or at an onshore plant.

This handbook primarily applies the principles of process safety to HC leak prevention in the production phase. The term "HC leak" is used throughout as a standard term in the industry. Otherwise, "hydrocarbon" is written in full.

The Petroleum Safety Authority Norway (PSA) defines a major accident as an acute incident, such as a major discharge/emission, fire or explosion, which immediately or later causes several serious personal injuries and/or loss of human life, serious harm to the environment and/or a major loss of economic assets. Working purposefully to avoid such occurrences is therefore important.

1.2 Accident prevention

Insights into accident causes show that it is not sufficient to look only at technical faults or human actions. Organisational factors are now considered crucial to the understanding of causes. This means that accident prevention efforts must concentrate attention on these conditions, and that companies must identify and follow up relevant measures.

Recognition that it is human to err represents an important factor in understanding incidents and accidents. "Human error" is not considered a satisfactory cause of an accident today. Identifying an error is the starting point for understanding why the people made the error they did. Even more significant is identifying why the personnel involved thought their actions were correct. This understanding is important for learning lessons and for the ability to identify effective measures which can avoid such actions.

"Culture" plays an important part in preventing incidents and accidents. Cultural factors regarded as important in this handbook are:

- management's involvement in building and developing the culture
- how the organisation complies with governing documentation, and particularly with procedures related to work on hydrocarbon systems
- how management communicates its expectations that procedures are complied with.

The operator or the responsible party shall have a conscious appreciation of the culture and how this is built and developed, including concentrating attention on risk management. Implementing and following up both measures and systems for HC leak prevention depend on a "good" culture in the company. Such a culture encourages systematic and positive behaviour when working on hydrocarbon systems – such as encouraging compliance with this handbook.

An example of culture building and development is the Always Safe programme created by Equinor, AkerBP and Vår Energi [ref 1].

Examples of tools which can be used to build and develop a culture relevant to HC leak prevention are the lifesaving rules [ref 2] and process safety fundamentals [ref 3] from the International Association of Oil & Gas Producers (IOGP).

Management plays an important role in achieving open discussion on procedures and practice, and on the need for possible changes to these. An open reporting culture makes an important contribution to continuous improvement.

Investigating incidents and near-misses can provide insights into the culture and help to manage how this should be developed to avoid undesirable conditions and actions. Investigations can also provide an understanding of why the system was not designed with sufficient barriers to make allowance for possible human and technical errors.

Norwegian Oil and Gas has conducted cause and effect analyses for HC leaks on offshore facilities and at onshore plants. These can be used to improve understanding of why such incidents occur, and thereby which measures should be deployed to prevent HC leaks [ref 4].

1.3 Barriers and barrier strategy

The PSA has produced a barrier memorandum which contains definitions and describes a system for barrier management [ref 5]. This system provides an important context for HC leak prevention.

Figure 1.1 presents the context for how barriers can be established and how performance standards can be determined and followed up.

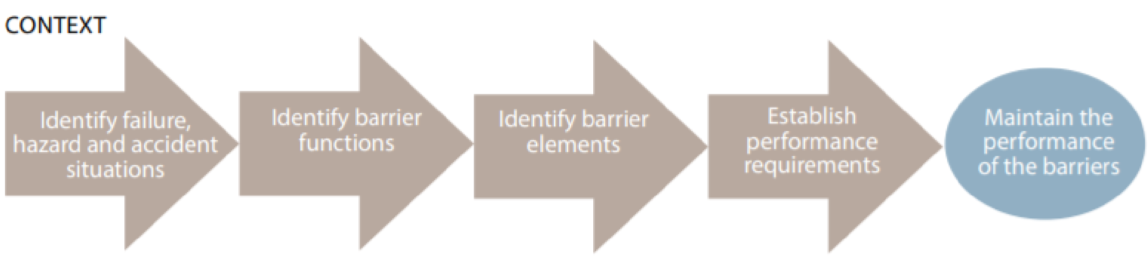


Figure 1-1 Context for barriers.

The term "maintaining performance of the barriers" covers verification that the barriers have functionality (will function as intended), integrity (will have sufficient

reliability) and robustness (have sufficient redundancy and are not vulnerable to external factor).
Figure 1-2 presents the relationships between barrier function, barrier elements, performance requirements and performance-influencing factors.

Figure 1-2 Relationship between barrier function, barrier elements, performance requirements and performance-influencing factors.

The purpose of these figures is to show that effective barriers depend on technical, organisational and operational barrier elements. All these must be assessed in order to ensure that the barriers can function satisfactorily.

2 OFFSHORE FACILITY INTEGRITY

Good process safety is achieved by designing offshore facilities and onshore plants in such a way that the opportunities for error are reduced, establishing and applying an inspection and maintenance system to safeguard the design throughout its life, and operating within the established operational parameters. The management has a responsibility to ensure that good process safety is maintained. The company shall also establish a management system which describes what shall be done and how, and an internal control system which ensures compliance with the management system.

Offshore facility integrity can be described as an interaction between design, technical and operational integrity. Leadership integrity shall ensure their integration. See figure
2-1.

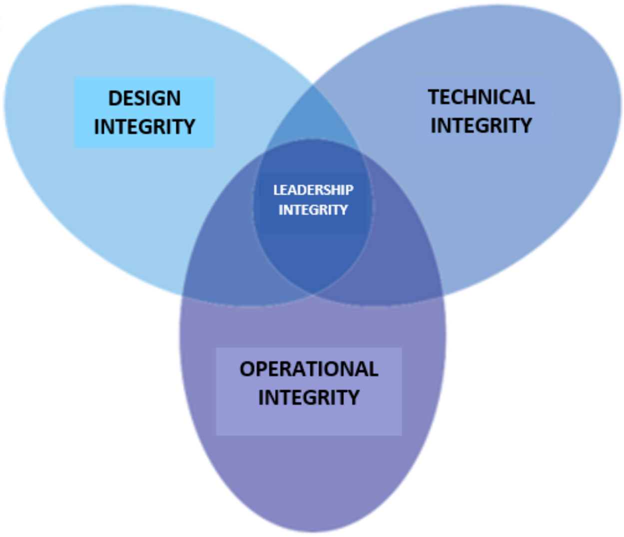


Figure 2-1 Overview of offshore facility integrity.

2.1 Design integrity

A process plant is designed in accordance with applicable regulations and standards, and with good industry practice. The overarching principles are that a design shall ensure prudent use of the offshore facility or onshore plant throughout its life cycle, and that risk is reduced to the lowest level practically possible. During the design process, operational limits shall be determined for the offshore facility/onshore plant. A prudent design should take account of lessons from both earlier designs and operations

The “inherently safer” principles should form the basis for a prudent design. These principles are as follows.

> Eliminate – if possible, hazards related to the offshore facility/onshore plant should be eliminated by such measures as avoiding the use of hazardous materials.
>
> Minimise – reduce the quantity of hazardous materials.

Replace – replace hazardous materials with less hazardous alternatives.

Render harmless – reduce the temperature, the pressure and the concentration of the materials used.

Simplify – reduce plant complexity to avoid erroneous actions.

2.2 Technical integrity

Once an offshore facility/onshore plant has been designed and built, it needs to be maintained and inspected in order to take care of its design and design assumptions, and to ensure prudent use. Systems, equipment and components are subject to ageing and degrading, and inspection and maintenance routines are important for maintaining adequate control of these processes.

Identifying safety-critical equipment is an important requirement for establishing adequate maintenance and inspection routines, and for prioritising work assignments.

The operator or the responsible party shall have a maintenance and inspection system and develop indicators which ensure that routines are carried out as planned and achieve their intended purpose.

