

Chapter 4.9 | The Blowout Preventer

The **blowout preventer** (BOP) is a routine drilling tool. It is also designed to shut in a well in case of a kick, thereby “preventing” a blowout. As described in [Chapter 4.8](#), the rig crew attempted to close elements of the BOP and to activate the emergency disconnect system (EDS) in response to the Macondo blowout. Automatic and emergency activation systems should have also closed the BOP's blind shear ram and shut in the well. Though preliminary evidence suggests one of these systems may have activated and closed the blind shear ram, the blind shear ram never sealed the well.

The federal government has recovered the BOP from the blowout site, and forensic testing is ongoing. Until that testing is complete, a full examination of blowout preventer failure is impossible. In the meantime, the Chief Counsel's team has made preliminary findings and identified certain technical faults that may have prevented the BOP system from activating and shutting in the well.

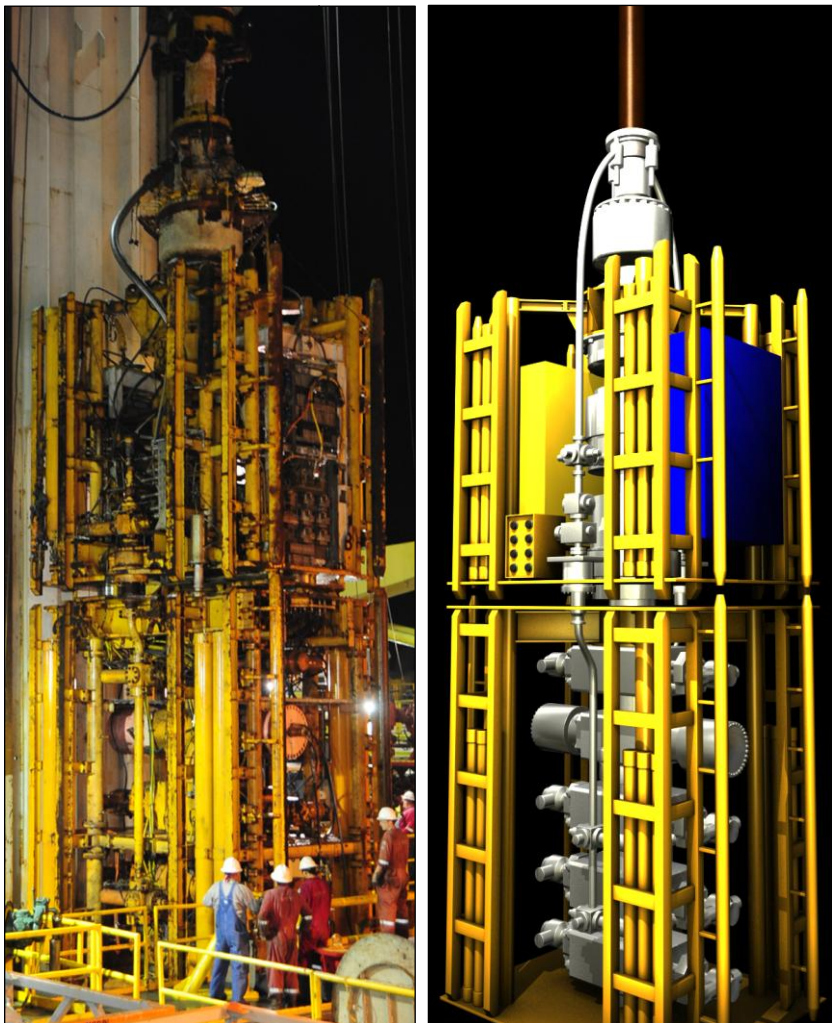
Figure 4.9.1. Transporting the *Deepwater Horizon* BOP.



U.S. Coast Guard photo/Petty Officer 3rd Class Stephen Lehmann

The *Deepwater Horizon*'s blowout preventer on the Mississippi River in transit to Michoud, Louisiana, to undergo forensic testing, September 11, 2010.

Figures 4.9.2 and 4.9.3. The *Deepwater Horizon* blowout preventer stack.



U.S. Coast Guard photo/
Petty Officer 1st Class Thomas M. Blue

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Left: Photo of the recovered *Deepwater Horizon* BOP.
Right: 3-D model of the *Deepwater Horizon* BOP.

Blind Shear Rams

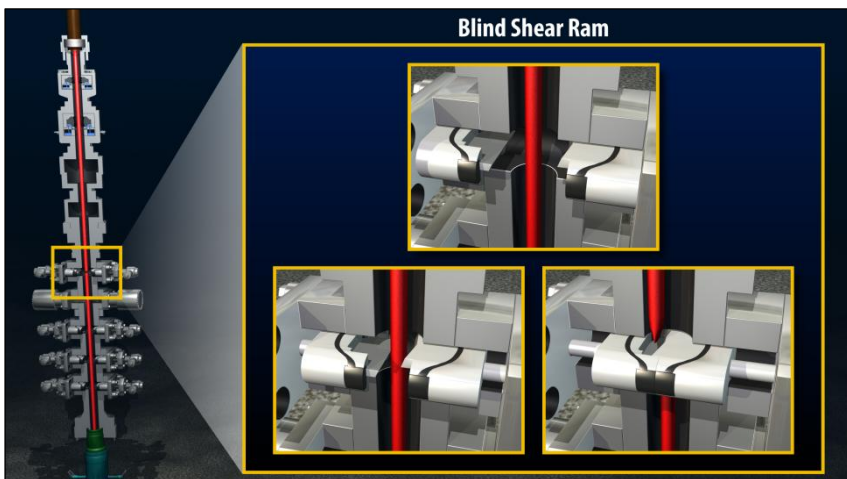
Federal regulations required the *Deepwater Horizon* to have a BOP that included a **blind shear ram** (BSR).¹ The blind shear ram is designed to cut drill pipe in the well (as shown in Figure 4.9.4) and shut in the well in an emergency well control situation.* But even if properly activated, the blind shear ram may fail to seal the well because of known mechanical and design limitations. In order for a blind shear ram to shut in a well where drill pipe is across the BOP, it must be capable of shearing the drill pipe.² And blind shear rams are not always able to perform this critical function, even in controlled situations.

Blind Shear Rams Cannot Cut Tool Joints or Multiple Pieces of Drill Pipe

Blind shear rams are not designed to cut through multiple pieces of drill pipe or **tool joints** connecting two sections of drill pipe.³ It is thus critically important to ensure that there is a piece of pipe, and not a joint, across the blind shear ram before it is activated.⁴ This fact prompted a 2001 MMS study to recommend every BOP to have two sets of blind shear rams such that if a tool joint prevented one ram from closing, another adjacent ram would close on drill pipe and would be able to shear the pipe and shut in the well.⁵ MMS never adopted the recommendation.

