Progress Report 2

Deepwater Horizon Study Group

Center for Catastrophic Risk Management

University of California, Berkeley

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Acknowledgements

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Executive Summary

President Obama tasked the Graham-Reilly Commission with providing recommendations on how to prevent future spills and mitigate their impacts. The University of California, Berkeley (UCB) Deepwater Horizon Study Group (DHSG, http://ccrm.berkeley.edu/deepwaterstudygroup.html) has been asked to submit monthly reports of its findings to the Commission and to the public. This second progress report is a sequel to the May 24, 2010 report from UCB's Center for Catastrophic Risk Management (CCRM, http://ccrm.berkeley.edu/), ***Failures of the Deepwater Horizon Semi-Submersible Drilling Unit,*** and addresses both "looking back" and "looking forward" issues and recommendations to avoid future spills from deepwater offshore operations.

The DHSG has three major goals: (1) to produce a final report documenting results from the studies of the failures of the Deepwater Horizon Mississippi Canyon Block 252 well drilling project and the subsequent containment and mitigation activities; 2) to serve as advisors to the public, governments, industry, and environmental advocates who want timely, unbiased well-informed insights and information regarding the failures and what should be done to reduce the future likelihoods and consequences associated with such failures in ultra deepwater and arctic hydrocarbon resource developments, and 3) to develop a central archive and communications system for data and information accumulated during the investigations that can be used by researchers and others for subsequent analysis and documentation of their investigations, studies, and reports.

The first progress report concluded: *"This disaster was preventable had existing progressive guidelines and practices been followed. This catastrophic failure appears to have resulted from multiple violations of the laws of public resource development, and its proper regulatory oversight."* A vast amount of new information has become available since the first report was issued. The DHSG analysis of this information indicates these failures (failures to contain, control, mitigate, plan, and clean-up) appear to be deeply rooted in a multi-decade history of organizational malfunction and shortsightedness. There were multiple opportunities to properly assess the likelihoods and consequences of organizational decisions (i.e., Risk Assessment and Management) that were ostensibly driven by the management's desire to "close the competitive gap" and improve bottom-line performance. Consequently, although there were multiple chances to do the right things in the right ways at the right times, management's perspective failed to recognize and accept its own fallibilities despite a record of recent accidents in the U.S. and a series of promises to change BP's safety culture.

A fundamental premise in the DHSG work is: *we look back to understand the why's and how's of this disaster so we can better understand how best to go forward.* The goal of the DHSG work is not 'blame and shame'. The goal of this vital work is to help us all to help the public, support our governmental institutions and industrial enterprise, and revisit our environmental stewardship responsibilities in defining how to best move forward – assessing what major steps are needed *looking forward* to develop our national oil and gas resources in a reliable, responsible and accountable manner.

These major steps forward will require implementation of an effective Technology Delivery System (TDS). An effective TDS endeavors to unify and address the needs and requirements of the concerned public, governmental agencies, industrial–commercial enterprise, and environmental communities so that vital resources and services can be delivered that will have desirable and acceptable Quality (serviceability, safety, compatibility, durability, resilience, sustainability) and Reliability (likelihoods and consequences of Quality) characteristics. This is one of the most crucial and difficult parts of the process. The TDS must be founded on a continuous improvement process to assure that the desired level of Quality and Reliability is achieved and maintained.

The DHSG recommends that TDS be integrated with effective life-cycle (concept development through decommissioning) Risk Assessment and Management (RAM) approaches, strategies and processes that address two key factors: the likelihoods of catastrophic failures (Probabilities of failure, Pfs) and consequences of those failures (Cfs). Risks associated with a given system and its operations are expressed with combinations of Pfs and Cfs. The goal of Risk Assessment is to properly characterize and quantify Pfs and Cfs. The primary goal of Risk Management is to ensure that acceptable and desirable Pfs and Cfs are achieved. RAM explicitly addresses the likelihoods and consequences associated with Intrinsic Uncertainties (natural variability, qualitative and quantitative modeling uncertainties), and Extrinsic Uncertainties (human and organizational performance, knowledge acquisition and utilization). Definition of acceptable and desirable risk, i.e., combinations of Pfs and Cfs, is an interactive social and political TDS process.

The recommended RAM based process is founded on application of three interdependent and interactive approaches to identify and manage risks throughout the life-cycles of deepwater and arctic hydrocarbon exploration and production systems: (1) Proactive (before activities are conducted), (2) Reactive (after activities are conducted to enhance learning and to control or mitigate failures), and (3) Interactive (during activities to ensure that desirable Quality and Reliability are achieved). Three fundamental strategies are used during implementation of these three approaches: (1) reduce the likelihoods of malfunctions (human and system supports), (2) reduce the effects of malfunctions (system Robustness and Resilience), and (3) increase the proper detection, analysis and correction of system malfunctions (Quality Assurance & Control).

Precedents for effective development and application of RAM based approaches and strategies exist in other offshore oil and gas development areas including those of Canada, the U.K., and Norway. These RAM based approaches and strategies are supported with cooperative industry – government - academic research and development programs fostering continued improvement and development of RAM approaches and strategies. These research programs are directly funded with revenues from oil and gas production activities. Effective government - industry 'leading' and 'lagging' Risk Indicators and sense-making processes have been developed to focus RAM resources on the operations comprising the highest risks. These risk indicators are used to help direct research and development programs that are focused on reductions in uncertainties and increases in reliabilities through technical and organizational improvement processes. Such advanced concepts should be utilized and integrated into the present as well as the next generation of U.S. oil and gas exploration and production processes and practices for deepwater and arctic exploration and production activities.

This report recognizes there is much to be learned from precursors to the Deepwater Horizon accident and identifies steps to be taken to prevent similar accidents in the future. The report focuses on three aspects of all large-scale complex systems failures: technical issues, organization and organizational systems issues, and environmental issues. This report looks back at hypothesized precursors that should be investigated in-depth, and looks forward to ways investigative teams can frame problems in their studies of this catastrophe.

Technical Issues

Looking Back

Although detailed reliable evidence about what happened at BP (British Petroleum), the U.S. MMS (United States Minerals Management Service) and onboard Transocean's Deepwater Horizon drilling unit is presently incomplete, experience shows that it is essential to progressively identify and corroborate how this complex system developed throughout its lifecycle to the point of failure, including development of conceptual and detailed design, construction, operation, and maintenance. The heritage of a system generally has much to do with its subsequent failures. We know that in a very large number of cases, the seeds for failure are sown very early in the life of a particular system - during the concept development and design phases (e.g. the design of the Macondo well). These seeds are then allowed to flourish during the operation and maintenance phases, and, with the system in a weakened or severely challenged condition, it fails.[1] This may prove to be true once again when the Deepwater Horizon technical and organizational issues are fully vetted and a thorough forensic examination of the evidence is possible.

The first DHSG progress report identified seven elements responsible for this disaster:

• Improper cement design (segmented discontinuous cement sheath).

• Flawed Quality Assurance and Quality Control (QA / QC) – no cement bond logs in critical sections of the well, ineffective oversight of operations.

• Bad decision making – removing the pressure barrier – displacing the drilling mud with sea water 8,000 feet below the drill deck.

• Loss of situational awareness – early warning signs not properly detected, analyzed or corrected (repeated major gas kicks, lost drilling tools, including evidence of damaged parts of the Blowout Preventer) during drilling and/or cementing, lost circulation, changes in mud volume and drill string weight).

• Improper operating procedures – premature off-loading of the drilling mud (weight material not available at critical time).

• Flawed design and maintenance of the final lines of defense – including the Blowout Preventers (BOPs) blind shear rams, hydraulic lines, and triggering equipment – and the Emergency Shutdown and Disconnect (ESD) systems.

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1 Bea, R. *Learning from Failures: Lessons: Lessons from the Recent Failures of Engineered Systems*, (working paper) Department of Civil & Environmental Engineering and Center for Catastrophic Risk Management, University of California, January 22, 2006

The first and last elements can be classified as failures in engineering controls, and the rest are considered failures in administrative controls - Human and Organizational Factor (HOF) malfunctions. The functionality of engineering controls to a large extent depend on issues of effective administrative controls.[2] For example, inadequacies and failures of engineering controls include BOPs malfunction, hydraulic failure, gauge or indicator equipment error or malfunction, power disruption, and valve failure. Engineering controls are subject to failure due to inadequate design, operation (application), and maintenance. Experience has clearly demonstrated that inadequate inspection, testing, and maintenance due to administrative control shortcomings can defeat the best engineered systems.

Administrative control failures also include deviation from standard operating procedures, e.g., not running a cement bond log, not completing bottoms-up circulation procedures, failure to follow accepted well completion procedures, failure to respond to trouble indicators, failure to maintain ESD systems, and failure to fully test and activate the BOPs. Administrative controls are subject to failure when procedures have not been adequately developed, implemented, audited, and enforced. This, in turn, can be due to an organizational culture and incentives that encourage cost-cutting and cutting of corners – that reward workers for doing it faster and cheaper, but not better.

In the interim, much additional discovery information and testimony has been produced that serves to further support and corroborate the initial findings of the DHSG documented in the first progress report. However, many questions remain unanswered and ultimately may remain unanswered in the final analysis. As BP's CEO, Tony Hayward has testified before the U.S. Congress – *"one thing is certain – that this incident should never have happened."*[3]

The Waxman Congressional Committee on Energy and Commerce issued a briefing memorandum on May 25, 2010 noting the following:[4]

> *"Several concerns about the blowout preventer were identified by BP including the failure of its emergency disconnect system (EDS), the failure of its automated mode function or deadman switch, the failure of the BOPs shearing functions, and the failure of*

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2 For example, Blowout Prevention. Ref. 3.10.10 Memorandum, OSHA Interpretation #27296 http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=27296

3 Testimony of Tony Hayward before the U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Oversight and Investigations, June 17, 2010: *Chairman Stupak, Ranking Member Burgess, members of the Subcommittee. I am Tony Hayward, Chief Executive of BP plc. The explosion and fire aboard the Deepwater Horizon and the resulting oil spill in the Gulf of Mexico never should have happened — and I am deeply sorry that they did.*

4 Memorandum To Members of the Subcommittee on Oversight and Investigations From Chairmen Henry A. Waxman and Bart Stupak
Re: Key Questions Arising from Inquiry into the Deepwater Horizon Gulf of Mexico Oil Spill, Ref. http://energycommerce.house.gov/documents/20100525/Briefing.Memo.ee.05.25.2010.pdf

the remote operated vehicle interventions. The BP investigation has also raised concerns about the maintenance history, modification, inspection, and testing of the BOP."