2.3 Operational integrity

Operational integrity shall ensure that operation falls within operational preconditions and restrictions, and that good routines and procedures are in place for work done on hydrocarbon systems.

2.4 Leadership integrity

Management has the overall responsibility for ensuring that design, technical and operational integrity are in order and that the offshore facility/onshore plant is prudently used. Managers set the terms for using and operating the offshore facility/onshore plant in accordance with applicable regulations, standards, and company practice and procedures. They shall make provision to ensure that everyone involved in the operation is sufficiently familiar with the management system and has the expertise required to do their work in a prudent manner. Managers shall detect signals which indicate whether operation of the offshore facility/onshore plant is prudent. That includes both positive/negative and strong/weak signals.

2.5 Internal control

The operator or the party responsible for the offshore facility/onshore plant shall establish an internal control system which ensures that the requirements for design, technical, operational and leadership integrity are met. This should form an integral part of the management system.

Requirements for the management system are described in section 17 of the framework regulations on the duty to establish, follow up and further develop a management system:

> The responsible party shall establish, follow up and further develop a management system designed to ensure compliance with requirements in the health, safety and environment legislation.
>
> The licensee and owner of an onshore offshore facility shall establish, follow up and further develop a management system to ensure compliance with requirements in the health, safety and environment legislation directed toward licensees and owners of onshore facilities.
>
> The employees shall contribute in the establishment, follow-up and further development of management systems.

The internal control system shall cover follow-up which ensures that offshore facility integrity is satisfactory and that use of the offshore facility/onshore plant is prudent.

Requirements for follow-up are described in section 21 of the management regulations on follow-up:

> The responsible party shall follow up to ensure that all elements in its own and other participants' management systems have been established and function as intended, and that a prudent level exists for health, safety and the environment.
>
> This follow-up shall contribute to identify technical, operational or organisational weaknesses, failures and deficiencies.
>
> The methods, frequency and scope of the follow-up, and the degree of independence in conducting it, shall be adapted to elements of significance to health, safety and the environment.

3 MEASURES FOR PREVENTING HC LEAKS

This chapter describes important measures for preventing HC leaks in the operations phase and supports operational integrity. These measures should be viewed in relation to other processes and systems associated with HC leak prevention, such as lifesaving rules and process safety fundamentals.

3.1 Follow-up of fugitive emissions and sweating

Ideally, an offshore facility/onshore plant is fully contained and no hydrocarbon escapes. In practice, fugitive emissions and sweating may occur from flanges, valve seals and the like. These may not be substantial enough to warrant repair. Following up such emissions/discharges systematically before they take a turn for the worse is nevertheless important for intervening before an HC leak occurs. Section 5 describes the difference between fugitive emissions and sweating on the one hand and HC leaks on the other.

An overview of fugitive emissions and sweating can also be used as an indicator. See section 6.

3.2 Isolation when working on a hydrocarbon system

Isolation and reinstatement are an important precondition for working safely on hydrocarbon systems. The operator or the responsible party shall establish procedures which cover planning, isolation, execution and reinstatement. These shall describe the isolation method and barrier requirements. Norwegian Oil and Gas has developed a recommended practice for isolation when working on hydrocarbon equipment [ref 6].

Risk assessments related to work on hydrocarbon systems shall take account of pressure, temperature and the quantity of hydrocarbon to be isolated.

Full isolation is required for some work operations on hydrocarbon systems, like entry of personnel into tanks and separators. In such cases, piping needs to be blinded or disconnected. Isolation requirements for critical work operations are also described in Norwegian Oil and Gas guideline 088 [ref 7]. Good control of spades, spectacle flanges and other equipment used for isolation is important here.

Some isolations may call for approved plugs, including work on pipelines and risers. In such cases, specific installation and testing procedures are required.

Verification during preparation/reinstatement is an important factor in ensuring correct isolation. Various methods for verifying isolation exist, such as checking that valves are secured in the right position for both preparation and reinstatement. This check could be independent verification, for example, or conducted by two people at the same time when the isolation is being established/reinstated. The method used should be assessed in relation to its risk potential in the event of error.

3.3 Use of valves

Correct use and operation of valves is important for HC leak prevention. The Norwegian Oil and Gas handbook on valve technology includes a description of how valves are operated to ensure they do not leak [ref 8]. In addition to covering typical valve types used in the petroleum industry, the handbook provides information on seals, seal surfaces and applications.

3.4 Use of check valves

Check valves shall be used for work on hydrocarbon systems which calls for the connection of temporary hoses or piping – for water-filling or nitrogen flushing, for example – to prevent hydrocarbons entering these systems. The valves shall be approved for the operating pressure and temperature. Piping, hoses and check valves should be included in the maintenance system to ensure that they are in order before use.

3.5 Draining hydrocarbon systems

Hydrocarbons will normally be drained to a closed drain system. The latter shall be monitored during operation to avoid overfilling or excess pressure.

In some cases, it is appropriate to remain at the work site during draining. The site shall not be left while a hydrocarbon system is being drained to the atmosphere.

When temporary equipment such as hoses are connected to the drain system and used to drain liquid or bleed off gas, the equipment should be able to tolerate the pressure which might arise in the drain system should be used. Hoses should be certified and maintained in accordance with the requirements in the maintenance system.

When operations involve transfer from a hydrocarbon system to another system using temporary equipment such as hoses, the equipment shall have a design pressure which corresponds to or is greater than the system it is connected to.

3.6 Ensure that equipment is drained and pressure-free before opening

Before opening a hydrocarbon system, a check shall always be carried out to ensure that it is drained and pressure-free. Such verification shall be done by opening a drain or air valve. Care shall be shown when reading off a manometer to verify that a system is pressure-free. A small deviation can indicate a substantial pressure potential, particularly on a high-pressure system. An important requirement is that the valve and pipe used to check the system has not become blocked by hydrate, wax or the like.

3.7 “Walk the line” before start-up

Before starting up, a full check shall be made to ensure that all equipment is in place and that foreign objects and temporary equipment have been removed. All valves shall be in the right position, control valves tested, all instruments in place and automatic valves connected to their operating system. Valves with locks or interlocks shall be locked in the right position. All safety systems shall be operational and maintained in accordance with established routines, such as PSV-r.

A "walk the line" shall be a systematic review of the system with reference to the P&ID.

3.8 Verification of integrity after maintenance work

When doing work on a hydrocarbon system which involves opening it – flanges, valves and so forth – the system shall be checked and tested to ensure its integrity before hydrocarbons are introduced to the system. This will normally be done with a leak test [ref 6].

3.9 Mechanical stress and degrading

Mechanical stress and degrading of piping and equipment on hydrocarbon systems are an important cause of HC leaks. Mechanical stress can include tension and vibration, which may be visible. Degradation can include erosion, corrosion and wear, and its signs can often be detected before any leaks occur. The operator or responsible party shall have maintenance and inspection routines for hydrocarbon systems based on reliability-centred maintenance (RCM) or risk-based inspection (RBI) types of analysis. Good observation and reporting are also important.

3.10 Ensuring good ventilation

Good ventilation is an important precondition for avoiding an accumulation of hydrocarbons in enclosed areas, and thereby for reducing the consequences of a possible HC leak. Such ventilation can be natural, mechanical or a combination of these, and shall ensure that a explosive mixture cannot occur in an enclosed area. Ventilation is also important for reducing the content of hazardous components, such as benzene, which could be present in the hydrocarbons.

The operator or the responsible party shall ensure that procedures are in place to ensure that the ventilation system functions and does not get disconnected in connection with other activities.

