



US CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

INVESTIGATION REPORT VOLUME 1

EXPLOSION AND FIRE AT THE **MACONDO WELL** (11 Fatalities, 17 Injured, and Serious Environmental Damage)



DEEPWATER HORIZON RIG

MISSISSIPPI CANYON BLOCK #252, GULF OF MEXICO

APRIL 20, 2010

KEY ISSUES IN VOLUME 1

- MACONDO INCIDENT BACKGROUND AND GENERAL DESCRIPTION
- DEEPWATER DRILLING AND TEMPORARY ABANDONMENT OF THE MACONDO WELL

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Volume 1

Macondo-specific incident events: Relevant background on deepwater drilling and temporary abandonment

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Acronyms and Abbreviations

APD	Application for Permit to Drill
BOEM	Bureau of Ocean Energy Management (United States)
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement (United States); the US offshore safety regulator between June 18 and October 1, 2011 ^a
BOP	Blowout Preventer
BSEE	Bureau of Safety and Environmental Enforcement (United States); US offshore safety regulator since October 1, 2011 ^b
CSB	United States Chemical Safety & Hazard Investigation Board
DWH	Deepwater Horizon
EDS	Emergency Disconnect System
IADC	International Association of Drill Contractors
MMS	Minerals Management Service (United States); US offshore safety regulator at the time of the Macondo accident until June 18, 2011 ^c
MODU	Mobile Offshore Drilling Unit
OCS	Outer Continental Shelf
ONRR	Office of Natural Resources Revenue (United States)
ppg	pounds per gallon
SEMS	Safety and Environmental Management System
UK	United Kingdom

^a Department of Interior, Order No. 3302, Change of the Name of the Minerals Management Service to the Bureau of Ocean Energy Management, Regulation, and Enforcement (June 18, 2011), <http://www.doi.gov/deepwaterhorizon/loader.cfm?csModule=security/getfile&PageID=35872>. Accessed February 19, 2014.

^b The Reorganization of the Former MMS, <http://www.bsee.gov/About-BSEE/BSEE-History/Reorganization/Reorganization/>. Accessed February 19, 2014.

^c Department of Interior, Order No. 3302, Change of the Name of the Minerals Management Service to the Bureau of Ocean Energy Management, Regulation, and Enforcement (June 18, 2011), <http://www.doi.gov/deepwaterhorizon/loader.cfm?csModule=security/getfile&PageID=35872>. Accessed February 19, 2014.

1.0 Macondo Background and Incident Summary

At the time of the accident, the Deepwater Horizon (DWH) crew had finished drilling and was completing temporary abandonment of the well so that a production facility could return later to extract oil and gas from the well.

The Macondo well was exploratory in nature, meaning significant uncertainty remained about the geology, the petroleum resources, and the formation characteristics that make the well easy or difficult to drill. Managing such uncertainties ultimately determines a company's success.

On the day of the April 20 tragedy, no effective safeguards were in place to eliminate or minimize the consequences of a process safety incident.^a The safeguards (or barriers) intended to prevent such a disaster were not properly constructed, tested, or maintained, or they had been removed. The management systems intended to ensure the required functionality, availability, and reliability of these safety critical barriers were inadequate. Ultimately, the barriers meant to prevent, mitigate, or control a blowout failed on the day of the accident.

1.1 Involved Parties

BP Exploration & Production Inc. (BP)^b was and is the main lease holder/operator of the block of land^c that includes the Macondo well site.^d BP identifies itself as the largest leaseholder in US Gulf of Mexico deepwater, owning more than 650 different blocks of land in water depths of 1,200 feet or greater.¹

Offshore lease holder/operators such as BP largely conduct deepwater well drilling and completion activities through a number of contractors. Effective selection, oversight, and coordination among the operator and various contractors are vital to safe offshore exploration. To drill the well at Macondo, BP

Chapter 1.0 Overview

This chapter provides general background as an introduction to the CSB's investigation of Macondo. It is not meant to be all-encompassing. Additional relevant information including key findings appears in subsequent volumes.

This chapter summarizes information on the companies and entities involved in the drilling and temporary abandonment of the Macondo well, the well itself, the Deepwater Horizon rig, and the drilling crew aboard the rig on the day of the incident. It concludes with an incident description summary that identifies the failures in the hours leading up to the explosions and fires aboard the DWH.

^a A process safety incident is the unexpected releases of toxic, reactive, or flammable liquids and gases in processes involving highly hazardous chemicals—*Process Safety Management*, OSHA 3132, 2000 (reprinted).

^b BP p.l.c. is the parent company of many BP group companies, including BP Exploration & Production Inc. (BXP). When referring to "BP," BXP is intended unless otherwise stated.

^c The Outer Continental Shelf has been divided into geographical areas referred to as blocks for identification purposes on maps and in databases, <http://www.data.bsee.gov/homepg/pubinfo/freeasci/leasing/leaselistdfn.asp>.

^d As of February 23, 2010, U.S. Department of Interior documents indicate Anadarko E&P Company LP (22.5%), Anadarko Petroleum Corporation (2.5%), MOEX Offshore 2007 LLC (10%), and BP Exploration & Production Inc. (65%), shared leasing title interests, but as of December 5, 2011, BP retained 100%, <http://www.data.bsee.gov/PI/PDFImages/ACTIVE-LEASE/130/133905.pdf>. Retrieved November 12, 2013.

contracted Transocean, the drilling contractor, and other well service providers, including Halliburton and Sperry-Sun Drilling Services, a subsidiary of Halliburton (Figure 1-1).

As of November 2013, Transocean operated a worldwide fleet comprising 80 different drilling rigs.² In the US Gulf of Mexico, the fleet included 13 ultra-deepwater drilling rigs, which have the same water depth capability as the Deepwater Horizon's, 7,500 feet and greater. Transocean has stated that BP was one of its most significant customers in 2012, accounting for approximately 11 percent of operating revenues.³

As indicated in Figure 1-1, Cameron was not directly contracted to BP, but the original contract between Transocean and BP specified the configuration of the blowout preventer and made specific references to "Cameron or equivalent" components throughout the contract.⁴ Cameron provided updated parts, testing, technical assistance, and repair services for the Deepwater Horizon BOP throughout its service period.^a

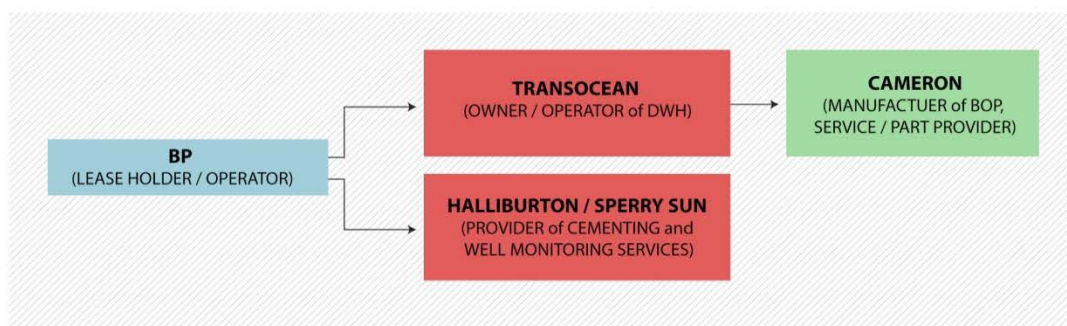


Figure 1-1. Relationship between key companies associated with the Deepwater Horizon accident.

Transocean owned and operated both the Marianas and the DWH drilling rigs that were used at Macondo. It also employed most of the onboard crew of both rigs. As the contracted driller, Transocean was in charge of furnishing and maintaining materials, supplies, equipment, and services required for the drilling and completion activities that occurred at Macondo.⁵ These services included maintaining well control equipment, which the contract between BP and Transocean stipulated would be done according to good oilfield practices and by "all reasonable means to prevent fire and blowouts."⁶ BP retained control of how various aspects of the drilling program would progress by specifying the completion activities (Section 1.5), the mud program (Section 2.1), and the casing program (Section 2.2).⁷

Halliburton Energy Services (Halliburton) and its subsidiary Sperry-Sun Drilling Services provided cementing and well monitoring services to BP during drilling, completion, and temporary abandonment activities at Macondo.⁸

BP, its contractors, and the BOP manufacturer operate worldwide and earn between \$8 and \$375 billion dollars annually (Table 1-1).

