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Estimated Occurrence Rates for Analysis of Accidental Oil Spills on the US Outer Continental Shelf

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ABSTRACT

The Minerals Management Service estimates the likelihood of oil spills of 1000 barrels and greater occurring in association with the production and transportation of offshore oil on the US Outer Continental Shelf (OCS). The estimation process uses a spill rate constant, based on historical accidents, expressed in terms of number of spills per 10^9 barrels of oil produced or transported. The mean spill occurrence estimate is obtained by multiplying the rate constant by the volume of oil projected to be handled. The probability of one or more spills occurring in a given production period is then estimated by using the mean number of spills in a Poisson process. The calculated occurrence rates of 0·60 spills per 10^9 barrels produced on US OCS platforms and 0·67 spills per 10^9 barrels transported in US OCS pipelines represent a decline of 40 and 58%, respectively, since last evaluated in 1983. Spill occurrence rates for worldwide tanker transport remained unchanged, since last evaluated in 1983, at 0·90 for 'at-sea' spills and 0·40 for 'in-port' spills.

1 INTRODUCTION

1.1 Background

The Minerals Management Service (MMS) of the US Department of the Interior (DOI) conducts oil and gas leasing on the US Outer Continental

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Shelf (OCS) and regulates activities on tracts that have been leased. The MMS normally prepares an Environmental Impact Statement (EIS) for each proposed offshore lease sale. Within each EIS, the MMS must evaluate the potential risks of oil spills occurring and contacting environmentally sensitive resources. In general, the analyses for the EIS are prepared 1–2 years in advance of the lease sale, and are followed by several years of exploration prior to the actual development and production. As such, the analyses must be performed at least 5 years in advance of knowing which tracts will be developed, the location or type of drilling rigs that will be employed, or the method of transporting the product to shore should production occur. Such data limitations preclude using elaborate spill-prediction techniques, such as 'fault tree analysis' (Slater & Cox, 1984), which require significantly more information than is available during the prelease stage. This paper presents a more appropriate approach to estimating oil spill risks in a prelease timeframe.

1.2 The oil spill risk analysis model

The Oil Spill Risk Analysis (OSRA) model was developed in 1975 by the DOI as a tool to assist in the evaluation of offshore oil spill risks (Smith *et al.*, 1982). This model is used primarily to provide environmental impact analysts with probabilistic estimates of oil spill occurrence and contact with biologic and economic resources located on the US OCS. The trajectory portion of the model uses seasonal surface current and local wind conditions to simulate many trajectories from potential offshore spill sites. Results of the trajectory runs are then used to estimate the statistics of potential contact. The OSRA also addresses the likelihood of oil spills occurring during the production and transportation of offshore oil. A realistic, objective methodology for estimating oil spill occurrence rates is needed for this application of the OSRA and will be outlined in this paper.

1.3 Spill rate definition

This paper presents the results of analyses of estimated oil spill occurrence rates (hereafter referred to simply as 'spill rates') for US OCS platforms and pipelines and worldwide spills from tankers. Spill rates are expressed in terms of number of spills per 10^9 barrels (bbl) of oil handled. Only spills of 1000 bbl and greater are addressed, since the OSRA is used primarily to estimate contacts over days, not hours, without explicit consideration of spreading, weathering, or cleanup of

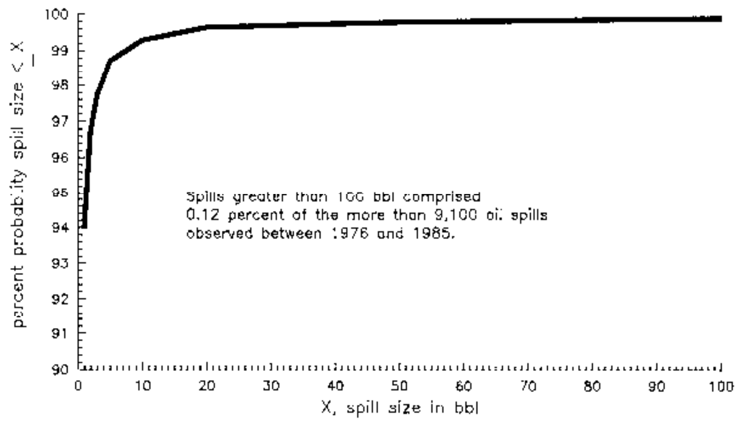

Fig. 1. Crude oil and condensate spills resulting from OCS activities in the Gulf of Mexico, 1976–85; cumulative probability frequency distribution. Sources: MMS (1986, 1988*d*).

