APPENDIX F

Spill Probability Assessment (SL Ross 2017)

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Spill Probability Assessment for Nexen Energy ULC Flemish Pass Exploration Drilling Environmental Assessment

For:

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EXECUTIVE SUMMARY

Nexen Energy ULC (Nexen) is proposing to drill up to ten exploration wells within Exploration Licenses 1144 and 1150, in the Flemish Pass region off the east coast of Newfoundland and Labrador. The probability and frequency of blowout and batch spills that may result from this activity were calculated based on a review of national and international records of historical offshore spill events.

The calculated oil spill probabilities and frequencies for the Nexen Flemish Pass exploration drilling project, expressed on a per well drilled basis, are summarized below:

Event	Spill Probability (spills per well drilled)	Spill Frequency
Blowout (All Types)[1]		
Deep blowout during exploration drilling	3.10×10^{-4}	1 per 3,226 wells
Blowout Resulting in Large Spill[2]		
Extremely Large (> 150,000 bbl)	3.92×10^{-5}	1 per 25,510 wells
Very Large (> 10,000 bbl)	7.84×10^{-5}	1 per 12,755 wells
Large (> 1,000 bbl)	9.80×10^{-5}	1 per 10,204 wells
Non-Blowout Batch Spill of Petroleum[3]		
Large (> 1,000 bbl)	6.33×10^{-5}	1 per 15,787 wells
Medium (50 to 999 bbl)	3.34×10^{-3}	1 per 298 wells
Small (1 to 49.9 bbl)	1.45×10^{-2}	1 per 69 wells
Very Small (<1 bbl)	1.50	1 per 0.67 wells
Synthetic-Based Mud Spills[4]		
Large (> 1,000 bbl)	-	-
Medium (50 to 999 bbl)	2.33×10^{-2}	1 per 2,100 wells
Small (1 to 49.9 bbl)	8.33×10^{-2}	1 per 12 wells
Very Small (<1 bbl)	0.17	1 per 5.9 wells

The highest frequencies are for the smaller, operational spills. Spills less than one barrel in size may occur one to two times per well, based on recent petroleum development experience off Newfoundland. Although these smaller spills may occur more often, the median volume is only 4 litres. Historical spill records for *very small* spills do not differentiate between production and exploration activities, and so the probability for *very small* spills may be overestimated for the proposed exploration drilling project.

Batch oil spills during exploration drilling that are larger than one barrel but less than 50 barrels have about a 1-in-70 chance of occurring per well. Oil spills in the 50 to 999 bbl range may have about a 1-in-300 chance of occurring per well, based on experience in the U.S. Outer Continental Shelf (OCS).

[1] Based on exploration wells drilled to North Sea Standard, 1985 to 2005.
[2] Based on world-wide blowout spills from exploration drilling, all time.
[3] *Large* and *medium* spill data based on U.S. OCS exploration drilling, 1980 to 2011; *small* spill data based on Newfoundland and Labrador exploration and delineation drilling, 2000 to 2016; *very small* spill data based on Newfoundland and Labrador exploration, delineation and production drilling, 2000 to 2016.
[4] Based on Newfoundland and Labrador exploration, delineation and production drilling, 1997 to 2016.

There is about a 1-in-3,200 chance per well of having any sort of blowout. (i.e., primarily liquid or primarily gas) during normal drilling, after the blowout preventer is set.

The chances of an *extremely large* (>150,000 bbl), *very large* (>10,000 bbl), and *large* (>1000 bbl) oil well blowout during exploration drilling are very small: about a 1-in-25,000, 1-in-13,000 and 1-in-10,000 chance per well, respectively. Due to the infrequency of these occurrences, these predictions are based on worldwide data, and are strongly influenced by blowouts that occurred in parts of the world where drilling regulations may be less rigorous, and in most cases prior to modern safety improvements.

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1 INTRODUCTION

Nexen Energy ULC (Nexen) is proposing to drill up to ten exploration wells within Exploration Licenses 1144 and 1150, in the Flemish Pass region off the east coast of Newfoundland and Labrador. This report summarizes the estimated spill probability on a per-well basis for the exploration program, derived from national and international records of spill events. Nexen may conduct the exploratory drilling at any time of the year. It is conservatively assumed that the target reservoir(s) where the exploration wells are to be drilled will contain oil or condensate.

