

Report

The Deepwater Horizon accident: Causes, lessons learned and recommendations for the Norwegian petroleum activity

Executive Summary

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Executive summary

Background and objective

On April 20, 2010, an uncontrolled blowout of oil and gas occurred on the Deepwater Horizon drilling rig, in the Gulf of Mexico off the Louisiana coast. The accident caused the loss of 11 lives and the resulting environmental oil spill has been estimated to almost 5 million barrels.

As a response to the Deepwater Horizon accident, hereafter referred to as the *DWH accident*, a number of investigations and studies have been carried out, some of them still ongoing. The Petroleum Safety Authority (PSA) Norway appointed a separate group for follow-up of the accident. The present report has been prepared by SINTEF as part of this work. Our mandate has been to “*review and systematise information from Deepwater Horizon investigation reports and from other major accidents in the petroleum industry. The main purpose has been to contribute towards lessons learned and provide recommendations for the industry in order to reduce the likelihood of a similar accident to occur in the Norwegian petroleum activity.*”

Lessons learned and recommendations

Lessons learned – Norwegian petroleum industry

When experiencing accidents like Deepwater Horizon, an obvious question is how could so much go wrong at the same time? Or said in another way; *how could so many safety barriers possibly fail simultaneously?* Answering this question is not straightforward, but two important aspects which are closely related are; *how to maintain control of the barriers* and *how to manage an increasing degree of complexity.*

Drilling and well operations differ from many other offshore operations by the dynamic nature of the safety challenges and the large number of different operations throughout the various phases of the well’s lifecycle. It is therefore challenging to maintain overview and control with all the barriers throughout the various lifecycle phases, including modifications and other changes. A number of control questions should therefore be asked. Are the specific barriers related to drilling and well operations generally adequate? Are our safety management systems appropriate to ensure control of the barriers through the entire lifetime of the well? Do the barriers fulfil the regulatory requirement concerning functional independence? And what about the performance requirements – are they strict enough?

When studying why barriers related to drilling and well operations fail, increasing *degree of complexity* is often found to be a common characteristic. This can be exemplified by; a large number of involved actors must interact, frequent reorganisations and new work processes, rapid technological advances in terms of deeper wells and more complex reservoirs. Hence, it is no wonder that offshore drilling into complex reservoirs is often referred to as *a continuous process of problem-solving* where new and unexpected situations arise and must be managed on the spot. This increasing complexity results in new demands on how we think about safety and it has been questioned whether safety research has failed to keep pace with the otherwise rapid technological development. It is therefore our opinion that a joint effort is required to initiate new advances within the safety research discipline. Furthermore, we need innovative thinking concerning how to cope with the unexpected – i.e. situations that can occur, but has not been considered or planned for. *Hence, we need to improve our capabilities to interact and make decisions in an environment of increasing degree of complexity and uncertainty.*

Operational decisions that are critical to maintain well integrity are often subject to challenging framework conditions and decision makers are frequently faced with conflicting interests between production and safety. Time pressure may be another disturbing factor, e.g. due to heavy workload, last minute changes of plans, or situations where operation is suspended until a decision is made. The investigation reports further reveal that the competence of the decision makers is a crucial aspect in order to maintain well integrity, not only related to individual skills, but also the ability of the decision maker to mobilise competent personnel when making critical decisions.

Recommendations for the industry

Based on the investigation reports from the DWH accident and other relevant accidents and incidents, SINTEF recommends to implement the following measures in the Norwegian petroleum activity (not in prioritised order):

1. Update NORSOK D-010 "Well integrity in drilling and well operations" with respect to the cement as a primary barrier, and the use of new technology.
 - **Why:** Failure of the cement barrier and the lack of adequate qualification was an important direct cause of the DWH accident and Montara accident. Shortcomings in relation to application of new technology (such as "managed pressure drilling") were a contributing cause to the Gullfaks C incident.
 - **How:** NORSOK D-010 should be updated in terms of improved procedures for planning, mixing, pumping and qualification of cement as a primary barrier. The method of placement and qualification of cement as a primary barrier should be better described. Moreover, the standard should be updated based on existing new technologies.
 - **Objective:** An improved best practice will increase understanding of the criticality of cement as the primary barrier and increase the likelihood of successful cementing. Description of best practices regarding new technologies will increase the likelihood of safe applications.

