DEEPWATER HORIZON

Lessons learned and follow-up

A Norwegian Oil Industry Association (OLF) report with contributions from the Norwegian Clean Seas Association for Operating Companies (NOFO) and the Norwegian Shipowners' Association (NSA)

Preface

The primary objective of this project is to gather and transfer lessons learned from the *Deepwater Horizon* accident in order to reduce the possibility of a similar accident occurring on the Norwegian continental shelf (NCS).

To establish a baseline for the work, the first step was a comparison of relevant US and Norwegian regulations. This work was completed by Det Norske Veritas (DNV) in September 2010.

A project team was formed in August to do the following:

- To collect the available information from the accident and evaluate its relevance to the Norwegian petroleum industry. This will serve as a basis for necessary actions.

- To assess the need for developing new methods, standards and equipment:
    - to prevent similar accidents
    - to stop and limit the consequences of discharges from subsea blowouts.

This report has been prepared by the *Deepwater Horizon* project team (hereinafter referred to as the project) at the Norwegian Oil Industry Association (OLF), which consisted of representatives from OLF member companies, the Norwegian Clean Seas Association for Operating Companies (NOFO), the Norwegian Shipowners' Association (NSA) and OLF.

The report was approved by OLF's Operations executive committee (OEC) on 3 May 2012.

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Executive summary

Introduction

In August 2010, OLF established a project to follow-up the *Deepwater Horizon* accident which occurred with the Macondo well in the US Gulf of Mexico (GoM) on 20 April 2010. The primary objectives of the work are to reduce the possibility of similar accidents on the Norwegian continental shelf (NCS) and to stop and limit the consequences of discharge from subsea blowouts.

The *Deepwater Horizon* accident has had a significant impact on the global offshore oil industry. Regulators, operators, and drilling and specialist contractors have found it necessary to review their operating and management practices.

The OLF *Deepwater Horizon* project has reviewed the major investigation reports and assessed their implications for Norwegian offshore activities. A number of international initiatives have been pursued in response to Macondo, including those from International Association of Oil and Gas Producer (OGP), Oil and Gas UK and American Petroleum Institute (API). OLF's recommendations also build on these.

Main conclusions

The project team has concluded that the NCS is characterised by robust legislation and safe operations. Even so, the Macondo accident and its follow-up have demonstrated that opportunities exist for further improvements in prevention, intervention and response.

The most important priority has been major accident prevention in the areas of well design, planning and execution, cementing and well control, which were identified as the root causes of the accident identified in the BP investigation. Other areas of prevention include management systems, culture, leadership, roles and responsibilities in addition to the design of mobile offshore drilling units (MODUs).

Improvements to intervention and response have also been important, including the areas of capping and containment, unified command (UC), oil spill preparedness and response, working environment and chemical exposure, and environmental impact.

Major accident prevention

The majority of the prevention recommendations will be implemented through changes to the Norwegian drilling standards, Norsok D-001 (drilling facilities) and D-010 (well integrity in drilling and well operations). These include operational issues such as critical cement jobs, lockdown requirements for tubing and casing hangers, negative pressure testing and fluid displacement requirements, enhanced well control exercises, diverter line-up, improved blowout preventer (BOP) back-up control systems and enhanced BOP testing requirements.

Important proposed improvements to management systems include management of change, well management systems, process safety, and enhancements of rig-site teamwork and communication.

The report's recommendations cover the assessment of internal verification processes and the well management system (WMS). Combined with improved management of change processes, this should ensure that well design and onshore support teams hold risks to levels as low as reasonably practicable (ALARP) throughout the well lifecycle.

Drill crew expertise is being addressed internationally through OGP, and OLF is discussing crew resource management in the OGP committees to improve well-site teamwork and communication.

The project has determined that the Norwegian regulations for MODUs already comply with the technical recommendations on rig design made by the US Coast Guard.

Intervention and response

Macondo has also been a source of lessons in the areas of well capping and oil spill response. Solutions for well capping and containment are being addressed through the joint industry subsea well response project (SWRP). This initiative provides solutions for both the NCS and international waters.

The Macondo unified command system proved to be an efficient way of managing a large and prolonged incident. This approach is now considered best practice for major incidents, and OLF will work closely with the Norwegian Coastal Administration (NCA) to make a case for implementing the unified command principles in Norway.

Through NOFO, the Norwegian oil industry is well prepared to handle a potential oil spill. NOFO's capacity will be further upgraded via its new preparedness strategy, which incorporates lessons learned from Macondo.

The project has also assessed the lessons learned concerning chemical exposure, which indicate that responders need to be provided with the necessary protection equipment and knowledge during and after any oil spill response.

An important conclusion from the project is that environmental studies conducted after the spill show its effects to be smaller than predicted. The rate of natural degradation of oil components by micro-organisms was much higher than expected, and the use of in-situ burning and underwater dispersants appears to have had a beneficial effect on the Macondo oil. OLF will encourage work on the underwater use of dispersants, and will continue monitoring scientific literature on the environment impacts of the Macondo blowout.

Recommendations to the Norwegian oil industry

This report contains 45 specific recommendations, which are described in detail in chapters 2, 3, 4 and 5 and summarised in chapter 6. The objective is that, wherever possible, these recommendations will be incorporated into industry practice and standards.

OLF considers it the responsibility of each individual operator and drilling contractor to review, evaluate and, if necessary, revise its internal management system and steering documentation to take account of the recommendations in this report.

1 Introduction

This section covers the background to the accident and its major causes, an overview of OLF's response, a list of sources of information for this review, and an analysis of the key regulatory and industry differences between the USA and Norway.

1.1 Background

On 20 April 2010, a blowout occurred on the BP-operated Macondo well. Tragically, 11 people died and the *Deepwater Horizon* rig sank. The well flowed oil into the GoM for 87 days before it could be controlled.

Deepwater Horizon was a semi-submersible, dynamically-positioned, mobile offshore drilling unit (MODU) designed to operate in deep water and to drill to a maximum depth of 30 000 feet. It was built in South Korea by Hyundai Heavy Industries. The blowout preventer (BOP) stack was built by Cameron and had been in use on *Deepwater Horizon* since the rig was commissioned in 2001.

Owned by Transocean, the rig was operated under the Republic of the Marshall Islands flag, and was under contract to BP from March 2008 to September 2013. At the time of the incident, it was drilling an exploratory well in a water depth of about 5 000 feet (roughly 1 500 metres) on the Macondo prospect. This well is located in Mississippi Canyon block 252 in the GoM.

Control of the well was lost on the evening of 20 April, allowing hydrocarbons to enter the drilling riser and reach *Deepwater Horizon*, causing explosions and subsequent fires. The latter continued to burn for about 36 hours. The rig sank on 22 April 2010.

From shortly before the explosions until 20 May 2010, when all remotely operated vehicle (ROV) intervention ceased, several efforts were made to seal the well. A sealing cap was finally installed and the well shut in on 15 July 2010. The well was then killed and later cemented on 3 August 2010. A relief well intersection on 16 September confirmed the well to be dead.

The following diagram (figure 1) summarises BP's conclusions concerning the sequence of events which caused the accident:

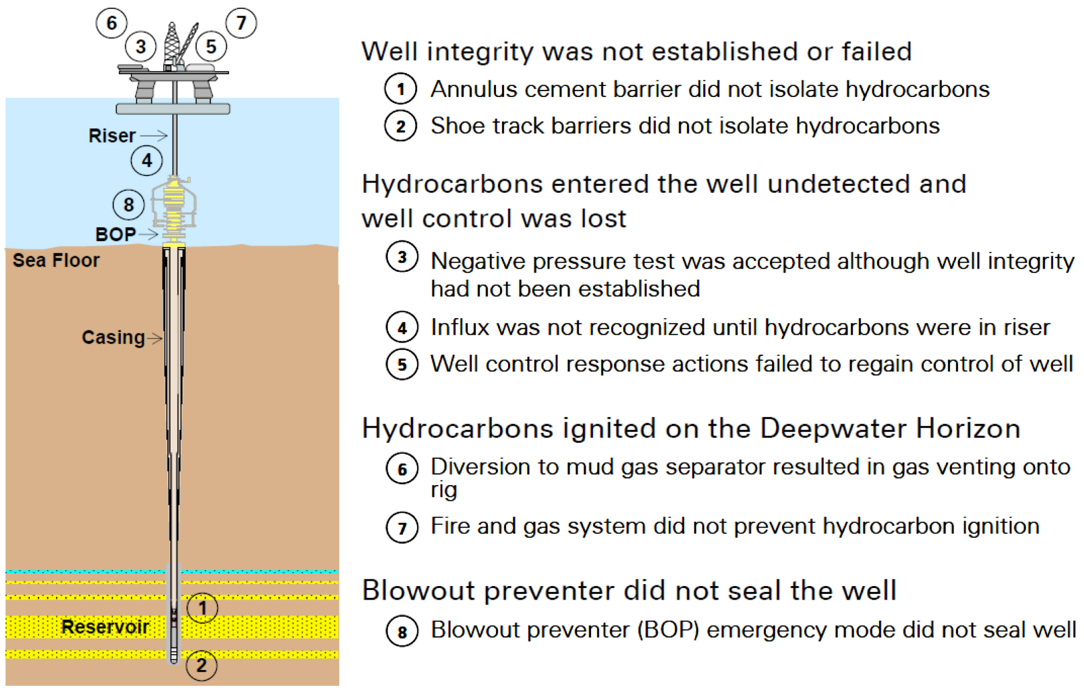

Figure 1. Extract from the BP investigation report [Ref 1]

1.2 Investigation findings and industry recommendations

Extensive analysis has been conducted on the causes of the accident, and new reports will continue to emerge, (eg the Chemical Safety Board investigation report). The project takes the view that important findings have been documented in the eight major reports it has reviewed (see Section 1.4).

As well as analysing what happened, each of the major reports contains clear recommendations on changes which should be made to the way drilling operations and, in the event of an accident, oil spill responses are executed and managed. That material has been the primary focus of this project, and more than 250 such recommendations have been reviewed in detail. An overview of these is presented in section 1.4.

Many of the recommendations studied were found to have already been implemented in Norway. The country's acknowledgement of compliance (AoC) process, for example, has ensured that new MODU requirements identified by the US Coast Guard are already in place on rigs approved to drill on the NCS. However, the oil industry is dominated by international standards and practices similar to those used in the US GoM and, as a result, the project has identified several opportunities for safety improvements, particularly in the areas of well control and management. Furthermore, since Macondo was the first deepwater blowout of its kind, lessons from it can also be applied to the NCS in the response and capping phases should such an incident occur there.

1.3 OLF response

After the *Deepwater Horizon* accident, OLF – working jointly with the Norwegian Clean Seas Association for Operating Companies (NOFO) – took a number of initiatives to

- gather available facts concerning the incident
- compare relevant regulations in Norway and the USA
- recommend changes and improvements on behalf of the Norwegian oil and gas industry to ensure that similar accidents do not happen on the NCS.

As a first step to improve understanding of the investigation reports which were to come, OLF and NOFO commissioned DNV to compare relevant regulations in Norway with those in the USA (see section 1.5 below).

A project was then formed in August 2010, reporting to the OLF's Operations executive committee (OEC). The project comprised representatives from OLF, NOFO and the OLF member companies. The Norwegian Shipowners' Association (NSA) has also contributed to the project. A list of team members and contributors is presented in Appendix A. The objective defined for the project was to assess the need for new methods and standards in Norway, both to prevent similar accidents in the future and to stop and limit the consequences of a subsea blowout should one ever occur.

The work was then conducted as follows:

- Available information and findings from the accident were collected and their relevance to the Norwegian petroleum industry evaluated. This served as a basis for necessary action.
- The need to develop new methods, standards and equipment was assessed in order to:
    - prevent similar accidents
    - stop and limit the consequences of discharges from subsea blowouts.

The diagram in figure 2 illustrates the OLF *Deepwater Horizon* project organisation and work areas. Group meetings were held twice a month to share views and track progress.

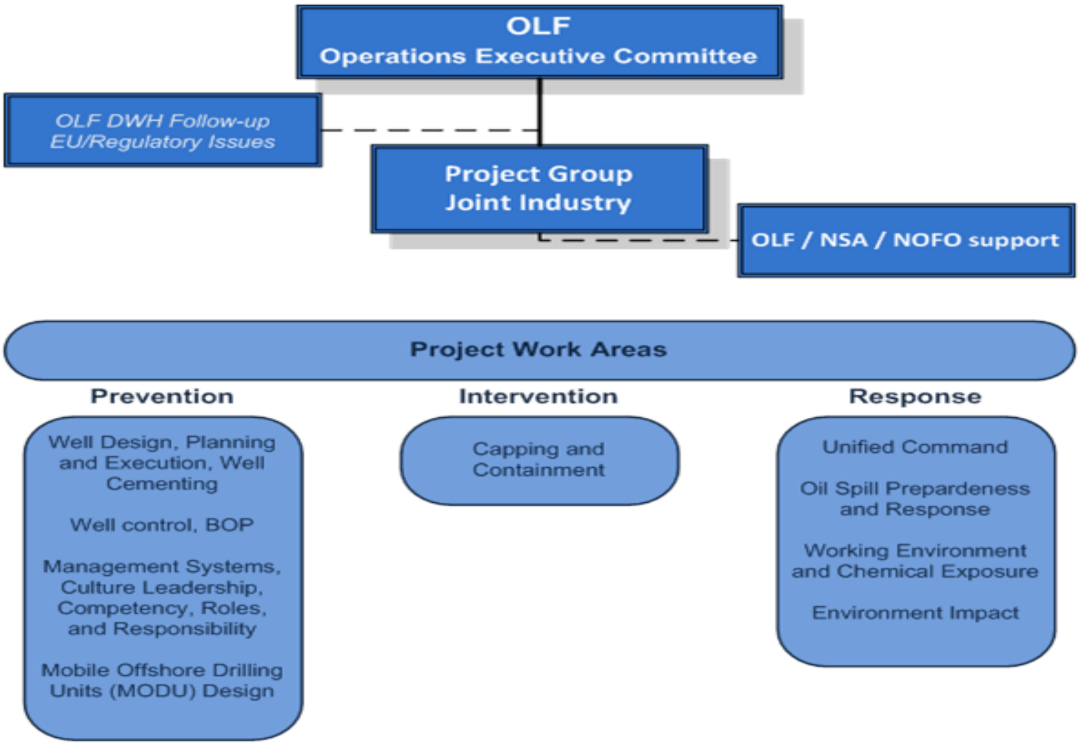

Figure 2. The OLF Deepwater Horizon *project organisation and work areas*

1.3.1 Process and approach

The project's first task was to analyse facts and material findings, initially from BP's *Deepwater Horizon* Accident Investigation Report [Ref 1]. The project then developed a number of initial proposals relevant to Norwegian petroleum activities. These early recommendations to operators were approved by OLF OEC and issued in March 2011. During 2011-12, additional recommendations were developed on the basis of further published reports and international initiatives led by groups such as OGP, API and the International Organisation for Standardisation (ISO).

A number of proposed revisions to Norsok drilling standards D-001 and D-010 are included in the OLF recommendations. The revision work is on-going, under the supervision of Standards Norway.

The project has developed recommendations based on published reports and aligned as far as possible with international initiatives such as the OGP's wells expert committee (WEC) and API. The underlying objective has been to achieve a broad industry consensus on key issues, both to optimise lessons learned and to simplify implementation across national and company boundaries.

During the project, OLF has collaborated closely with OGP, whose recommendations cover:

- prevention
- intervention (capping and containment)
- oil spill response.

While all three of these areas are important, it was deemed appropriate that the bulk of the effort made by the project should be aimed at preventing the possibility of a similar accident happening in Norway.

The project also has met with the Petroleum Safety Authority Norway (PSA), the Norwegian Costal Administration (NCA), BP, representatives from Norwegian offshore unions, Oil & Gas UK, the Netherlands Oil and Gas Exploration and Production Association (NOGEPA), the North Sea Offshore Authorities Forum (NSOAF), the International Regulators Forum (IRF), and representatives from the US Coast Guard, BOEMRE and the US Chemical Safety Board (CSB).

1.4 Sources of information and data analysis

The first task undertaken by the project involved collation and analysis of published information on the accident. This review covered the recommendations in all the major investigation reports, and the project used this information to develop and propose improvement measures for the NCS.

The most important sources are:

- **BP**: *Deepwater Horizon* Accident Investigation Report, September 2010 [Ref 1]
- **National Commission on the BP *Deepwater Horizon* Oil Spill and Offshore Drilling**: Deepwater. Report to the President, January 2011; Chief Counsel's Report 2011**,** Macondo the Gulf Oil Disaster, February 2011 [Ref 2]
- **US Coast Guard**: Report of Investigation into the Circumstances Surrounding the Explosion, Fire, Sinking and Loss of Eleven Crew Members Aboard the Mobile Offshore Drilling Unit *Deepwater Horizon*, April 2011 [Ref 3]
- **SINTEF report**: *Deepwater Horizon* Accident May 2011 [Ref 7]
- **Petroleum Safety Authority Norway**: *Deepwater Horizon*-ulykken - vurdering og anbefalinger for norsk petroleumsvirksomhet [The *Deepwater Horizon* accident – assessments and recommendations for the Norwegian petroleum industry], June 2011 [Ref 8]
- **BOEMRE**: Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout, September 2011 [Ref 4]
- **OGP**: Deepwater Wells, and Oil Spill Response, global industry response group recommendations, May 2011 [Refs 9 &11]
- **National Academy of Engineering**: Macondo Well Deepwater Horizon Blowout. Dec 2011 [Ref 6]

See Appendix B for the complete list of reports and documents.

Figure 3 summarises the recommendations extracted from the above reports. Recommendations directed at regulators for action are not reviewed further in this report.

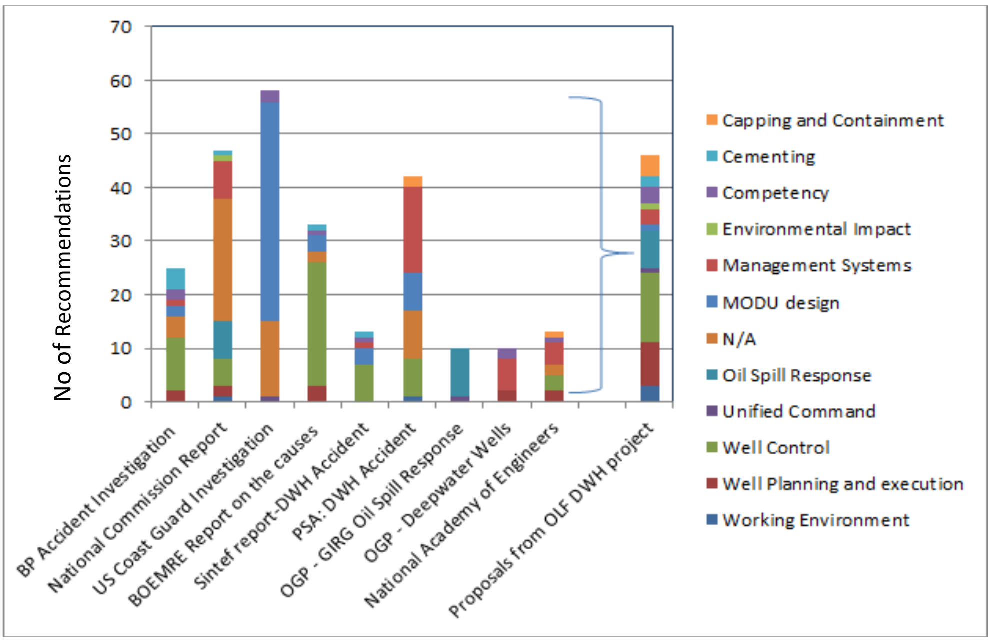

Figure 3. Major report recommendations and OLF proposals by topic

The project conducted a gap analysis and review of the recommendations to decide how they should be implemented in Norway. The project determined that many of these recommendations were already implemented in Norway.

OLF recommendations are identified in blue boxes in chapters 2, 3, 4 and 5, and summarised in chapter 6.

1.5 Comparison of Norwegian and US offshore drilling regulations

To provide a baseline for the *Deepwater Horizon* project, OLF commissioned a study to review and compare the offshore drilling regulatory regimes in Norway and the US Gulf of Mexico. This study [Ref 12] was completed by DNV in September 2010 and identified similarities, but also noted fundamental differences between the two regimes in place at the time of the incident in April 2010. The review concluded that the Norwegian legislation is robust.

1.5.1 Regulators

In Norway, the regulator for resource management – the Norwegian Petroleum Directorate (NPD) – is separate from the regulator for HSE management PSA, while both functions were exercised in the USA by the same agency, the Minerals Management Service (MMS). In both cases, various other government agencies with differing responsibilities are involved. In Norway, however, the PSA has a coordinating role in the development and supervision of all HSE regulations, while this responsibility is shared in the USA between different authorities. (Note: On 1 October 2011, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), formerly the Minerals Management Service (MMS), was replaced by the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE).)