The *Horizon's* blowout preventer had only one blind shear ram. Sections of drill pipe are joined by a tool joint at each interval and are often about 30 feet in length, though some of the drill pipe used on the *Horizon* varied in length.⁶ If one of those joints was in the path of the blind shear ram at the time of attempted activation, as portrayed in Figure 4.9.5, the ram would have been unable to shear the pipe and shut in the well.

Figure 4.9.4. Blind shear ram.

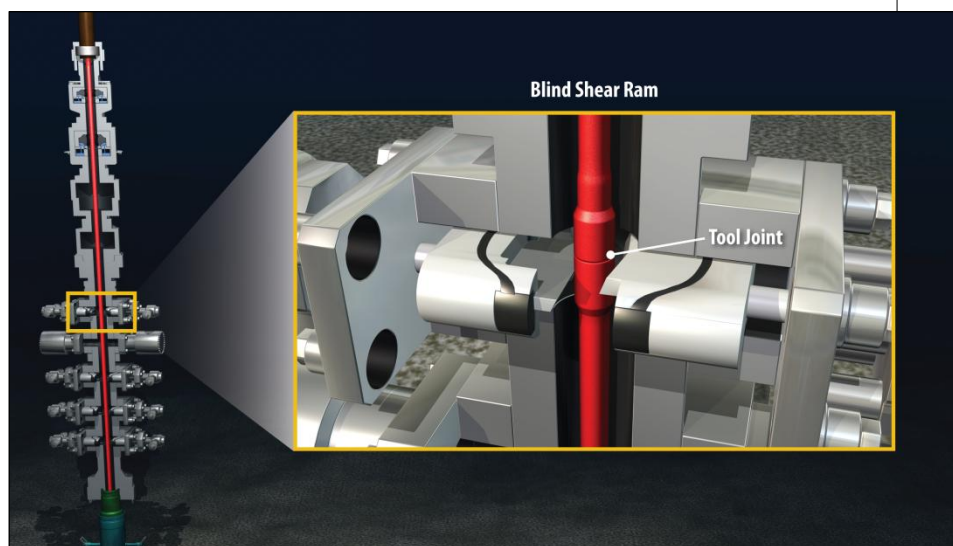


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* Although not separately depicted in Figures 4.9.3 and 4.9.4, there are hydraulic, power, and communications lines (cables), as well as the choke, kill, and boost lines (pipes) running from the rig to the blowout preventer.

Even if a tool joint did not prevent the blind shear rams from shutting in the Macondo well, the inability to shear tool joints is a recognized and significant limitation. The Chief Counsel's team agrees with the MMS study that installing a second blind shear ram would mitigate this risk and increase the probability of success in shutting in a well.⁷

Figure 4.9.5. Tool joint in the blind shear ram.



Blind shear rams cannot cut tool joints.

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Study Finds Deepwater Exacerbates Limitations

A 2002 MMS study conducted by West Engineering Services, a drilling consulting firm, presented “a grim picture of the probability of success when utilizing [shear rams] in securing a well after a well control event.”⁸ The study found that only three of six tested rams successfully sheared drill pipe under operational conditions.⁹ It also found that “operators often do not know how their shear rams would perform in a high pressure environment.”¹⁰ These problems worsen in deepwater because, among other things, deepwater operators often use stronger drill pipes that are more difficult to cut.¹¹ Increased hydrostatic and dynamic pressures in deepwater wells also increase the difficulty of shearing.¹²

Although the study found that these factors were “generally ignored,”¹³ it is not certain whether these factors affected the blind shear ram at Macondo.

Deepwater Horizon Blind Shear Ram Testing

Earlier Tests Establish Shearing Ability

The shearing ability of the *Deepwater Horizon's* blind shear ram was demonstrated on at least two occasions. During the rig's commissioning, the rams sheared a 5.5-inch, 21.9-pound pipe at a shear pressure of 2,900 pounds per square inch (psi).¹⁴ According to pipe inventory records, this was the same thickness and weight of the drill pipe retrieved from the Macondo well.¹⁵ The ram also successfully sheared drill pipe during a 2003 EDS function.¹⁶

The Rig Crew Regularly Tested the *Deepwater Horizon's* Blind Shear Ram, but Often at Reduced Pressures

Regulations require frequent monitoring and testing of the BOP blind shear ram both on surface and subsea. This includes testing the blind shear ram on the surface prior to installation¹⁷ and

subsea pressure testing after installation.¹⁸ The BOP stack was inspected almost daily by remotely operated vehicle (ROV).¹⁹ Like the positive pressure test, other **pressure tests** of the blind shear ram established that the ram was able to close and seal in pressure.²⁰ The rig crew also regularly **function tested** the blind shear ram, which tested the ability of the ram to close but did not test its ability to withhold pressure.²¹ Subsea pressure and function tests do not demonstrate the ability of the blind shear ram to shear pipe.²²

MMS regulations include, among other things, requirements regarding the amount of pressure a BOP must be able to contain during testing. MMS regulations normally require rams to be tested to their rated working pressure or maximum anticipated surface pressure, plus 500 psi.²³ However, BP applied and received MMS approval to downgrade test pressures for several of the *Deepwater Horizon*'s BOP elements. The departure that MMS granted allowed BP to test the *Deepwater Horizon*'s blind shear ram at the same pressures at which it tested casing.²⁴ Though the rig crew tested the blind shear ram to 15,000 psi prior to launch (showing that it would contain 15,000 psi of pressure), subsequent tests were at pressures as low as 914 psi.²⁵ The rig crew also tested the annular preventers at reduced pressures. MMS regulations require that high-pressure tests for annular preventers equal 70% of the rated working pressure of the equipment or a pressure approved by MMS.²⁶ BP's internal guidelines similarly call for annular preventers to be tested to a maximum of 70% of rated working pressure "if not otherwise specified."²⁷ In May 2009, BP filed an application to reduce annular tests to 5,000 psi.²⁸ In January 2010, BP filed another application to further reduce testing pressures for both annular preventers to 3,500 psi.²⁹ It is likely BP sought to test equipment at lower pressures in order to reduce equipment wear.³⁰

BP's lowered pressure testing regime was both approved by MMS and consistent with industry practice. BOP elements are designed to withstand and should be able to withstand higher pressures even if tested to lower pressures.³¹ Nonetheless, low-pressure testing only demonstrates that equipment will contain low pressures. At Macondo, many tests did not prove the blowout preventer's ability to contain pressures in a worst-case blowout scenario.³²

Blind Shear Ram Activated and Sealed During April 20 Positive Pressure Test

On the day of the blowout, the rig crew used the blind shear ram to conduct a positive pressure test.³³ As discussed in [Chapter 4.6](#), the blind shear rams closed and sealed as expected during the test. This fact suggests that the rams were capable of sealing the well when the blowout occurred. But the evidence on its own is inconclusive that the rams could have functioned in an emergency; during the positive pressure test the crew closed the blind shear rams using a low-pressure hydraulic system, rather than the high-pressure hydraulic system that would have activated the rams in the event of a blowout.

