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Oil Spill Risk Assessment

Final Report

September 1983

F.G. BERCHA AND ASSOCIATES LIMITED
LAVALIN OFFSHORE INC. - FENCO CONSULTANTS LIMITED
in conjunction with
DOME PETROLEUM LIMITED
ESSO RESOURCES CANADA LIMITED
GULF CANADA RESOURCES INC.

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EXECUTIVE SUMMARY

This report was commissioned by the Proponents in order to respond to questions and interventions raised to the E.I.S., particularly by Dr. Ray Lemberg (Specialist to the panel) and Dr. Phil Cohen (Environment Canada) and to clarify differences between published work of Fenco Consultants Ltd. and F.G. Bertha and Associates Limited. The work was undertaken jointly by Fenco Consultants Ltd. and F.G. Bertha and Associates under the guidance of a steering committee drawn from the Proponents, interveners, panel specialists and panel secretariat.

The method used was to prepare historical statistics for each component in the production and transportation systems. The statistics were:

Mean spill size (barrels);
Frequency of spill (spills/year); and,
Spill size probability distribution.

These statistics were then modified to make them appropriate for Arctic operation. In general, a more severe environment increases the risk whilst the remoteness from third parties and improved engineering decreased the risks.

These statistics were then used to predict the resulting oil spills for both pipeline and tanker systems with a base throughput of 100,000 barrels per day. Subscenarios were also considered, taking sections of the whole system and secondly, showing the effect of increasing throughput.

In preparing this report a comprehensive study was made of all available oil spills, both conventional and Arctic. This was made possible through the close co-operation of all parties concerned in using the supply of information from various regulatory, quality assurance and industry monitoring groups.

With minor exceptions where slightly more up-to-date statistics have been used, there are no significant changes from the information already tabled by

the Proponents. What has been achieved, however, is that apparently conflicting data has been compared on the same basis and has been found to be compatible.

The report shows that the various components comprising an Arctic production and transportation system, have different characteristics. Figure 1 shows the risk characteristics of each of the principle components. From this figure, the following may be noted:

Development drilling has a low probability of spills occurring but that these spills may be large if they occur.

A higher incidence of small spills are anticipated for pipelines, but the chances of large spills are much less and their spill volume is limited by pipeline size.

Tankers have similar risk characteristics to those of production and development drilling with slightly lower probabilities of a spill and slightly smaller maximum spill volumes.

Storage and cargo transfer have a relatively high probability of small spills and a small probability of a large spill.

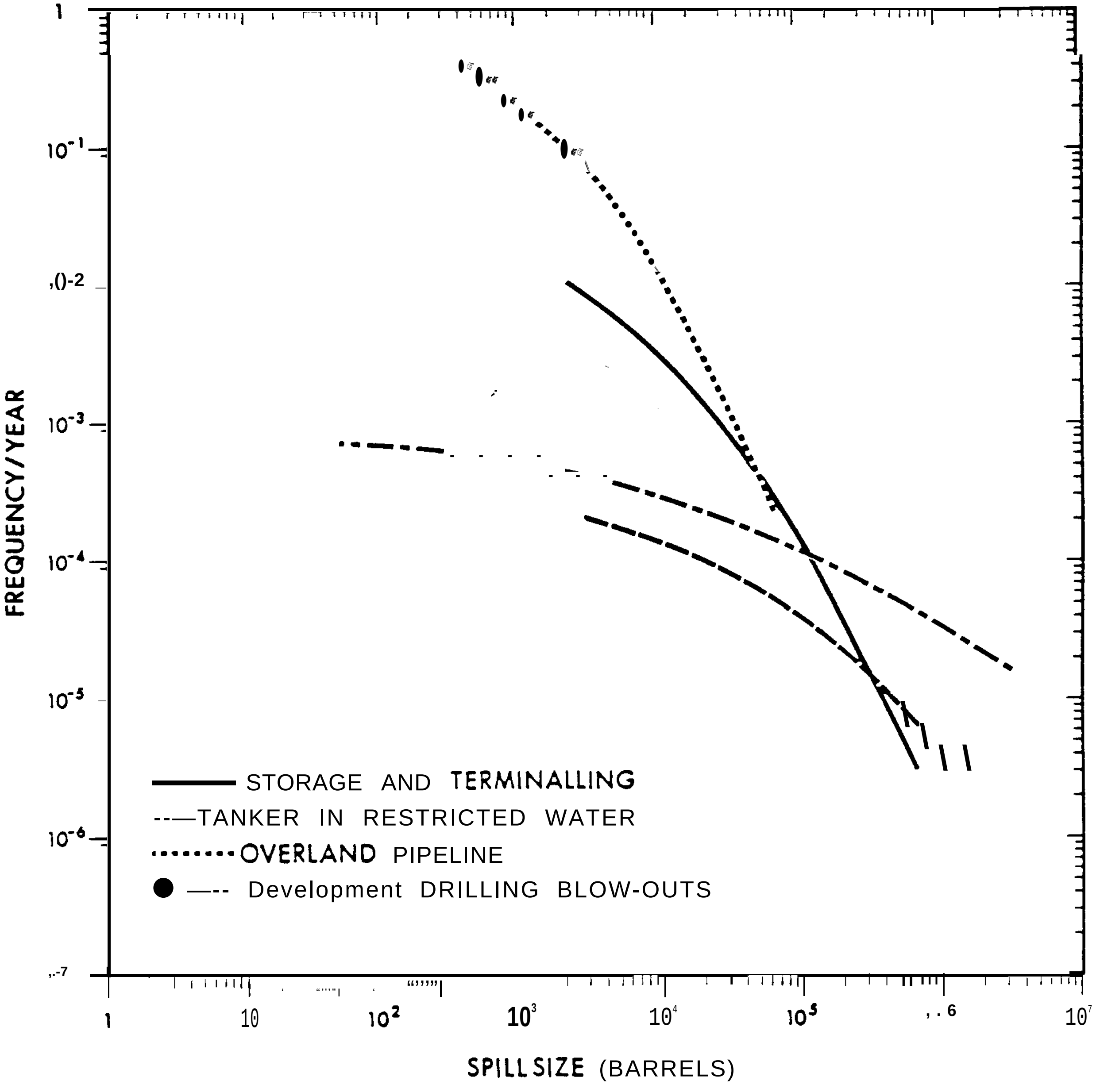


FIGURE 1 COMPONENT SPILL FREQUENCY AND SIZE

1.0 INTRODUCTION

The original Environmental Impact Statement submission contained sections dealing with both the possible environmental impacts under different scenarios and the risk of oil spills. As a result of various interventions and questions raised, particularly by Dr. Ray Lemberg (Technical Specialist to the Panel) and Mr. Phil Cohen (Environment Canada), it was felt that it would be helpful to show how the risks and the possible impacts link together.

By the end of June, a number of reports and documents had been tabled which by their very number had served to confuse rather than clarify. These are listed below:

1. The EIS

   VOL 2 - Development System
   VOL 6 - Accidental Spills

2. EIS Support Document

   "Final Report on Arctic Tanker Risk Analysis" (F.G. Bertha and Associates) [1] report to Dome Petroleum.

3. "Safety and Reliability Analysis of Arctic Petroleum Production and Transportation Systems". (Fenco Consultants Ltd.) Commissioned by Environment Canada [2].

4. Ray Lemberg Critique of the EIS (1 and 2 above).

5. Phil Cohen Critique of both the Bertha report (2 above) and the Fenco report (3 above).

6. Bertha's response to both critiques (4 & 5 above).

7. EIS deficiency response to the panel, "Supplemental Information - Environmental and Technical Issues" June 1983.

8. Pipeline Installation Protection and Repair Feasibility Study R.J. Brown report to Gulf, Dome and Esso [3].

The proponents, therefore, commissioned F.G. Bertha and Associates Ltd. and Fenco Consultants Ltd. (and its successor company Lavalin Offshore) to work together to produce a report identifying, explaining and hopefully resolving apparent differences. The work was carried out under the guidance of a steering group comprised of:

Mr. Brett Moore - Environment Canada
Dr. Phil Cohen - Environment Canada
Dr. Ray Lemberg - Lemberg Consultants - Technical specialist to the panel
Mr. Larry Wolfe - Panel Secretariat
Dr. Hans Kivisild - Lavalin Offshore - Fenco Consultants Ltd.
Dr. Frank Bertha - F.G. Bertha and Associates
Mr. Archie Churcher - Dome
Mr. Ed Caldwell - Esso
Mr. Jerry Gainer - Gulf

The proponents restricted the mandate of the group to risk analysis since that was the primary expertise of the group assembled. It should be noted however, that Ray Lemberg's Critique extended beyond risk into the areas of impact and cleanup capabilities. These are addressed in EIS Volume 6 and the response to deficiency statement pertaining to oil spill issues (June 1983).

While the proponents would like to extend their thanks to Messrs Moore, Cohen, Lemberg and Wolfe for their guidance, responsibility for the report rests solely with the proponents, F.G. Bertha and Associates and Fenco Consultants Ltd. who prepared the report.

The proponents included both tankers and pipelines in their EIS proposal since engineering and economics indicated that the choice could depend upon the development scenario under consideration as well as other factors. No direct comparison between the tanker transportation mode and pipeline mode was presented. The statistical base for marine (tanker) systems is significantly different (e.g. 1000 bbl minimum spill volume data cut-off) from production/pipeline statistics (50 bbl minimum spill volume data cut-off). For this and other reasons as noted in the Appendix C, "The Tanker/Pipeline Controversy", a comparison is rather like comparing apples and oranges and the reader is cautioned against making such an overly simplistic comparison.

The primary objective of this document is to show how data from both the original Environmental Impact Statement and the Fenco report to Environment Canada can be used in order to calculate risks at various levels; first, for a specific community; second, for a general area; and, third, for an entire system. Clarification is also given in areas where various interveners found ambiguity.

The method used is to show how the risks can be determined for the components of a base case. These risks are determined initially for conventional components (Section 3) and then modified for Arctic operation (Section 4).

The component risks are then used to calculate the risks for a number of different scenarios, particularly those scenarios used in the Environmental Impact Statement for the assessment of environmental impact (Section 5.0).

Appendix A gives a description of the mathematical approach used.

To avoid confusion between units, barrels have been used throughout this report as the unit of volume. Conversion factors are given in Section 2.0.

The EIS deficiency statement requested that risk be assessed for both chronic and episodic spills. For the purposes of this document, the following definitions are adopted. First, the distinction between intentional" and accidental spills. Some conventional non-Arctic petroleum activities, such as non-segregated ballast tanker operation, intentionally discharge small volumes of oil on a regular "basis. Because these discharges occur frequently, they may be called chronic. Such sources would be very few, and are limited to small concentrations of oil in produced water. Since accidents are individual by nature, they could be called episodic. We do know, however, that accidental oil spills have a size distribution. Experience world wide has shown that there are many more small oil spills (100 barrels) than there are large spills (100 000 barrels). The size distribution can be divided into three sections:

1) Small, frequent, chronic spills;
2) Medium, infrequent, spills; and,
3) Large, rare, episodic spills.

This analysis deals only with the probability or risk of spills of various quantities of oil; no other possible waste materials or pollutants have been considered.

. 2.0 BASE CASE AND GENERAL DATA

As the vehicle for this report, a base case has been chosen which represents an early production start point. Examples in Section 5.0 show how the base case can be used to calculate the risks for cases with differing throughputs or differing lifespans.

The base case supposes a hypothetical reservoir of some 750 million barrels of recoverable oil in a water depth of approximately 25 m. Given a 20 year life, this means a production of 100,000 barrels per day. This typically relates to a 16″ pipeline or to two tankers. For the purpose of this analysis, it is assumed that production would be achieved from 2S producing wells situated on two islands some five km apart.

The water depth of 25 m is appropriate since at this depth, both transportation systems are suitable. The water depth of 25 m represents a distance of roughly 65 km from the shore.

The overland pipeline from the Mackenzie Delta to its crossing of the Alberta border at 60-N would be approximately 1300 km long.

The pipeline would require a 12 hour storage volume, which is 50,000 barrels.

The tanker route would be approximately 4300 km (2300 nautical miles) to the same latitude of 60″N of which 2100 km would be within 50 nautical miles of land and is termed ‘restricted water’ and 2200 km would be in the ‘open sea’.

The tankers would have a capacity of 1,400,000 barrels (approximately 200,000 metric tons deadweight) and the tanker terminal would have a storage capacity of 2,300,000 barrels. Each tanker would make approximately 14 complete voyages per year. The loading time would be 12 hours.

A barrel is a measure of volume and is the standard oil barrel which was once used to transport oil by truck. There are 42 US gallons to a barrel, but only 35 Canadian gallons to a barrel. A cubic metre is also a measure of volume and there are .1591 cubic metres in a barrel. More conveniently, there are roughly 6 barrels to a cubic metre. A metric ton is a measure of mass and the density of the oil is needed to convert to barrels. There are roughly 7 barrels to a metric ton.

2.1 COMPONENTS

Components are the parts that are required to assemble a complete system. For instance, if the complete system is required to produce oil and move it south by pipeline, then the components are:

1) Development Drilling;
2) Production;
3) Sub-sea Pipeline;
4) Overland Pipeline; and,
5) Storage.

The total list of components for the systems proposed in the Environmental Impact Statement is as follows:

1) Development Drilling;
2) Production;
3) Subsea Pipeline;
4) Overland Pipeline;
5) Storage; and,
6) Tanker.

For each of the components, historical data have been used in ‘order to determine probabilities and spill sizes.

The first statistic determined is the frequency of oil spills. It is expressed as the number of spills per year. In the case of components involving distance, it is expressed as frequency per kilometre per year. It is found by considering the total number of recorded spills, and dividing by the length of time that these are recorded. Mathematically, when the frequency is small, it is interchangeable with probability. Many very small spills are not recorded in world statistics. The 'cut off' indicates the size below which spills are not recorded.

Associated with the probability of any spill larger than the cut off is the average or mean spill size. This is determined simply by taking the total volume spilled and dividing it by the total number of spills.

Probability of a spill and average spill size are important in determining the total volumes of oil spilled per year or for the life of the project.

There is a second environmental impact which may occur and this is" due to the release of a large volume of oil in a single accident. To examine this, a probability/size distribution graph is needed. In essence, we know that whereas small spills occur relatively frequently, large spills occur infrequently or have a lower probability of occurence. A probability/size distribution has been determined for each component.

3.0 CONVENTIONAL SYSTEM PROBABILITIES

3.1 INTRODUCTION

In presenting oil spill statistics regarding drilling and production, preferential use was made of the U.S.G.'S. information regarding the Offshore Continental Shelf - Gulf of Mexico (OCS - GOM) [41. This is the largest organized collection of spill data in existence and is virtually the only one with statistical significance. As such, it has been used extensively as a basis for estimating spill probability, both here and in the Supplemental Information - Environmental and Technical Issues filed by the proponents in June of 1983 and to which the reader is also referred.

It should be noted, however, tnat other data bases do exist. For instance, the Alberta Energy Resources Conservation Board (AERCB) has extensive data regarding the incidence of blowouts, as well as pipeline spills. While the AERCB data is not drawn from an offshore operation, they do clearly indicate Canadian climate operating experience. It is worthy of note that Canadian performance, particularly in the area of blowout prevention, compares favorably with worldwide statistics.

3.2 DEVELOPMENT DRILLING

Two categories of spills were analysed for Development Drilling (development drilling pertains to all drilling activity after exploration is complete when a reservoir has been identified as commercial and wells are being drilled for the purpose of producing). These categories are non-blowout related spills and blowouts.

a) Non-Blowout

As one would expect, the non-blowout spills tend to be small since they usually consist of spills of fuel oil or oil based drilling fluids brought to the rig. The upper limit of possible spill volume is virtually dictated by on-site storage capacity (about 500 bbl). Using data from the U.S.-GOM and [5], spill risks are estimated as 4.5×10^{-3} spills per well drilled with an average spill volume of 100 Bbls.

Spill sizes for rig spills are roughly exponentially distributed such that the probability that, given a spill, it will exceed size "x" is given as: $P(\text{spill} > x) = e^{-x/100}$.

b) Blowouts

Well control problems may be categorized into two classes:

1) Blow; and,
2) Uncontrolled Blow or blowout.

A <u>blow</u> is defined as a flow to the atmosphere of gas, oil, water or drilling fluid which is brought under control by closing appropriate equipment within a very short time frame (control regained almost immediately).

An <u>uncontrolled blow</u> is defined as a complete loss of control in which control can only be regained by the installation of equipment, killing the well, or drilling a relief well.

The latter incidents are generally called blowouts.

During 1970-1980, AERCB records show 19 drilling blowouts out of 45,062 wells drilled. The US-OCS-GOM statistics indicate a higher incidence of blowouts. This, more conservative, data base was used in the analysis but the reader should keep in mind the Canadian companies' superior record.

Using U.S. statistics from 1955-80 [5] some 12,400 wells were drilled resulting in 36 blowouts. During the same time period, there were 32 blowouts during production and workover operations. Of these 68 blowouts, only 8 released more than 50 bbls of oil (an additional 11 indicated a "trace" of oil) [41. Only one of the oil releasing blowouts, which occurred during workover, can be categorized according to production or drilling. The other 7 events could have occurred during either phase of operation. Therefore, the probability of an oil blowout during development drilling is estimated very conservatively as being less than or equal to 8 in 12,400 or 6.5×10^{-4} per well drilled with an average spill size of. 1300 bbls.

It is interesting to briefly consider how a well is likely to be brought under control. Of the 30 blowouts occurring during drilling on the U.S. O.C.S. from 1971 to 1978, 23 or-77% were controlled by <u>natural bridging in the well bore</u> while 7 or 23% were brought under control by surface kill methods. <u>None of the blowouts during that period required the drilling of a relief well</u>.

Larger spills can occur. In 1979, an exploration well in the Gulf of Mexico (Pemex - Ixtoc well) blew out producing the largest oil spill in history, roughly 3,100,000 bbls of oil, and requiring a relief well to bring it under control.

"Clearly the Ixtoc well was not subject to significant bridging in the wellbore. The hydrocarbon bearing formation in that well was a carbonate, whereas most of the Beaufort area is characterized by somewhat poorly consolidated sandstone. The latter type of geology would be expected to be somewhat more prone to "bridging" with consequent reduction or elimination of fluid discharge.

The matter of well productivities is also relevent to this discussion. Whereas the Pemex Ixtoc well initially flowed at a rate of 30,000 BOPD, well productivities tested in the Beaufort to date have been substantially less and, even flowing to atmospheric pressure, these wells would not normally be expected to sustain flows in the 30,000 BOPD range.

Needless to say, this single blowout has a profound effect on spill averages and other statistics.

The proponents took the conservative view that Ixtoc should be included and as a result figures are as follows:

Mean Size		34,000 bbls
Frequency		6.5×10^{-4} spills/well
Distribution	Lognormal	$\mu = 7.8$ $\sigma = 3.46$

3,.3 PRODUCTION

As with development drilling production, spills are sub-categorized into non-blowout and blowout spills.

a) Non-Blowout **Spills**

Because production lasts much longer than development drilling and entails a variety of equipment from the **wellhead** to trunk **line** (pressure vessels, etc.), one would expect more spills and this is substantiated by **USGS-GOM** statistics which show for the time period 1955-80, 1,083 reported production spills [51. Statistical analysis shows that the probability of having a spill greater than 50 **bbls** is 9.8 x 10^{-4} per well year with an average spill size of 290 **bbls** [41. The use of a data base which goes back to 1955 is conservative since more modern designs, materials and equipment are far less likely to spill oil.

The distribution is estimated as **lognormal** with
$\mu = 4.96$ $\sigma = 1.24$

b) Production Blowouts

Section 2.3.1 of Volume 6 of the EIS addresses offshore production accidents.

Only 4% of the "accidents'* resulted in blowouts; these blowouts in some instances resulted in significant oil spills. The Bravo blowout in the North Sea spilled between 150,000 and 200,000 **bbls** of oil, a blowout in the Gulf of Mexico (South **Timbalier**, 1970) spilled 53,000 **bbls** of oil, on the California coast a blowout spilled 77,000 **bbls** (Santa Barbara, 1969).

If only wells in the North Sea and Gulf of Mexico are considered, two blowouts are attributable to workover operations and up to 8 other blowouts (unspecified as to operation) have released oil over an exposure of about 37,000 well years [5,6]. The two blowouts during workovers account for about 95% of the oil spilled from all blowouts in the two areas. Assuming it quite likely that all 10 blowouts are in production operations, the blowout probability, P (spill > 50 bbls) becomes 2.7×10^{-4} per well year with a mean spill size of about 20,000 bbls.

The distribution is lognormal $\mu = 7.11$ $\sigma = 2.73$

3.4 SUBSEA PIPELINES

Subsea pipelines are divided into two subcategories, namely '*gathering lines" and "trunk lines". Gathering lines are typically relatively short pipelines (a few kilometres) which carry well fluids - oil, gas and sometimes water - from producing wells to processing facilities. In the case of an offshore production scenario, these lines would run from the satellite island to the main processing island. Because of the multi-phase nature of the fluids carried, leak detection is made more difficult and pin-hole leaks may not be recognized for several days. Total line failures or major leaks would be detected immediately by pressure drop. The base case gathering line system is assumed to be 5 km long.

Trunk lines would carry stabilized oil i.e. oil which has been separated from gas (and water), in a single phase line to the crude shipping terminal, either on shore (overland pipeline) or at sea (tanker system). The trunk line is assumed to be 65 km long in our base case.

Determining spill probabilities for subsea pipelines-is a difficult task, for several reasons:

1) Assuming the length of pipe as an exposure variable, the total length of pipeline within a study area is unknown. At best, only approximations can be made. [7,8,91 It has been assumed that the US-GOM data covered about 2000 km;

2) Reports do not usually distinguish between gathering and trunk lines; and,

3) Probabilities quoted in various reports are not necessarily compatible because of different minimum spill sizes included. Some samples of this are shown in the following - table:

Reference Source	cutoff	Probabilities	No. of Spills	Years of Exposure
[91	1000 bbls	0.25 x10^{-3} per km year	8	67-80 .
[41	50 bbls	0.79 x 10^{-3} per km year	24	67-81
[81	0 (?)	5.6 x10^{-3} per km year	134	69-80
[71	0 (?)	7.3 x 10^{-3} per km year	136	67-77

The proponents believe that the most applicable spill probabilities - would be obtained using North Sea statistics. Unfortunately, no one has compiled complete statistics from this area [71. For purposes of consistency, it was thus felt that using the USGS-GOM data [41 would be most comparable to other system probabilities presented in this chapter. The probability is thus presented as P (spill > 50 bbls) = 7.9 x 10^{-4} per km year. If only spills from 1975 forward are considered, then the number of spills drops to 9 with a probability of 4.9 x 10^{-4} spills per km year and a mean spill size of 1,200 bbls. Statistics from 1975 onwards are believed to be most indicative of current pipeline technology. If these spills are divided between gathering and trunk lines (from 1975) it is estimated that the average gathering line spill is 200 bbls , and trunk line spill 2,400. bbls. These estimates are approximate and moreover cannot be assigned unique probabilities as no information is available to clearly distinguish between lengths of subsea gathering and trunk lines.

The distribution of oil spill size for trunk subsea pipelines is lognormal $\mu = 6.49$ $\sigma = 2.37$

3.5 OVERLAND PIPELINE

Spills from overland pipelines are described on pages 7.3 and 7.4 of Volume 6 of the EIS. Additional statistical information is provided in the Environmental and Technical Issues - Oil Spills material provided by the proponents in June, 1983.

As with subsea pipelines, the total length of pipeline per year is chosen as an exposure variable. Using Canadian statistics [101 from 1977-1981, 206 spills occurred of > 10 bbls in some 146,000 km years of pipeline operating experience to give a spill probability P (spill > 10 bbls) of 1.4×10^{-3} per km year, with an average spill size of 900 bbls. For purposes of comparison with subsea pipelines, it is better to estimate the average spill size and probability of spills for a 50 bbl cutoff point. Choosing a 50 bbl cutoff would result in an approximate spill probability, P (spill > 50 bbls) of 9.7×10^{-4} per km with an average spill size of 1,300 bbls.

The distribution is estimated as lognormal with $\mu = 5.52$ $u = 1.52$

3.6 STORAGE

Using Oil Spill Intelligence Report as the primary data base [11], a total of 141 storage spills occured in the period 1979 to 1981. Of these, 100 spills were well documented, resulting in a total volume spilled of 1,380,000 barrels. This gives a mean spill size of 13,800 barrels.

From references [121, it was deduced that over the same period a total of 3.5×10^9 barrels were stored on an annual basis. The spill frequency is therefore, calculated as follows: 13.4×10^{-3} spills/million barrels stored per year.

The spill size distribution has been calculated as lognormal with $\mu = 6.97$ and $\sigma = 1.72$.

The cut off size is 250 barrels.

3.7 TANKERS

Specialized crude oil tankers have been carrying oil for the last one hundred years.

The rapid increase in consumption of oil products in the 1960's combined with the decline in continental U.S. production, resulted in increased volumes being transported. In the late seventies, the volumes transported annually were approximately 12.5×10^9 bbls . A corresponding increase in crude oil pollution was observed with a few very large spills being responsible for a large fraction of the spilled volume.