2. Improve the understanding of a comprehensive strategy for barrier control, including the application of the principle of two independent and tested well barriers, and the monitoring of these.
 - **Why:** The likelihood of effectively activating the secondary barrier is time critical. It is therefore important to detect warnings of an abnormal situation as soon as possible. Inadequate monitoring was a key factor leading up to the DWH accident, as well as the Snorre A and Gullfaks C incidents.
 - **How:** Adopt or develop operational tools (e.g. well barrier schematics) that can provide the different actors with simple visual aids, including descriptions of monitoring methods for each defined barrier element.
 - **Objective:** To enable activation of the secondary barrier as early as possible following a failure in the primary barrier.

3. By considering drilling operations on an individual basis, evaluate whether the present blowout preventers (BOP) design with single blind shear ram (BSR), is acceptable.
 - **Why:** The present BOP design impose some operational limitations such as lack of ability to cut through tool joints. It is not clear how the industry evaluate these limitations with respect to the criticality of individual operation.
 - **How:** Evaluate the criticality of drilling and well operations taking into consideration aspects such as water depth, location of BOP, complexity of reservoir, vulnerability of area, etc.
 - **Objective:** Increased reliability of BOP and reduced risk related to critical drilling and well operations.

4. Consider the need for new requirements and guidelines on design and operation of the diverter system in order to minimise the likelihood of mal-operation.
 - *Why:* In case of BOP failure and a topside blowout, the diverter system appears as the "last line of defence" with respect to reducing the amount of flammable hydrocarbons on the rig. The possibility of mal-operating the system therefore needs to be minimised.
 - *How:* Review today's systems and update relevant standards to reflect best available technology (BAT). In general, when activating the diverter system it should only be possible to route the flow overboard.
 - *Objective:* Reduce the likelihood of igniting a topside blowout.

5. Review safety instructions to ensure water tightening, as well as instructions for testing of doors and other passages through deck and bulkheads that are assumed to be watertight.
 - *Why:* Unintentional flooding of compartments is the main cause for disasters due to stability loss.
 - *How:* Establish company routines that insure integrity, including e.g. monthly control and reporting.
 - *Objective:* Reduce risk of stability loss.

6. Follow-up on a regular basis the drilling contractors' progression in managing the maintenance backlog.
 - *Why:* On Deepwater Horizon the operating company had to follow-up the drilling contractor's management of the maintenance backlog actively and systematically in order to reduce the backlog. This demonstrates the importance of active involvement by the operating company.
 - *How:* Regular (for instance weekly) meetings between the operating company and the drilling contractor to review status and plans for managing the maintenance backlog.
 - *Objective:* Control of the extent of maintenance backlog, particularly on safety critical equipment.

7. Consider developing improved methods for managing different types of blowouts.
 - *Why:* The DWH accident illustrates that upon BOP failure there are not many alternatives to drilling of a relief well, which is a very time-consuming endeavour. The industry should consider developing other possible solutions before a new accident occurs. Such a development should not only take place as trial and error during an accident.
 - *How:* Learn from, and contribute to the development that has taken place during and after the DWH accident, including development of equipment such as a well-capping device. The work should include methods, equipment, competence, training and exercises.
 - *Objective:* Faster control of a blowout.

8. Improve organisational and individual awareness and abilities to detect early warnings on lack of control.
 - *Why:* Monitoring and interpretation of danger signals are important means to detect lack of control and thus make it possible to handle situations before serious incidents occur. Both monitoring and interpretation of danger signals was inadequate in the period before the first explosion on the Deepwater Horizon.
 - *How:* R&D-activities based on the following general recommendations: create awareness of risky situations in normal operations; encourage scepticism and the ability to ask critical questions; and evaluate technological solutions that make faster detection of danger signals and errors possible.
 - *Objective:* Improved awareness and ability to detect and react to early warnings on lack of control.