3.11 Working on flanges

Correct flange installation is an important precondition for HC leak prevention. A handbook of flange work published by Norwegian Oil and Gas is relevant for flange verification. Covering typical flanges and seals used in the petroleum industry, it deals with their disassembly, inspection, alignment, installation and verification [ref 9].

3.12 Use of correct fittings

Correct use of fittings on instrumentation and hydraulic systems is an important precondition for HC leak prevention. Many types of fittings and small-bore tubing are used in offshore facility/onshore plant systems, and can be dimensioned in millimetres or inches. It is important that different types and dimensions are not mixed. A handbook on fittings and small-bore tubing published by Norwegian Oil and

Gas [ref 10] covers three examples of different fitting types. Other types can also be used.

3.13 React to critical alarms

Alarms provide an indication that operating parameters have exceeded the limits set. Critical alarms shall be identified and prioritised in an alarm management system. It is also important that the procedures describe which measures shall be initiated in the event of a critical alarm.

3.14 Inhibiting and overriding safety systems

The operator or the responsible party shall establish a system which specifies how inhibiting and overriding of safety systems shall be controlled, checked and executed. Such operations may be needed because of maintenance work or weakened components in a safety system. Compensatory measures shall be assessed, implemented and documented when inhibiting safety systems. The inhibition and overriding system shall satisfy the requirements in sections 26 of the activities regulations and 42 of the technical and operational regulations on safety systems.

A safety system shall only be inhibited and overridden in connection with a planned operation or as a countermeasure if a switch, sensor or the like fails. The operator or the responsible party shall have procedures for inhibiting and overriding safety functions. These shall describe who can do the inhibition and test the work, as well as requirements for a risk assessment and implementing measures.

An overview of safety-system disconnection and overriding can also be used as an indicator. See section 6.

3.15 Temporary measures if safety system fails

Should the safety system fail, the risk shall be assessed and temporary measures implemented until the equipment is back in operation. Such measures could include shutdown, temporary operational measures or monitoring. The risk assessment and identified measures shall be documented.

An overview of safety-system failures can be used as an indicator. See section 6.

3.16 Working with temporary equipment

Work on hydrocarbon systems may involve using temporary equipment and systems for such purposes as leak testing and calibrating metering systems. Temporary equipment will not normally be covered by the maintenance and inspection system. Detailed operating procedures should be reviewed. A thorough pre-use check of such equipment shall be carried out before it is used [ref 11].

3.17 Programme for leak seeking and monitoring

The operator or the responsible party should establish routines for seeking HC leaks, fugitive gas emissions and sweating. Such a search involves both visual checks and the use of portable equipment like an infrared camera. External resources with specialist gear may be required to support the searches. Their purpose is both to identify new leaks, fugitive emissions or sweating, and to monitor known cases of these. Monitoring is an important precondition for assessing possible improvements.

Continuing to operate an offshore facility/onshore plant where leaks have been identified presupposes that a risk assessment finds this to be acceptable. Establishing a deviation may be required in such cases. See section 4.7.

3.18 Wells and well operations

The principles in this handbook also apply to wells, any work on these, and well operations such as wireline and coiled tubing. Special challenges are presented by wells, and the consequences of a possible leak may be substantial because of the quantities of hydrocarbons which might escape. Well operations are normally conducted by specialists in accordance with a programme and detailed procedures. When working on or downstream from a well, two verified barriers against the reservoir shall always be in place. It would be appropriate to make people involved in planning and executing well operations aware of this handbook and the measures described in this section.

3.19 Work in connection with export pipelines or large volumes for hydrocarbon storage

Large volumes of hydrocarbons will always pose a high risk. For that reason, activities related to maintenance of or work with export pipelines/large storage tanks for hydrocarbons shall always be conducted with two verified barriers. Work on such systems should be conducted with risk assessments which include measures for handling any leak in one of the barriers.

4 SYSTEM FOR HC LEAK PREVENTION

This chapter describes important systems for preventing HC leaks in the production phase and is a key part of maintaining operational integrity.

4.1 Risk management

The operator or the responsible party shall have a system for managing risk, including risk related to HC leaks. Risk management shall cover hazards related to explosion/fire, exposure and so forth which could have consequences for people, the environment, material assets and the company's reputation.

All activities in a plant should be assessed with a view to preventing HC leaks. The following questions should be asked when planning the execution of activities.

- Could an HC leak occur in connection with the activity?
- What can be done to reduce the probability of an HC leak?
- What can be done to reduce the size of an HC leak?
- How large could the HC leak become?
- What uncertainties are present and what can be done to reduce these?
- What systems/procedures shall be used in planning, executing and concluding the work?
- How should a possible HC leak be handled? This is particularly important for work on systems containing large quantities of hydrocarbons.
- How could an HC leak influence other ongoing activities?

Assessing and understanding risk before the activity starts is an important precondition for avoiding HC leaks.

4.2 Procedures

Procedures shall have a clear purpose and area of application, and their details shall be tailored to the expertise of the personnel who are to use them. Various types of procedures exist – such as operating a complete offshore facility/onshore plant, operating individual systems and executing an individual activity. This section deals with procedures related to operating a process plant and individual hydrocarbon systems, and with activities which could lead to HC leaks.

Procedures shall take account of operating limitations and relevant design assumptions. They shall describe important preconditions for process safety systems, and protection against exceeding design pressure and temperature. This applies to both high and low pressure/temperature.

Procedures for individual systems shall describe hazards related to operating the system and how possible errors could lead to undesirable conditions. Where hydrocarbon systems are concerned, the procedures shall describe what should be done if a leak occurs in the system.

Procedures for individual activities shall describe important principles related to the activity, and a step-by-step description of what is to be done.

4.3 Work permit (WP)

The operator or the responsible party shall establish a system for controlling work which ensures that hazards are identified, adequate measures to prevent hazards are in place and the risk from the work is assessed.

A common practice for utilising WPs on facilities/at onshore plants has been established by Norwegian Oil and Gas [ref 7]. This common model covers all activity which requires a WP on such facilities, including work in the drilling area.

4.4 Safe job analysis (SJA)

The operator or the responsible party shall prepare a procedure for safe job analysis (SJA). This involves a systematic and step-by-step review of hazards ahead of a work operation. An SJA shall be performed to identify, eliminate or control risk. The SJA procedure should be coordinated with the procedures related to the WP system.

Guidelines on establishing a common model for SJAs on the NCS have been established by Norwegian Oil and Gas [ref 12]. These describe when and how an SJA shall be conducted.

4.5 Planning

Good preparation and planning of operations and work activities are an important preconditions for preventing HC leaks. The company shall establish procedures for planning which ensures that the following considerations are among those met:

- hazards and risk-reducing measures are identified and communicated
- procedures for execution are in place
- materials and parts are available
- relevant experience is reviewed to ensure learning lessons and continuous improvement
- relevant and qualified personnel are involved
- ensuring that those doing the work are competent and have adequate experience
- all equipment used can cope with the pressure and temperature
- all equipment used is maintained in line with the maintenance programme
- temporary equipment is suitable for use.

4.6 Change management

The operator or the responsible party shall have a system for managing technical, operational and organisational changes. Change management is an important precondition for HC leak prevention. Many serious HC leaks have occurred and the consequences of these have become more serious because of changes, and a failure to identify possible hazards associated with these. All changes which might affect the HC leak prevention systems should be regarded as critical and be subject to a detailed risk assessment.

4.7 Handling deviations

The operator or the responsible party shall have a system to identify and register deviations, risk assess these and implement any compensatory/mitigatory measures. It shall be clear which restrictions the deviation imposes on further operation of the offshore facility/onshore plant, and which preconditions shall be met. Nonconformities related to hydrocarbon systems should be regarded as critical.

