OLF hydrocarbon leak reduction project

Analysis of causes of hydrocarbon leaks in 2008 – 2011

Final report, 08.06.2012

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Preface

This report is prepared as an analysis of causes of hydrocarbon leaks in the Norwegian sector for OLF. The work has been based on submission of investigation reports (and similar) from all relevant companies, with leaks in the period 2008–2011. The scope of work for the report is limited to analysis of causes of hydrocarbon leaks. The report is used as a basis for the planned activities in OLFs hydrocarbon leak reduction project.

Preliminary results have been presented for various groups and forums in OLF and for the authorities. Various comments made to these presentations have resulted in additional presentations in the reports, we are therefore grateful to all those that have given comments, which have contributed to improvement of the report.

Our intention is that the second phase of this work will include cooperation with Oil and Gas UK, in order to include a similar analysis of leaks in the UK sector, as a basis for making comparisons.

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Willy Røed
Jan Erik Vinnem

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Preventor
Risk management research and development

P O Box 519, N-4341 Bryne, Norway
Tel: +47 5148 7880, Fax: +47 5148 7881
E-mail: post@preventor.no
Web: http://www.preventor.no

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Author(s): Jan Erik Vinnem, Preventor Willy Røed, Proactima	Signature:

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An analysis of causes of hydrocarbon leaks has been performed, based on submission of investigation reports (and similar) from all relevant companies, with leaks in the period 2008–2011. The scope of work for the report is limited to analysis of causes of hydrocarbon leaks in the process area on offshore installations on the Norwegian continental shelf. The report is used as a basis for the planned activities in OLFs hydrocarbon leak reduction project. The average number of leaks is 14 per year in the period 2008-2011, with the lowest value, 11 in 2011, only marginally higher than the value in 2007, 10 leaks. Several failure classifications and identification of root causes are presented for the leaks in the period.

Index terms, English:	Norsk:
Hydrocarbon leaks	Hydrokarbonlekkasje
Investigation reports	Granskingsrapporter
Causes of leaks	Årsaker til lekkasje
Circumstances of leaks	Omstendigheter for lekkasje

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0. Summary

Hydrocarbon leaks from process areas on installations in the Norwegian sector in the period 2008–2011 have been analyzed in depth. The data basis corresponds to what is defined as 'DFU1' in PSA RNNP annual reports, i.e. hydrocarbon leaks from process systems exceeding 0.1 kg/s initial flowrate. The work is based on investigation reports and similar documents submitted by the relevant companies.

The report has analyzed the hydrocarbon leaks, where relevant, in relation to a best practice for work processes during manual intervention in process systems, as part of execution of work according to a Work Permit. The analysis has taken a full MTO perspective, and discusses technical, organizational and human (operational) causal factors associated with hydrocarbon leaks.

The report presents an overview of the leaks in the period, as well as different perspectives on normalization of leaks in relation to installation years, number of leak sources (a simplified way to indicate process plant complexity) and activity levels (number of work permits in process area). It is demonstrated that although there is a reduction of the number of leaks in 2011, this is not a statistically significant reduction..

We conclude that 36 of 56 leaks (64%) in the period 2008–2011 are associated with manual intervention in the process systems. The most common activities involved are:

Incorrect fitting of flanges or bolts during maintenance (B2):	13 leaks
Valve(s) in incorrect position after maintenance (B3):	8 leaks
Break-down of isolation system during maintenance (C1):	5 leaks

It is further demonstrated that a number of hydrocarbon leaks are associated with implementation of isolation plans, and that a significant number of leaks can be traced back to work being performed during night shift, especially for the period after midnight until start of day shift.

The number of leaks in the period 2008–2011 associated with design weaknesses and technical degradation is as follows:

Design error:	7 leaks (13 %)
Technical degradation:	11 leaks (21 %)

When data for the period 2008–2011 is compared to the period 2001–2010, these two categories are slightly higher for the earlier (and longer) period, but not very different. Several of the leaks that are associated with manual intervention have also design aspects amongst root causes.

The errors associated with manual intervention have been classified according to which work process phases they have occurred in (some of the leaks involve more than one error), with the following distribution of errors:

Planning and isolation plan:	11 leaks (26 %)
Implementation of isolation plan:	13 leaks (31 %)
Execution of intervention:	12 leaks (29 %)
Reinstatement:	6 leaks (14 %)

Verification of the implementation of the isolation plan and verification of the resetting are crucial operational barriers. Verification has failed in all of the leaks associated with these work process phases[1]. The overall ratio between verification not carried out and verification fails to reveal the error is as follows:

- 2.1:1 (15 vs 7 cases)

'Verification not carried out' is thus clearly dominating. Not performing intended verification is often associated with 'silent deviations'.

When the leaks are classified according to the work process phase in which the leaks (not the errors) occur, the following distribution is observed:

- Preparation/isolation plan: 6 leaks (20 %)
- Execution of intervention: 10 leaks (33 %)
- Reinstatement: 8 leaks (27 %)
- After start-up: 6 leaks (20 %)

The major hazard potential is not well addressed in the investigations of hydrocarbon leaks on the Norwegian Continental Shelf. Most of the investigations do not recognize that there is a potential for major hazard consequences. The failure to identify the major hazard potential may reduce the potential learning from the incidents. This has also been remarked by PSA. The reason why the major hazard potential is disregarded is seen to be the interpretation of the term 'insignificantly changed circumstances', which should be reconsidered.

Immediate causes and potential root causes are documented in the majority of the investigations, but the thoroughness of these classifications is variable. The causal factors, which are taken as a combination of root causes and barrier failures in the investigations, have been taken directly from the investigations. Most leaks have several root causes and/or barrier failures. The three factors which are most commonly stated are failures of the following:

- Work practice: 29 out of 47 leaks
- Compliance with steering documentation: 20 out of 47 leaks
- Risk assessment/apprehension: 20 out of 47 leaks

The distribution of age of the installations at the time of leak has been analyzed for leaks due to degradation failure only. The overall conclusion is that there is a very weak support for the hypothesis that degradation failures are closely correlated with age. This has actually been considered in a few other studies, with the same observation; the correlation is impossible to substantiate.

A number of other causal factors are discussed in Section 7, such as isolation plan implementation and its verification, verification errors, errors during leak testing, non-compliance with steering documentation, management and supervision, A-standard, wrong gasket, failure in packing boxes and leaks from temporary hoses.

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[1] This is a natural implication of the basis of the study. There would not be a leak unless there were errors in the performance of the work process **as well as** error in the independent verification.

1. Introduction

1.1 Background

This report is part of the HC leak reduction project in OLF, started in 2011.

OLFs HSE Managers Forum has supported an in-depth analysis of leaks as part of the project. For this purpose, investigation reports have been collected from the companies that have experienced leaks in the period 2008 to 2011. The work is primarily based on leaks in the Norwegian sector.

1.2 Purpose

The purpose of the report is to perform an in-depth analysis of HC leaks on the Norwegian Continental Shelf (NCS), and if available, also data from the UK sector. The analysis shall be used as a basis for proposing risk reducing measures in order to reduce the number of leaks on the Norwegian Continental Shelf.

1.3 Limitations

The purpose of the analysis is to analyze in depth the causes of hydrocarbon leaks as a basis for risk reduction proposals. Reference is further made to Section 2.1 which discusses how the MTO perspective is interpreted for the present analysis. Discussion of barrier strategies with respect to the containment barriers would be an interesting extension of the present work.

1.4 Data basis

The data basis for this project is the hydrocarbon leaks occurred on the NCS in the period 2008 to 2011, limited to leaks from process systems, i.e. the same scope as for DFU1 (Unignited HC leaks) in RNNP. Also piping from platform wells are included downstream of the Christmas tree. This includes gas injection wells and gas lift systems, upstream of the Christmas tree.

HC leaks from risers, pipelines, wells and well operations are not included in DFU1 in RNNP, and are therefore not included in this report. Section 3.2 shows the events that are not included.

Investigation reports have been made available by the companies. It has been ensured that the analyses are consistent with corresponding analyses in RNNP, where relevant. Some of the research studies based on anonymous reporting from RNNP have also been used to some extent.

It should be noted that the leaks reported in RNNP are associated with the technical service provider and not the formal operator, in those cases where this is not the same company. This applies also in the present report.

1.5 Reporting structure

Chapter 2 outlines the analytical approach used in the study. Chapter 3 gives an overview of the leaks on NCS in the period 2008–2011, and the normalization is presented in Chapter 4. Chapter 5 presents the analysis of the HC leaks, with classifications and analysis of circumstances and causes.

1.6 Abbreviations

BORA	Barrier and operational risk analysis (research project)
DFU1	Unignited hydrocarbon leaks from process systems (based upon categories in RNNP)
HC	Hydrocarbon
NCS	Norwegian Continental Shelf
RNNP	“Risikonivå norsk petroleumsvirksomhet” (Risk level project)
UKCS	United Kingdom Continental Shelf

2. Analytical approach

The present analytical approach builds on the methodology developed in the BORA and Risk_OMT (Vinnem et. al, 2012) research projects. The approach adopted in these two projects has been extended somewhat with increased focus on modelling of work processes when preparing for and executing manual interventions in the process areas.

Sections 2.2–2.4 present the details of the analytical approach that has been selected.

2.1 MTO perspective on leaks

This analysis takes a full MTO perspective on hydrocarbon leaks, with emphasis on technical, as well as organizational and human (operational) factors that have contributed to causation of leaks, as emphasized by the categorisation of leaks presented in Section 2.3.

The report takes the pragmatic view that reduction of the number of leaks on the Norwegian Continental Shelf is primarily a matter of reducing leaks on existing installations. There are few new installations in the Norwegian sector, and current installations are commonly extended with respect to their production periods, through extension with new satellite fields, extension of reserves, etc.

Reduction of the number of hydrocarbon leaks on existing installations should address technical, organizational as well human factors, as indicated by the categories of leaks presented in Section 2.3. Technical degradation and design errors are discussed in Section 5.4 as well as 7.9–7.11.

With the present perspective it is natural that operational factors will be the main emphasis, as can be illustrated by the following. If a leak is caused by designing and building process equipment with the wrong type of gasket, this may be seen as a design issue. However, in case a wrong gasket is replaced during work on process equipment at an existing offshore installation, the error is in this report considered to be an operational issue.

Replacement of flanges would also have to be considered with respect to risk increase during the replacement period. Large scale cutting and subsequent welding would imply an extensive volume of hot work activity, which would increase risk substantially during the replacement period. It would be doubtful whether the reduced risk due to redesign of flange connections would compensate for the substantial risk increase due to the extensive hot work during replacement.

2.2 Work process modelling

Several of the companies have presented the requirements for planning and execution of manual interventions in the process systems as work process modelling, often using workflow modelling. Figure 1 presents a proposed best practice for intervention work with focus on work steps (OLF, 2012).