9. Facilitate improved competency and a better working situation for personnel who make safety critical decisions in drilling and well operations.
 - *Why:* Different accident investigations have identified needs for structured competency building and improvement of the working situation for personnel who make safety critical decisions in drilling and well operations. Inadequate competency and a demanding working situation contributed to a series of failures and misjudgements at the DWH accident.
 - *How:* Develop requirements for training and education for personnel who make safety critical decisions in drilling and well operations. Review the working situation for this group of personnel, including the organisational structure for today's drilling and well operations.
 - *Objective:* Ensure that personnel in safety critical functions have adequate competency and a working situation that enables them to perform their functions in a safe manner.

10. Improve the flow of information and the collaboration between different actors; secure support from onshore experts in safety critical decisions and operational tasks.
 - *Why:* Breakdown in the flow of information is a contributing factor to most major accidents, including blowouts at Deepwater Horizon, Montara, Snorre A and Gullfaks C.
 - *How:* Ensure that offshore personnel maintain adequate communication with the correct onshore teams and are aware of their own information needs; develop and implement tools for validation of flow of information and secure adequate interpretation of information; R&D-activities to generate knowledge on how new ICT-based working processes influence major accident risk.
 - *Objective:* Ensure adequate decision support during safety critical situations by flow of information and collaboration between actors.

11. Develop new methods and tools for risk evaluation, which, in a better manner than today, can support operational personnel in everyday decisions.
 - *Why:* Today's methods are too static, too comprehensive or do not focus sufficiently on the risk for major accidents. The individual need for decision support in a complex and dynamic working-day environment should to a larger degree govern the development of future methods.
 - *How:* R&D-initiative to develop user friendly methods for risk evaluation and decision making support. The methods should among other things, focus on increased awareness related to the state of the safety barriers, dependencies and connections between the barriers, and the effect of changes during drilling and well operations.
 - *Objective:* Develop simple and user friendly methods that support operational personnel in terms of better insight and understanding of the consequences from various decisions.

12. Develop safety management strategies that both ensure compliance to requirements, as well as resilient abilities to adapt to changes, to both handle anticipated and unanticipated situations.
 - *Why:* In drilling and well operations a wide range of demanding situations can occur. Different strategies are required to deal with this variability. One approach constitutes development, implementation and compliance to requirements. However, there is also a need to make organisations resilient so that they can adapt to different situations quickly and thus bounce back and normalise the situation.
 - *How:* R&D-activities to identify which critical elements (actions, processes and resources) that must be in place to adapt to changes in assumptions and situations in drilling and well operations, including unexpected situations that may occur during operation.
 - *Objective:* Identify actions and processes that create resilient drilling and well operations, including management strategies for such operations (e.g. training; communication, risk management and monitoring).

13. Facilitate the systematic exchange of experience and learning from incidents in various industries (globally).
 - *Why:* Investigations of accidents and incidents often show repeating underlying causes, and the industry is being criticized for lack of experience transfer and learning from incidents.
 - *How:* The industry should establish a “learning unit” - internally or externally - with responsibility for reviewing accidents and incidents, and for dissemination of lessons learned to the industry and authorities. In addition to learning from what went wrong, it is important to learn from the successful recovery of situations that were about to get out of control. One can take advantage of experiences from a similar initiative in the French nuclear industry.
 - *Objective:* Improve the industry’s ability to apply knowledge about the causes of adverse events and successful recovery, in order to implement effective measures in their own organisation (“learning to learn”).