^a Cameron provided the CSB with numerous engineering report sheets, signed factory acceptance tests, repair sales orders, and purchase orders.

Table 1-1. Total number of employees and revenue as reported by companies associated with the Deepwater Horizon⁹

	BP	TRANSOCEAN DRILLING CONTRACTOR	HALLIBURTON DRILLING CONTRACTOR	CAMERON
EMPLOYEES WORLDWIDE	85,900	21,000	75,000	27,000
APPOX. REVENUE WORLDWIDE (2012)	\$375.6 billion	\$9.2 billion	\$28.5 billion	\$8.5 billion
APPOX. REVENUE US (2012)	\$130.9 billion	\$2.5 billion	\$12.2 billion	\$3.8 billion

1.2 The US Offshore Regulator

At the time of the Macondo incident, Minerals Management Service (MMS), a division within the Department of the Interior, was the primary offshore regulator responsible for overseeing offshore energy operations to ensure compliance with relevant laws and regulations, predominantly the Outer Continental Shelf Lands Act and 30 CFR Part 250.^a MMS managed the nation's natural gas, oil, and other mineral resources on the Outer Continental Shelf (OCS). Its jurisdiction incorporated developing and implementing plans for leasing conventional and renewable energy resources, safety and environmental protection in all offshore energy activities, and revenue management. MMS minerals revenue amounted to approximately \$13 billion annually, approximately 95% of the total revenue collected by the Department of the Interior.^{b,10}

On May 19, 2010, four weeks following the Deepwater Horizon incident, then-Secretary of the Interior Ken Salazar signed a Secretarial Order to separate and reassign the responsibilities of the Minerals Management Service¹¹ into three independent entities:

^a In addition to the Department of the Interior, several other federal agencies regulate safety and environmental activities on the OCS. For instance, the US Coast Guard regulates marine safety, particularly the "safety of life and property on Outer Continental Shelf (OCS) facilities, vessels, and other units engaged in OCS activities." 33 C.F.R. §140.1. The Environmental Protection Agency regulates air pollution from OCS sources (40 C.F.R. § 55.1) and manages oil spill response in inland waters (40 C.F.R. Pt. 110 and 112). The Outer Continental Shelf Lands Act grants the Occupational Safety and Health Administration the authority to enforce its regulations on the OCS. However, if the working conditions are already regulated by another agency, the Department of the Interior and the US Coast Guard, 4(b)(1) of the Occupational Safety and Health Act and 21(d) of OCSLA prevent OSHA from duplicating their efforts.

^b The Department also manages other natural and cultural resources, including Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, National Park Service, Office of Surface Mining, Reclamation and Enforcement, U.S. Fish and Wildlife Service, and U.S. Geological Survey, <http://interior.gov/whoware/index.cfm>. Retrieved October 28, 2013.

- The Office of Natural Resources Revenue (ONRR), responsible for the royalty and revenue management function, including the collection and distribution of revenue, auditing and compliance, and asset management. On October 1, 2010, the office began its duties.¹²
- The Bureau of Ocean Energy Management (BOEM), responsible for the sustainable development of the Outer Continental Shelf's conventional and renewable energy resources, including resource evaluation, planning, and leasing-related activities.
- The Bureau of Safety and Environmental Enforcement (BSEE), responsible for the comprehensive oversight, safety, and environmental protection of all offshore energy activities.

The changes could not immediately take effect, so in the interim Salazar renamed MMS to Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), to identify the agency's role more accurately.¹³ On October 1, 2011, BOEMRE ceased to exist after transferring its remaining responsibilities to BOEM and BSEE.¹⁴

In the aftermath of the incident, BOEMRE and then BSEE took significant proactive steps to promulgate new safety regulations, including the Interim^{15,a} and Final [Drilling] Rules,^{16,b} the Safety and Environmental Management Systems (SEMS) Rule [30 CFR Part 250 Subpart S],¹⁷ and subsequent amendments (SEMS II).¹⁸

While these are the principal entities of the Macondo case, additional companies, government agencies, and stakeholder organizations are associated with the incident aftermath and general offshore operations. Background information on relevant entities appears throughout the CSB Macondo Investigation Report volumes.

^a Requirements included a one-time recertification of BOPs, ROV capabilities and testing, autoshear and deadman on dynamically positioned rigs, stump test of autoshear and deadman, deadman initial seafloor test, documentation of BOP inspections and maintenance according to API RP 53, and, if shear rams activated on pipe during well control, retrieval and inspection of the BOP.

^b Requirements included third-party verification of subsea BOP "compatibility" and up-to-date engineering, subsea secondary BOP intervention capability and testing, BOP drillpipe shearing capacity at the maximum anticipated surface pressure (MASP), third-party verification of shear calculations, and a BOP surface test between each well.

1.3 The Well, the Rig, and the Crew

The Macondo well is in the Central Gulf of Mexico, in Mississippi Canyon Block #252, approximately 50 miles from Louisiana, the nearest shoreline (Figure 1-2).



Figure 1-2. Location of the Macondo well.

BP acquired the lease for the Macondo well in March 2008¹⁹ and began drilling there in October 2009²⁰ after the offshore regulator approved BP's exploration plan and issued BP a permit to drill.²¹ Two rigs, first the Marianas and then the DWH, were used to drill the Macondo well (Figure 1-3). The Marianas drilled the Macondo well from October 6 to October 29,²² but the Marianas had to be moved to a shipyard for repairs after being significantly damaged by a hurricane;²³ the Deepwater Horizon replaced it, arriving on site with a crew on January 31, 2010,²⁴ and began setup and testing. Drilling resumed in February.²⁵



Figure 1-3. Timeline from when BP acquired the Macondo well lease until the Deepwater Horizon took over drilling the well.

BP planned to drill two exploration wells—Macondo being the first—and follow with a production facility if the oil and gas-bearing region revealed commercial potential.²⁶ The plan was to drill beyond the primary target of approximately 18,400 feet to a total depth 20,200 feet to also assess the sections below the target.²⁷ The water depth of the Gulf at the location was just short of 5,000 feet.

BP designed Macondo for use as a producing well if successful, but the well was, in fact, exploratory because of the uncertainty about both the type and quantity of the oil and gas (hydrocarbons) present at the site and the effort necessary to actually extract the oil and gas. If the well proved commercially viable, data concerning the well's geology and hydrocarbon properties would be collected and used to create a production plan; alternatively, if the well was not viable, the data would be gathered to determine why the commercial predictions failed.²⁸

Ultimately, as BP hoped, the Macondo well was appropriate for conversion to a producing well.

1.3.1 The Deepwater Horizon Rig

The DWH was a mobile offshore drilling unit (MODU) measuring 396 by 256 feet^{29,a} with housing capacity for 146 people.³⁰ The DWH was a dynamically positioned rig that used global satellite technology and thrusters to maintain position over the well rather than cables and anchors to hold it in place.³¹ By their very nature, offshore rigs like the Deepwater Horizon MODU face unique hazards compared to their onshore counterparts. For example, on a rig a substantial number of workers occupy a small living and working area, where escape and rescue from a catastrophic event, such as a hazardous chemical release, fire, or explosion, are inherently more difficult due to the offshore location.

1.3.2 The Crew

At the time of the blowout, 126 people employed by 13 different companies were onboard the DWH (Table 1-2).

Table 1-2. Personnel On Board on April 20 by Company³²

Company	Number of Personnel on Board	General Personnel Roles (not all-inclusive)
BP	8	Engineers, Well Site Leader, Well Supervisor
Transocean	79	Including but not limited to Drillers, Toolpushers, Roustabouts, Mechanics, Crane Operators
Halliburton	2	Cementers
Sperry Sun	2	Mudloggers
Catering	14	Food Service, Laundry Workers, etc.
Other	21	Technicians, Mud Engineers, Tank Cleaners, Coordinators

Eighteen of these individuals are typically identified as the crew intimately involved in the drilling and temporary abandonment activities or having direct oversight responsibilities for those activities. (Table

^a For comparison purposes, the dimensions of a National Football League football field are 360 by 160 feet.

