APPENDIX E

Assessment of Iceberg Impact Frequencies

WHITE ROSE
DEVELOPMENT APPLICATION

APPENDIX E

ASSESSMENT OF ICEBERG IMPACT FREQUENCIES

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TABLE OF CONTENTS

Page No.

LIST OF FIGURES

Page No.

LIST OF TABLES

Page No.

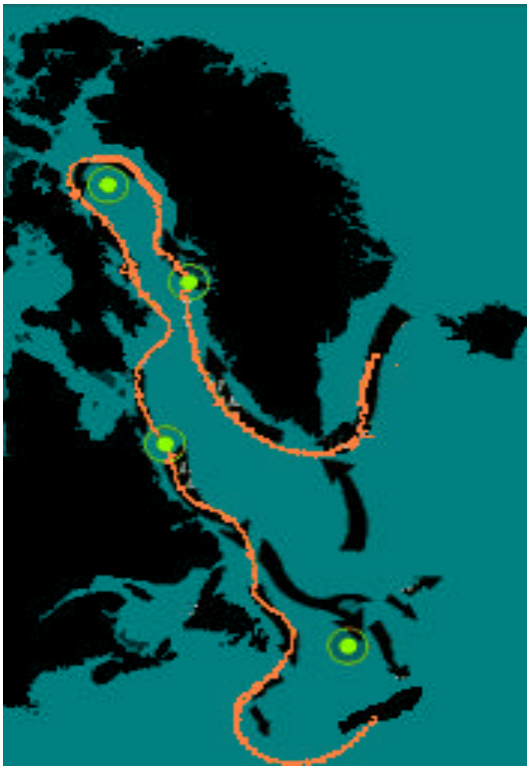
1 ASSESSMENT OF ICEBERG IMPACT FREQUENCIES

1.1 Introduction

The Husky Oil White Rose oilfield development site is located approximately 350 km east of Newfoundland on the Jean d'Arc Basin region of the Grand Banks. The Grand Banks is an area frequented by icebergs, and any offshore development plan must take into consideration the danger that icebergs, and sea ice, pose to any installation.

The majority of icebergs that are found on the Grand Banks originate from the 100 glaciers that are present on the West Coast of Greenland, while others originate from the east coast of Greenland or from Ellesmere Island. These icebergs are captured in pack ice and drift north as a result of West Greenland current where they are stopped due to the pack ice present in Baffin Bay.

Figure 1.1-1 Iceberg Circulation



Upon emerging from the edge of Baffin Bay these icebergs then travel southwards along the coast of Labrador as a result of the Labrador Current. They continue to travel southwards and upon reaching the Straight of Belle Isle where some icebergs drift directly southward to the north coast of Newfoundland, while others continue in a more southeasterly route to the Grand Banks.

Upon reaching the shallow and warmer waters of the Grand Banks some of the icebergs will ground, and eventually all will melt during the early summer months. Typical seasons for icebergs range from early April to the latter part of June and early July, however, icebergs have been seen on the Grand Banks during every calendar month of the year. A typical circulation pattern is shown in Figure 1.1-1.

The maximum number of icebergs observed on the Grand Banks occurred in 1984, when 2,202 icebergs were sighted passed 48° N while in 1966, there were no recorded iceberg sightings. The White Rose site is located on the edge of the Grand Banks, adjacent to the Labrador Current. As a result of this, the number of icebergs that pass through this area are higher than those for Hibernia and Terra Nova. Consequently, any installation located in this area will be more exposed to the risks associated with icebergs.

1.2 Data Sources

There were three major iceberg data sources specific to the Grand Banks of Newfoundland:

- PERD (Program on Energy Research and Development) Grand Banks Iceberg Database, Ref. [1].
- PAL (Provincial Airlines) Iceberg Data, Ref. [2].
- Terra Nova Concept Safety Analysis (CSA) and Terra Nova Detailed Development Plan – Environmental Impact Statement, Refs. [3] and [4].

The PERD Database was compiled by Fleet Technologies for the National Research Council in 1999. The database was a result of the compilation of several different sources of data. These being:

1. IIP (International Ice Patrol) – This data was very extensive and was recorded from 1960 to 1998
2. MEDS (Marine Environmental Data Services) – Industry compiled data gathered from well and drilling sites.
3. Isometrics (Isometrics Consulting Corp.) – Information compiled for the Terra Nova project between 1984 – 1990.
4. C-CORE (Center for Cold Ocean Research Engineering) – Small data set containing position and size.
5. Agra Earth and Environmental – Information gathered from the Hibernia platform for 1998.
6. CORETEC – Data gathered from a well site in 1985.
7. IMD (Institute for Marine Dynamics) – Historical data compiled by Brain Hill.