Recommendations for the authorities

SINTEF considers the following recommendations as being most important for the Norwegian authorities (not in prioritised order):

1. For critical operations, consider to require increased redundancy of BOPs, as for example double blind shear ram (BSR) or single BSR that works in all conceivable scenarios.
 - *Why:* Today’s design has operational limitations e.g. related to cutting of tool joints.
 - *How:* Depending on the type of operation (topside or subsea BOP, complexity of reservoir, vulnerability of area, etc.) consider the need for stricter BOP requirements through regulations.
 - *Objective:* Reduce the risk related to critical drilling and well operations.
2. Ensure and follow-up that the companies have implemented performance requirements (including reliability requirements) for critical safety functions related to drilling and well operations, and verify that these requirements are followed-up during operation.
 - *Why:* Regulations already state that performance requirements for safety critical equipment shall be stipulated and followed-up during operation, but this is not consequently implemented by the companies.
 - *How:* Through supervision verify that the companies (1) stipulate performance requirements and (2) follow-up these requirements. In particular, consider systems for kick detection, diverter system, mud treatment system and BOP.
 - *Objective:* Ensure required integrity of barriers during drilling and well operations.
3. Revise the Stability Code, to ensure integrity of water tight compartments.
 - *Why:* System errors and operational errors are main causes for incidents of stability loss.
 - *How:* Requirements to internal log documentation when watertight doors etc. need to remain open longer than a defined maximum duration. Requirements to periodical control and reporting.
 - *Objective:* Reduce risk of stability loss.
4. Maintain continuous focus on maintenance management through audits and dialogue with the industry.
 - *Why:* Inadequate maintenance is a recurring contributing cause of major accidents. Many installations on the Norwegian Continental Shelf extend their lifetime after a period of controlled phase out and reduced maintenance. As a result, they have built up a substantial amount of backlog.

- *How:* Auditing the companies' maintenance management, including management of maintenance backlog. Contribute in further development of maintenance management on the Norwegian Continental Shelf, through dialogue with the industry.
 - *Objective:* Improved maintenance management in general, and justifiable (risk based) amount of backlog in particular.
5. Provide for necessary competence regarding well control methods, to enable the authorities to follow-up the decision processes in the companies on well control accidents of national significance.
- *Why:* During the DWH accident the authorities were criticized for not contributing actively in controlling the runaway well. Some of the well control attempts could have made the situation worse, and required approval by the authorities. A competent authority is a prerequisite for such approvals.
 - *How:* By the exchange of experience on well control measures attempted during the DWH accident, and by stimulating research and development in this field.
 - *Objective:* Fast and proper control of a blowout.

Basis for recommendations

What happened on Deepwater Horizon?

On April 20, 2010, the Deepwater Horizon drilling rig was about to complete its work on the Macondo exploratory oil well - 79 kilometre off the Louisiana coast in the Gulf of Mexico. Around 9 pm the well however started to get out of control, and some 45 minutes later large amounts of drilling mud, oil and gas was sprayed onto the drill floor. This was later described by one of the survivors: *“as a freight train coming through my bedroom and then there was a thumping sound that consecutively got much faster and with each thump, I felt the rig actually shake”*. A few minutes later the first explosion occurred, then another huge explosion, followed by fires and more explosions.

Of the 126 people onboard Deepwater Horizon, eleven crew members died. The rig burned for one and a half day before sinking, and for another 87 days oil blew out from the well at the seabed some 1.500 meter below sea level. The largest oil spill in U.S. history was a fact – about 20 times larger than the oil spill from *Exxon Valdez* when it ran aground off the coast of Alaska in 1989.

Blowout response

On the rig an inferno of heat, smoke and flames developed, and the surviving crew members soon abandoned any efforts to control the event. They evacuated using lifeboats, a life raft and by jumping overboard, and were taken onboard the supply vessel Damon B. Bankston, which was located alongside Deepwater Horizon. The U.S. Coast Guard entered the scene fairly quickly and various vessels and aircrafts were mobilised to search for missing personnel and to reduce the consequences of the fire.