1.5.2 Regulations and safety management

In Norway, offshore regulations are primarily performance-based and supplemented by prescriptive requirements through established norms and standards, whereas US regulations are generally prescriptive and do not require the application of systematic risk management. To implement this requirement, Norwegian regulations specify the performance or acceptable level of risk to be attained and maintained by the industry.

The prescriptive regulations in the USA define specific technical requirements for structures, technical equipment and operations to prevent accidents and mitigate hazards. And while these are in some respects simpler to review, implement and assess, they are generic and not linked to any level of risk. They also require frequent updating – when new technology is introduced, for instance. In contrast, the Norwegian regulations require compliance with the latest applicable regulations and updated reference standards such as Norsok D-001 and D-010. The regime focuses the operator's attention on its HSE performance through self-regulation and continuous improvement, rather than relying on the regulator to ensure that specific HSE requirements are met. The USA sets no specific requirement to establish a safety management system, whereas in Norway the operator is responsible for demonstrating how its safety management system and performance complies with the regulations for drilling and well operations. The responsibility of the operator in Norway is undivided and explicit, with a duty to verify that all its petroleum activities are conducted in accordance with the regulations. In the USA, this responsibility is shared between the regulators and the operators.

1.5.3 Well barriers and blowout preventers

Another major difference between the regulations on well design and operation is the Norwegian requirement for the systematic application of two independent and tested well barriers. Active use of well barrier schematics in planning and execution is described in Norsok D-010.

A mandatory requirement exists in Norway for the recertification of well control equipment every fifth year and drilling and well control equipment must be subject to independent review by a classification society. An alternative (back up) BOP control system is also required on all mobile rigs operating on the NCS.

1.5.4 Oil spill response

Norwegian emergency preparedness against acute pollution is risk-based. Hence, the capacity and design of oil spill preparedness is specific for the offshore installation or exploration well, and based on environmental risk assessments. Offshore environmental risk assessments are based on weighted blowout rates and duration for exploration drilling, and 90 percentile of possible blowout rates for field development.

US emergency preparedness against acute pollution is based on "worst case discharge", and the design of oil spill preparedness is not site-specific. While the effectiveness of oil recovery systems is calculated in Norway on the basis of local weather, operational conditions and oil weathering data, capacity is determined in the USA by reducing the given manufacturer's specification to 80 per cent of stated collection capacity.

The Norwegian Climate and Pollution Agency (Klif) defines the main strategy for oil spill recovery as:

- mechanical recovery as close to the source as possible
- prevention of further drifting
- chemical dispersion
- continuous monitoring
- utilisation of national resources
- beach cleaning if necessary.

In Norway, the use of dispersants is subject to approval by Klif and based on a net environmental benefit analysis (Neba). In the USA, accepted spill response techniques fall into three general categories including, but not limited to, mechanical recovery, in-situ burning and dispersants.

1.5.5 Mobile offshore drilling unit (MODU) requirements

Specific safety requirements are placed on a rig in order for it to gain approval to work in Norway. Specifically, a MODU must receive an acknowledgement of compliance (AoC) from the PSA to be accepted for work on the NCS. The AoC is issued on the basis of an assessment of the facility's technical condition as well as the applicant's organisation and management systems. Furthermore, the rig must comply with the Norwegian Maritime Authority (NMA) regulations for maritime requirements. Generally speaking, rigs subject to conventional MODU class or international MODU codes will not conform to Norwegian safety standards.

Relevant investigation reports and recommendations related to rig design, equipment and safety systems were reviewed by the NSA and DNV and American Bureau of Shipping (ABS) classification societies.

The MODU areas evaluated included:

- gas detection systems
- emergency shutdown systems
- passive fire and explosion protection
- air intakes
- fire fighting systems
- emergency power
- flooding integrity/watertightness
- design risk analysis.

Industry experience suggests that, in a blowout, a gas cloud may be expected to extend outside gas hazard areas (which are protected with explosion-proof equipment). This was exacerbated on *Deepwater Horizon* by routing the wellstream into the mud gas separator and up the derrick instead of overboard.

One of the major findings from the Macondo accident was the lack of automatic shutdown for ventilation and ignition sources when gas was detected on the rig. For MODUs to comply with NMA requirements, automatic shutdown of ventilation air intakes and ignition sources is required, whilst manual shutdown is accepted by the MODU code from the International

Maritime Organisation (IMO). NMA also requires separate individual combustion air intakes for the main engines, with automatic shutdown on the detection of gas in the air intake/overspeed shutdown.

Where passive fire protection is concerned, the NMA requires a risk analysis to define dimensioning fire and explosion loads, which may increase requirements for walls and partitions above the minimum prescriptive standards.

In general, NSA and DNV and ABS classification societies found that a MODU accepted for operation in Norway complies with all relevant recommendations for rig design and equipment stemming from the *Deepwater Horizon* accident. A number of clarifications in the forthcoming revision of the NMA's prevention of fire and explosion regulations will make these requirements more precise.

1.5.6 US and Norwegian petroleum industries – differences and similarities

The DNV report has highlighted important differences in the safety regimes between the Norwegian and US petroleum industries. The project team has concluded that the NCS is characterised by robust legislation and safe operation. Nevertheless, a residual risk always exists in any activity.

Despite the regulatory, geological and environmental differences between the GoM and the NCS, the equipment used and the organisation of drilling activities are essentially the same.

Drilling activities all over the world are characterised the use of drilling facilities owned and operated by contractors and by use of subcontracting. Hence, the challenges of coordination and communication between those involved are not just a characteristic of the US petroleum industry. They represent global challenges inherent in the high degree of contractor specialisation which characterises drilling operations. The same can be said of the challenges facing management oversight and awareness of operational performance.

There is reason to believe, therefore, that the organisational and management challenges highlighted by the *Deepwater Horizon* accident investigations are relevant to the Norwegian petroleum industry. These are discussed further in section 2.2.

2 Prevention

Prevention of future accidents has been the main focus of the project. This review of the recommendations from the major reports has enabled the project to identify a number of improvements to reduce blowout risks on the NCS even further. These typically relate to drilling standards, operator and contractor management systems, well control exercises, steering documentation and emergency equipment. Further improvements will continue to be made over time as international standards evolve from groups such as the OGP's WEC, in which OLF participates, API and the International Association of Drilling Contractors (IADC).

The first section of this chapter addresses operational/technical recommendations for accident prevention. These are presented in section 2.1. Management recommendations for prevention are covered in section 2.2.

2.1 Prevention – operations and technical

BP's comprehensive analysis of the accident, as summarised in section 1.1, has been generally accepted as factual in other published investigation reports. Given these data, the prevention recommendations developed by OLF are targeted at each of the eight primary and sequential causes of the accident identified by BP.

In figures 4-7 below:

- **green text indicates that a Norwegian requirement is already in place**
- **purple text indicates a new OLF recommendation**
- **red text indicates that R&D is proposed.**

A description of the mitigations already in place on the NCS or proposed as new recommendations for each of the eight primary causes is provided in subsequent sections.

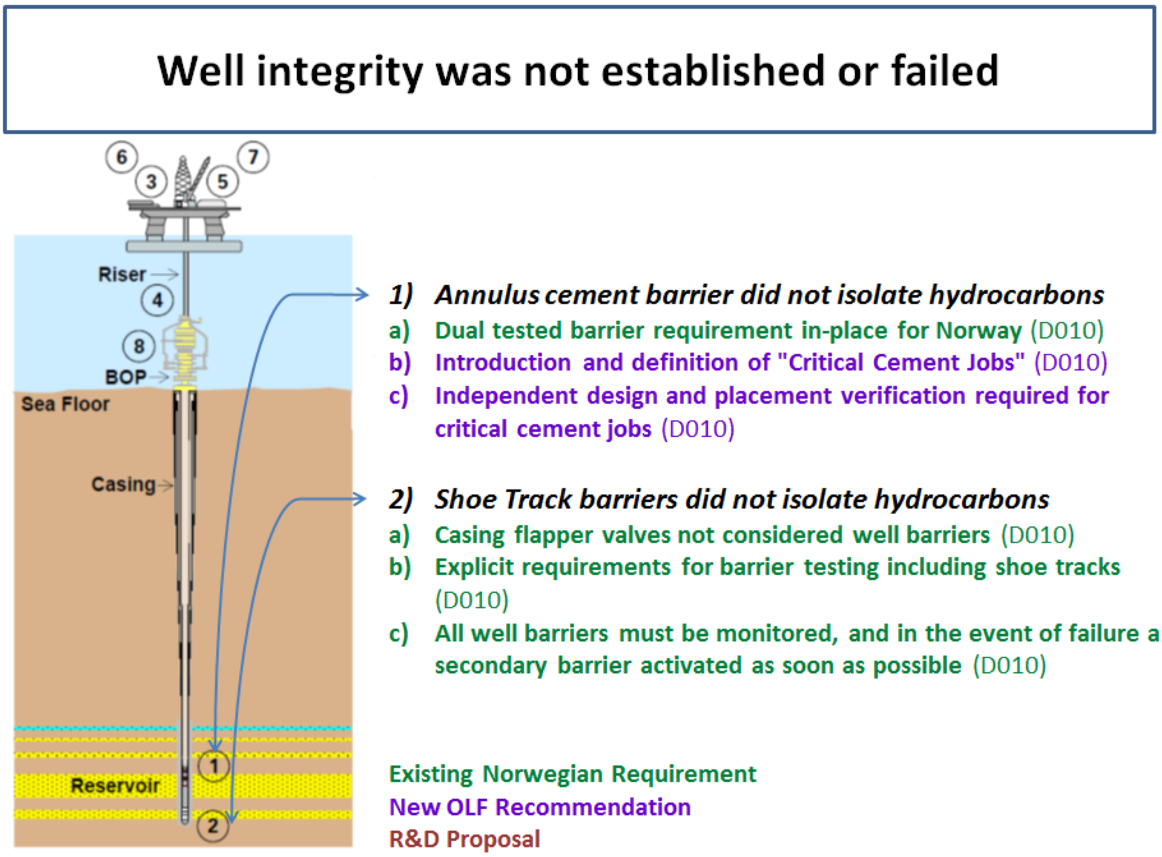

Figure 4. Well integrity failure

2.1.1 Annulus cement barrier did not isolate hydrocarbons

Failure of the cement barrier and the lack of adequate qualification of this barrier was an important and direct cause of both the 2008 Montara well blowout and the *Deepwater Horizon* accident.

a) A two-barrier requirement already exists in Norway. Norwegian legislation states that "There shall be two tested well barriers available during all well activities and operations, including suspended or abandoned wells, where a pressure differential exists that may cause uncontrolled outflow from the borehole/well to the external environment". Furthermore, Norsok D-010 states that "Methods and frequency for verifying the condition of the well barrier elements (WBEs) shall be defined and documented". Given the criticality of a cement job of this nature, and to achieve acceptance as a barrier, comprehensive evaluation of the cement job would be required to comply with Norsok D-010, such as running a cement bond log (CBL). Mitigation already in place.

   However, improvements should be made to the way critical cement jobs are managed in future operations. The following actions should be implemented in Norsok D-010:

b) Norsok D-010 should be updated to include the term “critical cement job”. A requirement for independent design verification of “critical cement jobs” should also be introduced. This verification can be performed by either an independent in-house department or an external third party.

Recommendation no 1

c) Norsok D-010 should furthermore require that cement and casing design for slurries placed across hydrocarbon zones be verified in cementing company labs prior to use. For critical slurry designs, such as those containing foam cement or gas block additives, the slurry design, slurry properties, waiting on cement times and cementing plan should be independently verified. This verification can be performed by either an independent in-house department or an external third party.

Recommendation no 2

2.1.2 Shoe track did not isolate hydrocarbons

a) Norsok D-010 and most operators do not consider the shoe and float flapper valves to be a well barrier. These valves are designed to assist cement placement. Only the cement in the shoe track can be qualified as a barrier. Mitigation already in place.
b) Norsok D-010 also has explicit requirements for testing well barriers including documentation and for approval by an authorised person. Mitigation already in place.
c) After testing, Norsok requires that each barrier be monitored and that, in the event of primary barrier failure, activation of the secondary barrier should be implemented as soon as possible. Mitigation already in place.

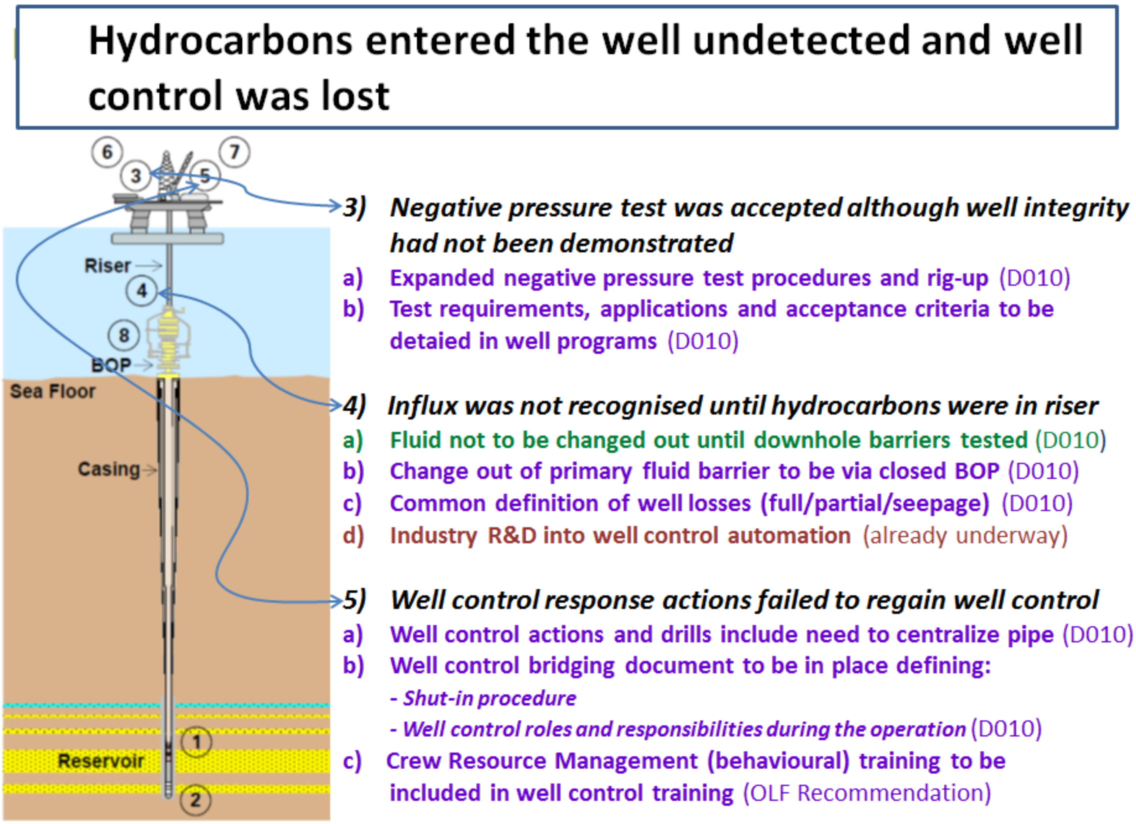

Figure 5. Well control failure

2.1.3 Negative pressure test was accepted although well integrity had not been demonstrated

Personnel on *Deepwater Horizon* missed a key opportunity to recognise cement failure during the negative pressure test, which clearly showed that the cement was failing to seal the wellbore. Well-site leaders also misinterpreted the results.

a) Norsok D-010 should be updated to define the requirements related to inflow (negative) pressure testing clearly.

b) Well programmes should provide a detailed procedure and acceptance criteria for all inflow tests. Inflow tests should be conducted in a controlled manner with detailed procedures which have been approved by an authorised person, and accompanied by a demonstrated risk analysis. This should be covered in Norsok D-010.

Recommendation no 3

2.1.4 Influx was not recognised until hydrocarbons were in riser

On Macondo, the fluid barrier was removed by circulating water into the wellbore. This was implemented as part of the test and, critically, before the well barrier had been accepted.

a) Under Norsok D-010, the fluid barrier should never be replaced until the cement barrier has been tested – Mitigation already in place.

b) Norsok D-010 should be further clarified to state that, when changing out the fluid barrier element while the remaining barrier consists of untested cement or mechanical plugs, all displacement to a lighter underbalanced fluid should be done with a closed BOP and through the choke and kill lines.

Recommendation no 4

Inconsistencies exist in the industry's descriptions of mud losses which can lead to the severity of well instability problems being misunderstood.

c) Norsok D-010 should be updated to include descriptive values for full/partial/seepage and static/dynamic fluid losses so that deviations in return flow can be reported using a common frame of reference. Such data can be used to generate acceptable downhole loss rates for specific fields.

Recommendation no 5

Ideally, well control could be automated to a greater degree. R&D on this issue has been underway for some time across the industry, but has proved challenging. It should not be implemented on a rig until fully proven in field trials.

d) OLF recommends that operators and contractors develop simple solutions for well control automation which are reliable and driller-friendly.

Recommendation no 6

2.1.5 Well control response actions failed to regain well control

What should have been a routine well control operation on Macondo, had it been recognised earlier, became an uncontrolled inflow of hydrocarbons. Several recommendations are made to improve crew response to a potential well influx.

a) Norsok D-010 should be updated to specify that well control actions must include the need to centralise pipe and space-out in the BOP prior to closure. This can be achieved by closing the annular BOP first. Also included should be the requirement to conduct routine well shut-in exercises, including pipe space-out and centralisation as the first steps (see recommendation no 9 in section 2.1.8 c).

b) OLF proposes that a well control bridging document be established between the operator and drilling contractor to describe the chain of command, procedures for well control, ram configurations and the implementation of the required exercises. The document should state that the operator's well control methods should be followed and that the contractor should have defined procedures for each method as well as roles and responsibilities for well control scenarios in the contractor's steering documentation.

OLF recommends that well control bridging documents be prepared for all future drilling operations**.** (OLF issued this recommendation to Norwegian operators and contractors in January 2011. It has also been referred to the Norsok D-010 revision committee.)

Recommendation no 7

c) Analysis by OLF of the events of 20 April 2010 indicates that communication breakdowns between crew members were similar in nature to several documented aircraft accidents. The aviation and maritime industries have implemented crew resource management (CRM) training to improve team dynamics and communications in hazardous situations. OLF suggests that a similar approach be considered for well activities on the NCS (see recommendation no 29 in section 2.3.9).

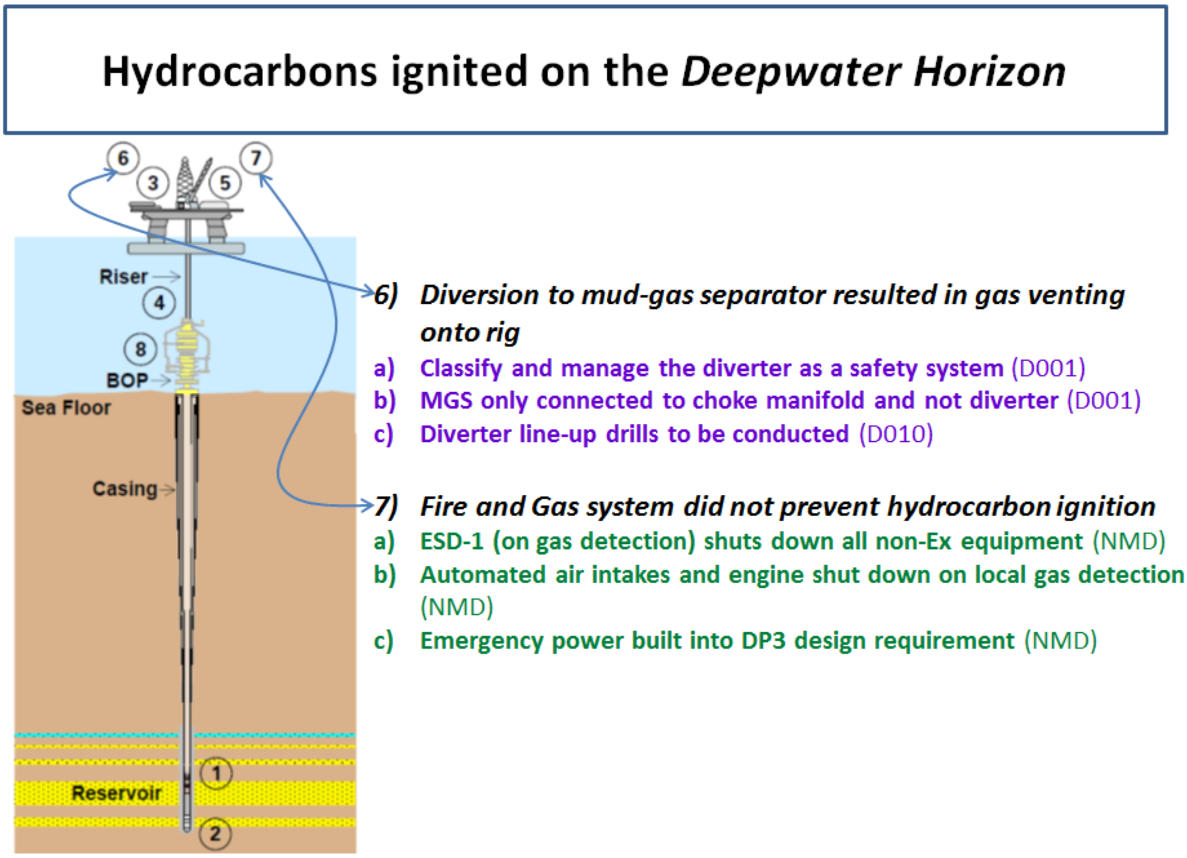

Figure 6. Hydrocarbon ignition

2.1.6 Diversion to mud-gas separator resulted in gas venting onto rig

The release of a gas cloud over the rig's main deck was a fundamental cause of the accident.

a) Norsok D-001 should be updated to identify the diverter system as a safety system designed to handle gas in the riser above the BOP, and to eliminate the possibility of a gas cloud being released over the rig. The use of the diverter in such circumstances should ensure that all explosive hydrocarbons are released in a safe area to the side and ideally downwind of the rig.

b) To eliminate the possibility of overloading the mud gas separator (MGS), Norsok D-001 should be updated to prevent any connection between the diverter system and the MGS. However, a connection from the downstream end of the choke manifold to the MGS is permitted.