In the case of the Deepwater Horizon's BOPs, the first few days following the incident are very revealing and symptomatic of BP's failed Safety Management System (SMS). The initial response by engineers was focused on trying to fully engage the rig's single functional blind shear ram using Remote Operated Vehicles (ROVs). However, it did not work and, in fact, the BP engineers reportedly did not even have accurate information about how the BOPs had been previously modified and wasted precious time trying to activate the BOPs. Excerpts of the New York Times article best tell this story:[5]

"The handwritten log was among hundreds of pages of unreleased documents obtained by The New York Times in which managers describe the desperate bid to control the subsea gusher that has spewed millions of gallons of oil into the gulf. Covering roughly the first month of the crisis, they provide a vivid, though incomplete, picture of what were mostly unsuccessful engineering efforts to seal the well or contain the leaking oil. These efforts were hampered by the lack of information on the condition of the well, logistical problems, unexplained delays and other obstacles, the documents show. There are moments of great frustration recorded in the documents, especially over the inability to activate the devices on the blowout preventer with robotic submersibles. Upon discovering that one safety device, called the middle pipe ram, or M.P.R., had been modified years before — meaning that more than a week's worth of effort to activate it had been doomed from the start — one engineer was obviously displeased. "So for approx. 10 days, we have been closing on M.P.R. port," the engineer wrote. "But in reality it was the lower pipe rams. This is a modification to the original system."

This is but one example of many investigations pointing to ignoring fundamental safety (reliability) policies and practices. Having up-to-date process and safety system equipment drawings is one of the mandated 14-key elements of basic process safety management.[6] It is also an issue that has been called into question on other BP deepwater facilities, i.e., the Atlantis floating production platform, by Ken Abbott, whose testimony addresses the importance of engineering documents and BP's alleged failure to properly approve and maintain this vitally important data.[7]

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5 Notes From Wake of Blowout Outline Obstacles and Frustration, New York Times, June 21, 2010, by Henry Fountain

6 29CFR1910.119

7 Statement of Ken Abbott, House Subcommittee on Energy and Mineral Resources Hearing, June 17, 2010; ref. http://resourcescommittee.house.gov/images/Documents/20100617/2010_06_17_energy/testimony_abbott.pdf

As reported in the New York Times, a senior oil industry executive said of (being able to engage) the Deepwater Horizon's blind shear ram – "*If that would've worked that rig wouldn't have burned up and sunk.*"[8] However, the failure of the BOP, although foreseen and foreseeable based on results from full-scale testing and studies of the generation of BOPs onboard the Deepwater Horizon, was ostensibly never contemplated by BP – there were no contingency plans to address the developing situation as there were no spill contingency plans to deal with the scope of the disaster. As reported by the New York Times:

> *"When the rig's control panels fail, two separate backup systems, the deadman and the autoshear, are supposed to close the blind shear ram automatically. The deadman is designed to close the shear ram if the electronic and hydraulic lines connecting the rig to the blowout preventer are severed. An underwater robot cut several lines at 2:45 a.m. on April 22. The situation was rapidly deteriorating. "2 explosions around 3:30-4:00 this morning & rig listing at about 35 degrees," a crisis manager wrote. "High risk of sinking."*
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> *"The autoshear is designed to trigger the blind shear ram if a rig drifts out of position and yanks its riser loose from the blowout preventer."*
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> *"At 7:30 a.m., a submersible cut a firing pin on the blowout preventer, simulating the rig's pulling free. This time, the blowout preventer shuddered, as if struggling to come back to life. "L.M.R.P. rocked & settled," one note says, referring to the top half of the blowout preventer. But after a few moments, as oil continued to flow, it became clear that this, too, had failed. Soon after, the Deepwater Horizon sank."*
>
> ***Stunning Discovery***
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> *"The deadman, the autoshear and the underwater robots constitute the critical backup systems that have given regulators and oil industry officials great confidence that no matter what, they could always find a way to activate their last line of defense. This was more an act of faith than a fully tested proposition. The Minerals Management Service had never required any of these backup systems to be tested despite a report it commissioned in 2003 that said these systems "should probably receive the same attention to verify functionality" as the rest of the blowout preventer. The agency had also declined to take the modest step of requiring rigs to have these backup systems in place at all, though it had sent out a safety alert encouraging their use."*
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> *"At a BP complex in Houston after the Deepwater Horizon's sinking, in a room called the hive with video screens displaying feeds from as many as a dozen underwater robots,*

[8] *Regulators Failed to Address Risks in Oil Rig Fail-Safe Device*, New York Times, June 20, 2010, by David Barstow, Laura Dodd, James Glanz, Stephanie Saul and Ian Urbina with Michael Moss and Henry Fountain contributing

engineers considered their options. BP officials theorized — perhaps based on the lower estimates of leakage in those first days — that the blind shear ram might have crimped, but not quite severed, the pipe. The idea provided a comforting mental picture. Just a few more inches with the blind shear ram, the reasoning went, and perhaps it would snap shut and stanch the spewing oil."

"So six days after the explosion, they began the fifth effort to close the blind shear ram. This time they sent down tanks of pressurized hydraulic fluid that a submersible could inject directly into the ram. Shockingly, the blind shear ram's hydraulic system leaked, meaning pressure could not be maintained on its shearing blades. This leak shocked engineers because the blowout preventer's hydraulic system was obsessively checked for leaks. "We see tests fail because the hydraulics leaked two drops," said Benton Baugh, a leading authority on blowout preventers. Indeed, the blind shear ram had been tested for leaks only hours before the blowout, and according to Transocean, no hydraulic leaks had been detected in the weeks before the blowout. The underwater robots tried to find and fix the leak, but by now, leaks were springing up on nearly every component of the blowout preventer. "Retighten leak," reads a note from 4 a.m. on April 26. At 4:45: "Retest & leak still present." Fifteen minutes later: "Retighten loose connection." Some of those leaks appeared to be coming from shuttle valves leading to the blind shear ram — possibly the "single-point failure" that had been identified as the blowout preventer's biggest vulnerability back in 2001. Or the leaks could have come from shuttle valves that let hydraulic fluid from the robots reach the blind shear ram."

"The leaks pointed to a gaping hole in the government's mandated leak tests. Those tests do not require rig operators to look for leaks in the connection points used by submersibles to activate a blowout preventer in an emergency."

"Finally, seven long days after the explosion, operators of the underwater robots managed to repair the leak on the blind shear ram and apply 5,000 pounds per square inch of hydraulic pressure on its blades. This was nearly double the pressure it typically takes to shear pipe. A BP report tersely described the results: "No indication of movement."

"But engineers could not be absolutely sure. Without any way to see into the blowout preventer, engineers had essentially been operating blind, using the rate of oil flow, for example, to deduce the conditions inside. Help came from Scott Watson, an expert in gamma ray imaging at Los Alamos National Laboratory. Gamma rays, a form of electromagnetic radiation similar to X-rays but higher in energy, might at least penetrate a few inches into the blowout preventer's thick steel walls. Then engineers might be able to see a device called a wedge lock, which slides into place behind the shear ram to hold it closed. In mid-May, Mr. Watson ventured to the well site, where robotic submersibles were sent down to the seafloor with cobalt 60, a radioactive isotope that generates

> *gamma rays. The team from Los Alamos was able to get a clear view of only one half of the blind shear ram. But the images showed one wedge lock fully engaged, meaning at least one half of the shear ram had deployed. "I don't think anybody who saw the pictures thought it was ambiguous," Mr. Watson said. It was a crushing moment. Engineers realized that all their efforts to revive the blowout preventer had probably never budged the critical component at the machine's core, the blind shear ram. They had assumed that at some point early on, the blades had tried to close. They had hoped to close them all the way. But now, the gamma ray images showed that at least one blade was fully deployed, and they had run out of options for forcing the other one closed. Continuing to push on the ram's pistons with more hydraulic fluid would achieve nothing. The last line of defense was a useless carcass of steel."*

Prior to Mr. Hayward's referenced testimony on June 17th, the Waxman Committee sent him an advisory letter asking the Chief Executive Officer (CEO) to be prepared to address key issues focusing on five crucial decisions made by BP:

> *"(1) the decision to use a well design with few barriers to gas flow; (2) the failure to use a sufficient number of "centralizers" to prevent channeling during the cement process; (3) the failure to run a cement bond log to evaluate the effectiveness of the cement job; (4) the failure to circulate potentially gas-bearing drilling mud out of the well; and (5) the failure to secure the wellhead with a lockdown sleeve before allowing pressure on the seal from below.*"

The committee observed that – "*[T]he common feature of these five decisions is that they posed a trade-off between cost and well safety*."[9]

The extent to which this observation is true will be determined over the coming months as the many ongoing incident investigations proceed. At this point in time the inductive phase of the DHSG investigation is continuing and, as Mr. Hayward often repeated much to the annoyance of the committee members – "*The investigations should be completed before any conclusions can be affirmed."* Nevertheless, the record indicates that BP's reported efforts to improve its corporate safety culture following the Texas City and North Slope incidents of 2005 and 2006 have fallen short of that goal.

This conclusion is not unfounded in light of testimony from Mr. Hayward's peers who uniformly have testified that their companies would not have done it that way. Exxon-Mobile's Chairman and Chief Executive Officer, Rex Tillerson, told the Waxman Committee that the Gulf spill would not have occurred if BP had properly designed its deep-water well – "*We do not*

[9] The Waxman Committee Letter of June 14, 2010 to Tony Hayward, Ref. http://energycommerce.house.gov/documents/20100614/Hayward.BP.2010.6.14.pdf

proceed with operations if we cannot do so safely - We would not have drilled the well the way they did." [10, 11]

Similar observations were made by the executives of Chevron, Shell, and ConocoPhillips – "*It certainly appears that not all the standards that we would recommend or that we would employ were in place*" - said John S. Watson, chairman of Chevron. *"It's not a well that we would have drilled in that mechanical setup"* - said Marvin E. Odum, president of Shell Oil Company.

BP's own partner on the Macondo well, Anadarko, has taken it a step farther with CEO Jack Hackett stating that – "*the mounting evidence clearly demonstrates that this tragedy was preventable and the direct result of BP's reckless decisions and actions.* He further observed that - *BP's behavior and actions likely represent gross negligence or willful misconduct.*"[12]

The testimony of Rex Tillerson affirmed the first goal of the DHSG:

"It is essential that we understand the events that led to this unprecedented accident, and take corresponding steps to further reduce the likelihood of a similar event ever occurring again."

"An expert, impartial and thorough approach to understanding what happened is crucial because this incident represents a dramatic departure from the industry norm in deepwater drilling."

"Understanding the facts surrounding this incident is critical to informing the long-term policy and operational response."

"We are eager to learn what occurred at this well that did not occur at the 14,000 other deepwater wells that have been successfully drilled around the world. It is critical we understand exactly what happened in this case, both the drill well design and operating procedures, and the execution of the drilling plans, which led to such severe consequences."

"We need to know if the levels of risk taken (sic) went beyond industry norms. Based on the industry's extensive experience, what we do know is that when you properly design wells for the range of risk anticipated… follow established procedures… build in layers of redundancy… properly inspect and maintain equipment… train operators… conduct

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[10] *Oil Execs Tell Senators Gulf Spill Blame Rests With BP*, Foxnews.com, June 15, 2010, ref. http://www.foxnews.com/politics/2010/06/15/republicans-accuse-obama-exploiting-oil-crisis-pass-stalled-energy/

[11] *Oil Executives Break Ranks in Testimony*, New York Times, June 15, 2010, by John Broder

[12] Anadarko says BP 'negligent' on Macondo, Upstream Online, June 18, 2010, ref. http://www.upstreamonline.com/live/article218290.ece

tests and drills… and focus on safe operations and risk management, tragic incidents like the one in the Gulf of Mexico today should not occur."