Blind Shear Ram Activation at Macondo

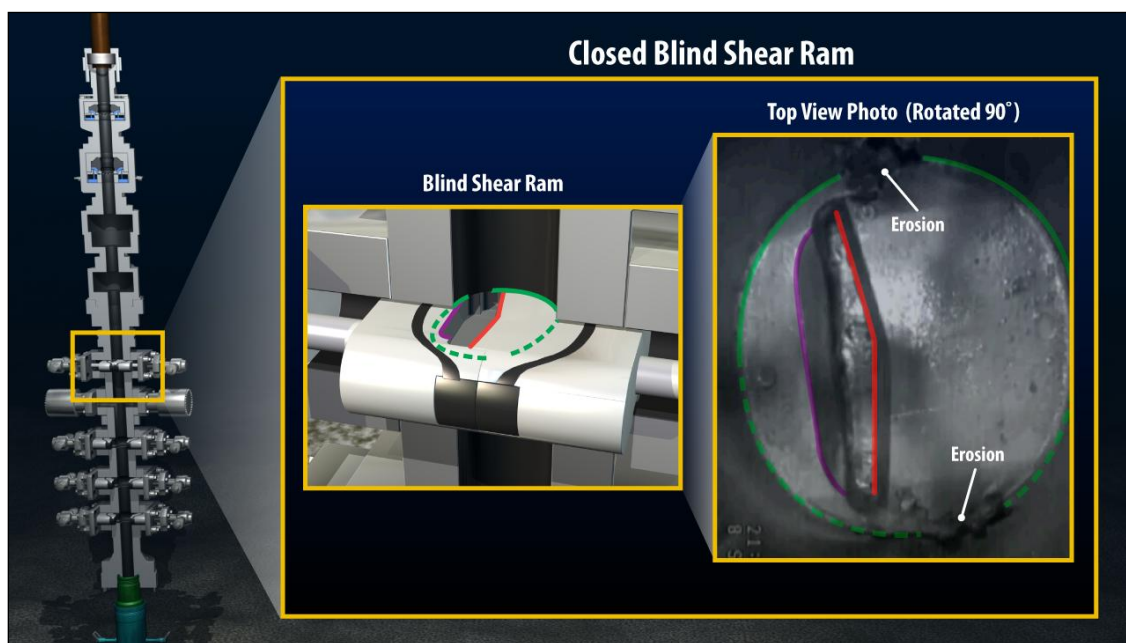
There are five ways the blind shear ram on the *Deepwater Horizon* blowout preventer could have been activated:

- direct activation of the ram by pressing a button on a control panel on the rig;
- activation of the EDS by rig personnel;
- direct subsea activation of the ram by an ROV "hot stab" intervention;³⁴

- activation by the automatic mode function (AMF) or “deadman” system due to emergency conditions or initiation by ROV; and
- activation by the “autoshear function” if the rig moves off location without initiating the proper disconnect sequence or if initiated by ROV.

Preliminary information from the recovered blowout preventer suggests the blind shear ram may have been closed and indicates erosion in the BOP on either side of the ram as pictured in Figure 4.9.6.³⁵ This suggests one of these mechanisms may have successfully activated the blind shear ram but failed to seal the flowing well because high-pressure hydrocarbons may have simply flowed around the closed ram.

Figure 4.9.6. Deepwater Horizon blowout preventer's closed blind shear ram (top view).



TrialGraphix, BP photo

As discussed in [Chapter 4.8](#), there is no evidence that rig personnel attempted to directly activate the blind shear ram from the rig's control panels. Rig personnel did attempt to activate the EDS system after the explosions, but those attempts did not activate the blind shear ram. Emergency personnel in the days following the blowout were unable to shut in the well by directly activating the blind shear ram using an ROV. At various points in time, the deadman function should have closed the ram. Though Transocean has suggested that this system activated the blind shear ram, faults discovered post-explosion may have prevented the deadman from functioning. BP has suggested that post-explosion ROV initiation of the autoshear system activated the blind shear ram.

It is clear that some of these mechanisms failed to activate; forensic testing will likely confirm which, if any, of these triggering mechanisms successfully activated. Even if activated, none of these mechanisms shut in the flowing well.

ROV Hot Stab Activation at Macondo

Rig personnel can also close the blind shear ram by using an ROV to pump hydraulic fluid into a **hot stab** port on the exterior of the BOP. The hot stab port is connected to the blind shear ram hydraulic system; fluid flowing into the port actuates the ram directly, bypassing the BOP's control systems.

In theory, this function should close the blind shear ram when other methods fail. But an MMS study by West Engineering found ROVs may be unable to close rams during a well control event due to lack of hydraulic power.³⁶ The study also found that a flowing well may cause rams to erode or become unstable in the time it takes for an ROV to travel from the surface to the BOP on the seafloor.³⁷

ROVs deployed at Macondo at about 6 p.m. on April 21.³⁸ ROV hot stab attempts to shut in the well on April 21 and 22 with the pipe rams and the blind shear ram failed.³⁹ As discussed below, on April 22 ROVs may have successfully activated the blind shear ram through the AMF/deadman system or autoshear system.⁴⁰ But despite these efforts, the blind shear ram did not shut in the well.⁴¹ Efforts to shut in the BOP through an ROV hot stab continued without success until May 5.⁴² By May 7, BP had concluded that “[t]he possibility of closing the BOP has now been essentially exhausted.”⁴³

Efforts to close the BOP stack were frustrated by organizational and engineering problems. In December 2004, Transocean had converted the lower variable bore ram on the BOP into a test ram⁴⁴ at BP's request.⁴⁵ Because of an oversight that likely occurred during the modification, a hot stab port on the BOP exterior that should have been connected to a pipe ram was actually connected to the test ram, which could not shut in the well.⁴⁶ Unaware of this fact, response teams tried to use that hot stab port to shut in the well.⁴⁷ For two days, they tried to close a pipe ram but were actually activating the test ram instead.⁴⁸ This error frustrated response efforts⁴⁹ until crews discovered the mistake on May 3.⁵⁰ After discovering the mistake, response crews attempted on May 5 to activate the BOP's pipe rams again, with no success.⁵¹