This study derives some spill and blowout statistics for the proposed Nexen exploration drilling program from worldwide statistics on these activities. It is assumed that the practices and technologies that will be used by Nexen during drilling will be comparable to those used in other offshore oil and gas operations around the world, and will be in accordance with the accepted practices of the international petroleum industry and comply with Canadian regulations.

Two types of environmental incidents that could occur during the exploration drilling program are blowouts and "batch" spills. Blowouts are continuous spills lasting hours, days or weeks that could involve the discharge of natural gas and crude oil or condensate into the environment. Batch spills are instantaneous or short-duration discharges of oil that could occur from accidental events on the drilling rig where fuel oil and other petroleum products are stored and handled, or during transfers between the Mobile Offshore Drilling Unit (MODU) and supply vessels. The purpose of this report is to provide estimates on the probability of both blowout and batch spills in the context of the proposed exploration drilling program.

1.1 SOURCES OF PETROLEUM RELEASES

Petroleum releases to the sea originate from many different sources, including natural seeps, runoff, and accidental releases during drilling, production, transportation and use. Compared with other endeavours that have potential for discharging petroleum oil into the marine environment, the industry of exploring, developing and producing offshore oil and gas (the offshore E&P industry) has a very good safety and environmental performance record. A comprehensive study on marine oil pollution (National Research Council (U.S.), 2002) estimated the amounts of petroleum released from the various sources of discharges (see Table 1).

The 2002 report is the most recent update in a series, with previous versions having been released in 1985 and 1975. The study indicated that accidental petroleum discharges from exploration and production platforms contributed only 0.07% of the total petroleum input to the world's oceans (0.86 thousand tonnes per year versus 1,300 thousand tonnes per year); in North America, accidental discharges from platforms were responsible for only 0.06% of the total (160 tonnes per year out of 260 thousand tonnes). As well, analysis of incident records from Newfoundland and Labrador (C-NLOPB, 2017) indicated that operational spills from exploration drilling activities have occured at a lower rate than similar spills during production activities (see Section 3.2). However, releases from petroleum exploration and production activities, while relatively small compared to other sources, are not negligible and their impact can be significant.

Table 1: Best estimate of average annual (1990 to 1999) releases of petroleum by source[5]

	North America (tonnes x 10^3)	Worldwide (tonnes x 10^3)
Natural Seeps	*160*	*600*
Extraction of Petroleum	*3*	*38*
Platforms	**0.16**	**0.86**
Atmospheric Deposition	0.12	1.3
Produced waters	2.7	36
Transportation of Petroleum	*9.1*	*150*
Pipeline Spills	1.9	12
Tank Vessel Spills	5.3	100
Operational Discharges [Cargo Washings]	NA[6]	36
Coastal Facility Spills	1.9	4.9
Atmospheric Deposition	0.01	0.4
Consumption of Petroleum	*84*	*480*
Land-Based [River and Runoff]	54	140
Recreational Marine Vessel	5.6	ND[7]
Spills [Non-Tank Vessels]	1.2	7.1
Operational Discharges [Vessels 100 GT]	0.1	270
Operational Discharges [Vessels <100 GT]	0.12	ND[8]
Atmospheric Deposition	21	52
Jettisoned Aircraft Fuel	1.5	7.5
TOTAL	*260*	*1,300*

1.2 SOURCES OF INFORMATION ON RELEASES DURING DRILLING

The Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) maintains a database of spill incidents that have occurred during drilling and production activities in Newfoundland waters. For smaller spills, there is a reasonable record of such incidents from 1997 to the present, and the historical frequency of smaller spills is used as a predictor for future events. For larger spills, there have been few such incidents, so records from other jurisdictions must be used in order to have a satisfactory sample size to calculate the probability of similar occurrences.

Statisticians at the U.S. Bureau of Ocean Energy Management (BOEM) and later the Bureau of Safety and Environmental Enforcement (BSEE) have produced a large body of literature on marine oil-spill

[5] National Research Council (U.S.), 2002
[6] Cargo washing is not permitted in U.S. waters, but is permitted in international waters. It was assumed that it does not occur to a significant degree in U.S. waters.
[7] The worldwide population of recreational vessels was not available.
[8] Insufficient data was available to develop estimates for this class of vessels.

probability in the U.S. Outer Continental Shelf (BSEE, 2017). Because these oil-spill statistics have been extensively peer-reviewed and are updated regularly, they will be used as a primary source for this review.