Recommendation no 8

c) To ensure that routines with diverter operations are understood by drill crews, Norsok D-010 should be updated to specify that diverter exercises should be routinely conducted (see recommendation no 9 in section 2.1.8 c).

2.1.7 Fire and gas system did not prevent hydrocarbon ignition

The source of gas ignition on *Deepwater Horizon* is unknown, but a number could have been involved, including overspeeding engines or non-Ex equipment.

a) NMA regulations require that, in the event of positive gas detection on deck, an ESD1 is initiated. That should automatically shut down non-Ex-protected electrical equipment which might be exposed to explosive gasses – Mitigation already in place.

b) These regulations also require that, when gas is detected at the engine air intakes, the intake baffles close automatically and the engines shut down – Mitigation already in place.

c) Emergency power must be provided by at least two fully independent power sources. This ensures that, if any one group of engines shuts down, redundant power is still available for fire fighting and for dynamically positioned (DP) operation on DP vessels – Mitigation already in place.

Although the requirements above are currently included in the NMA regulations, see section 1.5.5, the upcoming revision of the NMA's prevention of fire and explosion regulations will make them more precise.

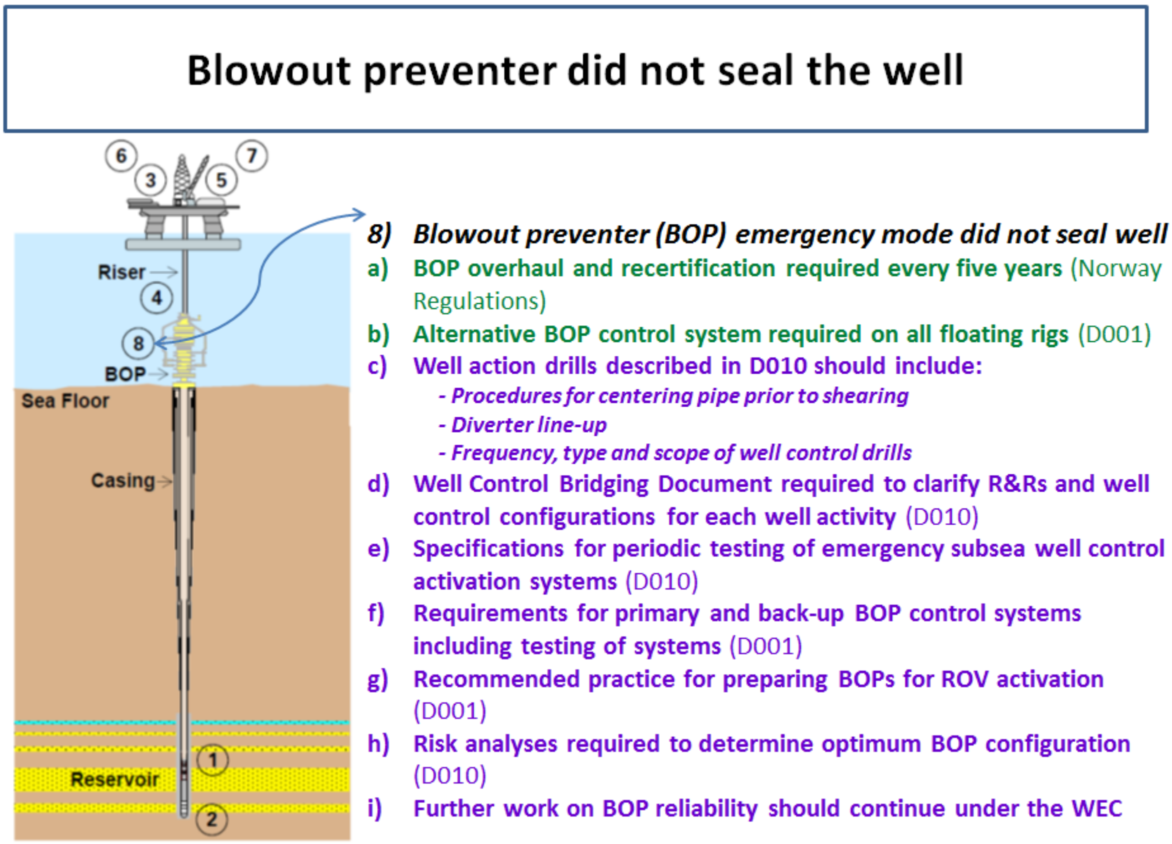

Figure 7. Blowout preventer failure

2.1.8 Blowout preventer (BOP) did not seal the well

The primary role of a BOP stack is to seal off the well when required. The BOP on Macondo failed to do this, and has since been subjected to detailed causal and forensic analysis [Ref 5]. The following comments and recommendations reflect findings from the investigations.

a) Complete overhaul and recertification of the BOP and its control systems is already a requirement every five (5) years pursuant to section 51 of the Norwegian activities regulations – Mitigation already in place.

b) An alternative or secondary BOP control system is a requirement, pursuant to chapter 49 of Norway's facilities regulations, on all mobile rigs on the NCS in case the primary control system malfunctions or is interrupted. The norm in Norway for alternative systems is the acoustic system – Mitigation already in place.

c) The need for more practice with well control emergencies is recognised. Norsok D-010 should be updated to include requirements for routine well control exercises, specifically in the areas of:
- spacing out and centralising pipe prior to shearing and disconnecting
- diverter line-up to overboard lines
- well control exercises to be conducted (scope, frequency, acceptance, etc).

See also sections 2.1.5 and 2.3.4.

Recommendation no 9

d) To achieve clear communication between the relevant parties on an installation, Norsok D-010 should be updated to include a requirement for a well control bridging document to be in place for each well activity. This document should also specify the proposed ram configurations for the well being drilled (see recommendation no 7 in section 2.1.5 b).

e) Norsok D-010 should specify and require periodic testing of emergency subsea well control activation systems, with due regard to operational activities.

Recommendation no 10

f) Norsok D-001 and D-010 should include more explicit requirements for primary and back-up BOP control systems, their ability to perform in emergencies and testing of them.

Recommendation no 11

g) Norsok D-001 should contain a requirement for activating BOP functions via ROV intervention. This will facilitate external activation of BOP elements or release functions should all other systems fail. It is recognised that a BOP ram may not be closed fast enough by an ROV to seal off a flowing well.

Recommendation no 12

The recently developed fourth edition of the API Standard 53 on blowout prevention equipment systems for drilling wells identified several changes and new requirements, including a new BOP dual shear ram recommendation for subsea BOP stacks. OLF considers that this may not always offer the safest option. Given the diverse range of well operations and rigs operating on the NCS, a standard for BOP configurations will not suit all cases – in particular, the number and location of blind shear rams fitted to a particular BOP stack. The API standard accepts that variations may be required in certain circumstances and/or operating environments, and operators should always take these into account.

h) Operators should conduct a risk assessment to determine the optimum BOP configuration for each well, utilising the latest BOP reliability, performance and assessment data, the design of the well to be drilled, and the rig in use. The findings should be recorded in the well control bridging document.

Recommendation no 13

i) OLF recommends that the industry supports further work on BOP reliability to be coordinated by the WEC, where OLF is represented.

Recommendation no 14

See also Appendix C for a discussion of BOP configurations and reliability.

Several areas for Research & Development (R&D) work have been identified by the project. The following list details potential R&D proposals for consideration when prioritising R&D through the Research Council of Norway or others:

- The effect of water depth on kick detection and response times compared with shallow water. Placement and accuracy of flow meters for the purpose of kick detection.
- The effects of a flowing well on the ability of a subsea BOP to shear pipe and different components, such as well screens and pipe under axial compression.
- Blind shear ram design which incorporates an improved pipe-centring shear ram
- Operational tools (eg, well barrier schematics) which can provide the various well-site crew members with simple visual aids, including descriptions of monitoring methods for each defined barrier element. This could include a review of the instrumentation and alarm systems facing the drilling crew which fail to provide them with the decision-making support they need to perform the operation safely.
- BOP condition monitoring systems, including instrumentation for pressure, temperature, ram positions, tool joint positioning, and real-time analysis of electrical BOP system status and faults.
- Technologies for well control automation, including the use of expert systems for well control and improvements which make driller's instrumentation easy to use and visualise.
- Technology which permits monitoring of well barriers even when the well contains no drilling or circulating fluid.

2.1.9 Casing hanger lock-down

At an early stage in the analysis of the blowout by BP, concern existed that the well flow was passing up through the casing hanger and seal assembly annulus barrier, which may not have been locked down correctly.

> Norsok D-001 should be updated to ensure that subsea wellhead casing/tubing hangers are locked down on all strings in contact with hydrocarbon-bearing zones.
>
> Recommendation no 15

2.2 Well integrity guidelines

It is recommended that Norwegian operators and drilling contractors consult the OLF document 117 on recommended guidelines for well integrity [Ref 13] to obtain further guidance.

This guideline has the following chapters:

- well integrity training
- well handover documentation
- well barrier schematics for the operations phase
- well integrity – well categorisation
- well integrity management system
- sustained casing pressure.

The guidelines include detailed explanations of the two-barrier system, and a well integrity categorisation (colour code system) to help focus attention on the safety status of a well.

> OLF recommends that NCS operators and drilling contractors review and utilise the OLF well integrity guidelines for all aspects of well planning and execution.
>
> Recommendation no 16

2.3 Prevention – management systems

Management failures have been identified as a major contributor to the Macondo accident in several investigation reports.

In order to structure the recommendations, the following diagram sourced from OGP has been used (figure 8). This presents the multiple causes of a failed leadership and safety culture addressed along a time line both before and after a possible well incident. The changing influence of organisational and human factors is identified along the top axis.

Evidence of a broken or ineffective safety culture is often provided by the reaction that "this can't happen here" or by the tendency of employees to pass only good news up to management.

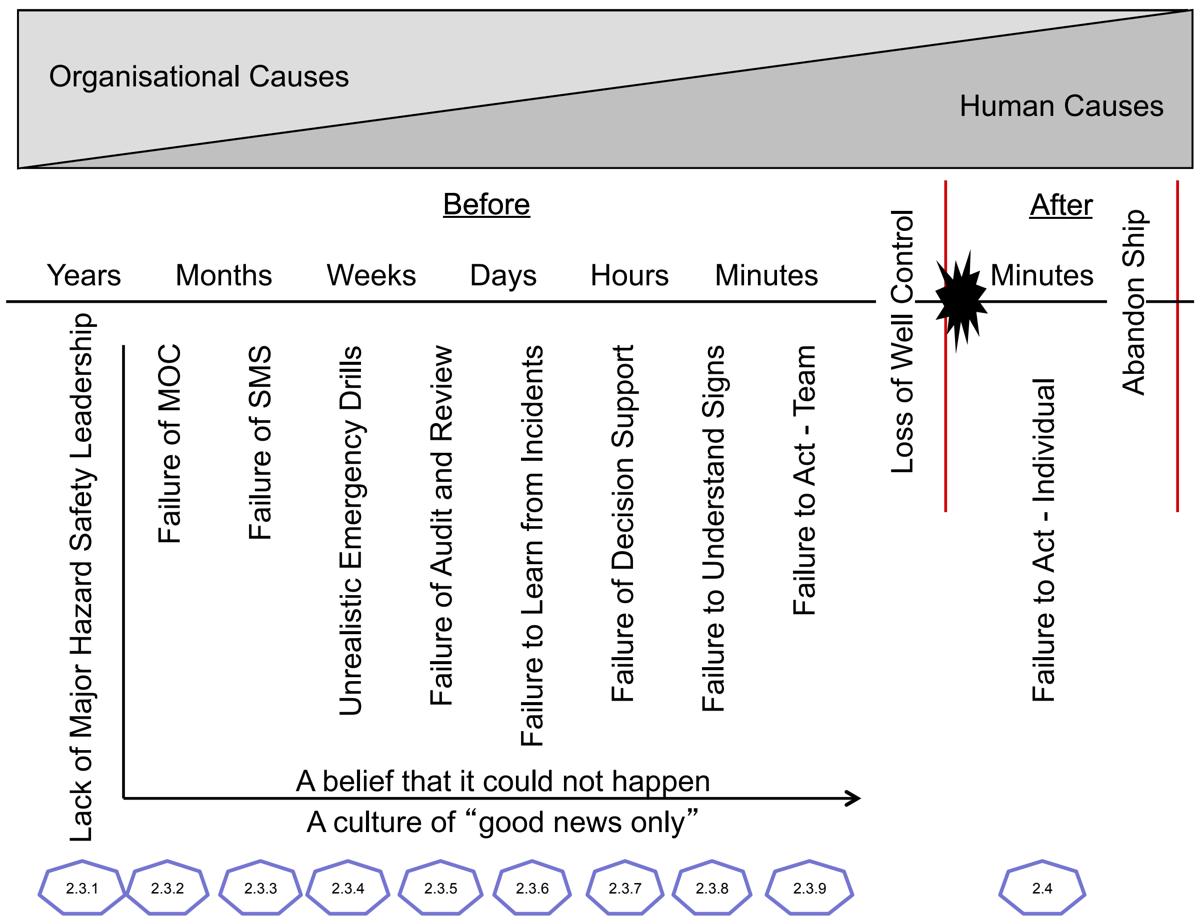

Figure 8. Safety leadership failures indicating the section where each cause is discussed.
(Extracted from "Human and organisational factors – lessons from the loss of the Deepwater Horizon*": Rob Miles, UK HSE),(Safety management system – SMS)*

These causes identified above are discussed in sections 2.3.1-9 below:

2.3.1 Major hazard and safety leadership

The leadership of any organisation has a key role in establishing its culture for and attitudes on safety. The inadequate safety culture on *Deepwater Horizon* is likely to have originated in lack of leadership and safety management which may have existed for a number of months or even years prior to the accident.

Safety statistics for the NCS have been improving over the past 10 years, as shown in the annual trends in risk level in the petroleum activity (RNNP) reports [Ref 14]. However, the *Deepwater Horizon* accident has emphasised the need for the industry to pay greater attention to major accident prevention.

Two areas have emerged as offering opportunities to reduce major accident risks:

- Managing and controlling simultaneous operations (Simops) in drilling, production, hot work and high-risk maintenance activities.
- Maintaining technical and operational integrity of key safety systems, where a key performance indicator could be, for example, the maintenance backlog for safety-critical systems.

The industry is seeking more key performance indicators, and especially proactive ones, to manage these risks better.

> OLF will assess the OGP's work on process safety and key performance indicators related to asset integrity and major accident risk.
>
> Recommendation no 17

The project has also initiated a study of the published reports in order to determine the primary human and organisational factors (HOFs) which contributed to the Macondo blowout. Some important aspects of the study are presented in Appendix D.

The project concluded that inadequate management was a major cause of the accident, and that communication failures at several levels also contributed. Some examples include ad-hoc procedures developed on the rig in order to keep up with the pace of the operation, the failure of employees new to the rig or less familiar with deepwater drilling to receive the appropriate follow-up on *Deepwater Horizon*, and well data being sent to land with no procedures in place for staffing the computer rooms which could have been used to monitor the well.

Several failures of risk management also occurred both before and during the operation which eventually led to the accident. Formal requirements for risk analysis were not observed, analyses were not updated as the operation progressed, and there were no risk assessments of changes made in plans and procedures. Several critical decisions made to save time during the operation proved to be at the expense of safety.

The following list summarises the issues raised in the PSA assessment [Ref 8]:

- leadership expertise and visibility
- contractor review and performance audit
- overview of maintenance systems and effectiveness
- internal awareness and implementation of best practice
- company processes to incentivise safety
- safety critical maintenance – corporate oversight.

OLF recommends that the findings from the PSA assessment [Ref 8] should be reviewed by NCS operators and drilling contractors.

Recommendation no 18

2.3.2 Management of change

The planning process for wells requires that well designs and operational procedures are reviewed, checked and approved by competent engineers and regulators. Poor control of later changes to the well and during operations will threaten both the integrity of the well itself and operational safety.

The reports indicate that additional risks were created on Macondo by changes to the organisation and to well design and procedures which took place both months and days before the accident.

An OLF recommendation letter issued to operators and rig contractors in January 2011 recommended a formal management of change (MOC) process to be in place for well activities. OLF proposes the following.

A recommendation on management of change (MOC) should be implemented in Norsok D-010 as follows:

a) An MOC procedure covering the well life cycle should be included in the operator's management system steering documentation. The MOC procedure should describe the processes used to assess risk and to mitigate, authorise and document material changes to previously approved information or procedures. Material changes subject to an MOC process include, but are not limited to, the following:
    - changes in surface and downhole well control equipment
    - changes that impact well barriers
    - change in well type (eg, producer to injector)
    - changes in procedures
    - changes in rig or contractor well control equipment while on hire to an operator
    - changes of key personnel.

b) An MOC procedure covering the following elements of rig systems and key personnel should be included in the drilling contractor's management system steering documentation. The MOC procedure should describe the processes used to manage, maintain, modify, risk analyse, authorise and document material changes to rig systems and procedures. Elements subject to an MOC process include, but are not limited to, the following:
    - safety critical systems
    - changes of key personnel
    - changes in procedures
    - changes in the contractor's well control equipment while on hire to an operator.

Recommendation no 19

2.3.3 Safety management system

A defective or little-used safety or HSE management system can make a significant contribution to increasing operational risk in the months and weeks before an accident. The project team has made recommendations on a well management system and operational barriers.

Well planning and management

Most of the technical recommendations in section 2.1 have an operational focus, but it is important to bear in mind that drilling risks are often created in the well design and planning phase. A well should be designed from a lifecycle perspective to ensure that risks in all phases are managed to be as low as reasonably practicable (ALARP).

It is evident from the investigation reports that the Macondo well design team made a challenging exploration well even more difficult to drill and complete. Examples include:

- Conversion from an exploration to a production well increased the complexity and functional requirements of the well and casing.
- Selection of a "full string" production casing rather than a liner design, which reduced the operational margins for achieving a successful casing cement job.

The project proposes that a well management system (WMS) should cover the full lifecycle of the well. The WMS should include a description of the well's objectives as well as its delivery, resourcing and planning processes. A management of change (MOC) process should also be in place, which can adjust the well plan in the event that operational risks are becoming unacceptable.

OLF recommends that operators and contractors review their well management system (WMS) to the relevant extent in order to ensure that well design and planning will reduce operational risks to ALARP.

Recommendation no 20

Operational barriers

A key function of an organisation's safety management system is the formal implementation of barriers to reduce risks. An example is the use of the two-barrier requirement for well management in Norway, which is widely understood.

An operational barrier may be defined as the characteristics of a person, a work community or a work site which promotes safe work performance. Management, expertise, communication, work practices, organisational learning, risk management and workplace design are examples of operational barriers. The safety culture of a workplace may thus be defined as an overall expression of the integrity of its operational safety barriers.

The concept of operational barriers emphasises human action and intervention capabilities as *resources* for safety. The importance of such factors has been thoroughly demonstrated through research on human factors, and in organisational perspectives such as high-reliability organisations and resilience engineering.

Improved monitoring of operational barriers and their inclusion in safety management systems should contribute to:

- Company managers becoming more hands-on with the cultural and operational aspects of safety.
- Maintaining the concentration on major accident risks on installations being monitored, and in the organisation as a whole.
- Providing a snapshot of an installation's safety culture, and identifying specific and practice-related areas of improvement.

OLF recommends that operators on the NCS should exchange experiences related to operational barriers.

Recommendation no 21

2.3.4 Realistic emergency exercises

The design, implementation and assessment of emergency exercises are essential means of ensuring appropriate responses to potential incidents by the people involved. The need to put improved well exercises in place and to practise them routinely in the months before exposure to such risks was discussed in section 2.1.8 c. Changes to Norsok D-010 are therefore recommended to make exercises more realistic. Specifically, the following recommendations have been made by OLF to Norsok:

Choke exercise – existing choke exercises should be extended to include the worst-case scenario of a flowing well with gas at the drill floor as a table-top exercise. The exercise should include the steps for lining up to divert overboard, the effects of gas on the drill floor and, if possible, shutdown of the drilling control room (DCR), manual shearing of the drill string with a casing shear ram (CSR) (if installed), closing the blind shear rams and disconnecting.