the spilled oil. Consequently, only those spills that are large enough to travel long distances on the ocean surface and that could persist for several days or longer are appropriate for simulation by this model. Another consideration is that a large spill is unlikely to go unnoticed; therefore, reporting records should be more reliable. The 1000-bbl cutoff meets the above requirements. In addition, the estimation of the size of an oil spill is generally an inexact measurement, which is often rounded up or down by onsite observers to the nearest 500 or 1000 gallons, barrels, or metric tonnes. Therefore, spills near 1000 bbl are likely to be reported as 1000 bbl. Large spills account for less than 1% of all spill events on the US OCS: almost all smaller spills (99%) are less than or equal to 10 bbl in size (see Fig. 1). These smaller spills do not lend themselves to trajectory modeling. Any further reference to 'spills' in this paper should be assumed to be 'spills of 1000 bbl and greater', unless otherwise specified.

1.4 Poisson distribution for estimation of oil spill occurrence

Efforts to estimate the probability of a spill occurring are part of the MMS's assessment of potential programmatic impacts. Spill occurrence has been modeled previously as a Poisson process (Smith *et al.*, 1982). A stochastic process, $N(t)$, is a counting process, if $N(t)$ represents the total number of events that have occurred up to time t. To determine if the counting process of spill occurrence is a Poisson process with volume of oil exposure t, the occurrence of spills must meet the following three criteria (Ross, 1985):

1. $N(0)$ must equal zero with a probability equal to 1. This is true because no spills can occur when 0 bbl of oil are handled.
2. The process must have independent increments. This would apply to spill occurrence if, for any given disjoint time interval, the number of spill occurrences does not depend on the previous or following intervals. This condition is satisfied since the record shows that individual spill events are independent of previous spill events over time and production.
3. The number of events in any interval of length t must be Poisson distributed with a mean of λt. Thus, this process must have stationary increments. The process of spill occurrence would have stationary increments if the distribution of the number of spills that occur in any interval depends only on the length of the interval. Our review of the data indicates that there has been a decrease in the frequency of spill events over time and production. To satisfy this criterion, we performed sensitivity analyses to identify where the increments became relatively stationary. Each spill rate was calculated from that point forward.

Because spill occurrences meet the criteria for a Poisson process, the following equations were used in our estimation of spill rates. The estimated volume of oil handled is the exposure variable. Smith *et al.* (1982), using Bayesian inference techniques, presented a derivation of this process, assuming the probability of n spills over some future exposure t is expected to occur at random with a frequency specified by eqn (1):

$$P[n \text{ spills over future exposure } t] = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \tag{1}$$

where λ is the true rate of spill occurrence per unit exposure. The predicted probability takes the form of a negative binomial distribution:

$$P(n) = \frac{(n + \nu - 1)!\, t^n \tau^\nu}{n!(\nu - 1)(t + \tau)^{n+\nu}} \tag{2}$$

where τ is past exposure and ν is the number of spills observed in the past. The negative binomial is then shown to converge over time to the Poisson with λ estimated using eqn (3) (Smith *et al.*, 1982):

$$\lambda = \nu/\tau \tag{3}$$

1.5 Selection of exposure variable

Two basic criteria for selecting an exposure variable are that the exposure should be simple to measure, and that it should be a quantity