None of the attempted hot stab activations prevented the flow of hydrocarbons from the well. The rig crew had tested the hot stab function before installing the *Deepwater Horizon* BOP, in accord with Transocean's Well Control Handbook.⁵²

There are a number of possible reasons why ROVs were unable to activate the rams using hot stabs. First, the ram may have activated, but the presence of a tool joint or more than one piece of pipe prevented the ram from shearing the pipe and sealing the well. Second, ROV pumps failed during early intervention efforts.⁵³ Third, ROVs were incapable of pumping fast enough and as a result were not able to build pressure against a leak in the BOP hydraulic system.⁵⁴

Automatic Blind Shear Ram Activation at Macondo

Transocean and BP both claim an automated backup system activated the blind shear ram. According to Transocean, the automatic mode function activated.⁵⁵ According to BP, the autoshear system activated.⁵⁶ If activated, neither system sealed the well.

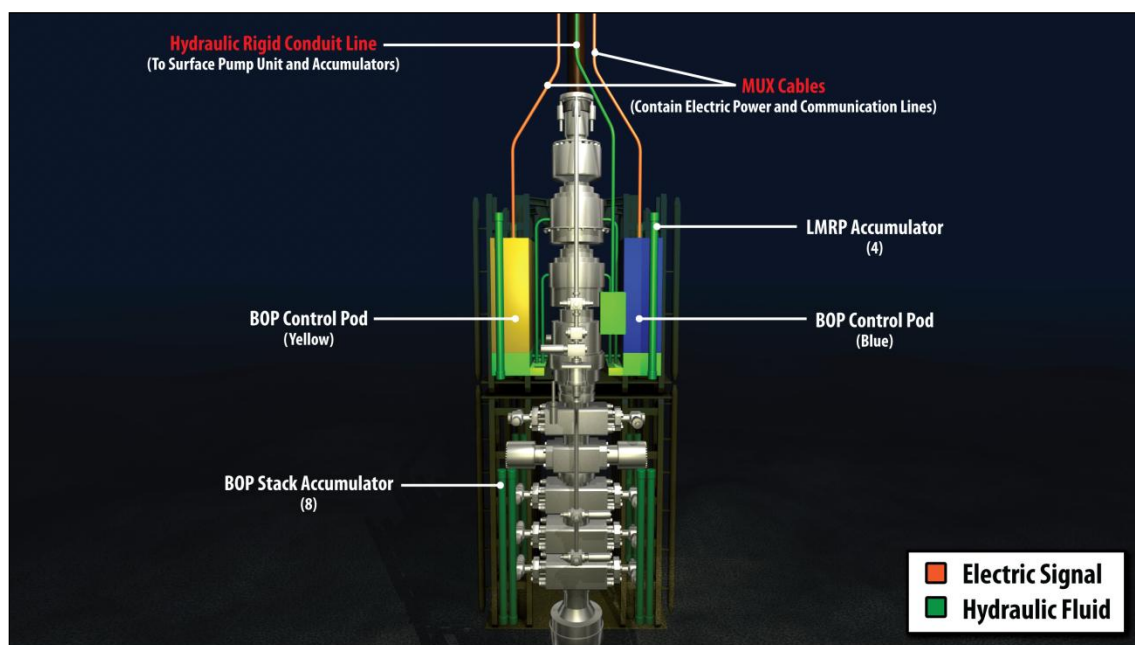
Automatic Mode Function (AMF)/Deadman

The **AMF** or **deadman** system is designed to close the blind shear ram under certain emergency conditions. The system should activate when all three of the following conditions are met:

- loss of electrical power between the rig and BOP;⁵⁷
- loss of communication between the rig and the BOP;⁵⁸ and
- loss of hydraulic pressure from the rig to the BOP.⁵⁹

Catastrophic events on a rig can create these conditions, or emergency workers can trigger them by using an ROV to cut power, communication, and hydraulic lines to the BOP (these components are labeled in Figure 4.9.7).⁶⁰ The AMF will not operate unless rig personnel “arm” it at a surface control panel.⁶¹ Notes from response crews and post-explosion analysis of the BOP **control pods** indicate the AMF system on the *Deepwater Horizon* BOP was likely armed.⁶²

Figure 4.9.7. AMF system.



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The AMF, or deadman, system is activated in emergency conditions.

Based on available information, it appears likely that the explosion on April 20 created the conditions necessary to activate the deadman system. The multiplex (MUX) cables, which carried the power and communication lines, were located near a primary explosion site in the rig's moon pool and would probably have been severed by the explosion.⁶³ The hydraulic conduit line was made of steel⁶⁴ and less vulnerable to explosion damage.⁶⁵ However, the BOP would have likely lost hydraulic power at least by April 22 when the rig sank, and the deadman should thus have activated by that date.⁶⁶ Response crew personnel also tried to activate the deadman on April 22 by cutting electrical wires using an ROV.⁶⁷ According to Transocean, the AMF activated the blind shear ram.⁶⁸

Unclear Whether AMF Activated

It is currently not clear whether the AMF activated the blind shear ram. However, the Chief Counsel's team has identified issues that may have affected the AMF.

First, the universe of available test records may be limited because Transocean destroyed test records at the end of each well.⁶⁹ Second, the deadman system was not regularly tested.⁷⁰ Although Transocean's Well Control Handbook calls for surface testing the deadman system,⁷¹ based on available evidence the AMF was not tested prior to deployment.⁷²

Third, the deadman system relied upon at least one of the BOP's two redundant control pods (yellow or blue) to function. If both pods were inoperable, the system would not have functioned. The rig crew function tested and powered both pods at the surface in February 2010 prior to splashing the BOP.⁷³ But post-explosion examination revealed low battery charges in one BOP control pod and a faulty solenoid valve in another. If these faults were present at the time of the incident, they would have prevented the deadman and autoshear functions from closing the blind shear ram.