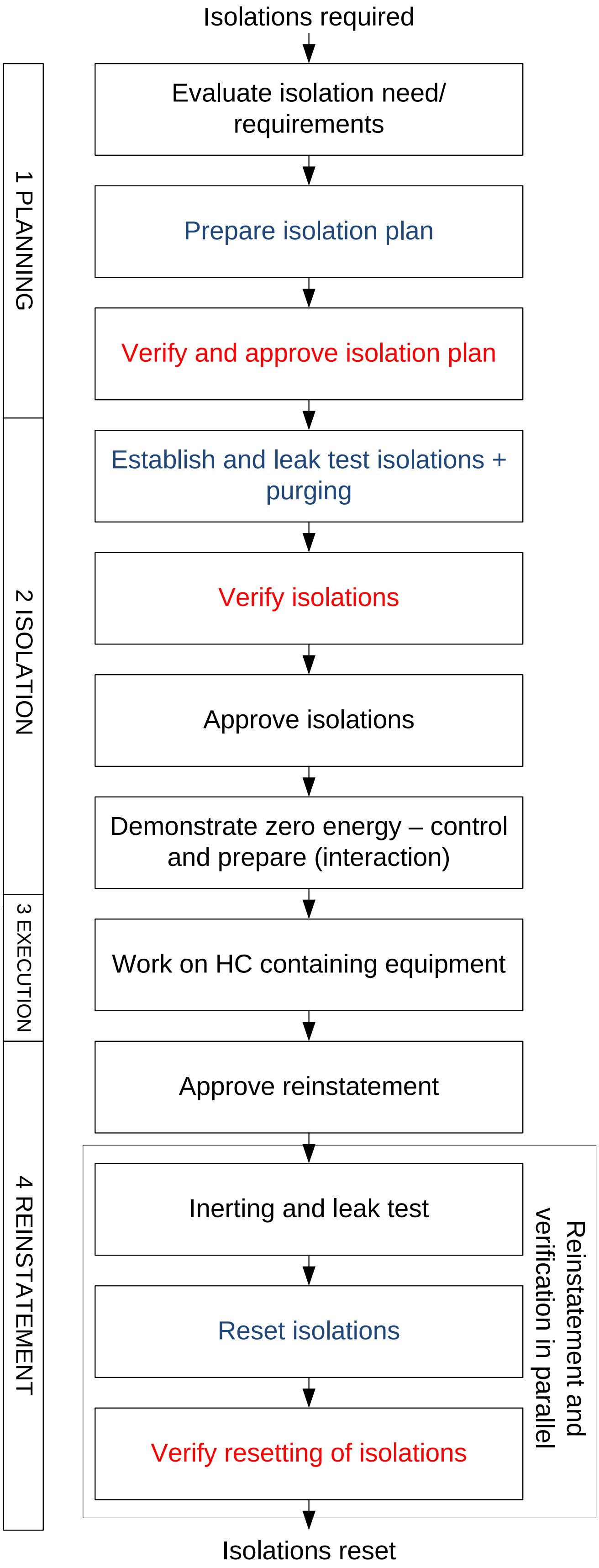

Figure 1 Illustration of best practice with respect to intervention in process systems

A simplified version of the steps in Figure 1 is presented in Figure 2, which is an illustration of the main steps of the workflow, where emphasis has been put on the verification activities. The following are the main phases as in Figure 1:

- Planning
- Isolation/preparation
- Execution
- Reinstatement

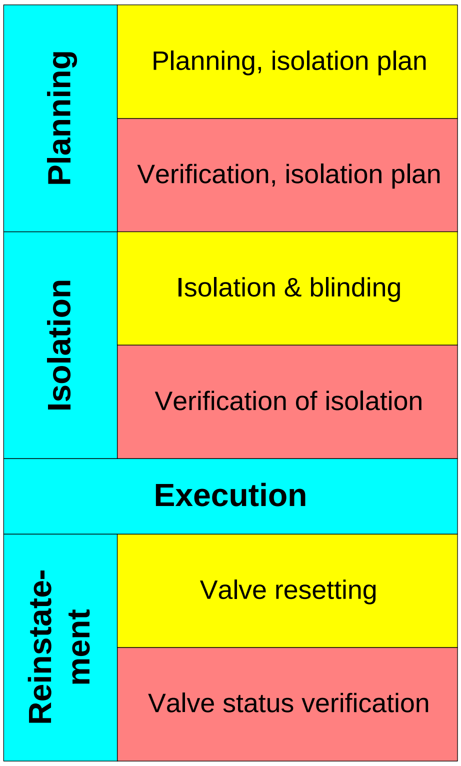

Figure 2 **Illustration of main work process steps in manual intervention in process systems**

Figure 2 shows the main phases, and has made a split between the actual work in three of the phases, and the verifications performed in order to ensure that correct performance has been achieved. The pink boxes are therefore focused on:

- Verification of isolation plan
- Verification of the isolation (the implementation of the isolation plan)
- Verification of the resetting of valves (according to the isolation plan)

The following are the main groups of personnel involved in the work process:

- Planning personnel
- Operations responsible
- Executing personnel (mechanics)
- Area technician

Mechanics are often subcontractor personnel. Previous work and investigation reports may show a trend to focus more attention on the role of the subcontractor personnel (mechanics) than on the production personnel. There may have been too little focus in the past on the planning, isolation and reinstatement phases, compared to the execution phase.

2.3 Initiating events which may cause leaks

The development of the approach to main circumstances of the scenarios when the leaks occur on the installations has been documented in Vinnem et al. (2007) and Haugen et al. (2011), and the annual trends are documented by PSA. Vinnem et al. (2007) and Haugen et al. (2011) have documented how latent errors have been introduced by different personnel groups involved in the planning and implementation of manual interventions. Latent errors may result from errors made during planning, if this results in a faulty work instruction, such as opening or closing the wrong valve. This has been known to occur. The classification of leaks that has been used in the works referred to, has the following main categories in 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 combination of initiating event categories and the work process modelling is the basis of the analysis of HC leaks in an MTO perspective. The detailed codes for these six categories are shown in Table 1.

Table 1 Overview of codes for manual intervention

Code	**Description**
A1	Degradation of valve sealing
A2	Degradation of flange gasket
A3	Loss of bolt tensioning
A4	Fatigue
A5	Internal corrosion
A6	External corrosion
A7	Erosion
A8	Other
B1	Incorrect blinding/isolation
B2	Incorrect fitting of flanges or bolts during maintenance
B3	Valve(s) in incorrect position after maintenance
B4	Erroneous choice of installations of sealing device
B5	Maloperation of valve(s) during manual operations
B6	Maloperation of temporary hoses
C1	Break-down of isolation system during maintenance (technical)
C2	Maloperation of valve(s) during manual operation
C3	Work on wrong equipment (not known to be pressurised)
D1	Overpressure
D2	Overflow/over filling
E1	Design related failures
F1	Impact from falling object
F2	Impact from bumping/collision

2.4 Classification of leaks

Table 2 presents the format used for classification of leaks with the work process model that is described above. There is some additional textual information, as well as information about name of the installation, date, initial leak rate, etc. This has been omitted here.

Table 2 Overview of the classification of leaks in the work process model

ID no	Initiating event	Time	Phase in which errors are made							Phase in which leak occurs			
			Planning	**Planning, verification error**	**Preparation, isolation**	**Preparation, verification error**	**Execution**	**Reinstatement**	**Reinstatement verification error**	**Preparation**	**Execution**	**Reinstatement**	**After start-up**
1102	C1	16:48:00	1		1	1					1		
1103	B6	06:20:00			1	1				1			

Table 2 also presents two examples where the leaks have been classified using the categories. The leak with ID 1102 is caused by errors during planning as well as during the preparation (isolation) and the verification of the isolation. It should be noted that since only leaks are classified, there will always be both failure during the actual work and its subsequent verification activity. If the verification is completed successfully, then the error during the work would be detected, and the leak avoided. The leak with ID 1103 is caused by errors during the isolation/preparation and the verification of the isolation. The leak occurs in the execution phase for 1102, and during isolation for 1103.

The classification of the leaks is based on the company investigation reports, and is made completely independent of the companies. This has the advantage that all the classifications are made in a consistent manner, without random variations made by different persons in different companies. At the same time, the study has had to rely on the information provided by the companies.

Diagrams are based on the seven columns under the heading 'Phase in which error are made' and the four columns under the heading 'Phase in which leak occurs'. Also combinations of these columns are used in order to present statistical overviews.

3. Overview of leaks 2008–2011

3.1 HC leaks above 0.1 kg/s not normalized

Figure 3 presents an overview of the number of HC leaks per month on the Norwegian Continental Shelf for the period which this report has particular emphasis, 2008–11. The number of leaks was 14 in 2008, 16 the following year, 15 in 2010, and 11 in 2011, of which eight occurred during the first six months of 2011. If the leaks are grouped in periods of six months, the following results emerge:

First half, 2008:	8 leaks
Second half, 2008:	6 leaks
First half, 2009:	10 leaks
Second half, 2009:	6 leaks
First half, 2010:	9 leaks
Second half, 2010:	6 leaks
First half, 2011:	8 leaks
Second half, 2011:	3 leaks

The OLF HC leak reduction project was initiated in second quarter 2011, after the publishing of the RNNP report for 2010. The reduction of leaks in 2011 is discussed in Section 3.3.

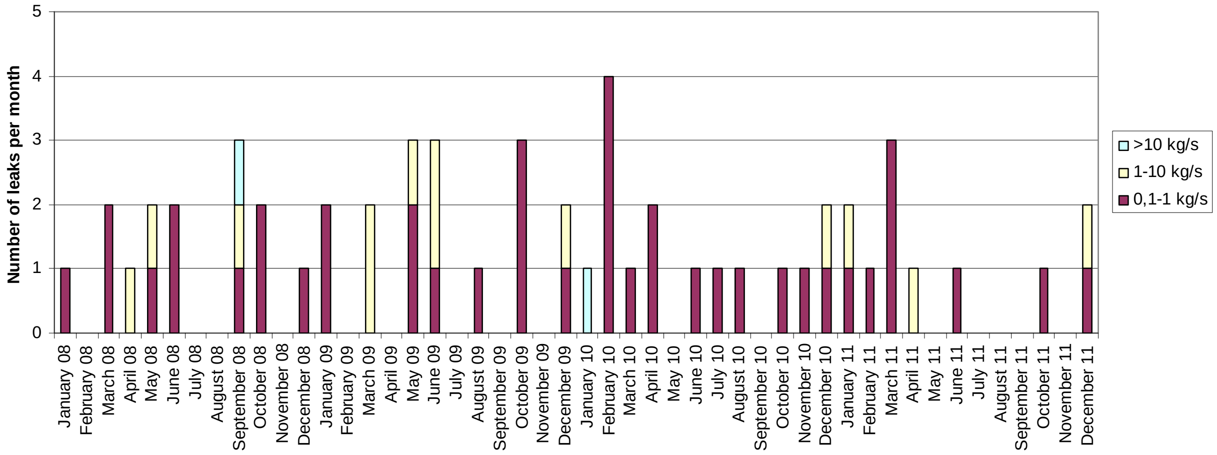

Figure 3 **Overview of leaks per month, NCS, 2008–11**

It is worth noting that the number of leaks exceeding 1 kg/s was the lowest ever (since 1996) in 2010, with only two leaks exceeding this limit. In the preceding years, the numbers were 3; 5; 4; 6 leaks per year over 1 kg/s. Three leaks exceeding 1 kg/s occurred in 2011.

It should be considered that occurrences of leaks will fluctuate somewhat due to randomness and fluctuations in the activity levels. Figure 4 also shows some of these fluctuations. The diagram indicates a peak around the end of 2009 and beginning of 2010, with a gradual fall after first quarter of 2010. The 12 months rolling average number of leaks per month was 1.7 in April 2010, and is about 0.9 at the end of 2011.

Figure 4 presents the long term trends in the number of leaks on the Norwegian Continental Shelf. It is demonstrated that there has been a stable level around 15 leaks per year during the five year period 2006–10 (except a lower value in 2007). Please note that Figure 4 is slightly different from the corresponding diagram in RNNP for the period 2008–2010, due to a few leaks that were not originally included in RNNP.

None of the two diagrams are presented in a normalized manner, such as leaks per installation years. If this was done, the diagrams would be virtually unchanged for the last five years, as the number of installation is virtually unchanged during these years. This is not the case obviously, if seen over the period 1996–2011, but the number of producing installations has not changed dramatically, the increase is just above 50% over a period of 16 years.

