Chapter 5

Risk Assessment

Contents **Page**

5 Risk Assessment

5.1 Introduction and Definitions

Construction and operation of the Nord Stream pipelines give rise to many hazards which present risks to the public/third parties[(1)], workers and the environment. The focus of this chapter is to describe the risk assessments that have been undertaken to assess the risks to third parties and risks to the environment. Risks to construction workers have also been assessed; however these risks and the necessary mitigation measures will be addressed by the safety management systems of Nord Stream and its construction/contractor organisations, and are not therefore included in the assessments described here.

5.1.1 Hazards and Risks

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.

5.1.2 Risk Assessment and Risk Controls

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.

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.

5.1.3 Risk Management

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 of 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 Stream's approach to risk management is described in relevant Project documents(1),(2).

(1) Nord Stream AG. August 2007. Introduction to Health, Safety and Environmental (HSE) Management in Nord Stream AG. Nord Stream Report No. G-GE-HSE-PRO-000-000604L1.

(2) Nord Stream AG and Snamprogetti. 03 January 2008. HSE Activities Management Plan. Nord Stream Report No. G-EN-HSE-REP-102-00085000.

5.1.4 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.

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 5.1**(2).

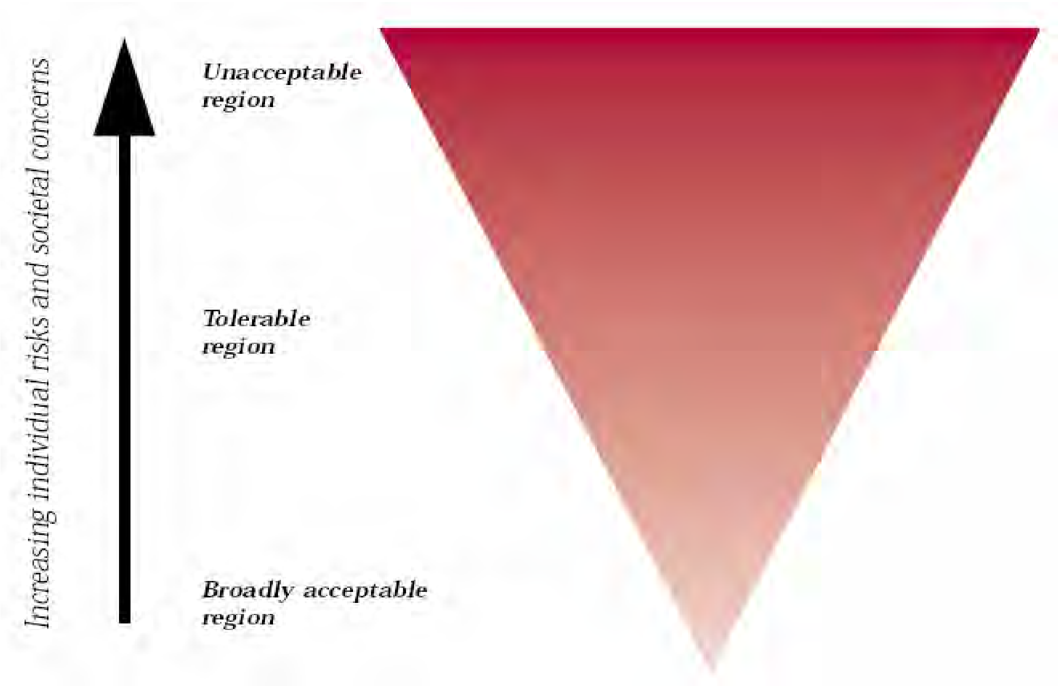

Figure 5.1 Framework for the tolerability of risk

(1) For example South Africa, The Netherlands, Hong Kong, Australia

(2) UK Health and Safety Executive. 2001. Reducing Risks, Protecting People: HSE's decision-making process. ISBN 0 7176 2151 0.

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

Hence in this 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, which 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.

Project specific pipeline failure frequency criteria for critical pipeline sections

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

For pipeline operation, critical pipelines sections are considered to be those where the frequency of ships crossing the pipeline exceeds a criterion value of 250 ships/km/year. This value corresponds to less than 1 ship/km/day and is used to distinguish those pipeline sections corresponding to intense ship traffic. For each identified section where this level or greater of ship activity exists, the interaction frequency and pipeline damage frequency is estimated.

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 **Section 5.3.2**).

Individual risk

Individual risk is the risk to specific individuals (e.g. members of the public, crews of other vessels). 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 Project, are as follows(2):

(1) Pipeline damage mechanisms considered are 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

- Maximum tolerable risk for workers 1×10^{-3} per person per year
- Maximum tolerable risk for the public 1×10^{-4} per person per year
- Broadly acceptable risk 1×10^{-6} 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 susceptible groups of people (e.g. very young and very old).

To enable these risk tolerability criteria to be compared with more familiar causes of death, the risks of fatality in certain European counties (from cancer, cardio-vascular disease and road accidents) are highlighted in **Table 5.1.**

Table 5.1 Annual probabilities of death in various countries

Country	Probability of dying from cancer (2002)	Probability of dying from cardio-vascular disease (2002)	Probability of being killed in a road traffic accident (2004)*
Denmark	1.7 E-3	1.8 E-3	6.8 E-5
Estonia	1.5 E-3	4.4 E-3	1.3 E-4
Finland	1.2 E-3	2.0 E-3	7.2 E-5
Germany	1.4 E-3	2.1 E-3	7.1 E-5
Latvia	1.6 E-3	4.8 E-3	2.2 E-4
Lithuania	1.6 E-3	3.9 E-3	2.2 E-4
Russian Federation	1.5 E-3	6.9 E-3	2.4 E-4
Sweden	1.2 E-3	1.8 E-3	5.3 E-5
Average	**1.4 E-3**	**3.5 E-3**	**1.3 E-4**

Source: Data from World Heath Organisation Statistical Information System (WHOSIS), except * which is from United Nations Economic Commission for Europe

Societal 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 be 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, estimates have to be made, for each identified accidental event and its possible outcomes, 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 5.2**, together with the criterion lines adopted for this Project.

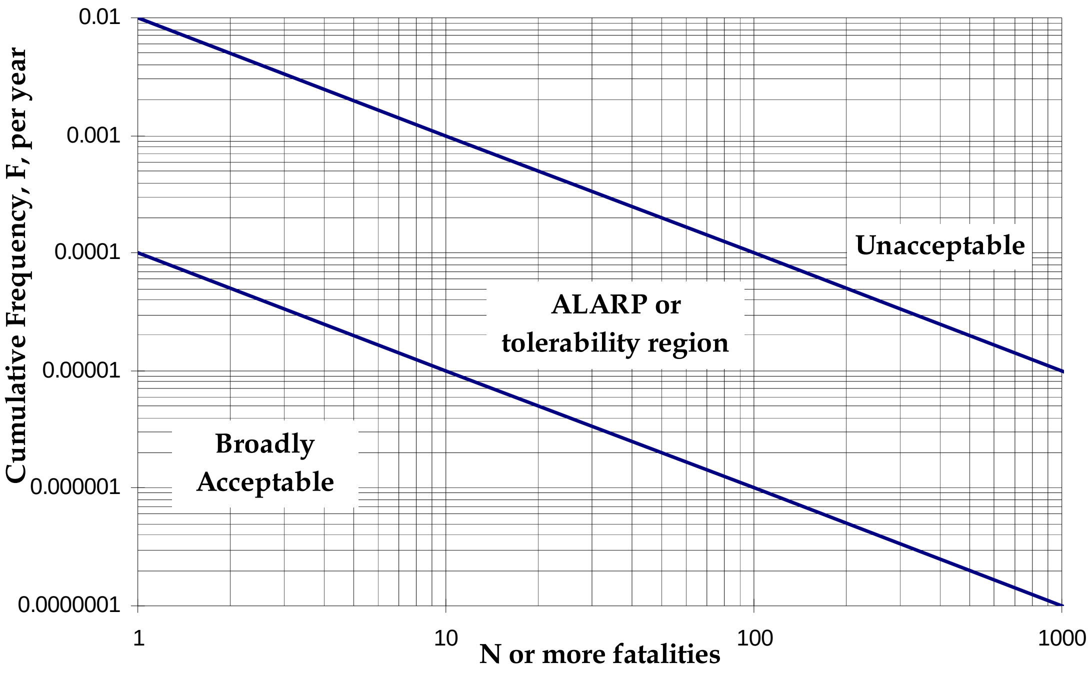

Figure 5.2 Example F-N curve

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.

5.1.5 Risk Control Hierarchy

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 construction 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.

Project specific risk reduction measures adopted in the design, during construction and during pipeline operations are presented in **Sections 5.6.1**, **5.6.2** and **5.6.3** respectively.

5.2 Project Phases Giving Rise to Hazards & Risks

From the Project description presented in **Chapter 4,** it can be seen that within the system boundary of the Project, there are two key phases for which the risks (to people and the environment) need to be assessed, namely:

- Construction of the pipelines
- Operation of the pipelines

There are certain risks which have been mitigated through changes made as the design has evolved. For example, at one stage the design envisaged offshore platforms along the pipelines route, giving rise to the risks associated with ship-platform collision (and potential gas release); however, this risk has been completely mitigated by the removal of the offshore platforms 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.

5.3 Risk Assessment Methodology

The methodology adopted for the risk assessment is in accordance with the recommended risk management practice from DNV(1) 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 Snamprogetti amongst others.

5.3.1 Qualitative Assessment – Pipeline Construction

Construction activities/hazards addressed

The assessment covers the whole construction phase of line 1 (West) and line 2 (East) including preparation of the landfall facilities, pre-lay and post-lay intervention (works/rock placement including vessel loading operation), the main pipe-lay operations (including the pipe load out and transportation) and pre-commissioning operations. These construction/installation activities can be broken down into a number of sub-activities and for which the hazards can be identified

(1) Det Norske Veritas (DNV). January 2003. Risk Management in Marine and Subsea Operations. Recommended Practice. DNV-RP-H101.

and the risks assessed. The key assessment for the construction phase has been undertaken by Global Maritime[1].

Risk matrix

The qualitative assessment has used the risk matrix presented in **Figure 5.3***,* based on DNV recommended practice[2]. 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 covering from *illness/slight injury* to *fatality.* The judgments were made by personnel with considerable relevant experience (including the disciplines of Master Mariner, Naval Architect, Pipeline Engineer and Subsea Engineer).

This matrix also includes the risk tolerability criteria (i.e. high - unacceptable risks, low – broadly acceptable risks, and the area in between - the ALARP or tolerability region).

