Analysis of the Deepwater Horizon Accident in Relation to Arctic Waters

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ABSTRACT

One of the major concerns associated with drilling in the arctic regions is the possibility of an environmental disaster. The arctic region is generally perceived as pristine but sensitive and major efforts should be taken to prevent an oil spill there. In this context the accident with the Deepwater Horizon in the Gulf of Mexico has caused great concern, both in the offshore industry and in society in general. This paper analyses the various events that have played a role in the accident, although it is recognized that the exact circumstances are not yet fully known. Through a probabilistic analysis the individual contribution of the various factors is analysed to show in which combinations a major oil spill accident is likely to occur. Subsequently the paper makes a first step to compare the probability of occurrence of the Deepwater Horizon accident in the GOM to the probability of a similar accident in the Arctic region. Many factors related specifically to arctic circumstances are not yet fully known or quantified, but a sensitivity analyses has been performed to analyse the impact of various factors. Initial cakculations show that the risk of drilling in the arctic should be considerably lower than in GOM, but further research will be needed to better quantify these risks.

KEY WORDS: Fault trees, Event Trees, Oil Spills, Arctic, Risk

INTRODUCTION

The Deepwater Horizon accident took place on April 20, 2010 in the Gulf of Mexico. Due to an uncontrolled well a blowout occurred leading to explosions and fire onboard the drilling rig 'Deepwater Horizon'. Eleven people lost their lives and 17 others were injured. The fire continued for 36 hours until the rig sank. Hydrocarbons continued to flow from the reservoir through the well bore for another 87 days, making this one of the worst environmental disasters in the history of oil drilling. In this paper the accident is evaluated on a probabilistic basis with fault tree and event tree techniques (Van Gelder and Vrijling, 2008), and probabilistic comparisons are made with possible oil drilling in arctic conditions. In (Cooke et. al., 2011) it is advocated that probabilistic techniques and precursor analyses are inevitable to bring cost effective, risk-informed oversight to bear on the threat of catastrophic oil spills. In another paper the basics of this approach have been outlined (Willemse and Van Gelder, 2011). In this paper the analysis has been refined to include some specific site conditions in the arctic, such as the waterdepth and the water temperature. The mitigating measures taken during the GoM accident are evaluated in the light of arctic circumstances and hence the risks of oil spill in the arctic are investigated for a range of events. The authors realize that a lot of arctic data is not yet available so the numbers presented should not be seen as absolute values. However the sensitivity of some parameters can be observed, which can give a direction for further research.

PROBABILISTIC ANALYSIS OF THE DEEPWATER HORIZON ACCIDENT

General

The accident was investigated by a team from BP and a major report was made public on September 8, 2010 (BP report, 2010). The report identifies 8 'key findings' which have contributed to the accident. These key findings can be categorized as follows (Willemse and Van Gelder, 2011):
1) Factors related to drilling procedures and techniques
2) Factors related to equipment and maintenance
3) Factors related to competence of staff.

The key findings have been defined as the basic events in a fault tree analysis. For a detailed description of the events reference is made to the BP report. In the following paragraphs a summary is given. It should be noted that not all is known yet about the exact circumstances that have led to the accident and certainly not regarding the degree to which the individual errors have contributed to the overall accident. As official investigations proceed, gradually more information is expected to become available, which may cause the need to adjust some of the conclusions in this paper.

Drilling procedures and techniques

Three basic events fall into this category:

Event E1. The annulus cement barrier did not isolate the hydrocarbons. Due to the narrow margin between pore pressure and fracture gradient, the accuracy of cement placement was critical. The annulus cement that was placed was a light, nitrified foam cement slurry. This annulus cement probably experienced nitrogen breakout and migration, allowing hydrocarbons to enter the wellbore annulus. (BP key finding no 1).

Event E2. The shoe track barriers did not isolate the hydrocarbons. Flow entered the casing rather than the casing annulus. For this to happen, both the cement barrier in the shoe track and the float collar barrier must have failed. (BP key finding no 2).

Event E3. Well control response actions failed to regain control of the well. The first well control actions were to close the BOP and diverter, routing the fluids existing the riser to the Deepwater mud gas separator system rather than to the overboard diverter line. In hindsight, if fluids had been diverted overboard there may have been more time to respond and the accident may have been less severe. The shut-in protocols did not fully address how to respond in high flow emergency situations after well control has been lost. (BP key finding no 5).

