DEEPWATER HORIZON DISASTER AND INFLUENCE ON OFFSHORE INDUSTRY REGULATIONS

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Abstract: The article presents the risk management analysis of Deepwater Horizon drilling rig into the context of international trend in exploiting oil and gas reserves in high water depth. Legislation influence in oil and gas industry and competent on site risk management entities added value for maintaining risk as low as possible considering development of offshore industry are also presented.

Keywords: Deepwater Horizon, blowout, risk analysis, offshore, accidents aftermath.

1. INTRODUCTION

Development of undersea reserves of oil and gas, must take into account a large number of risks in the areas of human life lost, environmental disasters and material/financial assets wasted. All involved in offshore industry know those risks and the fact that major accidents are always likely to happen in this hazardous industry.

Eruption and then the explosion which tear apart Deepwater Horizon drilling rig last year on 20th April while workers were completing an exploratory well off coast Louisiana in Gulf of Mexico, developed into a tremendous human, economic but particularly environmental disaster. Why was this possible? Increase of oil price lately has encouraged oil and gas industry to drill in higher water depths. Macondo well was situated at 5000 feet below surface and reaching 13000 feet under sea bottom [1].

Drilling in deep water is a technology young enough and not fully developed on matters of risk identification and mitigation, considering low temperatures and visibility or high distance and pressure. "When a failure happens at such depths, regaining control is a formidable engineering challenge - and the cost of failure…. can be catastrophically high" [2].

Risk element may be any decision that has a measurable probability of deviation from the initial plan. This of course presumes that this initial plan exists. Plans, strategies and procedures are the elements that facilitate foreseeing the reality and then comparison between results obtained and those expected.

Risk management is a cyclic process with several distinctive phases as: risk identification, risk analysis and risk mitigation measures. Identification of internal and external risks is of high importance as it allows managerial teams to point especially the internal risks.

Psychological approach on upper management regarding risks refers to their decisional behaviour. One subject must be able to choose between two or more alternatives, with different degrees of danger, uncertainty and

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randomness. Because during managing activities and especially during risk managing, decision factor is present in high percentage, is very influential to study the psychology of risk.

The reliability and safety assessment of operational systems should not only focus on hardware failure but also include human error. In a large-scale and complex industrial system, human is prone to produce various errors by the effects of error-forcing conditions. If a potential human error has a high occurrence probability or potential severe effects, this error is termed critical human error. To prevent and reduce human errors, it is important to identify these potentially critical human error modes by human error risk assessment [3].

2. CHAIN OF EVENTS

2.1. Road to disaster [2]

At the end of last decade offshore industry in Gulf of Mexico has recovered after the effects of hurricanes and tornados. This and increase in request of hydrocarbons has pushed the industry towards deep water drilling. All due companies as Anadarko Petroleum, Hess, Marathon, etc. had licences and were exploring on behalf of holdings as Statoil or Petrobras, new players in have tackled this domain.

In September 2009, semisubmersible drilling rig Deepwater Horizon, from Transocean, has made an important finding in Tiber prospect. Drilling in ~122m water depth at more that 10.000m drilling depth, was discovered a reservoir of 4 to 6 billions BOE one of the largest in USA.

Pride in this discovery cannot hide the technological challenges encountered during drilling and production in those very deep waters combined with different, unique undersea geology. When water depth exceeds 10.000 m we are expecting pressures of over 7000 ton/m^2 and temperatures at borehole over 180°C, which are a few of de problems for those developments.

2.1.1. Deep water drilling

Drilling in extreme deep water needs to consider a series of technological risks that must be mitigated through research on testing scale. Raisers who travel literally kilometres from BOP to drillship must overcome the effect of stressing underwater currents. Huge volumes of mud and drilling fluid require a tremendous work effort for offshore workers. Placing and maintaining blowout preventers at high depth is made with remotely operated vehicles with obvious shortcomings. “Fire ice” (methane trapped into ice) is another aspect that must be considered, as quantity of gas freed could reach 160 cubic meters per cubic meter of methane hydrate.