BOP on deck exercise – include a new exercise every time the BOP is on deck in order to operate the control panels. The exercise should include the above-mentioned steps for the choke exercise. On DP rigs, the scenario should start with a DP incident and include communication from the bridge to the drill floor on operating the emergency disconnect sequence.

Diverter exercise/gas-in-riser exercise – include a new exercise as the BOP is landed and before the seawater is displaced from the riser system. The exercise will provide training in the scenario of gas in the riser above the BOP and lining up to divert overboard. The exercise can use seawater for flow through overboard lines.

OLF proposes that, further to recommendation no 9 in 2.1.8 c, extended choke exercises, BOP on deck exercises and diverter/gas-in-riser exercises are also included in Norsok D-010. It is a reasonable assumption that all exercises with a well control objective are conducted in order to achieve a specific level of performance. A pass/fail criteria or a set of acceptance KPIs should be established before each exercise to ensure that the objectives of the exercise have been met. An evaluation should then be conducted after each exercise to consider whether its objectives had been met.

> OLF recommends the inclusion of a requirement in Norsok D-010 for setting either pass/fail criteria or assessment KPIs for all key well control and safety exercises.
>
> Recommendation no 22

2.3.5 Audit, review and verification

Audit, review and verification of safety critical points are important activities in the weeks and months before and during an operation to ensure that organisation and equipment are ready to manage all anticipated operational risks.

The PSA assessment [Ref 8] stated that:

> " Prevention and resilience begins with three levels of review to provide further assurance that a company is adhering to its own processes and procedures within the framework defined by the local regulator:
> 1. Operators and contractors carry out regular and meaningful audits of themselves and their associated operators, contractors and service providers to verify adherence to applicable standards, processes and procedures, including technical audits of all well control equipment and personnel expertise
> 2. Operators and contractors are encouraged to promote independent oversight of the well design and procedures, both prior to and during day-to-day construction activities, by establishing clear monitoring and verification processes to assure adherence to applicable procedures and standards. Our recommendation is that such processes are implemented by an engineer or engineers (either in-house or third-party) who is/are independent of the project…
> 3. The third level can be provided by the regulator undertaking robust and meaningful inspections of all operations to assess adherence to applicable local regulations."

The Presidential Commission [Ref 2] recommended that operators perform an independent review/audit of drilling activities (ie, by outside parties – for example, the use of nuclear industry inspection teams).

Regulation 18 in the UK offshore installation and wells regulations 1996 requires well operators to have arrangements in writing for the examination of wells as an independent check, to assure that the well is designed and constructed properly and maintained adequately thereafter.

OLF has made recommendations to be included in Norsok D-010, recommendation no 1 in section 2.1.1 b on critical cement designs, to ensure that they are independently verified by third-party labs or by in-house technical cementing authorities. However, other areas may exist where independent verification provides a significant risk reduction. Note: verification of well design and operations is the responsibility of operators and contractors, and should be implemented in the way best suited to their internal organisations or licence partnerships.

> OLF recommends that operators consider the use of independent verification for high-risk areas, through the identification of critical well design elements or activities. The requirements for independent verification should be described in the well management system, and can be performed by either an independent in-house department or an external third party. See section 2.3.3.
>
> Recommendation no 23

Verification of safety critical points in the well
A series of integrity tests is performed throughout the well construction process to ensure that the well has the necessary barrier envelopes in place, as specified in the well design. The tests include pressure or inflow (negative) tests on installation of well components, and periodic pressure tests of the BOP. These are referred to as safety-critical points in the well, and should be clearly defined during the planning/design phase of the well.

The Academy of Engineering [Ref 6] has recommended that checklists of the safety-critical points are maintained and verified independently for all wells:

"The Bureau of Safety and Environmental Enforcement (BSEE) of the US Department of the Interior and other regulators should identify and enforce safety-critical points during well construction and abandonment that warrant explicit regulatory review and approval before operations can proceed."

The project recommends that such a system should be incorporated in the well management system referred to in section 2.3.3 above, and implemented though the completion of check sheets which are verified and recorded as part of the completion documentation for the well.

OLF recommends that a system for the verification and documentation of safety critical points in the well is developed. OLF will work with the WEC to establish a common industry practice with efficient workflow management.

Recommendation no 24

2.3.6 Learning lessons from well incidents

The Macondo incident demonstrated that, had lessons been learned and understood by the *Deepwater Horizon* well crew from a similar incident on a Transocean rig operating in the North Sea some four months earlier, more caution might have been taken with the well operations being conducted at the time. [Ref 2]

Learning lessons is crucial, and OLF has therefore been supporting a standardised reporting and investigating methodology for documenting and sharing well control incidents across industry networks on the NCS. Commonly referred to as Sharing to be Better, this OLF initiative has been in place since 2009.

The WEC has also established a working group to design a global well incident database. A trial database format was circulated to the OGP member companies in November 2011. The results and the way forward will be managed by the WEC.

OLF will progress alignment of well incident reporting with future WEC recommendations.

Recommendation no 25

2.3.7 Decision support and risk management

Decision support for the drill crew should be considered. Had the driller on *Deepwater Horizon* possessed simple, easily understood information readily available on the status of downhole barriers or well conditions, better well control decisions would probably have been made. Such support could include improvements to the instrumentation and alarm systems facing the drilling crew to provide them with the decision-making input they needed to perform the operation safely.

In addition, the requirement to report daily on the status of well barriers could be helpful for increasing the attention paid to these. Furthermore, documenting safety-critical points during well construction should improve the focus on barrier testing and integrity (see section 2.2).

> OLF recommends that operational tools (eg, well barrier schematics) should be developed by NCS operators to provide the various well-site crew members with simple visual aids, including descriptions of monitoring methods for each defined barrier element.
>
> Recommendation no 26

A significant contribution to blowout risk on Macondo was inadequate management of Simops. These are simultaneous operations conducted where danger signals in one activity are masked by the attention which has to be paid to other activities. On Macondo, displacing oil-based drilling mud to the supply boat at the same time as underbalancing the well prevented drill crew and mud loggers from effectively monitoring well inflow status.

> OLF recommends that formal risk assessments should be implemented by operators and drilling contractors when Simops are planned, and where one activity could affect the safety barriers intended to prevent incidents in the other activity.
>
> Recommendation no 27

2.3.8 Understanding and expertise

The inability of key individuals to understand and react to the danger signals evident on *Deepwater Horizon* just minutes before the accident is rooted in a lack of basic expertise and awareness of what was happening in the well. It appears that this lack of expertise was in basic well engineering, such as the inability to understand pressure on the drill pipe or an increase in flow or pit volume. Key operational staff and leaders in all aspects of well operations need this basic knowledge.

Expertise, training and human behaviour have generally been recognised as critical areas in a number of the investigation reports. Globally recognised organisations such as OGP and Oil & Gas UK have identified the need to enhance management of the expertise of well personnel across the industry. Regulators globally are aligned with this need and are looking to these recognised entities to develop and deliver guidelines and structures for a global approach for expertise assurance. However, it should be noted that expertise assurance is not founded on training alone, but on ensuring staff have a combination of experience, knowledge and appropriate behaviour. Any such guidelines on expertise assurance should also consider these factors.

It has been OLF's intention to align with Oil & Gas UK (OSPRAG) and the OGP Global industry response group (GIRG) recommendations on expertise requirements. These recommendations are being followed up by Oil & Gas UK's well life cycle practices forum (WLCPF) and the WEC's human factors – training, competency and behaviour task force, which are developing guidelines for specific focus areas. OLF is participating in the WEC task force.

Oil & Gas UK's proposed guidelines are expected to be reviewed by the WEC and considered for adoption as an OGP guideline, and possibly further developed into an ISO standard. While OLF is generally supportive of the expertise guidelines developed by the WLCPF, it also recognises that the guidelines are primarily founded upon UK regulations.

> OLF will follow up further development of expertise guidelines for well personnel through the OGP WEC HF (Human factors) task force. This will require careful study and adjustment to accommodate Norwegian vocational education and training systems in delivering the best solution for Norway.
>
> Recommendation no 28

2.3.9 Well crew teamwork and response

It is generally accepted that the performance and reactions of the well site crew in the seconds before the accident were inadequate. The project analysed two key aspects in order to achieve a better understanding of how the lessons learned from the major reports can promote and facilitate improved well-site performance and teamwork:

- How far do they affect the formal structure of the organisations involved, or do they affect cultural or behavioural norms.
- Where do these changes have the biggest impact – remote from the rig site or close to the rig floor.

The analysis identified that very little has been proposed in the major reports to enhance well-site working culture and interpersonal relationships. This is in distinct contrast to airline, who has benefited over recent years from the use of crew resource management (CRM) training.

This was originally developed as a response to a number of major aviation accidents in the 1970s, where poor teamwork was ranked as an important causal factor. It is now applied in civil aviation and also used in other sectors.

CRM is a training strategy to manage human error by focusing on teamwork skills which promote error avoidance, early detection of errors and minimising the consequences of crew errors. The training focuses on non-technical skills and comprises such elements as leadership, decision-making and stress, situation awareness, cooperation, communication, threat and error management, high-reliability organising, and human performance.

The CRM approach can also be defined as a set of instructional strategies designed to improve teamwork by applying well tested tools, such as performance measures, exercises, feedback mechanisms and appropriate training methods – eg, simulators, lectures, videos targeted at specific content such as teamwork knowledge, skills and attitudes.

CRM aims to increase the safety and efficiency of a team's work performance by focusing on interpersonal communication, situational awareness, problem solving, decision-making and management (non-technical skills).

Two arguments in favour of implementing CRM training for drilling crews are:

- The social dynamics on *Deepwater Horizon* have been identified as a contributing factor to the incident, and CRM aims to change and improve that aspect of teamwork.
- CRM has been a success in other industries (aviation, maritime).

This issue should be evaluated further prior to any final decisions. The syllabus under development by the University of Aberdeen will probably give a good indication of the resources needed to initiate CRM training.

The potential of CRM training in offshore drilling has been assessed, and the results show that potential benefits exist for accident prevention if a long-term commitment is made and if this is aligned with other expertise initiatives. [Ref 18] CRM has already been implemented in the Netherlands, and OGP is also evaluating it.

> OLF recommends that the industry gives consideration to introducing CRM or similar scenario-based team behaviour training for well-site and support personnel.
>
> Recommendation no 29

2.4 Failure to act effectively

During the minutes when the accident was occurring, a number of actions could have saved the rig and possibly reduced some of the injuries. However, poor decisions were made by key personnel over handling gas alarms, riser disconnection, fire fighting, rig evacuation and subsequent incident management which later led to the sinking of the rig.

The clear message is that personnel who may be required to respond to accidents such as the one on *Deepwater Horizon* should be able to do so without having to stop and think. Their actions should be controlled and proportionate, and based on well-drilled exercises.

Furthermore, it is important that leadership and command protocols are fully understood and “what if” scenarios – such as the temporary absence of the offshore installation manager (OIM) or master – are fully rehearsed.

OLF takes the view that it is the combination of emergency training (2.3.4) expertise (2.3.8) and teamwork (2.3.9) which ensures that rig-site crews are fully prepared for any eventuality.

> OLF recommends that training and emergency exercises should involve the wider rig-site crew and also, where appropriate back-up staff and management on land. Operators should ensure exercises are based both on common accidents and on higher-impact, low-probability events.
>
> Recommendation no 30

3 Intervention, capping and containment

The *Deepwater Horizon* accident illustrates that, following BOP failure and an uncontrolled subsea blowout, at least three intervention actions should be considered: the initiation of a relief well (or wells), the deployment of equipment to cap and control the flowing well and the use of a containment system to minimise hydrocarbon escape to the environment.

3.1 Relief wells

The following requirement for relief well planning is established in Norway (Norsok D-010): "An outline plan for drilling a relief well shall be developed for each well or well cluster location." This includes site surveys, kill methods and well capacities, and equipment and rig availability assessments. In addition, the operator should be capable of initiating relief-well drilling no more than 12 days after a decision to drill has been declared.

The Well Life Cycle Practices Forum (WLCPF) of Oil & Gas UK has recently released new guidelines on relief well planning, though it is thought unlikely that these guidelines will influence current Norwegian requirements.

3.2 Capping and containment

In early 2011, the OGP (GIRG) provided a set of recommendations for intervention on flowing wells following a well control incident. [Ref 10] A number of initiatives have been taken across the industry, some driven by local regulatory requirements (eg, US GoM). Subsequently, OLF has supported the subsea well response project (SWRP) as one of a number of suitable solutions for the NCS. The project is organised in Stavanger to design, deliver and deploy these new technologies and methods for a wide range of potential circumstances. In due course, this requirement is also expected to be included in Norsok D-010 (see section 3.2.6).

Providing well interventions for wide-ranging conditions is a major technical and logistical challenge. The geological contexts in which oil and gas are found vary greatly in type of fluid, reservoir size, water depth and locality. Weather and ocean conditions (such as wind and wave strength and day-to-day changes) can affect the suitability and effectiveness of any offshore incident response system.

The SWRP is designing equipment which will be stored in different locations around the world to enable a swift and efficient response in the unlikely event of an uncontrolled subsea well control event. Deployment methods which minimise response time for the new well capping equipment will also be developed by the SWRP.

3.2.1 SWRP joint industry project

The subsea well response project is a not-for-profit joint initiative managed by Shell as operator. Its project team consists of technical experts and management personnel selected from the nine major oil companies involved (BG Group, BP, Chevron, ConocoPhillips, ExxonMobil, Petrobras, Shell, Statoil and Total). As well as managing the selection and design of capping stacks and associated equipment which can enhance the industry's ability to respond to well control incidents, the project will recommend a model for international storage, maintenance and deployment of the equipment.

Enhancing international well incident intervention capabilities is an opportunity for – and dependent on – international cooperation. This is central to the SWRP's approach. The project team is actively engaging with national and international regulators and working closely with other organisations to ensure that its efforts build on and complement existing practices.

3.2.2 SWRP work scope and equipment

The SWRP has focused on four core tasks:

- designing a capping toolbox to allow subsea wells to be shut in
- designing hardware for the subsea injection of dispersant
- assessing the need for, and feasibility of, a containment system suitable for international use
- evaluating potential approaches to equipment deployment.

The capping stack toolboxes include four capping systems – two 18 3/4-inch bore capping stacks developed to handle pressure up to 15 000 psi, and two 7 1/16-inch bore capping stacks for pressure up to 10 000 psi. This should enable the industry to cap most subsea oil wells in water depths up to 3 000 metres around the world, as well as providing flexibility for various contingencies. The stacks are designed to be swiftly transportable by sea and/or air.

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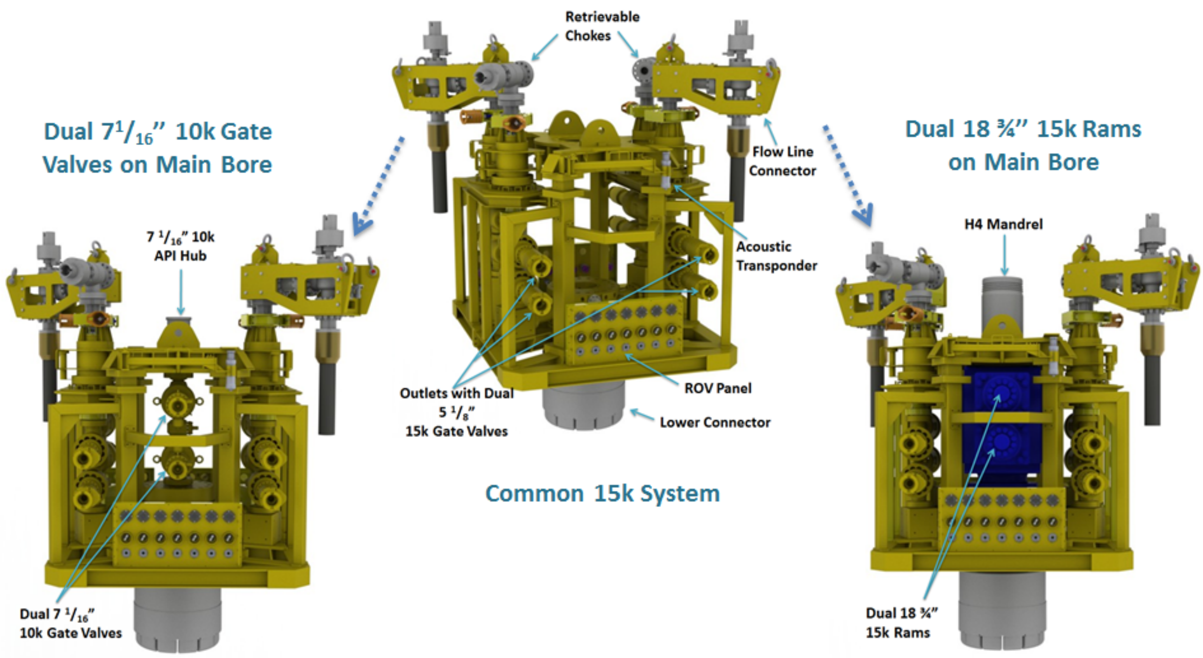

Figure 9. SWRP capping toolbox

Industry experience has now demonstrated the importance of the underwater application of dispersant at the wellhead during a well capping operation. This will create safer surface working conditions for response personnel and enhance the degradation of the oil. The SWRP will provide two hardware kits for the subsea application of dispersant at a flowing subsea BOP.

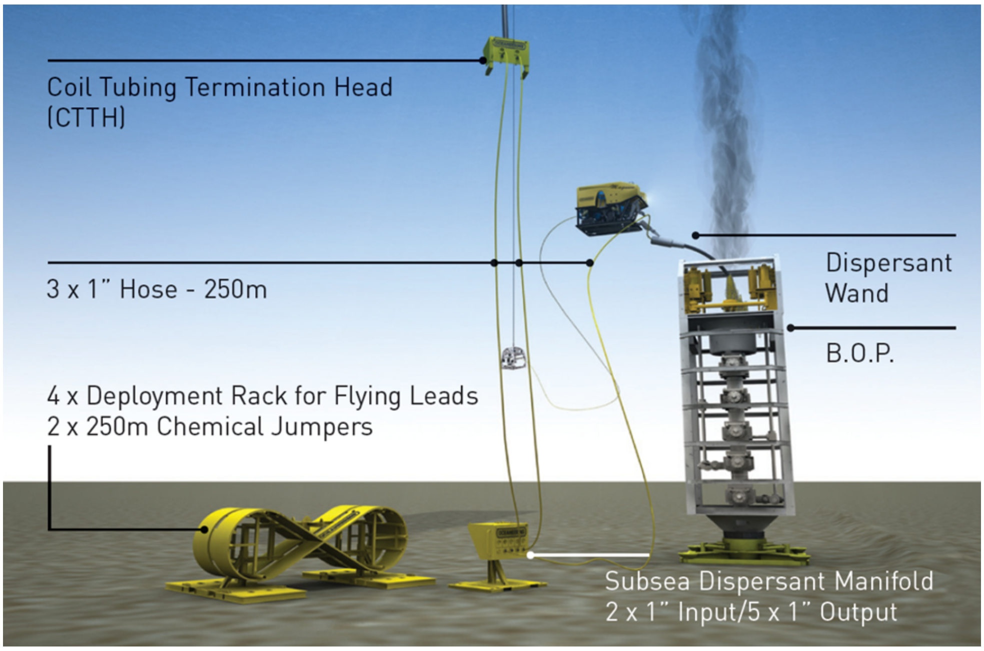

Figure 10. Subsea dispersant injection system

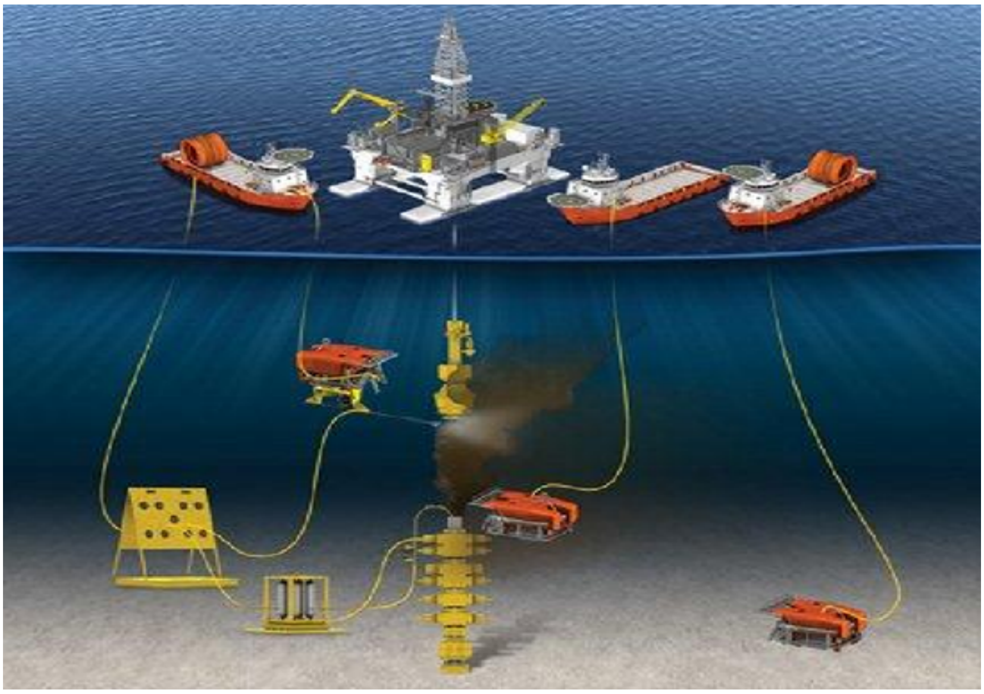

Figure 11. Hardware for subsea dispersant injection and cap deployment

The intervention system also includes:

- Tools for site surveys prior to commencing work, eg, 2D and 3D sonar.
- Debris-clearing equipment with cutting, grappling and dragging tools to gain access to the BOP where necessary.
- Flying leads, distribution manifold and dispersant wands to inject dispersant at multiple locations.
- High-pressure and high-volume accumulators for closing the existing BOP.