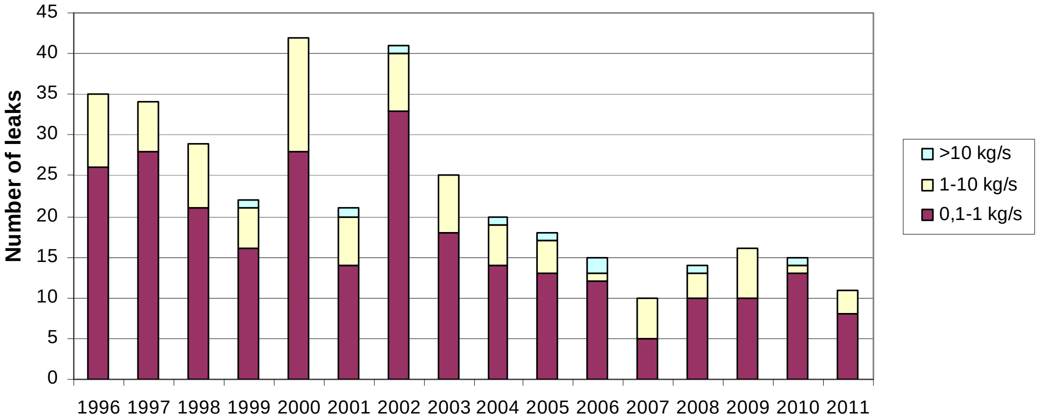

Figure 4 **Overview of HC leaks, NCS, 1996–2011 (source: RNNP)**

Figure 5 presents prediction interval for 2011 compared to the average of the five year period 2006–2010. The value in 2011 falls within the hatched (middle) part of the right most bar in Figure 5, which implies that the reduction in 2011 is not a statistically significant (90% interval) reduction, compared to the average (14 leaks/yr) in the period 2006–2010. A value of eight leaks in 2011 would have implied a statistically significant reduction.

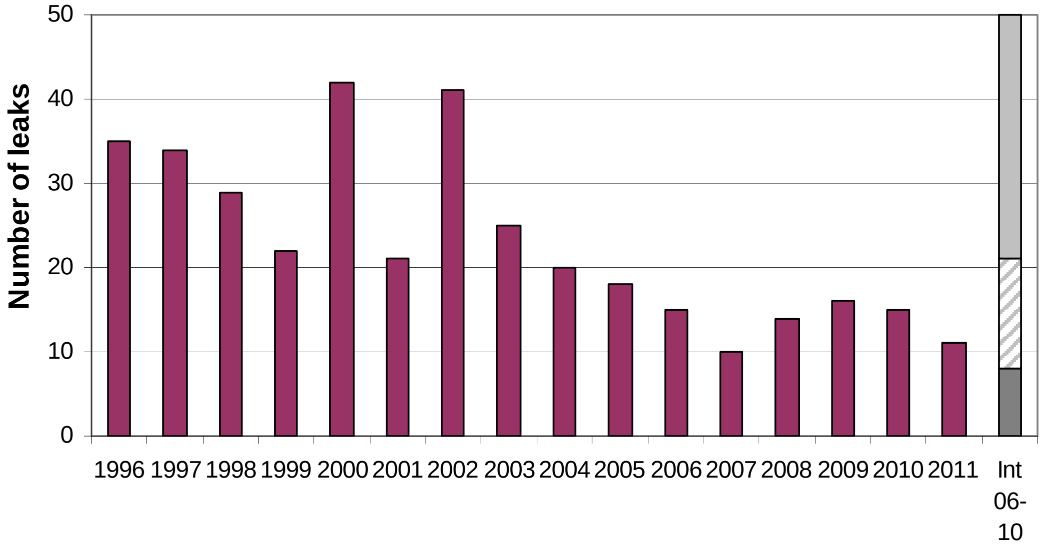

Figure 5 **Prediction interval for HC leaks, NCS, 1996–2011, not normalized, 2011 compared to average in period 2006–2010 (source: RNNP)**

3.2 Reported leaks that are not included

The scope of coverage of data in the present report is identical with what is covered in relation to DFU1 in RNNP. There have been some few release events reported by the companies that have not been included in the statistical analyses, as they did not fall within the scope of DFU1. These events are presented in Table 3 below. Several of the disregarded events are relevant for DFU9 (leaks due to failure of risers, pipelines or subsea production equipment) in RNNP. These leaks may be just as critical as the 'DFU1' leaks, but they are substantially fewer in number and usually quite different failure mechanisms. It is therefore not advisable to combine DFU1 and DFU9 leak occurrences. The other main reason for omission is that the leak rate has been below 0.1 kg/s, which are not considered to have escalation potential.

In addition, a few releases in 2011 have been discussed in relation to possible inclusion, but then concluded to be lower than the limit 0.1 kg/s when investigations were available. These have not been included in Table 3.

Table 3 Overview of reported leaks that are not included in the analysis, 2008–2011

Year	Installation code[2]	Brief scenario description	Comments regarding reasons for not including leak
2008	BV	Leak on pipeline from installation to shore	Pipeline leaks are not DFU1, but DFU9
2008	–	Drain valve open on gas line to burner boom (MODU)	Leaks on mobile drilling units are not included in DFU1
2010	AR	Rupture of hose for bleeding off wellhead pressure	Leaks with leak rate < 0.1 kg/s are not included in DFU1
2010	AU	Leak from manifold to cells	Leaks with leak rate < 0.1 kg/s are not included in DFU1
2011	AW	Shaker ventilation system recorded increased gas return during circulation	Not an accidental event. Well control event rather than accidental gas leak
2011	BH	Subsea leak on flexible riser	Riser leaks are DFU9, not DFU1
2011	AM	Riser leak form carcass on flexible riser detected on riser platform	Riser leaks are DFU9, not DFU1
2011	AX	Injury and uncontrolled leak from hose used for bleeding off annulus pressure	Injury not relevant for DFU1. Leaks with leak rate < 0.1 kg/s are not included in DFU1
2011	BB	Gas leak from flange on LT flare drum	Leaks with leak rate < 0.1 kg/s are not included in DFU1

3.3 About the reduction in 2011

The average number of leaks in the period 2008–2010 was 15 leaks for the entire Norwegian sector, the number in 2011 was 11. According to the trend diagrams shown above, this is not a significant reduction, but it is still a marked reduction.

The history of leaks per year (see Figure 5) has shown that some years have had low values, more as a random occurrence, without representing a sustainable reduction. 2007 is the most typical example; the 10 leaks in 2007 did not represent a new low level, as demonstrated by the average of 15 leaks in the period 2008–2010.

It is therefore far too early to conclude that 2011 represents a reduction to a new low level, and that the actions taken by the industry have had effect so early. The current leak reduction project is scheduled to run through 2013, which is a confirmation of the long term commitment needed in order to create

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[2] The installation codes that are used in this report correspond to the codes used in RNNP.

permanent changes in the manner in which process plants are operated and maintained, and thus contribute to reduction of the number of leaks.

A major operator introduced 'A-standard' in 2010 (see Section 7.8), but there are several investigations from leaks in 2010 and 2011 where it is observed that 'A-standard' has not been implemented or is not being adhered to. It would nevertheless be expected that over time the focus on compliance with 'A-standard' will increase, and hopefully contribute to fewer leaks. The challenge for the industry is to achieve a sustainable reduction with long term effect.

4. Normalization of leaks

4.1 Trend presentation with normalized leak frequencies

Figure 6 presents the same as Figure 5, but now in a normalized manner, per installation years. There are some significant changes to the trends prior to 2004. After 2004, however, there are virtually no principal differences between Figure 5 and Figure 6, and there are no changes with respect to what is statistically significant.

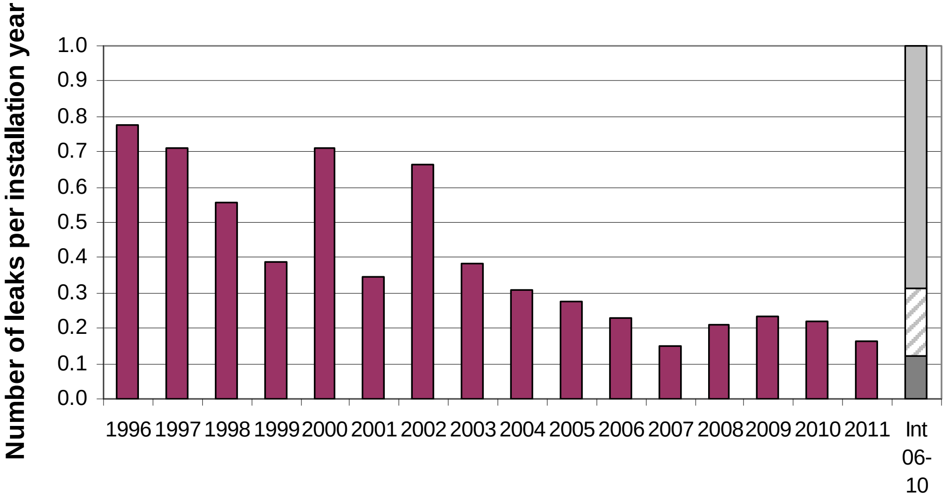

Figure 6 **Prediction interval for HC leaks, NCS, 1996–2011 normalized per installation years, 2011 compared to average in period 2008–2010 (source: RNNP)**

4.2 Installations with highest leak frequency per installation years

Table 4 presents the list of installations with highest average frequency (per installation year) on NCS. This list is in principle the "top ten", but includes all installations with at least two leaks during the period. The basis for the list is leaks per installation year, corresponding to the listing in RNNP reports.

Table 4 **Installations on NCS (anonymous) with at least two leaks in period 2008–2011, sorted according to falling average leak frequency**

#	Installation code	Average number of leaks per year 2008–11
1	AU	1.0
2	AI	0.75
2	AX	0.75
2	BC	0.75
2	BK	0.75
2	BW	0.75
7	AJ	0.50
7	AP	0.50
7	AR	0.50
7	AW	0.50
7	AÆ	0.50
7	BR	0.50
7	AY	0.50
7	D	0.50

The listing in Table 4 is corresponding to presentation in RNNP, and does not differentiate between large and small installations, manned and unmanned, old and new installations, complex and simple installations or installations with extensive or limited amount of manual interventions. This has been the recognized weakness of the listing in RNNP for years.

In the RNNP 2010 report, the corresponding list based on years 2005–2010, is AU ; AG ; AÆ ; BH; AI ; BQ, with respect to first (AU), second (AG) and third place. The most significant difference is that installation AG in not in the top ten anymore in Table 4.

4.3 Installations with highest leak frequency per number of leak sources

The number of leak sources was collected for the majority of production installations on NCS during the Risk_OMT research project (available for all of the installations in Table 4 except the last one). This information should to some extent reflect the technical complexity of the different installations. The number of leak sources is obviously not a perfect representation of the complexity, but no better representation could easily be found. This information has not been used so far to normalize the data in Table 4. Such normalization is presented in Table 5.

Table 5 Installations on NCS (anonymous), top ten list in period 2008–2011, sorted according to falling average leak frequency per 1,000 leak points

#	**Installation code**	**Average number of leaks per 1,000 leak points 2008–11**
1	AJ	1.12
2	BW	0.81
3	AX	0.64
4	AY	0.59
5	AM	0.46
6	BK	0.45
7	AØ	0.40
8	BC	0.33
9	AU	0.31
10	AN	0.24

Six of the installations on the top ten list in Table 5 are also present in the top ten list in Table 4. Two of the three top positions are common for the two lists, but there are also significant differences.

4.4 Installations with highest leak frequency per number of operations

Data have been made available with respect to the number of work permits issued for work in the process areas of the installations (all of the installations in Table 4 except one). It has been shown in previous RNNP reports that about 60–70% of the leaks are due to manual interventions, the number of work permits should therefore be a reasonable normalization parameter.

Five of the installations in Table 6 are also on the top ten list in Table 4. Only one of the installations in the top three in Table 6 are also in the top of Table 4. The same applies to the listing based on the number of leak points in Table 5.