1-3 provides additional details relevant in subsequent volumes of the CSB Macondo Investigation Report.)

Table 1-3. Well Control Personnel On Board the Rig on April 20, 2010³³

POSITION	EMPLOYER	RESPONSIBILITIES	No. ON-BOARD	No. ON-DUTY
Driller	Transocean	Operates drilling equipment and monitors rig instruments	6	3
Senior Toolpusher / Toolpusher	Transocean	Supervises and coordinates drilling operations	3	1
Subsea Supervisor	Transocean	Supervises maintenance and repair of subsea and surface equipment and systems	2	1
Offshore Installation Manager (OIM)	Transocean	Manages crew and resources of the rig to achieve optimum performance and ensures the well program is carried out	1	0
Well Site Leader	BP	Leads all activity, HSSE, operations, and logistics at well site	2	1
Cementer	Halliburton	Executes cement programs, including planning and pumping cement jobs, and providing technical expertise	2	2
Mudlogger	Sperry-Sun	Monitors the drilling operation parameters to understand downhole conditions and advises BP and TO on safety / efficiency implications	2	1

1.4 Planning the Well

The goal of drilling a deepwater well is to create a pathway between oil and gas reservoirs trapped beneath the seafloor and the surface.^a To reach the reservoirs, a hole (the wellbore) is drilled through

^a The general references describing drilling used in this chapter include Van Dyke, K. *Fundamentals of Petroleum*, 4th ed. Austin: University of Texas, 1997; *Offshore Well Construction*, 1st ed. Austin: University of Texas, 2005; and *A Primer of Oilwell Drilling*, 7th ed. Austin: University of Texas, 2008. Readers may also review the Chief Counsel's report by the National Commission, which offers more detail than this report, but still at an introductory level. See the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Chief Counsel's Report: The Gulf Oil Disaster*, http://www.oilspillcommission.gov/sites/default/files/documents/C21462-408_CCR_for_web_0.pdf (February 14, 2011). Accessed August 14, 2013.

various layers (formations) of rocks and/or unconsolidated sediments such as sand, shale,^a gravel or silt.^b The formations, such as the target reservoir, are porous^c and permeable, and they contain water, oil, and/or gas which are under pressure. An unplanned flow of these fluids into the wellbore is called a “kick,” which, if not managed, can progress to a “blowout,” the uncontrolled release of oil and gas (hydrocarbons) from the well. This is most dangerous for people and property when the hydrocarbons release onto the drilling facility, where ignition sources are present.

Thus, the flammable and potential explosive nature of oil and gas contained in the reservoir(s) of a potential well is one of the most significant major hazards that must be managed throughout the lifecycle of a drilling and production operation, beginning with the planning stages of the well. Part of the planning process is a well-specific hazard analysis of the operation to determine the appropriate safeguards for mitigating the hazard and control of the risks. (Volume 2, Chapters 4 and 5, of the CSB Macondo Incident Investigation Report addresses the hazard analysis issue further).

1.5 Incident Description

On April 20, 2010, the drilling activities were completed after several productive oil and gas zones had been discovered at Macondo, and the crew was performing a series of steps to temporarily abandon the well. Abandonment activities would essentially plug the well so that the rig could move on to a new drilling site and a production installation could return to the Macondo site at a later date to extract the hydrocarbons.

BP’s temporary abandonment plan^d called for removal of most of drilling fluid column in the well before installation of a surface cement plug.^e Earlier, a critical cement barrier intended to keep the hydrocarbons below the seafloor had not been effectively installed at the bottom of the well, and the cement integrity was not not conducted in a way that provided a clear “pass” or “fail” result to the workers. Both BP and Transocean personnel on the DWH rig misinterpreted the test results concerning the cement integrity, leading them to erroneously believe that the hydrocarbon bearing zone at the bottom of the well had been sealed when in fact it was not. When the drilling fluid column was removed, pressure gradually reduced above the hydrocarbon reservoir at the bottom of the well. Eventually, this action allowed hydrocarbons to flow past the failed cement barrier and up toward the DWH. Meanwhile, because of a failure to recognize the increase in fluids from the well, the crew continued to remove more of the drilling fluid column, causing both the hydrocarbon influx rate into the well and movement of hydrocarbons toward the rig to increase. The hydrocarbons continued to flow from the reservoir for almost an hour without human intervention or the activation of automated controls.

^a Shale is a common deepwater rock.

^b Silt is loose sedimentary material of a size between sand and clay.

^c Porous formations constitute rock or other material that contains small spaces or holes that can hold liquids.

^d A well may be temporarily sealed with cement or mechanical plugs to allow removal of the blowout preventer and departure of the drilling rig.

^e Cement plugs are portions of cement put into a wellbore to seal it. “Surface” is typically used to refer to the most shallow cement plug used in a well.

The force of the hydrocarbons accelerating up the mile-long drilling riser^a resulted in well fluids gushing onto the drilling rig floor—a blowout. At this point, the crew took action to activate the blowout preventer (BOP). This safety critical element,^b located at the sea floor, temporarily sealed the well but could not stop the hydrocarbons that had already traveled above the BOP from releasing onto the rig.

Once oil and gas had risen above the BOP, the only action the crew could take was to divert it to a safer location than onto the rig floor. However, the flow from the diverter had been preset to route well fluids to the mud-gas separator rather than over the side of the Deepwater Horizon. The mud-gas separator was rapidly overwhelmed, as it was not designed to safely handle a flow of the magnitude of the Macondo blowout. As a result, drilling mud and hydrocarbons rained down onto the rig floor. The hydrocarbons found an ignition source, and explosions and fire ensued.

As discussed in detail in Volume 2, both manual and automated emergency systems within the blowout preventer were activated in an attempt to shear the drillpipe and seal the well. However, pressures in the well had caused the drillpipe to buckle, which inhibited the BOP from sealing the well.

The explosion and fire resulted in 11 crew members suffering fatal injuries and 17 others being critically injured.³⁴ The Deepwater Horizon rig sank on April 22, 2010, about 36 hours after the initial explosions.³⁵ Approximately 5 million barrels of oil spilled into the Gulf of Mexico.^c

Ultimately, in the hours leading up to the incident, no effective barriers were in place to prevent or mitigate a blowout. The physical barriers intended to prevent such a disaster were not properly designed for the well conditions, constructed, tested, or maintained, or they had been removed. The management systems intended to ensure the required functionality, availability, and reliability of these barriers were inadequate. An examination of the treatment of safety critical equipment and tasks at Macondo, such as the BOP and cement barrier testing, reveals opportunities for further improvements in effective barrier safety management. Furthermore, a comparison of the US regulatory requirements for these safety critical elements to other international offshore regimes illustrates gaps in the US model and offers support for further post-Macondo changes to the US offshore safety regulations.

^a A drilling riser is a large diameter pipe that connects a drilling rig to the BOP attached to the wellhead.

^b As defined by the UK Health and Safety Executive, safety critical elements are controls (hardware, people systems, or software) or tasks whose failure could cause or contribute to a major accident or which the purpose is to prevent or limit the effects of a major accident; UK Offshore Installations (Safety Case) Regulations 2005, 2 Interpretation, http://www.legislation.gov.uk/uksi/2005/3117/pdfs/uksi_20053117_en.pdf.

^c The total volume of oil spilled has yet to be determined by the U.S. District Court in the multidistrict litigation, but estimates range from approximately 3.2 million to 5 million barrels. *In Re: Oil Spill by the Oil Rig "Deepwater Horizon" in the Gulf of Mexico*, on April 20, 2010, U.S. Br. 1, January 27, 2014, ECF No. 12237; BP Br. 29, January 24, 2014, ECF. No. 12227.

2.0 Deepwater Drilling and Temporary Abandonment of the Macondo Well^a

Drilling a well requires controlling the pressure exerted by oil and gas trapped within the reservoirs that drillers are trying to reach. The pressure, known as pore pressure or formation pressure, is created in part by the weight of the water and rock pushing down from above.

