Paper #2-13

OFFSHORE WELL CONTROL MANAGEMENT AND RESPONSE

Prepared by the Offshore Operations Subgroup
of the
Operations & Environment Task Group

On September 15, 2011, The National Petroleum Council (NPC) in approving its report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic and White Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic and White Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 57 such working documents used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix C of the final NPC report provides a complete list of the 57 Topic and White Papers and an abstract for each. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

Offshore Operations Subgroup		
Chair		
Kent Satterlee III	Manager, Regulatory Policy – Offshore, Upstream Americas	Shell Exploration & Production Company
Assistant Chair		
David L. Smith, Jr.	Chief Global Technical Advisor	Halliburton Company
Members		
Jennifer J. Barringer	Health, Safety and Environment Manager, Upstream BD Support & New Ventures	ConocoPhillips
Brad J. Blythe	Oceanographer, Bureau of Ocean Energy Management, Regulation and Enforcement	U.S. Department of the Interior
Louis P. Brzuzy	Marine Science and Regulatory Policy, Upstream Americas	Shell Exploration and Production Company
Catherine E. Campbell	Geologist	Encana Oil & Gas (USA) Inc.
Jill E. Cooper	Group Lead – Environment	Encana Oil & Gas (USA) Inc.
Elmer P. Danenberger, III	Offshore Safety Consultant	Reston, Virginia
Michael Else	Safety Research Engineer, Bureau of Ocean Energy Management, Regulation and Enforcement	U.S. Department of the Interior
Austin Freeman	Technical Applications Manager/Administrator, Industry Regulations/Product Certification/Strategic Initiatives	Halliburton Energy Services
James L. Gooding	Manager & Senior Consultant	Black & Veatch Corp.
C. Webster Gray	Senior Technical Advisor	Federal Energy Regulatory Commission
Carliane D. Johnson	Consultant	SeaJay Environmental LLC
Kevin Lyons	Asset Development Geologist	WesternGeco
Jan W. Mares	Senior Policy Advisor	Resources for the Future
James M. Morris	Senior Facilities Consultant	ExxonMobil Production Company
Kumkum Ray	Senior Regulatory Specialist, Bureau of Ocean Energy Management, Regulation and Enforcement	U.S. Department of the Interior

Thomas A. Readinger	Independent Consultant	Harrisburg, Pennsylvania
Paul D. Scott	Drilling Fluids Specialist	ConocoPhillips
E. J. Thomas	Senior Principle HSE Consultant, New Ventures & Business Development Upstream HSE	ConocoPhillips
Denise A. Tuck	Global Manager, Chemical Compliance, Health, Safety and Environment	Halliburton Energy Services, Inc.
Ian Voparil	Environmental Science Specialist	Shell International Exploration and Production B.V.
David Wilson	Operations Manager	WesternGeco
Mark S. Witten	Former Senior Regulatory Advisor, Gulf of Mexico	Chevron Corporation
John V. Young	Senior Technical & External Network Advisor, Strategic Capabilities – Marine Sound	ExxonMobil Exploration Company
Ad Hoc Member		
Douglas W. Morris	Director, Reserves and Production Division, Energy Information Administration	U.S. Department of Energy

Table of Contents

EXECUTIVE SUMMARY

Well control is a discipline needed both during construction of oil and gas wells and during subsequent operation of the wells to produce hydrocarbons. The purpose of well control is to assure that safety and environmental integrity are not compromised by uncontrolled releases of hydrocarbons during oil and gas well operations. The integrated view of well control includes blowout prevention, prevention and cleanup of spills, and fire control.

Blowout prevention has been extensively studied and many technological, organizational and operational solutions have been developed to avoid or manage subsea well blowouts. Keys for effective management are early detection of blowout risks and multiple, redundant ways for activating hardware installed within or above wells. Main findings on blowout prevention are:

- Improvements are needed in predictive capabilities of drilling abnormalities.
- Research and development are needed to provide for multiple control systems to detect undesired events and to deploy last-resort blowout preventer (BOP) systems.
- Increased capabilities are needed for remotely-operated underwater vehicles, including untethered operations.

Oil-spill response (OSR) includes multiple methods/tools such as: (1) oil sensing & tracking; (2) dispersants; (3) in-situ burning; (4) mechanical recovery; and (5) shoreline protection and cleanup. All of those methods/tools must be properly developed, available, and pre-approved effectively respond to a large event. Main findings on OSR are:

- Oil-spill response should have access to a broad range of response options that provide the greatest flexibility in being able to deal with rapidly changing offshore environments.
- Response capabilities for oil-spill cleanup largely reside within a specialized-services support industry that includes some not-for-profit organizations. Although such organizations are known to, and often are employed by, oil and gas development companies, expertise on spill remediation tends to be separate from expertise on hydrocarbon resource development.
- Because developments in Arctic regions are expected to grow in importance, improvements would include (1) expanded recognition of current technologies already developed for oil spills in the Arctic; (2) a best practices guidance document on oil spill preparedness and response in the Arctic.

Fire control is addressed most effectively as an integrated part of blowout prevention. Once a fire has started, additional complicated decisions become necessary. Opportunities for progress in fire control include studies of environmental trade-offs between potential air and potential water pollution based on a range of fire-management strategies, thereby providing for improved on-scene decision-making for a better overall event outcome.

INTRODUCTION

Well control is a multifaceted endeavor that is meant to assure commercially successful and environmentally responsible drilling and completion of hydrocarbon wells and the subsequent operation of such wells after they are placed into production. One approach to defining the relevant subject matter is to consider well control to include the prevention of uncontrolled hydrocarbon releases ("blowouts") of wells, the contingency plans aimed at preventing oil spills or responding to spills if they cannot be prevented, and the prevention or control of fires that could be fueled by uncontrolled releases of oil or gas. The review of those three main sub-topics as presented here includes equipment, strategies and operational practices, including regulations.

A. Subsea Blowout Prevention

BOEMRE (formerly MMS) regulations and industry standards require all offshore producing platforms to have safety shutdown equipment. Fail-safe sub-surface safety valves must be installed in all wells at least 100 feet below the sea floor. These safety valves can be manually closed. They are also designed to shut tight whenever there is a loss of pressure from the surface facility. For example, if a surface platform is pushed over by a hurricane or ocean-going vessel, the safety valves will activate and shut in the well. This prevents the wells from blowing out. The assembly of pipes, rams and valves that are applied to blowout prevention at a wellhead is called a blowout preventer (BOP).

B. Oil-Spill Prevention and Response

The primary response objectives in any open water marine spill are to stop or reduce the source of hydrocarbon, recover as much hydrocarbon as possible, protect sensitive ecological, economic, and cultural resources, and speed the removal of unrecovered oil to minimize harm to the ecosystem. Mitigating the effects of a spill includes mechanical recovery of released hydrocarbon, booming and in situ burning; dispersing oil both at the surface and at the well-head; and enhancing natural degradation. Other mitigation technologies include shoreline cleanup and restoration, collection and rehabilitation of oiled wildlife, and protection of environmentally sensitive areas.

C. Fire Control

Offshore fire control includes both prevention and control aspects embodied in management and technical activities associated with offshore developments. In recognition of the sequence of events that commonly is involved in the outbreak of a fire, the fire-control subject matter usually is divided into a succession of topics that include prevention (failure), loss of containment, flammable atmosphere, occurrence of fire, and control of fire.

SUBSEA BLOWOUT PREVENTION

A. Overview

There are a limited number of deepwater drilling blowout control options. In controlling blowout risk it is imperative that every preventive measure available is considered and planned in advance. Detecting a blowout scenario as early as possible allows one to mitigate the problem before an actual blowout event can occur. Once a blowout becomes uncontrollable, mitigation becomes very difficult. A proper well design along with planning for a worst-case scenario can ensure a safe operation.

Table 1 summarizes recent studies and regulations that address blowout prevention, detection and mitigation strategies through the use of technical, operational and organizational barriers.

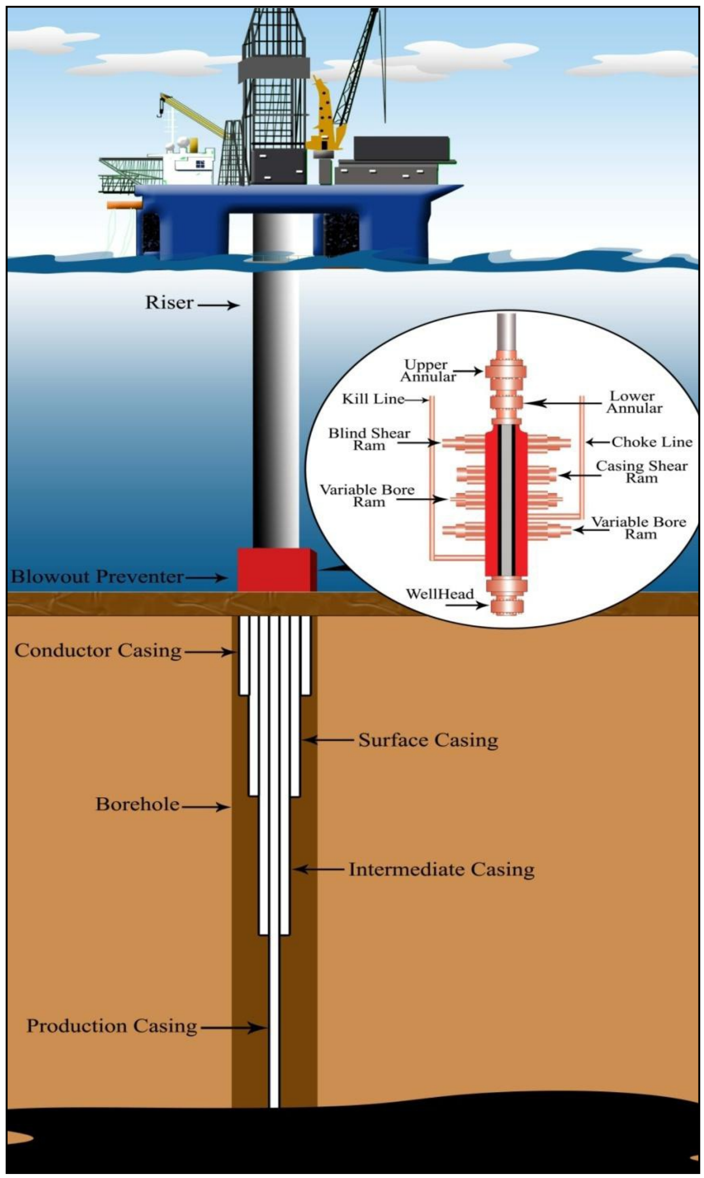
Table 1. Subjects Addressed by Key Well-Control Studies and Regulations.

Reference	Organizational	Technical	Operational	Prevention	Detection	Mitigation
BPC (2010)	□	□	□	□	□	□
U.S. DOI (2010)	□	□	□	□	□	
MMS (2010)	□	□	□	□	□	□
FRO (2010a)	□	□	□	□	□	□
FRO (2010b)	□	□	□	□		□
BOEMRE (2010b)	□	□	□	□		□
DNV (2010)	□	□	□	□		□
API (2011)		□	□	□		
WCID (cited in BOEMRE, 2010a)	□		□			

B. Blowout Prevention Practice and Technologies

Proper blowout prevention practices require the pressure in the wellbore to be monitored and maintained to prevent gas and fluids in the geologic formation from escaping. Multiple layers of prevention practices and containment barriers are used to maintain well control and to ensure that if one barrier is breached due to operational error or equipment failure, this does not result in the loss of well control. Key components of subsea blowout prevention that create mechanical barriers include:

Figure 1. Diagram of Well and Blowout Preventer (DOI, 2010).



- Riser
- Subsea BOP
- Pipe Rams
- Shear Rams
- Blind Rams
- Annular preventers
- Drilling fluids
- Casing
- Cement

A Blowout Preventer (BOP) is a technical barrier that consists of a series of ram and annular preventers that sits atop the wellhead and connects to one of the outermost casing strings, allowing the narrower casing strings and drill pipe to be lowered down the borehole through the center of the BOP. In the event of significant loss of well control, one or more of the preventers can be activated from the drill rig.