(1) Global Maritime. 22 Sept. 2009. Nord Stream Pipeline Project Risk Assessment Construction Phase. Report No: GM-45190-0708-49203. Nord Stream Report No. G-GE-RSK-REP-126-GM-000049203.

(2) Det Norske Veritas (DNV). January 2003. Risk Management in Marine and Subsea Operations. Recommended Practice. DNV-RP-H101.

Consequences			Probability (increasing probability →)			
Descriptive	**People**	**Environment**	**Remote** ($< 10^{-5}$/y)	**Unlikely** (10^{-5} - 10^{-3} /y)	**Likely** (10^{-3} - 10^{-2} /y)	**Frequent** (10^{-2} - 10^{-1} /y)
1 Extensive	Fatalities	Global or national effect. Restoration time > 10 year	**A1**	**B1**	**C1**	**D1**
2 Severe	Major Injury	Restoration time > 1 yr. Restoration cost > USD 1 mil.	**A2**	**B2**	**C2**	**D2**
3 Moderate	Minor Injury	Restoration time > 1 month. Restoration cost > USD 1 K	**A3**	**B3**	**C3**	**D3**
4 Minor	Illness or Slight Injury	Restoration time < 1 month. Restoration cost < USD 1 K	**A4**	**B4**	**C4**	**D4**
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					
MEDIUM	The risk should be reduced if possible, unless the cost of implementation is disproportionate to the effect of the possible safeguards					
LOW	The risk is considered tolerable and no further actions are required					

Figure 5.3 Risk Matrix & Associated Tolerability Criteria

The risks associated with the activities/hazards noted above have initially been appraised using the matrix (although some have been previously screened out i.e. are considered insignificant based on reasoned arguments). Risks identified as *medium* or *high* have been taken forward for a detailed, quantitative assessment (including the identification of potential measures to reduce the identified risks).

5.3.2 Quantitative Assessment – Pipeline Construction & Operation

In general, the quantitative risk assessments have comprised the following stages:

- *Hazard Identification* to determine the incident scenarios, hazards and hazardous events, their causes and mechanisms
- *Frequency Estimation* to determine the frequency of occurrence of identified hazardous events and the various outcomes (e.g. using event tree analysis)
- *Consequence Analysis* to determine the extent of the consequences of identified hazardous outcomes
- *Risk Summation* to determine the risk levels
- *Risk Assessment* to identify if the risk is tolerable/intolerable and to identify potential risk mitigation measures and prioritise these using techniques such as risk ranking and cost-benefit analysis

These elements are shown in the flow diagram in **Figure 5.4.**

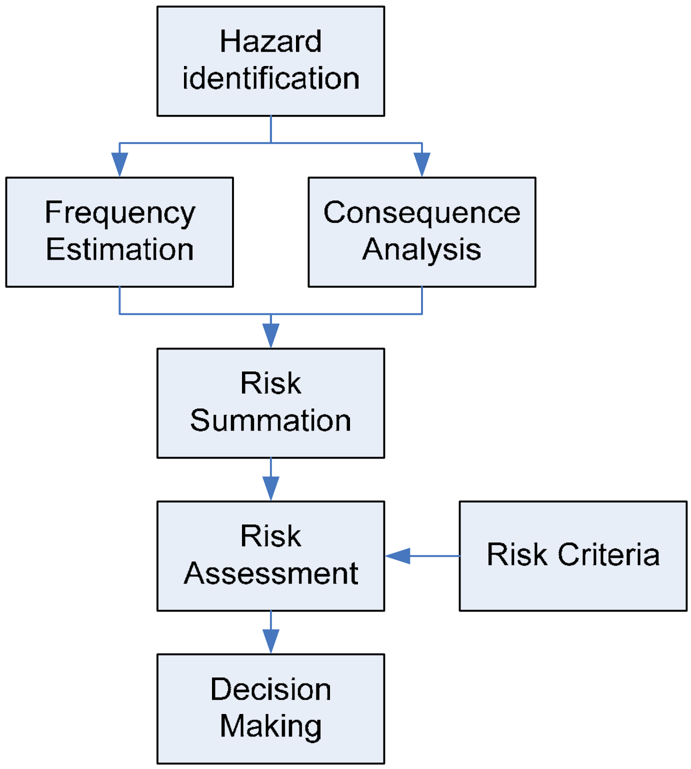

Figure 5.4 Quantitative Risk Assessment Methodology

For the Project, for the pipeline operational phase, separate technical studies have been undertaken for each of the Exclusive Economic Zones (EEZ) through which the pipeline runs, namely: Russia, Finland Sweden, Denmark and Germany. A dedicated set of documents have been prepared which consider the risks in each of the countries, taking into consideration the country specific characteristics of the pipeline section.

These documents include:

- Interaction scenario frequency assessment
- Pipeline damage assessment
- Risk Assessment report

Hazard identification

As noted earlier, for the pipeline construction, the hazards identified for detailed quantitative assessment are those identified a medium or high from the qualitative assessment (see methodology in **Section 5.3.1**).

For the pipeline operation, the following potential causes of failure of the pipeline have been considered:

- Corrosion (internal and external)
- Material and mechanical defects
- Natural hazards, e.g. current and wave action, storm
- Other/unknown, e.g. sabotage, accidental transported mines
- External interference, e.g. fishing, navy and commercial ship traffic, etc.

These were derived based on a hazard identification exercise and a literature review of gas pipeline incidents. Identification of the potential causes of incidents is important as this can affect how an event may develop. For example, pipeline damage caused by a sinking ship is generally likely to result in a greater damage (e.g. gas release) than a dropped anchor, due to the far greater mass of a ship.

Each of these potential causes of failure is further discussed below.

Corrosion

Internal and external corrosion failures are considered to be a negligible contributor to the overall failure rate for the following reasons:

- The gas is dry (and thus the potential for internal corrosion is reduced)

- Use of an internal pipeline coating (primarily to reduce hydraulic friction/ improve the flow, but which also protects against internal corrosion)

- External corrosion protection, comprising a primary system (high quality anticorrosion and concrete coatings) and secondary system (cathodic protection by sacrificial anodes)

- Large pipe wall thickness (which reduces the likelihood of corrosion causing a failure before it is detected)

- Use of intelligent pigging for planned periodic inspection (allowing the identification of any potential corrosion before it becomes critical)

Material & mechanical defects

This category comprises both material defects in the steel pipe (plate manufacturing defects or defects in the longitudinal pipe weld) and construction faults (typically critical defects in the girth welds). Historical experience shows such events to be extremely rare causes of pipeline failures(1), 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 defect is considered negligible as the following measures have been adopted:

- All materials, manufacturing methods and procedures will comply with recognised standards, practices and/or purchaser specifications

- Non Destructive Examination (NDE) at fabrication site (pipe mills) will be performed according to DNV standards

- Pressure testing of each single pipe joint is undertaken at the pipe mill

- Automated Ultrasonic Testing (AUT) and approval of each weld on board the laybarge prior to laying the pipe on the seabed

- Continuous monitoring of the stress on the pipe during the laying operation to ensure the integrity of the pipeline

(1) Energy Institute. 2003. PARLOC 2001: The update of Loss of Containment Data for Offshore Pipelines. Report prepared by Mott MacDonald Ltd for The Health and Safety Executive, The UK Offshore Operators Association and The Institute of Petroleum. ISBN 0 85293 404 1.

- Continuous monitoring of the touch down point of the pipe on the seabed by remotely operated vehicle (ROV) to provide visual confirmation of the integrity of the pipeline on the seabed

- Intervention works (rock placement and post trenching) to ensure final stabilization of the pipelines on the seabed

- Pressure testing of the pipelines system will be undertaken after installation offshore

Differing levels of inspection are also undertaken; by supplier's and installation contractors' inspectors, Nord Stream inspectors and DNV inspectors (for Germany also SGS-TÜV).

Natural hazards - earthquake

Geological data have been collated and evaluated and an extensive seismic hazard assessment has been performed(1). **Figure 5.5** shows the historical data and distribution of seismic activity from the 14th century until 2006. Southern Finland, the Baltic Sea, and surrounding regions (i.e., northern Germany, Poland, Lithuania, Latvia, and Estonia) are almost aseismic. Based on these results it has been concluded that seismic activity is not the governing design load for the pipeline (engineering judgement). Nonetheless, given the robustness of the pipeline it is expected that it would require a severe earthquake to cause a significant failure. In such an event, the major impacts on people are unlikely to be related to the release of gas from the pipelines but from the likely tsunami that may result.

(1) Snamprogetti. 28 March 2008. Seismic Design Basis, Snamprogetti report. Nord Stream Report No. G-EN-PIE-REP-102-00071738.

