Nord Stream

The new gas supply route for Europe

Section 9

Assessment of risks related to unplanned events

9 Assessment of risks related to unplanned events

9.1 Introduction

9.1.1 Aim and scope

Unplanned events are incidents of accidents. From the project description presented in Chapter 3 there are two key phases for which the risks to people and the environment need to be assessed, namely:

- Installation of the pipelines
- Operation of the pipelines.

Installation is the term commonly used to encompass the off-shore construction activities. In this project it includes seabed intervention works, line pipe transport and pipe lay. There are certain risks that were mitigated as the design evolved. For example, at one stage the design envisaged an offshore platform along the pipeline route in the Swedish EEZ. This would have yielded risks associated with ship-platform collisions - and resultant gas release. However, this risk has been completely negated by the removal of the offshore platform from the design.

This chapter addresses the risks associated with the latest design. It does not discuss risks that no longer exist as a result of design changes.

The environmental risks related to pre-commissioning activities in the Finnish sector were assessed as negligible during the qualitative screening. For this reason they are excluded from detailed risk assessment.

Likewise, the risks arising from future decommissioning of the pipelines have not been assessed in detail. If the pipelines are removed at the end of their operational life the risks may be similar to those for the installation phase. There is also the possibility of leaving the pipelines in situ, flooding and sealing them. In this case the risks would be similar to those for pre-commissioning. Decommissioning is discussed in more detail in Chapter 10.

This chapter:

- Lists the unplanned events that could occur during installation and operation of the Nord Stream pipelines;

- Details the risks identified as medium or high during the qualitative risk assessment that have been taken forward for a detailed, quantitative assessment; and

- Explains the qualitative and quantitative risk assessments that were undertaken and the results that were obtained.

If more information is required about project risks relating to unplanned activities that are not addressed in this report then refer to chapter 5 of the Nord Stream Espoo Report.

9.1.2 Findings & conclusions

The results of the comprehensive risk analyses undertaken for the installation and operation of the Nord Stream pipelines show that no risks to people and the environment from unplanned events are unacceptable when compared to the risk tolerability criteria agreed for the project.

This is not surprising given that natural gas pipelines are used worldwide and considered as a safe means of transporting large volumes of gas. For example, there are more than 122,000 km of gas pipelines in Europe /450/; over 548,000 km of natural gas pipelines in the US /451/; 21,000 km of pipelines are used to transmit natural gas in Australia /452/; and there are many more kilometres of gas pipelines in Russia and Canada.

The highest individual risks to people are, not surprisingly, those to which the project's workers are exposed during pipeline installation. During installation, the risk to third parties is limited to the crews and passengers of passing vessels that could collide with installation vessels. These risks are well below the project's risk criterion set for members of the public.

The most significant risks to the environment during installation arise from the potential for oil spills as a result of tanker collisions with the installation vessels. The exclusion zones enforced around the installation vessels will minimise the occurrence of this scenario.

During pipeline operation the risk to third parties arises as a result of the potential for pipeline failure resulting in a gas release and ignition. This risk has been shown to be very low. The dominant cause of pipeline failure is dragging anchors (or sinking ships for some sections). However, the pipeline will be marked on the relevant nautical charts to ensure shipping in the vicinity of the pipeline is aware of its location and the pipeline will be protected by rock placement in specified areas to prevent dragging anchors from leading to pipeline damage.

9.2 Explanation of the risk management process

Installation and operation of the Nord Stream pipelines give rise to some hazards which present risks to the public/third parties[1], project workers and the environment.

Risk management is the overall process of assessing the risks, interpreting the results, and taking appropriate actions. Risk management uses the results of risk assessments to consider whether enough precautions have been taken or whether more should be done to prevent harm, often utilising cost benefit analysis to examine the cost effectiveness of alterative risk reducing measures.

In essence, risk assessment is used to help identify the measures needed to ensure that risks from the hazards are adequately controlled/managed or completely eliminated. Nord Steam's approach to risk management is described in relevant project documents /453, 454/.

9.2.1 Definitions

Although hazard and risk are often used interchangeably in everyday vocabulary, it is useful to make a conceptual distinction between a 'hazard' and a 'risk' as follows:

- **hazard** - the potential for harm arising from an intrinsic property or disposition of something to cause detriment

- **risk** - the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard.

An alternative and simple definition of risk is 'the possibility of danger'. Irrespective of the precise definition, risk has two key components:

- **likelihood** or frequency component (representing the extent of the chance or possibility)

- **consequence** or severity component (representing the extent of the adverse impact or danger).

Risk is the product of these components (which can be summed for all potential accident scenarios associated with a system, operation or process).

1 The public and third parties are used interchangeably in this chapter to refer to people who are not connected to the Project, for example, the crews and passengers of commercial shipping in the Baltic.

9.2.2 Risk assessment

Regulatory regimes commonly require hazards to be identified, the risks they give rise to be assessed and appropriate control measures to be introduced to address the risks.

A risk assessment is a careful examination of what, in the project activities, could cause harm to people or the environment, consideration of the likelihood of the harm being realised and the severity of the impacts, thereby allowing an estimation of the risks. For the Project, the risk assessments have been undertaken in accordance with the relevant Det Norske Veritas (DNV) codes, standards and recommended practices.

The methodology adopted for the risk assessment is in accordance with the recommended risk management practice from DNV /455/ and consistent with the approach and criteria suggested by the International Maritime Organisation (IMO) in its formal safety assessment guidance on risk evaluation. In preparing this chapter, reference has been made to various detailed risk assessment reports prepared by Ramboll, Global Maritime and SES (Saipem Energy Services, former Snamprogetti) amongst others.

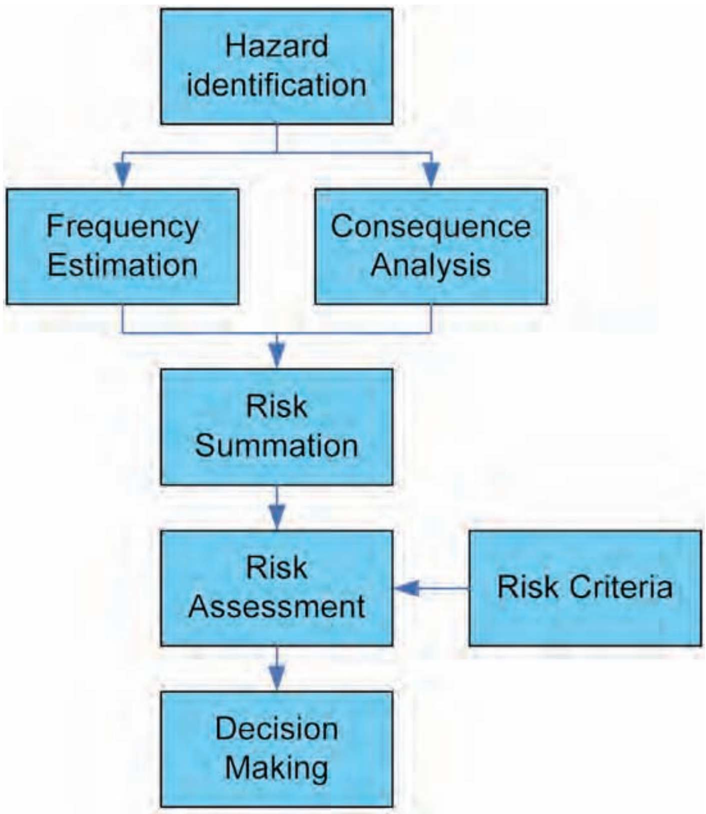

Figure 9.1. Main activities in risk assessment

Risk assessment can be either qualitative or quantitative:

- **Qualitative** (e.g. assessing likelihood and consequences using scales from ‘very low’ to ‘very high’)

- **Quantitative** (e.g. assessing likelihood in terms of annual frequencies of occurrence and estimating consequences in terms of specific numbers of casualties).

Risk assessment is a predictive technique, usually making use of historical data, modelling, assumptions and expert judgement and as such there is always a degree of uncertainty in the risk estimates. Where significant gaps in knowledge exist, risk assessment and risk management decisions tend to be suitably cautious, providing higher levels of protection as the significance and level of uncertainty about the risk increases.

9.2.2.1 Hazard identification

Referring to Figure 9.1 and 9.2 the starting point for a formal risk assessment is to identify hazards. This is also called HAZID. In the Nord Stream Project this was undertaken formally in workshop formats using multidisciplinary teams of specialists with knowledge and experience relating to installation and operation of offshore gas pipelines.

9.2.2.2 Qualitative risk assessment

The Nord Stream project has used the qualitative risk assessment matrix presented in Figure 9.2, based on DNV recommended practice DNV-RP-H101 /455/. It can be seen that use of the matrix involves making judgements of event likelihoods (in four categories covering remote to frequent) and event consequences (in four categories ranging from illness/slight injury to fatality. This matrix also includes the risk tolerability criteria (i.e. high - unacceptable risks, low – broadly acceptable risks, and the area in between - medium - the ALARP or tolerability region). The matrix is used as a tool for qualitatively screening the risk level posed by identified hazards.

Consequences			Probability (increasing probability →)			
Descriptive	Environment	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.	International impact Neg. exposure	A1	B1	C1	D1
2. Severe	Restoration time > 1 yr. Restoration cost > USD 1 mil.	Extensive National impact	A2	B2	C2	D2
3. Moderate	Restoration time > 1 month. Restoration cost > USD 1K.	Limited National impact	A3	B3	C3	D3
4. Minor	Restoration time <1 month. Restoration cost < USD 1K.	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 9.2. Risk matrix and associated tolerability criteria

9.2.2.3 Quantitative risk assessment

Quantitative risk assessment consists of the following activities:

- Identification of the possible unplanned events (HAZID);
- Quantitative evaluation of the expected frequency of the unplanned events;
- Quantitative or qualitative evaluation of the consequences of the unplanned events;
- Assessment of risk levels and comparison to risk tolerability criteria to determine whether the risk is tolerable / intolerable; and
- Identifying potential risk mitigation measures and prioritising these using techniques such as risk ranking and cost-benefit analysis.

These elements are shown in Figure 9.1.

For the Finnish Exclusive Economic Zone (EEZ) specific risk studies have been conducted and form the basis of sections 9.3 and 9.4.

9.2.3 Tolerability of risk framework

The UK Health and Safety Executive (HSE) developed a tolerability of risk (TOR) framework which has been widely adopted by countries/regulators that routinely use risk based approaches[1]. Under this framework the main tests that are applied for reaching decisions on what action needs to be taken are very similar to those people apply in everyday life. In everyday life there are some risks that people choose to ignore and others that they are not prepared to entertain. But there are also many risks that people are prepared to take by operating a trade-off between the benefits of taking the risks and the precautions we all have to take to mitigate their undesirable effects. This framework is shown in Figure 9.3 /456/.