Equipment and maintenance

Event E4. The fire and gas system did not prevent hydrocarbon ignition. Hydrocarbons migrated beyond areas on Deepwater Horizon that were electrically classified to areas where the potential for ignition was higher. The heating, ventilation and air conditioning system probably transferred a gas-rich mixture into the engine rooms, causing at least one engine to overspeed, creating a potential source of ignition. (BP key finding 7).

Event E5. The BOP emergency mode did not seal the well. Three methods available to seal the well in case of an emergency all failed. (1)The primary emergency disconnect sequence which should have been operated manually by the rig crew failed probably due to the fire and explosions on board. (2) The yellow and blue control pods which should have sealed the well without rig intervention in case of a loss of hydraulic pressure, electric power and communications from the rig, failed probably due to malfunctioning or lack of maintenance. (3) The blind shear ram which could be operated by ROV intervention was probably closed after 33 hours but failed to seal the well. Altogether it appears that the BOP had not been sufficiently tested and maintained. (BP key finding 8).

Competence of staff

Event E6. Incorrect interpretation of negative pressure test The test involved replacing heavy drilling mud with lighter seawater to place the well in a controlled underbalanced condition. In retrospect, pressure readings and volume bled were indications that the integrity of the barriers had not been reached, but the rig crew wrongly concluded that well integrity had been established. (BP key finding 3).

Event E7. Influx of hydrocarbons not recognized. When the heavy drilling mud was replaced by seawater hydrocarbons flowed up through the production casing and past the BOP. It took a long time (40 minutes) before the crew recognized the influx and the resulting overpressure in the drill pipe. By that time the hydrocarbons had already passed the BOP and entered the riser. (BP key finding 4).
Event E8. Diversion to the mud gas separator not a good decision. Hydrocarbons were directed to the mud gas separator, leading to the venting of large quantities of gas onto the rig. The system was quickly overwhelmed and this increased the potential for the gas to reach an ignition source. (BP key finding 6).

Fault tree analysis

The basic events can be presented in a fault tree and the probability of the Undesired Top Event (UTE), the oil spill, can be calculated if the probabilities of the basic events are known. Thereby it is of particular concern whether these events should be connected through an AND gate or through an OR gate. In (Willemse and Van Gelder, 2011) it is demonstrated that certain dependencies between the basic events must in fact exist, leading to a modified fault tree as shown in Fig. 1. In this modified tree a number of basic events has been combined:
- E1 and E2 (related to drilling procedures and techniques) have been assumed 100% dependent;
- E7 and E8 (related to staff competence and human errors) have been assumed 100% dependent and related to E6.

Event tree - and risk analysis

After the accident of the Deepwater Horizon occurred, several actions were taken to minimize the oil spill damage. These actions have been described as events in an Event Tree, which analyses the ultimate risk as a combination of various measures taken to minimize the damage. The damage itself has been expressed in “days of oil spill” and the risk is then the product of the damage and the probability of occurrence of that damage.

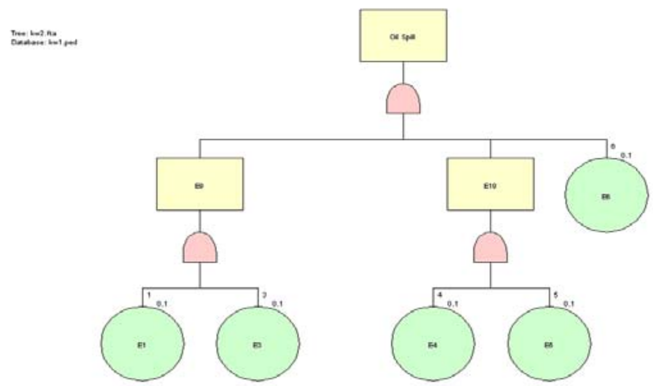

Fig. 1 Modified Fault Tree for Oil Spill (see also Appendix)

Successively, the following steps were taken after the Deepwater Horizon accident:

Event E12. Re-activating the BOP.
This was attempted several days immediately after the blowout occurred. If it had worked the damage would have been limited to say 3 days of oil leaking.

