Nord Stream 2
Offshore Pipeline Detail Design

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CONTENTS

1 INTRODUCTION AND SCOPE

1.1 Introduction

The Nord Stream 2 AG pipeline system (NSP2) comprises of two (2) 48" diameter subsea pipelines including onshore facilities. The lines shall extend from the Russian southern coast of the Gulf of Finland to the German coast in Greifswald area, through the Baltic Sea, with no spur lines or intermediate landfalls.

The pipeline route will cover a distance of approximately 1200 to 1300 km, depending on final route selection. While routing through the Baltic Sea the pipelines are generally independent from the existing Nord Stream AG pipeline system (NSP1), but they do run in parallel to NSP1 lines for a substantial length.

The pipeline route crosses the Territorial Waters (TW) of Russia, Denmark and Germany and runs within the Exclusive Economic Zones (EEZ) of Russia, Finland, Sweden, Denmark and Germany. Figure 1.1 below gives an overview of the routing considered.

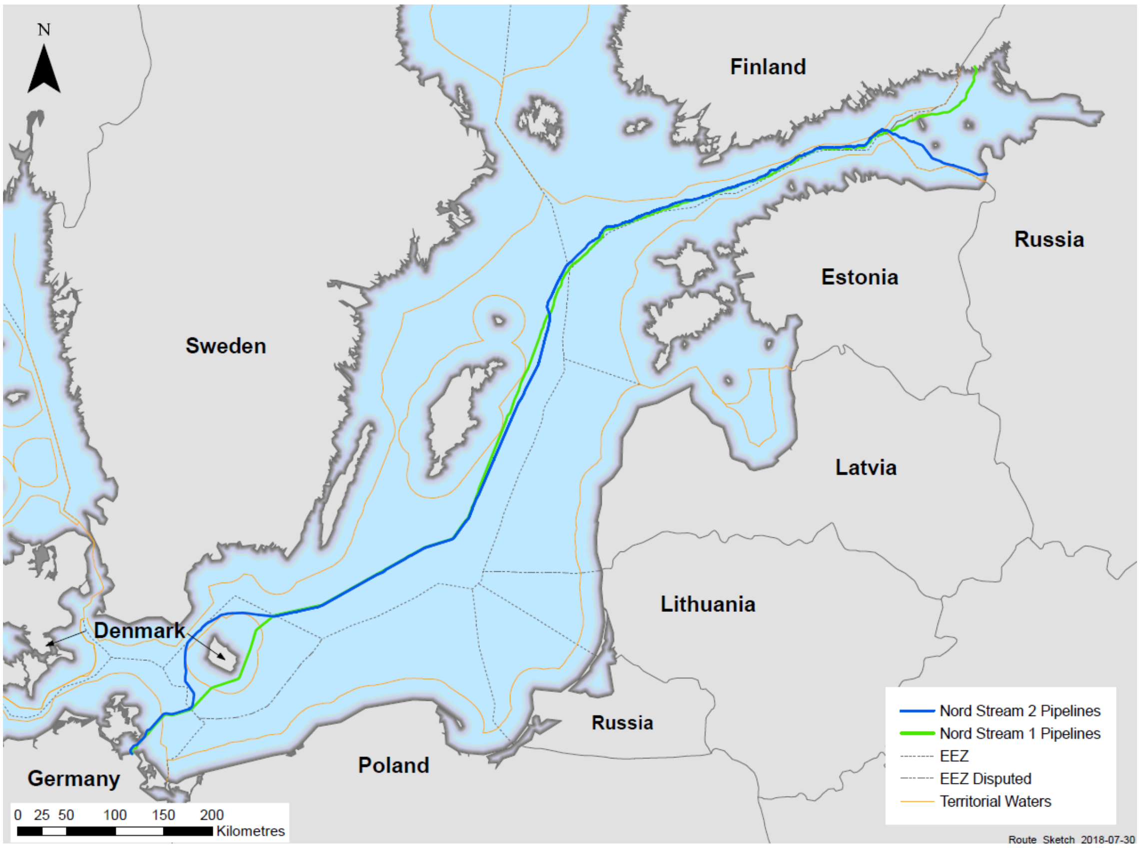

Figure 1.1: Nord Stream 2 AG pipeline system overview

The Nord Stream 2 pipeline system is designed for a nominal capacity of 27.5 GSm³/y per pipeline at reference conditions of 20°C and 1 atm. It will be operated at an inlet pressure of up to 218 bar (g) at a reference elevation of MSL +50m and a minimum outlet pressure of 103 bar (g) at reference elevation.

In Denmark there is a possibility that the pipeline path at South of Bornholm Island would not be acceptable by the relevant Authorities. Due to this, an alternative path, North of Bornholm Island, is investigated. This report is relevant to the pipeline design along the path North of Bornholm.

1.2 Scope of this Document

This document applies to the operational phase of NSP2 offshore pipelines inside Denmark EEZ.

The battery limits of this assessment are:

- At Swedish side – KP 0
- At German side – KP approx. 174.

The route analysed in this study is named:

- BH_North_9A_2 – 174km length.

The analysis has been performed for Line A, but the same results can be applied to Line B as it is generally 75 m apart and parallel to Line A.

The objectives of this document are to:

- evaluate the system residual risk for human safety, environment and economical losses/reputation and compare it with the Company risk acceptance criteria;
- identify risk reducing measures so as to ensure that the overall risk associated to the facilities complies with the target values.

2 DEFINITIONS AND ABBREVIATIONS

2.1 Definitions

Company: Nord Stream 2 AG
Contractor: Saipem S.p.A.

Nord Stream AG	The Company operating NSP1
NSP1	Nord Stream 1 Pipeline system
Nord Stream 2 AG	The Company building NSP2
NSP2	Nord Stream 2 Pipeline system
NSP2 A	Nord Stream 2 Pipeline A
NSP2 B	Nord Stream 2 Pipeline B

2.2 Abbreviations

AIS	Automatic Identification System
DNV GL	Det Norske Veritas Germanischer Lloyd
EEZ	Exclusive Economic Zone
ESD	Emergency Shut Down
ETA	Event tree analysis
FB	Full bore
FF	Flash Fire
GRT	Gross registered tonnage
GSm^3/y	Billion Standard Cubic Metres per Year
KP	Kilometre Point
LFL	Lower Flammable Limit
MSL	Mean sea level
P/L	Pipeline
SOW	Scope of Work
SPF	Saipem Fano
SR	Social Risk
TBC	To be confirmed
TOR	Tolerability of Risk
TW	Territorial Waters
WD	Water Depth
WT	Wall Thickness

3 REFERENCES

The reference documentation has been subdivided as follows:
1. Codes & Standards;
2. Company Documents;
3. Contractor Documents
4. Other Documents

In case of conflict between the documents listed in this section, priority is given as per the above order.

3.1 Codes & Standards

/A1/ DNV OS-F101-2013, “Submarine Pipeline Systems”
/A2/ DNV RP-F109-2011, “On-bottom stability design of submarine pipeline”
/A3/ DNV RP-C205-2014, “Environmental conditions and environmental loads”
/A4/ DNV RP-F105-2006, “Free spanning pipeline”
/A5/ DNV RP-F111-2014, “Interference between trawl gear and pipelines”
/A6/ DNV RP-F110-2007, “Global buckling of submarine pipelines structural design due to high temperature/high pressure”
/A7/ DNV RP-F107-2010, “Risk assessment of pipeline protection”

3.2 Company Documents

/B1/ W-PE-HSE-PDK-DAS-805-RN0800EN-01, “AIS data for EIA0 routes”

3.3 Detail Design Documents

/C1/ W-EN-ENG-GEN-REP-804-D80100EN-02, “North of Bornholm – Design Basis (Detail Design)”
/C2/ W-EN-OFP-POF-REP-804-D80103EN-02, “North of Bornholm – Metocean Design Basis”
/C3/ W-EN-HSE-POF-REP-804-080344EN-02, “North of Bornholm - Offshore Pipeline Frequency of Interaction (Danish EEZ Option)”
/C4/ W-EN-OFP-POF-REP-804-D80347EN-02, “North of Bornholm - Offshore Pipeline Damage Assessment (Danish EEZ Option)”
/C5/ W-EN-PRO-POF-REP-804-D08100EN-04, “Flow Assurance Design Report”
/C6/ W-EN-OFP-POF-REP-804-D80106EN-02, “North of Bornholm - Pipeline Route Optimisation Report (Danish EEZ Option)”
/C7/ W-EN-OFP-POF-DWG-804-D80109EN-02, “North of Bornholm - Route Maps (Danish EEZ Option)”

3.4 Basic Design documents

/D1/ W-EN-HSE-POF-REP-804-085023EN-04, “Offshore Pipeline Frequency Of Interaction - Denmark “
/D2/ W-EN-HSE-GEN-REP-804-085803EN, “HAZID report”

/D3/ W-EN-HSE-POF-REP-804-085028EN-04, "Offshore Pipeline Risk Assessment - Denmark "

3.5 Other Documents

/E1/ PARLOC 2001, "The update of Loss of Containment Data for Offshore pipelines"

/E2/ PARLOC 2012, "Pipeline and riser loss of containment 2001 – 2012 (PARLOC 2012)"

/E3/ "OLGA 2014" User's Manual, Scandpower Petroleum Technology

/E4/ "User guide for POL-PLUME" software, Snamprogetti, 2004

/E5/ OTH 95 465, Dispersion of Subsea Releases, Health and Safety Executive, 1995

/E6/ DNV-Det Norske Veritas, "PHAST", Version 6.7

/E7/ CPR 18E - "Guidelines for Quantitative Risk Assessment – Purple Book", P.A.M. Uijt de Haag, B.J.M. Ale, TNO Committee for the Prevention of Disasters, 1999

/E8/ N-PE-PER-DWG-705-BP4410000, "Nord stream extension – constraints in Swedish, Latvian and Danish waters"

/E9/ G-GE-PIE-REP-102-00085213, "Risk assessment report for Sweden area – Operational phase"

4 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

This section summarizes the main outcomes of the quantitative risk assessment for the offshore pipelines (see Section 8 for detailed results) based on the methodology described in Section 5 and input data reported in Section 7.

The Quantitative Risk Assessment (QRA) aims at evaluating the residual risk associated to the operational phase of the NSP2 and at establishing the need of risk reduction measures on the basis of the TOR criteria reported in section 6.

The analysis has been performed considering the following set of data:

- Results of the frequency of interaction assessment (ref. /C3/)
- Results of the pipeline damage assessment (ref. /C4/)
- Failure frequency statistics from database (ref. /E1/).

The risk to people, environment, reputation and asset has been evaluated for the route in the sensitive sections (see Figure 10-4) identified in the frequency of interaction assessment (ref. /C3/):

Route BH_North_9A_2

- Sensitive Section S1 (KP 31 to KP 47);
- Sensitive Section S2 (KP 55 to KP 74);
- Sensitive Section S3 (KP 103 to KP 115);
- Sensitive Section S4 (KP 132 to KP 141);
- Sensitive Section S5 (KP 164 to KP 173).

The analysis has been performed for Line A, but the same results can be applied to Line B as it is generally 75 m apart and parallel to Line A.

The future trend has been evaluated on the basis of the forecasted data in the respective sensitive sections.

The main steps of the risk assessment are:

- Identification of failure causes;
- Evaluation of release frequency;
- Consequence assessment and definition of outcome scenarios;
- Risk assessment and comparison with the risk acceptance criteria.

The risk to people has been evaluated by means of a quantitative approach based on the F-N curve.
The risk to environment and reputation has been evaluated by means of a semi-quantitative approach based on a risk matrix.
The risk to assets has been evaluated according to the DNV target failure criteria (ref. /A1/).

4.2 Conclusions

Detailed results are presented in section 8.5. In particular Figure 10-5 shows the results of the social risk for all sections of route BH_North_9A_2; Table 8-9 and Table 8-10 report the results associated to the risk on environment and reputation; Table 8-11 and Table 8-12 report detailed results relevant for comparison with the DNV acceptance criteria in terms of failure/km/year and failure/section/year.

4.2.1 Route BH_North_9A_2

From the assessment carried out in this study, the following conclusions are drawn:

- the evaluated social risk for all sections is within the acceptable region;
- the risk for the environment is 'low' for all scenarios;
- the risk for reputation is 'low' for all scenarios other than for the full bore scenario in sensitive section 3, where the risk falls in the 'medium' region;
- according to the DNV acceptance criteria, the target failure rate per P/L section (**10^{-4} pipeline failure/section/year),** is fulfilled for all sections;
- the target failure rate of **10^{-5} pipeline failure/km/year** is fulfilled along the whole pipeline, exception made for KP 110 considering 2014 ship traffic data;
- the future trend has been evaluated considering forecasted ship traffic data: risk for people slightly increases but remains in the acceptable region (see Figure 10-6); same conclusions for environment and reputation are applicable; the target failure rate of **10^{-5} pipeline failure/km/year** is fulfilled along the whole pipeline, exception made for KP107 to KP111.

