CDOIF

Chemical and Downstream Oil Industries Forum

Guideline

Leak Detection

Foreword

In promoting and leading on key sector process safety initiatives, CDOIF has developed through its members this guideline on available leak detection techniques for Above-ground Storage Tanks (AST).

The intent of this document is to provide a reference for those organisations wishing to consider the use of leak detection systems to provide mitigation against the loss of product from an AST.

It is not the intention of this document to replace any existing corporate policies or processes. The intent is to provide a reference to users to help in the selection of appropriate leak detection techniques.

There are no limitations on further distribution of this guideline to other organisations outside of CDOIF membership, provided that:

1. It is understood that this report represents CDOIF's view of common guidelines as applied to leak detection.
2. CDOIF accepts no responsibility in terms of the use or misuse of this document.
3. The report is distributed in a read only format, such that the name and content is not changed and that it is consistently referred to as "CDOIF Guideline – Leak Detection".
4. It is understood that no warranty is given in relation to the accuracy or completeness of information contained in the report except that it is believed to be substantially correct at the time of publication.

It should be understood that this document does not explore all possible options for leak detection, nor does it consider individual site requirements – Following the guidance is not compulsory and duty holders are free to take other action.

Contents

1. EXECUTIVE SUMMARY

Hazardous substances which are stored in above-ground storage tanks could have the potential to pollute the environment or harm people if the primary containment measure in which they are stored (i.e. the tank) fails.

Leak detection is one method by which hydrocarbons can be detected should primary containment fail. Early indication of the failure may ensure that mitigation measures to prevent escalation of the scenario can be deployed quickly.

The final report of the Process Safety Leadership Groups (PSLG) safety and environmental standards for fuel storage sites was published in December 2009. Part 2 of that report provides limited guidance on the use of gas and liquid detection systems to detect overflows from a bulk storage tanks. A research report commissioned by the Health and Safety Laboratory (HSL), entitled 'A review of leak detection for fuel storage sites, ECM/2008/08' provided further guidance.

As part of its role to deliver improvements in health, safety and the environment, the CDOIF Process Safety Work-stream agreed to examine the types of leak detection that had been successfully implemented in the UK. A working group was commissioned to develop this guideline to assist duty holders in the selection of appropriate techniques and what impact these systems may have in terms of risk reduction.

There are different leak detection methodologies available, which each have their own strengths and weaknesses. Methodologies considered in terms of their benefits, limitations and indicative costs are described in section 3, Techniques for Leak Detection.

Leak detection systems may reduce the risk to people or the environment. They could be considered as a further layer of protection against specific scenarios or be considered a more cost effective risk reduction technique as part of an ALARP (As Low As Reasonably Practicable) demonstration. The possibility of spurious trips will discourage their use in automatic systems, whether in the Basic Process Control System (BPCS) or Safety Instrumented System (SIS). As per other guidance, any claims for risk reduction as an additional mitigation barrier will require justification in terms of clearly defined operating procedures and emergency responses.

2. INTRODUCTION AND SCOPE

Leak detection in the context of this guidance relates to the detection of hydrocarbons following the failure of primary containment. Primary containment inside a bund consists of the tank shell and associated pipe work. Primary containment may fail in any of the following ways:

- The tank is over-filled, resulting in loss of product from the top of the tank, or through roof vents
- Failure of the tank floor
- Failure of the tank wall joints
- Catastrophic tank failure
- Failure of pipe-work associated with the tank
- Failure of pipe-work running through the bund

The risk of these failures occurring can be reduced significantly through measures such as good inspection, maintenance and repair processes, and where appropriate the installation of preventative systems such as overfill protection. Leak detection systems can complement these other measures to reduce the risk further, or they may also provide an alternative means of risk reduction when other systems or processes are disproportionate in terms of the risk reduction achieved versus the cost.