There are two variations of offshore BOPs; the sub-sea blowout preventer which sits on the ocean floor, and the surface blowout preventer which sits above the riser pipe and below the drilling rig. This paper will focus on the subsea blowout prevention technology and practices.

The most basic technical barrier is to use a drilling fluid of sufficient density that its hydrostatic pressure will prevent the influx of subsurface fluids. Additional technical barriers include a set of nested steel pipes (casing), cemented to the walls of the borehole.

Failure of either the casing or the cement may lead to undesirable wellbore fluid flow into the reservoir or reservoir flow into the wellbore.

MMS regulations and industry standards require all offshore producing platforms to have safety shutdown equipment. Fail-safe, sub-surface safety valves must be installed in all wells at least 100 feet below the sea floor. Those safety valves can be manually closed and they are also designed to shut tight whenever there is a loss of pressure from the surface facility. For example, if a surface platform is pushed over by a hurricane or ocean-going vessel, the safety valves will activate and shut in the well to prevent the wells from blowing out.

C. History of Development

BOPs have been used for nearly a century in control of oil well drilling on land. The onshore BOP equipment technology has been adapted and used in offshore wells since the 1960s. Because BOPs are meant to be fail-safe devices, efforts to minimize the complexity of the devices are employed to ensure ram BOP reliability and longevity. As a result, despite the ever-increasing demands placed on them, state of the art ram BOPs are conceptually the same as the first effective models, and resemble those units in many ways. A key difference in surface and subsea BOPs is in the remote control technology required for subsea BOP operation. One particularly interesting new technology is the use of underwater remotely operated vehicles (ROV). ROVs are unoccupied, highly maneuverable and operated by a person on board a vessel. They are linked to the ship by a tether (sometimes referred to as an umbilical cable), a group of cables that carry electrical power, video and data signals back and forth between the operator and the vehicle. High power applications will often use hydraulics in addition to electrical cabling. Most ROVs are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle’s capabilities. These may include sonar, magnetometers, a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration and temperature.

It is recognized within the petroleum industry that deepwater conditions create special challenges for critical equipment, including the blowout preventer. In a 2007 article in Drilling Contractor, Melvyn Whitby of Cameron’s Drilling System Group described how BOP requirements became tougher as drilling went deeper (Whitby, 2007) Today, he says, “a subsea BOP can be required to operate in water depths of greater than 10,000 ft, at pressures of up to 15,000 psi and even 25,000 psi, with internal wellbore fluid temperatures up to 400° F and external immersed temperatures coming close to freezing (34° F).” One possible enhancement he discussed involved taking advantage of advances in metallurgy to use higher-strength materials in ram connecting rods or ram-shafts in the BOP. He suggested that “some fundamental paradigm shifts” were needed across a broad range of BOP technologies to deal with deepwater conditions.

Working deeper below the surface of the ocean creates myriad problems after a loss of well control or a blow out. Containment problems become much more challenging and real-time decisions become more difficult when environmental knowledge is not perfect (Presidential Oil Spill Commission, 2011).

Through the BOEMRE Technical Assessment & Research (TA&R) Program, numerous studies have been conducted to address operational safety, technology, pollution prevention and spill response capabilities associated with offshore operations (Table 1, Table 2). The TA&R Program serves to promote new technology and safety through the funding of collective research with industry, academia, and other government agencies and disseminate findings through a variety of public forums (DOI, 2010).

C. Environmental Benefits and Economic Impacts

Blowout prevention technology and practices are designed to prevent direct environmental impact from the drilling process. The blowout prevention system keeps drilling fluids and reservoir flows within the well, preventing discharges into the water and air. The blowout prevention technology also provides a drilling solution without a large physical platform that can create other environmental risks. Once a discharge occurs the environmental impact can be devastating to marine life, water, air, and coastal areas in addition to the potential for loss of life to drilling personnel.

Operators have drilled about 700 wells in water depths of 5,000 feet or greater in the OCS (Fig. 2; DOI, 2010). These wells could not have been drilled without subsea blowout preventers. By 2009, 80 percent of offshore oil production (25% of all domestic oil production) and 45 percent of natural gas production (5% of domestic gas production) occurred in water depths in excess of 1,000 feet.

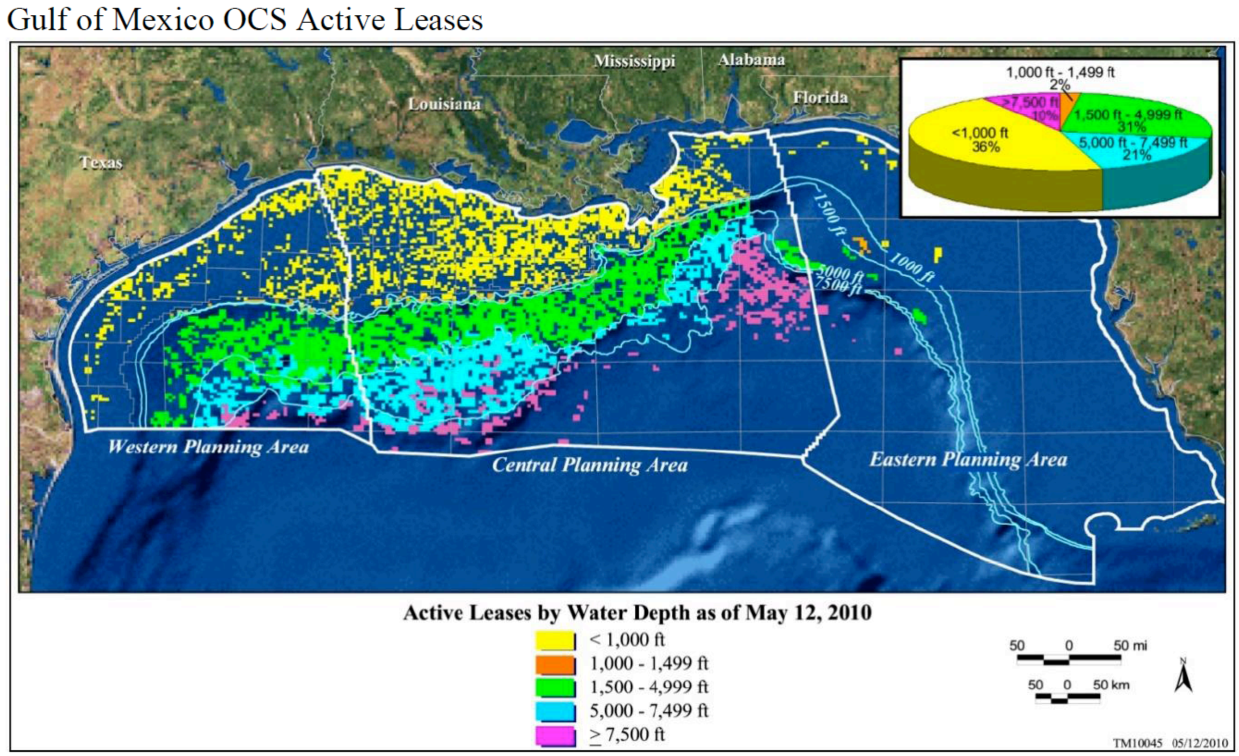
Economic impacts of subsea blowout prevention:

- Allows the production of 25% of USA oil.
- Allows the production of 5% of USA gas.
- Saves the cost and environmental footprint of a physical platform.
- Allows wells to be drilled by floating rigs, which can quickly begin drilling and work-over operations.

Table 2. TA&R-Funded Well-Control Research. See document links at: http://www.boemre.gov/tarprojects/

Study Number	Title of Study	Completion Date
8	Blowout Prevention Procedures for Deepwater Drilling	1978 to 2003
150	Floating Vessel Blowout Control	December 1991
151	Investigation of Simulated Oil Well Blowout Fires	1989 to 1993
170	Improved Means of Offshore Platform Fire Resistance	1991 and 1994
220	Study of Human Factors in Offshore Operations	1995 to 1997
253	Blowout Preventer Study	December 1996
264	Development of Improved Drill String Safety Valve Design and Specifications	1996 and 1998
319	Reliability of Subsea Blowout Preventer Systems for Deepwater Applications–Phase II	November 1999
382	Experimental Validation of Well Control Procedures in Deepwater	December 2005
383	Performance of Deepwater BOP Equipment During Well Control Events	July 2001
403	Repeatability and Effectiveness of Subsurface-Controlled Safety Valves	March 2003
408	Development of a Blowout Intervention Method and Dynamic Kill Simulated for Blowouts in Ultra-Deepwater	December 2004
431	Evaluation of Secondary Intervention Methods in Well Control	March 2003
440	Development and Assessment of Well Control Procedures for Extended Reach and Multilateral Wells	December 2004
455	Review of Shear Ram Capabilities	December 2004
463	Evaluation of Sheer Ram Capabilities	September 2004
519	Drilling and Completion Gaps for High Temperature and High Pressure In Deep Water	June 2006
540	Risk Assessment of Surface vs. Subsurface BOP's on Mobile Offshore Drilling Units	August 2006
541	Application of Dual Gradient Technology to Top Hole Drilling	November 2006
566	Using Equipment, Particularly BOP and Wellhead Components in Excess of the Rated Working Pressure	October 2006
582	A Probabilistic Approach to Risk Assessment of Managed Pressure Drilling in Offshore Drilling Applications	October 2008
631	Risk Profile of Dual Gradient Drilling	Final report expected in 2010
640	Risk Analysis of Using a Surface Blow Out Preventer	April 2010

Figure 2. Locations of subsea oil and gas wells in the Gulf of Mexico (DOI, 2010).



Source: Minerals Management Service Database, 2010.

D. Industry Assessment of Needs and Directions

Blowout prevention technology and practices have been studied intensively by many different groups both as part of ongoing industry research and development efforts and also in response to the *Deepwater Horizon* incident, and Macondo well blowout, in the Gulf of Mexico in April 2010. Many of the key studies are referenced in Tables 1 and 2. The following paragraphs highlight important findings from some of the more prominent reports and are provided here as context for mapping future directions for progress in offshore blowout prevention.

<u>BPC (2010) – Letter to Presidential Oil Spill Commission</u>. The Presidential Commission that investigated the *Deepwater Horizon* accident (Presidential Oil Spill Commission, 2011) requested that the BPC assist the Commission in its consideration of the use of moratoria as a method for mitigating future oil-spill harm. The BPC report focused on areas of regulatory resources, real-time monitoring, corporate culture and research and development (R&D). One of the issues discussed was that response systems had not kept pace with advances in exploration technology. It was noted that response technologies and management have received substantially less attention than prevention and containment. The BPC also recommended that new BOEMRE requirements for worst-case incidents and worst-case discharges should be quickly incorporated into response plans. Oil-spill response organizations should have fire-rated boom and equipment to conduct large-scale in situ burning operations, effective large-volume skimming operations,

processes for managing vessels of opportunity, and enhanced dispersant techniques to lower volatile organic compounds (VOCs) for responder safety and to improve effectiveness of subsea application.

The BPC suggested that BOEMRE, USCG and industry consider expanding the Marine Well Containment Company (MWCC) to encompass a public-private partnership that would address key response needs. The MWCC or a similar industry collaborative, in partnership with BOEMRE and USCG should consider contracting for assets, equipment and multi-purpose vessels that would be available to dispatch within 72 hours following a spill of national significance. The USCG response to a large maritime fire should be better coordinated into overall response plans and the USCG should emphasize this in large-scale training exercises. The USCG must also improve planning and training for lifesaving missions.

Key areas for R&D were identified as:

- Subsurface surveillance and protocols to approve and monitor disbursements.
- Flow measurement methods to better quantify the volume of oil released.
- Riser and well-control technologies and kill methodologies to improve response and deployment capabilities.