Pore pressure needs to be controlled throughout the subsea drilling and well completion operations to minimize the occurrence of well kicks—Macondo was a particularly challenging well in this regard. Well control actions must be initiated before a kick develops into an uncontrolled hydrocarbon release into the environment—a blowout—because gas that travels up the riser and is released onto the rig where ignition sources are present, is a serious threat to people.

To control pore pressures and prevent kicks during drilling and completion activities, drillers commonly use a variety of physical barriers, including:

- the weight of a column of fluid that fills the hole being drilled (wellbore) and the riser
- steel casing and the cement used to secure it for protecting the sides of the wellbore and preventing hydrocarbons from entering
- cement placed at the bottom of a well to seal the hydrocarbon bearing zone
- a “surface” cement plug—cement placed in a shallow location in the well close to the surface at the seafloor—to seal the wellbore
- drilling equipment known as a blowout preventer (BOP).

Each of these barriers is discussed briefly throughout this chapter, but the BOP receives additional in-depth discussion in Volume 2 of the CSB Macondo Investigation Report. An introductory discussion of these barriers is necessary for a broader examination of the systemic, human, organizational, and regulatory issues that contributed to the incident. This chapter provides a basic description of some

Chapter 2.0 Overview

This chapter focuses on the issue of controlling formation pressures of the well during the deepwater drilling and temporary abandonment operations at Macondo. Basic drilling and completion activities are described, integrated with facts pertaining to the events of April 20, 2010. This information provides the foundation for the CSB’s technical, systemic, organizational, and regulatory analyses in subsequent report volumes.

^a This section focuses on deepwater drilling and temporary abandonment operations from a floating vessel, such as the Deepwater Horizon rig. General references describing drilling include Van Dyke, K. *Fundamentals of Petroleum*, 4th ed. Austin: University of Texas, 1997; *Offshore Well Construction*, 1st ed. Austin: University of Texas, 2005; and *A Primer of Oilwell Drilling*, 7th ed. Austin: University of Texas, 2008. The Chief Counsel’s report by the National Commission offers more detail than this report, but still at an introductory level. See the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling *Chief Counsel’s Report: The Gulf Oil Disaster*, http://www.oilspillcommission.gov/sites/default/files/documents/C21462-408_CCR_for_web_0.pdf (February 14, 2011). Accessed August 14, 2013.

underlying premises to offshore drilling and completion operations and the essential concepts that support the CSB's investigative analysis in subsequent volumes.

2.1 Controlling Pore Pressures with Drilling Fluids

The primary barrier used to control pore pressures while drilling is a column of fluid that fills the wellbore and the riser. Various drilling fluids, such as water or water-based and oil-based drilling muds,^a are circulated down from the rig through the pipe used to drill the wellbore (drillpipe) and the drill bit used to cut through the formations to create the wellbore. Afterwards, the same fluids carry the crushed rock back around the drill bit up through the annular space between the drillpipe and wellbore (also called the annulus) to the surface via the riser, a large diameter pipe that connects a drilling rig to the BOP attached to the wellhead (Figure 2-1). The column of drilling fluid exerts hydrostatic pressure^b on the walls of the wellbore. When the hydrostatic pressure in the wellbore is greater than the pore pressure, the well is said to be overbalanced. In this instance, the fluid column acts as a barrier by pushing back against the pore pressure, thus keeping the hydrocarbons from entering into the wellbore. Keeping a well in this overbalanced state is typically the primary means for controlling pore pressures and the basis of well control. If for some reason the hydrostatic pressure drops below the pore pressure, the well becomes underbalanced and a kick can occur.

Alternatively, if the pressure exerted by the drilling fluids is too high, it can exceed the “fracture gradient,” or the pressure at which the walls of the exposed wellbore break down and drilling mud is lost into the formation.^c These “lost returns” or “lost circulation” events are costly due to expenses related to the lost drilling mud, and they are also dangerous due to the resulting drop in the height of the drilling fluid column, which may result in an underbalanced state if a sufficient volume of the fluid column is lost to the formation and not replaced at the surface fast enough. This, too, can potentially result in a kick or, even worse, a blowout.^d

^a Drilling muds are liquids and mixtures of liquids and solids circulated through the wellbore during drilling operations.

^b Hydrostatic pressure is exerted by liquid at a given point as a result of the weight of the column of fluid above it.

^c The total pressure exerted by the drilling fluids will be a combination of the hydrostatic pressure and additional pressure generated when the drilling fluids are circulated through the annulus. This can be expressed as “equivalent circulating density” (ECD).

^d Closing the BOP on a combined lost circulation event and well kick can lead to an underground blowout. In some cases, an underground blowout can cause pressures to exceed either casing failure pressures or the burst pressure of pressure relief valves known as rupture disks, which are designed to fail before the casing. (See Section 2.2 for casing description). An underground blowout was a serious concern at Macondo because if the installed rupture disks had burst due to the high blowout or kill pressures, a well flow up the annulus ultimately could have resulted in a surface blowout. See National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Chief Counsel's Report: The Gulf Oil Disaster*, Chapter 4.2, http://www.oilspillcommission.gov/sites/default/files/documents/C21462-408_CCR_for_web_0.pdf (February 14, 2011), Accessed August 14, 2013.

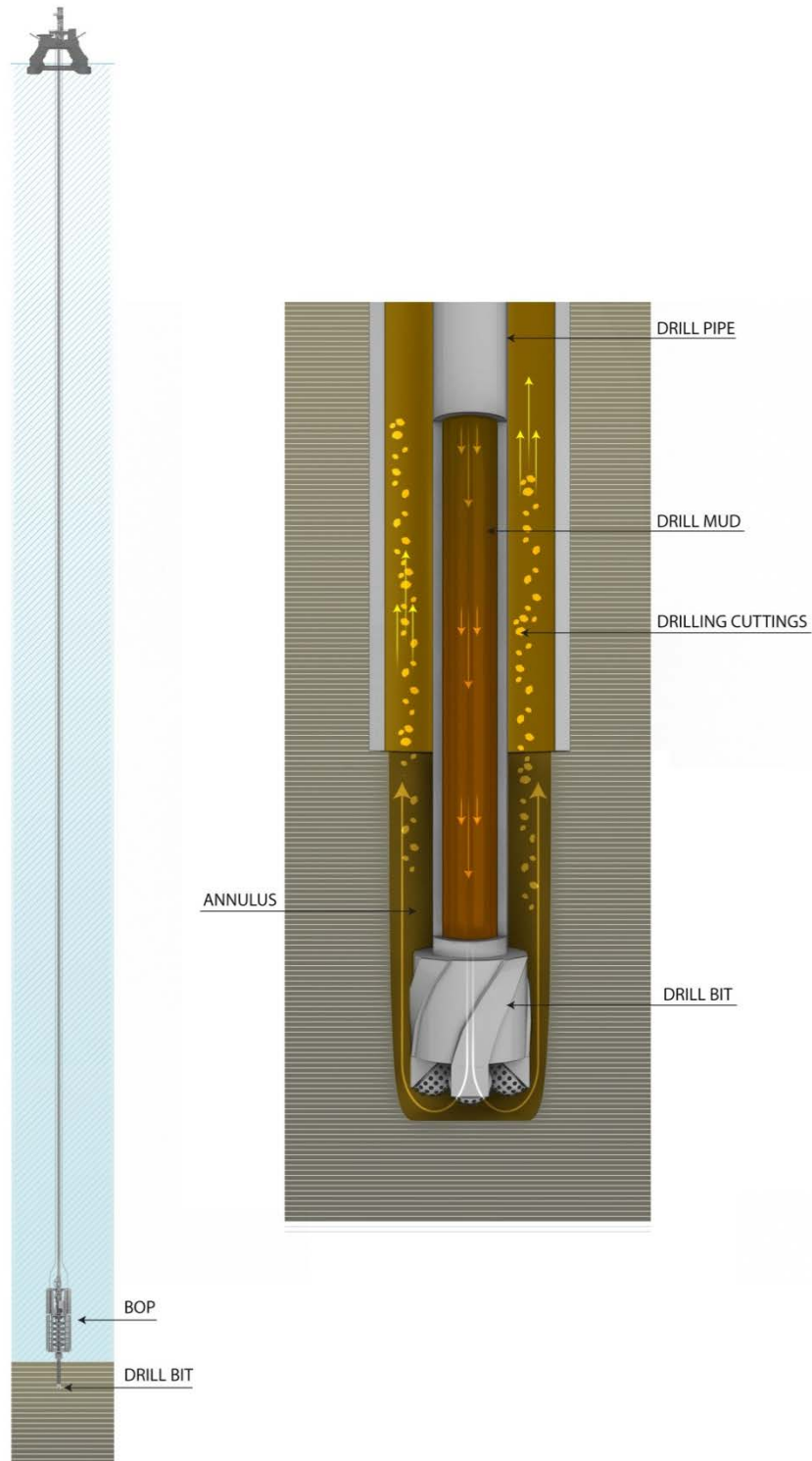


Figure 2-1. During drilling, mud travels down the drillpipe, through the drill bit, and then back up the annulus (yellow), carrying crushed rock back to the rig.

