and promotion of women in engineering? Can you think of any examples from your own experience of men being advantaged and women being disadvantaged as a result of gender schemas?

CASE 29

The 2010 Macondo Well Blowout and Loss of the Deepwater Horizon

The Deepwater Horizon was a $340 million semisubmersible deep water drilling rig owned and operated by Transocean. Transocean was contracted by British Petroleum (BP) to drill the 18,360 ft Macondo well in about 5,000 feet of water in the Gulf of Mexico about 40 miles off the coast of Louisiana. Deepwater Horizon drilling operations, planned for 51 days at a cost of about $1 million per day, began at the Macondo well site in February 2010, resuming drilling operations that had been initiated in October 2009 by another rig. The well was being shut in and abandoned (for later production) on April 20, 2010, when an explosion and fire resulted in the loss of 11 lives (out of 126 workers on the rig at the time), the sinking of the rig, and a prolonged uncontrolled release of oil and gas from the wellhead on the seafloor. Efforts to control the well were unsuccessful for months, resulting in the largest oil spill in U.S. history. As of July 2016, well owner BP has spent nearly $62 billion for clean-up and compensations for damages resulting from the Macondo blowout.

House Committee on Energy and Commerce hearings in the weeks following the disaster focused attention on several aspects of the drilling and completion operations that suggest owner BP repeatedly cut corners to reduce costs with several risky design decisions. What follows is from testimony to the committee as summarized in a June 14, 2010 letter from the Committee Chairman Henry Waxman to BP CEO Tony Hayward that outlines five areas where questionable decisions were made by BP managers and engineers seemingly favoring economy over safety.[105] These areas were well design, the number of centralizers used in cementing the final string of casing, a decision not to require a cement bond log, abbreviated mud circulation prior to cementing the final string of casing, and a decision not to use a lockdown sleeve.

- *Well Design*: A critical decision in the design of the Macondo well was to use a full string casing in the final 1192 feet of the wellbore rather than the more conservative liner/tieback casing design. Full string casing is faster and therefore less expensive than the liner/tieback casing design, but does not offer as much redundancy in the control of gas in the annular space surrounding the casing, and it may have failed to meet Minerals Management Service (MMS) regulations. This conscious decision by BP in the final days before the blowout reduced the cost of the well completion by several million dollars, but with a reduction in safety against blowout.
- *Centralizers*: Centralizers are annular spacers that center the casing in the borehole prior to cementing to improve displacement of mud by the cement slurry. When casing is not centered in the wellbore, American Petroleum Institute (API) Recommended Practice 65 says that mud will not effectively be displaced by the slurry, which can result in weak or porous cement seals, leading to gas leakage and the risk of blowout. BP chose to use six centralizers on the final 1192 feet of casing despite predictions by the contractor Halliburton that 21 centralizers were required to reduce the risk of a gas flow problem from "severe" to "minor." An additional 15 centralizers were located, but evidently the time required to get them to the rig, 10 hours, represented an unacceptable delay, so the decision was made to use only the six available centralizers.
- *Cement Bond Log*: This standard nondestructive test is designed to detect if any mud inclusions or other problems have caused voids or channels in the cement seal, reducing the integrity of the cement seal. MMS regulations may have required such a test on the Macondo well. BP flew a Schlumberger crew to the rig on April 18 to stand by to perform such a test, but dismissed them on April 20. A cement bond test on the Macondo well would have taken about 9–12 hours, and the

discovery of any voids in the cement would have led to further delay.

- *Mud Circulation*: Before the cement slurry is placed in the annular region, displacing the mud to form the annular seals, it is good practice to circulate the mud to remove cuttings, gas bubbles, and decrease the viscosity of the mud to allow better cement flow and mud displacement. API guidelines recommend circulating the greater of 1.5 annular volumes of mud or 1.0 casing volume, at a minimum. Circulating this much mud takes time, perhaps as much as 12 hours on the Macondo well, and BP chose to circulate a much smaller amount, 261 barrels of mud.
- *Casing Hanger Lockdown Sleeve*: BP had not installed a casing hanger lockdown sleeve (LDS) designed to lock the wellhead and casing in the seal assembly at the seafloor. This may have just been a delay while waiting for MMS approval of a design change, but the end result was that an LDS not installed at the time of the April 20 blowout. LDS devices represent another safety feature against blowouts by preventing the casing from rising up and damaging the wellhead seal.

In at least the first four of these questions raised by the committee, it appears that BP engineers' and managers' design decisions represented the faster (cheaper) and less conservative (riskier) alternatives. Well team leader John Guide reportedly reversed drilling engineering team leader John Walz's decision to order the additional 15 centralizers because of the 10-hour delay for delivery. In making this decision, Guide reportedly made use of a "risk/reward equation," but the details of that decision are not public knowledge. The "risk/reward" approach is a management tool commonly used in making investment and stock-trading decisions, and is not common engineering terminology, suggesting that this critical engineering decision may have been based on logic foreign to engineering, perhaps without an appropriate engineering consideration of public health, safety, and welfare.