2.1.2. Risk management tools [4, 5]

Currently for risk quantification purposes in industrial activities of high risk are used two basic tools: probabilistic risk analysis (PRA) and accident sequence precursor (ASP). Different as they are in methods and application, both end-up quantifying risk. Probabilistic risk analysis has its roots in aerospace industry and models complex systems with huge number of components, giving the probability of failure composed for entire assembly. As input for analysis we can consider statistic information on failure probability or in absence test data used to predict it. Methods utilised for modelling are event trees and fault trees.

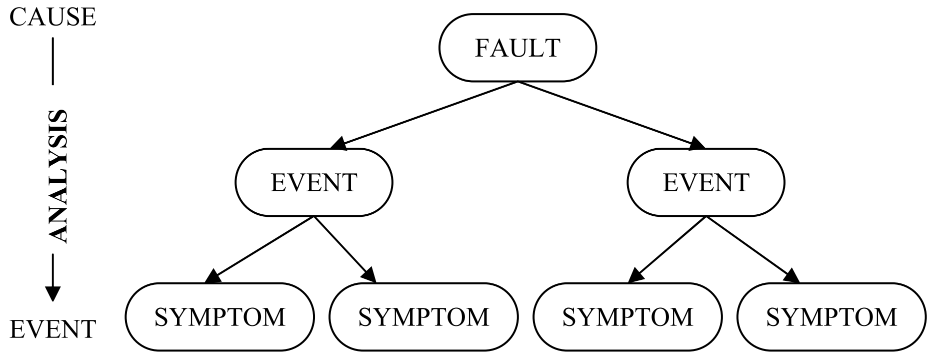

Fig. 1. Fault tree.

Event tree (Figure 1) uses the symptoms that threaten the system and follow their progressive influence in each layer of engineering protections. Faults tree (Figure 2) models the response of each component in case of a known cause, which grants study of different responses and construction of an overall system reliability image. This modelling may reveal lack of independence of engineered safeguards, missing redundancy, unusual mixture of system control and safety functions. The downside is the amount of data which is not always available or accurate. Human factor has also a great impact over those models as is difficult to anticipate his impact.

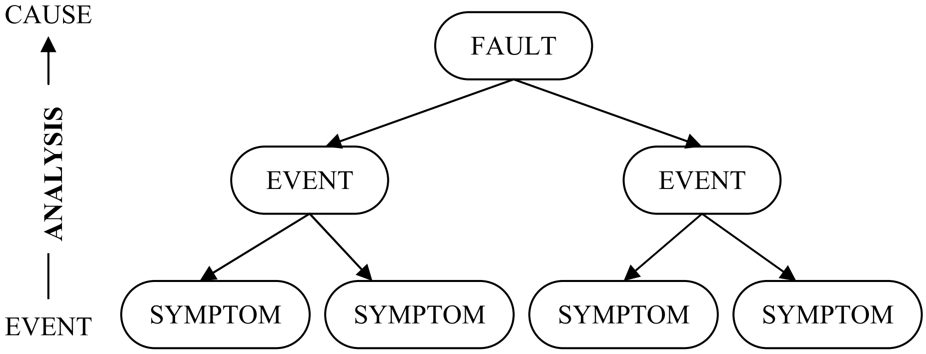

Fig. 2. Event tree.

On the other hand event tree can model the response to a generic event and has the origin in nuclear industry where the facts were pretty much expectable (failure in cooling system that cools the reactor). Is feasible to obtain a general response of the facility containing information about all involved members (including human factor), but disregards specific details that may be essential in real situation.

Currently ASP is performed through strict format reports and specific guidelines to ensure capture of all possible problems. After collection of those report precursors of accident are identified and classified in initiating event and degraded conditions.

Identified precursors are iterated into the model with different generic tree of events having various initiating events. All the final results are ranked on their probability to create a disaster and that particular causal precursor. A recent study over the factors that lead to a risk-informed decision has resulted in following list [6 … 11].:

- "Strong top management support and leadership both at the regulator and the licensee level;
- Education and training in risk principles and probabilistic risk assessment;
- A slow and steady introduction of risk initiatives in areas that can show value to both regulator and industry;
- A transparent regulatory foundation built around safety goals;
- Development of a strong safety culture in industry allowing for more independence in safety compliance and risk management".