The problem of oil pollution from tankers began to be studied scientifically in the middle sixties. At that time, however, the data base describing the types of accidents that occurred was too redictions of future oil spills could not be made with lar accuracy. A key study was performed in 1973 the U.S. OCS development [13]. That study clearly he problems relating to the statistical analysis of s. These were:

e range of spills is extremely large;

reat majority of spills are at the lower end of this and,

the oil is spilled in a few very large spills.

ase Selection

osing a data base for this risk analysis, the following s were considered:

he completeness of the data base, which is measured by he total number of spills and the total volume of oil pilled;

he detail of the information, in particular, the ocation of the spill and the size of the individual pills;

he time period of the data base; and,

he cut-off size used for the data base.

y, we were looking for a data base:

hat was complete in that it recorded all spills that ad happened;

2) That the detail showed us whether the spill had occurred in open sea or in restricted waters or in port;

3) That the size of the individual spills were recorded;

4) That the time period for the records was at least five years and preferably, ten years; and,

5) That the cut-off size was not in excess of 1000 barrels.

The following data bases were examined. Firstly, the data base provided by I'Institute **Francais** du **Petrole** [14, 15, 161; second, the Oil Spill Intelligence Report [111; third, the International Tanker Owner's Pollution Federation [171; and fourth, the Minerals Management Division [181.

The best data base came from Minerals Management Division, which had a cut-off of 1000 barrels, a life of nine years and had the spills broken down with the volume of each spill and the location of port, restricted water and open sea. None of the other data bases gave the breakdown of location of spill; however, the Minerals Management Division did not appear to be the most complete data base, as, when compared with other data bases, it gave lower yearly totals.

The approach used, therefore, was to use the Minerals Management Division in order to obtain the spill size distribution and then to take the spill size distribution related to the frequency of spills and increase the number of spills to achieve the maximum recorded in the other data bases. In this way, a workable data base was obtained.

3.7.2 Calculation of “Conventional” Probabilities

Using the Minerals Management Division data base, the following table is obtained for the years 1974 to 1982 inclusive (9 years).

Location	Number of Spills	Volume Spilled	Average Volume Spilled (bbls)
Port	86	2,801,533	33,351
Restricted Water	126	8,555,217	67,893
Open Sea	20	1,675,371	83,768
Unspecified	14	170,243	
TOTAL	244		

“Port” includes when the vessel is **manoeuvreing** in the **harbour** and is tied up to the pier. “Restricted Water” means within 50 nautical miles of land.

The first step is to reallocate the unspecified spills in the same ratio as the spills with recorded location.

Port	84	+ 5	= 89
Restricted Water	126	+ 8	= 134
Open Sea	20	+ 1	= 21
		14	244

The second step is to increase the number of spills to match the maximum total volume spilled. The highest numbers recorded are from [14, 15, 161, which when averaged over the 9 year period in question, predict a total volume of oil spilled as 25,500,000 barrels. The spills are increased again holding the ratios between spill location constant.

Port 168 x 33,351 = 5,602,968
Restricted Water 252 x 67,873 = 17,109,036
Open Sea 40 x 83,768 = 3,350,720
26,062,724 bbls

The third step is to calculate spills per year.

Port 168/9 = 18,6 spills/year
Restricted Water 252/9 = 28.0 spills/year
Open Sea 40/9 = 4.4 spills/year

The fourth step is to examine the total performance of the world fleet in order to obtain spills per port call and spills per kilometre year. The data are drawn from the United Nations Conference for Trade and Development (UNCTAD) [19]. During the period in question, the world tanker fleet averaged the following performance.

1,774,000,000 tons shipped per annum (12.5 x 10^9 barrels)
8,707,000,000,000 tons miles transport capacity (100.8 x 10^{12} barrels km)
337,000,000 tons deadweight fleet capacity (2.4 x 10^9 barrels)

This gives an average voyage length of 4,908 miles (7,896 km). From Reference [12], the average number of tankers in operation was 3,100.

This gives an average vessel size of 112,000 tons dead weight (806,400 barrels), and gives 15,839 average voyages per year and 5.3 voyages per ship. Conservatively assuming 2 port calls per voyage, this gives 31,679 port calls per year.

Unfortunately, no split is made between "restricted water" and "open sea". **At** first sight, it might appear that much of the voyage is in "open sea", giving say a **90:10** split, Further examination showed many coastal voyages around North America and Northern Europe are totally in restricted water and the ratio of the split would rise. Since the "restricted water" has the highest risk, a-conservative value of **50:50** is assumed.

Using these figures, the following spill frequencies can be calculated:

Port 18.6/31,679 = 5.8×10^{-4} spills/port call
Restricted Water **28.0/(3,100x5.3x3,948)** = 4.3×10^{-7} spills/km year
Open Sea 4.4/(3,100x5.3x3,948) = 6.7×10^{-8} spills/km year

The final step is to use the sizes of each individual spill to calculate the distribution based on the log normal approach described in Appendix A. This gives:

Port μ = 7.93 a = 1,86
Restricted Water μ = 8.97 a = 2.19
Open Sea μ = 9.90 a = 2,30

4.0 ARCTIC SYSTEM PROBABILITIES

4.1 INTRODUCTION

The environment over the long term, has a predictable pattern but the individual events are not predictable. For instance, the 20 year return period storm for the Beaufort Sea may have a wave height of 6 metres. This predicts that once every 20 years a storm of this severity will occur but it does not predict when it will occur, i.e. the first year or the sixth or the fifteenth year.

Engineers, when designing equipment, use this approach to set safety design criteria. For instance, for North Sea Oil operations the generally accepted value is the 100 year return period. This is used for such environmental factors as waves, wind, temperature, etc. So in the case of a North Sea platform, the 100 year wave may be 25 metres and this is the basis for the design. If for instance North Sea risk statistics are to be used as a basis for Arctic risk statistics, then it is important to see that the safety design criteria are set at the same level, i.e. the 100 year return period. This means that an Arctic platform or island would be designed for the 100 year wind, 100 year ice island, 100 year wave, etc.

The proponents have made the commitment that the environmental safety design criteria for Arctic operations will never be less than the 100 year return period criteria for each of the environmental factors, which is the same as the North Sea. This then allows the use of North Sea and other world statistics.

The methodology adopted was to use historical statistics and then to adjust those probabilities to reflect Beaufort plans and conditions and the particular 100,000 BOPD scenario. In so doing, it became clear that while significant improvements are expected in most components due to safer operating methods or new technology, the effect of some improvements would be very difficult to quantify. Where this has occurred, the conservative or higher risk number has been used.

4.2 DEVELOPMENT DRILLING

4.2.1 Development

Drilling - Non-Blowout

This is a relatively unimportant component from the point of view of oil spill risk contributing less than 1% of the 'expected spill volume'. Industries' performance in the Arctic has been without major incident. Worldwide statistics can be applied, unmodified, to Arctic conditions. That is, a mean spill size of 100 bbl with a spill probability of 4.5 x 10^{-3} per well drilled. The distribution remains the same.

4.2.2 Development

Drilling - Blowouts

Technology and methods used in the Arctic are comparable to those used elsewhere. Historically, spill rates have decreased as development and operations continue. Operations in the Beaufort Sea will use and build upon the experiences of operations in the Gulf of Mexico, North Sea and Alaska; however, the likely improvement is difficult to quantify. Therefore, despite Canadian industries' superior record (AERCB statistics, 1970-1980), it was decided to rely upon the Gulf of Mexico data base. In order to take a conservative assessment, worldwide statistics are used without modification.

4.3 PRODUCTION

4.3.1 Production Non-Blowouts

No modification of worldwide statistics was undertaken since there is no significant change to either the equipment or the mode of operation. Like non-blow out spills in development drilling this is a relatively unimportant component from the point of oil spill risk contributing less then 1% of the expected spill volume. The mean spill size is 290 barrels with the spill frequency 9.8 x 10^{-4} spills/well year. The distribution is log normal $\mu = 4.96$ $\sigma = 1.24$.

4.3.2 Production Blowouts

Two factors affect the transfer of worldwide blowout statistics to the Arctic. The first is the introduction of newer technology and safety measures. The use of storm chokes or down-hole safety valves (DHV's), as recently became mandatory (Canada Oil and Gas Production Regulations; Section 27 - Draft, September 1982) is expected to reduce the probability of a blowout due to damaged surface equipment. Tests on D.H.V. have indicated a high success rate and hence the probability of a blowout is conservatively reduced by 50%.

The second factor affecting transference, is the estimated time to drill a relief well should one be required. Roughly 10% of blowouts have required wells to bring them under control [51. The remainder of the wells either bridged naturally or were controlled from the surface. These wells have taken as little as 5 days to as long as 137 days to stop the blowout. Section 4.4.7 of volume 2 of the EIS (page 4,64) addresses the issue of relief well drilling in Beaufort Operating and 45–60 days are assumed to be necessary to drill

1

a relief well in the Beaufort. This is longer than conventional relief wells and accordingly the mean spill size has been increased by taking into account the 10% of which required relief wells. The mean spill size has therefore been increased by 10%.

The mean spill size becomes 22,000 barrels and a spill frequency of 1,3 x 10^{-4} spills/well year - the distribution is $\mu = 7.20$ $\sigma =$ 2.73.

This mean spill size might typically be caused by a well flowing at 3,000 barrels a day initially. The flow would reduce due to presume drop in the reservoir, natural bridging and control measures. Allowing 15 days for control the spill would result in 22,000 barrels. The EIS however in Volume 6 " page 6.24 considered the worst case where a 60 day period is required and further assumed the well flows, undiminished at a 12,000 BOPD rate. The maximum spill volume becomes 720,000 bbl .

4.4 SUBSEA PIPELINES

Two factors have been applied to the conventional subsea pipeline statistics for the Arctic situation. First, the spill probability was reduced due to the expected decrease in corrosion failures. Second, the spill probability was increased due to the risk of ice scour.

A third factor concerns third party damage. Typically this ocurs when the anchor of a vessel drags over the pipeline. It can be argued that due to the small number of ships in the Beaufort Sea that this would reduce the frequency. In addition what ships are there are controlled by the proponents and this would further reduce the frequency. One proponent however have taken the conservative view point that there will be no reduction in frequency due to reduction of third party damage.

The proponents expect that corrosion can be essentially eliminated as a potential source of subsea pipeline failure. External corrosion will be mitigated by cathodic protection systems, high quality anti-corrosion coatings, heavy wall pipe, and wall thickness monitoring (by instrumented pig). Internal corrosion **will** be mitigated by corrosion inhibitor (if necessary), heavy **wall** thickness and wall thickness monitoring. **A** conservative **75%** reduction in corrosion related failures has been assumed. This, combined with the 32% of failures caused by corrosion [7] results in a 24% reduction in overall failure probability.

While the probability of a spill has been reduced due to a **reduction** in corrosion related failures it must be increased due to the potential for ice scour. The design criteria established by **R.J.** Brown was a system return period of 1250 years. **For** a subsea system consisting of 65 km of trunk line and 5 km of gathering line this implies a probability of a failure of

$$\frac{1}{1250 \text{ year} \times (65+5) \text{ km}} = 1.1 \times 10^{-5} \text{ spills/km-year}$$

This conservatively assumes that every ice keel/pipeline contact results in a pipeline failure and a spill. Considering the conventional probability of 4.9 x 10^{-4} spills per km/year. An overall reduction of 24% and an increase of .1 x 10^{-4} (or 1.1 x 10^{-5}) results in an Arctic subsea pipeline **spill** probability of 3.8 x 10^{-4} spills per km-year (see Table 4.4.1),

It is generally assumed that the smaller the pipeline the smaller the oil spill the calculations carried out by **R.J.** Brown indicate that for a 16″ time expected spill volumes are 1300 **barrels**.

Unfortunately world wide statistics on subsea pipeline oil spills do not correlate volume with time diameter or with cause [4]. Te proponents have therefore adopted the conservative number of 2400 barrels for the trunk line which is the same as the world wide all pipeline statistics. The mean gathering system failure was thus left at 200 barrels and the mean trunk line failure left at 2400 barrels.

4.5 OVERLAND PIPELINES

In the case of the Arctic overland pipeline, North American Statistics are used as a basis since these are the most comprehensive available. Judgement is similarly exercised in altering both anticipated spill size and probabilities, where this is thought reasonable.

An overall reduction of 26% in the anticipated probability of pipeline related spills results from the analysis. Corrosion failures are reduced by 75%. This is felt reasonable due to enhanced corrosion mitigative measures and monitoring programs.

Another source of pipeline failures is attributable to third party damage. This typically happens when mechanical excavation equipment inadvertently makes contact with the pipe. Since Arctic pipelines will be located remotely from populated areas it is unlikely that third party construction will interfere with the system. In the event that other pipeline or third party construction is required in the vicinity of the existing system these activities would be strictly monitored and controlled. It has been conservatively assumed that there will be a 50% reduction in spill probability related to third party damage.

TABLE 4.4.1

SUBSEA PIPELINES

CONVENTIONAL VERSUS ARCTIC SPILL PROBABILITIES

CAUSE OF SPILL	% OF CONVENTIONAL FAILURES [71	% FAILURE REDUCTION	RESULTING % OF ARCTIC FAILURES RELATIVE TO CONVENTIONAL
Corrosion	32	75	8
Other	<u>68</u>	0	<u>68</u>
TOTAL	100		76

Conventional Spill Probability	4.9×10^{-4}
Reduction from Corrosion	1.2×10^{-4}
Addition due to ice scour	0.1×10^{-4}
Arctic Spill Probability	3.8×10^{4}

TABLE 4.5.1

OVERLAND PIPELINES

CONVENTIONAL VERSUS ARCTIC SPILL PROBABILITIES

CAUSE OF SPILL	% OF CONVENTIONAL FAILURES [101	% FAILURE REDUCTION	RESULTING % OF ARCTIC FAILURES **RELATIVE** TO CONVENTIONAL
Corrosion	21	**75**	5
Third Party Damage	20	50	10
Other	**59**	0	59
TOTAL	100		74

TABLE 4.5.2

OVERLAND PIPELINES

ARCTIC MEAN SPILL SIZE CALCULATION

	CONVENTIONAL			ARCTIC	
	SPILL **FREQUENCY** **BY** CAUSE (%)	PART OF TOTAL SPILLED (%)	REDUCTION	SPILL FREQUENCY **BY** CAUSE	PART OF TOTAL SPILLED
Corr.	21	9	.25	5.25 (, 7%)	2.25 (2.9%)
3rd P.	20	29	.50	10 (13.5%)	14.5 (18.4%)
Other	**59**	**62**	**1.0**	**59** **(79.5%)**	**62** **(78.7%)**
TOTAL	**100**	**100**		74.25 (100%)	78.75 (100%)

Frequency of spills reduced by 26% (74,25/100) overall

Mean spill size **increased** by 6% (78.75/74.25)

or 1300 x 1.06 1400 **bbls**. per spill

It should be **noted** that a major contribution to pipeline failure statistics is referred to as “Other” in Table 4.5.1. This category combined several reasons for pipeline spills including, operator error, mechanical failure etc. It was felt that it would be difficult to assess the degree to which these could be individually reduced. It was therefore decided to leave this value unchanged in order to reflect a worst case overall estimate of anticipated pipeline spills.

Table 4.5.2 details how the mean Arctic spill size of 1400 barrels is derived. The elimination of most of the small corrosion spills results in an increase in mean spill size despite a net decrease in both probability of spills and total expected spill volume.

The overall conclusion for both subsea and overland pipelines is that the Arctic pipelines will have about the same **oilspill** performance record as conventional modern pipelines.

4.6 STORAGE AND TERMINALLING

Analysis of conventional storage facilities showed the causes of storage oil spills as displayed in Table 4.6.1. In view of the fact that the storage for the tanker is offshore, the contribution of vandalism and warfare has been deleted. The spill frequency is, therefore, reduced to 10.7 x 10^{-3} spills/million barrels stored per year. For the particular storage considered in the base case (2,300,000 million barrels) this becomes 24.6 x 10^{-3} spills/per year. The frequency of overall failure of the production facility is estimated at 3.3 x 10-3/year. The spill frequency is therefore 27.9 x 10^{-3} spills/per annum.

The Arctic storage would have secondary containment as is the case with conventional storage system. Since the storage tank volumes in the **Arctic** are not dissimilar to those of conventional systems

TABLE 4.6.1

CAUSES OF STORAGE SPILLS [111

	%
Human Error	37.5
Material Failure	25.9
Vandalism	16.8
Warfare	3.8
Weather Conditions	6.1
Fire and Explosion	7,6
Collision	1.5
Unknown	- 8
	100. o%

is was felt that the mean spill size should remain the same at 13,800 **bbl**.

The **lognormal** distribution remains unaltered.

4.7 TANKERS

The problem of oil spills from Arctic tankers was addressed by **Fenco** in [21 and Bertha in [11. In [21, **Fenco** looked at the tanker designed according to the Canadian Arctic Shipping Pollution Prevention Regulations **(CASPPR)** and concluded that a tanker designed to these regulations and operating in the Arctic would have approximately the same level of safety as the conventional open water tankers have on the major trading routes of the world. In [11, Bertha considered a tanker that not only complied with all the **CASPPR** regulations, but also had additional features as follows:

1) The hull strength exceeding **CASPPR** by ratios of up to three.

2) The **compartmentation** of the hull giving 100% segregated ballast, and in addition, no potential pollutant is carried next to the shell of the vessel;

3) The main hull girder strength being approximately three times greater than that of a conventional tanker;

4) The stresses in the hull being monitored in real time and displayed on the bridge;

5) There are two rudders;

6) There are two propulsion systems;

7) That both propulsion systems will have high speed reversing capabilities;

8) That both propulsion systems will generate full power astern;

9) There are duplicated inert gas systems;

10) There are duplicated iceberg detection systems;

11) The level of manning being increased to provide duplication of watch officers at all times;

12) There is no pump room and deep well pumps are used; and,

13) That compressed air will be used to maintain buoyancy if bottom damage is sustained.

Bertha used a fault tree analysis method in order to evaluate the effect of these changes for the main modes of failure; namely, collision, explosion, grounding, iceberg collision, ramming and structural failure. Bertha concluded that for an Arctic tanker operating the complete route from the Beaufort Sea to the Canso area of Nova Scotia, Route #1, the level of safety would be increased by 147 times [1] compared to a conventional tanker on a route of similar length. In essence, this is the expected total spill volume reduction factor. This factor consists of two parts, approximately 100 times improvement in the probability of a spill and a 1.5 times improvement in the spill size.

During the work undertaken for this report, both Bertha and Fenco worked together with the objective of checking each other's data and checking each other's methodology. Both parties concluded the following:

1) Since the Bertha EIS tanker is under consideration, engineering data for this vessel would be used and not the Fenco CASPPR tanker;

2) That the fault tree method used by Bertha is more applicable for this exercise than that used by Fence. The fault tree method is, therefore, adopted for this report; and,

3) Fence, having checked Bertha's data, for the input into the fault trees and having checked the fault trees themselves, agrees with all aspects of Bertha's work with the exception of two areas.

Fenco questions the assumptions used in the Bertha fault tree analysis to determine oil spill reductions due to iceberg and multi-year ice collision accidents. These questions were based on Fenco experience in actual iceberg monitoring and reporting on ice strength surveys.

A sensitivity analysis was performed to assess the effect if no reduction was assigned to the iceberg collision scenarios shown in Table 5.3 of [11, Route #1, and if a factor of 1 instead of 0.5 was assigned to damage risk for conventional tanker in ice. This analysis showed that there was only a small change in the oil spill probability reduction factor and consequently the original values are used.

Secondly, although Fenco could see some evidence for the reduction of the mean spill size, they concluded that there was insufficient evidence to justify the 30% reduction proposed in the Bertha report. For this report, a conservative value was adopted, namely, that there would be no reduction in spill size.

Thirdly, the probability of a pollution causing incident is calculated P_{PI} by multiplying the P_I by F_E. These are summed (or the three areas of operation to obtain $'_{PI}$ Arctic

The last stage is to find the ratio of the probability of a spill causing incident for Arctic and conventional tankers as follows:

$$\text{Ratio} = \frac{P_{PI}\ \text{Arctic}}{P_{PI}\ \text{Conventionally}}$$

The important parts of the results of Bertha's fault tree analysis are shown in Figure 4.7.1, 4.7.2 and 4.7.3. As has been stated the volume factor originally included in the Bertha report has been deleted in these tables.

The tables can be explained as follows. Firstly the fault trees are run for a conventional tankers on a similar route to obtain the probabilities of pollution causing incident for the five types of incident. These are the proportioned according to Table 4.7.2 [21,221 to take account of the differences between port, restricted water, and open sea. These were then checked against historical statistics to ensure that the results checked with history. These are the numbers marked P_{PI} conventional.

Secondly the fault trees are run using ten all improvements such as twin rudders which will be fitted to the Arctic tanker. These improvements decrease the probability of having an incident. These are marked P_I and are calculated for five types of incident and the tree areas of operations.

Thirdly the increased strength of the Arctic tanker is assessed. Since this is done by calculating the increase in energy to penetrate a cargo tank using **Minorsky's** method. This is shown in Table 4.7.3 used in Table 4.7.1 as F_E energy factor. Again these are calculated for the five types of incident and the tree areas of operation.

The conventional tanker probabilities and data can, therefore, be modified to the Arctic tanker as follows. There is no change in the mean spill size and consequently, the shape of the log normal distribution does not change. There will be changes in the spill frequencies as shown below.

<u>Location</u>	<u>Spill Frequency</u>
Port	$5.8 \times 10^{-4} \times 0.85 \times 10^{-2} = 4.93 \times 10$-6/voyage
Restricted Water	$4.3 \times 10^{-7} \times 1.0 \times 10^{-2} = 4.3 \times 10$-9/km year
Open Sea	$6.7 \times 10^{-8} \times 1.1 \times 10^{-2} = 7{,}37 \times 10^{-10}$/km year

Since these values are extremely small, it is more convenient to consider a full year's operation of one ship, i.e. a ship year.

Port	$4.93 \times 10^{-6} \times 14$	= 6.9 x 10-5/ship year
Restricted Water	$4.3 \times 10^{-9} \times 14 \times 2{,}000$	= 1.44×10^{-4}/ship year
Open Sea	$7.37 \times 10^{-10} \times 14 \times 2{,}200$	= 2.26 x 10-5/ship year

Appendix D explains in more detail, the effect of the engineering changes for the Bertha EIS Arctic Tanker.

Appendix E explains

1) How the histograms 5.1 through 5.10 of Reference [1] can be used to show the relative effects of the engineering changes; and,

2) How the probabilities in Table 4.4 Reference [11 were obtained and the sensitivity of these numbers to the final risk reduction factors.

TABLE 4 ..1

SUMMARY OF ARCTIC TANKER OIL SPILL ACCIDENT PROBABILITY REDUCTION

PROBABILITY	PORT					RESTRICTED WATER					OPEN SEA				
	C	E	G	R	SF	C	E	G	R	SF	C	E	G	R	SF
P_I	1.72×10^{-4}	8.91×10^{-8}	7.53×10^{-4}	2.61×10^{-4}	1.00×10^{-4}	1.10×10^{-5}	1.14×10^{-9}	1.17×10^{-4}	6.53×10^{-5}	3.52×10^{-7}	4.69×10^{-6}	6.17×10^{-9}		5.24×10^{-5}	1.19×10^{-5}
F_E	1.40×10^{-2}	1.55×10^{-1}	8.40×10^{-3}	6.0×10^{-3}	1.22×10^{-1}	2.45×10^{-2}	1.85×10^{-1}	1.35×10^{-2}	6.0×10^{-3}	1.39×10^{-1}	2.67×10^{-2}	1.03×10^{-1}		1.25×10^{-2}	8.91×10^{-2}
P_{PI}	2.40×10^{-6}	1.38×10^{-8}	6.32×10^{-6}	1.57×10^{-6}	1.22×10^{-5}	2.69×10^{-7}	2.12×10^{-10}	1.58×10^{-6}	3.92×10^{-7}	4.89×10^{-8}	1.25×10^{-7}	6.36×10^{-10}		6.56×10^{-7}	1.06×10^{-6}
ΣP_{PI} Arctic	$2.25 \times 10^{-5} = 0.00852$					$2.29 \times 10^{-6} = 0.010$					$1.84 \times 10^{-6} = 0.0109$				
ΣP_{PI} Conventional	2.69×10^{-3}					2.24×10^{-4}					1.69×10^{-4}				
RATIOS	117:1					100:1					92:1				

P_I Probability of an incident

F_E = Energy Factor

P_{PI} = Probability of a pollution causing incident

Accident Type

C = Collision

E = Explosion

G = Grounding

R = Ramming

SF Structural Failure

TABLE 4.7.2

RATIO OF ALL ACCIDENT TYPES BY TANKER LOCATION

ACCIDENT TYPE	LOCATION			
	PORT	RESTRICTED WATER	OPEN SEA	TOTAL
Collision	73	18	9	100
Explosion	52	12	36	100
Grounding	20	80	0	100
Ramming	15	60	25	100
Structural Failure	4	15	81	100

TABLE 4.7.3

REDUCTION FACTORS FOR ARCTIC TANKER ENERGY FACTORS

ACCIDENT TYPE	FACTOR
Collision	.07
Grounding	,03
Ramming	.05
Explosion	.43
Structural Failure	.33
Iceberg Collision	.015

5.0 SCENARIOS

5.1 INTRODUCTION

The data from Sections 3.0 and 4.0, which is tabulated in Table 5.1.1, can now be used in order to show the expected spill volumes for both tanker and pipeline scenarios. **A** total of ten scenarios has been chosen; five for the pipeline case and five for the tanker case. These are discussed below under 5.3 Detailed Scenarios. For each case, the appropriate components have been tabulated showing the expected spill volume, both on a one year basis and on a twenty year basis. In order to show the relationship between the probability of a spill occurring and the size of a spill, a probability exceedance curve has been used and this is discussed below. In order to link Volume 6 of the **E.I.S.** "Accidental Spills", the actual spill volumes considered in Volume 6 have been plotted on the probability exceedance curves prepared for the system components.

