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Deepwater Horizon Oil Spill: A Review

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Abstract— ***The Deepwater Horizon was a semi-submersible offshore oil rig, built to operate in deep waters as deep as 8000 feet and to drill down 30,000 feet, owned by Transocean. During the time of the accident, it was licensed to BP by Transocean Ltd. While drilling an exploratory well about 41 miles off the coast of Louisiana, on April 20, 2011, an explosion and fire on the Horizon killed 11 workers and released approximately 4.9 million barrels of crude oil into the Gulf of Mexico. The oil spill was ultimately capped and contained on July 15, 2011. Damages to BP, the environment, and the US gulf coast economy are estimated to be $36.9 billion. Various studies were conducted to ascertain the extent of damages, causes, impact on environment from different field of expertise in order to understand, avoid and handle similar accidents in the future which is almost next to irreversible. This paper presents a state-of-the-art review of this incident and presents the lessons learnt in order to avoid occurrence of similar accidents in the future.***

Keywords— offshore oil rig, explosion, oil spill, environmental damages, accidents

I. INTRODUCTION

The Deepwater Horizon spill occurred on April 20th, 2010. Almost 4.9 million barrels of Louisiana light crude oil were released into the northern Gulf of Mexico following the blowout. This was the largest marine oil spill in United States history. On July 15th, 2010, the leaking wellhead was ultimately capped and was declared dead on September 19th, 2010. Oil was primarily released at a depth of approximately 1500 m which led to the formation of a large deep plume at 1100 m which was characterized by light hydrocarbons **[**1].

A huge amount of the oil was transported to the sea surface and spread over 1600 km of shoreline. The Deepwater Horizon platform was owned by Transocean and was leased to British Petroleum (BP) as a fifth-generation dynamic positioned semi-submersible oil rig. The cost of building up the Horizon wad $365 million and was designed to operate in water as deep as 2.4 km and to drill down 9.1 km. The platform was located 66 km off the Louisiana coast and was 121 m long and 78 m wide. Observations showed that a large amount of natural gas such as methane, propane, and ethane were spilled along with crude oil [2].

The fire raged for 36 hours, damaging the platform, killing 11 oil rig workers, and severely injuring 17 others among the 126 people onboard. The charred superstructure collapsed and sank into the Gulf, producing a "wellhead blowout" as the oil inlet disconnected at a seafloor depth of 5,100 ft. Over the subsequent period of 87 days, before the wellhead was successfully capped on 15 July 2010, more than 4.9 million barrels of petroleum (210,000,000 US gal; 780,000 m3) flowed into the Gulf [3].

This paper is aimed at providing a detailed account of the accident, environmental issues it caused and remediation efforts that were employed to remediate the situation. The lessons learnt from this major environmental accident are also presented in the hopes that such incidents shall be averted in future.

1. CAUSE OF ACCIDENT

On April 20, 2010, the drilling activities were finalized after several productive oil and gas zones had been found at Macondo, and the crew was performing a series of steps to temporarily abandon the well. Abandonment activities would essentially plug the well so that the rig could move on to a new drilling site and a production installation could return to the Macondo site at a later date to extract the hydrocarbons [5].

The temporary abandonment plan for BP involved removal of most of drilling fluid column in the well before installation of a surface cement plug. Earlier, a critical cement barrier intended to keep the hydrocarbons below the sea floor had not been effectively installed at the bottom of the well. Below is a series of causes that led to the blow out:

A. Cement integrity

This test was not conducted in a way that described a clear "pass" or "fail" result to the workers. Both BP and Transocean personnel on the Deepwater Horizon rig misinterpreted the test results concerning the cement integrity, leading them to erroneously believe that the hydrocarbon bearing zone at the bottom of the well had been sealed when in fact it was not [5].

B. Early removal of drilling Fluid

When the drilling fluid column was removed, pressure gradually reduced above the hydrocarbon reservoir at the bottom of the well. Ultimately, this action allowed hydrocarbons to flow past the failed cement barrier and up toward the Deepwater Horizon. Meanwhile, because of a failure to recognize the increase in fluids from the well, the crew continued to remove more of the drilling fluid column, causing both the hydrocarbon influx rate into the well and movement of hydrocarbons toward the rig to rise. The hydrocarbons continued to flow from the reservoir for almost an hour without human intervention or the activation of automated controls [5].