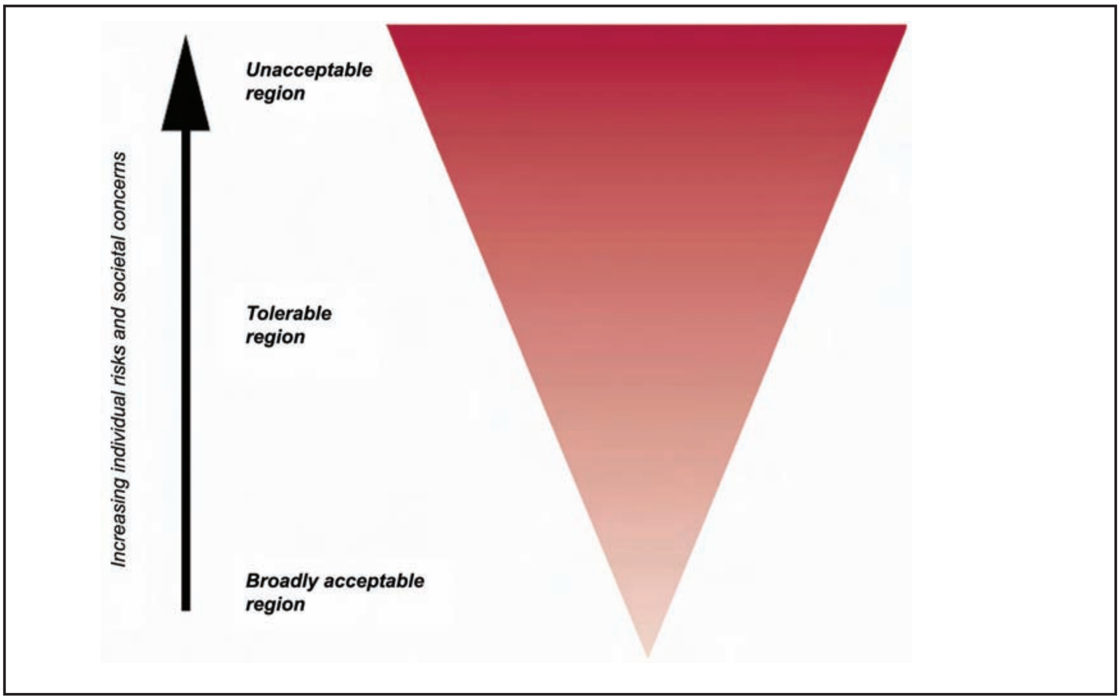

Figure 9.3. Framework for the tolerability of risk

In this framework, the dark zone at the top represents an unacceptable region, where the level of risk is regarded as unacceptable whatever the level of benefits associated with the activity. The light zone at the bottom represents a broadly acceptable region, where risks are generally regarded as insignificant and adequately controlled.

The zone between the unacceptable and broadly acceptable regions is the tolerable region. In this context 'tolerable' refers to a willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking and that it is properly controlled. It does not imply that the risk will be accepted by everyone. However,

1 For example, South Africa, The Netherlands, Hong Kong, Australia.

general acceptance becomes increasingly the case as the broadly acceptable region is approached.

Hence in the tolerable region risks are tolerated in order to secure benefits, in the expectation that:

- the nature and level of the risks are properly assessed and the results used properly to determine control measures
- the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle)
- the risks are periodically reviewed to ensure that they still meet the ALARP criteria.

In principle the TOR framework can be applied to all hazards. However, when determining reasonably practicable measures for any particular hazard, whether the option chosen to control the risk is good enough or not depends in part on where the boundaries are set between the unacceptable, tolerable or broadly acceptable regions.

It should be noted that the tolerability of risk framework described above is a conceptual model and its application is not mandated through legislation. Furthermore, there are no legislated quantified boundaries between the different ranges, although various regulatory regimes have produced guidance on tolerable levels of risk. These have been adopted by various industries as a basis for determining the reasonable practicality of control measures. It should be noted that the upper (maximum tolerable) limit of risk (for individual or societal risk) is not set by some scientific calculation, but by observation of what contemporary society at present tolerates. It is therefore a socio-political rather than a scientific matter.

9.2.4 Risk tolerability criteria

One important aspect of risk assessment is the development of a method by which the results of a risk analysis can be translated into recommendations on the tolerability of the overall system risk, and the extent to which taking further measures to reduce the risk may be justified. Risk criteria are essentially anchor points for such a method.

9.2.4.1 Nord Stream pipeline failure frequency criteria

As described in subsequent sections, the potential for pipeline damage and failure due to shipping-related interactions (e.g. dragged anchors, sinking ships) has been evaluated in detail for the project.

During pipeline operation, critical pipeline sections are deemed to be those where the frequency of ships crossing the pipeline exceeds 250 ships per kilometre per year. This criterion value corresponds to less than 1 ship per kilometre per day and is used to distinguish those pipeline sections corresponding to intense ship traffic. The interaction frequency and pipeline damage frequency has been estimated for each section of pipeline with this – or higher - level of ship activity.

In discussion with DNV, and in accordance with the relevant DNV standards, Nord Stream agreed a criterion value of 10^{-4} failures per critical pipeline section per year[1].

Where the section pipeline failure (damage) frequency can be shown to be below this value, the associated risks are taken to be broadly acceptable such that no further analysis is necessary. Nonetheless, Nord Stream has also undertaken consequence analyses and risk calculations to enable the associated risks to be compared with agreed risk tolerability criteria (see discussion in following sections and quantitative risk assessment methodology description in Chapter 9.3.3).

9.2.4.2 Tolerability criteria for individual risk

Individual risk is the risk to specific individuals (e.g. workers or members of the public). This usually refers to the risk of death, and is commonly expressed as the individual risk per annum (IRPA) or a fatal accident rate (FAR) per 100 million exposed hours. The tolerability criteria generally set for individual risk (of fatality) in the offshore industry, and adopted for the Nord Stream project, are as follows[2]:

- Maximum tolerable risk for NS project workers 1×10^{-3} per person per year
- Maximum tolerable risk for the public 1×10^{-4} per person per year

The lower figure for members of the public reflects the fact that members of the public gain no direct benefit from their exposure, they have no control over the risk, and generally do not necessarily voluntarily choose to accept it. The public also includes especially susceptib-

1 Pipeline mechanical damage mechanisms considered included loss of concrete coating/steel exposure, pipe dent/notch and over bending. These in turn can activate failure mechanisms such as loss of bottom stability, prevention of pigging, reduction of burst capacity, local buckling/collapse, fracture/plastic collapse, fatigue and puncture.

2 Normalised Scientific Notation
Normalised scientific notation is a simple way of working with very large or small numbers, and regularly used scientists, engineers and mathematicians. Without normalised scientific notation, very large or very small numbers are cumbersome.
For example, 1,000,000,000,000 is written as 1.0×10^{12} or 1.0 E12 and 0.000000015 as 1.5×10^{-8} or 1.5 E-8. This format can be used in Microsoft Excel© and is used for presenting the results in this chapter. Examples of the number formats are given below

Normal decimal notation	Normalised scientific notation	E notation
1,000	1.0×10^{3}	1.0 E3
0.00000000095	9.5×10^{-10}	9.5 E-10
1,560,000,000,000	1.56×10^{12}	1.56 E12
0.001	1.0×10^{-3}	1 E-3
0.0001	1.0×10^{-4}	1 E-4
0.000001	1.0×10^{-6}	1 E-6

le groups of people (e.g. very young and very old). To put these probabilities in context with the risks to individuals in various countries from other more common threats such as motor vehicle accidents, cardio-vascular disease and cancer refer to Table 5.1 in the Nord Stream Espoo Report.

9.2.4.3 Tolerability criteria for societal/group risk

Societal risk (sometimes called collective or group risk) is a measure of the aggregate risk associated with a system or operation. It accounts for the likely impact of all accidental events, not just on a particular type of individual, as in the case of individual risk, but on all individuals who may be exposed to the risk, whether they are workers or third parties. This again usually refers to the risk of death, and is usually expressed as an average number of fatalities per year that would be expected to occur. It is also sometimes called the annual fatality rate or potential loss of life (PLL).

To calculate societal risk (for each identified accidental event and its possible outcomes), estimates have to be made of the frequency of the event per year, f, and the associated number of fatalities, N. The resulting data takes the form of a set of f-N pairs, and it is usual to consider the cumulative frequency, F, of all event outcomes that lead to N or more fatalities. These data are usually plotted as a continuous curve against logarithmic axes for both F and N, which makes for ready comparison against criteria for intolerable and broadly acceptable risk, themselves represented as F-N curves.

A typical F-N diagram is shown in Figure 9.4, together with the criterion lines adopted for this project.

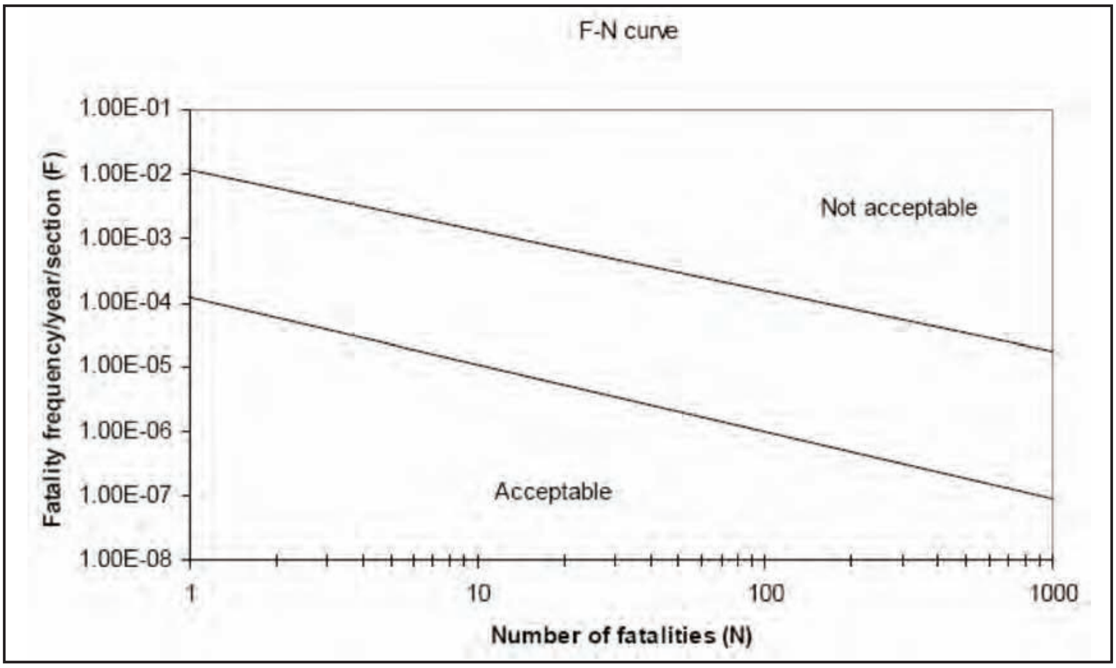

Figure 9.4. Example F-N curve

The F-N criteria lines show the relationship between the frequency and severity of accidents in terms of tolerability. For example, if the cumulative frequency of accidents resulting in 10 or more fatalities is greater than 0.001 (or 1 E-3) per year (equivalent to accidents resulting in 10 or more fatalities occurring more often than once in 1,000 years) it would be considered unacceptable. Whereas if the cumulative frequency of such accidents is less than 0.00001 (or 1 E-5) per year (i.e. occur less than once in 100,000 years), it would be considered broadly acceptable.