As the seriousness and extent of the event became apparent to the American people, the accident became breaking news in the weeks to follow. The U.S. Government and President Obama engaged themselves in stopping the blowout and collecting the oil. In particular, Secretary of Interior Ken Salazar and Secretary of Energy Steven Chu got directly involved.

On the seabed the well blew out through the blowout preventer (BOP) which was installed to stop a blowout, but failed to do so. In such a situation there are no quick-fixes to shut in the well and stop the flow. The only “proven” method is to drill a relief well, which for deep wells can take several months. Meanwhile a number of innovative solutions were attempted, developed more or less on the spot. Finally, one succeeded to stop the well flow by using a purpose made “BOP capping stack” on top of the ordinary BOP. 87 days had then elapsed since the blowout started and almost 5 millions barrels of oil had gushed into the Gulf of Mexico.

In mid-September, when the first relief well intercepted the Macondo well, BP was able to pump in cement and permanently seal the reservoir. On September 19, 152 days after the blowout, Admiral Allen could announce that the well was effectively dead.

Why did the accident on Deepwater Horizon occur?

Deep wells and operations in ultra-deepwater areas (> 1.500 m) require extensive planning and preparations. Further, the complex operations require that the various actors interact effectively. However, there were no conditions at Macondo, related to the underground, water-depth or the environment that were too exceptional to manage. Well qualified and internationally leading companies were involved and had previous experience from similar prospects. Therefore, the drilling and well operations should have been carried out safely. However, BPs safety reputation had become somewhat frayed as a result of accidents such as the Texas City refinery explosion in 2005 and the Prudhoe Bay pipeline leak in 2006.

The DWH accident did not happen as a result of one crucial misstep or a single technical failure, but as a result of a series of events, decisions, misjudgements and omissions that reveal a systemic breakdown.

Important direct causes

Important *direct causes* of the DWH accident:

1. The cement outside the production casing and at the bottom of the well (at the “shoe track”) did not prevent influx from the reservoir
2. The crew misinterpreted the result of the negative pressure test and considered the well as being properly sealed
3. The crew did not respond to the influx of oil and gas before hydrocarbons had entered the riser
4. The crew routed the hydrocarbons to the mud gas separator instead of diverting it overboard
5. The fire and gas system did not prevent ignition
6. The BOP did not isolate the wellbore and the emergency methods available for operating the BOP also failed

In order to avoid collapse of the wellbore and prevent uncontrolled influx of oil and gas, the wellbore is reinforced with pipes of steel – casing – which are anchored with cement on the outside. Cement is also used at the bottom of the well to avoid influx of oil and gas from below. However, *the cement outside the production casing and at the bottom of the well (at the “shoe track”) did not prevent influx from the reservoir*. Oil and gas escaped through the cement and up through the casing. In order to test the integrity of the well including the bottom-hole cement, a “negative pressure test” was conducted by displacing drilling mud, thereby creating under pressure – negative pressure – in the well. Influx of hydrocarbons would then be an indication of something wrong. However, *the crew misinterpreted the result of the negative pressure test*. The test indicated influx of oil and gas (i.e. a “kick”) but the crew considered the well as being properly sealed.

Oil and gas had started flowing into the well, but *the crew did not respond to the influx* before hydrocarbons were already above the subsea BOP and expanding up through the drilling riser towards the rig. Indications of influx were detectable some 45 minutes before the crew responded. When finally doing so, they attempted to close the BOP and then *routed the hydrocarbons to the mud gas separator instead of diverting it overboard*.

However, the mud gas separator had insufficient capacity to handle the large flow from the well, and the gas quickly overwhelmed the separator and escaped through gas vent lines, discharging onto the rig. Here, it encountered a number of potential ignition sources, first on the drill floor and subsequently in the engine rooms. *The fire and gas system did not prevent ignition* of the flammable gas cloud, partly due to the size of the gas cloud, but also since equipment were bypassed and/or defective. Manual action in terms of closing ventilation inlets to the main engine rooms were not taken, neither from the driller’s control panel nor the bridge. The BOP did not isolate the well and the blowout continued. After the explosion *the emergency*

methods available for operating the BOP also failed. The cause of BOP failure is not finally concluded, but a main theory is that the drill pipe was elastically buckled within the wellbore and was partly outside the shearing blade surfaces of the blind shear ram.

