

Analysis of Hydrocarbon Leaks and Verification as an Operational Barrier

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Abstract

Prevention of hydrocarbon leaks is important; they are the most critical precursor events that may lead to major accidents, such as the Piper Alpha catastrophe in 1988. The number of hydrocarbon leaks on offshore production installations on the Norwegian Continental Shelf peaked just after year 2000, with more than 40 leaks per year with initial rate above 0.1 kg/s. The Norwegian Oil and Gas Association carried out a reduction project from 2003 until 2007, which resulted in ten hydrocarbon leaks above 0.1 kg/s in 2007. The number of leaks increased in the years after 2007, and was in average 15 in the period 2008–2010, without any significant increase in the number of installations. A new initiative was launched early in 2011, in order to reduce the number of hydrocarbon leaks further. A study performed by the project concludes that more than 50% of the leaks are associated with failure of operational barriers during manual intervention into the process systems. Human and organizational factors are dominating with respect to circumstances and root causes. The study has further demonstrated the high importance of verification as an operational barrier, and has shown that many of the failures do not have multiple operational barriers in the form of several verifications and a leak test at the end. This finding is crucial in order to understand the criticality of performing the planned verifications, perform them in an independent manner according to the procedures and make sure that the focus is on detecting failures during the verification. This paper presents the analysis of hydrocarbon leaks, with emphasis on operational barriers and importance of verification.

Keywords: Hydrocarbon leaks, operational barriers, verification of isolation.

1. Introduction

It has been demonstrated over the last ten years that personnel involved in process system

interventions are involved in the causation of more than half of the leaks (96 out of 175, see Figure 2) from process plants of offshore installations in the Norwegian sector (Vinnem et al., 2012b). The leaks in question are those with escalation potential, and a mix of gas, condensate and crude oil leaks, see further details in Section 2. Competence, attitudes, motivation and other relevant factors would therefore influence the performance of interventions and the associated probability of leaks as well as the performance of Emergency Shutdown (ESD) valve maintenance. This is discussed in some depth by Vinnem et al (2010).

Major accidents are rare in offshore operations, the last major accident, at least with fatalities, in offshore operations on the Norwegian Continental Shelf (NCS) occurred in 1985. Even precursor events are quite rare, typically in the order of one event per installation per year. It is therefore crucially important to maintain motivation and awareness in order to prevent as far as possible the occurrence of such precursor events. The next precursor event may be the next major accident if the battery of mitigation barriers on offshore installations has a complete failure.

Major hazard precursor events can be many types of events, such as vessels on collision course, structural defect, temporary loss of well control as well as hydrocarbon (HC) leaks.

Kongsvik et al (2011) has explored the extent to which a safety climate measure from a survey on working conditions used in an oil and gas company can be used as a leading and lagging indicator in relation to hydrocarbon leaks on offshore installations. It was found that the safety climate measure could serve as both a leading and lagging indicator for hydrocarbon leaks, based on the empirical evidence in the study.

Other aspects of circumstances of leaks have been discussed by Vinnem (2012a, 2012b, 2013a, 2013b), Røed, Vinnem & Nistov (2012) and Vinnem & Røed (2013).

When it comes to details of circumstances of such leaks, we find only to a limited extent such information published. UK Health and Safety Executive (HSE) has published annual reports on the hydrocarbon leaks reported from the UK offshore industry, but has not focused on work process modelling. Petroleum Safety Authority (PSA) [Norway] has also published annual statistics; see Figure 1.

Edmondson (2004) has published a paper on the experience of HSE, and its campaign to reduce the number of leaks by 50%. Edmondson notes that causes are not associated with great technical complexity, but often failures in basic controls and procedures. This is in line with the findings previously by this author, and the main message of the present paper. The most recent study of leaks reported to HSE is Li (2011), which confirms the previous analysis. Apart from the general conclusion, HSE data give no detailed information about operations or controls, the data are mainly focused on equipment details and technical barriers.

The objective of the paper is to study details about the hydrocarbon leaks, particularly the aspect of verification as an operational barrier or control. The importance of verification has been briefly addressed in some of the other papers, but not in any depth. Relevant aspects in this context are also addressed by PSA in their investigation report of one of the most severe HC leaks on the NCS in May, 2012 (PSA, 2012).

Chapter 2 gives an overview of the hydrocarbon leaks and associated trends. Chapter 3 presents an analysis of the leaks with emphasis on verification as an operational barrier. Chapter 4 discusses the findings of the study and their applicability. The conclusions are presented in Chapter 5.

2. Overview of major accident precursor events

The source of the data in this section is PSA, but it is important to stress that the reports and investigations are submitted to PSA on a voluntary basis by the oil companies. The companies submit data on special formats published by PSA twice per year, after which PSA spends

considerable time on quality assurance activities. The raw data are held by PSA, but the result presentation is quite extensive, allowing many of the details to be reviewed. PSA is also generous in giving permission for researchers to have access to the data for analysis purposes, provided that presentations are generic or anonymized. PSA has permitted analysis of the data, with the proviso that the result presentations shall be anonymous. All the raw data from the companies have therefore been available for the analysis which is conducted independently. PSA has stated that they encourage analysis of the data, because none of the companies would be able to perform similar analysis, due to confidentiality issues. Only leaks with initial leak rate above 0.1 kg/s are included in the analysis, those below this threshold are not considered to have the potential to escalate into a major accident. The Norwegian data collection is only based on initial leak rate, without considering total volume, duration or any other parameter in a similar manner as in the UK.