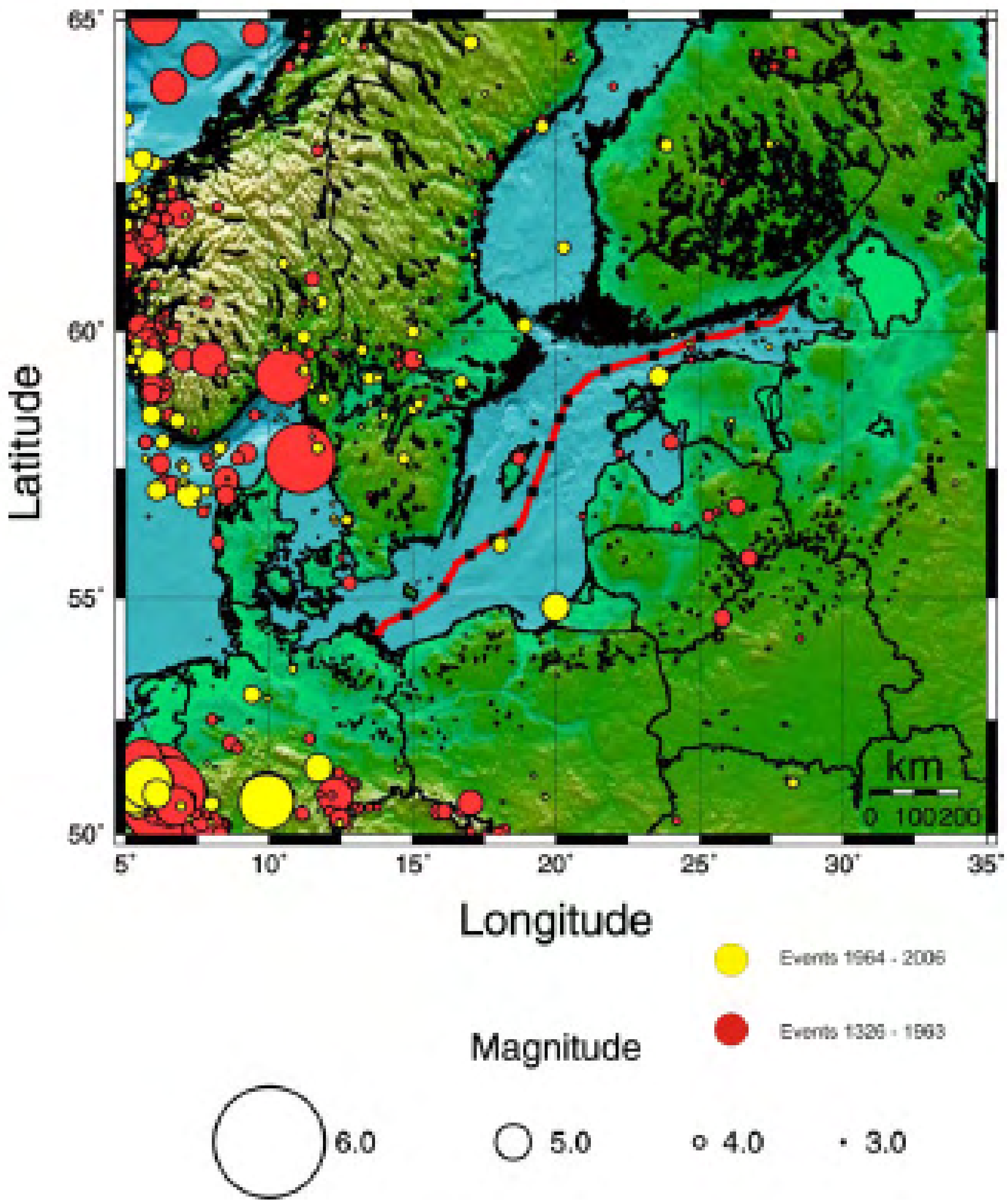

Figure 5.5 Seismicity of Study Area

Natural hazards - Landslides

The generation of landslides that could potentially affect the pipeline integrity has been qualitatively evaluated at the outset of the Project for the entire pipeline route. It was concluded that the pipelines are not threatened by landslide.

The occurrence of a landslide is due to the coexistence of various conditions such as:

1) Thick layers of very soft sediments lying on steep slopes
2) Slope angles able to trigger the development of soil instability
3) Triggering mechanisms causing the landslides (e.g. seismic loads, wave loads, rapid accumulation of soft sediments)

No such conditions have been found along the pipeline routes. In addition the proposed pipeline routing is far from any significant cross slope.

Natural hazards - extreme storm

The following metocean design conditions have been used for the detailed design of the Nord Stream pipelines for 1, 10 and 100 years return periods.

- Seasonal and whole year directional extremes of wind, waves and currents
- Directional significant wave height
- Wave and current climate for fatigue analysis
- Air temperature extremes and climate at landfall locations
- Persistence of storm and calm conditions for on site operations
- Variability of the sea level
- Hydrological sea water parameters (temperature, salinity and density)
- Occurrence and extension of ice coverage

Figure 5.6 shows a typical example of the extreme wind speed and wind direction data for 1, 10 and 100 year return periods at one location of the pipeline.

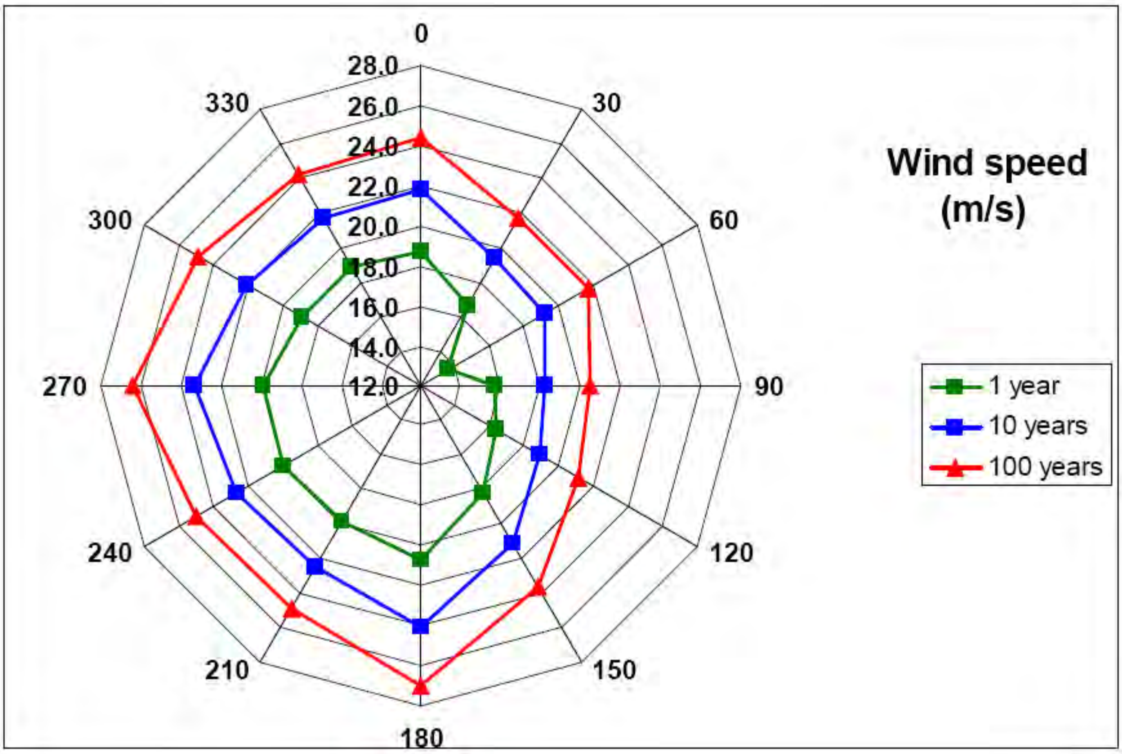

Figure 5.6 Directional wind speed extremes for 1, 10 and 100 year return periods

The conditions providing the largest load for various points along the route have been selected as design conditions. The pipeline had been designed to withstand the maximum forces exerted by a 100 year storm event (DNV-Code requirement).

No loss of containment (release) from steel pipelines has been caused by natural hazards[(1)] and hence this contributor is also considered negligible.

It should also be noted that in the event of extreme weather during construction, the pipe carriers, rock placement and supply vessels will shelter in the nearest designated safety area, e.g. harbour or port. The pipe-lay barges are much larger and can generally ride out a storm without leaving for shelter, although it may be necessary to lay the pipe down before the onset of severe weather. In extreme conditions the pipe-lay barges could also move to a sheltered location for the duration of the storm. There are no reported incidents of a pipe-lay barge sinking or capsizing.

(1) PARLOC. 2001. The update of Loss of Containment Data for Offshore pipelines

Natural hazards – historical experience

The PARLOC 2001 database contains incidents and related loss of containment events from offshore pipelines operated in the North Sea. It reports 13 incidents due to natural hazards (10 were due to current and wave action, 1 resulted from storm damage, 1 was due to scouring and 1 was due to subsidence. However, none of these caused loss of containment (release) from steel pipelines, and only 3 lines sustained damage (but only to their coating). The Nord Stream pipelines are designed against natural hazards due to current and wave action as per DNV RP F109.

Overall, the contribution of natural hazards to pipeline failure is considered negligible.

Other/unknown

Other/unknown causes include all the incidents for which no specific causes where identified, although no such leakage has been recorded for large diameter operating steel lines. For this project, the design systematic failures will be reduced to a negligible level applying appropriate QA/QC procedures, design review meetings and dedicated HSE reviews and studies.

Only sabotage and/or accidental transported mines are identified as possible *other/unknown* causes, but these are considered very unlikely. The threat of sabotage will be mitigated through a robust security system.

External interference

It is only the external interference from ship related incidents which is considered to be a significant contributor to potential pipelines failures for this Project. This has thus been the subject of considerable scrutiny and detailed analysis, including consideration of:

- Dropped objects
- Dropped anchors
- Dragged anchors
- Sinking ships
- Grounding ships (where relevant)

Frequency estimation

Frequency assessment comprises the estimation of the initiating event frequency (e.g. sinking ship) and scenario modelling to determine the frequencies the hazardous outcomes (e.g. ignited gas release impacts ship crew).

The risk assessments have utilised *event tree analysis* to show how a specified undesired event may lead to a number of different outcomes, depending on relevant circumstantial factors (e.g. good weather), the success or failure of various human response activities (e.g. evacuation) and the performance of relevant safety systems (e.g. fire extinguishing).

The various protective devices, safety systems or procedures can be thought of as "*safety barriers"* which are intended to prevent an incident developing (i.e. to limit its consequences). Where a number of safety barriers exist, an event tree can be drawn in which the success of each relevant safety barrier is represented as a branch point. By assigning probabilities to each branch of the event tree, the final frequency of each outcome can be established: the frequency of each outcome is the product of the frequency of occurrence of the initiating event and the probabilities that the event develops to that outcome.

An example of an event tree for assessing recovery from a watch-keeping failure is shown in **Figure 5.7.**

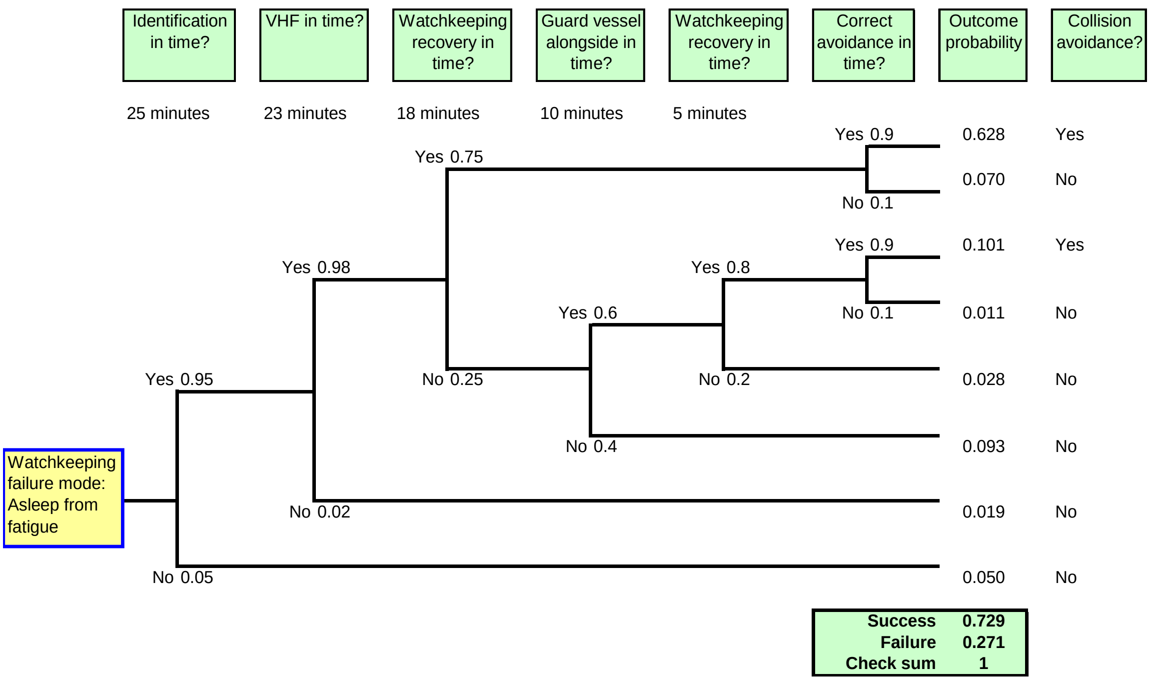

Figure 5.7 Example of an event tree

Interaction scenario frequency assessment

The frequency of interaction is thus the frequency with which contact is made with the pipeline (e.g. by a dragging anchor or sinking ship), irrespective of the damage to the pipeline that may be caused as a result (which is assessed separately in the pipeline damage assessments).