This guidance should not be interpreted as a requirement to install such systems, but instead provide a useful reference to those duty holders who may be considering the installation of leak detection for the reasons stated. Other techniques are available, and cost will be variable depending on the technology adopted and existing site infrastructure. Consideration should also be given to the sensitivities of any installed system to spurious trips during routine operations (such as flushing), and procedures should be updated accordingly.

The following sections provide an overview of typical leak detection systems adopted by the downstream oil industry in the UK – this list is not exhaustive and other techniques may also be available.

3. TECHNIQUES FOR LEAK DETECTION

Leak detection may be considered as one mechanism for the early detection of failure of primary containment. Typical examples of Hydrocarbon detection techniques include:

- Gas detection (point sensors)
- Point detectors placed around the circumference of the tank or in the bund floor
- Interface or level detectors placed in an interceptor or sump
- Hydrocarbon detection ‘tapes’ installed in the bund floor, or underneath the base of the tank
- Under tank membrane with tell-tail leak detection
- Interspace loss of vacuum detection
- Tank level gauging with product loss alarm (wet-stock reconciliation)
- Point or interface detectors located at the outlet to a floating roof drain valve
- Point or interface detectors located at the outlet to a bund drain valve
- Point or interface detectors located at the outlet to a tank water draw valve

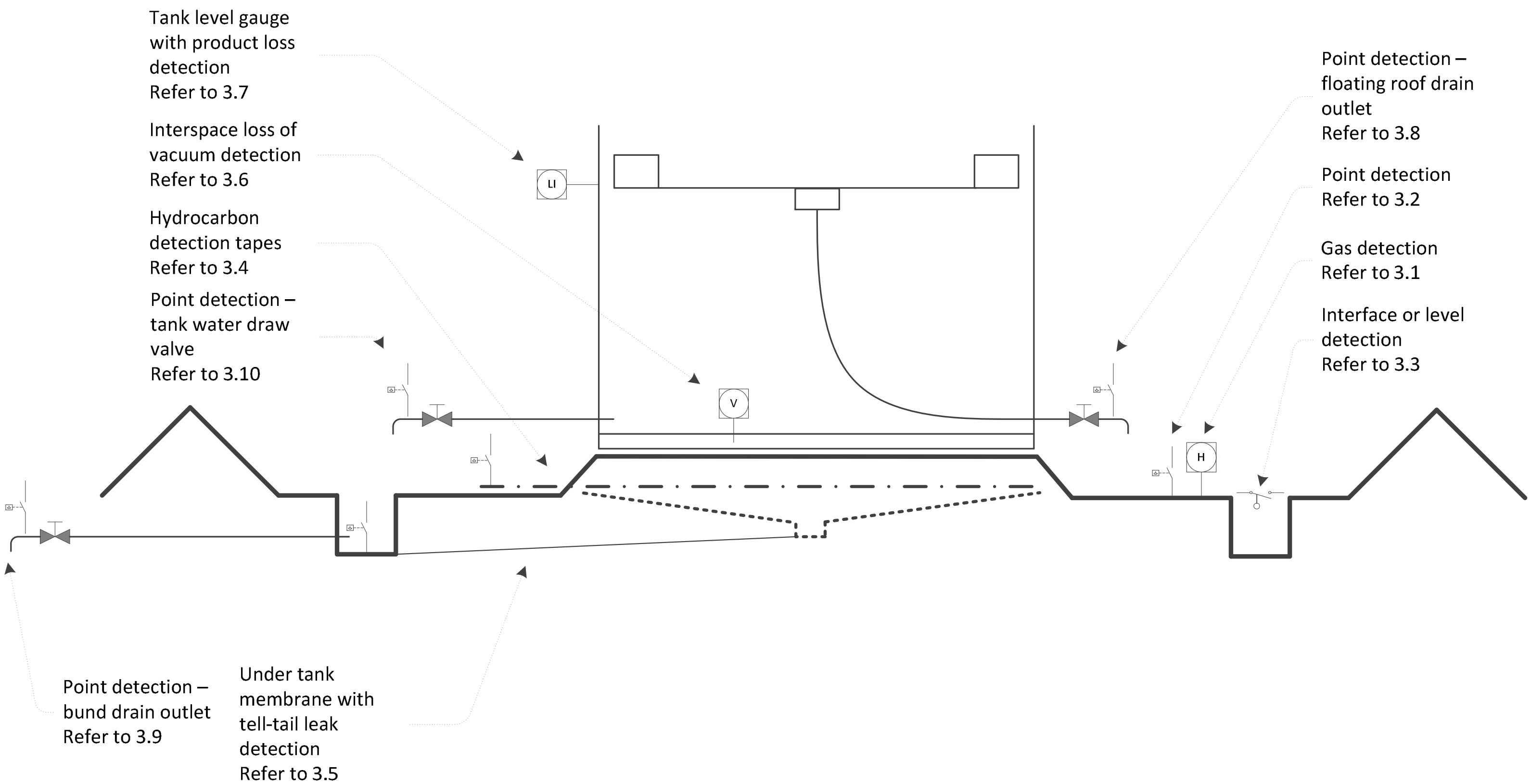

Figure 1 – Examples of Hydrocarbon detection points

When reviewing the applicability of leak detection techniques, it is important to consider the circumstances under which it will be used, and the scenario(s) it is intended to detect, for example:

- Installing liquid or gas detection is unlikely to have an effect on reducing the risk to people or the environment following catastrophic tank failure, or loss of very large volumes of product after the failure of wall joint as the volumes lost would be significant over a very short space of time. However smaller leaks may be a pre-curser to more significant failures, and therefore leak detection may prove beneficial.