Table 6 **Installations on NCS (anonymous), top ten list in period 2008–2011, sorted according to falling average leak frequency per 1,000 work permits**

#	Installation code	Average number of leaks per 1,000 WPs 2008–11
1	AØ	10.2
2	BW	6.0
3	AY	5.0
4	BV	3.8
5	AJ	3.6
6	BC	3.4
7	AX	3.3
8	AU	3.2
9	AK	2.5
10	AV	2.5

4.5 *Installations with highest leak frequency with combined parameters*

Table 7 is based on leak points as well as work permits, each with equal (50%) weight. Six of the top ten installations in Table 7 is also in the top ten per installation years in Table 4. Two of the top three are the same in both tables.

Table 7 **Installations on NCS (anonymous), top ten list in period 2008–2011, sorted according to falling average leak frequency per 1,000 leak points and 1000 work permits, each with 50% weight**

#	Installation code	Average number of leaks per 1,000 leak points & WPs 2008–11
1	AJ	1.7
2	BW	1.4
3	AX	1.1
4	AY	1.1
5	AØ	0.8
6	BK	0.7
7	AM	0.7
8	BC	0.6
9	AU	0.6
10	BA	0.3

4.6 *Comparison of different normalizations*

Figure 7 presents a summary of the different normalizations. It is clearly demonstrated that normalization according to installation years only gives an incomplete picture.

Please note that the diagram is somewhat special to read. The installations with the highest leak frequencies are the ones with highest bars, according to Table 4–Table 7. The values plotted in Figure 7 are the same values as in Table 4, Table 5, Table 6 and Table 7, with the exception that the values in Table 6 have been divided by 10, in order to fit to a common scale.

The different series in Figure 7 correspond to the data in Table 4, Table 5, Table 6 and Table 7. If the rankings were completely consistent independently of which parameter that is used, the rankings would have been similar for all installations in the diagram.

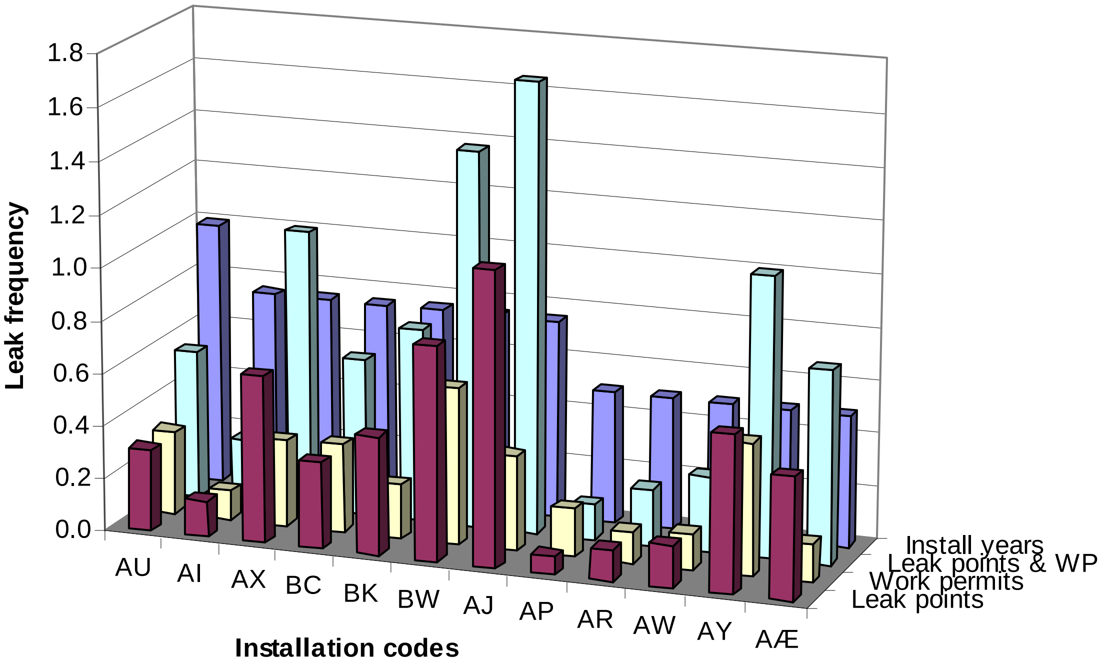

Figure 7 **Comparison of ranks according to the different normalizations**

The four installations which altogether have the highest leak frequencies for all parameters combined are BW; AJ, AX, and AY. Interestingly, these installations represent one old (>25 years in operation), two medium aged (10–20 years in operation) and one new (< 5 years in operation) installation. Hence, age does not appear to explain the observed differences.

5. Classification of leaks

5.1 *Initiating event categories*

The first presentation is an overview of the failures relating to work flow phases. The data in the period 2008–11 is compared to the entire period 2001–10, for the entire Norwegian sector, where the data for the period 2001–2010 is presented in Vinnem (2012a).

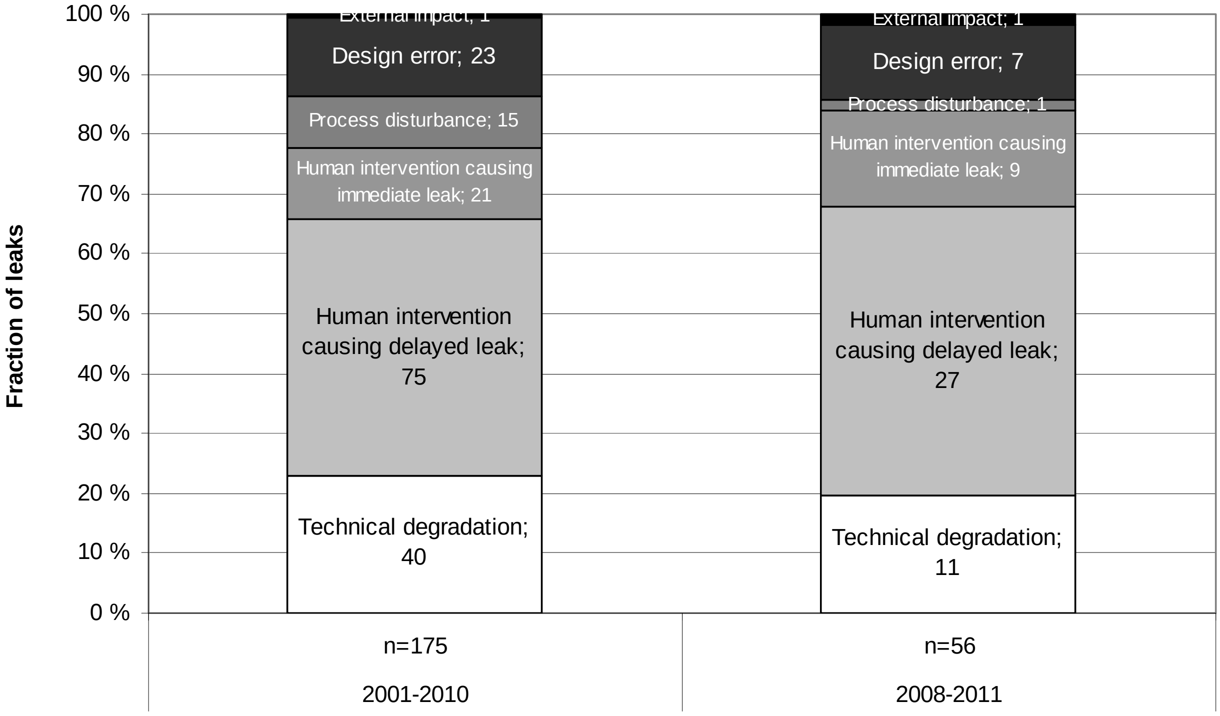

Figure 8 **Hydrocarbon leaks distributed on operational circumstances, Norwegian Continental Shelf, average 2008–11 (n =56) and average 2001–10 (n =175) (partly based on Vinnem, 2012a)**

The fraction of leaks due to technical degradation are slightly lower in the period 2008–11 period when compared to the previous ten year period, but is surprisingly close. The contribution from manual intervention is even higher in the 2008–11 compared to the ten year period, especially for immediate leaks due to errors made during the intervention. The contribution from process distributions is the most significant change (reduction) for the period 2008–11 compared to the previous 10 year period.

5.2 *Activity types involved in leaks*

Section 2.1 gave an overview over the main categories of initiating events. Each main category has several subcategories, according to BORA (Haugen et al., 2007). The subcategories were presented in Table 1.

The distribution on the main categories is presented in Figure 8. Please consider the subcategories for categories B&C, i.e. the failures during manual intervention.

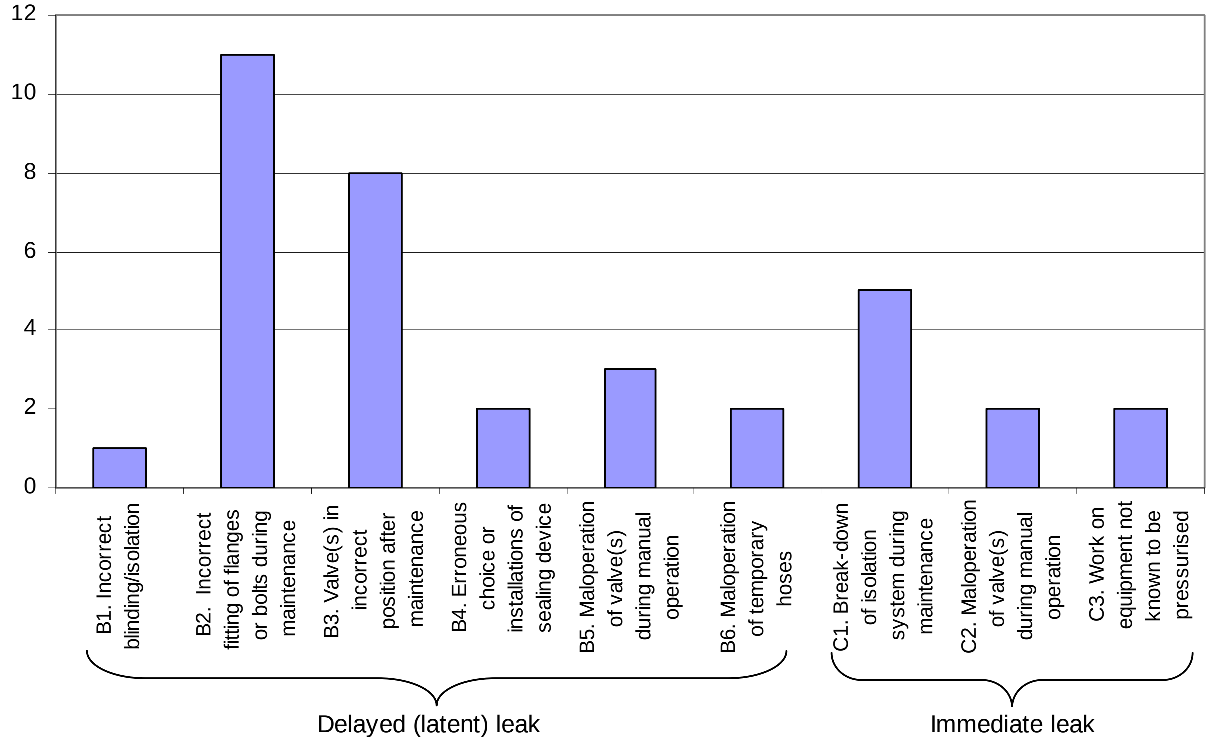

Figure 9 **Distribution of subcategories for failures due to human intervention (B&C), leaks NCS, 2008 – 2011 (n=36)**

B1, B2, B3 and B4 are often grouped together, because they are all associated with incorrect position of valves or connections, which have the same type of barriers. These four subcategories correspond to 22 of the 36 cases of failures due to manual intervention. Maloperation of valves and hoses, B5, B6 and C2 represent seven leaks together, whereas isolation failure or pressurized equipment, C1 and C3, comprise seven leaks.