Low Battery Charge in the Blue Pod

In the event that electric power from the rig to the BOP is cut off, the BOP's control systems are powered by a 27-volt and two 9-volt battery packs contained in each pod.⁷⁴ These batteries power a series of relays that cause the pod to close the blind shear ram if there is a loss of power, communication, and hydraulic pressure from the rig.⁷⁵ BP tests suggest that it takes at least 14 volts of electricity to power the relays,⁷⁶ and a Transocean subsea superintendent has stated that the activation sequence may require as many as 20 volts.⁷⁷

Tests on the blue pod conducted by Cameron after the blowout on July 3 to 5, revealed that battery charge levels may have been too low to power the sequence to shut the blind shear ram. The 27-volt battery was found to have only a 7.61-volt charge.⁷⁸ One of the 9-volt batteries was found to have 0.142 volts, and the other 9-volt battery had 8.78 volts.⁷⁹ If these battery levels existed at the time the deadman signaled the pods to close the blind shear ram, the low battery levels very likely would have prevented the blue pod from responding properly.⁸⁰ Transocean disputes whether the batteries were depleted at the time of the explosion. Transocean has suggested battery levels were adequate to power the AMF but, due to a software error, may have been left activated and discharged after the explosion.⁸¹ The Chief Counsel's team has not received evidence in support of this assertion but anticipates ongoing forensic testing of the pods will evaluate expected battery levels at the time of the incident.

Available records suggest that Transocean did not adequately maintain and replace its BOP pod batteries.⁸² Cameron recommends replacing pod batteries at least annually, and recommends yearly battery inspection.⁸³ Transocean itself recommends yearly inspection of batteries.⁸⁴

An April 2010 Transocean ModuSpec rig condition assessment stated that all three pods had new batteries installed.⁸⁵ But internal Transocean records suggest that the crew had not replaced the batteries on one pod for two-and-a-half years prior to the Macondo blowout and had not replaced the batteries in another pod for a year.⁸⁶ This appears to have been a pattern: Company records show that rig personnel found all of the batteries in one *Deepwater Horizon* BOP pod dead in November 2007.⁸⁷

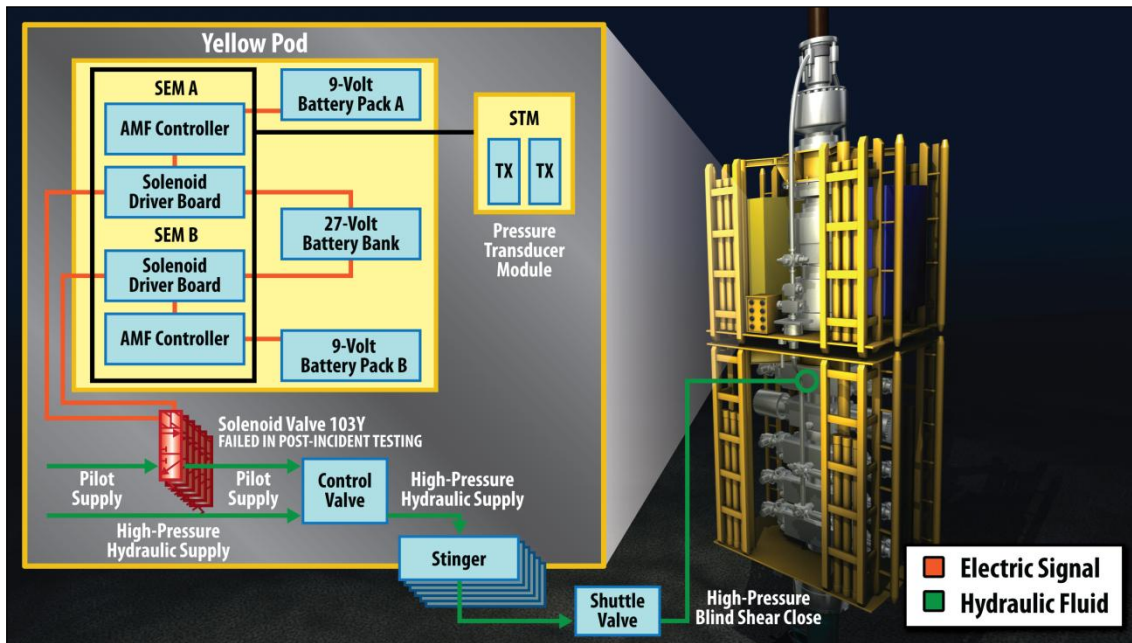
Table 4.9.1. Control pod battery replacements (based on available records).⁸⁸

| Pod | Battery Replacement Dates | Time Between Battery Replacements | Time Between Replacement and Blowout |
|--------|---|-----------------------------------|--------------------------------------|
| Pod 1* | January 26, 2006; April 25, 2009 | 3 years | 1 year |
| Pod 2 | May 28, 2004; December 29, 2005; October 13, 2009 | 1-3 years | 6 months |
| Pod 3 | March 26, 2004; November 4, 2007 | 3 years | 2.5 years |

*The *Deepwater Horizon* had three pods for its BOP; at any given time, one was the “blue” pod, one was the “yellow” pod, and one remained on the surface.

Solenoid Valve Problems in the Yellow Pod

Control pods also rely on functioning solenoid valves (diagrammed in Figure 4.9.8). The solenoid valves open and close in response to electrical signals and thereby send hydraulic pilot signals from the pods to the BOP elements.⁸⁹ The pilot signals in turn open hydraulic valves, which then deliver pressurized hydraulic fluid into BOP rams to close them.⁹⁰ Each solenoid activates when electric signals energize one of two redundant coils in the solenoid.⁹¹

Figure 4.9.8. BOP’s electrical schematic.

TrialGraphix

Tests on the *Deepwater Horizon*’s yellow pod revealed that the solenoid valve used to close the blind shear ram was inoperable.

According to maintenance records, the yellow pod’s solenoids were changed on January 31, 2010.⁹² However, tests on the yellow pod conducted by Cameron after the blowout on May 5 to 7⁹³ revealed that a key solenoid valve used to close the blind shear ram was inoperable.⁹⁴

If this fault existed prior to the blowout, an alarm on the rig's control system should have notified the rig crew and triggered a record entry by the rig's event logger.⁹⁵ According to witness testimony, the rig crew believed the solenoid valve in the yellow pod was functioning as of April 20.⁹⁶

Autoshear System May Have Activated but Failed to Shut in Flowing Well

Like the emergency disconnect system (EDS), the **autoshear** function is designed to close the blind shear ram in the event that the rig moves off position. The autoshear is activated when a rod linking the lower marine riser package (LMRP) and BOP stack is severed. The rod can be severed by rig movements; if the rig moves off position, it will pull the LMRP out of place and sever the rod. Rig personnel can also sever the rod directly by cutting it with an ROV.⁹⁷ Like the deadman, the rig crew must arm the autoshear system at the driller's or toolpusher's control panel.⁹⁸ According to BP's internal investigation, the autoshear function was armed at the time of the incident.⁹⁹ Transocean policy required its personnel to surface test the autoshear system before deploying the BOP, and the *Deepwater Horizon* rig crew conducted a test on January 31, 2010.¹⁰⁰

Response crews used an ROV to activate the autoshear function directly by cutting the rod on April 22 at approximately 7:30 a.m.¹⁰¹ According to BP, response crews reported movement on the stack, which may have been the accumulators discharging pressure and activating the blind shear ram.¹⁰² Even if the autoshear did activate and close the blind shear ram, the blind shear ram did not stop the flow of oil and gas from the well.

