10 Causes and measures related to well control incidents in Norwegian petroleum activities

10.1 Introduction

The negative development in the period 2008-2010 related to reported well control incidents on the Norwegian shelf[1] and experiences following the Deepwater Horizon accident in the Gulf of Mexico in 2010 have reminded the petroleum industry of the risk potential in well control incidents[2].

Here, we[3] will present results from a study connected to (1) key causes of well control incidents on the Norwegian shelf, (2) what measures are proposed/implemented, (3) whether there is sufficient accordance between identified causes and measures and (4) how the petroleum industry can continue working to reduce the number of well control incidents. The study is based on a review of investigation reports and incident reports, other reports and documents submitted by the industry, as well as interviews with select personnel in the industry.

10.1.1 Challenges in connection with drilling and well operations

Drilling and well operations are characterised by considerable complexity and represent the largest percentage of costs on the Norwegian shelf. A number of involved players must interact and the technological development is driven forwards rapidly by deeper wells and more complex reservoirs. A significant activity level with frequent reorganisations and other changes in interaction with the players, results in challenges to competency associated with, for instance, well control. Operative decisions that are critical as regards safety are often made during demanding conditions with great uncertainty. Key decision-makers could also face goal conflicts where the efficiency and cost reduction requirements could impact safety. Costs related to downtime (stopped operations) are high. The drilling supervisor and toolpusher could experience high work pressure (Forseth, et al., 2011). Integrated operations with experts in distributed teams require information flow and good decision support. The interaction between humans, technology and organisation will thus be the key to maintain safe drilling and well operations.

Exploration and field development in new and marginal oil and gas provinces and the industry's ambitions for improved oil recovery (IOR[4]) with extended plateau production on producing fields results in new safety challenges. Use of advanced well technology and IOR techniques for stimulation and pressure support in the reservoir are crucial for more efficient drilling and increased production, but also result in challenging dynamic temperature and pressure conditions in the well. More stringent requirements for monitoring safety and the ability for continuous well control in all phases of a well's lifetime are a natural consequence of the margins being stretched. The most easily available occurrences of oil and gas are drained and new fields include wells in more complex and

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[1] http://www.ptil.no/risikonivaa-rnnp/category20.html

[2] In RNNP, a "well control incident" is defined as follows: Well control incident means inflow of formation fluid in the well, with pressure build-up with a closed BOP, after positive flow check. The kill method is determined and implemented. For a more detailed definition of well control incidents, reference is made to Chapter 6.3.1. Note that the definition is limited to incidents that take place in the well's structure or completion phases, and does not include incidents during the operations phase. Figure 50 shows the development in the number of well control incidents from 1996-2010, normalised per 100 drilled wells.

[3] In this chapter the pronoun "we" refers to the researchers that carried out this study.

[4] IOR: Improved Oil Recovery.

unfamiliar geology. The trend is deeper and more complex wells, often combined with operations in steadily deeper waters far from land.

Control of the technical condition of the well's barrier elements becomes more critical with extended use, e.g. related to issues regarding aging and wear, but also outdated and partially missing documentation. This particularly applies to the permanent components such as casings and cement. The challenges and costs of permanent plugging and abandonment of old wells is partly neglected area which will require development of new, safe and cost-efficient techniques. This is so that such operations can be implemented in reasonable time and at an acceptable price. In summary, the future challenges within drilling and well operations stipulate considerable requirements for up-to-date competence, but also development and qualification of new technology. Drilling and well operations represent a steadily larger percentage of the field development costs and time. Rigs availability is a crucial element in this. Drilling with advanced and automated rigs and well equipment with associated services, have become more specialised and high-tech.

A driller's control system is currently based more on computerised systems than analogue and easily recognisable physical systems and instruments. The competence requirements for safe handling of advanced, large and heavy equipment, changes the requirements for training with need for continuous training and follow-up. Safe drilling, in theory, deals with relatively simple principles such as having continuous hydrostatic control in the well and the possibility for quick correction in the event of imbalance. However, this can still be complex in practice. A well's "drillability" is an important term and requires a dynamic balance between pressure and stability in the well to prevent hydrocarbons from flowing in the well and potentially up on the facility. More complex systems in the well for dynamic control of the well's pressure conditions through use of pressure sensors and valves, as well as juggling multiple mud systems, pose significant requirements for awareness, the ability to interpret information and form a correct situational understanding, and for effective alarm systems.

10.1.2 Objective and issues

The objective of the study was to describe challenges which the petroleum industry can tackle to reduce the number of future well control incidents. The topic is addressed through a review of available documentation on well control incidents in the period 2003-2010, interviews with professionals in the industry, as well as a review of literature and other materials received from the industry[5].

The following main issues were addressed in the study:

1. What emerge as the key human, technical and organisational causes of well control incidents on facilities on the Norwegian shelf?
2. What are the most key measures proposed/implemented to reduce the number of well control incidents?

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[5] Members of the Norwegian Oil Industry Association's (OLF's) Drilling Managers Forum have contributed actively on gaining access to key informants and contacts in relevant operation and contractor companies in connection with this study.

3. Is there accordance between identified causes and proposed/implemented measures?

4. How can the petroleum industry continue working to reduce the number of incidents?

Other topics discussed include the companies' implementation of risk analyses and application of risk analyses when establishing barriers.

10.1.3 Method

The study was carried out as a combination of document reviews and interviews with select professionals. Important sources of information have included:

- Investigation reports
- Incident reports (from Synergi, etc.)
- Other relevant documentation received from the industry, including an overview of causes and measures, as well as well control procedures.
- Various reports from different research environments, consultant firms, authorities and industry organisations.
- Interviews with professionals from three operating companies and three drilling contractors (33 people in total).

10.1.3.1 Review of investigation and incident reports

A crucial part of the work has involved a detailed review of available investigation and incident reports. The data material includes the following reports and types of incidents:

- For the period 2003-2010, a total of 146 well control incidents have been registered. Of these, 117 are classified in Category 1 ("Regular"), seven in Category 2 ("Serious"), three in Category 3 ("High Risk"), 17 in Category 4 ("Shallow Gas") and one incident in Category 5 ("High Risk Shallow Gas").
- For ten of these incidents (in Categories 2-5), we had access to investigation reports, of which two incidents were investigated by both the operating company and the Petroleum Safety Authority Norway (PSA).
- The investigated incidents comprise four operating companies and six drilling contractors, and a total of eight different facilities/rigs.
- Focus has been directed at causes and measures that can reduce the frequency of well control incidents. In total, the reviewed company investigations contain 38 registered triggering causes, 56 underlying causes and 74 proposed measures. Causes and measures related to consequences, as well as emergency preparedness related factors are discussed to a small extent.
- For another 21 of the incidents (in Categories 2-5), we have had access to Synergi type reports or similar.
- Includes incidents related to exploration and production drilling (incidents during well intervention are not included in the definition of "well control incidents").
- Includes incidents during drilling from mobile facilities (rigs), as well as fixed production facilities.

As a basis for the review of investigation reports and other information related to incidents, a classification form has been developed for indicated causes and proposed measures. The form used to categorise triggering and underlying causes and the type of measures is shown in Table 29[6].

Table 29 Classification form for triggering and underlying causes and the type of measures for well control incidents

General	**Specified type of cause or measure**
Human	Error type slip/ carelessness / mistakes
	Cognitive error (due to deficient expertise and/or risk understanding)
	Error directly connected to poor/deficient design
	Error connected to breach of applicable practice/procedures
Organisation	Company management, facility management
	Work management
	Risk assessments/analyses (SJA, etc.)
	Planning/preparation
	Procedures/documentation
	Work practice/operational follow-up of the barriers
	Work load
	Inspection/check/verification
	Communication/cooperation/interfaces
	Competence/training
	Goal conflicts – safety/efficiency
	Change management
Technology	Technical well design (cement, plugs, casings, etc.)
	Technical fault in, or inadequate detection of well kick
	Technical fault/weaknesses in primary barriers/mud column
	Technical fault/weaknesses in secondary barrier/BOP
	Other technical equipment fault or weaknesses in safety-critical equipment
	Ergonomics/human-machine interface/design of workplace
	External causes – geology and reservoir

Note: Generally, “deficient” can be put in front of the organisational causes

It should be noted that, for instance, “insufficient mud weight” or “unforeseen conditions in the reservoir” in this study are classified as technical triggering causes (classified under “technical fault/weaknesses in primary barrier/mud column” and “external causes – geology and reservoir”, respectively). The cause of such weakness is not necessarily connected to technical equipment failure, but could be due to deficient planning or risk assessment. This will then emerge as an underlying cause.

In the analysis, the data material has been normalised so each well control incident has the same weight. This was done to avoid an incident with, for instance, five identified underlying causes weighing five times as much as an incident where only one such cause is described. Therefore, for each incident, the sum of direct causes is distributed in different categories represented with a total

[6] A basis was taken in the three main categories, Human, Technology and Organisation (HTO). The further distribution is based on a hybrid of multiple methods and approaches, including, among others “Operational Condition Safety” (OCS) (Sklet et al., 2010), literature related to human reliability and human errors, as well as the project employees’ own experiences.

of 1. The same was done for underlying causes and measures. These shares form the basis for the summation from all investigations and calculation of percentage distribution indicated in the result presentation.

10.1.3.2 Other reports and documentation

In addition to investigation reports and incident reports, we have received extensive written material from the industry (total of 18 companies; eight operating companies and ten drilling contractors), which has e.g. included:

- Tables with a description of key causes which the companies' experts believe lead to increased risk of well control incidents
- Tables with measures *implemented* by the companies, and also *possible* future measures
- Different well control procedures and manuals

This material was used as a foundation for interviews and as supplementary information when analysing the data material.

Reports from various research environments, consultant firms, authorities (PSA and BOEMRE[7]) and industry organisations (OLF, OGP[8]) have also been used as a basis. The following is noted:

- Reports following the Deepwater Horizon accident (Chief Counsel's Report, 2011; Petroleum Safety Authority Norway, 2011c; Tinmannsvik et al., 2011)
- DNV/PSA's report on human factors in drilling and well operations (Jærnes et al., 2005)
- IRIS'[9] investigation of the Gullfaks C incident (Austnes-Underhaug et al., 2011)
- Reports from the PSA's project: "Framework conditions' significance for working environment risk and major accident risk" (Forseth et al., 2011; Rosness et al., 2011a; Rosness et al., 2011b)
- Reports and results from the OMT[10] and PDS[11] projects

10.1.3.3 Interviews

In the period 2002-2009, 158 hydrocarbon leaks were reported (> 0.1 kg/s) on Norwegian production facilities, of which about 130 were investigated. Compared with hydrocarbon leaks and other incidents with major accident potential, very few investigations have been carried out in relation to well control incidents. As discussed above, we have, for instance, only had access to investigations from ten relevant incidents on the Norwegian shelf for the period 2003-2010. In addition to the

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[7] The US BOEMRE ("Bureau of Ocean Energy Management, Regulation and Enforcement"), previously Minerals Management Service (MMS), was, on 1 October 2011, replaced with the "Bureau of Ocean Energy Management" (BOEM) and the "Bureau of Safety and Environmental Enforcement" (BSEE). One of the main objectives of the reorganisation was to separate management and allocation of resources (BOEM) from safety-related issues that are now organised under BSEE (http://www.bsee.gov/)

[8] OGP: the "International Association of Oil and Gas Producers" has, in the aftermath of accidents such as Montara and Deepwater Horizon, prepared international guidelines for preventing and reducing the consequence of well control incidents, see www.ogp.org.uk

[9] IRIS: «International Research Institute of Stavanger»

[10] OMT: A project which integrates organisational, human and technological factors in development of a model for quantification of barrier performance (related to major accident risk), see www.preventor.no

[11] PDS: Reliability of computerised safety systems, see www.sintef.no/pds

information documented in incident reports and investigation reports, information has also been gathered through interviews with professionals in the industry. The interviews are a supplement to the written information and have ~~also~~ provided the possibility for gaining information that, to a limited degree, is highlighted in the written material. Examples are related to barrier management, use of risk analyses, perceptions on framework conditions and routines and practice that impacts the risk of well control incidents.

Types of personnel interviewed:

- Drilling supervisors (offshore)
- Toolpushers and drillers (offshore)
- Drilling and subsea contractors (offshore/onshore)
- Operations managers/rig managers (onshore)
- Managers/technically responsible for well operations (onshore)
- Responsible for maintenance (onshore)
- Operational advisers – drilling and well (onshore)

In total, 18 two-hour interviews were held with six companies; three operating companies and three drilling contractors. The companies cover drilling from both floating and fixed facilities. The interviews were carried out as one-on-one interviews or group interviews and a total of 33 people were interviewed.

10.2 Results from the review of investigation and incident reports

The investigation reports form the primary data basis for the result presentation. To compensate for a small number of investigated incidents (ten incidents), a paragraph has been included at the end of each section which presents results from similar analyses of incident reports (Synergi reports, etc.)

10.2.1 Triggering causes

The triggering causes identified from the investigation reports are dominated by technical factors (67%), cf. Figure 152.