2.1.3. Initiating event & secondary precursors

Aspects that influence the effect of precursors or themselves may be considered precursors if contract bonding terms. As on 20 April 2010, BP team in charge with drilling of Macondo well were 45 days behind the schedule and $58 millions over budget [12]. At this we must also add the value of Transocean leased rig which values around $1 million per day are more than sufficient reasons for the team to finish as fast as they can the abandon of this well.

Cementing job meant to seal the well until the production unit will arrive on site had in plan a cement sample testing combined with pressure testing of the sealed well. As the expenses from delays were sky high already it was decided that if the pressure test is fine, cement will pass without testing. Here intervened human factor, likely to fail under pressure, which accepted this obvious wrong shortcut.

Pressure testing a well before after-drilling abandon has several positive and negative pressure testing to evaluate the resistance of the cement plugs mounted. Here another precursor if not the initiating event appears. From BOP stack mounted over the well annular preventer has a rubber seal failure and releases small amounts of fluids during positive pressure testing. Due to this release tolerance during positive testing, who accounts for the effect of an overpressure that might become a blowout, were achieved.

Negative pressure testing, used as quick method of ascertaining quality of cement plugs, had the character of improvisation, as no procedure in BP drilling dossier contained reference, to such an operation. Moreover no legislation or common practice document stated the limits of this pressure testing or collateral checks that are required. As it was performed pressure testing had only one set of information and no witness value to evaluate that result.

Inspection committee has summarised negative pressure testing shortfalls in this set of conclusions which says much about risk management perception in operational team:

- "There was no standard procedure for running or interpreting the test in either MMS regulations or written industry protocols. Indeed, the regulations and standards did not require BP to run a negative-pressure test at all.
- BP and Transocean had no internal procedures for running or interpreting negative-pressure tests, and had not formally trained their personnel in how to do so
- The BP Macondo team did not provide the Well Site Leaders or rig crew with specific procedures for performing the negative-pressure test at Macondo
- BP did not have in place (or did not enforce) any policy that would have required personnel to call back to shore for a second opinion about confusing data.
- Finally, due to poor communication, it does not appear that the men performing and interpreting the test had a full appreciation of the context in which they were performing it. Such an appreciation might have increased their willingness to believe the well was flowing. Context aside, however, individuals conducting and interpreting the negative-pressure test should always do so with an expectation that the well might lack integrity."

Minding the lack of testing for cement used for this job is common practice to flush the well with mud until the return is obtained before cementing. This creates a clean space for cementing and grants engineers the chance to a final check of hydrocarbons concentration from the bottom of the well. Cementing job on Macondo was also compromised by some other aspects among which low rate of cement flow and reduced volume particularly caused lack of resistance to internal kick.

Inadequate temporary abandonment procedure could also be considering one of the precursors for this blowout. Replacing high density mud with sea water over the cement plugs has clearly increased the load on cement from below. Water had also negative effect over the lockdown sleeve as it successfully transmitted the overpressure [13 … 17].

2.2. Kick, blowout and immediate action

With all the causes acting, the finality could've been avoided or the amplitude diminished if personnel in charge have paid attention to signals announcing the kick. One of the symptoms that should lead to a through investigation and shutdown the well was the increase of pressure on drill pipe when all the pumps were off. On control panel driller or tool pusher, could spot pressure difference between drill pipe and kill line, fact that should raise questions among drilling team members. Knowing the importance of those signals maybe a computerised alarm system must witness the differences instead of a human subject to human error.

Normal emergency procedure stated that in order to avoid ignition of accompanying gas, erupting mud needs to be diverted over board and the blind shear ram activated. Neither happened on Horizon, fact the intrigued aftermath inspection and various possible causes were assumed. Did the emergency team make a optimistic estimation of that eruption or they've been in such position in which the 6-8 minutes from eruption to explosion were not enough to act? Most likely explanation is that their training was not adequate and emergency response lacked in speed and precision [2].

