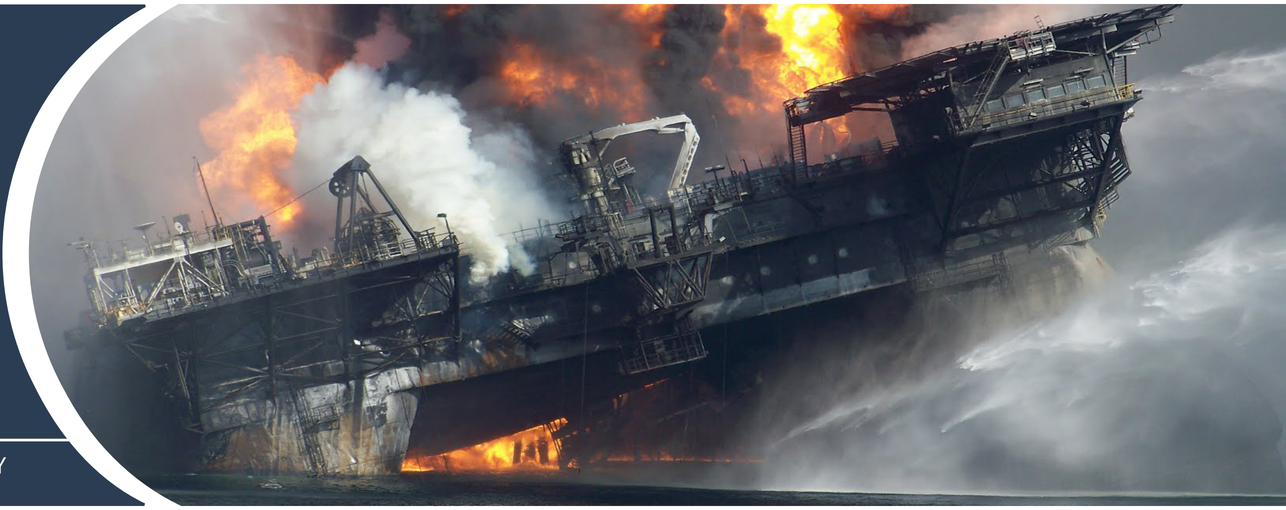

NASA SAFETY CENTER

SYSTEM FAILURE CASE STUDY

FEBRUARY 2013 *VOLUME 8 ISSUE 2*

Lessons From Macondo

The Senior Management Walkaround

April 20, 2010, Macondo Prospect, Gulf of Mexico, 7:45 P.M. Central Daylight Time (CDT): Two Transocean executives and two BP executives flew aboard the Deepwater Horizon oil rig for a Management Visibility Tour. The purpose of the tour was to meet the 162 rig workers and to check for and discuss key occupational hazards recently found on other Transocean oil rigs in the fleet. The agenda included crediting the crew for their outstanding 7-year safety record with no lost time injuries. During the next 7 hours, the executives watched the crew prepare to cap off the well and move to a new site. However, deep beneath their feet, incredible pressure built inside the well casing. Two safety indicators occurred concerning the oil well's dangerous unsealed state that went undetected. This story, adapted from a 2011 analysis by sociologist Anthony Hopkins, describes how these two precursor events went unnoticed and resulted in the worst oil well blowout and oil spill in U.S. history.

PROXIMATE CAUSE

- High-pressure methane gas from the well expanded up through the well, riser, and into the rig where it ignited and exploded.

UNDERLYING ISSUES

- Focus on Physical Hazards Instead of System Safety

AFTERMATH

- Loss of Deepwater Horizon
- Over $13 million paid in damages, claims, and advances by BP as the recognized majority share of cause of accident
- Unprecedented fallout as the worst oil spill in U.S. history.

BACKGROUND

Deepwater Horizon

Deepwater Horizon was an ultra-deepwater, semi-submersible offshore oil drilling rig, built in 2001 by Hyundai Heavy Industries for Transocean. Transocean, a major offshore drilling rig operator, was contracted by BP to drill on the Macondo Prospect (a BP-leased property in the Gulf of Mexico). BP purchased drilling rights to the Macondo Prospect in 2008. At that time, it was estimated that the Macondo Prospect had the potential to produce upwards of 50 million barrels of oil. In February, 2010, the rig's crew commenced drilling beneath approximately 5,000 feet of water at the Macondo Prospect.

Drilling and Sealing

Deep-ocean oil drilling requires cutting-edge technology to deal with enormous pressures in and around a well. During drilling, well pressure is maintained by injecting a heavy fluid, or mud, into the shaft. The mud, nearly twice as heavy as seawater, equalizes the pressure of the hydrocarbons (oil and/or gas) trapped under the shale and miles of seawater. If counter pressure is not applied, the thin shale at the bottom of the shaft would crack from the upward pressure of the lighter-than-seawater hydrocarbons.