Based on the results obtained, no protective measure is recommended in view of the following considerations:

- the risk for people and environment is always acceptable;
- even though reputation risk is medium in case of full bore scenario in sensitive section 3, it is highlighted that the probability falls in the lower side (10^{-5} event/year) of the probability class B (10^{-5} - 10^{-3} event/year);
- Dragged Anchors scenario represents the major contribution to the pipeline total failure probability;
- the consequences related to a dragged anchor hooking the pipeline have been conservatively associated to a full bore rupture;
- on the basis of operational experience, it is expected that pipeline failure with gas release due to dragged anchors is at maximum 30% of the values reported in Table 8-12 (this 30% is on the basis of operational experience considering any pipeline with the concrete coating protection and thick steel wall, decreasing to 10% considering only large diameter pipelines);
- Furthermore, it has been conservatively assumed that the 4th class vessel anchor is the smallest anchor that can hook the pipeline. Actually, the smallest pipeline diameter along the Danish section, considering the coating thickness, is always larger than the maximum diameter that can be hooked by anchors of class 4 vessels, thus anchor hooking for these vessels is not feasible. Disregarding the contribution of 4th class vessel anchor (which would be the case), the total failure probability (failure/km/year) would be considerably reduced and target fulfilled.

- Eventually, considering the 2014 interaction frequencies, the target failure rate taken equal to **10^{-5} pipeline failure/km/year** for *Safety Class Medium* in accordance to DNV OS-F101 (Ref. /A1/) is **not met** at **KP 110** (failure is equal to 1.09E-05). However, it is noted that this KP is included in the sensitive section S3 (KP103÷KP115), for which the acceptance criterion based on target failure rate **10^{-4} pipeline failure/section/year is met**. The same conclusion applies to the forecasted 2025 interaction frequencies, where the target failure rate is not met from **KP 107** to **KP 111**.

Therefore, from the considerations made here above, it can be concluded that **no pipeline protection is deemed necessary**.

4.3 Recommendations

During the operational lifetime of the pipeline it is also recommended to:

- monitor the real ship traffic trend;
- implement an adequate integrity management plan and an emergency and repair plan.

At a later stage of design the analysis shall be revised and updated, if required, once the following data will be confirmed:

- pipeline route, configuration and bathimetric profile:
    - in case of any change in the pipeline route considerations shall be made to evaluate any major difference with respect to the pipeline alignment where ship traffic data for the frequency of interaction analysis have been collected;
- pipeline pressure profile: once the flow assurance calculations are finalised, the release rate shall be re-evaluated for the specific pipeline pressure profile.

5 METHODOLOGY

5.1 General

The main steps of the risk assessment are:

- Identification of failure causes;
- Evaluation of release frequency;
- Consequence assessment and definition of outcome scenarios;
- Risk assessment and comparison with the risk acceptance criteria.

These are described in detail in the following paragraphs.

5.2 Identification of failure causes

The possible failure causes leading to unplanned releases of the transported fluid are identified on the basis of literature data on offshore gas pipeline incidents (ref. /E1/) and HAZID report (ref. /D2/).
The following hazards that may threaten the pipeline integrity are managed adequately through the application of the relevant DNV standards:

- Natural hazards due to current and wave action – DNV RP-F109 (ref. /A2/,/A3/)
- Pipeline free spanning sections – DNV RP-F105 (ref. /A4/)
- External interference with fishing activities – DNF RP-F111 (ref. /A5/)
- Operating temperature and pressure conditions – DNV RP-F110 (ref. /A6/).

The following failure causes are identified as applicable and considered in this risk analysis:

- interaction with third party activities (commercial ship traffic);
- corrosion (internal and external);
- mechanical defects;
- natural hazards (storm, scouring);
- other/unknown (sabotage, accidental transported mines, etc.).

5.3 Frequency assessment

For offshore pipelines, the interaction with third party activities is related to commercial ship traffic and the following initiating events are identified:

- Sinking ships;
- Grounding ships;
- Dropped objects;
- Dropped anchors;
- Dragged anchors.

Release frequencies due to interaction with third party activities related to commercial ship traffic are evaluated by means of mathematical modelling in the frequency of interaction assessment (ref. /C3/) and pipeline damage assessment (ref. /C4/)

The release frequencies for the following failure causes are estimated from PARLOC 2001 database (ref./E1/):

- corrosion;
- mechanical defects;

- natural hazards;
- other/unknown.

The PARLOC database contains incidents and related loss of containment from offshore pipelines operated in the North Sea. It has been used since no specific data are available for the Baltic Sea.

In this database, incidents are grouped in the following leak size categories:

- hole size less than 20mm;
- hole size between 20 and 80mm;
- hole size greater than 80mm.

An updated database (PARLOC 2012 – ref. /E2/) has been issued in March 2015. Since from the conclusions of this report the overall failure frequencies for steel pipelines are similar to those estimated in PARLOC 2001, for consistency with NSP2 basic design (ref. /D3/), reference is made to PARLOC 2001.

The use of failure statistics from database, in many cases, leads to over-conservative results since:

- no information on characteristics of transported medium is given;
- databases often refer to the "average" pipeline population and do not take into account pipeline characteristics (e.g. age and quality of pipeline, wall thickness, inspection frequency, etc).

Therefore, in this analysis, engineering judgement has been applied to calculate, if necessary, appropriate values.

5.4 Consequence assessment

5.4.1 General

The consequences assessment of subsea gas releases involves several steps, from depressurisation calculations, underwater release, through the effects at sea surface and the atmospheric modelling of gas dispersion, to the assessment of the physical effects of the final outcome scenario. The physical effects are related to the exposure to the thermal effects in case of ignition of the released fluid.
The methodology utilised for the consequence assessment is detailed in the following paragraphs:

- Definition of incident outcome scenarios;
- Underwater dispersion and effects at sea surface;
- Consequences of outcome scenarios.

5.4.2 Definition of outcome scenario

In this context, an incident is considered the loss of containment of the transported fluid.
The physical manifestation of the release is the incident outcome scenario. Therefore, a single initiating incident (e.g. leak of flammable gas) may in principle have several outcomes (e.g. jet fire, flash fire, harmless dispersion) depending on whether an ignition takes place (immediate or delayed) and on the degree of confinement.

The sequence of events following an initiating event (e.g. external corrosion) determines the occurrence of an incident outcome scenario. The factors and intermediate events concurring to the outcome scenario definition are:

- Size of rupture (pinhole, hole or full bore rupture);
- Type of released fluid (gas, liquid, two-phase);
- Process parameters (i.e. P and T that determine the outflow rate);
- Water depth;
- Atmospheric conditions (i.e. Pasquill stability class and wind speed);
- Likelihood of ignition.

In case of a subsea gas release the type of hazardous scenarios that can occur depends on the behaviour of the gas at sea surface and the level of confinement/congestion encountered by the cloud. In particular if the gas reaches a congested area at the sea surface and encounters a source of ignition, either a flash fire or an explosion can occur. On the contrary if no congestion/confinement is present, in case of ignition only a flash fire can occur.

The assessment of the consequences of a potential gas release has been performed for three damage categories, according to the hole dimension.
The following hole sizes have been selected in accordance to PARLOC 2001 database (ref. /E1/):

- PINHOLE: 20mm (representative of hole sizes lower than 20mm);
- HOLE: 80mm (representative of hole sizes between 20 and 80mm);
- FULL BORE: internal pipeline diameter (representative of hole sizes greater than 80mm).

5.4.3 Source term

Source models are used to quantitatively define the release scenario by estimating discharge rates and duration of releases.
The input data necessary for the pipeline release calculations after rupture are the following:

- offshore pipeline profile, diameter, thickness, roughness;
- composition of the fluid;
- total mass flowrate at pipeline inlet;
- fluid temperature at pipeline inlet;
- outlet pressure;
- valve position and activation data;
- leak detection behaviour and control system data;
- dimension and position of the ruptures.

Flow assurance calculations to determine the pressure profile in the pipeline are carried out by means of OLGA 2014.2 (ref. /E3/). Usually the same model is then used to perform simulations of accidental releases from the subsea pipeline. However at this stage of detail design, the model for the flow assurance calculations of accidental releases is not yet set up. The approach adopted is to use the release rates calculated for NSP1 in the Swedish sector (ref. /E9/). The choice is based on the comparison to the operating pressure in the Danish sector for the analysed route (around 150-135 barg) and the operating pressure used for the discharge calculations during NSP1 in Sweden (147 barg). This is deemed to be a sufficiently good approximation for the purpose of this analysis considering that operating parameters (Gas Temperature and Pressure) are comparable.

Source term outputs constitute the input for underwater dispersion models.

5.4.4 Underwater dispersion and effect at sea surface

The subsea dispersion is modelled in order to provide parameters such as plume width, gas volume fraction and mean velocities at the sea surface; these parameters constitute the input to the atmospheric dispersion model.
Subsea dispersion calculations have been performed by means of the computer program POL-PLUME (ref. /E4/).

According to published literature (ref. /E5/), the underwater dispersion of the gas from the release point to the surface can be split in three distinct regions:

- *Zone of Flow Establishment (ZOFE)*. At the release source the gas enters the sea in the form of a relatively low-density momentum jet. At some distance above the release point, buoyancy forces becomes the major influence in plume characteristics and a radial Gaussian bubble distribution exists. This is the region between the release point and the height at which the dispersion appears to adopt a plume-like structure. At this height the effects of the initial release momentum are considered to be secondary to the momentum induced by the buoyancy.
- *Zone of Established Flow (ZOEF)*. The plume-like region of dispersion that extends from the ZOFE to a depth beneath the free surface that is of the order of one plume diameter. On the basis of experimental evidence, it is generally assumed that this region forms a cone having a total vertex angle of approximately 10°.
- *Zone of Surface Flow (ZOSF)*. Near the surface, the vertical momentum of the plume is converted to a radial flow forming a *central boil* region slightly wider than the theoretical ZOEF cone at the surface. In this region above the ZOEF, the plume interacts with the surface causing widening of the bubble plume and radial flow of water at surface. The ZOSF has again been predicted on the basis of experimental evidence, since analytical methodologies have not been yet fully tested.

The equations used in the model describe the conservation of mass by incorporating buoyancy terms for a low-density fluid rising through a high density, stationary fluid. The model assumes a unidirectional (vertically upward) bulk flow; the increase in plume width height is empirically evaluated by an entrainment coefficient.
On reaching the surface, the gas will begin to disperse within the atmosphere. The nature of the dispersion depends upon the molecular weight and on the source conditions at the surface. In general, the resulting source has a large diameter but the gas has a very low velocity.
The parameters that define the input conditions to the atmospheric dispersion model are:

- Mean gas concentration – assumed equal to the void fraction in the rising plume;
- Gas velocity at sea surface – assumed to be the top hat velocity at the sea surface

- Source diameter.

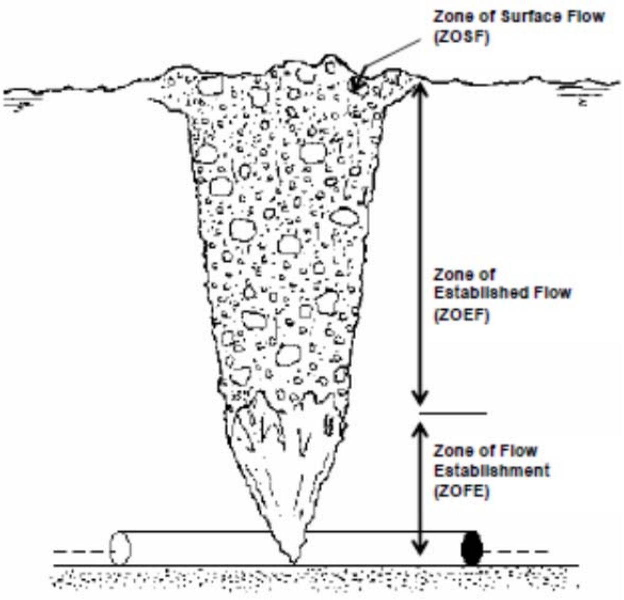

Figure 5-1: Underwater plume dispersion

5.4.5 Consequences of the outcome scenarios

Following a loss of containment event from the subsea pipelines, the possible outcome scenarios are:

- Atmospheric dispersion;
- Flash fire.

The effects of outcome scenarios are assessed using the software DNV PHAST 6.7 (ref. /E6/).

The flash fire occurs if a flammable cloud engulfs an ignition source before it is diluted below its flammable limits (delayed ignition).
Flash fires generally have a short duration and therefore do less damage to equipment and structures than to personnel caught in a flash fire. It is conservatively assumed that anyone caught in the flash fire would probably be killed. To determine the area that could be involved in the flash fire and therefore the effect on people, flammable gas dispersion results (distances of LFL/2 concentration) will be considered in the risk analysis.

Neither congested nor confined areas can be reached by a flammable cloud along he offshore pipeline, thus explosion scenarios cannot occur.

Since the gas is not toxic, atmospheric dispersion has no impact.

5.5 Frequency of outcome scenarios

Starting from the release frequency evaluated as described in section 5.3, the frequency of each specific scenario (flash fire and dispersion) has been calculated by Event Tree Analysis, taking into account the probability of ignition.