SINTEF, a private research and consulting organization headquartered in Trondheim, Norway, maintain an online database of offshore blowouts that have occurred in the U.S.Outer Continental Shelf (OCS), North Sea, and Canadian waters (SINTEF, 2017). As of this writing, the database has records on 642 offshore blowouts that have occurred since 1955. The database is confidential and available only to project partners, but it has been reviewed by others over the years, notably by IOGP (2010), Bercha Group (2013, 2014) and Exprosoft (2017) to derive useful statistics on blowout frequencies that can be applied to the proposed Nexen exploration drilling program.

Where possible, historical spill data from exploration drilling activities was used to calculate probabilities of similar incidents for the proposed project. In some cases, insufficient exploration drilling data was available and so records from other types of drilling (e.g., production, delineation and exploration) was used.

1.3 CATEGORIES OF SPILL SIZE

It is useful for discussion of the statistics and evaluation of risk to break down spill occurrences on a size basis. Six spill size categories have been defined for this report, as shown in Table 2, and the data analysed accordingly.

Table 2: Spill size category definitions

Spill Size Range	bbl	m^3	tonnes[9]
Extremely Large spills	> 150,000	> 23,850	> 20,830
Very Large spills	> 10,000	> 1,590	> 1,390
Large spills	> 1,000	> 159	> 139
Medium spills	50 to 999	7.95 to 158.9	6.94 to 139
Small spills	1 to 49.9	0.16 to 7.95	0.07 to 6.94
Very small spills	< 1	< 0.16	<0.07

Note that the three largest categories are cumulative (e.g., *very large* spills include spills also classified as *extremely large*). Good worldwide statistics are available for historical spills in the *extremely large* category. *Very large* and *large* spills follow the size classification used by the U.S. BSEE.

1.4 STRUCTURE OF REPORT

The analysis begins with a review of the probabilities of offshore blowouts, and then presents an assessment of blowouts that result in the discharge of oil to the environment. This is followed by a probability analysis related to other kinds of spills of oil that can happen on the drilling rig over the course of the drilling project, including spills of crude oil, fuel oil, lubricating oils and other petroleum products, and synthetic-based muds are also reviewed. A summary table is presented at the end of the report that includes all the key statistics for the proposed project.

[9] Assumes specific gravity of oil of approximately 0.873

2 BLOWOUTS DURING EXPLORATION DRILLING

A blowout is defined as "an incident where formation fluid flows out of the well or between formation layers after all the predefined technical well barriers, or the activation of the same, have failed" (Holand, 2007). A blowout is a result of a Loss of Well Control (LOWC). In U.S. regulations (30 CFR 250.188 (3)), a loss of well control is defined as:

i) Uncontrolled flow of formation or other fluids. The flow may be to an exposed formation (an underground blowout) or at the surface (a surface blowout);
ii) Flow through a diverter; or
iii) Uncontrolled flow resulting from a failure of surface equipment or procedures.

Blowouts that result in a release to the environment can be broken down into releases that are primarily gaseous, and those that involve primarily liquid hydrocarbons. The main consideration in the context of the proposed drilling program is the possibility of a well blowout that releases large quantities of crude oil into the marine environment.

In the oil and gas industry, a distinction is made between two stages of petroleum field drilling: exploration drilling (including *delineation* or *appraisal* drilling), where knowledge of the geological and depositional environment is speculative or limited; and development drilling, where the subsurface structure is better understood, and potential drilling issues can be better anticipated. The main purpose of this report is to analyze the risk of a blowout during exploration drilling.

2.1 BLOWOUT FREQUENCY

The frequency of all types of blowouts (i.e., primarily gas and primarily liquid) is analysed below.

2.1.1 U.S. OCS Experience

Table 3**Error! Reference source not found.** provides U.S OCS data on all drilling blowouts (gas and liquid), representing the period from 1980 to 2011. Table 3**Error! Reference source not found.** includes *large* spills presented in Table 6, below, that occurred in the U.S. OCS from 1980 and later, as well as smaller liquid blowouts and gas blowouts. Note that there is only one *large* spill (> 1000 bbl), Macondo, reflected in this time period.