9.2.4.4 Tolerability criteria for environmental and reputation risk

The acceptance criteria for environmental and reputation risk are stated in the Risk Matrix in Figure 9.2. Risks are assessed as being in one of three categories:

- High (red): – risk level is intolerable/unacceptable and additional mitigation of probability or consequence (or both) is required to reduce risk level such that the project becomes feasible.

- Medium (orange): - risk level is tolerable/ALARP. Measures should be sought to reduce risk further and implemented only if the cost is not disproportionate to the benefits.

- Low (light blue): - risk level is broadly acceptable and no additional mitigation is required.

9.2.5 Mitigation/control of risk

All reasonably practicable steps must be taken to eliminate or reduce each risk identified during a risk assessment. Risk-reducing measures should be prioritised according to a control hierarchy. This is based on the concept that elimination or prevention of a hazard is fundamentally better than living with the risk by controlling or mitigating it. A typical control hierarchy is as follows:

- **Elimination** – implement measures to eliminate hazards altogether, e.g. removing hazardous obstacles such as munitions.

- **Substitution** – implement measures to reduce hazards, e.g. using a different and less hazardous material.

- **Engineering controls** – implement measures to prevent or reduce hazards using engineering controls built into the process design, e.g. using high integrity equipment designed to reduce the likelihood of failure due to mechanical or process hazards. Engineering controls can be passive (e.g. large wall thickness), i.e. they require no effort to operate, or active (e.g. corrosion monitoring, safety warning devices, etc.), i.e. they require a response. In the hierarchy of controls, passive controls are higher than active controls.

- **Segregation/separation** – implement measures to separate the hazard from other hazards or people, assets and the environment; e.g. increasing the separation distance between a hazard and the pipeline by rerouting and segregating from things that could cause or be affected by an incident e.g. keeping other vessels away, providing large separation distances to other plant and buildings.

- **Reduction in exposure** – reduce the time during which exposure to the hazard may occur, e.g. minimising the duration of installation during unfavourable sea conditions, reducing time spent in environmentally sensitive areas, etc.

- **Procedures** – use safe systems of work (i.e. procedures, instructions, control of work, supervision etc.) to control hazards by ensuring the operation is carried out safely by the personnel involved

- **Personal Protective Equipment (PPE)** - protect the worker from the hazard using PPE, e.g. gloves, hard hat, safety boots, fire retardant overalls, safety glasses etc.

9.3 Risk assessment of unplanned events during installation of the pipelines

This section is a summary of key information from a detailed risk assessment report produced by Global Maritime on behalf of Nord Stream /457/.

The assessment covered the whole installation phase of line 1 and line 2 including pre-lay and post-lay intervention (works/rock placement including vessel loading operation), the main pipe-lay activities (including the pipe load out and transportation) and pre-commissioning operations. Very limited pre-commissioning activities are anticipated to occur in the Finland EEZ and the risks were assessed as negligible so no quantitative risk assessment was undertaken.

The assessment considered:

- Risk to humans: vessel crews, onshore crews, third party personnel (i.e. on ships passing by); and

- Risk to the environment.

9.3.1 Identification of installation hazards

The installation activities can be broken down into a number of sub-activities for which the following hazards were identified.

- **General marine activities including**
  - fishing activities
  - collision (passing and attendant vessels)
  - grounding
  - foundering
  - sinking
  - vessel fire
  - vessel bunkering operations
  - military exercises
  - munitions & drums
  - helicopter transport
  - sightseers
  - adverse weather.

- **Environmental hazards**
  - sediment spreading
  - operations in spawning grounds
  - noise
  - seabed disturbance
  - waste disposal from installation vessels.

- **Pre-lay activities**
  - crossing supports installation (if any)
  - pipeline support foundation installation.

- **Pipe-lay initiation**
  - rigging operations at height over water
  - initiation wire failure
  - dead man anchor movement
  - tensioner failure.

- **Normal pipe-lay operations**
  - tensioner failure
  - loss of position
  - munitions
  - collision
  - adverse weather (low temperatures, high winds and seas).

- **Support vessel operations**
  - injury /fatality to support vessel crew
  - loss of communication to lay barge
  - ROV failure during TDM operation.

- **Anchor handling operations**
  - injury/fatality to the anchor handling crew
  - loss of communication to lay barge
  - damage to any adjacent pipelines.

- **Cable crossings.**

- **Pipe-lay abandonment and recovery operations**
  - tensioner failure
  - abandonment and recovery winch or wire failure
  - failure of lay-down head welds
  - sudden onset of bad weather.

- **Pipe transport and offshore handling operations.**

- **Buckled pipe repair (contingency).**

- **Hyperbaric tie-ins**
  - crane/rigging failure
  - dive support vessel loss of position during installation
  - malfunction of subsea handling equipment
  - loss of control of subsea equipment
  - diving incidents.

- **Rock Placement operations**
  - vessel instability
  - vessel grounding
  - vessel collision in port
  - loss of position
  - passing vessel collision with rock dumper.

- **Pipeline testing and pre-commissioning**
  - passing vessel collision with support vessel
  - equipment failure under pressure
  - marine contamination by test water.

9.3.2 Qualitative risk assessment of installation activities

The safety and environmental risks of these installation hazards listed above were assessed qualitatively using the project risk assessment matrix below taken from DNV-RP-H101 /457/. See Figure 9.2. Some hazards were previously screened out i.e. considered insignificant based on reasoned arguments. The judgments were made by personnel with considerable relevant experience (including the disciplines of Master Mariner, Naval Architect, Pipeline Engineer and Subsea Engineer).

Risks assessed as medium were taken forward for a detailed quantitative assessment and to identify potential measures to reduce the risk levels where necessary i.e. when the risk acceptance/tolerability criteria were exceeded. No risks were assessed as high.

The risks associated with munitions and military exercises were also identified as medium risks, although these risks are more difficult to quantify due to limited data. Nonetheless, these risks are recognised and discussed qualitatively, including relevant mitigation measures.

Munitions screening surveys have been performed to establish the quantity, location and type of unexploded munitions and drums in the pipe-lay corridor that could constitute a danger for the pipeline or the environment during the installation works and the operational life of the pipeline system. Details and findings are described in Chapters 5.6.5 and 5.6.6 and the environmental impact associated with munitions is discussed in Chapter 8, Impact Assessment. The environmental risks due to drums and barrels findings are described in Chapter 9.3.3.3. The survey shall be extended to cover the entire anchoring corridor which extends 1 km either side of the pipe-lay corridor.

On the basis of such surveys, the pipeline shall be routed to avoid munitions wherever possible – or alternatively, potential explosives and munitions will be removed. The results of the anchoring corridor survey shall be used as the basis of a formal risk assessment to be conducted prior to pipe-lay. The ‘clearance corridor’ dimensions are based on detailed analysis of the effects of underwater explosions[1], to ensure that any exploding munitions on the edge of the corridor could not damage the pipeline.

There is also a remote possibility that munitions could be disturbed during installation operations and drift onto the pipe after installation. However near-bottom currents in the dumping areas are reported to be too weak to move heavy munitions[2] and this risk is considered to be low. Provided that relevant precautions are taken it is considered that munitions risks will be reduced to an acceptable level.

1 Effects of Underwater Explosions, Snamprogetti report, 10 June 2008. Nord Stream document no. G-EN-PIE-REP-102-0072528-2

2 Report on Chemical Munitions Dumped in the Baltic Sea - Helcom March 1994

9.3.3 Quantitative risk assessment for pipeline installation

The qualitative assessment identified the following medium risks categories for further, quantitative, assessment:

- passing vessel collision with installation vessels
- installation vessel fire
- installation vessel grounding
- oil spills during bunkering operations
- installation vessel sinking or capsize
- helicopter accident
- vessel position loss (moored and dynamically positioned)
- dropped objects.

Of the above, the following potential hazards could impact the environment:

- collision between installation vessels and third party ship traffic leading to an oil spill
- risk of oil spill during bunkering operation (lay barge)
- objects dropped from installation vessels
- risk related to installation of line 2, while line 1 is in operation.

The risk during bunkering operations related to the lay barge has been assessed to be low and was not considered for quantitative assessment /457/.

During loading of pipe joints from the pipe carriers to the lay barge there is a risk that a pipe joint could be dropped. Since this hazard only has a very limited impact on the environment it was not considered for quantitative assessment.

During the installation of line 2, line 1 will be operating and the risk assessment considered potential damage to the line from dropped pipe joints during pipe loading operations. The risk was found to be very low with pipe separation distances of 100 meters. However, in some sections of the route the separation distance will be reduced and it may be necessary to restrict pipe loading operations in these areas /457/.

9.3.3.1 Assessment of frequency for ship-to-ship collisions

Before, during and after the installation of the pipelines and until the pipelines become operational, there will be an increase in ship traffic due to the movements of the pipe carriers, the lay barge and intervention work vessels. This section presents a quantitative estimate of the frequency of collisions during the installation period of one pipeline and the conditional probability of having an oil spill.

By applying the general ship traffic information for the routes in the Baltic Sea, the pipe carriers, the lay barge and the intervention work vessels the collision frequencies can be obtained, /458/. The general ship traffic information in the vicinity of each pipeline route was obtained from AIS data, /459/, while the information for ship traffic associated with pipeline installation is based on the planned off-shore logistics for the pipeline installation phase. Please refer to Atlas Maps SH-1-F–SH-6-F for detailed information regarding ship traffic and navigation routes.

