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Deep Water Drilling Risk Reduction Assessment

PRODUCED FOR: Bureau of Ocean Energy Management, Regulation and Enforcement under subcontract to Industrial Economics, Inc

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IN RESPONSE TO: **E-MAIL AND TELEPHONIC DISCUSSIONS**

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1. Background

The Deepwater Horizon oil spill (also referred to as the BP oil spill, the Gulf of Mexico oil spill, the BP oil disaster or the Macondo blowout) is a massive oil spill in the Gulf of Mexico that is the largest offshore spill in U.S. history. The spill stems from a sea floor oil gusher that resulted from the April 20, 2010 Deepwater Horizon drilling rig explosion. The explosion killed 11 platform workers and injured 17 others. At the time of the explosion, it was drilling an exploratory well at a water depth of approximately 5,000 feet (1,500 m) in the Macondo Prospect, located in the Mississippi Canyon Block 252 of the Gulf of Mexico in the United States exclusive economic zone about 41 miles (66 km) off the Louisiana coast.

The gusher was estimated by the quasi-official Flow Rate Technical Group to flow at 35,000 to 60,000 barrels of crude oil per day while it was leaking. For comparison, this is an amount equal to the 1989 Exxon Valdez oil spill every one to two weeks.

This is a study to determine the reduction in risk associated with the use of blowout preventers in deep water drilling. Where possible the study will determine the risk associated with individual blowout preventer (BOP) approaches to compare the value of each approach. The study will also consider the risk associated with the failure of the blowout preventer control systems. In specific, the study will review:

- The risk reduction associated with BOPs having two sets of blind shear rams spaced at least four feet apart to prevent BOP failure if a drill pipe or drill tool is across one set of rams during an emergency
- The risk reduction associated with emergency back-up control systems and their requirements.

The following documents will be reviewed:

- The May 27th Report[1] to the President recommending new actions that can be taken to reduce the chance of another catastrophic oil spill.
- Beaufort Sea Drilling Risk Study (DNV 2010) and data used in this study.
- Other available testing and incident data and analyses to supplement the study.

This analysis occurs in the broader context of the development of an updated version of the Offshore Environmental Cost Model (OECM), a decision-making tool used by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) as it develops five-year leasing programs for oil and gas exploration and production on the outer continental shelf (OCS). An important component of this effort is the review of literature relevant to the identification and evaluation of the environmental costs that the model will consider. Many of those costs are the direct or indirect result of oil spills associated with OCS exploration and production activities. Therefore, the results of this analysis may help inform specification of one or more model components.

[1] *Increased Safety Measures for Energy Development on the Outer Continental Shelf* (The 30-Day report).

2. Overview of the SINTEF Blowout Database

Midé purchased access to the SINTEF database through ExproSoft. The database has details on 573 blowout events, dating back to 1/1/1955 and as recent as 11/23/2009.

2.1. Acoustic Backup System

The SINTEF Blowout Database only reports one case where an acoustic backup system was available but it failed when the rig power was lost disabling the fixed transducer. The portable transducer was possibly on the pontoon or there was not enough pressure in the subsea accumulator.

The only other reference to an acoustic backup system was for a surface blowout with totally uncontrolled flow from a deep zone. This occurred on 2/28/2000 on MC538, well 2. The reference states that the BOP failed to close and that there was NO acoustic backup.

2.2. ROVs

The SINTEF Blowout Database references the use of ROVs but no cases are included where the ROV was used as a backup system to activate a BOP. The references are to blowout cases where the ROV was used to observe leaks from the well.

2.3. Loss of Control Functions

The SINTEF Blowout Database contains no details on control systems and their reliability.

2.4. Incidents where Kick was Controlled

Appendix D provides information on incidents where the type of event was either classified as a "well release" or as a "diverted well release" in the SINTEF database. In general these are incidents where a kick resulted in release of hydrocarbons but flow was controlled by either diverting the flow or activating a second barrier.

3. Review and Verification of the DNV Beaufort Sea Study

The DNV Beaufort Sea Drilling Risk Study[2], dated March 11, 2010 was conducted for Imperial Oil Resources Ventures Limited and posted on the web site of the Canadian- National Energy Board (www.neb-one.gc.ca). The study's analysis and conclusions of BOP ram and control system reliability were studied, recreated and verified to form the basis of the results and conclusions offered in this report.

In order to use the Event Trees, Fault Trees and associated data in the Beaufort Sea Study, this Section reviews the data and sources of the data presented in this study.

[2] https://www.neb-one.gc.ca/ll-eng/livelink.exe/fetch/2000/90463/589151/594086/594088/600443/609664/C-05-6C_-_Appendix_A_Beaufort_Sea_Drilling_Risk_Study__-_A1S2V8_.pdf?nodeid=609512&vernum=0

3.1. Exploration Drilling Data

The Beaufort Sea Study only includes "Loss of Well Control" data for the time period 1/1/1980 to 12/31/2007. The quality of earlier data is such that it was excluded from the study. In order to include recent events, such as the Macondo blowout, data are needed on the recent number of exploratory wells that were drilled. Since well database updates lag by 4 – 6 months it was decided to limit the data used to the DNV (1/1/1980 to 12/31/2007) time period.

Following the approach of the Beaufort Study and limiting the SINTEF database to four exploration regions (East Canada, UK, Norway and United States - Gulf of Mexico Outer Continental Shelf (US GoM OCS), but more appropriately including incidents associated with four phase types (Completion, Exploratory, Wireline, and Development Drilling) yields a total of 101 relevant incidents (listed in Table 1 below), 18 more than the number reported in Table 4-1 of the Beaufort Study.

Table 1: List of Incidents included in the analyses.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
2/25/1980	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	15	JACKET	WIRELINE
3/24/1980	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	96	JACKET	DEV.DRLG
8/24/1980	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	85	JACKET	COMPLETION
8/29/1980	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	29	JACKUP	EXPL.DRLG WILDCAT
8/31/1980	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	11	JACKUP	EXPL.DRLG APPRAISAL
11/27/1980	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	17	SEMISUBMERSIBLE	DEV.DRLG
1/24/1981	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	69	JACKET	COMPLETION
6/14/1981	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	261	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
6/19/1981	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	10	JACKET	COMPLETION
7/26/1981	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	12	JACKET, JACKUP	COMPLETION
10/5/1981	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	56	JACKET	COMPLETION

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
10/19/1981	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	15	JACKET	COMPLETION
12/27/1981	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	85	SEMISUBMERSIBLE	DEV.DRLG
2/7/1982	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	43	JACKET	WIRELINE
5/15/1982	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	77	JACKET	DEV.DRLG
10/21/1982	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	93	JACKET	DEV.DRLG
2/11/1983	Blowout (underground flow)	Underground flow only	US/GOM OCS	104	JACKET	DEV.DRLG
2/15/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	54	JACKET, JACKUP	DEV.DRLG
5/26/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	198	JACKET	DEV.DRLG
7/20/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	21	JACKUP	EXPL.DRLG WILDCAT
8/1/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	122	JACKET	DEV.DRLG
8/20/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	90	JACKET	DEV.DRLG
10/12/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	285	JACKET	DEV.DRLG
10/25/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	72	JACKUP	EXPL.DRLG WILDCAT
2/7/1984	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	111	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
2/22/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	CANADA EAST	158	SEMISUBMERSIBLE	EXPL.DRLG

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
7/20/1984	Blowout (underground flow)	Underground flow only	US/GOM OCS	30	JACKUP	EXPL.DRLG WILDCAT
9/10/1984	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	96	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
9/14/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	447	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
9/20/1984	Blowout (underground flow)	Underground flow only	CANADA EAST	0	JACKUP	EXPL.DRLG
1/29/1985	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	144	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
4/1/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	54	JACKUP	EXPL.DRLG WILDCAT
8/25/1985	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	30	JACKUP	EXPL.DRLG APPRAISAL
10/6/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	221	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/4/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	24	JACKUP	EXPL.DRLG WILDCAT
11/23/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	135	SEMISUBMERSIBLE	DEV.DRLG
12/22/1986	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	49	JACKET, JACKUP	DEV.DRLG
3/20/1987	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	38	JACKUP, JACKET	DEV.DRLG
6/19/1987	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	35	JACKUP	EXPL.DRLG APPRAISAL
12/17/1987	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	29	JACKUP	EXPL.DRLG APPRAISAL
2/25/1988	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	528	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
5/29/1988	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	263	JACKET	DEV.DRLG
6/1/1988	Blowout (underground flow)	Underground flow only	NORWAY	70	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
9/22/1988	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	UK	94	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
1/8/1989	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	64	JACKUP	EXPL.DRLG APPRAISAL
1/20/1989	Blowout (underground flow)	Underground flow mainly, limited surface flow	NORWAY	68	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
3/26/1989	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	29	JACKUP	EXPL.DRLG APPRAISAL
4/14/1989	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	64	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
11/12/1989	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	190	JACKET	DEV.DRLG
12/1/1989	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	28	SATELLITE, JACKUP	DEV.DRLG
12/7/1989	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	150	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
3/1/1990	Blowout (underground flow)	Underground flow only	US/GOM OCS	10	UNKNOWN	UNKNOWN
5/30/1990	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	41	JACKET, JACKUP	DEV.DRLG
7/8/1990	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	66	JACKUP	EXPL.DRLG APPRAISAL
10/14/1990	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	36	JACKET, JACKUP	EXPL.DRLG WILDCAT
5/8/1991	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	35	JACKUP	EXPL.DRLG WILDCAT
10/28/1991	Blowout	Totally uncontrolled flow, from a shallow	US/GOM	29	JACKUP	DEV.DRLG

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
	(surface flow)	zone	OCS			
11/11/1991	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	24	JACKUP	EXPL.DRLG WILDCAT
3/12/1992	Blowout (underground flow)	Underground flow only	US/GOM OCS	78	SEMISUBMERSIBLE	DEV.DRLG
11/22/1992	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	26	JACKUP	DEV.DRLG
12/26/1992	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	60	JACKUP	EXPL.DRLG APPRAISAL
2/25/1993	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	64	JACKET, JACKUP	DEV.DRLG
4/18/1993	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	58	JACKUP	EXPL.DRLG APPRAISAL
1/3/1995	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	8	JACKUP	EXPL.DRLG WILDCAT
1/24/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	103	JACKET, JACKUP	COMPLETION
7/1/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	UK	0	JACKET	WIRELINE
9/23/1996	Blowout (underground flow)	Underground flow only	NORWAY	365	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/10/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	38	JACKUP	EXPL.DRLG WILDCAT
11/27/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	12	JACKUP	COMPLETION
12/3/1996	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	43	JACKET, JACKUP	DEV.DRLG
3/20/1997	Blowout (underground flow)	Underground flow only	NORWAY	72	JACKUP	EXPL.DRLG WILDCAT
4/1/1997	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	73	JACKET	DEV.DRLG
5/31/1997	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	18	JACKUP	COMPLETION

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
11/1/1997	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	342	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
1/6/1998	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	25	JACKUP	EXPL.DRLG APPRAISAL
3/2/1998	Blowout (underground flow)	Underground flow only	US/GOM OCS	11	JACKUP	DEV.DRLG
2/10/1999	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	902	SEMISUBMERSIBLE	DEV.DRLG
1/2/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	10	JACKUP	EXPL.DRLG APPRAISAL
1/5/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	76	JACKUP	DEV.DRLG
1/12/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	94	JACKUP	EXPL.DRLG WILDCAT
2/28/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	678	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
3/22/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	18	JACKUP	UNKNOWN
4/7/2000	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	89	JACKET	DEV.DRLG
7/1/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	UK	0	SEMISUBMERSIBLE	WIRELINE
7/30/2000	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	90	JACKUP	DEV.DRLG
11/18/2000	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	26	JACKUP	EXPL.DRLG WILDCAT
3/1/2001	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	58	JACKUP, JACKET	DEV.DRLG
5/10/2001	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	96	JACKET, JACKUP	DEV.DRLG
7/13/2001	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	28	JACKUP	EXPL.DRLG WILDCAT

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
8/9/2002	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	69	JACKUP	DEV.DRLG
9/7/2002	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	120	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
9/19/2002	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	UK	40	JACKUP	COMPLETION
11/14/2002	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	64	JACKUP, JACKET	DEV.DRLG
7/3/2003	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	161	SEMISUBMERSIBLE	DEV.DRLG
9/2/2003	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	15	DRILLSHIP	EXPL.DRLG APPRAISAL
2/9/2004	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	50	JACKET	DEV.DRLG
6/1/2004	Blowout (underground flow)	Underground flow only	US/GOM OCS	32	JACKUP	DEV.DRLG
3/8/2005	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	49	JACKUP	EXPL.DRLG WILDCAT
4/30/2006	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	736	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
11/19/2006	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	15	JACKUP	EXPL.DRLG APPRAISAL
9/7/2007	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	28	JACKUP	EXPL.DRLG WILDCAT

Note: Incidents in the BOEMRE (previously MMS) database are highlighted in yellow.

Key characteristics of the incidents that were included in the study are reported in Table 2. For example the incidents that were included in the study include one involving a drillship, 25 involving semisubmersibles, and 75 involving Jack-up/Jacket rigs.

Table 2: Summary of Incidents included in the analyses.

Installation Type	No.	Country	No.	Type of Event	No.	Description	No.
Drillship	1	Canada East	2	Blow Out with Surface Flow	88	Underground flow only	13
Semisubmersible	25	UK	8	Blow Underground Flow	13	Underground flow mainly	3
Jack-up / Jacket	75	Norway	8			Totally uncontrolled flow, from a shallow zone	39
		US GoM OCS	83			Totally uncontrolled flow, from a deep zone	49
Total	101		101		101		101

3.2. Water Depth

When the data are limited to water depths > 100 m, only 23 incidents remained. These incidents are summarized in Table 3.

Table 3: List of Incidents where Water Depth > 100 meters.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
6/14/1981	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	261	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
2/11/1983	Blowout (underground flow)	Underground flow only	US/GOM OCS	104	JACKET	DEV.DRLG
5/26/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	198	JACKET	DEV.DRLG
8/1/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	122	JACKET	DEV.DRLG
10/12/1983	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	285	JACKET	DEV.DRLG
2/7/1984	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	111	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
2/22/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	CANADA EAST	158	SEMISUBMERSIBLE	EXPL.DRLG
9/14/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	447	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
1/29/1985	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	144	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
10/6/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	221	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/23/1985	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	NORWAY	135	SEMISUBMERSIBLE	DEV.DRLG
2/25/1988	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	528	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
5/29/1988	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	263	JACKET	DEV.DRLG

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
11/12/1989	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	190	JACKET	DEV.DRLG
12/7/1989	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	150	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
1/24/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	103	JACKET, JACKUP	COMPLETION
9/23/1996	Blowout (underground flow)	Underground flow only	NORWAY	365	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/1/1997	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	342	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
2/10/1999	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	902	SEMISUBMERSIBLE	DEV.DRLG
2/28/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	678	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
9/7/2002	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	120	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
7/3/2003	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	UK	161	SEMISUBMERSIBLE	DEV.DRLG
4/30/2006	Blowout (surface flow)	Totally uncontrolled flow, from a shallow zone	US/GOM OCS	736	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL

Key characteristics of these 23 incidents are reported in Table 4.

Table 4: Summary of Incidents after Water Depth is limited to > 100 meters.

Installation Type	No.	Country	No.	Type of Event	No.	Description	No.
Drillship	0	Canada East	1	Blow Out with Surface Flow	19	Underground flow only	2
Semisubmersible	16	UK	2	Blow Underground Flow	4	Underground flow mainly	2
Jacket/ Jack-up	7	Norway	4			Totally uncontrolled flow, from a shallow zone	11
		US GoM OCS	14			Totally uncontrolled flow, from a deep zone	8
Total	23		23		23		23

3.3. Shallow versus Deep Incidents

When the data are further limited to deep water incidents, 12 remain.

Table 5: List of Incidents with Water Depth > 100 meters and Flow is from a Deep Zone.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
2/11/1983	Blowout (underground flow)	Underground flow only	US/GOM OCS	104	JACKET	DEV.DRLG
2/22/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	CANADA EAST	158	SEMISUBMERSIBLE	EXPL.DRLG
9/14/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	447	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
1/29/1985	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	144	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
5/29/1988	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	263	JACKET	DEV.DRLG
11/12/1989	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	190	JACKET	DEV.DRLG
1/24/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	103	JACKET, JACKUP	COMPLETION

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
9/23/1996	Blowout (underground flow)	Underground flow only	NORWAY	365	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/1/1997	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	342	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
2/10/1999	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	902	SEMISUBMERSIBLE	DEV.DRLG
2/28/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	678	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
9/7/2002	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	120	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT

Note: Incidents that involve limited surface flow are included and highlighted in blue.

Key characteristics of these 12 incidents are reported in Table 6.

Table 6: Summary of Incidents with Water Depth > 100 meters and Flow is from a Deep Zone.

Installation Type	No.	Country	No.	Type of Event	No.	Description	No.
Drillship	0	Canada East	1	Blow Out with Surface Flow	8	Underground flow only	2
Semisubmersible	16	UK	0	Blow out with Underground Flow	2	Underground flow mainly	2
Jacket/ Jack-up	4	Norway	1	Underground flow with limited surface flow	2*	Totally uncontrolled flow, from a deep zone	8
		US GoM OCS	10				
Total	12		12		12		12

* *These cases were retained in the analyses.*

3.4. Underground Releases

Once the data are filtered to exclude incidents during which hydrocarbons were released underground, 10 remain. Table 7 summarizes these 10 incidents. Also reported in this table is whether the BOP failed or not (last column).

Table 7: List of Incidents with Water Depth > 100 meters and Flow is from a Deep Zone with Surface Flow.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type	Description	BOP Failed
2/22/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	CANADA EAST	158	SEMISUB	EXPL.DRLG	B/S Shear Ram not enough power to cut pipe. Acoustic closure failed - transducer on pontoon and not enough pressure in accumulator	YES
9/14/1984	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	447	SEMISUB	EXPL.DRLG WILDCAT	Failed to disconnect riser and close SR because hyd. lines had been severed by explosion.	YES
1/29/1985	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	144	SEMISUB	EXPL.DRLG WILDCAT	This blowout is categorized as a deep blowout because the BOP was run and finally used to close in the well.	NO
5/29/1988	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	263	JACKET	DEV.DRLG	Other sources indicates that the BOP was removed and thereby it was impossible to activate it	NO
11/12/1989	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	190	JACKET	DEV.DRLG	Two hours after the surface csg. was cemented on well A-9, the well began flowing on the surface casing annulus. The well was subsequently put on diverter.	NO
1/24/1996	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	103	JACKET, JACKUP	COMPLETION	The blind rams were closed, but the flow did not change.	YES
11/1/1997	Blowout (underground flow)	Underground flow mainly, limited surface flow	US/GOM OCS	342	SEMISUB	EXPL.DRLG WILDCAT	The BOPs were closed but gas had migrated upward into the stack above the LMRP.	YES

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type	Description	BOP Failed
2/10/1999	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	902	SEMISUB	DEV.DRLG	BOP not used	NO
2/28/2000	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	678	SEMISUB	EXPL.DRLG APPRAISAL	The SSE inadvertently contacted the LMRP disconnect button while he was drilling mounting holes in the BOP panel. The LMRP disconnected from the BOP stack	YES?
9/7/2002	Blowout (surface flow)	Totally uncontrolled flow, from a deep zone	US/GOM OCS	120	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT	BOP not used	NO

Note: Underground releases with limited surface flow are retained. These incidents are highlighted in Light Blue.