Of the 11 cases with incorrect fitting of flanges or bolts during maintenance (B2), there are four cases with errors involved in tightening of bolts is involved. These four cases are distributed as follows:

Bolts not tightened/incorrect tightening:	2 leaks
Incorrect torque used in tightening:	2 leaks

5.3 Time when leaks occur

Figure 10 shows the distribution of times, and the average number per hour during day shift (07–18) and night shift (19–06), 2.8 and 1.6 respectively. The average number of leaks during 01–06 is 2.2 leaks/hour.

For obvious reasons, there are fewer leaks occurring during night shift. There are few leaks during the period from 1900 hrs until 0100 hrs, but quite some leaks during the period 0200 until 0600. This is the period where regulations state that work on process systems only should be done if this implies lower risk, compared to day shift (Framework regulations §43).

This study shows (see Section 5.2) that a considerable number of leaks are associated with errors made during the implementation of the isolation plan, i.e. the setting of valves and blindings. If only the C category leaks (immediate release during manual intervention) are considered, then half of the leaks (four of eight) occurred during night shift and the other half during day shift.

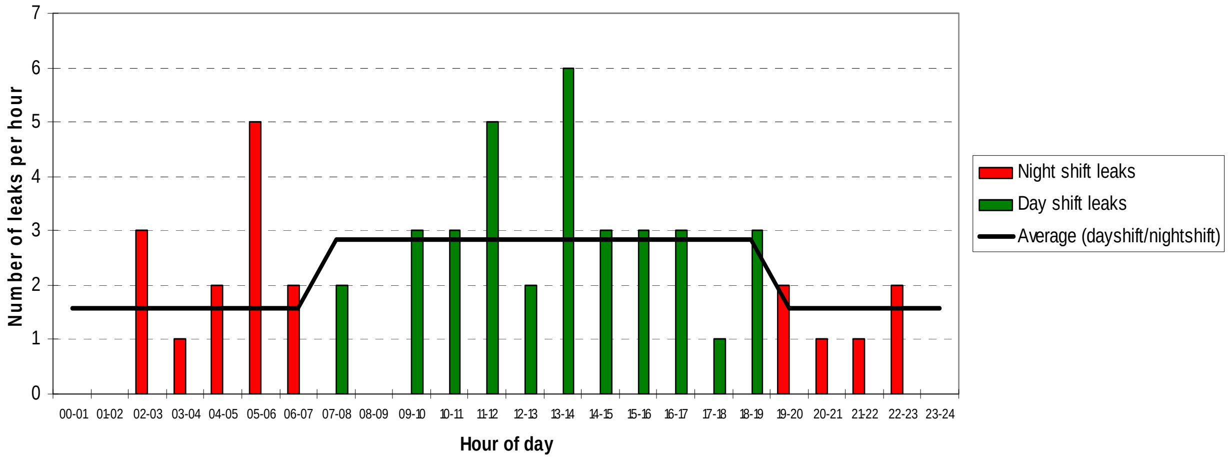

Figure 10 Distribution of times when leaks occur, NCS, all causes, 2008 – 2011 (n=53)

Is it likely that the leaks could be avoided if the implementation of the isolation plan was carried out on day shift? Not necessarily, if failure of verification of the implementation of the isolation plan is due to lack of compliance with steering documentation, such failure of compliance may occur irrespective of what time of the day the work is carried out. On some installations however, it appears that the number of production personnel on night shift may be low (one person) and therefore there may be a shortage of the right technical staff to perform independent verification during night shift. Supervisory personnel could be called in even during night shift, but some reluctance to wake up supervisory personnel in the middle of the night may be an issue at some installations. In this respect, it may be easier to comply with steering documentation verification performance during day time.

5.4 Design weaknesses and technical degradation

Figure 8 shows that the number of leaks in the period 2008–2011 can be categorized as follows for design and degradation:

- Design error: 7 leaks (13 %)
- Technical degradation: 11 leaks (21 %)

It should be recognized that some aspects of occurrence of leaks are associated with design issues, such as for instance how a manual valve has to be operated in order to be completely closed (such as a number of turns in one direction followed by one turn back, etc). However, many of the design aspects have to be kept as they are for the rest of the installations' lifetime. To alter the design of process systems is very costly and will usually involved quite a bit of hot work activity, implying that the temporary increase of risk during implementation can be substantial.

Marking of process lines and fittings is in the RNNP report considered as a design issue. This is also only partly relevant. When the installation is new, marking is a design aspect, but the need to refresh marking will always occur during operation, and it should therefore also be considered an operational issue.

In addition, new installations in the Norwegian sector are quite few in number, whereas the main picture of offshore petroleum production is relatively old installations that often have been the subject to, or will experience, lifetime extension. The main efforts relating to prevention of hydrocarbon leaks therefore have to be focused on leak prevention on existing installations and their systems and characteristics. Extensive modifications, such as improved access to valves and instruments are often out of the question, partly due to increased risk during modification.

The main issue of this report is therefore on prevention of leaks as an operational issue. Hydrocarbon leaks have been analyzed in a work phase context in Section 6 below. Consequently, the current OLF initiative has so far had its primary focus on operational aspects. Improvement of design is also an important topic, which will have to be addressed separately.

5.5 Major hazard risk potential

One of the most remarkable features of the investigations of hydrocarbon leaks on the Norwegian Continental Shelf is that major hazard potential is not well addressed. Most of the investigations do not recognize that there is a potential for major hazard consequences. Vinnem (2012b) has documented that there is large difference between what is considered to be the potential consequences in the investigations and the major hazard risk potential reflected in the RNNP classification of the same hydrocarbon leaks.

It is also documented by Vinnem (2012b) that hydrocarbon leaks have been subject to both investigations by PSA and company internal investigations. Differences have been identified related to the potential consequences. The companies find essentially no major hazard potentials, whereas PSA has identified significant major hazard potentials for the four leaks they have investigated.

The reason why the companies may disregard the major hazard potential is that the potential consequences are considered in relation to insignificantly changed circumstances. Such circumstances are defined as events which have at least 50% probability of occurring. Since barrier elements have high reliability, none of the barrier failures will have 50% occurrence probability. This practice should be reconsidered, as discussed in Vinnem (2012b).

It should also be noted that the IRIS report 2011/156 (‘Learning of incidents in Statoil’, Austnes-Underhaug et al., 2011) has documented that there is inadequate learning from investigations in order to prevent further hydrocarbon leaks. Other reasons are stated, the arguments are not related to failure to address the major hazard potential, but this relationship should not be ruled out.

6. HC leaks during work process phases

6.1 Overview of work flow phases

Figure 1 presents an overview of the different steps and phases of a manual intervention into process systems (OLF, 2012). The four main phases are planning, isolation, execution and resetting. Three of the main phases have a verification activity. The classification of the leaks into which work flow phases that the leaks have occurred during is presented in the following subsection. Each of the main phases is thereafter discussed separately.

6.2 Classification of leaks during work process phases

Figure 11 presents an overview of the errors made during the various work flow phases, for leaks due to manual interventions (B & C categories; see Section 2.1). The data set is limited to 32 B & C leaks in the period 2008–11, where the information was sufficient to be able to determine which work flow phase that the error had been made in.

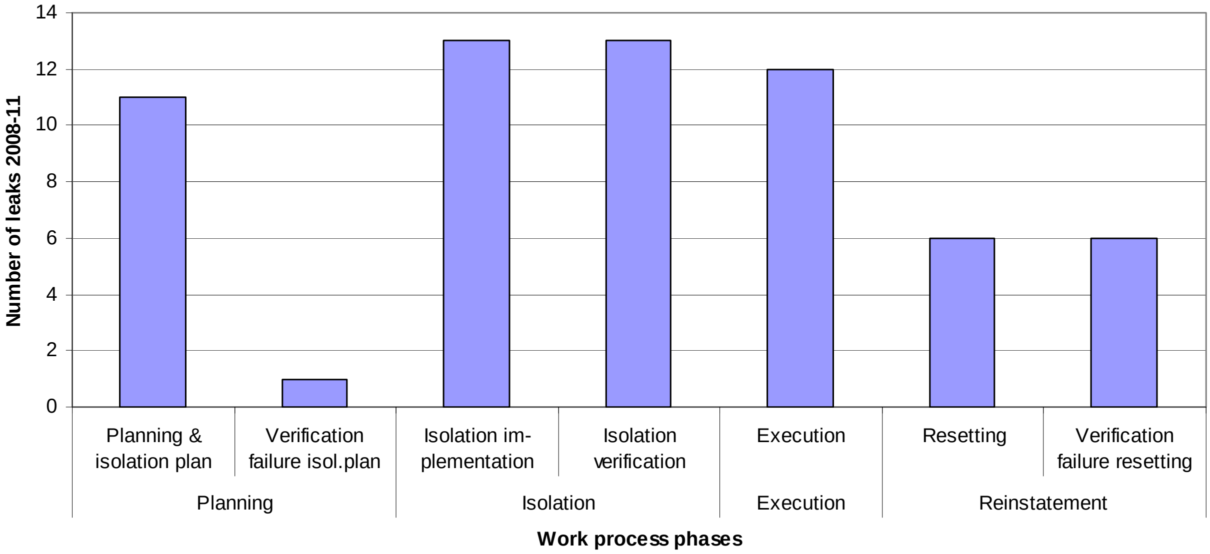

Figure 11 Distribution of errors during leaks due to manual intervention (B & C categories), NCS, 2008–11, for each work process phase separately (n=32)

It should be noted that there are several errors made during planning, but only one of these could have been picked up during verification of the isolation plan, see further discussion in Section 6.3.

It should also be noted that during the isolation phase, in order for a leak to occur, there has to be an error during the isolation implementation together with an error during verification, see further discussion in Section 6.4. There are therefore 13 leaks with failure both during isolation implementation and corresponding verification, including cases where no verification was made.

Separate verification of the actual intervention work has not been considered. Separate verification has been considered during resetting. A failure due to resetting also for this phase requires that failures are made during the resetting and not discovered during verification, including leak testing. This is discussed further in Section 6.6.

6.3 Planning

Planning includes evaluation of the need for isolation, and the isolation requirements, the implementation of the isolation plan and the verification of the isolation plan.

The majority of the errors made in relation to planning have been of such nature that they are not directly associated with the isolation plan. Only one case demonstrated an error associated with failure to establish an isolation plan (claimed not to be the practice on the installation in question), but no verification was carried out, and the lack of isolation plan was therefore not identified.

The errors during planning were in all other cases associated with other aspects of planning rather than the actual isolation plan, where verification of the isolation plan would not be relevant in order to identify the error made during planning. The other failures relating to planning were the following

- Qualification of tools was not carried out, no system had been established for monitoring the communication and decision-making relating to risk, between the project, asset integrity, operations and between different levels of management and for a for decision-making.
- Work permit was insufficient in relation to work process requirements with respect to isolation.
- Description of work was not updated according to latest practice.
- Experience from earlier operations not included, known errors not rectified.
- Inadequate risk assessment prior to operation, a HAZOP should have been carried out when an alternative method had to be implemented.
- Insufficient communication prior to planning of tasks, WP not prepared.
- The process plant was restarted after a prior (six days earlier) gas leak without proper testing of the systems, assuming what was the fault, which was shown not to be actual fault.
- Error during planning, bolt torque table was not available, too low torque specified.
- Error during planning, not established practice on the installation in question to prepare isolation plan.
- Manufacturer’s drawings not in accordance with what has been installed.

6.4 Isolation

Isolation implies to implement the isolation plan, including leak testing. This shall normally be followed by verification and demonstration of zero energy (used by some companies so far). The setting of the plan and the verification are shown separately in Figure 11.

It should be noted that the number of cases with error during setting of the isolation plan is equal to the number of verification errors in Figure 11. This may be somewhat surprising, but may be easily explained in the following manner:

- There will not be a leak associated with isolation if there is no error made during the setting of the plan.
- If the verification is carried out effectively, then there is no leak, even if errors were made during setting of the plan. This implies that when there is a leak associated with isolation, it will always imply that both the setting and the verification failed.