4.8 Focus group for HC leaks

The operator or the responsible party should establish a focus group for HC leak prevention. This should comprise personnel working on the offshore facility/at the onshore plant, supervisors, engineers in relevant disciplines, safety delegates and HSE advisers. It should meet regularly to discuss how the HC leak prevention systems are functioning and to identify measures for reducing the probability of HC leaks.

Specific duties of the focus group could include:

- identifying the causes of HC leaks
- mapping and monitoring fugitive gas emissions and sweating
- assessing new measures for HC leak prevention
- learning and experience transfer from internal and external incidents
- mapping vibration and pipe supports in hydrocarbon systems
- learning and experience transfer from HC leak prevention work on other facilities or at other companies.

An assessment should be made of the tools which the group ought to have in order to exercise its function, such as IR cameras.

4.9 Verification

The operator or the responsible party shall establish verification routines which ensure that systems, processes and procedures relevant for HC leak prevention function as intended. The operator or the responsible party shall identify which systems, processes or procedures shall be verified and which methods shall be used. Internal verification shall be implemented and verifications by external parties should be arranged. Having at the activity looked at by outside eyes from time to time is important.

4.10 Digitalisation

Digitalisation is about applying technology to renew, simplify and improve. This is a matter of offering new and improved services which are easy to use, effective and reliable. Digitalisation can make an important contribution to reducing HC leaks and lay the basis for improving the systems already in place to prevent HC leaks.

Digitalisation can help ensure that personnel involved in activities and their control have:

- a better overview of hazards and other activities in the area
- better access to information and documentation related to the activities

- better access to learning materials, including on relevant incidents which can be used for experience transfer, pre-job meetings and so forth.

Digitalisation is generally described as positive and forward looking, and the petroleum industry is clearly looking more in this direction. However, it can have its downsides, and assessing both advantages and disadvantages is important when introducing new systems.

4.11 Simulation and animation

Research has shown that simulations provide good learning effects and are motivating for users. Simulating work operations and activities gives the people involved an opportunity to develop both skills and knowledge. Process simulators and training can contribute a great deal to safe and efficient operation.

Animation of assignments and activities can be useful in planning work operations and communicating information to people who are involved. This is also useful in passing on details of incidents and accidents.

5 HC LEAKS

This chapter defines an HC leak, how its rate can be measured or calculated, and what threats it poses.

5.1 Properties

Hydrocarbons can exist in gaseous, liquid and solid forms.

Solid forms such as wax and asphaltenes can lead to problems with processing and by blocking pipes, drains, valves and the like.

Liquid hydrocarbons can be oil or condensate. The latter comprises lighter components and is more volatile than oil, which consists of heavier fractions.

Gaseous hydrocarbons can be lighter or heavier than air, depending on the composition of the leaking gas. When used for export or as fuel, hydrocarbon gas has a high methane content and is lighter than air if it leaks. Condensate comprises propane and butane, and will be heavier than air when leaking out.

The specific gravity of the hydrocarbon gas will influence its dispersion pattern, and this must be taken into account when assessing the location of gas detectors. It is also an important factor for leak seeking.

5.2 Definition of an HC leak

An emission/discharge of hydrocarbons is defined as a leak in the following circumstances.

- The measured hydrocarbon content is greater than 20 per cent LEL at a point 10 centimetres from the leak source in the direction with the highest readings. Such a measurement will normally be done manually using a portable gas detector.
- More than four drops per minute of liquid hydrocarbons are escaping from the leak point.

Hydrocarbon emissions/discharges registered by detectors linked to the fire and gas system will normally exceed the above-mentioned criteria, and are thereby defined as an HC leak.

The operator or the responsible party should establish procedures for measuring the leak rate. HC leaks fall primarily into two categories: small (< 0.1 kilograms per second) and those with a major accident potential (> 0.1 kg/s). See appendix 1.

5.3 Definition of fugitive emissions/sweating

Hydrocarbon releases smaller than an HC leak are defined as fugitive emissions (for gas) and sweating (for liquids).

5.4 Reporting HC leaks

Incidents and accidents which result in or could have led to an HC leak shall be reported in accordance with internal routines.

Reporting HC leaks to the PSA shall accord with section 29 of the management regulations:

> The operator shall ensure coordinated and immediate notification via telephone to the Petroleum Safety Authority Norway in the event of hazard and accident situations that have led to, or under slightly altered circumstances could have led to
>
> a. death
> b. serious and acute injury
> c. acute life-threatening illness
> d. serious impairment or discontinuance of safety related functions or barriers, so that the integrity of the offshore or onshore offshore facility is threatened
> e. acute pollution.

This means that reporting is based not only on the leak rate, but also on an assessment of the potential in the incident.

Leaks greater than 0.1 kg/s shall be reported to the PSA and are incorporated in the trends in risk level in the petroleum activity (RNNP) survey [ref 13]. The leaks are further categorised in the RNNP reporting. Figure 5-1 shows an example from the RNNP 2020 report.

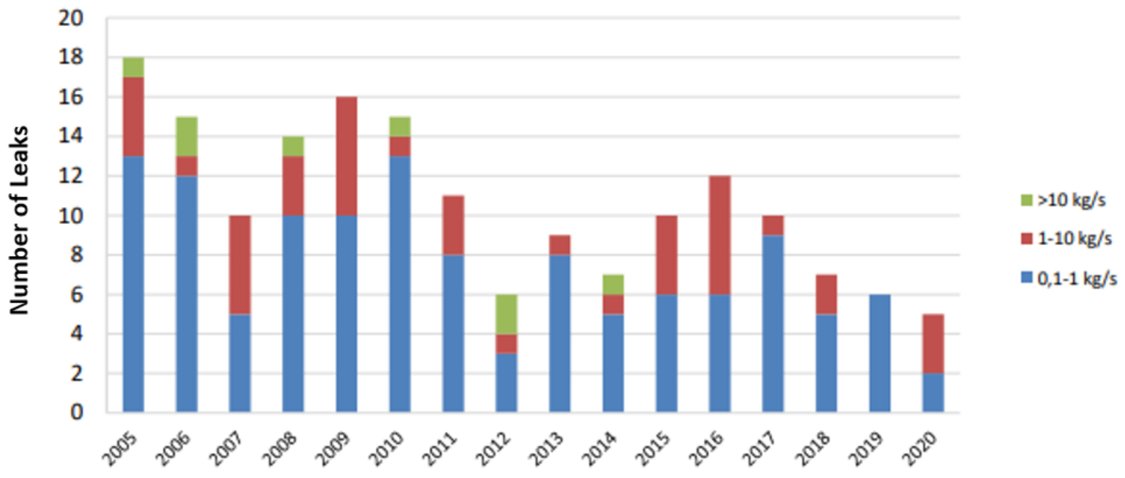


Figure 5-1: Number of leaks, all facilities on the NCS.

5.5 Measuring HC leaks

Two methods are available for calculating the rate of an HC leak. The operator shall develop procedures which cover both.

5.5.1 Method 1

The rate can be calculated from pressure and temperature changes in equipment affected by the leak. See appendix 2.

5.5.2 Method 2

The rate can be estimated by simulating measurements from gas detectors and the dispersion of hydrocarbons in the area. See appendix 2.

5.6 Hazards posed by HC leaks

Hydrocarbons are hazardous in both liquid and gaseous form, and it is important that everyone working with them understands the dangers.

Hazardous compounds may accompany the wellstream from the reservoir or through pipelines to an onshore plant, and may also be formed when processing hydrocarbons.

5.6.1 Fire

Three factors must be present for a hydrocarbon fire to occur – oxygen, normally from the atmosphere, enough flammable material, in this case hydrocarbons, and a sufficiently high temperature to ignite the mix of hydrocarbons and oxygen and thereby start the fire process. Figure 5-2 shows the fire triangle

Figure 5-2 The fire triangle.