- Leak detection is likely to be beneficial in mitigating the risk arising from tank over-fill, or from other significant tank leaks.

- Gas detection may be effective in detection of vapour formation following over-topping thus limiting the size of a Flammable Vapour Cloud (FVC), but it is unlikely to be effective in detecting a leak from the base of the tank.

- The positioning of gas detectors can be impacted by prevailing weather conditions. Gas detectors will be much less sensitive to leaks down-wind of the detector.

Reference should be made to section 4, Risk Reduction Consideration, for further information on the benefits that could be claimed, and the restrictions that should be applied when considering the chosen leak detection system in a risk assessment.

Installations appropriate to new build tanks may not be appropriate for tanks which are refurbished.

The following sub-sections provide an analysis of typical leak detection techniques, their benefits and limitations and indicative cost.

3.1 Gas detection within the tank bund

Usage	Potential benefits	Considerations	Indicative Cost
Gas detectors positioned within the bund can be used to detect vapour cloud formation caused either from tank over-fill or failure of the tank shell (where these failures are located in such a place as to cause cascade of product likely to form a vapour cloud) Early detection of loss of containment could reduce the size, or prevent the formation of a large flammable vapour cloud which may lead to a Vapour Cloud Explosion (VCE) Early detection of loss of containment could reduce the risk of a pool fire by detecting vapour within the bund before ignition.	Gas detection is a well proven technology, which is generally robust and cost effective where a suitable integrity, reliability or preventative maintenance strategy is applied.	Effective positioning of detectors is important as the spread of a vapour cloud will be directly affected by weather conditions. Suitable technology should be selected depending upon the product and conditions to be detected - technology includes point and open path. Further information can be found here: http://www.hse.gov.uk/pubns/gasdetector.pdf Gas detection would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to periodic testing.	Medium