Fleet Technologies was responsible for compiling this data and refining it in order to produce a searchable database, which now contains nearly 170,000 entries.

PAL (Provincial Airlines) has been responsible for tracking icebergs and pack ice on the Grand Banks for several years, and thus has created their own iceberg database. The draft report presented to the White Rose project from PAL outlines the iceberg data that they have gathered. Along with using their own information, the report also cites several sources of information, including the PERD database.

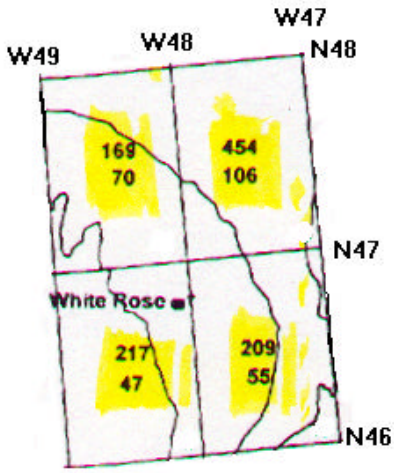
While some use was made of the iceberg analysis data specific to the Terra Nova and Hibernia development projects, this was of limited value for the White Rose project, where increased water depth and closer proximity to the Labrador current has to be taken into account.

Current data, specific to the White Rose site, was compiled by Ocean ltd. of St. John's. This is reported in Ref. [5] and the key data is also reproduced in Ref. [6]. This data was used to determine the drift rates and travelling speeds of any icebergs in the White Rose region.

1.3 Frequency of Icebergs At the White Rose Site

Part of the iceberg count data from the PAL database (of Ref. [2]) is shown in Figure 1.3-1.

Figure 1.3-1 White Rose Geographical Detail



The top number shown in each grid square represents the maximum number of icebergs sighted in this region since 1966. The bottom number represents the average number of icebergs sighted in this area. As can be seen from the picture, the White Rose site occupies the 1 degree grid square with an average iceberg count of 47 and a maximum number of 217. The maximum number was observed in 1990 with the majority of the sightings were from the Petro-Canada drilling semi-submersible, King's Cove A-26.

It can also be seen from this chart that the White Rose site sits in close proximity to three other grid squares. As such, the frequency of icebergs in these areas must also be taken into account. The upper right hand grid square represents an area with much deeper water than White Rose and is also located in the path of the Labrador current. Subsequently, a greater number of icebergs will frequent this area. It is anticipated that due to the wind current and water depth conditions, the majority of icebergs which will be observed at White Rose will originate from the area directly North of the White Rose Grid Square. As such, it is important that the number of icebergs which have been witnessed here are taken into account. Consequently, the average iceberg flux on the White Rose site will be taken to be 70, the average number seen for the square directly north of White Rose. While this provides for a conservative estimate, it is considered more reliable than any calculations completed using the maximum values.

1.4 Iceberg Size Distribution At the White Rose Site

Icebergs are generally classified by their estimated mass, however since proven mass determination techniques do not presently exist there is some discrepancy in the associated values. Along with the definitions of the size classifications, a breakdown of the percentage of each size is shown. These percentages are specific to the White Rose area and were taken from PAL (Table 1.4-1).

Table 1.4-1 Iceberg Size Classification

Size Classifications	
Category	**Estimated Mass (tonne)**
Growlers and Bergy Bits	< 10, 000
Small	< 100, 000
Medium	100, 000 to 1 million
Large	1 million to 10 million
Very Large	> 10 million

With the total iceberg flux now available, and using the iceberg size breakdown shown previously. A more in-depth model of the size distribution and frequency can now be defined specifically for the White Rose site (Figure 1.4-1).

Of the 70 (average) icebergs per year assumed for the White Rose site (Figure 1.4-2):

- 21.7 - Growlers or Bergy Bits
- 23.8– Small
- 17.5 – Medium
- 7 - Large.