Additional details on the incidents where totally uncontrolled flow from a deep zone occurred is provided in Appendix F.

Key characteristics of these 10 incidents are reported in Table 8. Note that in 5 of the 10 incidents, the BOP was able to close and secure the well.

Table 8: Summary of Incidents with Water Depth > 100 meters and Flow is from a Deep Zone with Surface Flow.

Installation Type	No.	Country	No.	Type of Event	No.	Description	No.
Drillship	0	Canada East	1	Blow Out with Surface Flow	10*	Underground flow only	0*
Semisubmersible	7	UK	0	Blow Underground Flow	0	Underground flow mainly	0
Jacket/ Jack-up	3	Norway	0			Totally uncontrolled flow, from a deep zone	10
		US GoM OCS	9				
Total	10		10		10		10

Note: Underground releases with limited surface flow are retained.

The DNV study reported 11 incidents. This is one more than what our review of the SINTEF database concluded. In the DNV study, in 6 of the 11 blow out incidents the BOP could close and secure the well while in 5 incidents the BOP failed (the same number reported in Table 7). Since the DNV personnel may have a better understanding of the incidents in the Sintef database, it was decided to perform the analyses with the DNV numbers (5 BOP failures and 6 successes). The five failure incidents are described in more detail in Appendix II of the DNV report. Incidents details were copied from the DNV report and included in this report as Appendix

3.5. BOP Reliability Analysis

Most of the BOP reliability numbers used in the BOP Fault Tree Analyses is from Table 4-6 in the Beaufort Sea Study (Table 9). The last column of Table 9 provides the source of the event probabilities in the Fault Tree Analyses. However, extensive literature research could not duplicate the Probability of Failure (2.84 x 10^{-3}) used for the Event of Total Control System failure (E2 in Figure III-1 of the DNV study) for the case where the probability of failure for two blind shear rams is determined and Probability of Failure (4.07 x 10^{-3}) used for the Event of Total Control System failure (E2 in Figure III-4 of the DNV study) for the case where the probability of failure of a single blind shear ram is determined. These numbers seem reasonable given that the Mean Fractional Dead Time (MFDT) of a control system losing all of one pod's functions (Table 9) is 3.49 x 10^{-3}.

Two other probabilities could not be verified. The first is the Probability of Failure (1.49 x 10^{-3}) of the control of a shear ram (E6 in Figure III-1 of the DNV study) and the second is the failure probability of a preventer to seal after it was used to shear. The 1999 study observed six cases where the ram preventer failed in the safety critical period. Two failures were external leakage through a closed shear ram. This suggests a probability of failure of 2/6 = 33.33% which is slightly higher than the value used in the Fault Tree Analyses. Changing this probability from 25.94% (the probability used by the DNV study) to 33.33% had negligible impact on the reliability of the BOP system.

Table 9: Table 4-6 in the DNV Beaufort Sea Study showing the Source of the BOP Fault Tree Failure Probability Numbers. This table is from the 1999 BOEMRE funded study[3].

Component	Failure Mode	Mean Time To Fail (MTTF) (days)	Test Interval (days)	MFDT	Event in Fault Tree Analysis (Fig. III-1: DNV Study)	Cross-Reference to 1999 study[4]
Preventer	Internal Leak	5398*	14	0.1297%	E4	Table 4.3
	Fail to Close	16193	14	0.0432%	E5	Table 4.3
	Fail to Seal			25.94%	E9 in Fig. III-2	Page 88
Choke and Kill valve	Internal Leak / Fail to close	15705	14	0.0446%	E1	Table 5.4
	External Leak	62820	14	0.0111%		
Hydraulic Line	External Leak	5708	14	0.1226%		
Wellhead Connector	External Leak %	2005	14	0.3491%	E3	Table 4.5
Lower Marine Riser Package (LMRP) Connector	Failure to Unlock	8018	190	1.1848%		
	Spurious disconnect	48108	190	0.1975%		
Control System	Loss of all functions: both pods	4009	7	0.0873%		
	Loss of all functions: one pod	1002	7	0.3493%		
	Loss of several functions: one pod	1336	7	0.2620%		
	Loss of one function: both pods	4009	7	0.0873%		
	Loss of one function: one pod	573	7	0.6108%		
	Unknown	2005	7	0.1746%		

* *This entry is believed to be incorrect. It should be 4048 (Table 4.3 in the 1999 study). However since the incorrect number (5398) yield s more conservative estimate, a probability for external preventer leakage of 0.1297was used in the analysis.*

[3] *Reliability of Subsea BOP Systems for Deepwater Application, Phase II DW, 1999*
[4] *Reliability of Subsea BOP Systems for Deepwater Application, Phase II DW, 1999*

3.6. Verification of the BOP Reliability Analysis

Recreation of the fault trees in the DNV Beaufort Sea Study confirmed that study's major conclusions, namely that the reliability of a two blind shear system is 99.32% versus that of a BOP system that only uses a single blind shear ram (99%.) The Fault Trees and the results are appended at the end of this report. Additional effort was performed to examine the impact of the chances of a total control failure on the BOP reliability by assigning the "single blind shear ram" Total System Control Failure probability (4.07×10^{-3}) to the event in the cases where the reliability of the two blind shear rams is determined. The conclusion is that it increases the chances of failure by approximately 0.12%. Such variations in the reliability of the BOP are considered in the Event Tree Analyses.

3.7. BOP's Ability to Control a Blowout

As explained earlier it was decided to accept the DNV study's conclusion that in 6 of the 11 incidents the BOP system was able to control the blowout. It was verified that the DNV's approach to adjusting the Event Tree for changes to the reliability of the BOP systems, due to design changes, for example adding a second blind shear ram, is correct.

3.8. Control System Failure

In the remaining 5 (of the 11) incidents, the BOP system failed to close and control the blowout. DNV concludes, based on the results of a 1999 study that in 86% of the incidents, the failure of the BOP to close and control the well can be attributed to a Control System Failure[5]. This number could not be verified. Although a review of literature provides evidence that "Control System Failure" is the most significant contributor (See Figure 1 through Figure 4) it cannot support the 86% conclusion. As will be discussed later this probability of failure was adjusted to 50%.

Table 4.8 – SINTEF BOP failure rates. [8]

BOP Element	BOP Days	Service Days	Num. Failures	Failure Rate
Annular Preventer	4,009	7,449	12	1.61E-03
Hydraulic Connector	4,009	8,018	10	1.25E-03
Flex/Ball Joint	4,009	4,009	1	2.49E-04
Pipe Ram (Generic)	4,009	16,193	11	6.79E-04
Kill & Choke Control Valves	4,009	35,419	21	5.93E-04
Control System (BOP)	4,009	4,009	60	1.50E-02

Figure 1: SINTEF BOP Failure Rates[6]. Note the number of failures attributed to the Control System. Based on this table 52% of the BOP failures can be attributed to control system failures.

[5] *Reliability of Subsea BOP Systems for Deepwater Application, Phase II DW, 1999*

[6] *Table 4.8 in Jorge Melendez, J. , " Risks Assessment of Surface versus Sub-Surface BOP's on Offshore Drilling Units."*

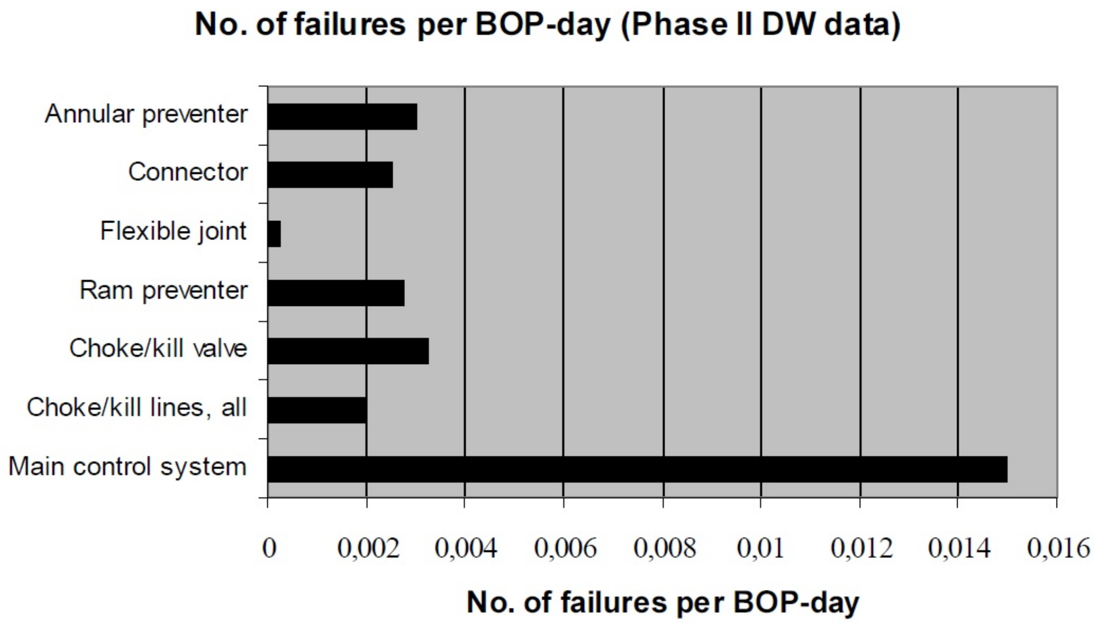

Figure 2: Failure Rates of Different Components in the BOP System[7]. Note the number of failures attributed to the Control System. *Note that the X-axis values are in SI format where a comma is used for the decimal separator. In U.S. format the values are 0, 0.002, 0.004, etc.*

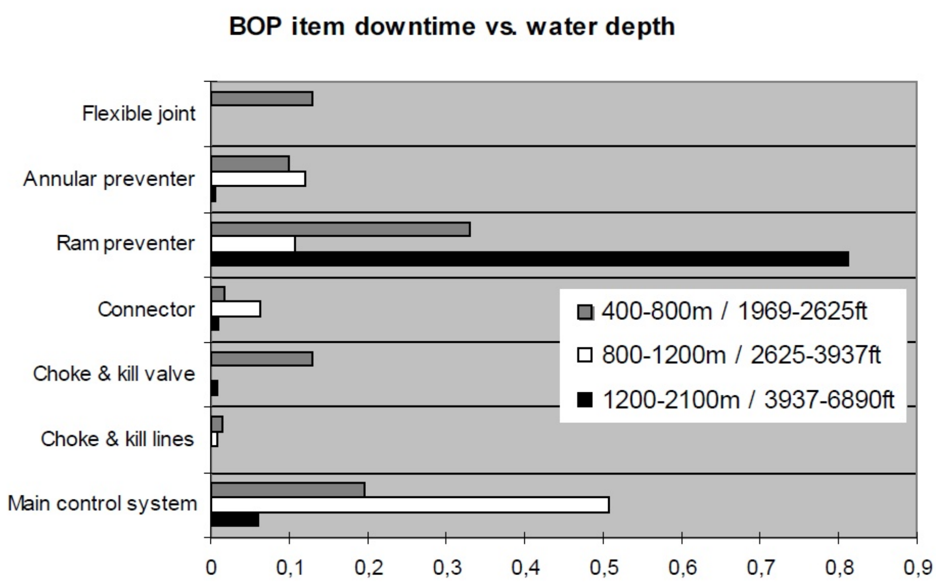

Figure 3: Average Lost Hours per BOP-day.[8] Note the number of failures attributed to the Control System, especially at water depths between 800 and 1,200 meters. *Note that the X-axis values are in SI format where a comma is used for the decimal separator. In U.S. format the values are 0, 0.1, 0.2, etc.*

7 *Figure 3.2, Holland, P. and Skalle, P., "Deepwater Kicks and BOP Performance, Unrestricted version."*
8 *Figure 3.8, Holland, P. and Skalle, P., "Deepwater Kicks and BOP Performance, Unrestricted version."*

Table 7.1 Observation of BOP failures

BOP subsystem	*BOP on the rig*			*Running BOP*		BOP on the wellhead				
	Observed on test prior to running BOP	Other obser-vation	Un-known	Test during running of BOP	Other obser-vation	Install-ation test	Test after running casing or liner	Test scheduled by time	Other obser-vation	Total
Flexible joint									1	1
Annular preventer	1					1	4	3	3	12
Ram preventer	3				1	1	5	1		11
Connector	2	2				2			4	10
Choke and kill valve	9					1	1	2		13
BOP attached line	1			1						2
Riser attached line	1			2					1	4
Jumper hose line				1			1			2
Control system	16		3	5		10	6	7	13	60
Dummy Item	2									2
Total	**35**	**2**	**3**	**9**	**1**	**15**	**17**	**13**	**22**	**117**
		34%			**9%**			**57%**		

As seen from Table 7.1, 34% of the failures were observed when the BOP was on the rig prior to running the first time, or subsequent time. Approximately 9% of the failures were observed during running of the BOP and the remaining 57% were observed when the BOP was on the wellhead. Of the 67 failures that were observed when the BOP was on the wellhead, 15 were observed during installation testing and the remaining 52 were observed during regular BOP tests or during normal operations.

Figure 4: Observation of BOP Failures.[9] Note the number of failures attributed to the Control System.

3.9. Duplicate Control Systems (Acoustic, Dead-Man, etc.) Reliability

A thorough review of literature did not provide any evidence that support or contradicts the 75% reliability number offered for the reliability of an Acoustic Backup system in the DNV study. However, as will be discussed later, a 75% reliability for an acoustic control system is considered to be too high, especially for deep sea drilling where thermal water layers and dispersion of the acoustic signal would significantly diminish the system's ability to activate the BOP. It was adjusted down to 25%.

3.10. ROV Ability to Address Failure

Regulations call for ROV capabilities that should provide all desired functions needed to activate a BOP system. A thorough review of literature did not provide any evidence that supports or contradicts the 75% reliability number offered by the DNV for the reliability of an ROV to address a non-control system failure. Our Event Tree analyses considered how sensitive the study's conclusions are to this assumption and determined that this number appears to be justifiable.

[9] *Table 7.1 Holland, P. and Skalle, P., "Deepwater Kicks and BOP Performance, Unrestricted version."*

3.11. ROV Success Rate

A thorough review of literature did not provide any evidence that support or contradicts the 90% success rate offered by the DNV for the ability of an ROV to activate the BOP system. As will be discussed later, we determined that a 75% success rate is more appropriate

4. Event Tree Analyses

4.1. Verification

The BOP process event tree is presented in Figure 5 through Figure 7. The first is essentially the event tree presented in the DNV Beaufort Sea Study. The only modification is that an additional branch was added to include a secondary control system. However to verify the DNV study the probability of success for this event is set to 0%. This confirms the accuracy of the DNV event tree analyses. Small differences with what is reported in the DNV report are due to rounding.

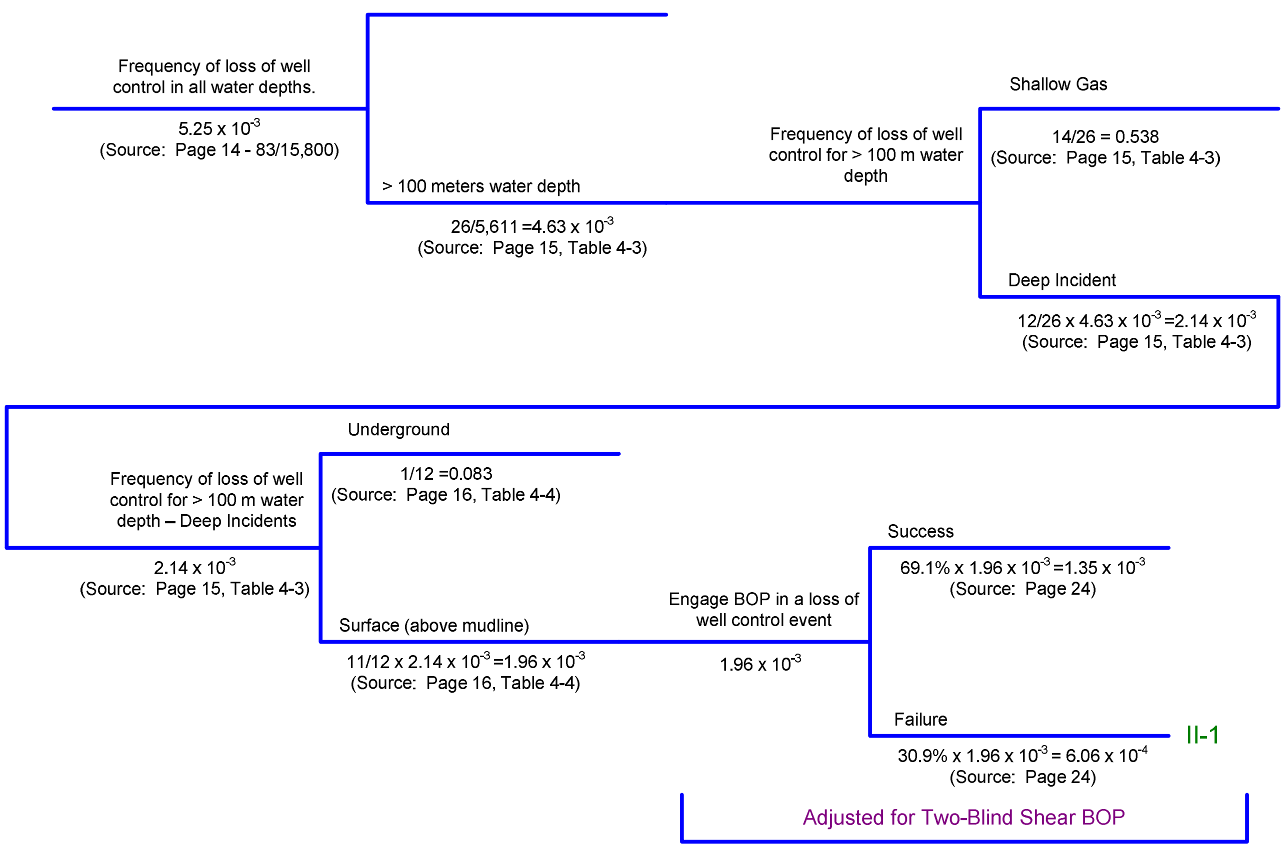

Figure 5: Event Tree for a Two Blind Shear Ram BOP System. Duplication of the Event Tree(s) in the DNV Beaufort Sea Study.