Potential Reasons the Blind Shear Ram Failed to Seal

Figure 4.9.9. Erosion in the BOP.



BP

Erosion above the blind shear ram on the BOP's kill side.

Flow Conditions Inside the Blowout Preventer

Even if the blind shear ram activated, it failed to seal the well. One possible explanation is that the high flow rate of hydrocarbons may have prevented the ram from sealing. Initial photos from the recovered BOP show erosion in the side of the blowout preventer *around* the ram, which was a possible flow path for hydrocarbons, as seen in Figure 4.9.9.¹⁰³ Therefore even if the ram closed, the hydrocarbons may have simply flowed around the closed ram.

Presence of Nonshearable Tool Joint or Multiple Pieces of Drill Pipe

As discussed above, the ram may not have closed because of the presence of a tool joint across the blind shear ram. If a tool joint or more than one piece of drill pipe was across the blind shear ram when it was activated, the ram would not have been able to shear and seal the well. Though preliminary evidence suggests these factors may not have impacted the blind shear ram's ability to close, the Chief Counsel's team cannot rule out the possibility of such interference.¹⁰⁴

Accumulators Must Have Sufficient Hydraulic Power

The *Deepwater Horizon* blowout preventer had subsea **accumulator bottles** that provided pressurized hydraulic fluid used to operate different BOP elements. If the hydraulic line between the rig and BOP is severed, these accumulators must have a sufficient charge to power the blind shear ram.

The lower marine riser package had four 60-gallon accumulator bottles were on.¹⁰⁵ On the BOP stack, eight 80-gallon accumulator bottles capable of delivering 4,000 psi of pressure provided hydraulic fluid for the deadman, autoshear, and EDS systems.¹⁰⁶ These tanks were continuously charged through a hydraulic rigid conduit line running from the rig to the blowout preventer.¹⁰⁷ Should the hydraulic line disconnect, the tanks contained compressed gas that could energize hydraulic fluid to activate the blind shear ram. The rig crew checked the amount of pre-charge pressure in the accumulators prior to deploying the BOP in February.¹⁰⁸ However, the available amount of usable hydraulic fluid in the accumulators at the time of autoshear and AMF activation is unknown. If the charge levels were too low, the accumulators would not have been able to successfully power the blind shear ram.¹⁰⁹

BP's internal investigation suggests accumulator pressure levels may have been low based on fluid levels discovered post-explosion.¹¹⁰ Responders discovered 54 gallons of hydraulic fluid were needed to recharge accumulators to 5,000 psi.¹¹¹ BP's investigation suggests a leak in the accumulator hydraulic system may have depleted available pressure levels but not to levels that would have prevented activation of the blind shear ram.¹¹² Response crews observed additional leaks from accumulators during post-explosion ROV intervention.¹¹³

Leaks

It is relatively common for BOP control systems to develop hydraulic fluid leaks on the many hoses, valves, and other hydraulic conduits in the control system. Not all control system leaks affect the ability of the BOP to function: Because BOP elements are designed to close quickly, a minor leak may slow, but not likely prevent, the closing of the BOP.¹¹⁴

Even if a leak is minor, rig personnel must first identify the cause of a leak to ensure that more severe system failures do not occur.¹¹⁵ Constant maintenance, inspections, and testing are required to prevent and detect such leaks.¹¹⁶ Leaks discovered during surface testing should be repaired before deployment.¹¹⁷ If rig personnel discover a leak after deployment, they must decide whether the leak merits immediate repair. Raising and lowering a BOP stack is a complicated operation with risks of its own; taking this action to repair a minor control system leak may actually increase rather than reduce overall risk.¹¹⁸

Leaks May Have Been Unidentified Prior to Incident

According to Transocean senior subsea supervisor Mark Hay, the *Deepwater Horizon*'s BOP had no leaks at the time it was deployed at Macondo.¹¹⁹ Even if no leaks existed when the BOP was deployed, rig personnel identified at least three leaks in the months before the blowout after the BOP was in service.¹²⁰ And rig personnel identified several more leaks during response efforts that according to independent experts were not likely created during the explosion.¹²¹ It is possible leaks developed during the response effort. But it is also possible leaks already existed and the rig crew had not identified or analyzed the impact of the leak.

A leak on the ST lock close hydraulic circuit (leak 3 in Table 4.9.2) may have prevented ROVs from pumping enough pressure to fully close the blind shear ram.¹²² Both BP and Transocean have suggested that a leak on the ram lock circuit (leak 4 in the table) may be proof that the blind shear ram in fact closed.¹²³ Ongoing forensic testing will likely determine if leaks on the BOP control system otherwise affected the BOP's functionality, though it is unlikely these leaks prevented the BOP from sealing.

Table 4.9.2. Leaks on the *Deepwater Horizon* blowout preventer (partial list).

| | Leak | Time of Identification |
|---|---|--|
| 1 | Test ram, pilot leak on yellow pod open circuit shuttle valve ¹²⁴ | Pre-explosion (February 23, 2010 ¹²⁵) |
| 2 | Upper annular preventer, blue pod leak on the hose fitting connecting the surge bottle to operating piston ¹²⁶ | Pre-explosion (February 19, 2010 ¹²⁷) |
| 3 | ST lock close hydraulic circuit leak (this is in the same hydraulic circuit as the blind shear ram) ¹²⁸ | Post-explosion (April 25, 2010 ¹²⁹) |
| 4 | Blind shear ram ST lock circuit leak ¹³⁰ | Post-explosion (April 26, 2010 ¹³¹) |
| 5 | Lower annular preventer open circuit ¹³² | Pre-explosion (date not available ¹³³) |

Identified Leaks Not Reported to MMS

Even if forensic testing concludes leaks on the BOP control system did not impact functionality, it is not clear BP and Transocean adequately responded to known leaks. According to Transocean senior subsea supervisor Owen McWhorter, "the only thing I'd swear to is the fact that leaks discovered by me, on my hitch, were brought to my supervisor's attention and the Company man's attention."¹³⁴