The development of the number of leaks per year is documented by Petroleum Safety Authority in the RNNP report (PSA, 2013). Figure 1 presents the overall trends in the period 1996–2012. The number of leaks and the weighted number of leaks have been normalised according to the number of installation years. Figure 1 is presented in a ‘relative risk fashion’, which is used extensively in RNNP. The actual value in year 2000 has been set at 1.0 separately for the number of leaks and the weighted number of leaks. All other years are expressed relative to the value in 2000.

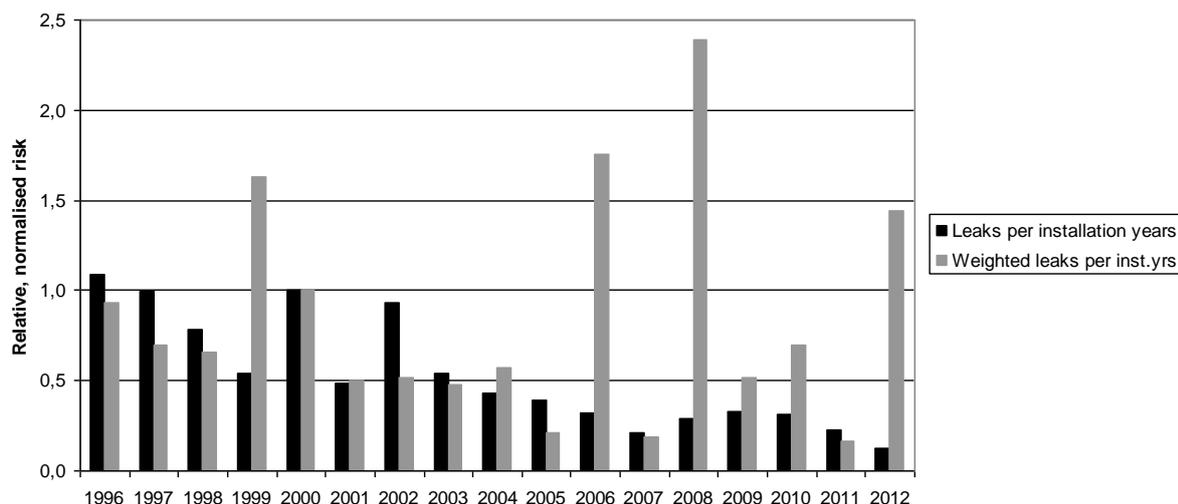


Figure 1 Hydrocarbon leaks on NCS, 1996–2012, with and without weight according to risk potential, normalized according to installation years and value in 2000 defined as 100 (n =372, PSA, 2013)

The weights that are applied to each leak reflect the potential to cause fatalities, and are mainly reflecting the leak rate. The values follow the normalised number of leaks reasonably well, with some exceptions where the values are considerably higher. The years where these high values occur (such as 2006, 2008, 2010 & 2012) are the years where there have been one or two (such as in 2012) leaks above 10 kg/s leak rate. These few leaks have much higher risk potential. The basis for the weights is documented in Vinnem et al. (2006).

There was a quite stable decline during more than 10 years, which culminated with the so-far lowest frequency of leaks per installation years, 10 leaks, in 2007. Thereafter the value increased and was stable around 15 in the period 2008–2011. In the spring of 2011 PSA requested improved efforts by the industry in order to achieve further reduction. The new minimum was achieved in 2012 with 6 leaks in total for NCS, corresponding to 8.8 leaks per 100 installation years. The number of installations has been virtually constant during the period after 2005. Figure 1 also shows that 2012 was the fourth highest year when it comes to weighted leaks, due to the two leaks with initial leak rate well above 10 kg/s. One of these two leaks was in fact the second highest ever to occur after 1.1.1996 on the NCS.

The raw data has information about the type of hydrocarbon leaking in the various events. It should first of all be emphasized that only ‘production fluids’ are included in the statistics, i.e. petroleum products (after refining) such as diesel, hydraulic oil, lube oil, etc. are not included. This is one of the main differences from the leak statistics published by HSE for the UK continental shelf (Edmundson, 2004; Li, 2011). The systems involved are process systems and flowlines downstream of the christmas tree (excluding subsea wells) for production wells, including gas injection and gas lift wells. With respect to type of media in the leaks, the following is the distribution for the period 2008–2010 (Vinnem, 2012b):

- Stabilized oil leak: 9 leaks (21%)
- Oil/gas leak: 3 leaks (7%)
- Condensate leak: 2 leaks (5%)
- Gas leak: 29 leaks (67%)

Two thirds are gas leaks, with stabilized oil as the second main category (21%), whereas oil/gas and condensate are seven and five percent. This could be compared to the distribution reported by Li (2011): Oil–24%; ‘dual phase’–3%; condensate–4%; gas–44%; non-process liquids & other–25% (Oil–32%; ‘dual phase’–4%; condensate–5%; gas–59%, if non-process leaks are omitted). The oil leaks have a larger contribution in the UK, and the gas leaks a lower contribution. Li has argued that these percentages are to some extent dominated by the smallest leaks. Since these smallest leaks (<0.1 kg/s) are not reported from the Norwegian sector, this may be the explanation of the difference.

Figure 1 shows that two peaks in the normalised number of leaks occurred in year 2000 and 2002, and that there were significant reduction until 2007. The purpose of the paper is not to analyze in detail the reasons for the decrease in the number of leaks in this period. It should be noted however, that the Norwegian Oil and Gas Association (previously known as OLF) formulated two campaigns for the periods 2003–05 and 2006–08, each with the target to

reduce the 3 year average number of leaks to 50% of the value in the previous three year period. The targets were reached at the end of the first period (in 2005) and in the middle year (in 2007) in the second period. Many experts believe that these reductions were caused by the high focus on prevention of leaks due to these two campaigns. There were no such campaigns earlier, and the new focus was probably a motivation factor for reduction of the number of leaks. Different actions were implemented at the same time in order to improve the quality of the work relating to interventions in the process systems, such as mandatory courses in bolt tightening. A common work permit system was also implemented during this period, and training courses were conducted in this regard.