Important underlying causes

Important *underlying causes* of the accident:

1. Ineffective leadership
2. Compartmentalisation of information and deficient communication
3. Failure to provide timely procedures
4. Poor training and supervision of employees
5. Ineffective management and oversight of contractors
6. Inadequate use of technology/instrumentation
7. Failure to appropriately analyse and appreciate risk
8. Focus on time and costs rather than control of major accident risks

Most of the events and missteps related to the Deepwater Horizon disaster can, according to the President Commission, be traced back to an overarching *failure of management and communication*. As an example the BP's onshore team was aware of the cementing-related risks, but did not emphasise them to the individuals conducting the negative pressure test. Correspondingly, BP's drilling supervisor did not contact onshore experts regarding the dubious results from the negative pressure test.

The report from the Chief Council further identifies a number of managerial deficiencies including *failure to provide timely procedures* and *poor training and supervision of contractors*. As an example neither BP nor Transocean had any internal, formal procedures on how to carry out and interpret the results from the negative pressure test, and they did not provide any formal training on how to properly conduct and interpret a negative pressure test.

The report further points to *ineffective management and oversight of contractors*. Although BP was aware of uncertainties related to how Halliburton conducted their cement tests, they did not sufficiently compensate these weaknesses.

Inadequate use of technology/instrumentation was also identified. Well monitoring equipment on the Deepwater Horizon was inadequate, and neither did BP nor the other companies utilise the information from available data displays and monitoring equipment adequately. This contributed towards the crew's failure to timely detect the kick.

Failure to appropriately analyse and appreciate risk is clearly expressed when the President Commission concludes that "*the immediate causes of the Macondo well blowout can be traced to a series of identifiable mistakes made by BP, Halliburton, and Transocean that reveal such systematic failures in risk management that they place in doubt the safety culture of the entire industry*". BP's management system required separate risk analyses to be conducted during the planning phase of the well, but not during the execution phase. Critical decisions were therefore made during the execution phase without any formal risk evaluations. At the same time the crew was working with a mindset that they were aware of all the hazards, whereas in fact they were probably not capable of keeping oversight of the hazards, i.e. they had an inadequate risk perception.

BP *focused on time and costs rather than control of major accident risks*. BP made a number of decisions with the priority of time and cost savings over safety. By the time of the blowout the operation was 38 days delayed and an estimated \$58 million above budget. This may explain the lack of focus on assuring well integrity. On the day of the accident the crew on Deepwater Horizon was congratulated by representatives from BP management for achieving seven years of drilling without any "lost time incidents". The

investigation of the Texas City explosion in 2005 revealed that BP has had a strong focus on personal safety, but less attention to process safety.

Could this have happened in the Norwegian petroleum activity?

Every accident is unique, as is also the case for the Macondo blowout. However, many of the causal factors have similarities to previous accidents and incidents. This applies for the Montara accident in Australia in 2009, the Snorre A incident in 2004 and the Gullfaks C incident in 2010. The two latter events are of particular interest since they exemplify that things can go wrong also on the Norwegian sector, and only narrow margins saved us from major blowouts.

The direct causes of accidents often differ, but many of the underlying causes are identified as recurring problems. Examples of such problems are inadequate verification of the well barriers, failure to perform risk evaluation during changes and modifications, and lack of involvement and follow-up by management.

The oil industry is global, and various actors and facilities move between countries, adapting to national regulations if required. However, the design standards very often have a common basis, e.g. represented by the American API-standards. There are however a number of differences, related to for example type of regulatory regime (balance between prescriptive requirements and functional requirements) and regulations. There are also differences between standards since the Norwegian petroleum industry has developed their own NORSOK standards. Furthermore, there are differences with respect to operational practice and safety culture.