This interaction frequency assessment takes into account the following:

- The pipeline size and location
- The location and width of shipping lanes
- The ship traffic intensity, crossing angles, and the distribution of ship classes and types based on Automatic Identification System (AIS) data
- Ship characteristics (e.g. length, beam, weight, speed, anchor mass)
- Cargo ship containers sizes and weights
- Ship accident and incident data (e.g. frequency of collisions, machinery failures and steering failures which may result in emergency anchoring)
- Various conditional probabilities (e.g. that a sinking is in the vicinity of the pipeline)

The primary shipping routes are presented in **Figure 5.8**.

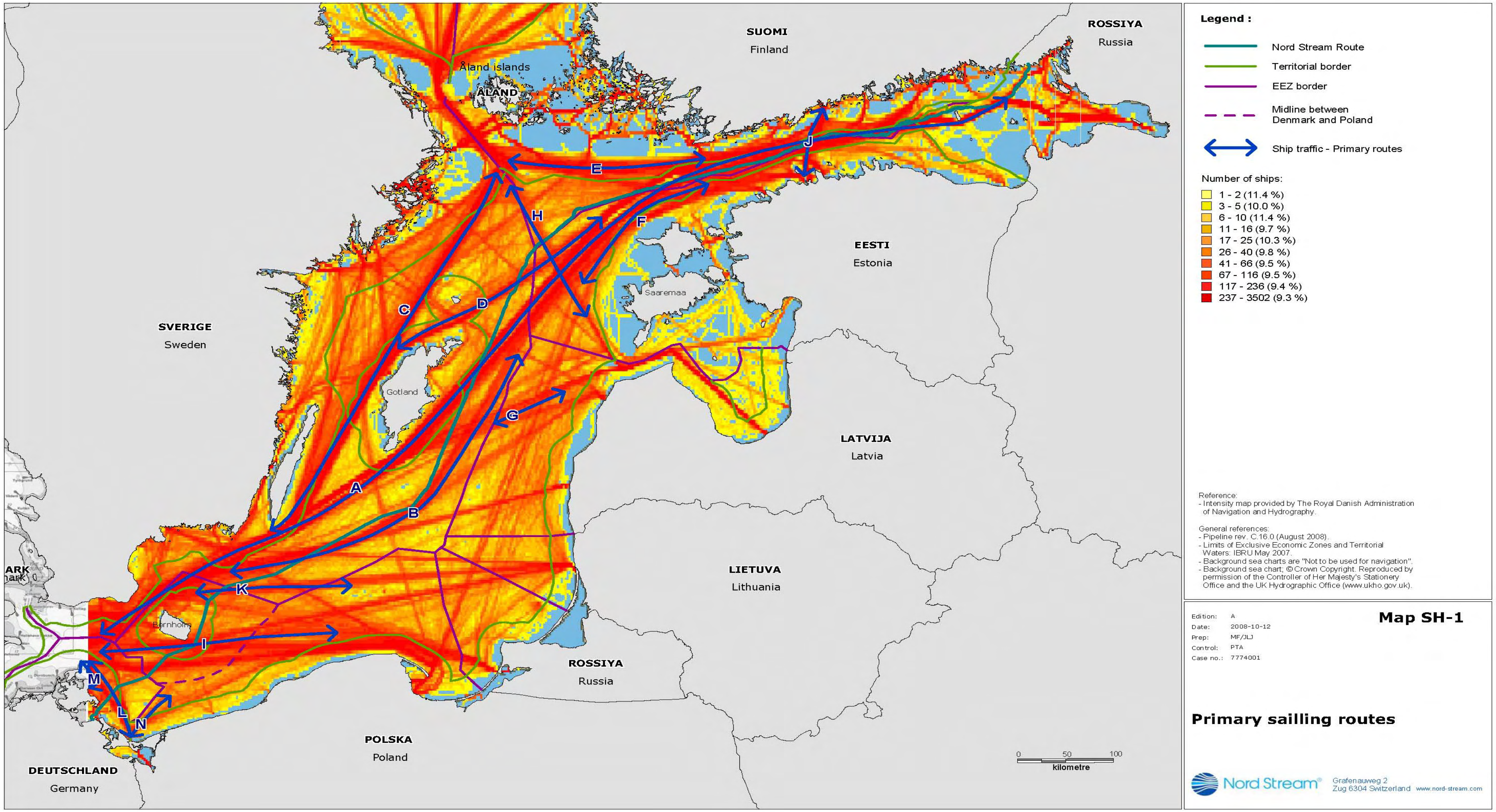

Figure 5.8 Primary shipping routes

Pipeline damage assessment

An overview of the analysis steps is presented in **Figure 5.9.** The pipeline damage assessment aims to:

- Quantify pipeline damage and the associated pipeline failure rate at the critical pipeline locations identified in the interaction scenario frequency assessment

- Define pipeline protection measures, if any, at the critical pipeline locations where the pipeline failure rate exceeds the Nord Stream Project acceptance criteria (of 10^{-4} failures per critical pipeline section per year, as described previously in **Section 5.1.4**)

The pipeline failure rate at the critical locations is calculated by summing the failure rates associated with the different interference mechanisms taking into account the interaction scenarios (dropped objects, dropped anchors, dragged anchors, sinking ships and grounding ships) and pipeline configurations (exposed, buried or protected). This failure rate is actually the rate at which damage to the pipeline is estimated to occur; only a proportion of damage events are expected to results in gas release (for example, some damage may be a dent in the pipeline which prevents pigging until a repair is made).

The analysis includes calculation of the kinetic energy of the falling object (ship, container, anchor), the mechanical behaviour of the soil under surface loads and of the pressure transmitted to the pipeline, calculation of the resistance of the pipe to tackle impact forces, impact energy, local forces and global bending moments, and a damage and pipe failure probability assessment.

Based on these analyses, no gas release is expected in the case of dropped objects or anchors. For dragged anchors, 30% of the damage cases are assumed to result in gas release (all full bore ruptures). In the case of damage from sinking or grounding ships, all damage is assumed to result in gas release (the majority of which are assumed to be full bore ruptures).

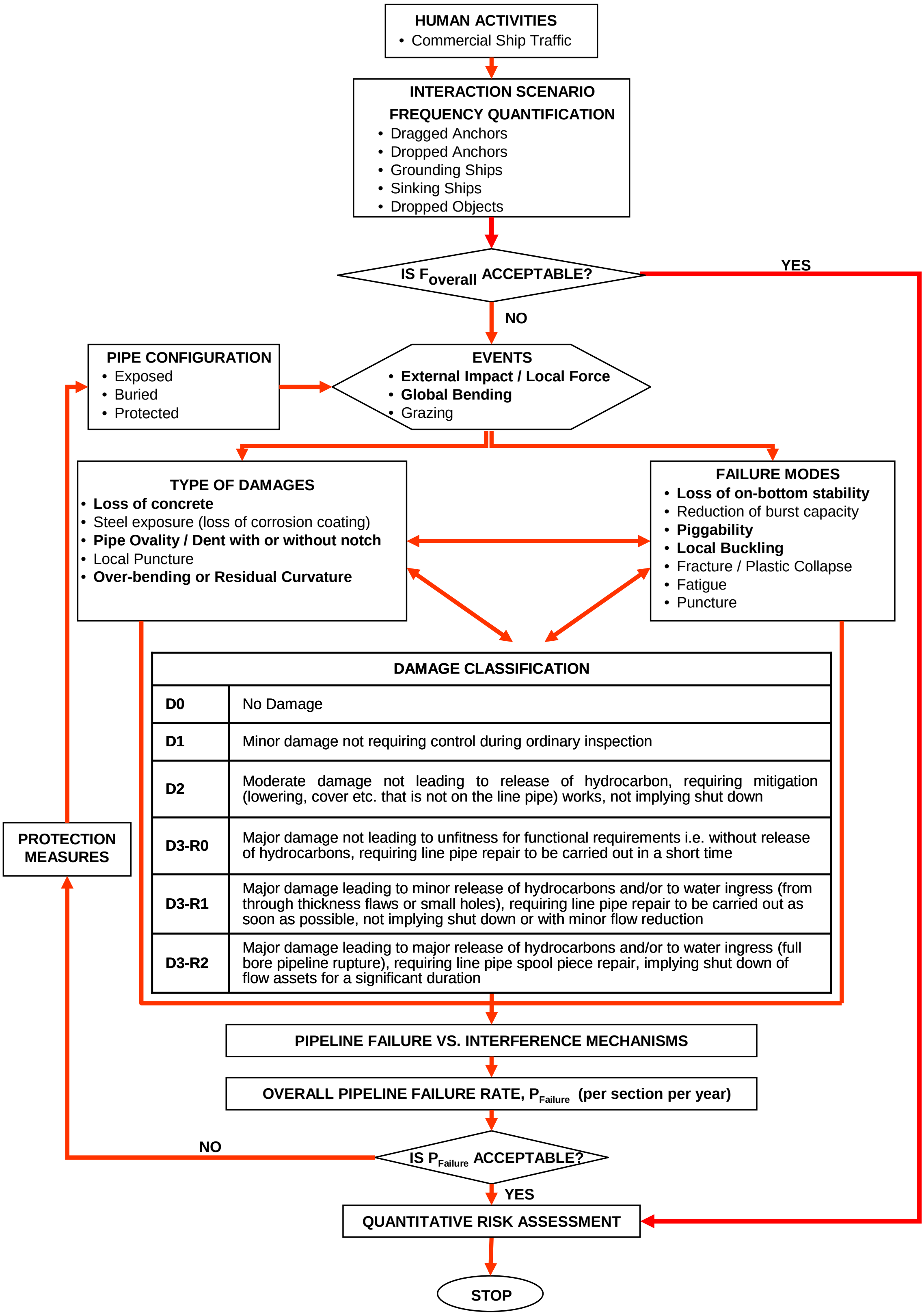

Figure 5.9 Pipeline damage assessment overview

Consequence analysis

For the pipeline operation, the analysis focuses on the consequences of a subsea gas release. This involves several stages, from underwater release rate and associated depressurisation calculations, 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. There are several outcomes to consider (e.g. jet fire, flash fire, explosion, harmless dispersion) depending on whether an ignition takes place (immediate or delayed) and on the degree of confinement.