C. Failed blow out preventer

The force of the hydrocarbons accelerating up the mile-long drilling riser resulted in well fluids gushing onto the drilling rig floor—a blowout. At this point, the crew took action to activate the blowout preventer (BOP). This safety critical element, located at the sea floor, temporarily sealed the well but could not stop the hydrocarbons that had already traveled above the BOP from releasing onto the rig [5].

D. Mud-gas separator overwhelmed

When oil and gas had risen above the BOP, the crew tried to divert it to a safer location than onto the rig floor. However, the flow from the diverter had been preset to route well fluids to the mud-gas separator rather than over the side of the Deepwater Horizon. The mud-gas separator was not designed to safely handle a flow of the magnitude of the Macondo blowout therefore it was rapidly overwhelmed. Consequently, drilling mud and hydrocarbons rained down onto the rig floor. The hydrocarbons found an ignition source, and explosions and fire ensued [5].

E. Buckling of drill pipe

The manual and automated emergency systems within the blowout preventer were activated in an attempt to shear the drill pipe and seal the well. However, pressures in the well had caused the drill pipe to buckle, which inhibited the BOP from sealing the well [5].

Ultimately, in the hours leading up to the incident, no effective barriers were in place to prevent or mitigate a blowout. The physical barriers intended to prevent such a disaster were not properly designed for the well conditions, constructed, tested, or maintained, or they had been removed. The management systems intended to ensure the required functionality, availability, and reliability of these barriers were inadequate. An examination of the treatment of safety critical equipment and tasks at Macondo, such as the BOP and cement barrier testing, reveals opportunities for further improvements in effective barrier safety management. Furthermore, a comparison of the US regulatory requirements for these safety critical elements to other international offshore regimes illustrates gaps in the US model and offers support for further post-Macondo changes to the US offshore safety regulations.[5]

2. EXTENT OF ACCIDENT

BP set up an escrow account of $20 billion to meet an unspecified number of claims for consequential losses arising from the oil spill. The amount of oil and gas, escaping from the subsurface well has been estimated to have been in the range of 35,000-60,000 barrels of oil a day, making the incident the largest oil spill in US history. However, the termination of the oil spillage does not, necessarily, entail a simultaneous end to the legal aspects of the incident. The imposition of fines, the adjudication of class action law suits by the thousands of victims, the cleansing and environmental rehabilitation operations are only some of the consequences of the oil spillage. It is highly possible that, in order to meet the above and other claim demands, BP, may have to sell further assets in addition to those which are already planned for sale and are being estimated at a value of $30 billion [2].

BP's shares fell from 655.40 pence/share on the day of the accident to 308 pence/share hardly 10 weeks after the accident. This deep drop in share price reflected the market's loss of confidence in BP because of the catastrophe's financial consequences for the company. If the oil spill had been controlled in a week, there would have been far less damage to the environment and probably to the share price as well. BP's cancellation of dividends for the remainder of 2010 did not improve the mood of the shareholders. However, BP's creditors and the general public reacted positively to the dividend cancellation. Their attitude was that the company's owners should also suffer consequences from the environmental disaster. The spill and its subsequent clean-up methods generated 80,276 tons of solid waste and 956,350 BBLs of liquid waste as of October 17, 2010 [4].

3. ENVINRONMENTAL DAMAGES

A. Ecosystem

The Deepwater Horizon oil spill was the largest environmental disaster and response effort in U.S. history, spewing an estimated 4.1 million barrels of crude oil into the Gulf of Mexico. Massive areas of the Gulf of Mexico were contaminated with oil, including deep-ocean communities and more than 1,600 kilometers of shoreline. Multiple species of birds, fishes, polychaetes, mollusks, sea turtles, crustaceans and marine mammals were affected, and over 20 million hectares of the Gulf of Mexico were closed to fishing [12]. The amount of PAHs (polycyclic Aromatic Hydrocarbons) detected two months post the spill in was found to increase to 40 times than usual [10]. PAHs are carcinogens which poses serious health threat to humans and marine life and the oil eating microbes can reduce the concentration of dissolved oxygen. According to a 2014 study on the effects of the oil spill on Bluefin tuna, it was found that the toxins from the spill could cause irregular heartbeat leading to cardiac arrest and the scientists also claimed most likely the same effect on large predators and humans. The spill increased the fatality and shortened the life of amberjack and tuna which developed deformities of the heart and other organs after the spill [6].