DOI (2010) – Safety Report. This report, which was published about one month after the *Deepwater Horizon* incident, details increased safety measures implemented for energy development on the Outer Continental Shelf and it recommended specific measures to improve BOPs and related safety equipment that are used on floating drilling operations. The enhanced safety measures include: new BOP requirements and their backup and safety equipment; changes to deepwater well-control procedures, new safeguards for the displacement of kill-weight drilling fluid from the wellbore; new requirements for casing and cementing an exploratory well; and the development of a study to identify more rapid and effective response methodologies for deepwater blowouts. Changes to the systems-based approaches to safety include verification that the requirements have been implemented, the enhancement of requirements related to organizational and safety management practices, and the requirement that operators have comprehensive, systems-based approaches to safety and environmental management.

MMS (2010) – NTL No. 2010-N06 Information Requirements. On June 18, 2010, MMS (which was replaced thereafter by BOEMRE) implemented NTL No. 2010-N06 related to information requirements for Exploration Plans, Development and Production Plans, and Development Operations Coordination Documents on the OCS. This NTL focused on prevention planning and mitigation planning and requires operators to:

- Develop a blowout scenario for the highest volume of liquid hydrocarbons that could be expected from a proposed well. This would include estimated flow rate, total volume and maximum duration of the potential blowout and other conditions.

- Describe the assumptions and calculations that are used to determine the volume of such a worst case discharge scenario.

- Describe the measures that would be used to enhance the ability to prevent a blowout, to reduce the likelihood of a blowout or to conduct effective and early intervention in the event of a blowout.

30 CFR Part 250 - Drilling Safety Final Rule (Federal Register Online, 2010a). The purpose of this final rule, which was published on October 14, 2010, is to increase safety measures for energy development on the OCS. The rule codifies the requirements in NTL 2010-05, which was rescinded, and it makes mandatory several requirements for the drilling process that were described in the DOI (2010) Safety Report. The rule prescribes proper cementing and casing practices and the appropriate use of drilling fluids in order to maintain well bore integrity. The regulation also strengthens oversight of the BOP and its components, including remotely operated vehicles, shear rams and pipe rams. Operators must secure independent and expert reviews of their well design, construction and flow intervention mechanisms. Some of the key elements of this rule:

- Makes mandatory American Petroleum Institute's (API) standard, RP 65 – Part 2.

- Certification by a professional engineer is necessary to ensure that the casing and cementing program is appropriate.

- Approval required from the BOEM District Manager before a heavier drilling fluid can be replaced with a lighter fluid.

- Enhanced deepwater well control training is required for rig personnel.

- Requires a trained ROV crew on each floating drilling rig on a continuous basis

- Requires two independent test barriers across each flow path.

- Requires ROV intervention capability.

- Requires assurance of proper installation, sealing and locking of the casing or liner.

- Requires testing of all ROV intervention functions.

- Requires function testing auto shear and deadman systems.

30 CFR Part 250 - Workplace Safety Rule (Federal Register Online, 2010b). The Workplace Safety final rule was published on October 15, 2010. It requires operators to develop and implement Safety and Environmental Management Systems (SEMS) for their operations on the OCS. This establishes programs to identify potential hazards when they drill, protocols for addressing those hazards, and procedures and risk-reduction strategies for all phases of activity, from well design and construction to operation, maintenance, and decommissioning. This final

rule makes mandatory American Petroleum Institute (API) Recommended Practice (RP) 75, which was previously a voluntary program to identify, address and manage safety hazards and environmental impacts in offshore operations. Thirteen elements that were already industry practice in API RP 75 became mandatory and include:

- Development of a hazards analysis.
- Implementation of a "Management of Change" program.
- Evaluation of operating procedures.
- Evaluation of safe work practices.
- Requirement for safety and technical training.
- Development of a preventive maintenance program.
- Verification of facility function, personnel training, and safe work practices.
- Assurance that emergency evacuation plans and oil spill contingency plans are in place and ready for immediate implementation.
- Development of accident investigation procedures.
- Requirement for independent third-party audits.
- Safety documentation.
- Requiring two independent test barriers across each flow path.
- Documentation that describes the 13 elements of the operator's SEMS program.

<u>BOEMRE (2010b) – NTL No. 2010-N10 Statement of Compliance</u>. NTL 2010-N06 became effective on November 8, 2010 and applies only to operators conducting operations using subsea BOPs or surface BOPs on floating facilities. It requires a statement by an authorized company individual that states the operator will conduct activities in compliance with all regulations. It also requires operators to provide information related to surface and subsea mitigation equipment that the operator can access in the event of a spill or a threat of a spill. The type of information that BOEMRE will evaluate includes, but is not limited to, the following, as applicable to each operations:

- Subsea containment and capture equipment.
- Subsea hydraulic power and dispersant injection systems.
- Riser systems.

- Remotely operated vehicles.
- Oil-capture vessels.
- Support vessels.
- Storage facilities.

DNV (2010) – Report for the Norwegian Oil Industry Association and Norwegian Clean Seas Organization for Operating Companies. This report summarizes differences between offshore drilling regulations in Norway and US. Gulf of Mexico. The comparison is limited to regulations, as of April 2010, which are specific to rigs and facilities, drilling and well operations and oil-spill preparedness. The report noted that the major difference in the regulations is the Norwegian requirement for a systematic application of two independent and tested well barriers in all operations. There also is the requirement in Norway for an additional casing shear ram in the BOP for dynamic positioned mobile offshore drilling units (MODUs) and to re-certify well control equipment every five years. Those well-barrier and BOP requirements do not pertain in the US. The report recommends an approach to blow out prevention practice including technical, operational and organizational barriers.

- In Norway the operator is required to verify that all workers comply with regulatory health, safety and environment (HSE) requirements.
- Norway requires adequate competence in all phases of petroleum activities.
- The US has competence requirements related to a few critical activities or operations.
- For well design, Norwegian regulations rely on the operators to show compliance to their safety philosophy.
- Norwegian regulations require two independent and tested well barriers to prevent unintentional flow in the case of an unwanted event.
- For the BOP, Norwegian regulations require an additional casing shear ram to the blind shear ram for dynamically positioned MODUs, while US regulations do not.
- Norwegian regulations require an alternative activation system of the BOP and a system that ensures release of the riser before a critical angle occurs due to loss of position of the drilling unit.
- NORSOK Standard D-010, Well Integrity in Drilling and Well Operations, defines how the barrier requirements should be applied.
- US regulations set detailed requirements to the content of the Application for Permit to Drill, which is approved by BOEMRE.

- For pressure control equipment, Norwegian regulations require re-certification of BOPs every five years while US regulations do not require recertification (as of April 2010).

- Norway requires that the latest edition of applicable regulations and referred standards are used as the basis for compliance evaluations irrespective of a unit's age.

API (2011) – Recommended Practice (RP) 96 for deepwater well design. API RP 96 is currently under development although the essential features are known (for example, BOEMRE, 2010a). It is a well designer's tool that considers operational and technical barriers. This recommended practice requires more than one operational barrier and two physical (technical) barriers in place for any flow path.

- Identifies technical barrier considerations.

- Two technical barriers recommended.

- Provides installation practices.

- More than one operational barrier recommended.

WCID (2010) - API/IADC Bulletin 97. The goal of the Well Construction Interface Document (WCID) is to link the safety case to existing well design and construction documents and improve owner-operator alignment regarding management of change (MOC) and well execution risk assessments. The WCID remains under development although the essential features are known (for example, BOEMRE, 2010a). Principal features are:

- Provides discussion and sharing of drilling plan among operator and contractors.

- Agreement on MOC process.

- Agreement on Risk Management practices.

- Define any special procedures required to bridge any gaps in operators and contractors well control procedures.

In addition to the reports highlighted above, the American Petroleum Institute (API) is revising other documents to address issues related to offshore drilling well control operations. Key updates will be:

- API Recommended Practice 53, Blowout Prevention Equipment Systems for Drilling Operations, undergoing revision.

- API Recommended Practice 65—Part 2, Isolating Potential Flow Zones During Well Construction, undergoing revision.

- API Specification 16A, Specification for Drill-Through Equipment, undergoing revision.

- API Recommended Practice 16C, Choke and Kill Systems, undergoing revision.
- API Recommended Practice 16D, Control Systems for Drilling Well Control Equipment, undergoing revision.
- API Specification 17D, Subsea Wellhead and Christmas Tree Equipment, undergoing revision.
- API Recommended Practice 17H/ISO 13628-8, Remotely Operated Vehicles, undergoing revision.

OIL-SPILL PREVENTION AND RESPONSE

A. Overview

Proper planning and sound procedures are the keys to creating safe and reliable oil-spill prevention and contingency plans that address numerous operational factors in open water and a broad range of ice conditions. Responders must be allowed to utilize all procedures and multiple tools (mechanical recovery, dispersants, in situ burning, etc.), as appropriate, to effectively respond to a spill.

For offshore operations, hydrocarbons released to water pose unique challenges. The oil may float on the surface of the water and quickly spread into a thin layer, or it can remain just below the surface of the water, or sink in other cases (EPA, 1999). Most oil spills on water are associated with transportation of hydrocarbons, either by ship or pipeline, which results in a fixed volume of oil released. However, a blowout of a development or production well can result in a continuous release of hydrocarbons until the well is brought under control. Wells drilled in deep water, and in areas where ice is present, require additional considerations. The primary response objective is to keep the oil from reaching the shoreline, where impacts will be more severe, and clean up is substantially more difficult.

The type of hydrocarbon released and the environment in which a release occurs are major factors in determining spill response strategies. Thus, it is important that a variety of spill response and mitigation strategies are available, including: mechanical recovery (skimmers), dispersants, in situ burning and shoreline protection. This paper summarizes the current national response framework and describes the technology and strategies utilized during a spill.

Spill prevention is accomplished through both design specifications and operational practices such as: well construction with multiple stop variables, leak detection systems, and blowout prevention system with multiple triggering options. Operational practices include integrity testing of well casing and cementing activities, training of personnel, and assessment and mitigation of risks.

B. Regulatory Structure

Until 1967, the United States had not formally addressed the potential for major oil or hazardous substance spills. On March 18, 1967, a 970-foot oil tanker, the Torrey Canyon, ran aground 15 miles off Land's End, England, spilling 33 million gallons of crude oil that eventually affected more than 150 miles of coastline in England and France. The spill had negative impacts on beaches, wildlife, fishing, and tourism. Recognizing the possibility of a similar spill in the United States, the federal government sent a team of representatives from different federal agencies to Europe to observe the cleanup activities. Based on what was learned from the Torrey Canyon spill and the response, the result was the passage of the National Oil and Hazardous Substances Pollution Contingency Plan, or National Contingency Plan (NCP) on November 13, 1968. The NCP established the National Response System, a network of individuals and teams from local, state, and federal agencies (EPA, 1999).

Further significant changes to expand the role and breadth of the NCP occurred with the passage of the Oil Pollution Act of 1990 (OPA 90) largely in response to the *Exxon Valdez* accident in Prince William Sound, Alaska, in 1989. OPA-90 Section 4202 amended Section 311(j) of the Clean Water Act to require the development of comprehensive oil spill response plans for all industry sectors including exploration and production, marine transportation, refining, and distribution. The change was intended to ensure that adequate resources and processes were in place to manage up to a Worst Case Discharge (WCD) (Ramseur, 2010).

For offshore operations, an oil-spill response plan (OSRP) is submitted to and approved by the Bureau of Offshore Energy Management, Regulation and Enforcement (BOEMRE). Each plan must be consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and applicable Regional and Area Contingency Plans (RCPs and ACPs). Planning for an effective spill response encompasses a variety of aspects including, but not limited to: Spill detection and source control; Initial actions and assessment; Internal and external notification requirements; Incident management team(s) and processes; Response techniques including dispersants and in situ burning; Sensitive areas and protection measures; Wildlife rescue and rehabilitation; and Technological aspects of response communication and information exchange.