Table 3: Blowouts (gas and liquid) and spilled volume from U.S. OCS wells, 1980 to 2011

		Drilling Blowouts				Non-drilling Blowouts							
Period	**# Wells**	**Exploration**		**Development**		**Production**		**Workover**		**Completion**		**Total Blowouts**	
		#	**bbl**	**#**	**bbl**	**#**	**bbl**	**#**	**bbl**	**#**	**bbl**	**#**	**bbl**
1980 to 1989	11,071	19	0	21	0	7	0	19	113	6	60	72	173
1990 to 1999	8,765	17	300	16	0	2	0	5	0	3	0	44	302
2000 to 2011	12,988	9	4×10^6	9	1	8	378	7	12	1	0	29	380
Total	**32,824**	**45**	**4×10^6**	**46**	**1**	**17**	**378**	**31**	**125**	**10**	**60**	**145**	**855**

The total number of exploration wells drilled in the U.S. Federal OCS from 1980 to 2011 was 12,429 (Bercha Group, 2014). The number of blowouts from exploration drilling was 45; therefore, the blowout frequency is 45/12,429 or 3.62×10^{-3} blowouts per well drilled, or one blowout for every 276 wells drilled.

2.1.2 Experience in Eastern Canada

Table 4**Error! Reference source not found.** summarizes the drilling and blowout experience in operations on the east coast of Canada, in Newfoundland and Labrador (C-NLOPB, 2017), and Nova Scotia (C-NSOPB, 2017), since drilling activities began in 1966.

Table 4: Exploration and development wells and blowouts in Eastern Canada

Region	Exploratory Wells	Development Wells	Blowouts	Exploration Blowout Frequency	Overall Blowout Frequency
Newfoundland[10]	226	220	0	0	0
Nova Scotia[11]	156	53	1 (exploration)	6.4×10^{-3}	4.8×10^{-3}
TOTAL	382	273	1 (exploration)	2.6×10^{-3}	1.5×10^{-3}

The one exploration well blowout was the Uniacke G-72 gas and condensate blowout that happened off the coast of Sable Island, Nova Scotia, in 1984. The blowout frequencies calculated for operations on the east coast of Canada are consistent with the experience in the U.S. OCS (i.e., 2.6×10^{-3} blowouts per exploration well drilled in Canada compared with 3.1×10^{-3} in the U.S. OCS).

2.1.3 North Sea Standard Operation

The blowout frequency for the U.S. (3.62×10^{-3}) is based on blowout records from 1980 to 2011, and does not account for improvements in safety and blowout prevention that have tended to reduce blowout frequencies. Drilling in Canada is consistent with North Sea Standard Operation, in which deep drilling is performed with a blowout preventer (BOP) installed, including shear ram and two-barrier principle. Analysis of incident records in the SINTEF blowout database from 1985 to 2005 (IOGP, 2010) determined that historical drilling that followed this standard resulted in a lower rate of blowouts. Rates for blowouts during normal exploration drilling following North Sea Standards (i.e., deep drilling after the BOP is in place) are presented in Table 5.

Table 5: Blowout statistics (deep drilling, gas and liquid) for the Nexen Flemish Pass exploration drilling project.

Spill Category	Spill Probability (spills per well drilled)	Spill Frequency (wells drilled per spill)
Exploration Blowout (deep drilling)	3.1×10^{-4}	3,226

[10] Updated July 2017
[11] Updated September 2016

2.2 BLOWOUTS RESULTING IN CRUDE OIL SPILLS

2.2.1 *Extremely Large* and *Very Large* Oil Spills from Blowouts

In Canada, there have been no blowout spills offshore that fall into these spill size ranges. In the U.S., five offshore oil-well blowouts (including the 2010 Macondo blowout in the Gulf of Mexico) involving oil spills larger than 10,000 barrels have occurred since offshore drilling began in the mid-1950s. Five incidents is a very small sample size from which to derive probabilities of future events. One must therefore look beyond North America to find a statistically relevant database on very large and extremely large oil-well blowouts. Table 6 lists all worldwide blowouts that resulted in spills of more than 10,000 barrels.