3. ACCIDENT'S AFTERMATH AND IMPACT IN LEGISLATION

To clarify the causes and quantify effects of this accident a National Commission has been designated in order to have an independent and impartial outcome. As a result of their investigation, following conclusions were drawn:

- "The explosive loss of the Macondo well could have been prevented.
- The immediate causes of the Macondo well blowout can be traced to a series of identifiable mistakes made by BP, Halliburton, and Transocean that reveal such systematic failures in risk management that they place in doubt the safety culture of the entire industry.
- Deepwater energy exploration and production, particularly at the frontiers of experience, involve risks for which neither industry nor government has been adequately prepared, but for which they can and must be prepared in the future.
- To assure human safety and environmental protection, regulatory oversight of leasing, energy exploration, and production require reforms even beyond those significant reforms already initiated since the Deepwater Horizon disaster. Fundamental reform will be needed in both the structure of those in charge of regulatory oversight and their internal decision making process to ensure their political autonomy, technical expertise, and their full consideration of environmental protection concerns.
- Because regulatory oversight alone will not be sufficient to ensure adequate safety, the oil and gas industry will need to take its own, unilateral steps to increase dramatically safety throughout the industry, including self-policing mechanisms that supplement governmental enforcement.
- The technology, laws and regulations, and practices for containing, responding to, and cleaning up spills lag behind the real risks associated with deepwater drilling into large, high-pressure reservoirs of oil and gas located far offshore and thousands of feet below the ocean's surface. Government must close the existing gap and industry must support rather than resist that effort.
- Scientific understanding of environmental conditions in sensitive environments in deep Gulf waters, along the region's coastal habitats, and in areas proposed for more drilling, such as the Arctic, is inadequate. The same is true of the human and natural impacts of oil spills" [2].

Studies over the precursors for blowouts show an ascendant trend on cementing related issues. As per blowout analysis performed by Danenberger in 2007, between 1991-1997 cementing issues reach 26% from precursors for blowout, while in 1992-2006 percentage reached 46%. As BP internal inquiry decided that failure of cementing was the initiating event we built in Figure 3 an event tree that includes failure scheme for Deepwater Horizon platform [8].

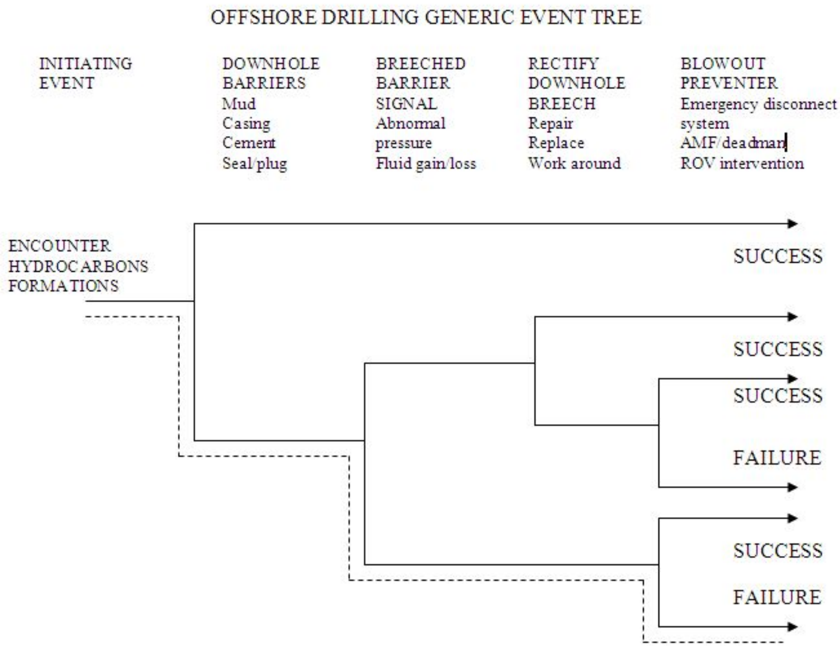

Fig. 3. Event tree path for Deepwater Horizon disaster.