When the industry association did not continue the formal campaigns after 2008, this coincided with the increase of the number of leaks. Similar experience occurred in UK a few years earlier, where campaigns were not continued, the number of leaks increased again. At the same time Statoil and Hydro merged their petroleum divisions, which according to Austens-Underhaug et al. (2011) implied a severely deteriorated safety culture, unable to learn from experience.

The development of the approach to main circumstances of the scenarios when the leaks occur on the installations has been document by Vinnem et al. (2007) and Haugen et al. (2011), and the annual trends are documented by PSA. Vinnem (2012b) and Haugen et al. (2011) have documented how latent errors have been introduced by different personnel groups involved in the planning, preparation or implementation of manual interventions. Latent errors may result from errors made during planning, if this results in a faulty instruction for the work, such as to open or close the wrong valve. Latent errors are errors that are introduced without being revealed, such as operating the wrong valve or leaving a valve in the wrong position, or tightening bolts in a flange with insufficient torque. When a line or section is pressurized, such as during reinstatement, an open valve may leak instantly, or a

gasket may fail due to bolts with insufficient torque. There are many examples of such leaks from the investigations. The classification of leaks that has been used in these works has the following main categories (Vinnem et al., 2007):

- Technical degradation of system (Category A)
- Human intervention
 - introducing latent error (Category B)
 - causing immediate release (Category C)
- Process disturbance (Category D)
- Inherent design errors (Category E)
- External events (Category F)

The data in the last five years, 2008–2012, are compared to the average of the period 2001–2010, resulting in some few changes in the distributions as shown in Figure 2. The most significant change is the contribution from process disturbances which has been significantly reduced in the latest period. The categories associated with human intervention have also increased, especially the latent errors (correspondingly to 'delayed leaks').

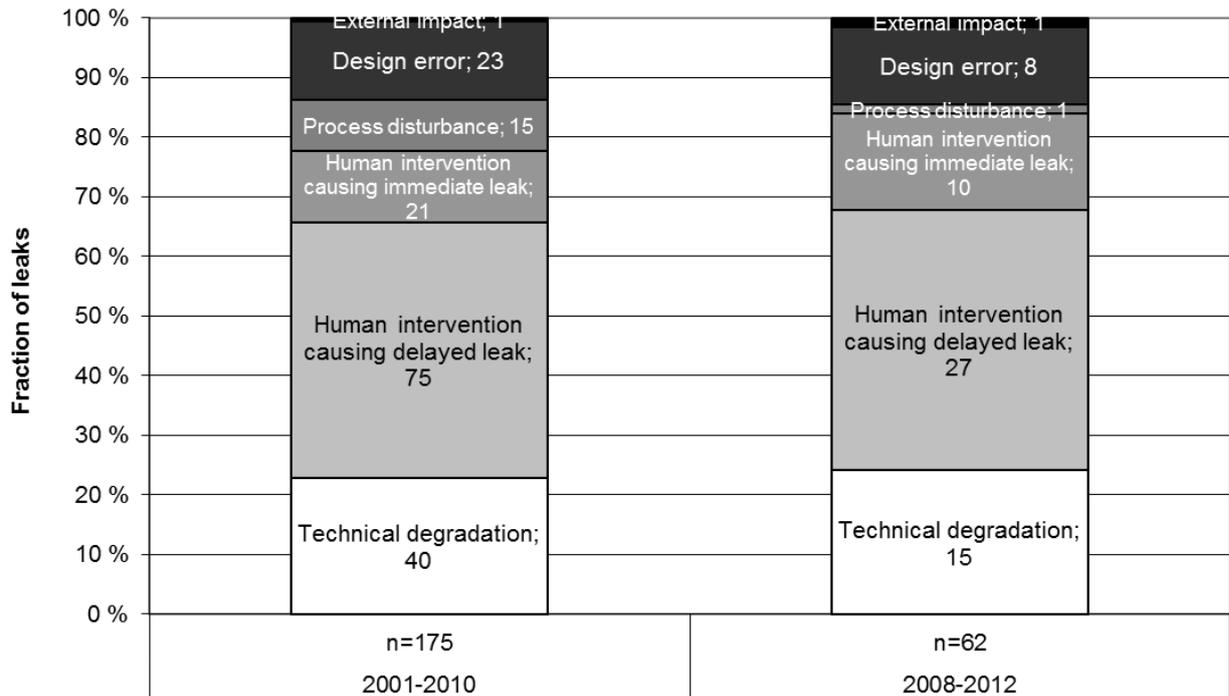


Figure 2 Hydrocarbon leaks distributed on operational circumstances, NCS, average 2001–2010 & 2008–2012 (n =175; 62)

Work processes are defined in procedures and will usually involve a long list of steps, at least for a complex maintenance or modification task. For our analysis in this study we have structured the work process into four main steps:

1. Planning
2. Preparation
3. Execution
4. Reinstatement

Planning involves long term and short term planning, including overall schedules, Safe Job Analysis, preparation of the isolation plan, etc. Preparation implies shut down, isolation and depressurization according to the isolation plan, etc. Execution is the completion of the task at hand, the opening of flanges and connections, replacements and the remaking of

connections. Reinstatement is the resetting of valves and controls according to the isolation plan, as well as the leak testing and starting up.