This in turn means consideration has to be given to:

- Size of rupture (pinhole, hole or full bore rupture)
- Type of material released (i.e. natural gas)
- Process parameters (i.e. pressure and temperature that determine the outflow rate)
- Water depth
- Atmospheric conditions (i.e. atmospheric stability and wind speed)
- Likelihood of ignition

Final estimation of the likely casualties in the event of an ignited release is based upon the exposed populations, taking account of the typical numbers of people on the different vessels (cargo ship, tanker, passenger vessel etc) and their vulnerability (e.g. only people on open decks are expected to be killed in the event of being engulfed in a flash fire).

Risk summation

This stage involves bringing together the frequency and consequence information for all event outcomes and producing measures of risk to support decision making. For the quantitative assessment, this involves calculation of individual and societal risks which can be compared with the previously defined risk tolerability criteria.

Trawling & risk to fishing vessels

Nord Stream has ongoing dialogue with Baltic Sea fishing organisations and authorities to discuss and agree action required to coordinate fishing and construction activities.

To address issues related to fishing activities across all countries involved, a Fishing Working Group (FWG) was established within Nord Stream to organise and co-ordinate all fishing related activities. FWG also defines and implements a common policy within the national task forces of the countries of origin and other affected countries. The policy will be based on studies, tests and risk assessments undertaken by FOGA, SINTEF, Rambøll and DNV.

Experience with numerous offshore pipelines in the North Sea show that fishery and offshore pipelines can co-exist safely. However, the situation in the Baltic Sea is potentially different, in terms of trawling gear types, size of vessels/engines and seabed conditions. Therefore, trawl gear pipeline interaction during the operations phase need to be assessed carefully.

During construction, fishing activity must be temporarily suspended within a safety zone around the pipe-lay barge and support vessels. It is also standard practice to carry a fisheries representative on one of the construction vessels to harmonise activities when required and to provide information to the fishermen both before the start and during of the operation.

During normal pipeline operation trawling will be carried out in areas around the pipelines. In the areas where the pipeline is buried in a trench, or rock placement has been undertaken to cover the pipeline, trawling can be carried out without risk of trawling gear interfering with the pipeline. However, if the pipe is unburied, the trawl board or clump weight may interfere with the pipeline when trawling at the bottom of the sea.

In most cases it will be pulled over, but there is a potential for the trawl equipment to become snagged on the pipeline, especially where there are free spans or where the approach angle to the pipeline is small. This may lead to damage to the trawling equipment or high forces being exerted on the trawl wire which could result in the wire breaking and subsequent loss of the gear. The type of sediment also influences the likelihood of snagging as it affects the extent to which the pipeline settles into the seabed, and the extent to which a trawl board may cut into the seabed if dragged along the pipe.

Snagging may lead in extreme cases of incorrect handling to loss of a fishing vessel and its crew, as occurred in UK waters in 1997. However, the final capsize of the vessel occurred during the recovery of the snagged gear and not as a result of the actual snagging. This emphasises the importance of providing information and training to the fishermen about what to do and not to do in case of snagging or hooking of the trawling gear.

Nord Stream has examined and still is examining these issues in some considerable detail. This has included:

- The identification of fishing techniques, fishing vessels and gear used in the Baltic Sea (FOGA)
- A pipeline trawl gear interaction study (Snamprogetti) focussing on pipeline integrity. This considered the following pipeline trawl gear interaction phases:
    - Impact, including impact energy evaluation (assessment of bare steel pipe worthiness to withstand impact forces and, separately, concrete capacity to dissipate trawl gear kinetic energy)

- Pull-over, including interaction force calculations and analysis of pipe response during and after trawl gear interference. Interaction loads from the largest expected trawl equipment are considered for the pipe response analysis

- Hooking/snagging, including the analysis of pipe response after lift off from the seabed

- An assessment of the risk of trawling gear damage (Rambøll). This took into account trawling time per haul, the trawl speed and the number of trawls per day in order to estimate the number of trawls crossing the pipeline and the associated risks

- An overtrawlability scale model test with up to 2 metre free spans performed by SINTEF in Hirtshals, Denmark, during the period 16-19 December 2008. Fishing organizations from GER, DK, FIN, SWE, POL, NL and representatives of BS-RAC, FOGA and DNV participated.

5.4 Risk Assessment Results

5.4.1 Risks to People – Pipeline Construction

The qualitative assessment identified no 'high' risks involving third parties or the environment. However, the following "medium" risks categories were identified which were taken forward for further quantitative assessment(1):

- Passing vessel collision with construction vessels

- Oil spills during bunkering operations

- Dropped objects

The quantitative assessment estimated the individual risks to third party personnel on passing vessels to be as follows (all figures are per person per year)(2):

- Cargo ship 4.0×10^{-6}

(1) A number of other "medium" risk affecting only construction workers were also identified and taken forward for quantification, including construction vessel fires, groundings, sinking or capsize, helicopter accidents, instability of bailey bridges, tensioner failure, A&R winch and wire failure, vessel position loss (moored and dynamically positioned) and diving operations.

(2) Note 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.

- Tanker 8.2 x 10^{-7}
- Passenger ship 1.7 x 10^{-8}

It can be seen that the risks to these third party personnel are well below the criterion value agreed for the Project for risks to members of the public of 1 x 10^{-4}.

The breakdown by country is shown in **Table 5.2**.

Table 5.2 Individual risks to third party personnel on passing vessels by country and vessel type

Country	Pipeline length (km)	Individual risk to personnel on		
		Cargo ship	Tanker	Passenger ship
Russia	123	6.4 E-8	1.3 E-8	2.7 E-10
Finland	370	5.6 E-7	1.1 E-7	2.3 E-9
Sweden	506	2.7 E-6	5.5 E-7	1.1 E-8
Denmark	136	2.6 E-7	5.3 E-8	1.1 E-9
Germany	85	4.2 E-7	8.6 E-8	1.8 E-9
Total	**1220**	**4.0 E-6**	**8.2 E-7**	**1.7 E-8**

The risks associated with munitions, military exercises and chemical warfare agents 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, in **Section 5.5.1**.

The group risks for third party personnel are presented on the *F-N* curve in **Figure 5.10**, together with the risk tolerability criteria. **Section 5.1.4** previously described how *F-N* curves are generated and how they should be interpreted.

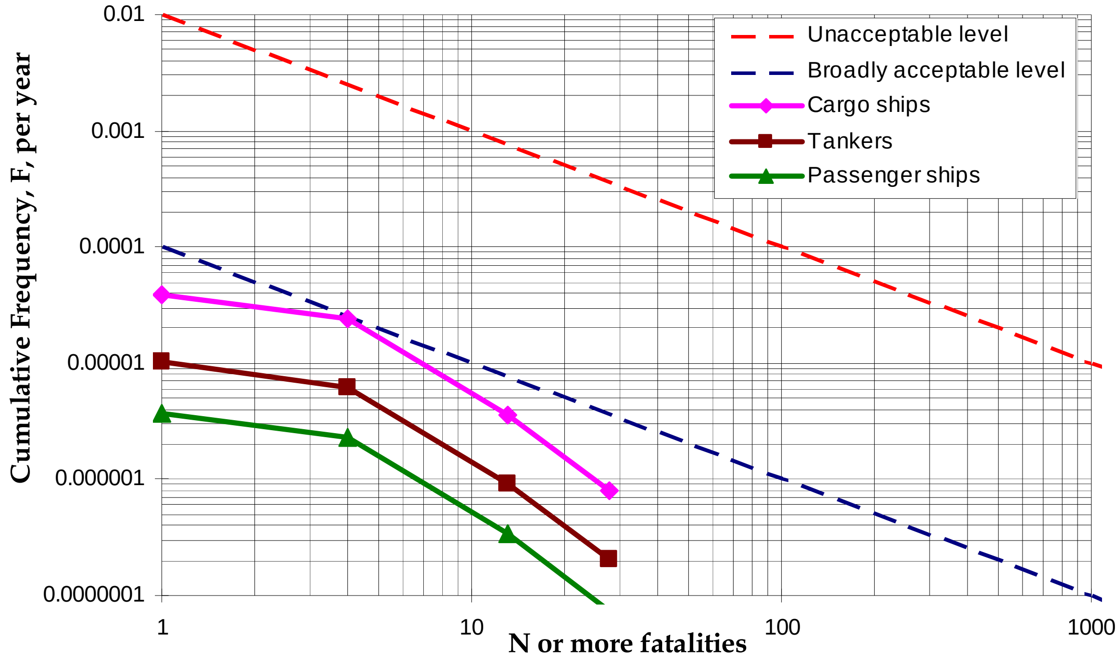

Figure 5.10 F-N curve for passing vessel collision risks during construction

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).

5.4.2 Risks to People – Pipeline Operation

The risks have been examined for a number of different pipeline route options (see **Chapter 6 – Alternatives**). However, following recent discussions with the relevant national authorities, Nord Stream's preferred option is the route South of Bornholm Island and the Kalbadagrund Corridor re-routing. Therefore in the following section, the results are presented for the preferred route option only.