The oil dispersant Corexit was used with the intent of making it easily biodegraded by naturally occurring microbes in the sea, which proved to be harmful to the aquatic life and the consumers of sea food including birds and humans, as the mixture entered the food chain through zooplankton [12].

Toxins from the spill were detected in migratory birds as far away as Minnesota. Petroleum compounds and Corexit was detected in Pelican eggs [7]. In 2012, scientists and fishing community witnessed disturbing numbers of mutations in commercial fishes which is believed to be caused by the dispersant and PAHs from oil, including 50% of shrimp found lacking eyes and eye sockets. In November 2010, fishermen noted fish with oozing sores and lesions [6]. Louisiana pancake batfish mostly contained within the spill-affected area were adversely affected due to the damage caused in the sea bed. In March 2012, it was evident that the spill caused the death of a Gulf coral community [8].

After the spill, during the first birthing season, the number of dead baby dolphins washed up along Mississippi and Alabama shorelines was about 10 times the normal number. By 2013, more than 650 dolphins had been found stranded in the oil spill area, four times increase over the historical average. Reports of stranding of endangered Kemp's Ridley sea turtles after the spill was found to be approximately 400 more than the average of 100 [12].

In 2013, Tar balls continued to wash up along the shorelines of Mississippi and Louisiana, along with oil sheens in marshes and signs of severe erosion of coastal islands killing trees and marsh grass. In 2013, a phenomenon called a "dirty blizzard" was observed in the ocean floor where oil in the water column forms clumps around suspended sediments and falls to the ocean leaving the traces of oil in the food chain for generations. A 2014 Bluefin tuna study in Science found that oil already broken down by wave action and chemical dispersants was more toxic than fresh oil. A 2015 study of the relative toxicity of oil and dispersants to coral also found that the dispersants were more toxic than the oil. A 2016 study published in Diseases of Aquatic Organisms reported about 88 percent out of 360 stillborn dolphin babies within the spill area had abnormal or under-developed lungs as compared to 15 percent in other areas [14].

B. Health consequences

Chemicals from the oil and dispersant are believed to be the cause of the 183 spill-exposure reported in to the Louisiana Department of Health and Hospitals in 2010, out of which 108 were involved in the oil spill remediation effort. And it is believed that the addition of dispersants added to the toxicity of the spill [13].

On May 2010, seven fishermen working in the cleanup crew were hospitalized, following which BP requested a Health and Hazard Evaluation by the National Institute for Occupational Safety and Health. The test came out to be negative and NIOSH concluded that the reason to be most likely due to heat, fatigue, and terpenes. Later another 10 hospitalizations were reported and similarly no link could be established between the spill and the hospitalizations.

Air monitoring was performed by the NIOSH around the cleanup workers at sea, on land, and during the application of Corexit and it was found that air concentrations of VOCs and PAHs never exceeded permissible exposure levels which might be because some VOCs may have already evaporated from the oil prior to the investigation. In their report, they suggested that respiratory symptoms might be due to the presence of high levels of ozone in the air, resulting from photochemical reaction from the oil. Important thing to be noted in their report was the personnel involved were not using personal protective equipment (gloves and impermeable coveralls) as per the instructions and no use of respirators was mentioned. The most pressing safety concern was the exposure of the workers to heat stress.

Two years later, NIOSH conducted a study where they found biomarkers matching the oil from the spill in the bodies of cleanup workers. Similar studies have reported a variety of health issues related to mental, skin, breathing, coughing, and headaches.

Several reports of physical or mental health symptoms among children including bleeding ears, nose bleeds, and the early start of menstruation among girls were reported by the parents living within 10 miles from the coast in Louisiana and Florida [13].

