DEEPWATER HORIZON - WHAT WENT WRONG

Jeff Parnes - 10 July 2024

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Contents

What was the Deepwater Horizon?

- Deepwater Horizon was an ultra-deepwater, dynamically positioned, semi-submersible offshore drilling rig owned by Transocean and operated by BP.
- Built in 2001 in South Korea by Hyundai Heavy Industries, the rig was commissioned by R&B Falcon (a later asset of Transocean), registered in Majuro, and leased to BP from 2001 until September 2013.
- In 2002, the rig was upgraded with "e-drill", a drill monitoring system whereby technical personnel based in Houston, Texas, received real-time drilling data from the rig and transmitted maintenance and troubleshooting information.
- In September 2009, the rig drilled the deepest oil well in history at a vertical depth of 35,050 ft (10,683 m) and measured depth of 35,055 ft (10,685 m) in the Tiber Oil Field at Keathley Canyon block 102, approximately 250 miles (400 km) southeast of Houston, in 4,132 feet (1,259 m) of water
- Advanced systems played a key role in the rig's operation, from pressure and drill monitoring technology, to automated shutoff systems and modelling systems for cementing. The OptiCem cement modelling system, used by Halliburton in April 2010, played a crucial part in cement slurry mix and support decisions. These decisions became a focus for investigations into the explosion on the rig that month.

What happened to the Deepwater Horizon?

- In February 2010, Deepwater Horizon commenced drilling an exploratory well at the Macondo Prospect about 41 miles off the southeast coast of Louisiana, at a water depth of approximately 5,000 feet
- The Macondo prospect exploration rights had been acquired by BP in 2009,with the prospect jointly owned by BP (65%), Anadarko Petroleum (25%) and MOEX Offshore 2007 (10%).
- Deepwater Horizon was still working on the Macondo site on 20 April 2010, when a violent explosion occurred leading to destruction of the rig and the subsequent oil spill..
- The blowout caused an explosion on the rig that killed 11 crewmen and ignited a fireball visible from 40 miles away. The fire was inextinguishable and, two days later, on 22 April, the Horizon sank, leaving the well gushing at the seabed and turning into the largest marine oil spill in history.
- This oil spill has been recorded as the largest offshore spill to occur to date, resulting in 40 miles of coastal pollution.
- The well was in the final stages of completion after cement had been emplaced for its last casing string. The exploratory work had been described as "concluded" with permission already having been requested from Minerals Management Service (MMS), an agency of the United States Department of the Interior that managed the nation's natural gas, oil and other mineral resources on the outer continental shelf, to terminate operations at the Macondo site..
- The rig was scheduled to move to its next roles as semi-permanent production platforms, initially at the Tiber site followed by a return to the Kaskida field, an oil dome 50 miles off the coast of Louisiana.

What Caused the Explosion on the Deepwater Horizon?

- The Macondo well was dug 5,000 feet beneath the ocean's surface. There were problems from the very beginning of the project, including:
  - *A drillpipe that got stuck during drilling*
  - *Drilling mud leaking out of the well through cracks in the surrounding rock*
  - *The presence of gas at unexpectedly high pressures, which entered the well from the surrounding rock formation*
  - *All of these issues caused significant delays in drilling.*
- Everyone involved was feeling considerable pressure to finish the project without further delays or expense. At the beginning of April, engineers working on the project determined that the risks involved in further drilling were very high. The concern was that additional fracturing of the rock formation was likely to occur if they continued to drill.
- On 20 April the project was 45 days behind schedule and over budget by US$58m. So there was some pressure to get this project finished without further delays and cost over-runs.
- Although the planned depth of the Macondo well was supposed to be 20,200 feet, the engineers decided to stop drilling at 18,360 feet due to these concerns. The next step was to install a steel production casing into the final section of the well in order to pump cement around the well. The purpose of the cement was to seal gas and oil into the well until it was time to produce oil

What happened to submerged infrastructure?

- The force of oil surging up BP's Macondo well forced a piece of drill pipe into the emergency shutoff device and buckled the pipe, making any shutoff impossible, a forensic study concluded.
- The shutoff device that should have stopped the BP oil spill failed largely because of a faulty design and a trapped piece of pipe which shifted some blame for the blowout from the oil giant and toward the companies that built and maintained the 300-ton safety device.
- The 551-page report said the piece of drill pipe prevented the blowout preventer's blind shear rams, or BSRs, from sealing the well around the time of the April 20 oil rig explosion off the coast of Louisiana. The shear rams are components in a blowout preventer that cut, or shear, through drill pipe and form a seal against well pressure.
- "The primary cause of failure was identified as the BSRs failing to fully close and seal due to a portion of drill pipe trapped between the blocks," the report stated.
- The drill pipe's position within the wellbore caused it to buckle and bow when the well lost control, impeding the rams, according to the report.