Figure 1.4-1 Iceberg Distribution at White Rose

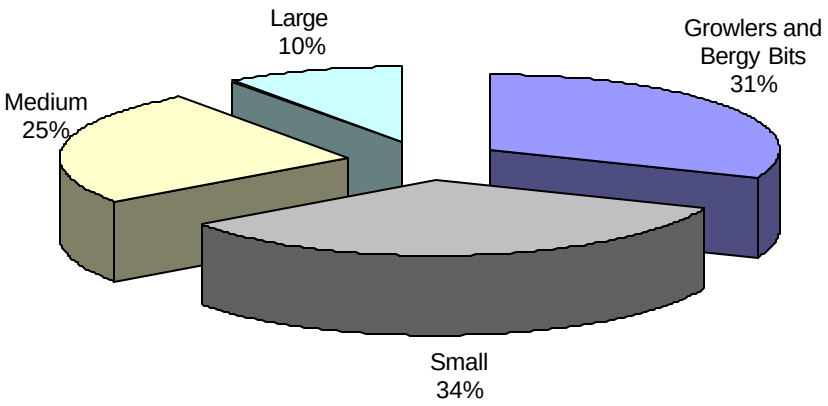
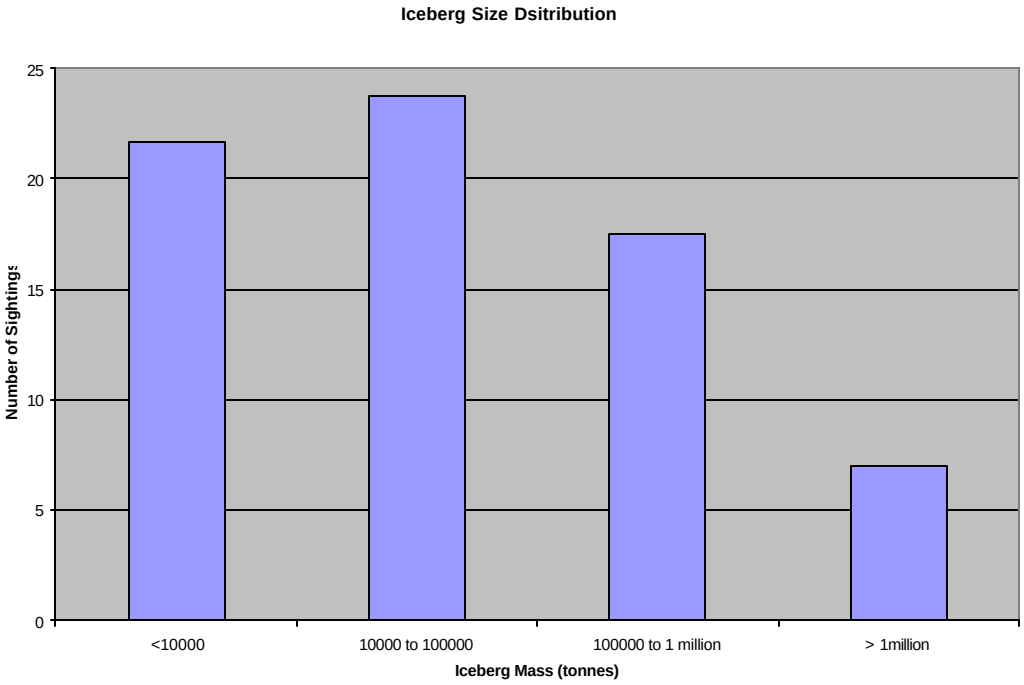


Figure 1.4-2 Iceberg Frequency at White Rose

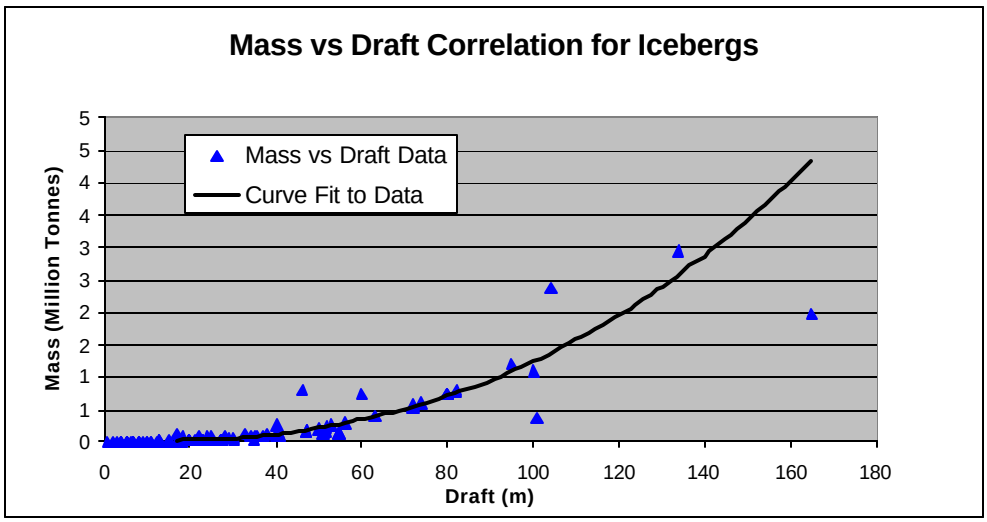


1.5 Iceberg Drafts

In order to determine the likelihood of iceberg scouring at the White Rose site a list of the observed mass and corresponding drafts was gathered from the PERD database, Ref. [1]. From this information a relationship between the mass of an iceberg and its draft was determined (see Figure 1.5-1). This relationship was used to estimate the range of iceberg sizes that would cause scour at the White Rose site. The maximum observed scour depth observed in the White Rose area is approximately 1.5 m, with an average scour depth observed to be 0.6 m (Ref. 2).