There will be two weight-coating yards, one in Sassnitz-Mukran, Germany, and one in Kotka, Finland. The two coating yards will supply the lay barge and three trans-shipment sites (interim stock yards) with pipes. The trans-shipment site in Finland is Hanko. The lay barge will receive pipes from the coating yards and the trans-shipment sites as it moves through the Baltic Sea. Figure 9.5 depicts the main shipping routes (blue lines with arrow heads) and Hanko trans-shipment site (red dot) and the pipeline route (green irregular line) for the Finnish EEZ. The yellow line is the shipment route for vessels transporting line pipe for the Nord Stream project.

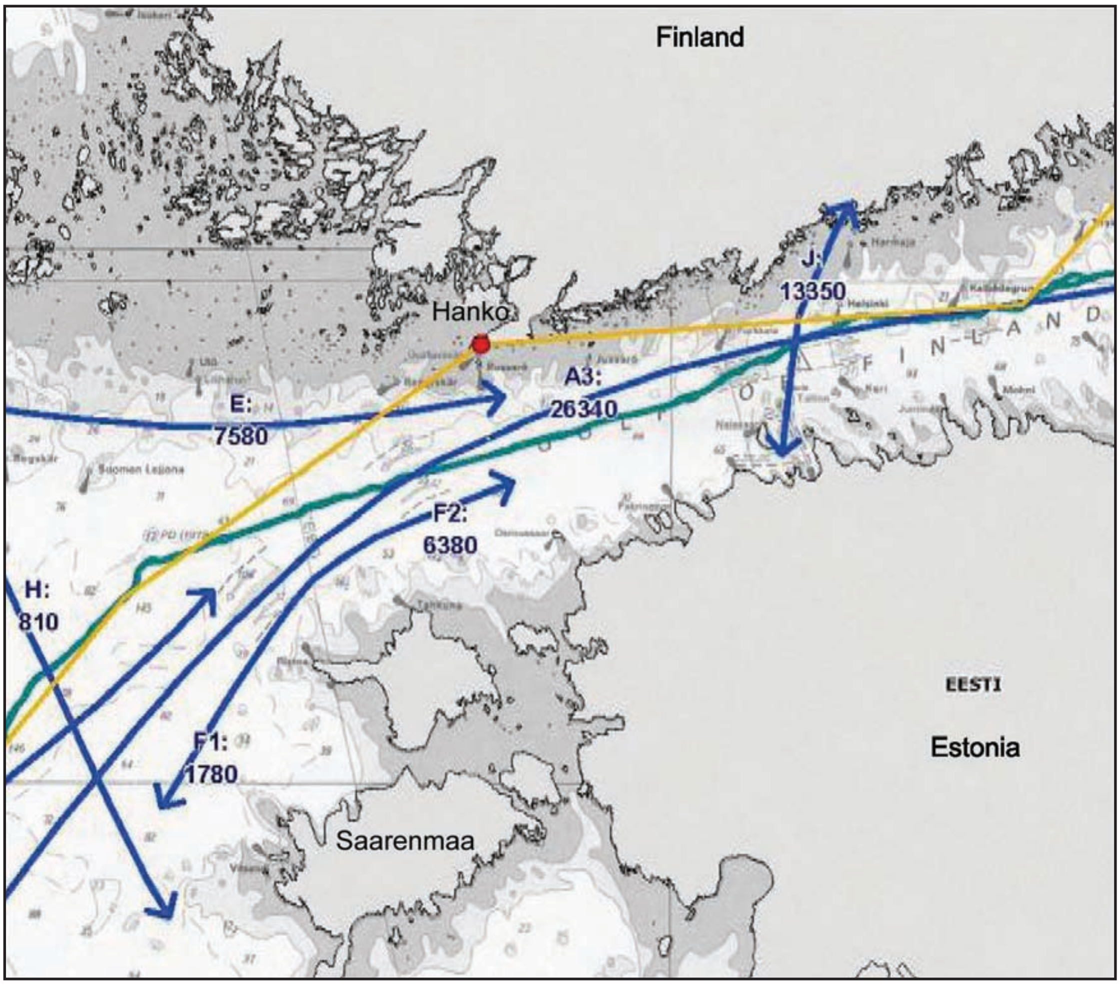

Figure 9.5. Trans-shipment routes for line pipe to/from Hanko in relation to major shipping routes in the Finnish EEZ

The Figure below (Figure 9.6) indicates the sections of the proposed Nord Stream pipeline that shall coincide with the main shipping routes. These sections are marked in yellow. The red lines are Exclusive Economic Zone (EEZ) boundaries and the green lines are the limits of Territorial Waters (TW) for the respective Baltic Sea countries.

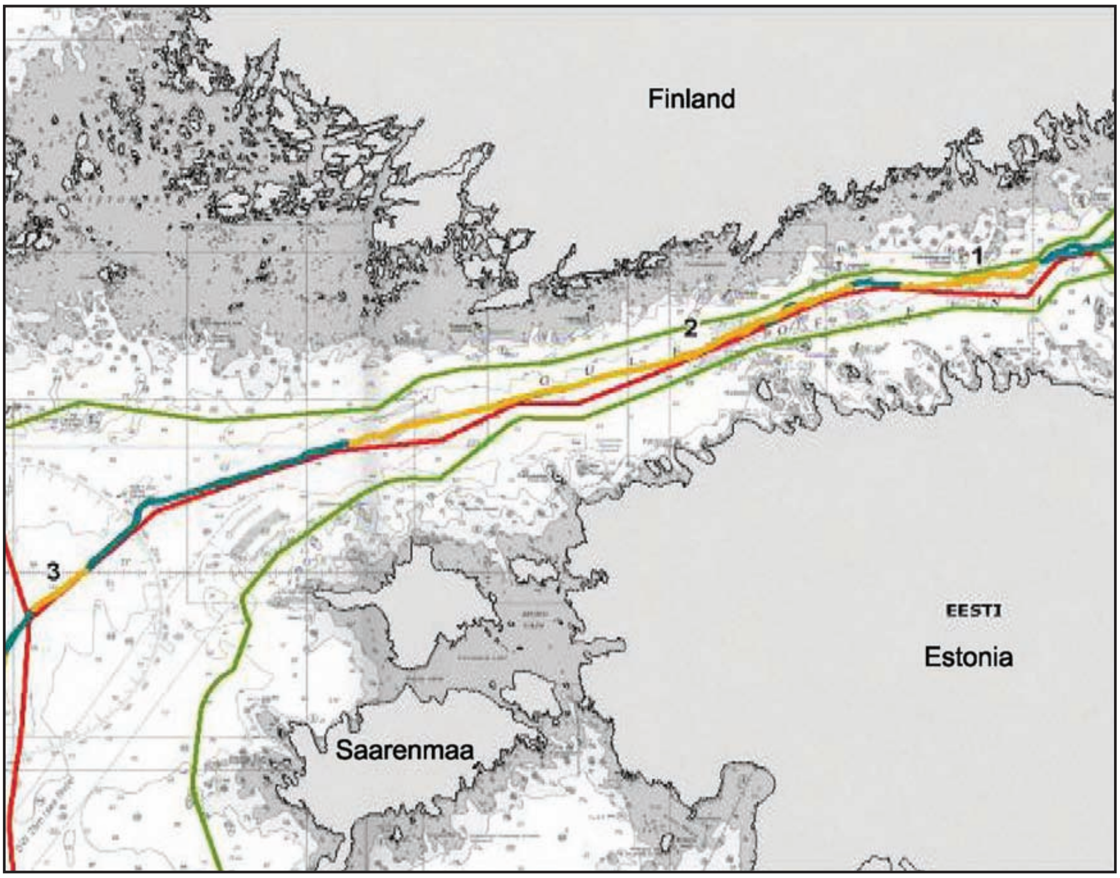

Figure 9.6. Three pipeline segments (marked in yellow) where the pipeline route will coincide with major shipping routes

The frequency of ship-to-ship collisions between the installation vessels and the general ship traffic present in the Baltic Sea has been assessed using the methodology depicted in Figure 9.7, /458/. The main results are presented in this Chapter.

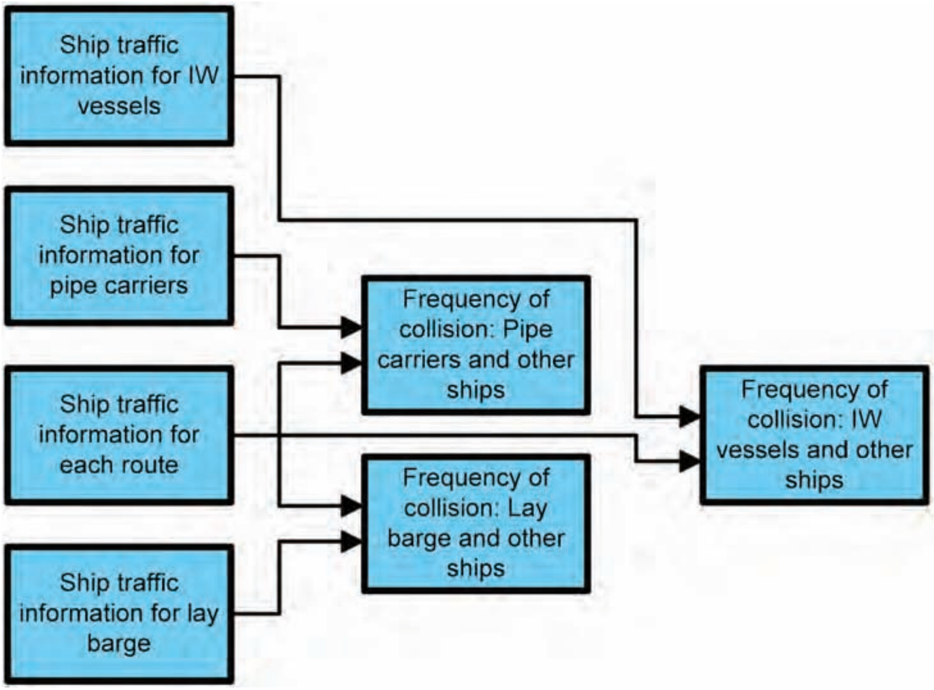

Figure 9.7. Method for calculating ship-to-ship collision frequency during installation phase

Pipe-Lay Barge

Table 9.1 contains the projected probabilities for vessel collisions involving the pipe lay barge and attending vessels. The lay-barge with supporting vessels will introduce an additional increase in the risk of ship collisions. In the analysis it is conservatively assumed that the lay-barge with supporting vessels (anchor holding vessels and survey vessels) will effectively occupy an area of approximately 2 x 2 km.