3. Verification as an operational barrier

Figure 2 has demonstrated that 60% of the HC leaks (> 0.1 kg/s) are associated with manual intervention (Type 'B' and 'C' in the list in Section 2) in pressurised systems, associated with inspection, maintenance, modifications, etc. The majority of these works are carried out based on the steps of an approved work permit, usually also in compliance with an isolation plan which defines explicitly the valves and blindings that are needed to isolate the section or equipment on which the work be carried out. Major maintenance tasks are often carried out during annual (or biannual) shutdown periods with the installation in a safe state, such that many work tasks may be done in parallel without increased risk. Such shutdown periods are usually very well planned and prepared. It has been observed that few leaks occur in association with such periods.

Virtually all of these operations are manually implemented by platform personnel, the compliance with procedures and instructions is crucial. The implementation of the isolation plan prior to the work tasks is carried out by process personnel, usually employed by the operating company. This also applies to the reinstatement, which is the preparation of the process plant for start-up when the work tasks have been completed. The actual inspection, maintenance or modification tasks are often carried out by contractor personnel, mainly from the mechanical trade. Verification of the performed work tasks is very crucial in order to ensure that the work has been carried out in compliance with all steering documentation, such as procedures, instructions, isolation plans, work descriptions, torque tables, etc.

3.1 Verifications and verification failures

Vinnem and Røed (2013) have described a recommended practice to follow during isolation,

execution and reinstatement of process equipment. The following verifications are recommended:

- Verification of isolation plan (prior to implementation)
- Verification of isolations (after implementation)
- Verification of resetting of isolations and split points.

The last verification also includes verification of the actual maintenance or modification work. It is no dispute about the requirement that these verifications need to be independently carried out, but there is some disagreement on how independency can be achieved most efficiently. The typical disagreements are for instance associated with whether the person implementing the isolations and the independent verifier shall carry out the work together, or whether they shall work separately from each other. Some companies prefer one solution, others the opposite, and it is probable that local circumstances on each installation will affect what should be considered the best solution. Verification failures have been seen with both options.

Vinnem and Røed (2013) also presented statistics for the different types of failure associated with verification for the period 2008–2011:

- Failure to carry out verification in compliance with isolation plan: 15 out of 22 cases
- Verification fails to reveal the errors made: 7 out of 22 cases.

The 22 cases referred to here are leaks (> 0.1 kg/s) that have occurred on NCS in the period 2008–2011, where it based on the investigation reports could be determined that verification had been done or should have been done. Please note that this is a subset of the total number of leaks in the period 2008–2011, 56 leaks with initial leak rate above 0.1 kg/s. 36 of these are associated with manual interaction (type ‘B’ and ‘C’ above). Corresponding values for the period 2008–2012 are 62 and 37, respectively. Some of these are not sufficiently well described in order to conclude whether verification had been performed or

should have been performed. We thus end up with 22 leaks for the period 2008–2011 where verification has been done or should have been done. A further breakdown of the type of verification failure and operational errors is presented in Figure 3. ‘Verification omission failure’ implies that no verification was carried out in spite of being required, whereas ‘verification execution failure’ implies that verification was carried out, but failed to reveal the error made initially.

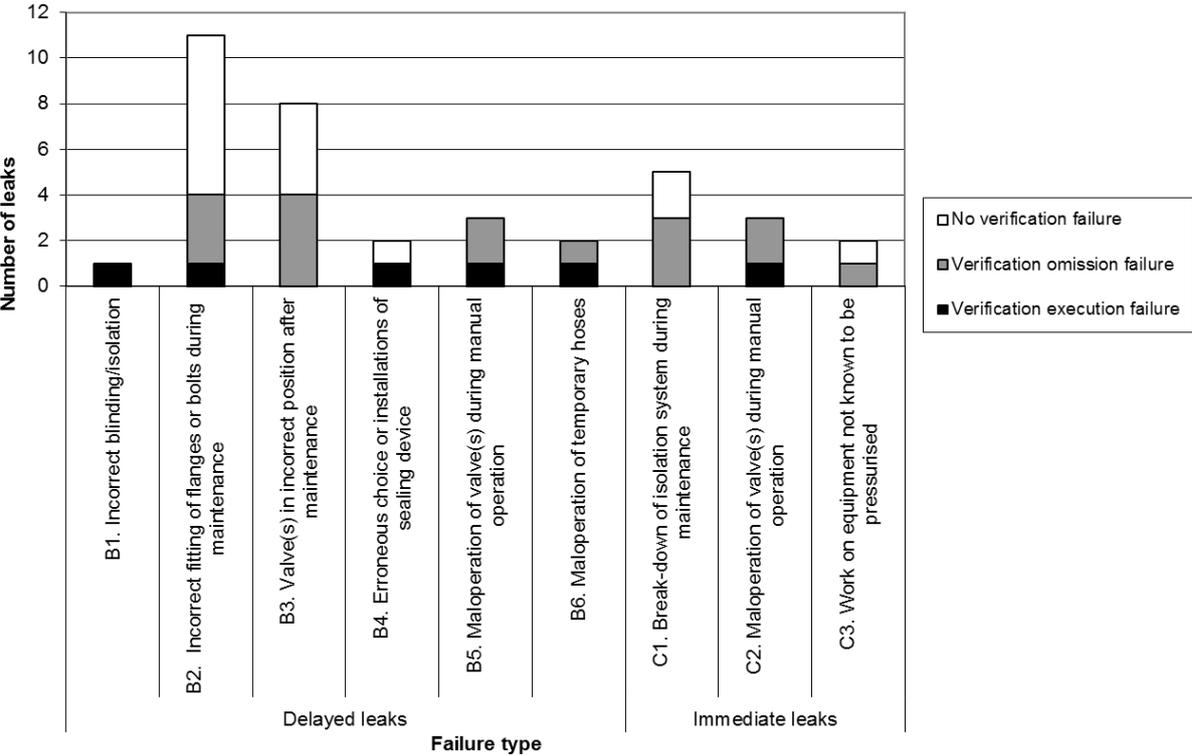


Figure 3 Hydrocarbon leaks distributed on verification failure type and operational circumstances, NCS 2008–2012 (n=37)