5.2 PROBABILITY EXCEEDANCE CURVES

In order to graphically display the data from Section 3.0 and 4.0, the probability exceedance graph has been chosen. In this method, the bottom axis of the graph (see Figure 5.1), is the spill size and the vertical axis is the probability.

The graph can be used by taking a specific spill size, say 10^5 barrels, and reading up to the appropriate component curve and then reading across to find the probability of occurrence. For instance, in the case of the overland pipeline spill (Curve 4), a 10^4 barrel spill has an annual probability of approximately 8 x 10^{-6}.

TABLE 5.1.1
CONVENTIONAL AND ARCTIC SPILL ɐʌᴉΛ

COMPONENTS	CONVENTIONAL				ARCTIC		
	CUTOFF	MEAN	FREQUENCY	DISTRIBUTION	MEAN	FREQUENCY	DISTRIBUTION
Development Drilling Excluding Blowouts	<5 bbl	100 bbl	4.5×10^{-3} Spills/Well	Exponential $P(x) = e^{-x/100}$	100 bbl	4.5×10^{-3} Spills/Well	Exponential $P(x) = e^{-x/100}$
Development Drilling Including Blowouts	50 bbl	34,000 bbl	6.5×10^{-4} Spills/Well	Lognormal $\mu = 7.80$ $\sigma = 3.46$	31,000 bbl	6.5×10^{-4} Spills/Well	Lognormal $\mu = 7.80$ $\sigma = 3.46$
Production Excluding Blowouts	50 bbl	290 bbl	9.8×10^{-4} Spills/Well Year	Lognormal $\mu = 4.96$ $\sigma = 1.24$	290 bbl	9.8×10^{-4} Spills/Well Year	Lognormal $\mu = 4.96$ $\sigma = 1.24$
Production Including Blowouts	50 bbl	20,000 bbl	2.7×10^{-4} Spills/Well Year	Lognormal $\mu = 7.11$ $\sigma = 2.73$	22,000 bbl	1.3×10^{-4} Spills/Well Year	Lognormal $\mu = 7.20$ $\sigma = 2.73$
Subsea Pipeline Gathering	50 bbl	200	4.9×10^{-4} Spills/km Year	No Distribution	zoo bbl	3.8×10^{-4} Spills/km Year	No Distribution
Subsea Pipeline Trunk	50 bbl	2,400	4.9×10^{-4} Spills/km Year	Lognormal $\mu = 6.49$ $\sigma = 2.37$	2400 bbl	3.8×10^{-4} Spills/km Year	Lognormal $\mu = 6.49$ $\sigma = 2.37$
Overland Pipeline	50 bbl	1300	9.7×10^{-4} Spills/km Year	Lognormal $\mu = 5.52$ $\sigma = 1.52$	1400 bbl	7.2×10^{-4} Spills/km Year	Lognormal $\mu = 5.58$ $\sigma = 1.52$
Storage	250 bbl	13,800 bbl	13×10^{-3} Spills/10^6 bbl year	Lognormal $\mu = 6.97$ $\sigma = 1.72$	13,800 bbl	11×10^{-3} Spills/10^6 bbl year	Lognormal $\mu = 6.97$ $\sigma = 1.72$
Tanker in Port	1000 bbl	33,351 bbl	5.8×10^{-4} Spills/Port Call	Lognormal $\mu = 7.93$ $\sigma = 1.86$	33,351 bbl	4.93×10^{-6} Spills/Port Call	Lognormal $\mu = 7.93$ $\sigma = 1.86$
Tanker in Resticted Water	1000 bbl	67,893 bbl	4.3×10^{-7} Spills/km Year	Lognormal $\mu = 8.97$ $\sigma = 2.19$	67,893 bbl	4.3×10^{-9} Spills/km Year	Lognormal $\mu = 8.97$ $\sigma = 2.19$
Tanker in Open Sea	1000 bbl	83,763 bbl	6.7×10^{-8} Spills/km Year	Lognormal $\mu = 9.90$ $\sigma = 2.30$	83,763 bbl	7.37×10^{-10} Spills/km Year	Lognormal $\mu = 9.90$ $\sigma = 2.30$

EXCEEDANCE CURVE FOR OVERLAND PIPELINE

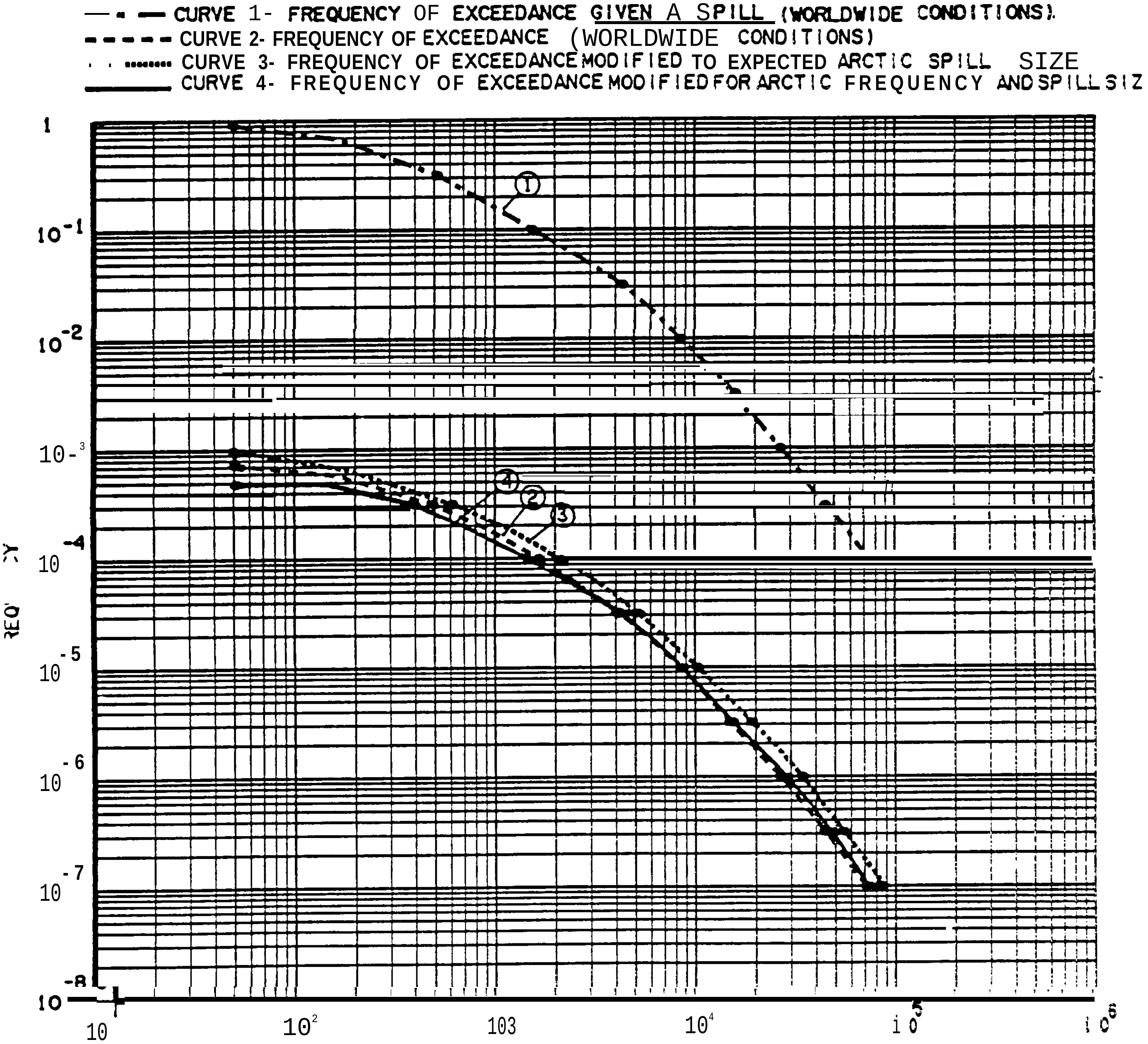


FIG. 5.1

Graphs 5.2-5.19 are the final completed graphs and a word of explanation is necessary as to how these have been derived. The process is essentially one of four steps. The first step involves the plotting of the distribution of conventional oil spills on an exceedance probability basis. The lognormal distributions derived in Section 3 are plotted on an exceedence basis and this predicts the exceedance of that size of an oil spill for conventional systems given that the oil spill occurs (Figure 5.1, Curve 1).

Step two involves modifying the curve to take account of the probability of any spill. The curve of the size of the spill is multiplied by the probability of the spill occurring (Curve 2).

The next step, step 3, is to modify the curve for the Arctic spill - size distribution if it is different from the conventional system and this involves modifying both the mean and possibly the standard deviation. If Arctic spills are similar to conventional spills this step involves no change (Curve 3).

The last step, step 4, is to make a further modification to the probability of spill occurrence if the Arctic system has a different probability of spill occurrence.

The final curve, Curve 4 (Arctic), is therefore the probability exceedence curve for a particular component for one year of operation. As has been indicated, it can be interpreted either by choosing the size of spill and calculating the probability that a spill of that size or larger will occur, or alternatively choosing a probability of let us say 10^{-6}, or the one in a million situation, and reading off from the graph the size of spill or greater related to this 'probability. If this approach is used, then the formal statement would read as follows:

DEVELOPMENT DRILLING

EXCLUDING BLOWOUTS ———

BLOWOUT (ARCTIC AND W. W.) ▬ ▬ ▬ ▬ ▬ ▬

PRODUCTION

EXCLUDING BLOWOUTS (ARCTIC AND W. W.) - - • - * -

BLOWOUTS (ARCTIC) • , . = . * * * . * . .

BLOWOUTS (WORLDWIDE) ▬ ▬ ▬ ▬ ▬ .

SUBSEA PIPELINE

TRUNK (ARCTIC) — ———

TRUNK (WORLDWIDE) • • • • • •

STORAGE

ARCTIC ▬ • ▬ • ▬

WORLDWIDE • • • • • • • • • • • •

OVERLAND PIPLINE

ARCTIC ———

WORLDWIDE ▬ ▬ ▬ ▬ ▬ ▬

TANKER

PORT / VOYAGE (ARCTIC) • • • • • • • • • • • •

PORT / YEAR (ARCTIC) —

PORT / VOYAGE (WORLDWIDE) ▬ • ▬ • ▬

RESTRICTED WTR / kmYEAR (ARCTIC) * . . * . * • • • • • •

RESTRICTED WTR / YEAR (ARCTIC) ———

RESTRICTED WTR / kmYEAR (WORLDWIDE) - - - - -

OPEN SEA / kmYEAR (ARCTIC) • • . . . .

OPEN SEA / YEAR (ARCTIC) — .

OPEN SEA / kmYEAR (WORLDWIDE) - - - - - -

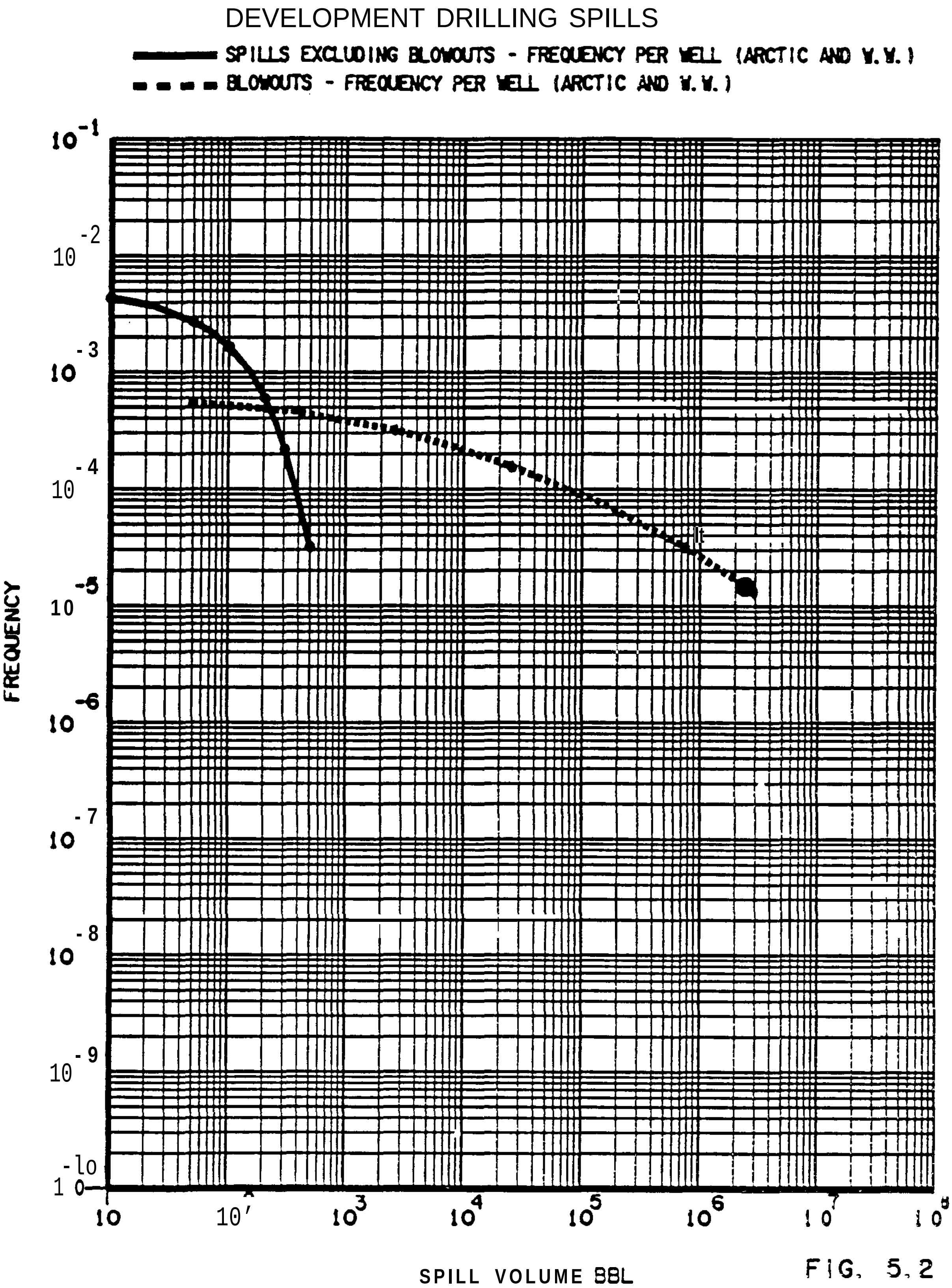
EIS MAXIMUM VOLUME CONSIDERED ✳

TABLE 5

COMPARISON OF SPILLS

COMPONENT	MAXIMUM RECORDED SPILL (bbls)	EIS VOL. 6 SPILL (bbls)
Non Blowout	300	
Blowout	3,100,000	2,100,000
Production		
Non Blowout	1500	
Blowout	150,000	720,000
Sub Sea	160,000	4,500
Gathering	500	
Onland	60,000	50,000
Storage	740,000	270,000
Tanker		
Port	870,000	270,000
Rest.	1,520,000	1,500,000
Open	600,000	270,000

839-



DEVELOPMENT DRILLING SPILLS

FIG. 5.2

PRODUCTION SPILLS

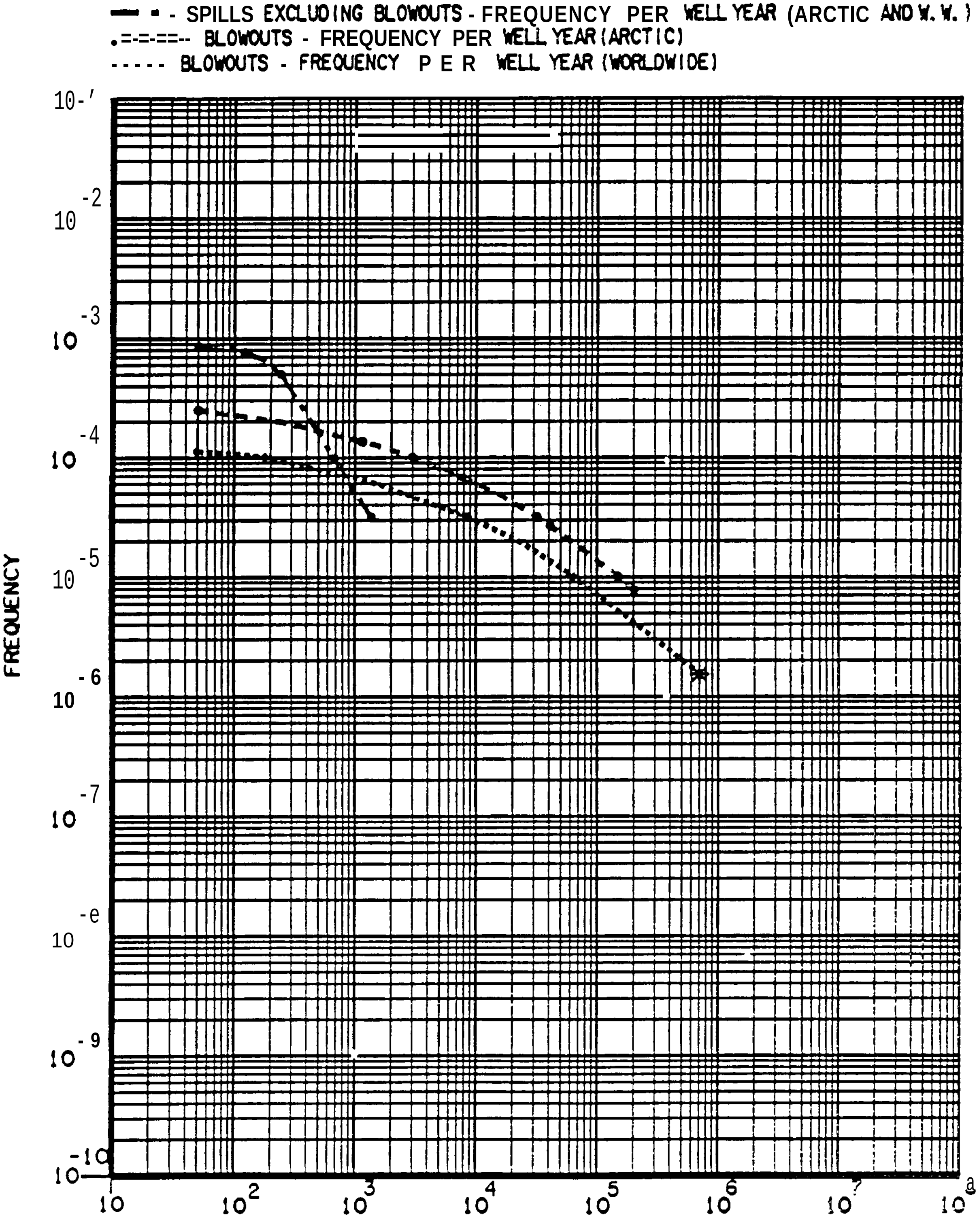


FIG. 5.3

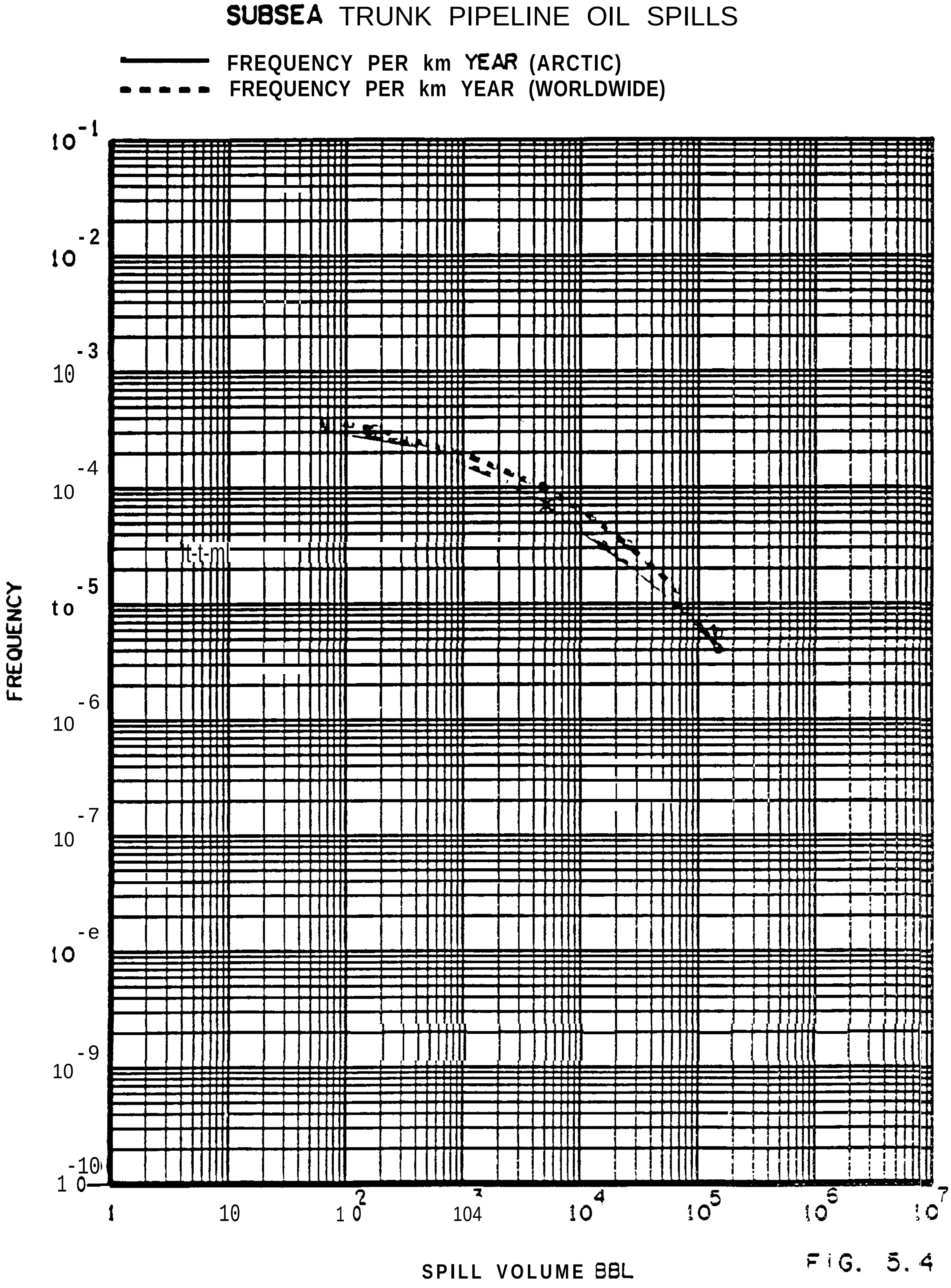

SUBSEA TRUNK PIPELINE OIL SPILLS
FREQUENCY PER km YEAR (ARCTIC)
FREQUENCY PER km YEAR (WORLDWIDE)
FREQUENCY
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
SPILL VOLUME BBL