Event E13. Installation of a Dome.
A hastely engineered and fabricated dome was lowered over the BOP in an attempt to contain the leaking oil. If it had worked the damage would have been limited to approx 15 days of oil leaking.

Event14. Top kill procedure.
For the top kill procedure several new lines were connected to the BOP and it was attempted to pump heavy mud into the well against the outflowing oil, which should have stemmed the leak. If this complicated and high-tech attempt had worked, the leaking damage would have been limited to approx 30 days.

Event 15 Static kill procedure
For the static kill procedure the Lower Marine Riser Package (LMRP) needed to be removed and replaced by another component which then allowed for a static mud column to oppose the oil flow and ultimately kill it. This was successfully applied after approximately 90 days (87 to be precise).

Event 16 Relief well.
As a back up measure the drilling of a relief well was started a week after the accident occurred. This comprises the drilling of a second well parallel to the original well, with the drill head ultimately cutting into the original well just above the reservoir. Subsequently the intersected

pipe can then be blocked with cement, thus stopping the oil flow. This measure was carried out and completed even after the static kill procedure had already been successfully executed. The relief well is considered to be a 'last haven' with a high probability of success. But it takes at least 4 months (120 days).

A final path is reserved in the event tree for the failure of a relief well. It is assumed that the oil spill will then continue for a total of 360 days until the well is killed through another attempt. With the events E12 – E16 the event tree has been defined.

PROBABILISTIC ANALYSIS OF A SIMILAR ACCIDENT HAPPENING IN ARCTIC REGIONS

General approach and base case

The fault tree and the event tree can be combined to calculate the risk (R) of drilling in the arctic. The event tree has been adapted for the arctic situation by the introduction of 'arctic coefficients', by assessing how effective every mitigating measure would be under arctic circumstances. The result is shown in Fig. 2. This tree shows the total risk as a summation of risks related to each mitigating measure that could be taken to limit the damage due to the oil spill. The tree also shows the probability of success of each measure. If a mitigating measure is not successful, the next measure needs to be applied, but as this takes more time to mobilize, more damage will then occur.

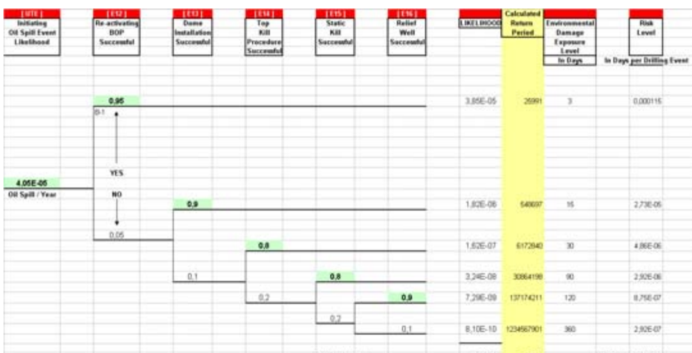

Fig. 2 Event Tree for Arctic Conditions (see also Appendix)

In table 1 the results of various scenario's are shown. The base case for ARC shows a Probability of occurrence P{UTE} = 8.1E-4, which is substantially lower than for GOM, where P{UTE} = 1.1E-2. However the mitigating measures in ARC are less effective and hence the damage is higher. The risk R is the product of the probability of a spill times the damage. In the table we see that R{ARC-base case} = 2.1E-2, which is a factor 4 times lower (thus more favourable) than R{GOM}. Furthermore, the ARC base case can be improved by introducing better equipment, better procedures and better staff competence (var 4). The risk for ARC is then reduced by a further factor 10, making the total risk under 'improved' arctic conditions a factor 40 more favourable than in GOM.

Factors related to a specific arctic location

Specific conditions at an arctic site can differ substantially from the conditions at GOM where the Deepwater Horizon accident happened. In particular the waterdepth at arctic drilling sites is often much less, leading to a much better access to the BOP and also making the probability of success of the mitigating measures much higher. This is reflected in a further refinement of the calculations. In addition, the drilling will usually take place in the summer season, implying that there will usually not be much drift ice, so the probability of success of the mitigating measures E12 (re-activating the BOP) and E13 (the dome) would further increase. This is reflected in Table 1 (var 5).