To date compelling indicators have been surfaced to suggest that: 1) BP's drilling and well completion operations did not meet industry standards, 2) operations were "Faster" and "Cheaper," but not "Better" – the operation records point to excessive economic and schedule pressures resulting in compromises in the Quality and Reliability of the Macondo deepwater oil and gas development system, and, thus ignoring risks and potential consequences, 3) the involved parties did not anticipate a blowout and, accordingly, did not develop effective, collaborative and constructive interactions to ensure that the resources needed in case of a blowout would be available. This working hypothesis remains to be corroborated and tested once the record is complete and all salvageable physical and documentary evidence has been recovered and examined.

It is well established that failure to address human and organizational malfunctions in design and operation of deepwater marine structures, including floating and fixed platforms, pipelines, and ships[13] is a pervasive problem and a primary contributor to accident causation.[14] This observation has proven to be true for a very wide variety of complex systems that operate in hazardous environments (e.g. commercial aviation, military operations, space exploration, health care). As discussed earlier in this report, failures in administrative controls can lead to failures in the highest quality engineered systems. During the past two decades, detailed studies have been made of more than 600 'very high consequence' disasters. These studies indicate the failure development process - 'map to disaster'- can be organized into three categories of events: 1) initiating, 2) contributing, and 3) propagating. The dominant initiating events are developed by 'operators' performing erroneous acts of commission or interfacing with the hardware – structure components that have 'embedded pathogens' that are activated by such acts of commission (about 80%); the other initiating events are acts or developments involving acts of omissions – important things omitted. The dominant contributing events are organizational; these contributors act directly to encourage or 'trigger' the initiating events. In the same way, the dominant propagating events are also organizational; these propagators are generally responsible for allowing the initiating events to unfold into multiple failures. The DHSG study of the currently available evidence regarding the multiple failures of the Mocando exploration – production drilling project clearly indicate these failures follow this map to disaster.

13 floating production, storage and offloading vessels such as BP Atlantis and Thunder Horse

14 *Human & Organizational Factors in Design and Operation of Deepwater Structures,* R.G. Bea, University of California, Berkeley, Offshore Technology Conference, OTC Paper #14293, 2002

Looking Forward

The Moratorium

On May 27, 2010, the Department of the Interior sent a report to The President recommending *"a number of specific measures that can be taken on both a short and longer term basis to enhance the safety of offshore oil and gas activities. (T)he report focuses on two key aspects of drilling safety: (1) well design and construction and well control procedures and (2) blowout preventer equipment and backup control systems."* The report also recommended *"that you impose a moratorium on all oil and gas drilling activity from floating rigs for 6 months."* Those recommendations were accepted by the Administration on May 28th.

Subsequently, the US Department of the Interior Minerals Management Service issued a National Notice to Lesees (NTL) and Operators of Federal Oil and Gas Leases, Outer Continental Shelf (OCS) detailing "Increased Safety Measures for Energy Development on the OCS." This NTL required *"each operator must certify that they have conducted the following specific reviews of their operations:*

1. *Examine all well control system equipment (both surface and subsea) currently being used to ensure that it has been properly maintained and is capable of shutting in the well used to ensure that it has been properly maintained and is capable of shutting in the well during emergency operations. Ensure that Blowout Preventers (BOPs) are able to perform their designated functions. Ensure that the ROV hot-stabs are function-tested and are capable of actuating the BOP.*

2. *Review all rig drilling casing, cementing, well abandonment (temporary and permanent), completion, and workover practices to ensure that well control is not compromised in any point while the BOP is installed on the wellhead.*

3. *Review all emergency shutdown and dynamic position procedures that interface with emergency well control operations.*

4. *Ensure that all personnel involved in well operations are properly trained and capable of performing their tasks under both normal drilling and emergency well control operations."*

On June 22nd, the U.S. Federal District Court Judge, Martin Feldman, issued a temporary injunction striking down the President's six-month moratorium on offshore drilling operations of new and currently permitted deepwater wells that was imposed on May 28, 2010 by the Department of the Interior and the Minerals Management Service (MMS). On July 8th, the 5th U.S. Circuit Court of Appeals refused to restore the government's moratorium on deep water drilling.

On July 12th, The Secretary of the Interior directed the new Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM) which replaced the Minerals management

Service (MMS), to suspend offshore permitting and drilling activities on the Outer Continental Shelf of the Gulf of Mexico and the Pacific regions through November 30, 2010; *"subject to modification if I determine that the significant threats to life, property, and the environment set forth in this memorandum have been sufficiently addressed. These suspensions do not apply to production activities; drilling operations that are necessary to conduct emergency activities, such as the drilling operations related to the ongoing BP Oil Spill; drilling operations necessary for completions or workovers (where surface BOP stacks are installed, they must be utilized during these operations); abandonment or intervention operations; or waterflood, gas injection, or disposal wells. BOEM shall order any current drilling operations covered by this decision to proceed to the next safe opportunity to secure the well and take all necessary steps to cease operations and temporarily abandon or close the well."*

This Decision Memorandum identified risks to continued drilling in deepwater: *"The OCSLA (Offshore Continental Shelf Lands Act) requires that operations on the OCS be conducted in a "safe manner…using technology, precautions, and techniques sufficient to prevent or minimize the likelihood of blowouts, loss of well control, fires, spillages, physical obstruction to other users of the waters or subsoil and seabed, or other occurrences which may cause damage to the environment or to property, or endanger life of health." 43 U.S.C. § 1332(6). The following categories of risks related to deepwater drilling activities must be addressed to ensure fulfillment of the requirements of this law: (1) The current status of drilling and workplace safety and the implementation of safety measures; (2) the current status of well control and spill containment capabilities; and (3) the current status of spill response capabilities."*

Given these developments, the DHSG recommends the following actions be considered by the DOI and BOEM for deepwater floating drilling unit exploratory wells in the Gulf of Mexico (GOM):

1. Target specific wells - identify wells or prospects having:
   a) a history of abnormal repetitive well control events during the drilling and completion life cycle, i.e., have experienced multiple gas kicks – both large and small;
   b) well completion programs based on a 'long string' vs. a 'liner tieback';
   c) BOPs with only one set of blind shear rams;
   d) BOPs that have not been proven to be effective by testing and documentation for the drill strings being handled by the rig;
   e) modified and or/repaired their BOPs but have not fully tested these modifications;
   f) BOPs subject to single point failures, including shuttle valves, disabled redundant control pods (i.e., loss of redundancy);
   g) BOPs where the drillpipe to be used has not been tested with the same back pressure from hydraulic head anticipated at the drilling site
   h) nitrogen-agent cement slurries;
   i) insufficient cement bond logs;

j) wellheads with unsecured locking sleeves;
k) casing strings incorporating burst subs for pressure relief;
l) untested or problematic emergency disconnect systems not incorporating the best and safest available technology;
m) experienced a high rate of injuries and accidents, including fires and explosions;
n) drilling crews with insufficient training and experience;
o) an insufficient structured safety management systems and management of change (i.e., local v. centrally monitored);
p) the highest number of MMS and USCG (U.S. Coast Guard) citations and the most requested permit modifications; and
q) unrealistic and ineffective emergency containment and spill response plans.

2. For those targeted wells, implement immediate remedial measures to mitigate the identified risks using appropriate engineering and administrative controls in those instances where the risk cannot be otherwise eliminated. Depending on the nature and severity of the particular risk, suspension of further operations until such time that appropriate risk management measures can be effect may be appropriate – to be determined on a case-by-case basis. In this regard, use of established process safety management practices and procedures should be confirmed, including Mechanical Integrity, Management of Change, Training, and Auditing (see 4) as prescribed by 29CFR1910.119. A timeline and implementation plan should be developed and approved for each case.

3. Provide an effective regulator auditing procedure for each of the identified wells to ensure that safety management system is functioning as intended, proper documentation, record keeping, reporting, and quality control and assurance measures are implemented; and independent 3rd party assessment is accomplished by a recognized agency with extensive experience with drilling deepwater wells, such as Det Norske Veritas (DNV) or the American Bureau of Shipping (ABS).

4. Instigate single-agency responsibility for all deep-water drilling and production operational safety, be it the U.S. Coast Guard or the newly created Bureau of Safety and Environmental Enforcement. This agency should be staffed with a sufficient number of experienced drilling and petroleum engineers with hands-on operational experience and process safety training at the highest levels to provide 24 hour coverage of the well during the drilling process. The inspectors should have the power to immediately shut in any well where they determine that regulations are not being followed. Their power would be equivalent to a bank examiner who closes the bank, then asks for explanations.

5. Establish a separate oil spill response agency funded by all oil and gas operators in the GOM to support both research and development for developing the best available technology for oil spill response and remediation, and to establish and maintain sufficient response capabilities to effective handle major oil spills. This contemplates having staged pre-constructed

subsurface collection systems and equipment for responding to leaks at the sea floor as well as environmental remediation measures for aquatic and shoreline impacts. A VAT (ad valorem) approach linked to oil company profits is suggested with prohibitions for passing this burden on to consumers.

Based on information presently available to the DHSG, the following additional recommendations are made for consideration by the DOI and BOEM:

1. Ensure all BOPs have sufficient built-in redundancy to eliminate single-point failure modes in both control systems and functional elements, i.e., two sets of blind shear rams.

2. Ensure redundant design features are fully functional at all times (i.e., dual control pods) during rig/platform operations.

3. All leaks, repairs, modifications to BOPs must be performed, completed, and tested with operations shutdown and the well(s) secured.

4. BOP testing must be comprehensive, including checking for leaks at ROV connection points, such that the entire operating and control system is fully examined and verified.

5. Verify that the installed BOP is suitable for the drill pipe and casing being used or planned for the well. Shear capability must be proven and demonstrated by independent 3rd party certification.

6. Ensure all BOPs are suitably equipped with the best available technology including the EDS for wireless control.

7. Verify that all BOP drawings, hydraulic logic and piping diagrams, and control system loop diagrams are accurate and up-to-date for the installed equipment.

8. Review and verify that an effective Management of Change (MOC) procedure and auditing system is in place and being documented and followed, subject to 3rd party verification and certification.

9. Ensure that a comprehensive Mechanical Integrity program is in effect and functional, with required inspection, testing and maintenance records kept in accordance with process safety management standards.

10. Review crew training and experience for adequacy, including contractor and owner management personnel assign to each rig.

11. Review policies and procedures for conducting simultaneous maintenance and repair work during drilling operations; ensure adequate routine and non-routine maintenance and job safety analysis procedures are in place and being followed.

12. Review all deepwater rigs using suggested target criteria detailed in this section and identify the most risk-prone operators/operations working in deepwater.

13. Institute a special program for those risk prone operations and organizations, including more rigorous inspections, enforcement and frequent reviews. Identify specific deficiencies in safety culture and mandate specific improvements in practices and procedures.

Long Term

The first DHSG recommendation for long term actions is to have the DOI and BOEM implement the 'specific' recommendations contained in the May 27^{th} report to The President titled *"Increased Safety Measures for Energy Development on the Outer Continental Shelf"* (pp 19 – 28) – with particular attention given to the recommendations addressing *"Organizational and Safety Management."*

Of particular importance are the recommendations in this report addressing Risk Assessment and Management (RAM) life-cycle (design, construction, operations, maintenance, decommissioning) based operations (Safety Case Regime) and associated development and maintenance of the essential High Reliability Organizations (HROs) to conduct these operations. The technology, knowledge, and experience enabling realization of these recommendations exists. The challenge is to properly implement this background, maintain the improvements, and continually upgrade and adapt the improvements to address important new risks associated with development of U.S. public oil and gas resources. This is an opportunity to once again become world leaders in such operations.