Figure 5-2 shows the event tree adopted for this project for the offshore section, only the flash fire scenario is considered, since the gas reaches the sea surface at low velocity and no congested/confined region is present.

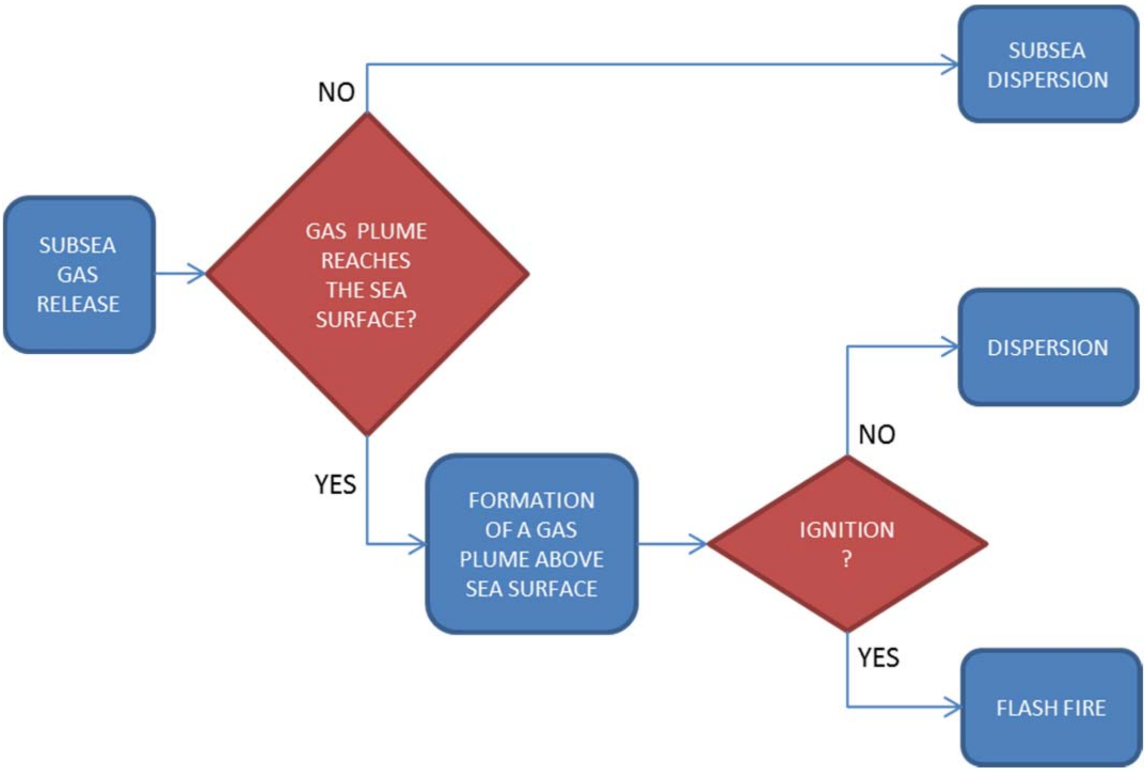

Figure 5-2: Event tree for subsea release

Flash fires represent the only possible offshore scenario that has an impact on people. These may occur if the mixed gas cloud engulfs an ignition source while drifting due to the wind. The only ignition source that the mixed gas cloud might encounter is a ship navigating across the hazardous area. The hazardous area is assumed to be the cloud envelope at LFL/2 gas concentration.
In order to assess the ignition probability, two contributions have been evaluated:

- probability of a ship crossing the hazardous area in the time interval of cloud persistence;
- conditional probability of delayed ignition given a ship present in the area

In accordance to ref. /E7/ the conditional probability at time t given one ship crossing the hazardous area is calculated as follow:

$$P(t)=\left(1-e^{-wt}\right) \qquad \textit{Eq. (1)}$$

where

t time needed by a ship to cross the hazardous area [s]
w the ignition effectiveness of a single ship [s^{-1}]

The ignition effectiveness, *w*, can be calculated given the probability of ignition for a certain time interval. The probability of ignition in one minute for ships is assumed to be 0.5, as suggested by /E7/.
Therefore, the calculated value of ignition effectiveness (w) is 0.0115 s^{-1}.
The time needed by a ship to cross the hazardous area is calculated as:

$$t=\frac{L}{V} \qquad \textit{Eq. (2)}$$

where

L dimension of the flammable cloud
V mean vessel velocity

Conservatively the dimension of the flammable cloud used for this calculation has been taken as the largest distance reached by the LFL/2 envelope.
The average vessel velocity for each GRT class (as per Table 9-3) has been used to obtain the time for a ship crossing the hazardous area.
The average traffic density is calculated as follow:

$$X = N \cdot \Delta t \qquad \textit{Eq. (3)}$$

X number of ships crossing the hazardous area in Δt [sh]
N average number of ships crossing the pipeline [sh/h]
Δt time of persistence of the hazardous area [h].

If X≤1, X is the probability that the ship is present when the cloud passes and the probability of ignition is calculated as follow:

$$P_{ign}^{off} = X \cdot P(t) \qquad \textit{Eq. (4)}$$

If X>1, X is the average number of ship present when the cloud passes and the probability of ignition is calculated as follow:

$$P_{ign}^{off} = \left(1-e^{-Xwt}\right) \qquad \textit{Eq. (5)}$$

The actual extent and the persistence time of the hazardous area have been estimated based on the results of consequence modelling.

5.5.1 Credible scenarios

As per international best practice, each scenario will be considered credible when its frequency of occurrence will be higher than 1.00 E-07 event/year, that is the threshold value separating possible events from unrealistic occurrences. Therefore, following the ETA, each scenario with an associated frequency of occurrence lower than 1.00 E-07 event/year (less than one occurrence in 10 million years) will not be further analysed.

5.6 Risk assessment

5.6.1 Risk to people

Risk to people is quantified in terms of damage to people (i.e. death) caused by the exposure to thermal radiation following the ignition of the released gas.
The most exposed Company and/or 3rd party people is represented by crew members/passengers on-board of vessels crossing the pipelines. Thus for the offshore section the adopted methodology foresees to quantify the risk level for people in terms of Social Risk (SR).
Social risk is defined as the frequency and the number of people suffering a given level of harm in a given population from the realization of specified hazards. The harm considered in this study is the death. Social Risks are usually expressed in the form of a chart, with N, the number of fatalities on the X-axis and the frequency of N or more fatalities on the vertical scale (FN curve).

For any combination of the accidental event occurrence with the release orientation and location, the atmospheric stability class/wind speed, the ignition probability, the frequency of the final event, f_{ij}, is calculated as:

$$f_{ij} = \lambda \cdot P_{ignition}{}^{i} \cdot P_{wind}{}^{j} \cdot P_{presence} \qquad \textit{Eq. (6)}$$

where

- f_{ij} — frequency of the final event with n_{ij} deaths which is the combination of the i-th scenario and the j-th atmospheric condition
- λ — release frequency due to an accidental event (PINHOLE/HOLE/RUPTURE) [occ/section/year]; this value corresponds to the accidents in the section length of the pipeline that may be hazardous for humans;
- $P_{ignition}{}^{i}$ — probability of ignition of flammable cloud [-]
- $P_{wind}{}^{j}$ — probability of the combination of *j*-th atmospheric stability class/wind velocity [-] and wind direction
- $P_{presence}$ — probability of human presence in the area interested by the accidental scenario [-]

The number of deaths, n_{ij}, corresponding to each final event with frequency f_{ij} is obtained as:

$$n_{ij} = \int_{area} V(A) \cdot N \cdot dA \qquad \textit{Eq. (7)}$$

where

$V_{ij}(A)$ vulnerability in the hazardous area determined by the *i*-th scenario and the *j*-th atmospheric condition

N_{ij} density of population in the hazardous area determined by the *i*-th scenario and the *j*-th atmospheric condition

A Hazardous area.

In this analysis, the extension of flammable cloud has been evaluated considering the most probable combination of atmospheric stability class and wind velocity only and without considering the wind direction. Therefore, P_{wind} is assumed equal to 1. This is considered a conservative approach on the basis of Contractor experiences.

Ignition probability is related to the presence of a vessel over the hazardous area.

The density of population in the hazardous area is determined based on the number of crossings within the hazardous area. In case the section runs parallel to a shipping lane, parallel traffic has been taken into account for the evaluation of the population density.

The number of deaths corresponding to flash fire scenarios occurring in the offshore sections has been conservatively assumed to be the average number of individuals present on board and according to the ship type distribution in each sensitive section.
The ship traffic in the Danish sector consists of cargo, tanker, fishing and other vessels. Conservatively the percentage of 'other vessels' has been considered entirely associated to passenger type vessels.
In analogy with NSP2 Basic design phase (ref. /D3/) vulnerability has been assumed as per Table 5-1 depending on the ship type.
The probability of death is assumed equal to 1 inside the flame envelope and 0 outside. However, realistically not all people on board will be on the vessel deck in case of an incident and therefore directly exposed to the effects of thermal radiation, thus vulnerability takes into account that some people on board will not be directly exposed to thermal radiation.

Ship type	Vulnerability
Cargo	0.6
Tanker	0.6
Fishing	0.6
Other	0.1

Table 5-1: Individuals vulnerability per vessel type

5.6.2 Risk to environment and reputation

A semi-quantitative approach has been adopted by means of the risk matrix methodology to predict the risk level for the environment and reputation.

5.6.3 Risk to assets

The risk to assets has been evaluated according to the DNV acceptance criteria and by means of the risk matrix (Figure 6-3).

6 RISK TOLERABILITY CRITERIA

In analogy with NSP2 Basic design phase (ref. /D3/), the overall residual risk of the installation shall be evaluated against the risk tolerability criteria.

The tolerability of risk (TOR) framework, depicted in Figure 6-1, divides the risk into three regions:

- **Unacceptable** – risks regarded as unacceptable except in extraordinary circumstances. Activities causing such risks would be prohibited, or would have to reduce the risks whatever the cost;
- **Tolerable -** risks that are tolerated provided that they are as low as reasonably practicable (ALARP) by adopting reduction measures unless their cost is grossly disproportionate to the improvement gained.
- **Broadly acceptable** – risks that most people regard as insignificant. Further action to reduce such risks is not normally required.

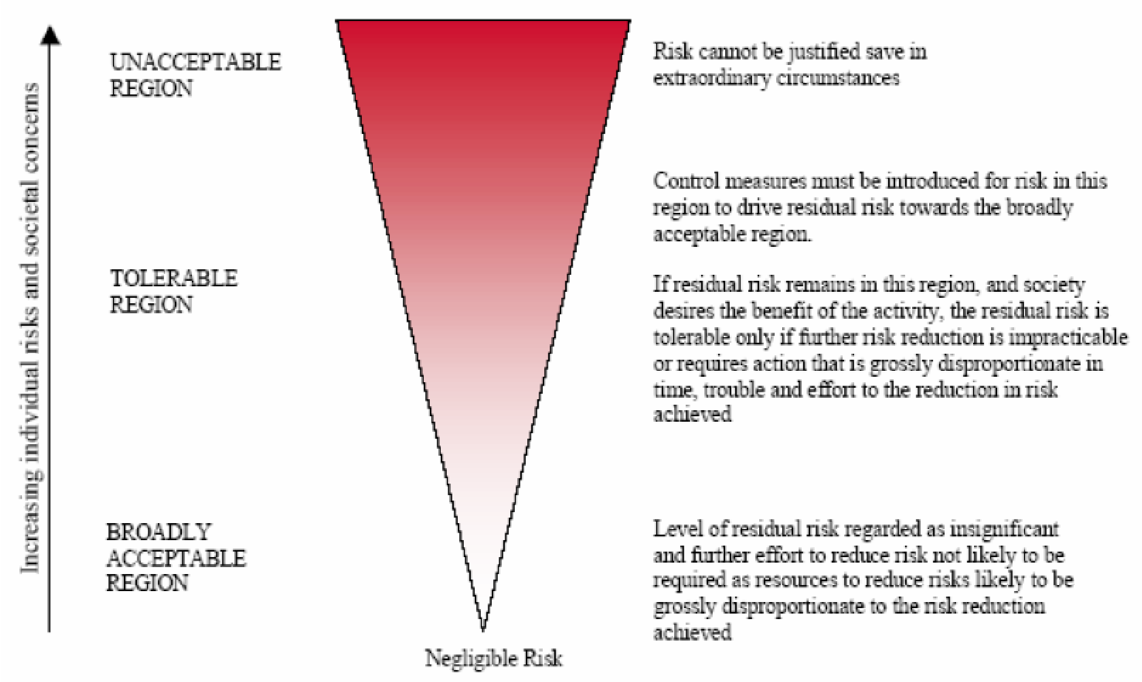

Figure 6-1: Tolerability of risk framework

Specific criteria for human safety, environment, assets and reputation are detailed in the following paragraphs.

6.1 Social risk

The social risk is intended to limit the total risk of death imposed by the facility on its workers and on any third party.