The way to avoid is not only the legislation but also the technology must evolve to coop with challenges in deepwater environment. According to a study made by DNV over the remains of BOP and few spools of drill pipe, the preventer was not capable to fulfil his role. In existing configuration, presented in Figure 4 none of the preventers in the stack would've had necessary power to seal the well.

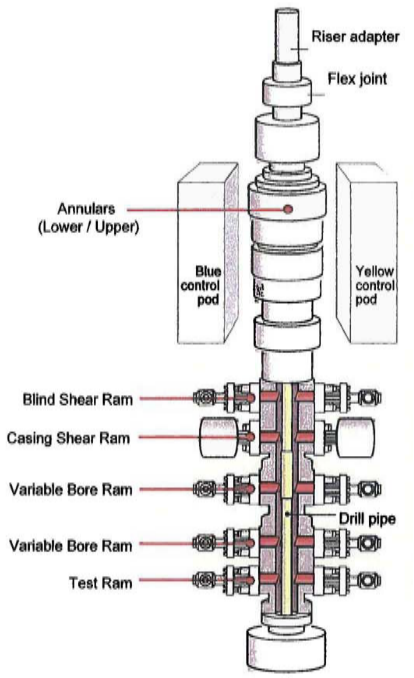

Fig. 4. Deepwater Horizon BOP stack scheme † (*UAP- upper annular preventer, rated 10k, LAP-lower annular preventer, rated 5k, BSR-Blind Shear Rams, well seal, CSR-casing shear rams, not sealing, UPR-upper pipe rams, rated 15k and 3 ½'' - 6 5/8'' OD, MPR-middle pipe rams, rated 600k stripped and 3 ½'' - 6 5/8'' OD, LPR-lower pipe rams, rated 15k*).

Det Norske Veritas report has concluded after investigating at Michaud base in USA, recovered BOP stack together with additional drill pipe segments that event tree of this BOP failure has the following components [18]:

a. BSR failed to close and seal the well;
   - b.1 BSR could not move pipe in shearing surfaces;
   - b.2 Piece of drill pipe in between plates prevented full closing and sealing;
   - b.3 Buckling of drill pipe in wellbore due to kick overpressure;
   - b.4 Stuck of tool joint under closed UAP;
   - b.5 Upper VBR closing centred the drill pipe in unfortunate position;
   - b.6 Uncontrolled flow acting on pipe from downhole of upper VBR.

New development modular well capping device was fabricated on order of Shell in UK. New device can be deployed from any supply vessel in various parts of installation in order to seal or cap the flow of oil. Such a contingency will limit the effect of a blowout to a restricted areal close to the well. If the tests will prove it may this equipment become a mandatory contingency measures on drilling and production operation in deep sea.

4. CONCLUSIONS

Major accidents, and even major accident precursors are so rare events, that it is easy for an organization to loose focus and concentrate solely on prevention of occupational accidents. It is therefore essential that the indicators that are used have a certain volume of data, and some fluctuations regularly, in order to create the basis for maintaining high awareness and motivation.

UK Health and Safety Executive defined **safety culture** as "the product of individual and group values, attitudes, and perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and

† Diagram courtesy of British Petroleum Ltd.

proficiency of, an organisation's health and safety management." Safety culture has the implication of human factor in both her rams occupational safety and process safety.

As the implication of deepwater accidents keep increasing a natural decision is to adopt measures where risk assessment is far more developed. One of these industries is nuclear industry, where multiple study and research have come up with ASP program to evaluate the precursors long before an event could appear.

Use of a program feed with results of inspections, audits and lesson learned from previous accidents, saves the time and resourced spent of multiple reviews of the same peers or creating duplicative analysis. Database built this way could be start point of shared resource program as SINTEF is for blowout records.

"However, each time the industry has thought its was secure in its ability to anticipate problems and design defences, new, unanticipated challenges have arisen, such as shut-down risk, stress corrosion cracking, and inadequacies in safety culture. The industry continues to learn, forget, and relearn a difficult lesson—that anticipation must be combined with resilience in responding to precursors." (Marcus and Nichols, 1999; Weick et al., 1999; Wildavsky, 1988) [19-23].