As noted earlier, the results are calculated and presented separately for each of the countries through which the pipeline runs, namely: Russia, Finland, Sweden, Denmark and Germany. The results for each country are presented in the following figures and tables; they comprise the following:

- Interaction scenario frequencies for the critical pipeline sections

- The pipeline total failure probability for the critical pipeline sections (note the term *probability* is used here in a general sense, as the figures presented are actually annual frequencies of pipeline damage)
- The gas release frequency for the critical pipeline sections
- The *F-N* curve for the critical pipeline sections, together with the acceptance criteria (**Section 5.1.4** previously described how *F-N* curves are generated and how they should be interpreted)

Comments are also provided on the dominant contributors to the interaction scenario frequencies and pipeline failure probability, and on how the pipeline failure probability and *F-N* data compare with the tolerability/acceptance criteria described previously.

Russia

Table 5.3 Interaction scenario frequencies – Russia

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**	**Grounding Ships**	**Total**
[#]	[km]	[km]	[km]	[ships/section/year]	[occ/section/year]					
1	**1**	**10**	**10**	**189**	**1.0 E-6**	**2.8 E-8**	**2.2 E-7**	**5.6 E-8**	**8.3 E-7**	**2.2 E-6**
2	**112**	**123**	**12**	**2042**	**9.4 E-6**	**3.5 E-7**	**3.6 E-6**	**1.6 E-7**	**-**	**1.4 E-5**

It can be seen that dropped objects is the dominant contributor to the total interaction frequency (48% for section 1 and 70% for section 2), with grounding ships also contributing 38% to section 1 and dragged anchors dragged anchors contributing 10% and 27% to sections 1 and 2 respectively.

Table 5.4 Pipeline total failure probability & gas release frequency – Russia

Section ID	**From KP**	**To KP**	**Section Length**	**Dropped Objects**	**Dropped Anchors**	**Dragged Anchors**	**Sinking Ships**	**Grounding Ships**	**Total Failure Probability**	**Gas Release Frequency**
[#]	[km]	[km]	[km]	[failure/section/year]					[failure/section/year]	
1	**1**	**10**	**10**	**1.0 E-10**	**2.8 E-13**	**3.0 E-15**	**2.1 E-8**	**8.3 E-7**	**8.5 E-7**	**8.5 E-7**
2	**112**	**123**	**12**	**9.4 E-10**	**3.5 E-12**	**3.4 E-6**	**5.9 E-8**	**-**	**3.5 E-6**	**1.1 E-6**

The total pipeline failure probability is dominated by grounding ships (98%) for section 1 and by dragged anchors (98%) for section 2. It can be seen that all sections meet the acceptance criterion of 10^{-4} failures/section/year.

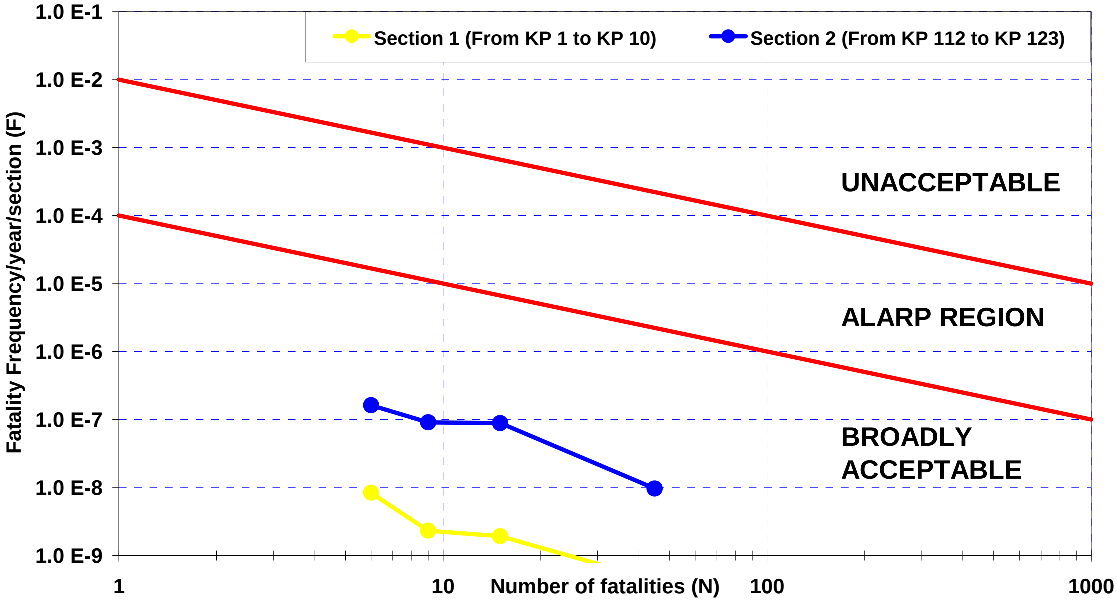

Figure 5.11 F-N curve – Russia

The *F-N* results show the frequency of fatalities is broadly acceptable for all sections.

Finland

Table 5.5 Interaction scenario frequencies – Finland

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**	**41493**	**6.2 E-4**	**3.0 E-6**	**8.6 E-5**	**4.8 E-6**	**7.2 E-4**
2	**211**	**241**	**31**	**26056**	**3.3 E-4**	**6.0 E-6**	**5.8 E-5**	**3.6 E-6**	**4.0 E-4**
3	**251**	**284**	**34**	**23745**	**5.3 E-4**	**3.7 E-6**	**2.0 E-6**	**2.7 E-6**	**5.4 E-4**
4	**293**	**310**	**18**	**4033**	**7.4 E-5**	**5.3 E-7**	**1.5 E-6**	**3.9 E-7**	**7.7 E-5**
5	**316**	**325**	**10**	**1590**	**1.3 E-5**	**1.1 E-7**	**2.0 E-6**	**1.9 E-7**	**1.6 E-5**
6	**336**	**345**	**10**	**1474**	**2.2 E-5**	**1.1 E-7**	**1.2 E-6**	**1.3 E-7**	**2.3 E-5**
7	**364**	**384**	**21**	**14634**	**2.1 E-4**	**9.7 E-7**	**1.4 E-5**	**1.5 E-6**	**2.3 E-4**

The total interaction frequency is dominated by dropped objects (between 83% and 98%) for all sections, with dragged anchors also contributing 14%, 13% and 12% to sections 2, 5 and 1 respectively.

Table 5.6 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.

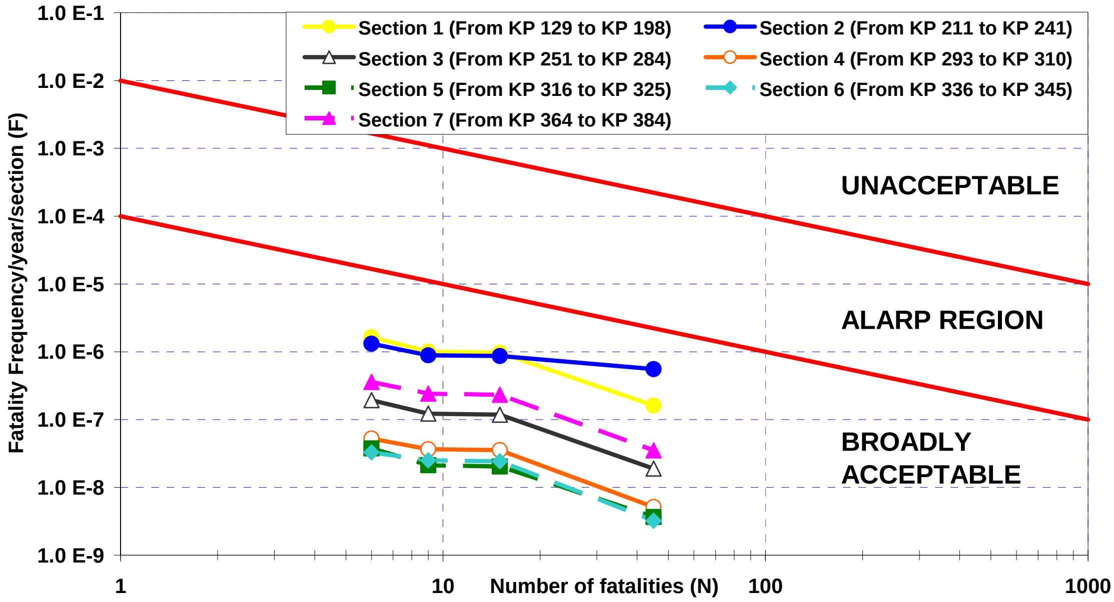

Figure 5.12 F-N curve – Finland

The *F-N* results show the frequency of fatalities is broadly acceptable for all sections.

Sweden

Table 5.7 Interaction scenario frequencies – Sweden

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	**521**	**546**	**26**	**4573**	**6.5 E-5**	**1.3 E-7**	**4.7 E-6**	**1.7 E-7**	**7.0 E-5**
2	**593**	**602**	**10**	**822**	**4.2 E-6**	**2.0 E-8**	**1.0 E-6**	**2.8 E-8**	**5.3 E-6**
3	**625**	**636**	**12**	**6691**	**1.1 E-4**	**2.6 E-7**	**1.2 E-7**	**3.0 E-7**	**1.1 E-4**
4	**650**	**667**	**18**	**7523**	**1.4 E-4**	**3.6 E-7**	**2.4 E-7**	**3.0 E-7**	**1.4 E-4**
5	**706**	**725**	**20**	**4672**	**6.2 E-5**	**1.1 E-7**	**4.7 E-6**	**2.3 E-7**	**6.8 E-5**
6	**909**	**918**	**10**	**2176**	**1.5 E-5**	**8.0 E-8**	**1.1 E-6**	**6.7 E-8**	**1.7 E-5**
7	**950**	**959**	**10**	**1646**	**4.4 E-6**	**4.5 E-8**	**2.4 E-6**	**4.6 E-8**	**6.9 E-6**

Dropped objects dominate the total interaction frequency for all sections (over 90% in most cases), although dragged anchors contribute 35% and 19% to sections 7 and 2 respectively.

Table 5.8 Pipeline total failure probability & gas release frequency – Sweden

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	521	546	26	6.5 E-9	1.4 E-12	3.3 E-6	6.1 E-8	3.4 E-6	1.1 E-6
2	593	602	10	4.2 E-10	2.0 E-13	8.2 E-7	1.0 E-8	8.4 E-7	2.6 E-7
3	625	636	12	1.1 E-8	2.7 E-12	5.9 E-8	1.1 E-7	1.8 E-7	1.3 E-7
4	650	667	18	1.4 E-8	3.8 E-12	1.6 E-7	1.1 E-7	2.8 E-7	1.6 E-7
5	706	725	20	6.2 E-8	1.1 E-12	2.3 E-6	8.4 E-8	2.4 E-6	7.7 E-7
6	909	918	10	1.5 E-8	8.6 E-13	1.0 E-6	2.5 E-8	1.1 E-6	3.3 E-7
7	950	959	10	4.4 E-9	5.0 E-13	2.3 E-6	1.7 E-8	2.3 E-6	7.0 E-7

Dragged anchors dominate the total failure probability for sections 1 to 2 and 5 to 7 (94% or more); for section 4 dragged anchors still dominate (55%), although sinking ships are also a major contributor (40%). For section 3 sinking ships dominate (61%), with dragged anchors contributing 33%. It can be seen that all sections meet the acceptance criterion of 10^{-4} failures/section/year.