3.2 Tank base perimeter/bund floor point detectors

Usage	Potential benefits	Considerations	Indicative Cost
Liquid point detectors positioned around the base of the tank, or in the bund floor (typically in the lowest gradients of the bund floor) can be used to detect loss of containment into the bund, either from tank over-fill or failure of the tank shell. In some instances this may also detect loss of containment from the tank floor, though this will be dependent on the topology and geology of the bund underneath the tank Early detection of hydrocarbons in the bund could reduce the size, or prevent the formation of a large flammable vapour cloud which may lead to a VCE Early detection of hydrocarbons in the bund may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund may also provide an early indication of loss of containment, reducing the risk of a Major Accident to the Environment (MATTE)	Liquid point detectors can provide an early indication of hydrocarbons within the bund, reducing the escalation of several scenarios which if undetected could lead to a VCE or a MATTE.	Liquid point detection may be subject to spurious trips due to bund materials which may already be contaminated, or through rain water collecting in the bund. Detection is only effective at the point of measurement, and therefore the positioning and number of detectors require careful consideration Care should be taken when claiming credit for the reduction in size of a flammable vapour cloud, as liquid would only be detected in the bund if the tank was already overflowing – giving time for the vapour cloud to form. Liquid point detection within the bund would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to periodic testing.	Medium

3.3 Sump/interceptor point or interface detectors

Usage	Potential benefits	Considerations	Indicative Cost
Detectors positioned in the bund sump or interceptor can come in two forms: 1. Simple level switch (fitted with a displacer for greater accuracy), or 2. Interface level detectors These technologies can be used to detect loss of containment into the bund either from tank over-fill or failure of the tank shell. In some instances this may also detect loss of containment from the tank floor, though this will be dependent on the topology and geology of the bund underneath the tank Early detection of hydrocarbons in the bund sump or interceptor may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund sump or interceptor may also provide an indication of loss of containment, reducing the risk of a MATTE	Bund sump or interceptor liquid/interface detectors can provide an early indication of hydrocarbons within the bund, reducing the escalation of several scenarios which if undetected could lead to a MATTE. Interface level detectors in particular have been shown to be very reliable and easy to maintain.	Simple level switches in particular can be subject to spurious trips due to rain water collecting in the bund. Detection is only effective at the point of measurement, and therefore detection will only occur where product collects in the bund sump/interceptor Bund sump or interceptor liquid/interface detection within the bund would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to period testing. Hydrocarbon detection may be linked with executive action (for example closing an automated valve) if failure is likely to result in hydrocarbon release into the bund	Low

3.4 Hydrocarbon detection tapes installed in the bund floor or underneath the tank

Usage	Potential benefits	Considerations	Indicative Cost
Hydrocarbon tape/cable detectors positioned underneath the tank floor can be used to detect loss of containment from the tank floor. Early detection of hydrocarbons underneath the tank may provide an indication of loss of containment, reducing the risk of a MATTE	Tape/cable detectors are an effective method for detecting leaks from the tank floor, which otherwise may be undetected for some time. Arranged in a lattice format, this method of detection may also provide some accuracy as to the location of the leak within the tank floor. Tape or cable detectors can either be installed underneath the tank base (typically using a boring technique) or between two floors of a double bottomed tank.	Tape/cable detectors can be sacrificial, and would require replacement following detection. There is a risk of premature failure of the system if installation is not carefully planned and executed. Care should be taken in assessing the contamination that may already exist underneath the tank before installation Tape/cable detection underneath the tank would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to period testing.	High

3.5 Under tank membrane with tell-tail leak detection

Usage	Potential benefits	Considerations	Indicative Cost
Liquid point detectors positioned at the outlet of under tank floor/over membrane leak detection pipes can be used to detect loss of containment into the bund from tank floor failure. Early detection of hydrocarbons underneath the tank may provide an indication of loss of containment, reducing the risk of a MATTE	Liquid point detectors can provide an early indication of hydrocarbons within the bund, reducing the escalation of several scenarios which if undetected could lead to a MATTE.	Liquid point detection may be subject to spurious trips due to bund materials which may already be contaminated, or through rain water collecting in the bund. Detection is only effective at the point of measurement, and therefore the positioning and number of detectors require careful consideration Under tank membranes are primarily concerned with detecting tank floor leaks. Other leaks leading to FVC are unlikely to be detected. Liquid point detection within the bund would form part of a mitigatory protection layer – routine operator monitoring or alarm activation would be required to initiate further action and/or emergency response, however the system indicates failure of only one of the containment systems, and therefore immediate response may not be required. Any further activity would be required to be clearly defined and subject to periodic testing	Low/ Medium