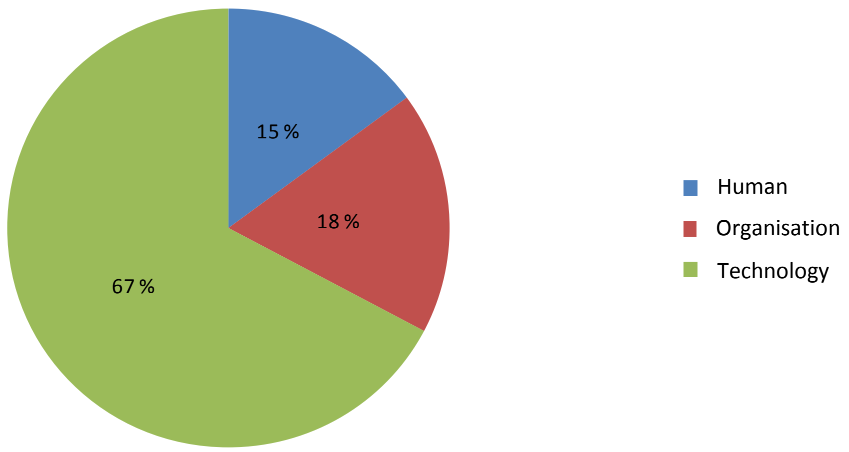

Figure 152 Triggering causes of well control incidents distributed by human, organisation and technology

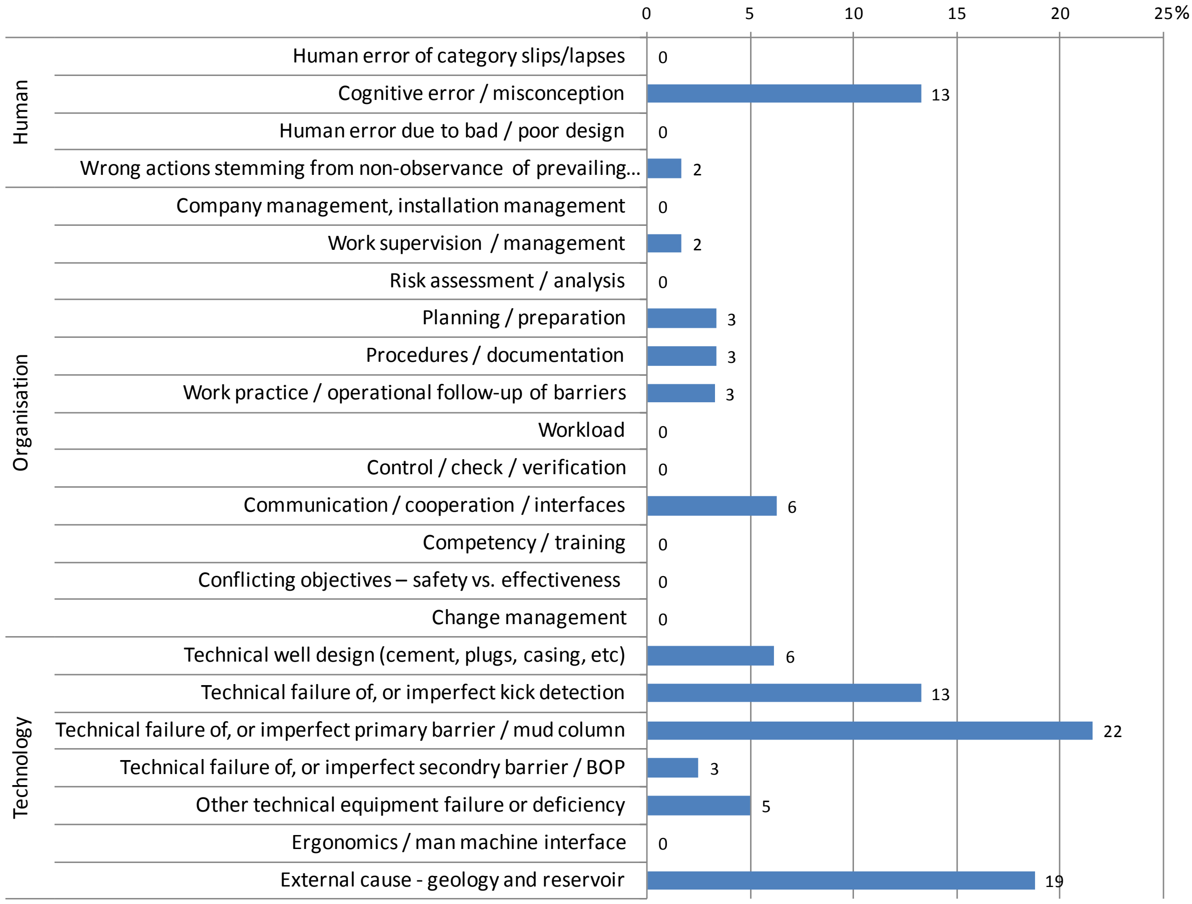

Figure 153 Percentage distribution of triggering causes for well control incidents based on internal company investigations.

Furthermore, from Figure 153 we can see that the three most common technical causes are:

- "Technical failure of, or imperfect primary barrier/mud column" (22%)
- "External cause – geology and reservoir" (19%), and
- "Technical failure of, or imperfect kick detection" (13%)

It should be noted that the triggering causes – particularly the two first – are closely linked. As a result of unforeseen conditions in the subsurface/reservoir a consequence could be using the incorrect mud weight and this could contribute to a well kick. Failed or deficient detection of the well kick could in turn entail that the situation becomes more critical than necessary. It is also noted that inadequate detection is closely related to the interaction between human/technology and can have human causes ("deficient awareness and attention") and/or more technical causes.

Specific examples of recurring technical causes include: "Too low/insufficient mud weight", "higher pore pressure than expected", "unforeseen gas in the formation", "unforeseen shallow gas", "deficient alarms/sensors", "poor placement of sensors" and "deficient synchronisation between systems". As an explanation of why there was an incorrect mud weight and/or unforeseen conditions in the well, reference is made to deficient risk assessments or preparations in several of the incidents. See sub-chapter 10.2.2.

As you can see from Figure 152 and Figure 153, human and organisational causes are to a limited degree classified as directly triggering. However, the following two categories have relatively large contributions:

- Cognitive errors (faulty assessments due to lack of competence and/or risk understanding) (13%)
- Deficient communication/cooperation/interfaces (6%)

Corresponding analyses of incident reports (Synergi reports, etc.)
In general, the review of incident reports takes place at a much more general level than the investigation reports, and shows that 91% of triggering causes are related to technical conditions. The majority of this is in external causes related to geology and reservoir (60%). No triggering causes have been classified under organisation, while a total of 8% has been classified as human error. It should be noted that a large share of the incidents where only Synergi reports or similar are available are shallow gas incidents, and that this could impact the distribution of causes.

10.2.2 Underlying causes

Based on the reviewed internal company reports, a classification was carried out of underlying causes in relation to the categories H, T and O, as shown in Figure 154 and Figure 155.

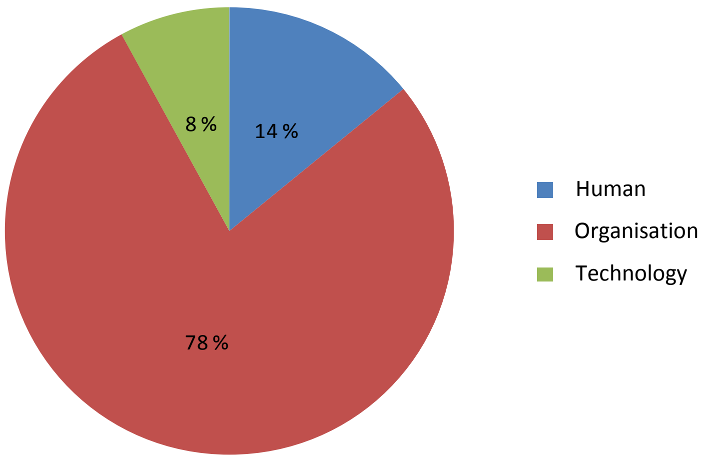

Figure 154 Underlying causes for well control incidents distributed by human, organisation and technology

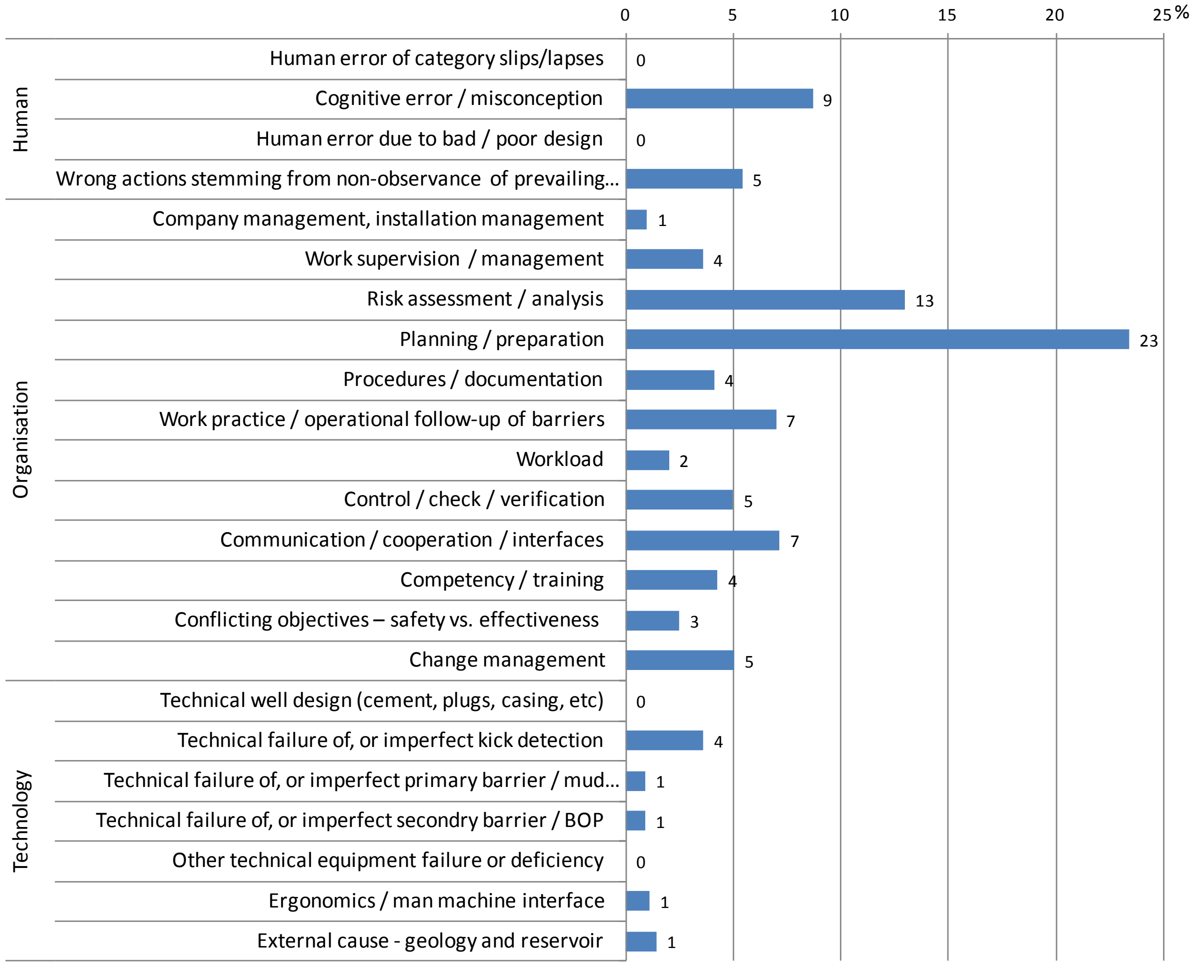

Figure 155 Percentage distributions of underlying causes of well control incidents based on internal company investigations

Underlying causes are related to circumstances and conditions that are present prior to the actual well control incident. It is therefore reasonable that organisational factors play an important part. In our review we see that organisational factors constitute as much as 78% of the defined underlying causes. From Figure 155, we see that the most key contributors within this category have emerged as:

- Deficient planning/preparation (23%)
- Deficient risk assessments/analyses (13%)
- Deficient communication/cooperation/interfaces (7%)
- Deficient work practice/operational follow-up of barriers (7%)

Deficiencies in planning/preparation and risk assessments/analyses constitute as much as 36% of the underlying causes. Examples of recurring causes within these categories are “too poor predictions of pore pressure”, “deficient description of barrier situation”, “risk assessments/risk registry did not detect risk of gas” and “underestimating the risk picture”.

As discussed in the previous sub-chapter on triggering causes, deficient risk assessments and/or preparations are often an explanation of why the incorrect mud weight was used or for having run into unforeseen geological conditions. This could involve the risk analysis identifying the problem, but not assigning this sufficient focus (“the risk analysis for the well included the risk for higher pressure, but this was classified as *Low*”), or the analysis did not detect the risk at all (“risk assessments did not address possibility for gas/pressure build-up” or “the Risk-It document does not address risk of gas during the operation”). Reference is also made to deficient preparations and interpretations of seismic data without this being explicitly explained in deficient risk analyses (“prediction of pore pressure during planning phase did not predict the possibility for water breakthrough from surrounding zone”). The common denominator for the investigation reports is that they to a small degree, or not at all, indicate how the risk assessments could be improved.

Note that deficient planning and risk assessment are also closely linked with the H category “Cognitive error (due to deficient competence and/or risk understanding)”, which constitutes a considerable 9%. Deficient assessments prior and/or during the operations are connected with deficient competence and risk understanding and, together, these categories constitute 45% of underlying causes in our survey. Examples of causes within the “deficient communication/cooperation/interfaces” category are that input from colleagues is not given good enough treatment, that the established expert environment has not been sufficiently involved in operational decisions and that, in general, there has been too poor communication between technical disciplines both prior to, and during operations.

As regards the deficient work practice/operational follow-up of barriers” category, examples here are “deficient quality assurance when using perforation equipment”, “deficient understanding of the need to carry out risk assessments” and “too late response to warning signals/too poor follow-up of developing situation”. The latter example can also be tied to the category “goal conflicts – safety/efficiency”, where we have some examples that the operative personnel have had too much focus on other simultaneous activities, instead of on the well control situation that was about to develop.

Corresponding analyses of incident reports (Synergi reports, etc.)
To the degree underlying causes are identified, the review of the incidents based on Synergi and other incidents strengthen the main characteristics vis-à-vis the greatest contributors. A total of 78% of the underlying causes are classified under organisational factors, of which 43% are explained as deficient planning/preparation, while 10% are classified as deficient risk assessments/analyses. Then there is 7% in work management, procedures/documentation and competence/training.

10.2.3 Measures registered in investigation reports
Based on the reviewed investigation reports, identified measures were classified according to the HTO categories. Of the measures described in the investigation reports, 78% are classified as being organisational in nature, 19% are technological and 3% are human. In this connection it should be noted that measures directed at increasing competence and training, are classified under organisation (“competence/training/risk understanding”).