The OCS Lessees and the DOI-BOEM should develop and sustain a technically superior, challenging, collaborative, and diligent program of life-cycle Quality Assurance – Quality Control (QA/QC) based on effective and timely detection, analysis and correction of defects and flaws in deepwater oil and gas operations (exploration AND production). This requires High Reliability Organizations that effectively practice High Reliability Management (planning, organizing, leading, controlling) in all segments of the operations. This requires organizational commitment (to develop acceptable Risks throughout the life-cycle), capabilities (technical and managerial superiority), cognizance (awareness of hazards and uncertainties that threaten acceptable Risks through the life-cycle), culture (balancing production and protection), and counting (development of acceptable Quality including costs, benefits, profitability, and environmental quality).

This will require long-term sustainable programs of international industry – government – academia collaborative Research and Development projects. This will require Public Outreach to help educate the public, development of long-term collaborations with international regulatory agencies and industrial organizations to enable realization of continuous improvements and implementation of best practices in regulations of deepwater oil and gas exploration and production, and effective deepwater oil and gas development. It is suggested that a Technology

Delivery System (TDS) be effectively employed that effectively engages the public interests, the responsibilities of the governments (of, by, and for the people), the technology of industry and commerce, and the stewardship of the environment. In this regard, it is recommended that an in-depth across-the-board comparison be made the safety management systems and corporate safety culture of BP compared to Exxon-Mobil exploration and production. Differences not only in organizational structure but also in management execution and dynamics should be identified and analyzed to assess what future steps must be taken by all deepwater operators. Such actions are characteristic of 'rapid learning' organizations.

It is well established that failure to address human and organizational factors in design and operation of deepwater marine structures, including floating and fixed platforms, pipelines, and ships[15] is a pervasive problem and a primary contributor to accident causation.[16] And, as already discussed, failures in administrative controls can lead to failures in the highest quality engineered systems. No matter how reliable the hardware is that comprises a system, the very painful experience associated with high consequence – low probability disasters (catastrophies) cleary shows it is the peopleware that determine the overall reliability of the system.

An important starting point in addressing human and organizational factors (HOF) in the Quality and Reliability of offshore exploration and production operations is to recognize that while human and organizational malfunctions are inevitable, their occurrence can be reduced, their proper detection and correction increased, and their effects mitigated by improving how offshore systems are designed, constructed, operated, and maintained. Engineering can improve the processes and products of design, construction, operations, maintenance, and decommissioning to reduce the malfunction promoting characteristics, and to increase malfunction detection and recovery characteristics. Engineering can help develop systems for what people can and will do, not for what they should do. Engineering can also have important influences on the organization and management aspects of these systems.

Organizations have important and pervasive influences on the reliability of offshore exploration and production systems. High reliability organizations (HRO) have been shown to be able develop high reliability systems that operate relatively error free over long periods of time and in many cases, in very hazardous environments. HRO go beyond Total Quality Management and International Standards Organization certifications in their quest for quality and reliability. They have extensive process auditing procedures to help spot safety problems and they have reward systems that encourage risk mitigating behaviors. They have high quality standards and maintain their risk perception and awareness. Most important, such organizations maintain a strong command and control system that provides for organization robustness or defect tolerance.

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15 floating production, storage and offloading vessels such as BP Atlantis and Thunder Horse

16 *Human & Organizational Factors in Design and Operation of Deepwater Structures,* R.G. Bea, University of California, Berkeley, Offshore Technology Conference, OTC Paper #14293, 2002

Organizational and Organizational Systems Issues

Looking Back

Organizational and organizational systems issues are as important as technical issues. Technical problems are caused by people, organizations and systems of organizations operating together. The current BP tragedy is shrouded in statements about its mismanagement, mostly made by people with no training in managing risk. Prior to any real evidence being made public about BP's management, the best place to look for managerial issues that may deserve the most investigative attention is at BP itself. BP's Texas City refinery accident in 2005 has probably been investigated more thoroughly than any other major catastrophe.[17] BP commissioned James Baker to form an investigative panel,[18] The U.S. Chemical Safety and Hazards Board did an investigation,[19] and Andrew Hopkins wrote a book about the incident.[20] It is recognized that the Texas City event happened in the downstream part (oil refining, marketing and sales) of BP's business while the Deepwater Horizon accident happened in the upstream part (oil exploration, development and production) of the business, still there may be similarities because there are organizational and organizational system similarities across all organizational catastrophes. Then, too, BP has suffered other safety issues.

As pointed out in the U.S. Chemical Safety and Hazards Board (CSB) report (2007) and by Hopkins (2010) the usual organizational approach to thinking about safety is to examine classical industrial accidents; trips, slips and falls, and to account safety as the number of these that happen in any given time frame. <u>These individually based data points have nothing to do with the catastrophic systemic accidents we see in growing numbers</u>. The classical way of thinking about accidents is evidenced in the Texas City disaster. An interesting facet of that accident is that shortly before the explosion a meeting was held in the control room that included about twenty people. The reason for the meeting was to celebrate safety! A thirty-five day maintenance shutdown of two other process units at Texas City was just completed without a single recordable injury and with only two first aid treatments. All three publications discuss BP's failure to consider the Texas City disaster as a process safety catastrophe.

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17 Often cited by accident investigation authorities as the quintessential accident investigation is NASA's investigation of the space shuttle Columbia's demise. (Columbia Accident Investigation Board, 2003, *Columbia Accident Investigation Report.* Washington, D.C.: U.S. Government Printing Office)

18 The BP U.S. Refineries Independent Safety Review Panel. (2007) *The Report of the BP U.S. Refineries Independent Review Panel.* London: BP (also known as the Baker Report).

19 U.S. Chemical Safety and Hazards Investigation Board (2005) *Investigation Report: Refinery Explosion and Fire* Washington, D.C.: U.S. Chemical Safety and Hazards Board.

20 Hopkins, A. (2010) *Failure to Learn: The BP Texas City Refinery Disaster.* CCH Australia, Limited.

According to both the CSB and Baker commission reports the Texas City disaster was caused by organizational and safety issues at all levels of BP. Warning signs of imminent disaster were around for years. The extent of serious safety deficiencies was revealed in the months after the accident by two further incidents.

From the top down, the BP Board did not provide effective oversight of BP's safety, culture, and major accident prevention programs. Cost cutting, failure to invest, and production pressures characterized BP executive manager behaviors. Fatigue, poor communication, and lack of training characterized Texas City employees. On the day of the accident many start-up deviations occurred. Many aspects of the work environment encouraged such deviations, such as the fact that the start-up procedures were not regularly updated. Operators were allowed to make procedural changes without proper management of change (MOC) analysis. BP had replaced classroom training with some computer training. However, computer training doesn't allow the trainee to have to think through problems. It is more appropriate to memorization. BP did not offer its rig employees simulation training. Simulation training is the appropriate form of training to give people practice with thinking through problems. The start-up procedure lacked sufficient instruction to the board operator for a safe and successful start up of the unit.

BP has a management of change (MOC) plan. Supposedly all new and ongoing procedures are subject to MOC analysis. Not only does it appear that start up changes were not subject to MOC analysis, it also appears that corporate changes (such as tightening budgets, reducing staff, etc.) were not subject to MOC analysis.

All of the reports on the Texas City disaster focus on some aspect of management. Both the CSB and Baker reports focused on culture as the prevailing problem. Hopkins focused on organizational structure, leadership, blindness to risk, failure to learn, and other factors as major precursors. BP's organization is decentralized so that the refineries themselves make decisions about how they do business. Hopkins argues that this strategy fails to allow plant managers to learn from incidents that top management might have sequestered as institutional memory.

Hopkins reminds us that the wider context of the Texas City accident is worth thinking about because it demonstrates that Texas City's problems were part of a broader pattern.[21] In 2000, BP's Grangemouth Complex was the only BP site to include all three of its major business streams – exploration, oil, and chemicals.[22] Over a two week period in 2000, three potentially life threatening accidents happened at Grangemouth. The U.K. Health and Safety Executive's (HSE) investigation noted that there were "a number of weaknesses in the safety management

[21] Hopkins, op.cit.
[22] The Grangemouth Complex was sold to INEOS in 2005.

system on site over a period of time.[23] The HSE also identified common themes over all three incidents:

- BP Group Policies set high expectations but these were not consistently achieved because of organizational and cultural reasons;
- BP Group and Complex Management did not detect and intervene early enough on deteriorating performance
- BP failed to achieve the operational control and maintenance of process and systems required by law (HSE, 2003, p.9).

At the end of 2005 BP's partially completed deep water production platform in the Gulf of Mexico, Thunder Horse, suffered a structural collapse and tipped sideways. The cause of the accident was insufficient engineering caused by the company's desire to cut costs. In March, 2006, oil was discovered leaking from BP's pipeline in Alaska. The cause of the leak was corrosion. BP's problems were not limited to its oil business. In 2003 the company was fined for manipulating the US stock market and it admitted to manipulating the North American propane market in 2004.24

BP had a similar failure in the midstream (gas and oil processing and pipeline transportation) portion of its business with the failure of a major pipeline in Alaska. Here again, industry norms related to "pigging" operations were not followed resulting in serious corrosion and pipeline failure, a completely predictable incident.

Looking Forward

All the accident reports about BP's previous accidents noted that cost cutting, lack of training, poor communication, poor supervision and fatigue were contributors to the accidents. Failures in these areas should be examined in the most current catastrophe. Drivers of those failures need to be identified. BP's Management of Change (MOC) program also needs to be examined. Investigators need to know what to look for and how identify potential issues. Engineers are not trained to examine these issues in situ.

In discussing Texas City, the CSB Report and Hopkins draw on high reliability organization theory. A number of organizations are trying to implement high reliability processes to increase safety performance. HRO theory offers a set of conceptualizations and a way for both practitioners and investigators to organize material about management processes.

[23] Health and Safety Executive (HSE) (2003) *Major Incident Investigation Report BP Grangemouth, Scotland 29 May – 10 June, 2000.* A Public Report Prepared by the HSE on Behalf of the Competent Authority. London: HSE.

[24] Hopkins, ibid.

None of these reports fully examines constituencies and their relationships to each other and with the focal organization. The CSB makes recommendations to constituents but they are poorly contextualized. It is often said that Wall Street guides the behavior of energy companies, but constituencies also guide the behavior of organizations. Important constituencies therefore should be examined in detail; if for no other reason than the academic literature on crises is beginning to look at interdependencies among organizations with different goals from the focal organization.

In the BP Gulf case it is clear that one stakeholder, the BOEM, ex Minerals Management Service , may have had questionable relationships with BP. Any investigation can't afford to neglect the interdependence across the two organizations. The September 10, 2008 New York Times makes a strong statement about allegations against MMS, "including… financial self dealing, accepting gifts from oil companies, cocaine use and sexual misconduct."[25] The Washington Post published similar allegations the next day. BP has relationships with many other organizations from contractors to environmental groups. Some of these must be considered in examining the etiologies of the Gulf oil spill.