Figure 1. The Deepwater Horizon oil rig before the April 20, 2010 blowout. Source: National Commission of the BP Deepwater Horizon Oil Spill and Offshore Drilling

When a rig finishes drilling a well, a lining or casing is inserted and bonded to the sides of the shaft with cement. Ideally, the seal created with the cemented liner or casing prevents hydrocarbons from leaking into the bottom of the well. Because of the seal's weight and integrity, lighter seawater is used to replace the heavier drilling mud to maintain the pressure balance in the well. The volume of seawater should match the volume of mud it is replacing.

To verify that the seal is operational, well pressure is temporarily reduced to check if fluids flow out the top of the well, which would indicate pressure increasing from below. If all of the mud is removed while the well is flowing during the pressure reduction, the well could blow.

What Happened

Approximately 7 hours before the blowout, two Transocean executives and two BP executives flew aboard Deepwater Horizon for a management visibility tour. Management visibility tours were regularly scheduled social visits to BP/Transocean jointly operated Gulf of Mexico rigs. The tour did not follow a strict itinerary, but the executives' main reason for visiting was to communicate specific safety messages to the crew, particularly the use of harnesses when working from heights, the use of non-slip materials, hand injury awareness, and dropped object hazards. Each of the executives carried out informal safety audits such as inspecting safety harnesses in lockers for accurate tagging and other workplace safety micro-audits.

The executives also congratulated the crew of Deepwater Horizon for accruing a total of 7 years without a lost time injury and were interested in learning how the record had been achieved. Although a previously scheduled, high-energy drilling process unfolded around the rig, process safety (e.g., physical rig controls and procedures and well pressure containment) was not on the agenda.

Because operations directly involved the rig's senior managers and experts, the executives saw and heard real-time cues as the crew evaluated oil well condition. As they visited the drilling shack, they witnessed rig personnel debate how to perform negative pressure testing and interpret pressure test results where no company or industry standard existed. One rig manager explained they were "having a little trouble getting lined up [for the test] but it's no big deal." The executives continued their tour and took up conversation concerning the history of BP. The senior Transocean executive later testified that he sensed the drillers were confused, and suggested that the accompanying on-site rig manager stay behind to help and that the executives move on rather than distract those engaged in the test. An executive returned later in the day to ask the manager if the test had gone well, and the manager responded with an assuring "thumbs up." This was the first missed precursor.

That afternoon, work commenced on replacing the drilling mud in the well with seawater. At some point during the process, oil began flowing into the bottom of the well and the flow began to increase. Had the negative pressure test results been correctly interpreted, the crew would have known that the well was already leaking oil internally. The result was that workers were removing mud, but unknowingly replacing it with a lesser volume of seawater as oil collected in the bottom of the well. Had the rig workers realized the volumes did not match, the correct response to this scenario would have been to "shut in"

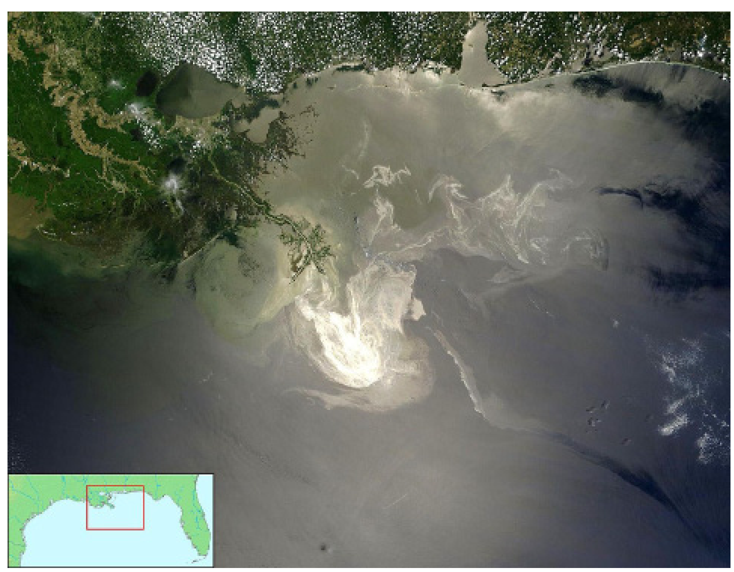

Figure 2. Sunlight illuminated the lingering oil slick off the Mississippi Delta on May 24, 2010. Source: NASA

the well and closely monitor the volumes. With the well under control, later corrective action could have been attempted. However, monitoring the situation was an exercise in futility; mud was being offloaded from the rig to a supply vessel, the cement cap for the well was being set in place, and tension on drilling risers was being eased all at once. Besides affecting fluid flow instrument readings, these simultaneous operations distracted the crew from monitoring the readings. This was the second missed precursor.

Later investigations found that no one including the executives knew that rig design and operational procedures together prevented effective flow monitoring at this critical time, despite policy requiring it. Post-blowout analysis showed that 43 minutes before the blowout, the first clear indicator of fluid flow imbalance appeared, but was not seen and correctly identified.

The executives (all former rig managers or offshore drilling experts) understood that the rig workers were removing one of the last barriers against blowout that afternoon, but they did not observe or audit that practice, even though Transocean suffered a blowout in the North Sea, off the coast of Scotland 4 months earlier. The crew in the North Sea had also assumed that the well was secure and no longer monitored flows. Transocean management wrote a 10-page advisory against complacency in flow monitoring and circulated it within the company. Yet the Transocean executives testified they were unaware of the North Sea event.