Under 30 C.F.R. § 350.466(f), drilling records must contain complete information on "any significant malfunction or problem."¹³⁵ This provision may require control system leaks or other anomalies to be recorded in daily drilling reports and thus subject to review by MMS inspectors.¹³⁶ At least two of the leaks identified pre-explosion were not listed in daily drilling reports. A pilot leak on the test ram open circuit shuttle valve (leak 1 in the table) was not

mentioned in the daily drilling report for February 23.¹³⁷ However, the leak was reported in BP's internal daily operations report from February 23 until March 13.¹³⁸ BP wells team leader John Guide and BP regulatory advisor Scherie Douglas made the decision not to report the leak to MMS, a failure which Guide admits was “a mistake in hindsight.”¹³⁹ BP well site leader Ronnie Sepulvado also admits this leak should have been noted in the daily drilling report but stated that it was not reported because the leak did not affect the ability to control the well since it was on a test ram and the test ram was still operable.¹⁴⁰

The rig crew failed to include at least one other known leak in the daily drilling reports. Although the rig crew discovered a leak on an upper annular preventer hose fitting (leak 2 in the table) on February 19,¹⁴¹ the leak was not listed on the daily drilling report.¹⁴² Although subsea personnel in the past had been required to produce documentation on the leak so that the leak could be explained to MMS, McWhorter was not asked to produce documentation for this leak.¹⁴³ A failure to report these leaks potentially violated MMS reporting regulations.¹⁴⁴

Inconsistent Response to Identified Leaks

There is little industry guidance as to what constitutes an appropriate response to minor leaks.¹⁴⁵ It appears the rig crew was able to identify the cause and impact of some leaks but not others. Evidence indicates both BP and Transocean personnel assessed the leak on the test ram shuttle valve (leak 1 in the table) and determined the ram would still function properly.¹⁴⁶ Records appear to indicate the rig crew planned to further evaluate this leak when the rig moved from Macondo to the next well.¹⁴⁷

In response to a leak on an upper annular hose fitting (leak 2 in the table), the rig crew appears to have isolated and monitored hydraulic pressure.¹⁴⁸ The crew eventually measured this leak at 0.1 gallons per minute.¹⁴⁹ Sepulvado noted the leak on his office white board.¹⁵⁰ Although the leak was later erased from the board, Transocean crew questioned whether the leak was resolved and a similar leak was still present during post-explosion ROV intervention.¹⁵¹ According to witness testimony, the rig crew never determined the source of a leak on the lower annular (leak 5 in the table).¹⁵²

BOP Recertification

Recertification of a blowout preventer involves complete disassembly and inspection of the equipment.¹⁵³ This process is important because it allows individual components to be examined for wear and corrosion. Any wear or corrosion identified can then be checked against the manufacturer's wear limits.¹⁵⁴ Because this process requires complete disassembly of the BOP at the surface, it can take 90 days or longer¹⁵⁵ and generally requires time in dry dock.¹⁵⁶ Industry papers suggest that “the best time to perform major maintenance on a complicated BOP control system [is] during a shipyard time of a mobile offshore drilling unit (MODU) during its five-year interval inspection period.”¹⁵⁷ The *Deepwater Horizon* had not undergone shipyard time since its commission.¹⁵⁸

MMS regulations require that BOPs be inspected in accordance with American Petroleum Institute (API) Recommended Practice 53 Section 18.10.¹⁵⁹ This practice requires disassembly and inspection of the BOP stack, choke manifold, and diverter components every three to five years.¹⁶⁰ This periodic inspection is in accord with Cameron's manufacturer guidelines, and Cameron would have certified inspections upon completion.¹⁶¹

The *Deepwater Horizon* Blowout Preventer Was Not Recertified

It was well known by the rig crew and BP shore-based leadership that the *Deepwater Horizon* blowout preventer was not in compliance with certification requirements.¹⁶² BP's September 2009 audit of the rig found that the test ram, upper pipe ram, and middle pipe ram bonnets were original and had not been recertified within the past five years.¹⁶³ According to an April 2010 assessment, BOP bodies and bonnets were last certified December 13, 2000, almost 10 years earlier.¹⁶⁴

Although the September 2009 audit recommended expediting the overhaul of the bonnets by the end of 2009 and emails between BP leadership discussed the issue,¹⁶⁵ the rams had not been recertified as of April 2010.¹⁶⁶ A Transocean rig condition assessment also found the BOP's diverter assembly had not been certified since July 5, 2000.¹⁶⁷ Failure to recertify the BOP stack and diverter components within three to five years may have violated the MMS inspection requirements.¹⁶⁸ An April 1, 2010 MMS inspection of the rig found no incidents of noncompliance and did not identify any problems justifying stopping work.¹⁶⁹ The inspection did not identify the fact that the *Deepwater Horizon's* BOP had not been certified in accordance with MMS regulations.¹⁷⁰

“Condition-Based Maintenance”

Transocean did not recertify the BOP because it instead applied “condition-based maintenance.”¹⁷¹ According to Transocean's Subsea Maintenance Philosophy, “[t]he condition of the equipment shall define the necessary repair work, if any.”¹⁷² Condition-based maintenance does not include disassembling and inspecting the BOP on three- to five-year intervals,¹⁷³ a process Transocean subsea superintendent William Stringfellow described as unnecessary.¹⁷⁴ According to Stringfellow, the rig crew instead tracks the condition of the BOP in the Rig Management System and “if we *feel* that the equipment is—is beginning to wear, then we make...the changes that are needed.”¹⁷⁵ Transocean uses condition-based monitoring to inspect all of its BOP stacks in the Gulf of Mexico.¹⁷⁶ According to Transocean witnesses, its system of condition-based monitoring is superior to the manufacturer's recommended procedures and can result in identifying problems earlier than would occur under time-based intervals.¹⁷⁷

The Chief Counsel's team disagrees. Condition-based maintenance was misguided insofar as it second-guessed manufacturer recommendations, API recommendations, and MMS regulations.

Moreover, the decision to forego regular disassembly and inspection may have resulted in necessary maintenance not being performed on critically important equipment. As discussed in [Chapter 4.10](#), the Rig Management System used to monitor the BOP was problematic and may have resulted in the rig crew not being fully aware of the equipment's condition. Given the critical importance of the blowout preventer in maintaining well control, the Chief Counsel's team questions any maintenance regime that could undermine the mechanical integrity of the BOP.

Technical Findings

As discussed above, this report does not make any conclusive findings regarding whether and to what extent the *Deepwater Horizon's* BOP may have failed to operate properly because forensic testing is still ongoing. At this point, the Chief Counsel's team can only identify possible reasons why the BOP's emergency systems failed to activate.