FIG. 5.4

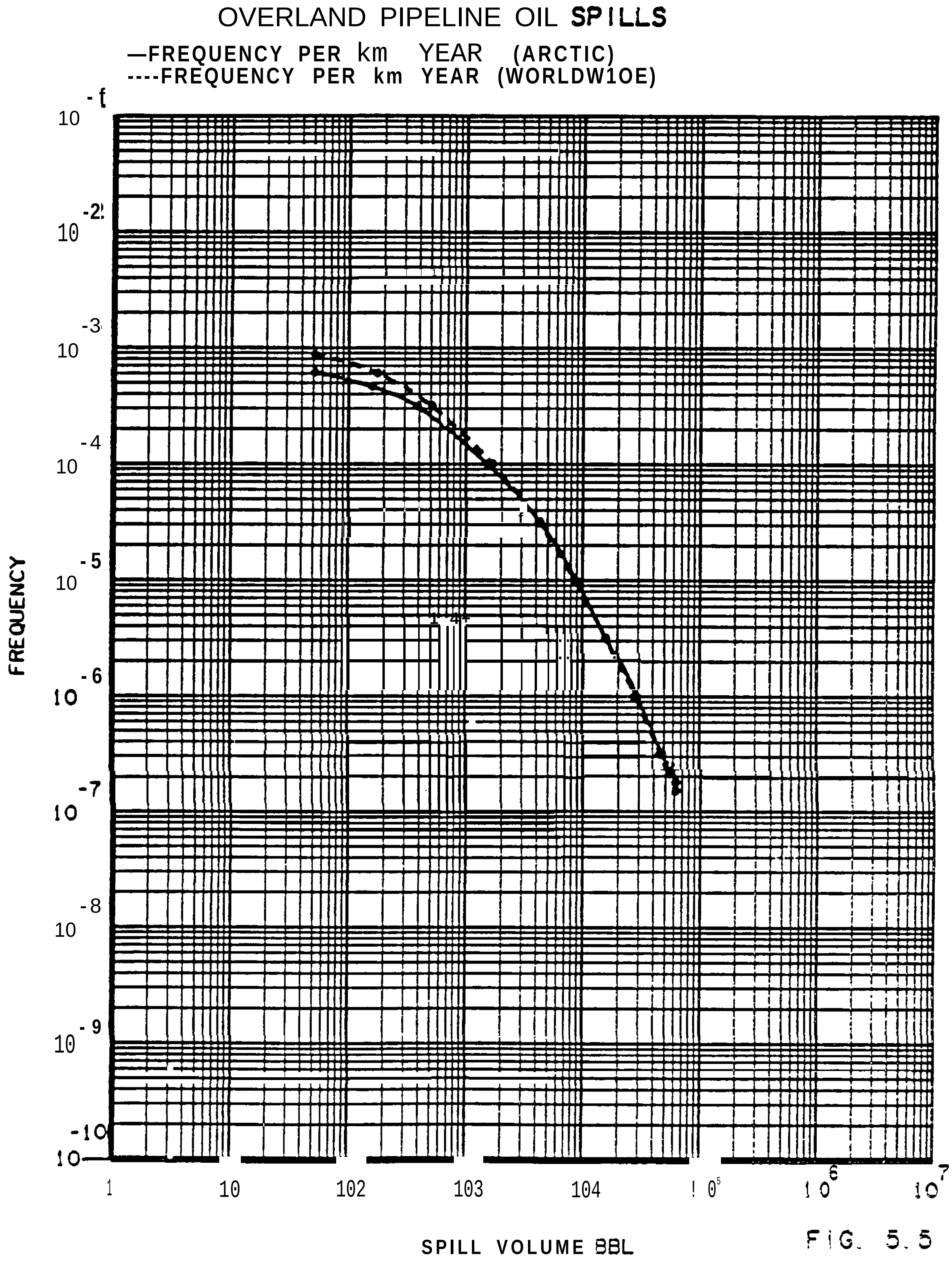

OVERLAND PIPELINE OIL SPILLS
—FREQUENCY PER km YEAR (ARCTIC)
----FREQUENCY PER km YEAR (WORLDWIDE)
FREQUENCY
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
SPILL VOLUME BBL

FIG. 5.5

TANKER OIL SPILLS IN PORT

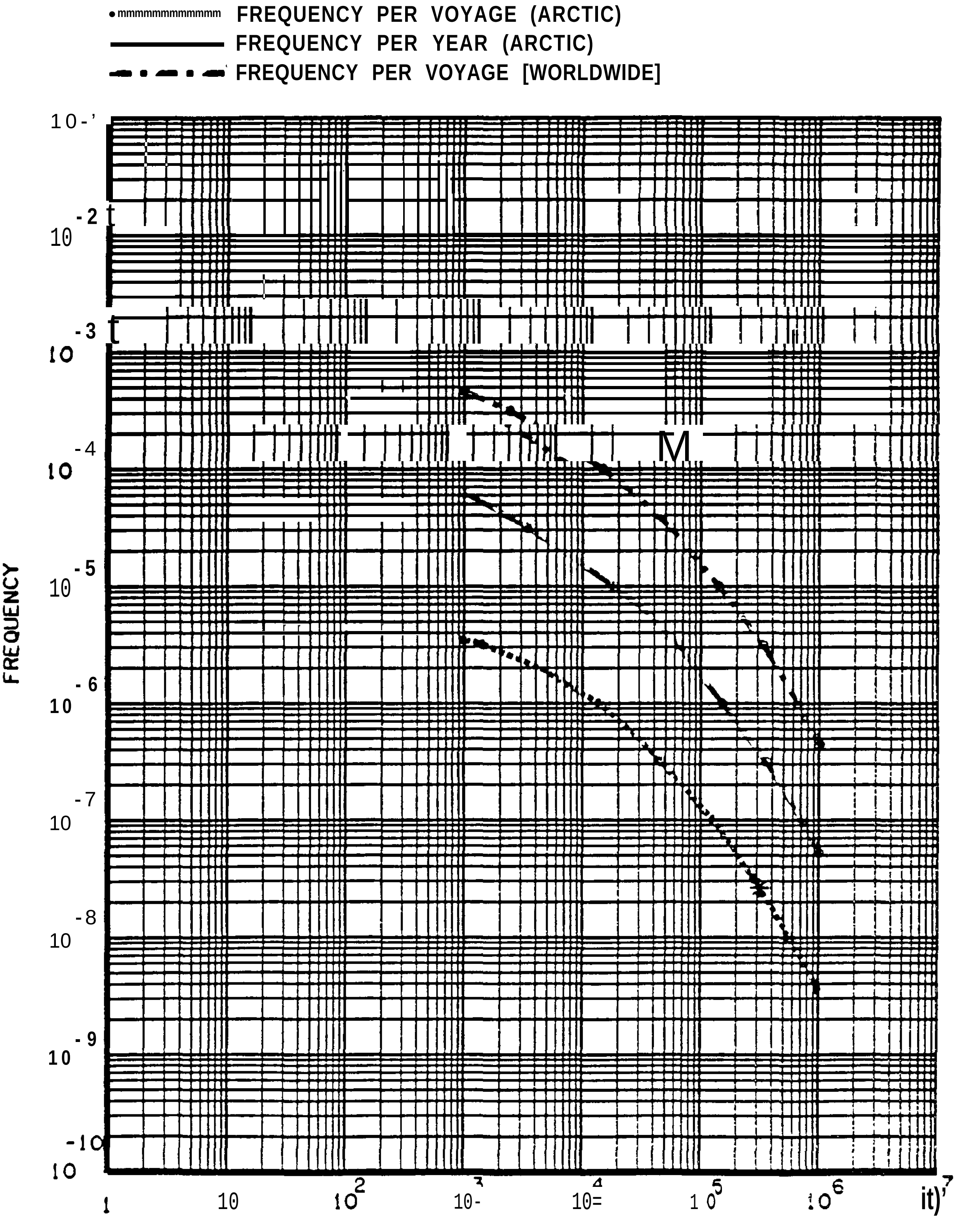


FIG. 5.6

TANKER OIL SPILLS IN RESTRICTED WATERS

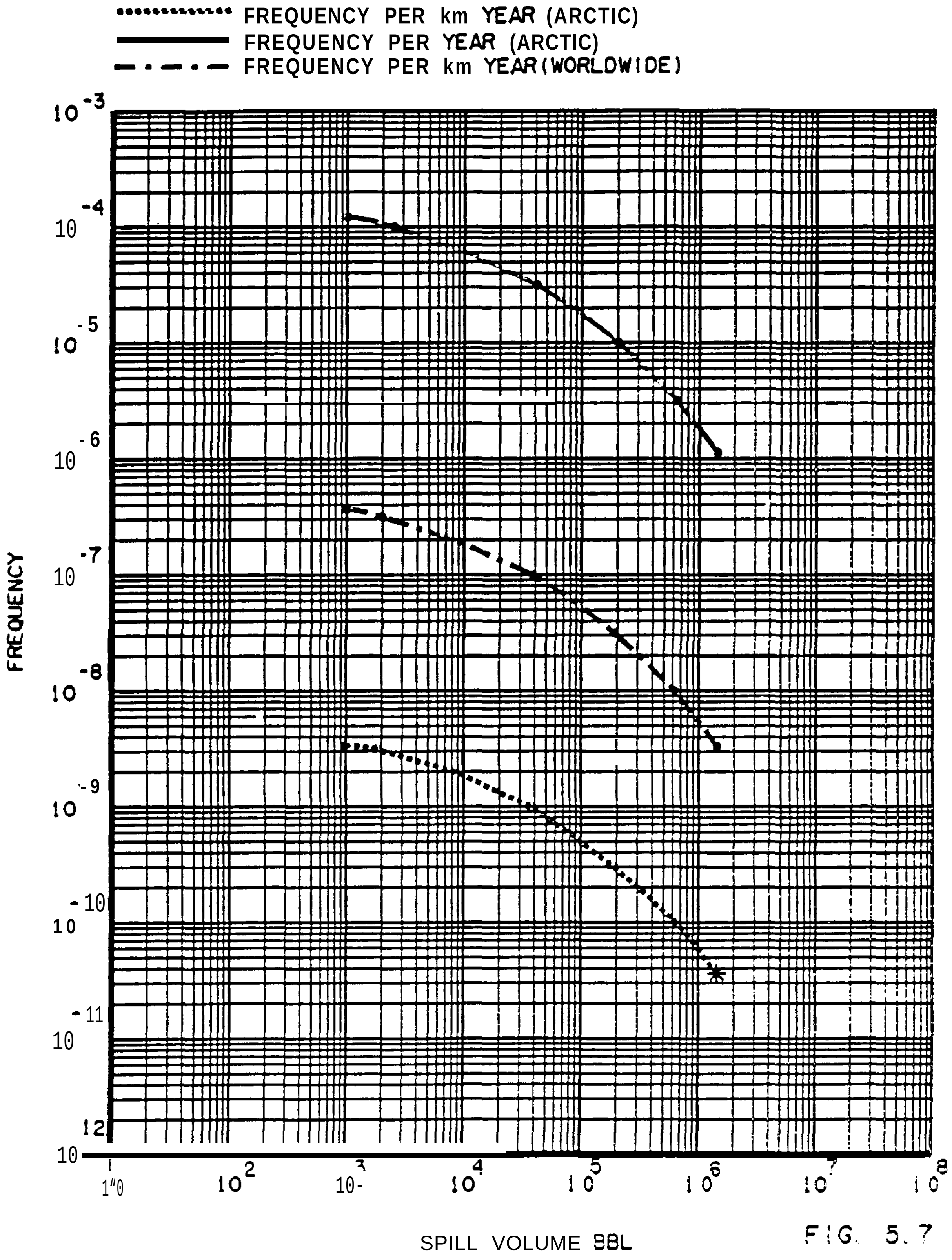


FIG. 5.7

TANKER OIL SPILLS AT SEA

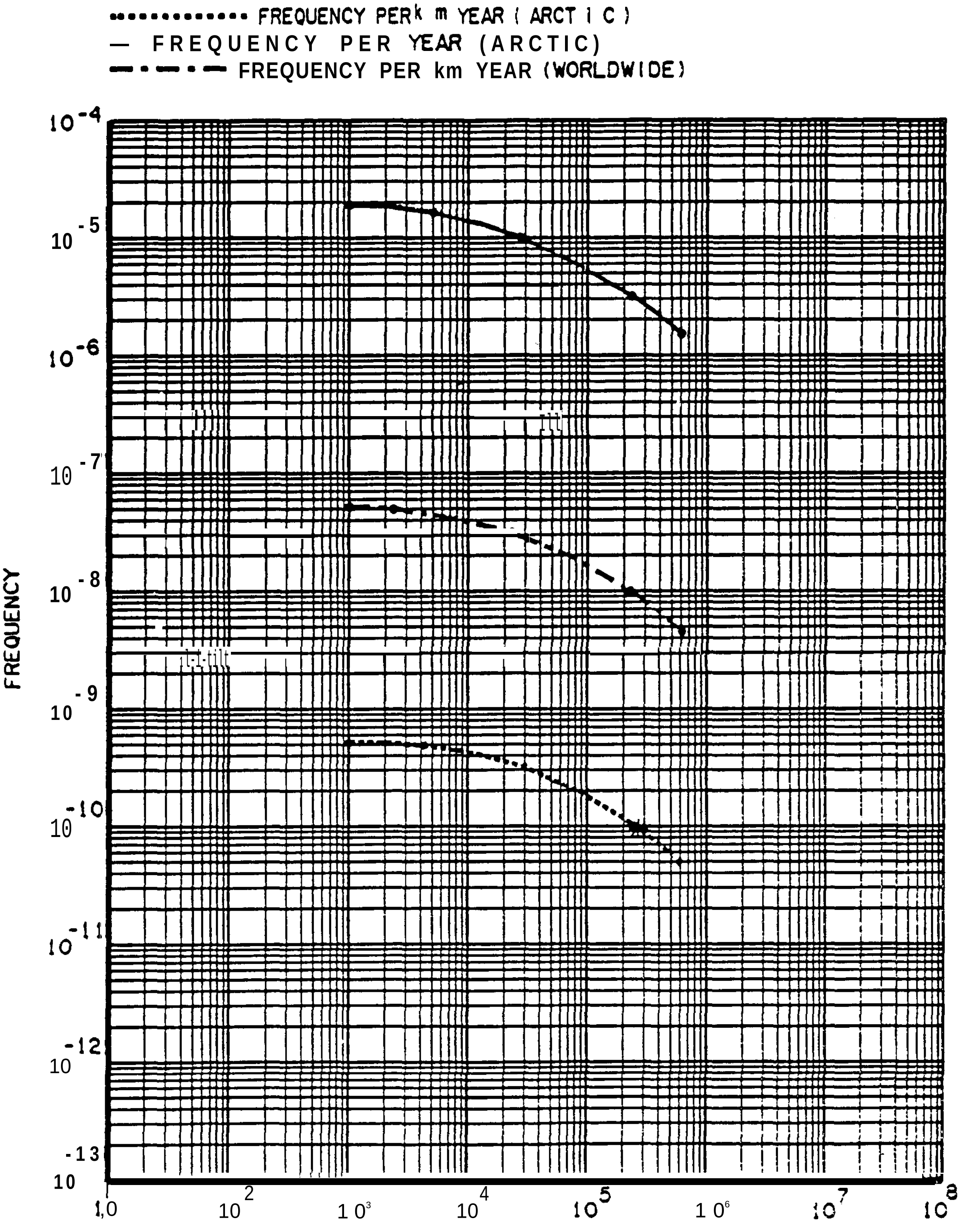


FIG. 5.8

STORAGE 01 L SPILLS

▬•▬ FREQUENCY PER MILLION BBLS STORED PER YEAR (ARCTIC)
•mas,sama FREQUENCY PER MILLION BBLS STORED PER YEAR (WORLDWIDE)

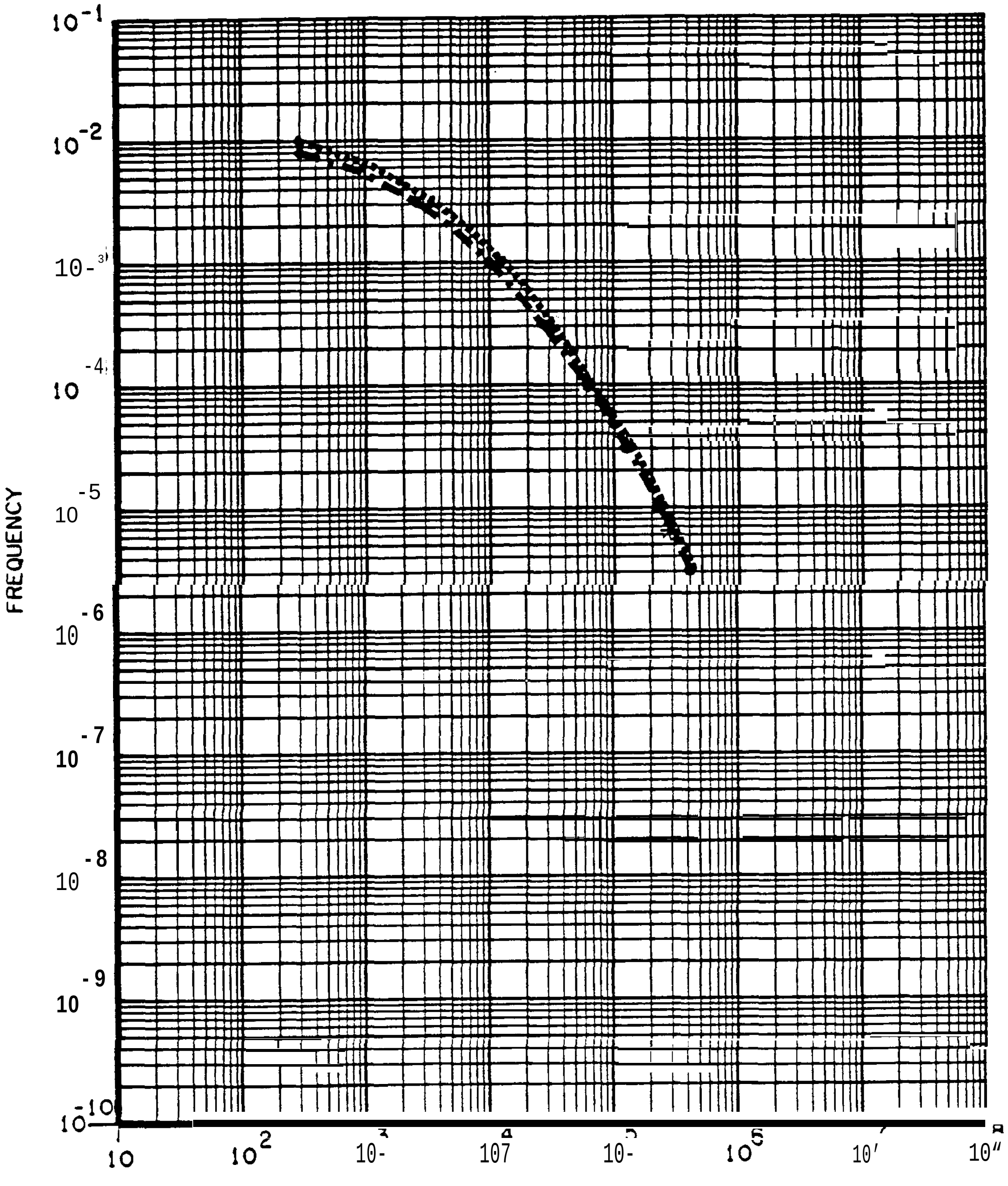


FIG. 5.9

'*There is a one in a million chance that a spill of this size or greater will occur for one year of operation for this particular component'*. Figure 5.2 to 5.9 show the **exceedance** curves for the individual components of the proposed systems. The * on the curve is the spill used in the various scenarios in Volume 6 of the **E.I.S.**

5.3 DETAILED SCENARIOS

5.3.1 Scenario 1 is the base pipeline case when the production of 100,000 barrels moves south by pipeline. In this instance, 25 wells are drilled and oil flows from one production structure (12 wells) via the 5 kilometer **subsea** gathering line to the other structure. Final treatment is undertaken and the oil is then transported to shore via the 65 kilometer subsea trunk line. On shore, it then moves 1300 kilometers through the 16" buried line to the Alberta border. Storage is 50,000 **bbls**. Table 5.2 gives the expected spill for this scenario and exceedance curves are , shown in Figure 5.10.

5,3.2 Scenario 1A is a sub-case of Scenario 1 and deals only with the Beaufort Sea location. In this, the oil flows from the first platform to the second platform via the subsea gathering line. It then flows to shore via the 65 kilometer subsea trunk line and then a 5 kilometer section of the online pipeline is included since spills in this area would still have an effect in the littoral region of the Beaufort Sea (see Table 5.3, Figure 5.11).

5.3.3 Scenario 1Bis a section of the **pipeline and** in this scenario a 40 kilometer section of the online pipeline is considered somewhere between the MacKenzie Delta and the crossing of the Alberta border (see Table 5.4, **Figure** 5.12).

5.3.4 Scenario 1C is identical to Scenario 1 with the exception that the throughput is boosted from 100,000 bbl/d to 200,000 bbl/d. To achieve this, the number of wells is increased by a factor of 2 to 50 wells, the gathering lines are increased from 5 kilometers to 10 kilometers, the subsea trunk line is still 65 kilometers, and the online pipeline is still 1,300 kilometers. Storage is 100,000 bbls (see Table 5.5, Figure 5.13).

5.3.5 Scenario 1D. In this case the throughput has been increased to 300,000 bbl/d from 75 wells, with 15 kilometers of subsea gathering lines. In all other aspects this scenario is similar to Scenario 1. Storage is 150,000 bbls (see Table 5.6, Figure 5.14).

5.3.6 Scenario 2. This is the base case for the tanker transportation, and in this case the 100,000 bbl/d production is moved south by tankers. It includes 25 wells with oil being gathered from one production structure to the second production structure via a 5 kilometer subsea pipeline. On the second structure, the storage facility of 2,300,000 bbls for the tanker is located, and from here the production is moved by two 200,000 ton Arctic tankers, the 4,300 kilometers, to the 60 north parallel (see Table 5.7, Figure 5.15).

5.3.7 Scenario 2A is the equivalent tanker scenario for the Beaufort Sea area. It is the same as Scenario 1 with the exception that the tanker distance is limited to 550 kilometers, that being the distance for the vessel to sail out of the Beaufort Sea area (see Table 5.8, Figure 5.16).

5.3.8 Scenario 2B is a section of the tanker route, 40 kilometer coastal section and would typically run to an area, for instance, 20 kilometers either side of Resolute (see Table 5.9, Figure S.17).

5.3.9 Scenario 2C is the tanker case for the production increased from 100,000 bbl to 200,000 bbl. All the components of the system remain the same with the simple exception that the number of tankers increases to 4 (see Table 5.10, Figure 5.18).

5.3.10 Scenario 2D is the tanker case with the production increase to 300,000 bbl, in which case the number of Arctic tankers increase to 6 (see Table 5.11, Figure 5.19).

SCENARIO 1
OIL SPILL FREQUENCIES
PRODUCTION MOVES SOUTH VIA PIPELINE

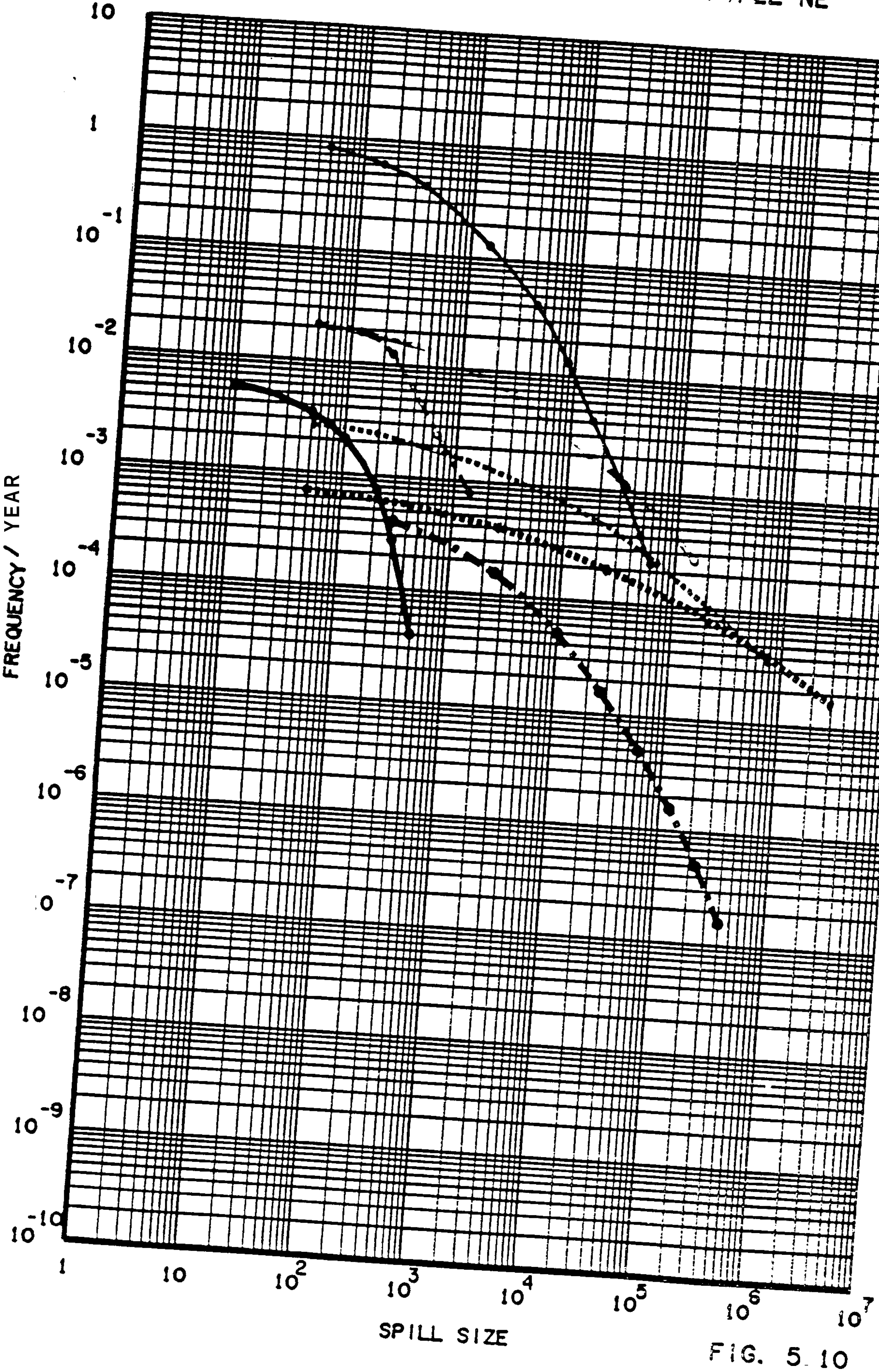


FIG. 5.10

TABLE 5.2
SCENARIO 1
PRODUCTION MOVES SOUTH VIA PIPELINE

SYSTEM COMPONENT	EXPOSURE.	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE bbl .	EXPECTED VOLUME bbl./yr.	bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	25 wells	0.11	100	0.5	11
b) Blowouts	25 wells	0.016	1300	1.0	21
Production					
c) Excluding Blowouts	25 wells	0.025	290	7	145
d) Blowouts	25 wells	0.0033	22000	73	1450
Subsea Pipeline					
e) Gathering	5 km	0.002	200	.4	8
f) Trunk	65 km	0.025	2400	59	1190
Onland Pipeline					
g) Pipeline	16" 1300 km 25 km between 2 stations	,94	1400	1300	26000
h) Storage	1/2 day Production (50,000 bbls)	,0005	13800	7	140
			TOTAL	1560	28965