OSRPs are routinely tested through drills and exercises. Lessons learned are then incorporated into the plans. The experience of plan holders and agency personnel in executing strategies and tactics and adapting them to various scenarios during drills or exercises has improved the functionality of plans across the response community. However, one of the primary areas for improvement is the need to comprehensively ramp up the level of response effort for a Spill of National Significance (SONS). That upgraded effort includes initially utilizing resources from the region, then cascading in additional resources from elsewhere in the US and finally from international sources. Most plans only identify internal local and regional oil-spill personnel for initiation and longer term management of a response, respectively. The common reliance on local and regional resources might not be adequate to manage very large incidents. The Joint Industry Oil Spill Preparedness and Response Task Force identified several potential solutions to this problem that included (Joint Industry OSPR Task Force, 2010):

- Create an inter-industry memorandum of understanding to provide personnel trained in spill response.
- Include in the planning requirements a process for identifying and cascading in resources.
- Address, in advance, processes for waivers and approvals and Jones Act limitations.

C. Response Capabilities

The majority of marine oil-spill response capability in North America is provided by not-for-profit corporations established and funded by industry, as well as for-profit companies that contract response equipment and services. The major oil-spill response organizations (OSRO) are described in the following paragraphs.

The Marine Spill Response Corporation (MSRC) is a non-profit organization formed in 1990 that currently has more than one hundred oil company members. Equipment is staged at 80 locations around the US and Caribbean with operations coordinated from four regional response centers. Capabilities include mechanical recovery in shallow and deep water, protective booming, shoreline cleanup, and aerial dispersant application (Marine Spill Response Corporation, 2001).

Clean Gulf Associates was founded in 1972, and has 135 members who are all operators in the Gulf of Mexico. It provides boom, skimmers, and dispersant-related equipment in the event of a spill. Clean Gulf owns high-volume open-sea skimmers, fast response vessels, and portable skimming equipment. Since 1997, Clean Gulf has partnered with MSRC in which Clean Gulf owns equipment and MSRC stores, maintains, and operates this equipment in the event of a spill in the Gulf of Mexico (Clean Gulf Associates, 2002).

Alaska Clean Seas, which operates out of Prudhoe Bay, Alaska, is a non-profit formed in 1979 for the purpose of maintaining spill response equipment for companies operating in Alaska. Potential client companies include: Alyeska Pipeline Service Company, Anadarko, BP, Brooks Range Petroleum Corporation, ConocoPhillips, Eni Petroleum, ExxonMobil, FEX LP, Pioneer Natural Resources, and Shell (Alaska Clean Seas, 2010).

The National Response Corporation (NRC) is a for-profit OSRO that was founded in 1992. It has an independent contractor network of more than 144 local emergency response and cleanup companies, located in more than 538 locations nationwide that store NRC's response equipment. In the event of an emergency or training exercise, NRC serves as the central client contactor, coordinating and deploying the resources as needed (National Response Corporation, 2003).

The Marine Well Containment Company (MWCC) is a non-profit organization that is formed by Chevron, ConocoPhillips, ExxonMobil and Shell with partnerships available to other interested oil and gas offshore producers. The companies are accelerating the engineering, construction and deployment of equipment designed to improve capabilities to contain a potential future underwater blowout in the Gulf of Mexico. Other Gulf of Mexico operators are being encouraged to participate in this new organization. The system offers key supplements to the current response capabilities in that it will provide pre-engineered, constructed, tested and ready for rapid deployment equipment for well containment in the deepwater Gulf of Mexico. The system will be flexible, adaptable and responsive to a wide range of potential scenarios, deepwater depths up to 10,000 feet, weather conditions and flow rates exceeding the size and scope of the Macondo well blowout. Initial investment to construct the new subsea and modular process equipment is expected to be approximately $1 billion (Marine Well Containment Company, 2011).

D. Response Objectives and Technologies: General Conditions

The *Deepwater Horizon* incident, and Macondo well blowout, underscored the need for incident response techniques and technologies to keep pace with advances being made in deepwater exploration, drilling and production. The response techniques described below can be used regardless of a facility's location but future research and development should be focused on advancing response and recovery capabilities specific to deep ocean environments.

Oil Sensing and Tracking. Oil surveillance and tracking operations can be critical in planning spill countermeasure options. During a response, immediate deployment of resources is required to maintain, gather and relay information to responders on the location of oil. Most of the remote sensing technologies can either detect hydrocarbons directly or indirectly or are related to environmental data recorders that are needed to model and predict spill trajectories. They include, but are not limited to, satellite imagery/Doppler radar, X-band radar, high-frequency radio waves (including Coastal Ocean Dynamics Applications Radar, CODAR), forward-looking infra red cameras and side-looking airborne radar (FLIR and SLAR), optical and infrared cameras on airborne or undersea vehicles (manned or unmanned), underwater acoustics, fluorometry, stationary oil-sensing equipment (e.g., buoy mounted) and marine environmental data sensing systems used to aid in tracking released oil (Joint Industry OSPR Task Force, 2010).

There have been advances in remote sensing, tracking and trajectory modeling, but technology as a whole has been advancing slowly, especially with respect to subsea plume modeling. A methodology for subsurface remote sensing does not exist and is needed. In addition, improvements are needed in the connectivity between remote sensing data and trajectory modeling, with the goal of developing standardized protocols. Effort is needed to validate and standardize instruments to detect different sizes of oil aggregates in the water column, and to differentiate oil dispersions from other types of particles in the water. That technology will be very useful for proving the effectiveness of dispersants applied at depth as well as for use in ecological and natural resource damage assessments of baseline/impacted planktonic communities (Joint Industry OSPR Task Force, 2010)

Other obstacles are regulatory in nature. For example, the Federal Aviation Administration (FAA) continues to oppose the use of Unmanned Aerial Vehicles (UAV) during spill response operations. Industry has made numerous requests to test the UAV platform for its viability in spill responses and tracking but has been denied airspace, even in open water trials away from any airport. Generally the most effective way to direct resources in the field is by aerial observation and this potentially could be done more safely, at higher frequency, and in a more cost-effective manner with UAVs.

Dispersants. Dispersants convert surface oil slicks into tiny droplets (<100 micrometers in diameter) that mix into the water column, where oil can more easily undergo natural biodegradation. The principal ecological benefit of this dispersion is to keep oil from entering near-shore bays and estuaries, or stranding on shorelines, thereby protecting sensitive coastal habitats and the species that inhabit them. However, dispersing oil into the water column presents a trade-off; mitigating damage to the shoreline and to organisms that may encounter surface slicks means exposing organisms in the water column temporarily to elevated concentrations of dispersed oil.

Industry, government, and academia have conducted many studies evaluating the efficiency, aquatic marine toxicity, and biodegradation rates of dispersants and dispersed oil (Joint Industry OSPR Task Force, 2010). It is known that dispersants and dispersed oil rapidly biodegrade in an offshore environment. Taken together, those data and current studies suggest that concentrations acutely toxic to marine organisms are likely to persist in only a relatively small region and for a short period of time, as long as sufficient dilution can occur. Uncertainties remain regarding long-term effects on aquatic life from dispersants but it is known that dispersants are generally less toxic than the oils they break down and can increase biodegradation of the oil by 50% (EPA, 2011; OSAT, 2010). By contrast, impacts to wildlife, coastal habitats, recreation, commercial fishing, and other assets from floating oil that is not dispersed can be severe and long-lasting.

Given the benefits weighed against the risks, world-wide regulatory approval of dispersant use has continued to expand and even consideration of dispersant application closer to shore has gained a level of acceptance in some locales. Furthermore, dispersants are favored over other options like mechanical recovery for large-volume offshore spills due to the fact that dispersants allow for rapid treatment of large surface areas even in poor weather conditions whereas mechanical recovery and in situ burns are ineffective on rough seas (i.e., generally at sea states of six feet and above and winds of greater than 15 knots).

Dispersants can be mobilized and can provide the initial capability to respond to an oil spill, while other mechanical means are still being mobilized and deployed. There are also sufficient stockpiles of dispersants to respond to a major spill, and manufacturing can be quickly ramped up to meet the demands of an on-going spill.

Further study is needed to understand the effects of subsea release of dispersants in deep water ecosystems, but subsea injection of dispersants at the source is now viewed as an effective method for reducing the amount of oil that reaches the surface and using less dispersant than would be needed if the oil does reach the service (EPA, 2011). Additional efforts concerning subsea injection should involve developing a summary of how subsea injection was utilized during the *Deepwater Horizon* response including evidence of efficiency and effectiveness. Researchers should model and scale-test subsea dispersant injection to develop implementation criteria such as limits on dispersants-to-oil ratio, oil type and temperature. There also is a need to understand how oil behaves and disperses (both naturally and after application of dispersants) within the water column when released at significant depth, temperature, and pressure (Helton, 2010).

Changes to regulatory procedures also must be considered that would allow a process under emergency situations for interim EPA approval to use dispersants stockpiled by response agencies outside of the US. Those emergency provisions should include dispersants which have been approved for use in United Kingdom, France, Norway, Australia, or other countries where rigorous screening criteria have been applied to products that have demonstrated effectiveness on similar oil types.

<u>In Situ Burning</u>. In situ burning refers to the controlled burning of oil spilled from a vessel, facility, pipeline, or tank truck close to where the spill occurred. For spills on open water, the oil must be collected and contained using fire-resistant booms to provide for the necessary minimum thickness for the oil to be ignited and sustain the burn. When conducted properly, in situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment. In situ burning has been demonstrated to be effective in a deepwater blowout and in ice-covered waters.

In situ burning does not completely remove spilled oil from the environment; the burned oil is primarily converted to airborne residues (gases and large quantities of black smoke or soot) and burn residue (incomplete combustion of by-products). However, when in situ burning is properly conducted, it significantly reduces the amount of spilled oil on the water, which prevents that oil from remaining in the water or moving to and impacting coastal resources and habitats (EPA, 1999). Prior to the *Deepwater Horizon* incident, controlled in situ burning of spilled oil had occurred only one time in open U.S. waters and that was during the *Exxon Valdez* incident in 1989 (BP, 2010); however, burning of inland spills is frequently conducted by the states (EPA, 1999). Through the use of advanced methodology and new equipment, in situ burning was shown to be a fully proven technique for oil recovery during the *Deepwater Horizon* spill. More than 400 burns were conducted remediating 265,000 barrels or more than 11 million gallons of oil (BP, 2010).

In situ burning on water requires more extensive logistics than burns on land. The oil must be contained to a minimum thickness to start and maintain the fire. Fire resistant boom and vessels for towing the boom are required unless there is natural containment (e.g., in ice, trapped in debris). Spotters in aircraft usually direct the boat crews to the oil. Once the oil is contained in a safe place, an ignition source is needed. Depending on how far offshore the burn is located, support vessels may also be needed.

In situ burning can be more efficient than mechanical recovery under similar spill conditions particularly if recovery devices such as skimmers and temporary storage for skimmed oil, are not immediately available or if a spill occurs in waters where a slick may be contained by ice (EPA, 1999; National Research Council, 2003). With in situ burning, there is no need for handling and disposal of the oil. However, in situ burning has its own logistical tradeoffs to be considered, particularly, having enough fire boom available to conduct the number of burns necessary to remove all the oil that can be contained.

A second advantage of in situ burning is its relatively high removal efficiency. Studies have shown that as much as 90% to 99% of the oil volume boomed and maintained at the required thickness, can be removed by burning under normal conditions (Joint Industry OSPR Task

Force, 2010). Case studies of actual burns, in particular on land, support this high efficiency. Burning in the early phase of the spill removes most of the oil before it can cause further damage on the water or on land.

A third advantage is that burning reduces the amount of oily wastes for collection and disposal. This factor can have significant weight in the decision to conduct an in situ burn in remote or difficult-to-access areas. Limited access might make mechanical or manual recovery impractical (or even harmful to the environment) to implement. Thus, in situ burning provides an option for oil removal where traditional response countermeasures are impossible to implement or would cause environmental damage (as with spills on ice or near marshlands). When a situation presents ideal conditions, in situ burning can significantly reduce the environmental impact of the spill as well as the spill response (Barnea, 2002).