REFERENCES

[1] Thornton, G., The Implications of the April 2010 Oil Spill on Deepwater Exploration and Production, August 2010.
[2] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Deep Water - The Gulf Oil Disaster and the Future of Offshore Drilling, report to President, 2011.
[3] Le, P., Chen, G., Dai, L., Zhang, L., Fuzzy logic-based approach for identifying the risk importance of human error, Safety Science No. 7, Elsevier Ltd., 2010, p. 902-913.
[4] Phimister ,J.R., Bier, V.M., Kunreuther, H.C., Accident Precursor Analysis and Management: Reducing Technological Risk through Diligence, National Academy, 2004.
[5] Vinnem, J.E., Risk indicators for major hazards on offshore installations, Elsevier Ltd., 2010.
[6] Miller, R., Lessard, R.D., The strategic management of large engineering projects - Shaping institution, Risk and Governance, Massachusetts Institute of Technology, USA, 2001.
[7] Cooke, R.M., Ross, H.L., Stern, A., Precursor Analysis for Offshore Oil and Gas Drilling -From Prescriptive to Risk-Informed Regulation, Ed. Resources for the Future, Washington, USA, 2011.
[8] Tarek, E., Risk assessment of marine LNG operations, Natural Gas edited by Primož Potočnik, 2010.
[9] Measuring the Economic Impacts of Modifying Jones Act Regulation of Offshore Oil and Natural Gas Production Vessels, IHS Global Insight, November 2009.
[10] Kemeny, J.G., Babbitt, B., Haggerty, P.E., Lewis, C., Marks, P.A., Marrett, C.B., McBride, L., McPherson, H.C., Peterson, R.W., Pigford, T.H., Taylor, T.B., Trunk, A.D., Report of the President's Commission on the Accident at Three Mile Island. New York: Pergamon Press, 1979.
[11] Palmer, A., Ramakrishna, S., Cheema, H.M., Nuclear power in Singapore, The IES Journal Part A: Civil & Structural Engineering, 3: 1, 2010, p. 65 — 69.
[12] Testimony of Richard Tink, Hearing before the Deepwater Horizon Joint Investigation Team, May 26, 2010, 392; Deepwater Horizon Joint Investigation Team, AFE Summary for the Macondo Well, October 7, 2010.
[13] Duffey, R.B., Saull, J.W., Managing risk - the human element, Ed. John Wiley & Sons, United Kingdom, 2008.
[14] Sitkin, S.B., Learning through failure: the strategy of small losses, Research in Organizational Behavior 14, 1992, p. 231–266.
[15] Carroll, J.S., Rudolph, J.W., Hatakenaka S., Learning from experience in high-hazard organizations. Research in Organizational Behaviour, 24, 2002, p. 87–137.
[16] Carroll, J.S., Incident reviews in high-hazard industries: sense-making and learning under ambiguity and accountability. Industrial and Environmental Crisis Quarterly, 9, 1995, p. 175–197.
[17] Carroll, J.S., Organizational learning activities in high-hazard industries: the logics underlying self-analysis. Journal of Management Studies, 35, 1998, p. 699–717.
[18] Det Norske Veritas, Final report for United States Department of the Interior - Bureau or Ocean Energy Management, Regulation and Enforcement, Washington, USA, 20 March 2011.
[19] Novac, L.E., Brezeanu, P., Metode moderne de identificare a riscurilor in managementul riscului, Academia de Studii Economice, Bucuresti, 2007.

[20] Mannan, S., Lees' loss prevention in the process industries - Hazard identification, Assessment and control, 3rd Edition, Elsevier Inc., Oxford, UK 2005.
[21] Aven, T., Vinnem, J.E., Risk management - with applications from the offshore petroleum industry, Published by Springer-Verlag Ltd., London, 2007.
[22] Worthington, D.R.E., Cavanagh, N.J., The development of software tools for chemical process quantitative risk assessment over two decades, ESREL 2003 Conference, Safety and Reliability, Maastricht, The Netherlands, June 2003.
[23] Narayanan, S. P., Mohammad, K., Structural integrity management for fixed offshore platforms in Malaysia, World Academy of Science, Engineering and Technology, 58, 2009.