Drilling fluid is formulated as a barrier to keep the pressure at the bottom of the well within the drilling window or margin, which the International Association of Drill Contractors (IADC) defines as “the difference between the maximum pore pressure and the minimum effective fracture pressure.”³⁶ In its well control manual in effect at the time of the Macondo incident, Transocean stated well planning is highly influenced by the drilling margin, as it dictates how drilling is conducted to achieve an efficient and safe operation.³⁷

Applications to drill in the Gulf of Mexico must include the planned drilling margin,³⁸ which is usually submitted in graphic form. Figure 2-2 represents a simplified drilling margin plot and demonstrates that the fracture gradient and the pore pressure typically increase as well depth increases, but not necessarily uniformly or constant relative to one another. The planned drilling margin is given in terms of equivalent mud density, reported in pounds per gallon (ppg), so that pressure can easily be related to the density of the drilling mud column. Mud weight is formulated to remain within the drilling margin to keep well fluids contained and to avoid fracturing the walls of the wellbore, risking a lost circulation event and potentially a subsequent kick. Offshore US drilling regulations state: “[w]hile drilling, you must maintain the safe drilling margin identified in the approved APD [Application for Permit to Drill]. When you cannot maintain this safe margin, you must suspend drilling operations and remedy the situation.”³⁹ The regulations do not specify what the minimum drilling margin should be, but keeping the mud weight at least 0.5 ppg under the fracture gradient is typically accepted practice.⁴⁰

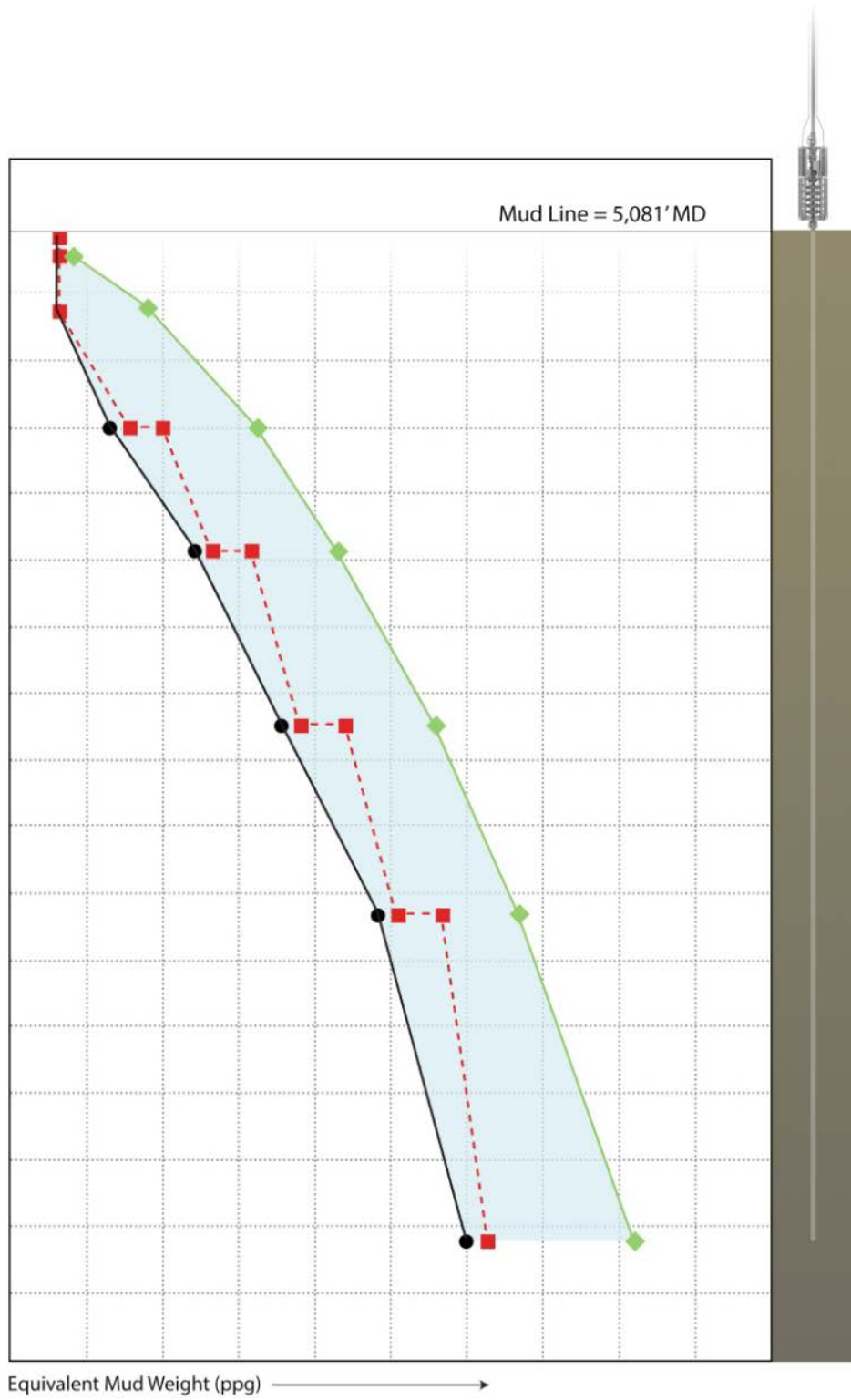


Figure 2-2. A simplified drilling margin plot. The planned mud weight (red dashed line) is formulated to remain less than the fracture gradient (green line) and greater than the pore pressure (black line). New casing transitions (green diamonds) are installed when the fracture gradient is approached.

2.2 Controlling Pore Pressures with Casing and Cement

To avoid exceeding the fracture gradient, the crew drills a well until the total pressure exerted by the drilling fluids approaches the fracture gradient, at which point steel casing lines the wellbore to cover the weaker formations.^a Among other purposes,⁴¹ casing serves to strengthen the wellbore so that it does not fracture or collapse during drilling. Casing is secured in a well by pumping cement into the annular space between the casing and the formation, where it sets and hardens (Figure 2-3). The cement in the annulus and at the bottom of the casing, referred to as the shoe track, should keep drilling fluids from flowing up around the outside of the casing, thus protecting the wellbore, and it should prevent any hydrocarbons in the surrounding formation from flowing into the well. Cement is a crucial physical barrier to secure the integrity of the well, preventing ingress of hydrocarbons into the well and loss of well control. Yet, an MMS study of offshore blowouts published in 2007 noted the most common contributing factor for blowouts between 1992 and 2006 was cementing operations.⁴² Accordingly, cementing operations need to be designed and managed in a manner that does not assume a successful cement job.

^a “Casing” is a generic term for steel pipe. Formally, casing also refers to pipe if it extends up to the wellhead. A section of pipe also can be hung from the bottom of a previous casing. In this case, it is called a “liner.” Liners can hang from casing or from another liner. The intended effect on control of drilling margin is the same.