It should be observed that with ‘no verification failure’ this implies that the verification did not influence the occurrence of the leak, such as when the leak occurs immediately when the error is made. It should also be observed that all of the cases in Figure 3 are leaks, implying that operational errors have been made at some point.

Verification omission failure is always the highest contribution, except for error types B6 and C2, where the contributions are low and equal (one each). The omission failure

implies failure to carry out verification in compliance with isolation plan. This is typically what often is referred to as ‘silent deviations’. Silent deviations imply that an unofficial practice is accepted on the installation, whereby it is acceptable not to follow procedures and instructions.

As an illustration of relevant incidents, the following could be considered: two mechanics and an area operator were involved in recertification of two pressure safety valves. After having replaced the first valve two persons were working on reinstatement of isolations for the first valve. The third person started to loosen one bolt on the flange of the second valve, before the necessary isolations had been implemented. A part of the gasket was blown out from the flange, resulting in a gas leak. Obviously, this was not according to the required work practice and isolation plan, and it was also lack of verification of isolation before the work started.

Finally, it could be observed that with exception of two events, all of the incidents with verification failures in Figure 3 have occurred in one company.

3.2 Verification failures and time of leak

Figure 4 shows the distribution of verification failure types for leaks associated with manual intervention for different periods of the day. The dayshift covers the two periods 07–12 (actually the period 0700–1259) and 13–18 (i.e. 1300–1859). Vinnem (2012a) has documented that significantly more leaks occur during night shift than what should be expected, especially during the period from midnight until 0700 when dayshift starts. It is prohibited on NCS to conduct activities during the period after midnight which may imply increased risk. It would therefore be expected that the leaks should be at a minimum during this period. Figure 4 shows that the vast majority (75% of the verification failures) of the leaks in this period is associated with failure to carry out required verification activities.

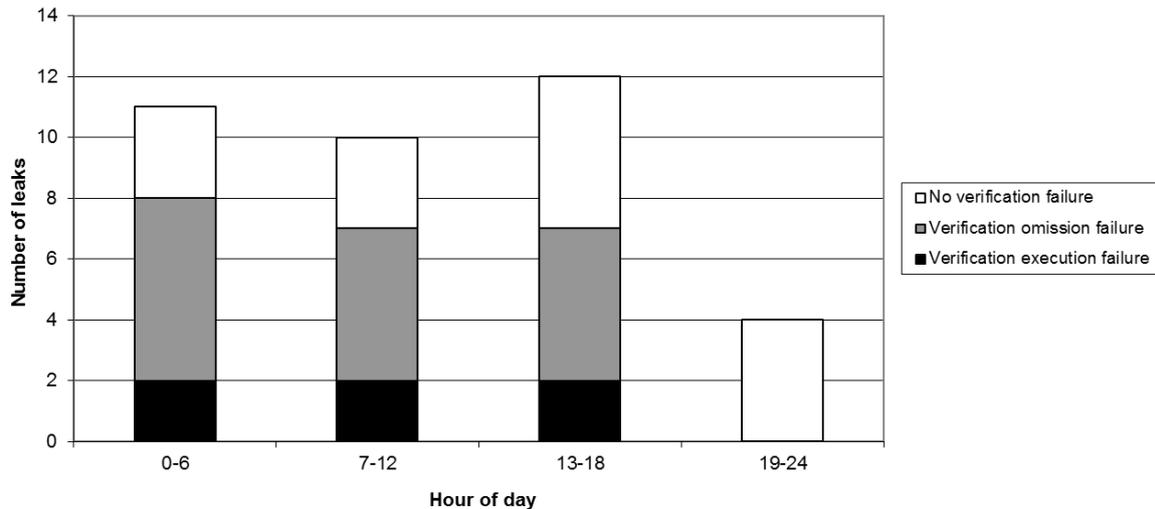


Figure 4 Hydrocarbon leaks, manual intervention (B & C type), distributed on verification failure type and time when leaks occur, NCS 2008–2012 (n=37)

3.3 Verification failures and root causes

It is indicated in Røed, Vinnem and Nistov (2012) root causes are extracted from the investigation reports, in fact this is the only information that has been copied in extenso from the investigation reports without independent assessment. Figure 5 shows the root causes as specified by the investigation reports for all leaks in the period 2008–2011 as well as leaks associated with verification failure. Two of the investigations of the 22 leaks with verification failure (see Section 3.1) did not specify root causes, and are therefore omitted, thus leaving us with n=20. There are usually several root causes indicated for each leak. It is clearly shown that the following root causes have significantly higher fraction for the leaks associated with verification failure:

- Work practice
- Compliance with steering documentation
- Risk assessment
- Management of change

It is unlikely that these differences are statistically significant, due to the low number of root causes in each category, but these differences are nevertheless interesting to note. They point in the direction of management system weaknesses for those leaks with verification failure.