Various types of fire can occur. All have their own challenges, which must be understood when designing and operating a plant.

A jet fire occurs when sufficient pressure is present in the system to maintain a considerable length of flame. For example, a leak from a pipe with 30 barg of pressure and a 24-millimetre-diameter hole could form a jet of flame about 14.2 metres long. This would pose a threat to personnel within 34 metres of the flame because of heat radiation. The possibility of a jet fire is an important consideration when designing fire protection for both structures and individual systems such as piping and valves. Figure 5-3 shows a jet fire and the length of flame which could be experienced. A jet fire will decline when the segment involved is shut in and the pressure reduced.


Figure 5-3 Jet fire.

A pool fire arises when liquid hydrocarbons accumulate on the deck/floor and burns. Figure 5-4 presents a typical example. This type of fire will continue until all the flammable material which has leaked out is consumed, or it has been extinguished.


Figure 5-4 Pool fire.

5.6.2 Explosion

hydrocarbons can combine with air to create an explosive mixture. Igniting this will cause an explosion, which will release a great deal of energy in the form of heat and high pressure (blast overpressure). Figure 5-5 shows the explosion on the Piper Alpha platform in the UK North Sea on 6 July 1988. This occurred when a riser in the gas export system fractured and the released gas exploded.

Figure 5-5 Explosion on Piper Alpha 6 July 1988.

5.6.3 Hazardous components accompanying the hydrocarbon stream

Some components which may accompany the hydrocarbon stream can be hazardous. Since the presence of the various components varies from field to field and from offshore facility to offshore facility, it is important that everyone who works with the hydrocarbon system is aware of which hazardous compounds are present. Examples include hydrogen sulphide (H_2S), carbon dioxide (CO_2), mercury and benzene. When working with substances which can contain these components, it is important to measure their content before work starts and to use the correct PPE based on these measurements.

H_2S is often present in a hydrocarbon stream, but normally in small quantities for typical fields on the NCS. A colourless, toxic and flammable gas at room temperature, H_2S has a characteristic smell of rotten eggs. It is slightly heavier than air. H_2S is hazardous for people and can also cause corrosion in some types of steel.

CO_2 is normally present in the hydrocarbon stream, and is corrosive when mixed with water.

The mercury content in the hydrocarbon stream is normally small. Even at low levels, however, it can cause corrosion in some material types such as copper-based alloys. Mercury is also hazardous to health and special measures shall be required when entering vessels which may by contaminated by this substance.

Benzene, a natural component in the hydrocarbon stream, is an acute narcotising substance with locally irritating effects on skin and mucous membranes. Long-term exposure can lead to serious anaemia. In serious cases, blood formation in bone marrow is damaged. Some cases of leukaemia have also been reported after benzene exposure.

5.6.4 Spontaneous combustion

Iron sulphide (scale) is a chemical compound which can be formed from substances produced with hydrocarbons. It can spontaneously combust on contact with air, and is thereby a possible ignition source for a possible HC leak.

5.6.5 Narcotic effect

Hydrocarbons have a narcotic effect at low concentrations. This can affect the behaviour and judgement of people so that they are unable to act rationally. Figure 5-6 shows how hydrocarbons can affect humans.

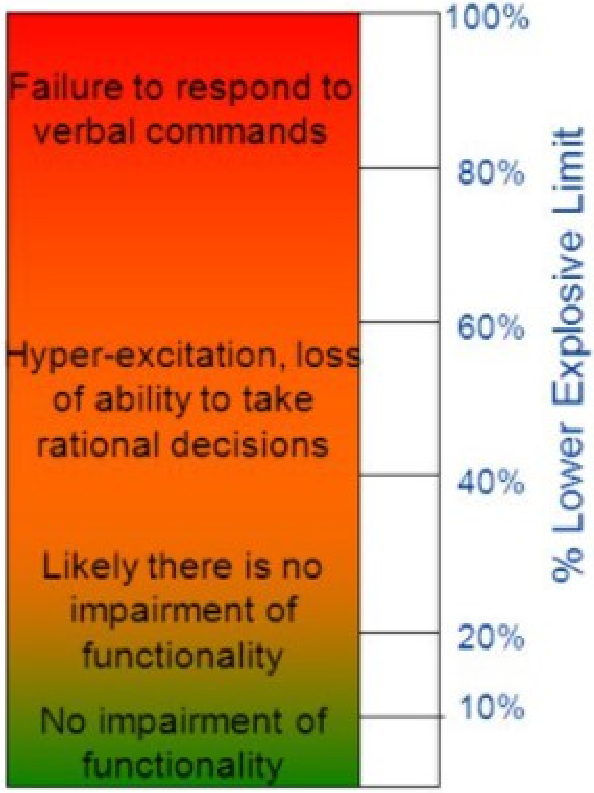


Figure 5-6 The narcotic effect of hydrocarbons.

5.7 Hydrates

Hydrates are a blend of water and light hydrocarbon molecules, such as methane, ethane and/or propane. They form at low temperature and high pressure, and in areas with low throughflow and little turbulence. Hydrates are relevant to HC leak prevention because they may block piping, valves, instruments and so forth. They can also form through internal leaks in valves and the like. When removing a hydrate plug/ blockage, there may be pressure behind it. The plug/blockage can therefore loosen with great force and damage equipment, which can lead to an HC leak. Procedures should be established which ensure that the pressure differential is limited across a hydrate plug/blockage when it gets heated up. Hydrates liberate hydrocarbon gas when they melt and may burn. See figure 5.7.

Figure 5-7 Burning ice (hydrates).

5.8 Wax and asphaltenes

Wax is hydrocarbons which have solidified at low temperature. It can block small pipes, valves and instruments, and cause control-system problems. Preventing wax formation involves keeping the temperature above its precipitation point, by either heating the process or using heated cables. The temperature should preferably lie above the melting point, which is typically higher than the formation point.

Asphaltenes are solid hydrocarbons formed by pressure reductions close to the bubble point or when condensate is added to crude oil. They can block small pipes, valves and instruments, and cause control-system problems. Asphaltene prevention is challenging, and measures are usually directed at preventing the consequences of their precipitation.

5.9 Hydrocarbon detection

Hydrocarbons can be detected both automatically and manually.

5.9.1 Automatic detection

An offshore facility producing or processing hydrocarbons shall have a fire and gas (F&G) system which detects hydrocarbons, activates alarms and initiates actions such as emergency shutdown and blowdown of the process plant.

Various methods are available for detecting and measuring the hydrocarbon content.

Catalytic gas detectors oxidise the hydrocarbon over a catalyst and measure the heat produced. See figure 5-8.

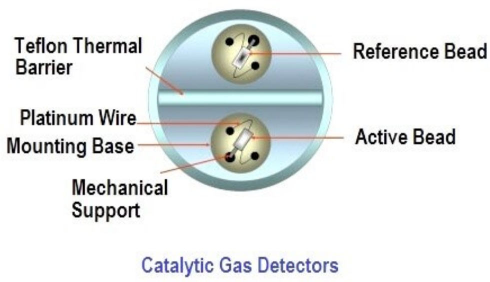


Figure 5-8 Catalytic gas detector.

An infra-red (IR) point gas detector uses IR radiation to measure the hydrocarbon content in a continuous throughflow of the ambient atmosphere. See figure 5-9.