What were initial attempts to seal the well? (1 of 2)

- The first attempts to stop the oil spill were to use remotely operated underwater vehicles to close the blowout preventer valves on the well head; however, all these attempts failed.
- The second technique, placing a 276,000 lb containment dome (which had worked on leaks in shallower water) over the largest leak and piping the oil to a storage vessel on the surface, failed when gas leaking from the pipe combined with cold water formed methane hydrate crystals that blocked the opening at the top of the dome.
- On May 14, engineers began the process of positioning a 6-inch wide riser insertion tube into the 21-inch wide burst pipe. There was a stopper-like washer around the tube that plugs the end of the riser and diverts the flow into the insertion tube. The collected gas was flared and oil stored on the board of drillship Discoverer Enterprise Before removal of the tube. 924,000 US gallons (22,000 barrels) of oil was collected
- On May 26, BP tried to close the well using a technique called "top kill", which also failed. This process involved pumping heavy drilling fluids through two 3-inch (7.6 cm) lines into the blowout preventer to restrict the flow of oil before sealing it permanently with cement

What were initial attempts to seal the well? (2 of 2)

- On June 16, a second containment system connected directly to the blowout preventer became operational carrying oil and gas through a subsea manifold to the Q4000 service vessel with a processing capacity for about 5,000 barrels (210,000 US gallons) of oil per day. Oil and gas are both burned on Q4000 in a clean-burning system.[20]
- As Discoverer Enterprise's processing capacity was insufficient, drillship Discoverer Clear Leader and the floating production, storage and offloading (FPSO) vessel Helix Producer 1 were added, offloading oil with tankers Evi Knutsen, and Juanita Each tanker has a total capacity of 750,000 barrels (32,000,000 US gallons). In addition, FPSO Seillean, and well testing vessel Toisa Pisces would process oil. They are offloaded by shuttle tanker Loch Rannoch.
- On July 5, BP announced that its one-day oil recovery effort accounted for 24,980 barrels of oil, and the flaring off of 57.1 million cubic feet of natural gas. The total oil collection to date for the spill was estimated at 657,300 barrels The government's estimates suggested the cap and other equipment were capturing less than half of the oil leaking from the sea floor as of late June.
- On July 10, robots removed the containment cap to replace it with a better-fitting cap ("Top Hat Number 10"); this meant all of the leaking oil would escape until the new cap was in place.. A broken pipe was taken out on July 11 and replaced with a flange spool resembling a pipe, on top of which the new cap was located. The well integrity test was scheduled to take place after the installation of a three-ram capping stack over the lower marine riser package of the Deepwater Horizon semi-submersible rig on July 13. On July 14, BP announced that the test would be delayed under Allen's orders; oil continued to flow into the Gulf.

How was the well temporarily closed?

- On July 15, 2010, BP announced that it had successfully plugged the oil leak using a tightly fitted cap. The cap, weighing 75 tons and standing 30 feet high, was bolted to the failed blowout preventer. It consisted of a Flange Transition Spool and a 3 Ram Stack and was a temporary solution.
- President Barack Obama cautiously welcomed the news that the leak had been stopped, while stressing "it is important we don't get ahead of ourselves". If the cap held for the planned 48 hours, the plan was to temporarily reopen the valves in order to allow for seismic tests to ensure that oil was not escaping into the bedrock At the time of the stoppage, oil had been leaking continuously into the Gulf of Mexico for 85 days, 16 hours and 25 minutes since the Deepwater Horizon drilling rig exploded on April 20, 2010.
- Until July 19, 2010, there was no evidence that the well had ruptured, meaning that the cap appeared to be working. According to Thad Allen, the retired US Coast Guard admiral in charge of the operation to stop the leak, the cap would be used to channel the flowing oil to surface ships for collection after the 48-hour test period and would be used to shut the well down during bad weather rather than permanently cap the well, which was expected to happen in mid-August 2010, when relief wells had been completed. On July 19, 2010, seepage was detected from the seafloor within two kilometres of the well. Allen believed that it probably has nothing to do with the well, as oil and gas are known to ooze naturally from fissures in the bottom of the Gulf of Mexico.
- On July 22, forecasts of the track of tropical storm Bonnie made it imperative that the support ships and rigs leave the site. Allen, in consultation with Energy Secretary Steven Chu, made the decision to leave the valves closed despite the lack of supervision from the support ships. Kent Wells, a senior vice president of BP, said "We have enough confidence to leave the well shut in." Since the storm proved weaker than expected, on July 24 the ships returned, and efforts to close the well on a permanent basis soon began.