Another factor, but one that is not in favour of the arctic situation, is the degradation of the oil in the cold arctic waters. Literature shows that the degradation of oil by bacteria in water with a temperature of 1 deg C is 20-50% slower than in water of 22 deg C (Gerdes et al, 2005). To incorporate this effect in variant 5 an environmental coefficient Cenv has been introduced. One could argue that Cenv can vary for the different mitigating measures because it will also depend on the duration of the oil spill and hence the season in which it takes place. However the calculations presented in Table 1 are based on a constant Cenv = 4, implying that oil spill in arctic waters causes a damage rated as 4x as bad as in the warm waters of the GOM.

Table 1.

	P{UTE}	Return period	Risk [days of oil leak/ drilling event]	Change
GOM	1.1E-2	93	7.3E-2	
ARC base case	8.1E-4	1235	2.1E-2	
ARC Var4:	8.1E-5	12346	2.1E-3	Better procedures, equipment and competence
ARC Var 5	4.05E-5	24690	6.1E-4	Shallow water and summer

It can be seen that under these assumptions, if the drilling in arctic region is done in shallow waters, and with better procedures, equipment and competence, the risk of an oil leak in the arctic can be reduced by a total factor of 80-100 compared to GOM, the Deepwater Horizon accident.
One should be aware that there are other arctic issues which have not yet been included in this paper, such as the possiibility of summer ice intrusions, and the occurrence of reservoir pressures that differ significantly from the GOM situation. These factors are likely to have an impact on the risk of drilling in the arctic, and they require further research.

The effect of the BOP failure

The BOP plays a particularly important role in the total risk, both in terms of the probability of the initial failure (event E5) and in the probability of success of re-activating it (event E12). This is illustrated in Fig. 3 below, for a range of probabilities related to Variant 5.

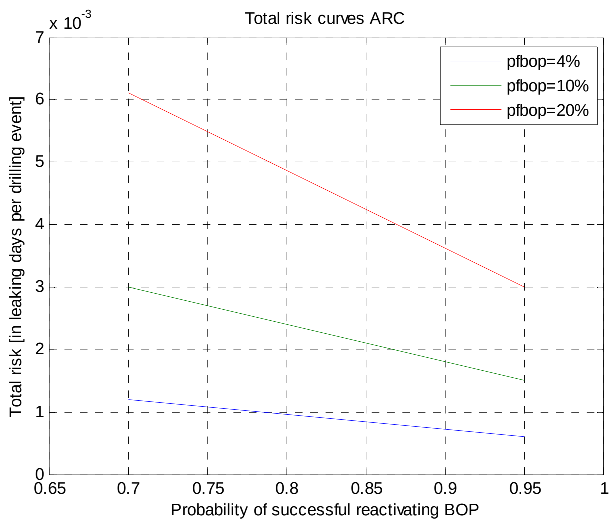

Fig. 3 The effect of BOP failure and re-activation on the total risk

However another major concern is the event that, despite all the extra measures, the BOP could still not be re-activated. In that situation the next mitigating measure, the dome, would become of dominant importance for the overall risk. This is shown in Fig. 4 for different values of the environmental coefficient Cenv for events E12 and E13 (for the other events Cenv is kept at 4).

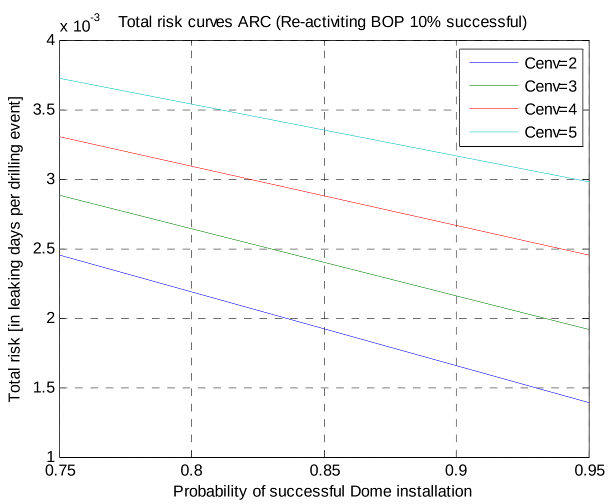

Fig. 4 The effect of the dome on the total risk

Other considerations and effects

There are a number of other factors which make the situation in ARC different from GOM.

a) The arctic regions are also very remote, causing a large mobilization time for rescue equipment. This could be reflected in the damage expressed in days, because it takes longer to apply a mitigating measure. In the current analysis the complication of working in the arctic has been reflected in the coefficients for the basic mitigating measures E12-E16, but not in an extra duration of the leaking in case the measure would fail. This could be a further refinement of the model.

b) As soon as the oil started to leak at the Deepwater Horizon site, various measures were taken to minimize the effect of the oil. These measures included skimming equipment, burning of oil at the water surface, adding dispersants and protecting the shore with absorbent booms. These operations would generally be more complicated under arctic circumstances. For the purpose of this study they have not been included.