3.2.3 International deployment

Following research into existing industry resources, incident response requirements and international metocean conditions, the SWRP team has planned an integrated intervention system for international use.

It is now collaborating with Oil Spill Response Ltd (OSRL) to make this integrated intervention system available to the industry.

Designed to enhance response capabilities in the unlikely event of a subsea well incident, the equipment will be available for the majority of international subsea oil wells. It will be transportable by sea and/or air and will be stored in the following four strategic locations around the world from 2013:

- Northern Europe
- South America
- Africa
- Asia-Pacific.

OSRL has contracted with Trendsetter to manufacture the capping stack toolboxes and with Oceaneering to manufacture the subsea dispersant hardware kits.

3.2.4 Next phase

The next phase of activities will include:

- Identifying precise locations around the world where capping and dispersant equipment can be stored and maintained.
- Completing conceptual engineering of a controlled process to divert leaking oil from a subsea wellhead to a surface collection and storage system based on vessels of opportunity (mapping available vessels).
- Supplementary subscriptions now open for access to internationally-deployable well capping equipment.

OSRL and SWRP are making an integrated internationally-deployable system available to the industry to enhance subsea well incident response capabilities. SWRP planned the intervention system, which includes newly-designed subsea capping and dispersant application equipment. OSRL will procure, own and maintain the equipment and make it available to subscribers. SWRP will provide project management support to OSRL during the construction phase.

3.2.5 OLF recommendations on the SWRP

The following summarises OLF's recommendations on SWRP:

OLF recommends on-going support for the SWRP as planned.

Recommendation no 31

OLF supports the development of options for containment.

Recommendation no 32

OLF supports opportunities for non-participants to gain access to the equipment.

Recommendation no 33

3.2.6 Future Norsok requirement on capping

Following the delivery of operable capping equipment in Norway or nearby:

OLF recommends that Norsok D-010 should require an outline plan and procedure for capping and shut-in of a flowing subsea well, in which the operator demonstrates how to access and install equipment to shut in the well within a reasonable time.

Recommendation no 34

4 Incident response

This section covers four main topics:

- Lessons learned from the management of the incident following the blowout
- Issues to be addressed in Norway regarding oil spill response
- An assessment of the spill's environmental impact and its relevance to Norway
- A study of working environment issues for personnel engaged in the clean-up.

4.1 Incident management and unified command

Important lessons can be learned from the oil spill response which took place in the GoM during the days and weeks following the blowout.

The Macondo spill in the GoM released around 4.2 million barrels of oil into the sea. The response effort was massive, involving roughly 48 000 people at peak, with more than 6 000 boats deployed daily in the area responding to the spill (see figure 12).

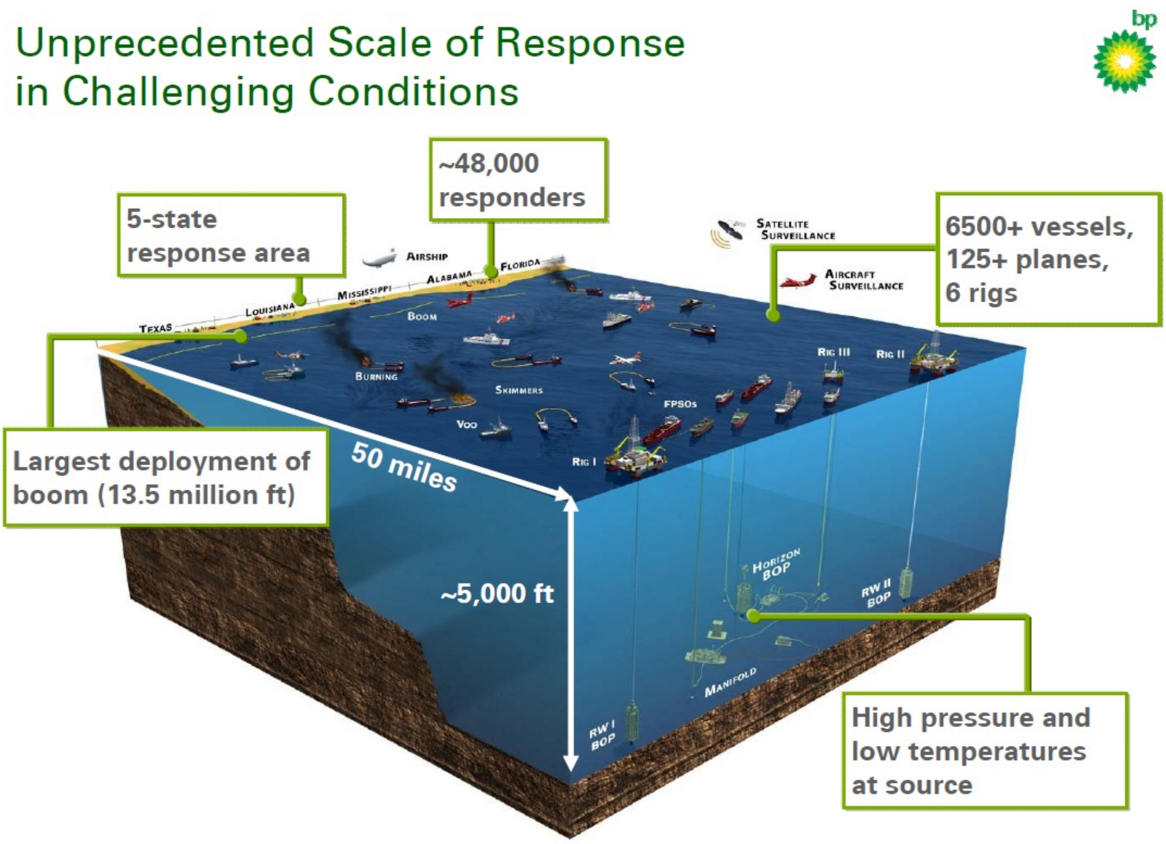

Figure 12. Overview of Macondo responders

By mid-August, 762 000 metres of containment boom and 2.66 million metres of absorbent boom had been deployed to contain the spill. In addition, 222-313 000 barrels of oil are estimated to have been burned in situ.

The scale of the response placed enormous pressures on BP as the operator, and it became clear from an early stage that a new approach was required.

4.1.1 Command structure

The Macondo subsea blowout was the first "spill of national significance", and as such triggered the establishment of a national unified command headed by the US Coast Guard, with BP as the responsible party. The unity of effort worked well and is now regarded as best practice for management of a complex and long-lasting oil spill response. [Ref 17]

A unified command (UC) is "an application of the incident command system (ICS) used when there is more than one agency with incident jurisdiction or when incidents cross political jurisdictions. It is a structure that brings together the incident commanders of all major organisations involved in the incident in order to coordinate an effective response, while at the same time allowing each to carry out their own jurisdictional, legal and functional responsibilities".

It also creates a unified team which manages an incident by developing a common set of incident objectives and strategies, shares information, maximises the use of available resources, and enhances the efficiency of the individual response organisations. The UC directs incident activities and approves ordering and releasing of resources and work in cooperation with other agencies, regulators and authorities to coordinate a unified response to the incident.

4.1.2 Unified command in Norway

The principles of unity of effort practised in this GoM incident are not applied in Norway. The regulations (see the framework regulations) state that the operator will lead and coordinate the use of oil spill response resources, even for a major spill of national significance involving public resources. Pursuant to the Pollution Control Act, however, the Norwegian Coastal Administration (NCA) could choose to take command if it deems this to be necessary. But the criteria for taking over the command are not defined, and this situation is not part of training and exercises.

4.1.3 Status

OLF considers that the Norwegian authorities should adopt the principles of unified command in order to ensure that the readiness and efficiency exists to manage a major accident or oil spill in a national context. The main driver for OLF is the scenario of an oil spill on the NCS where the oil company would be the responsible party. Work should be conducted within the current regulatory framework. Responsibilities and the "polluter pays" principle will remain unchanged. OLF acknowledges that a UC should be established and led by the government, but in conjunction with the responsible party. The overall goal is to enhance the efficiency of individual response organisations.

In moving forward, the NCA should clarify criteria for establishing a UC with the relevant government agencies and ministries before the actual work can start. Criteria for establishing a UC should be agreed, and a unified organisational model developed.

OLF will continue working closely with the Norwegian Coastal Administration to make a case for implementing the principles of unified command for incidents of national significance on the NCS**.**

Recommendation no 35

4.2 Oil spill response

The project was tasked to address issues arising from the *Deepwater Horizon* spill. While the response to the Macondo oil spill is widely acknowledged to have been successful, post-event analysis has created potential opportunities to strengthen future spill response protocols and technologies in Norway even further. This could potentially be developed as “good practice” and promoted internationally.

To prepare for a possible incident, NOFO has developed a regime in which cooperation agreements have been entered into with organisations and agencies able to provide oil spill response and oil pollution countermeasures. In the event of an incident, these agreements allow NOFO to call on predefined resources from all these partners.

NOFO can also request international assistance through the NCA, the operators and OSRL. This regime gives NOFO access to extensive resources readied for oil spill response, clean up and restoration.

NOFO’s emergency response centre is established in accordance with the “enhetlig ledelse system” (ELS), a Norwegian version of ICS.

Figure 13 below provides an overview of Norwegian oil spill response resources and key interfaces with operators and NOFO. The sections in this chapter provide a further explanation of the way these resources are organised and readied to respond to different incident requirements.

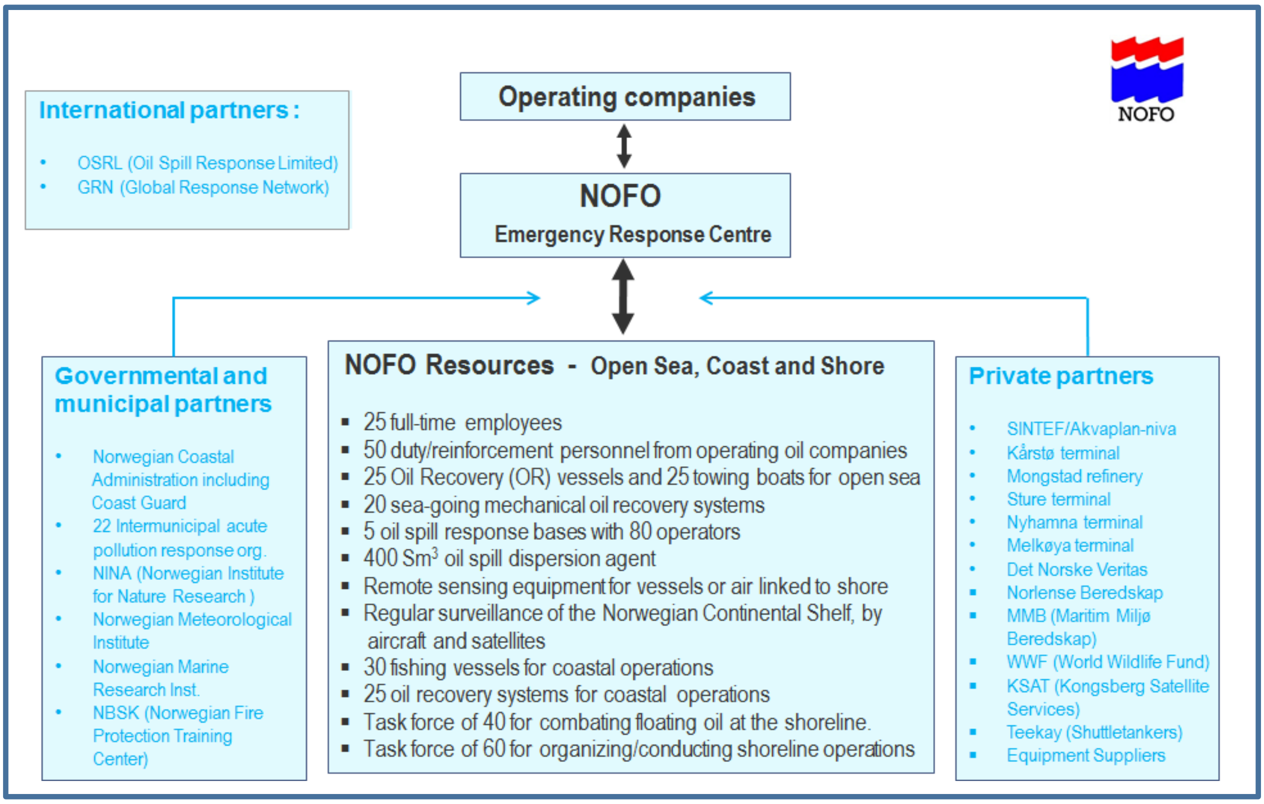

Figure 13. NOFO *oil spill response resources*

A new NOFO strategy has been developed for 2012-16, with the following key drivers:

- lessons learned from Macondo
- demand for improved coast and beach oil spill response
- demand for improved emergency preparedness in Finnmark for the Goliat field
- demand for operationalisation of dispersants
- NOFO capacity and robustness
- continuous technology development.

Recommended oil spill response actions and proposed R&D are summarised in section 4.2.11.

GIRG (OGP) recommendations

The sections below detail NOFO's responses to the conclusions and recommendations of the OGP's global industry response group (GIRG) [Ref 11], and in particular the oil spill response (OSR) team.

4.2.1 Dispersants

The use of dispersants in Norway is regulated by the government through the assessment of preparedness analyses and discharge permit applications for the individual activities of the oil companies. This assessment considers the ability to disperse specific oil types, likely weather conditions, and vulnerable natural resources such as spawning areas for fish and seabird populations in the affected area. When dispersants are used, control and verification of success are required in accordance with the regulations.

4.2.2 In-situ burning

A range of documents, global protocols, and standard implementation methodologies *for in-situ burning of oil* will be developed by the Oil Spill Response JIP to optimise its use in the future.

The NCA will now take the lead in evaluating in-situ oil burning as a supplementary clean-up method. NOFO will assist where necessary.

4.2.3 Assessing response preparedness

Through NOFO, the oil industry in Norway has developed the ability and process for cascading additional resources, both local and international. NOFO can access additional resources under contracts/agreements with private providers, various local authorities, central government (the NCA) and OSRL, and exercises are conducted on a regular basis with the procedures/routines for mobilising these resource.

4.2.4 Effective exercises

NOFO exercises can be divided between three different types of objectives:

- Exercises to learn best practice and corresponding procedures.
- Exercises to see that everybody is familiar with the plans and procedures and to ensure that the plan is sufficient to meet the defined criteria.
- Exercises to verify plans, procedures and cooperation between all the parties taking part in an oil spill response, including oil company contingency plans.

The first type is normally performed as a single unit exercise, with courses and training prior to practical implementation. Each exercise is carried out using the actual equipment and/or facilities, including oil recovery vessels, land-based staff, tugs and operational personnel.

The second type exercises are table-top or on-paper activities. They form part of the training programme prior to exploration drilling and the development of new production fields. Table-top exercises are used to confirm the contingency plan and to verify the ability to establish necessary resources to handle the incident.

The third type exercises will be held three-five times a year, and the operator involved will change from one exercise to the next. These activities will involve resources from all four barrier levels and last two-four days. All exercises are scheduled in a 12-month plan.

4.2.5 Oil spill surveillance

The NCA and NOFO perform daily satellite surveillance of the NCS, including all offshore petroleum activity. This early-warning system may also be used for large area mapping of oil during incidents.

NOFO and NCA are funding a dedicated aerial surveillance service, which comprises two aircraft. These carry state-of-the-art remote sensing equipment, including radar and an infrared camera.

NOFO operates oil detection radars on oil recovery vessels. Hand-held infrared cameras are also in use.

4.2.6 Tiers 2 and 3 capability

The responsibility for combating a spill in Norway is divided into four hierarchal layers depending on the magnitude of the spill.

The first hierarchal layer (Tier 1) represents the responsibility of the polluter to respond to a spill. Land-based response in Norway (Tier 2 equivalent) involves an individual local authority. A Tier 3 equivalent represents a spill in which several local authorities work and act together through inter-municipal agreements. Tier 4 is a spill of such magnitude that none of the players previously mentioned can combat the spill, so that the government must mobilise all necessary national resources and take over operational management itself. See also the discussion of a unified command in Section 4.1.

Through NOFO, the Norwegian oil and gas industry is capable of responding to Tiers 1, 2 and 3 in cooperation and liaison with relevant inter-municipality and NCA resources. NOFO's oil spill preparedness approach is based on the multi-barrier principle. Barriers 1, 2, 3 and 4 include all measures located between the source of the discharge and environmentally vulnerable resources (see figure 14 below).

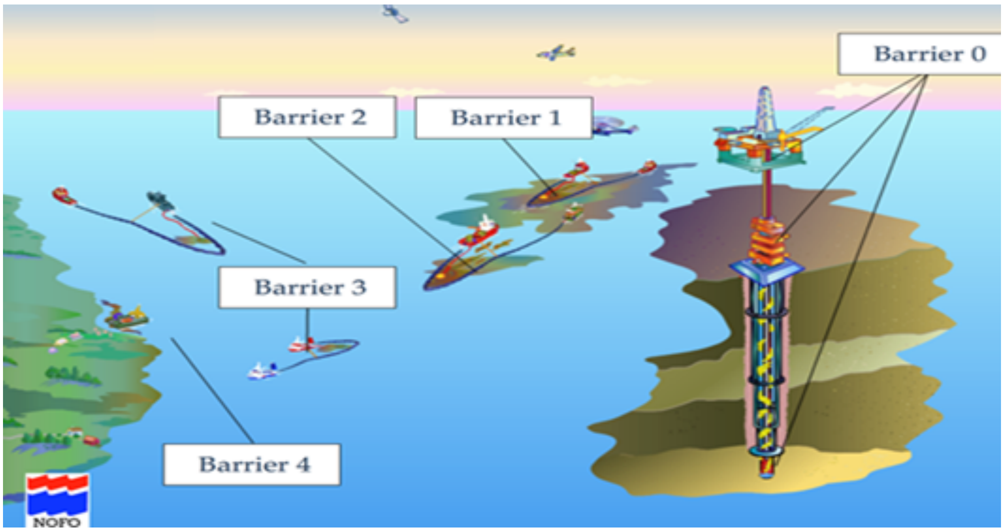

Figure 14. NOFO's defined oil spill barriers 0-4

4.2.7 Oil spill trajectory and subsea plume modelling

Continuous work and development has been pursued with oil plume trajectories at SINTEF in Norway. The latter was hired by BP during the Macondo spill, and claimed that its results were in good agreement with the actual drift of the oil spill. However, a potential still exists for improving this model, and further research will be performed as a JIP recommended by GIRG.

4.2.8 Communications

A real-time picture of the position is provided by the Nora decision-making support system, which also contains a live automatic identification system for ships and surveillance aircraft. All major oil recovery vessels have internet access.

Helicopters and aircraft have line-of-sight downlink systems to vessels providing live information reports to ships during booming operations and dispersant application.

4.2.9 Mobilising

In accordance with the Norwegian model, all publicly controlled resources are mobilised through the NCA. Control of these resources will be transferred to the company in charge of the response once the necessary approval has been given. The agreed cost will be covered by the requesting unit, in its capacity as the polluter.

4.3 Responding to different types of oil

Oil companies in Norway are required to perform a thorough analysis of weathering and other physical properties of their oil before drilling appraisal and production wells. For exploration wells, a specific oil is selected for reference before drilling on the basis of best available information from geological and seismic data. Should a spill occur, therefore, NOFO will normally have a good record of the oil, including its viscosity, density, degree of emulsification, ratio of evaporated and dissolved oil, in both summer and winter conditions, at varying wind speeds (2, 5, 10 and 15 m/s) and over time (1, 2, 3, 6, 9, 12, 24, 48, 72, 96 and 120 hours of drift).