How was the well permanently closed? (1 of 2)

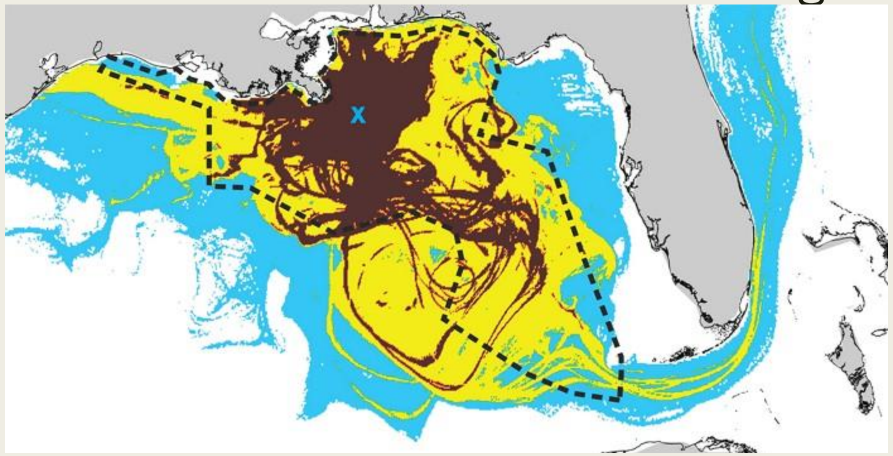
- BP drilled two relief wells into the original well to enable them to block it. Once the relief wells reached the original borehole, the operator pumped drilling fluid into the original well. Transocean's Development Driller III started drilling a first relief well on May 2 and was at 13,978 feet out of 18,000 feet as of June 14. GSF Development Driller II started drilling a second relief on May 16 and was halted at 8,576 feet out of 18,000 feet as of June 14 while BP engineers verified the operational status of the second relief well's blowout preventer. The relief wells began operating in August 2010 at a cost of about $100 million per well.
- Despite delays caused by Tropical Storm Bonnie, the first phase of stopping the leak was expected to start on July 30. Lining a relief shaft with steel casing was expected to resume on July 28, and a relief tunnel would take a week to drill but may be needed if phase one did not work.
- Adm. Thad Allen said on July 26 that the "static kill", using mud and cement poured into the top of the well, could start on August 2. The "bottom kill" would follow, with mud and cement entering the well under the sea floor, possibly by August 7.

How was the well permanently closed? (2 of 2)

- On August 3, first test oil and then drilling mud was pumped at a slow rate of approximately two barrels/minute into the well-head. Pumping continued for eight hours, at the end of which time the well was declared to be "in a static condition".
- At 09:15 CDT on August 4, with Adm. Allen's approval, BP began pumping cement from the top, sealing that part of the flow channel permanently.
- On August 4, Allen said the static kill was working. Two weeks later, though, Allen said it was uncertain when the well could be declared completely sealed. The bottom kill had yet to take place, and the relief well had been delayed by storms. Even when the relief well was ready, he said BP had to make sure pressure would not build up again.[50]
- On September 10, Allen said the bottom kill could start sooner than expected because a "locking sleeve" could be used on top of the well to prevent excessive pressure from causing problems. BP said the relief well was about 50 feet from the intersection, and finishing the boring would take four more days. On September 16, the relief well reached its destination and pumping of cement to seal the well began. Officials said on September 18 that the cement pumped in from the base of the well had completed the sealing of the well.On September 19, after pressure testing, Allen declared that operations to permanently seal the well were completed and it was "effectively dead".

What were the consequences?

- The Deepwater Horizon disaster of 2010 caused 134 million gallons of oil to pour into the Gulf of Mexico, killing 11 people and injuring 17 more. It had devastating ecological and economic impacts from Texas to Florida. The consequences of this event are still affecting marine life and residents along the Gulf Coast today. An investigation revealed that what happened at the Deepwater Horizon was completely preventable and was the result of failures in communication, poor regulatory practices for deepwater drilling, and a disregard for warning signs.
- From the loss of income to negative health outcomes and death, hundreds of plaintiffs and their families who felt the impact of the Deepwater Horizon crisis filed suit against the responsible parties. Those companies have since paid out billions of dollars in reparations for what has become known as the largest offshore oil spill in United States history.