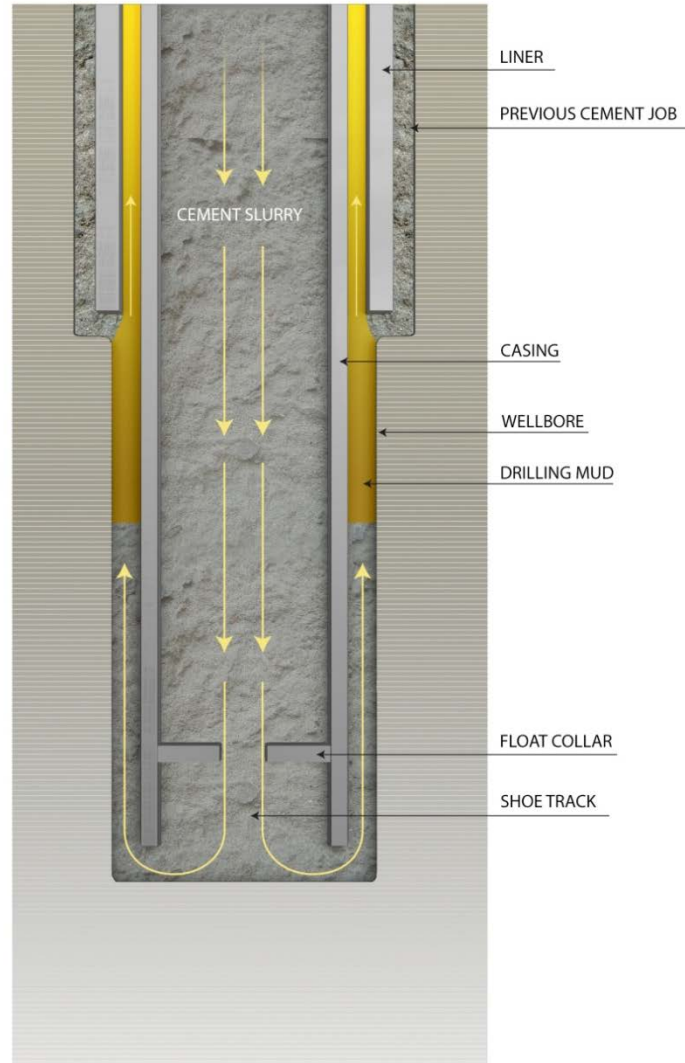


Figure 2-3. Cementing casing in place involves filling the annulus with cement above any hydrocarbon bearing zones if they are present as well as a small length (30'-90') in the shoe track.

After casing has been installed, heavier mud can then be introduced into the wellbore, and operations continue by drilling past the cement at the bottom of casing. The steps observed in the red line of Figure 2-2 are points in the well where the intention is to install casing to protect the weaker formations higher up in the well. Installing new casing can be exercised only a limited number of times because each new installation has to fit down through the casings installed immediately before, so the new casing must be smaller in diameter than the last. Few transitions can be made before the wellbore simply gets too narrow for additional drilling. Current drilling mechanics and the size of well logging instrumentation limit the minimum practical hole size to be a 6-inch diameter except in extraordinary circumstances.⁴³

During the planning of the Macondo well, BP calculated how many times and at what depth to install a casing or liner transitions.⁴⁴ When drilling the Macondo well, the crew encountered differences in the

predicted geology, which resulted in shallower-than-anticipated transitions and ultimately a shallower-than-planned final depth. BP has acknowledged that the final section of the well was difficult to drill due to a narrowing of the drilling margin as a result of an unusual reduction in the fracture gradient at the bottom of the wellbore,⁴⁵ but the already small diameter casing prohibited installation of additional casing large enough to drill further.

Thus, drilling stopped on April 9, 2010, at 18,360 feet below sea level, short of the original well planned depth of 19,650. Despite this change, the well had already encountered a good productive hydrocarbon region for later production. Once the hydrocarbon zone was reached, BP decided to plug and abandon the well for later hydrocarbon extraction.

The process of preparing the well so that the drilling rig can depart until another rig or production facility returns is called temporary abandonment. For temporary abandonment to occur, the well needs to be sealed; until it is, the hazards of a well kick and blowout are still very real. US regulations require cement to be placed at the bottom of the well and the installation of a surface “retrievable or a permanent-type bridge plug or a cement plug at least 100 feet long in the inner-most casing” with the top of the plug required to be “no more than 1,000 feet below the mud line [sea floor]”⁴⁶ unless the company seeks approval for an alternative plan from the regulator.⁴⁷ At Macondo, BP gained approval to set a surface plug at approximately 3,000 feet below the seafloor.^{a,48} In its request, BP acknowledged this was a deep surface plug and stated it planned to extend the surface plug length to 300 feet rather than the minimum requirement of 100 feet “to compensate for the added setting depth.”⁴⁹ In addition to choosing the deep placement of the surface plug, BP also decided to set the surface plug in seawater rather than drilling mud.^b (Figure 2-4).

BP did not have a company standard for developing a temporary abandonment plan. For Macondo, BP considered numerous temporary abandonment plan options in the week or so leading up to implementation. These changes included the location of the surface plug, which ultimately affected the negative pressure test conditions used to assess the bottom hole cement integrity (Section 2.3.1) and displacement of the well.⁵⁰ Many variations are possible for cement integrity testing, each with advantages and disadvantages based on the particular circumstances of the well. (See Appendix 2-A, *Deepwater Horizon Blowout Preventer Failure Analysis*, for details.) While the various temporary

^a This depth was three times the regulatory maximum listed in MMS regulations (30 C.F.R. § 250.1721(d), 2010). The Application for Permit to Modify cites concerns with a piece of equipment called a lockdown sleeve (LDS) for the deviation. Post incident, BP stated in its investigation report that the depth of the surface cement plug was governed by the procedure for installing the LDS. The crew would hang 3,000 feet of pipe in the well to generate the 100,000 lbs. of weight necessary for installing the lockdown sleeve (BP, Deepwater Horizon Accident Investigation Report, September 8, 2010, p. 72). The *Chief Counsel’s Report* generated by the National Commission has challenged this assertion, stating other means were available to generate the necessary weight that would not have allowed the surface cement plug to be set more shallow (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Chief Counsel’s Report: The Gulf Oil Disaster*, February 14, 2011, p. 141).

^b See the panel discussion that BP, Transocean, and Halliburton participated in concerning setting cement plugs in mud versus seawater, National Oil Spill Commission Meeting, November 8, 2010, pp. 209-216. <http://www.oilspillcommission.gov/sites/default/files/documents/Transcript-%20Meeting%2005.pdf>. Last accessed July 25, 2013.

abandonment options BP explored improved the procedure, the CSB found no explicit risk assessment for the final procedure used at Macondo.

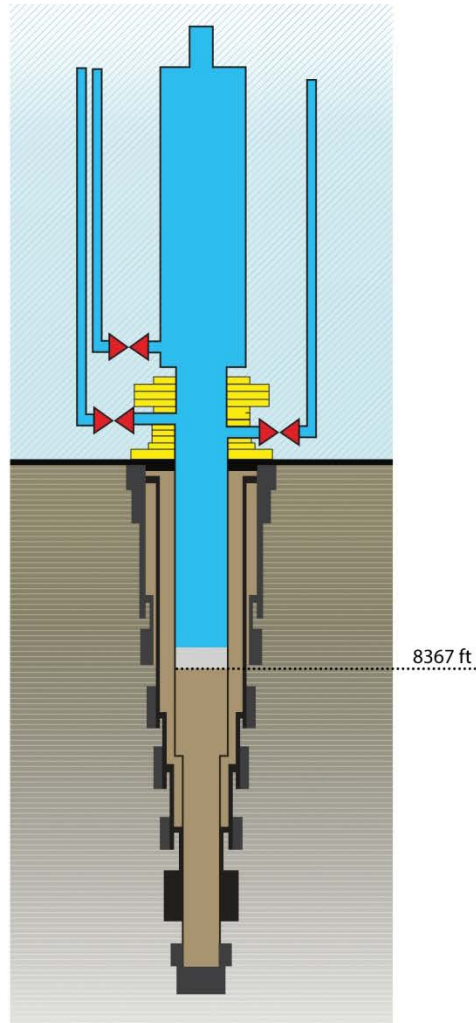


Figure 2-4. The final Temporary Abandonment configuration intended to remove drilling mud down to 8,367 feet to install a cement plug in seawater.