Levels of concern for public health associated with burning spilled oil in situ should be assessed in the context of the effect of oil spills in general and the risk the spill poses to people and the environment. The impact of a temporary reduction in air quality from particulates due to burning should be weighed against the impact of an untreated spill on the environment. A large percentage (20%-50%) of the spilled oil may evaporate and cause a temporary reduction in air quality from volatile organic compounds. In other words, whether the oil is burned or allowed to evaporate, air quality will be compromised. The general public can be protected by minimizing exposure and conducting the burn only when conditions are favorable and exposure to particulates from the burn is below the National Response Team's recommended level of concern for the general public of 150 micrograms of particulates per one cubic meter of air, over a one hour period (National Response Team, 1998). In general, burn residues are less toxic than the original oil and contain less of the more toxic, volatile organic hydrocarbons.

Localized smothering of benthic habitats and fouling of fishing gear may be the most significant concern when semi-solid or semi-liquid residues sink after burning. These residues, whether they float or sink, can be ingested by fish, birds, mammals, and other organisms, and may also be a source for fouling of gills, feathers, fur, or baleen. However, these impacts would be expected to be much less severe than those manifested through exposure to a large, uncontained oil spill (Joint Industry OSPR Task Force, 2010).

Even the most efficient burning will leave a taffy-like residue that must be collected and treated or sent to a waste treatment facility. However, burning the oil at sea will minimize the overall waste generated by a spill because there will be less solid and liquid wastes generated by beach cleanup and less energy will be needed in support of the response operations.

Improvement in the ability of fire boom to contain and concentrate oil in an effective manner in higher sea states and at a higher advancing speed would significantly assist the efficiency of in situ burning operations. Improvements in remote sensing and mechanical recovery technology would allow responders to locate the thickest patches of oil and improve oil encounter rates, as well as to herd oil more effectively to enhance in situ burning.

The effectiveness of in situ burning on open water is complicated by two logistical factors. First, fire boom might not be pre-deployed in the needed location, and cross-response region movement of boom is constrained by existing regulations. The regulations developed to implement OPA 90 focused on port staging areas, identifying "High Volume Ports" by name and specifying requirements for OSROs that serve plan holders in High Volume Ports. That scheme did not address spill response requirements for offshore exploration and production of oil and natural gas because BOEMRE oversaw such operations.

Second, complications and delays in obtaining approvals derive from the fact that under federal law, and a number of state laws, in situ burning is considered an 'alternative' response technology. Time is consumed in the decision process for proposals to burn offshore concentrations of oil that adversely affect deployment and logistical schedules, and can lead to misses in opportunities for weather and/or sea-state windows that are optimum for burning operations. A pre-approval process or an expedited approval process for in situ burning is necessary to remove procedural obstacles to in situ burning that compromises the rapidity and efficiency of an integrated response effort.

Pre-approvals for in situ burning of oil spills have been widely adopted in RCPs and ACPs across the US. However, the exact details of where one can burn with pre-approval remain a patchwork due in large part to varying state and local requirements. In situ burning should be considered a suitable and advanced spill response technology, instead of an alternative response method that can or should only be considered as a supplement to mechanical recovery.

Given the responsibilities of individual state governments to their constituents, it is unlikely that a single uniform set of in situ burn policies and procedures can be adopted nationwide. Therefore, the focus for improved utilization of in situ burning as a response practice should focus on ensuring an efficient pre-approval and rapid case-by-case approval process through the regional response teams and the states. That expedited pathway should include development and adoption of a common form for in situ burning pre-approvals in conjunction with USCG, EPA, NOAA and industry (Joint Industry OSPAR Task Force, 2010).

<u>Mechanical Recovery</u>. Mechanical recovery of oil spills has been the primary response tool in the NCP for more than forty years. The basic premise involves containing the oil with boom, and/or recovering it with a skimming device or sorbent material, storing the recovered oil on board the skimming vessel, and then disposing or recycling the recovered material. Environmental constraints on mechanical recovery techniques include poor weather, high winds, heavy sea conditions, and fast currents. Historically, mechanical recovery has not been an efficient response method in the open ocean.

A key parameter for mechanical recovery to be effective and efficient is the encounter rate: the amount of oil which comes into contact with the skimmers over a given time period. Encounter rate is negatively impacted through oil rapidly spreading on the water's surface under the effects of gravity, surface tension, current movement, and wind. Spilled oil will quickly spread out over the water surface to a thickness of about one millimeter. As a reference point, visible oil sheen is only 0.003 millimeters thick, and a cup of spilled oil can create a visible sheen over an area the size of a football field (Joint Industry OSPR Task Force, 2010). Additionally, it does not take long for wind to further reduce the encounter rate by moving spilled oil into fragmented fingers or windrows of oil on the surface. As oil rapidly spreads and reduces in layer thickness and breaks into patches or windrows, the encounter rate and recovery efficiency of skimmers is greatly reduced.

All oil boom is constrained by the laws of hydrodynamics and physics and will entrain oil beneath the boom if subjected to a current greater than about 0.75 knots. Oil can also splash over the boom in higher sea states.

Considerable advancements have been made on skimmer technology, sorbents, inflatable ocean boom, improved coordination and control of offshore assets (radar/aerial observation techniques/communications), and research and continued development of fire boom. Enhanced recovery rates have been achieved for oleophilic (oil-attracting) discs and drum skimmers by coating the rotating surfaces with a fuzzy fabric material or by adding grooves to skimmers to increase surface area (Joint Industry OSPR Task Force, 2010). Other variables include:

- <u>Skimmer types</u>. There are currently four main types of skimmers that have been used to recover oil at sea: oleophilic, weir, vacuum, and mechanical. Oleophilic systems rely on the property of oil adhering to a drum, belt, brush, disc or mop type arrangement. The oil is then scraped off into a chamber from where it is pumped to storage. Oleophilic skimmers are the most used type of mechanical oil spill response equipment (Broje and Keller, 2006). Weir skimmers rely on oil passing over a weir arrangement that is used to separate the oil and water phases. The units are less efficient than their oleophilic counterparts and often the recovered liquid has more water than oil. For this reason, they require large storage capacity. Vacuum skimmers units rely on the use of vacuum or air movement technology to lift oil from the surface of the sea or the shore. Vacuum systems are versatile and can be used on a variety of oil types although refined volatile products must be avoided for safety reasons. Mechanical skimmer systems rely on the physical collection of oil from the surface and include devices from conveyor belts to actual grab buckets. These types of skimmers are more suited to very viscous oils.

- <u>Storage</u>. A major limiting factor in effective containment and recovery operations is the availability of waste oil storage on the skimming vessel. Gaining permission to pump water that has been separated from the recovered oil is critical to extending the operating capability of the system. The nature of the recovered product is also an important factor as heavy oils will be difficult to handle. Specialized pumps may be required and storage tanks may require heating coils to remove the recovered product.

More consistency is needed among standards for USCG, EPA, BOEMRE, and state regulations with respect to mechanical recovery requirements. Continuing advancements are needed to enable boom systems to be used in current speeds in excess of 0.7 knots perpendicular to the boom, which could improve encounter rate, reliability, and sustainability. Industry should investigate the effectiveness of large-volume skimming vessels in response scenarios. Efforts should be made to identify a suitable training program for various skimming systems (Joint Industry OSPR Task Force, 2010).

Improvements in technology used in other parts of the world (particularly Japan and Norway) should be considered, including at-sea oil containment and recovery systems, and work done on pumping systems in the Joint Viscous Oil Pumping System Workshop (Joint Industry OSPR Task Force, 2010). The results of a technology challenge by the Norwegian oil industry during the 2008 International Oil Spill Conference should be reviewed as it represents the latest in industry research and development on recovery systems and operations enhancements.

Shoreline Protection and Cleanup. Once an oil spill has occurred, every attempt should be made to contain it immediately and prevent it from spreading, particularly from reaching the shore. Keeping the spill offshore generally will reduce environmental impacts, duration of cleanup operations and generated wastes. The tools described in the above sections are all methods to prevent oil from affecting sensitive shorelines and near-shore areas. Although those tools are a first line of defense to mitigate oil impacts on shorelines, there are misconceptions related to their effectiveness in near-shore applications. For example, it is not feasible or effective to completely boom a shoreline. Initial deployment of boom may often be difficult, but maintaining boom where it is deployed is sometimes even more difficult.

There are also misconceptions and knowledge gaps regarding dispersants that can lead to unnecessary restrictions on dispersant use and consequently more oil impacting shorelines and sensitive coastal habitats. Dispersants can reduce impacts by lowering the adhesive properties of oil. Reviewing barriers to dispersant use, developing improved communications, and working with the government to streamline approval processes should be undertaken. Addressing trade-offs is essential (i.e., short-term water column impacts vs. shoreline oiling) for considerations of human health and safety and the merits of applying dispersants in non-turbulent (calm) seas, on surface emulsions, and in near-shore environments.

If the offshore-focused tools should fail to prevent oil from reaching shore, then methods to divert slicks from a more sensitive area to a less sensitive area should be employed. Response strategies have been developed for various shoreline types based on their specific characteristics. The primary consideration is to select the appropriate technique to recover oil while minimizing the impact of treatment operations.

E. Response Objectives and Technologies: Arctic Conditions

Oil-spill response options in Arctic environments will vary depending on seasonal oceanographic and meteorological conditions. Each season presents different advantages and drawbacks for spill response. Oil-spill response strategies and tactics for cold climates must be designed to deal with a mix of open water and ice conditions that could occur throughout any portion of the operating period. Crude oil and oil products will also behave different in cold water environments due to the physical and chemical properties of the oil spilled. Those properties influence the selection of response equipment and methods applicable for spill cleanup (MMS, 2009).

Knowledge of the ultimate fate and behavior of oil will drive countermeasure decisions. The physical distribution and condition of spilled oil under, within or on top of the ice are significant factors in determining the most effective response strategies at different stages in the ice growth and decay cycle. Therefore, it is important to understand the chemistry and physical behavior of the oil and how its characteristics change over time to utilize the best response options. Proper planning and response would generally include:

- A thorough understanding of oil and ice interactions under different spill scenarios.
- An operations and curtailment plan with strict procedures to accurately monitor weather and hazardous conditions.
- The availability of rugged equipment designed to operate in cold and icy environments that can be activated immediately and continue to operate for extended periods in open water and broken ice conditions.
- The training and experience of response personnel to work safely and effectively under harsh conditions.
- A comprehensive assessment of all applicable response tools that are proven to be reliable in ice and extreme cold climates.
- The identification and preparation of specific response strategies and tactics that could be implemented safely and effectively under a broad range of conditions including: drifting floes at break-up, open water, summer ice incursions, new ice at freeze-up, consolidated fast ice and very close pack ice in winter.
- Strong relationships with government agencies and oil spill response organizations including alignment of contingency plans and strategies. Engagements with stakeholders, including communities, are an important part of this process.

Coping with the dynamic nature and unpredictability of ice can present a challenge for spill response. However, research and response experiences in sub-arctic and Arctic areas have shown that low temperatures and ice can also enhance spill response and reduce environmental impacts under certain conditions (MMS, 2009). Deliberate ice management can also be used in some situations, for example, to extend the window or operation for booms and skimmers (ice deflection), and to release/expose trapped oil for burning.

<u>Oil Sensing and Tracking Under Freezing Conditions</u>. The tracking of spilled oil during the open water period in cold water environments is similar to that in warm waters but it is enhanced by the extended periods of daylight in the Arctic summer. Tracking can be aided with FLIR systems, Synthetic Aperture Radar (SAR), SLAR, Global Positioning System (GPS), and marine radars. Tracking buoys and various types of radar reflectors can also be launched from vessels on location at the beginning of a spill and at appropriate intervals thereafter to help track the oil in both open water and ice.

Although oil spills in ice-covered waters are generally contained within a much smaller area (compared with open water spills), the presence of ice in conjunction with limited daylight complicates initial detection, mapping and subsequent monitoring and tracking of the oil

(Dickens and Andersen, 2009). The ability to reliably detect and map oil trapped in, under, on, or among ice is critical to mounting an effective response in Arctic waters. Within certain limitations, ground penetrating radar (GPR) has been found to be an operational tool that can detect oil in a wide range of ice conditions (MMS, 2009).