A 2012 survey of the health effects of the spill on cleanup workers reported "eye, nose and throat irritation; respiratory problems; blood in urine, vomit and rectal bleeding; seizures; nausea and violent vomiting episodes that last for hours; skin irritation, burning and lesions; short-term memory loss and confusion; liver and kidney damage; central nervous system effects and nervous system damage; hypertension; and miscarriages".

3. REMEDIATION MEASURES

A. Containment of dispersants

During an offshore oil spill, containment and deployed to hold the oil in place prior to skimming and burning. Containment boom are either of rigid or inflatable type, high-strength polyurethane-coated fabric that remains partially submerged below the water surface. Containment boom is often provided with a vertical skirt that extends below the water surface to enhance stability and improve capture efficiency. Booms are monitored and replaced to keep pace with spill, weather, and tidal conditions [16].

In order to protect marshes, mangroves, shrimp/crab/oyster ranches and other ecologically sensitive areas containment booms stretching over 4,200,000 feet (1,300 km) were deployed. During the Deepwater Horizon spill, almost 4.2 million feet of containment boom and approximately 9.1 million feet of sorbent boom were deployed which is considered to be one of the largest deployment of boom in the history of spill response in order to aid in skimming, in-situ burning, and temporary shoreline protection [16]. Unfortunately, it was proved to be helpful only in relatively calm and slow-moving waters as the boom depth extend 18–48 inches above and below the water surface. Booms were criticized for ineffectiveness in containment in waves three to four foot high and washing up on the shore with oil failing to contain oil effectively.

In order to protect the coast of Louisiana, plan was developed to build barrier islands, but it was criticized for its expenses and poor results. The EPA expressed its concern over booms threatening wildlife [16].

B. Removal

The three fundamental approaches for eliminating the oil from the water were: combustion, offshore filtration, and collection for later processing. According to United States Coast Guard, 33 million US gallons of tainted water was recovered, including 5 million US gallons of oil [15]. It is estimated that about 5% of leaked oil was burned at the surface and 3% was skimmed.

From April to mid-July 2010, 411 controlled in-situ fires remediated approximately 265,000 barrels which released small amounts of toxins, including cancer-causing dioxins. According to EPA's report, the released amount is not enough to pose an added cancer risk to workers and coastal residents, while a second research team concluded that there was only a small added risk.

In total 2,063 Skimmers were used to collect oil. Corexit made the oil too dispersed to be collected. The EPA regulations prohibited use of skimmers that left more than 15 parts per million of oil in the water and many large-scale skimmers exceeded the limit. In Mid-June, BP ordered 32 skimmers with the capacity to extract 2000 barrels per day and by the 28th of June, had removed 890000 barrels of oil [17].

On beaches the basic ways of removal were sifting sand, removing tar balls, and digging out tar mats manually or mechanically [16]. On marshes, vacuum and pumping, low-pressure flush, vegetation cutting, and bioremediation were used.

C. Use of Corexit dispersant

The application method and volume of Corexit oil dispersant over the spill was purely experimental. In total 1.84 million US gallons of dispersants were used; of this, 771,000 US gallons were released at the wellhead [18]. Due to the spill's unprecedented nature, BP with USCG and EPA decided to go for subsea injection that had never been tried before. To release the dispersants 400 sorties were flown.

Environmental scientists expressed concerns over the use of dispersants that increased the toxicity of the oil and as it gets picked up by the waves and gets washed though the Gulf also increasing the threat to sea turtles and Bluefin tuna [16].

Corexit EC9500A and Corexit EC9527A were the principal variants which according to a NALCO manual obtained by GAP is an eye and skin irritant. Continuous exposure may cause central nervous system effects, nausea and vomiting, anesthetic or narcotic effects and may cause injury to RBC, kidney or the liver.

Among EPA's approved dispersants, the dispersants used are neither the least toxic, nor the most effective and BP justified its use saying its availability at the week of the rig explosion [16]. On 24 May, EPA Administrator Lisa P. Jackson ordered EPA to conduct its own evaluation of alternatives after, BP determined that none of the alternative products met all three criteria of availability, non-toxicity and effectiveness. EPA also ordered BP to reduce dispersant use by 75%. Following the order, BP reduced Corexit use by 25,689 to 23,250 US gallons per day.