The possibilities include:

- explosions on the rig may have damaged connections to the BOP and thereby prevented the rig crew from using the emergency disconnect system to successfully activate the blind shear ram;
- ROV hot stab activation may have been ineffective because ROVs could not pump at a fast enough rate to generate the pressure needed to activate the relevant rams; and
- BOP control pods may have been unable to activate the blind shear ram after power, communication, and hydraulic lines were severed; low battery levels in the blue control pod and solenoid faults in the yellow control pod may have prevented pod function.

Even if activated, the blind shear ram did not seal in the well on April 20 or in subsequent response efforts. Possible reasons for failing to seal include:

- the high flow rate of hydrocarbons may have eroded the BOP and created a flow path around the ram;
- the BOP's blind shear ram may have been mechanically unable to shear drill pipe and shut in the well because it was not designed to operate under conditions that existed at the time. For instance, the ram may have been blocked by tool joints or other material that it was not designed to cut;
- subsea accumulators may have had insufficient hydraulic power; and
- leaks in BOP control systems may have delayed closing the BOP, though it is unlikely that they prevented the BOP from sealing. Leaks may have existed on the BOP control system but not been identified. Identified leaks were not reported to MMS and may have been inconsistently monitored.

Management Findings

Whether or not BOP failures contributed to or prolonged the blowout, the Chief Counsel's team has identified several major shortcomings in the overall program for managing proper functioning of the BOP stack.


- MMS regulations require only one blind shear ram on a BOP stack. But blind shear rams cannot cut the joints that connect pieces of drill pipe, which comprise a significant amount of pipe in a well. The Chief Counsel's team agrees with a 2001 MMS study that two blind shear rams would mitigate this risk.
- MMS approved the testing of the *Deepwater Horizon* blowout preventer at lower pressures than required by regulation. Though testing at lower pressures is in accord with industry practice, most tests of the blind shear ram did not establish the ability of the equipment to perform during blowout conditions with large volumes of gas moving at high speed through the BOP into the riser.

- Transocean’s practice of destroying test records at the end of each well creates unnecessary information gaps that may undermine BOP maintenance.
- Critical BOP equipment on the *Deepwater Horizon* may have been improperly maintained. The BOP ram bonnets, bodies, and diverter assembly had not been certified since 2000, despite MMS regulations, API recommendations, and manufacturer recommendations requiring comprehensive inspection every three to five years. Transocean and BP’s willingness to disregard regulatory obligations on a vital piece of rig machinery is deeply troubling.

Table 4.9.3. Modifications to the *Deepwater Horizon* blowout preventer.

| Date | Modification |
|------------------|---|
| November 2001 | Control pod subsea plate mounted valves changed from 1-inch to 0.75-inch valves. ¹⁷⁸ |
| October 2002 | Increased power supply to control pod subsea electronic modules (SEMs) to higher amp. rating. ¹⁷⁹ |
| December 2002 | ST locks modified. ¹⁸⁰ |
| January 2003 | Three high-shock flow meters were installed in BOP control pods, replacing ultrasonic flow meters. ¹⁸¹ |
| January 1, 2003 | Changed retrievable control pods to nonretrievable control pods. ¹⁸² <i>This required the LMRP to be retrieved to surface in order to perform maintenance on control pods.</i> ¹⁸³ |
| November 2003 | New high-interflow shuttle valve replaced on LMRP and BOP stack. ¹⁸⁴ |
| May 2004 | Control pod regulators modified. ¹⁸⁵ |
| June 2004 | Control pod subsea electronic modules (SEMs) software upgraded by Cameron. ¹⁸⁶ |
| July/August 2004 | New rigid conduit manifold installed and riser-mounted junction boxes removed. ¹⁸⁷ |
| August 2004 | Cameron conduit valve package replaced with ATAG conduit valve package. ¹⁸⁸ <i>This isolates LMRP accumulators if pod hydraulic power is lost.</i> ¹⁸⁹ |
| August 2004 | Fail-safe panels on choke and kill valves removed from LMRP and BOP stack. ¹⁹⁰ <i>Valves will close only by spring force.</i> ¹⁹¹ |
| November 2004 | “Add a second pod select solenoid functioned by an existing pod select switch—to add double redundancy to each control pod.” ¹⁹² |
| December 2004 | AMF/deadman accumulators: “[T]he pre-charge required on the subsea accumulators is 6800 psi while the maximum working gas pressure for subsea bottles is 6000 psi. This will mean different fluid volumes than are normal on the BOP control system.” ¹⁹³ The deadman accumulators “have now become part of the subsea accumulators since the deadman system has been modified.... There will be little appreciable differences in the system operability but it is important to know how the reduced pre-charge and extra accumulators work on the system.” ¹⁹⁴ |
| December 2004 | Lower variable bore ram converted to test ram. ¹⁹⁵ <i>A test ram holds pressure from above, instead of below.</i> ¹⁹⁶ <i>Possibly overlooked relabeling ROV hot stab connections, resulting in ROVs activating test ram during post-explosion efforts to close the BOP.</i> ¹⁹⁷ |
| February 2005 | Control pod modified: “[R]eplace all unused functions on pod with blind flanges. Possible failure points resulting in stack pull.” ¹⁹⁸ |
| September 2005 | Control system pilot regulator: “[R]eplace pilot regulator with a better designed, more reliable regulator leaks. (Gilmore is a larger unit and will require a bracket to be fabricated for mounting.)” ¹⁹⁹ |
| February 2006 | Control panel: “Modification to Cameron control software to sound an alarm should be a button stay pushed for more than 15 [seconds]. If a button is stuck and not detected it will lock up panel.” ²⁰⁰ |

Table 4.9.3 (continued)

| Date | Modification |
|--|--|
| June 26, 2006 | Installed new repair kit in autoshear valve. New repair kit came with new rod and the rod was too long, had to use old rod. ²⁰¹ |
| July 2006 (proposal for modification approved) | At BP's request, the lower annular preventer was changed to a stripping annular. ²⁰² |
| January 2007 | AMF/deadman—Cameron will remove the SEM from the MUX section to replace the pipe connectors (customer provided) and to install the AMF/deadman modification kit. ²⁰³ |
| September 2008 | Riser flex joint replaced. ²⁰⁴ |
| June 10, 2009 | Software changes made to allow all functions that were previously locked out from any of the BOP's control panels to become unlocked whenever the EDS command was issued from any control panel. ²⁰⁵ |
| August 3, 2009 | Autoshear valve replaced with new Cameron autoshear valve. ²⁰⁶ |
| 2010 | Combined the following ROV hot stab functions: ²⁰⁷ blind shear ram close; ST lock close; and choke and kill fail-safe valves.  |