From this draft data set the associated mass could be found using the correlation established earlier. Thus a size classification of the icebergs could be determined and the frequency of the particular iceberg size. It was then shown that 3 percent of icebergs that may reach White Rose could be of significant draft to cause scouring. This corresponds with actual numbers from the observations of the White Rose site gathered during previous operations. The total data set of 248 icebergs in the White Rose area Ref [1] was subdivided using a 50-km radius area around the proposed White Rose location. This resulted in 102 observed icebergs of significant size. Of these reported icebergs, only three were reported to have sufficient drafts to cause scour. This data agrees with the 3 percent gathered using the mass-draft correlations.

Figure 1.5-1 Mass vs. Draft Correlation



1.6 Velocity Distribution

The ocean currents at the White Rose site vary significantly depending on season and water depth. Icebergs however only appear during the period from late February to Early July. Currents present at the upper water depths will influence the movement and speed of an iceberg. The effect of waves and wind may also effect icebergs however their influence is small compared to that of the current and has been ignored in this study.

The seasonal information for the current at the White Rose site are shown in Tables 1.6-1 and 1.6-2.

Table 1.6-1 Seasonal Current Speeds (Ref. [5])

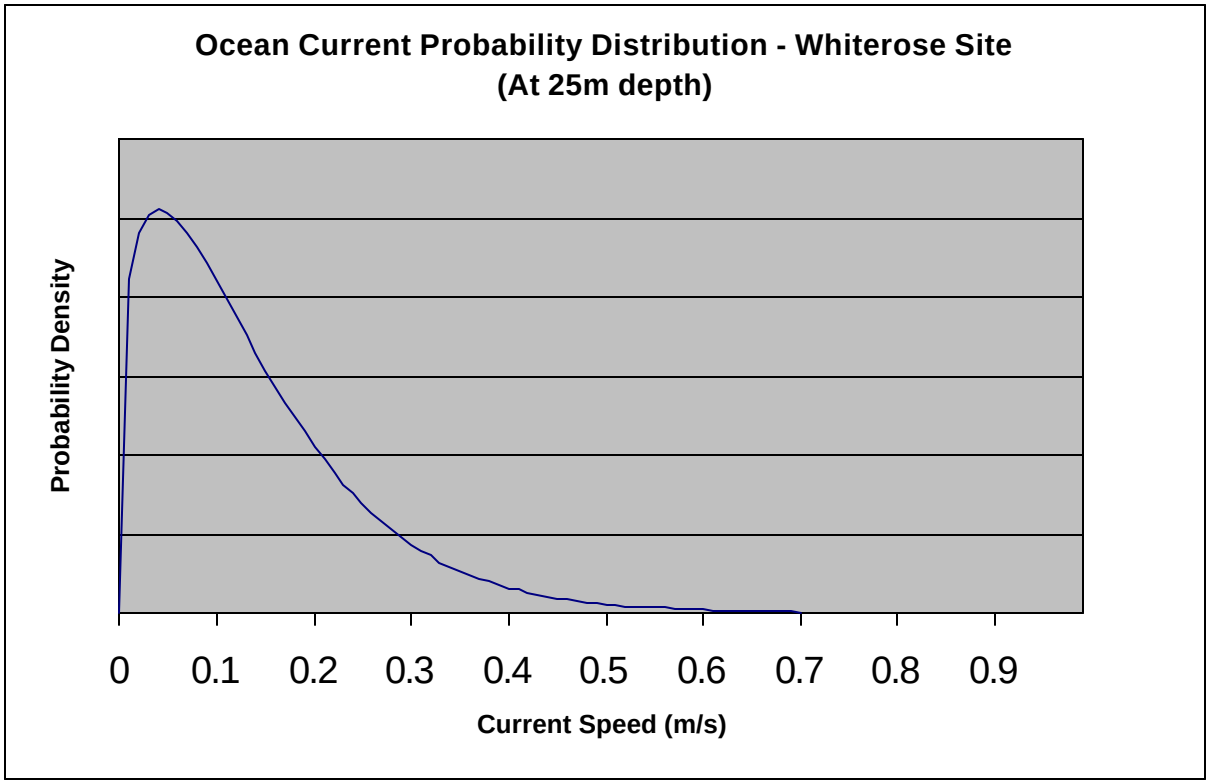
Depth	Season	Mean	Maximum
20m Below Surface	Fall (Sept/Oct/Nov)	0.20 m/s	0.90 m/s
	Winter (Dec/Jan/Feb)	0.12 m/s	0.40 m/s
	Spring (Mar/Apr/May)	0.10 m/s	0.46 m/s
	Summer (Jun/Jul/Aug)	0.11 m/s	0.52 m/s