The DHSG recommends the following be considered by the DOI and BOEM for arctic and deepwater exploratory drilling and production activities:

- Base the regulatory regime on life-cycle Risk Assessment and Management processes (Safety Case Regime) which utilize Proactive, Reactive, and Interactive approaches.
- Base the regulatory regime on development, maintenance, and continued improvement of High Reliability Organizations utilizing High Reliability Management methods.
- Develop a world-leading Research and Development cooperative program with Industry (e.g. American Petroleum Institute, Offshore Operators Committees), academia and with other international regulatory agencies (e.g. Norwegian Petroleum Directorate, UK Health and Safety Executive, Canadian Standards Association).
- Develop regulations based on a combination of Goal Based guidelines (for activities involving high uncertainties) and Prescriptive Based guidelines (for activities involving low uncertainties).
- Develop a Public Outreach program actively engaging the public in the science, engineering, and operations associated with U.S. OCS activities.
- Develop and implement an effective TDS actively engaging the public, the governments (Federal, State, Local), industry, and the environmental community to define acceptable

[25] Savage, C. (September 10, 2008) Sex, Drug Use, and Graft Cited in Interior Department *The New York Times*, A-1.

and desirable risks associated with U.S. OCS activities. Engage the TDS to monitor these operations to assure that the acceptable and desirable risks are achieved.

- Develop an incident, accident, and failure investigation program engaging the National Transportation Safety Board, the Chemical Safety Board, and the Nuclear Regulatory Agency and the Department of Energy.

- Develop a near-miss reporting, analysis, and communications program modeled after the Federal Aviation's Aviation Safety Reporting System.

This report takes the position that the industrial accident approach to understanding this and other similar disasters is inappropriate. It further states that such disasters are contributed to by human and organizational behavior. It sets out some of these behaviors found at the heart of BP's previous disasters and argues that these processes should be examined in the Gulf Oil spill. Finally it argues that interdependencies across organizations also need to be considered in such situations.

Environmental Issues

Looking Back

A careful look at current industry protocols and the collection of oil spill abatement technologies is necessary. Conventional protocol includes the use of chemical dispersants, in-situ burning, containment and absorbent booms, skimmers and shovels used for manual beach cleanup. Questions regarding the efficacy and environmental impacts of these technologies need to be addressed. Although each procedure contributes to oil spill cleanup and recovery, there can be tradeoffs, both positive and negative, with sole or combined use of different procedures.

Our concerns about conventional spill protocol are primarily related to the use of chemical dispersants and in-situ burning as a Stage 1 response and the limitations of all other conventional technologies. Both in-situ burning and dispersion of oil eliminate the possibility of recovering oil from the environment. Oil remains in the environment, but in a state that is not recoverable. Although the fate and transport of oil remaining in the environment after in-situ burning and chemical dispersion has been examined according to standard clean-up protocols, these procedures have been applied under unusual conditions and at extraordinary rates during the ongoing Deepwater Horizon event. Therefore questions remain about the fate and transport of oil, oil constituents, and dispersants in the northern Gulf of Mexico.

In the Deepwater Horizon spill, a precedent was set in using chemical dispersants underwater. This action represents a deviation from standard oil spill cleanup protocol. Dispersants are designed to emulsify oil at or near the water surface, with the intention of preventing oil from moving to shorelines. Based on the LC50 rating (lethal dose for 50% of a population of organisms) Corexit 9500 is toxic in concentrations as low as 2 milligrams per liter of water26. Dispersants are primarily soap, but also have small percentages of petroleum distillates, or solvents, that have a low evaporation point, and thus a high potential for evaporation when applied to a water surface. Consequently, dispersants have a short half-life when applied according to design. The fate and transport of dispersants in underwater environments, particularly when released in large volumes (as is the case with the Deepwater Horizon spill) remain unknown.

Finally, the logic behind the use of dispersants is to break the oil down into small droplets, increasing the surface area and accelerating the consujmption of the oil by naturally occurring microbes that consume oil and oxygen and excrete CO2 and Water. This works well at the surface. However, deep water is notably deficient in oxygen and the transport mechanisms

[26] Product Safety Data Sheet for Corexit 9500A
http://www.deepwaterhorizonresponse.com/posted/2931/Corexit_EC9500A_MSDS.539287.pdf

for the dispersed oil reaching the surface are not presently known. As a result further study is urgently needed to test the validity of using dispersants at depth.

The combustion of crude oil forms a mixture of compounds in solid, liquid, and gaseous phases. Carbon dioxide and water vapor are released as major products. Although both compounds are potent greenhouse gases, neither is considered immediate human health concerns. On the other hand, the minor components released by oil combustion, including particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO2), and nitrogen oxides (NOx) can directly impact human health.27 Volatile organic compounds (VOCs), which evaporate without ignition soon after reaching the water surface, are also harmful if inhaled. The U.S. Environmental Protection Agency (EPA) considers benzene, toluene, ethylbenzene, and xylene as “key toxic VOC” constituents in oil.28

Gases resulting from oil combustion and evaporation have a range of effects on human health. Both sulfur dioxide and nitrogen oxides irritate the eyes, nose, and throat by reacting with water to form sulfuric and nitric acid, respectively. Carbon monoxide, when it reaches the bloodstream, binds to active sites on hemoglobin molecules, decreasing capacity to carry oxygen.29 Of the VOCs mentioned above, benzene is a known carcinogen, possible mutagen, and is toxic to the blood, bone marrow, and central nervous system (MSDS); ethylbenzene is a known mutagen, possible carcinogen, and may be toxic to the central nervous system (MSDS); xylene is a possible teratogen and may be toxic to the kidneys, liver, upper respiratory tract, skin, eyes, and central nervous system (MSDS); toluene may be toxic to the blood, kidneys, the nervous system, liver, brain and central nervous system (MSDS).

Containment booms are designed to temporarily prevent the spread of oil at the surface of the water while sorbent booms aid in oil recovery. In many cases, the containment booms have failed as a result of rough water conditions common to the Gulf of Mexico. Conventional, polypropylene-filled sorbent booms require disposal at Department of Quality permitted landfills where they will persist in the environment indefinitely because the materials are non-biodegradable30. The recently formed Interagency Alternative Technology Assessment Program (IATAP) could provide a mechanism for adopting new and promising technologies, such as natural fiber boom technology. There is currently an abundance of EPA approved bagasse-filled (sugar cane fiber) booms made from material grown and manufactured in Southern Louisiana. Both the bagasse fill material and the absorbed oil can biodegrade.

[27] Barnea, Nir. 2005. Health and Safety Aspects of In-situ Burning of Oil, National Oceanic and Atmospheric Administration, Seattle, WA, U.S.A.
[28] Odors from the BP Spill, 2010. U.S. Environmental Protection Agency and Centers for Disease Control and Prevention, Washington D.C., U.S.A.
[29] Sadava, D., H.C. Heller, G.H. Orians, W.K. Purves, and D.M. Hillis, 2006. *Life: The Science of Biology*, W.H. Freeman, New York, New York, U.S.A.
[30] Coast Guard and EPA Directive on Waste Management. http:/www.epa.gov.bpspill/waste.html#plans

The ecological effects of oil in the environment range from immediate toxicity and death to sustained, generations-long population declines following exposure. The sensitivity of biota to oil, oil constituents and dispersants varies considerably. However, many species that occur in areas of oil exploration or oil production are considered to be at risk due to mechanical, physiological or life history characteristics that elevate the potential for exposure and the likelihood of major effects following exposure. Some life history traits that elevate risk include small population sizes, restricted geographic ranges, and sedentary behaviors (ie. territoriality) that lead to an inability to avoid exposure during a spill event. Some mechanical and physiological traits that elevate risk include filter feeding, retention of oils in fatty layers, and the absence of metabolic enzymes that degrade oil upon ingestion.

Much of what is known about species responses to oil in the environment reflects response and recovery efforts during oil spills rather that proactive research designed according to testable hypotheses. Consequently, knowledge of ecological impacts of oil is narrow, with most information available on systems that have experienced spills of large magnitude. For example, the impacts of oil on arctic shoreline habitats and constituent species have been well characterized over the course of thirty years of research and monitoring following the 1989 Exxon Valdez spill in Prince William Sound. Similarly, the effects of oil on northern Atlantic coastal habitats, including salt marshes, have been characterized in Buzzards Bay (Massachusetts) since the September 16, 1969 spill of 189,000 gallons of #2 fuel oil from the barge Florida, which ran aground off West Falmouth. In comparison, little is known about coastal or off-shore effects of oil in other areas of the United States, including the Gulf of Mexico, which accounts for 31% of domestic oil production.

The need for proactive research, particularly in areas that host extensive oil exploration and extraction activity, is well recognized, but funding has not been sufficient or consistent enough to produce comprehensive baseline understanding of how at-risk species and ecosystems respond to oil in the environment. Several Gulf of Mexico States that host energy industries, such as Louisiana, have maintained or funded small research programs to investigate ecological impacts of oil exposure. Work carried out in Louisiana, for example, has demonstrated that foundational plants in Mississippi Delta coastal marsh ecosystems, such as smooth cordgrass may recover following one growing season after an exposure event[31]. Although this finding suggests that some marsh ecosystems are resilient to exposure, little information is available on the recovery rates of species that depend on marsh habitat, including species that constitute major commercial fisheries such as brown shrimp and blue crab. It is therefore possible that oil exposure leads to “empty house” syndromes, where physical habitats recover but key inhabits do not. Without sufficient and consistent funding, this concern, and similarly important questions about responses to oil in ecosystems that are at high risk of exposure, will remain unanswered.

[31] Pezeshki, S.R., Hester, M.W., Lin, Q., Nyman, J.A. 2000. The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: a review. Environmental Pollution 108: 129-139.

Looking Forward

Lessons from the Deepwater Horizon oil spill can be used to inform future policy and cleanup protocol to better protect the environment. Protocol for dealing with any spill, especially one of this magnitude, should be prioritized as follows:

- Containment and Recovery –the oil needs to be confined to an area where recovery can take place. Open water systems are our best chance of recovering the maximum volume of oil. The recovery of oil from the environment is done through methods of skimming and absorbent booms.

- Remediation – whether through natural attenuation or assisted methods of biodegradation, individual ecosystems should be assessed and monitored to determine best practices for remediation

- Structural modifications – hard and soft structures including but not limited to dikes, berms, and temporary barges utilized for containment and recovery have the potential to change hydrology and undermine the structural integrity of existing coastlines and habitats, such as barrier islands. These interventions should be viewed as temporary and, to the extent that they are utilized, should be removed following stabilization post oil spill disaster.

The progress of these efforts should be closely monitored and thoroughly documented. The Deepwater Horizon well continues to release oil into the open ocean system, some reaching the surface, some remaining in the benthic region near its source and most of the oil collecting in so-called 'plumes' where it remains suspended in the water column. If the oil continues to flow from the well unabated, containment and recovery will be key to prevent damage to Gulf coast ecosystems and communities. Based on research and what we have learned from previous spills, it is possible to make some assumptions regarding the outcome of the Gulf spill as it begins to impact habitats.