Conditions of high ice concentrations, slush and brash in the water at freeze-up, and situations where the oil is trapped beneath floes present greater challenges. Tracking the likely location and general drift of oil ice is possible by using specialized ice-strengthened GPS buoys proven through many decades of experience over the winter season throughout the polar basin.

<u>Dispersants in Cold Water/Broken Ice Environments</u>. Dispersants are used in many parts of the world as a primary response strategy and to compliment other techniques. Dispersants provide an invaluable response option when strong winds and high sea states make mechanical cleanup and in situ burn techniques unsafe and/or ineffective. The application of dispersants is recognized worldwide as an environmentally acceptable and highly efficient means of rapidly eliminating spilled oil offshore under the right conditions.

Dispersants can be effective in broken ice if there is some mixing energy present. The presence of broken ice does indeed dampen wave energy in a broad sense, but at the “micro” level, energy may in fact be amplified by the reflection of waves among ice floes and brash ice. The pumping action of waves in brash ice and between ice floes can actually stimulate dispersant action. Vessels can be used to provide added energy by moving through and churning the surface ice and water (MMS, 2009).

<u>In Situ Burning Under Arctic Conditions</u>. Burning as a response tool for oil spills in broken ice has been researched since the early 1980s using both tank tests and medium to large-sized experimental spills. Many scientists and responders believe this technique is among the best option for oil spill response in the Arctic, especially with a high degree of ice coverage (MMS, 2009).

The burning of spilled oil in broken ice is quite feasible under most conditions in the Arctic since there is little concern that the burning oil might move and threaten any offshore or shoreline activities. Also the immediate impacts on air quality are less of a concern than in more populated regions. In situ burning can be conducted using the ice as a natural boom or with the use of fire-resistant boom to contain and thicken the oil. Burning requires the use of ignition devices and possibly sorbent material to remove any burn residue. Burn efficiencies vary and are based on the amount and type of oil spilled, and the meteorological and oceanographic conditions. Individual burn efficiencies between 55% and 98% have been achieved in cold water and broken ice (MMS, 2009).

If oil has solidified, burning should be applicable as long as the conditions are appropriate. Burning is a preferred technique for dealing with spills on ice and snow-covered surfaces (MMS, 2009). If the release is under the ice, equipment such as ice augers, pumps, and ice-breaking vessels can be used to expose the oil, which can then be burned. Burning is also a sound approach for oil that rises through brine channels into melt pools in the ice during spring thaw.

The performance of fire-resistant booms has improved. Containing and burning the oil in place has been developed into a viable response technique with special emphasis on the development of stronger, reusable fire-resistant containment boom as well as improved in situ burn protocols and methodologies. Advanced boom designs, such as the stainless-steel boom pocket and water-cooled booms may permit extended burn operations.

Mechanical Containment and Recovery in Ice Environments. The use of mechanical containment and recovery of spilled oil is often the primary response option used. In cold regions, mechanical recovery strategies are based upon the deployment of large ice-strengthened vessels and barges, carrying high-volume skimmers, and the use of containment booms. In ice-infested waters, an additional challenge for oil skimmers is their ability to process ice, meaning the skimmer should be able to deflect smaller floes and slush ice in order to have access to the oil. Oil spreads less and remains concentrated in greater thicknesses in broken ice than in ice-free waters. However, as the amount of broken ice in the water increases the efficiency of conventional mechanical recovery systems is reduced (MMS, 2009).

At some point ice cover would become too extensive for mechanical recovery of oil to continue. For high ice concentrations, most of the spilled oil (especially from a subsea blowout) will become immobilized and encapsulated within the ice. This oil is then effectively isolated from any direct contact with biological resources (marine or bird life) until the ice melts. Oil encapsulated within the ice is also isolated from any weathering processes (evaporation, dispersion, and emulsification). The fresh condition of the oil when exposed (e.g., through ice management or natural melt processes) enhances the potential for in situ burning.

Shoreline Protection and Cleanup in Cold Regions. Shoreline types vary in cold regions but they are not as diverse as in warmer regions. Shorelines with high energy and/or frequent ice coverage tend to have low biological diversity and abundance. Biological activity is highest on low energy shorelines and protected pockets occurring in rocky shorelines (MMS, 2009). In most instances, the presence of ice onshore or in the adjacent near-shore water prevents oil from contacting the shoreline substrate. For the majority of those shorelines, natural recovery is the preferred cleanup option, except for pockets of very thick heavier oil.

In situ treatment techniques, such as sediment relocation or mixing, may be preferred in remote areas where treatment is considered necessary and where the risk of remobilized oil affecting biological resources is low. Those treatment options minimize waste generation and have been shown to be effective in the acceleration of weathering and, in particular, biodegradation (EPA, 1999).

FIRE CONTROL

A. Overview

In the context of well control, fire control focuses on preparedness to prevent, contain, eliminate or suppress fires that might erupt in the aftermath of an uncontrolled release of oil or gas. Fire control will be most effective when it is fully integrated into planning for blowout prevention, spill prevention and spill response (Abel et al., 1994; Flak and Matthews, 1994).

Fire-control techniques generally are represented in a simplified flow diagram such as:

Prevention (Failure) □ Loss of containment ► Flammable Atmosphere ► Fire ►Control

Offshore Fire Prevention and Control evolved from the onshore oil and gas production and refining businesses Fire control in offshore developments recognizes several different historical beginnings:

- US offshore Louisiana south coast / California early 1900s.
- US Gulf of Mexico offshore in 1947 (out of sight of land).
- Caspian Sea (Eurasia) offshore in mid 1800s.
- Lake Maracaibo (Venezuela) early 1900s.

Therefore, fire control as a discipline dates to the earliest days of offshore operations in multiple, worldwide locations.

The general body of knowledge of offshore fire control can be found in the conference proceedings edited by BHR (1991) although improvements in techniques are ongoing and recommended practices have been formalized for many years (for example, API RP14G, 2007).

B. Management of Fire-Control Factors

Prevention of Release. Prevention of release is based on design and operation of production hydrocarbon systems in a manner which minimizes the likelihood of containment failure by ensuring hydrocarbon system integrity. Hydrocarbon piping systems (as are most other piping systems) are designed according to nationally recognized American National Standards Institute (ANSI) codes including:

ANSI 31.3 – Chemical Plant and Petroleum Refinery Piping

ANSI 31.4 – Gas Transmission and Distribution Systems

ANSI 31.8 – Liquid Transportation Systems for Hydrocarbons

Those ANSI codes provide the requirements for pressure containment calculations, corrosion allowances, pipe material manufacturing requirements, construction quality control and pressure containment quality testing minimum standards.

Similar for pressure vessels is the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Section 8) which provide the requirements for pressure containment calculations, corrosion allowances, pipe material manufacturing requirements, construction quality control and pressure containment quality testing minimum standards.

Specialty equipment such as well heads, drilling equipment, heat exchangers, boilers, valves, also have industry specific codes and standards which provide minimum requirements for design, construction and testing of the specialty equipment.

Operating a hydrocarbon system to minimize the risk of release requires a program that includes:

- Operating personnel competency (appropriate to their work responsibilities).
- Management oversight, control and decision processes.
- Hydrocarbon systems inspection and maintenance processes.

Minimization of Release Volumes. Minimization of volumes released after a release event occurs is achieved by a range of techniques that can be summarized as normal production controls and Emergency Shutdown (ESD) systems.

Normal production controls are those basic process controls and equipment which monitor and control the flow regimes (pressure, temperature, volume and composition) of a hydrocarbon production system. Those basic controls manipulate the hydrocarbon systems by adjusting the flow regime to achieve an economical, efficient and safe hydrocarbon processing environment. Inherent in the basic controls are selected limits which are intended to prevent the hydrocarbon system from experiencing flow regimes outside of the designed safety operating envelope. Exceeding the safety operating envelope greatly increases the likelihood of compromising the hydrocarbon systems integrity, resulting in a release event.

Normal production controls assist in minimizing event release volumes by detecting unsafe operating conditions (i.e., high pressure, low pressure, high flow, low flow), shutting designated valves and isolating various portions of the process system from each other. The isolation of portions of the hydrocarbon system minimizes the amount of hydrocarbon available to feed a potential release event, thereby greatly reducing the range of potential consequences.

ESDs are additional dedicated process controls and equipment which are generally separate from the normal production controls and have the dedicated functions of detecting critical unsafe operating conditions and shutting down (closing valves, stopping pumps and generators) the affected portion of the production system. ESDs generally consist of 2-4 levels of shut-down based upon the process system complexity and amount of manual operating interface selected for the specific development. The highest level of ESD usually results in a near total shutdown of the associated facility leaving only the basic critical lifesavings systems operational.

ESD systems also cascade down to the normal production controls where appropriate, to make use of existing equipment to enable adequate isolation and shutdown.

In addition to ESD systems, pressurized hydrocarbon production systems may include depressuring systems to allow manual or automatic depressuring (venting) of hydrocarbon inventory, down to a low internal system pressure, to a safety disposal location (usually a flare).

Depressuring systems are different from basic overpressure protection afforded through the use of pressure safety valves (PSVs) as PSVs only relieve excess pressure, above their set points, such that the hydrocarbon system still contains its designed inventory.

Flammable Atmosphere & Fire Dynamics. Petroleum is a mixture of many flammable and combustible hydrocarbon compounds and in initial production condition may contain a large proportion of natural gas constituents dissolved in the liquid. That comprises a liquid (under pressure) which could include methane, propane, natural gasoline, natural diesel oil and heavier oils through asphalt and tar.

The general fire hazard properties of those hydrocarbon mixtures include:

Ignition Temperature (Liquid Hydrocarbons):	~ 100º C to 260º C
Flammable limits in air:	1.1 % to ~ 10 % by volume

Combustion of hydrocarbons occurs when hydrocarbon vapor is mixed with air (oxygen) in appropriate concentrations within the flammable limits and an ignition source of sufficient energy is present. Hydrocarbon liquids do not burn directly but must become a vapor to allow mixing with air. Heavier hydrocarbons (liquids at normal temperature and atmospheric pressure) must be heated enough to vaporize and support combustion.

Once ignition occurs at a specific location, the combustion zone expands until the flammable mixture limits are exceeded. Complicating the simple basics of combustion, the physical evolution of a fuel-air mixture also impacts the dynamics of hydrocarbon fires; however convention simplifies the range of possibilities through categorizing fires either as pool fires or jet fires. Pool fires are simply liquids providing a surface area which emits flammable vapors; however they can range from simple ground spills to complex three-dimensional flowing liquid events. Jet fires are the result of a pressurized release where the hydrocarbon is flowing at a relatively high velocity projecting the hydrocarbon stream outwards and providing turbulence to enhance flammable vapor generation and mixing with air.

The nature of fire dynamics provides direction on the types of techniques and strategies applicable to control and extinguish hydrocarbon fires.

B. Strategic Decisions

Fire control incorporates the efforts to control a hydrocarbon fire event (reduce size and force of ongoing impacts) and eventually to extinguish the fire. Fire control encompasses both strategic and tactical aspects of emergency management, which must work in harmony to achieve safe, efficient control of a hydrocarbon release event. The fundamental strategic aspects of hydrocarbon fire control require a cogent plan for each of several decision points:

- Should the fire be extinguished (early) or allowed to burn out? The initial reaction by most people including emergency responders is that any uncontrolled fire should mean mobilization of all available resources so the fire can be immediately extinguished. In reality, each event requires individual assessment, with strategic decision-making through the National Incident Management System (NIMS), for very significant events, or an individual company's Incident Command System (ICS) for events which do not trigger NIMS.

  The answer to this key question is dependent upon a balanced assessment of case-by-case key factors; these key factors are explored further below.

- Is there is life safety risk or a property (asset) risk or both? This is a fundamental moral issue and the sanctity of human life drives the desire to save personnel when they are in danger, hence a major fire event where personnel are still at risk demands fire control measures sufficient to facilitate rescue of personnel.