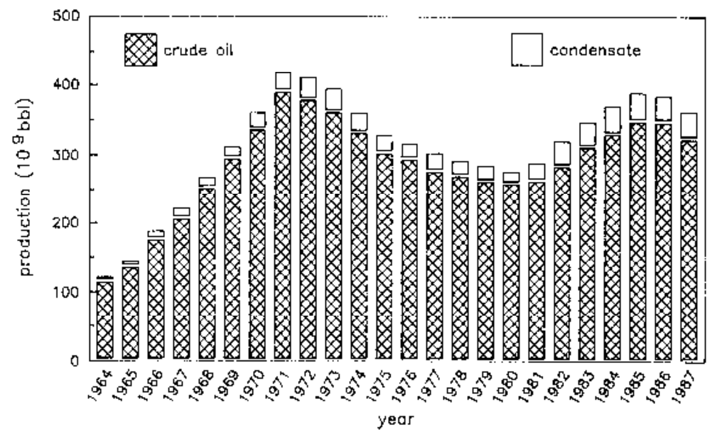

Fig. 2. US OCS production of crude oil and condensate, 1964–87. Sources: MMS (1988*a*, 1988*b*, 1988*e*).

that is predictable. Volume of oil handled is the chosen exposure variable primarily for these reasons. Past production is well documented, as shown in Fig. 2. Volume of oil handled makes the calculation of the spill rate simple — the ratio of the number of historic spills to the volume of oil handled — in the form of eqn (3). Volume is also predictable. Estimates of volume are prepared by the Resource Evaluation Program within the MMS, whose function and expertise are in the assessment of oil resources using comprehensive geological and geophysical data bases and related models. In addition, almost all other exposure variables that could be used — number of platforms, number of tanker trips, etc. — are currently estimated by the MMS as functions of amount of oil handled.

2 DATA

We separately addressed three sources of oil spills: platforms, pipelines, and tankers. Only spills of 1000 bbl and greater were analyzed. In each analysis, each spill event record was examined and verified to the extent possible. Each spill was classified based on its applicability to the analysis in terms of size, product spilled, and spill source.

2.1 US OCS platform and pipeline spills

Platform and pipeline spills were analyzed based upon US OCS experience from 1964 through 1987 (see Tables 1 and 2). Spills occurring

TABLE 1
Oil Spills of 1000 bbl and Greater from Platforms on the US OCS, 1964–1987

Date	*Area*	*Size (bbl)*	*Cause*
8–9 April '64	Eugene Island	2 559	Collision and fire
3–19 October '64	Ship Shoal/Eugene Island	11 869	Hurricane and blowout[a]
19–26 July '65	Ship Shoal	1 688[b]	Blowout
28 January '69–6 February '69	Santa Barbara	77 000	Blowout
16–19 March '69	Ship Shoal	2 500	Collision and blowout
10 February '70–31 March '70	Main Pass	30 000	Fire
1 December '70–17 April '71	South Timbalier	53 000	Blowout and fire
9 January '73	West Delta	9 935	Storage tank rupture
26 January '73	South Pelto	7 000	Storage barge leak
23 November '79	Main Pass	1 500[c]	Collision
14 November '80	High Island	1 456	Tank overflow

[a]Five platforms; includes 1589 bbl storage oil.
[b]Condensate.
[c]Diesel tank of semi-submersible drilling rig damaged.
Santa Barbara estimates vary: 10 000–77 000 bbl.
Sources: MMS (1988*e*); MMS (1988*f*).

TABLE 2
Oil Spills of 1000 bbl and Greater from Pipelines on the US OCS, 1964–1987

Date	*Area*	*Size (bbl)*	*Cause*
15–27 October '67	West Delta	160 638	Anchor dragging
12 March '68	South Timbalier	6 000	Anchor dragging
11–16 February '69	Main Pass	7 532	Cause unknown
12 May '73	West Delta	5 000	Internal corrosion
18 April '74	Eugene Island	19 833	Anchor dragging
11 September '74	Main Pass	3 500	Hurricane
18 December '76	Eugene Island	4 000	Trawler dragging
11 December '81	South Pass	5 100	Anchor dragging

Source: MMS (1988*f*).

on the platform, including those resulting from ruptures to storage tanks on the platforms, were classified as platform spills. For this reason, a spill from a barge that was moored at a platform for storage purposes has been included. Spills resulting from transportation of oil from the platform to shore through pipelines were classified as pipeline spills. These spills were analyzed over the production of crude oil and condensate between 1964 and 1987 — a total of $7{\cdot}5 \times 10^9$ bbl of liquid product handled. Total US crude oil and condensate production is used as a proxy for total volume transported by pipeline. Roughly 97% of all OCS production has been transported by pipeline, with no less than 95% in any single year (MMS, 1988*c*).