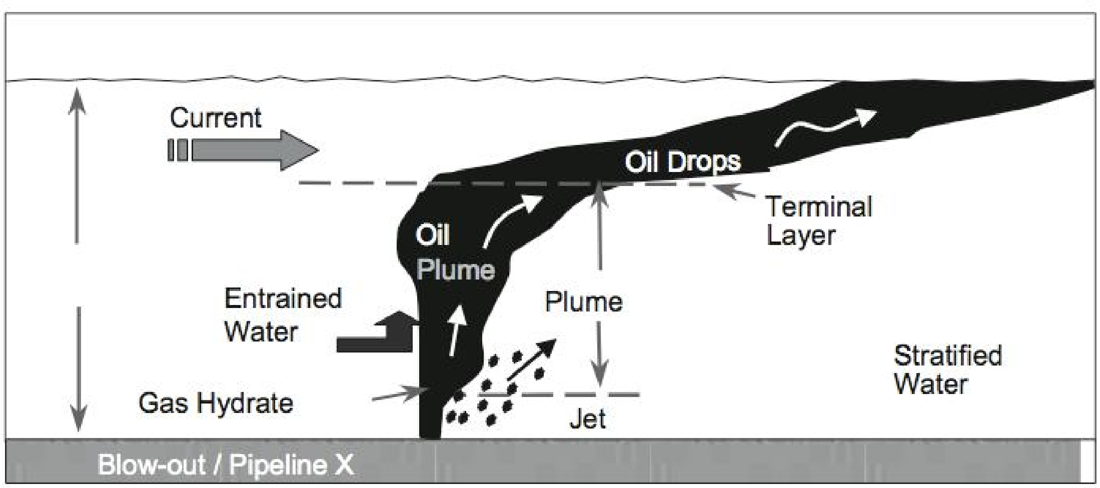
The toxicity of oil to Gulf ecosystems varies by the composition of the oil. Crude oil is composed of hundreds of compounds, including short-chain and long-chain hydrocarbons. Aquatic organisms receive greater exposure to the former due to its larger water solubility—ability to move below the surface. However, long-chain hydrocarbons persist in the environment for a greater length of time than short-chain because they are less volatile and more difficult to degrade by microorganisms. Samples of oil collected from Louisiana wetlands show that the oil is in an emulsion state. This is a result of the oil being degraded in nutrient-rich waters from the Mississippi River laden with fertilizers from agricultural runoff.

The extent of evaporation of oil that reaches the surface depends predominantly on its composition, with hydrocarbons containing fewer carbon atoms, and with lower boiling points, volatilizing more readily. The oil entering the Gulf is of a type known as Louisiana Sweet Crude

(LSC). LSC has small amounts of hydrogen sulfide and carbon dioxide, and is used primarily in gasoline. Based on gas chromatograph analysis of samples collected at the wellhead, the LSC contains a large fraction of short-chain hydrocarbons. Evaporation and dissolution are primary weathering processes, so we can expect the crude at the surface to lose a high percentage of its mass within a few days. This needs to be validated.

Ecosystems likely to be impacted, as currents and winds move the oil considerable distances, include open water systems, sandy beaches on barrier islands, and estuaries that host sea grass beds, mangroves, salt marshes, brackish marshes and freshwater marshes. Natural attenuation is a process whereby these systems recover without human intervention. The ability for an ecosystem to recover, or the rate of attenuation, is limited by a number of factors, including the volume of oil received, levels of biotic activity and abiotic factors such as water movement, temperature and dissolved oxygen levels, as well as sensitivity of constituent species to exposure. The attenuation process needs to be monitored.

A unique aspect of the Gulf spill is that oil and gas are being injected into the ocean at a water depth of 5000 ft. While traveling between the source reservoir and the broken riser pipe, the supercritical (gas+oil) fluid experiences a dramatic reduction in pressure (from ~850 bar to ~150 bar) and temperature (from ~120ºC to 4ºC). Available information from modeling studies and field studies suggest that a potentially significant fraction of oil and gas released during a deepwater blowout will become suspended in diffuse pelagic plumes. Such plumes form naturally and do not result, per se, from dispersant addition at the riser pipe. This suggests that significant attention be given to the issue of dispersant use.



Little is known about what happens to oil and gas in deepwater plumes. Oil in deepwater environments could be oxidized via microbially mediated oxidation and perhaps some of it would sediment to the seabed. The fate for methane and other alkanes in the deepwater is likely hydrate formation possibly followed by microbial oxidation. In the aerobic water column, oil and methane oxidation are coupled to oxygen respiration, therefore hydrocarbon degradation could lead to oxygen depletion. Deepwater oxygen depletion is a concern because oxygen is replenished only by physical processes and such processes could take many years to reestablish pre-spill oxygen concentrations. This should be an issue of concern to the Commission.

Legislation including the Gulf of Mexico Energy Security Act started dedicating funds in 2007 from federal oil and gas leases explicitly to support coastal conservation, restoration and hurricane protection for the Gulf States producing oil and gas (Louisiana, Mississippi Alabama and Texas). The expansion of deepwater leases in 2017 was expected to be in the hundreds of millions of dollars per year. However, because of the structure of deepwater drilling rig contracts, the adverse economic effects of the moratorium could continue for a number of years, jeopardizing the funding of these restoration efforts. It follows that the dependence on these funds to restore these Gulf coast wetland ecosystems should be balanced with safety in future exploration.

Appendix A - Hardware

A1 – Deepwater Horizon Drilling Unit Specifications[32]

Deepwater Horizon		
The DEEPWATER HORIZON is a Reading & Bates Falcon RBS8D design semi-submersible drilling unit capable of operating in harsh environments and water depths up to 8,000 ft (upgradeable to 10,000 ft) using 18¾in 15,000 psi BOP and 21in OD marine riser.		
Rig Type	5th Generation Deepwater	
Design	Reading & Bates Falcon RBS-8D	
Builder	Hyundai Heavy Industries Shipyard, Ulsan, South Korea	
Year Built	2001	
Classification	ABS	
Flag	Marshall Islands	
Accommodation	130 berths	
Helideck	Rated for S61-N helicopter	
Moonpool	21 ft x 93 ft	
Station Keeping	Dynamically Positioned	
Max Drill Depth	30,000 ft / 9,144 m	
Max Water Depth	8,000 ft / 2,438 m	
Operating Conditions	Significant Wave: 29 ft;@ 10.1 sec; Wind: 60 knots; Current: 3.5 knots	

[32] Source: Transocean Website, Fleet Specifications, Retrieved July 14, 2010
http://www.deepwater.com/fw/main/Deepwater-Horizon-56C17.html?LayoutID=17

Storm Conditions	Significant Wave: 41 ft @ 15 sec; Wind: 103 knots; Current: 3.5 knots

Length	369 ft	121 m
Breadth	256 ft	78 m
Depth	136 ft	41 m
Operating Draft	76 ft	23 m
Ocean Transit Draft	29 ft	9 m
VDL Operating	8,816 ft	8000 mt

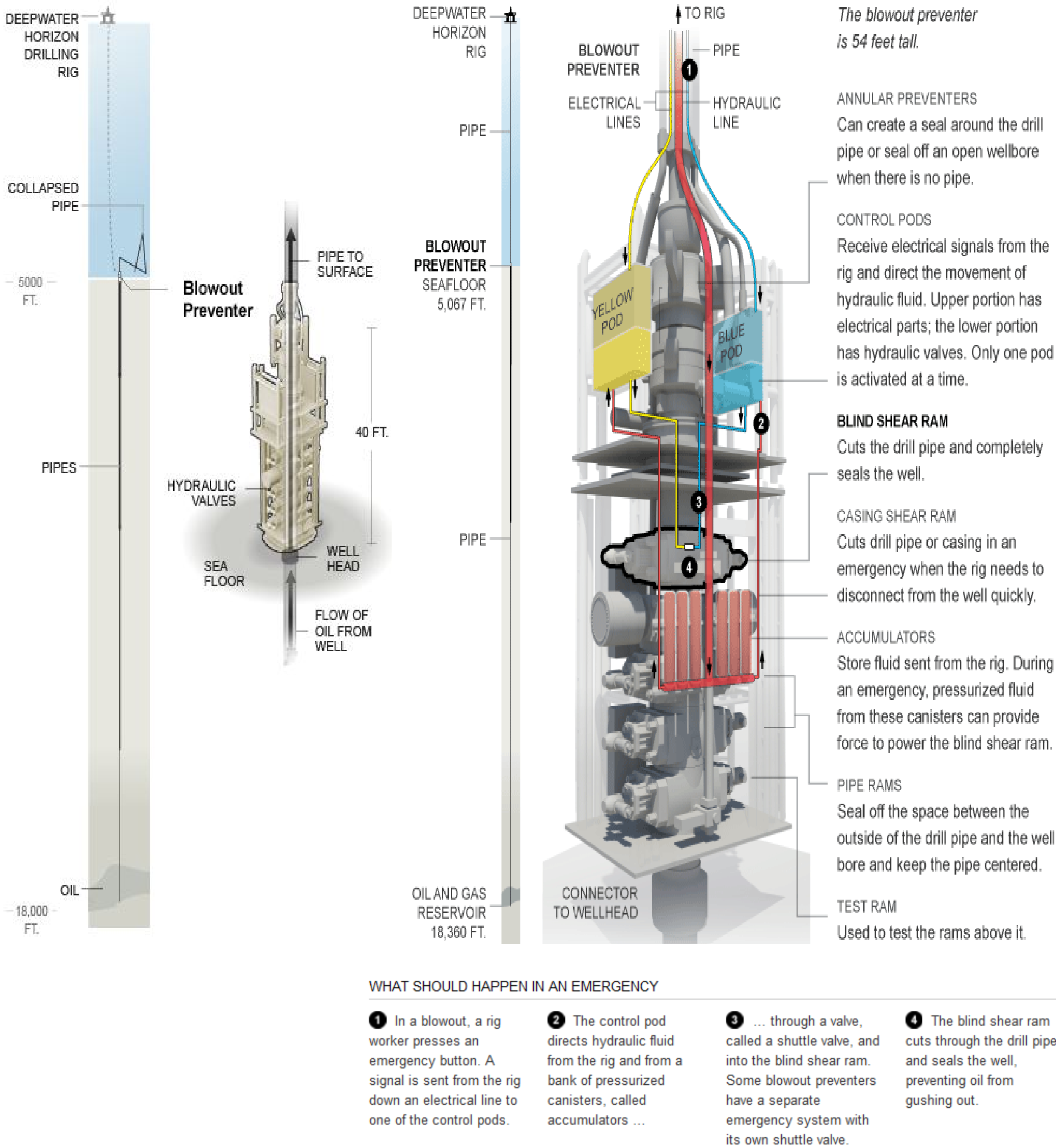
Liquid Mud	4,435 bbls	24,900 cu ft	705 cu m
Drill Water	13,076 bbls	73,415 cu ft	2,078 cu m
Portable Water	7,456 bbls	41,862 cu ft	1,185 cu m
Fuel Oil	27,855 bbls	156,392 cu ft	4,426 cu m
Bulk Mud		13,625 cu ft	386 cu m
Bulk Cement		8,175 cu ft	231 cu m
Sack Material	10,000 sacks		