SCENARIO 1A
OIL SPILL FREQUENCIES
BEAUFORT SEA AREA USING PIPELINE

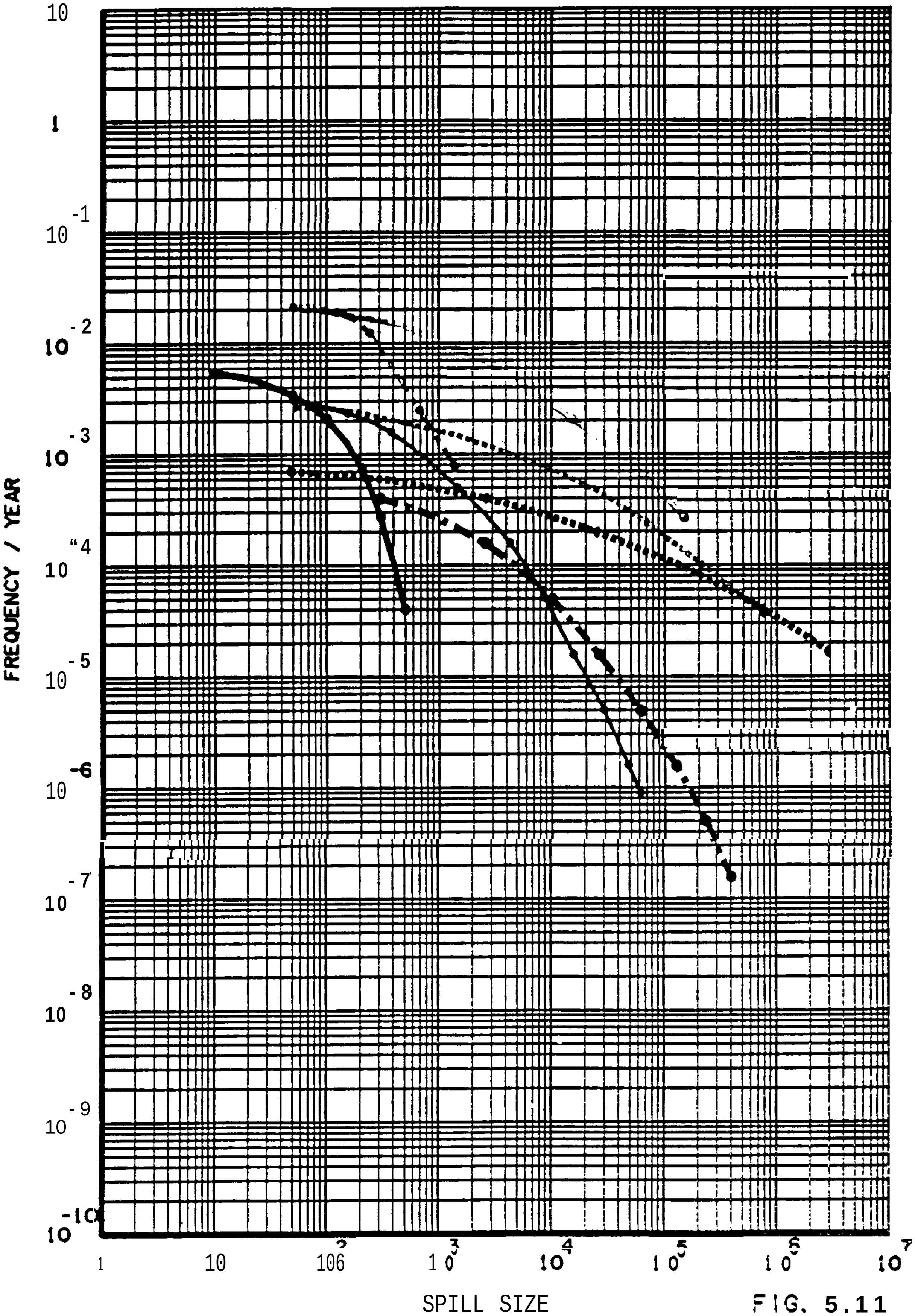


FIG. 5.11

TABLE 5,3
SCENARIO 1A
BEAUFORT SEA AREA USING PIPELINE

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl .	bbl./yr.	bbl./20 yr.
Development Drilling .					
a) Excluding Blowouts	25 wells	0.11	100	0.5	11
b) Blowouts	25 wells	0.016	1300	1.0	21
Production					
c) Excluding Blowouts	25 wells	0.025	290	7	145
d) Blowouts	25 wells	0.0033	22000	73	1450
Subsea Pipeline					
e) Gathering	5knl	0.002	200	.4	8
f) Trunk	65 km	0.025	2400	59	1190
Onland Pipeline					
g) Pipeline	16” 5 km	.0036	1400	5.2	100
h) Storage	50,000 bbls	.0005	13800	7	140
			TOTAL	154	3065

SCENARIO 1B
OIL SPILL FREQUENCIES
SECTION IN PIPELINE ROUTE

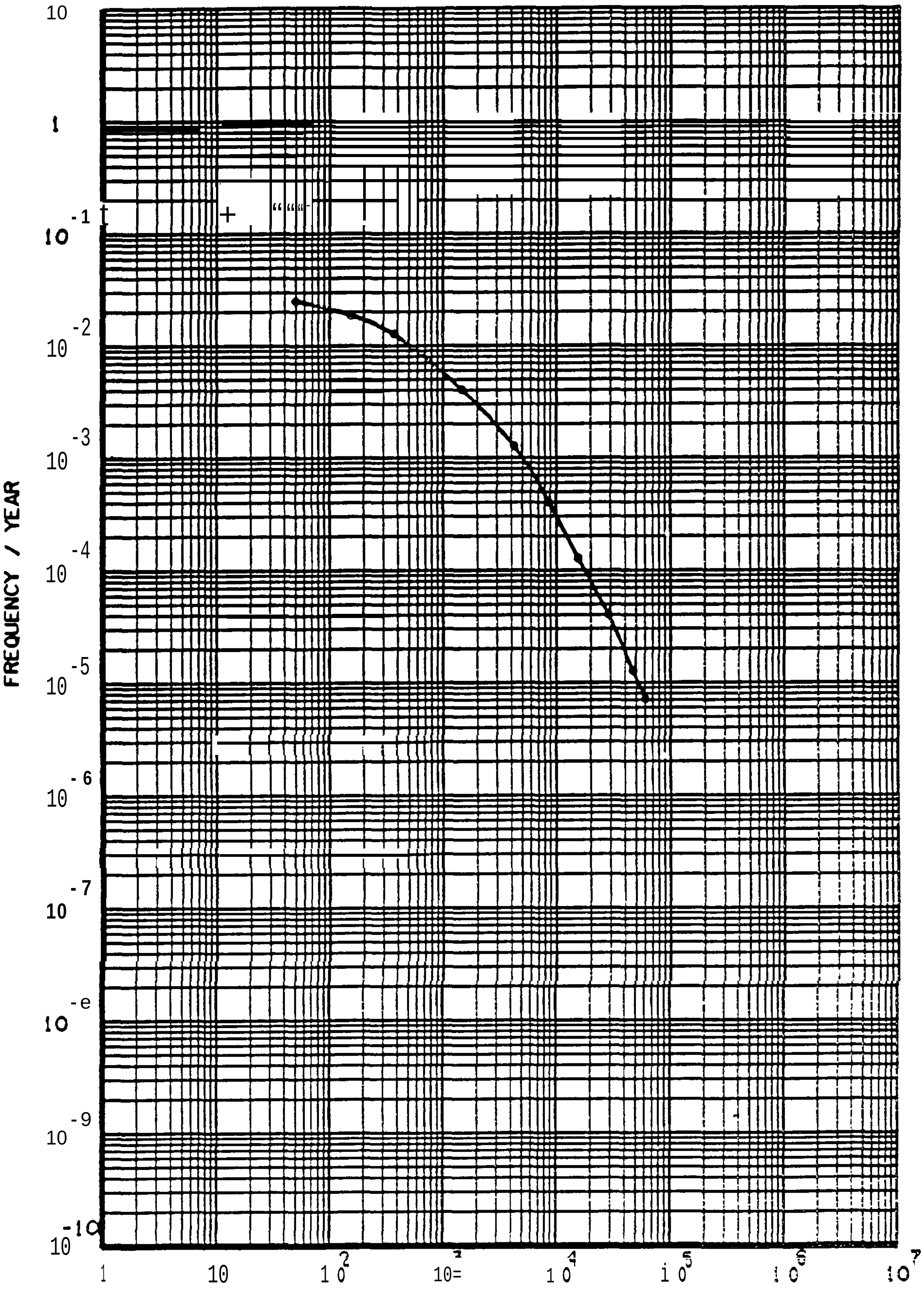


FIG. 5.12

TABLE 5.4
SCENARIO 1B
SECTION IN PIPELINE ROUTE

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl .	bbl./yr.	bbl./20 yr.
Onland Pipeline					
	16” 40 km	0.0029	1400	40	800

SCENARIO 1C
OIL SPILL FREQUENCIES
INCREASE THROUGHPUT 2X

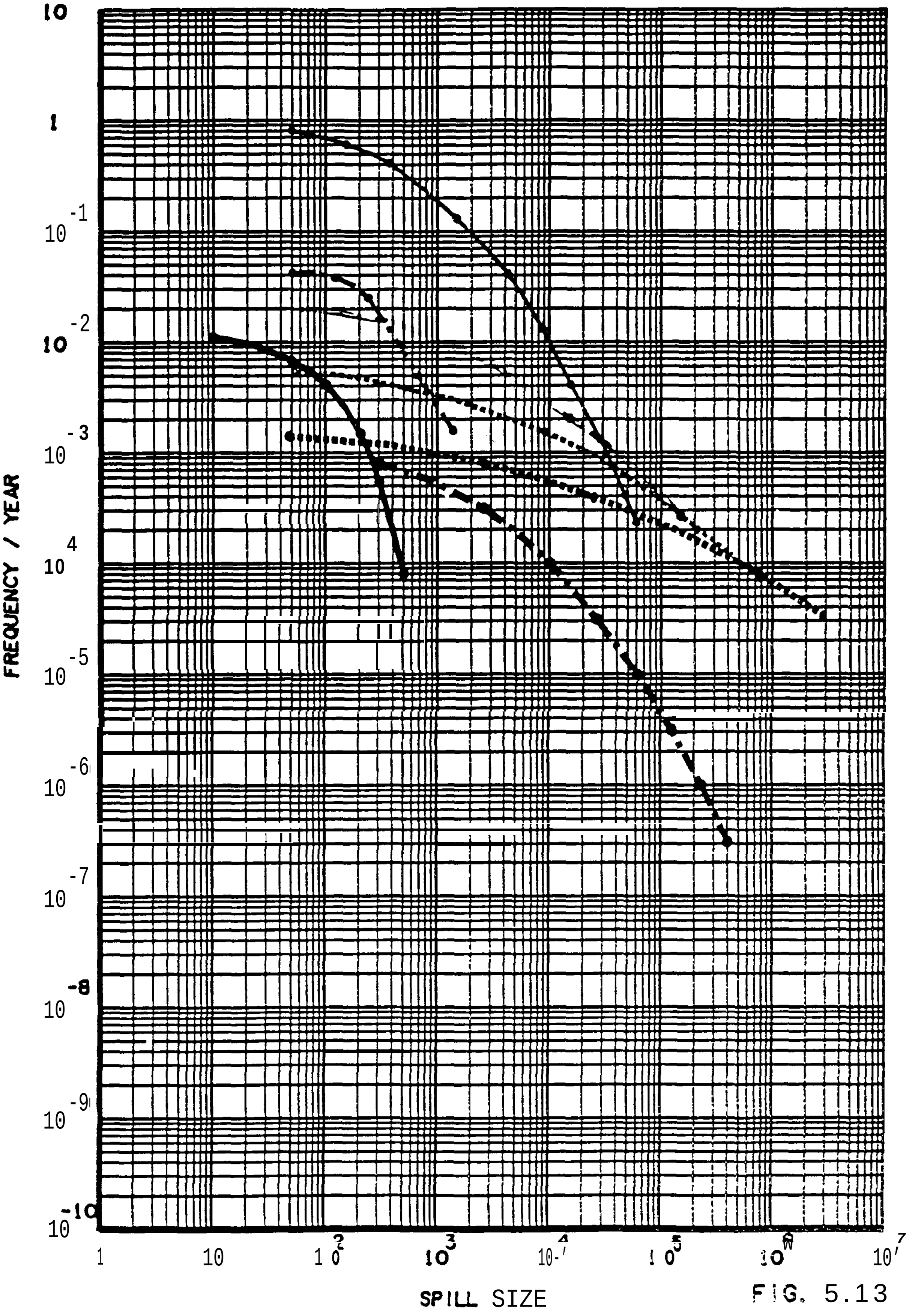


FIG. 5.13

TABLE 5.5
SCENARIO 1C
INCREASE THROUGHPUT 2x

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE bbl.	EXPECTED VOLUME bbl./yr.	EXPECTED VOLUME bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	50 wells	0.22	100	1.1	22
b) Blowouts	50 wells	0.032	1300	2.1	42
Production					
c) Excluding Blowouts	50 wells	0.05	290	14	290
d) Blowouts	50 wells	0.0066	22000	145	290
Subsea Pipeline					
e) Gathering	10 km	0.004	200	0.8	16
f) Trunk	65 km	0.025	2400	59	1190
Onland Pipeline					
g) Pipeline	16″ 1300 km 150 km between stations	.0094	1400	1300	26000
h) Sto-rage	1/2 day production (10,000 bbl)	.0011	13800	15	295
			TOTAL	1537	28145

SCENARIO 1D
OILSPILL FREQUENCIES
INCREASE THROUGHPUT 3X

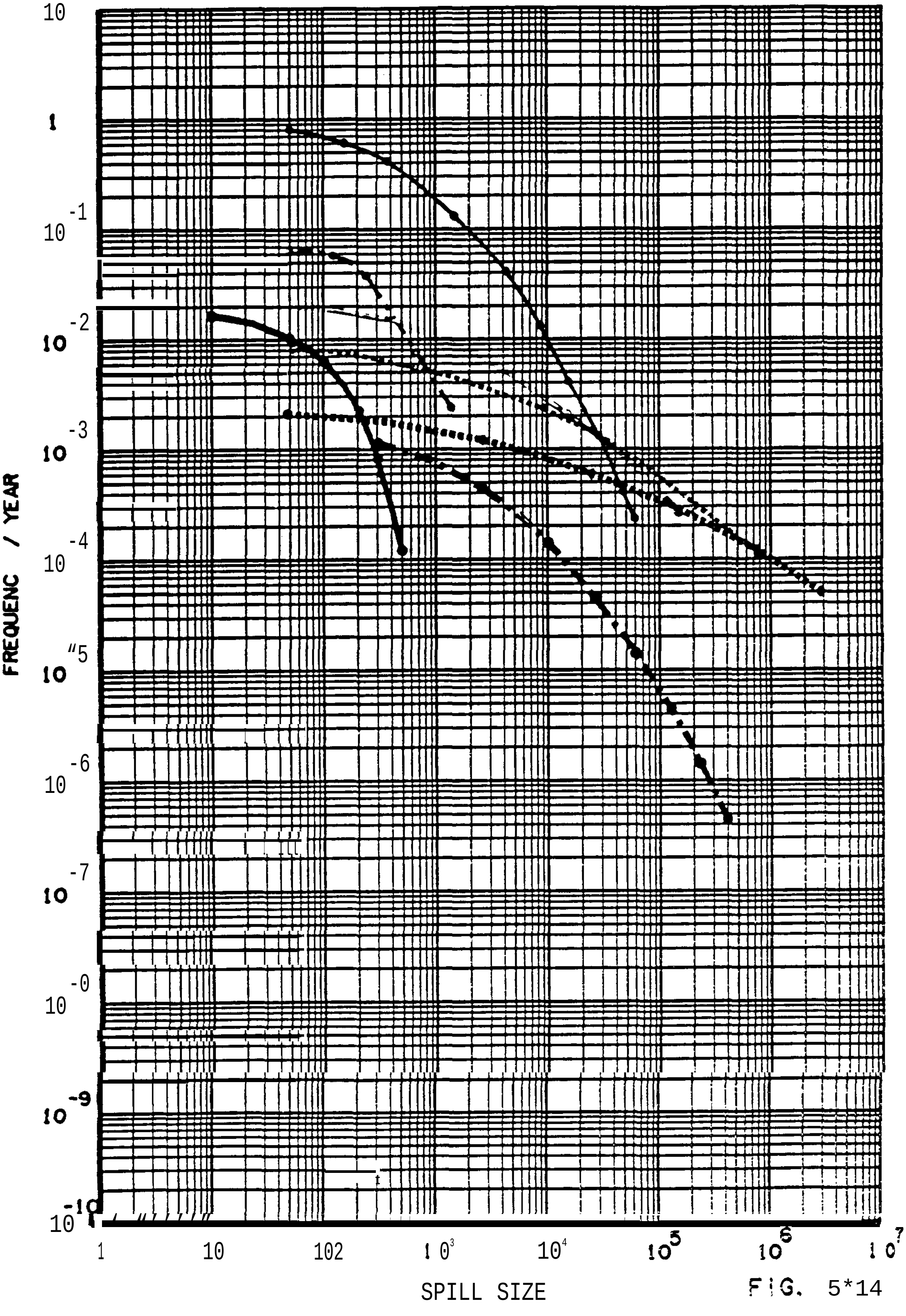


FIG. 5.14

TABLE 5.6
SCENARIO 1D
INCREASE THROUGHPUT 3X

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE bbl .	EXPECTED VOLUME bbl./yr.	EXPECTED VOLUME bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	75 wells	0.34	100	1.7	34
b) Blowouts	75 wells	0.049	1300	3.2	63
Production					
c) Excluding Blowouts	75 wells	0.07	290	21	430
d) Blowouts	75 wells	0.0098	22000	214	4300
Subsea Pipeline					
e) Gathering	15 km	0.006	200	1.2	24
f) Trunk	65 km	0.025	2400	59	1190
Onland Pipeline					
g) Pipeline	16″ 1300 km 150 km between stations	,0094	1400	1300	26000
h) Storage	1/2 day production (150,000 bbl)	.0016	13800	22	440
			TOTAL	1622	32481

SCENARIO 2
OIL SPILL FREQUENCIES
PRODUCTION MOVES SOUTH VIA TANKER

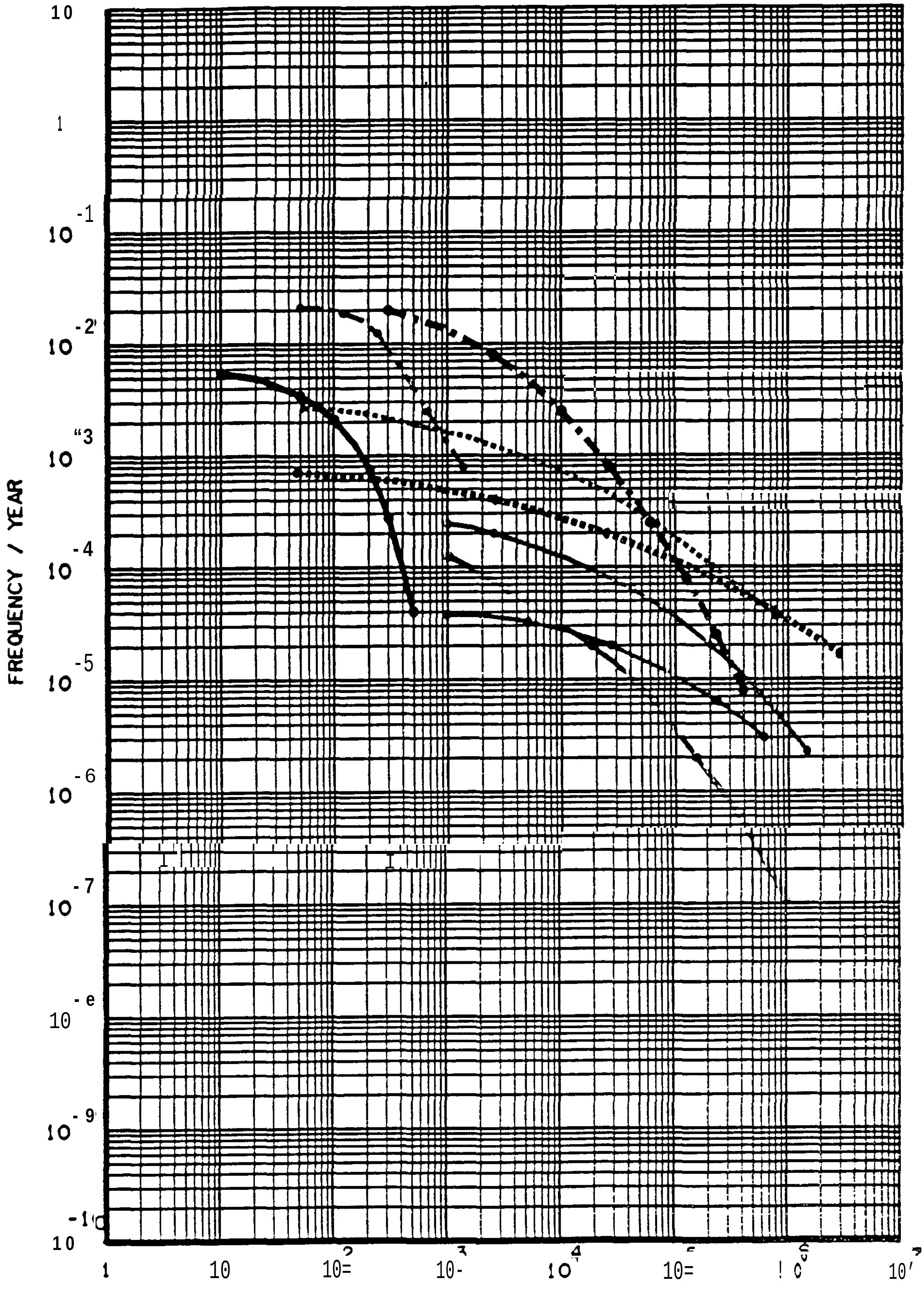


FIG. 5.15

TABLE 5.7
SCENARIO 2
PRODUCTION MOVES SOUTH VIA TANKER

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl .	bbl./yr.	bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	25 wells	0.11	100	0.5	11
b) Blowouts	25 wells	0.016	1300	1.0	21
Production					
c) Excluding Blowouts	25 wells	0.025	290	7	145
d) Blowouts	25 wells	0,0033	22000	73	1450
Subsea Pipeline					
e) Gathering	5 km	0.002	200	0.4	8
Storage					
h) Storage	2.3 x10^6 bbls	.028	13800	386	7730
Tanker					
i) Harbour	2 x 4300 km/trip 2 x 14 ports	1.38 10^{-4}	33400	4.6	92
j) Restricted	2000 km x2x 14 voyages	2.88 10^{-4}	67900	19.5	391
k) Open	2200 km x 2 x 14 voyages	4.52 10^{-5}	83800	3.8	76
			TOTAL	496	9924