Table 9.1. Collision frequencies and corresponding return periods for lay barge in the Finnish EEZ

Segment	Collision frequency (per year)	Return period (years)
Segment 1 - Crossing route A-4	$9.6 \cdot 10^{-6}$	103,899
Segment 2 - Crossing route A-3 and J	$2.3 \cdot 10^{-5}$	43,533
Segment 3 - Crossing route H	$5.5 \cdot 10^{-7}$	1,830,452
Total	$3.3 \cdot 10^{-5}$	30,173

Line Pipe Carriers

As the pipe carriers transport pipes from the transhipment sites a number of shipping routes will be crossed in order for the pipe carriers to arrive at the lay barge. The collision frequencies for the pipe carriers are listed in Table 9.2 for each of the routes the pipe carriers must cross in order to reach the lay barge in the Finnish EEZ as depicted in Figure 9.5.

Table 9.2. Collision frequencies and corresponding return periods for pipe carriers in the Finnish EEZ

Route	Collision frequency (per year)	Return period (years)
Crossing route A-4	$4.3 \cdot 10^{-5}$	23,199
Crossing route A-3	$7.4 \cdot 10^{-5}$	13,503
Crossing route E	$7.0 \cdot 10^{-6}$	143,610
Crossing route J	$1.1 \cdot 10^{-5}$	90,879
Total	$1.4 \cdot 10^{-4}$	7,407

Vessels undertaking sea-bed intervention works

The collision frequencies due to the intervention work vessels (tie-in support and rock placement) for the Finnish EEZ are shown in Table 9.3 together with the shipping routes that are identified to be potentially influenced during the planned sea-bed intervention works.

Table 9.3. Collision frequencies and corresponding return periods for the intervention work vessels in the Finnish EEZ

Route	Collision frequency (per year)	Return period (years)
Crossing route A-4	$3.5 \cdot 10^{-5}$	28,582
Crossing route J	$4.4 \cdot 10^{-5}$	22,477
Crossing A-3	$1.1 \cdot 10^{-5}$	89,122
Crossing A-3	$9.2 \cdot 10^{-6}$	108,978
Total	$9.9 \cdot 10^{-5}$	10,081

By aggregating the probabilities for collision frequency contributions due to all Nord Stream project vessels the total increase in the annual ship collision frequency for installation of the first pipeline in the Finnish EEZ is then calculated to be $2.7 \cdot 10^{-4}$ collisions per year, which is equivalent to a return period of 3,729 years. The pipe carriers are responsible for the highest contribution to the total increase in collision frequency. The contribution from constructing the second pipeline is of the same magnitude.

The ship traffic in the Baltic Sea is dense and each year a number of ships are involved in accidents. Table 9.4 contains the number of ship-to-ship collisions in the Baltic Sea area in the period from 2004 to 2006 /460/.

Table 9.4. Number of ship-to-ship collisions in the Baltic Sea 2004 – 2006 /460/

Year	Number of ship-to-ship collisions per year
2004	19
2005	30
2006	28

Results

Comparing this to the estimated increased risk of ship collisions introduced during the installation phase, it can be concluded that Nord Stream will have a theoretically low impact on the current risks of ship-to-ship collisions. The increase in the annual ship-to-ship collision frequency due to the Nord Stream project shall be very limited to a total increase of less than 0.02 %.

9.3.3.2 Assessment of frequency of oil spills during installation

For an oil spill, a collision must occur and then result in leakage of oil – either bunker oil (passenger and cargo ships) or crude oil (tankers). The risk of an oil spill is thus a product of the collision frequency and the conditional probability of having a spill in case of collision.

The main risk during installation is the increased collision frequency due to ship traffic generated by the project. This increased traffic is caused by the project's line pipe carriers, lay-barge and sub-sea intervention work vessels as mentioned in the above sections. In the unlikely event of a collision the cargo and/or fuel of the involved ships may enter the sea. See Table 9.5.

Table 9.5. Potential sources of oil spills

Vessel	Fuel	Cargo
NSP Vessel	Diesel	Nil
3rd party Vessel (existing traffic)	Diesel, bunkers etc.	Oil products or crude oil

Potential oil spill scenarios for consideration in the scope of this project include:

- leaks from NSP vessels causing a spill of diesel. (The lay barge Castoro Sei has for comparison a fuel capacity of 3,122 m^3 diesel.); and

- spills due to collisions between NSP and 3rd party vessels or between NSP vessels.

In /457/ based on a study on pollution in UK waters, a conditional probability of 0.18 was derived for maritime oil spills using events trees. Combining this number with the estimated increase in ship-to-ship collision frequency it is calculated that the additional oil spills due to the Nord Stream project is $4.8 \cdot 10^{-5}$ oil spills per year. This corresponds to a return period of 20,718 years.

Statistically, the number of oil-spill accidents in the Baltic Marine Area is estimated to be 2.9 per year /189/. The annual oil spill frequency in the Baltic Sea due to the Nord Stream project shall increase by less than 0.003 % compared to the situation without installation activities. Therefore Nord Stream shall contribute to a negligible increase in the risk.

9.3.3.3 Assessment of environmental risks of barrels

This subchapter comprises environmental risk assessment concerning the barrel findings presented in Chapter 5.6.6. The assessment is based on the assumption that none of the drums are related to munitions and do not contain chemical warfare agents.

The drums presented in Chapter 5.6.6 may contain substances harmful to the environment. In the long run contents of all the drums will be leached, dispersed etc in the sea water or in the bottom sediment. However, the release of possible contaminants may be enhanced due to breaking of drums caused by the construction or maintenance works of the pipeline.

Environmental risks depend on the chemical composition of the materials in the drums. Exact risk assessment is not possible because inspection of the screening survey video material did not give any detailed information of the content for any of the drums. Only one barrel (see Figure 5.98 (top left) in Chapter 5.6.6) had a label on it, but most likely there is no original hydraulic oil left in it.

Drums of categories 1 and 2 (presented in Chapter 5.6.6) have at least one wide open end. Solid materials in these drums have been exposed to sea water for some time. Material which is left is presumably in insoluble form. Therefore it is improbable that sudden further breaking of these drums would cause significantly increased environmental risks. Materials may become “scattered” on the seabed which would increase the area exposed to sea water. As the materials are assumed to be quite insoluble this would not increase significantly the amount of dissolved materials.

Three of the drums of category 3 (presented in Chapter 5.6.6) have an extra hole or holes in it, and therefore they most likely were empty when were disposed of. Other two are small 40 l vessels not typical for storing hazardous chemicals or wastes. Three of the 200 l barrels of category 3 have an open cap-hole and possible were empty when disposed of. However, they may have contained and still contain hazardous substances. ID numbers of these barrels are: R-11-3380 (offset from pipeline route -130.08 m), R-11-3434 (offset 51.73 m) and R-W13CG-EE-004-A (offset -6.96 m).

Drums of category 4 (presented in Chapter 5.6.6) may have contained and may still contain hazardous substances not exposed to sea water, but this is not certain since there is video material only from one end of the barrels. ID numbers of these barrels are: R-06-008 (offset 0.82 m) and R-10-3281 (offset -18.6 m).

Combining the information on the category of the drum and on the position of the drum the most critical drums are R-W13CG-EE-004-A and R-06-008. These drums may contain hazardous materials up to approximately 300 kg and are within 7.5 meters of the centreline of the route. There is not enough video material to assess whether these drums have wide openings or not.

9.3.4 Results of environmental risk assessment due to oil spills

The findings of the environmental risk assessment are indicated on the risk matrix below in Figure 9.8 and it can be seen that there are no high risk events but there are a number of medium risks which are listed below the matrix.

	Probability (increasing probability →)			
Consequences	Remote (< 10^{-5}/y)	Unlikely (10^{-5} - 10^{-3} /y)	Likely (10^{-3} - 10^{-2} /y)	Frequent (10^{-2} - 10^{-1} /y)
Extensive				
Severe	e, p, q, r, s, t	c, d, f, g, h, i, j		
Moderate	k, l, m, n	b,o		
Minor		a	u, v	

Figure 9.8. Risk assessment results for oil spills

The low risk (green background) scenarios that were identified are:

- a – 3rd party vessel collision 1–10 t spill
- b – 3rd party vessel collision 10–100 t spill
- e – 3rd party vessel collision greater than 10,000 t spill
- k – pipe carrier or anchor handling tug fire
- l – rock placement vessel fire
- m – pipe lay barge fire
- n – diver support vessel or trench support vessel fire
- o – pipe carrier grounding
- p – rock placement vessel grounding

- q – diver support vessel or trench support vessel sinking
- r – pipe carrier or anchor handling tug sinking
- s – pipe lay vessel sinking
- t – rock placement vessel sinking
- u – anchor handling tug bunkering operations
- v – pipe lay barge bunkering operations.

The medium risk (white background) scenarios are identified as follows:

- c – 3rd party vessel collision 100 – 1,000 t spill
- d – 3rd party vessel collision 1,000 – 10,000 t spill
- f – pipe lay vessel collision
- g – DSV/Trench support vessel collision
- h – rock dump vessel collision
- i – pipe carrier collision
- j – anchor handler collision.

It can be seen that all of these risks are related to passing vessel collision and collision risk reduction is required to minimise the potential for environmental damage. The installation vessels are all required to have a shipboard oil pollution emergency plan (SOPEP), emergency oil spill procedures and equipment on board and oil spill response is included in the Nord Stream emergency notification procedure that will be in place for the installation phase.

9.3.5 Results of installation risk assessment for individuals on third party vessels

In the rare event of collisions between third party vessels and the installation vessels there is a risk of fatalities of persons onboard the passing vessels – and this has been assessed. For the Nord Stream project a criterion for individual risk of 10^{-4} fatality per person per year has been set for third parties /457/.

Using the approach in /457/ the individual risks to third party personnel on passing vessels in the Finnish EEZ is estimated to be as follows:

- Cargo ship 5.6×10^{-7} per person per year
- Tanker 1.1×10^{-7} per person per year
- Passenger ship 2.3×10^{-9} per person per year

It can be seen that the risks to third party personnel are well below the criterion value agreed for the project for risks to members of the public of 10^{-4} (taken to apply also to third party workers). Note that it is not appropriate to add these figures as they are the risk to specific individuals, taking account of their exposure (e.g. a full time crew member of a cargo ship). No individual is exposed to the annual risk on all three vessels types.