Table 6: Extremely large and very large spills from offshore blowouts, worldwide

Well	Region	Spill Size (bbl)[12]	Year	Duration (d)	Type of Well	Intervention Technique
Extremely Large Spills						
Ixtoc-1	Mexico	6,745,000	1979	293	Exploration	Relief Well
Macondo MC-252	U.S, GOM	4,000,000	2010	91	Exploration	Relief Well and Capping
Bull Run	UAE	2,000,000	1973	NA	Unknown	Unknown
Abkatun 91	Mexico	247,000	1986	NA	Workover	Unknown
Funiwa 5	Nigeria	200,000	1980	13	Development	Bridged
Ekofisk Bravo B-14	Norway	158,000	1977	16	Workover	Capped
Very Large Spills						
Montara	Australia	121,450	2009	74	Development	Relief Well
Iran Marine Intl.	Iran	100,000	1971	NA	Development	Unknown
Alpha Well 21 A	U.S., Pacific	77,000	1969	11	Production	Capped
Hasbah 6	Saudi Arabia	60,000	1980	8	Exploration	Capped
Yum II	Mexico	56,000	1987	51	Exploration	Unknown
South Timbalier B-26	U.S., GOM	53,000	1970	138	Wireline	Relief Well and Capping
Trinimar Marine 327	Venezuela	36,650	1973	5	Development	Capped
Main Pass 41	U.S., GOM	30,000	1970	49	Production	Capped
Timbalier Bay/Greenhill	U.S., GOM	11,500	1992	11	Production	Unknown

As can be seen from Table 6, there have been six *extremely large* spills from blowouts in the history of offshore drilling, two of which occurred during the exploration phase (Ixtoc-1 and Macondo MC-252). It is estimated that 51,000 offshore exploration wells have been drilled worldwide (Deloitte Petroleum Services, 2012). Therefore, based on two *extremely large* spills during offshore exploration drilling, the probability is 3.92×10^{-5} per well drilled (1 *extremely large* spill per 25,500 exploration wells drilled).

[12] Estimated spill sizes for the Ixtoc-1, Macondo MC-252, and Montara blowouts varied significantly depending on the source; the average of the high and low values found in the literature is listed here.

A similar calculation can be done for *very large* spills. Table 6 lists four *very large* spills from blowouts that occurred during offshore exploration drilling (two of which are also considered *extremely large*). Therefore, the historical frequency of *very large* spills is 7.84×10^{-5} per well drilled (1 *very large* spill per 12,750 exploration wells drilled).

We note that the very low spill frequencies calculated above for *extremely large* and *very large* spills are based on spills in the 1970s and 1980s, in countries that do not generally have regulatory standards as stringent as those in Canada, with the notable exception being the 2010 Macondo MC-252 blowout in the US. For example, one of the largest hydrocarbon spills in history, the *Ixtoc-1* oil-well blowout in the Bay of Campeche, Mexico, that occurred in 1979, was caused by drilling procedures that are not practised in US or Canadian waters and that are contrary to US and Canadian regulations and to the accepted practices within the international oil and gas industry. Therefore, actual frequencies for these spills in North America are expected to be even lower.

2.2.2 *Large* Crude Oil Spills from Blowouts

In the entire history of oil and gas operations in Canadian waters, the U.S. OCS, and the North Sea there have been no *large* (>1,000 bbl) spills during exploration drilling, other than those already discussed in Table 6.

It is difficult to obtain and be confident of data elsewhere in the world. A comprehensive search was made of the records of the Oil Spill Intelligence Report (Oil Spill Intelligence Report, 1978-2017) the U.S. National Oceanic and Atmospheric Administration (NOAA) Incident News Database (NOAA Office of Response and Restoration, 2017), and of other internet sources. The search revealed only one additional exploration-drilling blowout that resulted in a *large* oil spill. The spill occurred in the offshore Ankleshwar field in Gujarat, India, in 1998 and the spill size was reported as 2,380 bbl. If it is assumed that this was the only large-spill blowout to occur after the ones accounted for above, then the spill probability for *large* (>1,000 bbl) spills from exploration drilling becomes 9.80×10^{-5} spills per well drilled.