2.2.1 Cement Integrity Testing and Final Displacement

US regulations require conducting a positive pressure test to verify that no leaks are in the well.^a On the day of the incident, the Deepwater Horizon drilling crew conducted a positive pressure test and

^a During a positive pressure test, a well is pressured up and then held in this condition to see if the pressure is maintained, indicating no leaks in the casing. If a decrease in pressure is observed, regulations require that either the well be re-cemented, the casing repaired, or additional casing installed to ensure the well is sealed. 30 CFR §250.423 (2010 and 2012).

determined the Macondo well passed the test.⁵¹ A major limitation of a positive pressure test is that it does not check the cement sealing off the hydrocarbon bearing zones at the very bottom of the well for inward leakage.^a Even though regulations at the time of the incident did not require a negative pressure test, BP's final temporary abandonment plan also called for one.^b

A negative pressure test can assess the integrity of the bottom-hole cement. It simulates an underbalanced well by displacing some of the heavy drilling mud from the well and closing the BOP to isolate the bottom of the well from the hydrostatic pressure exerted by fluids above the BOP. Various methods are available to accomplish the test, and the specific procedure was left to those planning the process.^c Yet, neither BP nor Transocean management provided the Deepwater Horizon crew with a negative pressure test procedure that included acceptance criteria to confirm test success or actions to take if any deviations occurred during the test,^d and the risks associated with conducting the negative pressure test were not formally assessed.

To prepare for the negative pressure test at Macondo, a drillpipe was lowered to the depth identified for the bottom of the cement plug (Figure 2-4). A viscous and dense water-based Loss Circulation Material (LCM) followed by seawater was pumped down the drillpipe to displace the mud by pushing it above the BOP toward the rig.^e After stopping displacement and closing the BOP,^f the crew observed the pressures and/or flow from the well four times over three hours.^g Each time, they observed unexpected results, so

^a A positive pressure test ensures no outflow from the well into its surroundings. One way to conduct the test entails closing the blind shear ram in the BOP (with no drillpipe present) and then pumping drilling mud down a pipe that connects to the BOP below the closed ram to pressure up the well. Cement at the bottom of a well is usually blocked from this pressure by a device known as a "wiper plug," which is installed as part of the casing cement job and which seals against outflow from the well.

^b Regulations have changed post incident to require the negative pressure test, 30 CFR §250.423(c) (2012).

^c Current regulations, 30 CFR §250.423(c), require the operator to submit a procedure and acceptance criteria for approval.

^d For example, instructions from the Ops Note included a single sentence, "With seawater in the kill close annular and do a negative test ... 2350 psi differential," Email communication, "Ops Note," April 20, 2010, BP-HZN-BLY00071107, http://www.md12179trialdocs.com/releases/release201302281700004/Trocquet_David-Depo_Bundle.zip, Exhibit 1992. Accessed December 10, 2013.

^e The *Chief Counsel Report* noted that BP chose to put the LCM into the well to avoid disposing the material as a hazardous waste pursuant to the Resource Conservation and Recovery Act (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Chief Counsel's Report: The Gulf Oil Disaster*, February 14, 2011, p. 151) . The LCM material had never been tested for this application, there was no operational reason to use it, and the lost circulation material spacer was pumped into the well to avoid disposal of the material as a hazardous waste pursuant to the Resource Conservation and Recovery Act. The viscous, gelling nature of the LCM could have plugged a line the crew used to conduct the negative pressure test, greatly contributing to the false positive interpretation of the test. See Appendix 2-A for more details.

^f Most likely the lower annular preventer was closed. Witnesses at the hearings before the Deepwater Horizon Joint Investigation Team gave contradictory recollections: May 27, 2010, p. 36; May 28, 2010, p. 120; August 25, 2010, p. 272.

^g When displacement of the well was stopped to conduct the negative pressure test, as expected some trapped pressure was in the drillpipe. The crew bled the pressure from the drillpipe, which should have resulted in a zero pressure reading on the drillpipe. If the hydrocarbon bearing zone at the bottom of the well had been sealed, no subsequent increase in pressure would have resulted. Pressure did increase and was bled two more times before

they made adjustments before deeming the well passed the final test. The crew's actions suggest they did not realize that the unexpected readings were indications of a failed negative pressure test and that integrity of the cement had not been secured. (See Appendix 2-A for details.)

After the final negative pressure test was erroneously accepted as a "pass," the Deepwater Horizon crew continued the process of displacement, replacing the drilling mud in the wellbore and riser with seawater in preparation to set the surface plug. Replacing dense drilling mud with seawater had the effect of lowering the hydrostatic pressure on the bottom of the well. With the fluid column removed and no surface plug yet set, the only means left for preventing the hydrocarbons from entering the riser and eventually making their way up the well to the rig was detection of the kick by the crew and manual activation of blowout prevention equipment to seal the well.^a

2.3 Controlling Pore Pressures with a Blowout Preventer

If the drilling column fluid (mud weight) barrier and the cement barrier both fail, and the well is still open (no plug installed), drilling crews depend on a blowout preventer (BOP) to control pore pressures. The BOP has two primary roles during drilling and completion operations. First, it is a tool the drill crew manually operates to control or regain control of the well during an initial kick by closing one or more sealing elements. Second, it is an emergency response mitigation device with both manual and automatic functions meant to shear drillpipe, seal the wellbore, and disconnect the rig from the well. A subsea BOP (Figure 2-5) can be massive; the Deepwater Horizon BOP was nearly 57 feet tall and weighed approximately 400 tons.⁵² The BOP is anchored to the top of the well casing at the seabed^b and is connected to a drilling rig by a riser. Drilling equipment, drillpipe, tubulars,^c and other tools used in the drilling process are lowered from the rig, through the riser, through the blowout preventer, and into the well.

While subsea BOPs share general physical characteristics, the actual configuration, the control system, and the performance requirements are specific to each BOP. The Deepwater Horizon's BOP was built by Cameron and had been used on the DWH since the rig began its service in 2001.⁵³

The BOP components vary in their capabilities. Some seal the well around drillpipe, some seal open holes (when no drillpipe is present), and others shear the drillpipe and seal the well. The arrangement of these components within a BOP is based on the characteristics of the offshore operation and the anticipated

the crew used a lack of flow from the well as an indicator of a passed test despite a pressure increase that was detected in the well.

^a Technically, mechanical float valves also are located at the bottom of the well installed as part of the production casing. These valves (also called check valves) allow cement used to install casing to flow one way out the bottom of the casing, but not back up into the casing once cement pumping stops. BSEE does not consider float valves by themselves a mechanical barrier, but they can and often do hold pressure. Float valves cannot be tested independently. Thus, they cannot be considered a reliable device, but they have to fail for the well to flow.

^b The National Commission generated a series of animations to depict not only BOP equipment placement and activation but also helpful drilling practices. See links to animations at <http://www.oilspillcommission.gov/chief-counsels-report>. Last accessed July 30, 2013.

^c As defined by *Schlumberger Oil Field Glossary* (<http://www.glossary.oilfield.slb.com/search.cfm>), a tubular is "A generic term pertaining to any type of oilfield pipe, such as drillpipe, drill collars, pup joints, casing, production tubing and pipeline."

complexities. These components are identified in Figure 2-5, and the specific details of these components on the Deepwater Horizon BOP are discussed in more detail in Volume 2.