9.3.6 Results for installation risk assessment to groups on third party vessels

Referring to the F-N curve in Figure 9.9 it can be seen that the risks to all ship crews lie in the broadly acceptable region, although the risks are greatest for cargo ship crews. Collision risks will be managed by the implementation of standard offshore oil and gas industry collision risk reduction measures such as the enforcement of a safety (exclusion) zone (which would be in addition to the normal navigational measures used by merchant shipping).

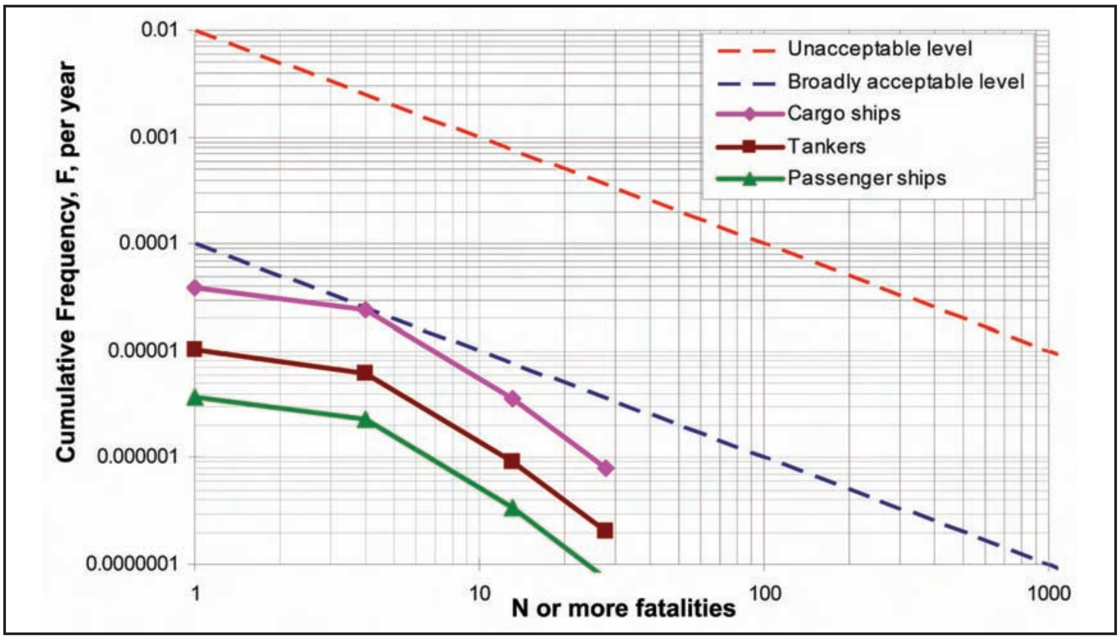

Figure 9.9. F-N curve for passing vessel collision risks during installation

9.3.7 Results of individual risk assessment for Nord Stream project workers

The project tolerability criterion for the individual risk to workers is 10^{-3} per person per year. The individual risks to personnel on the installation vessels were estimated for all hazards and found to be lower than the agreed tolerability criterion:

- Castoro 6 Pipe-lay vessel (anchored) 1.4×10^{-4} per person per year.
- Solitaire Pipe-lay vessel (dynamically positioned) 4.8×10^{-5} per person per year.
- Pipe carrier 3.9×10^{-5} per person per year.
- Anchor handler 2.1×10^{-5} per person per year.
- Rock placer 1.5×10^{-5} per person per year.
- Diver support vessel 3.9×10^{-5} per person per year.
- Trench support vessel 1.6×10^{-6} per person per year.

Although the collision risk assessment is conservative, the results indicate that passing vessel collision is the highest risk that installation vessels will encounter on the project. It is evident that the collision risk reduction measures normally used by in high traffic areas shall need to be implemented on this project.

9.4 Risk assessment of unplanned events during operation of the pipeline

9.4.1 Hazard identification

A HAZID study conducted by SES (Saipem Energy Services, former Snamprogetti) (the project's design contractor) in 2007 identified a number of hazards that may result in a pipeline failure which may in turn evolve into a subsea gas release.

These included:

- corrosion
- material & mechanical defects
- natural hazards,
  - ice gouging
  - landslides
- other/unknown causes
- munitions
- trawling interference /461/
- external interference related to ship traffic
  - sinking ships
  - grounding ships (only relevant for the shore approach)
  - dragged and dropped anchors
  - dropped objects
- sabotage/terrorism.

Each of the hazards listed above was subject to a qualitative risk assessment by a multi-disciplinary team of specialists using the Nord Stream Project risk assessment matrix in Figure 9.2.

External interference from ship related incidents was found to be the most significant contributor to potential pipeline failures for this project. Therefore these hazards were carried forward for further detailed quantitative risk assessment, the results of which are included in section 9.4.2.

The remaining hazards were assessed as presenting only negligible risk and were excluded from further analysis. The risks were determined to be negligible.

The frequency of loss of a fishing vessel due to hooking has been estimated to be 1.7×10^{-7} per year when both pipelines are operating, and hence the risk to any one individual is extremely small (of the same order of the likelihood of being killed by lightning). /461/ Nord Stream conducted a risk assessment on these unplanned events (engine or winch failure, failure of navigation system etc.) which will now be updated based on the results of the scale model test and further insights gained from the fishermen.

Nonetheless, given the small residual risk, it is recommended that the pipeline design ensures the number of free spans is reduced to a minimum; that training and information on the risks of fishing near the pipelines is provided to fishermen; and that the pipeline is plotted on nautical charts. Consideration may need to be given to restricting fishing in areas where free spans cannot be avoided.

The analysis of trawling has shown the pipeline can withstand trawl gear interaction in terms of initial impact and being pulling over the pipeline where the pipeline rests on the seabed[1]. The greatest forces would be exerted on the pipeline if trawl gear becomes snagged (hooked) under the pipeline. This only occurs where there are large free spans heights. In any case, the trawl gear generally includes weak link shackles and hammerlocks that would fail before any damage would be caused to the pipeline.

9.4.2 Quantitative assessment of risk due to ship related interactions in operation

The analysis was carried out in detail of the consequences of a subsea gas release due to pipeline failure caused by:

- sinking ships
- grounding ships
- dropped objects
- dragged and dropped anchors.

Following recent discussions with the relevant national authorities, the Kalbådagrund re-routing option was identified and the following results are presented for this route option only.

This section is a synthesis of information contained in the following three reports:

- Nord Stream & Snamprogetti, 2008. G-GE-PIE-REP-102-00085216 Frequency of Interaction Report (Kalbådagrund) /462/

- Nord Stream & Snamprogetti, 2008. G-EN-PIE-REP-102-00072525 Pipeline Damage Assessment against Commercial Ship Traffic Threats in the Finnish EEZ (Kalbådagrund Corridor Re-routing) /463/

- Nord Stream & Snamprogetti, 2008. G-GE-PIE-REP-102-00085217 Risk Assessment Report for Finnish Area Operational Phase (Kalbådagrund) /464/.

1 Pipe/Trawl Gear Interaction Study. Snamprogetti report, 25 January 2008. Nord Stream document no. G-EN-PIE-REP-102-0072505-3

The quantitative risk assessment (QRA) was performed in the following 3 steps:

- identification of failure causes and estimation of interaction and release frequency;
- estimation of the safety and environmental consequences of an accidental gas release; and
- evaluation of risk levels for the calculated event frequency and consequence, whereby the human life and environmental risks have been evaluated and compared with the project's risk acceptance criteria.

9.4.2.1 Assessment of pipeline gas release frequency

To begin with the frequency assessment is carried out by estimating the frequency of interaction between the pipelines and sinking ships, grounding ships, dropped objects, dragged and dropped anchors /462/.

The interaction frequency was estimated for the sections of the pipeline where the frequency of ships crossing the pipeline exceeds a criterion value of 250 ships/km/year. This is less than 1 ship/km/day and these sections are deemed as critical due to intense ship traffic. The total length of the critical pipeline sections is about 20% of the total pipeline length in the Finnish section.

The results for the Finnish EEZ shown in Table 9.6 below

Table 9.6. Interaction scenario frequencies in the Finland EEZ

Length and Location of the Sections with High Ship Traffic Density					Interaction Scenario Frequencies (event/section/year) at the Sections with High Ship Traffic Density (>250 ships/km/year)				
Section ID	From KP	To KP	Section Length	Ships - Total No.	Dropped Objects	Dropped Anchors	Dragged Anchors	Sinking Ships	Total
[-]	[km]	[km]	[km]	[ships/section/year]	[event/section/year]				
1	129	198	70	41,493	6.2 E-4	3.0 E-6	8.6 E-5	4.8 E-6	7.2 E-4
2	211	241	31	26,056	3.3 E-4	6.0 E-6	5.8 E-5	3.6 E-6	4.0 E-4
3	251	284	34	23,745	5.3 E-4	3.7 E-6	2.0 E-6	2.7 E-6	5.4 E-4
4	293	310	18	4,033	7.4 E-5	5.3 E-7	1.5 E-6	3.9 E-7	7.7 E-5
5	316	325	10	1,590	1.3 E-5	1.1 E-7	2.0 E-6	1.9 E-7	1.6 E-5
6	336	345	10	1,474	2.2 E-5	1.1 E-7	1.2 E-6	1.3 E-7	2.3 E-5
7	364	384	21	14,634	2.1 E-4	9.7 E-7	1.4 E-5	1.5 E-6	2.3 E-4

As can be seen, the results are within the DNV-approved acceptance criteria of 10^{-4} failures per section per year.

The pipeline failure rate at the critical locations is then analysed in the damage assessment report, /463/ where it is calculated by summing the failure rates due to dropped objects, dropped anchors, dragged anchors, sinking ships and grounding ships. Account was also taken of whether the pipeline is exposed, buried or protected.

For each critical section the failure probability must be less than the acceptance criteria of 10^{-4} failures per section per year /465/. The acceptance criterion of 10^{-4} failures per section per year has been agreed with DNV. If the acceptance criterion is exceeded then additional risk control measures are considered.

Referring to Table 9.7 it can be seen that not all pipeline failures leads to a gas release i.e. the gas release frequencies are only are part of the pipeline failure frequency. The total gas release frequency for the critical sections in the Finnish is estimated to be 3.53×10^{-5} releases per year or about once every 28,300 years.