This will be expressed, as shown in Figure 6-2, as an FN diagram in which the fatality frequency per year per system (F) is represented versus the number of fatalities (N).

With regards to the offshore facilities the criteria is applied to each pipeline sensitive section as identified within the scope of the interaction frequency assessment (ref. /C3/).

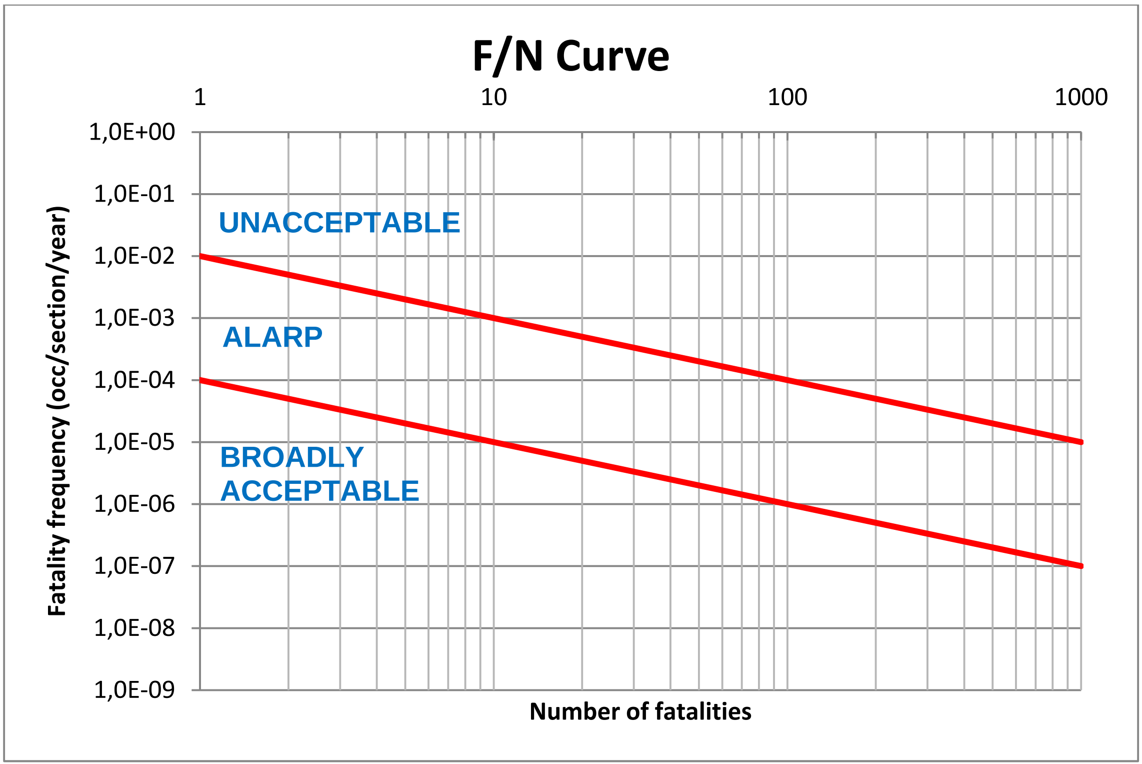

Figure 6-2: F/N diagram

6.2 Environmental and reputation risk

The Tolerability of risk criteria for environment and reputation are implemented in form of a risk matrix, as shown in Figure 6-3.

6.3 Assets risk

According to DNV-OS-F101 (ref. /A1/) the acceptance criteria for the failure probability is calculated per pipeline and also per km of pipeline.
As agreed for NSP2, in case of a very long pipeline the annual target probability of failure suggested in DNV-OS-F101 (ref. /A1/) for accidental loads per pipeline can be interpreted as per pipeline section where intense ship traffic is present. On this matter a concession (no. 5) was granted by DNV and the same approach is followed.
The DNV acceptance criteria is reported in Table 6-1.

Overall annual failure frequency			
Safety class	**Medium**	**High**	**Very high**
Per sensitive section	10^{-4}	10^{-5}	10^{-6}
Per km	10^{-5}	10^{-6}	10^{-7}

Table 6-1: Acceptance criteria for pipeline failure probability

Consequences				Probability (increasing probability →)			
Descriptive	Environment	Asset	Reputation	A. Remote (< 10^{-5} /y)	B. Unlikely (10^{-5}-10^{-3} /y)	C. Likely (10^{-3}-10^{-2} /y)	D. Frequent (10^{-2}-10^{-1} /y)
1. Extensive	Global or national effect. Restoration time > 10 yr.	Project/Prod. consequences > USD 10 mil	International impact Neg. exposure	A1	B1	C1	D1
2. Severe	Restoration time > 1 yr. Restoration cost > USD 1 mil.	Project/Prod. consequences > USD 1 mil	Extensive National impact	A2	B2	C2	D2
3. Moderate	Restoration time > 1 month. Restoration cost > USD 1K.	Project/Prod. consequences > USD 100 K	Limited National impact	A3	B3	C3	D3
4. Minor	Restoration time <1 month. Restoration cost < USD 1K.	Project/Prod. consequences < USD 100 K	Local impact	A4	B4	C4	D4
LOW	The risk is considered tolerable and no further actions are required.						
MEDIUM	The risk should be reduced if possible, unless the cost of implementation is disproportionate to the effect of possible safeguards						
HIGH	The risk is considered intolerable so that safeguards (to reduce the expected occurrence frequency and/or the consequences severity) must be implemented to achieve an acceptable level of risk; the project should not be considered feasible without successful implementation of safeguards						

Figure 6-3: Risk matrix for risk assessment on environment, reputation, assets

7 INPUT DATA

For the purpose of this assessment, simplified representative characteristics of the NSP2 system are taken into account.

7.1 Pipeline route and configuration

The route in the Danish sector analysed in this study is:

- BH_North_9A_2 – 174km length.

The East and North coordinates are represented in Figure 10-1.
The analysis has been performed for Line A, but the same results can be applied to Line B as it is generally 75 m apart and parallel to Line A.

The route coordinates considered for the ship traffic data collection have been defined on the route BH_North_8Abis_3. Meanwhile the pipeline route has been consolidated and corresponds to BH_North_9A_2 (ref. /C1/). As it can be observed in Figure 10-1 differences are minimal, thus the ship traffic data collected along the route BH_North_8Abis_3 are considered valid for the evaluation on the consolidated route. The last two KPs (KP175 and KP176) of route BH_North_8Abis_3 are already outside the Danish waters and not part of the assessed route.

For the purpose of this study, KP 0 indicates the start of the Danish section at the Swedish border.

In accordance with the recommendations presented in the PDA (ref. /C4/) the pipeline configuration (buried/exposed) is exposed on the sea bottom.

7.2 Seabed and pipeline profile

The seabed profile of the entire route considered for the analysis is reported in Figure 10-2.

7.3 Pipeline design characteristics

The main pipeline design characteristics in accordance with ref. /C1/ are reported in Table 7-1.

Design parameter	Value
Transported medium	Dry natural gas
Transport capacity per P/L [BCM/day]	27.5
Design life [year]	50
Nominal Internal Diameter [mm]	1153
P/L length [km]	1257.8
Length in Danish EEZ [km]	174
Wall thickness [mm]	26.8
Corrosion allowance [mm]	0
Material specification	DNV-OS-F101
Design pressure at Danish EEZ [barg]	177.5
Design temperature [°C]	+40/-10

Table 7-1: Pipeline design characteristics

The P/Ls are internally coated with epoxy coating and externally coated with 3-layer polyethylene (anti-corrosion coating) and with concrete (weight coating). Concrete thickness varies along the pipeline profile.

7.4 Process data

The transported gas is mainly methane. The design composition is reported in Table 7-2 (ref. /C1/).

Component	% mole
Methane	98.1848
Ethane	0.6848
Propane	0.2057
i-butane	0.0353
n-butane	0.0333
i-pentane	0.0046
Carbon dioxide	0.0339
Nitrogen	0.8176

Table 7-2: Gas composition

Operating conditions will depend on the selected route, pipeline burial configuration and transport conditions. Operating parameters in Table 7-3 will be used. These are relevant to the transport conditions with inlet pressure of 218 barg and outlet pressure of 130 barg (ref. /C5/).

Operating parameter	Value
Operating Pressure at KP 0 [barg]	150
Outlet pressure at KP 174 [barg]	135
Temperature (Min/Max) [°C]	-2/15

Table 7-3: Operating conditions (ref./C5/)

7.5 Environmental data

Environmental data are taken from detailed design and basic design project documents (ref. /C2/).
Annual frequency data of directional wind 1h average 10m above ground are relative to reference point 8 (Table 9-2) and are summarised in Table 9-1.
The probability of having a wind speed <16m/s is about 98% and the most probable wind speed is between 4 and 8 m/s. Therefore 8m/s has been conservatively selected as a representative value for the purpose of this analysis.
The corresponding Pasquill stability class selected for the analysis is class D, which is considered the most representative.
The most frequent omnidirectional current speed amongst all locations where measurements have been taken in Danish EEZ is 2 cm/s (ref. /C2/), thus this has been selected as a representative value for this analysis. Conservatively and based on a sensitivity analysis, the data relevant for this analysis are summarised in Table 7-4.

Environmental data	Value
Ambient temperature [°C]	15
Relative humidity [%]	70%
Most frequent wind speed [m/s]	8
Max wind speed [m/s]	24
Seawater temperature [°C] @ max depth (summer/winter)	7.2/5.3
Seawater temperature [°C] @ min depth (summer/winter)	12.5/2.3
Current speed [cm/s]	2

Table 7-4: Environmental data

7.6 Population data

The only relevant exposed third parties along the offshore pipeline route are represented by commercial and fishing activities.
The ship traffic in the Danish EEZ consists of cargo, tanker, fishing and other vessels as per the proportions reported in Figure 10-3 (ref. /B1/).
The mean number of people on-board is assumed as per Table 7-5 in analogy with NSP2 basic design phase (ref. /D3/) and based on Contractor experience.

Ship type	Individuals per vessels
Cargo	1-10
Tanker	20-30
Other vessel	10-20
Fishing vessel	1-10
Passenger vessel	>450

Table 7-5: Individuals on-board per vessel type

7.7 Ship traffic data

The AIS ship traffic data has been collected in the period January – December 2014 for the considered route at each P/L KP (ref. /B1/).

The interaction between the P/L and the ship traffic has been evaluated in the frequency of interaction report (ref. /C3/).
The ship characteristics used for this analysis and relevant to each ship class are reported in Table 9-3.
In particular the following hazardous scenarios have been analysed:

- Sinking vessels;
- Dragged anchors;
- Dropped anchors;
- Dropped objects from commercial vessels;
- Grounding vessels.

7.7.1 Route BH_North_9A_2

Based on the ship traffic intensity (>250 crossing/km/year) and the methodology outlined in the frequency of interaction report (ref. /C3/), five sensitive sections have been identified for route BH_North_9A_2.
Details are reported in Table 7-6 to Table 7-8.

Section ID.	From KP	To KP	Section length (km)	Min Water depth (m)	Max Water depth (m)	2014 Ship No. (ships/ section/ year)	2025 Ship No. (ships/ section/ year)
1	31	47	17	76	85	20298	28751
2	55	74	20	56	74	5906	8448
3	103	115	13	44	46	30074	41244
4	132	141	10	21	34	2823	4355
5	164	173	10	28	39	3634	5206

Table 7-6: Details of sections with high intensity ship traffic – Route BH_North_9A_2

Section ID	From KP	To KP	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
1	31	47	631	936	9260	9187	214	69
2	55	74	1336	667	2138	1586	81	98
3	103	115	2044	1645	15043	10866	347	131
4	132	141	459	337	1501	520	4	3
5	164	173	298	325	1871	1086	44	10

Table 7-7: Ship class distribution at sections with high intensity ship traffic - Route BH_North_9A_2

Section ID	From KP	To KP	Total	Cargo	Tanker	Fishing vessel	Other
1	31	47	20298	66%	24%	2%	9%
2	55	74	5906	52%	13%	20%	15%
3	103	115	30074	53%	21%	5%	20%
4	132	141	2823	51%	4%	6%	39%
5	164	173	3634	68%	18%	4%	10%

Table 7-8: Ship type contribution (%) at sensitive sections – Route BH_North_9A_2

In addition, the ship traffic forecast for 2025 reported in the Ramboll data (ref. /B1/) is analysed to estimate the developments in the traffic in the Baltic sea from 2014 to 2025. For the five identified sections results do not change significantly. Section 2 and section 4 extend slightly more than what identified based on 2014 ship traffic data.
No new sensitive section is identified.

Section ID	From KP	To KP	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
1	31	47	743	1426	13477	12739	260	106
2	55	75	1653	1078	3250	2235	94	138
3	103	115	2373	2466	21045	14778	399	183
4	132	142	561	550	2383	852	5	3
5	164	173	349	481	2652	1641	68	15

Table 7-9: Ship class distribution at sections with high intensity ship traffic - Route BH_North_9A_2 (2025)

8 OFFSHORE PIPELINE RESULTS

8.1 Identification of failure causes

The possible failure causes leading to unplanned releases of the transported fluid identified on the basis of literature data on offshore gas pipeline incidents (ref. /E1/) include the following:

- Corrosion (internal and external);
- Mechanical defects;
- Natural hazards (storm, scouring);
- Other/unknown (sabotage, accidental transported mines, etc.).