There are two categories of failure of verification that are represented in the data basis, either the verification is not carried out, or it is carried out but failed to reveal the error that has been made, Figure 12.

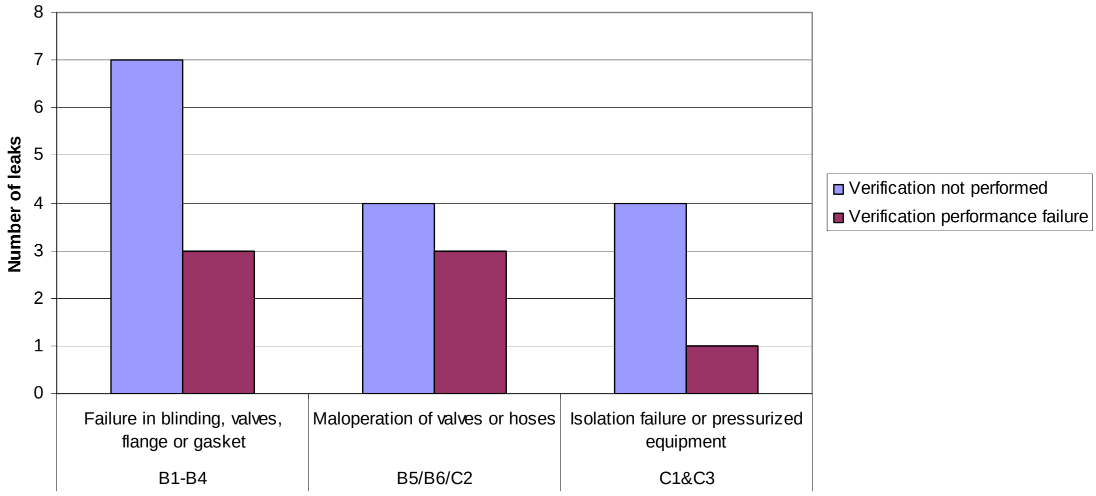

Figure 12 **Verification failure split in verification not performed and verification performed but failed**

Verification in this context covers verification of setting of the isolation plan as well as verification of resetting of valves after the work has been finished. The following categories of leaks have been considered separately:

- B1-B4: Failure in blinding, valves, flange or gasket
- B5&C2: Maloperation of valves
- C1&C3: Isolation failure or pressurized equipment.

The overall ratio between verification not carried out and verification failed to reveal the error is as follows:

- 2.1:1 (15 vs 7 cases)

'Verification not carried out' is often associated with 'silent deviations', 'it is not our practice to carry out verifications' is an expression often found in investigation reports. This is an important finding. For a more thorough discussion on verification errors and 'silent deviations' reference is made to Section 7.3

The isolation phase is the phase with the highest contribution to the number of leaks. There are 13 cases (registered as both setting and verification failure) of failure associated with the isolation phase.

6.5 Execution of intervention

Execution of intervention is the actual replacement, inspection or modification work to be carried out. This is the phase where the second highest number of leaks, 12 leaks in the period 2008–2010 has occurred, as compared to 13 leaks associated with the isolation phase. The following is a summary of the errors made:

- Unclear work permit caused error
- Work not performed in accordance with isolation plan
- Plugs removed without reinstatement: two cases
- Performance failure during flange installation: two cases
- Lack of clarity as to who was responsible for the task/lack of competence: two cases

6.6 Reinstatement

Leaks due to errors during resetting (or reinstatement) have the lowest contribution, six leaks caused by such cases, as shown in Figure 11. Five leaks are caused by errors during the reinstatement, whereas there have been six failure during verification of the reinstatement. The explanation is that the verification which failed was not associated with a failure during the reinstatement.

6.7 Phase when leaks occur

Figure 13 presents the distribution of when (i.e. in which work flow phase) the leaks occurred. Figure 13 may be compared against Figure 11, which shows in which phase the errors were made.

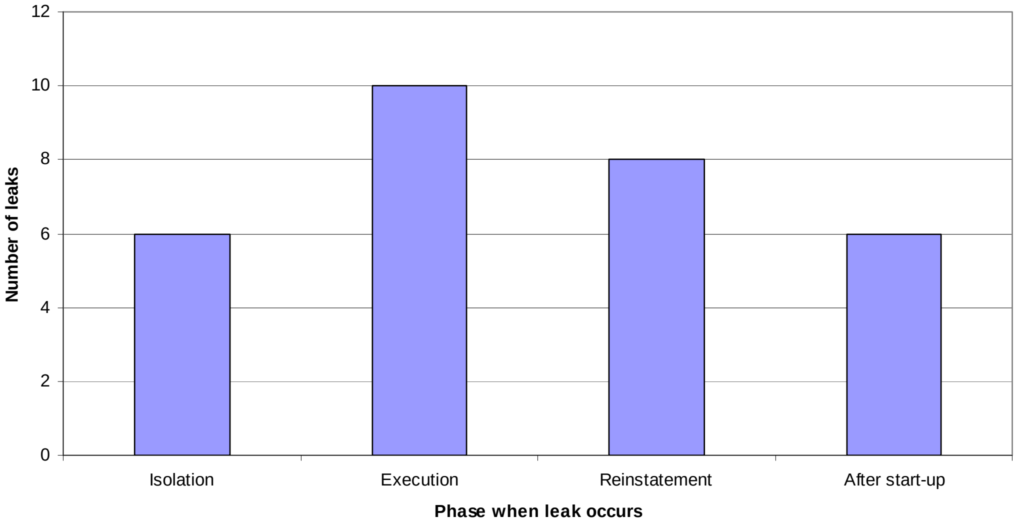

Figure 13 Phase in which leaks occur, NCS 2008–2011 (n=30)

Figure 11 shows that some errors have been made in the planning phase, these have caused leaks in subsequent phases. Planning errors are often made together with other errors, and the times at which the leaks occur will then be influenced by what other errors that are made. The type of error will also influence when leaks occur, some errors cause immediate leaks, other errors lead to delayed leaks, either during reinstatement or after start-up.

7. Causal factors

Immediate causes and potential root causes are documented in the majority of the investigations, but the thoroughness of these classifications is variable. Over the last few years, a trend appears to be that some companies' investigations are fewer in number, more thorough and involving personnel with professional investigation competence. The majority of the studies are not called 'investigations', but rather 'in depth studies' and are mainly carried out by personnel on the installation.

This section documents a number of causal factors, some very important, other less important, but still interesting to document, because there is some attention on these aspects.

7.1 Risk Influencing Factors from investigations

Most of the leaks are during the last years investigated or studied through 'in depth studies' as noted above. This implies that most of the investigations and studies have analyzed root causes and barrier performance. In fact, root causes and barrier performance have been available in 47 out of 56 leaks above 0.1 kg/s. This section is based on those 47 leaks. The analysis is primarily focused on root causes and barrier failures in the 'M & O' sphere, i.e. failures in the organizational systems and human errors.

The distinction between root causes and barrier failures is not very clear. Root causes are often defined in the investigations as those aspects that lead to one or more of the immediate causes. Barriers are in investigations usually defined rather loosely, as something that could have stopped the chain of events, i.e. prevented an accident or reduced the consequences. The investigations often distinguish between barriers that functioned, barriers that failed and barriers that were not in place or in use. The analysis in this section is limited to barriers that did not function or were not used.

The more precise terms barrier function, barrier systems and barrier elements are normally not used. This implies that root causes and barrier failures are difficult to distinguish between. For example, failure to comply with steering documentation, is in investigations (and similar) classified sometimes as a root cause and sometimes as a barrier failure.

The analysis has therefore not distinguished at all between what has been root causes and barrier failures, and has classified all of the factors that have been identified as Risk Influencing Factors (RIFs). Some investigations or 'in depth' studies have identified several root causes and barrier failures, whereas there may be only one or two in other documents. When all factors are summed for the 47 leaks where this is available, the total is 159 RIFs, implying that the average number of RIFs per leak is 3.4. Figure 14 presents the distribution of root causes and barrier failures identified in all the leaks in the period 2008–2011.

Work practice is the RIF that is cited in most of the investigations, 29 out of 47 leaks. Failure to comply with steering documentation (such as procedures) is the second most frequently used, with 20 out of 47 leaks. If we take failure of work practice **or** failure to comply with procedures, this applies to 35 or out of 47 leaks (74%). On the other hand, if we take failure of work practice **and** failure to comply with procedures, this applies to 14 or out of 47 leaks (30%). Work practice errors and failure to comply with controlling documentation are therefore the most critical RIFs associated with hydrocarbon leaks.

'Risk assessment', which should be interpreted as 'failure to perform relevant risk assessments' as well as 'lack of apprehension of risk', is almost as frequent as failure to comply with steering documentation, 20 out of 47 leaks.

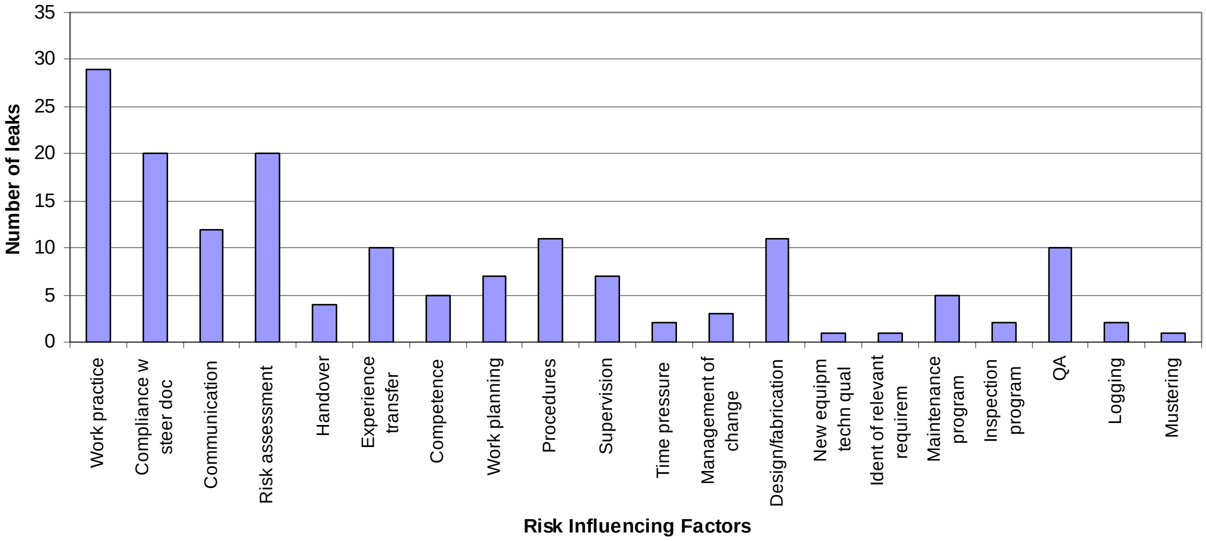

Figure 14 Overview of RIFs from investigations and 'in depth' studies, NCS, 2008–2011 (n=47)

If we focus on RIFs that are identified in at least ten cases, the following RIFs come in addition; failure of experience transfer, lack of/inadequate procedures and error during design/fabrication.

Some of the RIFs are possibly less influential than what would be anticipated, this applies to competence, supervision, time pressure and maintenance program.

The next diagram, see Figure 15, compares the RIFs for all leaks (as in Figure 14) with only those leaks that are associated with manual interventions (B and C type leaks, see Section 2.1). The same Risk Influencing Factors are used in Figure 15 and Figure 14, the majority of these are most relevant for the leaks that are associated with manual intervention, i.e. the B and C type leaks.