It has been suggested that Corexit had increased the toxicity of oil by 52 .The scientists concluded that "Mixing oil with dispersant increased toxicity to ecosystems" and made the gulf oil spill worse."

D. Oil-eating microbes

Genetically modified *Alcanivorax borkumensis* was added to the waters to speed up the digestion of oil with the dispersants breaking the oil into finer fractions that would provide larger surface area for digestion [16]. Various risks were identified and evaluated, in particular that an increase in microbial activity might reduce subsea oxygen levels, threatening fish and other animals. Several studies showed that microbes successfully digested part of the oil. By mid-September, other research claimed that microbes mainly digested natural gas rather than oil.

3. FOLLOW- UP: LESSONS LEARNT

The BP-Deepwater Horizon catastrophe clearly illustrates the complex linkage among the geological, technical, human, organizational and social systems risks in the oil industry. This complexity was simply overpowering for those with operational responsibility on the oil platform. A company engaged in oil exploration/extraction must be resilient enough to handle all these related risks [18].

A. Geological System Risk

Lack of knowledge about the properties of bedrock at extreme depths of the sea is an issue of some concern. Oil has been commercially extracted, at the depths at the Macondo Prospect, for fewer than ten years. Those companies working at such levels need more up-to-date and in-depth information about how the bedrock at such levels reacts. Until more is known, consideration should be given to ceasing such oil exploration/extraction [18].

B. Technical System Risk

The BP-Deepwater Horizon catastrophe also illustrates the importance of well-functioning safety systems on oil platforms. It is essential to identify the risks of potential accidents at each step of the operations and to verify that the safety systems are modern and well-maintained [18].

C. Human System Risk

Our knowledge of major disasters shows that the human factor is nearly always important for understanding the causes and consequences of such events. People make mistakes, ignore warning signs, react too passively, communicate ineffectively and so on. Technical systems should be constructed so as to minimize human inattention, misjudgments and paralytic inaction. In addition, the people who maintain/operate these technical systems should be trained in safety regulations and procedures and should be able to deal with the stress of work overload when critical situations occur [9].

D. Organizational System Risk

The BP-Deepwater Horizon case illustrates the complicated arrangement in which managers, explorers, excavators and suppliers share responsibility for oil exploration/excavation. Specialization by companies in niche areas, while often financially rewarding, can lead to poor risk management when consortiums or partnerships are formed. In this case, the shared responsibility by BP and the other companies led to dysfunctional communications that culminated in a chain of lawsuits that put at risk all reputations and future activities. The "blame game" that resulted when the various companies involved in the accident sought to hold others responsible did not enhance the world's respect for any of them [18].

E. Social System Risk

Last, the BP-Deepwater Horizon catastrophe highlights the risk to the environment of oil/gas production in areas with sensitive marine ecosystems and vulnerable, coastal wetlands. Perhaps the greatest risk to a company engaged in such activity is not the inevitable settlement of compensation claims by those damaged. Rather, it is the loss of the confidence in a company by its lenders, investors and customers as well as by governmental authorities, politicians and the general public. For companies, oil companies in particular, this may be the most important lesson from the BP-Deepwater Horizon case [18].

II. CONCLUSIONS

Deepwater Horizon spill is one of the worst environmental disasters and also probably the costliest one as well. After Exxon-Valdez incident, a number of protective measures were taken to prevent oil spill related accident, till Deepwater Horizon incident took place. A very expensive containment and management plan was executed to deal with this accident. A number of valuable lessons were learnt from this incident and hopefully similar accidents will be prevented and/or managed better in future.

REFERENCES

[1] D. R. Millemann, R. J. Portier, G. Olson, C. S. Bentivegna & K. R. Cooper,Particulate Accumulations in the Vital Organs of Wild Brevoortia Patronus from the Northern Gulf of Mexico after the Deepwater Horizon Oil Spill, Springer Science Business Media New York 2015.