The advantages of limiting the analysis to US events are that the rates will better reflect the magnitude of spill occurrence under US regulation and operational controls, and that the individual spill and production records are readily accessible to the MMS. The disadvantages include the limitations involved in analyzing a small number of observations. The limited observations preclude cross-sectional analysis of possible spill rate variations that may exist between the northern Pacific or Alaska waters vs the Gulf of Mexico and Southern California waters, where the majority of the US OCS experience has occurred. The rates should not be adjusted based on the intuition that more hostile environments are riskier. The more hostile environments have more stringent engineering and procedural regulations, which may offset or even reduce the risk of a spill occurring relative to historic OCS experience.

2.2 Worldwide tanker spills

Tanker spill rates were based on worldwide data for crude oil carriers from 1974 through 1985 (see Table 3). Prior to this time period, international spill occurrences were recorded on an irregular basis; more stringent reporting requirements were introduced in 1973 (The Futures Group and Environmental Research and Technology, 1982). Due to data limitations, a rate specific to US waters could not be calculated. Any tanker spill of crude oil equal to or greater than 1000 bbl was included; if the oil type could not be identified, it was assumed to be crude oil.

A compendium of oil spills during 1986 and 1987 is not presently available. Consequently, the spill rates were based on worldwide tanker data from 1974 to 1985. The best available exposure variable was the total estimate of international transportation of crude oil (British Petroleum Company, 1987; Davison, I. (BP 1974–85 statistics), 1987, pers. comm.), $107{\cdot}8 \times 10^9$ bbl over the 1974–85 time period. Inland spills and spills from barges were specifically excluded from the calculations under the assumption that international transportation of crude oil is performed by tanker to and from coastal ports. Rates for spills that occur offshore were analyzed separately from those occurring in harbors or at piers and were classified as 'at-sea' or 'in-port', respectively. This was necessary, since only spills occurring offshore are modeled by OSRA, using the at-sea rate.

3 METHODS

3.1 Spills of 1000 bbl and greater

Spill rates for spills of 1000 bbl and greater were calculated for each of the three spill sources.

3.1.1 US OCS platform and pipeline spill rates

Nonparametric tests were applied to determine whether the observations were random and independent. A variable that was independent of the spill rate distribution was constructed — crude and condensate observed between spills. A hypothesis that this new variable was random and independent was tested using Hotelling and Pabst's Test (Bradley, 1968, Table I) and Kendall's Test for Correlation (Bradley, 1968, Table XI). For both platforms and pipelines, the volume of oil handled between spills appeared to be nonrandom and to increase over time. This indicated that the spill rate, based on volume of oil handled, had declined over time.

TABLE 3
Worldwide Crude Oil Spills of 1000 bbl[a] and Greater from Tankers, 1974–1985

Year	*'At-sea' spills*	*'In-port' spills*	*Total spills*	*Crude oil transported (Bbbl)*	*'At-sea' spill rate*	*'In-port' spill rate*
1974	9(3)	6(2)	15(5)	10·2	0·88	0·59
1975	12(8)	3(2)	15(10)	9·3	1·29	0·32
1976	12(7)	2(0)	14(7)	10·5	1·14	0·19
1977	12(9)	3(0)	15(9)	10·7	1·12	0·28
1978	10(5)	3(1)	13(6)	10·5	0·95	0·29
1979	14(10)	10(6)	24(16)	11·0	1·27	0·91
1980	4(3)	3(1)	7(4)	9·7	0·41	0·31
1981	2(1)	4(1)	6(2)	8·5	0·24	0·47
1982	2(1)	3(1)	5(2)	7·3	0·27	0·41
1983	11(7)	2(1)	13(8)	6·9	1·59	0·29
1984	5(3)	0(0)	5(3)	6·8	0·74	0·00
1985	4(2)	4(2)	8(4)	6·4	0·63	0·63
Total	97(59)	43(17)	140(76)	107·8	0·90	0·40

[a]Spills of 10 000 bbl and greater in parentheses.
Sources: British Petroleum Company (1987); Davison, I. (BP 1974–75 statistics), 1987, pers. comm.); Oil Spill Bulletin (1985–1987); Oil Spill Intelligence Report (1979–1987); The Futures Group and Environmental Research and Technology (1982); US Coast Guard (1974–1986).