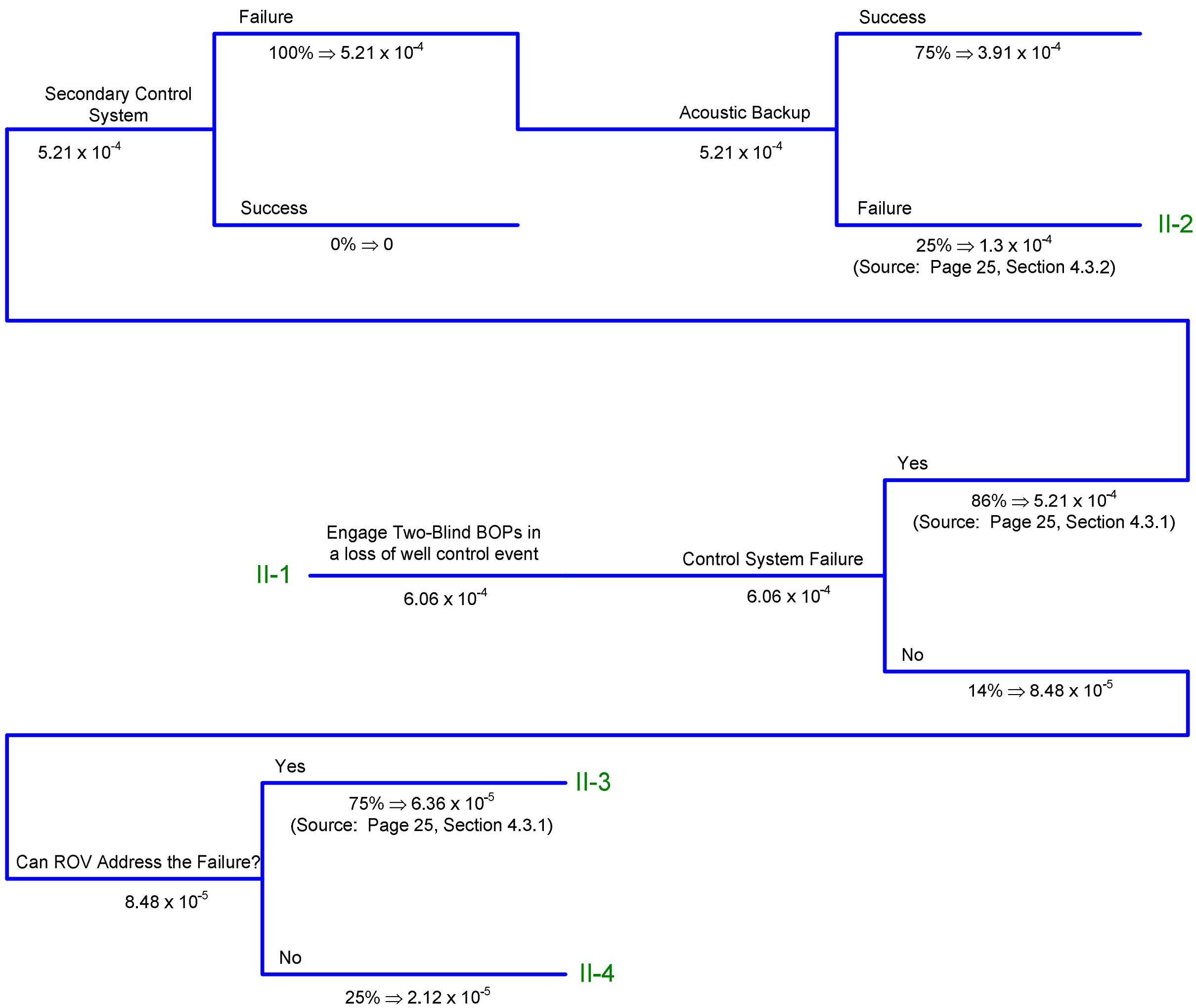

Figure 6: Continuation of the Event Tree for a Two Blind Shear Ram BOP System. Duplication of the Event Tree(s) in the DNV Beaufort Sea Study.

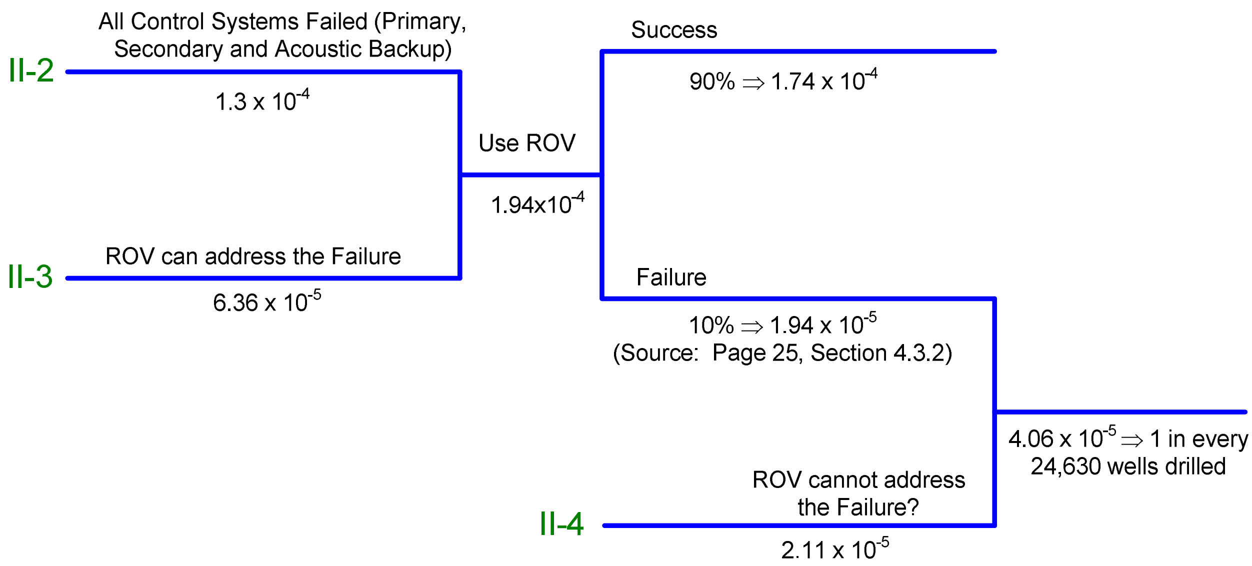

Figure 7: Continuation of the Event Tree for a Two Blind Shear Ram BOP System. Duplication of the Event Tree(s) in the DNV Beaufort Sea Study.

Table 10: Event Tree Model. Duplication of DNV Study.

EVENT		Events	Failures	Percentage	Prop.
Frequency of loss of well control in al water depths		15800	83		5.25E-03
> 100 meter water depth	< 100 m				
	> 100 m	5611	26		4.63E-03
Deep Incident	Shallow	26	14	53.8%	2.50E-03
	Deep	26	12	46.2%	2.14E-03
Surface	Underground	1	12	8.3%	1.78E-04
	Surface	11	12	91.7%	1.96E-03
Engage BOP	Success			54.5%	1.07E-03
	Failure			45.5%	8.91E-04
Taking into account Reliability of One Blind Shear	Failure				8.91E-02
Two blind shear	Success				8.85E-02
	Failure				6.06E-04
Adjusted Frequency for Two Blind Shear BOP	Success				1.35E-03
	Failure				6.06E-04
Control System Failure	Yes			86.0%	5.21E-04
	No			14.0%	8.48E-05
Secondary Control System	Success			0.0%	0.00E+00
	Failure			100.0%	5.21E-04
Acoustic Backup	Success			75.0%	3.91E-04
	Failure			25.0%	1.30E-04
Can ROV Address the Failure	Yes			75.0%	6.36E-05
	No			25.0%	2.12E-05
Combined Failure Probability (Secondary Control Systems Failure + Acoustic Backup Failure + ROV can address the Non-Control Related Failure)					1.94E-04
Use ROV	Success			90.0%	1.75E-04
	Failure			10.0%	1.94E-05
Combined Failure Rate (ROV Use + ROV Failure)					4.06E-05
Number of Wells Drilled Before Failure					**24,631**

4.2. Addressing Concerns with Respect to Reliability Estimates

It is the author's opinion that the some of the DNV study's reliability numbers are neither supported by data reported in the literature that was reviewed nor by sound engineering judgment. Therefore, the author proposes to adjust several reliability numbers downwards to ensure a conservative study. The next table (Table 11) summarizes and justifies the changes.

Table 11: Changes to the DNV Study's Probability Numbers.

Description	DNV Study Value	Recommended	Justification
Failure to activate the BOP is due to a control system failure	86%	50%	See Figure 1
Ability (Success) of an Acoustic Backup System to activate BOP	75%	25%	The acoustic backup system failed in a number of incidents and it is known to have a lower likelihood of success in deep water
Can ROV successfully activate the BOP	90%	75%	There are too many reasons why the ROV could fail in activating a blind shear ram. Failure of hydraulic valves, a joint in the BOP, etc.

With the new reliability numbers, the predicted failure rate for a BOP system that has one blind shear ram, no secondary or acoustic backup systems but with ROV capabilities is 3,265 wells drilled before an uncontrolled blowout will occur. With the original DNV reliability numbers the predicted number of wells that can be drilled with a similar system before a blowout occurs is 8,534.

Over the 1/1/1980 to 12/31/2007 period of the DNV study, the number of wells drilled is 15,800 with 5 blowouts from deep zones that could not be controlled. This yields a failure rate of 3,160 wells drilled before an uncontrolled blowout. This is in agreement with the model that uses the modified reliability numbers, providing some confidence that the revised reliability numbers are more accurate and that the models can be trusted to predict trends due to design enhancements.

In conclusion, using the modified reliability numbers associated with the two blind shear ram BOP system (Figure 5 to Figure 7) to predict the numbers of wells that can be drilled before an uncontrolled blowout occurs results in an answer of 6,213 (Table 12). This is almost a quarter of the number of wells predicted by the DNV study (Table 10).

Table 12: Event Tree Model for the Recommended Failure Rates and a Two Blind Shear Ram BOP System with Reliability of 99.32%.

EVENT		Events	Failures	Perc.	Prop.
Frequency of loss of well control in al water depths		15800	83		5.25E-03
> 100 meter water depth	< 100 m				
	> 100 m	5611	26		4.63E-03
Deep Incident	Shallow	14	26	53.8%	2.50E-03
	Deep	12	26	46.2%	2.14E-03
Surface	Underground	12	1	8.3%	1.78E-04
	Surface	12	11	91.7%	1.96E-03
Engage BOP	Success			54.5%	1.07E-03
	Failure			45.5%	8.91E-04
Taking into account Reliability of One Blind Shear	Failure				8.91E-02
Two blind shear	Success				8.85E-02
	Failure				6.06E-04
Adjusted Frequency for Two Blind Shear BOP	Success				1.35E-03
	Failure				6.06E-04
Control System Failure	Yes			50.0%	3.03E-04
	No			50.0%	3.03E-04
Secondary Control System	Success			50.0%	1.51E-04
	Failure			50.0%	1.51E-04
Acoustic Backup	Success			25.0%	3.79E-05
	Failure			75.0%	1.14E-04
Can ROV Address the Failure	Yes			75.0%	2.27E-04
	No			25.0%	7.57E-05
Combined Failure Probability (Secondary Control Systems Failure + Acoustic Backup Failure + ROV can address the Non-Control Related Failure)					3.41E-04
Use ROV	Success			75.0%	2.56E-04
	Failure			25.0%	8.52E-05
Combined Failure Rate (ROV Use + ROV Failure)					1.61E-04
Number of Wells Drilled Before Failure					**6,213**

4.3. Event Tree as a Tool to Examine Sensitivities

The event tree model, with the modified reliability numbers, was used to examine sensitivity of the BOP system to the probability of success or failure of its sub-systems. In these sensitivity studies, the number of wells before an uncontrolled blowout is calculated by using a "one-foot on the ground" approach. That is, in every study, the same values are used while only one parameter is varied.

Figure 8 is shows the dependence on the number of wells drilled before an uncontrolled blowout from a deep zone will occur as a function of Probability that past BOP failures were due to a control system failure. DNV concluded that 86% of cases were due to control system failure and they did not provide any logic or supporting numbers. This results in more incidents where an acoustic, secondary backup or ROV system can remedy the failure of the primary system. Only 14% of the incidents were going to the branch where the only "remedy" is the use of an ROV. Thus as the probability of primary control system failure goes up, the secondary control systems can deal with most of the cases - reducing the probability of an uncontrolled blowout from a deep zone. As discussed in Section 3.8, literature review concluded that the 86% estimate is high and that 50% presents a more realistic value.

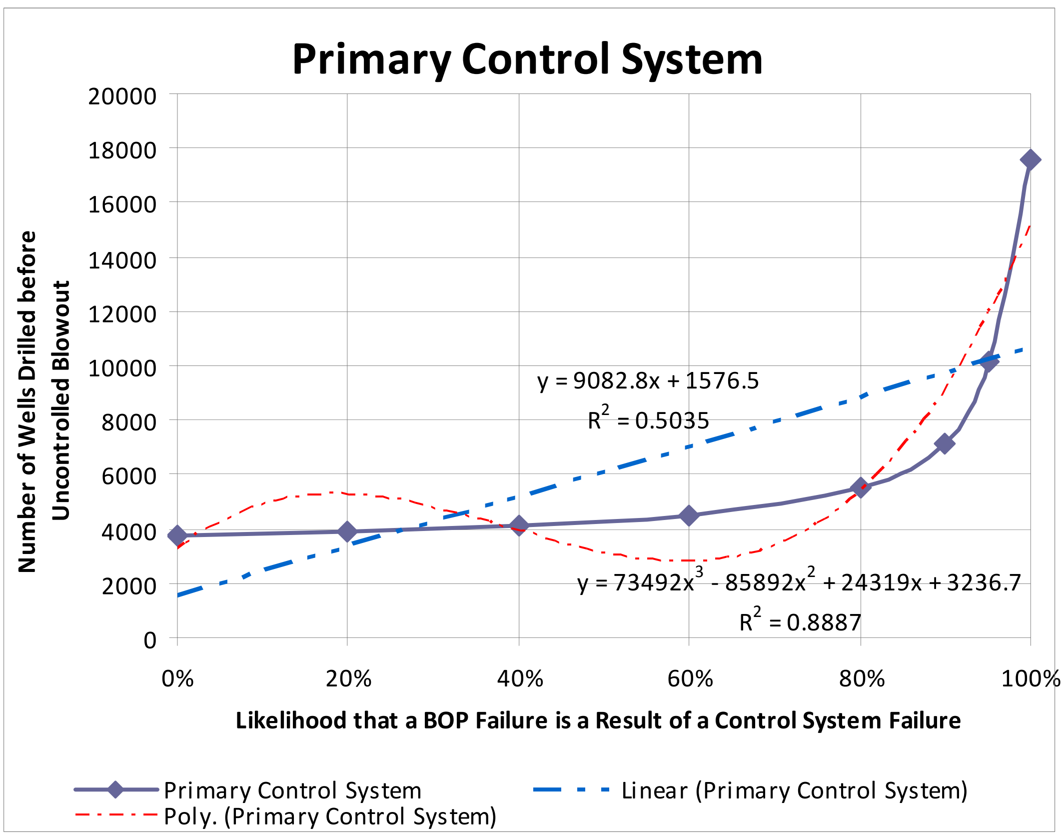

Figure 8: The Number of Wells that can be drilled before an Uncontrolled Blowout from a Deep Zone Occurs as a Function of the Likelihood that a BOP Failure is a Result of a Control System Failure. It should be noted that the results are sensitive to high likelihoods (for example the 86% likelihood that was used in the DNV study). For the 50% likelihood recommended in this report, the number of wells that can be drilled is less sensitive.

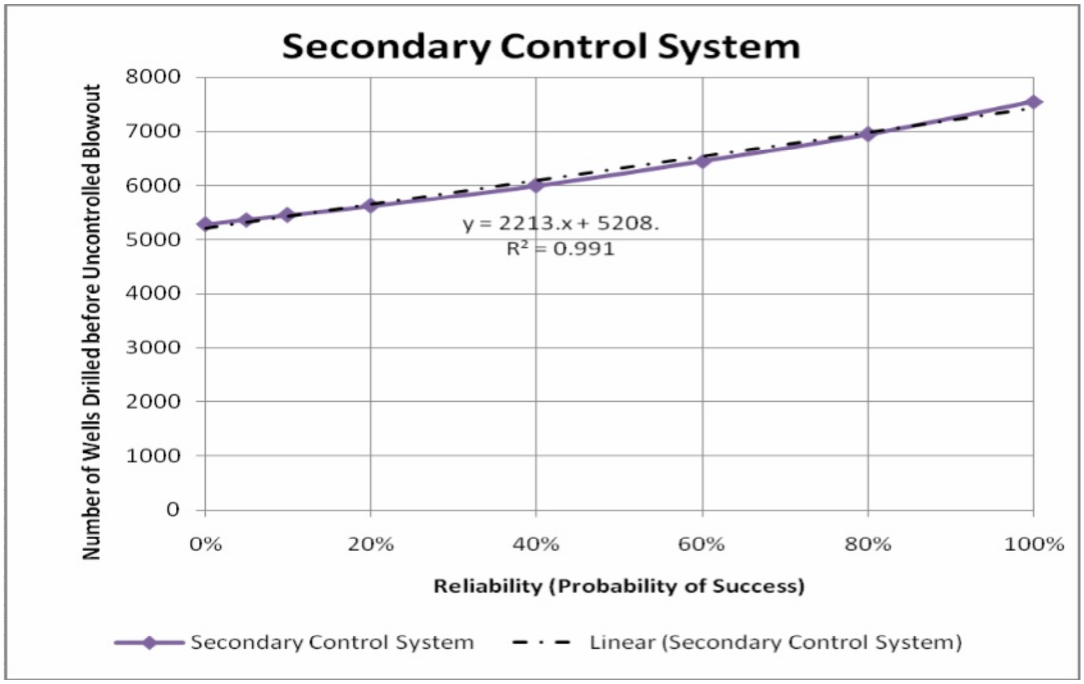

Figure 9: Sensitivity of the Number of Wells that can be drilled before an Uncontrolled Blowout from a Deep Zone Occurs on the Reliability of the Secondary Control System. Study conclusions are moderately dependent on this parameter and the number of wells that can be drilled before an uncontrolled blowout is linearly dependent on this sub-system's reliability. Note 50% reliability was assumed in the study.

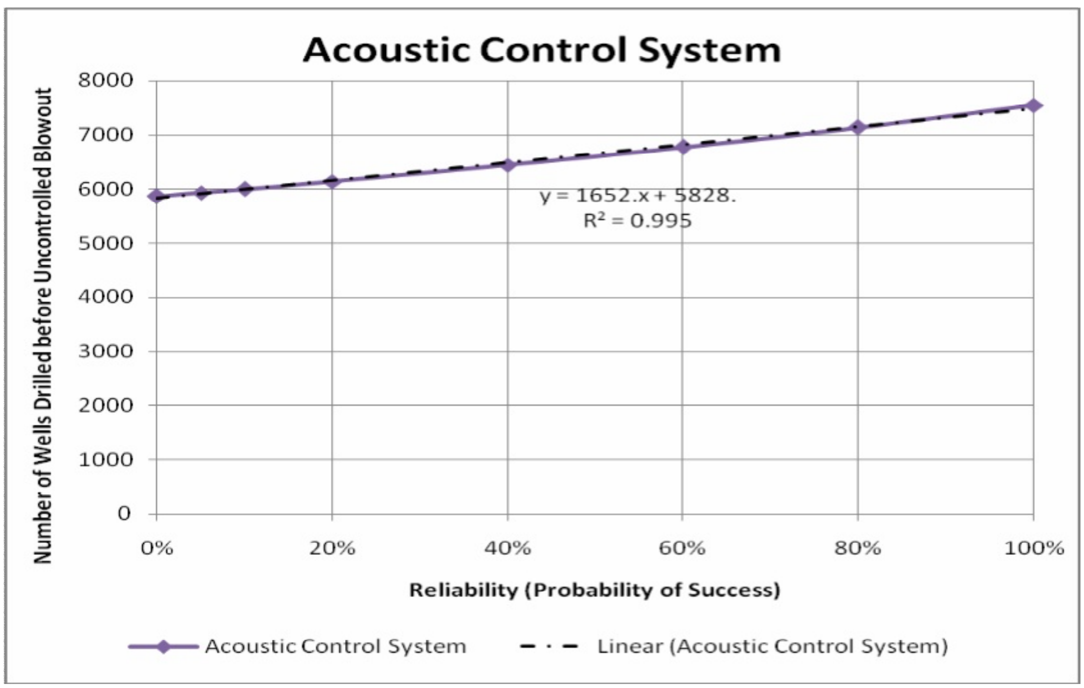

Figure 10: Sensitivity of the Number of Wells that can be drilled before an Uncontrolled Blowout from a Deep Zone Occurs on the Reliability of an Acoustic Backup Control System. Study conclusions are weakly dependent on this parameter and the number of wells that can be drilled before an uncontrolled blowout is linearly dependent on this sub-system's reliability. Note 25% reliability was assumed in the study.