Interaction with third party activities related to commercial ship traffic is evaluated on the basis of AIS ship traffic data collected in 2014 and analysed in the frequency of interaction analysis (ref. /C3/)

Other interferences are identified in the HAZID study carried out during Basic Design Phase and included in the HAZID report (ref. /D2/).

The risk of unexploded munitions is addressed with adequate UXO surveys in the pipeline corridor during design phase.
The risk due to munition dumping is addressed during design phase with adequate surveys along the offshore section and criteria to avoid such areas in pipeline routing activities. At operational phase, requirements for pipeline external inspections to keep the P/L corridor monitored will be developed as part of the inspection and monitoring plan.

Interferences with other systems crossing the pipelines are addresses under normal design activities.
Based on these considerations the above mentioned interferences are not considered further in this analysis.

Critical areas are identified in Figure 8-1. As it can be observed the route does not cross any emergency anchoring zones in Danish waters.

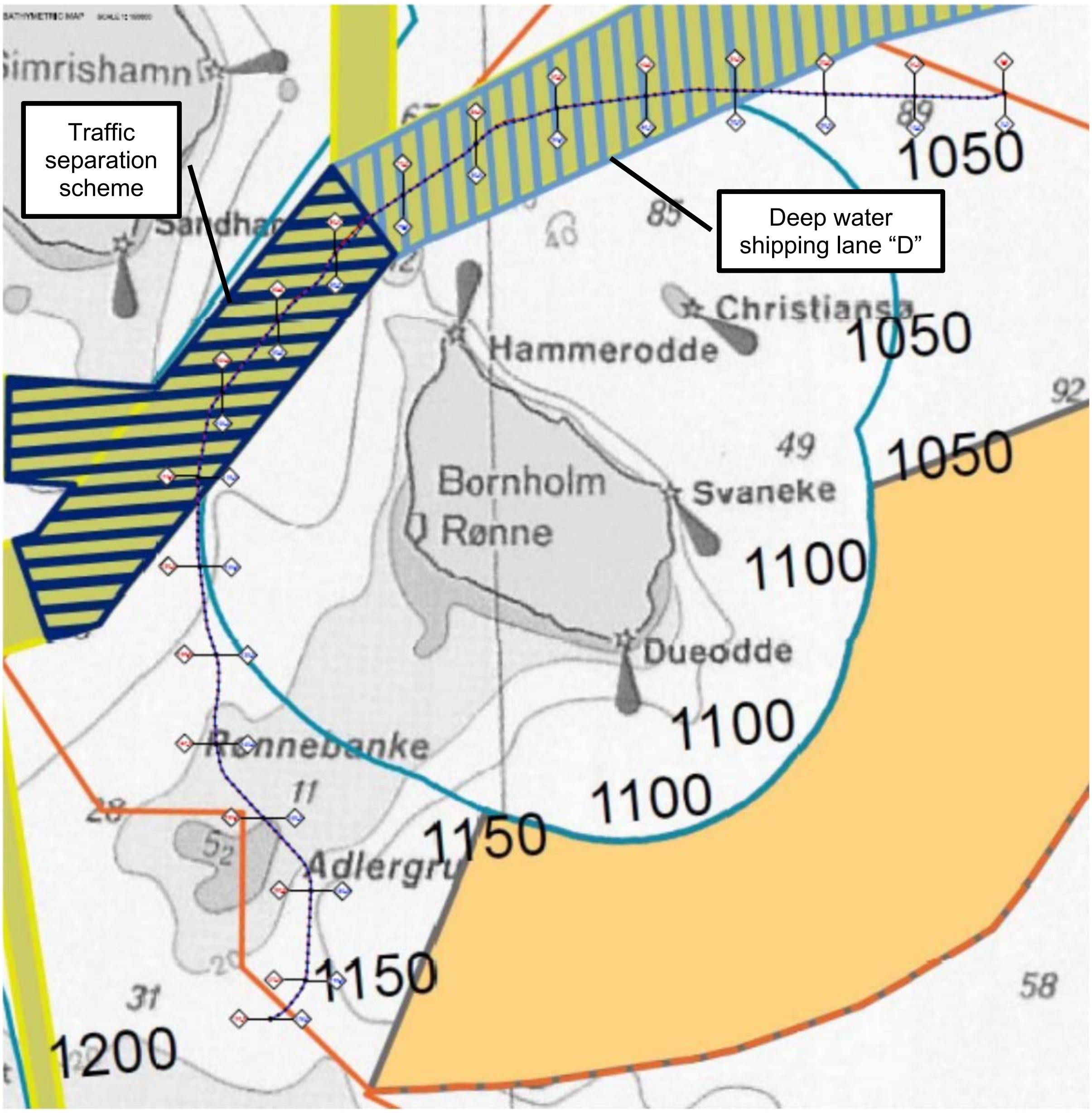

Figure 8-1: Critical areas for navigation in Danish EEZ (ref. /E8/)

8.2 Frequency assessment

8.2.1 Corrosion

In PARLOC 2001 database (ref. /E1/) 11 leakages due to corrosion are reported for midline (outside platform or well safety zone) operating steel pipelines during an operating experience of 292,745 km*y. However, only 2 leakages involved steel gas pipeline longer than 5 km (operating experience of 182,272 km*y) and have been recorded for small diameter pipelines (< 12”).

In PARLOC 2012 (ref. /E2/) the number of incidents due to corrosion reported for midline operating steel pipeline is 9 (this includes also incidents due to other material defects), however only 1 leakage involved a steel gas pipeline with a diameter >16”.

Therefore, the frequency of release due to corrosion is considered "negligible" for this project since:

- diameter of NSP2 offshore pipelines is very large (i.e. 48");
- the transported medium is dry and sweet natural gas and the internal flow coating will also reduce the probability of internal corrosion;
- external corrosion protection is achieved by an external corrosion coating in combination with the cathodic protection system. The external corrosion coating is formed by three layer of Polyethylene whereas the cathodic protection system is based on sacrificial anodes of cast in half shells to form a bracelet (ref. /C1/). Therefore, coating malfunctions or failures are not critical unless they are combined with deficiencies in the cathodic protection system. Moreover, the external field joints will be coated with a combination of Heat Shrink Sleeves, steel sheet formers and Polyurethane Foam giving robust corrosion protection of the field joints;
- wall thickness of NSP2 pipelines (i.e. between 26.8 and 41.0 mm) is considerable and intelligent pigging is foreseen to detect any possible loss of thickness caused by corrosion before the wall thickness achieves the critical size;
- the anode potential will be measured to verify anode operability and anode consumption which is indicative of coating deficiencies;
- an inspection and maintenance programme is foreseen.

8.2.2 Mechanical defects

According PARLOC 2001 database (ref. /E1/), the mechanical failure frequency can be subdivided in:

- material defects;
- construction faults.

Material defects are those defects produced during the line-pipe fabrication process; basically, these defects can be classified within two different categories, i.e., manufacture defects or defects in the longitudinal weld.

No loss of containment due to construction faults are reported for operating steel pipelines in PARLOC 2001 database (ref. /E1/), even if 2 incidents caused damage to the external coating.

According to PARLOC 2001 database (ref. /E1/), 2 loss of containment incidents due to material defects are recorded for midline operating steel pipelines for an operating experience of 292,745 km*y and only 1 of these involved a large diameter pipeline (i.e. ≥ 30").

In PARLOC 2012 database (ref. /E2/) the classification of incidents is slightly different, therefore direct comparison cannot be made: material defects are included in the same class as internal and external corrosion under 'material' causes while mechanical failure due to construction faults are reported under 'construction' category separately. Only 1 incident is recorded for steel pipeline in the midline area.

This means that release due to material defects is a "rarely" event, particularly for modern pipelines where advanced pipe technology and quality control, as well as welding technology and control procedures are applied.

Therefore, the frequency of release due to mechanical defects is considered "negligible" since the following measures have been adopted:

- all materials, manufacturing methods and procedures will comply with recognised standards, practices or Purchaser specifications;

- NDT examinations at fabrication site will be performed according to DNV standards.

8.2.3 Natural hazards

According to PARLOC 2001 database (ref. /E1/), 13 incidents due to natural hazards (including waves and current action) have been reported. However, none of these caused loss of containment (release) from steel pipelines. Only 3 lines sustained damage, this being to their coating.
In PARLOC 2012 database (ref. /E2/) natural hazards are included in the category ‘Others’. No incidents are reported for steel pipelines in the midline section under this category.
Therefore, this failure cause is considered “negligible”.

8.2.4 Other unknown

Other/unknown causes include all the incidents for which no specific causes where identified. However, no leakage has been recorded for large diameter operating steel lines.
For this project, the design systematic failures will be reduced to negligible level applying appropriate QA/QC procedure, design review meeting and dedicated HSE reviews and studies.
Only sabotage, military exercises and/or accidental transported mines are identified as possible “other/unknown” causes but are considered very unlikely for this section of pipeline within Danish EEZ. In particular the BH_North_9A, object of present study, has been designed to avoid crossing the submarine military exercise area Bravo 4 located in Danish EEZ and does not cross any mine threat area (see ref. /C6/ and Figure 10-7).

Other interferences that may derive from surveys and construction of nearby/crossing installations foreseen to be installed once NSP2 will be in operation are considered to be negligible as they will be addressed with dedicated interfaces between project teams at design stage.

8.2.5 Commercial ship traffic

8.2.5.1 Route BH_North_9A_2

For each sensitive section the interaction frequency has been calculated (ref. /C3/) and is reported in Table 8-1.

Route BH_North_9A_2								
Interaction Scenario Frequencies (event/section/year) at the Sections with High Ship traffic density (>250 ships/km/year)								
Section ID	From KP	To KP	Grounding	Dropped Objects	Dropped Anchors	Dragged Anchors	Sinking Ships	Total
[#]	**[km]**	**[km]**	**[event/section/year]**					
1	31	47	0.00E+00	2.87E-04	2.42E-06	5.00E-06	1.56E-06	2.96E-04
2	55	74	0.00E+00	6.54E-05	5.38E-07	7.45E-06	1.36E-06	7.48E-05
3	103	115	0.00E+00	3.30E-04	2.37E-06	8.89E-05	5.42E-06	4.27E-04
4	132	141	0.00E+00	2.87E-05	9.47E-08	3.33E-06	7.30E-07	3.29E-05
5	164	173	0.00E+00	5.05E-05	1.39E-07	6.13E-06	7.70E-07	5.75E-05

Table 8-1: Interaction scenario frequencies at sensitive sections (2014) – BH_North_9A_2

On the basis of frequencies interaction results, the pipeline failure frequency due to ship traffic interaction has been assessed in the PDA (ref. /C4/). Results at sensitive sections are summarised in Table 8-2.

Route BH_North_9A_2								
Failure frequency (failure/section/year) at the Sections with High Ship traffic density (>250 ships/km/year)								
Section ID	**From KP**	**To KP**	**Total**	**Dropped Objects**	**Dropped Anchors**	**Dragged Anchors**	**Sinking Ships**	**Grounding**
[#]	**[km]**	**[km]**	**[failure/section/year]**					
1	31	47	5.02E-06	2.87E-08	2.42E-11	4.41E-06	5.79E-07	0.00E+00
2	55	74	5.75E-06	6.55E-09	5.38E-12	5.24E-06	5.05E-07	0.00E+00
3	103	115	7.08E-05	3.30E-08	2.37E-11	6.88E-05	2.00E-06	0.00E+00
4	132	141	2.34E-06	2.87E-09	9.47E-13	2.06E-06	2.70E-07	0.00E+00
5	164	173	4.92E-06	5.05E-09	1.39E-12	4.63E-06	2.85E-07	0.00E+00

Table 8-2: Failure frequency at sensitive sections (2014) – Route BH_North_9A_2

8.2.6 Summary

The release frequencies of each section are reported in Table 8-3 for route BH_North_9A_2, disregarding “negligible” failure causes.

BH_North_9A_2							
Section ID	From KP	To KP	Failure cause	Release frequencies (occ/section/year)			
[#]	[km]	[km]		Pinhole	Hole	Rupture	Total
1	31	47	Ship traffic	2.89E-08	2.89E-08	1.84E-06	1.90E-06
2	55	74		2.52E-08	2.52E-08	2.03E-06	2.08E-06
3	103	115		1.00E-07	1.00E-07	2.24E-05	2.26E-05
4	132	141		1.35E-08	1.35E-08	8.62E-07	8.89E-07
5	164	173		1.42E-08	1.42E-08	1.65E-06	1.67E-06

Table 8-3: Overall release frequencies at sensitive sections split by hole size – BH_North_9A_2

8.3 Consequence assessment

8.3.1 Source term

The discharge flowrate for the three rupture scenarios used for the analysis is reported in Table 8-4.