Table 9.7. Pipeline total failure probability & gas release frequency – Finland

Section ID	From KP	To KP	Section Length	Dropped Objects	Dropped Anchors	Dragged Anchors	Sinking Ships	Total Failure Probability	Gas Release Frequency
[#]	[km]	[km]	[km]	[failure/section/year]				[failure/section/year]	
1	129	198	70	6.2 E-8	3.0 E-11	5.2 E-5	1.8 E-6	5.4 E-5	1.7 E-5
2	211	241	31	3.3 E-8	6.0 E-11	3.4 E-5	1.3 E-6	3.6 E-5	1.2 E-5
3	251	284	34	5.3 E-8	3.7 E-11	1.3 E-6	1.0 E-6	2.4 E-6	1.4 E-6
4	293	310	18	7.4 E-9	5.4 E-12	1.1 E-6	1.4 E-7	1.3 E-6	4.9 E-7
5	316	325	10	1.3 E-9	1.3 E-12	1.0 E-6	7.1 E-8	1.1 E-6	3.7 E-7
6	336	345	10	2.2 E-9	1.3 E-12	9.7 E-7	4.7 E-8	1.0 E-6	3.4 E-7
7	364	384	21	2.1 E-8	1.0 E-11	1.0 E-5	5.6 E-7	1.1 E-5	3.7 E-6

Dragged anchors dominate the total pipeline failure probability (>88 %) for all sections except section 3, where although dragged anchors still dominate (55 %), sinking ships also makes a significant contribution (43 %). It can be seen that all sections meet the acceptance criterion of 10^{-4} failures/section/year.

9.4.2.2 Assessment of consequences due to a gas release

The theoretical probability of a gas release from the pipelines during operation is negligible – being once every 28,300 years. However, due to requests from stakeholders during the consultation process, Nord Stream agreed to quantify the potential effects of such a gas release.

A possible gas rupture is primarily a safety hazard, possibly exposing ships, their crews and passengers in the sea above the rupture to a highly flammable gas cloud and a risk to the ship caused by the reduced buoyancy of the water.

The impacts on the environment are emission of natural gas (methane) to the atmosphere, as well as impacts on water quality, fish, marine mammals and birds.

If the pipeline is punctured or ruptured, the gas will disperse into the water forming a gas-plume in the water column, see Figure 9.10. Upon reaching the surface the gas will disperse into the atmosphere from a circular source. The nature of the dispersion (gas cloud) will depend on the molecular weight and the meteorological conditions.

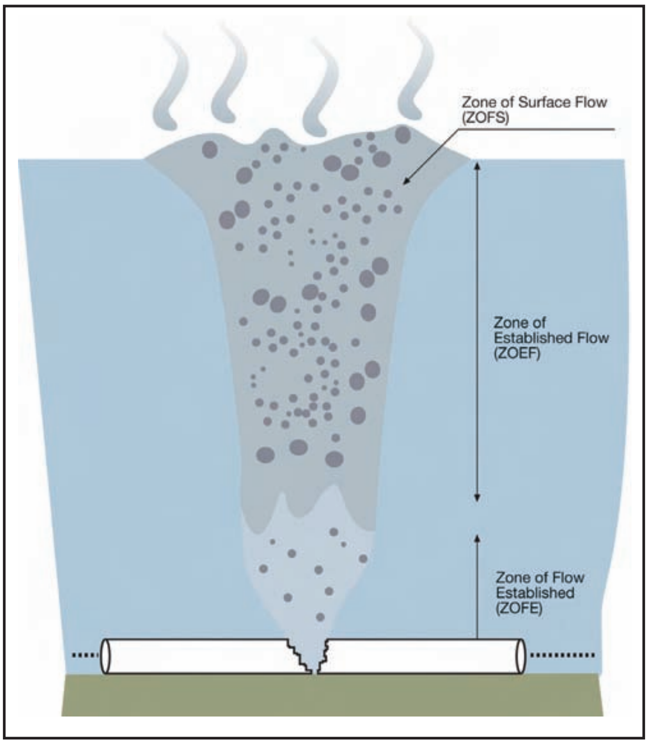

Figure 9.10. Schematic drawing of a gas release from an offshore pipeline

In /464/ the consequences of a gas release are studied in detail. The analysis involved the following steps:

- definition of incident parameters such as size of hole/rupture, pressure and temperature, water depth, etc
- modelling of the underwater dispersion
- effects at the sea surface
- atmospheric dispersion
- possible flash fire.

In the analysis leakages have been simulated at KP 147, KP 210 and KP 362 (water depth of 37.8 m) using OLGA 2000 software for the pinhole, hole and rupture scenario. The OLGA software is applied worldwide for transient multiphase flow scenarios. The location was chosen in order to obtain a conservative results applicable to the identified critical sections /464/. The discharge rates from the simulation are used as input to the underwater dispersion calculations. The radius of the zone of surface flow (central boil-region) for the three scenarios are summarised in Table 9.8.

Table 9.8. Results of underwater gas dispersion calculations for various releases /464/

Release point	Leakage	Water Depth [m]	Radius at surface [m]
KP 147	Pinhole	69.7	7.35
	Hole		8.20
	Rupture		17.40
KP 210	Pinhole	57.7	6.20
	Hole		7.60
	Rupture		15.90
KP 362	Pinhole	74.7	7.70
	Hole		8.70
	Rupture		18.00

In order to quantify the extent of the hazardous area with respect to flash fire, the dispersion of the gas is modelled. In order to account for the differences in concentrations that may lead to local concentrations higher than the Lower Flammable Limit (LFL), the extent of the gas cloud with ½ LFL concentrations is shown as well. The Upper Flammable Limit (UFL) is where the cloud is too rich to be ignited. The results are shown in Table 9.9.

Table 9.9. Extent of hazardous gas cloud for various releases, /464/.

Release point	Hole size	Distance of flammable limits at 10 m height above the sea		
		UFL [m]	LFL [m]	½LFL [m]
KP 147	Pinhole	0.0	0.0	33.5
	Hole	17.9	70.2	137.3
	Rupture	78.0	135.0	192.5
KP 210	Pinhole	0.0	0.0	33.0
	Hole	17.6	69.1	135.5
	Rupture	79.4	136.4	193.8
KP 362	Pinhole	0.0	0.0	29.0
	Hole	18.0	72.0	134.2
	Rupture	79.3	136.4	193.5

9.4.2.3 Results of assessment of operation risks to groups

As stated earlier the following events can occur in case of a subsea gas release and pose a safety risk to people:

- Flash fire
- Loss of buoyancy

Flash Fire

As mentioned above, in the rare (once in every 28,300 years) event of a sub-sea gas release there is a risk of ignition of the gas cloud with a resulting flash fire. Flash fires generally have a short duration and therefore do less damage to equipment and structures than to persons caught in the fire. Estimation of the number of fatalities in the event of flash fire is based upon the exposed population. This takes account of the typical number of people on different vessel types (cargo, tankers, passenger vessels etc). The risk to people is presented in terms of an F-N curve, plotting the number of casualties as a function of the frequency of an event. The results for the critical sections in the Finnish area are plotted in Figure 9.11, where it can be seen that for all critical sections of the pipeline, the risk to groups is "Broadly acceptable" /464/.

Loss of Buoyancy

Natural gas released from a possible rupture of the pipeline significantly lowers the density of the water. The loss of buoyancy happens because the density of the natural gas in the pipeline is more than 1,000 times lower than that of water. In worst case scenario the loss of buoyancy can cause instability and possible capsizing of a vessel directly above the rupture. The radius of the gas plume at the surface is correlated to the depth of the sub sea gas release. The deeper the gas release the larger is the radius. The safety distance for vessels due to loss of buoyancy therefore varies with the depth of the gas release. A safety distance corresponding to the radius of gas plume at the surface (central boil region) is recommended. The results of the underwater dispersion calculations are reported in Table 9.8. Comparing the size of the central boil region to the size of the ships only smaller ships could have a risk of sinking due to loss of buoyancy.

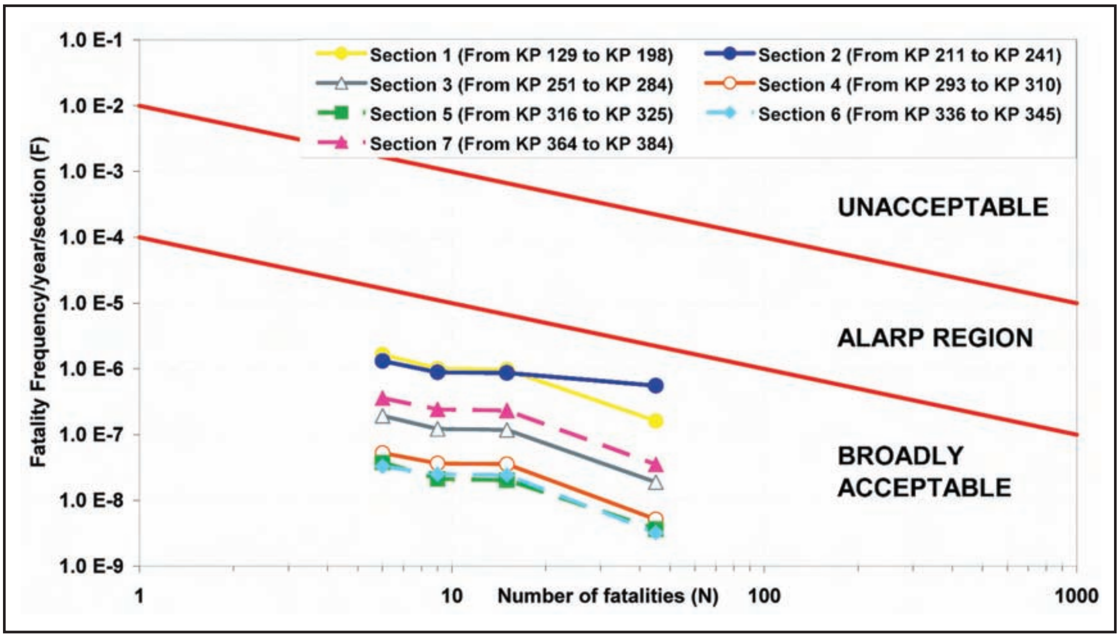

Figure 9.11. F-N curve for the Finnish EEZ

9.4.2.4 Results of assessment of operation risks to the environment

In the unlikely event of a gas release (once every 28,300 years) the following environmental impacts can occur:

- emission of greenhouse gases to the atmosphere
- impacts on water quality
- impacts on fish, marine mammals and bird.

Emission of greenhouse gases to the atmosphere

Each Nord Stream pipeline will carry 27.5 billion cubic metres[1] of dry sweet natural gas each year between Russia and Germany. A full-bore pipeline rupture is estimated to occur once every 28,300 years in the Finnish EEZ as described previously. Hence such an event is extremely unlikely to occur in the lifetime of the pipeline. Nonetheless, Nord Stream has considered the global warming potential of such a failure.