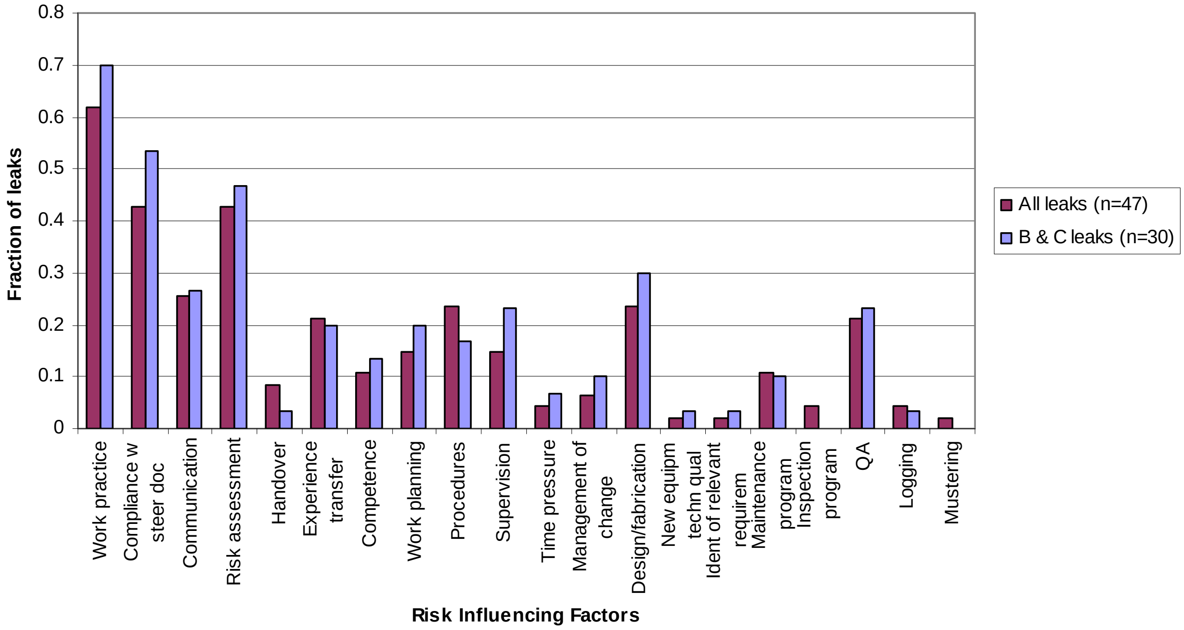

Figure 15 Overview of RIFs from investigations and 'in depth' studies, NCS, all leaks and leaks due to manual intervention, 2008–2011 (n=47&30)

Errors related to work practice and inadequate compliance with steering documentation become important if only leaks associated with manual intervention are considered. If we look at failure of work practice **or** failure to comply with procedures, this applies to 25 or out of 30 leaks (83%). On the other hand, if we analyse failure of work practice **and** failure to comply with procedures, this applies to 12 or out of 30 leaks (40%). This does certainly not represent a surprise; Errors related to work practice and inadequate compliance with steering documentation, are essential for leaks associated with manual intervention.

Also failure to perform risk assessment (or failure to apprehend risk) and supervision failure are considered more important for leaks associated with manual intervention. In addition lack of competence and work planning failure are more important for leaks associated with manual intervention, but these represent relatively low contributions. On the other hand, leaks associated with design or fabrication failure are somewhat increased. This was not expected, but may be due to random variation, as there are relatively few cases (9) involved in this category.

Work practice errors are dominating during execution of maintenance work (8 out of 9 leaks), but also occur quite frequently during isolation and reinstatement (18 out of 25 leaks). Failure of communication and failure to perform risk assessment or error in apprehension of risk, are more important during execution than during isolation and reinstatement. Supervision is also more important during execution of maintenance work. The only RIF that represents a higher fraction of leaks during isolation and reinstatement, is failure to comply with steering documentation. This will typically be failure to comply with the isolation plan.

7.2 Discussion of work practice errors

Table 8 presents an overview of the cases with failure of work process execution and their circumstances.

Table 8 Overview of cases with work process execution failure and circumstances, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Failure description
0809	AJ	B3	Error in work process execution; discovered that valve was laterally reversed, but not that function also was reversed.
0811	BC	B2	Error in work process execution, not followed requirements/ guidelines, flange bolts asymmetrically tightened up
0812	CA	C1	Error in work process execution, does not follow procedures
0909	BV	B4	Error in work process execution, removes plug without ensuring that it will be reinstalled
0910	AX	C1	Error in work process execution, no communication between installations during work
0912	AU	C3	Error in work process execution, requirements & deviations not implemented and followed up
0913	AR	B3	Error in work process execution, work is not performed in accordance with isolation plan
0915	AJ	B2	Error in work process execution, manometer not sufficiently tightened
0916	AÆ	B5	Error in work process execution, left installation with insufficient isolation
1008	BQ	E	Piping system inspected after increasing slugging, but failure was not detected
1014	AV	B2	Several work process failures, including inadequate combination of operators with relevant experience
1015	BH	B2	Work process requirements not followed when flanges were remounted

There is only one installation (AJ) that is represented twice in Table 8. This may indicate that most of the installations where leaks occurred due to some type of execution failure have learned from their experience gained through these failures.

There are several cases in this study that fall in the category of not complying with procedures, instructions and requirements; this applies to at least five out of 12 cases. Several cases are such that it is difficult to imagine that an experienced professional mechanic would carry out his or her work in such a manner if he/she worked diligently.

7.3 Discussion of verification errors

Verification failures were discussed in relation to work phases in Section 6.4, see Figure 12 in particular. In the present discussion we aim to go deeper into the circumstances of verification failures.

As shown in Section 6.4, almost 70% of the verification failures were due to the fact that no verification was carried out at all. There is lack of documentation available to confirm that verification should have been carried out in all these cases. Several of the investigations have documented that verification was not carried out due to 'silent deviation', i.e. that the installation had accepted a practice implying a deviation from internal requirements to perform verification of the setting of the isolation plan and verification of the reinstatement.

Seven (37%) of the verification errors are due to failure during the execution of the verification. These are shown in Table 9. The two first digits of the Event ID is the year, and the same installation codes as before are used. Five of the verification failures are related to setting of the isolation plan, the two remaining are related to verification of the reinstatement.

The verification was not carried out in the field in some of these cases. This is obviously one of the lessons learned from these cases, that is; the importance of carrying out the verification in the field, not in the office.

Table 9 Overview of cases where verification failed and essential circumstances, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Verification type	Failure description
0906	BU	C2	Isolation verification	Verification performed by night shift personnel did not reveal error made, not performed in field.
0909	BV	B4	Reinstatement verification	Pre punch and punch reviews did not reveal plug that was removed. Punching not performed with sufficient thoroughness.
0915	AJ	B2	Reinstatement verification	Fitting (manometer) not tightened up on threads. This was visible, and should have been discovered during punching.
1103	AG	B6	Isolation verification	Isolation plan verified by supervisor, but without noting that bleed was not according to controlling documentation
1105	BM	B1	Isolation verification	Verification did not reveal error made. Isolation plan implemented by night shift, but they did not perform verification, which was left to day shift. Verification was not performed in field.
1108	AM	B5	Isolation verification	Verification performed by person who had not been involved in planning and was not fully aware of valve status. This was not according to best practice.
1110	AY	B3	Isolation verification	Verification did not reveal the live hydraulic system

There is some discussion about whether the responsible professional/operator and the verification responsible/operator should review the isolations made or remade together or independently. Two of the investigations reveal information that implies that verifications were made independently, but still failed. Two of the incidents demonstrated that relevant information was not available in order to consider whether verification was carried out independently or not.

More than two thirds (68%) of the verification failures are due to not carrying out verification at all, as shown in Table 10. We have not been able to confirm that verifications were required in all these 13 cases. However, it has been confirmed by the investigations in the majority of the cases that verification should have been performed.

Table 10 Overview of cases where verification was not carried our and essential circumstances, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Verification type	Failure description
0807	BK	B2	Isolation verification	Performance according to personal evaluation, which replaced compliance with controlling documentation, without following procedures for deviating.
0808	BW	B5	Isolation verification	Details not available
0809	AJ	B3	Reinstatement verification	Bad communication probably influenced the events
0811	BC	B2	Reinstatement verification	Bad weather implied that work force was demobilized and mobilized the day after, but key personnel were not present then. May have contributed to verification being forgotten.
0812	CA	C1	Isolation verification	No WP, no isolation plan, no verification
0913	AR	B3	Reinstatement verification	Verification not performed
0916	AÆ	B5	Isolation verification	Bad communication probably influenced the events
1002	AU	B2	Reinstatement verification	Failure of supervision
1004	AI	B6	Isolation verification	No operations personnel involved in order to verify isolations.
1005	BV	B3	Isolation verification	Inadequate practice not to use isolation plan, thus no verification either, apparently due to silent deviation.
1012	BA	C3	Isolation verification	Several non-compliances with controlling documentation, including failure to perform independent verification in the field.
1014	AV	B2	Reinstatement verification	Bad communication influenced the events and lack of competence in addition to failure of supervision.
1102	AN	C1	Isolation verification	Details not available
1106	AØ	C2	Isolation verification	Several non-compliances with controlling documentation, including failure to perform independent verification in the field.

There are only two installations (AJ and BV) that are represented twice in Table 9 and Table 10. This may indicate that most of the installations were leaks due to some type of verification failure, the organizations actually have learned from the experience gained. The installation with code AJ also has two failures due to execution failures. This installation is the one with the highest number of work process failures. It also has a high score in several of the ranking lists in Section 4. One of the reasons for this is apparently that work process errors have been repeated several times during the last four years. It may still not be related to work on the same shifts, but one may question the ability to learn from experience.

The finding that more than two thirds (68%) of the verification failures were due to not carrying out verification at all is important when considering potential risk reducing measures. With reference to Figure 1, the step where the operations supervisor approves to the isolations before the work on the HC containing equipment turns out to be very important: This is the step where a common practice of *not* performing the essential verification activities can and should be revealed.

7.4 Errors in isolation plan and its verification

Several errors associated with isolation plan that may contribute to hydrocarbon leaks have been identified, that is failure to establish isolation plan, errors in established plan, and failure to verify the correct implementation of the isolation plan. The investigations are in general not sufficiently specific in order to provide a detailed overview of isolation plan errors. Some errors have been documented in the investigation reports, as presented below in Table 11.

Table 11 Overview of cases where isolation plan errors are known, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Failure description
0807	BK	B2	Isolation plan not complete
0808	BW	B5	Isolation plan not used
0812	CA	C1	No work permit and hence no isolation plan
0916	AÆ	B5	Approved isolation plan not followed
1005	BV	B3	Not common to prepare isolation plan on this installation
1106	AØ	C2	Approved isolation plan not followed

7.5 Errors during leak testing

It could have been useful to be able to present an overview of the leaks where leak testing either had failed or had not been performed. However, the investigations are not sufficiently specific in order to achieve this. There are six cases with failure during reinstatement, but only two cases where there is some indication that leak testing failed:

- Plant was started after first leak without testing, assuming that the leak had been found.
- Bad communication ahead of leak testing.