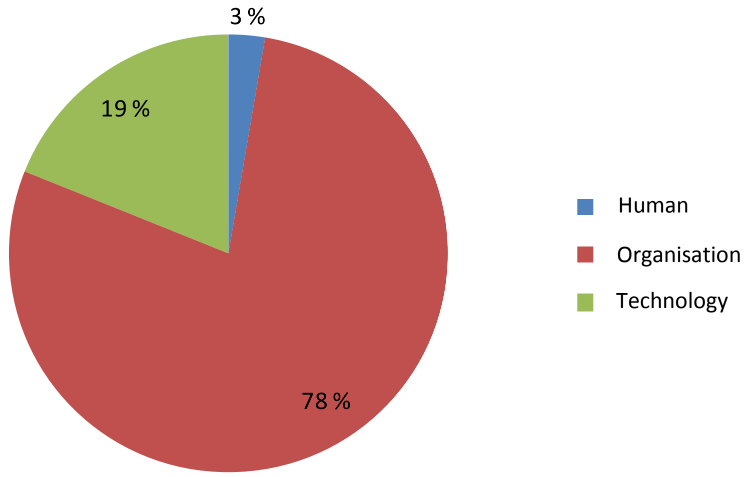

Figure 156 Proposed measures in investigations following well control incidents distributed by human, organisation and technology

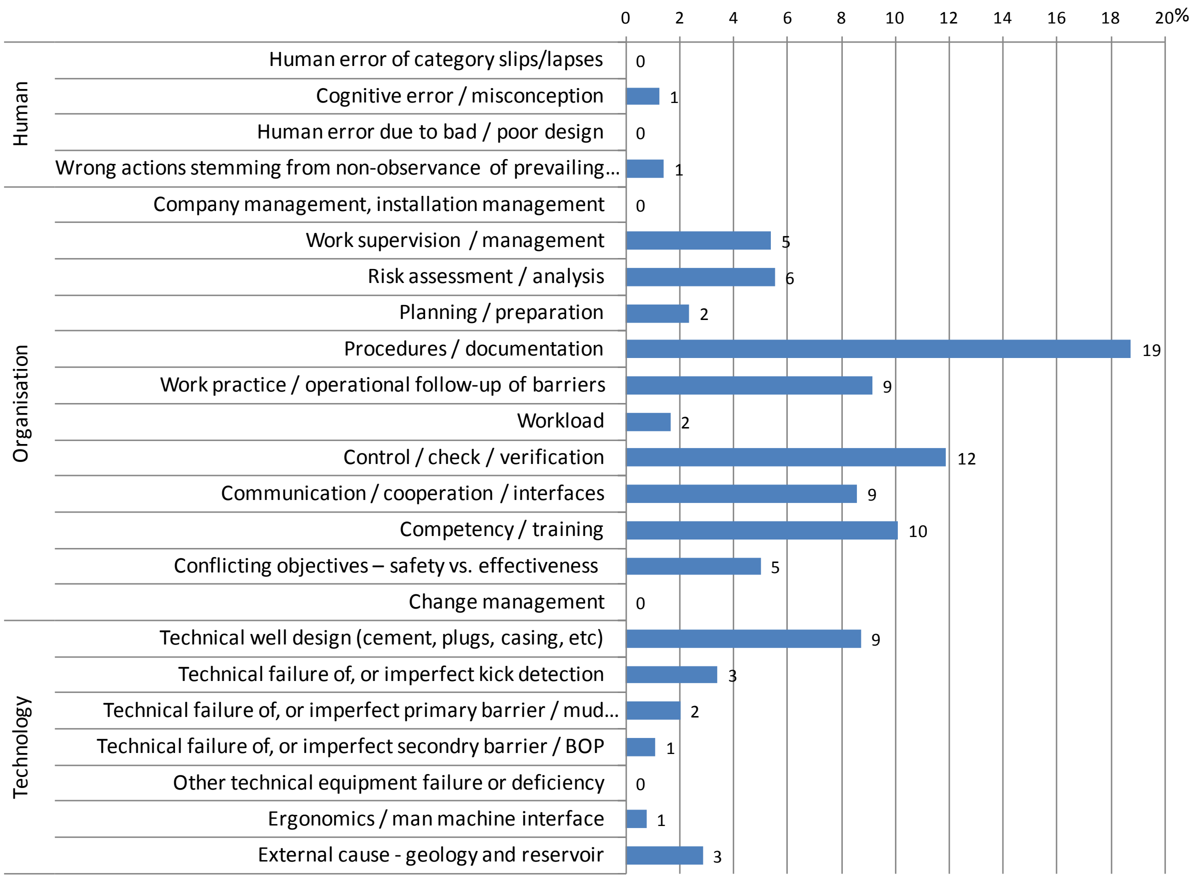

Figure 157 Percentage distribution of proposed measures following well control incidents in internal company reports

Figure 157 shows that the top five categories of proposed measures are:

- Improvement of procedures/documentation (19%)
- Increased or improved control/check/verification (12%)
- Strengthening competency/increased training (10%)
- Improved work practice/operational follow-up of barriers (9%)
- Improved technical well design (9%)

Measures connected with improvement of procedures and governing documentation constitute the largest category of measures with a total of 19%. Examples of such measures include "defining procedure for shutting in wells", "establish routine for improving planning phase", "drilling contractor should prepare a checklist for activating set points and alarms following a shutdown" and "the operator's procedure must be updated and harmonised with the drilling contractor's procedure".

As regards the two next categories of measures in the top five list above, some examples of measures in the inspection/check/verification category include: "Check and verify the well kick detection system", "evaluate the possibility for installing a high-high alarm on return flow that is not supposed to go off during normal connection" and "use a third party for independent verification of critical well programmes". Examples of measures to strengthen competence and training are "strengthen knowledge of governing documentation", "strengthen knowledge of well control and barriers" and "make a case out of the incident to use in connection with training on the rigs".

In general, when we look at the measures proposed in investigations, these are relatively concrete, which is considered positive as regards the possibility of them being implemented. However, there are examples of the opposite, where the indicated measures will require considerable work before they can be implemented, such as: "In the event of significant changes to the well plan, the next level of management must be informed", "measures must be implemented in order to carry out actual time readings of the trip tank" and "to maintain a focus on well control, the drilling contractor must consider whether well service companies can take over greater responsibility for monitoring the well in clearly defined periods". For some cases, such as in the last example, the reason why the measures are not very concrete is because the operating company has carried out an investigation and identified measures which the drilling contractor must define further.

Corresponding analyses of incident reports (Synergi reports, etc.)

The review of non-investigated incidents based on Synergi and equivalent incident reports paints a somewhat different picture of how the measures are distributed. Here, as many as 72% of the measures are classified technical in nature, of which 42% are directed at improvements in the primary barrier/mud column. We see that these measures pick up the most significant shallow gas conditions that are categorised under the "external causes – geology and reservoir" cause. Typical measures for recycling the primary barrier is weighing and pumping kill mud to stabilise/kill the well. Another significant percentage of measures (23%) are directed at technical well design. A common measure here in relation to shallow gas, is plugging and abandoning location. You then set a cement plug a few hundred metres directly in an open hole above the zone. The alternative is measures that make it possible to continue drilling the well after well kill has been carried out. The well is then first cemented back, whereupon you drill out and set (cement) a casing over the gas zone (shallow 20" casing). You then install a "marine riser" and BOP. Now the mud weight can be increased sufficiently to balance the counterpressure in the well, and you can drill safely through the shallow gas zone. The remaining measures are classified under organisational factors where planning/preparation and procedures/documentation constitute the largest contributions with 15% and 8%, respectively. Mainly, this deals with better routines with pre-studies of new areas and greater consideration to shallow gas in planning.

As we can see, the distribution of measures in Synergi reports deviates considerably from the measures defined in investigation reports. The Synergi reports primarily represent shallow gas incidents and specified measures are often linked to operational technical measures to gain control with the well, and then start drilling again. This means that the measures are directed at the specific incident. However, investigation reports have a greater focus on underlying causes – which are often organisational – and the measures are directed at preventing new similar incidents from occurring again.

10.2.4 To what extent is there accordance between identified causes and measures?

An important issue we want to highlight in this study is to what extent there is accordance between identified causes and the measures described in the investigations. Figure 158 shows a comparison of identified causes (direct and underlying) and proposed measures following investigations conducted.

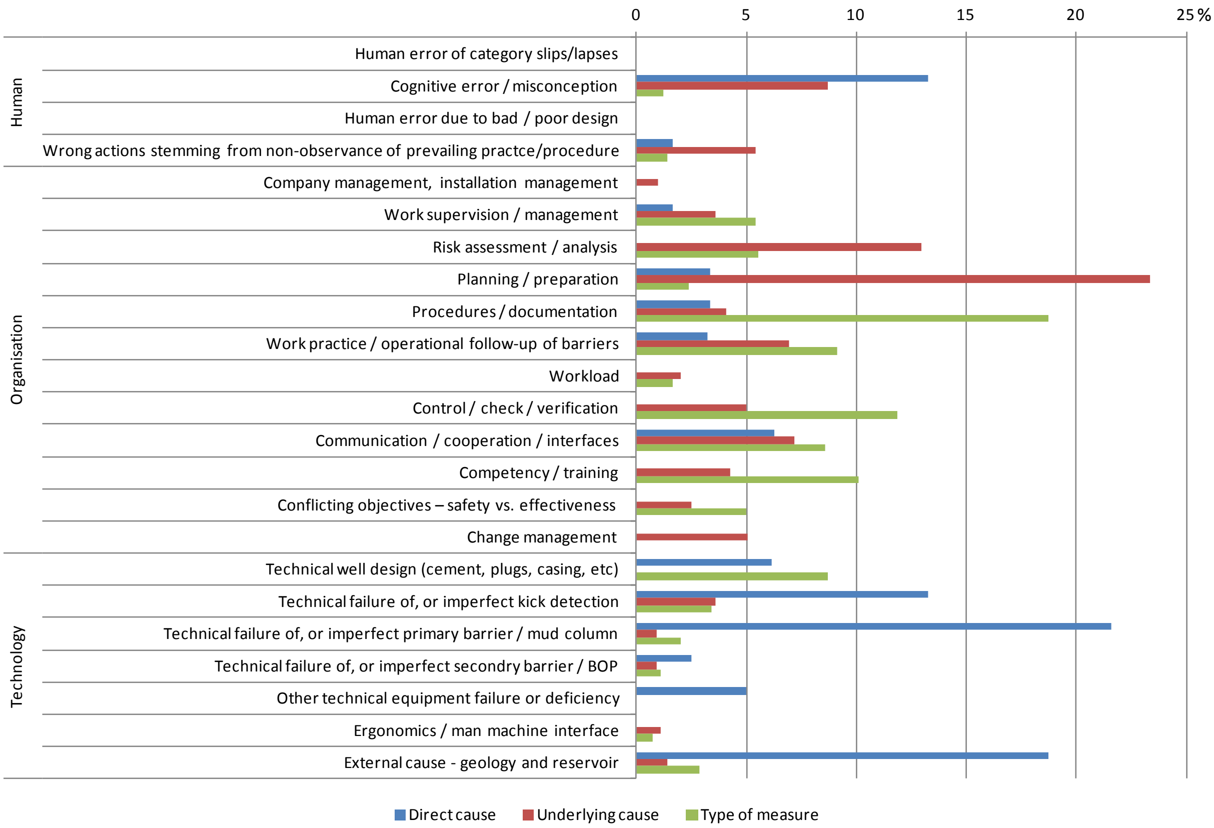

Figure 158 Comparison of identified causes (triggering and underlying) and proposed measures following well control incidents for the internal company investigations

Immediately, we can see from Figure 158 that there is no direct accordance between triggering and underlying causes and type of measures. First we can determine that it will not necessarily be natural to have a one-to-one ratio between causes and measures. For instance, it may not be possible for technical triggering causes to be solved through design changes or other technical measures, but it might require organisational measures such as new maintenance routines or better training. However, some of the disparity between causes and measures could be worth noting in particular:

- Similar as in the *HC leak study from RNNP 2010*, we see many measures to improve governing documentation, even though deficient procedures are to a limited extent identified as a causal problem.
- Furthermore, the percentage of technical measures is small if seen in relation to contributions from technical faults and deficiencies in triggering causes. As discussed above, this could in some cases have a natural explanation. As regards, for instance, a technical fault in, or deficient systems for well kick detection, there is however a reason to ask why this has not triggered technical system improvements to a greater extent. This is discussed in more detail in sub-chapter 10.7.
- Weaknesses in the mud column, which is an important triggering cause, often deal with deficient pore pressure predictions rather than technical equipment failure, and that is why it is natural that this has to a little extent been followed up with technical measures directed at the actual mud treatment systems. You would expect that these causes, together with external causes related to reservoir and geology, would be followed up with measures that describe how to improve reservoir predictions in the future. However, this is to a limited extent the case, and a general impression is that most measures are connected to improving the handling of the well situation *given* inflow in the well has already taken place.
- Inadequate proactive focus for measures has also emerged, as a limited percentage of the measures are directed at better planning, preparation and risk assessments – despite such factors contributing to a total of 36% of the underlying causes. Some of this can be explained by measures directed at “procedures/documentation” being partially related to improved planning, but in general, a majority of the measures deal with better handling of the nonconformity situation, rather than avoiding the situation in the first place.
- From Figure 158 we can see that multiple measures are classified under the category “control/check/verification”, while this contributes little as regards causes. A review of these measures show that they are generally along the lines of “check possible improvements in a technical system design”, “assess work practice and distribution of tasks” and “carry out an independent verification of interpretation of seismic data”. Whether such checks and verifications have resulted in concrete system changes is uncertain, but based on the interviews, the responses from the companies and investigations, it generally seems concrete technical measures have a limited focus.
- We see that several measures are classified under “training/competence”, while this category contributes little as a causal factor. An explanation of this is that errors in relation to deficient competence are classified under “human”, while training and competence strengthening measures are classified under “organisation”.
- Our review of the investigation reports shows that “change management” contributes five per cent of underlying causes. In addition, review of accidents/incidents such as Deepwater

Horizon and Gullfaks C shows that deficient change management and documentation related to changes in drilling operations is a problem. There is therefore reason to question the fact that no measures from the investigations can be explicitly linked to improved change management.

Corresponding analyses of incident reports (Synergi reports, etc.)
When we look at the incidents for which there is only a Synergi report or corresponding incident report, we see that there is far better accordance between the triggering causes and choice of measures. As discussed earlier in the chapter, this is mostly due to the Synergi incidents being shallow gas incidents where measures are directed towards the triggering causes to gain control of the specific incident, and there is therefore a large degree of accordance between direct causes and measures.

As regards underlying causes, "deficient planning/preparation and risk assessments" represent a total of 53% of the non-investigated Synergi incidents. However, it is worth noting that only 15% of the measures for these incidents appear to be directed at such conditions or deficiencies. In summary, this indicates that for incidents that are only reported in Synergi or similar, technological factors are mainly emphasised when defining measures, while organisational measures are to a greater degree emphasised in investigated incidents.

10.3 Results from the review of written documentation from the industry

This sub-chapter provides an overview of what the operative managers and professionals within drilling and wells in the companies indicate as key causes of well control incidents, as well as what measures the company has implemented to reduce the risk of well control incidents. A general picture of how the operating companies and drilling contractors perceive the effect of implemented measures[12] is also provided.

Several companies highlight the following causes:

- Deficient risk assessment, particularly in connection with changes to plans
- Deficient competence, communication and change management
- Deficient planning and poor mapping of reservoir conditions that could result in an insufficient margin between pore pressure and cracking pressure
- Unexpected shallow gas when drilling, shut-in gas under plugs, behind casings and similar when re-opening existing wells

Deficient risk assessments followed by deficient competence and communication are the most recurring underlying causes according to the responses from the operating companies. With drilling contractors, recurring causal factors include a deficient understanding of phenomena and competence in relation to conditions during well control. This is often attributed to the use of consultants and partially inexperienced personnel in key positions.

[12] Here, information acquisition is based on a form for description and assessment of implemented measures that was used in last year's study on hydrocarbon leaks in the process area (prepared by OLF). This was supplemented by a separate form for assumed causes. These forms were sent to a total of 18 companies, of which about two-thirds of the companies responded.

In questions on what measures the companies have implemented to reduce the number of well control incidents, the following measures are popular in the companies' feedback:

- Intensified training of personnel involved in well control situations
- Clarification of the requirements for risk management/risk analyses and operational risk during drilling and well activities/operations
- Establishment of a "good standard" in the companies for implementation of drilling and well operations, including defining the best practice
- Further develop procedures, including manuals for well control in line with the best practice
- Drilling a pilot hole[13] with weighted drilling mud prior to tophole sections on exploration wells
- Introducing inspection of measures for verification of well barriers in all operations
- Organisational measures that aim to build competence and spread experience and knowledge. Organise internal seminars and gatherings with topics within drilling and wells with major accident focus. Contribute actively in different external forums (OLF's Drilling Managers Forum) and in standardisation work.