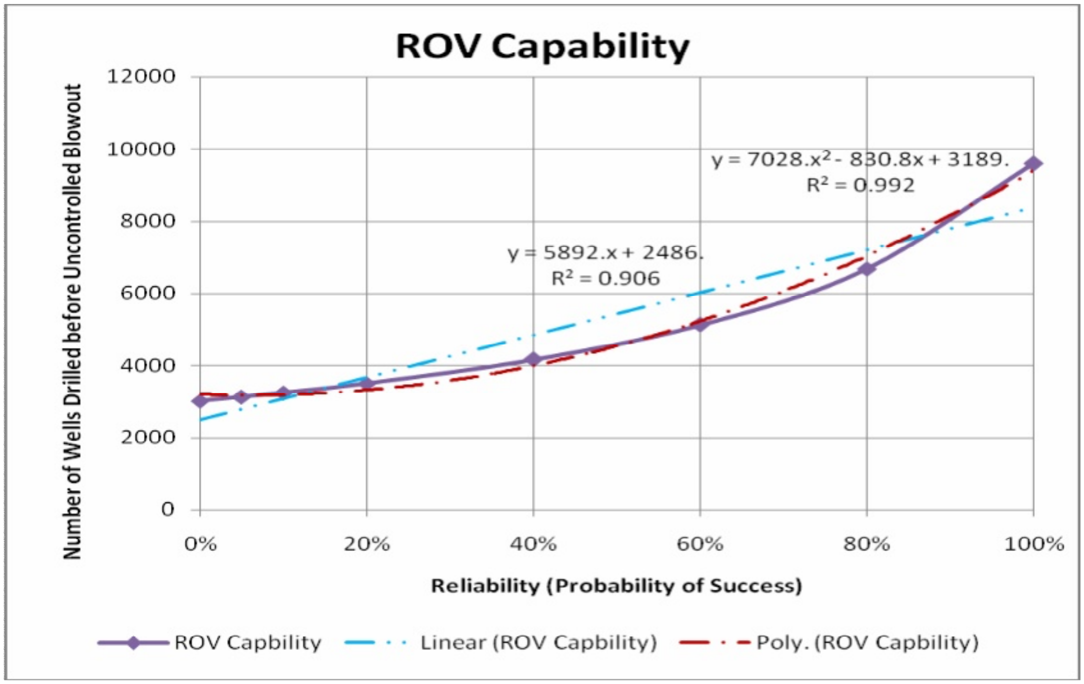

Figure 11: Sensitivity of the Number of Wells that can be drilled before an Uncontrolled Blowout from a Deep Zone Occurs on the ability of an ROV system to address the failures of the primary and secondary control systems. Study conclusions are strongly dependent on this parameter and the number of wells that can be drilled before an uncontrolled blowout is non-linearly dependent on this sub-system's reliability. Note 75% reliability was assumed in the study.

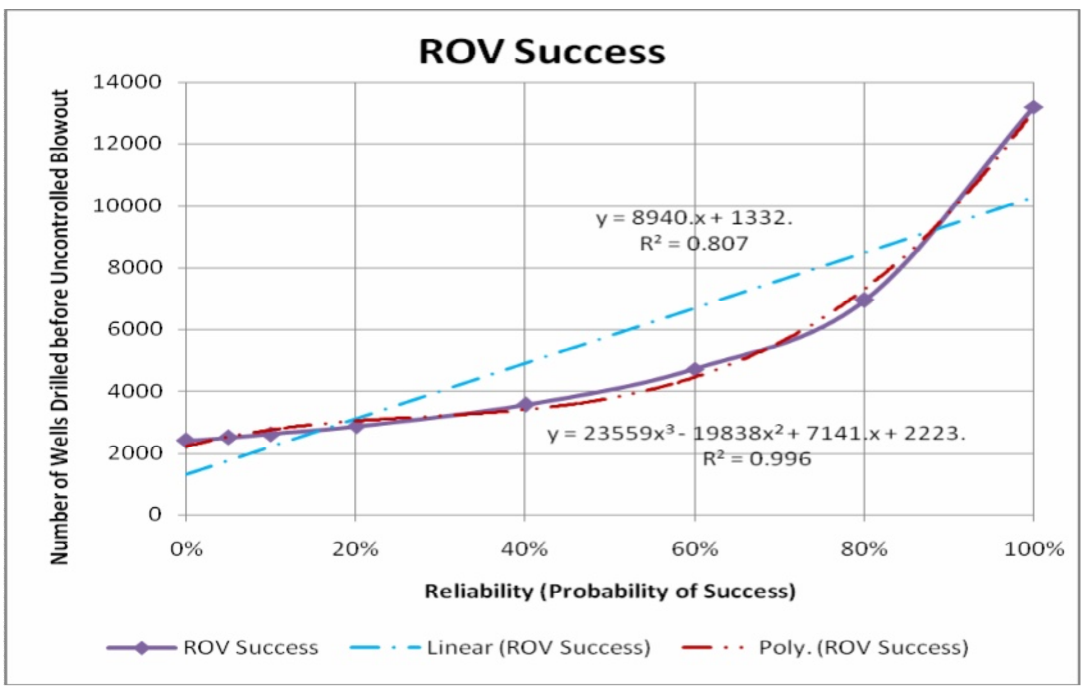

Figure 12: Sensitivity of the Number of Wells that can be drilled before an Uncontrolled Blowout from a Deep Zone Occurs on the ability of an ROV system to activate the BOP system. Study conclusions are strongly dependent on this parameter and the number of wells that can be drilled before an uncontrolled blowout is non-linearly dependent on this sub-system's reliability. Note 75% reliability was assumed in the study.

The impact of the reliability of a two blind shear ram BOP system was also considered (Figure 13). At approximately 99% reliability, the number of wells that can be drilled increases by 620 wells per 0.1% increase in reliability of the BOP systems. For example, the predicted reliability of the two blind shear ram BOP is 0.32% more than that of a single blind shear ram system. The number of wells that can be drilled before an uncontrolled blowout increases from 4,225 wells, for the single blind shear ram, to 6,213 (4,225 + 3.2*620 ≈ 6,213) wells for the two blind shear ram system.

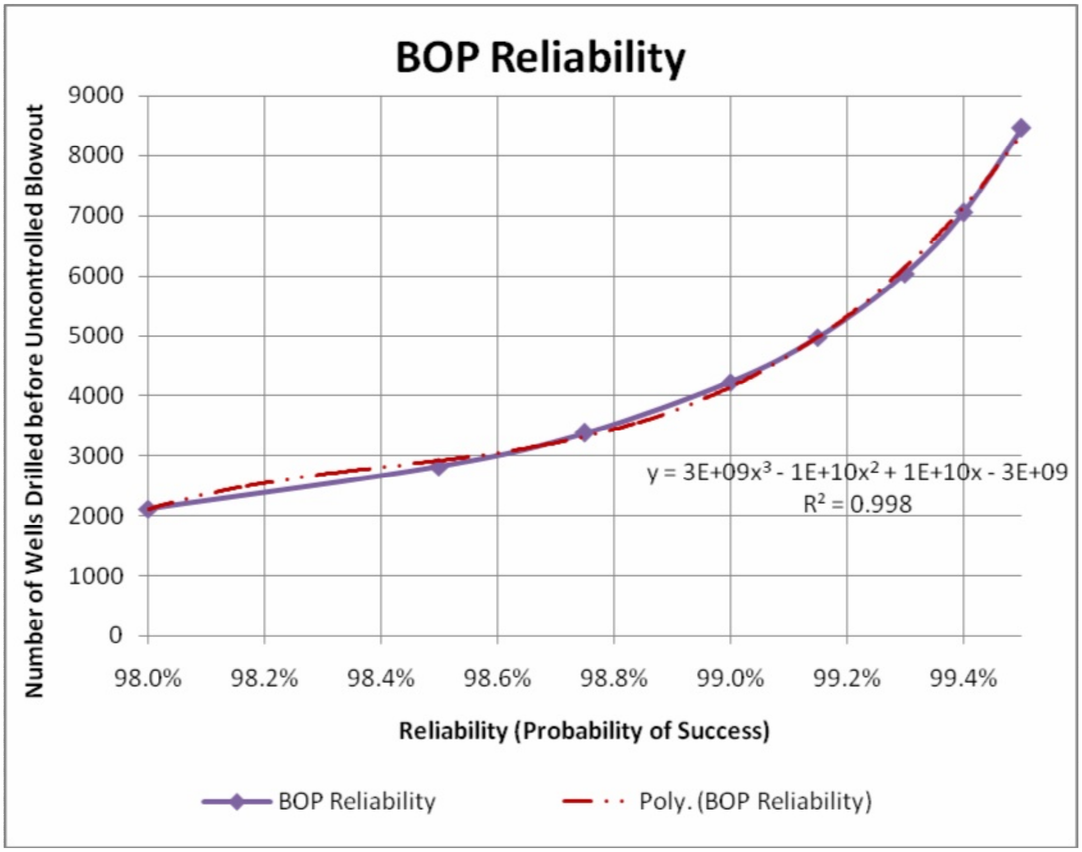

Figure 13: Sensitivity of the Number of Wells before a BOP system cannot close and secure a blowout to the reliability of two blind shear rams.

4.4. Improvement Estimates

In order to estimate the benefit of sub-systems in the BOP system, a baseline was established where the number of wells that can be drilled (1,122) before an uncontrolled blowout will occur is determined for a single blind shear ram BOP system that has no secondary or acoustic backup control systems nor any ROV capabilities (Table 13). Using this system as a baseline, the event tree model was used to estimate the number of wells that can be drilled before an uncontrolled blowout will occur when other sub-systems are added (Table 14). Also reported in this table are the cumulative improvements that are obtained as the sub-systems are added to the BOP system.

Table 13: Event Tree Model for the Selected Failure Rates and a Single Blind Shear Ram BOP System with Reliability of 99%. Note this system has no secondary control system, acoustic backup, nor the capability to be activated by an ROV.

EVENT		Events	Failures	Perc.	Prop.
Frequency of loss of well control in al water depths		15800	83		5.25E-03
> 100 meter water depth	< 100 m				
	> 100 m	5611	26		4.63E-03
Deep Incident	Shallow	14	26	53.8%	2.50E-03
	Deep	12	26	46.2%	2.14E-03
Surface	Underground	12	1	8.3%	1.78E-04
	Surface	12	11	91.7%	1.96E-03
Engage BOP	Success			54.5%	1.07E-03
	Failure			45.5%	8.91E-04
Taking into account Reliability of One Blind Shear	Failure				8.91E-02
Two blind shear	Success				8.82E-02
	Failure				8.91E-04
Adjusted Frequency for Two Blind Shear BOP	Success				1.07E-03
	Failure				8.91E-04
Control System Failure	Yes			50.0%	4.46E-04
	No			50.0%	4.46E-04
Secondary Control System	Success			0.0%	0.00E+00
	Failure			100.0%	4.46E-04
Acoustic Backup	Success			0.0%	0.00E+00
	Failure			100.0%	4.46E-04
Can ROV Address the Failure	Yes			0.0%	0.00E+00
	No			100.0%	4.46E-04
Combined Failure Probability (Secondary Control Systems Failure + Acoustic Backup Failure + ROV can address the Non-Cont. Related Failure)					
Use ROV	Success			0.0%	0.00E+00
	Failure			100.0%	4.46E-04
Combined Failure Rate (ROV Use + ROV Failure)					8.91E-04
Number of Wells Drilled Before Failure					**1,122**

Table 14: Summary of the Improvements predicted by the Event Tree Model.

System Description	Incremental Improvement (One system at a time)		Cumulative Improvement	
	Probability of an Uncontrolled Failure	Percentage Improvement in Reliability	Probability of an Uncontrolled Failure	Percentage Improvement in Reliability
Baseline – Single Blind Shear Ram BOP System	0.089%	0%	0.089%	0%
System with Two Blind Shear Rams (Increase BOP reliability from 99% to 99.32%)	0.061%	32%	0.061%	32%
Secondary Control System (auto-shear / dead-man) with a 50% Reliability	0.067%	25%	0.045%	49%
Acoustic Backup System (Can address 25% of a Control System Failures=)	0.078%	13%	0.042%	53%
ROV Capability (Can address 75% of all Control System Failures and it is 75% successfully in activating the BOP System)	0.031%	66%	0.016%	82%

From this table and Figure 14 it is clear that an ROV enabled BOP system provides the best improvement. An acoustic system with a low anticipated success rate does not provide a significant increase in the number of wells that can be drilled before an uncontrolled blowout from a deep zone will occur. The value of adding a second blind shear ram is of the same order as adding a secondary control sub-system.

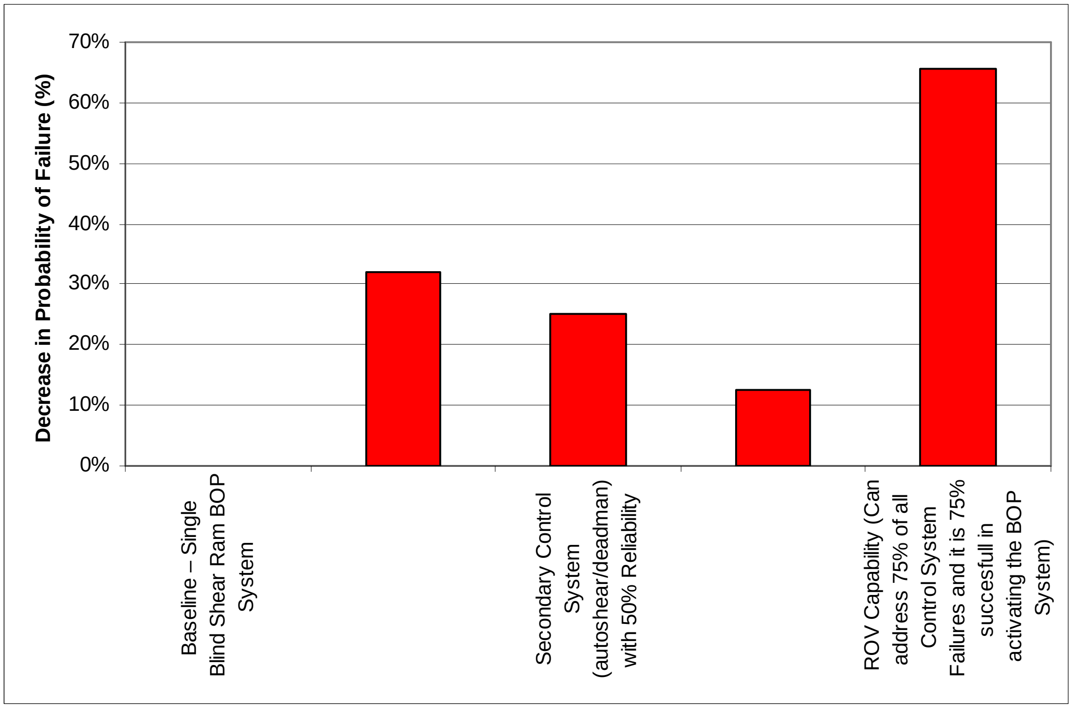

Figure 14: Summary of Improvement analysis. This figure presents the change in the probability of an Uncontrolled Blowout when a well is drilled at depths greater than 100 meters as a function of different sub-systems added to the BOP system. Note reliability of BOP system was assumed to be 99.32%.

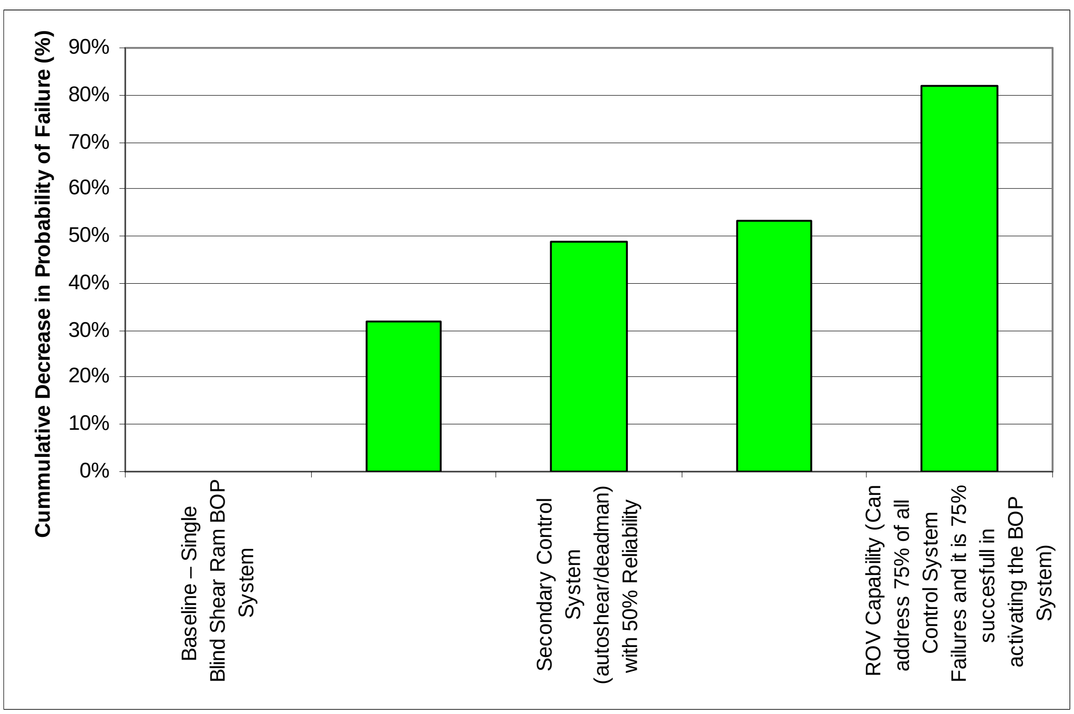

Figure 15: Summary of Improvement analysis. This figure presents the change in the cumulative probability of an Uncontrolled Blowout when a well is drilled at depths greater than 100 meters as a function of different sub-systems added to the BOP system. Note reliability of BOP system was assumed to be 99.32%.