2.2.3 Calculated Probabilities for the Nexen Flemish Pass Exploration Drilling Project

The probabilities of a blowout resulting in a *large, very large* or *extremely large* spill, and corresponding spill frequencies, for the Nexen Flemish Pass Exploration Drilling Project, expressed on a per-well basis, are summarized in Table 7.

Table 7: Blowout statistics for the Nexen Flemish Pass exploration drilling project.

Spill Category	Spill Probability (spills per well drilled)	Spill Frequency (wells drilled per spill)
Extremely Large (> 150,000 bbl)	3.92×10^{-5}	25,500
Very Large (> 10,000 bbl)	7.84×10^{-5}	12,750
Large (> 1,000 bbl)	9.80×10^{-5}	10,200

3 NON-BLOWOUT SPILLS

Oil spills other than from blowouts can occur from accidents during drilling and production activities. These include spills of diesel oil or lubricating oil on the drilling installation or during transfers between the MODU and supply vessels, spills of crude oils from transfer operations, spills of synthetic-based drilling muds (SBM), and spills from similar incidents involving the handling of oil that is needed to run operations. Most of these spills involve volumes less than 4 L.

3.1 *LARGE* AND *MEDIUM* NON-BLOWOUT HYDROCARBON SPILLS

There has been only one *large* spill in Canadian waters: the 2004 spill of 1,000 bbl of crude oil from the Terra Nova floating production storage and offloading vessel, which occurred during production activities. No *large* or *medium* spills have occurred in Newfoundland and Labrador or Nova Scotia during exploration drilling. Due to this small sample size, U.S. statistics were used to determine probabilities for such events for the proposed project.

3.1.1 Large Non-Blowout Spills

There have been very few *large* spills from exploration and production operations in U.S. OCS waters. In addition to the five *large* spills from blowouts noted in Table 6, there have been seven other *large* non-blowout spills, which includes all U.S. platform spills up to the present (Table 8).

Table 8: Non-blowout Hydrocarbon spills of ≥ 1,000 bbl from platforms in the U.S. OCS, 1964 to 2011.

Year	Location	Size (bbl)	Cause
1964	Eugene Island Block 208	2,559	Collision with freighter, fire
1964	Eugene Island 208, Ship Shoal 149, 199	11,869	Hurricane Hilda (5 platforms)
1969	Ship Shoal Block 72	2,500	Collision, storm
1973	West Delta Block 79	9,935	Storage tank rupture
1979	Main Pass Block 151	1,500[13]	Collision, weather, tank spill
1980	High Island Block 206	1,456	Hurricane Jeanne, pump failure, tank spill
2005	Cameron/Eugene Is./Green Canyon	6,981	Hurricane Katrina (9 platforms)

Of the seven non-blowout spills, three were caused by hurricanes. The spills occurred in the U.S. Gulf of Mexico (GoM), a region that is more prone to hurricanes than offshore Newfoundland and Labrador. None of the *large* non-blowout spills occurred during exploration drilling.

From 1980 to 2011, a total of 31,574 development and exploration wells were drilled in the U.S. GoM (Bercha Group, 2014). If we include the two spills from production platforms that occurred during this time frame, then the probability of a *large* spill occurring on a per well basis is 2/31,574 = 6.33×10^{-5} spills per well drilled.

3.1.2 Medium Non-Blowout Spills

There have been no recorded *medium* spills from exploration and development activities in Newfoundland and Labrador, or in Nova Scotia. Therefore, U.S. GoM and PAC statistics were used. 106 *medium* spills were reported in the U.S. GoM and PAC between 1980 and 2011 (Bercha Group, 2013).

[13] Spill was refined product.

During this period, a total of 31,574 wells (exploration and development) were drilled in these regions. On this basis, the probability of a medium spill is calculated as 106/31,574 = 3.34×10^{-3}.

Hurricanes were listed as the cause in 63 of the 106 *medium* spill incidents between 1980 and 2011. Since offshore Newfoundland and Labrador is not prone to hurricanes, the probability of *medium* non-blowout spills may be overestimated by the U.S. GoM and PAC statistics.

3.1.3 Calculated Probabilities for the Nexen Flemish Pass Exploration Drilling Project

The probabilities of a non-blowout incident resulting in a *large* or *medium* spill, and the corresponding spill frequencies, for the Nexen Flemish Pass Exploration Drilling Project are presented in Table 9**Error! Reference source not found.**.