Informants from the operating companies express a somewhat mediocre belief in the effect of making more thorough risk analyses. There is greater faith in competence-increasing measures to reduce the number of well control incidents. An important factor here is measures that ensure involvement of the correct technical competence in relation to the challenges you face during operation. Competence-increasing measures are mostly within topics such as well integrity and verification of barriers during different drilling and well operations.

Among the drilling contractors, risk assessments are generally not discussed as measures. They have the greatest faith in measures directed at improvement of procedures/instructions and compliance with these. The drilling contractors also have great faith in training measures and experience sharing.

10.4 Results from interviews

This sub-chapter repeats key findings and observations from the interviews without these being discussed or interpreted specially (this is done in sub-chapter 10.5 and beyond). Both positive and negative aspects of the industry were noted in the interviews, but since this study intends to find areas the petroleum industry can take charge of to reduce the number of well control incidents, the focus in repeating the findings from the interviews lies mostly on challenges and improvement areas.

10.4.1 Causes of well control incidents

10.4.1.1 General – causes considered most important

In general, the informants largely focused on "the human element" when we asked them to point to main causes of well control incidents. More specifically – in relation to humans' roles in well control incidents – the following factors were repeatedly emphasised:

- *Competence*. The formal competence is generally in place, but practical experience/actual competence may be lacking

[13] Pilot hole entails drilling a hole in two steps, first with a small diameter as a "safety check". This makes it easier to control the pressure and prevent an extensive blowout.

- *Attention/awareness*. Experience from different incidents shows that the warning signals were there, but these were for various reasons not perceived or taken into account
- *Compliance*. The procedures are generally perceived as "good enough", but they are not always followed – which could be due to inadequate knowledge of the procedures
- *Planning*. Failures during the planning phase are mentioned by many, both in relation to deficient reservoir/pressure predictions and inadequate risk assessments, generally
- *Culture for speaking up*. Having a culture where you can report and/or stop if you are uncertain, is emphasised as absolutely crucial, and something the industry itself believes it has improved on.

These factors are discussed in the following sub-chapters. As regards deficient attention/awareness with operators, this is discussed in relation with systems for well monitoring/detection of well kicks, while deficient planning is discussed in connection with the sub-chapter on use of risk analyses in connection with planning and implementation of drilling operations (sub-chapter 10.4.2).

10.4.1.2 Competence and training

A topic very many informants were concerned with was related to the competence level of operative personnel. It is generally emphasised that the theoretical competence is good, but that practical competence and experience is usually lacking, including detailed knowledge of the technical equipment.

The explanations of why operative personnel lack practical experience differ; it is noted that there was a "boom" in the industry in recent years with many new rigs and major circulation of people and that the experience level has generally declined as a result of this. It is therefore a considerable challenge for many companies to build up "in-house" competence. For instance, it is noted that different consultant firms have recruited considerable personnel which the operating companies and drilling contractors have a hard time replacing.

As a result of a shortage of personnel, it is also noted that promotions today are much faster than before: "*Now you go from the drill floor to driller in five years. Before this it took maybe 10-15 years*". It is similarly noted that it used to take ten years to advance from driller to toolpusher, while this takes about five years today.

Another aspect highlighted by many is the current offshore shift scheme with two weeks on and four weeks off ("2-4 rotation"). This scheme means that it takes a long time to gather practical competence in a number of operations. Or, as said by one of the informants: "*The 2/4 scheme doesn't exactly help – the fact that the authorities accepted it at all is incredible*".

With regard to practical competence and the "right person in the right place", the following conditions have e.g. been discussed during the interviews:

- Deficient practical experience with drilling supervisors from operating companies. This could be drilling contractors that do not necessarily have the competence to make important operative decisions.
- It is experienced that drilling contractor personnel sometimes have a too narrow focus and that they do not have a big picture perspective

- Deficient qualifications in personnel from service companies (including “drilling fluid loggers”) that are in the observation centres. Their tasks largely consist of reading graphs and continuously observing various drilling parameters, but due to inadequate offshore experience, it can be challenging to understand what the graphs mean in a purely operational sense.
- Increased use of hired consultants, for instance as drilling supervisors hired by the operating company. This is considered both positive and negative. There is often talk about experienced personnel, but knowledge of company and rig-specific procedures can be lacking at times.

As regards the so-called IWCF[14] course, i.e. the international testing/certification programme that leading drilling and well service personnel must carry out every other year, several informants noted that the quality of this course varies. Many considered the course too static and repetitive, e.g. in relation to what you learn about technical equipment. The fact that personnel – particularly from the contractors – that are normally not paid extra for the entire course period, often only choose to show up for the exam, is also a sign that the variation in the content of the course is limited. The IWCF course is therefore considered a useful refresher for old knowledge, but does not particularly help development.

During the period/year between the IWCF courses, a number of companies have the goal of their personnel participating in a major gathering or courses focusing on well control and case studies. This could include internal tailored courses or external courses. This was emphasised as positive by many informants and something that is at least as useful as the IWCF course. Such gatherings are considered a nice opportunity for facilitating experience transfer between the facility, an area several informants believe is not good enough.

10.4.1.3 Governing documentation and compliance

The general feedback from the industry is that procedure development is an area where much work has been done in recent years, and that governing documentation and well control procedures are currently considered “good enough”, but that the compliance is the problem. A typical statement was “the procedures are good enough, but they aren’t followed”. It was also expressed that incidents are rarely linked to deficient procedures, but rather deficient knowledge on, or erroneous interpretation of these.

However, it was also emphasised by several that the procedures are too extensive, and that they are not communicated well enough to operative personnel, that they are too “heavy” and not always updated, which makes it challenging to have good knowledge and overview of the procedures. In this connection, it was also expressed that inadequate knowledge on the procedures could in the worst case lead to repudiation of liability – that things just were not done in fear of breaking procedures.

Another factor which was highlighted as occasionally challenging is that the operators generally want to use their procedures, while the drilling contractors want to use their own procedures: “We could work for 3-4 operators during one year. Therefore it is important that we can use our own procedures – the responsibility for shutting in lies with us”. Bridging the operating companies’ and

[14] IWCF – International Well Control Forum, see www.iwcf.org

drilling contractors' procedures was in this context emphasised as an important tool to agree how to do things.

It was also expressed that use of hired consultants, such as drilling supervisors, could be challenging as they "jump from place to place" and therefore do not always have time to learn the governing procedures on board. "The consultants often have their own procedures in their minds and they are also reluctant to shut down a well since they are dependent on delivering results" was another statement we heard. However, it must be noted that it was also said that "there are getting to be a lot of skilled consultants out there" and that this also applied to hired drilling supervisors.

10.4.1.4 A culture for speaking up – stop criteria

A lot of informants noted the importance of having a culture which means that as soon as you are uncertain, you shut in the well. In this connection it was generally expressed that the industry has improved considerably, and that we currently have open doors and a "one for all – all for one" culture which means that a driller must always stop an operation if he/she is uncertain. While there was previously a tendency to wait and see and also consult the superiors, today's focus is on wells shutting down without this being questioned. A lot of new, young people in the industry was noted as one of the causes of this culture change.

Furthermore, it was expressed that you need clear criteria for when to stop an operation. This is often a separate topic for gatherings and meetings before starting up a new well, or in connection with choosing a new drilling contractor. When we asked the informants to exemplify how the stop criteria were formulated, the answers were somewhat evasive and mainly in the form of "when you're uncertain" and/or "when there are kick signals". Otherwise, reference was made to tables with requirements for testing and acceptance criteria in NORSOK D-010. It was also noted that concrete stop criteria are more extensive in HPHT[15] drilling which is generally more governed by procedures.

Despite a generally good culture for speaking up and stopping, certain problems were also highlighted, in the form of double communication and a disparity between doing and learning. Some representatives from the drilling contractors stated that they sometimes experience unreasonable pressure from some of the operating companies' representatives (usually the drilling supervisor), and that statements such as "you should have waited to shut down and talked to me first" or "you should have known that stopping wasn't necessary", are unfortunately not uncommon. The fact that the operating company is clear that you should never have doubts about shutting down in meetings, while communicating the opposite in the field, is most likely usually dependant on the person, but is also considered a culture problem driven primarily by finances. Use of hired consultants was also mentioned in this context, since they will have a certain self-interest in delivering results and maintaining operations.

[15] HPHT: High Pressure, High Temperature is connected to wells that are drilled in a formation with expected shut-in wellhead pressure greater than 690 bar and/or bottom hole temperature which exceeds 150 °C (NORSOK D-010). Such wells, due to high pressure and/or temperatures, have a greater risk potential than "traditional" wells with lower pressure/temperatures.

10.4.1.5 Technical systems and causes

Generally, the informants focused more on the human's role than the role of technology when explaining main causes of well control incidents. As regards the technical systems, some also expressed that these are largely "good enough" and it is therefore natural that the focus is directed at operative personnel in the form of training and attitude-shaping work.

Despite a certain degree of satisfaction with technology, there were particularly two areas where many informants believed there was room for improvement:

- Uncertainty in reservoir predictions
- Systems for well kick detection

Geological uncertainty is an important part of the workday for drilling and well personnel, and a topic most informants were concerned with. As opposed to production on a facility where equipment and surroundings can be touched and felt, many of the problems related to well control are hidden down in the well. "Fifty per cent of the incidents are based on incorrect pressure prognoses", was a statement uttered by many. Another popular statement was that few of the failures are located on the facilities; «problems are often connected to well design and casings and cementing, drilling window, etc. The subsurface is where the complexity is at". Inadequate reservoir understanding was primarily explained based on two factors: (1) new fields where you go in without sufficient prior knowledge of geological conditions in the subsurface, and (2) an increasing number of mature fields with old drained wells and reduced reservoir strength, where the pressure conditions change as a result of long-term water/gas injection, where there is significant differential pressure in the reservoirs and were you can also experience unforeseen "influences" between wells due to long-term injection.

Another technology topic which the informants were concerned with was well monitoring and well kick detection systems. These systems consist of a large number of sensors from different sources, and the actual implementation varies from facility to facility. In general, everyone uses level measurement in mud tanks and the rate of drilling mud in/out of the well. Possible improvements of this system are discussed in more detail in sub-chapter 10.7.

Well kick detection systems are closely linked with the design of the drilling cabin and presentation of information for drills and drilling fluid logs, and this was also a topic discussed by multiple informants. Modern drilling cabins are largely adapted to the "Playstation generation" and are therefore at risk of loosing the feeling of, and having physical contact with what you are doing, the forces you are operating. It was also noted that some screen-based systems are designed such that you need to scroll through several screens before arriving at the correct image. This was motivated based on the desire to reduce the number of screens, but is challenging as regards user-friendliness and vulnerability in the event of malfunction ("black screen").

At the same time as several pointed to challenges in relation to technical systems for well kick detection, a key question for many was the dilemma related to what the systems must discover, versus what you should expect the operators to discover themselves. It was noted that after the incidents, the warning signals were seen, but either due to inadequate attention with the operators, distractions from other activities, or possibly inadequate physical contact with the elements, these signals have been overseen. A tendency to try to explain/justify deviations from the normal, for instance incongruous pressure tests of inflow tests, is something also often seen following incidents.

The diverter system used to transport undesirable well stream away from the facility to prevent ignition of hydrocarbons was also considered a «grey area» by many, with varying design and practice, e.g. for testing. On certain fixed facilities this system was removed after a safety assessment, while this is mandatory on floating rigs. Increased standardisation and clearer diverter systems, e.g. through updating NORSOK D-010, were therefore emphasised.

10.4.1.6 About causes of increased number of well control incidents in recent years

The informants were asked to discuss the negative development in the number of well control incidents for the period 2008-2010. Several responded that they were uncertain what the causes could be, as the industry generally has had an increased focus on well control in recent years. However, increased complexity and more difficult wells were still factors mentioned by most. Reference was made to mature fields where you operate with wells where the drilling margins are smaller than before, and this may be a cause of more incidents. Deficient practical competence with new personnel was also mentioned as a possible cause. New drilling methods as a cause of more well control incidents were not addressed specifically by the informants.

Several informants also emphasised that the industry still has a relatively different reporting level for well control incidents, and that there is a need for clearer definitions and more harmonised reporting requirements and reporting criteria. For instance, examples were provided where the drilling contractor believed they were facing a well control incident, while the operating company had chosen not to define the incident as such. Some therefore believed that the statistics (incl. RNNP) are partially misleading, and have a skewed impression of the situation in the industry. In this context it was commented that they believe it is wrong to include shallow gas incidents as a part of the well control incidents due to their special nature and the fact that shallow gas normally takes place in connection with drilling pilot holes (and that an increasing percentage of wells with pilot holes is positive for safety).

10.4.1.7 Use of KPIs ("Key Performance Indicators")

All the companies we talked to were familiar with and used systems to measure key performance indicators (KPIs) related to HSE and efficiency. These systems include typical indicators related to lost time injuries, undesirable incidents, falling load, outstanding maintenance, number of corrective measures, delivery of wells per year, "trip speed", "slips to connection" time, number of drilled metres per hour/day, number of days per 10,00 drilled feet, deliveries within cost and time, etc.

Use of KPIs is a topic that gets people passionate, and where many and partially strong and diverse viewpoints emerged. It is therefore clear that the KPI systems are experienced very individually and subjectively, which could be related to how the KPI systems are implemented in the companies, but also with personal perceptions and preferences. Some believe such systems are entirely unproblematic and partially necessary, while others feel they can be stressful and sometimes come at the cost of safety. Some of the positive comments on the KPI systems included:

- Introduction of such systems has been an eye opener for the industry and has been important in reducing the cost level on the Norwegian shelf. It has lead to increased efficiency and has partially been a precondition for developing certain fields.
- Such systems are perceived as good and useful tools for benchmarking, both between shifts, facilities and also between companies.
- Such systems are useful for ensuring consistency in operations – doing things the same way and explaining why results vary from day to day. In this way, the systems have a mission in relation to getting the industry to think in the same way (standardisation).
- If it emerges that certain shifts/drillers perform much better than others, it is common to check why and take a closer look at the causes. It may then emerge that they person/persons in question take short cuts and do things in a way that other shifts do not. In this way, the system can have a positive effect on safety.
- Some people pointed out that during drilling, you were to a great extent limited by operational and technical conditions that limited the drilling speed and therefore believed the “KPI readings” were unproblematic.

As mentioned, several negative viewpoints on the KPI systems also emerged:

- The requirements for drilling as fast as possible while also taking it easy and exercising caution are perceived as contradictory by many (quote) “KPIs can point out that you’ve had an unproductive day, but safety can have been maintained in an excellent manner. However, this does not always emerge from the accounts”.

- The systems and the strong focus on KPIs are perceived as part of a steadily increasing efficiency requirement from the customers and can entail pressure as regards safety. The intentions are good, but the result is a considerable focus and pressure on certain shifts that are worse than others.
- The KPI systems require much time and resources, and partially detract the focus from well safety and major accident risk. It is noted that, for instance, much time is spent discussing “other things” at morning meetings, such as glove choice, diet, safety conversations, reporting, etc., which are important topics, but take time and focus away from well control and major accident risk.
- A well control incident will reduce the KPI result and will, in combination with partially unclear reporting criteria, entail that you do not report incidents that are in a grey area.
- The KPI systems do not safeguard the individual (quote) “We are human and no one drives a car the same way”.