Discharge rate (kg/s)		
Pinhole	Hole	Rupture
8.4	134.5	7946

Table 8-4: Discharge rate at t=180s (ref. /E9/)

8.3.2 Underwater dispersion

The discharge flowrates are used as input data for underwater dispersion calculations, performed by means of the computer code POLPLUME (ref. /E4/). An average water depth along the analysed route is used for the calculations. The results of underwater dispersion calculations are reported in Table 8-5.

Release size	Water depth (m)	Radius at sea surface (m)	Top hat gas fraction (%)
Pinhole	54	5.9	8.0
Hole		6.7	100
Rupture		20.3	100

Table 8-5: Subsea release characteristics

On reaching the surface, the gas or vapours will begin to disperse within the atmosphere.

8.3.3 Gas dispersion

Gas dispersion simulations have been performed by means of the computer code DNV PHAST 6.7 (ref. /E6/) taking into account Table 8-5 (i.e. characteristics of gas at sea surface), environmental data and a vertical release direction.
The results of gas dispersion simulations are reported in Table 8-6.

Release size	LFL distance at 10m height (m)	LFL/2 distance at 10m height (m)	LFL/2 distance at plume centreline (m)	Plume centreline height (m)
Pinhole	Not reached	Not reached	42.6	5.8
Hole	47.4	66.6	120.6	30.7
Rupture	52.3	65.4	442	279

Table 8-6: Atmospheric dispersion results

8.4 Frequency of outcome scenarios

Conservatively the dimension of the flammable cloud used for this calculation has been taken as the largest distance reached by the LFL/2 envelope for each scenario.
The frequency of the possible outcome scenarios is calculated as per Eq. (6) taking into account the release frequencies (Table 8-3) and the conditional on ship presence ignition probability and ship presence probability reported in Table 8-7. Conservatively P_{wind} is assumed equal to 1.
The conditional probability of delayed ignition for each release scenario has been calculated according to the methodology described in section 5.6.1 based on the calculated LFL/2 distance and maximum time spent by a vessel in the cloud (Table 8-7).
The cloud persistence time has been assumed in analogy to NSP2 (ref. /D3/) taking into account leak detection time and local ship traffic.

Release size	Conditional ignition probability	Persistence time (h)
Pinhole	0.2	6
Hole	0.64	4
Rupture	0.98	2

Table 8-7: Conditional ignition probability and cloud persistence time

8.4.1 Route BH_North_9A_2

Flash fire scenario frequencies for each sensitive section associated to route BH_North_9A_2 are reported in Table 8-8.

Section ID	From KP	To KP	Crossings	Max num. crossing per KP in the section	Release scenario	FF frequency (occ/sec/year)	Cumulative FF frequency (occ/sec/year)
[#]	[km]	[km]					
1	31	47	20298	2542	PINHOLE	1.00E-12	1.59E-08
					HOLE	1.39E-11	
					FB	1.59E-08	
2	55	74	5906	451	PINHOLE	4.50E-14	9.04E-10
					HOLE	6.27E-13	
					FB	9.03E-10	
3	103	115	30074	4653	PINHOLE	9.39E-12	5.25E-07
					HOLE	1.31E-10	
					FB	5.25E-07	
4	132	141	2823	395	PINHOLE	1.01E-14	1.61E-10
					HOLE	1.40E-13	
					FB	1.61E-10	
5	164	173	3634	1398	PINHOLE	4.85E-14	1.40E-09
					HOLE	6.75E-13	
					FB	1.40E-09	

Table 8-8: Flash fire scenario frequencies – BH_North_9A_2

Based on the frequency of occurrence (<$1.0*10^{-7}$ event/year), only one scenario is credible.

8.5 Risk assessment

8.5.1 Social risk

For each identified scenario the number of fatalities has been evaluated based on the number of individuals present on board and on the vulnerability.
The F-N curve for each sensitive section is shown in Figure 10-5 and Figure 10-6 (respectively for 2014 and 2025) and compared with the tolerability criteria.
In all sections the social risk falls in the broadly acceptable region and therefore no further action is required.

8.5.2 Environment and reputation risks

A semi-quantitative approach has been adopted by means of the risk matrix methodology to predict the risk level for the environment and reputation.
Same criteria used for NSP2 (ref. /D3/) are applied.

As per DNV-RP-F107 (ref. /A7/), environmental impact due to natural gas release could be considered not relevant. However, for the purpose of this analysis, the following severity classes are associated to the identified release scenarios:

- 4 (minor consequences) for pinholes;
- 3 (moderate consequences) for holes and pipeline ruptures.

Results are reported in Table 8-9. According to the risk tolerability criteria, all scenarios are acceptable.

Environment – BH_North_9A_2							
Section ID [#]	From KP [km]	To KP [km]	Release scenario	Release frequency (occ/section/year)	Frequency class	Severity class	Risk
1	31	47	PINHOLE	2.89E-08	Not Credible	4	Low
			HOLE	2.89E-08	Not Credible	3	Low
			FB	1.84E-06	A	3	Low
2	55	74	PINHOLE	2.52E-08	Not Credible	4	Low
			HOLE	2.52E-08	Not Credible	3	Low
			FB	2.03E-06	A	3	Low
3	103	115	PINHOLE	1.00E-07	A	4	Low
			HOLE	1.00E-07	A	3	Low
			FB	2.24E-05	B	3	Low
4	132	141	PINHOLE	1.35E-08	Not Credible	4	Low
			HOLE	1.35E-08	Not Credible	3	Low
			FB	8.62E-07	A	3	Low
5	164	173	PINHOLE	1.42E-08	Not Credible	4	Low
			HOLE	1.42E-08	Not Credible	3	Low
			FB	1.65E-06	A	3	Low
Denmark	0	174	PINHOLE	1.82E-07	A	4	Low
			HOLE	1.82E-07	A	3	Low
			FB	2.88E-05	B	3	Low

Table 8-9: Risk on the environment – BH_North_9A_2

The reputation of the Client is linked and can be affected by HSE incidents or accidents of all types. Although reputation can be considered as an ‘intangible’ asset, it is important because it can affect the ability of the Client to establish or maintain business at all stages of the development cycle.

Considering the environmental impact due to natural gas releases, the lack/decrease of supplied gas for the consumers and the possible impact on human life, the following severity classes are associated to the identified release scenarios:

- 4 (minor consequences) for pinholes;
- 3 (moderate consequences) for holes;
- 2 (severe) for pipeline ruptures.

Results are reported in Table 8-10. According to the TOR criteria, all scenarios have an acceptable risk exception made for the full bore scenarios in section 3. For this outcome scenario the risk is Medium and it should be reduced if possible (i.e. unless the cost of implementation is disproportionate to the effect of possible safeguards).

Reputation – BH_North_9A_2							
Section ID [#]	From KP [km]	To KP [km]	Release scenario	Release frequency (occ/section/year)	Frequency class	Severity class	Risk
1	31	47	PINHOLE	2.89E-08	Not Credible	4	Low
			HOLE	2.89E-08	Not Credible	3	Low
			FB	1.84E-06	A	2	Low
2	55	74	PINHOLE	2.52E-08	Not Credible	4	Low
			HOLE	2.52E-08	Not Credible	3	Low
			FB	2.03E-06	A	2	Low
3	103	115	PINHOLE	1.00E-07	A	4	Low
			HOLE	1.00E-07	A	3	Low
			FB	2.24E-05	B	2	Medium
4	132	141	PINHOLE	1.35E-08	Not Credible	4	Low
			HOLE	1.35E-08	Not Credible	3	Low
			FB	8.62E-07	A	2	Low
5	164	173	PINHOLE	1.42E-08	Not Credible	4	Low
			HOLE	1.42E-08	Not Credible	3	Low
			FB	1.65E-06	A	2	Low
Denmark	0	174	PINHOLE	1.82E-07	A	4	Low
			HOLE	1.82E-07	A	3	Low
			FB	2.88E-05	B	2	Medium

Table 8-10: Risk on reputation – BH_North_9A_2

8.5.3 Risk to assets

The risk to assets has been evaluated according to the DNV acceptance criteria.
In particular the need of protection measures has been established comparing the damage frequency with the annual target failure frequency for the applicable safety class.
According to the results of the PDA (ref. /C4/) reported in Table 8-11 and Table 8-12 for route BH_North_9A_2, the DNV target (1E-04 failure/sect/year) for safety class 'Medium' is respected at all sensitive sections, while the criteria per km (1E-05 failure/sect/year) is slightly exceeded at KP 110.

BH_North_9A_2					
Section ID	**From KP**	**To KP**	**Total failure frequency (Failure/Section/Year)**	**Target Value (DNV-OS-F101, ref. /A1/)**	
1	31	47	5.02E-06	1.00E-04	√
2	55	74	5.75E-06	1.00E-04	√
3	103	115	7.08E-05	1.00E-04	√
4	132	141	2.34E-06	1.00E-04	√
5	164	173	4.92E-06	1.00E-04	√

Table 8-11: Total failure frequency vs DNV target – BH_North_9A_2

BH_North_9A_2						
Section	**From KP**	**To KP**	**Max Failure Frequency (Failure/km/Year)**	**@KP**	**Target Value (DNV-OS-F101, Ref.)**	
P/L Route -2014	1	176	1.09E-05	110	1.00E-05	×
Section S1 - 2014	31	47	9.72E-07	34	1.00E-05	√
Section S2 - 2014	55	74	7.58E-07	62	1.00E-05	√
Section S3 - 2014	103	115	1.09E-05	110	1.00E-05	×
Section S4 - 2014	132	141	9.61E-07	141	1.00E-05	√
Section S5 - 2014	164	173	2.21E-06	172	1.00E-05	√

Table 8-12: Failure frequency per km vs DNV target – BH_North_9A_2

8.5.4 Future trend

The results of the pipeline damage assessment against commercial ship traffic related threats based on forecasted data (2025) (ref. /C4/) have been used to estimate the future risk trend.
The social risk has been evaluated according to calculated release and flash fire frequencies based on 2025 forecast ship traffic data in order to assess potential variation of the social risk during the pipeline operational life.
Results are shown in Figure 10-6. For section 3 the risk is at the border of the ALARP region.
The environmental and reputation risk has been calculated and results are shown in Table 8-13 and Table 8-14.

Environment – BH_NORTH_9A_2							
Section ID [#]	**From KP [km]**	**To KP [km]**	**Release scenario**	**Release frequency (occ/section/year)**	**Frequency class**	**Severity class**	**Risk**
1	31	47	PINHOLE	4.00E-08	Not Credible	4	Low
			HOLE	4.00E-08	Not Credible	3	Low
			FB	2.31E-06	A	3	Low
2	55	74	PINHOLE	3.48E-08	Not Credible	4	Low
			HOLE	3.48E-08	Not Credible	3	Low
			FB	2.65E-06	A	3	Low
3	103	115	PINHOLE	1.36E-07	A	4	Low
			HOLE	1.36E-07	A	3	Low
			FB	3.03E-05	B	3	Low
4	132	142	PINHOLE	2.00E-08	Not Credible	4	Low
			HOLE	2.00E-08	Not Credible	3	Low
			FB	1.37E-06	A	3	Low
5	164	173	PINHOLE	1.98E-08	Not Credible	4	Low
			HOLE	1.98E-08	Not Credible	3	Low
			FB	2.46E-06	A	3	Low
Denmark	0	174	PINHOLE	2.50E-07	A	4	Low
			HOLE	2.50E-07	A	3	Low
			FB	3.91E-05	B	3	Low

Table 8-13: Risk on the environment – BH_North_9A_2 (2025)

Reputation – BH_North_9A_2							
Section ID [#]	From KP [km]	To KP [km]	Release scenario	Release frequency (occ/section/year)	Frequency class	Severity class	Risk
1	31	47	PINHOLE	4.00E-08	Not Credible	4	Low
			HOLE	4.00E-08	Not Credible	3	Low
			FB	2.31E-06	A	2	Low
2	55	74	PINHOLE	3.48E-08	Not Credible	4	Low
			HOLE	3.48E-08	Not Credible	3	Low
			FB	2.65E-06	A	2	Low
3	103	115	PINHOLE	1.36E-07	A	4	Low
			HOLE	1.36E-07	A	3	Low
			FB	3.03E-05	B	2	Medium
4	132	142	PINHOLE	2.00E-08	Not Credible	4	Low
			HOLE	2.00E-08	Not Credible	3	Low
			FB	1.37E-06	A	2	Low
5	164	173	PINHOLE	1.98E-08	Not Credible	4	Low
			HOLE	1.98E-08	Not Credible	3	Low
			FB	2.46E-06	A	2	Low
Denmark	0	174	PINHOLE	2.50E-07	A	4	Low
			HOLE	2.50E-07	A	3	Low
			FB	3.91E-05	B	2	Medium

Table 8-14: Risk on reputation – BH_North_9A_2 (2025)

The risk to assets has been evaluated according to the DNV acceptance criteria. Compliance with the criteria per section is confirmed also with 2025 ship traffic data (see Table 8-15) while criteria per km are exceeded from KP 107 to KP 111 (see Table 8-16).