Table 9: Large and medium non-blowout statistics for the Nexen Flemish Pass exploration drilling project.

Spill Category	Spill Probability (spills per well drilled)	Spill Frequency (wells drilled per spill)
Large, non-blowout (> 1,000 bbl)	6.33×10^{-5}	15,787
Medium, non-blowout (50 to 999 bbl)	3.34×10^{-3}	298

3.2 *SMALL* AND *VERY SMALL* NON-BLOWOUT HYDROCARBON SPILLS

There is a reasonably-sized database on smaller (<50 bbl) spill incidents in Newfoundland and Labrador waters, which is maintained and published by the C-NLOPB. This data was used to determine probabilities for smaller spills of petroleum products, which included crude oil, hydraulic oil, lubricating oil, seal oil, diesel, and condensate.

3.2.1 *Small* Non-Blowout Spills

Offshore drilling in Newfoundland and Labrador waters commenced in 1966 with 445 wells drilled to date. Spill incident data is available from 1997 when production began (C-NLOPB, 2017). The spill incidents from exploration drilling involving 1 bbl (159 L) or more of hydrocarbon during that period are listed in Table 10.

Table 10: Number of small non-blowout spills during exploration drilling, Newfoundland and Labrador, 1997 to 2016

Spill Category	Number of Spills
Small (1 to 49.9 bbl)	10

A disproportionate number (9 of 10) of these spills occurred in the first three years of operations (i.e., 1997 to 1999), so it is reasonable to focus on the more recent years. For the period from 2000 to 2016, 255 wells were drilled, including 186 development wells, and 69 exploration and delineation wells. The frequency of *small* spills from exploration drilling is calculated as $1/(42+27) = 1.45 \times 10^{-2}$ spills per well drilled.

If spill records from all types of drilling are included (i.e., production, delineation and exploration), the number of incidents rises to 11 over the period from 2000 to 2016.The probability of a *small* spill based on incidents from all drilling is calculated as $11/255 = 4.31 \times 10^{-2}$ spills per well drilled. The data indicates that production activities have resulted in a significantly higher frequency of small spills than exploration.

3.2.2 *Very Small* Non-Blowout Spills

The C-NLOPB also provides a statistical record of spills of greater than 1 L but less than 1 bbl (159 L), and of spills of 1 L and less (Table 11), although the records do not differentiate between spills during exploration or production activities. As above, we will focus on the period from 2000 to 2016. For these years, there were a total of 255 wells drilled, with 131 spills in the 1 to 159 L category, and 252 spills less than 1 L.

Table 11: Record of very small non-blowout spills, Newfoundland and Labrador, 2000 to 2016

Year	Spills > 1 L and < 159 L		Spills of 1 L and Less	
	Number	Total volume (L)	Number	Total volume (L)
2000	2	62	2	1.10
2001	7	26	8	4.21
2002	5	16	19	5.20
2003	10	186	9	2.48
2004	21	193	30	8.97
2005	11	181	28	8.96
2006	5	20	27	9.24
2007	3	93	34	4.28
2008	12	337	23	3.89
2009	11	216	30	9.15
2010	3	20	15	3.42
2011	29	396	7	4.26
2012	3	10	4	1.00
2013	4	178	5	0.25
2014	3	17	7	3.15
2015	1	3	1	0.10
2016	1	2	3	0.36
Total	**131**	**1956**	**252**	**70.02**

The total number of recorded spills less than 159 L (1 barrel) results in a historical frequency of 1.50 spills per well drilled (131 + 252 / 255 wells).

Based on the frequency of *small* spills from all types of drilling activities compared to those strictly from exploration drilling (see Section 3.2.1), the records of *very small* spills from all drilling activities may overestimate the probability of those occurring for the proposed exploration drilling project.

3.2.3 Calculated Probabilities for the Nexen Flemish Pass Exploration Drilling Project

The probabilities of a non-blowout incident resulting in a *small*, or *very small* spill, and the corresponding spill frequencies, for the Nexen Flemish Pass Exploration Drilling Project are presented in Table 12. The statistics are presented on a per-well drilled basis.

Table 12: Non-blowout spill statistics for the Nexen Flemish Pass exploration drilling project.