  The confirmation that personnel are now safe or no personnel are at risk (within the event) shifts the need for fire control to an asset protection (loss of property) consideration. As a business owner or operator, the asset is fundamental to continuing the business venture, however the risks to fire control personnel and the cost of fire control weighted against the monetary damage from loss of the asset needs careful evaluation. Decisions can be required very quickly as hydrocarbon fire events are dynamic and decision delays of several minutes to an hour will be superseded by the actual event progression.

  Industrial experience with hydrocarbon fires has resulted in owners pre-determining a general philosophy and providing authority to on-scene incident commanders to make necessary decisions without recourse.

- Environmental impact differences of early extinguishment versus burn out. The environmental impact trade-off between potential air pollution versus potential water pollution is a delicate decision which does not appear to have a solid basis for decision guidance. Rather, it tends to be emotionally driven by political and public image and perception and not a well-founded pre-assessment of the range of potential environmental impacts associated with one decision versus the other.

  An opportunity exists for a series of studies of environmental trade-offs between potential air and potential water pollution based on a range of fire-management strategies, such that those studies provide clear comprehensive guidance to incident command organizations, allowing them to further improve on-scene decision-making for a better overall event outcome.

- Is it even practical to extinguish early (before inventory is exhausted)? Regardless of the desire to control a major offshore hydrocarbon fire event, the realistic practical capability of achieving early fire extinguishment, or even some level of control, is assessed by on-scene commanders. The challenge for on-scene commanders is to develop a pragmatic assessment based on facts including actual logistics in place, resources available, environmental (weather) forecasts in relation to the size and physical nature of the fire and its fuel sources.

  In the context of offshore oil and gas operations, fuel being released from specific production equipment may have limited inventory and actually consume most of the hydrocarbon in a few minutes to a few hours time, thereby minimizing the duration of the event. Fuel originating from well bores, however, presents potentially extended flow duration from days to years and can prove more technically challenging to extinguish.

- Escalation potential. Escalation is the effect of an initial fire event causing damage to neighboring hydrocarbon equipment resulting in the release of additional hydrocarbons, thus expanding the size, duration, complexity and potential damage beyond the initial event. Escalation can occur in both production system events and events where multiple wellbores are in close proximity. Evaluating the potential for escalation impacts the decisions on level of response, proximity of responders to the fire scene and the need for increased resources to execute an effective fire control response.

C. Tactical Decisions

Tactical aspects of fire control relate to the equipment and techniques deployed to achieve the agreed strategy. Tactical response is focused on use of one or more of the technologies described below.

- Direct Fire Control

Cooling is simply the removal of heat from a fire event and traditionally is based on the application of water as water is an effective, inexpensive medium, usually available (especially offshore) and easy to collect or manage.

For example, a 100 gallon per minute of water converted to steam (by absorbing heat) will absorb the heat generated by combustion of ~ 6.3 gallons per minute of a liquid hydrocarbon.

Water application has been and still is the mainstay fire control material in world-wide use for normal combustible and hydrocarbon-fueled fires. Application rates and techniques have evolved since the first use of water in the Roman era. Continued research, development and testing of application methods and techniques have resulted in a wide range of fire control and extinguishment capabilities, each with specific uses and constraints. Control of large hydrocarbon fires requires large volumes of water applied in specific methods to be effective. Those methods are well known within the current emergency response practices world.

Chemical chain-reaction control operates by interrupting the chemical sequence needed to sustain a fire. In the 1950s, the traditional fire triangle (Fuel-Heat-Air) was beginning to be replaced by a 4-sided polygon where the sides of Fuel, Heat and Air were recognized as requiring a chemical reaction to produce and sustain actual fire. That recognition opened a new world of fire control, based upon the concept of extinguishing fire by interrupting this chemical chain reaction. The chain-reaction control concept, along with continued research, resulted in the development of a range of extinguishing agents including:

Dry Chemicals such as:

- Sodium Bicarbonate
- Potassium Bicarbonate
- Monoammonium Phosphate
- Potassium Chloride
- Carbamic (potassium bicarbonate and urea reaction)

Liquid / Gaseous chemicals such as:

- Halon 1211 (nearly phased out of use)
- Halon 1301 (nearly phased out of use)
- Carbon tetrachloride (obsolete and banned)
- FM 200

Those chemical agents are highly effective in extinguishment, especially for enclosed areas and "smaller" fire events, including hydrocarbon-based fire events. They have been considered for very large hydrocarbon fires however the practical logistics and post-extinguishment risk of "re-flash" of hydrocarbon vapors limits those chemicals to very specific case-by-case applications.

- Air Exclusion

This technique is based on the concept of removing or displacing the oxygen needed to support combustion, thereby extinguishing the actual fire. This technique is achieved by two types of materials generically categorized as:

Gaseous agents such as:

- Carbon Dioxide (CO_2)
- Inergen™ (a blend of CO_2, N_2 and Ar)

Water additive foaming agents such as:

- Chemical Foam (Obsolete)
- Mechanical Foam
  - Protein based
  - Fluoroprotein type
- Synthetic Detergent type (not valid for hydrocarbon fires)
- Aqueous Film Forming Foam (AFFF) Type

The gaseous agents are quite effective when used within their intended limitations of closed spaces and effective concentrations. Water additive foaming agents are also quite effective when applied within their individual application rates and conditions. Some foam agents have limited effectiveness on hydrocarbons, others have highly effective quick fire control and still others have a post extinguishment persistence to minimize vapor re-flash hazards. Foams are applicable for pool fires which are contained in a known surface area and, to a very limited degree, foams can be used on flowing hydrocarbon spills such as in drainage troughs. Foam-type agents are recognized for offshore use in smaller facility hydrocarbon spills; however they are not appropriate for open water pool fires due to break-up of the foam blanket by water motion. Foams likewise have limited applicability in very large fire events where the logistics of mixing and applying sufficient foam are not practical.

- Fuel isolation

Fuel isolation after a fire event has initiated is focused on shutting in or blocking the continued feed of fuel to the fire event, thereby eliminating fuel supply to the event. Fuel isolation can be achieved by pre-installed isolation valving as part of facilities ESD systems, both automatic and manual, or though manual intervention techniques using existing operational isolation valves in the hydrocarbon piping system. The design, operation, maintenance and testing requirements of the subject equipment are provided in a range of industry and regulatory documents.

D. Decisions Based Upon Resource Type and Location

Offshore fire control efforts are selected and implemented upon consideration of the strategic and tactical aspects as discussed above. Several key variations associated with an offshore fire event preclude or direct the appropriate range of response, as discussed below.

- Natural Gas Only

Natural gas releases provide only a vapor-based fuel eliminating the potential of hydrocarbons pooling on the water surface. Although gas-feed fires can be extinguished with dry chemicals, this is not normally a recommended practice as the risk of a re-ignition is significant and therefore the hazard is very high for personnel as well as asset damages... Selected well blowout specialist companies will use this technique only after extensive pre-planning, extra risk mitigation efforts and elimination of safer fire-control techniques. Water is used extensively to reduce heat exposure to surrounding areas and exposures but foam is not applicable in any manner as it is immediately destroyed or disrupted by the velocity of gas flow.

- Gas + Condensate / Oil

Combination gas and oil events include the challenges of gas-only releases and include the formation of liquid pools which provide for a larger surface area of fire to be controlled. Until the gas flow can be stopped, significant fire control is very unlikely hence the importance of prevention and the ability to block fuel flow. As with gas-only fires, dry chemical agents have very limited application however water is used extensively to reduce heat exposure to surrounding areas. Foam is not applicable for the gas portion of the event although for contained pool fires foam is very effective for extinguishment. It must be recognized that if foam is being utilized, water application will necessarily be limited and only directed to non- pool areas -- otherwise the water will disrupt and breakdown the foam blanket quickly. When a pool fire is not contained to prevent flowing or spreading, foam application is not considered a worthwhile endeavor.

- Oil / Condensate Only

Oil (liquid)-only events will benefit from the importance of prevention and the ability to block fuel flow. As with gas-only fires, dry chemical agents have limited application however water is used extensively to reduce heat exposure to surrounding areas. Contained pool fires, if not excessively large in area, can be effectively controlled with foam which is very effective for extinguishment. If foam is being utilized, water application will necessarily be limited and only directed to non-pool areas so that the water will not disrupt and breakdown the foam blanket. When a pool fire is not contained to prevent flowing or spreading, foam application is not considered a worthwhile endeavor.

E. Decisions Based Upon Facility Type and Crew Status

Manned facilities suggest personnel have been present and may still be on the facility and at risk. This dictates consideration of fire control to enable search and rescue efforts until all personnel are accounted for. Effective personnel accounting and tracking methods assist this by quickly confirming if any personnel are unaccounted for (presumed missing). Normally unmanned facilities affect the fire-control strategy by eliminating the personnel rescue needs and fire control is then conducted in a manner appropriate for environmental and/or asset damage minimization.

Unlike traditional offshore fixed facilities, which are permanently connected to the sea bed on towers (called jackets), floating (FPSO/ tension leg) facilities require buoyancy and some form of station-keeping so they can maintain the required position in the ocean. Hydrocarbon fire events on floating facilities present different challenges as fire damage can disconnect the facility from its station-keeping system through loss of anchor lines or loss of electronic positioning equipment. Loss of buoyancy is a possible concern as damage to the buoyancy systems directly or loss of ballast pumping will lead to sinking of the facility. Loss of a floating facility tends to escalate hydrocarbon events if sufficient isolation is not provided, leading to increased duration and magnitude of a fire event. As part of the overall fire control process the prevention of initial release and mitigation of hydrocarbon releases due to escalation are more important for floating type facilities. Those protective measures are generally described in industry, regulatory and marine classification standards and regulations.

FINDINGS

Offshore blowout prevention has been the subject of many studies. Particular opportunities exist for research and development related to pre-event detection of indicators and to detect potential environmental impacts due to a blow out.

Improvements are needed in predictive capabilities of drilling abnormalities.

A gap exists in technologies and practices for the detection of potential environmental impacts due to a subsea well blowout. Specific topics in blowout prevention that need focused, development attention include:

- Multiple control systems to detect undesired events and to deploy last-resort BOP systems.

- Increased ROV capabilities, including untethered operations.

Response capabilities for oil-spill cleanup largely reside within a specialized-services support industry that includes some not-for-profit organizations. Although such organizations are known to, and often are employed by, oil and gas development companies, expertise on spill remediation tends to be separate from expertise on hydrocarbon resource development.

Oil-spill response (OSR) includes multiple methods/tools such as: (1) oil sensing & tracking; (2) dispersants; (3) in-situ burning; (4) mechanical recovery; and (5) shoreline protection and cleanup. All of those methods/tools must be properly developed, available, and pre-approved to effectively respond to a large event.

OSR should have access to a broad range of response options that provide the greatest flexibility in being able to deal with rapidly changing offshore environments. Because developments in Arctic regions are expected to grow in importance, improvements would include:

- A detailed analysis of technology advances and research needs related to oil spills in the Arctic.

- A best practices guidance document on oil spill preparedness and response in the Arctic.

Fire control is addressed most effectively as an integrated part of blowout prevention. Once a fire has started, additional complicated decisions become necessary. Opportunities for progress in fire control include:

- Studies of environmental trade-offs between potential air and potential water pollution based on a range of fire-management strategies, thereby providing for improved on-scene decision-making for a better overall event outcome.

REFERENCES

Abel, L.W., Bowden, J.R. Sr. and Campbell, P.J. (1994) *Firefighting and Blowout Control,* Wild Well Control, Spring, Texas, 380 p., ISBN 0-9640030-9-0.