A summary report[106] by a blue-ribbon panel of the National Academy of Engineering (NAE) identified several findings that contributed to the disaster. Briefly, these findings confirm that there were engineering failures in designing, constructing, and testing the cement seals intended to contain the pressurized hydrocarbons in the Macondo well during subsequent abandonment, and a failure to recognize clear symptoms that the seals were leaking during negative pressure tests. Furthermore, the failure of the blowout preventer (BOP) was attributed to engineering failures in designing, testing, operating, and maintaining the BOP. The report faults a lack of a strong safety culture because of a deficient overall systems approach to safety for the "multiple flawed decisions that led to the blowout."

The personnel in the BP chain of command responsible for these questionable decisions did not include many, if any, registered professional engineers, which raises another very important question about BP's operation and culture. The rules of the Texas Board of Professional Engineers (and probably those boards in other gulf states) do not require licensure of Houston-based individuals holding these jobs, because an exemption in Texas law allows individuals employed by industrial employers who do not offer services to the public to perform engineering work without being licensed. But the apparent absence or scarcity of licensed engineers in this chain of command raises serious questions about the level of professionalism behind several critical engineering decisions. The team responsible for design and drilling of the well included numerous experienced but unlicensed individuals, but the only licensed engineer the authors have identified having any authority over operations at the Macondo well was David Sims, an experienced and licensed (Texas) professional engineer who was assigned to be John Guide's supervisor only 18 days before the blowout, perhaps in response to reported difficulties in drilling the "well from hell." Whether his earlier assignment to this project might have resulted in better engineering decision-making in response to the critical events during the drilling and abandonment process can only be speculated, but it is the author's belief that unprofessional decision-making, likely influenced by the pressures of time and cost, was the most significant factor contributing to this disaster.

One comment in the House Committee letter, attributed to BP drilling engineer Brian Morel, suggests that BP discounted or ignored, without technical justification, a contractor's quantitative simulations that indicated the use of only six centralizers would not ensure a safe cement job—the kind of decision a professional engineer would surely not make. Morel's e-mail to the contractor said, "We have 6 centralizers, we can run them in a row, spread out, or any combination of the two. It's a vertical hole, so *hopefully* the pipe stays centralized due to gravity … it's too late to get any more product on the rig. Our only option is to rearrange placement of these centralizers" (emphasis added). The essence of engineering is the reliance on accurate quantitative simulations to develop safe designs, yet Morel's comment suggests that the decision may have relied on "hope" rather than calculated safety. One would expect an experienced professional engineer would have not made or accepted a decision based on *hope*. The authors believe that the industry exemption to engineering registration requirements, or the overreliance on that exemption by some employers involved in this incident, deserves much of the blame for this disaster.

Finally, the oversight by the MMS has been questioned. Many aspects of the design process appear to have been approved without challenge by the MMS or justification by BP. The choice of a single string of casing instead of the potentially safer liner/tieback casing was approved the same day it was requested. While excessive regulatory oversight can stifle economic growth, safety in some industries necessarily relies on responsible and competent regulatory oversight, and that appears to have been lacking in this case.

A question for discussion: The apparent link between critical engineering decision-making by unlicensed engineers and the Macondo blowout suggests a serious problem with the so-called "industry exemption" that allows unlicensed individuals to perform engineering services for employers so long as their services are not offered to the public—the safety, health, and welfare of the public (and the natural environment) seems to be at higher risk. Yet, industrial employers argue that if this practice were not permitted, if anyone performing any engineering service was required to be a licensed engineer, the cost of industry operations would increase because of a shortage of licensed engineers, harming the economy (and public welfare). Is there some creative middle-way public policy that might satisfy both of these competing ethical obligations?

CASE 30

Units, Communications, and Attention to Detail—the Loss of the Mars Climate Orbiter

The Mars Climate Orbiter was a 629 kg Mars satellite launched by NASA on December 11, 1998, with a mission to map the Martian surface and atmosphere for about two years and serve as a communications relay station for future Mars landers for about three additional years. The Orbiter was lost during entry into Martian orbit; it is presumed to have burned up during atmospheric entry or overheated and skipped into space.

The following, taken from the official report of the investigation into the loss of the Climate Orbiter, indicates the probe was inserted into Mars orbit much lower in the atmosphere than designed because of cumulative navigation errors resulting from the use of data in English units provided by a contractor in onboard calculations requiring metric units.[107]

> At the time of Mars insertion, the spacecraft trajectory was approximately 170 kilometers lower than planned. As a result, MCO either was destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere. The Board recognizes that mistakes occur on spacecraft projects. However, sufficient processes are usually in place on projects to catch these mistakes before they become critical to mission success. Unfortunately for MCO, the root cause was not caught by the processes in-place in the MCO project.
>
> A summary of the findings, contributing causes and MPL recommendations are listed below. These are described in more detail in the body of this report along with the MCO and MPL observations and recommendations.
>
> Root Cause: Failure to use metric units in the coding of a ground software file, "Small Forces," used in trajectory models.

In addition, the report lists eight contributing causes, including inadequate communications between project elements, inadequate staffing, and inadequate training.