To properly examine the data, uniform intervals based on volume of crude and condensate production, rather than time, were selected. Interval lengths were calculated to maximize the percentage of intervals with a single spill occurrence. This minimized misleading observations of zero spill intervals created by using production intervals of such short length that it was highly unlikely that a spill would be observed. Historical spill rates were calculated cumulatively from the first available interval forward through 1987, dropping the previous interval's record. The spill rate to be used in OSRA modeling was selected by identifying the point in the data base where major increases or decreases in the spill rates were no longer apparent, while maximizing the historical production record used (see Figs 3 and 4).

3.1.2 Worldwide tanker spill rates

The data base of worldwide tanker spills provided substantially more observations than the US OCS pipeline and platform data. Rates for tanker spills of 1000 bbl and greater were calculated directly from the data and were relatively constant from 1974 through 1985 (see Table 3).

3.2 Spills of 10 000 bbl and greater

Rates for spills of 10 000 bbl and greater for each of the three spill sources were calculated by applying the percentage of historical spills equal to and greater than 10 000 bbl, against the 1000 bbl and greater spill rate. These rates had previously been analyzed using a log-normal distribution

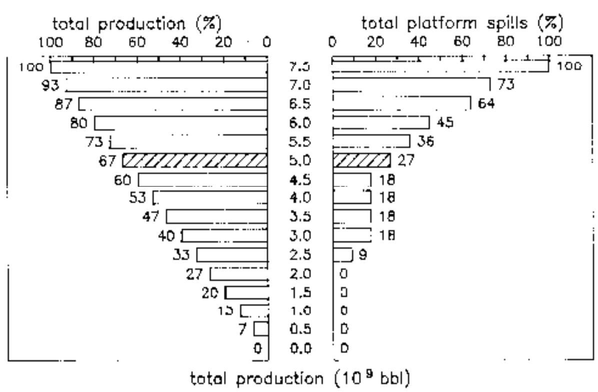

Fig. 3. Percentage of production and platform spills in the record, disregarding previous $0{\cdot}5 \times 10^9$ bbl intervals. Total production includes crude oil and condensate. 100% includes entire US OCS records, 1964–87. Subsequent percentages represent distribution, as the oldest $0{\cdot}5 \times 10^9$ bbl intervals are disregarded.

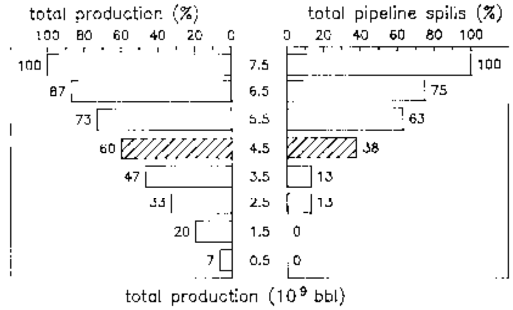

Fig. 4. Percentage of production and pipeline spills in the record, disregarding previous $1{\cdot}0 \times 10^9$ bbl intervals. Total production includes crude oil and condensate. 100% includes entire US OCS records, 1964–87. Subsequent percentages represent distribution, as the oldest $1{\cdot}0 \times 10^9$ bbl intervals are disregarded.

(Lanfear & Amstutz, 1983) and logarithmic regressions (Anderson & LaBelle, 1988). These previous methods were replaced because the small number of observed spills reduced the need for or benefit from exhaustive statistical treatment. The worldwide tanker spill rates can be calculated directly from the data with essentially the same result.

4 RESULTS

4.1 Spills of 1000 bbl and greater

Spill rates of 0·60 and 0·67 spills per 10^9 bbl were calculated for US OCS platforms and pipelines, respectively. These rates were selected because they reflect the observed decline in spill occurrence compared to the intervals based on the longest records, and they are based on the most recent 60% or more of the historical production record. Figures 3 and 4 illustrate the comparison of the historical production record against the spill record, showing that the percentages of the record included as the oldest data are dropped in increments of $0{\cdot}5 \times 10^9$ bbl and $1{\cdot}0 \times 10^9$ bbl production intervals, for platforms and pipelines, respectively. The shaded areas indicate the percentage of the record included in the spill rates selected for use in the OSRA. For example, Fig. 3 indicates that the selected 0·60 platform spill rate is based on the most recent 67% of the production record, which includes only 27% of the total number of historical spills (three spills over the last $5{\cdot}0 \times 10^9$ bbl of crude and condensate production). This means that 73% of all platform spills occurred during the first $2{\cdot}5 \times 10^9$ bbl of production and are discounted.