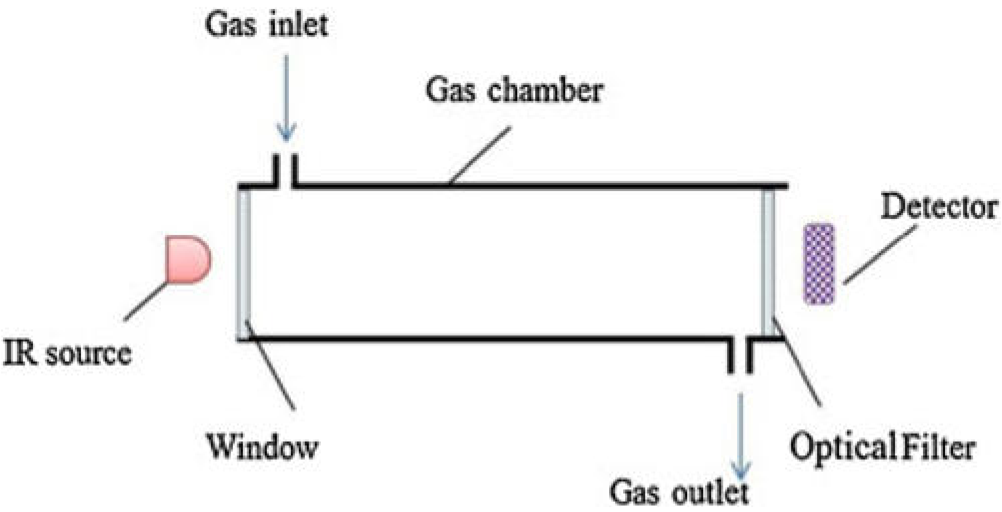


Figure 5-9 IR point detector.

An IR line-of-sight gas detector uses IR radiation over a longer distance and measures the average hydrocarbon content in the area covered by the beam. See figure 5-10.

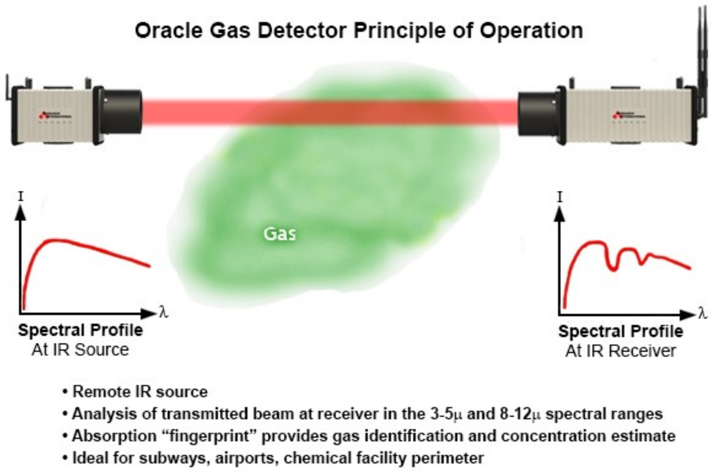


Figure 5-10 IR light-of-sight detector.

5.9.2 Manual detection

Various types of equipment are available for measuring hydrocarbon content manually. These devices are normally portable. Usual sensors include ones with photoionising detectors as well as IR point, ultrasonic, electrochemical and metal oxide semiconductor (MOS) sensors.

An IR camera and IR thermography can be used to detect small hydrocarbon emissions/ discharges. See figure 5-11. Increasing use is being made of IR cameras in systematic monitoring of hydrocarbon systems to keep track of fugitive emissions.

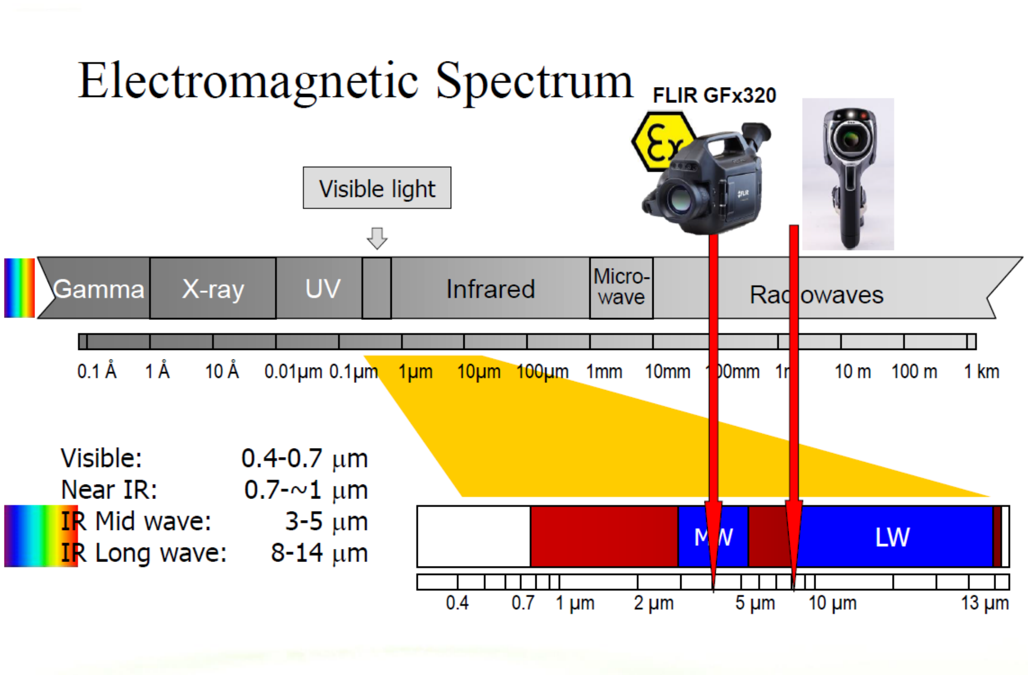


Figure 5-11 IR camera for hydrocarbons.

5.9.3 Vibration detection

Vibration in a hydrocarbon system can cause fatigue and weakening, and thereby HC leaks. Systems have been developed to visualise vibrations in order to prevent leaks occurring. Figure 5-12 shows an example from Noisevision. The equipment is portable and comprises a high-speed camera with signal amplification to reveal vibrations. The information is acquired in real time, so that vibration in piping, for example, can be observed as measurement takes place.

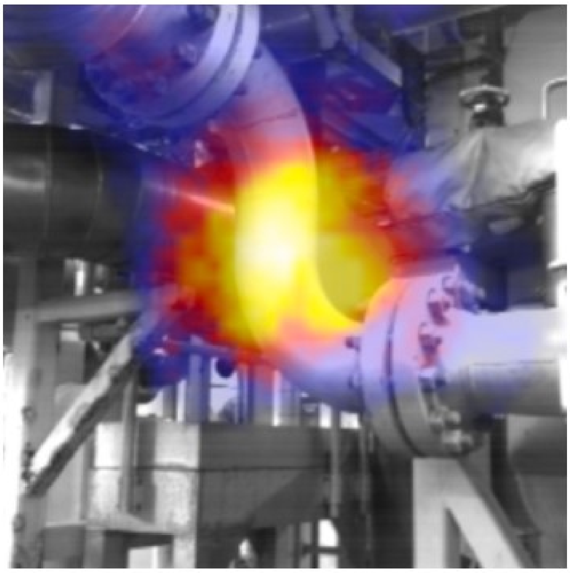


Figure 5-12 Visualising vibrations.

5.10 Hydrogen

This handbook focuses attention on hydrocarbons and HC leak prevention. Much of its information is also relevant for preventing hydrogen leaks. On the other hand, hydrogen has characteristics which make it more challenging to prevent leaks and handle their potential consequences. Hydrogen/air mixtures are explosive in the range of four to 67 volume per cent of hydrogen. Hydrocarbons also react with many materials, and can causes fractures in some types of steel. Its combustion temperature may be extremely high, and explosions can be extremely powerful. Work on hydrogen calls for good processes and procedures to handle the hazards and for it to be done by personnel with special expertise. Among other considerations, hydrogen poses stricter requirements for EX equipment than hydrocarbon systems.