3.6 Interspace loss of vacuum detection

Usage	Potential benefits	Considerations	Indicative Cost
Loss of vacuum on vacuum annulus systems installed on tank floors can be used to detect loss of containment from the tank floor. Early detection of hydrocarbons underneath the tank may provide an indication of loss of containment, reducing the risk of a MATTE	Loss of vacuum techniques are an effective method for detecting leaks from the tank floor, which otherwise may be undetected for some time. Loss of vacuum detection systems are installed in the space between an internal epoxy/steel tank floor and the external tank floor.	Loss of vacuum detection systems would form part of a mitigatory protection layer – routine operator monitoring or alarm activation would be required to initiate further action and/or emergency response, however the system indicates failure of only one of the containment systems, and therefore immediate response may not be required. Any further activity would be required to be clearly defined and subject to periodic testing	Medium/ High

3.7 Tank level gauging with product loss alarm

Usage	Potential benefits	Considerations	Indicative Cost
Liquid level monitoring (wet-stock reconciliation) of the product within the tank can be used to detect a loss of containment over a period of time (for example, where product is leaking from the tank). Monitoring of the tank level for loss of containment is only relevant during the period when the product in the tank is stationary (for example when no transfers into or out of the tank are in progress, such as when a terminal is closed overnight). Tank gauging systems can detect comparatively small leaks of product loss Early detection of hydrocarbons in the bund could reduce the size, or prevent the formation of a large flammable vapour cloud which may lead to a VCE Early detection of hydrocarbons in the bund may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund may also provide an early indication of loss of containment, reducing the risk of a Major Accident to the Environment (MATTE)	Liquid level monitoring is a well proven technology with proven reliability and repeatability for accuracy	Monitoring is normally via the tank gauging system The system should be configured with a change in level (discrepancy) alarm that is relayed to relevant personnel who can take appropriate action/. This could either be the central control room or security office.	Low

3.8 Point or interface detection at floating roof drain valve outlet

Usage	Potential benefits	Considerations	Indicative Cost
Leak detection installed on the outflow from a floating roof drain valve can provide indication of a failure of the drain line (hose or flexible joint) or a sunken floating roof. Early detection of hydrocarbons in the bund may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund may also provide an early indication of loss of containment, reducing the risk of a Major Accident to the Environment (MATTE)	Cost effective when installed in drain lines from the outlet of the drain valves	Functionality is only relevant where the policy on the site is to leave the roof drain normally open, in this instance leak detection could be beneficial. The detection will not function if the drain line is closed. Close care and attention is needed during the set-up and commissioning of such systems to prevent spurious alarms and avoid loss of confidence. Detection in the drain line would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to period testing. Hydrocarbon detection may be linked with executive action (for example closing an automated valve) if failure is likely to result in hydrocarbon release into the bund.	Low

3.9 Point or interface detection at bund drain valve outlet

Usage	Potential benefits	Considerations	Indicative Cost
Leak detection installed on the outflow from the bund drain valve can provide indication of over-fill or loss of containment into the bund. Early detection of hydrocarbons in the bund may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund may also provide an early indication of loss of containment, reducing the risk of a Major Accident to the Environment (MATTE)	Cost effective when installed in drain lines from the outlet of the drain valves	Functionality is only relevant where the policy on the site is to leave the bund drain valve normally open, in this instance leak detection could be beneficial. The detection will not function if the drain line is closed. Close care and attention is needed during the set-up and commissioning of such systems to prevent spurious alarms and avoid loss of confidence. Detection in the drain line would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to period testing.	Low