Table 1.6-2 Estimated Current Velocities for Different Return Periods (Ref. [6])

Estimated Return Current Speeds			
Return Period	**1 year**	**10 year**	**100 year**
Current Speed (m/s) Mid Depth – 25m	0.60	0.76	0.95

From the return periods in Table 1.6-2, the probability distribution of current velocities was determined for the White Rose site (see Appendix 1). The resulting distribution I shown in Figure 1.6-1.

Figure 1.6-1 Probability Distribution of Current Speed at 25m Depth



The above distribution has been used, in combination with the mass distribution from Figure 1.4-2 to determine the distribution of likely kinetic energy values for incident icebergs. This is described further in Section 1.8.

1.7 Risk to Personnel

The main hazard to personnel will occur when the facility, whether a fixed or floating structure, is impacted by an iceberg. The Terra Nova FPSO has been designed to withstand the impact of a 100,000 t iceberg, and has the capability to move off station in the event that an iceberg of greater size threatens the platform.

Ice management systems have been established by both groups to ensure that any iceberg within radar range is tracked to determine its proper path. There are also frequent fly-overs which ensure that new icebergs are tracked as they proceed along the Grand Banks.

The extent of any impact damage is governed by the kinetic energy of the impacting body[1]. The kinetic energy is dependent on both the mass of an object, and on the velocity at which it is travelling. As discussed, both the mass of icebergs in the area and the speed with which they are travelling (i.e., the current speed) are both random variables. Consequently, the kinetic energy of any iceberg that may impact a facility will also be a random variable. The following section describes how the probability distribution of the kinetic energy of the icebergs can be estimated from the probability distribution of iceberg mass and the probability distribution of current speeds.

1.8 Kinetic Energy Analysis

A kinetic energy frequency table was generated which determined both the kinetic energy generated by the iceberg masses and current velocities, as well as the frequency of such combinations. The kinetic energy was calculated using:

$$KE = \frac{1}{2} MkV^2$$

Where:

- KE – Kinetic Energy
- M – mass of iceberg
- V – velocity of iceberg
- k – added mass coefficient (1.2)

The added mass coefficient is included to account for the entrained mass of water surrounding the iceberg. Typical values for ship collisions are 1.1 for head on impact, and 1.4 for broadside impact, Ref. [8]. The difference reflects the fact that a broadside drifting vessel will entrain a greater amount of water than a powered vessel proceeding normally. For the case of an iceberg impact the value of 1.2 has been assumed.

The frequency of a specific mass iceberg moving at a specific speed was calculated as:

Frequency of iceberg of specific mass and specific speed
*= Frequency of specific iceberg mass * Prob. of specific current speed.*

[1] More correctly, damage is governed by the amount of kinetic energy absorbed by the impacted facility. Glancing, oblique impacts mean that not all of the incident kinetic energy will be absorbed and damage will thus be less than it would be for full head-on impacts. This study conservatively ignores oblique impacts and assumes that 100 percent of incidents kinetic energy must be absorbed by the target (e.g., the FPSO).

The above frequency was determined for four separate mass values,

- 10,000 t (Growlers and Bergy Bits)
- 100,000 t (Small)
- 1 million t (Medium)
- 2 million t (Large).

And for a range of current values from zero to a maximum value of 1.0 m/s, in 0.1 m/s steps.

The associated frequency of iceberg masses was taken from the distribution shown in Figure 1.4-2 and the current distribution was taken from the distribution shown in Figure 1.6-1. The results of this analysis are shown in Table 1.8-1.