4.5. Impact of the Uncertainty with regard to the Probability of a Total Control System Failure

As discussed in Section 3.6 and in Appendix A, one of the issues remaining with the DNV study is the probability of failure used for a total control system failure. When there are two blind shear rams, the DNV study used a probability of 2.84 x 10^{-3} for a total control system failure. This is lower than the value that was used when a single blind shear ram is used (4.07 x 10^{-3}). When the two blind shear rams fault tree analysis is performed with this more conservative probability the reliability of the system is calculated to be 99.2% (See blue block in Figure 15.) In order to ensure that this more conservative estimate does not alter the conclusions in the previous section, the event tree analyses were repeated with this BOP reliability (99.2%).

Table 15: Summary of the Improvements predicted by the Event Tree Model based on a BOP reliability of 99.2%.

System Description	Incremental Improvement (One system at a time)		Cumulative Improvement	
	Probability of an Uncontrolled Failure	Percentage Improvement in Reliability	Probability of an Uncontrolled Failure	Percentage Improvement in Reliability
Baseline – Single Blind Shear Ram BOP System	8.91E-04	0%	8.91E-04	0%
System with Two Blind Shear Rams (Increase BOP reliability from 99% to 99. 2%)	7.13E-04	20%	7.13E-04	20%
Secondary Control System (auto-shear / dead-man) with a 50% Reliability	6.68E-04	25%	5.35E-04	40%
Acoustic Backup System (Can address 25% of a Control System Failures=)	7.79E-04	13%	4.90E-04	45%
ROV Capability (Can address 75% of all Control System Failures and it is 75% successfully in activating the BOP System)	3.06E-04	66%	1.89E-04	79%

The conclusion (Table 15 and Figure 16) is that the change in the total control system probability of failure only impacts the probability of BOP failure and that it does not change previous conclusions with regard to the value of BOP systems.

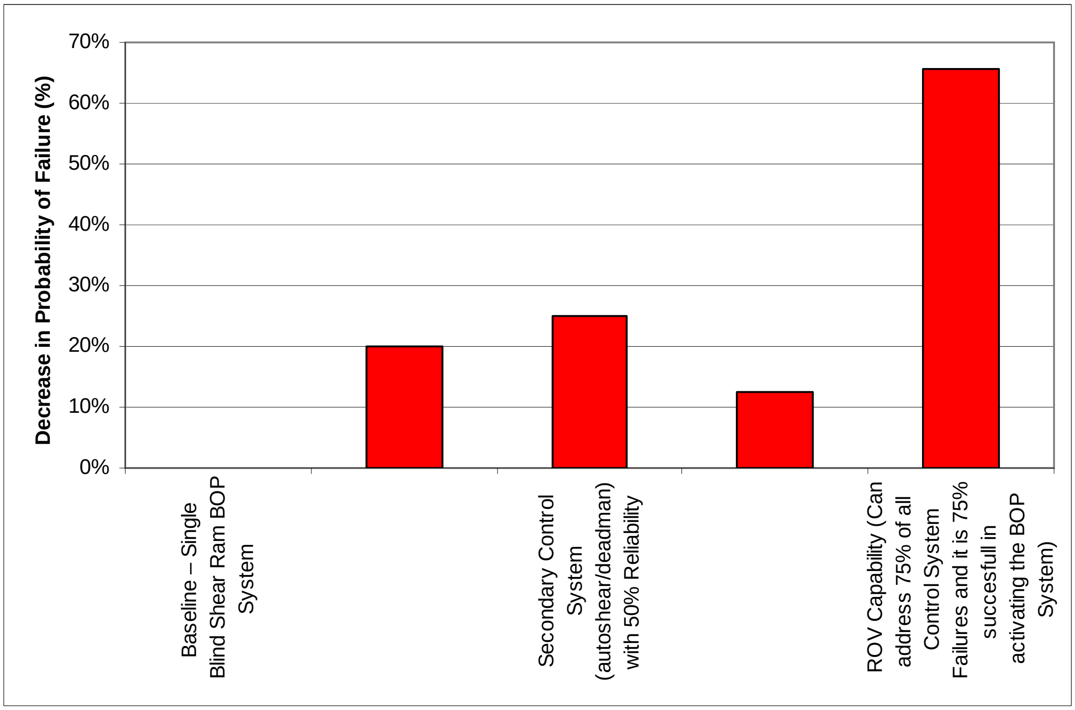

Figure 16: Summary of Improvement analysis. This figure presents the change in the probability of an Uncontrolled Blowout when a well is drilled at depths greater than 100 meters as a function of different sub-systems added to the BOP system. Note reliability of BOP system was assumed to be 99.2%.

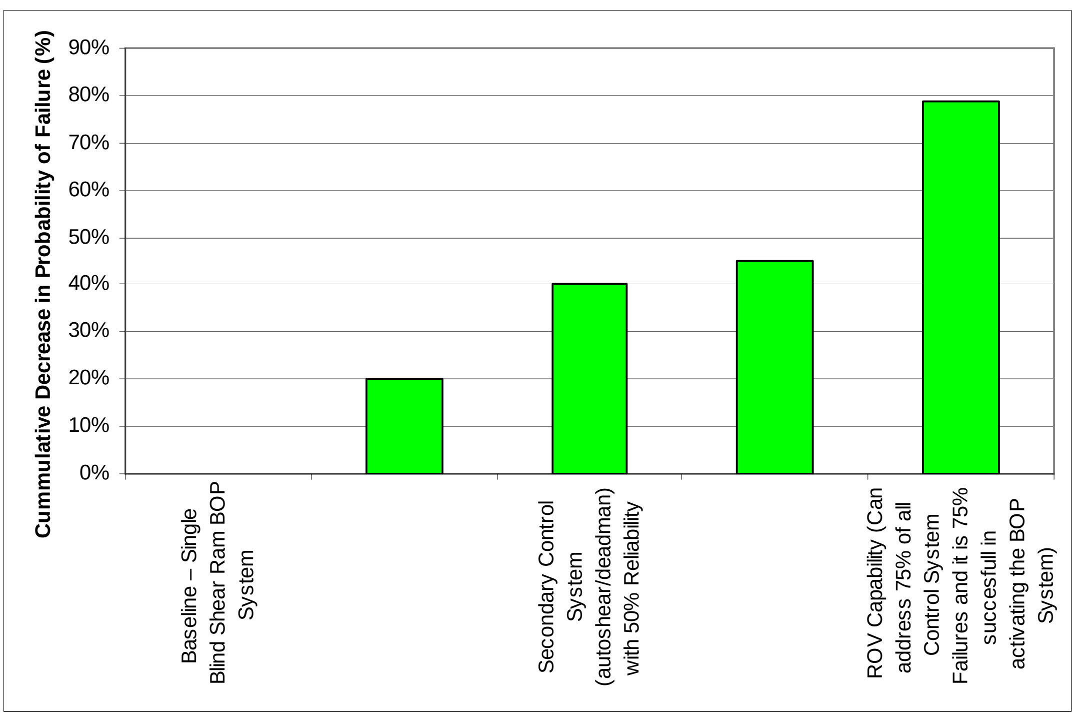

Figure 17: Summary of Improvement analysis. This figure presents the change in the cumulative probability of an Uncontrolled Blowout when a well is drilled at depths greater than 100 meters as a function of different sub-systems added to the BOP system. Note reliability of BOP system was assumed to be 99.2%.

5. Observations on Water Depth

Given that the vulnerability of a system is often affected by the system's exposed length (or area or volume), for example the very long drill string that is needed in deep waters, initial thoughts were to include in the Event Tree Analysis consideration for the well water depth. However a review of the literature concluded that this may not be justified. The reasons are presented in the next two sections.

5.1. Not Supported by Reported Data

As can be seen in Figure 18 and Figure 19, both the number of reported blowouts and the number of kick frequencies decreases with water depth.

Water Depth (ft.)	Oil and Gas Exploration Wells	Oil and Gas Development Wells	Total Oil and Gas Wells	Total blowouts (minus sulfur blowouts)	Wells drilled per blowout (minus sulfur wells)
0 - 200	3,156	5,566	8,722	19	459
201 - 500	965	2,251	3,216	14	230
501 - 1,000	203	443	646	1	646
> 1,000	1,347	1,146	2,493	5	499
Total, all depths	5,671	9,406	15,077	39	387

Table 1: From 1992 through 2006, the average blowout rate was one every 387 wells drilled, compared with the 1971-1991 rate of one every 246 wells.

Figure 18: Blowouts as a Function of Water Depth[10]

[10] *Table 1 - Izon, D., Danenberger, E.P., Mayes, M., "Absence of fatalities in blowouts encouraging in MMS study of OCS incidents 1992-2006."*

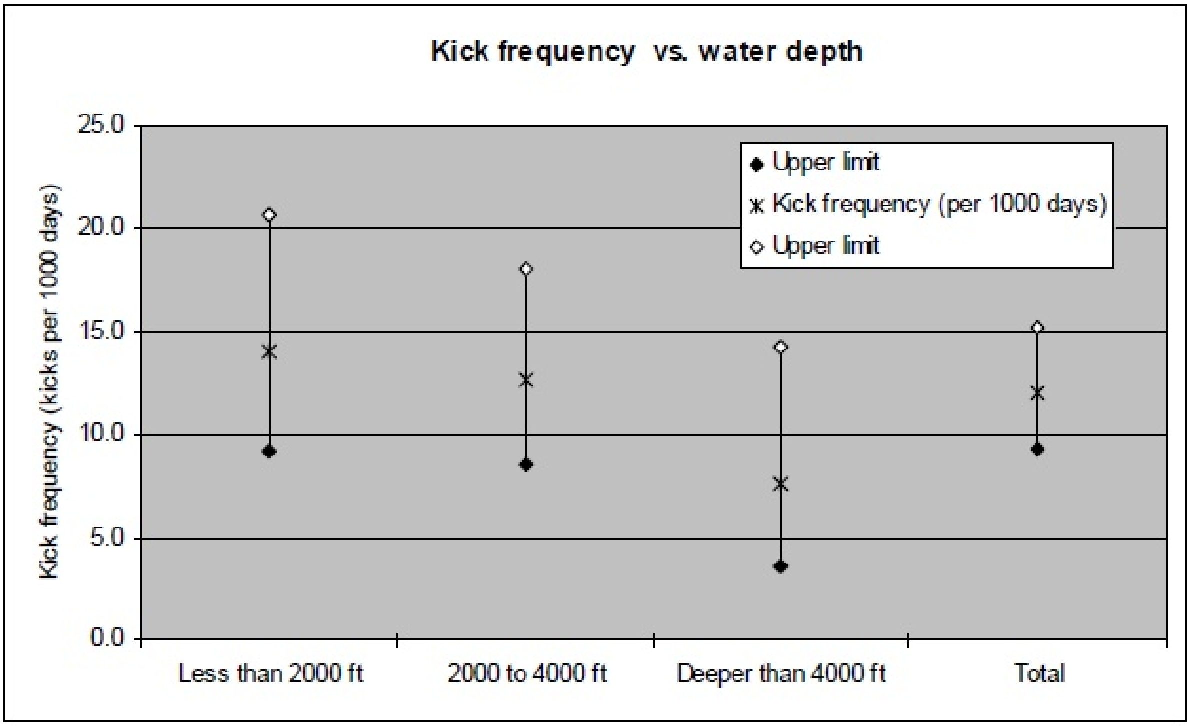

Figure 2.3 Kick frequency vs. water depth

Figure 19: Kick frequency versus Water Depth[11].

5.2. Currents Decay with Water Depth.

Drilling in deep water Figure 20 offers the benefit that the well head is experiencing significantly lower current speeds. This may explain why well blowouts decrease with water depth.

[11] *Figure 2.3 - Holland, P. and Skalle, P., "Deepwater Kicks and BOP Performance, Unrestricted version."*

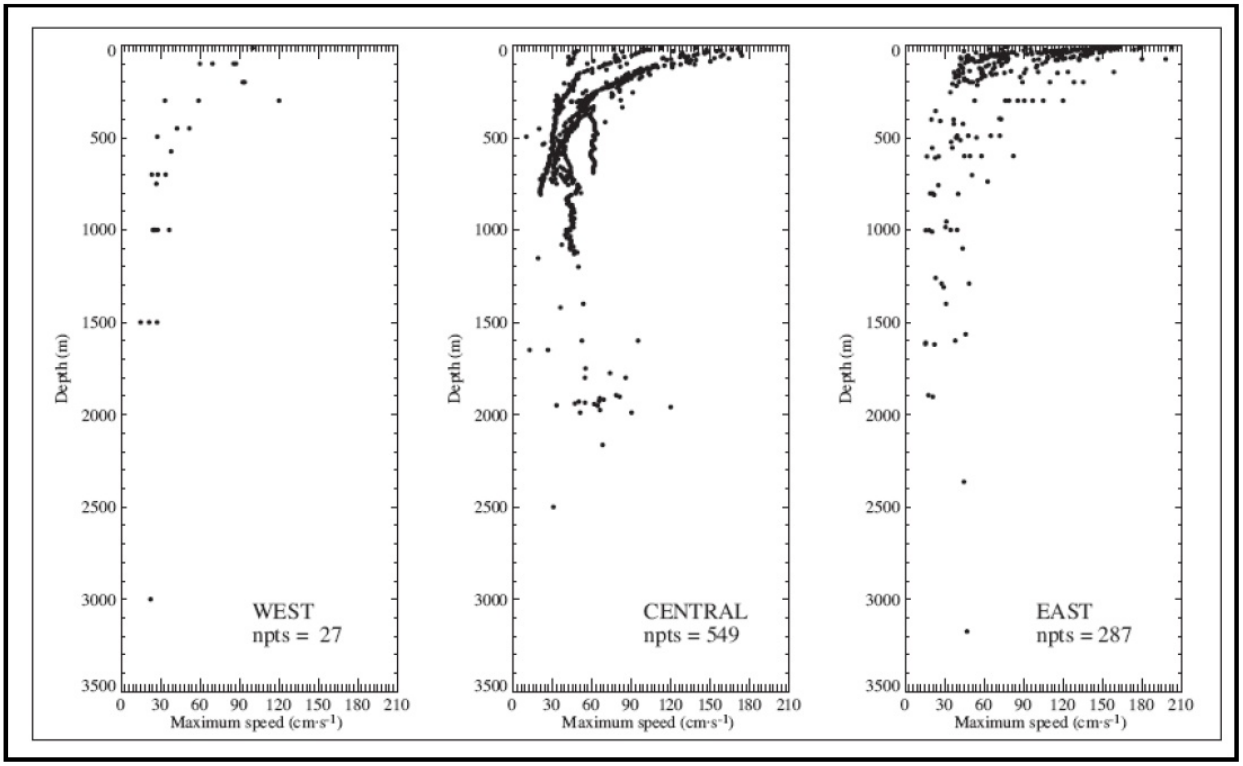

Fig. 1.5 – GOM maximum currents profile vs. depth. [22]

Figure 20: Gulf of Mexico maximum currents profile versus depth[12].

6. Casing

From the literature:[13]

> *"Cementing problems increased significantly during the current period as these problems were associated with 18 of the 39 blowouts, compared with 18 of the 70 blowouts with identified contributing factors during the previous study. During the current period, all but one of the blowouts associated with cementing problems occurred in wells with water depths less than 400 f t."*

This indicates that regulations may focus on shallower wells and their potentially unique challenges.

[12] *Figure 1.5 in Jorge Melendez, J. , " Risks Assessment of Surface versus Sub-Surface BOP's on Offshore Drilling Units."*
[13] *"Absence of fatalities in blowouts encouraging in MMS study of OCS incidents 1992-2006."*

7. Conclusions

A general conclusion is that the DNV study, after some reliability numbers were adjusted downwards, is reasonably accurate and presents an acceptable approach to estimate the value offered by BOP system improvements. Additional work is needed to determine or obtain reliability numbers for estimates. Sensitivity studies should also consider combinational variances in parameters to obtain an understanding of interaction.

8. References

30 CFR, Part 250

API Recommended Practice 65 – Part 2, "Isolating Potential Flow Zones during Well Construction," First Edition, May 2010.

Andersen, L.B. "Stochastic modeling for the analysis of blowout risk in exploration drilling," Reliability Engineering and System Safety 61 (1998) 53-63.

APPENDIX A - Beaufort Sea Drilling Risk Study Energy Report, Imperial Oil Resources Ventures Limited, DNV ref no: EP00485, Rev. 6, 11 March 2010.

Department of the Interior, May Report to the President, "Increased Safety Measurements for Energy Development, May 27th, 2010.

Draft JIHT Recommendations, May 2010. White Paper: Recommendations for Improving Offshore Safety, Joint Industry Task Force to Address Offshore Operating Procedures and Equipment.

Grosso, D.S., Wallace, S.N.,"Gas-Influx Detection With MWD Technology," Paper Number 19973-PA, Volume 6, Number 4, December 1991, Pages 273-278. Society of Petroleum Engineers.

Holand, P. and Rausand, M, "Reliability of Subsea BOP Systems," Reliability Engineering 0143-8174, 1987.

Holand, P., "Reliability of Subsea BOP Systems for Deepwater Application, Phase II DW, Unrestricted version." Study performed for MMS, ISBN 82-14-01661-4, November 7th, 1999.

Holland, P. and Skalle, P., "Deepwater Kicks and BOP Performance, Unrestricted version," Minerals Management Service (MMS), STF38 A01419, 2001-07-24, ISBN: 82-14-01682-7.

Izon, D., Danenberger, E.P., Mayes, M., "Absence of fatalities in blowouts encouraging in MMS study of OCS incidents 1992-2006," This article is based on a presentation scheduled for the IADC Well Control Conference of the Americas, 28-29 August 2007, Galveston, Texas.

Jorge Melendez, J. , " Risks Assessment of Surface versus Sub-Surface BOP's on Offshore Drilling Units," Prepared for the Minerals Management Service Under the MMS/OTRC Cooperative Research Agreement 1435-01-04-CA-35515, Task Order 39226, MMS Project Number 540.

Molnes, E and Strand, G., "Application of a Completion Equipment Reliability Database in Decision Making,' Society of Petroleum Engineers Inc., This paper was prepared for presentation at the 2000 SPE Annual Technical Conference and Exhibition held in Dallas, Texas, 1–4 October 2000. SPE 63112.

National Notice to Lessees and Operators of Federal Oil and Gas Leases, Outer Continental Shelf (OCS), United States Department of Interior, Mineral Management Services, NTL No. 2010- N05 Effective Date: June 8, 2010, OMB Control Number: 1010-0182, OMB Expiration Date: 12/31/2010.

NORSOK Standard, "Risk and emergency preparedness analysis," Z-013, Rev. 2, 2001-09-01.

PCCI Marine and Environmental Engineering, "Oil Spill Containment, Remote Sensing and Tracking For Deepwater Blowouts: Status of Existing and Emerging Technologies," MMS Purchase Order Number 1435-01-98-PO-15135, August 12, 1999.

Shanks, E. Dykes, A., Quilici, M. and Pruitt, J. "Deepwater BOP Control Systems – A look at reliability issues," Presented at the 2003 Offshore Technology Conference held in Houston, Texas, U.S.A., 5–8 May 2003.

Signoret J.P. and Leroy, A. "The 1800 m Water Depth Drilling Project: Risk Analysis," Reliability Engineering 11 (1985) 83-92.