3.10 Point or interface detection at tank water draw valve outlet

Usage	Potential benefits	Considerations	Indicative Cost
Leak detection installed on the outflow from a water drain valve can provide indication of loss of containment into the bund. Early detection of hydrocarbons in the bund may be used to reduce the risk of pool fires. Early detection of hydrocarbons in the bund may also provide an early indication of loss of containment, reducing the risk of a Major Accident to the Environment (MATTE)	Cost effective when installed in drain lines from the outlet of the drain valves	Tank water draw is normally an attended operation, but can take place over long periods of time. In these instances, hydrocarbon detection may be of benefit. Close care and attention is needed during the set-up and commissioning of such systems to prevent spurious alarms and avoid loss of confidence. Detection in the water drain line would form part of a mitigatory protection layer – alarm activation would be required to initiate further action and/or emergency response. This further activity would be required to be clearly defined and subject to period testing. Hydrocarbon detection may be linked with executive action (for example closing an automated valve) if failure is likely to result in hydrocarbon release into the bund	Low

4. RISK REDUCTION CONSIDERATION

Whether or not a leak detection system is installed will be dependent on the benefits that it gives versus the costs of installation and maintenance - this decision should be made by the duty holder when completing a risk assessment for the credible scenarios which could result in loss of containment from an AST. Further guidance relating to risk assessment can be found here:

- For the protection of people, refer to the numerous publications by the Health and Safety Executive (HSE) for COMAH, http://www.hse.gov.uk/comah/
- For the protection of the environment, one methodology for environmental risk assessment is provided in the CDOIF publication 'Environmental Risk Tolerability for COMAH Establishments'

The installation of such systems may be appropriate to reduce the risk to people or the environment (or both). They could be considered as a further layer of protection against specific scenarios (for example reducing the risk of the formation of a flammable vapour cloud, or the risk of pollution to an environmental receptor), or be considered a more cost effective risk reduction technique as part of an ALARP (As Low As Reasonably Practicable) demonstration. However as any such system will only indicate the presence of hydrocarbons after they have escaped from the tank, they should only be considered as a mitigation layer.

Whilst leak detection mechanisms could be configured with an automatic action (for example closure of an inlet valve, drain valve or stopping a transfer pump), caution should be taken when considering these systems to be safety related as further mitigatory actions would be required even if the automatic action[1] completed successfully, i.e.:

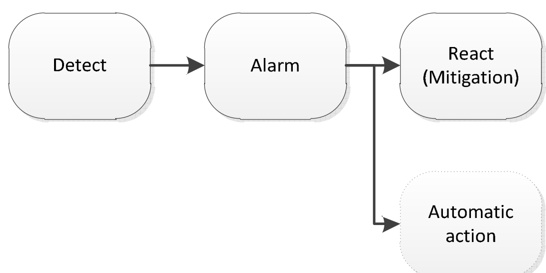

Figure 1 – Leak Detection Actions

These further mitigatory actions (for example emergency response) would themselves be required to have written procedures and be tested in order to claim credit as part of the risk assessment process.

[1] *There is a probability of spurious alarms with some types of leak detection technology used in this application (detection of hydrocarbons in a bunded area) therefore due consideration should be given to the robustness of installation before integration with an automated action.*

4.1 Defining the mitigation layer

Before determining the level of risk reduction that can potentially be claimed following the installation of leak detection, it is first important to understand what potential consequences it is intended to mitigate against, and whether it is in support of other systems such as a Basic Process Control System (BPCS) or Safety Instrumented System (SIS).

A risk assessment should determine if further measures are required to reduce the risk to Tolerable if ALARP (TifALARP), and

- Where leak detection is to be considered in support of other systems such as an SIS or BPCS to reduce overall risk (for example its purpose is to mitigate against the formation of a large FVC or the risk to an environmental receptor from over-filling a tank), independence from the BPCS would need to be demonstrated as with other protection/mitigation layers such as independent alarms. Further information on independence can be found in the following publications:
    - Process Safety Leadership Group (PSLG) final report, Appendix 4
    - CDOIF guideline 'Process Safety Leadership Group – Other Products in Scope'
- Where the leak detection system is to be considered to reduce the potential for a MATTE but not in conjunction with other automated systems such as an SIS or BPCS (for example its purpose is to mitigate the risk against a leak from the base of a tank), independence would not need to be demonstrated from the BPCS (or other systems) as the leak detection system is not providing a supporting mitigation layer to others provided by the BPCS. Further information on environmental risk assessments and MATTE definitions can be found in the following publication:
    - CDOIF guideline 'Environmental Risk Tolerability for COMAH Establishments'