Likewise, Fig. 4 indicates that the 0·67 pipeline spill rate is based on the most recent 60% of the OCS production record, which contains only 38% of the historical spills (three spills over the last $4{\cdot}5 \times 10^9$ bbl of crude and condensate production).

Spill rates for spills from worldwide tankers occurring at-sea were calculated separately from those occurring in-port, both of which were based on an exposure of $107{\cdot}8 \times 10^9$ bbl of crude oil transported. These spill rates are 0·90 and 0·40 per 10^9 bbl, which are based on 97 at-sea and 43 in-port spills, respectively, as shown in Table 3.

4.2 Spills of 10 000 bbl and greater

Rates for spills of 10 000 bbl and greater for each of the three spill sources were calculated by applying the percentage of historical spills equal to and greater than 10 000 bbl, against the 1000 bbl and greater spill rate. This resulted in a rate of 0·24 spills per 10^9 bbl of oil handled for platforms and 0·17 for pipelines (see Table 4). The 10 000 bbl and greater spill rates are 0·55 for at-sea tanker spills and 0·16 for in-port tanker spills.

4.3 Comparison to previous rates

The updated platform and pipeline spill occurrence rates are significantly reduced from those of Stewart (1975, 1976) and Lanfear & Amstutz (1983) (see Figs 5 and 6). The primary reason for the reduction in rates calculated in this study is the low incidence of spill occurrence since 1980. This may be due to improvements in technology and safety regulation over time, combined with overall gains in experience in offshore oil production.

TABLE 4

Summary of Revised Oil Spill Occurrence Rates[a] Now Used in the OSRA Model

Spill source	*Spills of 1 000 barrels and greater*	*Spills of 10 000 barrels and greater*
Platform	0·60	0·24
Pipeline	0·67	0·17
Tanker (total)	1·30	0·71
At-sea	0·90	0·55
In-port	0·40	0·16

[a]Expressed in spills/10^9 bbl of oil handled.

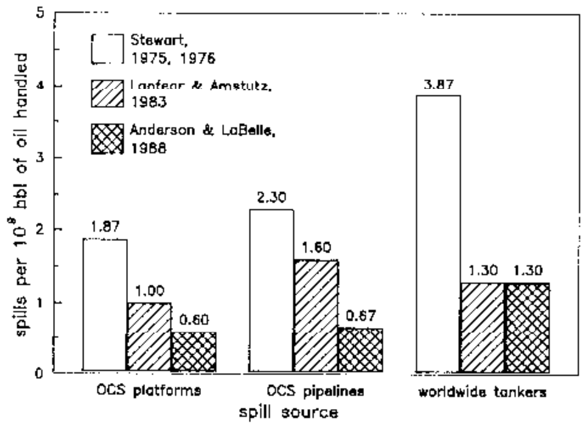

Fig. 5. OSRA model oil spill rates for spills of 1000 bbl and greater, 1988 revision compared with previous rates.

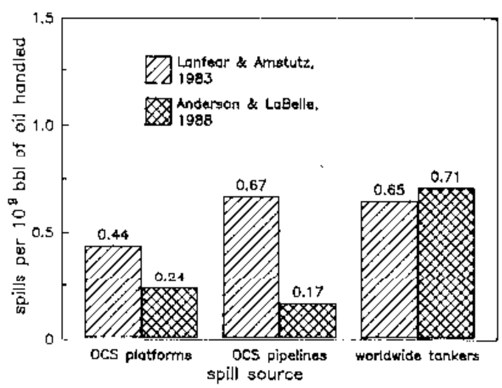

Fig. 6. OSRA model oil spill rates for spills of 10 000 bbl and greater; 1988 revision compared to 1983 rates.

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