Spill Category	Spill Probability (spills per well drilled)	Spill Frequency (wells drilled per spill)
Small (1 to 49.9 bbl)	1.45×10^{-2}	69
Very Small (<1 bbl)	1.50	0.67

3.3 SPILLS OF SYNTHETIC-BASED MUDS

The C-NLOPB records spills of synthetic-based mud (SBM), and these are summarized in Table 13 for the years 1997 through 2016. The largest such spill occurred in 2004, when approximately 96,600 L (608 bbl) of SBM were spilled from the diverter line of the GSF Grand Banks at the White Rose location.

Table 13: Spills of synthetic-based muds, Newfoundland and Labrador 1997 to 2016

Spill Category	Number of Spills
Large (> 1,000 bbl)	0
Medium (50 to 999 bbl)	7
Small (1 to 49.9 bbl)	25
Very Small (> 1 bbl)	51

3.3.1 Calculated Probabilities for the Nexen Flemish Pass Exploration Drilling Project

The probabilities of a SBM incident resulting in a large, medium, small, or very small SBM spill, and the corresponding spill frequencies, for the Nexen Flemish Pass Exploration Drilling Project, are presented in Table 14. The frequencies are based on the 300 wells (all types) drilled during this period.

Table 14: SBM spill statistics for the Nexen Flemish Pass exploration drilling project.

Spill Category	Spill Probability (spills per well drilled)	Spill Frequency (wells drilled per spill)
Large (> 1,000 bbl)	-	-
Medium (50 to 999 bbl)	2.33×10^{-2}	2,100
Small (1 to 49.9 bbl)	8.33×10^{-2}	12
Very Small (<1 bbl)	0.17	5.9

4 SUMMARY OF SPILL FREQUENCIES

The calculated probabilities and corresponding frequencies of spill incidents for the Nexen Flemish Pass Exploration Drilling Project are summarized in Table 15.

Table 15: Incident statistics for the Nexen Flemish Pass exploration drilling project.

Event	Spill Probability (spills per well drilled)	Spill Frequency
Blowout (All Types)		
Deep blowout during exploration drilling	3.1×10^{-4}	1 per 3,226 wells
Blowout Resulting in Large Spill		
Extremely Large (> 150,000 bbl)	3.92×10^{-5}	1 per 25,510 wells
Very Large (> 10,000 bbl)	7.84×10^{-5}	1 per 12,755 wells
Large (> 1,000 bbl)	9.80×10^{-5}	1 per 10,200 wells
Non-Blowout Batch Spill of Petroleum		
Large (> 1,000 bbl)	6.33×10^{-5}	1 per 15,787 wells
Medium (50 to 999 bbl)	3.34×10^{-3}	1 per 298 wells
Small (1 to 49.9 bbl)	1.45×10^{-2}	1 per 69 wells
Very Small (<1 bbl)	1.50	1 per 0.67 wells
Synthetic-Based Mud Spills		
Large (> 1,000 bbl)	-	-
Medium (50 to 999 bbl)	2.33×10^{-2}	1 per 2,100 wells
Small (1 to 49.9 bbl)	8.33×10^{-2}	1 per 12 wells
Very Small (<1 bbl)	0.17	1 per 5.9 wells

The highest frequencies are for the smaller, operational spills. Spills less than one barrel in size may occur one to two times per well, based on recent petroleum development experience off Newfoundland. Although these smaller spills may occur more often, the median volume is only 4 litres. Spill records for *very small* spills do not differentiate between production and exploration activities, and so the probability for *very small* spills may be overestimated for the proposed exploration drilling project.

Batch oil spills during exploration that are larger than one barrel but less than 50 barrels have about a 1-in-42 chance of occurring per well. Batch oil spills in the 50 to 999 bbl range may have about a 1-in-300 chance of occurring per well, based on experience in the U.S. OCS.

There is about a 1-in-3,200 chance per well of having any sort of deep blowout.

The chances of an *extremely large* (>150,000 bbl), *very large* (>10,000 bbl), and *large* (>1000 bbl) oil well blowout from exploration drilling are very small: about a 1-in-25,000, 1-in-13,000 and 1-in-10,000 chance per well, respectively. These predictions are based on worldwide data, and are strongly influenced by blowouts that occurred in parts of the world where drilling regulations may be less rigorous, and in most cases prior to modern safety improvements.

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