SCENARIO 2A
OIL SPILL FREQUENCIES
BEAUFORT SEA USING TANKER

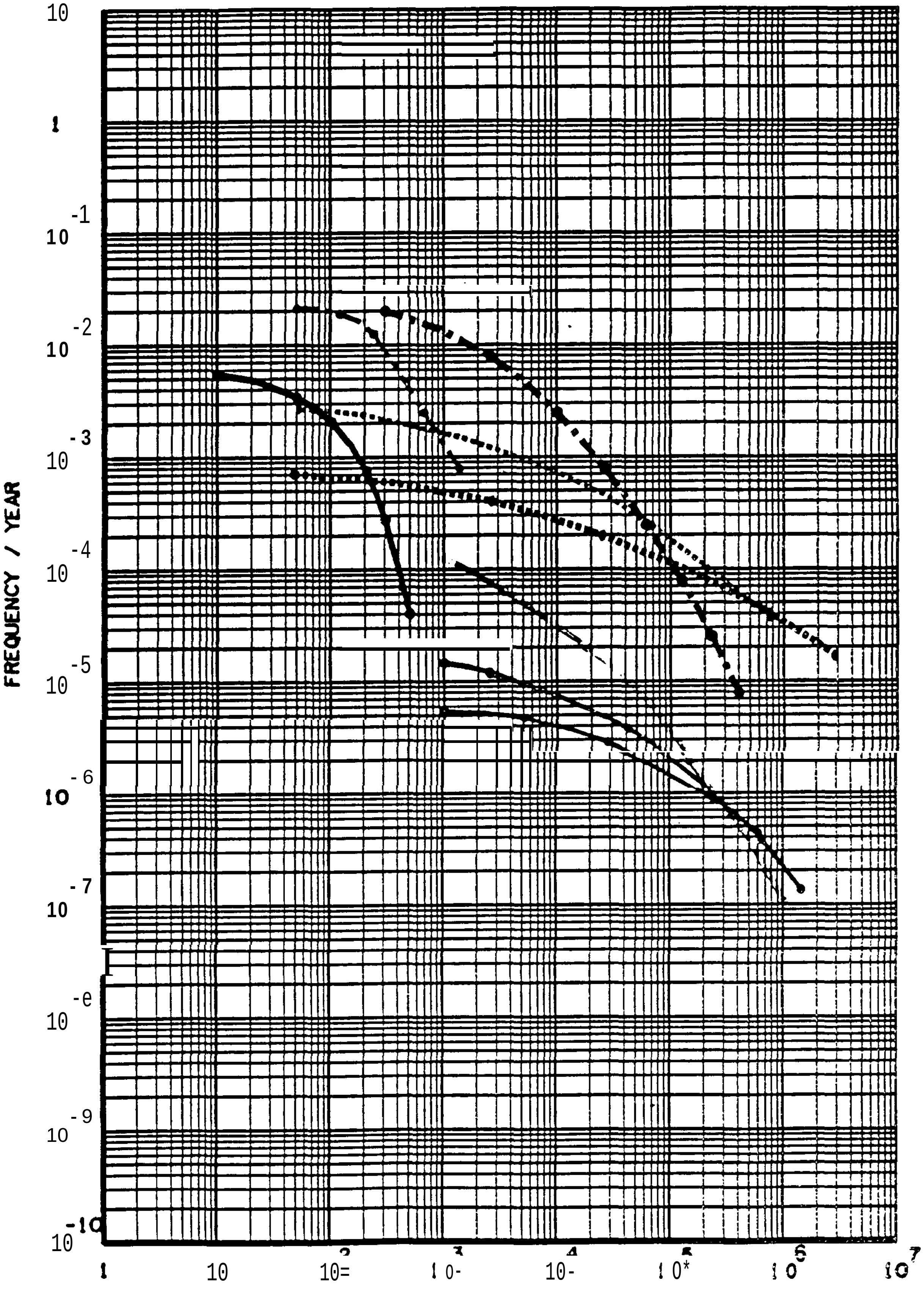


FIG. 5.16

TABLE 5.8
SCENARIO 2A
BEAUFORT SEA USING TANKER

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl.	bbl./yr.	bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	25 wells	0.11	100	0.5	11
b) Blowouts	25 wells	0.016	1300	1.0	21
Production					
c) Excluding Blowouts	25 wells	0,025	290	7	145
d) Blowouts	25 wells	0.0033	22000	73	145
Subsea Pipeline					
e) Gathering	5 km	0.002	200	0.4	8
Storage					
h) Storage	2.3 x 10^6 bbls	.028	13800	386	7730
Tanker					
i) Harbour	2 x 14 ports	1.38 10^{-4}	33400	4.6	92
j) Coast	50 km x 2 x 14 voyages	7.20 10^{-6}	67900	.5	10
			TOTAL	470	9500

SCENAR 10 2B
OIL SPILL FREQUENCIES
AREA IN TANKER ROUTE

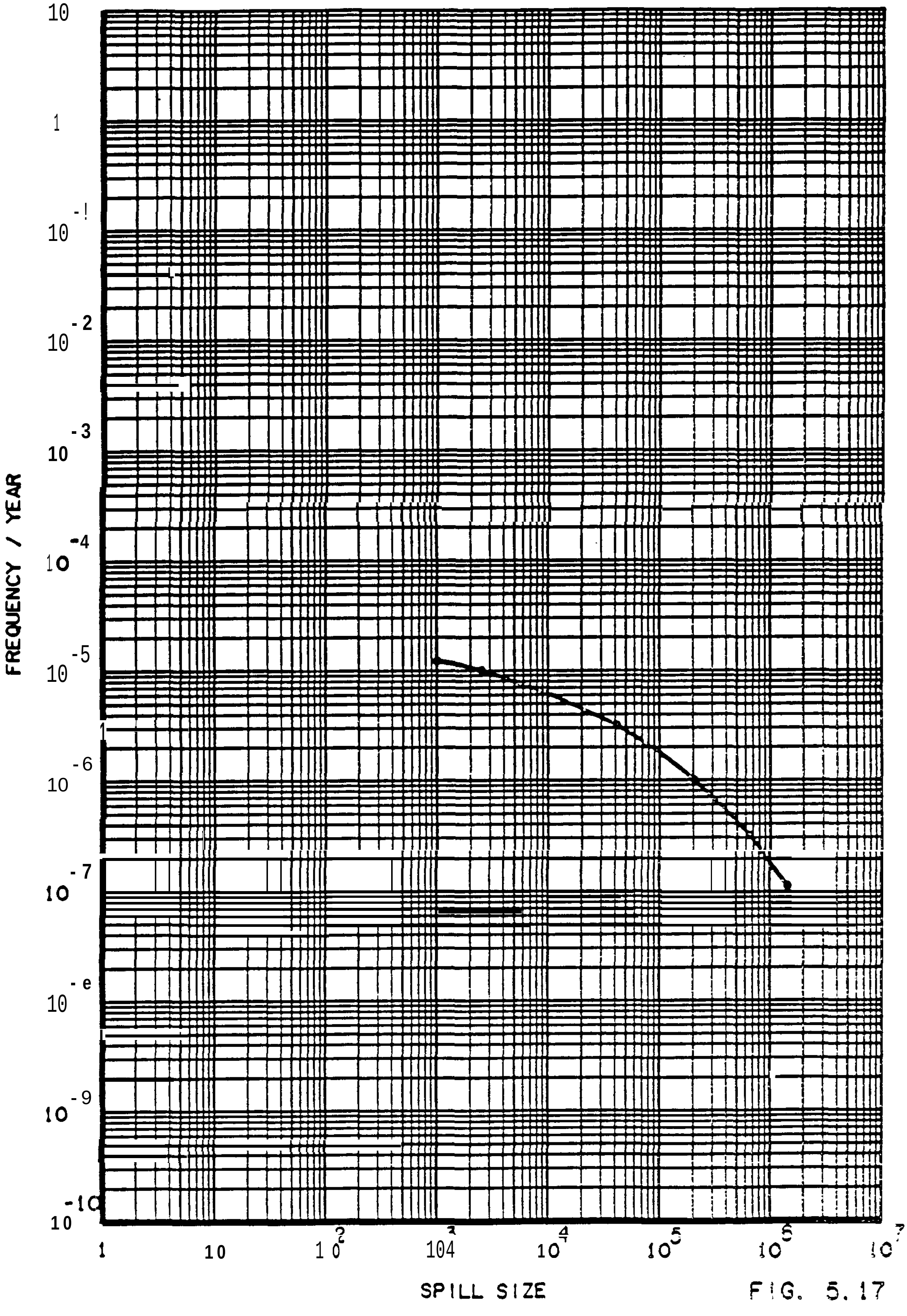


FIG. 5.17

TABLE 5.9
SCENARIO 2B
AREA IN TANKER ROUTE

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl .	bbl./yr.	bbl./20 yr.
Tanker					
a) Coast	40 km x 2 x 14 voyages	$5.7\ 10^{-6}$	67900	.4	7.7
			TOTAL	.4	7.7

SCENAR 10 2C
OIL SPILL FREQUENCIES
INCREASE THROUGHPUT 2X

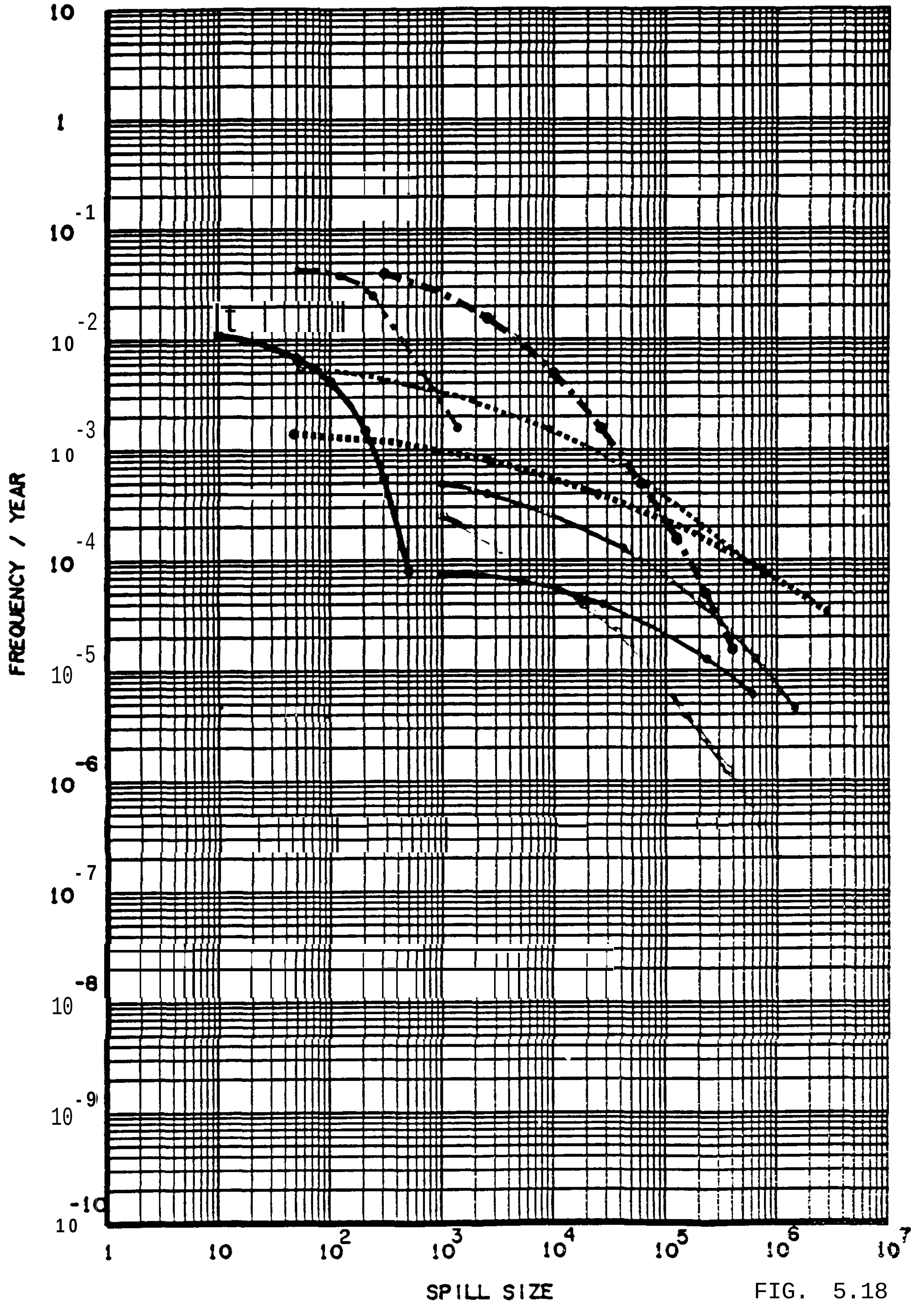


FIG. 5.18

TABLE 5.10
SCENARIO 2C
INCREASE THROUGHPUT 2X

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE bbl.	EXPECTED VOLUME bbl./yr.	bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	50 wells	0.22	100	1	22
b) Blowouts	50 wells	0.032	1300	2	42
Production					
c) Excluding Blowouts	50 wells	0.05	290	14	290
d) Blowouts	50 wells	0.0066	22000	145	2900
Subsea Pipeline					
e) Gathering	10 km	0.004	200	0.8	16
Storage					
h) Storage	4.6×10^6 bbls	.056	13800	770	15500
Tanker					
i) Harbour	4 x 4300km/trip 4 x 14 ports	$2.76\ 10^{-4}$	33400	9.4	190
j) Restricted	2000 km x 4 x 14 voyages	$5.76\ 10^{-4}$	67900	39	780
k) Open	2200 km x 4 x 14 voyages	$9.04\ 10^{-5}$	83800	7.6	150
			TOTAL	989	19890

SCENAR 10 2D
OIL SPILL FREQUENCIES
INCREASE THROUGHPUT 3X

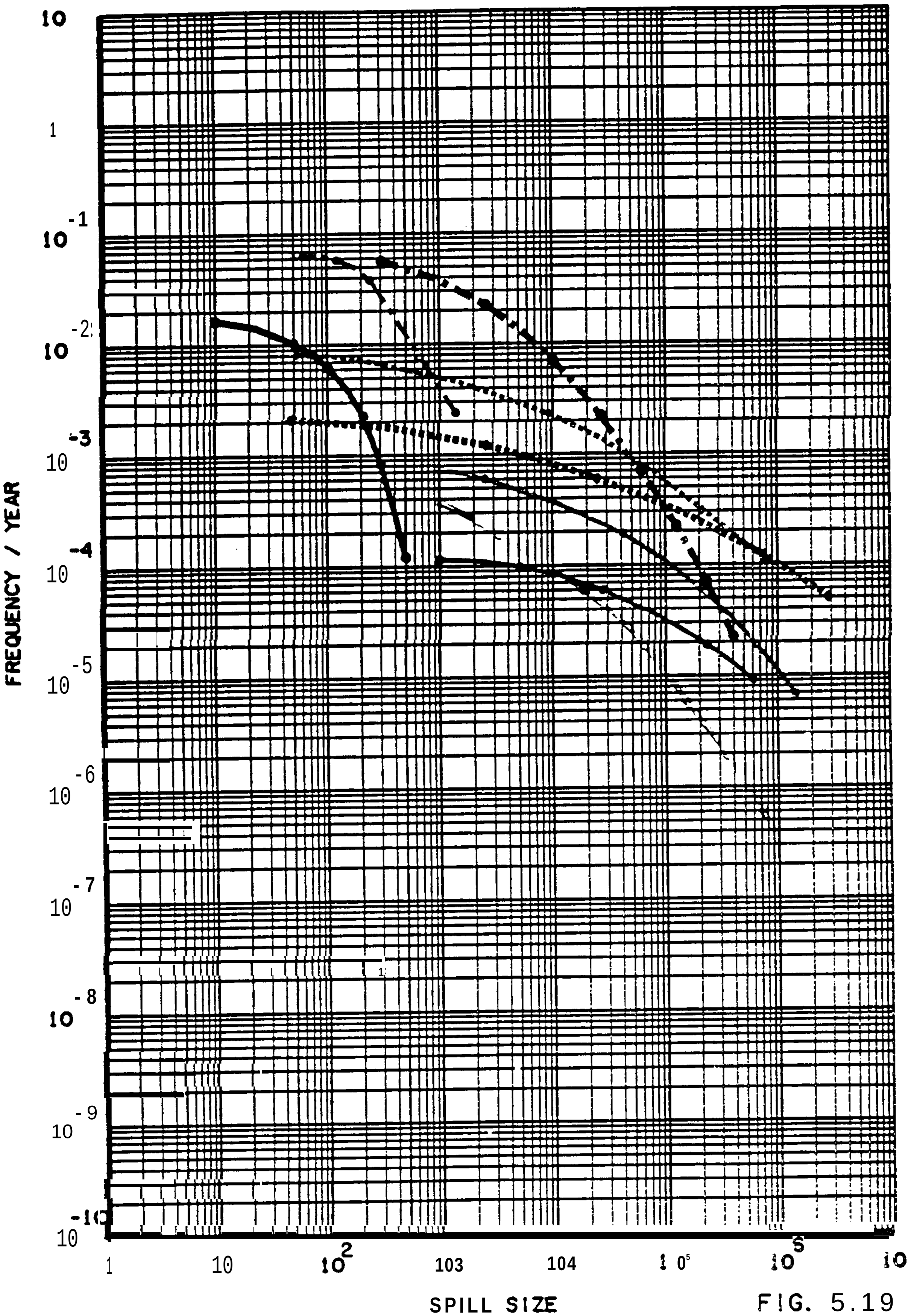


FIG. 5.19

TABLE 5.11
SCENARIO 2D
INCREASE THROUGHPUT 3x

SYSTEM COMPONENT	EXPOSURE	SPILL ACCIDENT FREQUENCY	MEAN SPILL SIZE	EXPECTED VOLUME	
			bbl.	bbl./yr.	bbl./20 yr.
Development Drilling					
a) Excluding Blowouts	75 wells	0.34	100	2	34
b) Blowouts	75 wells	0.049	1300	3	63
Production					
c) Excluding Blowouts	75 wells	0.07	290	21	426
d) Blowouts	75 wells	0.0098	22000	214	4290
Subsea Pipeline					
e) Gathering	15 km	0.006	200	1.2	24
Storage					
h) Storage	6.9 x10^6 bbls	.084	13800	1160	23200
Tanker					
i) Harbour	6 x 4300km/trip 6 x 14 ports	$4.14\ 10^{-4}$	33400	14	280
j) Restricted	2000 km x 6 x 14 voyages	$5.76\ 10^{-4}$	67900	59	1170
k) Open	2200 km x 6 x 14 voyages	$9.04\ 10^{-4}$	83800	11	230
			TOTAL	1484	29717

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APPENDIX A

THE LOGNORMAL AND EXPONENTIAL DISTRIBUTION

Collected data can be considered as belonging to a sample drawn from a large population. Since so many observations are available in the population, it is theoretically possible (for continuous data) to choose class intervals and still have sufficient numbers of observations falling within each class defining the density of data in this class. Densitities of statistical phenomena are often distributed approximately according to certain standard distributions. The density distributions define the frequency that an observation will be within a given range.

Two very common frequency distributions are the "normal" distribution and the "exponential" distribution. The normal distribution best fits data with the properties that:

1) Each datum (event) is independent of every other.

2) Events away from the mean are symmetrically distributed on either side of the mean.

3) Each event is a "sum" of smaller events, i.e. the sum of a large number of small independent random variables has an approximately normal distribution.

Normal distributions are typical of such data as the heights of males in a single age group, velocity of a molecule within a gas or test scores in an exam.

A distribution is called "lognormal" if the numeric logarithms of the data have these properties. In other words, instead of being a "sum" of smaller events the final event is a "product" of the events. Some examples of data which fits a lognormal distribution are flows in rivers, strength of concrete or (as in this report) size of oil spills. Figure Al shows a typical lognormal curve. "

The exponential distribution best fits data where:

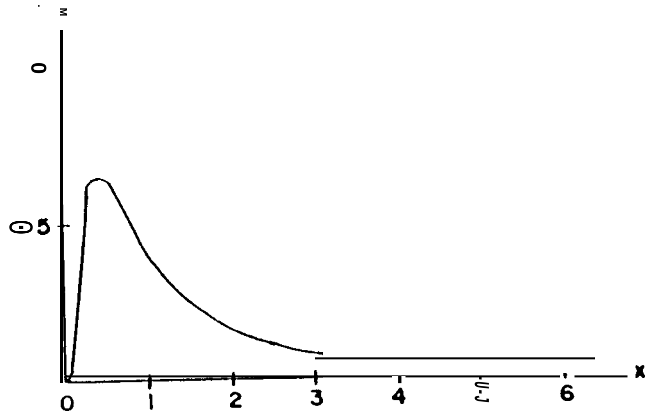
1) Each event is independent of every other.

2) Events are **"memoryless"**, i.e., the probability of an event does not increase with time since the last event.

3) The exponential distribution often arises, in practice, as being the distribution of the amount of time until some specific event occurs. For instance, the amount of time (starting from now) until an earthquake occurs, or until a new war breaks out, or until a telephone call you receive turns out to be a wrong number are all random variables that tend in practice to have **expontial** distribution.

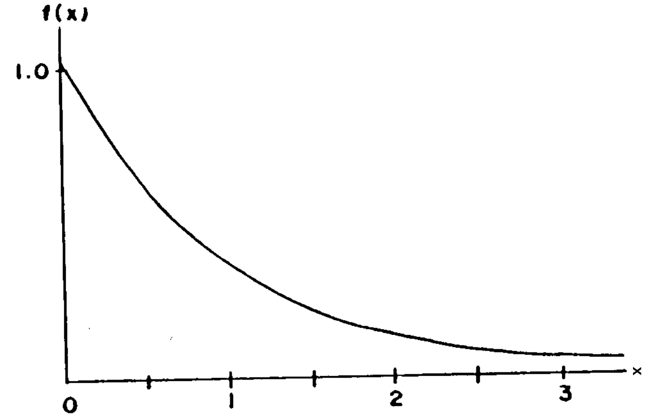
Unlike the **lognormal** distribuition, the exponential decreases rapidly beyond the mean so that events significantly larger than the mean are much less likely than with the **lognormal**. Figure A.2 shows a typical exponential curve.

Fig. A



Density of he lognormal distribution with $\mu = 0, \sigma^2 =$

Fig. A2



Density of the exponential distribution with $\beta = 1$

APPENDIX B

PIPELINE SPILL PREVENTION

The pipeline systems will incorporate the latest technology in leak detection systems, and surveillance programs. The pipelines will be continuously monitored and the emphasis will be placed on preventative maintenance. These programs will compliment each other to establish a system with a high degree of operational integrity. The components which make up such a system include.

1. Quality assurance which specifies material requirements.
2. Quality control which ensures that the objectives of 1 are met during material manufacture and construction.
3. Corrosion control methods including, line coatings and cathodic protection.
4. Leak detection methods and systems.
5. Internal inspection (instrumented pig).
6. Corrosion monitoring (coupons and/or probes).
7. "Right of Way" surveillance (initially more often than after several years operation).

The following extract discusses various types of pipeline leak detection systems that may be considered for use in Arctic pipeline systems.

A detailed description of leak detection systems was contained in the R.J. Brown and Associated report which was filed as a support document to the EIS. This description is reproduced below.

1.0 INTRODUCTION

The pipeline system will incorporate the latest technology in leak detection programs. The various leak detection programs which can be considered to have different operating characteristics and supplement one another when combined.

The basic parameters which determine the operating characteristics of any leak detection program are:

1) Leak rate necessary to trigger alarms;
2) Monitoring continuous or periodic; and,
3) Reliability.

Four monitoring programs which could be used to effectively monitor pipeline integrity are reviewed in the following paragraphs.

1.1 COMPUTER CORRECTED MASS FLOW COMPARISON

The mass flow comparison system is employed to detect leaks by monitoring the difference in flow rate into and out of the pipeline. The system consists of a computer and two flow meters, one installed at each end of the pipeline. The flow readings of each meter are temperature, pressure and density compensated. The computed inflow and outflow rates are periodically compared by the computer and if the difference exceeds an acceptable deviation, an alarm is automatically given. The detectable difference in flow for this type of system is approximately 0.5 per cent of the total flow. The interval of reliable periodical comparison can be accommodated to suit the specific detection requirements. Several hours are required for low leak rates to be detected whereas two minutes is an achievable time period to detect leaks of one to two per cent of the total flow. The reliability of existing systems is good .

1.2 RATE OF PRESSURE DECAY (ACOUSTIC SYSTEM)

This system uses the rate of pressure decay, or drop, as the indication of a pipeline leak. The underlying principle is that a pipeline leak will manifest itself in a rapid drop in pressure in the immediate vicinity of the leak, The resulting pressure wave, which moves in both directions from the leak, is detected by sensing devices.

These pressure sensors can be connected to the alarm and shutdown system similar to the mass flow system described previously. The threshold pressure must be set above the rates of pressure drop which will normally occur as a result of changes in flow rate. The amount of leak flow to trigger the system is two to three per cent of the total flow rate. The system records continuously and the reaction time is proportional to the length of the pipeline segment between the leak and the detection device. For purposes of leak determination, the reaction time is essentailly immediate. The reliability of this system is good.

1.3 SIMPLE MASS FLOW COMPARISON

This program consists of monitoring the volume flow and temperature at the input and discharge ends of the pipelines. This monitoring is generally done at least once per shift (12 hours) . Since the operating pressure and temperature will fluctuate during normal operation this method does not provide rapid leak detection; however, unlike the systems described above, there is no lower threshold in loss rate for leak recognition. Very slow leaks (less than .5 per cent of flow) are manifest as a trend which may extend over a period of several days . Any leak detection program implemented is expected to include this method as a matter of course. A possible application would prescribe a hydrostatic pressure test of the pipeline in the event that six successive readings over 36 hours indicated a loss.

1.4 SCHEDULED SURVEILLANCE

Active surveillance programs can provide an important means for leak detection especially in the range of extremely small leak rates. At present, periodic surveillance by low altitude aircraft using visual observation and colour photography appears to be most reliable during daylight conditions for a wide range of oil/ice/water mixtures.

Future development of new techniques, such as a portable laser fluorosensor, may provide more reliable sensing methods for night conditions which could add to the total reliability of surveillance systems. Such techniques are under development, but are not presently of sufficient reliability for use in the development scenario considered.

APPENDIX C

THE TANKER/PIPELINE CONTROVERSY (R.J. STEWART)

THE TANKER/PIPELINE CONTROVERSY

Robert J. Stewart
Mar rtingale Inc.
Cambridge, Massachusetts 02139

ABSTRACT

The problems of drawing comparisons between alternative tanker and *pipeline* transportation *systems are discussed. The statistical properties of mean values calculated for samples drawn from highly skewed populations are* outlined. *Existing U.S. spill data resources are* critiqued. A *sample regression result of number of spills versus port calls is presented.*

INTRODUCTION

There is a growing body of opinion that tankers are, in general, a less desirable transport mode for crude oil than are subsea pipelines. Opinions so this effect played a role in the legal controversies that accompanied the Department of the Interior's lease sale in the mid- Atlantic in August 1976. The apparent consensus has even induced policy makers to consider measures that would force developers to use pipelines in bringing oil to shore.