Table 1.8-1 Frequency of Occurrence of Various Kinetic Energy Levels

		Iceberg Mass (MTonnes)	0.01	0.1	1	2
		Mass + Added Mass	0.012	0.12	1.2	2.4
		Frequency (per year)	21.7	23.8	17.5	7
Current Speed (m/s)	Probability (%)					
0.1	0.465813	KE (MJ)	6.00E-02	6.00E-01	6.00E+00	1.20E+01
		Frequency	1.01E+01	1.11E+01	8.15E+00	3.26E+00
0.2	0.310373	KE (MJ)	2.40E-01	2.40E+00	2.40E+01	4.80E+01
		Frequency	6.74E+00	7.39E+00	5.43E+00	2.17E+00
0.3	0.140942	KE (MJ)	5.40E-01	5.40E+00	5.40E+01	1.08E+02
		Frequency	3.06E+00	3.35E+00	2.47E+00	9.87E-01
0.4	0.054824	KE (MJ)	9.60E-01	9.60E+00	9.60E+01	1.92E+02
		Frequency	1.19E+00	1.30E+00	9.59E-01	3.84E-01
0.5	0.019216	KE (MJ)	1.50E+00	1.50E+01	1.50E+02	3.00E+02
		Frequency	4.17E-01	4.57E-01	3.36E-01	1.35E-01
0.6	0.006215	KE (MJ)	2.16E+00	2.16E+01	2.16E+02	4.32E+02
		Frequency	1.35E-01	1.48E-01	1.09E-01	4.35E-02
0.7	0.001882	KE (MJ)	2.94E+00	2.94E+01	2.94E+02	5.88E+02
		Frequency	4.08E-02	4.48E-02	3.29E-02	1.32E-02
0.8	0.000538	KE (MJ)	3.84E+00	3.84E+01	3.84E+02	7.68E+02
		Frequency	1.17E-02	1.28E-02	9.42E-03	3.77E-03
0.9	0.000146	KE (MJ)	4.86E+00	4.86E+01	4.86E+02	9.72E+02
		Frequency	3.18E-03	3.49E-03	2.56E-03	1.03E-03
1	0.000038	KE (MJ)	6.00E+00	6.00E+01	6.00E+02	1.20E+03
		Frequency	8.27E-04	9.07E-04	6.67E-04	2.67E-04

To summarize the results, the impact energies in Table 1.8-1 have been sorted into five categories:

- 0 to 30 MJ
- 30 to 100 MJ
- 100 to 200 MJ
- 200 to 600 MJ
- Greater than 600 MJ.

The frequency of icebergs in each of the above kinetic energy bands and the associated percentage of the total frequency are summarized in the table below.

Table 1.8-2 Summary Table of Kinetic Energies

Kinetic Energy (MJ)	0 to 30	30 to 100	100 to 200	200 to 450	> 450	Total
Relative Frequency	89.0385%	8.0226%	2.4381%	0.4702%	0.0307%	100%
Actual Frequency	62.3269	5.6158	1.7067	0.3291	0.0215	70

1.9 Frequency of Iceberg Impact

The frequency of iceberg impact has been calculated using the following formulae:

*Frequency of iceberg impact = Total flux in 1 degree square * Prob. that trajectory could be on collision course * Probability that facility will fail to move aside*

As discussed earlier the average iceberg flux at White Rose site has been taken to be 70 icebergs per year.

The probability of an iceberg being on a collision course with the structure was determined as follows:

Prob. That a trajectory could be on Collision Course

$$= \frac{\textit{(Project Width of Target + Average Waterline Length of Iceberg)}}{\textit{Total Width of White Rose grid square}}$$

The proposed FPSO for the White Rose site is expected to be approximately 245 m in length. The FSU will also be a similar length. The semi-submersible will have projected widths of approximately 100 m. The maximum projected width, and thus highest chance of impact, for the FPSO and FSU, will occur when the iceberg path is perpendicular to the vessel orientation, exposing the entire length of the vessel. However, the vessel can be assumed to be randomly orientated with respect to the iceberg trajectory and in many orientations the projected width will be significantly less than the vessel length. It can be shown that the average projected width of the vessel is approximately two-thirds of its total length, assuming that the orientation is equally likely to be in any direction.

The average waterline length for an iceberg was assumed to 75 m (from Ref. [2]). The width of the 1 degree grid square at the White Rose latitude is 40 nautical miles (74 km).

If an iceberg is on a collision course the ice management vessels will attempt to deflect the iceberg by either towing, water jetting or pushing the iceberg to alter its course. As several hours warning will be available and only a moderate deflection is required to avoid a collision then this strategy is quite feasible. Tests have shown that there is an 86 percent success rate for such attempts. Thus, only 14 percent of the icebergs that are on a potential collision course will evade the ice management vessels and actually reach the site of the FPSO.

The probability that the target will fail to move aside in time is addressed in Appendix D as part of the ship impact risk assessment.