[2] E. Nyankson, D. Rodene & R. B. Gupta, Advancements in Crude Oil Spill Remediation Research After the Deepwater Horizon Oil Spill. Springer International Publishing Switzerland 2015.

[3] J. M. Shultz, L. Walsh, D. R, Garfin, F. E. Wilson, Y.Neria , The Trauma Signature of an Ecological Disaster, Journal of Behavioral Health Services & Research, 2014. 1–19.) 2014 National Council for Behavioral Health. DOI 10.1007/s11414-014-9398-7.

[4] S. Tengblad and M. Oudhuis, Ed., BP and Deepwater Horizon: A Catastrophe from a Resilience Perspective. Springer Nature Singapore Pte Ltd. 2018

[5] US Chemical Sand Hazard Investigation Board Investigation Report Volume 1, Deepwater Horizon Rig Mississippi Canyon Block #252, Gulf of Mexico April 20, 2010 Report no. 2010-10-i-os6/5/2014.

[6] Incardonaa JP, Gardnerb LD, Linboa TL, Browna TL, Esbaughc AJ, Magerc EM., Stieglitzc JD, et al. 2014. Deepwater Horizon crude oil impacts the developing hearts of large predatory pelagic fish. doi:10.1073/pnas.1320950111.

[7] Henkel JR, Sigel BJ, and Taylor CM. 2012. Large-Scale Impacts of the Deepwater Horizon Oil Spill: Can Local Disturbance Affect Distant Ecosystems through Migratory Shorebirds? Vol. 62 No. 7. BioScience 62: 676–685; doi:10.1525/bio.2012.62.7.10.

[8] Fishera CR, Hsinga PY, Kaiserb CL. 2014. Footprint of Deepwater Horizon blowout impact to deep-water coral communities. doi/10.1073/pnas.1403492111.

[9] Whitea HK, Hsingb PY, Choc W, et al. 2012. Impact of the Deepwater Horizon oil spill on a deep-water coral community in the Gulf of Mexico. Vol. 109, 20303–20308; doi:10.1073/pnas.1118029109.

[10] Regina Lamendell. 2014. Assessment of the Deepwater Horizon oil spill impact on Gulf coast microbial communities. DOI: 10.3389 /fmicb.2014.00130.

[11] Grattan LM, Roberts S. 2011. The Early Psychological Impacts of the Deepwater Horizon Oil Spill on Florida and Alabama Communities. Volume 119, number 6; doi:10.1289/ehp.1002915 [Online 17 February 2011].

[12] Barron MG. 2012. Ecological Impacts of the Deepwater Horizon Oil Spill: Implications for Immunotoxicity. Toxicologic Pathology, 40: 315-320; doi: 10.1177/0192623311428474

[13] Anderson SE, Franco J, et al. 2011. Potential Immunotoxicological Health Effects Following Exposure to COREXIT 9500A during Cleanup of the Deepwater Horizon Oil Spill. Volume 74, 2011- issue21: Bioactivity of Oil Dispersant in the Deepwater Horizon Clean-up Operation; doi:10.1080/15287394.2011.606797.

[14] Schwacke LH, Smith CR, et al. 2014. Health of Common Bottlenose Dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, Following the Deepwater Horizon Oil Spill. Environ. Sci. Technol., 2014, 48 (1), pp 93–103; DOI: 10.1021/es403610f.

[15] Mahmoudi N, Porter TM, Zimmerman AR, et al. 2013. Rapid Degradation of Deepwater Horizon Spilled Oil by Indigenous Microbial Communities in Louisiana Saltmarsh Sediments. Environ. Sci. Technol., 2013, 47 (23), pp 13303–13312; DOI: 10.1021/es4036072.

[16] Grier P. 2010. Containment boom effort comes up short in BP oil spill. The Christian Science Monitor. April 27, 2019.

[17] Schoof, Renee (17 July 2010). "Mother Nature left to mop up oily mess". The Sun News. April 27, 2019.

[18] Oudhuis M, and Tengblad S. 2017. BP and Deepwater Horizon: A Catastrophe from a Resilience Perspective. BP and Deepwater Horizon: A Catastrophe from a Resilience Perspective; https://doi.org/10.1007/978-981-10-5314-6_5.