Vinnem, J.E., "Offshore Risk Assessment – Principles, Modeling and Applications of QRA," Kluwer Academic, ISBN: 0-7923-5860-0, 1999.

West Engineering Services, "Shear Ram capabilities Study," U.S. Minerals Management Service, Requisition No. 3-4025-1001.

Appendix A – Fault Tree Analyses

In order to verify the Fault Tree Analyses of the DNV Beaufort Sea study, the Fault Trees were duplicated and the results in Table 16 were obtained. Since two different numbers for the probability of a total control system failure were used in the Beaufort Sea study, the Fault Tree Analyses were run with both values. In summary the more conservative probability number of 4.07×10^{-3} increases the probability of BOP failure by approximately 0.12%.

Table 16: Summary of the Fault Tree Analyses.

		Probability of Total Control System Failure	
	Figure No.	**2.84×10^{-3}**	**4.07×10^{-3}**
Two Blind Shear Ram – Open Hole	Figure 21	0.86%*	0.99%
Two Blind Shear Ram – Drill Pipe through BOP	Figure 22	0.68%	0.80%
Two Blind Shear Ram – Casing through BOP	Figure 23	0.73%	0.86%
Single Blind Shear Ram – Open Hole	Figure 24	0.86%	0.99%
Single Blind Shear Ram – Drill Pipe through BOP	Figure 25	0.74%	0.86%*
Single Blind Shear Ram – Casing through BOP	Figure 26	0.92%	1.04%

* = *For these cases our Fault Tree Analysis disagrees with the results published in the DNV report.*

[green box] = *The probability of failure predicted by the DNV study. A probability of total control system failure was assumed to be* 2.84×10^{-3} *for the Two Blind Shear Ram cases and* 4.07×10^{-3} *for the Single Blind Shear Ram Cases.*

Two Blind Shear Rams – Open Hole

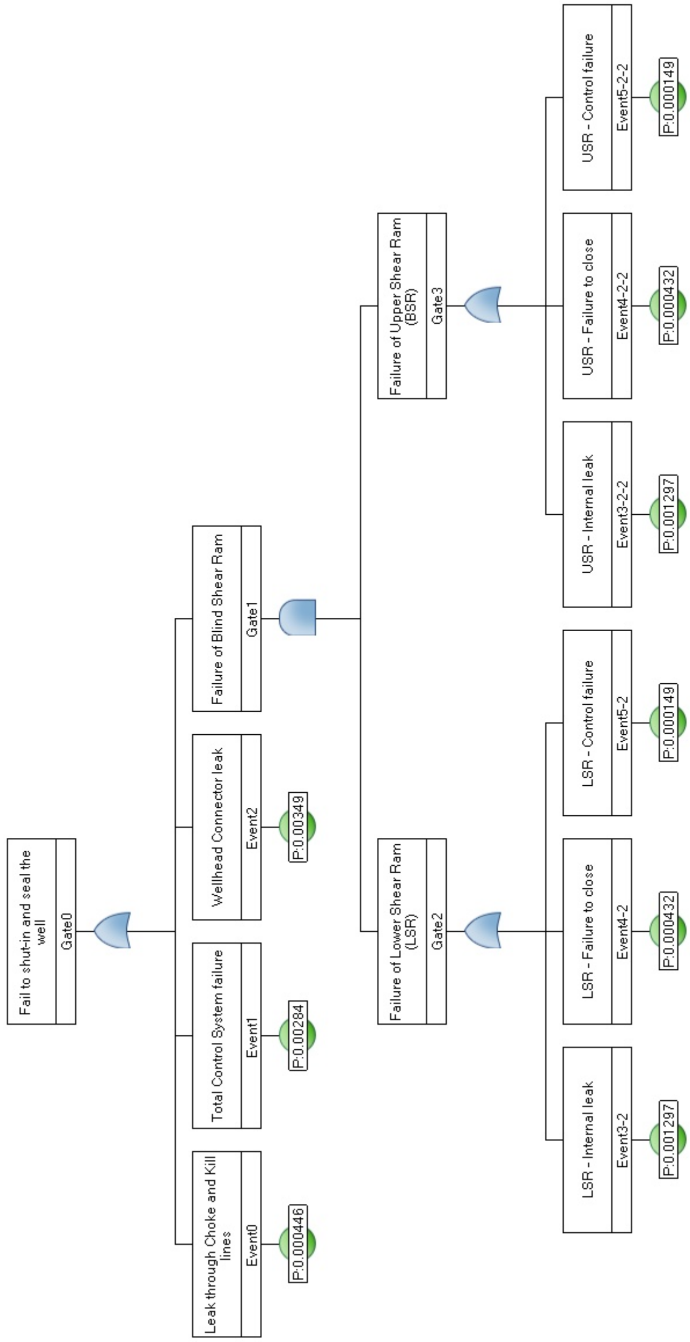

Figure 21: Two Blind Shear Rams – Open Hole (DNV Figure III-1). Probability of failure is 0.86%.

Two Blind Shear Rams – Drill Pipe through BOP

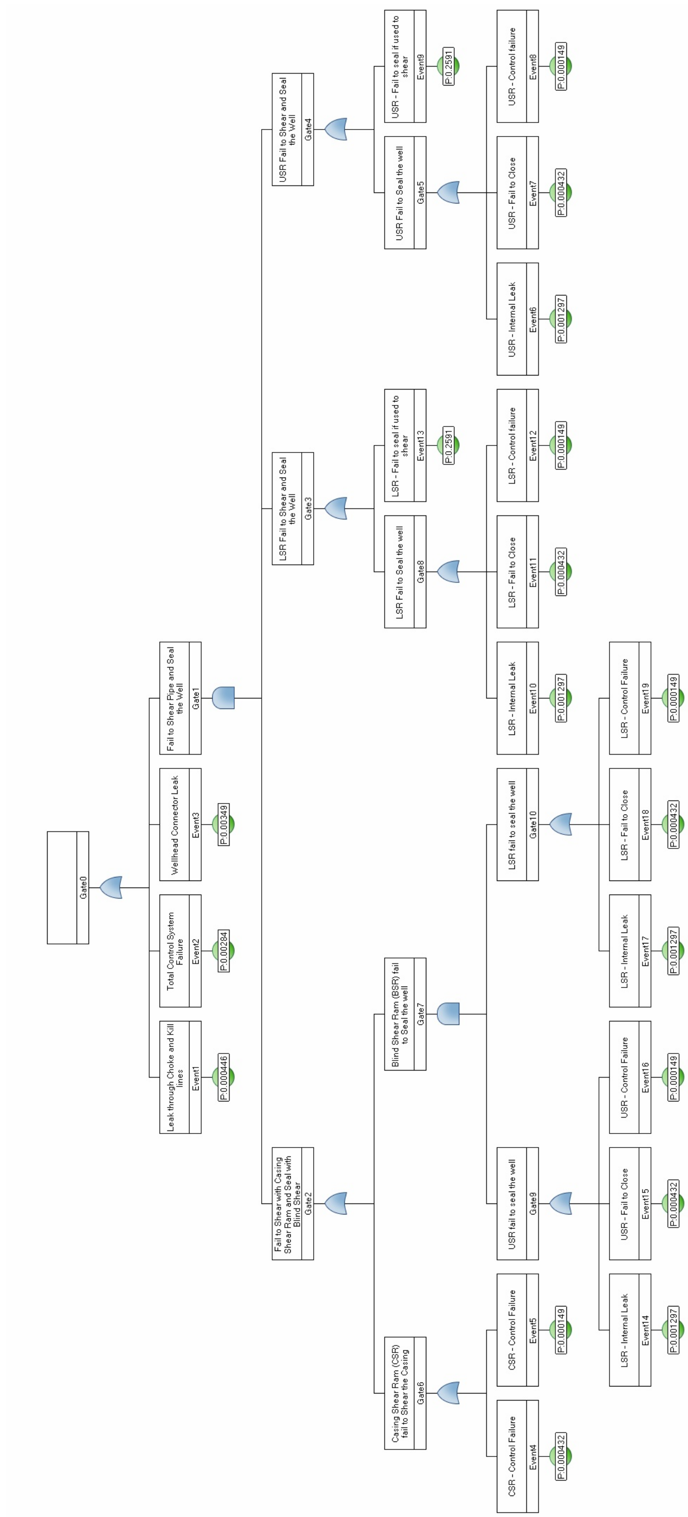

Figure 22: Two Blind Shear Rams – Drill Pipe through BOP (DNV Figure III-2). Probability of failure is 0.68%.

Two Blind Shear Rams – Casing through BOP

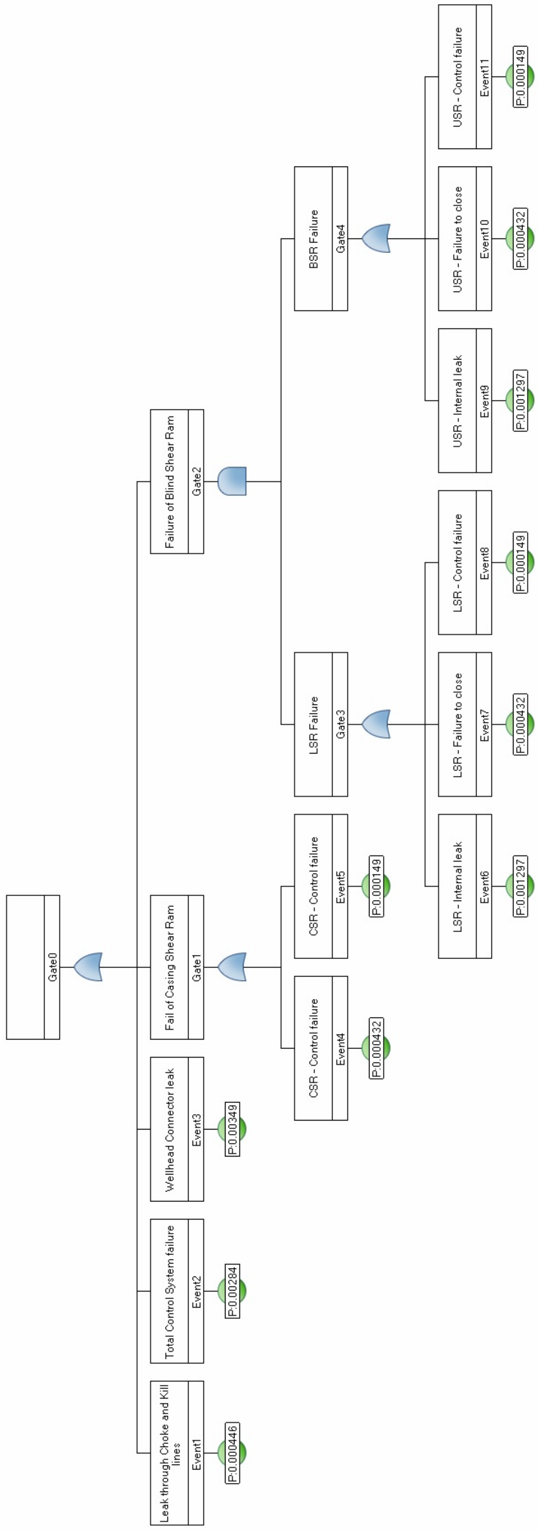

Figure 23: Two Blind Shear Rams – Casing through BOP (DNV Figure III-3). Probability of failure is 0.73%.

Single Blind Shear Ram – Open Hole

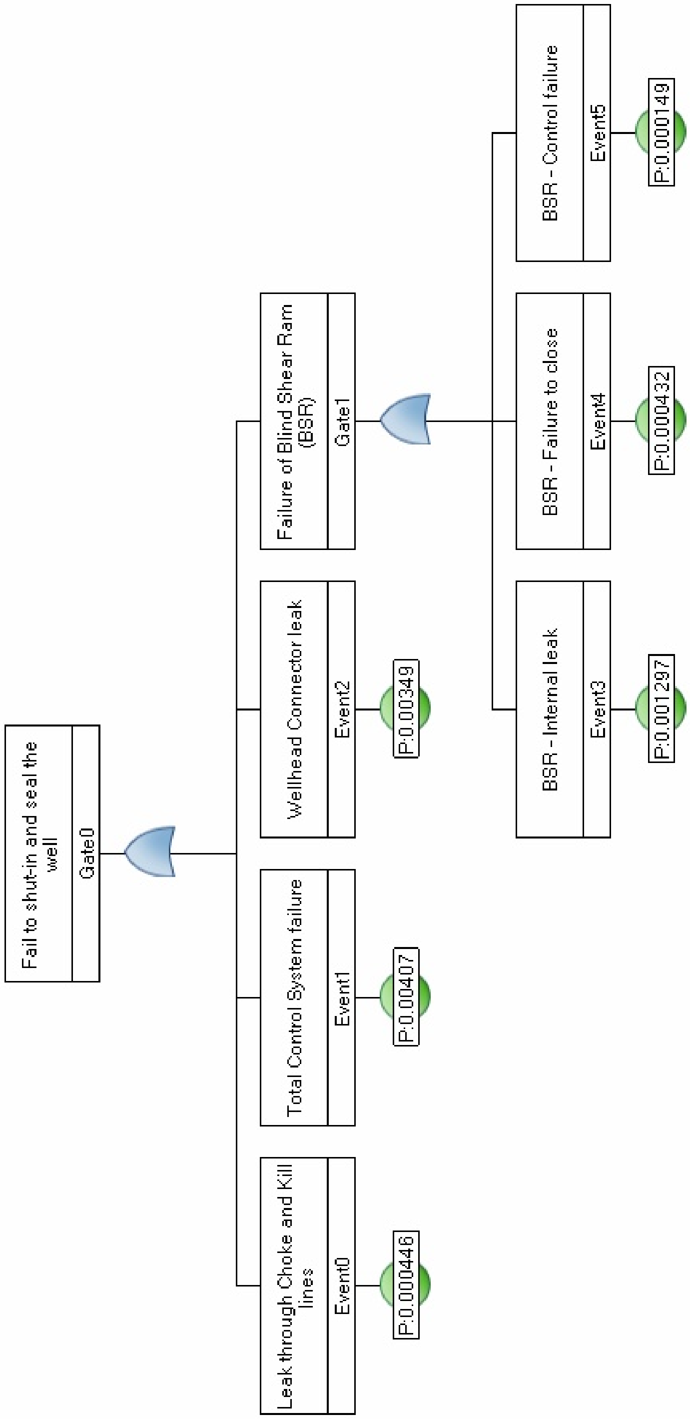

Figure 24: Single Blind Shear Ram – Open Hole (DNV Figure III-4). Probability of failure is 0.99%.

Single Blind Shear Ram – Drill Pipe through BOP

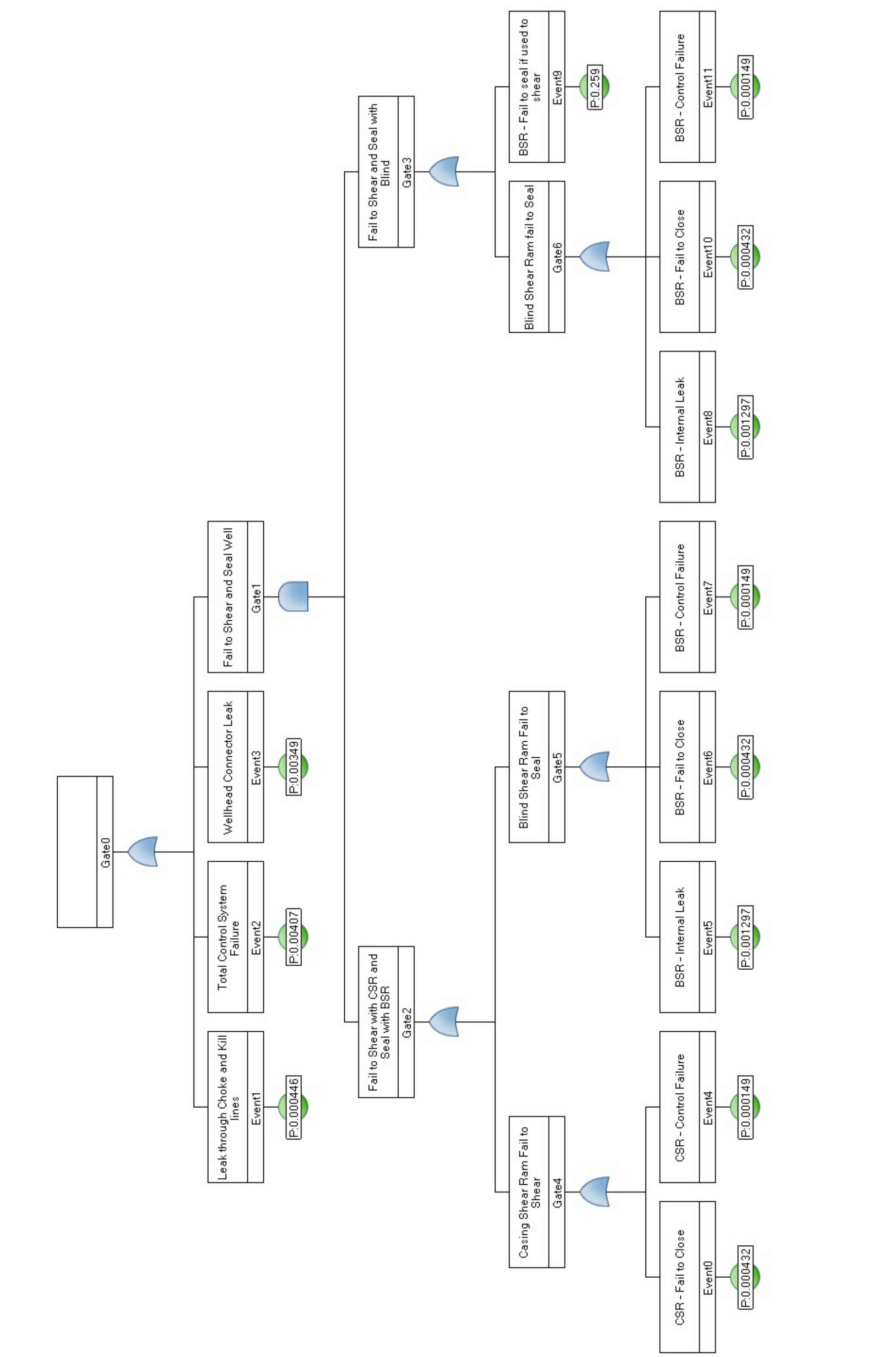

Figure 25: Single Blind Shear Ram – Drill Pipe through BP (DNV Figure III-5). Probability of failure is 0.86%. Note the error in the DNV Figure III-5. The AND gate (G1) should be simply the product of the probability of gates G2 and G3.