In the event of a full-bore pipeline rupture, the pipeline inlet valve would be closed, and as much gas as possible would be removed from the pipeline via the outlet valve. However, a typical worst case estimate of the amount of gas released can be made assuming simultaneous closure of both the intake and off-take valves, after which the settle out pressure in the pipeline will be approximately 165 bar (as shown see Figure 9.12).

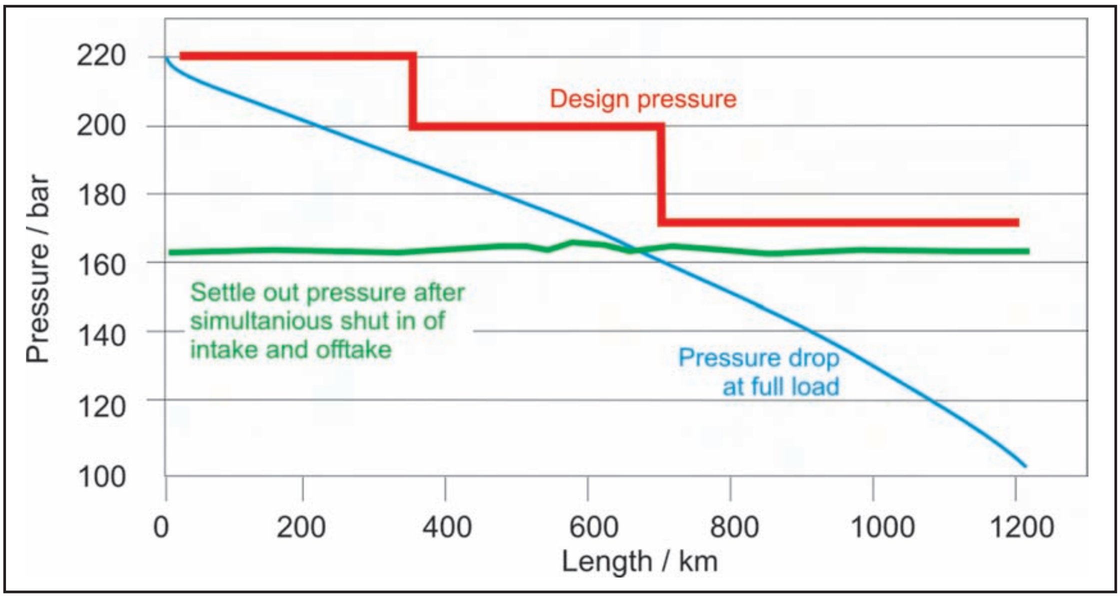

Figure 9.12. Methane pressure in the Nord Stream pipeline

1 Standard cubic metres – gas under a standard condition, defined as a pressure of 1 an atmosphere and a temperature of 15 °C.

From the pipeline dimensions given in the project description /464/ (internal diameter 1,153 mm, length 1,220 km) the volume of the pipeline can be calculated as 1.27 million cubic metres. At the settle out pressure of 165 bar, there will be the equivalent (at atmospheric pressure) of 210 million cubic metres of gas in the enclosed pipeline. The density of also methane varies with temperature; at one atmosphere pressure, methane has a density of 0.688 kg/m^3 at 20 ºC and 0.717 kg/m^3 at 0 ºC. According to the Swedish Meteorological Institute /466/, the temperature at the bottom of the Baltic varies between 4 ºC and 6 ºC; at 5 ºC the density of methane is 0.705 kg/m^3. Therefore the mass of gas in the pipeline (at 165 bar and 5 ºC) is around 148,000 tonnes.

The solubility of methane in water is low and it has been assumed for the calculations described here that all methane released in a rupture will enter into the atmosphere. The recent IPCC 4th Assessment Report, /467/, states that methane has a global warming potential 25 times greater than that of carbon dioxide, meaning the emission of one tonne of methane, is equivalent to 25 tonnes of carbon dioxide. Thus 148,000 tonnes of methane released into the atmosphere would be equivalent to the release of 3.7 million tonnes of carbon dioxide in terms of global warming potential.

In terms of national carbon dioxide emissions (see Table 9.10 below). 3.7 million tonnes of carbon dioxide is equivalent to less than one quarter of one percent of Russia's annual emissions (2004 data), less than 0.5 % of Germany's annual emissions, but equivalent to 7.0 % of Denmark or Sweden's annual emissions.

Table 9.10. National carbon dioxide emissions in 2004. Data from the Carbon Dioxide Information Analysis Centre published by the United National Statistics Division /468/

Country	Annual CO_2 emissions (thousand metric tonnes)	Equivalent annual emissions from ruptured pipeline (%)
Russia	1,524,993	0.24
Germany	808,767	0.46
Finland	65,799	5.6
Sweden	53,033	7.0
Denmark	52,956	7.0

For comparison, if the same volume of methane lost in a rupture was delivered to customers and burnt, forming carbon dioxide and water, then 407,500 tonnes of carbon dioxide would be produced. This means that the methane released from a potential rupture would have a carbon dioxide equivalence nine times greater than if the same volume of methane was burnt.

The total amount of carbon dioxide emitted from shipping in the Baltic Sea is currently estimated to be 41.4 million tonnes /469/, with tankers being the largest emitters, producing around 16 million tonnes of carbon dioxide (see Table 9.11).

Table 9.11. Carbon dioxide emissions from shipping in the Baltic Sea

Vessel type	Estimated CO2 emissions. (thousand tonnes/yr)	Equivalent emissions from ruptured pipeline (%)
Cargo	13,526.4	27.4
Tanker	15,995.8	23.2
Passenger	2,757.5	134.3
Other	2,899.3	127.8
Unknown	4,131.3	89.7
Combined (95% of traffic)	39,310.3	9.4
Total (100% of traffic)	41,379.3	9.0

As Table 9.11 shows, in terms of global warming potential, the methane released in a pipeline rupture would be equivalent to approximately 9% of the annual carbon dioxide emissions from total shipping traffic using the Baltic Sea. However, given the very low frequency of such an event (equivalent to approximately one failure every 24,400 years), the average annual mass released from a full bore rupture equates to 152 tonnes per year, or 0.0004% of the annual carbon dioxide emissions of shipping in the Baltic.

Impacts on water quality

Natural gas exhibits negligible solubility in water, and thus has little effect on water quality in the event of an underwater leak. The gas will rise to the water surface, from where it will be released into the atmosphere, the extent to which it dissipates depending on meteorological conditions and the weight of the gas in relation to the surrounding air.

A short-term thermal impact (temperature drop to below freezing point due to the Joule-Thomson effect of gas expansion) may occur in the surrounding water. Another possible impact on water quality from an accidental pipeline rupture and gas release is a possible updraft of bottom water. This could cause bottom water to be mixed with surface water, with an impact on salinity, temperature and oxygen conditions.

Impact on fish, marine mammals and birds

In the unlikely event of gas release it is judged that all fish, marine mammals and birds within the gas plume or the subsequent gas cloud will die or flee from the influenced area. The impact will be of limited duration and extent.

The environmental risks were assessed using the Risk Matrix below as adopted from DNV-RP-H101, /470/. A pinhole leak is ranked as a minor consequence, while holes and pipeline ruptures are categorised as a moderate consequence. In Figure 9.13 the risk levels due to ship traffic interaction (pinhole: A, hole: B and rupture: C) are plotted and it can be seen that all failure modes are within the acceptable region and no further mitigation measures are required /464/.

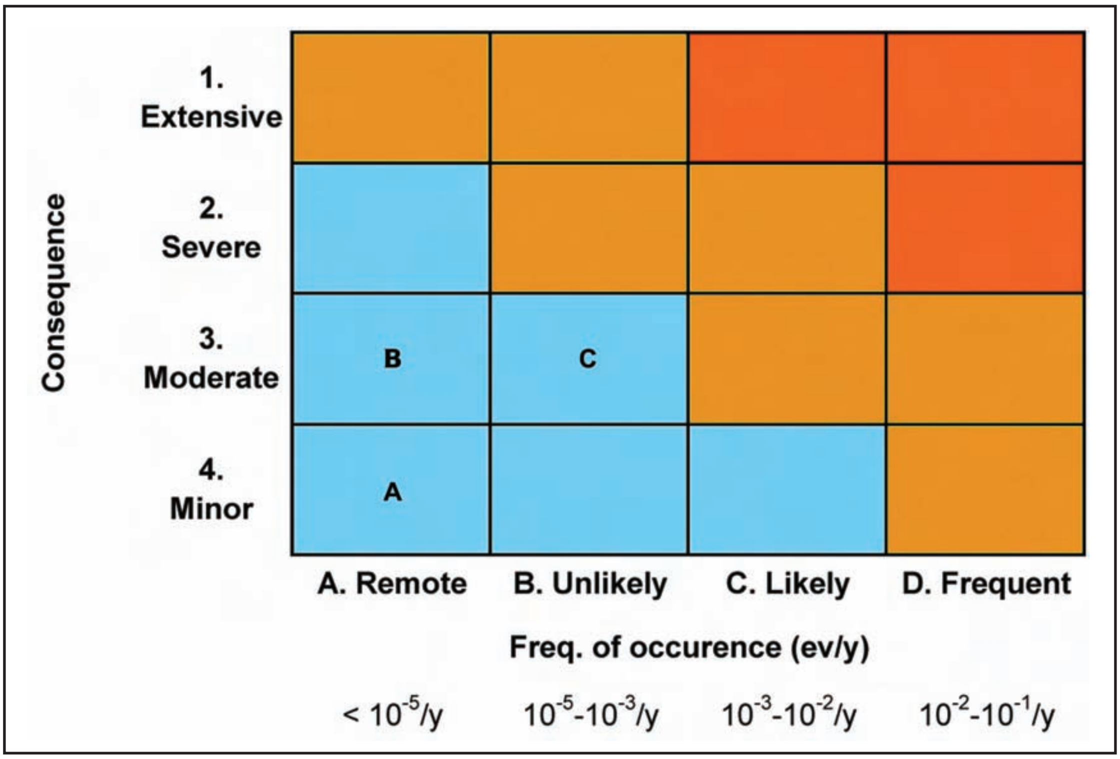

Figure 9.13. Environmental risk rating for gas releases due to ship traffic interactions

9.4.2.5 Summary of risk results for the operations phase

Various risk assessment studies have been undertaken for the operations phase of the Nord Stream project. The risks for all identified hazards due to unplanned events have been demonstrated to be broadly acceptable and meeting the project's relevant risk acceptance criteria. Consequently no additional risk mitigation is required.