Probability that the facility will fail to move away (ship collision) = 0.01

The above values however were based on ship impact risk where only 1 hour or less may be available as warning time in order to effect a disconnection. The warning time for potential iceberg impact will be significantly greater, thus allowing more time to disconnect in the event of any problems. For this reason the above probability has been halved for use in the iceberg risk analysis (i.e., probability that the facility will fail to move away (iceberg collision) = 0.005).

The calculation of impact frequencies for the FPSO and semi-submersible and FSU are summarized in Table 1.9-1.

Table 1.9-1 Iceberg Impact Frequencies for Various Facilities

Total Flux in 1 degree White Rose Site (60 nautical miles)	70 icebergs per year entering grid square		
Total Width of White Rose 1 degree site (60 nautical miles)	74,080 m		
	FPSO	**FSU**	**Semi-submersible**
Average Projected Width of Target (m)	163	163	100
Iceberg Width (m)	75	75	75
Probability that Trajectory will be on Collision Course - projected width of target/total width of White Rose	0.00322	0.00322	0.00236
Probability that Ice Management Vessels Fail	0.14	0.14	0.14
Probability that Facility will Fail to Move Aside	0.005	0.005	0.005
Annual Frequency of Iceberg Impact	0.00016	0.00016	0.00012
Annual Frequency in 30 to 100 MJ Category	1.28E-05	1.28E-05	9.63E-06
Annual Frequency in >100 MJ Category	4.70E-06	4.70E-06	3.53E-06

It should be noted that Table 1.9-1 gives the total impact frequency of all icebergs. In practice, a significant proportion of these impacts will cause little or no damage. Eighty-one percent of icebergs will have less than 15MJ of kinetic energy (Table 1.8-2). The floating installations will be designed to withstand at least this level of impact energy. Thus the frequency of iceberg impacts that are capable of causing damage will be no more than 19 percent of the values in Table 1.9-1. The frequency of iceberg impacts in each kinetic energy band of Table 1.8-2 will be used as input initiating frequencies for event trees modelling of the consequences. More severe consequences will be applied to the event trees in the case of the higher impact kinetic energies. Note that the consequences of iceberg impact will be primarily environmental, since the warning time for iceberg impact will be sufficient to allow a full precautionary evacuation to have been completed.

It should also be noted that the analysis does not take into account the possibility of ice management vessels successfully deflecting any iceberg that may be on collision course. The effect of the ice management program as a means of reducing this risk will be addressed through sensitivity studies in the main CSA report.

2 SCOUR DAMAGE TO FLOWLINES

The average frequency of groundings per year is estimated in Ref. [8] to be 0.25 groundings per 100 km² per year ($0.25 \times 10^{-8} m^{-2} yr^{-1}$) at the White Rose site. The frequency with which scours are likely to cross intra-field pipelines depends both on this grounding frequency and on the chance that any given grounding will produce a scour that is long enough to reach the pipe. Scour lengths have a large degree of variation. Ref. [2] indicates that the average scour length is 566 m but this has a standard deviation of 623 m. The maximum observed scour is 3,370 m.

An exact calculation of the frequency of scour/pipe crossings is complex due to the number of random variables involved (variable scour length combined with variable scour orientation). However, the following simplified approach gives a first approximation to the required frequency. Assume that all scours that originate within a band extending 283 m (half the average scour length) either side of the pipeline will result in a scour that crosses the pipe route. Further assume that all scours originating outside that band will not cross the pipe route. The frequency of scour/pipe crossings will thus be $0.25 \times 10^{-8} \times 566 = 1.415 \times 10^{-6}$/yr/m pipe. For example, a 10-km pipe[2] will be subject to 1.415×10^{-2} scour crossings per year.

The proportion of the above scour crossings that will cause damage to the pipe will depend on the depth of cover above the top of the pipe in its trench. Ref. [2] states that the average scour depth is 0.6 m with a standard deviation of 0.3 m. Thus, for various depths of cover above the top of the pipes, it can be shown that:

Depth of Cover Above Top of Pipe (m)	Proportion of Scour Crossings that will Damage the Pipe (%)
0	100
0.3	84
0.6	50
0.9	16
1.2	2
1.5	0.135

Thus the value of 1.415×10^{-2} scour crossings per year for a 10km pipeline would equate to 2.26×10^{-3} ($1.415 \times 10^{-2} \times 16\%$) damage incidents per year if the pipe was buried with 0.9 m of cover above it.

Currently, it is intended to bury the intra-field pipelines for thermal insulation. In this case, consideration will be given to providing enough cover to minimize the risk of scour damage if soil conditions permit.