Single Blind Shear Ram – Casing through BOP

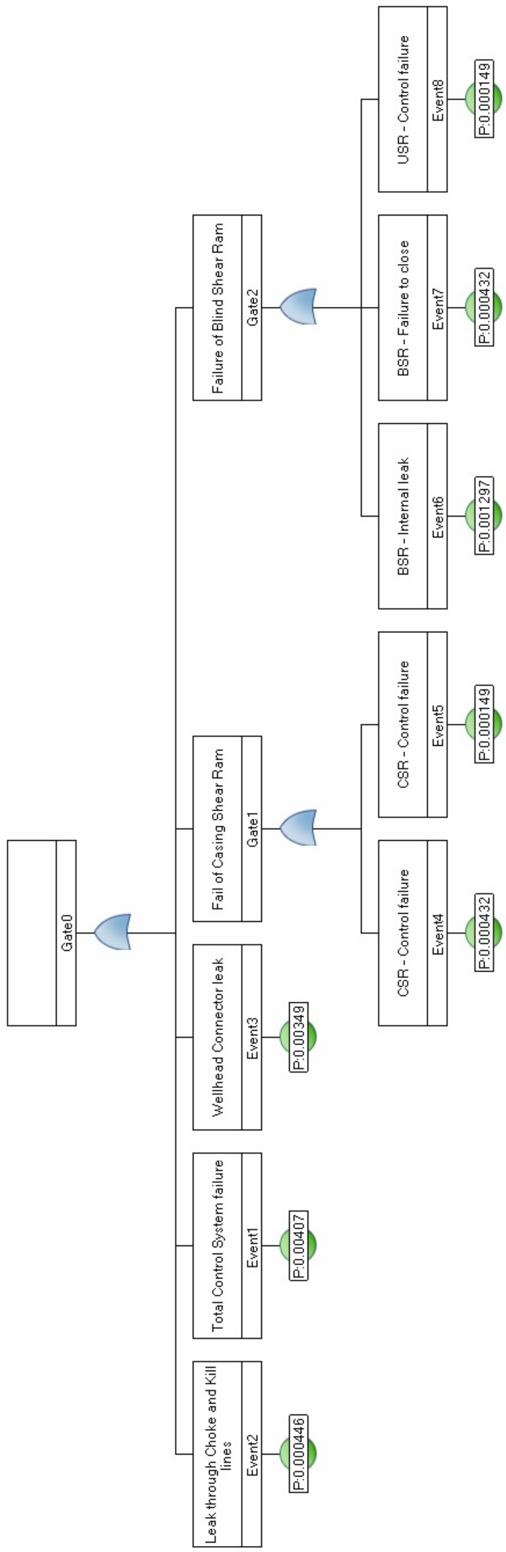

Figure 26: Single Blind Shear Ram – Casing through BP (DNV Figure III-6). Probability of failure is 1.04%.

Appendix B - Causes of Well Kick or Blowouts

A kick or blowout may result from one of the following:

- Mud weight less than formation pore pressure
- Failure to keep the hole full while tripping
- Swabbing while tripping
- Lost circulation
- Mud cut by gas, water, or oil

Mud Weighs Less

There has been an emphasis on drilling with mud weights very near to and, in some instances, below formation pore pressures in order to maximize penetration rates. It has been a practice in some areas to take a kick to determine specific pore pressures and reservoir fluid composition.

Failure to Keep the Hole Full While Tripping and Swabbing

Failure to keep the hole full and swabbing is one of the most frequent causes of well control problems in drilling. Swabbing is used to reduce pressure in a wellbore by moving pipe, wireline, tools or rubber-cupped seals up the wellbore. If the pressure is reduced sufficiently, reservoir fluids may flow into the wellbore and towards the surface. Swabbing is generally considered harmful in drilling operations, because it can lead to kicks and wellbore stability problems. Tripping is the operation of hoisting the drill stem out of and returning it to the wellbore

Lost Circulation

If returns are lost, the resulting loss of hydrostatic pressure will cause any permeable formation containing greater pressures to flow into the wellbore. If the top of the drilling fluid is not visible from the surface, as is the case in many instances, the kick may go unnoticed for some time. This can result in an extremely difficult well control situation

Mud Cut by Gas, Water or Oil

Gas-cut mud has always been considered a warning signal, but not necessarily a serious problem. Calculations demonstrate that severely gas-cut mud causes modest reductions in bottom-hole pressures because of the compressibility of the gas. An incompressible fluid such as oil or water can cause more severe reductions in total hydrostatic and has caused serious well control problems when a productive oil or gas zone is present.

Indications of Well Kick

Early warning signals are as follows:

- Sudden increase in drilling rate
- Increase in fluid volume at the surface, which is commonly, termed a pit level increase or an increase in flow rate
- Change in pump pressure
- Reduction in drill pipe weight
- Gas, oil, or water-cut mud.

When any of these warning signals are observed, the crew must immediately proceed with the established shut-in procedure.

Well Control Procedures

The Driller's Method was the first and most popular displacement procedure. With the advent of pressure control technology, the necessity of spreading that technology presented an awesome task. Simplicity was in order and the classic Driller's Method for displacing the influx from the wellbore without permitting additional influx was developed. The crew proceeded immediately to displace the influx. The required calculations were not difficult. The calculations were made, the kill-weight mud was easily displaced, and the drilling operation was resumed. One disadvantage of the Driller's Method is that at least two circulations are required to control the well.

The Wait and Weight Method is slightly more complicated but offers some distinct advantages. First, the well is killed in half the time. Modern mud-mixing facilities permit barite to be mixed at rates up to 600 sacks per hour with dual mixing systems; therefore, time required to weight up the suction pit is minimized and kill rate is not penalized. The Wait and Weight Method results in kill mud reaching the well sooner, and that is always an advantage.

Electrical Activation

An electrical cable or an optical fiber cable is used to send a signal down the drill string to activate the BOP.

ROV Activation

Figure 27: A robotic arm of a Remotely Operated Vehicle (ROV) attempts to activate the "Deepwater Horizon" Blowout Preventer (BOP), Thursday, April 22, 2010.

Activation Issues

Reviewing documents with respect to issues that may arise that would lead to a failure in activating a BOP, the following failure modes were identified:

- Flat battery in the BOP's control pod
- Hardware modifications that would lead to an increase risk of BOP failure
- Junction in the drilling pipe may have been positioned in the BOP stack in such way that its shear rams had an insurmountable thickness of material to cut through
- Debris (for example, a second piece of tubing) in the BOP stack
- Loss of riser (estimated to be 7% – 8%[14])

The riser is a special pipe which ensures the link between the drillship and the blow-out preventers located at the sea bed in order to provide a path for the mud return and a guide for the re-entry of the drill string in the well upon drilling. If the riser is lost, drilling IS no longer possible and two types of consequences have

[14] *J. P. Signoret and A. Leroy, "The 1800 m Water Depth Drilling Project: Risk Analysis," Reliability Engineering 11 (1985) 83-92.*

to be taken into consideration if no spare riser is available. The drilling is stopped but the companies have to pay for the drillship until the renting contract is over. If the riser loss is due to blow-out, the drilling of a relief well may be needed in order to stop the blow-out, and a riser is necessary to achieve that!

It is not very easy to make the decision of investing in a spare riser since it is a very expensive piece of equipment.

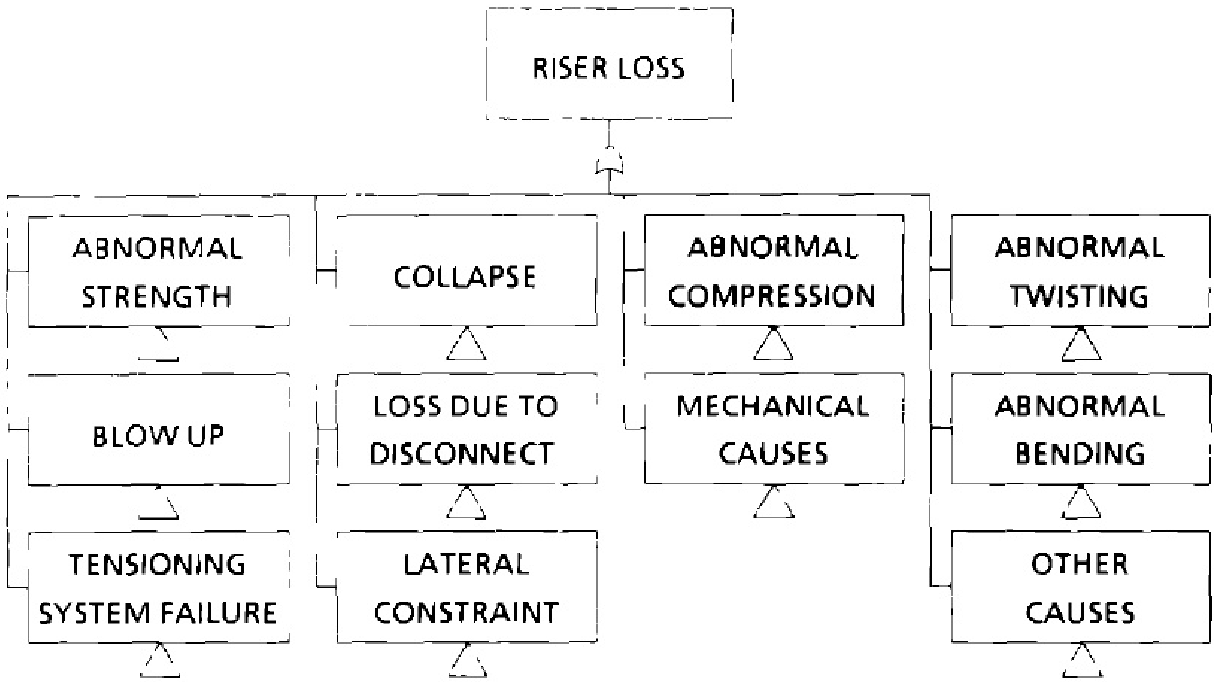

Fig. 1. Riser-loss causes

Figure 28: Riser Loss Causes[15]

[15] *J. P. Signoret and A. Leroy, "The 1800 m Water Depth Drilling Project: Risk Analysis," Reliability Engineering 11 (1985) 83-92.*

BOP Control Systems

The regulations are based on the use of a redundant (two) control system package. Shown in Figure 29 is a typical BOP Control System layout.

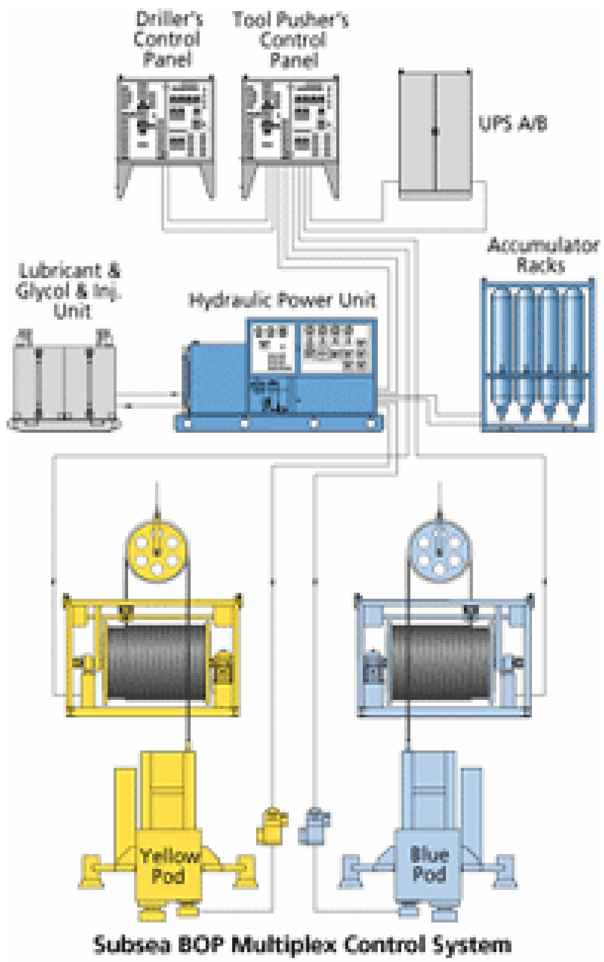

Figure 29: Schematic of a typical BOP Control System Layout.

Appendix C - Terminology

Choke Line

The Choke Line is a high-pressure pipe leading from an outlet on the BOP stack to the back pressure choke and associated manifold. During well-control operations, the fluid under pressure in the wellbore flows out of the well through the choke line to the choke, reducing the fluid pressure to atmospheric pressure. In floating offshore operations, the choke and kill lines exit the subsea BOP stack and then run along the outside of the drilling riser to the surface. The volumetric and frictional effects of these long choke and kill lines must be considered to control the well properly.

Kill Line

A high-pressure pipe leading from an outlet on the BOP stack to the high-pressure rig pumps. During normal well control an operation, kill fluid is pumped through the drill string and annular fluid is taken out of the well through the choke line to the choke, which drops the fluid pressure to atmospheric pressure. If the drill pipe is inaccessible, it may be necessary to pump heavy drilling fluid in the top of the well, wait for the fluid to fall under the force of gravity, and then remove fluid from the annulus. In such an operation, while one high pressure line would suffice, it is more convenient to have two. In addition, this provides a measure of redundancy for the operation.

Dead Man's Switch

A blowout preventer has several mechanisms designed to shut it in an emergency -- including one known as a "dead man's switch." It is designed to automatically cut the pipe and seal the well if communication from the platform is lost.

Secondary BOP control systems (often referred to as Dead-Man / Auto Shear) are to be required for all floating drilling rigs. A White paper from the Joint Industry Task Force[16] proposes that these systems are to be automatically activated if either of the situations below occurs:

1. Unintended disconnect of the lower marine riser package (LMRP).
2. Loss of surface control of the subsea BOP stack.

When activated, the BOP must automatically perform the following functions as a minimum:

- Close the blind / shear ram(s).
- Ensure closure of choke / kill line valves.

The secondary BOP system shall be armed when BOP stack is latched on the wellhead. Disarming and rearming the system shall only be performed through a formalized Management of Change approval process.

[16] *White Paper: Recommendations for Improving Offshore Safety, Joint Industry Task Force to Address Offshore Operating Procedures and Equipment.*

Acoustic Backup Discussion

When electrical and hydraulic connection with the well head is lost, an acoustic backup system, if installed, can be used to communicate with the BOP system. The acoustic communication system cannot deal with any other problems, for example; loss of pressure in the BOPs accumulators, loss of BOP battery power, etc. An extensive search for reliability data on Acoustic Backup Systems did not yield any quantitative data.

Appendix D - Down-hole Blowout Preventer Technology Overview

Blowout preventers (BOPs) are used to control blowout. The crew usually installs several blowout preventers (BOP stack) on top of the well, with an annular blowout preventer at the top and at least one pipe ram and one blind ram blowout preventer below. Also, some well control techniques require both the annular and the ram blowout preventers.

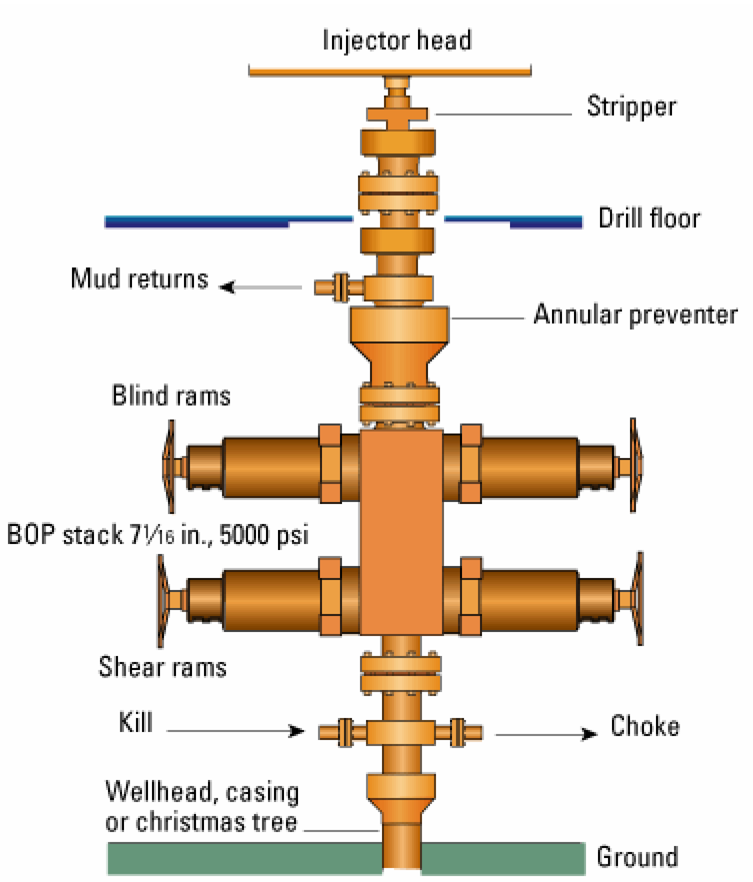

Figure 30: Blowout preventer. This BOP configuration is typical for a well drilled with a hole size greater than 4-in. diameter. (Courtesy: http://www.glossary.oilfield.slb.com).

Annular Blowout Preventer

An annular blowout preventer has a rubber sealing element that, when activated, seals the annulus between the kelly, the drill pipe, or the drill collar. If no part of the drill stem is in the hole, the annular blowout preventer closes on the open hole.

Hydraulic pressure applied to the closing chamber raises the piston forcing the packing unit into a sealing engagement. Wellbore pressure (or test pressure) acting on the piston from below the sealed off packing unit further increases the closing force. Drill pipe can be rotated and tool joints stripped through a closed packing unit while maintaining a full seal on the pipe. Typically annular blowout preventers have a separate pressure regulator valve with sufficient accumulator volume. The hydraulic operating fluid may be clean, light petroleum hydraulic oil, or water with a water soluble oil added. In cold climates, anti-freeze is added to prevent freezing. The closing time of the preventer is determined by the rate at which the hydraulic fluid can be delivered to the closing chamber. Minimum closing time is achieved by:

- Using short, large diameter control lines,
- Large bore control valves, and
- A large accumulator volume.