It is difficult to identify any one paper or report ax che foundation for this belief, but one of the earlier papers that states this conclusion explicitly u that of Milz and Broussard.[1] This paper has been referenced several times in recent years. A review of the paper reveals that rhe basis for their statement wax a rather superficial examination of some U.S. Geological Survey and Department of Transportation (COT) statistics coupled with so unsubstantiated and probably incorrect assertion that there was a total of "13,000 miles of *trunk* lines in the marine environment" in 1972. Nowhere did they address the issue of the quality and completeness of the data used to generate the statistics. Nor did dray address the subtle analytical problems that accompany such comparisons. Their whole argument required one small paragraph, although in fairness to these authors, it should be noted that the relative merits of tankers and pipelines wax M issue very much tangential to their central theme

In the interim, a number of related papers have drawn the same conclusion. It is not our contention that all of these papers were equally glib, because we have by m means examined all of the literature. However, of the rather substantial number we have reviewed, none does a significantly better job of addressing dre problems associated with using rhe existing statistics to compare tankers with pipelines.

As a general rule, these papers fail to state whether rhe sample population used to generate the statistics was in fat! the entire population or whether it was a subset of the population. *Further,* if the latter *is dre* case and if the paper mentions this, then it fails as tell how the sampling process might bias the conclusions.

As if these omissions were not enough, there is also a rather distressing reliance upon the ratio of *volume spilled per volume handled (historically)* as the parameter characterizing alternative transportation modes. Such approaches might have considerable usefulness in cases whether the number *of* incidents is large and where the volume spilled per incident ix a random variable with a standard deviation that *is small* compared to the mean. However. for the highly skewed distributions we find in the oil spill business, and for applications where the sample size is small (in Milz and Broussard's paper only four pipeline spills were identified), the use of average volume statistics is likely to & very misleading, as we show in the following section.

Nor does the simplistic conclusion that one mode is to be favored over the other account for the markedly different cost structures of operating and procuring pipelines and tankers. Tankers can be acquired either by chartering fors fixed period or by outright purchase. In either case, the real cost of owning and operating the tanker is determined by the going rate on the world tanker charter market. At present, these costs work out us shout 10^{-3} dollars/ton mik for non-U.S. vessels. Pipelines, on the other hand, are constructed for an application. They have high initial costs, but low operating costs. While tankers arc readily bought and said and readily transferred from one trade to another, pipelines am obviously of use only for carrying oil between two predetermined, fixed points.

Because of these differences, tankers and pipelines am not in general equivalent transportation modes, snd there is no meaningful way of comparing tankers and pipelines in a generic *fashion.* The idea that one mods is always to be preferred to the other without regard to dse application is. therefore, incorrect.

In any *gives* application, it may be possible to construct a number of scenarios and compare those pipeline and tanker transport systems providing equivalent services. The difficulty is that the definition of "equivalent" is complicated by the interplay of the economies of operating the alternative systems upon the other facets of the problem. For example, if a very large oil field were discovered close off the share of a region that had a modest refining capacity that was supported entirely by local crude production, the economies offered by pipeline transport might make expansion *of* the existing refinery an attractive alternative, particularly if the other option were long-distance tanker transport. In this use the "equivalent" options would be a short pipeline and a long tanker route.

Thus, the purpose of this paper is to examine both the data that have become available in recent yearn and the analytical techniques applied to the data to see if there is indeed a reasonable basis within the data for the preference given pipelines over tankers. Despite dre author's predilection as discount the previous literature an drc subject, no preference was established initially in support of either the pipeline case or the tanker case. We simply wanted to look u the data 10 see what could, or muid oat, be said.

Average volume comparison techniques

.$ As we mentioned in the'incmductioa. a substantial portion of rhe existing literature (e.g., impact statements and the like) make use of comparisons between modes baaed in some fashion upon an avenge spill volume statistic. This may be hidden in the analysis, but whenever one sees statements like "C.0006% of the oil handled by system' R' will be spilled," or "X will spill Q% less dsaa Y," then one has entered the world *of* the average statistic. Implicit in such a statement am the dual assumptions that dre number of spills will be in rough proportion os the volume handled; and that the average *volume per spill* incident may be accurately determined from the available data. Q'-

We would have no argument if these assumptions were indeed supported by the data and the accompanying analysis. In fact, we would be very interested in conclusions relating to such average values. However, in the problem at hand. the analyses usually are based upon small samples and superficial estimation techniques, the assumptions are rarely stated explicitly, and the validity of neither assumption is addressed. In the event that such analyses lead to the adoption *of* a policy that discriminates against tankers, then we may be imposing economic and perhaps environmental penalties that xsc not at all consistent with the data, or in the interest of the public or the developer.

The primary cause of the difficulty in conceptually handling m average spillage statistic springs from the possible variability in the value of the sum of several random numbers. Most people, professionals as well as laymen, expect such sums to exhibit nice statistical properties. This may be due to a popular. misconception regarding the universality of the Law of Large Numbers which rruy lead to a belief in the general normality of sums of random variables (of random variables that have a second moment, that is). However, the asymptotic character of dve prwf of the Law of Large Numbers requires very large numbers of summands and there is no basis for a belief in the general applicability of the law to small samples.

Furthermore, there arc classes of random variables that do not have first and second momenta and that are yet of value in looking at oil spill statistics.[8] Such distributions would completely fail to comply with the "law" of large numbers. Moreover. one need not look at unusual distributions before one uncovers random phenomena that exhibit highly irregular sums.

An example can best illustrate this point. Assume shas the distribution on the volume, v, of oil spilled in any one incident ix given by the Gamma distribution

$$f(v) = \frac{\lambda(\lambda v)^{R-1} e^{-\lambda v}}{\Gamma(R)} \tag{1}$$

where R and λ arc dsc shape and scale parameters respectively. Assume that the volume spilled in soy one incident is independent of the volume spilled in any other incident. If our sample comprises "N" incidents, then the ~~bu- 00ss 0ss the sum, y, of these "N" values of v,

$$Y = \sum_{i=1}^{N} v_i$$

is given by the related Gamma function

$$r(y) = \frac{\lambda(\lambda y)^{NR-1} e^{-\lambda y}}{\Gamma(NR)} \tag{2}$$

If we now take the average of these spills, z = y/N. we find that the aver-age is distributed like

$$f(z) = \frac{\beta(\beta z)^{NR-1} e^{-\beta z}}{\Gamma(NR)} \tag{3}$$

Where $\beta = N\lambda$, and z is dsc average of the sample.

Using this distribution and performing a few integrations,[18] we can readily show the probability that the value of z (the sample mean) will fall within a factor o(three of the desired value, $\bar z$. that is

$$P\left[\frac{1}{3}\bar z < z < 3\bar z\right] = \frac{\Gamma\left(NR, \frac{1}{3}NR\right) - \Gamma(NR, 3NR)}{\Gamma(NR)} \tag{4}$$

where $\Gamma(a,x)$ is dac incomplete Gamma function.[1]

We can see that dais probability is solely s function of NR. [n turn, R is related to the skewness of the underlying distribution. Thus, the probability that the estimated mean value will fall in the range ($1/3\bar z, 3\bar z$) will be a function of the product of the skewness of the underlying distribution and the number of samples.

It is certainly reasonable to expect that the underlying distribution will be highly skewed in the oil spill volume problem. In the case of pipelines the number of incidents is on the order of IO. and so the product NR might be about I. O or even smaller.

To provide a mat-c concrete understanding of the problem we have approximately evaluated Equation (4) for various values of NR using Figure 5.3 of Abramowitz[1] for small values of NR and the table of the CDF of X^2 in Benjamin and Cornell[2] for larger values. The results are tabulated us Table 1. Thus. for example, NR must fall in the range of 0.5 to 1.0 if we arc os have • 50% chance (P = 0.5) of estimating $\bar z$ within a factor of three.

It seems clear that if we cannot be very confident of estimating the average spill size wirhins factor of three, with 10 or even 100 samples, then we must be suspicious of dsc reliability of the comparison of two such means. Isa fats, if we make a number of reasonable assumptions and perform the necessary mathematics, we can show that for highly skewed underlying distributions, a *comparison based on the relative sizes of rwo sample means is strongly dependent upon the relative number of samples used to calculate the sample means.*[18] In the case of pipelines and tankers, the equations suggest that if the actual population mean for tankers is 1/ 10 that of pipelines, there is sail a one in 10 chance that we would find z tanker sample mean larger dsan a pipeline sample mean duc solely to the facr that we have 20 times more tanker spills than pipelines (see below).

Table 1. Probability that the sample mean will fall within a factor of three of the real mean

NR	$P\left(\frac{1}{3}\bar z < z < 3\bar z\right)$
.5	.44
1.0	.64
2.0	.85
3.0	.91

Summary and critique of U.S. oil spill data resources

Comparisons of pipelines and tankers generally arc baaad on very large (more than 1,000 bbl) worldwide tanker spills and very large Gulf of Mexico pipeline spills. This leads to a number of problems (not the least of which is unreliability of such comparisons, as we discuss above), and an interesting alternative approach would be IO usc just U.S. oii spill data. This promises to give us a much mora exhausitve collection of data, including small spills as well aa large ones. and this rather paradoxically gives us a larger number of samples, relieving soma of the difficulties discussed above.

Since "equivalent" pipeline and tanker systems may involve vastly different routes, production schedules, and related activities, it behooves us so disaggregate the incidence of oil spills into subsystem specific elements. This allows us to establish where the spillage will occur. Given the spill location it may then be possible to estimate what fraction of she oil will be recovered and the nature of the environmental impact.

An appropriate level of disaggregation for these purposes may be constructed as follows. The pipeline system may be considered to be made up of the pipeline and its pumping stations and associated equipment like surge tanks. Each subsystem will have s particular geographic location and this must be known. The tanker system will be composed of a loading facility, including storage tanks and an SBM of some type; the tanker fleet and the route to port; and an offloading facility.

U.S. oil spill data bases are *in principle* sufficiently comprehensive 10 allow us to address most of the important questions regarding the subsystems. (The single exception to this generalization is the offshore tanker loading facility for which there is no example within the waters covered by the various U.S. data bases.) An important question is how reliable is this data as it relates 10 these subsystems, given our requirements.

Offshore pipeline spill data is compiled by dsc U.S. Geological Survey (Department of the Interior), the U.S. Coast Guard (WIT. and (for comman carrier or trunk lines) the Of fice of Pipeline Safety and Operation (DOT). The Geological Survey data applies to the federally-controlled outer continental shelf (OCS) region. It is, therefore, a subset of the total (state waters have historically ● ccounted for about one. third of ail offshore oil and condensate production). The OPSO data applies only to offshore pipelines that carry oil produced and owned by entities other than the pipeline operator. The pipeline operator merely is given custody of the 011 while it is in the pipeline system. As such, this is again but a subset of the total, although in this case spills in state waters will be reported. The Coast Guard's Pollution Incident Reporting System (PIRS) should contain ail spills (from pipelines or whatever) out to three miles irrespective of size. Beyond three miles, spills must be reported in writing 10 both the Coast Guard and the Environmental Protection Agency if they exceed 50 bbi (2.100 gallons). Thus, the PIRS data should encompass ail the OPSO data.

larger spills in the USGS data. Leona and Wallace.' Frenkel and way,[a] and Snider. Buffleben, Harrald, Bishop, and Card[1a] provide complete discussions of the various data collection arrangements.

'ar the most useful of the data resources is the Coast Guard's PIRS data : it is more nearly a complete compilation of pipeline spills, at least in However, in this business discrepancies between theory and practice to be the rule father than the exception.

ven if we assume, for example, that all spills arc reported to the Coast there still is the problem of verifying that the incident is properly :d and encoded within the PIRS format. This requires considerable ·tion and experience on the part of the encoder, particularly in distin- ing transportation-related pipeline spills from spills occurring at ·e production facilities (in the gathering net, for example).

method for investigating this problem is to compare the different data In particular, the OPSO dasa applies only 10 tnsrsporution-related ines, and so an interesting question is that of how the incidents in the file are recorded in the Coast Guard and Geological Survey files. We :d copies of all the offshore oil spill reports received by OPSO. In the 1973 through 1975, the following spill incidents were reported (this d was selected as it is covered by* revised ● nd expanded PIRS data).

" ble 2. Summary of all spills in the office of pipeline safety and operations data (1973 -197S)

Dale	Name of carrier	Vol. spilled (bbl)	Location
11-3-73	Gulf Refining co.	75	Barataria Bay, Louisiana
5-21-74	Shell Oil Co.	65	Eugene Island Block 331
8-1.74	Shell Pipe tine Corp.	2s0	Quarantine Bay, Louisiana, near Brenton Sound Block 35
9-1o-74	Shell oil co.	1,S00-3,500	Main Pass Block 73

'e cross-reference these spills to those within the Coast Guard' ng system we find the following information on these spills in dse RS data.

: 3. Spills as reported in the U.S. Coast Guard data (1973-1975]

Date	Operator	Source	Quantity spilled (Gallons)	Location
11-3-73	(Petroleum Refiner)	Transport pipeline	3,150	29° 08'N 90° 44'W
S-21-74	Shell oil co.	platform	?..730	E1331
8-1-74	Shell Oil co.	Platform	6,300	2?° 24'N 89° 30'W
9-16-74	(Crude petroleum producer)	Pla t form	16,800	(bay or sound)

Spills 2 and 3 almost certainly are the same incidents. Spills 1 and 4 may properly identified, although the choice seems 20 be the best one le. (The location of Spill 1 is listed in dsc Coast Guard data as being in them part Of "Lake" Pelto.) Notice that the trunk line spills are buted improperly to production platforms in three out of the four cases. so notice that the operator is mistakenly identified as Shell Oil Co. in spill r 3.

We also can look for some of these spills in the data kept by the Geological Survey. In this case only those spills that occur in the federal OCS region are likely to be reported. Consequently, [he Barataria Bay spill and the Quarantine Bay spill arc not found, nor should they have been.

Table 4. Spills as reported in the U.S. Geological Survey data (1973 "1975)

Ref. No.	Date	Lessee	Volume spilled (bbl)	Location
1.	11-3-73	—	Slate Waters	—
2.	5-21-74	Shell Oil Co.	100	El-331 (Structure A)
3.	8.1-74	—	State Waters	-
4.	9-9-74	Shell Oil Co.	2213	MP-73 (Cobia pipeline)

This data is in good agreement with the OPSO dau. in fact, by combining dre three data sources we can determine a great deal about the four spill events. Unfortunately, if we use only [he Coast Guard's data we would be grossly in error in assessing the spillage from common carrier pipelines.

Another problem of considerable interest is how complete is the Coast Guard data for the larger spills occurring in federal waters—those that would be contained in the Geological Survey's records—irrespective of source code. Snider et al.[1a] maintain that only three of 14 large spill events in the Geological Survey's records am 10 be found in the PIRS data. This ia lower than our experience wish the two files would suggest, and so we attempted to cross-reference she USGS and the USCG spill records. The USGS data was takers from Table D of dsc July 1976 summary, '" Accidents Connected with Federal Oil and Gas Operations in the Outer continental Shelf.'. A total Of 1S events were identified in the period 1973-1975, one more than Snider found. (Snider apparently threw out a barge spill.) Of these, wc identified eight in the PIRS data. There were substantial discrepancies in the volume spilled, and some minor variations in che dase of the incident.

Of these two errors in the Coast Guard's PIRS data, it is clear that the mislabeling of pipeline and platform spills "u the most harmful with respect to addressing the pipeline spillage problem. if the Coast Guard data was simply a nonexhaustive collection of spill events, a way could be found to proceed. However, with the confusion that exists between pipeline and platform spills, no simple technique is available to correct or accommodate the resultant misinformation. Neither the OPSO nor the USGS data are sufficiently complete to allow further analysis based solely on either.

A similar analysis of the tanker spillage problem demonstrated that the PIRS data could be used to good effect as there did not appear to be any systematic and uncorrectable miscoding.[12] However, as we mentioned above, the SBM subsystem is not properly covered in presently available U.S. data bases. In a previous study ' we compiled as complete a listing of SBM spill incidents as is available today. The data is perhaps of some value in addressing the problem, but we had some strong reservations regarding the accuracy and completeness of the information We managed to uncover. Frenkel and Hathaway[4] have attempted a fault tree analysis of SBM systems, but they did not take the matter to its final conclusion. They did calculate some interesting numbers regarding large spills from the connecting hose and dsey discussed techniques for determining optimal hose replacement strategies. (They calculate an average of 4.6 major hose spills per year and a spillage rate of 8.8 x 10^{-4} bbl spilled per bbl handled.)

The spillage associated with tankers en route and while offloading is well represented in the PIRS data, although we have some strong doubts regarding the completeness of the data as it applies to ships in the offshore region.

Among dsc several regressions we attempted on the incidence of ship spills based on the PIRS data, the moss useful appears to be the regression of the number of tanker port calls against the number of large (more than 100 gallons) tanker spills. In this case we aggregate crude and product carriers: Wc neglected smaller spills due to so apparent variability in reporting policy. The number of port calls was obtained from dse Army Corps of Engineers publication, *Waterborne Commerce of the United States*, and the Portland Pipe Line Corporation Of Portland, Maine. Figure 1 is a scatter diagram of the data, less the Portland crude spill points. There is a strong trend evident us the data. We have fitted a line through the origin according to

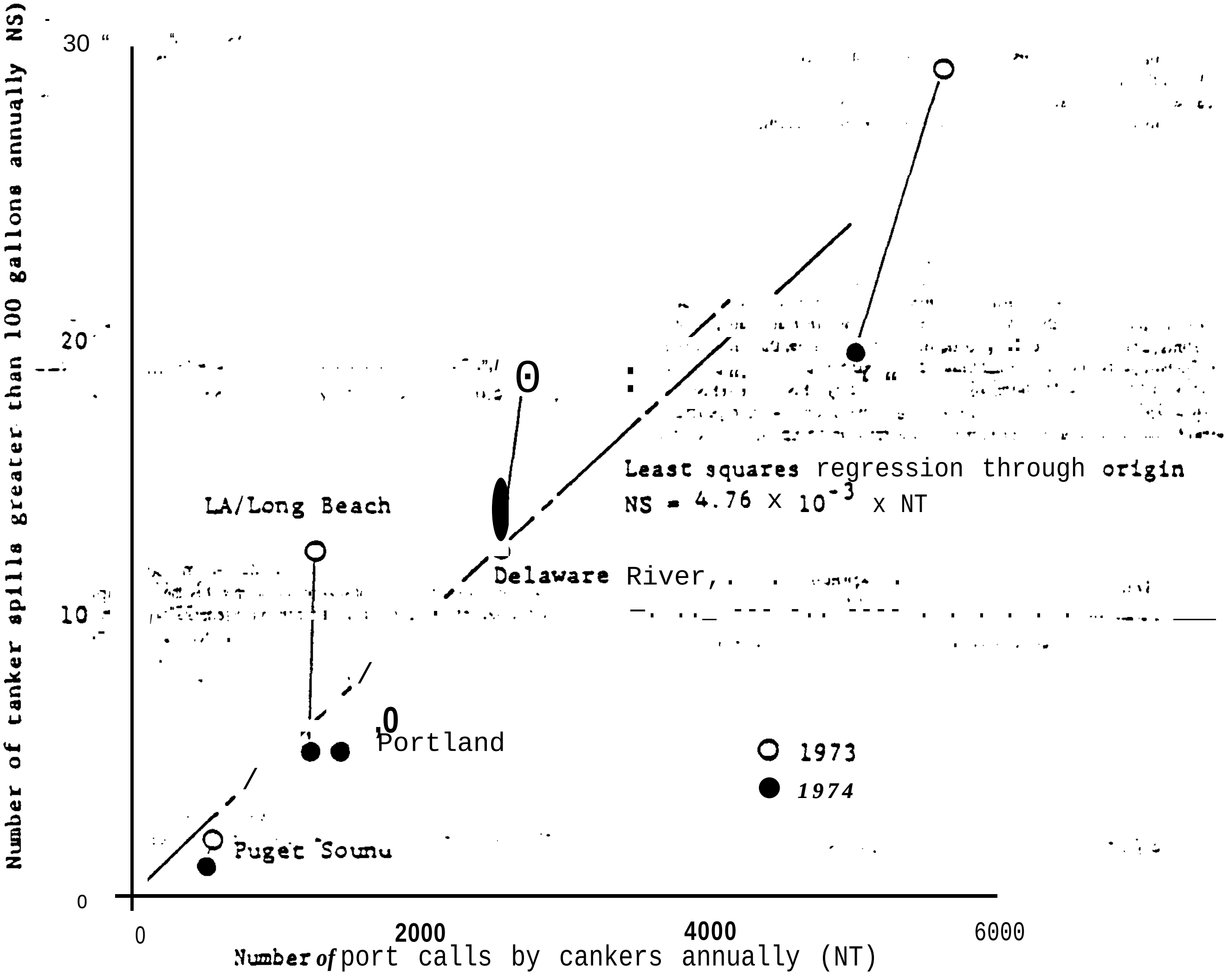


Figure I. Scatter diagram of large tanker spills (> 100 gallons) versus number of tanker port calls

a minimized squared error criterion. If we were to plot the Portland crude oil spills on this graph (four or five spills, wish several hundred port calls), we would see that they would fail to the left and slightly above the Puget Sound points. They would not be so far away from the regressed line as to suggest the truck oil spills occurred at a substantially different rate than the aggregated population of tankers. However, if (for example) we double the number to account for the non.crude spills accompanying these tankers, we would find that tankers bringing in crude oil have substantially greater numbers of spills per port call. This is not M unusual finding, and it bears further investigation.

GENERAL STATISTICAL SUMMARY

Table 5 serves to encapsulate some important features of the oil spillage problem as it exists today. This table was created using Fearnley and Egers's[4] shipping statistics PIRS data, USCG Office of Merchant Marine Safety data, and USGS production and spillage data.[11] The first four rows summarize the appropriate spillage and throughput figures for the period indicated. The bottom four rows combine these figures in the sort of fashion we recommended against earlier. We have done this for a reason, however, because it illustrates fire difficulty in making the pipeline/tanker comparison. If on the one hand, we use number of large spills per ton mile as our criterion in comparing pipelines and tankers, while on the other we use barrels spilled per barrels transported, we can readily see we would come to opposite conclusions regarding one mode versus the other. Either criterion could be chosen and justified on quite reasonable grounds.

Table 5. Spillage and throughput for tankers (world wide) and U.S. offshore transport pipelines[1]

	Tankers (worldwide) 1969-1973	Pipelines (U. S.) 1969-197S
Number of spills	178	5
Volume spilled (bbl)	6.65×10^{6}	35.6 X 103
Ton-mileage	37.9×10^{12}	39.0 x 109
Barrels carried	45.9 x 109	3.94 x 109
Number/ton-mile	4.69×10^{-12}	128.2×10^{-12}
Volume (bbl)/ton-mile	17s x 10-9	912×10^{-9}
Number/barrel	3.87×10^{-9}	1.26×10^{-9}
Volume (bbl)/barrel	144 x 10-6	9.01×10^{-6}[2]

1. Tanker spills include all spills over 125 tons (approximately 900 bbl); pipeline spills include all spills over 1,000 bbl

2. Had the period been selected as 1967 -197S, this figure would be 42 X 10^{-6}, another illustration of the variability of the sums of such highly skewed random variables

Pipelines would prevail under the barrels-handled criterion because of the ratio of the two comparable figures (144 and 9.0!. bottom row, Table 5), while tankers would prevail if the criterion were chosen to be number of spills per ton-mile (i.e., 4.69×10^{-12} versus 128.2×10^{-12}) or barrels spilled per ton-mile (i.e., 175×10^{-9} versus 912x 10’). Because of the small number of samples in the pipeline data base. our results mentioned previously suggest that neither result is reliable. By way of illustrating this point, let us note that the decision to usc 1969 ss rhe first year in both the pipeline and tanker calculations wss motivated both by the nonavailability of comprehensive tanker spill data prior to 1969 and a certain irrational love of symmetry. We might just as well have chosen 1967 as the first year in the pipeline calculation. Had we done so. the pipeline spill rate in barrels/barrel would have soared to 42×10^{-6}, obscuring the seemingly sharp contrasts between the alternatives.

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APPENDIX D

TANKER SAFETY SYSTEMS

1.0 GENERAL

Pollution from tankers began to concern the nations of the world in the mid-sixties with the dramatic growth of the oil tanker trade. At that time, and since, a number of methods which can dramatically reduce pollution have been identified. After due consideration and discussion at the international marine governing body, IMO (Intergovernmental Maritime Organization; formerly IMCO), the conclusion was reached that only some of the measures should be adopted and those only after a considerable period of elapsed time. For instance, the MARPOL (Marine Pollution) 1973 and Tanker Safety Pollution Prevention Protocol 1978 are only coming into force in October of 1983.

In view of the sensitive nature of the environment of the North West Passage, the proponents, however, propose to include in their tanker design not only all the mandatory measures but also many additional safety functions discussed below.

2.0 HULL STRENGTH

The strength of the hull of a vessel can be assessed in three ways; first, by pressure which is important with regard to operation in ridges and iceberg impact; second, by force which is important with regard to iceberg impact; and third, by energy which is important when assessing the extent of damage. The Arctic tanker, as described by the proponents, is massively stronger than a conventional tanker and approximately 2-3 times stronger than required by existing legislation.