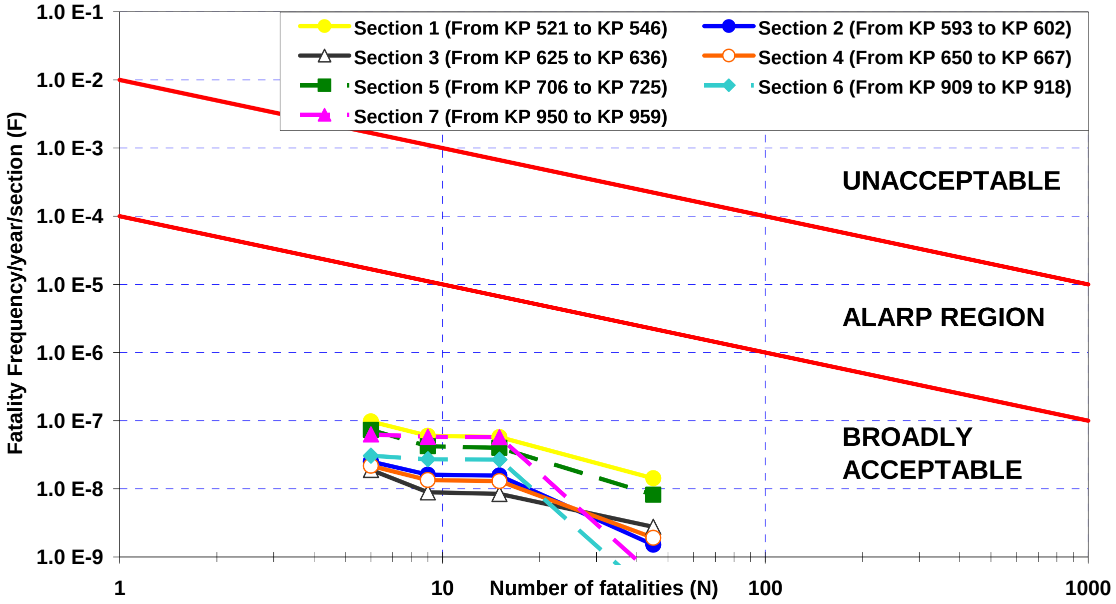

Figure 5.13 F-N curve – Sweden

The *F-N* results show the frequency of fatalities is broadly acceptable for all sections.

Denmark

Table 5.9 Interaction scenario frequencies – Denmark

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	1014	1023	10	1991	2.6 E-5	8.8 E-8	4.3 E-6	4.2 E-7	3.1 E-5
2	1072	1086	15	4151	5.2 E-5	1.9 E-7	4.6 E-6	1.1 E-6	5.8 E-5
3	1124	1133	10	4681	6.6 E-5	2.0 E-7	9.0 E-6	9.8 E-7	7.6 E-5

Dropped objects dominate the total interaction frequency for all sections (between 85% and 90%), with dragged anchors contributing 14% and 12 % to sections 1 and 3 respectively.

Table 5.10 Pipeline total failure probability & gas release frequency – Denmark

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	1014	1023	10	2.6 E-8	1.0 E-12	2.9 E-6	1.5 E-7	3.0 E-6	1.0 E-6
2	1072	1086	15	5.2 E-8	1.9 E-12	2.3 E-6	3.9 E-7	2.8 E-6	1.1 E-6
3	1124	1133	10	6.6 E-8	2.0 E-12	4.4 E-6	3.6 E-7	4.8 E-6	1.7 E-6

Dragged anchors dominate the total failure probability (>84%) for all sections, although sinking ships contributes 14% to section 2. It can be seen that all sections meet the acceptance criterion of 10^{-4} failures/section/year.

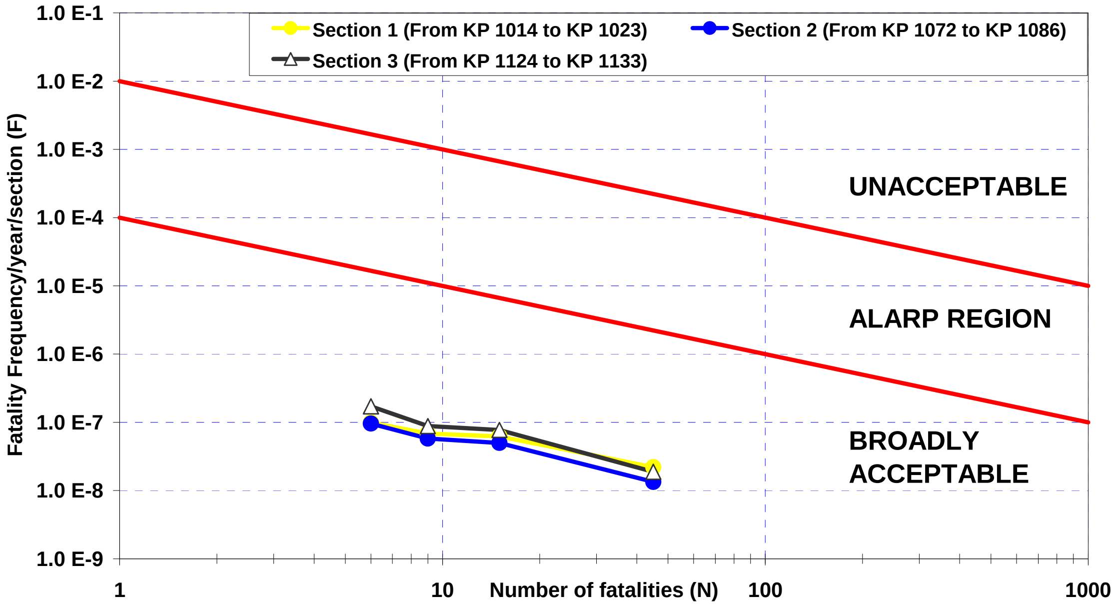

Figure 5.14 F-N curve – Denmark

The *F-N* results show the frequency of fatalities is broadly acceptable for all sections.

Germany

Table 5.11 Interaction scenario frequencies – Germany

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	Grounding Ships	Total
[-]	[km]	[km]	[km]	[ships/section/year]	[event/section/year]					
1	1163	1172	10	3321	6.6 E-6	1.2 E-7	6.4 E-6	4.1 E-7	-	1.3 E-5
2	1180	1189	10	5625	7.9 E-5	1.5 E-7	7.0 E-6	1.3 E-6	-	8.7 E-5
3	1206	1215	10	3350	7.9 E-5	3.8 E-7	5.8 E-6	2.1 E-6	8.9 E-5	1.8 E-4

Dropped object contribute 49%, 90% and 45% to the total interaction frequency for section 1, 2 and 3 respectively, with dragged anchors contributing 47% to section 1 and grounding ships contributing 50% to section 3. However, as noted earlier, the grounding scenario occurs only at KP 1213 and 1214 (Elsagrund) of section 3 where the pipeline will be buried and hence pipeline failures due to grounding have been disregarded.

Table 5.12 Pipeline total failure probability & gas release frequency – Germany

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	1163	1172	10	6.6 E-9	1.2 E-12	5.4 E-6	1.5 E-7	5.6 E-6	1.8 E-6
2	1180	1189	10	7.9 E-8	1.5 E-12	3.6 E-6	4.7 E-7	4.2 E-6	1.6 E-6
3	1206	1215	10	7.9 E-8	3.8 E-12	1.6 E-7	7.9 E-7	1.0 E-6	8.3 E-7

Dragged anchors dominate the total failure probability for sections 1 and 2 (97% and 86% respectively). For section 3 sinking ships dominate (77%), with dragged anchors contributing 16% and dropped object 8%. It can be seen that all sections meet the acceptance criterion of 10^{-4} failures/section/year.

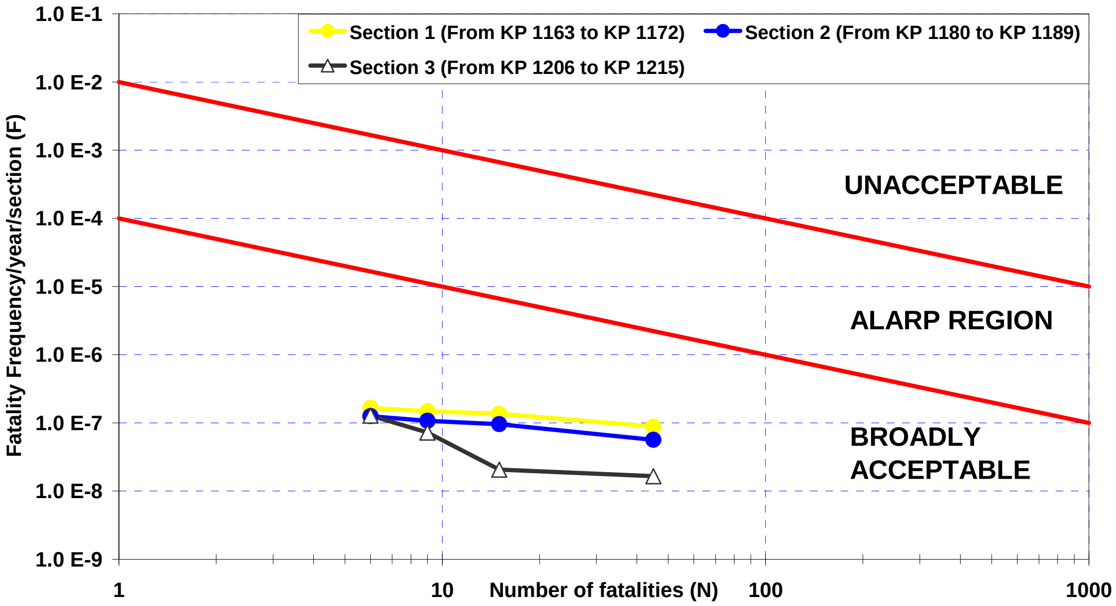

Figure 5.15 F-N curve – Germany

The *F-N* results show the frequency of fatalities is broadly acceptable for all sections.