Derrick	Dreco 242 ft x 48 ft x 48 ft, 2000 kips GNC
Drawworks	Hitec active heave compensating drawworks, 6900 hp rated input power continuous, 2in drilling line
Motion Compensator	Hitec ASA Active Heave Compensator, 13.7 ft stroke, 500 st operating, 1000 st locked
Top Drive	Varco TDS-8S, 750 st, 1150 hp with PH-100 pipe handler
Rotary	Varco RST, 60.5in opening, 1000 st
Pipe Handling	2 x Varco PRS-6i Pipe Packers; Varco AR-3200 Iron Roughneck
Mud Pumps	4 x Continental Emsco FC-2200, 7500 psi
Shale Shakers	7 x Brandt LCM-2D CS linear motion / cascading shakers
Desander	2 x Brandt SRS-3 with 6 x 12in cones
Desilter	Brandt LCM-2D/LMC with 40 x 4in cones over one linear motion shaker, 2400 gpm
Mud Cleaner	See Desilter

BOP	2 x Cameron Type TL 18¾in 15K double preventers; 1 x Cameron Type TL 18¾in 15K single preventer; 1 x Cameron DWHC 18¾in 15K wellhead connector
LMRP	2 x Cameron DL 18¾in 10K annular; 1 x Cameron HC 18¾in 10K connector
Diverter	Hydril 60 with 21¼in max bore size, 500 psi WP and 18in flowline and two outlets
Control System	Cameron Multiplex Control System
Riser	Vetco HMF-Classs H 21in OD riser; 90 ft long joints with C&K and booster and hydraulic supply lines
Riser Tensioners	6 x Hydralift Inline, 50f t stroke, 800 kips each
Guideline Tensioners	N/A
Podline Tensioners	N/A
Choke & Kill	Stewart & Stevenson 3-1/16in, 15K, with 2 x adjustable chokes and 2 x hydraulic power chokes
Cementing	Halliburton (third party equipment)

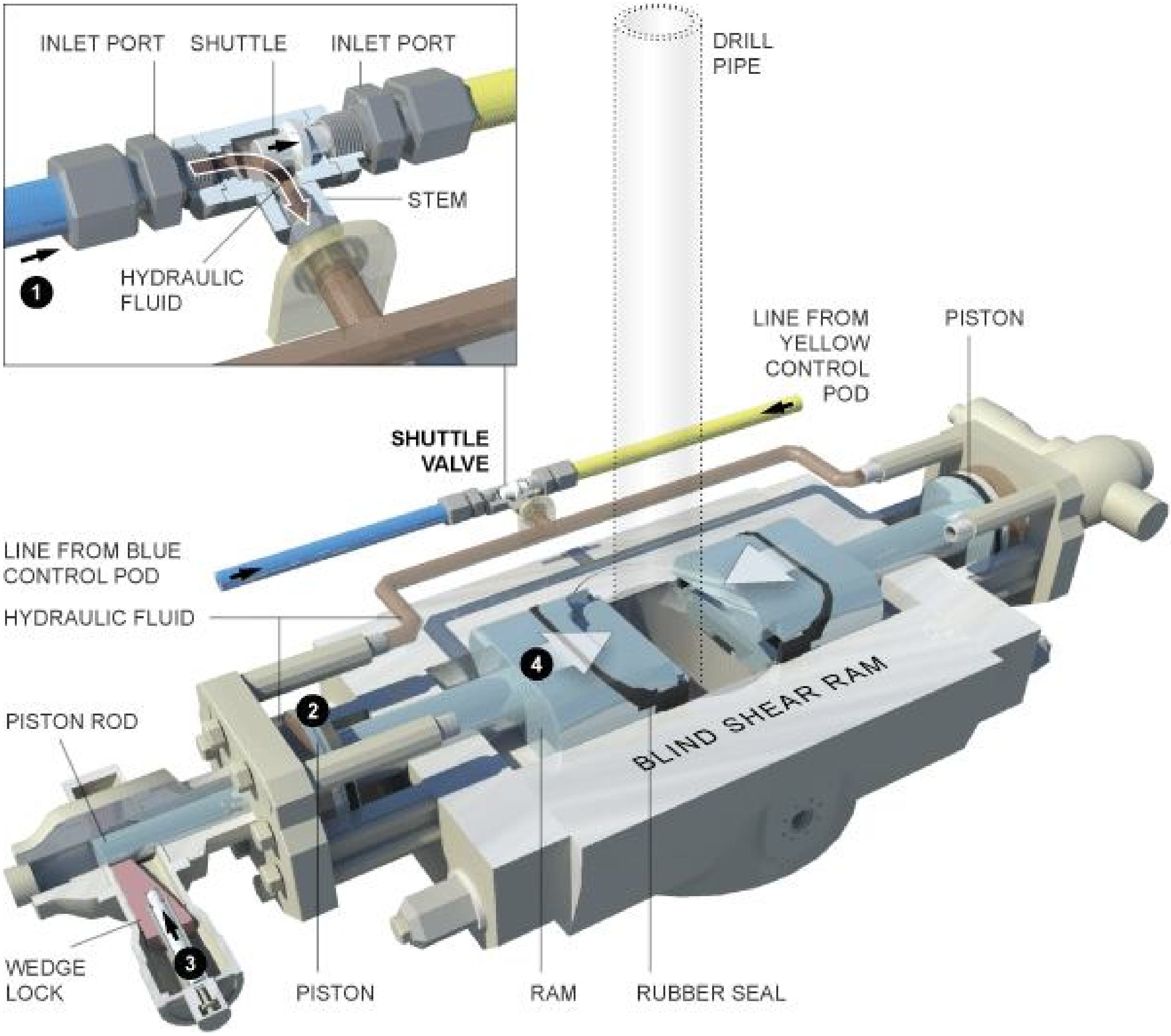
Main Power	6 x Wartsila 18V32 rated 9775 hp each, driving 6 x ABB AMG 0900xU10 7000 kW 11,000 volts AC generators
Emergency Power	1 x Caterpillar 3408 DITA driving 1 x Caterpillar SR4 370 kW 480 volts AC generator
Power Distribution	8 x ABB Sami-Megastar Thruster Drives, 5.5 MW and 6 x GE Drilling Drive Lineups 600 V 12 MW
Deck Cranes	2 x Liebherr, 150 ft boom, 80 mt @ 35 ft
Thrusters	8 x Kamewa rated 7375 hp each, fixed propeller, full 360 deg azimuth
Propulsion	See Thrusters

A2 – Blowout Preventer Stack [33]:



[33] Source: New York Times, *Investigating the Cause of the Deepwater Horizon Blowout*, June 21, 2010. Retrieved July 13, 2010. http://www.nytimes.com/interactive/2010/06/21/us/20100621-bop.html

Blind Shear Ram[34]:



[34] Source: New York Times, *Investigating the Cause of the Deepwater Horizon Blowout,* June 21, 2010, Retrieved July 13, 2010. http://www.nytimes.com/interactive/2010/06/21/us/20100621-bop.html

HOW IT WORKS

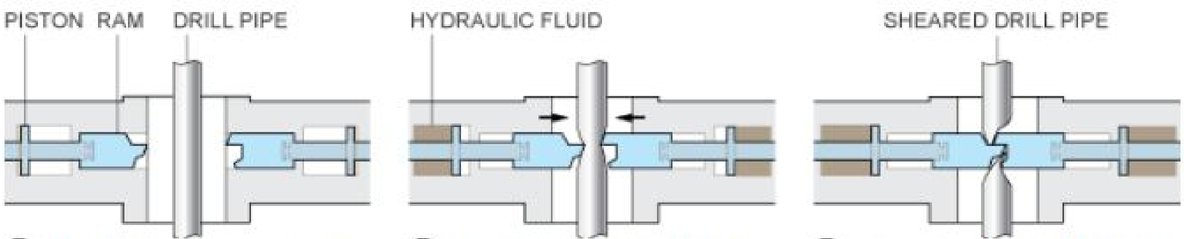
❶ Fluid enters the shuttle valve from one of two inlet ports and pushes a metal "shuttle" to one side and flows down the stem of the T-shaped valve.

❷ The fluid flows behind pistons, which drive the ram to shear the drill pipe.

❸ Wedge locks slide in to prevent the pistons from moving back.

❹ Rubber seals on the ram close off the well. Oil pushing up from the well adds pressure below and behind the ram, helping to keep the ram closed.

HOW THE RAM CUTS THE DRILL PIPE

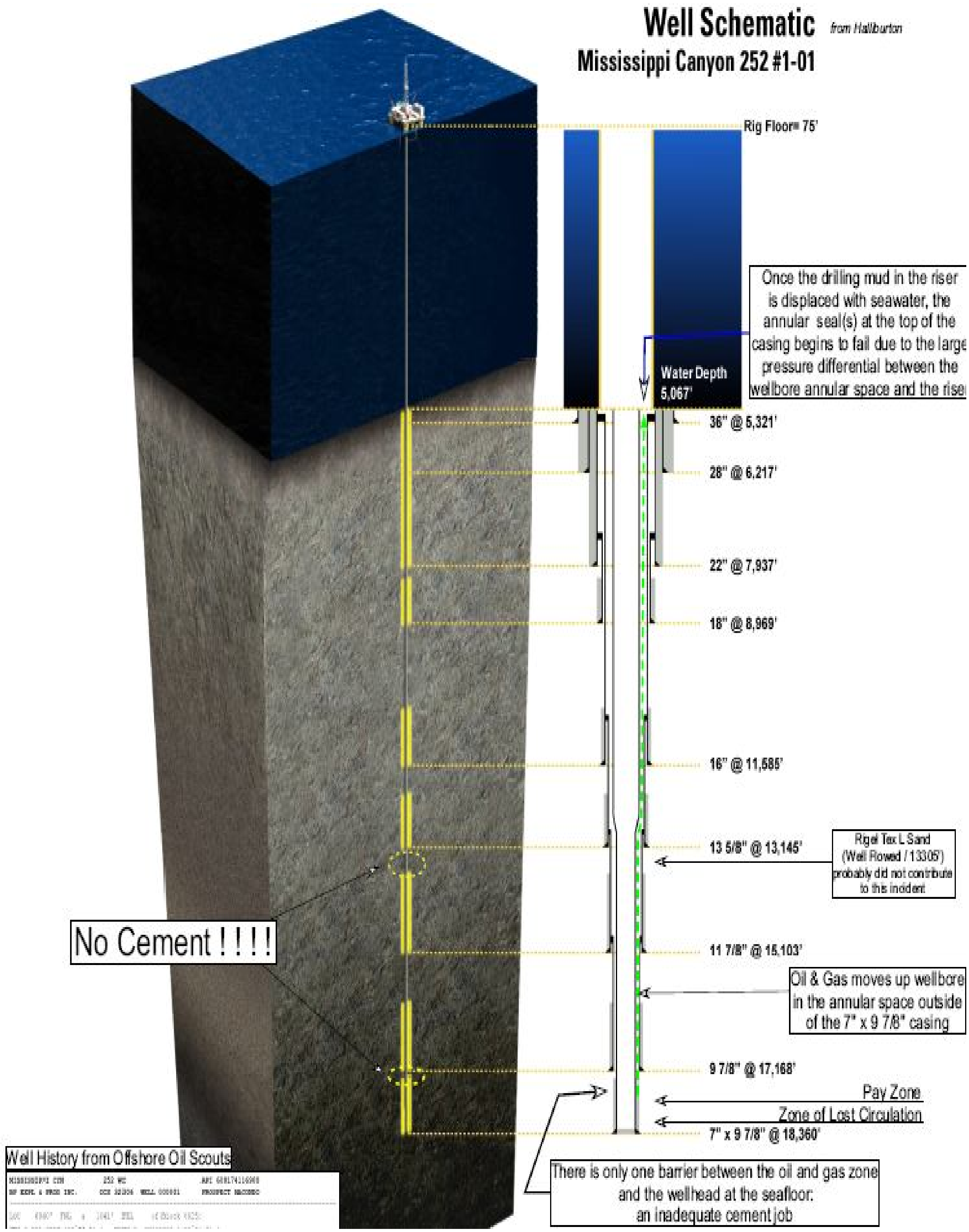


❶ Pistons push the ram toward the pipe.