It is unclear what effects such KPI systems have on each individual (Quote) “There is too little knowledge of what such KPI systems do to people that are measured all the time”. A point emphasised by many informants, is the importance of how KPIs and overall results are presented and communicated to operative personnel. Here it is vital that the results are filtered and presented in a manner which emphasises positive conditions, and cannot be perceived as pressure on individuals. Several companies, including operating companies and drilling contractors, had designated positions that e.g. worked on comparison, presentation and communication of KPI results.

It must finally be mentioned that it was not the case that operating companies and drilling contractors were in two different “camps” as regards viewpoints in the KPI systems. There were people with fundamentally different viewpoints on these measuring systems in both operating companies and drilling contractors.

10.4.2 Use of risk analyses in planning and implementation of drilling operations

As a part of the interviews, the informants were asked several questions related to use of risk analyses in planning, preparation and implementation of drilling operations. There were also more general questions related to planning. Some selected results from the interviews are referenced below. The topic is also discussed in more detail in sub-chapter 10.8.

10.4.2.1 General comments on the current risk analyses

The informants generally expressed that the risk registry (see sub-chapter 10.8 for discussion/explanation) was a well incorporated tool that was considered particularly useful in connection with planning an operation. It was also noted that there had been considerable development in the use and scope of risk analyses in recent years. Some challenges the informants also noted in relation to the risk analysis process:

- Involvement. Responsible drilling/well engineer with the operating company prepares and often heads the work on preparing the risk registry and drilling plans and has already prepared a draft risk registry when the drilling contractors and personnel from well service companies are involved in the process as needed. It was noted that the process with risk identification and active involvement of personnel from drilling contractors and well service companies, depended on what preparatory work was done, and the process that was run in the meetings where the parties participate. It was considered a challenge to get everyone involved in the meetings and achieve efficient identification of new risk.
- Resource use. Several pointed out that the process on preparing and maintaining the risk registry was very resource-intensive and often involved a large number of people. At the same time, many noted that the process is often characterised by “copy paste” and that the risk registry for a new well often becomes a copy of the last drilled well. Others believed that the considerable resource use actually indicated that they are not good enough at reusing results from before, and that it was generally difficult/time consuming to acquire sufficient experience from neighboring projects.
- Communicating the “risk picture” to personnel in the field. Several noted challenges in relation to transferring the experience from all the analyses and assessments made onshore to offshore personnel, and have an overview of all the preconditions used as a basis for the analyses (“difficult to know about the considerable work done onshore”). Several informants wanted another way of doing “risk assessments” which was simpler to carry out, and easier to communicate in the field. For instance, it was noted that it was a significant challenge to communicate long risk matrices out to operative personnel.
- Focus for analyses. In analyses where you assess the frequency and consequence classes of different incidents, the focus often goes to the actual quantification, and much time is spent on this at the cost of other important aspects such as assessment of new risks and good measures. The actual well control aspect can thus fall somewhat to the background, and the effect of an analysis could in the worst case be that (quote): “You can make a difficult well

look easy, and similarly make an easy well look difficult". It was also noted that the risk registry is often very long, and that we are not able to prioritise the risks well enough, for instance using acceptance limits.

- Deficient flexibility for changes. The risk registry is normally available as a spreadsheet, and it was noted that this system has limited flexibility, particularly in relation to assessing changes. This is discussed in more detail in sub-chapter 10.8.

10.4.3 Barriers and barrier management

Here, barrier management means the processes, systems, solutions and measures needed to ensure the barriers always maintain their functionality so you achieve the required risk reduction (Petroleum Safety Authority Norway, 2011d). In addition to the discussion below, the topic is discussed in more detail in sub-chapter 10.8.

10.4.3.1 Barriers and barrier management in general

When directly asked what the informants consider barriers, most mention the primary and secondary barriers during normal drilling, i.e. the mud column and BOP. Some also note cement, casings, wellhead and well kick detection systems. In relation to organisational barriers and barrier elements and requirements for these, we did not receive very precise and clear answers to what the informants believe this to be, but expertise (course) requirements were mentioned by several informants.

When asked what the informants believed barrier management to be, most note the barrier diagrams as a concrete example of how the barriers are identified and described. One company also emphasised "Bow-tie" as a method used to identify and describe the barriers. As regards the barrier diagrams, several expressed that this was something much time was spent on, and that such diagrams are developed for each well section. It was furthermore noted that the barrier diagrams were to a little extent connected directly with the risk registry, but that the diagrams were normally attached to the detailed drilling procedures. It was also stated that barrier diagrams could at times be difficult to read and understand, and that they were to varying degrees used actively during the actual drilling.

10.4.3.2 Testing barriers and equipment requirements

As regards testing and equipment requirements, BOP is mentioned by everyone, and clearly receives the greatest attention in the industry, not least following the Deepwater Horizon accident. This barrier is subject to a very extensive test regime – some believe too extensive ("we're testing the BOP to death"). For other systems such as mud mixing equipment, instruments for detection of well kicks and the diverter system, there was greater variation in the answers and there does not seem to be a uniform practice in the industry.

As regards BOP performance requirements, functional requirements in the form of response/closing times, accumulator capacity and hydraulic consumption, pressure integrity, etc. are in focus. Some companies claim that they have self-imposed reliability requirements, for instance that they accept a 1.5% error in BOP components, without this appearing to be key in connection with BOP follow-up. In general, it appears reliability requirements for technical well barriers and barrier elements are not widely used and known in the industry, and that the general understanding of the reliability term is somewhat limited ("there is no fault in our equipment").

10.4.4 Measures to reduce the number of well control incidents

When asked what measures would be most vital to reduce the number of well control incidents in the future, the greatest focus appears to be on measures related to organisation and management. Concrete measures related to improved technology were also proposed.

10.4.4.1 Measures connected to organization and management

The following measures/measure areas were particularly emphasised by the informants:

- More practical system competence and training in realistic scenarios
- Building a culture of openness
- Better compliance with procedures
- Better work situation for personnel in the drilling cabin
- Increased presence out in the field for the operating company's representatives
- Better well planning processes
- Better experience transfer and learning from incidents

<u>More practical system competence and training in realistic scenarios</u>

There is a need for more practical system competence among the employees in drilling and well operations, i.e. better knowledge of and familiarity with the technical systems and barriers used during drilling. This need has increased in line with a lower experience level in the industry, due to considerable turnover and a steep career ladder. The informants want more training in realistic scenarios for handling well control situations and increased use of simulators. The current simulator training focuses on what happens after a shutdown; they want more training in handling situations before a potential shutdown. More internal courses are requested, with a greater part of the crew (operating company/drilling contractor/suppliers) so we gain a comprehensive overview of the challenges we face, and how these can be solved in unison. According to several informants, there is also a need to adjust the contents of the mandatory well control courses (IWCF[16] courses).

<u>Building a culture for openness</u>

There is a need to further develop a culture where speaking up is allowed and where it is completely fine to stop an operation and shut in the well as soon as you are uncertain. You need to be able to shut down without this being questioned. "We need a safety culture originating from the management". The informants were concerned with good framework for being able to work safely, develop good interaction between personnel where they take responsibility for their disciplines and join in the community. We should develop a culture with plenty of room underneath the ceiling, where disagreements and worries are out in the open and are taken seriously in the organisation.

<u>Better compliance with procedures</u>

Informants from both operating companies and drilling contractors believed better compliance with procedures is important to reduce the number of well control incidents. The degree of compliance will depend on several factors, e.g. 1) if the procedures are considered sensible and effective, 2) whether you have received the necessary training, 3) if the number of procedures each person needs to relate to is kept at a reasonable level, and 4) if the degree of detail is adapted to the work task at hand. Use of signed lists and step-by-step procedures were noted as an important tool for ensuring

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[16] IWCF: International Well Control Forum

compliance. It was claimed that signing with names will result in greater ownership and be more binding. Furthermore, detailed step-by-step procedures could be compensating for limited operational experience. At the same time, the informants were clear that you should think through the needs for new procedures thoroughly. Many and detailed procedures can lead to repudiation of liability and exemptions, in fear of breaking procedure, while also losing the training in solving unforeseen problems.

<u>Better work situation for personnel in the drilling cabin</u>
According to the informants, the work situation for drillers and planners in the drilling cabin can be improved through the following instruments:

- Provide a more detailed decision basis for the driller and planner by establishing trends from statistics and ensure visualisation of key parameters in drilling and well operations.
- Protect the driller as much as possible from disturbances, e.g. by avoiding uncessesary phone calls and visits in the drilling cabin ("driller can be perceived as a pilot of an airplane"). The driller needs peace and quiet to perform his/her core tasks.
- Facilitate better volume control related to drilling mud in/out of the well and early well kick detection.
- Ensure robust organisation of the drilling team, e.g. related to work distribution and routines for shift changes.

<u>Increased presence of company representative in work areas for the operating company's representatives</u>
Informants from the operating companies wanted less interruptive elements, so you can focus 100% on what is important in the job. There is a need for less bureaucracy and reporting requirements for the operating company's representatives out on the rig. You spend too much time at the office, instead of being a resource and being able to supervise activities on the drilling deck. A representative from the drilling supervisors claimed that one of his most important tasks was counteracting complacency by always challenging and motivating to make things better. A review of the drilling supervisor's work tasks and prioritisation of time use was proposed, e.g. factors related to:

- What "eats up" the drilling supervisor's time (reporting, meetings)
- The benefit of drilling reports becoming longer and longer (drilling reports are very technical; who/how is the information used in the reports?)
- Limitations related to ICT solutions (e.g. that deficient fibreoptics on certain rigs make the work on reporting to onshore difficult)

<u>Improved work processes for well planning</u>
The informants expressed that there is much to gain in improved well planning processes. It is important to take time to make the correct strategic choices in the planning phase of the well; think section by section and have a strategy for being able to handle incidents if you get stuck in problems. Good reservoir understanding (based on input from geologists with the operating companies) is a precondition for good well planning, and better pressure prognoses are needed. The experiences from one drilling programme are to a significant degree implemented in the next programme, but high turnover makes it difficult to look more than two years back. To ensure good interaction

between operating companies and the drilling contractor/suppliers in the operations phase, it is important to have early involvement in plans, and have physical meetings where you can gain insight into other players' operations. There is a need to increase the understanding that each well is unique and requires special attention and follow-up. Proposals to involve the drilling supervisor in workshops (in connection with development of the well programme) also emerged, as the drilling supervisor is a link with onshore.

<u>Improved experience transfer and learning from incidents</u>
Some informants claimed that there has been a somewhat one-sided focus on reporting HSE incidents (personnel injuries, emissions/discharges to the environment), and to a lesser extent incidents with major accident potential. Furthermore, it was claimed that in the search for underlying causes, the focus on technology is maintained as systematically as human and organisational causes. Other factors emphasised by the informants included:

- Improved communication of experience and measures between the rigs
- More physical meetings for internal experience exchange, and across companies
- Need for developing good methods for communicating experiences and learning from incidents

10.4.4.2 Measures related to improved technology

When discussing the technical systems we received several suggestions for possible improvements. Some of the measures mentioned are listed below:

- Develop systems for early well kick detection were noted by many. Including taking a closer look at the alarm system and driller's working environment. This is discussed in more detail in sub-chapter 10.7.
- Experience and routines from drilling HPHT wells can to a greater degree be used in traditional drilling, for instance use of "Fingerprinting"[17], and the maximum number of permitted active mud tanks in use at the same time (to reduce uncertainty in volume calculations related to drilling mud in/out of the well).
- Setting the top casing a little deeper was noted as a useful measure used to improve safety
- Better seismic models (4D) that see faults are important to uncover the risk of shallow gas, and to discover alternative leakage routes in the subsurface. It was noted that data processing can be improved and that we currently do not utilise the subsurface understanding well enough.
- More automation related to handling drilling mud. Today, the method for starting the pumps can be different between different shifts/crews. It should be a goal to standardise operations.
- Better systems for logging the cement quality and possible gas pockets behind casings during sidetrack drilling, e.g. TTRD (Through Tubing Rotary Drilling).

[17] "Fingerprinting" is a technique used to check that a drilling operation is running as expected. You pump against a closed well (i.e. before drilling through the cement shoe) and establish a curve on pressure development measured against time, both in pumping and return. You then use this as a guide to check against actual curves during the actual drilling operation. If there are nonconformities, this could be a sign of inflow or loss of circulation, and you should then shut in and check out.

- Look closer at the diverter system and requirements for separator for drilling fluid. The informants note different design and operation of these systems. For instance, there is uncertainty regarding whether there are systems with a connection between the separator for drilling fluid and the overboard lines on "Norwegian facilities" (so in the worst case you can lead the wellstream incorrectly in an emergency situation). It is also pointed out that requirements for the diverter system in regulations and standards (such as NORSOK D-010) are limited.

10.5 Discussion of results from interviews and a review of investigation reports

10.5.1 Some main impressions from the interviews

The conversations with the experts within drilling and well operations revealed that each person's experience with well control incidents was limited. Some had experience from two, but rarely more than three incidents, and these were generally not considered serious enough to warrant investigation. Generally, it is somewhat unclear what criteria the industry uses as regards when to investigate an incident. This, along with a general perception that well kicks – and not least shallow gas incidents – are something you mainly handle operationally, could be an explanation of why so few incidents have been investigated in total.

Furthermore, we are meeting an industry which believes the systems, both the technical and administrative, are generally good, and that the human aspect is initially responsible for failures. This is exemplified, e.g. through the Deepwater Horizon accident, where it is noted that there were many signals that something was wrong, but a series of misinterpretations and justifications (cf. for instance the "bladder" effect) led to a catastrophe. The industry's main focus is therefore to a great extent on increasing competence and increasing risk understanding with operative personnel, as well as compliance with procedures.

As regards the industry's viewpoint on new technology, introduction of integrated operations (IO)[18] and new drilling methods (for instance pressure balanced drilling), "reserved skepticism" might be the appropriate term. The drilling contractors in particular expressed such viewpoints, which might be historically motivated by the fact that the operating companies have mainly dictated the strategy as regards choice of technology and drilling method.

We are left with the main impression of an industry that is fully aware of the risk potential inherent in well control incidents, and which works practically and systematically on becoming better, but also believes they maintain quite good control, e.g. in reference to the limited number of serious incidents that are actually experienced.

[18] IO: "Integrated operations" is used as an umbrella term for new forms of cooperation between offshore and onshore, and which aim for better utilisation of the technical competence onshore when implementing offshore operations. This is to optimise and make the processes more efficient. A main precondition for efficient IO is real time transfer of significant data volumes between offshore and onshore.

10.5.2 Factors where investigations and interviews partially support each other

From the investigations, we can see that inadequacies in planning/preparation and risk assessments/analyses constitute a considerable share of the underlying causes. This is amplified by the results from the interviews where it is noted that the problems are often "located in the subsurface" and that difficult wells/reservoirs, geological uncertainty and too poor reservoir predictions are a considerable challenge. Furthermore, several informants point out that well kick detection systems have improvement potential, which is supported by results from the investigations.