7.6 Management and supervision

The following are some of the weaknesses in the management and supervision that are found in investigation reports:

- Weaknesses in management (including management of change) systems
    - Warnings of vibration and noise were not responded to. Incident report not taken seriously
    - Qualification of the tool is not implemented, it was not established a system for monitoring communication and decision on risk between the project, construction integrity and management and between different levels of management and decision-making forums
    - No safety system activated; appears to be high threshold for such actions
    - Documentation not updated after the modification
    - The system has not been given priority with respect to modification, work order from several years ago not performed
    - Questions asked of management's handling of start-up after an extensive turnaround
    - Insufficient manning level and inadequate quality assurance
    - Inadequate inspection and maintenance program
    - Risk apprehension, awareness and work performance is not in accordance with accepted standard
    - Previous experience is not taken into account, known errors not corrected
    - Steering documentation is not adequate to prevent this type of problem
    - Weak apprehension of risk in relation to what damages a truck could cause
    - Work permit approved without being aware of a specific exception
    - Changes were implemented without a HAZOP or SJA being carried out
    - Lack of understanding of risk potential on the involved installations
    - Three inadequate plugs supplied and installed several years ago without discovering the error performed by suppliers
    - Valve replacement several years ago with outdated type of valve stuffing box
    - Process plant started after one leak without testing thoroughly, just assuming that the error had been found
    - Inadequate procedures for verification and control
    - Work order issued several years ago, but not given priority by management
- Supervision error and weaknesses
    - No supervisor realized the hazard involved with a large un-insulated volume at low pressure
    - Unclear ‘ownership’ of temporary equipment
    - Supervisors have not followed up the work proactively

7.7 Lack of compliance with steering documentation

First of all, please note that for the 20 leaks where verification had failed, shown in Figure 12, 68% failures were related to deficient performance of the verification, whereas 32% were failure of the verification itself. It is to be expected, although not identified clearly, that many of the failures to conduct specified verification activities are associated with ‘silent deviations’ from steering documentation. Unacceptable practices have been developed over time on some installations, implying that it is considered acceptable not to follow steering documentation, and that instead so-called ‘qualified evaluations’ conclude that simplifications are just as good. Often such simplifications imply that verification activities either are not carried out at all, or made in a simplistic manner.

This is recognized explicitly in some investigation reports, with descriptions such as the following:

- ‘Silent’ deviations documented
- ‘Silent’ deviation, made similar error just a few days before
- Lack of compliance with work process requirements when flanges were remounted
- ‘Silent’ deviation

It should also be noted that when root causes and barrier failures in investigation reports are recorded (see Section 7.1), lack of compliance with steering documentation have been reported in 20 out of 47 leaks, i.e. just over 40%.

It is therefore reasonable to consider that over one third of all hydrocarbon leaks in the period 2008–2011 are associated with aspects relating to ’silent deviations’. This implies that eliminating these failures should have a high priority in order to reduce the number of hydrocarbon leaks.

In Table 12 all the leaks associated with manual intervention (B & C type leaks) are presented. If we consider the interpretation that error in work practice may be closely associated with failure to comply with steering documentation, then it is only five of the 30 B & C events that are classified without any of the categories; failure to follow steering documentation and work practice error, as shown in Table 12.

Table 12 Overview of manual intervention cases (B & C) with root causes either as work practice error or failure to comply with steering documentation, NCS, 2008–2011

Event ID	Work practice	Compliance with steering documentation
0805	X	
0807		X
0809	X	X
0810	X	X
0811	X	X
0812	X	X
0904	None of	these
0906	X	X
0909	X	
0910	X	
0912	X	X
0913	None of	these
0914	X	
0915	X	
0916	X	X
1001	None of	these
1002	X	
1004	X	
1005		X
1009	X	
1012		X
1013	None of	these
1014	X	
1015	X	X
1102		X
1103	X	X
1105	X	X
1106	X	X
1108	X	X
1109	None of	these

IRIS report 2011/156 ('Learning from incidents in Statoil') has documented that lack of compliance has been essential for the Snorre A subsea gas blowout in 2004 as well as the well incident on Gullfaks C on 19th May 2010. This report also claims that compliance with steering documentation is a general problem within this company, strongly influenced by a complicated and unclear documentation system following the merger of ex Statoil's and ex Hydro's system as a consequence of the merger of the two companies in 2007.

7.8 A-standard

Statoil started late 2009 to introduce the concept 'A-standard' (Ellingsen, 2012). A-standard is a work pattern which describes the process in order to achieve good results. A-standard specifies how planning is performed, how tasks are carried out and evaluated when the performance is excellent. A-standard consists of dialogue, interactions and reflection. Use of A-standard shall reduce the likelihood of hazards to occur through:

- Ensuring that all personnel improve their ability to identify hazards.
- Ensuring that all personnel understand the hazards that are identified and that they are able to assess risk to health and safety associated with these hazards.
- Increasing the knowledge about how to reduce risk to health and safety.

It has been shown that the frequency of the most serious incidents and near-misses in Synergi has been significantly reduced in Statoil in the period 2010 and 2011 (2011 less than 50% of 2009 value). The reduction of the number of hydrocarbon leaks above 0.1 kg/s has so far (i.e. up to the end of 2011) been moderate.

7.9 Age of installation with degradation failure

Figure 16 shows the distribution of age of the installations at the time of leak, for leaks due to degradation failure only. It may be argued that maintenance 'friendliness' has improved since the early days, but modern installations are on the other hand more compact. We have therefore chosen to assume somewhat simplified, that age is mainly – if at all – a factor related to technical degradation.

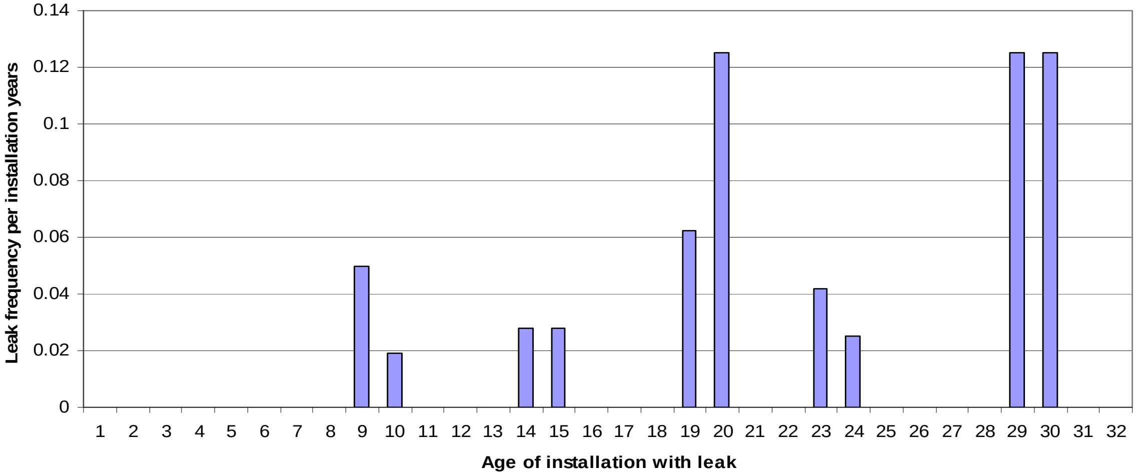

Figure 16 **Distribution of installation age when leak due to degradation failure occurred (n=13)**

It should be noted that there are two installations in Figure 16 that have experienced leaks in two consecutive years, which influence the trends significantly (this is due to the limited number of these leaks). This is the case for one installation with leaks at the age of 19 and 20 years, as well as another installation with leaks at the age of 29 and 30 years. The diagram would look quite different, essentially with random failures, without these four leaks.

The overall conclusion is that there is a very weak basis for the hypothesis that degradation failures are closely correlated with age. This has actually been considered in a few other studies, with the same observation; the correlation is impossible to substantiate.

This may confirm that preventative maintenance of safety critical equipment (such as process piping and fittings) should be implemented as intended. If there had been a clear correlation between degradation failures and age, it might have implied that process equipment was not replaced until it was severely degraded.

7.10 Leaks due to wrong gasket

There are some cases associated with installation of wrong gasket, but not as many as might be expected. There are more cases where a gasket has been involved, as shown below.

There are only two cases for NCS during the period 2008–2011 where wrong gasket has been installed, as shown in Table 13.

Table 13 Overview of cases where wrong gasket has been installed, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Failure description
0904	AP	B4	Leak in a flange due to wrong gasket installed and high pressure.
1013	P	B2	Wrong gasket was installed.

There are six cases where a gasket has been involved in the scenario for NCS during the period 2008–2011, but not associated with installation of wrong gasket, see Table 14.

Table 14 Overview of cases where gasket has been involved in the failure, but not wrong type gasket installed, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Failure description
0803	BW	B2	Plastic has been inserted between flange and gasket.
0811	BC	B2	Gasket blown out from flange due to bolts asymmetrically tightened up.
0813	BC	A4	Technical degradation (fatigue) in gasket.
0914	AI	B3	Erosion of hole in gasket in check valve due to particles in the well flow.
1009	AK	B2	Two bolts have worked loose, and gasket has ruptured.
1107	BK	A1	Stem gasket weakened due to flow in wrong direction.

In conclusion there are few cases where the wrong gasket has been installed, in fact only two during the last four years. Six other cases are reported where gasket has been involved in the scenario.

7.11 Leaks from packing boxes

Leaks from packing boxes are one of the hot topics, and it is therefore worthwhile to give an overview of the leaks associated with packing boxes during the period 2008–2011, and the causes of the leaks. Table 15 gives a summary of the leaks from packing boxes in the period 2008–2011. It should be noted that only one out of these five events was coded A1 (see Table 15) in the analysis, the others have different codes, but the failures are associated with failure of stem seal.

It is further noted that another analysis (company internal) identified eight cases of stem seal failure for the period 2005–08. Slightly more leaks occurred in that four year period, and the work also included some non-Norwegian installations. Therefore, the difference may be easy to explain due to different installations involved.

Table 15 Overview of cases where packing boxes have been involved in leaks, NCS, 2008–2011

Event ID	Installation code	Cause	Leak rate (kg/s)	Failure description
0804	AW	Defect packing box valve	1.2	Fragments have caused substantial damage to valve stem, bonnet and packing box. The valve design enables fragments to enter the valve from the process side, however it was not established whether the fragments had come from the process or from a surfacing weld.
0813	BC	Material defect in packing seal	0.9	Material defect has caused the packing seal to be damaged during the operation of a gate valve.
1002	AU	Inadequate material in packing box seal	0.4	A program with replacement of stem seals had been carried out. When the actual valve was replaced, a valve with the old type of seal had been supplied from onshore.
1003	AU	Inadequate material in packing box seal	0.4	Same cause as Event ID 1002, but the real cause of the leak was not discovered.
1101	BK	Stem seals not with correct tolerance	0.5	During depressurising of a gas injector flow line, an internal leakage on one of the two isolation valves on the gas injection manifold was discovered. As the second isolation valve was being closed, a gas leakage from this valves packing box occurred. Initial pressure in the piping was approx. 290 bar g. It was possibly the first time the valve had been closed with full pressure. Valve packing box was not within necessary tolerance criteria in relation to ring gaskets (packing) installed during maintenance of valve/packing box.

There are unique causes of all these cases, as can be seen from Table 15, but all of the leaks are associated with some kind of failure of the stem seal, either due to fragments, inadequate material or with wrong tolerances.

One of the investigation reports has an overview of packing box leaks in the company in the period 2000–2010, 21 leaks included in the overview, of which one red and two yellow, and the remaining 18 leaks are green, i.e. below 0.1 kg/s. But not all the relevant leaks in Table 15 are included, therefore the overview cannot be complete as far as the classified yellow and red leaks are concerned.

The observation from Table 15 and the company internal study referred to above is that stem seal leak is an important category, but probably more important for leaks <0.1 kg/s compared to leaks >0.1 kg/s.

7.12 Leaks from temporary hoses

Table 16 shows the leaks from the period 2008–2011 where a leak has been caused by errors in the use of temporary hoses. It is shown that all the three cases where this was the fundamental error, bleed or depressurization was established to an area where it should not have been located.

Table 16 Overview of cases where mal-operation of temporary hoses have been involved in leaks, NCS, 2008–2011 (see Table 1)

Event ID	Installation code	Scenario	Failure description
0912	AU	C3	Sufficiently long hose was not readily available and bleed to closed drain was therefore skipped.
1004	AI	B6	Hose to closed drain was not used.
1103	AG	B6	Bleed was made to inadequate area.

8. References

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