BH_North_9A_2					
Section ID	From KP	To KP	Total failure frequency (Failure/Section/Year)	Target Value (DNV-OS-F101, ref. /A1/)	
1	31	47	6.14E-06	1.00E-04	√
2	55	75	7.46E-06	1.00E-04	√
3	103	115	9.56E-05	1.00E-04	√
4	132	142	3.77E-06	1.00E-04	√
5	164	173	7.43E-06	1.00E-04	√

Table 8-15: Total failure frequency vs DNV target – BH_North_9A_2 (2025)

BH_North_9A_2						
Section	**From KP**	**To KP**	**Max Failure Frequency (Failure/km/Year)**	**@KP**	**Target Value (DNV-OS-F101, Ref. /A1/)**	
P/L Route -2014	1	174	1.47E-05	110	1.00E-05	×
Section S1 - 2014	31	47	1.27E-06	34	1.00E-05	√
Section S2 - 2014	55	75	9.27E-07	62	1.00E-05	√
Section S3 - 2014	103	115	1.47E-05	110	1.00E-05	×
Section S4 - 2014	132	142	1.39E-06	141	1.00E-05	√
Section S5 - 2014	164	173	3.27E-06	172	1.00E-05	√

Table 8-16: Failure frequency per km vs DNV target – BH_North_9A_2 (2025)

Major conclusions are mostly unvaried:

- risk for the environment and reputation is unchanged;
- risk for people slightly increases (see Figure 10-6);
- failure frequencies per km and per section show a slight increase: the target criteria per section are always met, whereas target criteria per km are exceeded at four additional KPs with respect to the ship traffic data of 2014.

9 TABLES

Dir. Blowing from (°N)	Wind speed (m/s)													
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**Tot**
0	0.49	1.25	1.05	0.89	0.54	0.22	0.06	0.02	0	0	0	0	0	0	4.5
30	0.46	1.24	1.1	0.83	0.58	0.25	0.04	0.03	0.01	0	0	0	0	0	4.5
60	0.47	1.4	1.64	1.14	0.73	0.41	0.14	0.07	0.01	0	0	0	0	0	6
90	0.48	1.69	2.26	1.69	1.06	0.38	0.1	0.01	0	0	0	0	0	0	7.7
120	0.48	1.77	2.34	1.6	0.81	0.3	0.06	0.01	0	0	0	0	0	0	7.4
150	0.5	1.72	1.82	1.3	0.67	0.28	0.08	0.03	0.01	0	0	0	0	0	6.4
180	0.53	1.87	1.77	1.36	0.77	0.31	0.17	0.05	0.02	0.01	0	0	0	0	6.9
210	0.55	1.96	2.19	1.82	1.15	0.73	0.29	0.13	0.04	0.01	0	0	0	0	8.9
240	0.53	2.27	2.96	3.16	2.34	1.44	0.89	0.43	0.13	0.04	0.02	0.01	0	0	14.2
270	0.54	2.52	3.88	4.06	3.1	2.13	1.19	0.57	0.23	0.07	0.02	0.01	0	0	18.3
300	0.53	2.07	2.33	2.01	1.4	0.82	0.39	0.17	0.05	0.01	0	0	0	0	9.8
330	0.51	1.48	1.35	1.05	0.67	0.25	0.1	0.03	0.01	0	0	0	0	0	5.4
Omnidir	6.07	21.25	24.69	20.9	13.82	7.51	3.5	1.55	0.49	0.15	0.05	0.02	0	0	100

Table 9-1: Wind frequency data – Direction from vs. speed at reference point 8 (ref. /C2/)

Point	**KP range**	**Lon.**	**Lat.**
8	0-174	14°30’	55°01’

Table 9-2: Reference points coordinates

Ship class	GRT Ship class	Avg. Length (m)	Avg. Width (m)	Draft (m)	Avg. Speed (knots)
1	100÷500	60.70	9.70	3.39	10.2
2	500÷1,600	81.25	12.90	4.66	11.8
3	1,600÷10,000	115.43	17.30	6.80	14.3
4	10,000÷60,000	193.90	27.90	10.75	16.6
5	60,000÷100,000	279.37	43.90	17.17	16.6
6	>100,000	342.97	54.90	21.26	15.0