What were the environmental consequences?

- Attempts to stop the flow of oil and cap the well failed. Oil leaked from the ruptured head of the Macondo well and into the Gulf of Mexico for 87 days. This equated to nearly four Olympic-sized swimming pools worth of oil spilling into the ocean each day for nearly three months.
- In addition to harming ecosystems and wildlife, as well as the economic damages to the fishing and tourism industries, there were concerns about health hazards to coastal residents and oil cleanup crews. Chemicals that were sprayed on the oil and gas to break it up and reduce the spread may have ultimately worsened the effects on marine life and caused additional ecological damage and health concerns.
- Environmental Damages
  - *The Deepwater Horizon incident was an ecological disaster for the ocean and coastline along the Gulf of Mexico. It affected 68,000 square miles of water and 1,000 miles of coastline, including many beaches. Fish, birds, bottom-dwelling organisms, deep sea coral, marine mammals, sea turtles, wetlands, beaches, and other ocean ecosystems were severely impacted and still haven't returned to normal today.*

What were the economic consequences?

- **Economic Losses**
  - Coastal residents and business owners who suffered economic losses from the Deepwater Horizon oil spill were eligible to seek compensation through the Gulf Coast Claims Facility. They either filed for an emergency claim or a long-term settlement in the years following. Plaintiffs who accepted an emergency payment are still able to sue for additional or future losses, while those who took long-term settlements are not.
- **Health Hazards**
  - Thousands of people who helped with cleanup and recovery efforts may have been exposed to harmful substances called hydrocarbons in the oil itself and in chemicals used to clean it up. Initial attempts were made to contain the spilled oil using a chemical called Corexit, which contained 2-butoxyethanol. Corexit was meant to disperse and prevent oil from evaporating into the water and ground. Exposed individuals expressed concerns about 2-butoxyethanol and its link to certain cancers, as well as respiratory and cardiovascular disease. Subsequent studies later revealed correlations between 2-butoxyethanol and the following:
  - Thrombocytopenia (reduced platelet count)
  - Irritation to eyes and skin
  - Chronic rhinosinusitis
  - Reactive airway dysfunction
  - Blood diseases
  - Kidney disease

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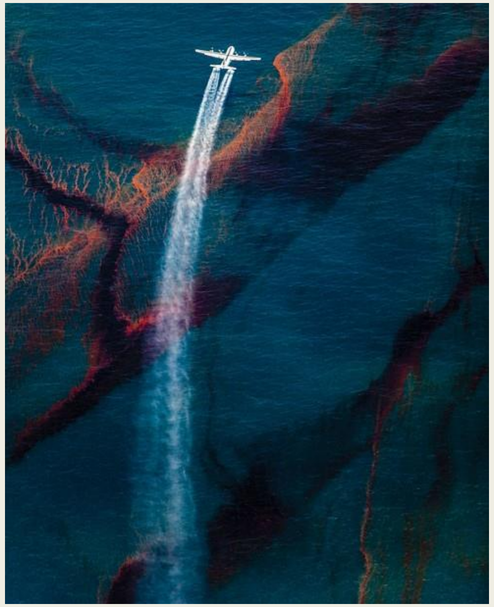

What were the health consequences (2 of 2)?

- Other symptoms of Corexit exposure include skin rashes, coughing up blood, wheezing, migraines, burning eyes, discharge from the ears, cognitive decline, anxiety attacks, and memory loss. The oil companies assured people that Corexit was safe to use and failed to provide protective gear. Seven million liters of Corexit were dropped from airplanes over the Gulf of Mexico in the days following the oil spill.
- Scientists expressed concerns at the time about exposure to the heavy metals found in Corexit, including benzene, hexane, and toluene, all known carcinogens. Even people not directly involved in the cleanup efforts may have been affected by Corexit because the droplets can be carried great distances by the wind, sickening anyone who inhales them.
- Additionally, airborne and skin exposure to hydrocarbons from oil itself can result in:
  - *Coma*
  - *Seizures*
  - *Irregular heartbeat*
  - *Kidney and liver damage*
  - *Permanent and irreversible lung damage*
  - *Death*
- Affected individuals have filed hundreds of lawsuits in both state and federal courts against the companies involved in the Deepwater Horizon oil spill, and many more are expected in the future. Plaintiffs claim that their health was jeopardized due to their exposure to 2-butoxyethanol and hydrocarbons.