Where shoreline clean-up is concerned, NOFO has personal protective equipment (PPE) and clean-up gear stored at one of the five bases. Agreements with partners (such as the NCA) give access to depots in various coastal locations where full PPE and other clean-up gear are stored. Personnel supplied under partnership agreements will have PPE with them, and will be supplied with PPE for as long as the operation continues.

The bottom line is that NOFO has PPE and clean-up gear in place, and can easily secure additional supplies through PPE suppliers whenever necessary.

4.3.1 NOFO actions and future research

The following summarises the agreed actions to be taken by NOFO:

> Implement a new strategy with measures to strengthen the capability and robustness of oil spill response.
>
> Recommendation no 36

> The development of cooperative agreements on oil spill response between North Sea oil producing countries is being pursued via the Operators' Cooperative Emergency Services (OCES)
>
> Recommendation no 37

NOFO should join the global response network.
Recommendation no 38

NOFO should continue to facilitate expanded/increased use of dispersants in the operators' emergency preparedness plans and in conjunction with the subsea well response project.
Recommendation no 39

NOFO should support the Norwegian Coastal Administration in taking the lead on evaluating in-situ oil burning as a supplementary clean-up method.
Recommendation no 40

NOFO should implement the Norwegian version of the incident command system (enhetlig ledelse system – ELS) and develop an emergency response centre based on this.
Recommendation no 41

The GIRG (OGP) summary report has recommended that member companies of OGP and the Global Oil and Gas Industry Association for Environmental and Social Issues (Ipieca) form a joint industry project (JIP) to pursue research in a number of areas related to oil spill response.

4.4 The working environment and chemical exposure

The *Deepwater Horizon* accident showed that many of the personnel involved in clean-up and capping were inadequately protected and could have been exposed to hydrocarbons and various chemicals used in mitigating the incident. Several of these chemicals can have unfortunate health effects.

The Presidential Commission [Ref 2] recommended that "EPA should develop distinct plans and procedures to address human health impacts during a Spill of National Significance".

The health hazard evaluation of *Deepwater Horizon* response workers is drawn from the interim reports included in the final report from the National Institute for Occupational Safety and Health (Niosh): *Health Hazard Evaluation Report* (August 2011).

A joint effort was established between the project and the OLF's chemicals project to study the findings and results from the above report. In May 2011, a workshop was convened to develop industry recommendations on exposure hazards for personnel involved in both mitigation of and clean-up work with accidental hydrocarbon spills.

The workshop produced nine recommendations to be applied in three phases including preparation for, during and after an incident.

OLF recommends that all operators and contractors which may require emergency response offshore should ensure that the following are implemented as part of their emergency preparedness planning process:

Clear responsibilities in emergency response plans
The emergency response plans should clearly indicate who is responsible for occupational health measurements, risk assessment, health examinations and health follow-up. This must be implemented for accidents where directly employed personnel, other active personnel or third parties are exposed to chemicals with potential health hazards.

Operators must also develop uniform systems for measurements, health examinations and follow up.

Access to the right expertise
Provide access to qualified personnel who can implement occupational hygiene measurements, risk assessments and health examinations, where relevant.

Ensure also that necessary measurement equipment is available.

Relevant education and training
Personnel who take part in oil spill response activities or accidents which lead to chemical exposure must be educated about potential health hazards, and how to protect themselves against hazards.

Information packages should be prepared for use as HSE awareness topics on the facilities.

Access to adequate protective equipment
Emphasis in the various exposure scenarios is placed on identifying adequate PPE, including respiratory protection, skin protection and any other gear. This equipment must be readily available for use during campaigns.

Recommendation no 42

OLF recommends that the following be implemented or provided during an incident as an integral part of emergency response plans.

Implement exposure measurements and risk assessment

Exposure measurements must be made quickly and preferably continuously, by qualified personnel, so that necessary risk assessment can be carried out and personnel can be equipped with adequate protective gear. This will form the foundation for providing affected parties with rapid and precise information. An evaluation should also be made of whether biological exposure data should be obtained.

Provide access to adequate protective equipment

Based on plans and risk assessments, ensure that correct protective equipment is used. For vessels used in oil spill response, it is recommended that active coal filters are available and used in the fresh air intake for ventilation air.

Ensure rapid and precise information

Rapid and precise communication of information about potential chemical exposure and any ensuing health effects. This is important both for the personnel involved, and in relation to other affected parties. Reliable scientific information should be emphasised. Information will reduce uncertainty and can help prevent stress reactions.

Recommendation no 43

OLF recommends that the following actions should be implemented after an incident for follow-up of involved personnel:

Ensure that the exposure is documented

It is important that all information about possible exposure is retained with an eye to possible delayed effects, and for learning and research purposes.

Ensure necessary monitoring and follow-up of health

Emphasis is placed on systematic gathering and subsequent evaluation of necessary health information, where this is considered appropriate. In the event of major accidents involving the exposure of many people, it is recommended that a systematic health monitoring and follow-up programme be implemented by qualified professionals over an extended period.

Recommendation no 44

Several areas for R&D work have been identified by the project. Potential R&D proposals for consideration when prioritising R&D through the Research Council of Norway or others include:

- Measurement and health impact of chemical exposure in short, intense doses.
- Health effects resulting from odours should be studied in more detail with respect to discomfort experienced with pronounced odours and somatic reactions.
- Learn more about long-term effects on exposed personnel in connection with blowouts and hydrocarbon leaks on installations.
- Follow-up studies of the clean-up work associated with the *Deepwater Horizon* accident to learn more about longer-term exposure and health effects.

5 Environmental impact

In order to gain a better understanding of the environmental impact of the *Deepwater Horizon* accident, OLF commissioned a review of the incident and its impact, with a desktop study of officially published reports in 2011.

The report from Akvaplan-niva [Ref 15] covers information and emerging hypotheses about which substances were released during the Macondo blowout in the GoM from 20 April, where these substances have gone, and what environmental impacts have been observed. It includes both a detailed review of sequential events as the incident unfolded during late 2010 and a review of officially published reports released up to February 2011.

The report is available at http://www.OLF.no/no/Publikasjoner/MIljorapporter/Marine-Environmental-Impacts-DWH/.

Following this report, Niva has been engaged by OLF to conduct an on-going review of the environmental effects of the accident in peer-reviewed journal articles and technical reports released by scientific agencies and research institutions. A preliminary summary of Niva's bi-monthly memos will be published as a report on the OLF's website.

OLF will continue these reviews of the scientific literature throughout 2012.

The present document sums up the main conclusions regarding known environmental effects to the end of 2011. It is important to be aware that a scientific study is a time-consuming task, and that the environmental impacts reported here are still considered incomplete.

5.1 Environmental impact

In total, some 4.2 million barrels (670 000 cubic metres) of crude oil were released to the water in the GoM. The oil spread widely and caused damage to marine and wildlife habitats and to the GoM's fishing and tourism industries. However, impacts identified after an extensive environmental monitoring were much smaller than forecast in the first few weeks after the accident. Some of the disparity between the doomsday predictions and the events which transpired may be attributable to favourable weather and ocean current patterns. The Loop Current, which could have pushed oil up the entire eastern seaboard, was truncated by a fortuitous eddy, removing a destructive path and containing the oil in a smaller basin.

5.2 Hydrocarbons released

The following summarises the best available estimate of the mass balance from the uncontrolled well flow in the Macondo incident:

- 17% of the well flow was recovered directly at the surface through a marine riser
- 15% of the uncontrolled well flow ended on sea surface
- 7% of the uncontrolled well flow ended as an airborne plume
- 36% of the uncontrolled well flow never rose out of the underwater plume 3 300 to 4 300 feet below the surface
- 25% of the uncontrolled well flow is still unaccounted for.

This is based on a rate of 11 350 tons of gas and oil per day (equal to about 59 200 barrels of liquid oil per day) and a total of some 4.2 million barrels of oil released from the well into the environment.

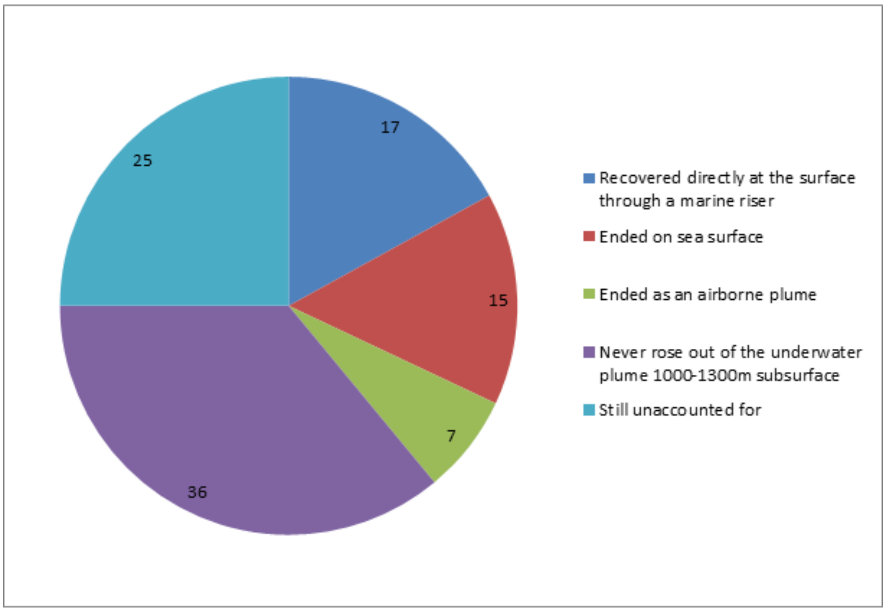

Figure 15. Distribution of produced oil from the Macondo well

Data sources:

- *Chemical data quantify Deepwater Horizon hydrocarbon flow rate and environmental distribution,* Proceedings of the National Academy of Sciences, January 2012.
- *Comprehensive Picture of the Fate of Oil from Deepwater Horizon Spill,* Science Daily, 10 January 2012.
- *Review of flow rate estimates of the Deepwater Horizon oil spill,* Proceedings of the National Academy of Sciences, 28 October 2011 published online December 2011.
- *Assessment of Flow Rate Estimates for the Deepwater Horizon / Macondo Well Oil Spill,* National Incident Command, Interagency Solutions Group, Flow Rate Technical Group, US Department of the Interior, 10 March 2011.

The oil released from the well was a light oil and relatively degradable. Oil-indigenous microorganisms played a significant role in degrading the crude, which was assumed to be important in reducing the overall environmental impact of the spill (bioremediation). Owing to numerous natural seeps of oil in the GoM, the diversity and specialisation of the microorganism community seem to be acclimatised to the presence of hydrocarbons. This may have predisposed the community to respond to and even exploit a seemingly catastrophic event such as the *Deepwater Horizon* oil spill. The highest bacterial degradation rates were found in deep water with temperatures around 4°C. Gases, mainly methane, were also released during the spill. As the blowout occurred in very deep water, these gases remained to a large extent in the sea rather than being evaporated to the atmosphere, but specialised hydrocarbon-degrading bacteria were able to respire nearly all the released methane.

Through degradation by microorganisms, oil carbon was incorporated into the planktonic food web. But negative effects of this have not yet been documented. In addition, the temperature of the surface water and the air was high, which contributed to a rapid evaporation process.

5.3 Impact on fisheries

The fisheries in the area were closed after the accident owing to the risk of seafood contamination. This closure had substantial economic consequences, estimated at USD 4.36 billion. However, the 2010 cohorts of commercial fish species were not negatively affected by the accident, and no impacts on the commercial fish stocks were observed about one year later. Furthermore, levels of PAH do not appear to be elevated and remnants of dispersants are not evident in seafood.

5.4 Environmental effects

In August 2010, oil was recorded on more than 10% of the US coastline in the GoM, and a detectable concentration of hydrocarbons could still be found on the beaches more than a year after the accident.

A total of 2 303 dead birds and 2 086 live birds with oil remnants had been recorded by April 2011. Figures for marine turtles were 517 dead and 456 alive with oil contamination. Only 10 dead marine mammals and two live ones with oil were found. It is important to be aware that several more dead animals were found but, because they had no visible oil on them, their deaths could not necessarily be attributed to the accident. Additionally, a study showed the actual number of deaths owing to the spill may be much higher than the number of recovered carcasses. However, negative impacts of this mortality are still not documented at the overall population level.

Furthermore, the research shows that the planktonic community exhibits an encouraging level of resilience. Evidence shows that oil carbon was incorporated into the planktonic food web, but negative impacts of this are yet not documented.

5.5 Dispersants

Large amounts of dispersants were used, mainly Corexit. Estimates suggest that 1.84 million gallons [6 965 cubic metres] of dispersant were applied, with 771 000 of those gallons [2 918 cubic metres] applied at the wellhead located 5 067 feet [1 544 metres] below the surface. The effectiveness of the chemical dispersants is estimated to be about 16 per cent, while 13 per cent was naturally dispersed.

Dispersants were applied for the first time under the sea surface and close to the leak. It is not clear at present whether the dispersants were successful in making the oil more available for microbial degradation. Although available data indicate that Corexit may be less toxic than other dispersants, it may reduce microbial activity and thus the capacity of the environment to bioremediate spills.

However, available data so far supports the conclusion that the decision to deploy almost seven million litres of dispersant achieved the objective of minimising the effects on the beaches and marshes along the coast, and on the tourism industry they underpin. Furthermore, underwater application of dispersants reduced the concentration of hydrocarbon gas in the air close to the site and thereby made it possible to continue work on the surface to close the well.

Monitoring of the underwater plume showed toxic levels of oil close to the source, which could follow the plume out about four kilometres at a depth of 1 200-1 300 metres. However, the concentrations there were below toxic levels. Beyond a maximum of about 10 kilometres, the concentration was roughly at background level. Furthermore, most of the short-term indicators suggest that the substances introduced do not appear to have inflicted severe environmental damage to date, given the volume involved.

However, misconceptions and knowledge gaps concerning the use of underwater dispersion remain. Areas for improvement include:

- The need for a common understanding of the risks and benefits of dispersant use, as well as the safety and effectiveness of dispersant products.
  Additional research on the behaviour and long-term fate of dispersed oil in the water column when dispersants are applied at the sea floor.
- Field trials to advance and validate existing knowledge.

> OLF will continue to follow up the results of relevant research programmes, including work packages by API with SINTEF as one of the contributors.
>
> Recommendation no 45

5.6 Relevance to Norway

Environmental monitoring and research carried out during and after the blow-out demonstrated that the rate of natural degradation of oil components by microorganisms was much higher than expected. Oil-indigenous microorganisms played a significant role in degrading the oil, which was assumed to be important in reducing the overall environmental impact of the oil spill (bioremediation). High concentrations of hydrocarbons were found about 1 000 metres down in the vicinity of the wellhead. The bulk of the natural degradation occurred at these water depths, where the temperature (around 4°C) and other ambient conditions are comparable to the NCS. This indicates that high degradation rates can also be expected off Norway.

The general approach in Norway has been based on mechanical recovery as close to the source as possible. Generally speaking, the capacity for mechanical oil recovery is large and the response capacity for oilfields is dimensioned on the basis of selected oil spill scenarios.

Since both in-situ burning and mechanical recovery imply capturing oil on surface, the Macondo total of eight per cent seems low in the light of the fact that the wind and sea conditions during the incident were favourable for capturing oil with booms. But the efficiency of mechanical recovery should be calculated on the basis of available oil at the sea surface. This means that about 50 per cent of the oil which ended on the surface was collected by booms and either burned in situ or handled as waste. This is comparable to the NCA estimate of recovering nearly 50 per cent of the oil from the *Godafoss* incident in February 2011.

However, mechanical recovery has been criticised as inefficient in light of the close-to-ideal conditions in the GoM. This is interpreted as a result of a generally limited mechanical recovery/capture capacity in the USA, and the subsequent choice of a dispersant strategy for the Macondo response. Skimming capacity during the incident was further limited by strict restrictions on maximum accepted wave heights and by confining recovery to daylight conditions alone.

The assumptions used in dimensioning offshore response capabilities in Norway will be evaluated and eventually revised as part of the on-going implementation of NOFO's strategy. Dimensioning criteria for dispersants will be considered for inclusion in future revised guidelines (see section 4.2.1 d). Owing to general stronger winds and higher waves on the NCS compared with the GoM, oil is generally expected to dissolve and naturally disperse faster under normal NCS conditions than in the GoM. This higher energy will further increase the efficiency of chemical dispersants applied on the sea surface.

The positive results of chemical dispersion in the Macondo incident, with reduced human exposure to volatile organic compounds (VOCs), and the beneficial environmental consequences, will probably accelerate the inclusion of dispersion in contingency plans for all fields on the NCS.

As a first step, OLF in cooperation with SINTEF and the Norwegian Deepwater Programme, held a seminar to discuss underwater dispersion as a response strategy on the NCS. In this context, the main difference between conditions at the Macondo well and on the NCS are water depths. Few Norwegian oil wells are in depths greater than 400 metres. Shallower depths mean that oil and gas will most probably surface even if subsea dispersion is applied, in contrast to what happened with the much deeper Macondo well. When gas is leaking together with oil from a subsea blowout in moderate to shallow water depths, gas bubbles will generate a strong buoyant plume which will entrain ambient water and lift towards the sea surface.

Surfacing of such entrained water will cause a strong outward surface flow. The rising plume will carry oil droplets towards the surface. When the droplets settle on the surface in the outward flow, a thin slick will be formed with a thickness in the order of 1/10th of a millimetre.

6 Summary of recommendations

The following table summarises the 45 recommendations presented in this report and the proposed party to take action on them. For more details on the proposed recommendations, see the relevant section.

Rec no	OLF recommendations on prevention – operational/technical	Action by	Section
1	Norsok D-010 should be updated to include the term "critical cement job". A requirement for independent design verification of "critical cement jobs" should also be introduced. This verification can be performed by either an independent in-house department or an external third party.	Norsok D-010 review team	2.1.1 b
2	Norsok D-010 should furthermore require that cement and casing design for slurries placed across hydrocarbon zones be verified in cementing company labs prior to use. For critical slurry designs, such as those containing foam cement or gas block additives, the slurry design, slurry properties, waiting on cement times and cementing plan should be independently verified. This verification can be performed by either an independent in-house department or an external third party.	Norsok D-010 review team	2.1.1 c
3	a) Norsok D-010 should be updated to define the requirements related to inflow (negative) pressure testing clearly. b) Well programmes should provide a detailed procedure and acceptance criteria for all inflow tests. Inflow tests should be conducted in a controlled manner with detailed procedures which have been approved by an authorised person, and accompanied by a demonstrated risk analysis. This should be covered in Norsok D-010.	Norsok D-010 review team	2.1.3 a and b
4	Norsok D-010 should be further clarified to state that, when changing out the fluid barrier element while the remaining barrier consists of untested cement or mechanical plugs, all displacement to a lighter underbalanced fluid should be done with a closed BOP and through the choke and kill lines.	Norsok D-010 review team	2.1.4 b
5	Norsok D-010 should be updated to include descriptive values for full/partial/seepage and static/dynamic fluid losses so that deviations in return flow can be reported using a common frame of reference. Such data can be used to generate acceptable downhole loss rates for specific fields.	Norsok D-010 review team	2.1.4 c

6	OLF recommends that operators and contractors develop simple solutions for well control automation which are reliable and driller-friendly.	NCS operators/drilling contractors	2.1.4 d
7	OLF recommends that well control bridging documents be prepared for all future drilling operations**.** (OLF issued this recommendation to Norwegian operators and contractors in January 2011. It has also been referred to the Norsok D-010 revision committee.)	Norsok D-010 review team	2.1.5 b and 2.1.8 d
8	a) Norsok D-001 should be updated to identify the diverter system as a safety system designed to handle gas in the riser above the BOP, and to eliminate the possibility of a gas cloud being released over the rig. The use of the diverter in such circumstances should ensure that all explosive hydrocarbons are released in a safe area to the side and ideally downwind of the rig. b) To eliminate the possibility of overloading the mud gas separator (MGS), Norsok D-001 should be updated to prevent any connection between the diverter system and the MGS. However, a connection from the downstream end of the choke manifold to the MGS is permitted.	Norsok D-001 review team	2.1.6 a and b
9	The need for more practice with well control emergencies is recognised. Norsok D-010 should be updated to include requirements for routine well control exercises, specifically in the areas of: - spacing out and centralising pipe prior to shearing and disconnecting - diverter line-up to overboard lines - well control exercises to be conducted (scope, frequency, acceptance, etc). See also sections 2.1.5 and 2.3.4.	Norsok D-010 review team	2.1.8 c
10	Norsok D-010 should specify and require periodic testing of emergency subsea well control activation systems, with due regard to operational activities.	Norsok D-010 review team	2.1.8 e
11	Norsok D-001 and D-010 should include more explicit requirements for primary and back-up BOP control systems, their ability to perform in emergencies and testing of them.	Norsok D-001 and D-010 review teams	2.1.8 f
12	Norsok D-001 should contain a requirement for activating BOP functions via ROV intervention. This will facilitate external activation of BOP elements or release functions should all other systems fail. It is recognised that a BOP ram may not be closed fast enough by an ROV to seal off a flowing well.	Norsok D-001 review team	2.1.8 g
13	Operators should conduct a risk assessment to determine the optimum BOP configuration for each well, utilising the latest BOP reliability, performance and assessment data, the design of the well to be drilled, and the rig in use. The findings should be recorded in the well control bridging document.	NCS operators	2.1.8 h