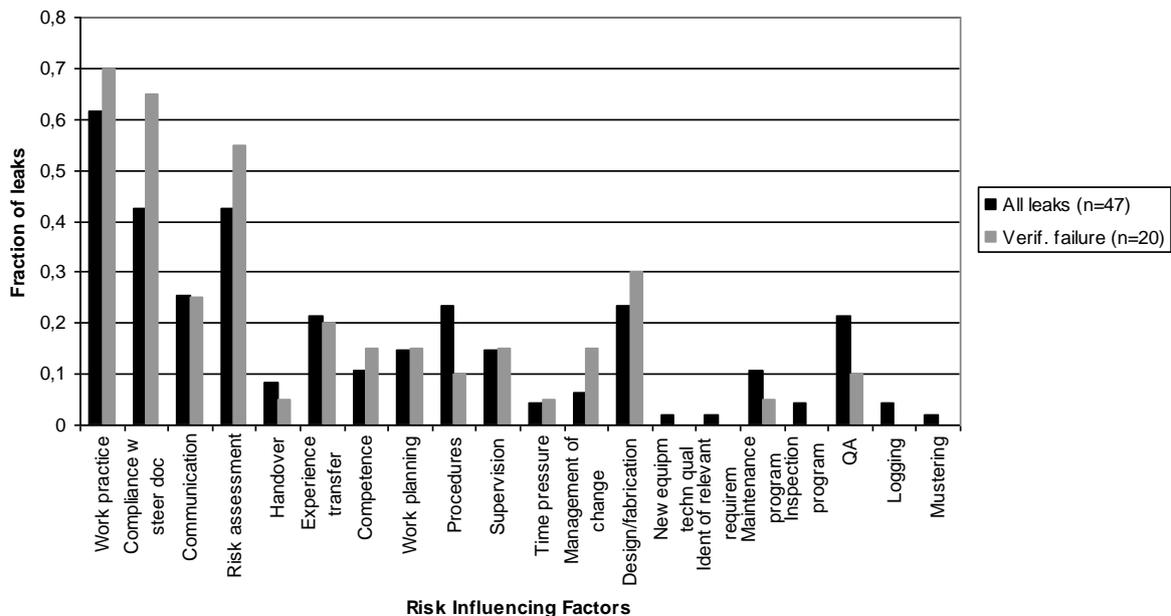


Figure 5 Root causes of hydrocarbon leaks, for all leaks and leaks with verification failure, NCS 2008–2011 (n=47; n=20)

When verifications are not carried out in accordance with steering documentation, this is a serious lack of compliance which may have dramatic consequences. The Piper Alpha accident (Cullen, 1990) with 168 fatalities started with a lack of compliance with procedures for work permits on the installation. An important issue is therefore how compliance with steering documentation may be kept at a highest possible level. This is discussed in Section 4.2.

3.4 Verification failures and use of work permits

Work permit (WP) is the administrative tool used in order to control manual work (interventions), for inspection, maintenance and modification. But activities that are

considered as part of ‘normal operation’ are not controlled by work permits, they are carried out according to operations procedures, and are as such ‘outside the work permit regime’.

Leaks in the period 2008–2012 are presented in Figure 6 with respect to the relevance of the WP regime.

The occurrences in Figure 6 are those where WP would be relevant, because manual intervention has been carried out. This implies that leaks associated with normal operation and plant shutdown periods are not considered, as well as faults that have been present since fabrication phase. It is demonstrated that one to three leaks per year could have been eliminated if work permit and isolation plan had been prepared and compliance had been ensured.

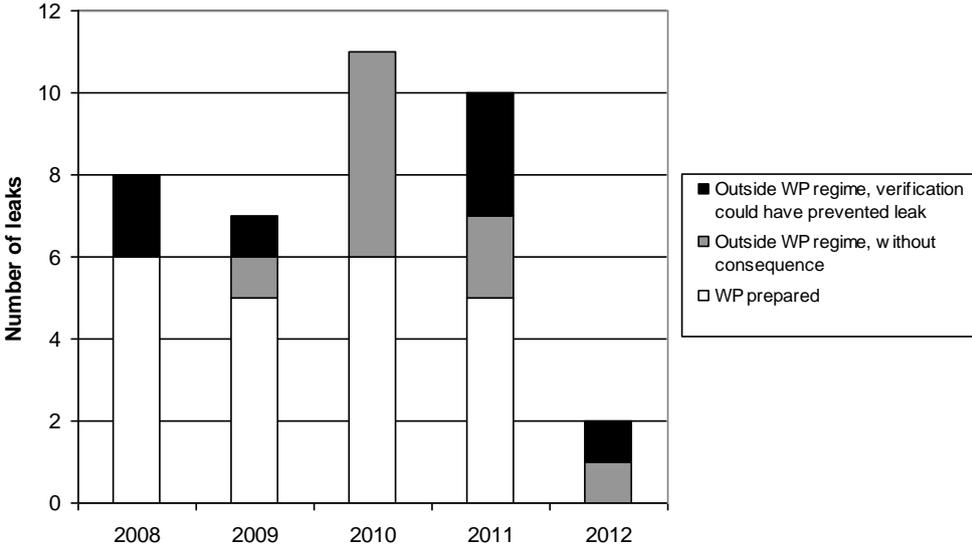


Figure 6 Hydrocarbon leaks in cases with WP prepared as well as outside WP regime, NCS 2008–2012 (n=37)

4. Discussion of findings

4.1 Robustness of findings

Most studies of accident or incident causes and circumstances rely on obtaining the largest possible sample size in order to promote the robustness of the analysis, it is therefore often

considered useful to include as many accidents or incidents as possible. This may be one of the reasons why too often major hazard precursor events and occupational accidents are analyzed together. HC leaks are somewhat special in the sense that there are quite few such events, especially when the leaks are limited to those that have major accident potential, i.e. with leak rate above 0.1 kg/s.