As regards measures to avoid well control incidents, we see the interviews and investigations support each other. In the investigations, primarily organisational measures have been suggested (procedures, verifications, training, etc.), and this is also the focus when we ask the informants what measures they consider most important. This picture is amplified further by the response we received on the forms the companies filled out on measures (see sub-chapter 10.3).

One important observation is that despite both interviews and investigation reports pointing out deficient risk analyses and deficient planning as important underlying causes, these are challenges where it is clearly difficult to develop concrete measures. This is discussed in more detail in sub-chapter 10.8.

10.5.3 Differences in cause explanations

Two areas stand out as particularly inconsistent when we look at the explanation of causes of well control incidents in investigations compared with the interviews; competence and the significance of technical causes.

10.5.3.1 Competence

A key cause of well control incidents mentioned in several interviews was deficient actual competence and practical experience with operative personnel. Here, reference was e.g. made to quick promotions, a general "boom" in the industry and also the current shift scheme which is the reason why operative personnel sometimes lack practical experience. When we analyse the investigations, however, we find that only 4% of underlying causes can be explained with deficient competence/training.

So why this discrepancy? A possible explanation could be that the interview situation is more informal than what emerges in a written investigation, and that in an investigation people are hesitant to point out conditions that could be perceived as politically incorrect and problematic for the companies ("the competence should be in place"). In this context it should be mentioned that the informants were careful to point out that the competence "on paper" was good enough (the formal competence), but that practical experience and technical system knowledge could be lacking.

Another possible explanation could be related to the fact that informants in an interview situation will primarily speak based on their daily operative experiences and own assessments of what could cause well control incidents. Since very few (luckily) actually had extensive experience with well control incidents, the informants will therefore discuss conditions they perceive as challenging on the rigs in connection with daily operations, without this necessarily being conditions that have actually caused many well control incidents. This is partially supported by some informants pointing out that inexperienced personnel are often careful and good at checking with colleagues, while more experienced personnel can "go right ahead" and in some cases make incorrect assessments – which is manifested by experienced personnel also being involved in serious incidents.

10.5.3.2 Technology and technical causes

Another difference between results from investigations/incident reports and results from the interviews, is related to technology and technical causes. From the investigations and Synergi reports we can see that a significant share of the incidents have technically triggering causes, much related to the mud column (as a result of deficient reservoir predictions), but also well kick detection systems. However, in interviews the clearly greatest focus is on "the human factor" in the form of deficient competence and compliance with procedures. The informants are also clear that too poor reservoir predictions are a major problem, but there is generally significant attention on the role of operative personnel, rather than the technology. This could be an expression of what the informants believe is within reach of improvement; that development of new technical solutions takes a long time and are therefore not considered a key cause of well control incidents to the same extent.

This is interesting and illustrates a point that the IRIS report from Gullfaks C (Austnes-Underhaug et al, 2011) also addresses, that generally, and with leading personnel in particular, we see that strong faith in the systems is good enough, and that the problems mainly lie with executing personnel (humans). The report notes that the managers perceive that faults that arise are connected to erroneous use of the administrative systems, rather than the systems themselves. We can also add that it appears, at an overall level, to be a general satisfaction with the technical systems and that they therefore choose to focus considerably now on improved compliance with procedures and training, rather than improving the actual technology. This is discussed in more detail in sub-chapter 10.7.

Based on the overall data material, we have identified four key challenges to reduce the number of well control incidents:

1. Create framework conditions for good interaction in the operator-supplier hierarchy

2. Stronger efforts in technical measures to improve safety

3. Increased efforts in planning, barrier management and better adapted risk analyses

4- More focus on major accident risk – more investigation of incidents.

10.6 Challenge 1: Create framework conditions for good interaction in the operator-supplier hierarchy

Both the review of investigation and incident reports, and the interviews with people in the industry show that factors related to communication and interaction between different players is an important contributing factor of well control incidents. This was also the case for the Deepwater Horizon accident (DWH accident) on 20 April 2010 and for the blowout on the Montara field outside Australia on 21 August 2009 (Petroleum Safety Authority Norway, 2011c; Tinmannsvik et al, 2011; Montara Commission of Inquiry, 2010). Results from the PSA's work on HSE in contracts, investigations and international research shows that framework conditions are key for preventing major accident risk.

"Framework conditions" means conditions that impact the practical possibilities an organisation, organisational unit, group or individual has to keep both major accident risk and working environment risk under control. The definition entails that framework conditions exercise an indirect impact on working environment risk and major accident risk, by impacting the latitude, cooperation possibilities, resources, incentives, etc. It deals with factors the relevant players do not have effective and immediate control of. Some examples of framework conditions include incentives in contracts and employment agreements, physical limitations and workplace design, employment conditions (for instance use of outsourcing) and decision processes in connection with safety measures. The framework conditions could, for instance, be created by the market, through previous decisions, through decisions in another organisation or at another organisational level (Rosness et al, 2011a).

Here we are concerned with the framework conditions the players in Norwegian petroleum activity can influence. We have chosen this angle e.g. because in the interviews we encountered a perception that both the technical and administrative systems are generally good, and that the human elements is firstly what fails (sub-chapter 10.5.1). Then the natural next question is how we can enable people to solve demanding, safety-critical tasks in the best possible manner.

10.6.1 Relevant focus areas for improving framework conditions

If you want to improve the framework conditions for interaction, it might be advantageous to take a point of departure in concrete situations or tasks that are critical to maintain safety. Here we will discuss four such situations, or tasks that can be the basis for improving framework conditions in drilling and well operations. Then we will address how you can go from improving the framework conditions for individuals, groups and organisational units that face challenging, safety-critical tasks.

10.6.1.1 Planning complex wells

The background for this item is the safety-related challenges associated with exploration and field development in marginal oil and gas provinces and ambitions for improved oil recovery (sub-chapter 10.1.1). Extended use of wells leads to challenges regarding aging and wear, and regarding procuring complete documentation on the well. The Snorre A and Gullfaks C incidents illustrate different aspects of this complexity. For Snorre A, the complexity was connected to the well's history, the damage it had sustained and the repair measures implemented. For Gullfaks C, the main challenge was small pressure margins between pore pressure and cracking pressure, but leaks from the reservoir through poorly cemented casings and cracking systems outside the well increased the complexity further (Tinmannsvik et al, 2011, based on Statoil's internal investigation report). In the study of underlying causes of the incident on Gullfakc C (Austnes Underhaug et al, 2011) reference is made to several framework conditions that could be significant for planning complex wells, for instance:

- Haste
- Decisions regarding technical conditions and progression in drilling activities were made without input and objections from technical personnel with the operator or contractor being handled satisfactorily
- Decisions were made to continue drilling activities without plans for solution of potential problems being available

- Representatives for operative personnel did not appear to be included in the onshore planning process

10.6.1.2 Risk assessment and quality assurance when operative plans must be changed on short notice

Operative plans are often changed on short notice. Both the Snorre A and Gullfaks C incidents illustrate these challenges. During the Snorre A incident, the plans for slot recycling were changed shortly before the operation was being implemented, and a meeting for risk assessment of these changes was cancelled because the drilling rig became available earlier than expected, according to the PSA's investigation report. During the Gullfaks C incident, a decision was made to switch to pressure balanced drilling at such a late point in time that this operation had to be planned in three months, while according to the informants of Austnes-Underhaug et al (2011), it was normal to use at least six months to plan such an operation.

The framework conditions connected to this item overlap with what was described in the previous paragraph. The difference is that the desire for sufficient time for planning and risk assessments can conflict with the desire for efficient utilisation of personnel and equipment.

10.6.1.3 Detection and interpretation of early signals of risk of loss of well control

Early signals of being at risk of losing well control, could be weak and ambiguous, for instance that the pressure or volume in the drilling fluid develop slightly differently than expected. In connection with the Macondo blowout, the operators on board received several indications that something was wrong, but they did not take immediate action before the drilling fluid spilled over the drilling deck (Chief Counsel's Report, 2011). This item consequently deals with creating preconditions for discovering and "correctly" interpreting early signals for risk of loss of well control. "Correct" can in some cases mean stopping the operations in a situation where it subsequently turns out that they were not about to lose well control (see also discussion in sub-chapter 10.7).

Relevant framework conditions could be the competence of operative personnel, a culture for seeking a second opinion in disputes, cooperation between drillers and "drilling fluid logger", possibilities for quickly mobilising technical onshore support, and to what degree the drilling plans give support for uncovering and interpreting signals for loss of well control. It is also crucial that operative personnel feel they have their backs covered for stopping the operations when they are uncertain. This is connected to the next item – safe handling of downtime situations.

10.6.1.4 Safe handling of downtime situations

Situations where drilling operations stop, could incur the operator and/or drilling contractor significant costs. In addition, a lot of downtime can be considered unfortunate for the reputation of the drilling contractor (Osmundsen et al, 2006; Forseth et al, 2011). Therefore, it is important to facilitate that operative personnel stop the drilling operation if they are uncertain in relation to well control, and to prevent haste and stress in downtime situations leading to unfortunate decisions.

In an interview study, Forseth et al. (2011) discovered that there was broad acceptance of the fact that haste in connection with downtime situations constitutes a potential safety issue. Several informants in the mentioned study believed that the pressure in downtime situations is often higher during rig drilling than during platform drilling, because downtime has greater financial consequences for the drilling contractor during rig drilling. The informants described specific measures they used to protect executive personnel during downtime situations, as well as to communicate that safety is prioritised during these situations. They emphasised being proactive in planning corrective maintenance to prevent downtime situations. Furthermore, they attempted to save up time-critical work tasks, so they could avoid interruptions in planned operations resulting in downtime. Many informants in Forseth et al.'s (2011) study believed that, in recent years, both operating companies and drilling contractors have become more aware of ensuring that haste in connection with downtime does not lead to undesirable incidents. However, they also experienced that this could vary from person to person – not all drilling supervisors were as effective at preventing stress in downtime situations. These results indicate that good practice already exists in the industry within this area, and that the most important jobs are to disseminate and maintain this practice. Some informants in our interview study had the impression that hired drilling supervisors experienced greater pressure to avoid downtime than permanently employed drilling supervisors (sub-chapter 10.4.1).

10.6.2 How can we create framework conditions for good collaboration?

In the paragraphs above, we have mentioned a few framework conditions which may be of significance for maintaining well control. The intent is not to prescribe which framework conditions the players in the petroleum industry should tackle, but rather to stimulate discussions on which framework conditions are important, and how they can be improved. The point of departure for such discussions should be the work situation of individuals and organisational units performing tasks that are critical in maintaining well control.

Some investigations and analyses of accidents thoroughly inspect why the players acted the way they did and follow the causal links from the sharp end to decisions and factors which affected the players' framework conditions on the sharp end.[19] Such investigations and analyses can provide valuable insight into which framework conditions are important as regards safety, and how these can be created and maintained. This in discussed in more detail by Rosness et al. (2011b).

Poor framework conditions as regards maintaining safety are often related to how goal conflicts between safety and competing goals are handled. Many of the informants in our study particularly representatives from the drilling contractors, mentioned situations with conflicting safety and efficiency goals, where they choose solutions which save time and money rather than safety considerations ("There is always a balancing acts between finances and risk, and this is something we experience every day. We have issues with the equipment and the way we operate that we want to address, but we can't do it because it costs money"). One example mentioned here was somewhat old, poor BOP solutions on fixed facilities, but where the NORSOK requirements have been satisfied and one therefore chooses to live with what we have. Another example that was mentioned was acoustic emergency BOP activation where there is currently a single "control pod" and this must therefore be pulled in the event of faults. In this case, the lack of redundancy is mainly related to regularity, but will also affect safety. However, this is also in accordance with requirements, so it is difficult to gat approval of a change with the rig owner/equipment owner. Furthermore, informants

[19] The following are examples of such investigations and analyses: CSB (2007), Austnes-Underhaug et al. (2011) and Schiefloe et al. (2005).

from drilling contractors claimed that they still receive efficiency requirements from customers and that they sometimes experience that the customer's offshore representatives question why they chose to stop the drilling operation.

Low-level goal conflicts arte often related to decisions at a higher organisational level, e.g. the deadlines set for a work task or project. Some times, goal conflicts cause gradual changes in work practice, thus diluting the safety margins and actually increasing the gap between requirements/procedures and actual work practice. This may result in approaching, consciously or unconsciously, a limit for acceptable work execution. If one lacks a comprehensive overview, many small deviations from requirements may interact in a manner which leads to an accident. This corresponds to the goal conflict-view of major accidents, Rasmussens (1997). At the same time, it is important to remind oneself that all organisations struggle with goal conflicts – the point is how to clarify, communicate and handle them.

Looking at the investigated incidents from this study, there are at least a couple incidents where we can question the presence of clear stopping criteria for when an operation should be interrupted. The companies' well control procedures describe some criteria/indicators of a potential well kick which shall result in manual well shutdown. However, these criteria may be perceived as insufficiently absolute (for example "unexplained gain in pit volume" and "increase in return flow rate"), and may as such be the object of individual and situation interpretation.

In connection with conflicts between safety and efficiency goals, Rosness et al. (2010) describe the following risk-reducing strategies:

- Increasing awareness of how the industry relates to goal conflicts, e.g. cost cuts decided at higher levels. Who is involved in discussions on consequences for the operative environment? Do decision-makers ”seek out” the impact of their own decisions – before and after decisions are made?
- Are involved players aware of when the limit for unacceptable risk is approaching; have they e.g. developed and communicated clear stopping criteria? Have experiences from major accidents (for example Deepwater Horizon) affected practice in this area?
- Increased awareness awareness on the forces pushing the limit for safe performance, and how such forces can be prevented, e.g. by following up performance goals for safety in line with finances.
- Clearly communicate conflicting financial and safety goals, with reference to concrete decisions one might face. Those who are on the operative level may face a dilemma where supervisors say that safety is prioritized, while they tacitly communicate the opposite through planning, follow-up, resource distribution and own behaviour (cf. the discussion regarding the use and dissemination of KPIs in sub-chapter 10.4.1).

10.7 Challenge 2: Stronger attention on technical measures to improve safety

We can see from Figures 152 and 153 in sub-chapter 10.2.1 that a technical fault and/or weaknesses in the systems/barriers, have been found to be the most important triggering causal category for the assessed incidents. Since the industry appears to have a relatively limited focus on technical measures, this topic has been selected for further discussion.

10.7.1 Regarding complexity and human/technology interaction

"Think of a drilling rig exploring for oil as a matchbox. Then imagine that the matchbox is placed on top of a two-story house, where the second floor is filled with water and the first with rock, sand and perhaps some salt. Striking the oil reservoir will then be like hitting a coin on the floor of the first level with a drillpipe as thin as a strand of hair ".[20]

Apart from the purely technical challenge inherent in hitting an invisible target far underground, there are also complicating factors such as collaboration between many involved players, frequent reorganisations and new work processes in these players, increased automation and barriers that change according to where they are in the drilling operation.