6 INDICATORS FOR PREVENTING HC LEAKS

The operator or the responsible party shall assess which indicators can be used to provide an overview of how the systems related to HC leak prevention are functioning. These indicators can be lagging – in other words, based on information from past incidents – or leading and thereby directed at influencing what will happen in the future. Indicators can be strong, such as relevant incidents and experience, or weak – in other words, ambiguous and possibly difficult to interpret. They can be both positive and negative. Positive indicators show that the HC leak prevention process is functioning satisfactorily, while negative ones show that room for improvement exists.

The operator or the responsible party should establish indicators which provide an overview of systems, processes and procedures related to HC leak prevention in order to verify that these function as intended. An indicator is something which can be measured. Both leading and lagging indicators should be used. The process of identifying indicators is demanding, and it is important that all positions involved in HC leak prevention participate.

A leading indicator looks ahead to the future outcome of activities and events.

A lagging indicator looks back at the relevant outcome of activities and events, and is an indication of whether the desired results were achieved.

The IOGP has published a recommended practice which can be useful for identifying and applying indicators [ref 14]. See figure 6-1. Levels 1 and 2 are lagging indicators and 3-4 are leading.

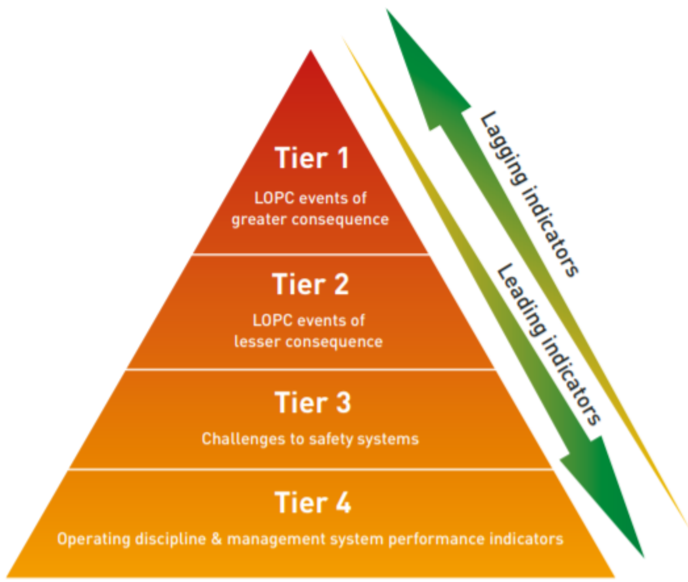


Figure 6-1 Process safety indicators.

7 INVESTIGATION OF HC LEAKS

Investigating incidents which have or could have led to HC leaks is important for learning lessons and continuous improvement. Every incident offers an opportunity to improve and thereby prevent more HC leaks.

An investigation is not only a matter of identifying what went wrong. It should also reach an understanding of why those involved in the incident thought that what they were doing was acceptable. It must be possible to achieve an acceptable understanding of the course of events and the actions taken. This means, in other words, that actions or conditions should be explainable in a rational manner regardless of whether they were erroneous or misunderstood.

The operator or the responsible party should use an established method of investigation and ensure that the investigating team has the necessary expertise.

Causes of an incident can be described at several levels:

- immediate (also termed direct)
- underlying (also termed root or systemic).

An investigation should not identify vague causes which add little of significance to an understanding of the incident, and which make it difficult to identify measures. Both immediate and underlying causes should be identified. Immediate causes relate to technical failures, human actions and actual conditions in the incident, and can be described as direct or initiating causes. Underlying causes are human, technical and organisational factors which must be present for one or more immediate causes to initiate an incident

The causes will determine the criticality of possible measures and the prioritisation of their implementation.

Identified measures should accord with the Smart principle:

S – specific
M – measurable
A – attainable
R – realistic
T – time constrained.

The operator or the responsible party shall have a system which ensures that the measures are implemented and followed up. It is also important to have a system for assessing whether a measure has had the desired effect.

8 LEARNING AND CONTINUOUS IMPROVEMENT

A basic principle in the HSE regulations is the requirement for continuous improvement. This assumes that a system is in place for learning from one's own experience and that of others, and to implement measures for improving established procedures and practice. The operator or the responsible party should focus attention on learning from experience with work on HC leak prevention in order to improve procedures and practice. Undesirable incidents shall be reported and relevant incidents should be investigated and measures initiated in accordance with company requirements in order to avoid more incidents.

Norwegian Oil and Gas has established a database of incidents involving HC leaks on the NCS [ref 15]. A data sheet has been created for each incident, and the information in this can be valuable in planning work on hydrocarbon systems and for discussions on HC leak prevention.

The Energy Institute (EI) has developed an app for learning and experience transfer. Go to:

https://toolbox.energyinst.org/

Free to use, Toolbox contains lessons learnt from incidents and safety information shared by global energy companies which you can utilise at work every day, and which will help you and your team to return home safely. Toolbox can be used on a smartphone, tablet or laptop, and provides the opportunity to scroll through the content in search of work activities or high-risk conditions. Content for quick access from My Toolbox can be stored, and the app can be used stand-alone when an internet connection is unavailable.

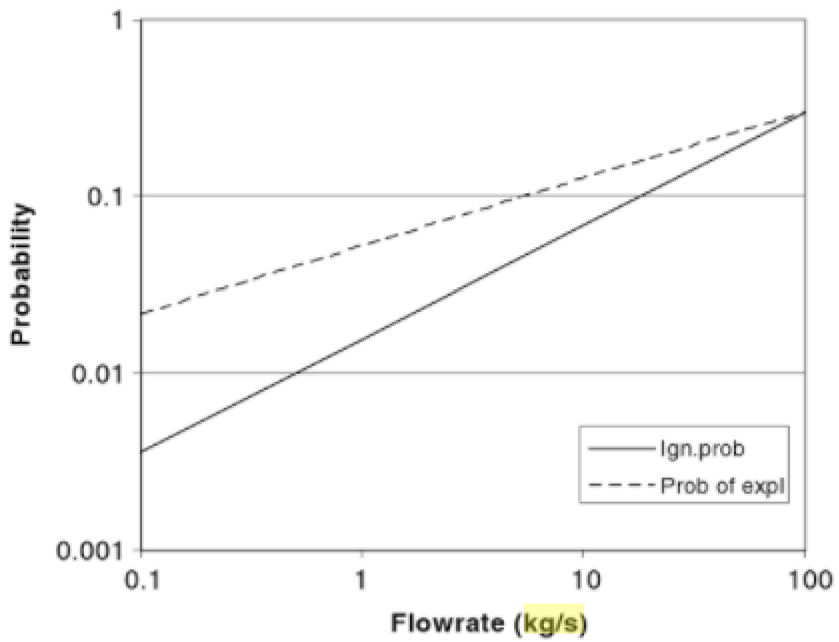
Toolbox quickly connects users worldwide to health and safety insights from leading energy companies which enter into collaboration with the EI, including BP, Chevron, ConocoPhillips, ExxonMobil, Global Offshore Wind Health and Safety Organisation (G+), Lloyd's Register Foundation, Phillips 66, Repsol, Shell and TotalEnergies.

APPENDIX 1 LEAK RATE WITH MAJOR ACCIDENT POTENTIAL

The purpose of this appendix is to specify the background for the HC leak rate (>0.1 kg/s) which represents a major incident potential.