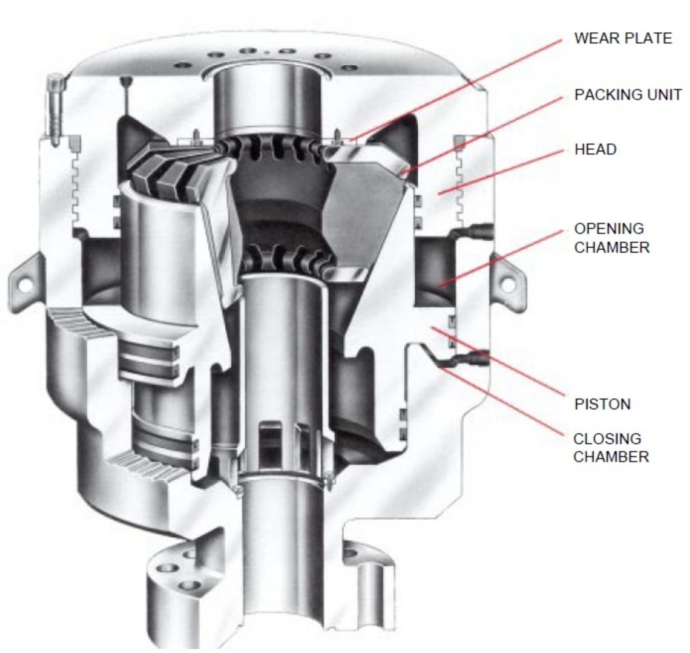

Figure 31: Cross-Section of an Annular Blowout Preventer

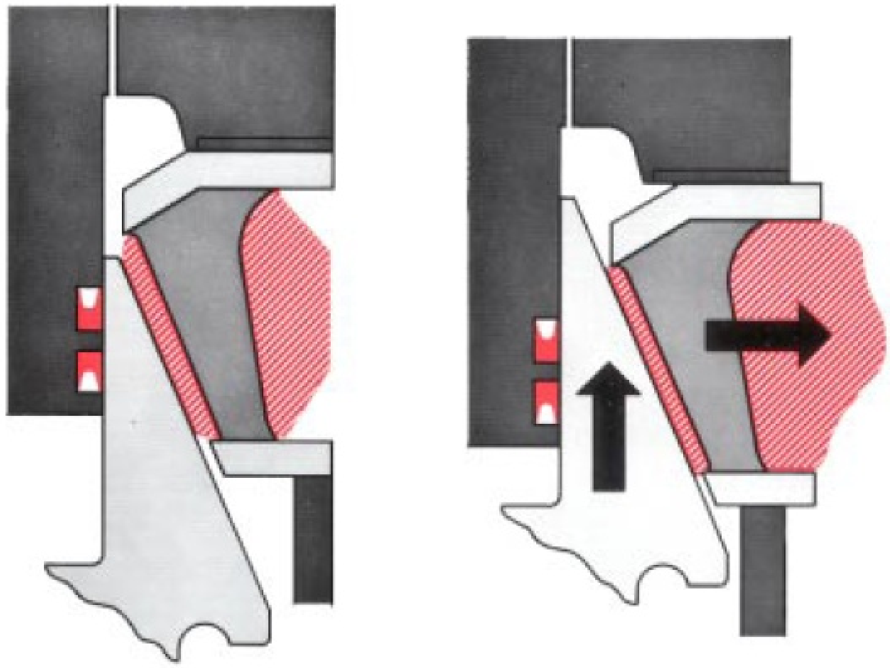

Figure 32: Operation of an Annular Blowout Preventer. Upward force exerted by the piston squeezes packing unit rubber inward into a sealing engagement.

Ram-Type Blowout Preventer

A ram-type BOP is similar in operation to a gate valve, but uses a pair of opposing steel plungers, rams. The rams extend toward the center of the wellbore to restrict flow or retract open in order to permit flow. The inner and top faces of the rams are fitted with packers (elastomeric seals) that press against each other, against the wellbore, and around tubing running through the wellbore. Rams, or ram blocks, are of four common types: pipe, blind, shear, and blind shear.

Pipe Rams

Pipe rams close around a drill pipe, restricting flow in the annulus (ring-shaped space between concentric objects) between the outside of the drill pipe and the wellbore, but do not obstruct flow within the drill pipe. Variable-bore pipe rams can accommodate tubing in a wider range of outside diameters than standard pipe rams, but typically with some loss of pressure capacity and longevity. Pipe ram blowout preventers cannot seal an open hole.

In addition to the standard ram functions, variable-bore pipe rams are frequently used as test rams in a modified blowout preventer device known as a stack test valve. Stack test valves are positioned at the bottom of a BOP stack and resist downward pressure (unlike BOPs, which resist upward pressures). By closing the test ram and a BOP ram about the drill string and pressurizing the annulus, the BOP is pressure-tested for proper function.

Blind Rams

Blind rams (also know as sealing rams), which have no openings for tubing, can close off the well when the well does not contain a drill string or other tubing, and seal it.

Shear Rams

Shear rams cut through the drill string or casing with hardened steel shears.

Blind Shear Rams

Blind shear rams (also known as shear seal rams, or sealing shear rams) are intended to seal a wellbore, even when the bore is occupied by a drill string, by cutting through the drill string as the rams close off the well. The upper portion of the severed drill string is freed from the ram, while the lower portion may be crimped and the "fish tail" captured to hang the drill string off the BOP.

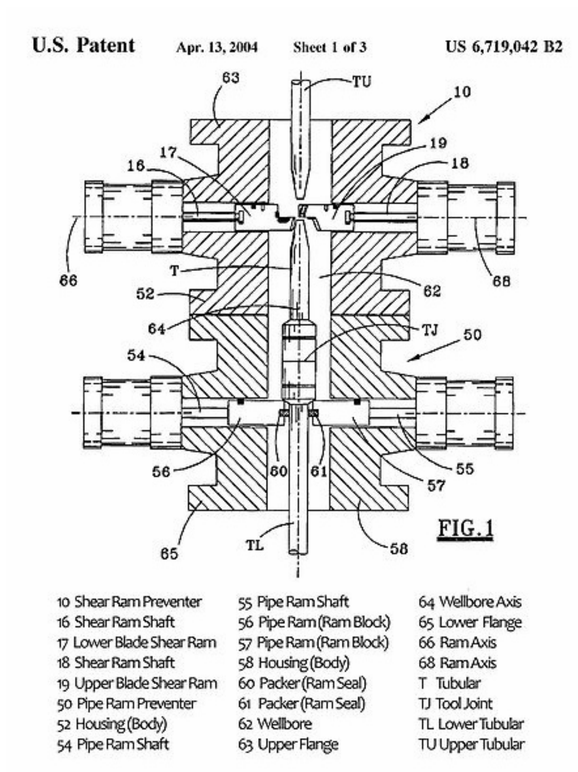

Figure 33: Figure 1 from US Patent 6,719,042. A shear ram BOP has cut the drill string and the pipe is hanging of a pipe ram.

Figure 34: A double Ram Blowout Preventer.

BOP Control Systems

Figure 35: A BOP Control System.

Prior to 1960, the most common method of well control was known as the Constant Pit Level Method or the Barrel In-Barrel Out Method. However, it was realized that if the influx was anything other than water, this method would be catastrophic. Consequently, classical pressure control procedures were developed.

Appendix E – Controlled Incidents in the SINTEF Database

The SINTEF database was scanned and incidents where well releases were controlled are reported in Table 17.

Table 17: List of Controlled Incidents from 1/1/1980 to 12/31/2007.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
2/19/1981	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	75	JACKET	DEV.DRLG
1/7/1982	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	66	JACKET	DEV.DRLG
4/14/1982	Well release	Limited surface flow before the secondary barrier was activated	UK	95	SEMISUBM ERSIBLE	DEV.DRLG
5/14/1982	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	103	JACKET	DEV.DRLG
6/3/1982	Well release	String blown out of well, then the secondary barrier	NORWAY	71	JACKET	WORKOVER
10/19/1982	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	168	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
12/17/1982	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	41	JACKET	WORKOVER
4/9/1983	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	62	JACKUP	EXPL.DRLG APPRAISAL
5/13/1983	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	33	JACKET	DEV.DRLG
6/28/1983	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	43	JACKET	WIRELINE
7/16/1983	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	335	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
10/10/1983	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	72	JACKUP	EXPL.DRLG WILDCAT
1/4/1984	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	90	JACKUP	EXPL.DRLG WILDCAT

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
6/11/1984	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	25	JACKET, JACKUP	WORKOVER
6/29/1984	Well release	Other	NORWAY	273	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
11/10/1984	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	137	JACKET	DEV.DRLG
4/2/1985	Diverted well release	Shallow gas controlled flow (diverted)	NORWAY	256	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
4/13/1985	Unknown	Unknown	UK	50	JACKUP	EXPL.DRLG APPRAISAL
12/23/1985	Well release	Limited surface flow before the secondary barrier was activated	UK	110	JACKET	DEV.DRLG
5/6/1987	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	18	SATELLITE	COMPLETION
9/6/1987	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	30	JACKET, JACKUP	WORKOVER
3/30/1989	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	90	JACKET	DEV.DRLG
5/6/1989	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	69	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
8/3/1989	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	14	SATELLITE	WORKOVER
8/7/1989	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	136	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
9/16/1989	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	190	JACKET	DEV.DRLG
4/30/1990	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	153	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
5/10/1990	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	25	UNKNOWN	DEV.DRLG
6/13/1990	Well release	String blown out of well, then the secondary	US/GOM OCS	59	JACKET	WORKOVER

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
		barrier				
10/9/1990	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	64	JACKET	WORKOVER
10/23/1990	Well release	Other	US/GOM OCS	150	JACKET	DEV.DRLG
6/4/1991	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	64	JACKET	DEV.DRLG
8/25/1991	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	190	JACKET	DEV.DRLG
9/2/1991	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	68	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
10/4/1991	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	536	TENSION LEG	WORKOVER
11/13/1991	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	145	JACKET	DEV.DRLG
1/21/1993	Well release	String blown out of well, then the secondary barrier	NORWAY	70	JACKET	DEV.DRLG
1/15/1994	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	331	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
3/15/1994	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	50	JACKET, JACKUP	WORKOVER
4/4/1994	Well release	Limited surface flow before the secondary barrier was activated	UK	140	JACKET	WIRELINE
10/11/1994	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	72	JACKUP	EXPL.DRLG WILDCAT
5/6/1995	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	145	JACKET	WORKOVER
7/1/1995	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKUP	COMPLETION
7/1/1995	Well release	Limited surface flow before the secondary barrier was activated	UK	0	TENSION LEG	WORKOVER

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
1/10/1997	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	103	JACKUP	EXPL.DRLG WILDCAT
1/21/1997	Diverted well release	Shallow gas controlled flow (diverted)	NORWAY	81	JACKUP	EXPL.DRLG APPRAISAL
3/4/1997	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	88	JACKET	DEV.DRLG
7/1/1997	Well release	Limited surface flow before the secondary barrier was activated	UK	0	SEMISUBM ERSIBLE	WORKOVER
7/1/1997	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKUP	COMPLETION
8/21/1997	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	57	JACKUP	WORKOVER
10/20/1997	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	64	JACKET	DEV.DRLG
12/12/1997	Diverted well release	Shallow gas controlled flow (diverted)	NORWAY	69	JACKUP	EXPL.DRLG WILDCAT
4/30/1998	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	198	JACKET	DEV.DRLG
7/1/1998	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKUP	UNKNOWN DRLG
12/4/1998	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	135	SEMISUBM ERSIBLE	DEV.DRLG
12/9/1998	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	7	JACKET	COMPLETION
8/11/1999	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	64	UNKNOWN	DEV.DRLG
12/5/1999	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	64	UNKNOWN	DEV.DRLG
4/5/2000	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	350	TENSION LEG	COMPLETION
8/15/2000	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	26	JACKUP	EXPL.DRLG WILDCAT

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
4/2/2001	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	73	JACKET, JACKUP	WORKOVER
4/4/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	17	JACKET	WORKOVER
5/24/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	11	JACKET	WIRELINE
5/27/2001	Well release	Limited surface flow before the secondary barrier was activated	UK	94	JACKET	WIRELINE
7/1/2001	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKET	WORKOVER
7/1/2001	Well release	Limited surface flow before the secondary barrier was activated	UK	0	SEMISUBM ERSIBLE	EXPL.DRLG
10/24/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	454	TENSION LEG	COMPLETION
11/21/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	393	UNKNOWN	DEV.DRLG
12/23/2001	Well release	Limited surface flow before the secondary barrier was activated	UK	69	SEMISUBM ERSIBLE	COMPLETION
1/12/2002	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	47	JACKET	WORKOVER
12/6/2002	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	39	JACKET	PRODUCTION
4/12/2003	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	60	JACKET	PRODUCTION
4/22/2003	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	46	JACKUP, JACKET	DEV.DRLG
12/2/2003	Well release	Limited surface flow before the secondary barrier was activated	UK	139	JACKET	COMPLETION

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
12/4/2003	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	17	SATELLITE	WIRELINE
10/21/2004	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	1175	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
12/18/2004	Well release	Limited surface flow before the secondary barrier was activated	UK	0	SEMISUBM ERSIBLE	WORKOVER
5/28/2005	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	33	JACKUP, JACKET	DEV.DRLG
11/30/2005	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	72	JACKET, JACKUP	DEV.DRLG
12/1/2005	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	35	JACKUP	EXPL.DRLG APPRAISAL
2/20/2006	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	30	JACKET	WORKOVER
4/23/2006	Diverted well release	Shallow gas controlled flow (diverted)	NORWAY	81	JACKUP	EXPL.DRLG APPRAISAL
3/14/2007	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	12	BARGE	WORKOVER
3/16/2007	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	16	JACKUP	WORKOVER
7/1/2007	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKUP	DEV.DRLG
7/1/2007	Well release	Limited surface flow before the secondary barrier was activated	UK	0	SUBSEA PROD	PRODUCTION
7/1/2007	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKET	WORKOVER
7/1/2007	Well release	Limited surface flow before the secondary barrier was activated	UK	0	JACKET	WORKOVER
12/3/2007	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	5	JACKUP	WORKOVER

Key characteristics of these 89 incidents are reported in Table 18.

Table 18: Summary of Incidents from 1/1/1980 to 12/31/2007.

Installation Type	No.	Country	No.	Type of Event	No.	Phase	No.	Description	No.
Drillship	0	Canada East	0	Diverted Well Release	30	Work over	24	Limited surface flow before the secondary barrier was activated	47
Semisubmersible	16	UK	19	Unknown	1	Production	3	Shallow gas controlled flow (diverted)	30
Jack-up / Jacket	73	Norway	16	Well Release	58	Wireline	5	String blown out of well, then the secondary barrier	9
		US GoM OCS	54			EXP/DEV	57	Other/Unknown	3
Total	89		89		89		89		89

Number of incidents at water depths greater than 100 meters was 25.

Table 19: List of Incidents at Water Depths > 100 meters from 1/1/1980 to 12/31/2007.

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
5/14/1982	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	103	JACKET	DEV.DRLG
10/19/1982	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	168	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
7/16/1983	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	335	SEMISUBMERSIBLE	EXPL.DRLG APPRAISAL
6/29/1984	Well release	Other	NORWAY	273	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT
11/10/1984	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	137	JACKET	DEV.DRLG

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
4/2/1985	Diverted well release	Shallow gas controlled flow (diverted)	NORWAY	256	SEMISUBM ERSIBLE	EXPL.DRLG WILDCAT
12/23/1985	Well release	Limited surface flow before the secondary barrier was activated	UK	110	JACKET	DEV.DRLG
8/7/1989	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	136	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
9/16/1989	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	190	JACKET	DEV.DRLG
4/30/1990	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	153	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
10/23/1990	Well release	Other	US/GOM OCS	150	JACKET	DEV.DRLG
8/25/1991	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	190	JACKET	DEV.DRLG
10/4/1991	Well release	String blown out of well, then the secondary barrier	US/GOM OCS	536	TENSION LEG	WORKOVER
11/13/1991	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	145	JACKET	DEV.DRLG
1/15/1994	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	331	SEMISUBM ERSIBLE	EXPL.DRLG APPRAISAL
4/4/1994	Well release	Limited surface flow before the secondary barrier was activated	UK	140	JACKET	WIRELINE
5/6/1995	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	145	JACKET	WORKOVER
1/10/1997	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	103	JACKUP	EXPL.DRLG WILDCAT
4/30/1998	Diverted well release	Shallow gas controlled flow (diverted)	US/GOM OCS	198	JACKET	DEV.DRLG
12/4/1998	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	135	SEMISUBM ERSIBLE	DEV.DRLG
4/5/2000	Well release	Limited surface flow before the secondary barrier was activated	NORWAY	350	TENSION LEG	COMPLETION

Event Date	Type of Event	Description	Country	Water Depth (m)	Installation Type	Phase Type
10/24/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	454	TENSION LEG	COMPLETION
11/21/2001	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	393	UNKNOWN	DEV.DRLG
12/2/2003	Well release	Limited surface flow before the secondary barrier was activated	UK	139	JACKET	COMPLETION
10/21/2004	Well release	Limited surface flow before the secondary barrier was activated	US/GOM OCS	1175	SEMISUBMERSIBLE	EXPL.DRLG WILDCAT

Key characteristics of these 25 incidents are reported in Table 20.

Table 20: Summary of Incidents at Water Depths > 100 meters from 1/1/1980 to 12/31/2007.

Installation Type	No.	Country	No.	Type of Event	No.	Phase	No.	Description	No.
Drillship	0	Canada East	0	Diverted Well Release	9	Work over	2	Limited surface flow before the secondary barrier was activated	13
Semisubmersible	9	UK	3	Unknown	0	Production	0	Shallow gas controlled flow (diverted)	9
Jack-up (1) / Jacket (15)	16	Norway	9	Well Release	16	Wireline	1	String blown out of well, then the secondary barrier	1
		US GoM OCS	13			EXP/DEV	22	Other/Unknown	2
Total	25		25		25		25		25

Appendix F – Details of the Blowouts where Safety Systems failed resulting in Totally Uncontrolled Flow from a Deep Zone

The details were copied verbatim from Appendix II of the DNV report.

February 22, 1984 - Vinland Blowout Notes

References: Oil & Gas Journal, July 16, 1984: http://www.ec.gc.ca/ee-ue/default.asp?lang=en&n=36857FD2

Loss of initial barrier = casing plug failure (HP zone isolating bridge plug broke at 5200 m).

Loss of secondary barrier = failed to close BOP (obstruction in BOP, then not enough power to cut, then acoustic close failed).

Human error = Waited too long to close BOP.

A plug was set to isolate the HP zone. Pit gain was observed, but BOP was not closed immediately. Attempt to close annular failed because wellhead wear bushing was blown in BOP. Increased well flow heaved the rotary table which cut coolant and air supply, and rig power was lost. An attempt was made to cut pipe with B/S ram, but there was not enough power. Acoustic closure failed because the transducer was on the pontoon, or there was not enough pressure on subsea acc. Initial well flows were estimated to be two million cubic meters/day of gas and 48 cubic meters/day of condensate.

September 14, 1984 - Zapata Lexington Blowout Notes

References: http://www.gomr.mms.gov/PDFs/1986/86-0101.pdf (MMS Investigation Report)

Loss of initial barrier = Hydrostatic head too low (trapped gas).

Loss of secondary barrier = failed to close BOP (hydraulic lines severed by explosion).

Human error = Lack of experience.

(No additional notes presented as the official investigation report is referenced.)

January 29, 1985 - Rowan Midland Blowout Notes

References: (no additional references found.)

Loss of initial barrier = Hydrostatic head too low.

Loss of secondary barrier = diverter failed after closure.

Human error = (nothing mentioned)

The diverter closed when the well started to flow, but line parted 45 ft from the end. Both annulars closed. The rig air line broke. Closed air valve at compressor, which caused loss of accumulator pressure. The subsea BOP annular preventers and the diverter reopened, and the well flowed. Unaware that the accumulator pressure was lost, closure of pipe rams was attempted. Repaired air line leaked gas until drill pipe could be stripped into the hole alongside the sheared pipe and well could be killed properly.

February 28, 2000 - Diamond Ocean Concord Blowout Notes

References: http://www.gomr.mms.gov/PDFs/2001/2001-005.pdf (MMS Investigation Report)

Loss of initial barrier = Hydrostatic head too low (accidental LMRP disconnect).

Loss of secondary barrier = Lost control of BOP.

Human error = Accidentally activated LMRP disconnect.

(No additional notes presented as the official investigation report is referenced.)

September 7, 2002 - Diamond Ocean Ambassador Blowout Notes

References: http://www.mms.gov/incidents/blow2002.htm (MMS Investigation Report)

Loss of initial barrier = Hydrostatic head too low (gas cut mud).
Loss of secondary barrier = Poor cement.
Human error = (nothing mentioned)

(No additional notes presented as the official investigation report is referenced.)