CONCLUSIONS

The accident with the Deepwater Horizon happened due to an unfortunate combination of events, and not all is known as yet about the circumstances contributing to the accident. In this paper a basic analysis based on several assumptions shows that the probability that a similar accident would occur in arctic waters could be smaller by a factor of 10-100. These probabilities are further reduced if one takes into account that drilling in the arctic often takes place in shallow water and in summer time. On the other hand the mitigating measures are more difficult under arctic circumstances, and degradation of the oil in the cold arctic waters takes much longer than in the GoM. When all these aspects are taken into account the overall risk of drilling in the Arctic could be a factor of 80-100 lower than at the GOM at the location of the Deepwater Horizon accident. It should be realized that other arctic factors, such as the probability of summer ice intrusion and the occurrence of reservoir pressure differences with the GOM have not yet been incorporated in these calculations. Finally the success of the mitigating measures can be further improved by having tailor made emergency equipment readily available at the drilling site, allowing a prompt and effective response in case an oil spill would occur. That improvement, which is currently engineered by several oil companies, has not yet been incorporated in the risk numbers presented in this paper and will be a subject for further research.
As the official investigations proceed more information is expected to become available, which may lead to an adjustement and refinement of the calculations presented in this paper.

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APPENDIX

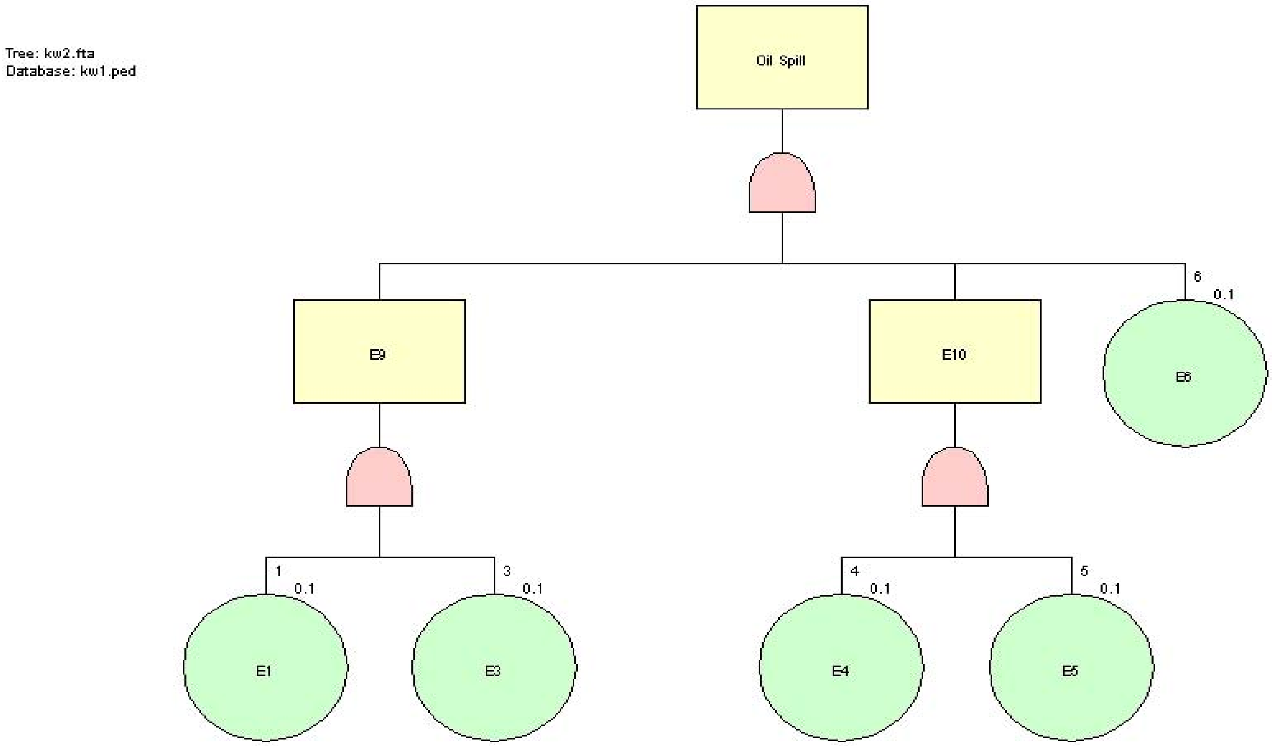

Fig. 1 Modified Fault Tree for Oil Spill

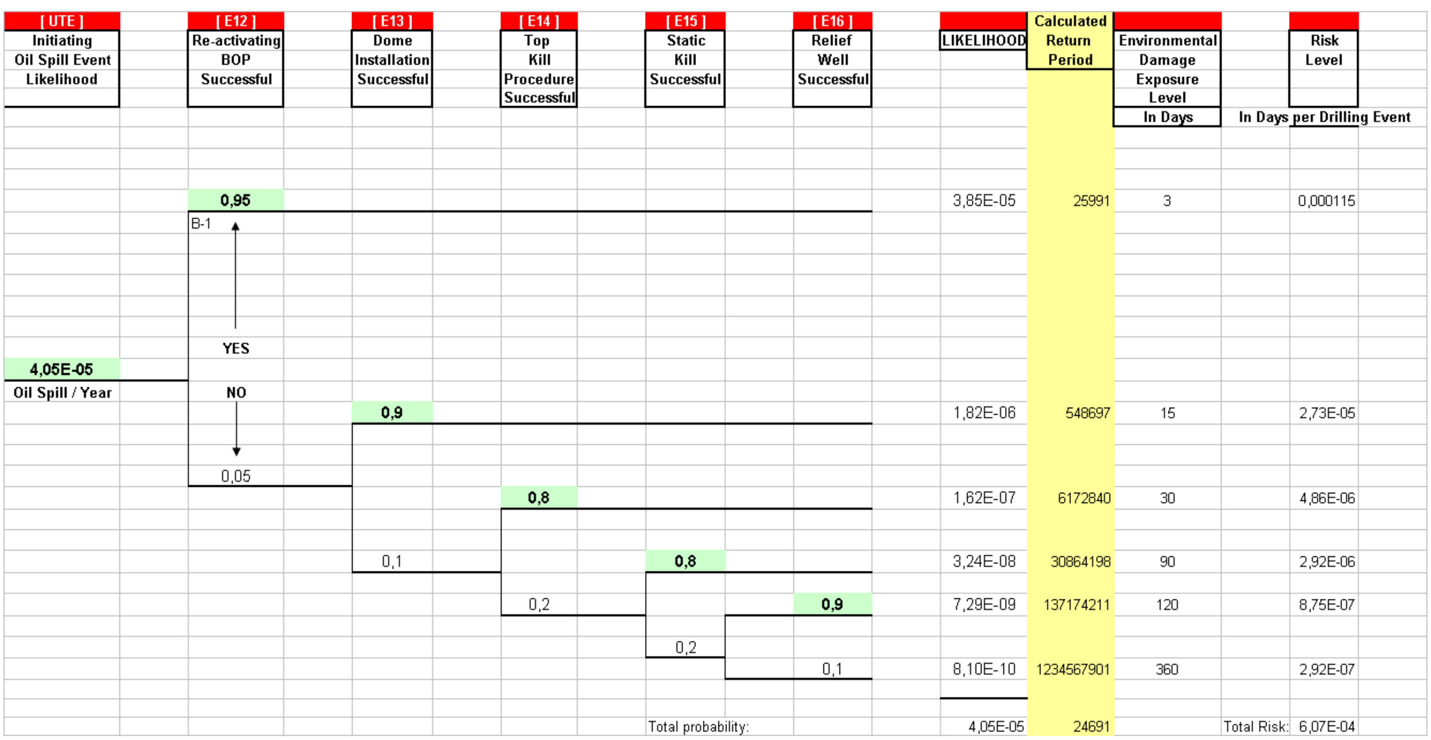

Fig. 2 Event Tree for Arctic Conditions