In such a reality, many have pointed to the interaction between humans, technology, organisation and the surroundings as a key factor in achieving safe and efficient drilling and well operations. As pointed out in the report "Human factors in drilling and well operations" (Jernæs et al., 2005): "TO reduce the risk potential in this type of activity, we must consider the entirety of all aspects which may affect the risk level. (...) The challenge is to get the interaction between humans, technology and the organisation to work in the best manner possible". Based on the interviews with industry professionals, our impression is that one is generally concerned with aspects related to humans, technology and the organisation, but that the human role received the greatest focus. This is reflected in the fact that one often ecplains incidents with "human error" without always putting this in a larger perspective, including e.g. framework conditions, goal conflicts or technology.

As regards the interaction between humans and technology, there are, as discussed in last year's HC leak study (RNNP 2010), at least two ways to approach this. One can either focus on that fact that the human is making the mistake in spite of well-adapted technology, or one could ask whether equipment and process design may in some cases "invite" mistakes. Let us review a few specific well control incidents:

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Incident A:

In connection with connection drillpipe after drilling cement and cleaning the rat hole[21] to the reservoir section (8 ½") a 15 m^3 well kick occurred. The direct cause of the well kick was that the well's pore pressure was higher than expected, thus making the drilling mud's specific weight too low.

The subsequent investigation of the incident indicated that the well kick could have been discovered earlier if the driller had observed the flowmeter or "flowline" camera. Because a single drillpipe needed to be laid out before connecting a new stand (3 drillpipes), the driller was concentrated on operating the drilling equipment via the "Top drive" camera, and did not discover that the well flowing back before the connection was complete and the TV monitor was switched back to the "flowline" camera. A computer engineer from the well service company discovered the backflow, but misinterpreted a message from the derrickman and assumed that it was due to a drilling mud tank being added to the active system.

[20] Found in "The Economist, Technology Quarterly, Q1, 2010" (regarding deepwater drilling); http://www.economist.com/node/15582301
[21] A rat hole is an extra hole drilled at the bottom of the hole to leave expendable completion equipment, such as the carriers for perforating gun charges.

The investigation also identified multiple weaknesses in the on-board technical systems, including that the two independent systems monitoring the well were not synchronised (4 min discrepancy), "fingerprinting" was not used in the logging unit, a flow out sensor in one of the logging systems was unfavourably placed and the alarm was not activated, the human-machine interface in the driller's cabin was not optimum and there had been several instances of screens "freezing".

Incident B:
In connection with milling out a gasket as preparation for pulling casing and subsequent sidestep drilling, fluid flowed into the well and caused a loss of the primary well barrier (mud column). The influx was confirmed and the BOP's upper "ram" was closed. During the work to restore the barrier, a situation arose where drilling mud squirted out on the drill floor when the BOP was erroneously opened. Due to a non-return valve, it was not possible to read the static pressure on the drillstring, and the pressure gauge which constantly measures the annulus pressure on the wellhead was not connected. With a pressure sensor to measure the annulus pressure on the wellhead, the pressure would have been available to read on the screen in the driller's cabin. It is likely that someone would have reacted to the presence of pressure under the BOP and that this would not then have been opened.

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The example incidents above, and several of the other reviewed incidents, show that incidents often occur as a result of human misjudgements combined with technical weaknesses. Incident A might have been avoided if the sensor for flow out of the well had been placed better and the alarm had been activated, or if the two well monitoring systems had been synchronised better. As said in the investigation of the investigation of the other incident, there was no sensor for pressure measurement of the annulus pressure on the wellhead that could have prevented faulty opening of the BOP.

Figure 153 shows that a significant part of the triggering causes can be linked to technical weaknesses. Weaknesses in the primary barrier/mud column are closely related to unforeseen geological conditions in the reservoir and constitute a total of about 40%. Weaknesses in the well kick detection system also provide a significant contribution of 13%. On the other hand, we can see from Figure 157 that measures aimed directly at these categories are relatively limited. A qualitative review of measures specified in investigation reports tell us that there are a number of actions that entail that existing systems must be "reviewed", "assessed" and "verified" in the inspection/check/verification category without us in this study discussing specifically how often this actually leads to technical system changes. From interviews and received response forms from experts in the companies, however, we receive a general impression that technical measures are not prioritised.

Furthermore, from Figure 157 and the interviews we see that specified measures are often associated with adaptation and improvement of procedures and work practice, as well as training and increasing awareness in operative personnel. In other words, it may appear that in the interaction human/technology – there is a tendency to focus on humans "adapting" to the technical solutions, rather than rebuilding the technical systems to adapt to the user. The informants also touched on this topic by, for instance, noting that the presentation of data from the well could be improved/simplified (see next sub-chapter).

10.7.2 Need for greater awareness on technology and technical measures

If we look at the results from review of the incidents and the input we received regarding the need for technology improvement in the interviews, there are two areas that stand out:

- Need for improved pore pressure/reservoir predictions
- Develop well kick detection systems

Regarding pore pressure prediction, key terms are new/improved technology, better management and communication of uncertainty and improved knowledge in areas we drill in.

Requirements to systems and instrumentation for well kick detection is complicated further by deep wells with considerable volumes, floating rigs that move and other ongoing activities on the rig, including crane use. However, this was an area where the informants had multiple viewpoints on challenges and possible measures:

- Automatic shutdown when detecting well kicks is generally not implemented, only alarms. You then depend on the driller and/or drilling mud logger reacting to these alarms and potentially shutting in the well. The people who deliver systems for monitoring various well parameters should therefore consider an intelligent system that looks at “all” signals in context and which presents this in a simple way for the driller and drilling mud logger, potentially automatically shutting in the well.
- It is also pointed out that alarm filtration and criticality ranking of alarms are often deficient (“regardless of what alarm is triggered, it is the same sound”) and that there might therefore be too many alarms to relate to. Improved filtration of critical alarms is therefore important.
- The quality of the systems depends on how alarm limits and margins are manually set up prior to an operation – the limits/margins are therefore to a great extent based on opinion and assessments from time to time. Increased standardisation and improved routines for setting up alarm limits and margins should therefore be considered.
- Experiences and routines from drilling HPHT wells can to a greater extent be used in “traditional drilling”, for instance use of “Fingerprinting” and the maximum number of permitted active mud tanks in use at the same time to reduce uncertainty in volume calculations related to drilling mud in/out of the well.
- The drillers’ environment and the layout of the drilling cabins were also mentioned. Considerable information is being digested in an environment characterised by several screens and significant traffic at times. Improved information presentation (see also Jernæs et al, 2005) and reduced drillers workload (e.g. by avoiding uncessesary telephones and visits in the drilling cabin) are therefore important measures.

In the aftermath of the Deepwater Horizon accident, a number of investigation reports and experts have noted that it was strange that the drilling personnel could overlook all the signals that a blowout was developing, and did not try to shut in the well sooner. It might be tempting to ask: Given the fact that all of these signals were available and this clear, why is there no system to automatically shut in the well?

A general impression from the interviews is that the informants from the drilling contractors to a somewhat limited degree are concerned with questions regarding new and improved technology.

There were several positive comments regarding gaining acceptance for installing new technology, but this mainly concerned minor things such as cameras and similar devices. As regards new drilling technology, and pressure-balanced drilling in particular (MPD – Managed Pressure Drilling), the drilling contractors were generally reserved, e.g. it is pointed out that MPD sets greater requirements for competence, reduced the margins by equipment faults becoming more critical and that the safety is therefore challenged. The technology driving factor is generally stronger in operating companies and the attitude for new drilling technology is therefore more positive. This is primarily financially driven and deals with a greater recovery rate and new drilling technology to drill deeper, and to drill in challenging and mature reservoirs with smaller margins. Here, technology development is often a precondition in order to be able to drill at all.

As regards technology that is to a greater extent related to improving safety during drilling (such as detection systems for well kicks, diverter system and BOP), our general impression is that this is primarily “driven” by requirements in standards and regulations, and that you need relatively good arguments to stretch any longer. As mentioned in sub-chapter 10.6.2, informants from the industry, e.g. point out that you choose to live with partially old and poor BOP solutions on fixed facilities, because the minimum requirements in NORSOK are fulfilled. There is therefore reason to challenge the players on this matter, and also emphasise the importance of making standards such as NORSOK D-001 and D-010 more offensive as regards setting requirements that contribute to continuous improvement in the industry.

10.8 Challenge 3: Increased initiative in planning, barrier management and better adapted risk analyses

Drilling and well operations are characterised by a dynamic risk picture which e.g. varies with changes to drilling activity plans, changed well parameters, but also with where in the drilling operation you are. It is therefore important that you (1) through use of risk analyses, map and assess the risk picture that is relevant at all times, and that you (2) identify, stipulate requirements and maintain the barriers established to handle the relevant risk picture. Experience from incidents and from interviews with experts in the industry show that there are occasional failures in both (1) and (2) above. As discussed previously in the chapter, the investigation reports e.g. point to deficient planning and deficient risk analyses as key underlying causal factors, and that it is challenging to find concrete measures to improve the analyses (see e.g. sub-chapters 10.3 and 10.5.2). Furthermore, we can see from the interviews that the industry has a somewhat narrow-minded interpretation of the barrier term. Planning, barrier management including risk analyses, are therefore chosen as topics for additional discussion.

10.8.1 In brief about the actual risk analysis process

In connection with the interviews, the risk analytical processes in connection with planning and implementation of drilling operations were discussed with the informants. Despite a certain variation from company to company and well to well, we found some typical common denominators. These are summarised below, as a basis for further discussion in the sub-chapter:

1. The responsible drilling/well engineer with the operating company has main responsibility for preparing the well and setting up a well programme, incl. a drilling plan. As input for this, results

from geological surveys and experiences from previously drilled wells in the same area/field are used (if available).

2. The "risk registry/risk matrix/risk log" is vital in the risk analysis process. This is a tabular overview of risk aspects associated with the well, with assessed frequencies and consequences, which in combination, result in different risk classes (typical: green, yellow and red). It is common for drilling/well engineers to prepare a first "draft" version of this risk registry, often based on the corresponding table from a previous comparable well.

3. This preliminary risk assessment is included in the first "major meeting" (normally headed by the operating company) which involved representatives from the operating company, drilling contractor and well service companies (and equipment suppliers as needed). Here the drilling progamme is reviewed section by section, and the risk registry is updated and completed with a focus on new/special risk and the most critical risk categories (yellow and red), where risk-reducing measures are specified with responsible persons/departments. Shallow gas, pore pressure and the length of casings could be typical topics for the risk review.

4. The risks and measures from the risk registry are included further and incorporated in steadily more detailed drilling and operations plans – so-called section plans – which are the procedures used by the drilling contractor during the actual drilling. The risk registry is kept as a separate document and can typically be an appendix to the detailed operations procedures.

5. Well barrier diagrams are also prepared which will become a part of the detailed operations procedures.

In connection with preparation and review of the risk registry, this can also "trigger" a need for special depth analyses, for instance related to wellhead fatigue (typical for HPHT wells with a large BOP), HAZOP analyses for selected sections of the well, etc.

In addition to the above analyses, the informants pointed out that quantitative risk analyses are carried out (QRA/TRA[22]). These analyses could be well specific and will then e.g. estimate the expected blowout frequencies from the specific well. They can also be rig specific and will then, for instance, contain preconditions on the number of exploration wells a given rig can drill during the course of a year, and what test regime is assumed for the most safety-critical equipment (such as BOP). These analyses are normally carried out by a consultant company and "owned" by technical safety with the operating company and/or rig owner.

10.8.2 "Deficient risk analyses" – 20/20 hindsight, justification or actual problem?

There have been several incidents on the Norwegian shelf where they have subsequently pointed to deficient risk analyses/risk assessments and too poor barrier control. A few examples are provided below:

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Incident C:

[22] QRA/TRA: Quantitative Risk Analysis/Total Risk Analysis

During preparations for drilling a sidetrack there was flowback of gas from the reservoir. The gas went through a hole in the casing at about a 1500 meters depth, and emerged on the seabed. This resulted in significant volumes of gas rising to the sea surface under and next to the facility.

The investigations following the incident e.g. pointed out that the drilling management on board underestimated the risk picture and an adequate risk assessment was not carried out prior to the activities. Furthermore, they had decided to open towards the reservoir before the 7 5/8" casing had been pulled out, but this change was not risk assessed, and gas was swabbed into the well when pulling the casing. Well barriers also failed due to holes in two casings and the well's technical condition made it difficult to maintain control over the well volume and analyse changes to the well volume.

Incident D:

When drilling out an old water injection well using a sidetrack, there was an increasing amount of gas in the drilling mud. They reacted too late to various signs and signals and the final result was gas on the drilling deck and alarm. The highest measurement showed 65% LEL.

In subsequent investigations it was pointed out that the sidetrack drilling was not prepared well enough and that risk assessments have not looked at the possibility for gas/pressure build-up in the formation surrounding the original water injection well. With regard to the barriers, poor cement around a "liner", deficient technical systems for kick detection in the form of a time delay between gas readings in drilling mud and the actual gas level, as well as insufficient mud weight, were noted.

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Firstly, there is reason to reflect somewhat regarding what actually lies behind the cause explanation "deficient risk analyses/risk assessments". For instance, you could ask whether Incident D could have been avoided if the right person with the right experience from the previous water injection well had participated in planning the sidetrack. Correspondingly, for a number of the incidents where deficient risk assessments are subsequently noted, you could ask whether the problem lies with the analysis method, in the implementation of the analyses, in deficient involvement of relevant personnel, in deficient knowledge with the people planning and/or implementing the operation, or if it could be connected with unrealistic expectations of what the risk assessments can actually provide.

It is not straight forward to answer the questions above based on investigations and results from the interviews. The investigation reports are generally satisfied with noting that the analyses, to a small extent or not at all, have assessed a specific condition (such as e.g. the possibility for gas influx), without any additional reflections on why this was not assessed. If "deficient risk assessments" are set in context with other underlying causes, we see that conditions such as "inadequate data basis", "deficient involvement of relevant technical personnel" and "deficient learning from previous incidents" are among the causes that occur the same time as deficient analyses. It is worth noting that neither the investigations nor the informants point to the actual risk analyses methods as a problem to a significant degree.

It is also relevant to ask whether "deficient risk analyses" are sometimes a more comfortable explanation than, for instance, deficient competence or deficient learning from previous incidents (experience transfer). In some cases, you could ask whether “deficient risk assessments” just express 20/20 hindsight in relation to what no one considered – but which “a more thorough analysis” could have predicted.

When asked what really lies behind “deficient risk analyses”, we can therefore not provide a clear conclusion. In some cases, more thorough analyses or other/better methods would be the answer, while other times involvement of technical personnel, competence or the data basis could have been the missing link. As a conclusion, you can therefore say that “deficient risk assessments/risk analyses” as a cause explanation is somewhat insufficient and that in future investigations you should focus on delving much deeper into this.

10.8.3 Risk assessment linked to changes

When you are located on a drilling rig with a daily rate of several million NOK, and something unexpected happens, it is not surprising that handling such situations can become a challenge. In the interviews several informants noted deficient risk assessments and clarification of consequences in the event of changes as an area with significant improvement potential (“We are very good at doing things in advance, but it is more difficult to handle things when they suddenly occur”). Changes in well-related parameters were e.g. emphasised as a challenging area, for instance, changes in the mud weight during the drilling operation was mentioned as a factor where potential consequences in some cases are not sufficiently assessed.