14	OLF recommends that the industry supports further work on BOP reliability to be coordinated by the WEC, where OLF is represented.	NCS operators and OLF	2.1.8 i
15	Norsok D-001 should be updated to ensure that subsea wellhead casing/tubing hangers are locked down on all strings in contact with hydrocarbon-bearing zones.	Norsok D-010 review team	2.1.9
16	OLF recommends that NCS operators and drilling contractors review and utilise the OLF well integrity guidelines for all aspects of well planning and execution.	NCS operators and drilling contractors	2.2
Rec no	**OLF recommendations on prevention – management**	**Action by**	**Section**
17	OLF will assess the OGP's work on process safety and key performance indicators related to asset integrity and major accident risk.	OLF	2.3.1
18	OLF recommends that the findings from the PSA assessment [Ref 8] should be reviewed by NCS operators and drilling contractors.	NCS operators and drilling contractors	2.3.1
19	A recommendation on management of change (MOC) should be implemented in Norsok D-010 as follows: a) An MOC procedure covering the well life cycle should be included in the operator's management system steering documentation. The MOC procedure should describe the processes used to assess risk and to mitigate, authorise and document material changes to previously approved information or procedures. Material changes subject to an MOC process include, but are not limited to, the following: - changes in surface and downhole well control equipment - changes that impact well barriers - change in well type (eg, producer to injector) - changes in procedures - changes in rig or contractor well control equipment while on hire to an operator -changes of key personnel. b) An MOC procedure covering the following elements of rig systems and key personnel should be included in the drilling contractor's management system steering documentation. The MOC procedure should describe the processes used to manage, maintain, modify, risk analyse, authorise and document material changes to rig systems and procedures. Elements subject to an MOC process include, but are not limited to, the following: - safety critical systems - changes of key personnel - changes in procedures - changes in the contractor's well control equipment while on hire to an operator	Norsok D-010 review team	2.3.2 a and b

20	OLF recommends that operators and contractors review their well management system (WMS) to the relevant extent in order to ensure that well design and planning will reduce operational risks to ALARP.	NCS operators and drilling contractors	2.3.3
21	OLF recommends that operators on the NCS should exchange experiences related to operational barriers.	OLF	2.3.3
22	OLF recommends the inclusion of a requirement in Norsok D-010 for setting either pass/fail criteria or assessment KPIs for all key well control and safety exercises.	Norsok D 010 review team	2.3.4
23	OLF recommends that operators consider the use of independent verification for high-risk areas, through the identification of critical well design elements or activities. The requirements for independent verification should be described in the well management system, and can be performed by either an independent in-house department or an external third party. See section 2.3.3.	NCS operators	2.3.5
24	OLF recommends that a system for the verification and documentation of safety critical points in the well is developed. OLF will work with the WEC to establish a common industry practice with efficient workflow management.	NCS operators and OLF	2.3.5
25	OLF will progress alignment of well incident reporting with future WEC recommendations.	NCS operators and OLF	2.3.6
26	OLF recommends that operational tools (eg, well barrier schematics) should be developed by NCS operators to provide the various well-site crew members with simple visual aids, including descriptions of monitoring methods for each defined barrier element.	NCS operators and contractors	2.3.7
27	OLF recommends that formal risk assessments should be implemented by operators and drilling contractors when Simops are planned, and where one activity could affect the safety barriers intended to prevent incidents in the other activity.	NCS operators and contractors	2.3.7
28	OLF will follow up further development of expertise guidelines for well personnel through the OGP WEC HF (Human factors) task force. This will require careful study and adjustment to accommodate Norwegian vocational education and training systems in delivering the best solution for Norway.	NCS operators and OLF	2.3.8
29	OLF recommends that the industry gives consideration to introducing CRM or similar scenario-based team behaviour training for well-site and support personnel.	NCS operators and contractors	2.3.9
30	OLF recommends that training and emergency exercises should involve the wider rig-site crew and also, where appropriate back-up staff and management on land. Operators should ensure exercises are based both on common accidents and on higher-impact, low-probability events.	NCS drilling contractors and operators	2.4

Rec no	OLF recommendations on capping and containment	Action by	
31	OLF recommends on-going support for the SWRP as planned.	NCS operators	3.2.5
32	OLF supports the development of options for containment.	SWRP	3.2.5
33	OLF supports opportunities for non-participants to gain access to the equipment.	SWRP	3.2.5
34	OLF recommends that Norsok D-010 should require an outline plan and procedure for capping and shut-in of a flowing subsea well, in which the operator demonstrates how to access and install equipment to shut in the well within a reasonable time.	Norsok D-010 review team	3.2.6

Rec no	OLF recommendations on incident response	Action by	
35	OLF will continue working closely with the Norwegian Coastal Administration to make a case for implementing the principles of unified command for incidents of national significance on the NCS.	OLF	4.1.3
36	Implement a new strategy with measures to strengthen the capability and robustness of oil spill response.	NOFO	4.3.1
37	The development of cooperative agreements on oil spill response between North Sea oil producing countries is being pursued via the Operators' Cooperative Emergency Services (OCES)	NOFO	4.3.1
38	NOFO should join the global response network.	NOFO	4.3.1
39	NOFO should continue to facilitate expanded/increased use of dispersants in the operators' emergency preparedness plans and in conjunction with the subsea well response project.	NOFO	4.3.1
40	NOFO should support the Norwegian Coastal Administration in taking the lead on evaluating in-situ oil burning as a supplementary clean-up method.	NOFO	4.3.1
41	NOFO should implement the Norwegian version of the incident command system (enhetlig ledelse system – ELS) and develop an emergency response centre based on this.	NOFO	4.3.1
42	OLF recommends that all operators and contractors which may require emergency response offshore should ensure that the following are implemented as part of their emergency preparedness planning process. • Clear responsibilities in emergency response plans The emergency response plans should clearly indicate who is responsible for occupational health measurements, risk assessment, health examinations and health follow-up. This must be implemented for accidents where directly employed personnel, other active personnel or third parties are exposed to chemicals with potential health hazards. Operators must also develop uniform systems for measurements, health examinations and	NCS operators and NOFO	4.4

	follow up. • Access to the right expertise Provide access to qualified personnel who can implement occupational hygiene measurements, risk assessments and health examinations, where relevant. Ensure also that necessary measurement equipment is available. • Relevant education and training Personnel who take part in oil spill response activities or accidents which lead to chemical exposure must be educated about potential health hazards, and how to protect themselves against hazards. Information packages should be prepared for use as HSE awareness topics on the facilities. • Access to adequate protective equipment Emphasis in the various exposure scenarios is placed on identifying adequate PPE, including respiratory protection, skin protection and any other gear. This equipment must be readily available for use during campaigns.		
43	OLF recommends that the following be implemented or provided during an incident as an integral part of emergency response plans. • Implement exposure measurements and risk assessment Exposure measurements must be made quickly and preferably continuously, by qualified personnel, so that necessary risk assessment can be carried out and personnel can be equipped with adequate protective gear. This will form the foundation for providing affected parties with rapid and precise information. An evaluation should also be made of whether biological exposure data should be obtained. • Provide access to adequate protective equipment Based on plans and risk assessments, ensure that correct protective equipment is used. For vessels used in oil spill response, it is recommended that active coal filters are available and used in the fresh air intake for ventilation air. • Ensure rapid and precise information Rapid and precise communication of information about potential chemical exposure and any ensuing health effects. This is important both for the personnel involved, and in relation to other affected parties. Reliable scientific information should be emphasised. Information will reduce uncertainty and can help prevent stress reactions.	NCS operators and NOFO	4.4

44	OLF recommends that the following actions should be implemented after an incident for follow-up of involved personnel: • Ensure that the exposure is documented It is important that all information about possible exposure is retained with an eye to possible delayed effects, and for learning and research purposes. • Ensure necessary monitoring and follow-up of health Emphasis is placed on systematic gathering and subsequent evaluation of necessary health information, where this is considered appropriate. In the event of major accidents involving the exposure of many people, it is recommended that a systematic health monitoring and follow-up programme be implemented by qualified professionals over an extended period.	NCS operators and NOFO	4.4
45	OLF will continue to follow up the results of relevant research programmes, including work packages by API with SINTEF as one of the contributors.	OLF	5.5

As far as possible, OLF has developed the recommendations presented in this report in line with international initiatives and discussions. This approach is aimed at securing a broad consensus on all key issues, promoting the development of new industry standards, and facilitating acceptance and implementation across national and company boundaries.

In general, the project recommendations should be followed up by the party identified in chapter 6. The OLF actions identified in the report will be followed up by the OLF administration. OLF will also follow up on-going revision work with the Norsok standards being pursued by Standards Norway.

7 Definitions and abbreviations

The following abbreviations have been used in the report:

ABS	American Bureau of Shipping
AIS	Automatic identification system
ALARP	As low as reasonably practicable
AoC	Acknowledgement of compliance
API	American Petroleum Institute
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BOP	Blowout preventer
Bopd	Barrels of oil per day
BSEE	Bureau of Safety and Environmental Enforcement
BSR	Blind shear ram
CBL	Cement bond log
CRM	Crew resource management
CSB	US Chemical Safety Board
CSR	Casing shear ram
DCR	Drilling control room
DNV	Det Norske Veritas
DP	Dynamically positioned
D-001 (Norsok)	Drilling facilities
D-010 (Norsok)	Well integrity in drilling and well operations
E&P	Exploration and production
ELS	Enhetlig ledelse system (unified management system)
EPA	Environmental Protection Agency
ESD	Emergency shutdown
Ex	Electrical equipment certified for gaseous conditions
GIRG	Global industry response group (OGP)
GIS	Geographic information system
GoM	Gulf of Mexico (USA)
GRN	Global response network
HOF	Human and organisational factors
HSE	Health, safety and environment
HSE (UK)	UK Health and Safety Executive
IACS	Integrated alarm and control system
IADC	International Association of Drilling Contractors
ICS	Incident command system
IMO	International Maritime Organisation
IRF	International Regulators' Forum
ISO	International Organisation for Standardisation
JIP	Joint industry project
Klif	Norwegian Climate and Pollution Agency
KPI	Key performance indicator

LMRP	Lower marine riser package
MGS	Mud–gas separator
MMS	Minerals Management Service
MOC	Management of change
MODU	Mobile offshore drilling unit
Neba	Net environmental benefit analysis
NCA	Norwegian Coastal Administration
NCS	Norwegian continental shelf
Niosh	National Institute for Occupational Safety and Health
NMA	Norwegian Maritime Authority
NPD	Norwegian Petroleum Directorate
NOFO	Norwegian Clean Seas Association for Operating Companies
NOGEPA	Netherlands Oil and Gas Exploration and Production Association
NSA	Norwegian Shipowners' Association
NSOAF	North Sea Offshore Authorities Forum
NTSB	National Transportation Safety Board
OCES	Operators' Cooperative Emergency Services
OEC	Operations executive committee (OLF)
OGP	International Association of Oil and Gas Producers
OIM	Offshore installation manager
OLF	Norwegian Oil Industry Association
OSPRAG	Oil spill prevention and response advisory group (Oil & Gas UK)
OSR	Oil Spill Response
OSRL	Oil Spill Response Limited
PDO	Plan for development and operation
PPE	Personal protective equipment
PSA	Petroleum Safety Authority Norway
R&D	Research & Development
ROV	Remotely operated vehicle (underwater)
Simops	Managing and controlling simultaneous operations
SOL	Small operators and licensees network (OLF)
SWRP	Subsea well response project
UC	Unified command
VOC	Volatile organic compounds
WEC	Wells expert committee (OGP)
WBE	Well barrier elements
WLCPF	Well life cycle practices forum
WMS	Well management system

APPENDICES

Appendix A *Deepwater Horizon* project members

The following were members of the project secretariat and the project working group:

Arild J Haugland	OLF – Statoil, project leader until the end of 2010
Olav Skotheim	OLF – Statoil, project leader from January 2011
Lars Petter Lundahl	OLF – Statoil
Bodil S Krohn	OLF
Karin Øvstebø	OLF
Kjetil Hjertvik	OLF
Øystein Joranger	OLF
David Llewelyn	OLF

The following were members of the project working group:

Rune Alterås	Shell
John R Burgess	ConocoPhillips
Hans Konrad Johnsen	Det norske
Eldar Larsen	BP
Fredrik Sønstebø	ExxonMobil until August 2011
Dag Heiret	ExxonMobil from August 2011
Einar Bekkevold	Seadrill/NSA
Stein Olaussen	Halliburton
Sjur Knudsen	NOFO
Oddbjørg Varhaug Greiner	NOFO
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Other experts who contributed:

Lars Brekke	Statoil
Kari Stokke	Statoil
Arne Jarl Ringstad	Statoil
Jacob Nærheim	OLF – Statoil
Åshild Tandberg Skjærseth	Statoil

Appendix B Reference reports and documents

The following reports and documents have been used in developing the recommendations in this report.

	Investigation reports
Ref 1	BP*: Deepwater Horizon* Accident Investigation Report, September 2010
Ref 2	National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling Deepwater: The Gulf Oil Disaster and the Future of Offshore Drilling. Report to the President, January 2011; National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling: Deepwater. Report to the President, January 2011; Chief Counsel's Report 2011**,** Macondo the Gulf Oil Disaster, February 2011
Ref 3	US Coast Guard: Report of Investigation into the Circumstances Surrounding the Explosion, Fire, Sinking and Loss of Eleven Crew Members Aboard the Mobile Offshore Drilling Unit Deepwater Horizon, April 2011
Ref 4	BOEMRE: Report Regarding the Causes of the APRIL 20, 2010 Macondo Well Blowout, September 2011
Ref 5	Det Norske Veritas: Final Report for US Department of the Interior. Forensic Examination of Deepwater Horizon Blowout Preventer, March 2011
Ref 6	National Academy of Engineering and National Research Council of the Academies, Blowout **-** Lessons for Improving Offshore Drilling Safety, December 2011
	Norwegian reports
Ref 7	SINTEF report: Deepwater Horizon-ulykken – Årsaker, lærepunkter og forbedringstiltak for norsk sokkel, May 2011
Ref 8	Norwegian Petroleum Safety Authority: Deepwater Horizon-ulykken – vurderinger og anbefalinger for norsk petroleumsvirksomhet, June 2011
	International Association of Oil & Gas Producers (OGP) reports
Ref 9	Deepwater Wells, Global Industry Response Group recommendations, May 2011
Ref 10	Capping & Containment, Global Industry Response Group recommendations, May 2011
Ref 11	Oil Spill Response, Global Industry Response Group recommendations, May 2011
	Other documents
Ref 12	Summary of differences between offshore drilling regulations in Norway and GoM, DNV Reg No: 2010-1220/ 12P3WF5-9
Ref 13	OLF recommended guidelines for well integrity guidelines: Doc 117
Ref 14	Risikonivå i petroleumsvirksomheten – RNNP (main report 2011)
Ref 15	Akvaplan-niva - The *Deepwater Horizon* oil spill, marine environmental impacts. A desk study. April 2011

Ref 16	API S53 Proposed BOP configurations
Ref 17	BP *Deepwater Horizon* Oil Spill – Incident Specific Preparedness Review USCG Mars 2011
Ref 18	DNV, 2011, Status and effects of CRM training - and an assessment of CRM in drilling operations, Report no 1 / 13VP42G-5)
Ref 19	Extracted from “Human and organisational factors – lessons from the loss of the Deepwater Horizon”: Rob Miles UK HSE

Appendix C Requirements for blowout preventers (BOPs)

The main internationally recognised document specifying the requirements for blowout preventers is API RP 53. In 2011, this document was revised from being a Recommended Practice to a Standard, under the new designation API S 53, proposed BOP configurations [Ref 16]. At the time of writing this report, that standard is being widely debated in the industry.

The API S53 draft (4th Edition Ballot 2) has the following revisions:

> "7.1.3.5 Subsea BOP stacks shall be Class 5 or greater consisting of the following:
> a) a minimum of one annular preventer
> b) a minimum two pipe rams (excluding the test rams)
> c) a minimum of two sets of shear rams (at least one capable of sealing) for shearing the drill pipe and tubing in use
>
> 7.3.17.1 Emergency disconnect sequence (EDS) shall be installed on all subsea BOP stacks that are run from a dynamically position vessel. An EDS is optional for moored vessels.
>
> 7.3.18.2 Autoshear shall be installed on all subsea BOP stacks.
>
> 7.3.19.2 A Deadman system shall be installed on all subsea BOP stacks."

The requirement to have two shear rams on subsea BOPs, with at least one capable of sealing, replaces the previous requirement for only one shear ram.

However, OLF has a number of concerns about whether this is the safest option for all wells, as pros and cons need to be considered before a general recommendation can be made (see the section below). Considerations would include:

- operational flexibility is reduced by cutting the number of pipe rams available
- inclusion of an additional ram cavity increases the BOP stack weight, thereby reducing the permissible fatigue life of the wellhead. In some cases (particularly in shallow water), the BOP may be too large for use on older wellheads
- any systematic weakness in the ability of the shear ram to close and seal may not be remedied simply by installing a second ram of the same type.

Research into overall BOP reliability under the sponsorship of OGP is underway, and new shear ram designs are also being developed which should be capable of cutting and sealing a wider selection of pipe sizes and types, and also of cutting off-centre pipe.

For these reasons, OLF recommends that well- and rig-specific risk assessments should always be conducted to determine the optimum ram configuration, taking into account the API recommendations, relevant operational considerations and the latest reliability and ram performance data (see section 2.1.8 h).

The objective is to agree and communicate the safest option for each well, taking into account all the factors relevant to the rig and to the well being planned. The resulting ram configuration should be summarised in the well control bridging document. See section 2.1.5 b.

Dual shear rams
This section reviews arguments presented in API 53S concerning dual shear rams:

- Shear rams are the last line of defence for blowout protection. Their function is to cut pipe in the hole and shut in the well thereafter. Shearing will part the string, whereby the bottom portion of the string might drop or hang off, while the upper portion moves upwards and allows the shear ram blocks to close and seal the well against the unwanted release of wellbore fluids. BOP stacks are designed to shear drill pipe, work strings and tubing.

- The philosophy behind the dual shear ram recommendation is to provide redundancy of the emergency disconnect system, which increases the probability of shearing the pipe.

- In the case where only one blind shear ram is incorporated in a BOP stack, it is extremely difficult for BOP manufacturers to remove all possible mechanical and design limitations related to the shear-seal action and ensure that the single blind shear ram will close in a well as intended. A high flow rate of hydrocarbons/wellbore fluids, for example, may prevent the ram from sealing after shearing (fluid flow would erode the ram seals). Hence, the second sealing shear ram mitigates this risk and increases the probability of sealing after shearing.

However, having dual shear capabilities may not reduce the overall well control risk picture. This would require modifications, particularly for existing rigs. Space and weight limitations will exist for the BOP. Sacrificing a pipe ram to replace it with a blind ram or squeezing in a double spool will change the space-out configuration of the BOP (the distance between rams). Unwanted conditions may occur, such as a tool joint getting across a blind/shear ram when spaced out to close a pipe ram. Sacrificing a pipe ram to gain a second blind/shear ram may also result in having to pull the BOP during operations to change out for a different pipe-ram size. Extra BOP runs incur additional safety and working environment risks and are undesirable.

The HSE cost impact analysis in Appendix E shows that implementing dual shear rams has a moderate benefit at a relatively high cost compared with other initiatives.

Dynamically positioned rigs working off Norway have a dual shear ram capability (Norsok D-001 requirement). New-builds can be designed with dual shear ram BOP stacks as an additional ram, avoiding the restrictions which would apply when upgrading an existing rig.

Even so, additional rams in the BOP will result in bigger and heavier BOP stacks. This is an additional weight loaded onto the wellhead during well operations. Wellheads have a limited fatigue life, and this will need to be monitored to ensure that operations stay within defined operating windows at all times. This is the subject of a current joint industry project being run by DNV.

Secondary activation systems for the BOP
Changes to API S 53 also include requirements to have an emergency disconnect system, deadman, autoshear and ROV closing capabilities in place. The project supports these requirements. Where the standard specifies that an acoustic system is optional, however, the working group recommends that this should be a requirement when working on the NCS. Where autoshear is used as part of an emergency disconnect system, space-out and pipe centring before shearing must be taken into account.

An alternative BOP control system on all mobile rigs is already a requirement in Norsok D-001. Acoustic systems are the norm for secondary BOP control on the NCS because of the operating weather envelope in these waters, which may limit the ability and availability for deploying and working with an ROV in certain weather conditions. Norway's petroleum activity is diversified, and factors affecting risk can vary a great deal from area to area. This confirms the importance of a risk-based approach in the industry, so that safety and emergency preparedness measures are tailored to the risk factors prevailing at any given time.