What were the legal consequences?

- Following the Deepwater Horizon oil spill, the parties found to be responsible faced both criminal and civil investigations and penalties. The United States government filed a complaint in District Court in December 2010 and launched criminal investigations of all companies involved. Investigations focused mainly on whether relationships between corporate officials and federal regulators were the cause of the Deepwater Horizon accident and a breach of environmental laws. Lawsuits included claims under the Clean Water Act and the Oil Pollution Act.
- Investigators also discovered that procedures used during the attempted capping of the Macondo well may not have undergone any formal risk assessment before they were put in place.
- The main party and developer of the drilling site agreed to plead guilty to criminal charges and to pay up to $1 billion for restoration projects in the Gulf of Mexico. They also released a statement that was filed with the court agreeing to pay all legitimate claims from plaintiffs, regardless of the Oil Pollution Act's limits on liability

What did the subsequent investigations reveal?

- **Flaws in Design and Execution**
  - Engineers were concerned that the cement would place additional pressure on the already fragile rock formation surrounding the well, leading to cracks in the formation. They were also in a hurry to finish this job and move on to the next one. As a result, they devised a new plan to reduce stress on the rock formation and cut time off the job.
  - Unfortunately, flaws in the design and execution of this plan ultimately led to the Deepwater Horizon's tragic end, including:
    - Failing to properly condition the mud produced by drilling to a low viscosity state necessary for settling on the ocean floor
    - Choosing a lower-than-usual value for the rate necessary to pump the cement around the well, which was supposed to displace the mud
    - Reducing the amount of cement used to prevent the cement column from being too high
    - Using a foam cement that contained tiny nitrogen gas bubbles to reduce the density of the cement
  - The choice to change cement material ended up being perhaps the gravest mistake engineers made. When not set correctly, foam cement is porous and permeable to other substances, making it weaker than the cement normally used for this purpose. Despite lab tests that showed unstable behavior, engineers went ahead with their decision to use the foam cement.
  - They also made changes to the procedure typically used to move the Deepwater Horizon off of the well.

What did the subsequent investigations reveal?

- Flaws in Testing
  - In order to test the integrity of the Macondo well, engineers used a material not normally used or tested for this purpose. Initial testing indicated that there was too much pressure building up in the well any time the drill pipe was closed off. Instead of accepting that there was a well integrity issue, examiners used a different test that yielded the results they wanted.
  - The reality was that the cement had not secured the well as it was supposed to. Instead of seawater displacing the drilling mud in the well, inflowing gases expanded in the well and quickly rose 18,000 feet toward the Deepwater Horizon rig. The gas pushed the mud up the well as it expanded.
- Ignored Warnings
  - Despite indications that something was very wrong, attempts to successfully complete the project continued until mud and gas began spilling onto the Deepwater Horizon's drill floor.

What did the subsequent investigations reveal?

- **Emergency Containment Failures**
  - Standard procedure was to seal off the well and route the flow of mud and gas over the side of the Deepwater Horizon. Instead, the crew decided to route the flow into a separator that was too small for the volume of material coming up from the ocean floor. Gas spread over the floor of the Deepwater Horizon and was ignited by the rig’s pump motors, causing the first explosion.
  - The crew continued its fruitless efforts to close the well. Emergency system control pods responsible for closing down the well and preventing further damage failed to activate. During a later investigation, it was discovered that poor maintenance of the emergency systems, including low batteries and other defects, was responsible for the system’s failure.
  - When all else failed, the crew initiated emergency evacuation of all personnel from the Deepwater Horizon, but not before several fatalities and injuries occurred.

What did we learn (1 of 2)?

- Applying lessons from one oil spill to the next is challenging. The necessary cleanup response varies according to any number of factors:
  - *the composition of the crude oil,*
  - *the temperature and microbial ecosystem of the water,*
  - *the prevailing water currents in the region,*
  - *and the weather on the days after the spill.*
- Even the Ixtoc I oil spill, the 1979 well blowout in the Gulf of Mexico that provides the closest analog to the *Deepwater* disaster, didn't prove that instructive to those cleaning up in 2010. For example, many of the lessons that responders could have learned from the 1979 disaster were recorded in industrial literature rather than in academic journals, making them difficult to access.
- Across many fields, experts echo the same refrain: long-term data before a spill are necessary for assessing disaster response. Without baseline data of marine ecosystems, it's nearly impossible to assess the damage to and recovery of those environments. Comprehensive surveys of microbial and fish populations, carried out regularly in areas susceptible to disaster or change, would establish a baseline that could help researchers understand the effects of oil spills or even climate change. And good public health data before and after a disaster would allow other researchers to tease out the potential effects of exposure—to either oil or dispersants—on human health, "Longitudinal cohort studies are the only way we're going to address some of those lingering questions."