When determining the appropriateness of leak detection as a mitigation layer, clear descriptions should be given of the definition of the alarm, where and how it is sounded, who will react to it and how and how much time is available to react. This review should include consideration of:

- Sounding the alarm in a different location to the Central Control Room, for example security building, to increase independence where necessary from the existing automation systems such as the BPCS and SIS.
- Whether or not there is a need for investigation by local operators should the leak detection system alarm, and how long this would take.
- Standard and Emergency operating procedures which define what needs to be done when the alarm is sounded, for example:
    - Transfer of the substance to another location

- Adding water to the tank (where this is a viable option for the type of substance)
- Shutdown of the process, sub-process or transfer

Note that leak detection introduced as a mitigation layer may reduce the consequence of loss of primary containment, but would not reduce the frequency.

4.2 Claiming risk reduction

The installation of appropriate leak detection, and supporting operational and emergency procedures can contribute to overall risk reduction in any of the following ways:

- Providing a layer of protection (or additional layer of protection) reducing the overall risk to people and the environment to TifALARP
- Providing an additional layer of protection in support of existing systems which may in turn reduce the Safety Integrity Level (SIL) required by a SIS (Note however installation of leak detection does not negate the need for an independent SIS for overfill protection on finished gasoline tanks within the scope of the PSLG)
- Providing the potential for an alternative (subject to ALARP and Cost Benefit Analysis (CBA)) and more cost effective mechanism for reducing the risk of a MATTE as part of an ALARP demonstration

Following existing guidance relating to alarm systems as layers of protection, the claimed risk reduction for leak detection systems can be 0.1 (subject to the requirements laid out in this guideline, and other applicable publications, and appropriate justification). A claim of better than 0.1 would not be credible where an operator response to an alarm/monitoring activity is required, and may be worse depending on the reliability placed on the chosen detection method.

When completing a risk assessment, appropriate conservatism should be applied when determining relevant conditional modifiers and the probability of failure on demand of other independent layers of protection.

Abbreviations

Abbreviation	Description
ALARP	As Low As is Reasonably Practicable
AST	Above-ground Storage Tank
BPCS	Basic Process Control System
CBA	Cost Benefit Analysis
CDOIF	Chemical and Downstream Oil Industry Forum
COMAH	Control of Major Accident Hazards
EEMUA	Engineering Equipment and Materials Users Association
FVC	Flammable Vapour Cloud
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
MATTE	Major Accident to the Environment
PSLG	Process Safety Leadership Group
SIL	Safety Integrity Level
SIS	Safety Instrumented System
TifALARP	Tolerable if As Low As is Reasonably Practicable
UK	United Kingdom
UKPIA	United Kingdom Petroleum Industry Association
VCE	Vapour Cloud Explosion

Other relevant publications

Further information relating leak detection techniques can be found in the following publications

1) Process Safety Leadership Group, final report – Safety and Environmental Standards for Fuel Storage Sites
2) Health and Safety Laboratory – A review of leak detection for fuel storage sites, ECM/2008/08
3) EEMUA 159 – User's guide to the inspection, maintenance and repair of above ground vertical cylindrical steel storage tanks, Third Edition
4) EEMUA 183 – Prevention of tank bottom leakage – a guide for the design and repair of foundations and bottoms of vertical, cylindrical, steel storage tanks, Second Edition
5) EEMUA 191 - Alarm Systems - A Guide to Design, Management and Procurement
6) EEMUA 213 – Emission reduction from oil storage tanks and loading operations, First Edition
7) Storage BREF (Best Available Techniques Reference Document), 2006
8) Energy Institute Model Code of Safe Practice Part 2
9) Energy Institute Environmental Guidelines for Petroleum Distribution Installations

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