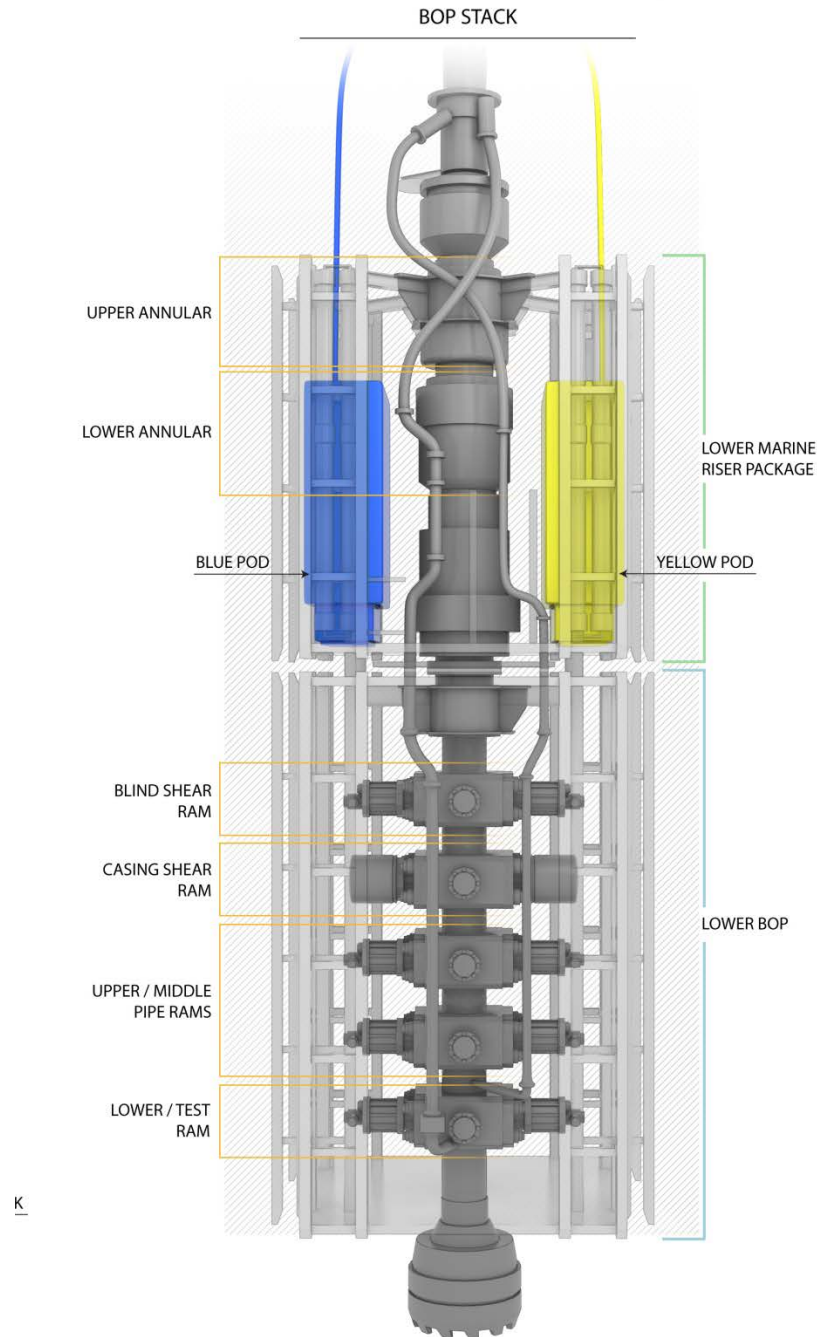


Figure 2-5. The Deepwater Horizon BOP

When drilling mud and hydrocarbons began pouring out of the well and onto the Deepwater Horizon, the drilling crew activated a component called an annular preventer, which should have sealed the space around the drillpipe and prevented further hydrocarbons from rising above the BOP.^a However, well data indicate that this component failed to seal the well.^b Not only did the riser fluids—the hydrocarbons, drilling mud and seawater—that already passed above the BOP continue to travel up the riser and release onto the rig floor, but the riser was also being replenished by the flow of even more hydrocarbons through the leaking component.

Immediately after activating this component, the rig crew also closed the diverter at the top of the riser.⁵⁴ When the diverter shut, flow up the riser exiting onto the rig floor was redirected to the diverter piping. The two potential piping destinations were overboard into Gulf waters or to the Mud-Gas Separator (MGS). On the day of the incident, the diverter was directed to the MGS. Moments after the diverter was closed, the MGS was overwhelmed and hydrocarbons began blowing out of four different exit points onto the rig.

Pressure data^c indicate that the crew closed at least one additional sealing component of the BOP called a pipe ram, which successfully shut in the well but caused the pressure in the drillpipe to build substantially as evidenced by the surface drillpipe pressure building. (See Volume 2, Section 2.3 for details.) Riser fluids above the BOP continued to unload onto the rig floor, but their replenishment temporarily ceased. About two minutes later, the first explosions occurred on the rig and data transmission from the rig to shore ceased.

In the minutes following the explosion, a crew member pressed the Emergency Disconnect System (EDS) button on the bridge BOP remote control panel.⁵⁵ This maneuver should have activated the BOP components that would shear the drillpipe, seal the well, and disconnect the rig and riser from the BOP, thus allowing the DWH to move away from the wellhead. However, there was no indication of EDS actuation which was likely a result of the explosion damaging the rig-based BOP control systems and power and communication lines between the rig and the BOP.

The explosion likely activated the AMF/deadman automatic emergency response system. This system was meant to shear the drillpipe and seal the well, but as evident from the major oil spill that ensued, the well remained unsealed. The likely activation of the AMF/deadman system and the failure of the BOP to seal the well is discussed in detail in Volume 2 (Chapter 3) of the CSB Macondo Investigation Report.

^a Witness statements said that the bridge remote control panel indicated that the lower annular was closed. Hearing before the Deepwater Horizon Joint Investigation, May 28, 2010, p. 145. However, upon recovery, the lower annular was found open [Bureau of Ocean Energy Management Regulation and Enforcement (BOEMRE), March 11, 2011. Forensic Examination of Deepwater Horizon Blowout Preventer, Report No. EP030842.] <http://www.uscg.mil/hq/cg5/cg545/dw/exhib/DNV%20Report%20EP030842%20for%20BOEMRE%20Volume%20I.pdf>, p. 27. Accessed August 14, 2013.

^b If the annular preventer had sealed, the drillpipe pressure at the surface would have rapidly increased to 5,000+ psig (as when the upper pipe ram sealed at 9:47 p.m.). Rather, the drillpipe pressure fluctuated between 1,800 and 400 psig in this time period.

^c See Appendix 2-A and the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Chief Counsel's Report: The Gulf Oil Disaster*, http://www.oilspillcommission.gov/sites/default/files/documents/C21462-408_CCR_for_web_0.pdf (February 14, 2011). Accessed August 14, 2013, p.191.

2.4 Consequences of Explosion and Fire

Of the Deepwater Horizon crew, 11 suffered fatal injuries from the explosion and fire and 17 others were critically injured.⁵⁶ The Deepwater Horizon rig sank on April 22, 2010, about 36 hours after the initial explosions.⁵⁷ Approximately 5 million barrels of oil were spilled into the Gulf of Mexico.^a

^a The total volume of oil spilled has yet to be determined by the U.S. District Court in the multidistrict litigation, but estimates range from approximately 5 million barrels to 3.2 million barrels. In *Re: Oil Spill by the Oil Rig "Deepwater Horizon" in the Gulf of Mexico, on April 20, 2010*, U.S. Br. 1, Jan. 27, 2014, ECF No. 12237; BP Br. 29, Jan. 24, 2014, ECF. No. 12227.

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¹⁸ Final Rule, Oil and Gas and Sulphur Operations in the Outer Continental Shelf—Revisions to Safety and Environmental Management Systems, Docket ID: BSEE-2012-0011, 78 Federal Register 66 (April 5, 2013), pp. 20,423-20,443.

¹⁹ Minerals Management Service, *High Bids Ranked by Bid Amount*, Mar.19, 2008; (OCS Number G32306), http://www.boem.gov/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Leasing/Regional_Leasing/Gulf_of_Mexico_Region/Isesale/206/rpt4_206.pdf. Lease ownership was shared with two other companies, Anadarko Petroleum (25%) and MOEX Offshore (10%); Macondo Prospect Well Participation Agreement Deepwater Gulf of Mexico (Exhibit 2852), http://www.mdl2179trialdocs.com/releases/release201302281700004/Strife_Stuart-Depo_Bundle.zip.

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²¹ MMS Control Number N-09349 (BP-HZN-CSB00093568), April 6, 2009. http://www.defenders.org/sites/default/files/publications/gulf_oil_disaster_complaint_exhibit_3_plan.pdf; Application for Permit to Drill a New Well Approval, Lease G32306, Area/Block MC 252. Publically accessed at <http://www.mdl2179trialdocs.com/releases/release201302281700004/TREX-04021.pdf>.

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