Pressure continued to rise even after the mud and seawater pumps were shut down, a sign of a mounting blowout. At approximately 9:45 p.m. CDT, methane gas expanded in the well, pushing drilling mud up the 35,000-foot well and out of the degasser system. The gas flowed up after the mud and exploded. The devastation that ensued took the lives of eleven rig workers, whose bodies were never recovered. The 4 executives and 111 rig workers were rescued. An official estimate of 4.9 million barrels of oil were spilled into the Atlantic Ocean before the well was finally controlled. Damage estimates and litigation continued years later with settlement payouts nearing $4.5 billion at the time this study was written.

Figure 3. An unsuccessful attempt to plug the well using a technique known as "top kill." Source: U.S. Coast Guard

Figure 4. Oil from the Deepwater Horizon oil spill approaches the coast of Mobile, Alabama on May 6, 2010. Source: U.S. Navy

Proximate Cause

High-pressure methane gas from the well expanded up through the well, riser, and into the rig where it ignited and exploded.

Underlying Issues

Eight major investigations listed more findings upstream of the blowout than this study can recount. This specific study focuses solely on the executive walkaround and the lack of focus on the safe operation of the complex system. The tour presented a potential for extra scrutiny. Had the executives been prepared to audit and intervene, their expertise could have formed the layer of protection that prevented the blowout.

Focus on Physical Hazards Instead of System Safety

In his paper, Hopkins found that despite their engineering experience, the executives focused on workplace safety, not process safety. Multiple interviews and investigative sources showed that auditing material conditions was easier than analyzing crew and manager behavior. Furthermore, the executives did not want to interfere with rig operations. Executives interviewed after the disaster said that they did not want to undermine the authority of the managers aboard the rig, or cast doubt upon the professionalism of the crew.

Only a handful of loss-of-rig accidents have occurred and none previously involved BP or Transocean. Process safety incidents, such as blowouts and kicks, do not contribute to annual workforce safety statistics. BP and Transocean measured corporate and subcontractor operational safety on traditional lost time and total case injury rates—the exact effects that a management tour focus on material conditions would mitigate (e.g., falling object debris, anti-slip materials, safety harness tagging). Mitigating lost time events equates to preserving minutes of drilling operations, which in the oil industry, could result in tens of thousands of dollars per minute.

The senior health and safety manager for BP drilling operations testified after the blowout, stating that safety for him involved hazards and risks to individual workers carrying out tasks and that engineers were responsible for process safety.

Aftermath

Deepwater Horizon burned for almost 36 hours and finally sank on April 22, 2010, nearly a mile deep and 1,300 feet northwest of the well it drilled. Oil seeped from the well for 87 days until it was temporarily capped on July 15, 2010. Relief wells were finally used to seal and kill the blown well on September 19, 2010.

Even now, analysts report that the aftermath of litigation, damages, and recovery (which are currently unknown) will continue to take years to resolve. At this time, the Macondo blowout is considered the worst offshore oil spill in history. Damages paid for claims, advances, and settlements have since crested $42.2 billion and may continue to rise.

Relevance to NASA

In his analysis, Anthony Hopkins avoids judging the BP and Transocean executives' actions in hindsight. Instead, he recommends moving forward with a proactive approach of planning and preparation. While the executives had significant experience with offshore operations, many senior management figures may not—necessitating the use of a translator or adviser with the right expertise during visits to high-energy facilities. Having the necessary knowledge facilitates probing inquiries and analysis of system operations.

All-time low NASA injury rates demonstrate that managers, operators, and maintainers of high-energy facilities, systems, and equipment understand the benefit of running effective institutional safety programs. Managers can go even further by anticipating vulnerability to severe process or system safety failure scenarios. Vulnerable means that gaps in system defenses do exist, regardless of any perceived likelihood of failure. Thinking of safety in terms of effective defenses rather than the apparent absence of hazardous conditions can prime a manager to turn a walkaround visit into an assessment of those defenses during critical operations.

Visits to high-energy facilities will benefit from prior review of defenses of similar systems. Advance knowledge of operator certification and currency and contingency planning and practices equip a manager to not only observe performance with an expert eye, but give him or her the confidence to intervene if cues leading to a mishap aren't recognized by the team.

A senior management walkaround is a matchless opportunity to not only audit, but to send a message: high-energy systems deserve constant vigilance. Everyone present owns some measure of risk per their authority and capability. Given expert preparation, the senior manager or executive can demonstrate care for the crew and the public, even intervening in all but the most time-critical arenas (where qualified operators must decide and execute in minutes and seconds). A senior manager can often gain enough systems knowledge (or bring along experts with that knowledge) to recognize a deteriorating situation by monitoring defenses. That manager or executive—just by being present—becomes responsible for stopping perceived unsafe work, until the situation is clarified or the actual risk is reduced to an acceptable level.

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