2.1 PRESSURE

The bow of the conventional tanker can withstand a pressure of .5 megapascals (MPa). The bow of a Class 10 CASPPR tanker can withstand a pressure of approximately 10 MPa which is a 20 fold increase in strength. The bow of the proposed Arctic tanker can withstand a pressure of 25 MPa which is a 50 fold increase. The design process for the Arctic tanker is described in [231. It is important to compare the strength of the vessel to the strength of ice. While the strength of ice varies depending upon its age, temperature, method of loading, etc. the majority of ice seen by the Arctic tanker would have strength of less than 25 M.Pa.

If a tomato is thrown against a brick wall, the tomato is much softer than the brick and is simply squashed. This is what would happen if a conventional tanker hit an iceberg. On the other hand, the Arctic tanker, as proposed by the proponents, is of equivalent strength to ice, which is similar to a brick being thrown against a brick wall. Only minor chipping occurs.

2.2 FORCE

In a conventional tanker, force is applied by waves and the way the vessel is loaded. In the Arctic tanker force is also applied by the way in which the vessel rides up on the ice. The vessel described by the proponents has a main hull girder strength (section modulus) 3 fold stronger than a conventional tanker. This has been determined by the full scale research work carried out by the proponents in testing their ice breakers in Arctic Operations. The Kigoriak and Robert LeMeur have been sailed at high speed into massive ice-pieces and the stresses recorded. This work which was initially carried out by the proponents alone is now being funded by the Canadian Coast Guard.

2.3 ENERGY

The previous sections dealt with pressure and force and the vessel is designed to withstand these without the steel yielding. In the case of collisions, however, when penetration may occur with plastic deformation it is more convenient to use energy as a method to assess the penetration. This is the method proposed by **Minorsky** [241 and adopted in [11 for the calculation of energy factors. The structure of a conventional tanker has been assessed by **Minorsky's** method and then compared to the Arctic tanker. This is shown in Table D-1 and is shown as the increase in the amount of energy which the Arctic tanker would absorb for penetration of the cargo tanks compared to a conventional tanker.

2.4 REAL TIME MONITORING OF STRESSES

In addition to the extreme strength of the Arctic tanker, the proponents have committed to provide a real time stress monitoring system which has been proven on supply vessels operating in the Arctic.

When a conventional ship is loaded and “sets sail, there is no way in which the Master of the ship is made aware of the stresses that are actually existing in the ship. If the vessel, as in the case of the <u>Pac Ocean</u> [251, encounters heavy weather, the Master has no warning whether the stresses will be rising to unacceptable levels. This can be remedied by fitting a stress monitoring system, using conventional strain gauges. The Master can then read the stresses in the steel of his vessel and take appropriate action, such as reducing speed or altering course, prior to any accident occuring. The proponents have committed to an extensive trial period, during which the vessel will be rammed at increasing speeds into massive pieces of multi-year ice, and the strain gauge system will be calibrated. The Master will then at all times be able to see the level of danger to which he is exposing his vessel.

There is a second way in which the steel of the vessel can be overloaded and that is due to incorrect loading. At present, loading is done under the control of the First Officer who monitors

TABLE D-1

INCREASE IN ENERGY ABSORPTION FOR CARGO TANK PENETRATION OF THE ARCTIC TANKER COMPARED TO A CONVENTIONAL TANKER

ACCIDENT TYPE	ENERGY ABSORPTION ARCTIC TANKER / ENERGY ABSORPTION CONVENTIONAL TANKER
Collision	14
Grounding	33
Ramming ‘	20
Explosion	2
Structural Failure	3
Iceberg Collision	66

the amounts of oil in each tank according to a pre-calculated loading sequence. If this loading sequence is not accurately adhered to, then the First Officer has, in the case of deviation from the sequence, no method of knowing whether the vessel is in a dangerous situation. A real time stress monitoring system described above would ensure that indication would be given before the stresses reached critical levels.

3.0 DOUBLE HULL

The proposed Arctic tanker has two hulls. The inner hull is as strong as the outer hull of a conventional tanker. The two hulls are separated by a distance of 6 m at the side and 4 m at the bottom. U.S. Coast Guard studies show that up to 9 out of 10 pollution causing incidents due to grounding which they have investigated, would have been avoided if this double hull approach had been used [261.

3.1 COMPARTMENTATION AND STABILITY

In a conventional tanker, the oil is carried in tanks adjacent to the sea. In the Arctic tanker, the crude oil will be separated from the sea by a distance of 4-6 m. In addition, the proponents , make the commitment that no potential pollution such as fuel oil, lub oil or glycol will be carried adjacent to the sea. The compartmentation and stability will exceed requirements laid down both internationally by Marpol 1973 and its Protocol 1978 and also nationally by the CASPPR.

3.2 SEGREGATED BALLAST

In addition to the double hull, a 100% segregated ballast will be used on the Arctic tanker. This means that ballast water is never loaded into tanks which have previously held oil. In conventional tankers, where water is loaded into cargo tanks, it is the ballast water which on discharge carries with it traces of oil and so causes marine pollution.

4.0 PROPULSION AND CONTROL

For a vessel to navigate safely, both the propulsion system (propellers) and control system (rudder) must be in operation. Isolated marine accidents have occurred when one or other of these systems have failed. The Arctic tanker will use mechanical duplication.

4.1 MECHANICAL DUPLICATION

This is the approach used for multi-engine aircraft. If the chance of an engine failing is once in every thousand (10^{-3}) hours then the chance of two engines failing together is potentially once in every million hours (10^{-6}). This dramatic improvement in safety is, however, not fully achieved as there are always some common cause effects. In the case of the steering gear which has a probability of failure of 2×10^{-6}, the proponents have committed to fitting two independent steering gears which should given a probability of 4×10^{-12}. A very conservative probability of 10^{-7} is used for the purpose of analysis. This approach has been used for the Arctic tanker which the proponents have committed to having twin propulsion systems, twin rudders, twin navigation systems, etc. Pollution incidents such as the Amoco Cadiz casualty occur as a grounding accident after the mechanical failure of the steering gear. This accident would have been avoided with duplicate steering gears. This approach of mechanical duplication provides a very high degree of protection from such accidents.

4.2 ASTERN THRUST

In addition to the duplication of propulsion and steering systems the proponents have committed to the propulsion having a high speed reversing capability and to having the ability to generate full power astern. The propulsion will have the ability to go from full ahead to full astern in 15 seconds. This is achieved by the use of controllable pitch propellers and has been proven on Kigoriak and Robert LeMeur.

In a conventional 200,000 ton tanker, the propulsion system is not capable of generating full power astern. The reason for this is that the normal propulsion system is a steam propulsion system which is not reversible. As a result, a separate astern turbine requires to be fitted in addition to the ahead turbine. Because the astern turbine is used infrequently, it is normal practice to install an astern turbine which has approximately 30-35% of the power of the ahead turbine. When this is coupled with the inefficiency of the propeller operating in the reverse direction, it is found that approximately only 25% of the ahead thrust is available as astern thrust. This significantly contributes to the long stopping distances associated with conventional tankers. The Arctic tanker, however, is different. It is fitted with a controllable pitch propeller, which can generate full power astern simply by reversing the pitch of the blades, as has been indicated this can take place in 15 seconds. Instead of only 25% of the ahead thrust being available as astern thrust, the value rises to approximately 65%.

The ability of a vessel to stop and to turn is a function of both the propulsion systems (propeller) and the control systems (rudder). A conventional 200 000 DWT tanker typically requires a stopping distance of 14 ship lengths or 4.5 kilometre. Two factors influence this: the time to put the propulsion machinery astern typically 60 seconds, and the astern thrust developed by the propulsion system. The astern thrust is typically 30 tons.

The Arctic tanker, by reducing the time to go astern to 15 seconds and having full power astern with a thrust of 600 tons, would have a stopping distance of 5 ship lengths or 1.5 kilometre.

A conventional tanker typically has a turning circle of 3 ship lengths of 1 km. By increasing the area of the rudders and having twin rudders, the turning circle would be reduced to 2 ship lengths or 700 metres. Further, the stopping distance in ice would be reduced to less than 1 ship length.

5.0 FIRE AND EXPLOSION

5.1 INERT GAS SYSTEM

For a fire or explosion to occur, combustible material, oxygen and a source of ignition must be present together. Until the mid-sixties, the approach used in tankers was to remove the source of ignition. Rare occurrences happened, however, when static sparks ignited fires and explosions. The inert gas system is a method which removes the oxygen and substitutes nitrogen and carbon dioxide. The Arctic tanker will be fitted with dual inert gas systems,

5.2 PUMP ROOM

In a conventional tanker, it is standard practice to locate all the pumping systems for loading and discharging the cargo in a single compartment, known as the pump room. This pump room is normally located low down in the ship, and a number of incidents have occured where leaks of crude oil in this compartment have given rise to an explosive atmosphere, which has caused an explosion. It is obviously impossible to inert this space, since the crew have to be working within the pump room. More recently, however, a number of tankers have been built using deep well pumps. This avoids the use of a pump room, since the pumps are individually sited on deck above each cargo tank. In this way, explosive mixtures are avoided. The proponents have committed to the use of deep well pumps for the Arctic tanker.

6.0 NAVIGATION EQUIPMENT

For a vessel operating out of the sight of land, and in an iceberg area, it is important to have working navigation systems and iceberg detection systems. A number of accidents have occured, such as the Olympic Bravery, where the navigation systems such as radars and gyro compasses have failed and there was no backup. More recent 1140 legislation has increased the level of backup required, but the proponents have committed to the Arctic tanker having duplicates of all major components of the navigation system and of the iceberg detection systems.

7.0 SOFT FAILURES

A number of ship accidents have been attributed to human error which is sometimes called 'soft failure'. The proponents have committed to ways to reduce thrust errors.

From the study of system failures, it becomes apparent that most failures involve some element of human error. Very few system failures, however, are due solely to human error, and studies of catastrophic failures indicated that it was unusual for a single human error or soft failure to cause major accident. The more usual course of events was that a number of soft failures combined together, with perhaps a hardware failure to cause the accident. Chronic soft failures appear to be endemic to any system but do not individually cause accidents. For instance, two senior officers who have difficulty communicating together represent a soft failure but will probably not result in a serious accident; however, combined with other circumstances, the lack of communications may be a contributing factor to an accident [271.

Studies indicated that human error accidents could be divided into a number of categories which are discussed below taking examples from the EIS support document, "Tanker Oil Spill Study", by Det **norske Veritas**.

Han/Machine Interface Failure

This occurs when the equipment is designed so that it is either difficult for a man to operate; examples include levers that cannot be reached and gauges that cannot be seen, or equipment on which it is easy to make mistakes such as the case of the Torrey Canyon when the helmsman thought he had control of the rudder but in fact the vessel was on auto pilot.

Incompetence

This is the case when a man is asked to do a job beyond his capabilities or without the proper training. The operator may initiate the accident but the human error occurred earlier when the management system placed the man in that position or when inadequate professional examinations gave the impression of competence. The standard of navigation on board the Olympic Bravery, for example, prior to its grounding appears to have been inadequate.

Flouting the Law

The international maritime laws and standard procedures such as loadline rules, passing port to port, north/south routing are in force, primarily, to achieve safe operation. There is, however, a temptation to break these laws by, for instance, loading deeper than the statutory loadline. This sort of overloading, which probably caused the break-up of the Pacocean, is illegal. The most dangerous combination occurs when the authority and temptation are vested in the same person [28].

Soft System Failures

This is the failure which occurs when the systems of operation involving communications, authority and control is not adequate for the job. For instance, in the case of the Amoco Cadiz, when the time necessary to agree on a Lloyds Open Salvage Form was more than the time required for the ship to be destroyed.

True Human Error

This occurs when a competent individual makes an uncharacteristic error. The incidence of errors increases when some additional factor, such as extreme fatigue, undiagnosed illness or psychological stress is involved.

Alcohol/Drug Induced Accidents

Socially acceptable behaviour during relaxation and recreation periods, such as drinking is completely unacceptable in a safety-conscious work environment. Accidents have occurred due to drugs and alcohol in the work place.

Proponents Approach

It is possible to quantify the improvement of safety due to hardware changes. It is harder to quantify the effects of measures taken by management to avoid soft failure. Researchers [291 have concluded that human errors will greatly reduce by:

1) Appropriate recruiting;
2) Appropriate training;
3) Doubling watch officers;
4) Clear statement of operating procedures;
5) Clear management and authority structure;

6) Discipline to enforce procedures and legal operation;
7) Absence of alcohol and drugs; and,
8). Ergonomics

The proponents have attempted to use this approach for their Arctic operations and have been successful. For instance, in 1981, there were 14.9 accidents per million man hours for Arctic drilling operations, which is a dramatic improvement over 37.5 accidents per million man hours for southern Canadian operations and 51.7 for U.S. operations.

Using tanker operations as an example, the proponents have commited to:

1) Recruiting only officers and men with qualifications equal to or exceeding Canadian Coast Guard regulations;

2) Providing the crew with appropriate training and updating courses - such as simulator training programmed.

3) Providing sufficient crew numbers so that at all times there are two crews members on bridge watch and two crew members on machinery watch ;

4) Operating a dual ship's master system; and,

5) Maintaining an alcohol and drug free operation.

APPENDIX E

TANKER SENSITIVITIES AND REDUCTION FACTORS

SENSITIVITIES

The Bercha report [1] presented a series of graphs in Figures 5.1 through 5.4 to illustrate the comparison of oil spill expectations determined for the conventional (CTANKER) and Arctic (ATANKER) tankers. The comparison was made for the 6 major accident scenarios on each of 4 proposed ATANKER routes. Figures 5.5 through 5.10 illustrate the sensitivity analysis performed to show the contribution of the various ATANKER features in reducing its oil spill expectation. The sensitivity analysis was done for each of the 6 major accident scenarios. Each series of graphs may be explained using examples as follows:

Figures 5.1 - 5.4

Spill expectations of the ATANKER and CTANKER have been compared for each accident scenario with comparisons shown separately for each of the four proposed routes. The Route 1 comparison (Fig. 5.1) is attached as an example for the following description.

The vertical axis is a measurement of spill rate (barrels spilled per barrel carried) which is shown as a percentage of the total CTANKER rate (5.54×10^{-5} bbl/bbl). For the CTANKER, the total of 100 per cent has been divided into the percentage caused by each of the 6 major accident scenarios. The vertical axis is a logarithmic scale where, for example, halfway between 1.0 and 10.0 equals 3.16 and halfway between 10.0 and 100.0 equals 31.6.

Histograms of each accident scenario and the total of all 6 scenarios are plotted along the horizontal axis. The first histogram represents the collision accident scenario where the top of the bar is drawn to show that 15 per cent of the total CTANKER spill rate is caused by CTANKER collision accidents. The shaded portion of this histogram shows that the spill rate from the ATANKER collision accident is 0.038 per cent of the total CTANKER spill rate.

The histogram shown as 'TOTAL' is a summation of all 6 accident types which add up to 100 per cent for the CTANKER and 0.68' per cent for the ATANKER . Over route 1, the ATANKER is predicted to spill 0.68 per cent of the CTANKER rate (bbl/bbl). A comparison over routes 2 to 4 is shown in a similar method in Fig. S.2 to 5.4 respectively.

Figure 5.5 - 5.10

A sensitivity analysis was performed on the ATANKER spill rate reduction (compared to the CTANKER) to determine the separate contributions of each ATANKER feature towards the total reduction, The sensitivity analysis was illustrated for each of the 6 accident scenarios in Figures 5.5 to 5.10 respectively, using route 1 as a basis. Figure 5.7 is attached as an example for the following explanation. This figure illustrates grounding which is the major accident type.

The vertical axis is presented in exactly the same format used in Figures 5.1 to 5.4 and previously described. The histogram bar with 'CTANKER' and 'ARCTIC TANKER' positions is the same bar shown in Fig. 5.1 for the grounding (GRND) accident-type. Forty-eight per cent of the total CTANKER spill rate is caused by CTANKER grounding accidents the spill rate is caused by ATANKER grounding accidents is 0.40 per cent of the total CTANKER spill rate. The reduction from 48 per cent to 0.4 per cent was due to various ATANKER engineering and other changes which are shown on the histogram bar of Fig. 5.7. The unshaded area at the top of the bar includes route related factors such as lower distance exposure per bbl carried for the ATANKER and these factors reduce the spill rate from 48 per cent to 28 per cent of the CTANKER total. The energy factor reduction shown reduces the spill rate from 28 per cent to 0.8 per cent of the CTANKER total. The redundant propulsion and steering system in the ATANKER reduce the spill rate from 0.8 per cent to 0.7 per cent of the CTANKER total. The remaining factor, navigation error reduction representing a conservative 50 per cent reduction in errors reduces the spill rate from 0.7 per cent to the final 0.4 per cent of the CTANKER total. The sensitivity of the ATANKER spill rate reduction (due to grounding accidents) has been illustrated as described above to present a visual picture of the contributions from each major ATANKER feature.

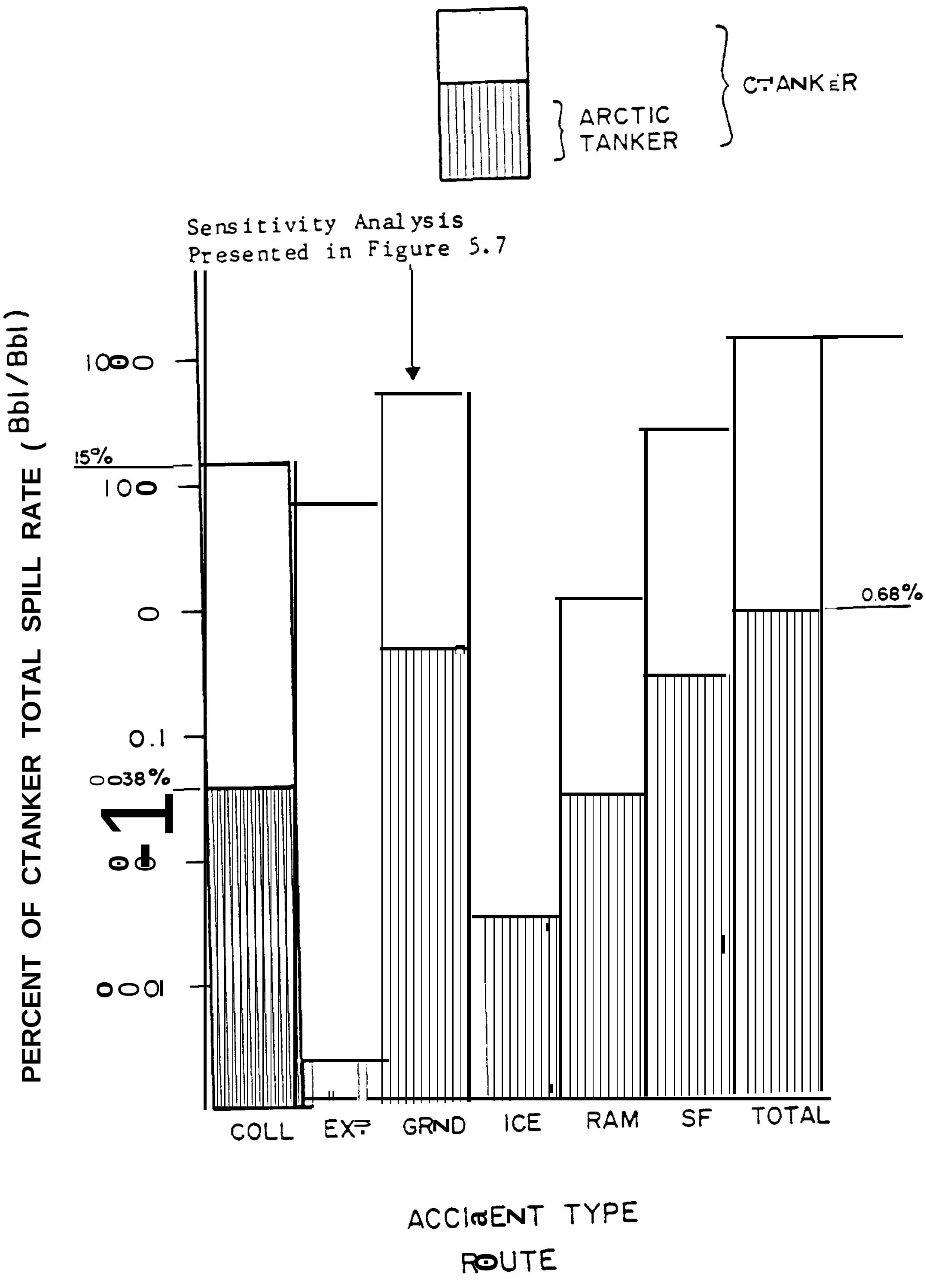

FIGURE 5.1 ARCTIC TANKER SAFETY FACTORS ON ROUTE 1
[Reference 1]

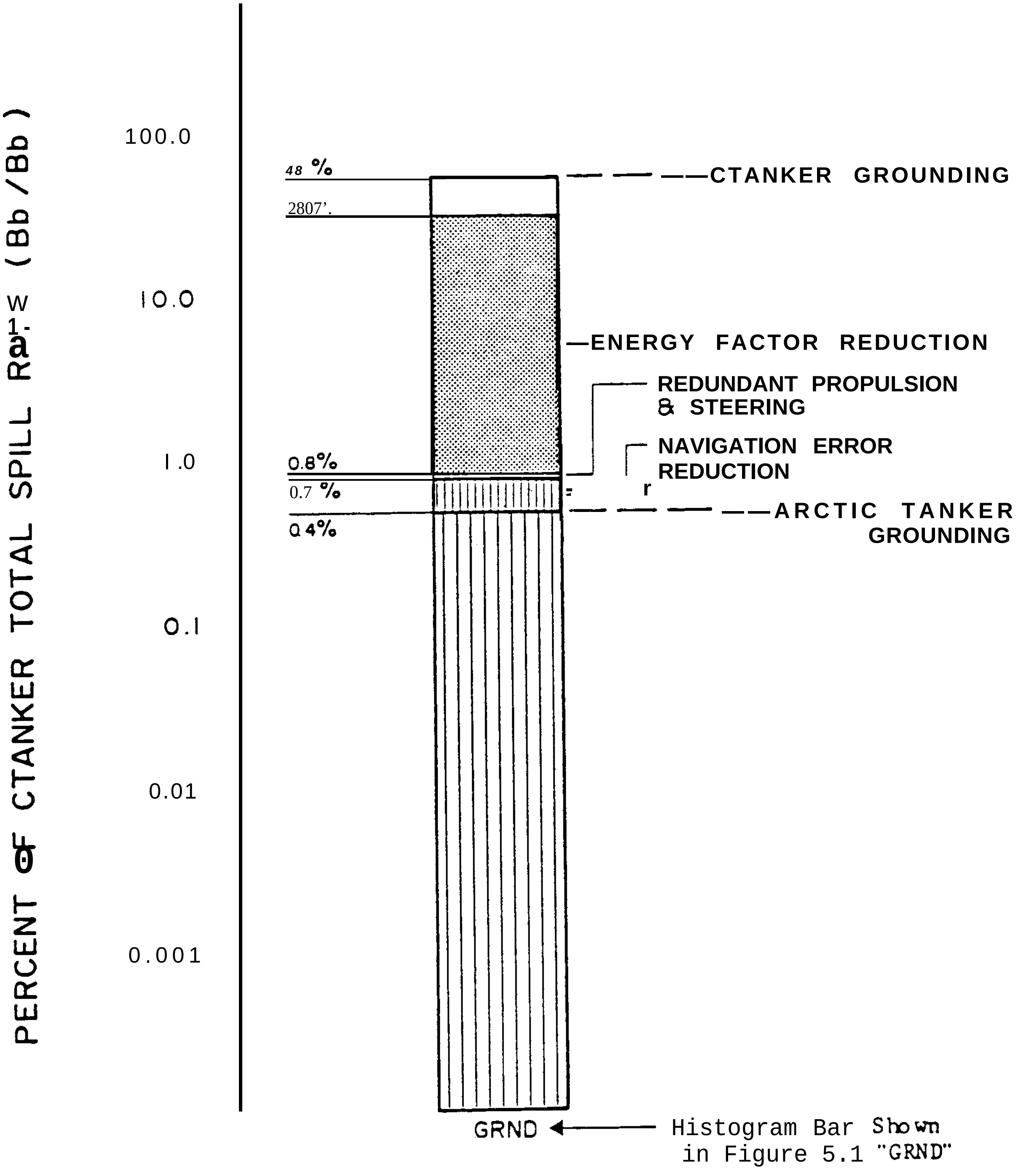

FIGURE 5.7 CONTRIBUTIONS OF ARCTIC TANKER DESIGN FEATURES TO ARCTIC TANKER SAFETY ADVANTAGE FOR GROUNDING

[Reference 1]

REDUCTION FACTORS

A number of ATANKER modification factors were presented in Table 4.4 of the Bertha report [1]. These factors were multiplied to the indicated input probabilities of the CTANKER fault tree to account for improvements in the ATANKER design. The reasons for the various modifications were presented in Table 4.4 and the following supplementary table presents the analysis of the modification factor values utilized.

ATANKER Modification Factors Applied to the CTANKER Fault Tree

FAULT TREE EVENT	MODIFICATION MULTIPLIER	ANALYSIS OF MULTIPLIER
Grounding		
Navigational Error	0.5	Independent navigational systems including satellite and Loran C systems: conservative 50% reduction in errors estimated.
Propulsion & Steering Failures	0.1	Both systems have redundant installations. Though redundant-system failure probabilities are the square of single-system failures, a conservative 90% reduction was utilized.
Raming		Similar analysis to that of "Grounding".