Table 9-3: Reference vessel parameters

10 FIGURES

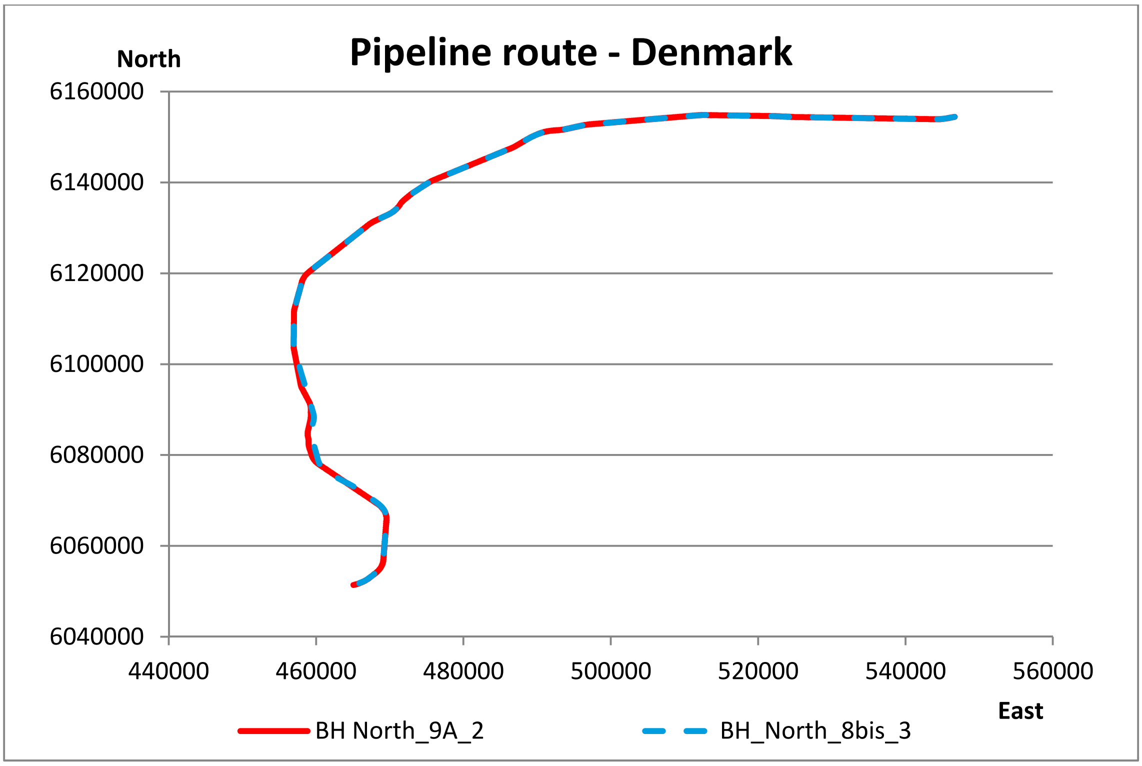

Figure 10-1: Route BH_North_9A_2 and BH_North_8bis_3 in Danish EEZ

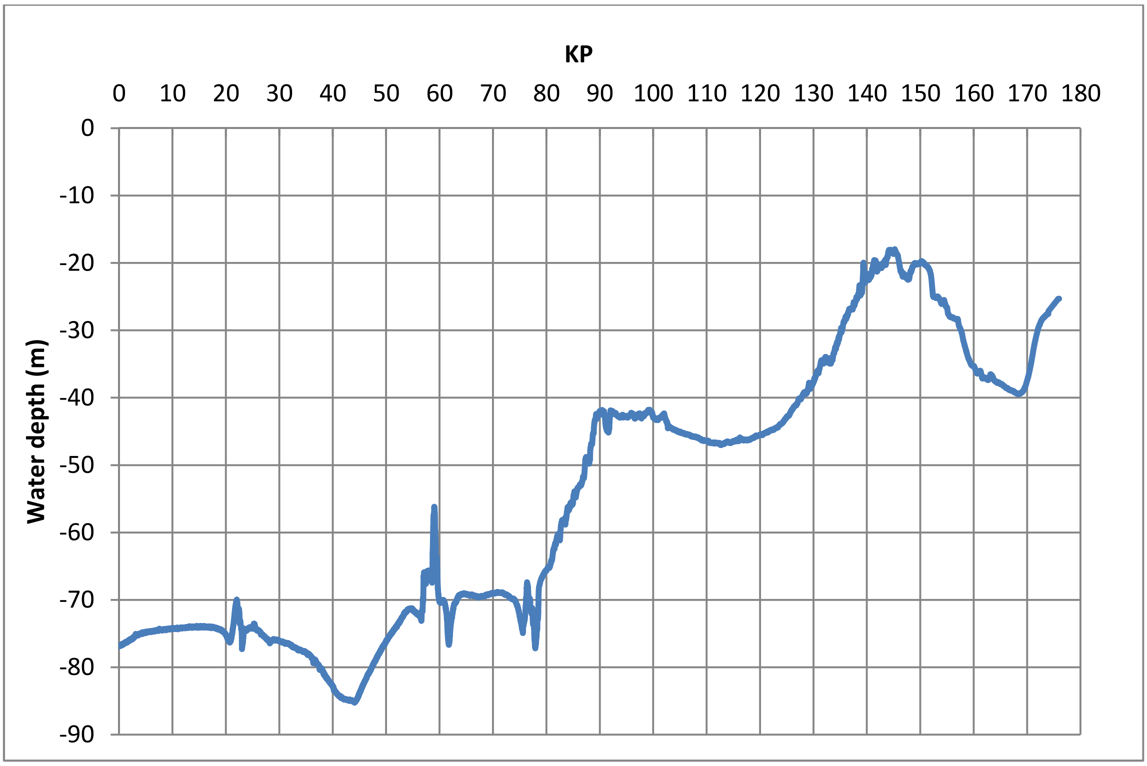

Figure 10-2: Seabed profile along the Danish EEZ – Route BH_North_9A_2

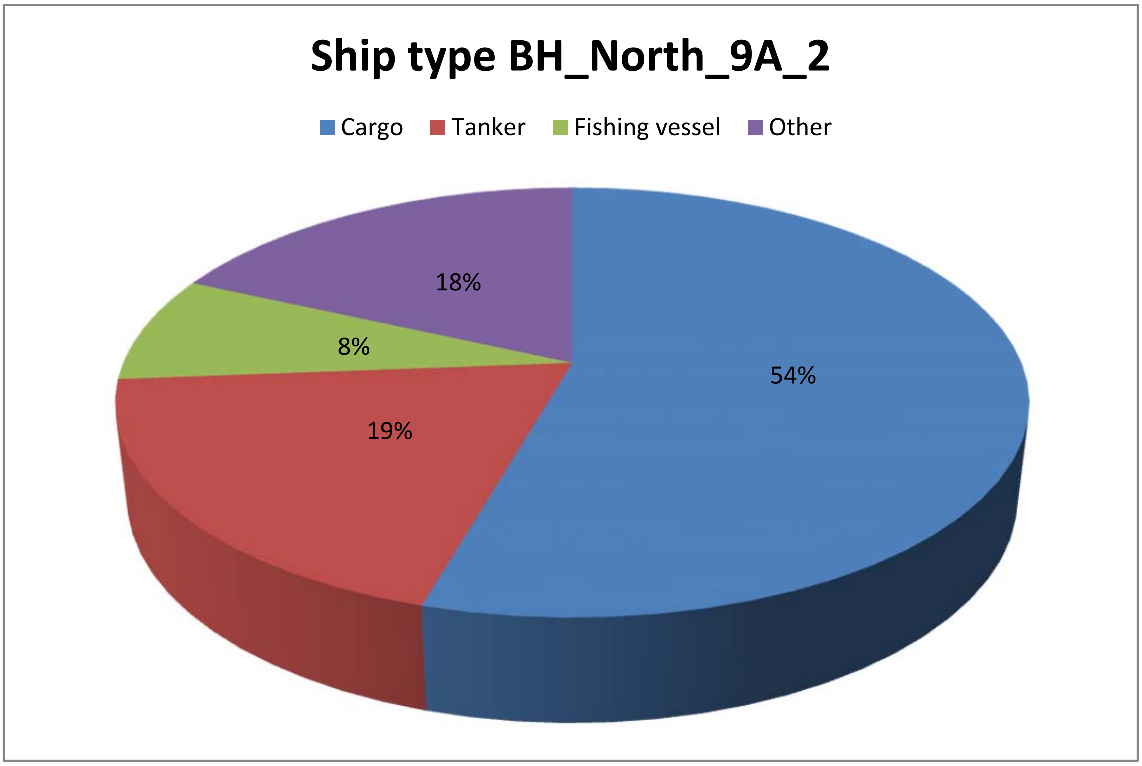

Figure 10-3: Ship type distribution percentage – Route BH_North_9A_2

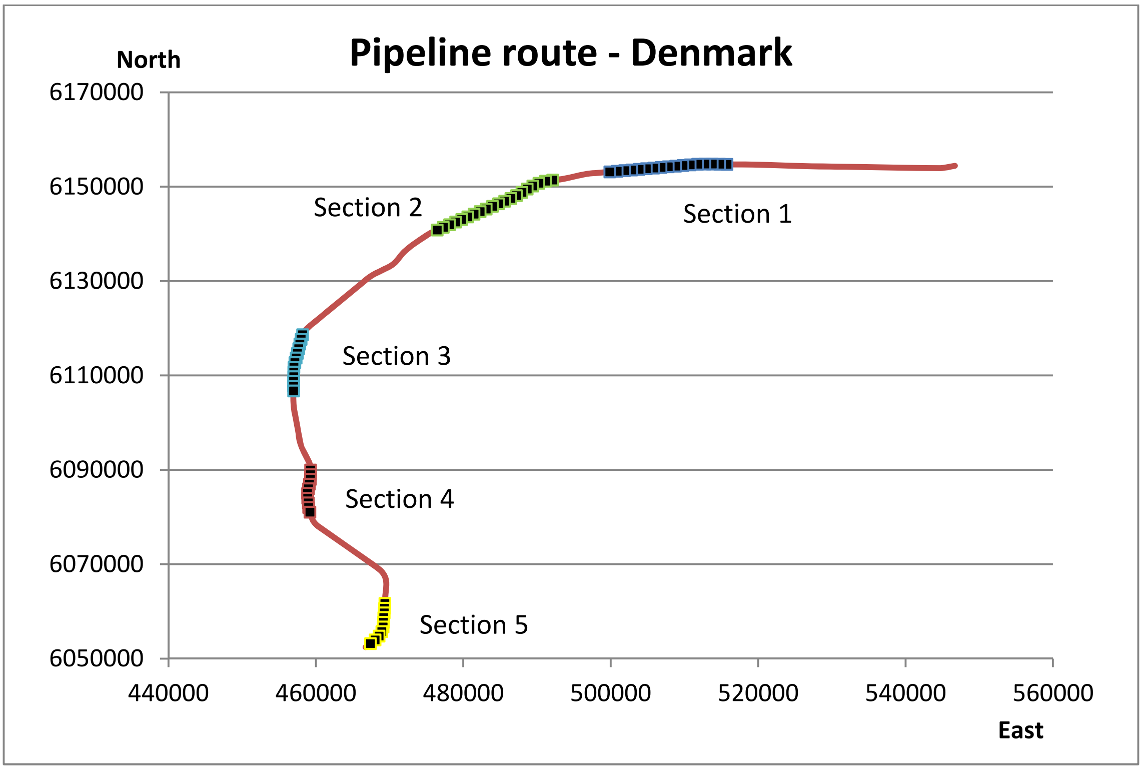

Figure 10-4: Pipeline route and sensitive sections

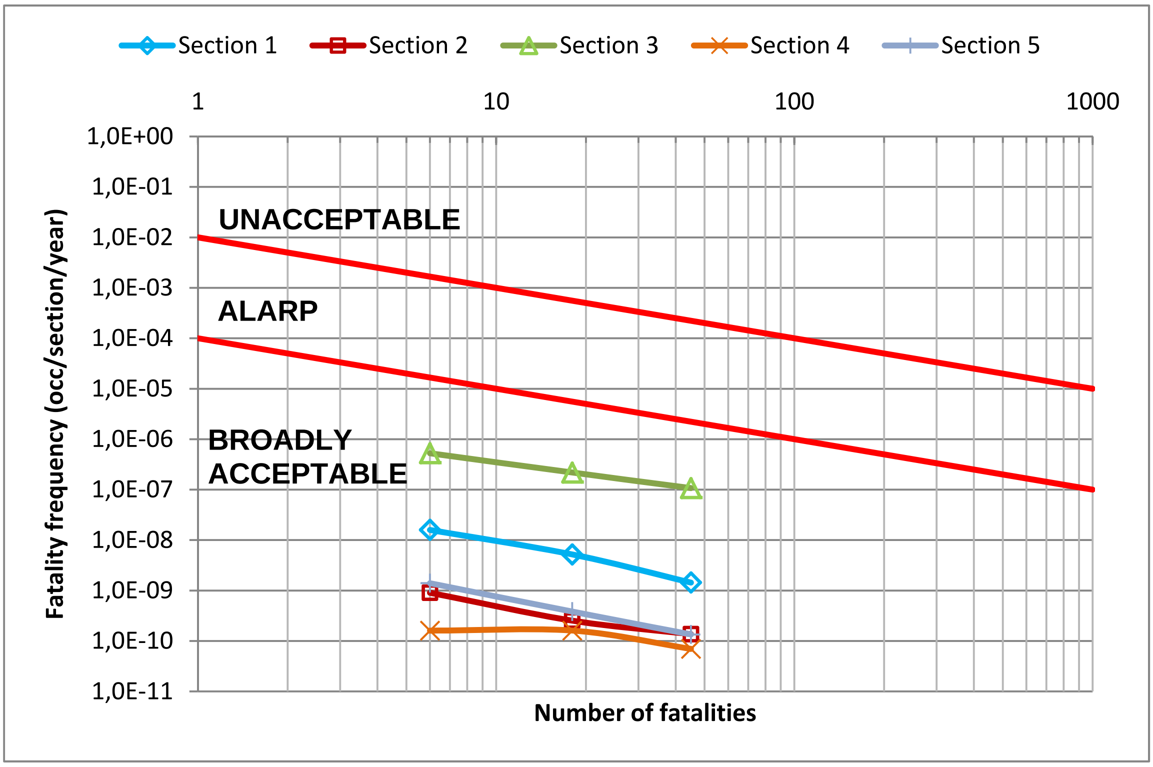

Figure 10-5: F-N curve of each sensitive section – Route BH_North_9A_2

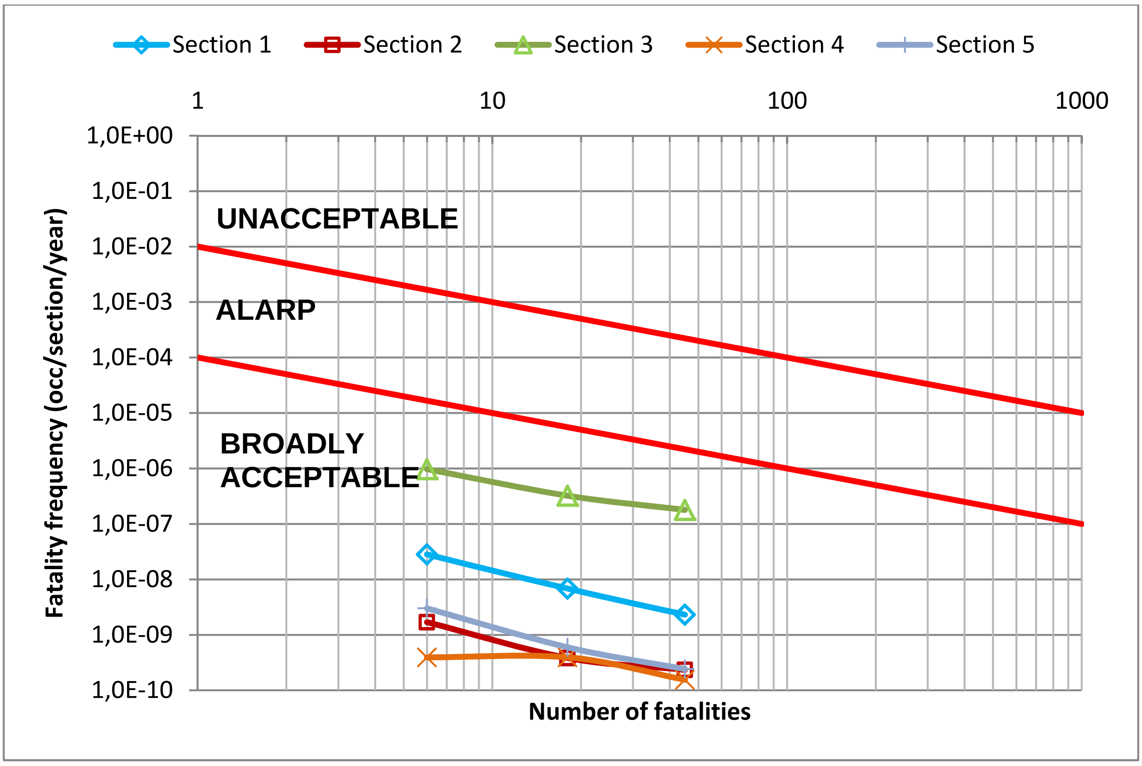

Figure 10-6: F-N curve of each sensitive section – Route BH_North_9A_2 (2025)

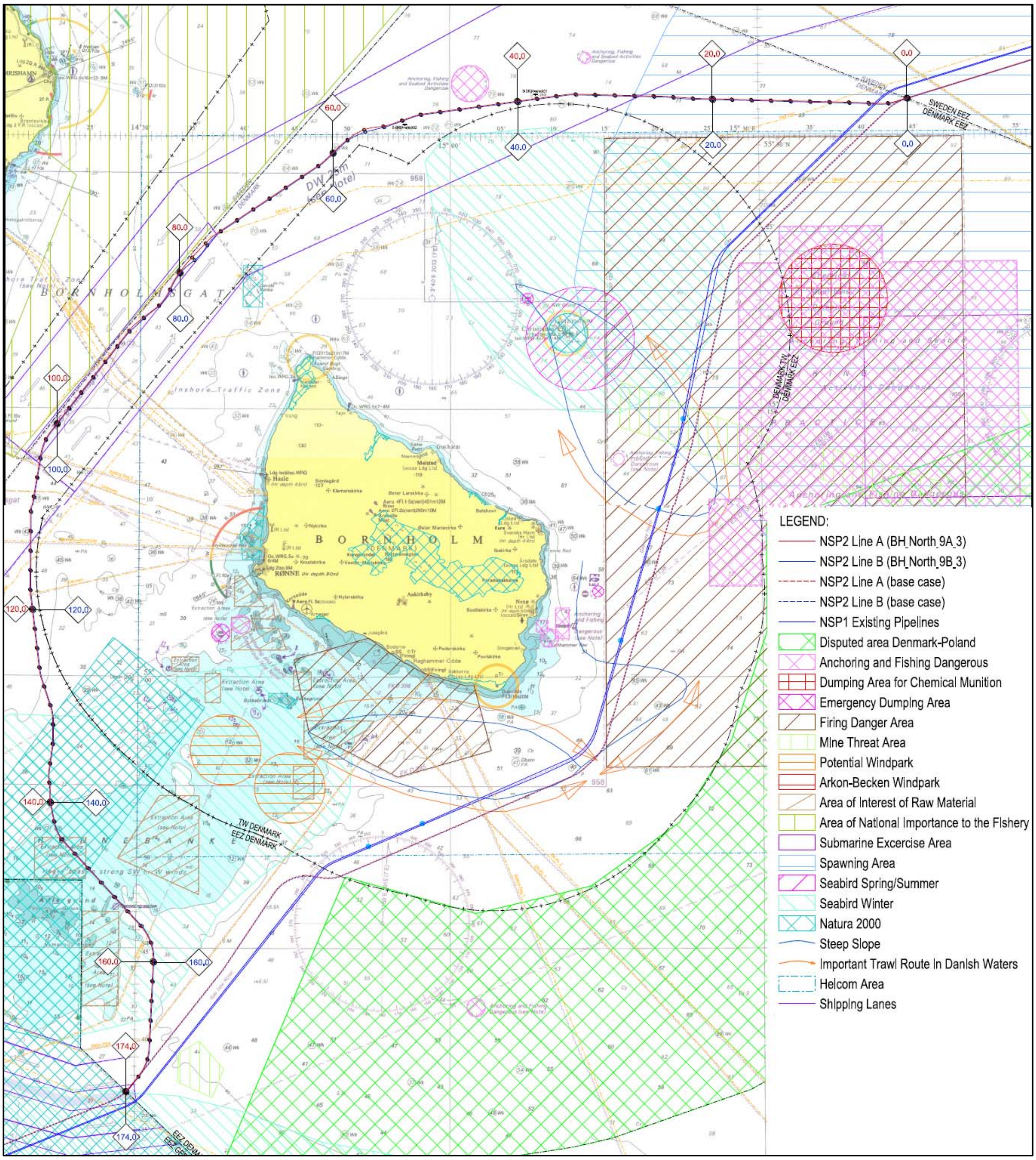

Figure 10-7: Route BH_North_9A_2 - Extract from Route map (Ref. /C7/)

11 REVISION RECORD

Rev. No.	Date	Description	Prepared	Checked	Approved	Date	Approved
02	29.03.2018	Issue for client comments	C. Zuliani	A. Massoni	D. Pettinelli		
01	23.03.2018	Issue for Internal Discipline Check	C. Zuliani	A. Massoni	D. Pettinelli		
			Saipem			Nord Stream 2	