A leak rate of 0.1 kg/s is regarded as the smallest which could provide a significant probability for an explosion. This is not an exact science, since other factors could be important in determining whether a leak might cause an explosion – in an enclosed space with poor ventilation, for example, a rate smaller than 0.1 kg/s could produce to an explosive mix. The figure below presents the probability of an explosion by leak rate. It has been taken from *Offshore Risk Assessment,* third edition, by Jan Eirik Vinnem, who refers to work by Cox in 1991. The figure shows that a gas leak of 0.1 kg/s will give a probability of about two per cent for an explosion and furthermore that roughly >2% is regarded as significant.

15 Analysis Techniques



APPENDIX 2 MEASURING HC LEAKS

Method 1

This method utilises calculations of leak size based on the size of the leak source and the pressure and temperature in the equipment which the hydrocarbons are leaking from. The calculation should take account of whether the leak is liquid or gas.

Model leak rate = A x Velocity x Density

~ A x f(MW, P) x f(MW, P, T, phase)

~ **f (A, MW, P,** T)

Gas (kg/s)

Pressure (bar)	Hole diameter (m)				
	0,01	0,02	0,05	0,1	0,2
5					
10					
20					
30					
50			10		
75					
100					
150					
200					

Liquid (kg/s)

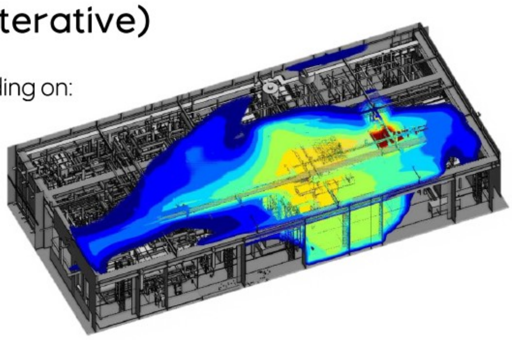
Pressure (bar)	Hole diameter (m)				
	0,01	0,02	0,05	0,1	0,2
5					
10					
20					
30					
50			109		
75					
100					
150					
200					

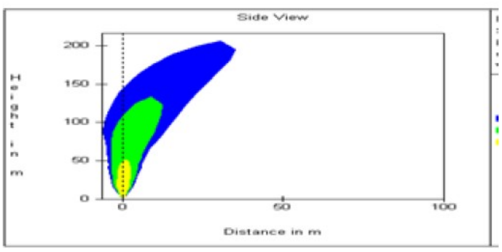
Method 2

This method uses readings from the gas detectors in the area to simulate the dispersion of the gas cloud, and thereby to estimate the leak rate.

Estimation of leak rate (indirectly/iterative)

- Gas dispersion and gas cloud formation are depending on:
  - Leak rate
  - Ventilation
  - Composition
  - Confinement and obstruction





APPENDIX 3 RELEVANT INCIDENTS

The following accidents offer important learning points with regard to process safety, and can be useful for raising awareness in connection with HC leak prevention. Links to information on these incidents (in either English or Norwegian) are included for follow-up.

Incident	Date	Relevance	Link
Piper Alpha	6 July 1988	Explosion Fire	Link to Piper Alpha investigation vol 1 Link to Piper Alpha investigation vol 2
Brent Bravo	11 September 2003	Narcotic effect	Link to Brent Bravo information
Texas City refinery	23 March 2005	Explosion Fire	Link to Texas City investigation
Statfjord A	24 May 2008	HC leak Screwed coupling loosened	Link to Statfjord A investigation Norwegian version only
Oseberg C	12 September 2008	HC leak Unintentional valve opening	Link to Oseberg C investigation Norwegian version only
Heimdal	26 May 2012	HC leak Valve in wrong position	Link to Heimdal investigation
Ula	12 September 2012	HC leak Corrosion	Link to Ula investigation
Oseberg A	17 June 2013	HC leak Erosion	Link to Oseberg A investigation
Gudrun	18 February 2015	HC leak Vibration, fatigue	Link to Gudrun investigation
Snorre B	1 May 2019	Fire Self-ignition	Link to Snorre B investigation
Melkøya	28 September 2020	Fire in turbine	Link to Melkøya turbine fire Norwegian version only
Tjeldbergodden	2 December 2020	Turbine breakdown and fire	Link to Tjeldbergodden turbine fire Norwegian version only

APPENDIX 4 DEFINITIONS AND ABBREVIATIONS

Area authority/ operations supervisor	The management function responsible for the area or plant to be worked on, which will thereby be involved in approving the work [ref 7].
Blinding	Isolation with the help of full-specification blind spade or flange.
Fugitive gas emission	Hydrocarbon gas emissions at a rate smaller than the one (< 20% LEL) which defines an HC leak.
HC leak	The hydrocarbon content is measured as greater than 20% LEL at a point 10 centimetres from the leak site. More than four drops per minute of liquid hydrocarbons.
Isolation	Separation of plant and equipment from any and all energy sources, such as chemicals, pressure, electrical energy and mechanical energy, so that the separation is secure.
LEL	Lower explosion limit.
NCS	Norwegian continental shelf.
Operational barrier element	The actions or activities which personnel must carry out to realise a barrier function.
Operator or the responsible party	The party responsible for prudent operation of an offshore facility or onshore plant may be an operator company or another enterprise.
Organisational barrier element	Personnel with defined roles or functions and specific expertise which are incorporated in a barrier function.
P&ID	Piping and instrumentation diagram.
PPE	Personal protective equipment.
PSA	Petroleum Safety Authority Norway.
RBI	Risk-based inspection.
RCM	Reliability-centred maintenance (risk-based maintenance)
RNNP	Trends in risk level in the petroleum activity.

SJA	Safe job analysis – a systematic and step-by-step review of hazards ahead of a work operation. It shall be conducted to identify, eliminate or control risk.
Shall	Indicates a requirement which must be complied with in order to achieve the intention.
Should	Indicates that one possibility among several is recommended.
Spacer	A circular metal plate with a hole in it which is installed in a pipe system or equipment, and which can be replaced by a spade.
Spectacle flange	A spacer and a spade in one unit
Sweating	Discharge of liquid hydrocarbons smaller than the rate which qualifies as an HC leak.
Technical barrier element	Equipment and systems involved in realising a barrier function.

APPENDIX 5 REFERENCES

	Document	Link
1	Always Safe	Link to Always Safe
2	IOGP lifesaving rules (LSR)	Link to IOGP LSR
3	IOGP process safety fundamentals	Link to IOGP Process Safety Fundamentals
4	Causal analysis of HC leaks	Norwegian Oil and Gas causes of HC leaks Norwegian version only
	Principles for barrier management in the petroleum industry – barrier memorandum 2017	PSA barrier memorandum 2017
6	Recommended practice for isolation when working on hydrocarbon equipment	Norwegian Oil and Gas recommended practice for isolations
7	Norwegian Oil and Gas guideline 088	Norwegian Oil and Gas guidelines on work permit systems
8	Norwegian Oil and Gas handbook on valve technology	Norwegian Oil and Gas valve handbook
9	Norwegian Oil and Gas handbook on flange work	Norwegian Oil and Gas handbook for flange work
10	Norwegian Oil and Gas handbook for fittings and small bore systems	Norwegian Oil and Gas handbook fittings and small-bore pipework
11	Norsok Z-015N Temporary equipment	Norsok Z-015 Temporary equipment
12	Norwegian Oil and Gas guideline 090	Norwegian Oil and Gas guidelines for safe job analysis
13	Trends in risk level in the petroleum activity (RNNP)	Link to RNNP
14	IOGP Process safety – recommended practice on key performance indicators	Link to IOGP KPIs
15	Norwegian Oil and Gas HC leaks data sheets	Link to HC leaks database