BOP reliability
BOP reliability will always depend on the BOP being configured in such a way that the pipe rams can close in the well on any size of tubular being used. Reliability is ensured through frequent testing, both functional and pressure. Testing will reveal faults with the BOP and discrepancies in maintenance. Frequent testing, as specified in Norsok D-010, is the main assurance activity that the BOP will perform as expected when activated. Testing of the BOP is done when it is on deck between use and when it is installed on the wellhead.

Recommendations for testing include the following:

BOP testing on deck
All primary, secondary and automated functions (all functions which affect the BOP as a well barrier element) should be tested with the BOP on deck. Testing should include the primary and back-up functions and the emergency disconnect system. Exercises can be performed with the BOP on deck to develop crew expertise for emergencies. Rigorous testing while on deck helps ensure a fully functioning and reliable BOP when installed on the well.

BOP testing when installed on the well
When testing a BOP installed on a well, safety function tests should be performed as described in Norsok D-010.

Appendix D Analysis of HSE culture and leadership

The project group has conducted an assessment of the published reports to determine the primary human and organisational factors (HOFs) which contributed to the Macondo blowout [Refs 2 and 7].

Compartmentalisation of information and communication
Failures of communication on several levels also contributed to the accident. These included insufficient handover of information between key decision-makers, compartmentalisation of information (both within BP and between the various companies involved), insufficient use of expertise in drilling and well, a lack of communication between the rig and the land-based organisation, and insufficient use of lessons learned from previous incidents.

Management and supervision of contractors
The operator failed in its follow-up of contractors on several occasions. These failures ranged from poor follow-up of individual employees and their performance, to confusion over the expertise and responsibilities of contracting companies. The contractors, for their part, showed acceptance in their relationship with the operator. This led to safety-critical issues being insufficiently discussed and consequently being overlooked in the further progress of the operation.

Review of measures proposed in the investigation reports
In response to the above findings, each of the investigation teams has made clear recommendations on actions to be taken by the industry and its regulators.

In order to better understand their effectiveness, the project has analysed two key aspects of the measures proposed:

a) To what extent do they affect the formal structure of the organisations involved, or cultural or behavioural norms?
b) Where do these changes have the biggest impact – *remote from the rig site* (eg, management procedures – on land) or *close to the rig floor* (eg, working methods)?

Figure 16 below presents examples of HOF measures categorised in accordance with the two axes [Ref 19].

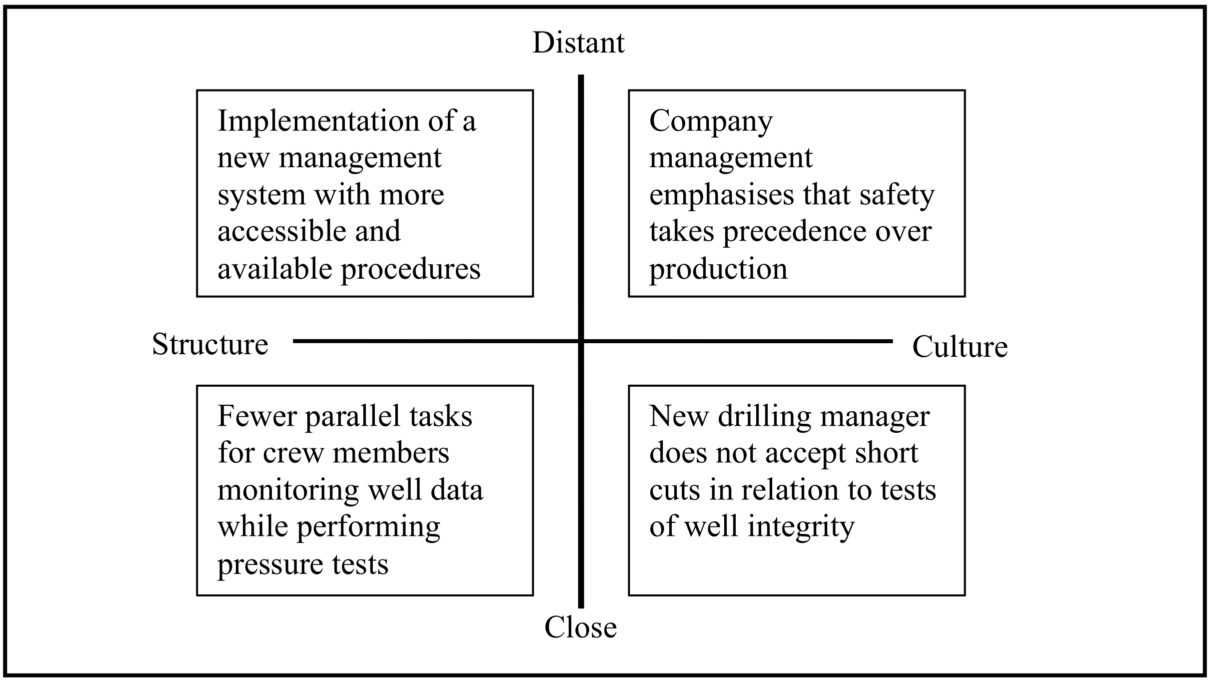

Figure 16. Examples of measures categorised by the proximity and structure/culture axes

The next diagram, figure 17, shows the recommendations (only those related to HOFs) from four reports referred to in the figure below [Ref 19].

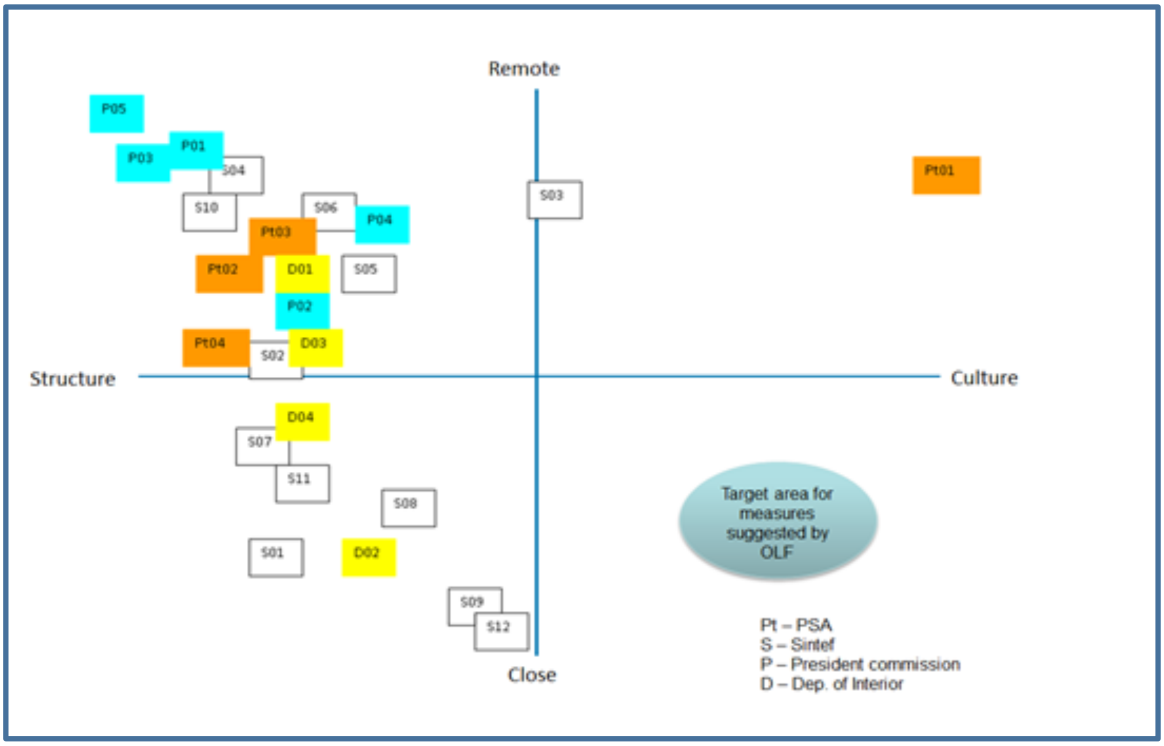

Figure 17. Distribution of management recommendations

As indicated in figure 17, the measures suggested in the existing reports are mainly directed at structural conditions with a certain distance from day-to-day operations. This is not surprising, given that the reports have been written by government agencies or on their behalf.

While structural measures of a generic nature may sometimes affect the performance of day-to-day operations, the project is convinced that the optimum effect can only be achieved by introducing a set of measures which belongs to *all the quadrants* depicted above, and particularly those related to rig-floor culture.

Appendix E HSE cost impact assessment

It is appropriate to assess the health, safety and environmental benefits of the recommendations made in this report to ensure that they are effective and that the resulting operational and cost impacts are generally aligned with those imposed in other regions. The assessment also permits a comparison between the preventive and emergency preparedness measures, allowing efforts to be focused on those improvements which are most effective.

The analysis is based on the bow-tie methodology, a well-established way of determining that risks have been reduced to as low as reasonably practicable (ALARP). To achieve this, each of the barriers designed either to prevent subsea blowouts or to reduce their environmental consequences are assessed for their relative effectiveness in contributing HSE improvements to NCS drilling activities (see figure 18 below).

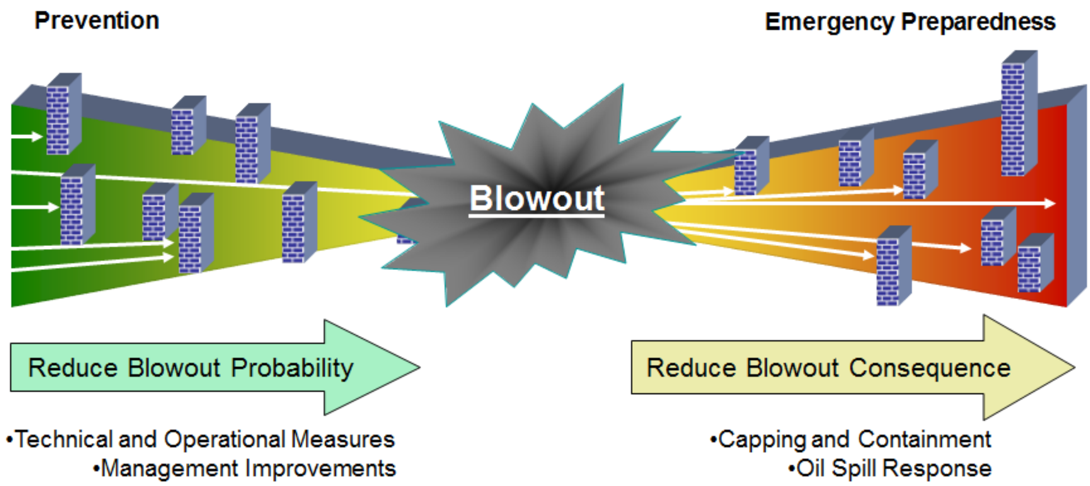

Figure 18. Bow-tie analysis of blowout prevention and consequence reduction.

Assumptions and methodology

The first step in the analysis is to rank the HSE contribution made by each recommendation. This assessment considers the potential HSE risk reduction relative to risk levels which prevailed on the NCS prior to the implementation of the findings from the Macondo accident. These risks are already considered very low. So the five different ratings used – major, significant, moderate, some and minor – indicate the contribution each recommendation makes to a further reduction of blowout probability or environmental consequences on the NCS.

For indicative purposes, the cost analysis has been conducted on a cost per well basis for a DP rig on an exploration well. The following assumptions have been applied:

- rig rates are assumed to be USD 500 000 per day
- well times are 100 days
- independent experts (for verification) cost USD 4 000 per day.

The costs indicated present the incremental expense of implementing the relevant improvement. However, several recommendations have been ranked at no or negligible cost, since they may already be in use as best practice (eg, negative pressure test procedures, effective management of change (MOC), etc), although in specific cases these may increase costs. Substantial costs are indicated for improved exercises (owing to rig time) and off-site training, such as CRM events. The costs of independent verification and well management systems are estimated but uncertain, since these will be organisation-dependent. New Capex and Opex costs for NOFO oil spill response and well capping are assumed to be allocated to wells through standard accounting procedures.

An asterisk* has been used to indicate those items which are also being implemented internationally under the guidance of organisations such as UK Oil & Gas, OGP and API. These include well capping provisions, CRM and expertise training.

The results were then plotted on two graphs (see figures 19 and 20), one for well barriers (technical and management) and one for oil spill response barriers (capping containment and oil spill response).

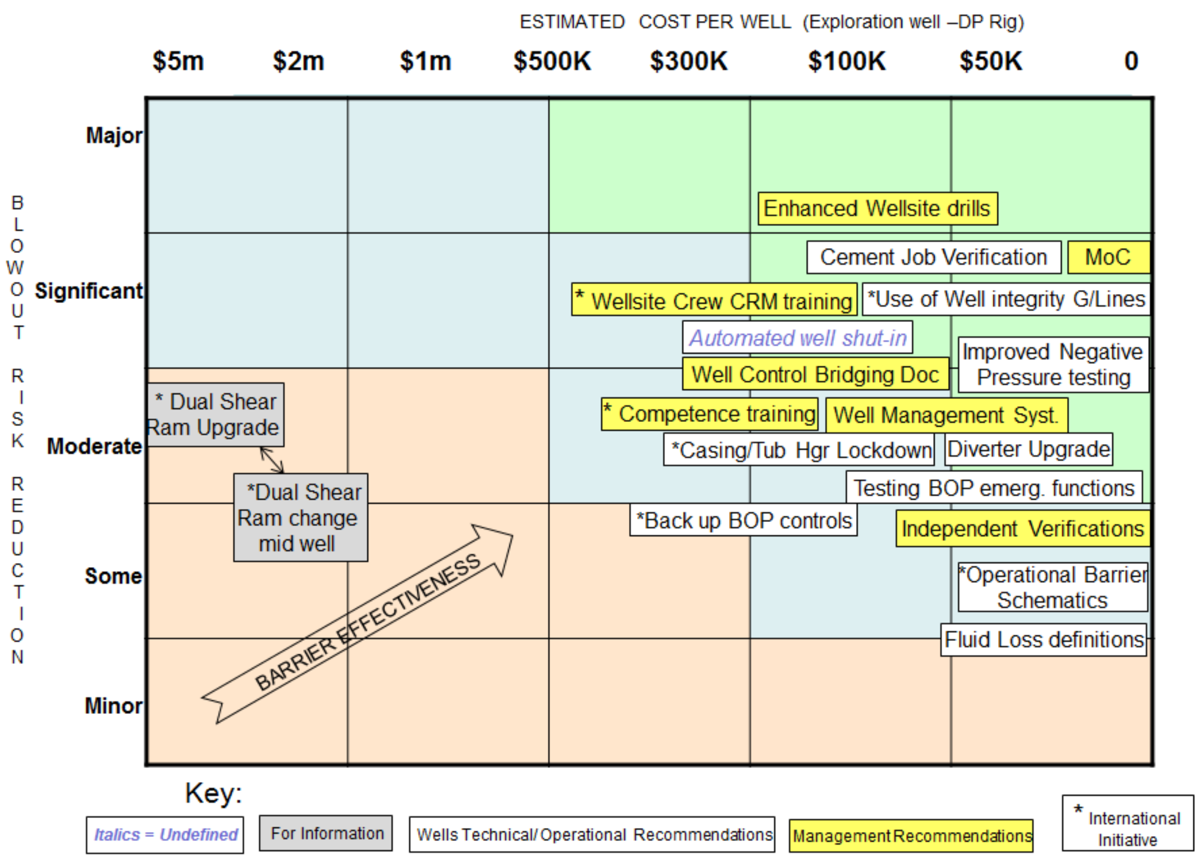

Figure 19. HSE impact assessment: blowout probability reduction

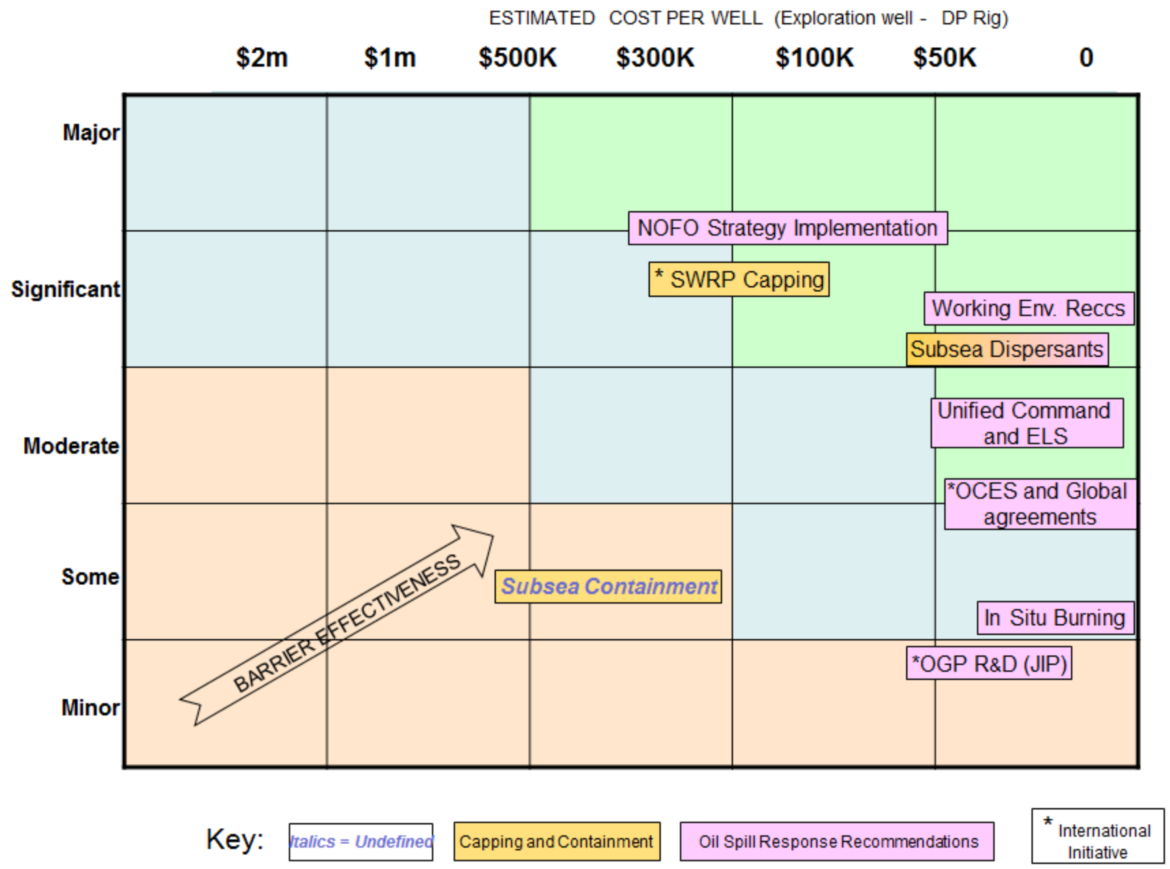

Figure 20. HSE impact assessment: oil spill consequence reduction

Results and overall cost impact

The following points cover the general conclusions from this analysis:

- The three most cost-effective recommendations for blowout prevention are implementation of enhanced well control exercises, independent verification of critical well cementation, and an improved regime for management of change.
- Also considered to be highly effective are the introduction of crew resource management (CRM) teamwork training across the entire well-site crew, full compliance with the OLF's revised well integrity guidelines, tighter procedures for the application and use of negative pressure testing, and use of a well management system.
- The use of dual shear rams as proposed by API 53 is shown for information only and, as indicated, appears to provide a relatively low cost benefit.
- For improving emergency preparedness, full implementation of the NOFO 2012-16 preparedness strategy and the provision of well capping systems should also make a big contribution to reducing environmental risk.
- Though several are more effective than others, all the recommendations in the report are considered to provide HSE benefits, and should be implemented.

An attempt has been made to estimate the overall cost impact on a well by summing all the additional costs However, this will inevitably provide an over-estimate of the costs because many of the recommendations will have been implemented already or more cost-effective ways of fulfilling these recommendations are likely to be found.

- For the exploration well analysed, full implementation of the report's recommendations could, in the worst case, increase overall costs by 2.1 per cent.
- Incremental blowout prevention costs account for 1.6 per cent, and emergency preparedness costs for 0.5 per cent
- Excluding the cost of international initiatives, however, the overall cost increase is 1.1 per cent.
- OLF does not support the use of dual shear rams as a standard policy on all rigs, since this may not represent the best option for NCS. If the rig's BOP has fewer than six rams, incremental shear ram well costs are estimated at between USD 2.7-5 million.
- Many of the well recommendations are likely to improve operational practice, resulting in cost or efficiency savings in other aspects of the well and thereby reducing the net cost of implementation.

It should be emphasised once again that these are worst-case costs. The scope of international standards is also likely to increase, thereby reducing the gap between these OLF recommendations for the NCS and international best practice.

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