Another reason may be the failure to realize that there are extensive differences between accident causation between major hazard precursor events and occupational accidents. This does not necessarily imply that there are very different root causes or Risk Influencing Factors (RIFs) or Performance Shaping Factors involved, competence, training, motivation, awareness, culture, etc. are important RIFs in both types of events. Compliance with steering documentation may also be a common factor. But the risk controls, the possible actions to reduce risk, will be significantly different. Also the time sequences and the intervals may be very different.

Occupational accidents occur more frequently than even major accident precursors, which imply that feedback of experience is achieved regularly without too long delay. In the case of major accident precursors, there may be a long delay between actions that are taken and the feedback with respect to the effect of these actions. The research into accident investigations and the learning from investigations need to take this into account.

We therefore consider it essential to make clear distinctions between major accidents and occupational accidents for the analysis of circumstances and investigations and identification of possible risk reduction actions. The present study is limited to one type of major accident precursors only. The disadvantage of this is that the data basis is limited considerably, when will affect the robustness of the findings.

In spite of using all available company internal investigation reports for major hazard precursor events, there are only about 25–30 leaks where a large set of variables could be

identified from the available documentation for the period 2008–2012. This is quite a limited data set, but has the main advantage that only the last five year period is used, implying that conditions and premises are reasonably constant. But even during this relatively short period there may be significant differences, as discussed below.

The accident investigations are relatively vague when it comes to the verification and possible errors in verification. The descriptions had to be interpreted quite extensively in order to determine if verifications had been carried out and to what extent they were successful. Some uncertainty is thus introduced.

4.2 Lack of compliance on offshore installations

Lack of compliance with steering documentation has been the strongest influencing factor behind HC leaks on NCS for many years. 22 out of 56 leaks in total for the period 2008–2011 are associated with verification failure, which reflect lack of compliance. One company appears to have had significant challenges in this regard.

Austnes-Underhaug et al. (2011) have documented that the safety culture has had severe weaknesses, including lack of ability to learn from previous incidents and accidents as well as lack of compliance with steering documentation. The company has worked profoundly to improve its performance, and the reduced number of HC leaks due to manual interventions in 2012 may be a first sign that this work has been fruitful.

Dahl and Olsen (2013) has shown that management leadership is essential for employees' compliance with rules and procedures. This is based on data from a questionnaire survey, and is most likely reflecting mainly occupational accidents. But there is no reason why this should be different between occupational accidents and major accident precursors. The implementation of the 'A-standard' work pattern has strong links with management and supervisory leadership.

Independent verification of manual performance according to rules, procedures or checklists is used in other high risk contexts, such as for instance pilot preparation for take-off and landing of commercial aircrafts. Pilots are high skilled employees with profound insight into requirements for safe take-off or landing. An independent verification of the adherence to checklists is nevertheless always required in the cockpit. Process and mechanical personnel on offshore installations are not as drilled as pilots, and perform less standardized tasks compared to pilots. The need for independent verification should correspondingly be even stronger in this context. But the need for verification appears to be less well accepted, at least in some companies.

Vinnem (2012b) has documented that a too large proportion of the leaks occur between midnight and start of dayshift, when operations that increase risk are prohibited due to regulations. It has been shown, see Figure 4, that the majority of the leaks in the middle of the night are associated with verification failure. This is likely to be strongly influenced by the low manning level on night shift on many installations, whereby only one process operator often is working during night shift. This implies that verification may only be carried out by the next shift. This is obviously not ideal, as it may be skipped due to time pressure, or it may fail to reveal errors that have been made.

The way to perform verification is in all cases a matter of discussion, especially with respect to roles of the responsible process technician and a colleague or supervisor performing the independent verification. These two persons may choose one of the following ways to perform their independent tasks:

- Shall the two persons work together in a pair, conscious of their independent roles, but walking together to make sure they relate to the same equipment?
- Shall the two persons work separately from each other, in order to ensure complete independence?

Different practices are chosen by different companies. There is probably no unique solution which is always preferable, when it is considered that a large process module may have more than 100 process valves, of which maybe only a dozen will need to be operated during the isolation. Some of these valves may be several meters up above the deck level, perhaps partly hidden by other equipment.

4.3 Work on offshore installations outside work permit regime

Some of the manual interventions in the process systems are carried out according to standard operational procedures, i.e. outside the work permit regime. There has been in the order of one or two leaks (>0.1 kg/s) per year in the period 2008–2012 where no work permit and no isolation plan has been prepared, the work is done according to operational procedures. With the low total number of leaks in 2012, one or two leaks per year are substantial contributions to the leak frequency, and hence need to be focused upon.

The use of standard operating procedures is likely not to have sufficient emphasis on the verification element as an essential operational barrier element. The recommended practice (Vinnem & Røed, 2013) that has been proposed for isolation, execution and reinstatement as described above, has increased the emphasis on verification and its importance. Such increase of importance is not likely to affect standard operating procedures unless the operating procedures are actively amended in order to increase the importance of verification.

5. Conclusions and recommendations

There has been substantial improvement in the frequency of HC leaks above 0.1 kg/s per installation year over the past 16–17 years. The last seven to eight years has on the other hand demonstrated that there is very variable risk potential from one year to the next. This illustrates the potential threat from this type of events; the next leak may, even though very

unlikely, follow the path of Piper Alpha if there is a massive failure of barrier functions.