[2] or bundle of pipes in the same trench

3 ICE IMPACT ON SPIDER BUOY AND ANCHORING SYSTEM

There is potential for damage resulting from iceberg collision with the spider buoy following disconnection by the FPSO to avoid iceberg impact. This scenario poses no risk to personnel since the FPSO has disconnected, however, there is a slight environmental risk that could occur.

The risk of riser releases is considered to be insignificant on the basis that (a) provided isolation works, there is only slightly more than 50 barrels available in any one riser to spill and (b) the frequency of large leaks from the riser large enough to spill the majority of the isolated riser content would be insignificant. Small to medium-sized riser leaks may be more frequent, however, these would be unlikely to spill more than a few barrels and could therefore be discounted in the Concept Safety Analysis. The scenario of icebergs hitting the spider buoy, however, could potentially cause a large enough breach to release the whole of the content of the isolated riser(s), but only the bigger icebergs would be likely to cause such a breach. The high degree of flexibility of the spider buoy, designed to move significant distances as the FPSO moves around, will most likely ensure that most icebergs ride over the buoy or deflect it to one side, with little or no damage. In addition, ice management vessels, even though they may have failed to intervene sufficiently to prevent a disconnection being necessary, will still continue to try and avoid a spider buoy impact even after the FPSO is safely out of the way. This should be a much easier task for the ice management vessels, as they need only deflect the iceberg a few tens of metres to avoid a direct hit on the spider buoy. If such a situation were to occur, lines would also be flushed with water to minimize potential impact. Therefore, the risk associated with an iceberg impact on the spider bouy and riser is expected to be minimal.

It is recommended that at detailed design stage this potential should be reviewed further.

4 SUMMARY AND CONCLUSIONS

A review has been carried out of available data on iceberg frequencies, masses, velocities and drafts in the vicinity of the proposed White Rose facility.

An average of 70 icebergs per year in a 1 degree grid square, has been identified as the frequency that should be used for risk assessment purposes.

The probability distribution of masses has been combined with the probability distribution of velocities to generate a probability distribution of kinetic energies. It has been shown that 81 percent of all icebergs will be of insufficient kinetic energy to cause any damage in the event of an impact.

Annual impact frequencies have been estimated for each of the main design options. These are:

Facility	**Impact Frequency**
FPSO	0.00016
Semi-submersible	0.00012

The frequencies are total impact frequencies and as already mentioned, 81 percent of these impact will be of insufficient energy to cause damage.

The risk of iceberg impact is primarily an environmental risk, since it is likely that there will be sufficient warning time for an orderly precautionary evacuation to take place.

The risk of scour damage to intra-field flowlines has been assessed. It is concluded that the annual frequency of scour damage to flowlines will be 1.415×10^{-2} incidents per year (for a 10-km pipe) assuming the pipe has no protection by being buried. This risk will halve if 0.6 m of cover is provided by burying the pipe and will further reduce to 2.26×10^{-3} incidents per year if 0.9 m of cover is provided. These frequencies must be pro-rated to reflect the actual length of pipelines that are installed.

5 REFERENCES

1. PERD (Program on Energy Research and Development) Grand Banks Iceberg Database

2. PAL (Provincial Airlines) Iceberg Data

3. Terra Nova Concept Safety Analysis (CSA)

4. Terra Nova Detailed Development Plan – Environmental Impact Statement

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Addendum to Appendix E
Probability Distribution
for White Rose Current Data

Ref. [6] gave the following current velocities for 1-year, 10-year and 100-year return periods (Table A1.1-1):

Table A1.1-1 Estimated Current Velocities for Different Return Periods

Estimated Return Current Speeds			
Return Period	**1 year**	**10 year**	**100 year**
Current Speed (m/s) Mid Depth – 25m	0.60	0.76	0.95

On any given day:

The probability of exceeding the 1-yr return period current is (1-1/365)=0.99726
The probability of exceeding the 10-yr return period current is (1-1/3650)=0.999726
The probability of exceeding the 100-yr return period current is (1-1/36500)=0.9999726

This gives three points on a probability distribution; (0.6 m/s, 0.99726), (0.76 m/s, 0.999726), (0.95 m/s, 0.9999726). Through these points it is possible to fit a probability distribution. The Weibull distribution has been used for this analysis and the fit has been achieved using the method described in Ref. [7]. The resulting probability distribution is:

$$\mathbf{F(v) = 1 - e^{[-(v/c)^k]}}$$

Where 'F(v)' is the cumulative distribution of current velocity 'v'.

'c' and 'k' are the parameters of the distribution which were determined to be:

c= 0.145 and k=1.2555

The probability density form of the above distribution function is shown in Figure 1.6-1.