Comprehensive experience from previous accidents has taught us that two events are never identical. It is therefore somewhat futile to question whether the same course of events that took place on Deepwater Horizon could have happened in the Norwegian petroleum activity. We can, however, conclude that our own offshore industry generally faces the same challenges and the same hazards, and we therefore need to maximise lessons learned from the DWH accident in order to avoid similar accidents in the Norwegian petroleum activity.

Major safety improvements are required

The President Commission identifies the need for major changes both with respect to how the petroleum industry is being regulated by authorities, as well as changes within the industry itself. Concerning the authorities, the President Commission claims that *fundamental reforms* are necessary, both concerning the structure of the bodies that are responsible for regulating the industry, as well as internal decision making processes within these bodies themselves. According to the Commission this is necessary to assure the independence and technical expertise of government institutions, and to receive full attention on environmental concerns from these institutions. As examples the President Commission here mentions Norway and U.K.

Concerning the petroleum industry itself, the President Commission challenges the industry to find measures and make decisions to *increase the safety level dramatically*. This includes the implementation of self-policing mechanisms that supplement governmental enforcement.

In Norway we must – by any means – avoid taking a defensive position by claiming that everything is much better here. Rather we should seize this opportunity to learn from the DWH accident. If we do, this may initiate a major effort for improving safety also in the Norwegian petroleum activity.

SINTEF's assignment

The DWH accident involved some major, global actors (BP, Transocean and Halliburton) and the media attention and coverage have been massive. As a result, the accident is likely to affect both the global and the Norwegian petroleum industry. In Norway, this is reflected by the increased attention given to operations in the northern areas, increased focus on accidents and incidents in the Norwegian petroleum activity and the demands for a more stringent safety regime also in the Norwegian petroleum sector.

The Petroleum Safety Authority (PSA) Norway appointed a separate group for follow-up of the DWH accident, and assigned SINTEF to conduct a systematic review of literature and investigation reports from this accident and other major accidents in the petroleum industry. The objective has been to provide a better knowledge base, to give a foundation for understanding major accidents in general, and to broaden the perspective on the DWH accident. The PSA wanted an overall consideration of causal factors and potential areas of improvement and particularly requested an evaluation of human and organisational factors. This work shall contribute towards lessons learned and improvements in order to prevent similar accidents in the Norwegian petroleum industry.

The work has been limited to analysing investigation reports and other available documentation from blowouts, well incidents and incidents involving loss of stability. Hence, SINTEF has not performed a separate investigation and data collection.

The DWH accident is the fundament of this project and constitutes approximately 80 % of the documentation reviewed. In addition, SINTEF has made comparisons with some other important accidents and incidents in the petroleum industry, including the Montara blowout off the coast of Australia in August 2009, the Snorre A blowout in November 2004 and the Gullfaks C well incident in May 2010.

The project is limited by areas being under PSA's regulatory responsibility. Lessons learned and recommendations related to the clean-up phase, being under the responsibility of the Climate and Pollution Agency and The Norwegian Coastal Administration, are not a part of this project.

Conclusions in this report are based on the content of the investigation reports and other information available as of April 20, 2011. Hence, the report has been finalised without the results from the BOEMRE/U.S. Coast Guard joint investigation report (expected by July 2011), and the report from the Chemical Safety Board (CSB) (expected by June 2012).

SINTEF has reviewed and categorised a total of 134 recommendations from Deepwater Horizon investigation reports. In addition, recommendations from the Montara blowout, the Snorre A blowout and the well incident at Gullfaks C have been considered. A majority of the recommendations are related to management and organisation, as well as drilling and well technology. These recommendations, together with input from the Project Reference Group, PSA personnel, other experts and the project group's general knowledge about the industry, constitute the basis for the recommendations to the Norwegian petroleum activity. Within the discipline of management and organisation, different perspectives on major accidents and resilient organisations have also been applied in recommending improvements.