Alaska Clean Seas (2010). Alaska Clean Seas, North Slope Spill Response. Alaska Clean Seas. http://www.alaskacleanseas.org

API RP14G (2007). Recommended Practice for Fire Prevention and Control on Fixed Open-type Offshore Production Platforms, 4th Ed., American Petroleum Institute, April 1, 2007, 38 p. http://documents.api.org/rrserver/browser?title=/14G_e4

Anderson, G., Bourgoyne, D., Burnett, D., Dokken, Q., Grigoriadis, K.M., Grossweiler, P., Haut, R.C., Holley, T., Martin, P., Overton, E., Shafter, D., Williams, T., and Yoskowitz, D.W. (2010, August 19) Research and Technology for Deepwater Development: Addressing Accident Prevention, Response & Environmental Impact Assessment. The Research Partnership to Secure Energy for America. http://www.rpsea.org/attachments/contentmanagers/3328/HARCWhitePaper.pdf

Barnea, N. (2002). Health and Safety Aspects of In-situ Burning of Oil. National Oceanic and Atmospheric Administration, US Department of Commerce, January 14, 2002, 9 p. http://response.restoration.noaa.gov/book_shelf/655_health.pdf

BHR (1991). *Management and Engineering of Fire Safety and Loss Prevention: Onshore and Offshore,* edited by BHR Group Ltd., Elsevier Applied Science, London, 295 p. http://www.scribd.com/doc/48015684/Management-and-Engineering-of-Fire-Safety-and-Loss-Prevention-Onshore-and-Offshore

BP (2010). Deepwater Horizon Containment and Response: Harnessing Capabilities and Lessons Learned. Report to the Bureau of Ocean Energy Management, Regulation and Enforcement. British Petroleum PLC, September 1, 2010, 84 p. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/incident_response/STAGING/local_assets/downloads_pdfs/Deepwater_Horizon_Containment_Response.pdf

BPC (2010). BPC Response to Oil Spill Commission, Bipartisan Policy Center, August 25, 2010, 21 p. http://www.bipartisanpolicy.org/sites/default/files/BPC%20Response%20to%20Oil%20Spill%20Commission_0.pdf

BOEMRE (2010a) Report on the progress of the Joint Industry Task Forces. Bureau of Ocean Energy Management, Regulation and Enforcement, US Department of Interior, September 7, 2010, 26 p. http://www.boemre.gov/forums/documents/Final_BOEM_Houston_Sept_7.pdf

BOEMRE (2010b) National Notice to Lessees and Operations (NTL) of Federal Oil and Gas Leases, Outer Continental Shelf - Statement of Compliance with Applicable Regulations and Evaluation of Information Demonstrating Adequate Spill Response and Well Containment Resources (NTL No. 2010-N10). Bureau of Ocean Energy Management, Regulation and Enforcement, US Department of Interior, November 8, 2010. http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/2010NTLs/10-n10.pdf

Broje, V. and Keller, A.A. (2006). Improved Mechanical Oil Spill Recovery Using an Optimized Geometry for the Skimmer Surface. *Environ. Sci. Technol., 40(24), p.* 7914-7918. http://pubs.acs.org/doi/pdfplus/10.1021/es061842m

Clean Gulf Associates (2002). Clean Gulf Associates. Clean Gulf Associates. http://www.cleangulfassoc.com/

Dickins, D. and Andersen, J.H. (2009). Oil in Ice – Joint Industry Program, Report no. 22: Remote Sensing Technology Review and Screening. SINTEF Materials and Chemistry, November 24, 2009, 40 p. http://www.sintef.no/project/JIP_Oil_In_Ice/Dokumenter/publications/JIP-rep-no-22-RSScreening-Final.pdf

DNV (2010). Report: OLF/NOFO- Summary of differences between offshore drilling regulations in Norway and U.S. Gulf of Mexico (Report no/DNV Reg No.: 2010-1220/12P3WF5-9; Rev 02). Det Norske Veritas, Høvik, Norway, August 26, 2010, 100 p. http://www.olf.no/PageFiles/6754/Report%20no%202010-1220%20Summary%20of%20differences%20REV%2002%202010-08-27%20signed.pdf

DOI (2010). Increased Safety Measures for Energy Development on the Outer Continental Shelf. US Department of Interior, May 27, 2010, 44 p. http://www.doi.gov/deepwaterhorizon/loader.cfm?csModule=security/getfile&PageID=33598

EPA (1999) Understanding Oil Spills and Oil Spill Response, Understanding Oil Spills in Freshwater Environments (EPA 540-K-99-007, OSWER 9200 5-104A, PB2000-963401) US Environmental Protection Agency, December 1999, 48 p. http://www.epa.gov/osweroe1/content/learning/pdfbook.htm

EPA (2011). Questions and Answers on Dispersants. US Environmental Protection Agency, January 10, 2011. http://www.epa.gov/bpspill/dispersants-qanda.html#general

Federal Register Online. (2010a). 30 CFR Part 250 - Oil and Gas and Sulphur Operations in the Outer Continental Shelf - Increased Safety Measures for Energy Development on the Outer Continental Shelf; Final Rule. US Government Printing Office, October 14, 2010. http://edocket.access.gpo.gov/2010/2010-25256.htm

Federal Register Online. (2010b) 30 CFR Part 250 - Oil and Gas and Sulphur Operations in the Outer Continental Shelf – Safety and Environmental Management Systems; Final Rule. U.S. Government Printing Office, October 15, 2010. http://edocket.access.gpo.gov/2010/2010-25665.htm

Flak L. H. and Matthews C. (1994). Blowout control: Response, intervention and management. Part 9: Firefighting. *World Oil, 215 (10),* p. 101-108. http://www.osti.gov/energycitations/product.biblio.jsp?query_id=1&page=0&osti_id=6781533

Helton, D. (2010). Written statement of Douglas Helton, Incident Operations Coordinator Office of Response and Restoration, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Hearing on "Turning Ideas Into Action: Ensuring Effective Clean Up and Restoration in the Gulf," before the Subcommittee on Oceans, Atmosphere, Fisheries and Coast, Guard, Committee on Commerce, Science, and Transportation. U.S. Senate, July 21, 2010, 9 p. http://www.legislative.noaa.gov/Testimony/Helton072110.pdf

Joint Industry OSPR Task Force (2010). Draft Industry Recommendations to Improve Oil Spill Preparedness and Response. Joint Industry Oil Spill Preparedness and Response Task Force, September 3, 2010, 101 p. http://www.scribd.com/doc/37060091/Draft-Industry-Recommendations-to-Improve-Oil-Spill-Preparedness-and-Response

Joint Industry Subsea Well Control and Containment Task Force (2010). Draft Industry Recommendations. Joint Industry Subsea Well Control and Containment Task Force, September 3, 2010, 15 p. http://www.chevron.com/documents/pdf/SubseaWellControlRecommendations.pdf

Marine Spill Response Corporation (2001). MSRC-Home. Marine Spill Response Corporation. http://www.msrc.org/

Marine Well Containment Company (2011). Home - Marine Well Containment Company. Marine Well Containment Company. http://marinewellcontainment.com/index.php

MMS (2009). Arctic Oil Spill Response Research and Development Program: a Decade of Achievement. Minerals Management Service, US Department of the Interior, August 13, 2009, 29 p. http://www.boemre.gov/tarprojectcategories/PDFs/MMSArcticResearch.pdf

MMS (2010). National Notice to Lessees and Operators of Federal Oil and Gas Leases, Outer Continental Shelf - Information Requirements for Exploration Plans, Development and Production Plans, and Development Operations Coordination Documents on the OCS (NTL No. 2010-N06). Minerals Management Service, US Department of Interior, June 18, 2010, 4 p. http://www.doi.gov/deepwaterhorizon/loader.cfm?csModule=security/getfile&pageid=35724

National Research Council (2003). Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. National Research Council, 304 p. http://www.nap.edu/openbook.php?isbn=0309087376

National Response Corporation (2003). National Response Corporation – Home. National Response Corporation. http://www.nrcc.com

National Response Team (1998). Marine In Situ Burning of Oil: Questions and Answers for Communicating with the Public. Science and Technology Committee, National Response Team, November 1998, 19 p. http://www.nrt.org/production/NRT/NRTWeb.nsf/AllAttachmentsByTitle/A-73isbqaforcomm/$File/isb%20qa%20nov%2098.pdf?OpenElement

OSAT (2010). Summary Report for Sub-Sea and Sub-Surface Oil and Dispersant Detection: Sampling and Monitoring (Deepwater Horizon MC252). Operational Science Advisory Team, US Coast Guard, December 17, 2010, 131 p. http://www.dep.state.fl.us/deepwaterhorizon/files2/osat_report_17dec.pdf

Presidential Oil Spill Commission (2011). *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling.* Report to the President, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, January 2011, 398 p. http://www.oilspillcommission.gov.

Ramseur, J.L. (2010). Oil Spills in U.S. Coastal Waters: Background, Governance, and Issues for Congress (7-5700; RL33705). Congressional Research Service, April 30, 2010, 38 p. http://fpc.state.gov/documents/organization/142741.pdf

Whitby, M.F. (2007). Design evolution of a subsea BOP: Blowout preventer requirements get tougher as drilling goes ever deeper. *Drilling Contractor*, May/June 2007, p. 36-38. http://www.drillingcontractor.org/dcpi/dc-mayjune07/DC_May07_BOP.pdf

APPENDICES

A. Appendix 1: Glossary

ACP. Area Contingency Plan.

ANSI. American National Standards Institute.

API. American Petroleum Institute.

ASME. American Society of Mechanical Engineers

BOEMRE. US Bureau of Ocean Energy Management, Regulation and Enforcement. As of June 2010, BOEMRE (sometimes shortened to BOEM) is the successor to the former Minerals Management Service (MMS).

BOP. Blow-out preventer. An assembly of ram-driven pipe cutters, connectors and valves that functions as an emergency system for shutting off hydrocarbon flow from a well. BOPs can be configured to sit directly atop the wellhead or at some distance above the wellhead.

BPC. Bipartisan Policy Center.

CODAR. Coastal Ocean Dynamics Applications Radar.

DOI. US Department of the Interior.

DOT. US Department of Transportation.

E&P. Exploration and production activities involving discovery, evaluation and recovery of oil and gas resources.

EPA. US Environmental Protection Agency.

FAA. Federal Aviation Administration

FLIR. Forward Looking Infrared Radar.

GoM. Gulf of Mexico.

GPS. Global Positioning System.

HSE. Health, safety and environment.

IADC. International Association of Drilling Contractors.

ISO. International Organization for Standardization.

JITF. Joint Industry Oil Spill Preparedness and Response Task Force.

MMS. US Minerals Management Service (MMS). As of June 2010, it was replaced by the BOEMRE (BOEM).

MOC. Management of Change.

MSRC. Marine Spill Response Corporation.

MWCC. Marine Well Containment Corporation.

NCP. National Contingency Plan.

NOAA. National Oceanic and Atmospheric Administration.

NOFO. Norsk Oljevernforening For Operatørselskap (Norwegian Clean Seas Organization for Operating Companies)

NRC. National Response Corporation.

NTL. Notice to Lessees. An official informational notice issued by BOEMRE to offshore operators. The purpose usually is to announce new or pending rule changes.

OCS. Outer Continental Shelf.

OLF. Oljeindustriens Landsforening (Norwegian Oil Industry Association).

OPA 90. Oil Pollution Act of 1990.

OSRP. Oil Spill Response Plan.

R&D. Research and development.

RCP. Regional Contingency Plan.

Riser. A pipe that connects a subsea well to a drilling, production or processing structure at the surface.

ROV. Remotely-operated vehicle. An underwater vehicle equipped with cameras and other sensors, as well as some external manipulators, which is operated from shipboard work stations in order to accomplish sub-sea observations and inspections.

RP. Recommended practice.

SAR. Synthetic aperture radar.

SEMS. Safety and Environmental Management Program.

SLAR. Side-Looking Airborne Radar.

T&AR. Technical Assessment & Research. A program operated by BOEMRE as part of its functions for oversight of offshore oil and gas developments.

UAV. Unmanned Aerial Vehicle.

USCG. US Coast Guard. A part of the US Department of Homeland Security with responsibility for offshore safety and security.

VOC. Volatile organic compound (a category of air emission).

WCD. Worst-case discharge.

WCID. Well Construction Interfacing Document.