❷ Offset blades on the ram cut the pipe.

❸ The pipe breaks and collapses.

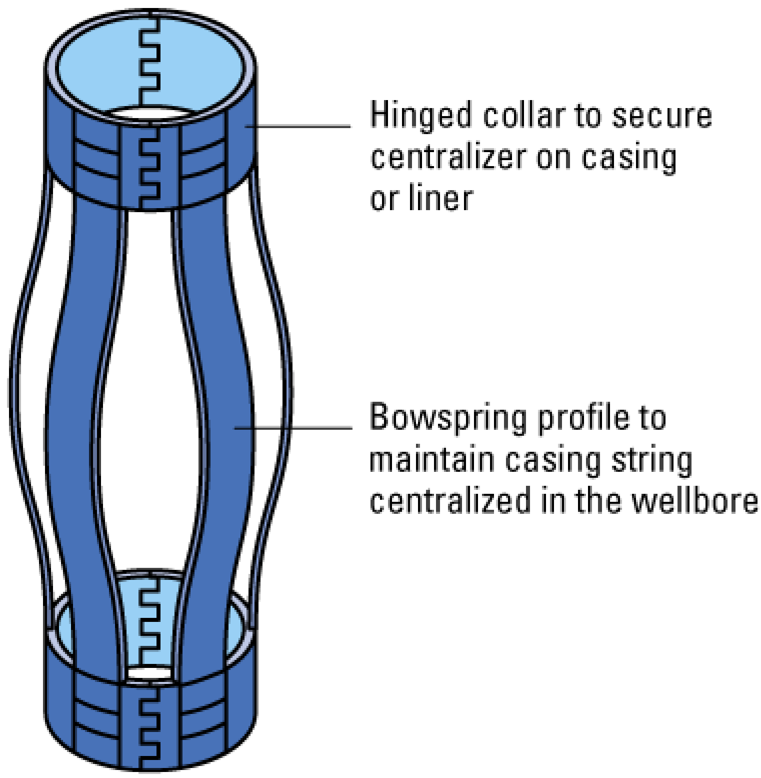
A3 – Casing and Wellbore[35]:



35Testimony to Committee on Energy and Commerce, May 2010.

Cement Centralizer [36]:

A device fitted with a hinged collar and bowsprings to keep the casing or liner in the center of the wellbore to help ensure efficient placement of a cement sheath around the casing string. If casing strings are cemented off-center, there is a high risk that a channel of drilling fluid or contaminated cement will be left where the casing contacts the formation, creating an imperfect seal.



[36] Source: Schlumberger Website, Oilfield Glossary, Retrieved July 15, 2010.
http://www.glossary.oilfield.slb.com/Display.cfm?Term=centralizer

Appendix B - Timeline of Events Leading to Blowout

2008

March

- BP purchases the mineral rights to drill for oil at the Macondo well at the Minerals Management Service's (MMS) Lease Sale #206, held in New Orleans. The well is located in Mississippi Canyon Block 252 in the United States sector of the Gulf of Mexico approx. 41 miles (66 km) off the Louisiana coast. [37]

2009

February

- BP files a 52 page exploration and environmental impact plan for the Macondo well with the MMS. The plan stated that it was "unlikely that an accidental surface or subsurface oil spill would occur from the proposed activities".[38] In the event an accident did take place the plan stated that due to the well being 48 miles (77 km) from shore and the response capabilities that would be implemented, no significant adverse impacts would be expected.[7]

April

- April 6 - The Department of the Interior exempted BP's Gulf of Mexico drilling operation from a detailed environmental impact study after concluding the unlikelihood of a massive oil spill. [39,40]

June

- June 22 - Mark E. Hafle, a senior drilling engineer at BP, warns of the likelihood of collapse of the metal casing for the blowout preventer under high pressure.[41]

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[37] US Minerals Management Service, Central Gulf of Mexico Planning Area Lease Sale 206 Information, http://www.gomr.mms.gov/homepg/lsesale/206/cgom206.html

[38] Burdeau, Cain; Mohr, Holbrook (2010-04-30), *BP didn't plan for major oil spill,* ABC News, Retrieved July 14, 2010. http://abcnews.go.com/Business/wireStory?id=10515973

[39] Eilperin, Juliet (2010-05-05). *U.S. exempted BP's Gulf of Mexico drilling from environmental impact study,* The Washington Post, Retrieved July 14, 2010. http://www.washingtonpost.com/wp-dyn/content/article/2010/05/04/AR2010050404118.html

[40] Jones, Jeffrey; Mason, Jeff, *RPT-BP's US Gulf project exempted from enviro analysis,* Reuters, Retrieved July 10,2010. http://www.reuters.com/article/idUSN0621334420100506?type=marketsNews

October

- October 7 -The Transocean Marianas semi-submersible rig begins drilling of the Macondo well."[42]

November

- November 18 - Transocean Marianas suffers damage from Hurricane Ida. As a result, BP and the rig operator Transocean, replaces the Marinas rig with the Deepwater Horizon. [11]

February

- February 15, 2010 - *Deepwater Horizon* commences drilling on the Macondo Prospect. [43] The planned well was to be drilled to 18,000 feet (5,500 m) below sea level, and was to be plugged and suspended for subsequent completion as a subsea producer.[44]

March

- March 8 - Target date for the completion of the well which had been budgeted to cost $96 million.[11]

- March 10 – Well flowed at 13,305 feet. Lost circulation. Stuck drill pipe.[45]

- March 17 – Unable to fish tools from drill pipe. Plug and sidetrack well.[45]

- March - Internal documents from BP show that there were serious problems and safety concerns with the deepwater horizon well casing and the blowout preventer. After several weeks of problems on the rig, BP was struggling with a loss of "well control". [10]

April

[41] Urbina, Ian (2010-05-30). *Documents Show Early Worries About Safety of Rig*, The New York Times, Retrieved June 14, 2010 http://www.nytimes.com/2010/05/30/us/30rig.html?pagewanted=all

[42] *Letter from Henry Waxman to Tony Hayward - June 14, 2010*, energycommerce.house.gov, Retrieved June 14, 2010 http://energycommerce.house.gov/documents/20100614/Hayward.BP.2010.6.14.pdf

[43] *UPDATED: Search Continues for 11 Missing Workers*, Rigzone, Retrieved July 15, 2010. http://www.rigzone.com/news/article.asp?a_id=91349.

[44] *Macondo Prospect, Gulf of Mexico, USA,* offshore-technology.com, Retrieved 9 May 2010. http://www.offshore-technology.com/projects/macondoprospect/

[45] *Scout Report Mississippi Canyon 252, API 608174116900.*

- April 1 - Marvin Volek, a Halliburton employee, warns that BP's use of cement "was against our best practices." [46]

- April 6 - MMS issues permit to BP for the well, noting: "Exercise caution while drilling due to indications of shallow gas and possible water flow."[47]

- April 9 - BP drills last section with the wellbore 18,360 feet (5,600 m) below sea level but the last 1,192 feet (363 m) needs casing. BP chooses to do a single liner with fewer barriers that is faster to install and cheaper ($7 to $10 million) against Halliburton's recommendation of using a liner/ tieback casing that will provide redundant barriers to flow. [11]

- April 14 - BP drilling engineer Brian Morel, emails a colleague "this has been [a] nightmare well which has everyone all over the place."[11]

- April 15 – Bp Drilling engineer Brian Morel informs Jesse Gagliano,a Halliburton executive, that they plan to use 6 centralizers for the casing. Gagliano's modeling showed that it would require 21 centralizers to achieve only "MINOR" gas flow problem. Morel's response in his email was "it's too late to get any more product on the rig, our only option is to rearrange placement of these centralizers." Gagliano also recommends to circulate the drilling mud from the bottom of the well all the way up to the surface to remove air pockets and debris which can contaminate the cement, saying in an email, "at least circulate one bottoms up on the well before doing a cement job." Despite this recommendation, BP cycles only 261 barrels (41.5 m^3) of mud, a fraction of the total mud used in the well.[11]

- April 15 – BP chose to install a single string of casing instead of a linear and tieback, applying for an amended permit on April 15. MMS approves amended permit for BP to use a single liner with fewer barriers on the same day. [11]

- April 17 - *Deepwater Horizon* completes its drilling and the well is being prepared to be cemented so that another rig will retrieve the oil. The blowout preventer is tested and found to be "functional." [48] Gagliano now reports that using only 6 centralizers "would likely produce channeling and a failure of the cement job." [11]

- April 18 - Gagliano's report says "well is considered to have a severe gas flow problem." Schlumberger flies a crew to conduct a cement bond log to determine

[46] Brown, R.; Zeller, T. (June 6, 2010) *In Gulf, It Was Unclear Who Was in Charge of Rig*, The New York Times, Retrieved July 14, 2010. http://www.nytimes.com/2010/06/06/us/06rig.html?pagewanted=3
[47] Wald, Matthew L. (2010-05-19). '*Exercise Caution,' the Drilling Permit Said,* Green Blog – The New York Times, Retrieved July 14,2010. http://green.blogs.nytimes.com/2010/05/19/exercise-caution-the-drilling-permit-said/?hpw
[48] Newman Testimony - May 11, 2010, senate.gov

whether the cement has bonded to the casing and surrounding formations. The cement bond log is required in rules. [10, 11]

- April 19 - Halliburton completes cementing of the final production casing string.[49]

- April 20 – 7 am - BP cancels a recommended cement bond log test. Crew leaves on 11:15 am flight.[11] BP officials gather on the platform to celebrate seven years without an injury on the rig. [50] 9:45 pm - Gas, oil and concrete from the Deepwater Horizon explode up the wellbore onto the deck and then catches fire. One hundred twentysix people were on the Deepwater Horizon drilling rig when the incident occurred. 11 remain unaccounted for; 17 were injured, 3 of them critically. [51]

- April 22 – The Deepwater Horizon drilling unit sinks.

[49] *Halliburton May Be Culprit In Oil Rig Explosion*, Huffingtonpost.com, Retrieved July 14, 2010. http://www.huffingtonpost.com/2010/04/30/halliburton-may-be-culpri_n_558481.html

[50] *Blowout: The Deepwater Horizon Disaster - 60 Minutes*, CBS News, Retrieved June 4, 2010 http://www.cbsnews.com/stories/2010/05/16/60minutes/main6490197_page2.shtml?tag=contentMain;contentBody

[51] DeepwaterHorizonResponse.com, http://www.deepwaterhorizonresponse.com/go/doc/2931/534651/