A topic addressed by many is unclear premises and deficient guidelines in relation to what entails a significant change and when/whether this will be risk assessed. This is therefore an area where rough assessments often reign, which can be positive as regards flexibility, but will to a greater extent be impacted by contextual conditions there and then (such as time pressure, finances, staffing, etc.), and which can also entail different practices. It was e.g. referenced that drilling programmes are changed according to decisions made by the operating company’s representatives on site, such as drilling a new pilot hole, without carrying out new risk assessments onshore. Another factor also repeated in the interviews was deficient linking between the risk registry and the assessments carried out in the event of changes. Often, section plans are updated in the event of changes without going back to check the risk registry.

10.8.4 Challenges related to the current risk analyses

Based on investigations, as well as experience from previous projects[23], we can see some challenges related to the methods currently used in connection with risk analysis of drilling and well operations:

- *QRA/TRA*-type methods are relatively extensive and resource-intensive, and have limited value in assessing operational decisions in a "day-to-day" context.
- The *risk register* is an ingrained method which is considered useful, but resource-intensive. The method is most useful in connection with planning operations, but is too static to effectively be used to analyse the effect of changes. Among other things, it may lack explicit connections

[23] Among other things, see the "Report following audit on execution, follow-up and use of risk assessments in operations and in connection with minor modifications" (Petroleum Safety Authority Norway, 2010); http://www.ptil.no/getfile.php/Tilsyn%20p%C3%A5%20nettet/tilsynsrapporter%20pdf/tilsynsrapport_risikoanalyser.pdf.

between the risks identified in the risk register and the barriers, or between the risks and various well/operational parameters.

- Our impression is that the current risk assessments, including the risk register as well as QRA/TRA analyses, largely focus on *technical risk factors*. For example, it was mentioned during the interviews that factors such as shallow gas, pore pressure and casing length are often key topics. As the results from reviewing causes, particularly underlying causes (cf. sub-chapter 10.2.2) indicate a broad spectrum of causes, and since company experts point out the human role and competence as key challenges, these are good arguments for the risk assessments to also include such organisational aspects, e.g. whether one has the correct competence during the different phases of the well.
- *Uncertainty* in pore pressure predictions is mentioned by many informants, as well as in the investigations, as a challenge. However, it is unclear how this uncertainty is reflected in the risk assessments performed, as well as the decisions made as regards e.g. the chosen mud weight. A more conscious relationship with uncertainty in the analyses and a better description of how the degree of uncertainty is reflected in operational decisions is therefore necessary.
- Operational analyses such as an *SJA* (safe job analysis) are frequently used to assess the risk associated with different work operations. However, one objection to the SJA is that is may have a limited focus on major accident risk (Tinmannsvik et al., 2011).

Based on the available experience with the use of offshore risk analyses from about 1980 until today, combined with knowledge from various incidents, it is natural to question how realistic it is to be able to predict all imaginable scenarios in advance. Will things not always change along the way and unforeseen situations occur regardless? In that case, analyses that "cover everything" may not necessarily be the way to go. Rather, this indicates – which was also mentioned during the interviews – a need for alternative ways to perform risk assessments which are simpler in their execution, and easier to communicate in the field.

10.8.5 Barrier management requirements – what is the relationship between practice and theory?

Barrier management can be defined as coordinated activities to establish and maintain barriers so that they fulfil their function at all times. Based on requirements in regulations and relevant standards, certain key elements in barrier management can be summarised as follows (based on Petroleum Safety Authority Norway, 2011d):

1. Perform risk assessments which will contribute to identify, establish and describe barrier functions, including:
   - Identifying hazard and accident situations;
   - Establish barrier functions and associated barrier elements;
   - Perform risk analyses and necessary safety studies/analyses;
   - Assess and evaluate risk, including sensitivity and uncertainty – establish the risk picture;
   - Examine the need for other/more effective barriers and/or alternative risk-reducing measures
2. Stipulate performance requirements for the technical, operational and organisational barrier elements and establish performance standards that document the requirements.
3. Establish a barrier strategy which summarises results from Items 1-2 and which also clarify:
   - Which hazard and accident situations may occur, their causes and potential consequences

- The relationship between identified hazard and accident situations and the established barriers during the different operations phases and for the various areas on a facility;
- The role/intent of the various barrier functions;
- The basis for the stipulated performance requirements, including the relationship between risk assessments and performance requirements

4. Monitor the barriers in operation and ensure that the required barrier performance is maintained during all relevant phases of the well's lifetime.

As regards *performing risk assessments to identify, establish and describe barrier functions* (Item 1), our impression is that the risk assessments, to a certain extent, are used as tools to establish "case-specific barriers". In general, established practice, regulations and standards, as well as input from previous reference projects, largely decide which barriers one starts out with. This is an effective, pragmatic approach to define barriers, but may lead to needs for extra barriers, as a result of new risk factors, being overlooked. In other words, the current practice is mainly that the risk analyses require that barriers are already in place (particularly the quantitative analyses). This is also supported by the fact that the informants themselves point out that clear connections are lacking between risks identified in the risk register and barriers.

As regards *stipulating performance requirements for the technical, operational and organizational barrier elements* (Item 2), we can determine that the drilling and wells environments still have room for improvement. Firstly, we lack performance requirements (including reliability requirements) for several of the barriers during drilling, e.g. for systems to detect well kicks, for technical systems to ensure a stable mud column and for the diverter system. We also see that performance standards are not significantly established and that a system is therefore lacking for how the companies define the various barrier elements. With regard to the last item, it is particularly unclear what to include in the term "operational and organisational barrier elements". The experts we interviewed talked a lot about competence, training, compliance with procedures and a culture of notification, without this being noticeably related to the barrier term. A general clarification is therefore needed for what is to be included in these terms.

As regards Item 3 above, establishing a barrier strategy, we can conclude that much of what is required as input for such a document, already exist today (risk analyses, barrier diagrams, design specifications, etc.). However, trailblazing will always be required, e.g. to document relationships between hazard and accident situations and the established barriers, and with regard to documenting how the barrier elements are defined, what role they play and which requirements have been set for them.

Item 4; monitoring the barriers in operation and ensure that required barrier performance is maintained, is also discussed in sub-chapter 10.4.3, where it is pointed out that the industry has a generally major focus on blow-out prevention (BOP) and that this barrier is subject to an extensive testing regime, which includes verification of requirements associated with response and closing times, accumulator capacity, hydraulics consumption and pressure integrity. For other systems, such as equipment for mud control and instruments to detect well kicks, there are, as discussed in sub-chapter 10.4.3, seemingly no singular practice as regards how these systems are followed up. If one examines relevant NORSOK standards (such as D-001 and D-010), one also sees that requirements for these systems are largely related to the systems' design (architecture, redundancy, capacity, etc.), and that limited focus is directed toward how good the systems should be (integrity). In turn, this means that it becomes more challenging to follow up the performance of e.g. a level gauge in a mud tank or a flowmeter out of the same tank, because one simply does not have concrete requirements for how good these systems must be.

10.8.6 Summary of challenges related to barriers and barrier management

According to the informants, the PSA's initiative related to barriers and barrier management has resulted in considerably increased awareness on this topic in the industry over the last couple years. It is also emphasised that we are still in an exploration phase and that the industry needs information and guidelines. Based on the interviews, we can see that "barriers" is a familiar term, even if several informants limit themselves to speaking about BOP and drilling mud when speaking about barriers. As regards "barrier management", this is most likely, as discussed in the previous paragraph, an area with a need for considerable maturation and further industry efforts.

If, based on interviews and investigations, as well as results from other relevant projects, we were to summarise a few key challenges related to barriers and barrier management, we believe the industry should tackle the following, among other things:

- There is a need for awareness in the companies across the industry as regards what in included in barrier management, e.g. related to which requirements are included in the current regulations.
- There is a need to clarify all barriers during drilling. Among other things, the industry should convene to clear up the confusion associated with how one should define "operational and organisational barrier elements". The PSA's recommendation that verifiable performance requirements must be set for the barrier elements, may well be a good point of departure for such a review.
- Focus must be directed toward stipulating performance requirements for all the barriers and follow them up in operation. As is stated in the interviews and other reports (see e.g. Hauge et al., 2011), performance requirements are lacking (including reliability requirements) for several of the technical barriers during drilling. Systems to detect well kicks and technical systems to ensure a stable mud column are typical examples of some of the systems for which there are currently deficient requirements.
- One should consider whether there is a need for clarifying the stopping criteria – when is the barriers' condition such that the operation should be stopped?

10.9 Challenge 4: More attention on major accident risk – more incident investigations

10.9.1 Different causal explanations in incident reports and investigation reports

Review and analysis of incident reports (Synergi reports, etc.), investigation reports and interviews with industry experts show that the different information sources weigh causes and measures related to well control incidents differently (see sub-chapter 10.5). The incident reports are generally very cursory, and do not cover underlying causes in detail. These reports are mainly technical, and proposed measures are usually related to operational technical aspects to control the well. This means that the measures are directed toward the specific incident, rather than being good instruments to prevent new incidents (see sub-chapter 10.2.3). This will often entail selecting short-term solutions to correct a specific problem, rather than investing in more long-term measures which contribute to lasting improvement in relation to the current situation. This corresponds to what Argyris & Schön (1978) term single and double circuit learning. Single circuit learning involves adjusting/improving an established work practice, while double circuit learning entails introducing new practice to remove more basic causes of undesirable incidents.

As opposed to the incident reports, the investigation reports have focused far more on underlying causes and organisational measures. The level of detail varies considerably, but a main rule is that the more thorough an investigation is, the more nuanced the picture of direct and underlying causes of the incident uncovered will be. As regards organisational factors, the PSA has experienced that the companies' investigation reports provide a good overview of factors related to structural aspects (e.g. roles, responsibility, procedures and training programmes), while factors related to e.g. cultural aspects, management conditions, power relationships and framework conditions at various levels in involved organisations, are less apparent in the investigations (Thunem, 2009).

This means that an incident which is not investigated, only registered in the form of an incident report (in Synergi, etc.), will not provide the necessary insight in causal mechanisms, complex relationships and framework conditions that are necessary to identify good, effective measures. This also applies to more thorough studies of potential technology improvements. One can also see tendencies where the technology is lost in the search for improvements within organisational aspects (see sub-chapters 10.4.4 and 10.7).

10.9.2 Need to investigate more well control incidents

The overview of the number of investigated incidents shows that there are significant differences between the various professional traditions in the petroleum activities. While crane and lifing accidents and hydrocarbon leaks in the process area are investigated often, well control incidents are almost never investigated. During the period 2002-2009, 158 hydrocarbon leaks were reported (> 0,1 kg/s) on Norwegian production facilities, of which about 130 were investigated. Correspondingly, for the period 2003 – 2010, we had a total of 146 well control incidents on the Norwegian shelf, of which only a couple dozen were investigated. One of the reasons why so few well control incidents are investigated may be the perception that well kicks – not least incidents involving shallow gas – is something one mainly handles operationally (see sub-chapter 10.5.1).

Another matter mentioned in the interviews was the impression of a somewhat one-sided focus on reporting HSE incidents (personal injury, spills to the environment), and to a lesser degree incidents with major accident potential (see sub-chapter 10.4.4). This may also be a factor in relation to prioritising time, resources and effort for thorough and more investigations of well control incidents. But even with such attitudes, one will lose a significant amount of knowledge and insight into underlying causes of well control incidents, and thus lose the basis for systematic improvement work, learning and experience transfer in the industry.

10.10 Summary: Four main challenges in maintaining well control in the petroleum activities

Finally, based on the results in this study, we want to summarise four key challenges facing the industry in relation to further reducing the number of well control incidents.

Stronger effort on technical measure to improve safety
In relation to the fact that a significant share of the triggering causes from the investigation reports can be related to technology, the number of technical measures appears low. There is therefore reason to emphasise the importance of standards such as NORSOK D-001 and D-010 becoming more aggressive as regards stipulating requirements which provide continuous improvement in the industry. The interviews mentioned the need for various measures such as better systems to detect well kicks, including better presentation of safety-critical information for the driller and drilling fluid logger, general design of the driller's cabin and systems /technology for better pore pressure predictions, which should be examined in particular in this connection. Following the Deepwater Horizon accident, many have questioned how the drilling personnel could miss all the signals that a blow-out was developing. It may be tempting to ask: *Given that all these signals were available and unambiguous, why do we not have a system to automatically shut in the well*? Is there a lack of technology, and/or the fear of an unnecessary shutdown which prevents such solutions from being considered and potentially introduced.

Increased focus on planning, barrier management and more adapted risk analyses
There is a need for alternative ways to perform risk assessments which are easier to execute and simpler to communicate in the field. It is particularly important to have methods for risk-assessing changes occurring during the drilling operations. There is also a need for examining the actual risk analysis process in more detail, e.g. with regard to involving correct competence and in assessing uncertainty in the analyses. Furthermore, all barriers under drilling with associated barrier elements must be clarified and performance requirements must be set, and one must ensure that the requirements are followed up in operation. In this connection it is important to clarify technical barrier elements beside the BOP and mud column, as well as prepare a joint understanding of how the industry should define "operational and organisational barrier elements ".

More focus on major accident risk – more incident investigations
During the period 2003 – 2010, a total of 146 well control incidents were reported on the Norwegian shelf, of which only about ten incidents have been investigated. The number of investigated well control incidents is far lower than e.g. crane and lifting accidents and hydrocarbon leaks in the process area. Since major accident potential in well control incidents is irrefutable, this disparity is striking. Since incident report and investigation reports weigh the causes of well control incidents differently, it is important that more incident are investigated. This will provide the necessary insight in causal mechanisms, complex relationships and framework conditions which contribute to such incidents, which in turn is a prerequisite for effective measures and experience transfer in the industry. Increased efforts with regard to barrier management, more investigations of well control incidents and operational risk assessments, will be instruments to ensure understanding of major accident risk in connection with well control incidents.

Create framework conditions for good collaboration in the operator-supplier hierarchy
Framework conditions are factors which affect the practical opportunities an organisation, organisational unit, group or individual has to keep major accident risk and working environment risk under control. Revise framework conditions concern facilitating individuals, groups and organisational units facing demanding and safety-critical tasks. One should direct particular focus toward: 1) Planning complex wells, 2) Risk assessment and quality-assurance when operative plans

must be changed on short notice, 3) Detection and interpretation of early warnings of the risk of losing well control and 4) Safety handling of downtime situations. The following are examples of key framework conditions:

Allocate sufficient time and resources for planning complex wells, as well as for risk assessment and quality-assurance if operative plans are changed

- Further develop good stopping criteria for when a drilling operation must be interrupted
- Further develop a culture of notification – avoid undue interference in decisions to stop an operation
- Further develop systems to present the well's condition for the driller and drilling mud logger
- Further develop KPIs which are focused more toward major accident risk.