Verification has been demonstrated to be a very critical operational barrier element. The main failure mechanism is that independent verification of isolation planning, implementation and reinstatement is not carried out in compliance with steering documentation. A best practice description for isolation work in association with manual intervention on process systems has been proposed, mainly in order to strengthen the emphasis on verifications.

The reduced number of leaks (above 0.1 kg/s) in 2012 compared with previous years is most likely due to a campaign within one of the main operators. The objective of this campaign has been to increase the focus on compliance with steering documentation during execution of manual work tasks, including manual intervention on process systems.

It has been shown that the main root causes that have been most dominant in cases of failure of verification are work practice execution errors, lack of compliance with steering documentation, failure to carry out adequate risk assessment as well as failure of management of change processes.

This work is based mainly on data from investigations of HC leaks during the period 2008–2012. This implies that the data on verification failures and successes is limited to the cases when leaks have occurred. It would have been an additional data source if one in the future could have access to data about verification performance in general, provided that this could be registered continuously. Some companies register failure of verifications on a general basis, but all companies need to provide such data in order to carry out such an exercise.

Abbreviations

CCR Central Control Room

ESD Emergency shutdown

HSE Health and Safety Executive
MTO Man, Technology and Organisation
NCS Norwegian Continental Shelf
NTNU Norwegian University of Science and Technology
PSA Petroleum Safety Authority
RIF Risk Influencing Factor
WP Work Permit

References

- Austnes-Underhaug, R. et al. (2011) Learning from incidents in Statoil (in Norwegian only), IRIS report 2011/156, 21.09.2011 (available from www.statoil.com)
- Cullen, WD. (1990) The Public Inquiry into the Piper Alpha disaster. Department of Energy, London (1990)
- Dahl, Ø. & Olsen, E. (2013) Safety compliance on offshore platforms: A multi-sample survey on the role of perceived leadership involvement and work climate, *Safety Science*, 54, pp 17-26.
- Edmondson, N. (2004) Results from a four year regulatory campaign to reduce offshore hydrocarbon releases, SPE 86599, Seventh SPE international conference on health, safety and environment in oil and gas exploration and production, Calgary, Alberta, Canada, 29–31 March 2004
- Haugen, S, Vinnem, JE & Seljelid, J. (2011) Analysis of Causes of Hydrocarbon Leaks from Process Plants, presented at SPE European Health, Safety and Environmental Conference in Oil and Gas Exploration and Production held in Vienna, Austria, 22–24 February 2011
- Li, A. (2011) Cross industry hydrocarbon release analysis, SPE paper 145449, presented at SPE Offshore Europe oil and gas conference and exhibition, Aberdeen, UK, 6–8 September, 2011
- PSA. (2011) Regulations relating to health, safety and the environment in the petroleum activities and at certain onshore facilities (the framework regulations), Petroleum Safety Authority, 1.1.2011, www.psa.no

- PSA, (2012). Report following the investigation of the hydrocarbon leak on Heimdal 26.5.2012 (in Norwegian only), Petroleum Safety Authority, 20.12.2012
- PSA, (2013). Trends in risk level in the petroleum activity. RNNP 2012 report. (Summary report in English, other reports only in Norwegian), 25. April 2013, Petroleum Safety Authority
- Røed, W., Vinnem, JE. and Nistov, A. (2012) Causes and Contributing Factors to Hydrocarbon Leaks on Norwegian Offshore Installations, SPE-156846, presented at SPE/APPEA International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Perth, Australia, 11–13 September 2012.
- Vinnem, JE. (2012a) On the analysis of hydrocarbon leaks from offshore installations in a work process context, paper presented at PSAM11/ESREL2012, Helsinki, 26–29 June, 2012
- Vinnem, J.E., (2012b). On the Analysis of Hydrocarbon Leaks in the Norwegian Offshore Industry, *Loss Prevention in the Process Industries*, 25/4, pp. 709–717
- Vinnem, J.E., (2013a). Use of accident precursor event investigations in the understanding of major hazard risk potential in the Norwegian offshore industry, *Journal of Risk and Reliability*, 227/1, 2013, pp 66-79
- Vinnem, J.E., (2013b). On the development of failure model for hydrocarbon leaks during maintenance work in process plants on offshore petroleum installations, *Reliability Engineering & System Safety*, 113/1, 2013, pp 112-121
- Vinnem, JE, Aven, T, Husebø, T, Seljelid, J & Tveit, OJ. (2006) Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector. *Reliability Engineering & Systems Safety*, Volume 91, Issues 7, (2006) 778–791
- Vinnem, JE, Seljelid, J, Haugen, S & Husebø, T. (2007) Analysis of Hydrocarbon Leaks on Offshore Installations, presented at ESREL2007, Stavanger, 25–27 June, 2007
- Vinnem, JE, Hestad, JA, Kvaløy, JT & Skogdalen, JE. (2010) Analysis of root causes of major hazard precursors (hydrocarbon leaks) in the Norwegian offshore petroleum industry, *Reliability Engineering and System Safety*, 95/11 (2010) 1142–1153
- Vinnem, J.E., Bye, R., Gran, B.A., Kongsvik, T., Nyheim, O.M., Okstad, E.H., Seljelid, J. & Vatn, J. (2012) Risk modelling of maintenance work on major process equipment on offshore petroleum installations, *Loss Prevention in the Process Industries* 25/2 (2012), pp 274–292
- Vinnem, JE. and Røed, W. (2013) Norwegian Oil and Gas Industry Project to Reduce the Number of Hydrocarbon Leaks with emphasis on Operational Barriers Improvement,

presented at SPE Europe HSE Conference and Exhibition, London, UK, 16–18 April
2013.