What did we learn (2 of 2)?

- There are some ways in which *Deepwater* has prepared the community for the next disaster. Technologies that were just beginning to come into their own a decade ago are now commonplace.
  - *The advances in mass spectrometry and ionization techniques have rapidly expanded scientists' understanding of oil-weathering processes.*
  - *Portable genome sequencers could allow researchers to assess microbial populations in real time to detect the stage of ecosystem recovery.*
  - *And increasingly complex 3-D ocean models can take chemical, physical, and biological processes into account to predict the extent and the path of the spilled oil.*
- These technologies are useful only as long as the people equipped to use them can reach the site of the spill. "When you're thinking about and planning for future spills, how does it work when you don't have an absolute perfect setup to be in theater and the infrastructure to support it?" In many ways, the Gulf of Mexico was perfectly set up for a spill response.
  - *Its currents, its petrochemistry, and its geology were all relatively well studied.*
  - *And the robust infrastructure of the Gulf states—their vast networks of highways, multiple deepwater ports, more than a dozen airports—meant that it was relatively easy to mobilize response teams and researchers alike.*

What changes to the Gulf oil extraction process were made after Deepwater Horizon?

- The aftermath of the *Deepwater Horizon* disaster led to improvement of technical procedures, such as
  - *operation and maintenance of BOPs*
  - *the provision of devices to cap wells under worst-case scenario situations such as the unrestricted flow of oil and gas from an open hole on the floor of the ocean (which nobody seemed to have thought of before this accident).*
- It also led to a complete overhaul of offshore oil and gas regulatory procedures in the US, moving them much closer to the goal-oriented system in place elsewhere.

What changes to the Gulf oil extraction process were made after Deepwater Horizon?

- Having a goal-oriented safety-case system is not guaranteed to avoid a disaster like the *Deepwater Horizon* incident. There is a need for continual review and improvement. In 2010, a root-and-branch review of the UK offshore regulatory system was carried out in the light of the *Deepwater Horizon* explosion and oilspill. This produced 27 recommendations for how the UK system needed to be improved in order to make the chances of a repeat accident in UK waters as low risk as possible. These covered areas such as:
  - improving well planning and control, based on best engineering principles and practice;
  - improving the learning culture and processes for spreading best practice;
  - increased focus on competency and training of the workforce;
  - enhanced workforce engagement and encouraging whistleblowing;
  - strengthening mechanisms to assure implementation of safety and environmental management systems;
  - ensuring the quality and high competence of regulators as well as competent and responsible operators;
  - greater integration between the regulatory authorities in the UK and the further separation of licensing and regulation (as was not the case in the US in 2010);
  - a clearer command and control structure in the event of a spill;
  - robust arrangements to ensure operators' level of liability and ability to pay in the event of a spill; and
  - intensified R&D to develop improved avoidance, capping, containment, cleanup and impact monitoring of major offshore oil spill incidents.

Quality implications of the tragedy

- There was clearly a conflict at times between best practice risk mitigation and savings of time or money. To avoid such conflicts requires a top-down safety culture that rewards those, both employees and contractors, who take the right action to manage risks irrespective of whether this adds extra time or costs.
- Alongside this, the *Deepwater Horizon* incident arose because of regulatory failures. It was clear that the MMS regulatory system in place at the time was not fit for purpose to address the management of risks involved in deepwater drilling, or even more routine hydrocarbon recovery operations.
  - *The prescriptive rules-driven checklist system in place in the US at the time, with inadequate processes, resources and expertise to review decisions by operators and their contractors was a stark contrast to the goal-oriented safety case regulatory regime in place in the UK and other parts of the world.*
  - *There the responsibility is on the operator to identify all the possible hazards associated with drilling and completion of oil and gas wells, to evaluate the risks and to present a mitigation plan for how these risks will be managed to reduce them. This is to be done not by some method or to some level prescribed by the regulator, but by whatever procedures are required to make them* ***as low as reasonably practicable*** *– the well-known ALARP principle*

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