Total interaction scenario frequency, pipeline failure (damage) probability & gas release frequency summary

The annual frequencies of interaction, pipeline damage and gas release frequencies presented in the previous sections are summarised in **Table 5.13**.

Table 5.13 Total interaction scenario frequency, pipeline failure (damage) probability & gas release frequency

Country	Section number	From KP (km)	To KP (km)	Section length (km)	No. ships	Interaction scenario frequency (occ./year)	Pipeline failure probability (failures/year)	Criterion met (✓ / x)	Gas release frequency (per year)	% total gas release frequency
Russia	1	1	10	10	189	2.2 E-6	8.5 E-7	✓	8.5 E-7	
	2	112	123	12	2,042	1.4 E-5	3.5 E-6	✓	1.1 E-6	
	Total			22	2,232	1.6 E-5	4.3 E-6		1.9 E-6	4.0%
Finland	1	129	198	70	41,493	7.2 E-4	5.4 E-5	✓	1.7 E-5	
	2	211	241	31	26,056	4.0 E-4	3.6 E-5	✓	1.2 E-5	
	3	251	284	34	23,745	5.4 E-4	2.4 E-6	✓	1.4 E-6	
	4	293	310	18	4,033	7.7 E-5	1.3 E-6	✓	4.9 E-7	
	5	316	325	10	1,590	1.6 E-5	1.1 E-6	✓	3.7 E-7	
	6	336	345	10	1,474	2.3 E-5	1.0 E-6	✓	3.4 E-7	
	7	364	384	21	14,634	2.3 E-4	1.1 E-5	✓	3.7 E-6	
	Total			194	113,025	2.0 E-3	1.1 E-4		3.5 E-5	72.7%
Sweden	1	521	546	26	4,573	7.0 E-5	3.4 E-6	✓	1.1 E-6	
	2	593	602	10	822	5.3 E-6	8.4 E-7	✓	2.6 E-7	
	3	625	636	12	6,691	1.1 E-4	1.8 E-7	✓	1.3 E-7	
	4	650	667	18	7,523	1.4 E-4	2.8 E-7	✓	1.6 E-7	
	5	706	725	20	4,672	6.8 E-5	2.4 E-6	✓	7.7 E-7	
	6	909	918	10	2,176	1.7 E-5	1.1 E-6	✓	3.3 E-7	
	7	950	959	10	1,646	6.9 E-6	2.3 E-6	✓	7.0 E-7	
	Total			106	28,103	4.2 E-4	1.1 E-5		3.4 E-6	7.0%
Denmark	1	1014	1023	10	1,991	3.1 E-5	3.0 E-6	✓	1.0 E-6	
	2	1072	1086	15	4,151	5.8 E-5	2.8 E-6	✓	1.1 E-6	
	3	1124	1133	10	4,681	7.6 E-5	4.8 E-6	✓	1.7 E-6	
	Total			35	10,822	1.6 E-4	1.1 E-5		3.8 E-6	7.8%
Germany	1	1163	1172	10	3,321	1.3 E-5	5.6 E-6	✓	1.8 E-6	
	2	1180	1189	10	5,625	8.7 E-5	4.2 E-6	✓	1.6 E-6	
	3	1206	1215	10	3,350	1.8 E-4	1.0 E-6	✓	8.3 E-7	
	Total			30	12,296	2.8 E-4	1.1 E-5		4.2 E-6	8.6%
TOTAL				**387**	**166,478**	**2.9 E-3**	**1.4 E-4**		**4.9 E-5**	**100.0%**

It can be seen that the pipeline failure (damage) probability for every critical section is below the criterion value of 10^{-4} failures per critical pipeline section per year.

The total figures for *all critical pipeline sections* are as follows:

- Frequency of interaction: 2.9 E-3 per year, equivalent to approximately one interaction every 350 years
- Frequency of pipeline failure (damage): 1.4 E-4 per year, equivalent to approximately one damage event every 7,000 years
- Frequency of gas release: 4.9 E-5 per year, equivalent to approximately one gas release event every 20,000 years

It can be seen that Finland dominates the results due to significantly greater ship traffic and hence greater length of critical pipeline sections.

A map of the pipeline route showing the critical pipeline sections is presented **Figure 5.16.**

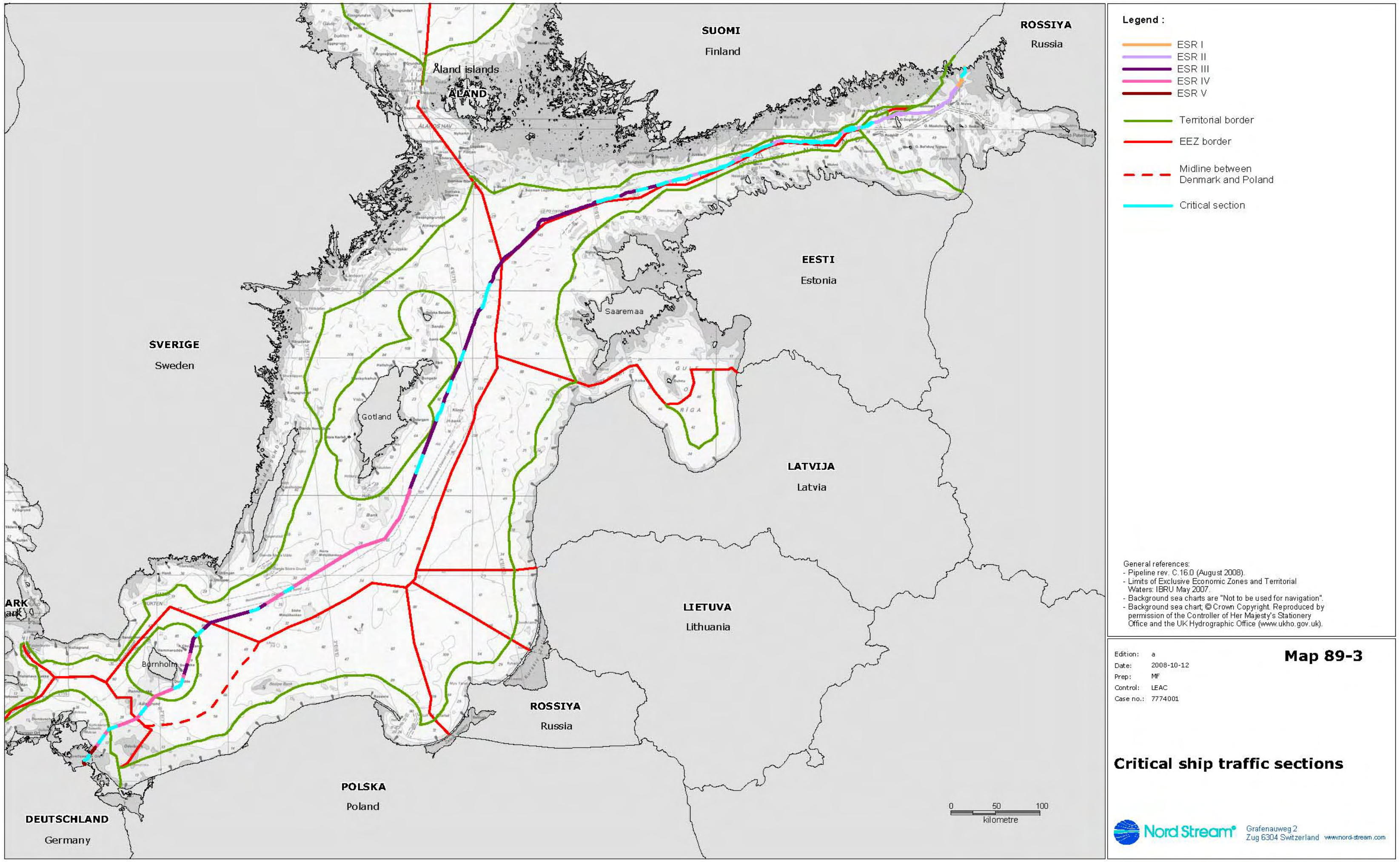

Figure 5.16 Critical pipeline sections

There are no relevant criteria against which to assess the tolerability of the overall gas release *frequency* highlighted above (i.e. one gas release event every 20,000 years). However, it should be noted that there is also no one individual or population group that will be exposed to risks over the entire pipeline length. Hence, as described earlier, the approach adopted by Nord Stream, in agreement with DNV, and in accordance with the relevant DNV standards, has been to demonstrate that the pipeline failure (damage) frequency is below the value of 10^{-4} failures per critical pipeline section per year.

As this criterion has been shown to be achieved for all critical pipeline sections, the associated risks are taken to be broadly acceptable such that no further analysis is necessary. Nonetheless, Nord Stream has also assessed the societal risks (and presented the results in terms on the F-N curves given previously) and demonstrated that the level of risk is broadly acceptable when compared with agreed *risk* tolerability criteria.

Risks to Reputation

In addition to assessing the risks to people and the environment, the Snamprogetti assessments also considered risks to reputation. These risks were assessed for each EEZ (5 countries) using the matrix shown previously in **Figure 5.3**, but with the additional consequence scales for reputation shown in **Table 5.14.**

Table 5.14 Additional risk matrix consequence scales

Consequence	Reputation
1. Extensive	International impact. Negative exposure
2. Severe	Extensive national impact
3. Moderate	Limited national impact
4. Minor	Local impact

The risks were deemed to be low in all cases other than the full bore rupture case in the Finnish EEZ which was considered medium (having severe consequences with a frequency of between 10^{-5} and 10^{-3} per year).

Trawling & risk to fishing vessels

The initial analysis of trawling gear damage estimated the frequency of damage due to pipeline snagging to be low, and the frequency of loss of a fishing vessel as extremely low in the case of incorrect handling. Data from Russia was not taken into account since no bottom trawl is carried out by Russian trawlers.

Nonetheless, given the importance of this issue, and the assumptions based on engineering judgment which are a necessary part of such an analysis, Nord Stream has initiated further studies and sensitivity analyses to ensure the robustness of this conclusion.

The analysis of trawling has shown the pipeline can withstand trawl gear interaction in terms of initial impact and being pulled over the pipeline where the pipeline rests on the seabed. The greatest forces would be exerted on the pipeline if trawl gear becomes snagged (hooked) under the pipeline. The trawl gear would fail before any damage would be caused to the pipeline.

5.4.3 Environmental Risks – Pipeline Construction

Environmental risks during pipeline construction are shown on the risk matrix in **Figure 5.17**.

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

a 3rd party vessel collision 1 – 10 t spill
b 3rd party vessel collision 10 – 100 t spill
c 3rd party vessel collision 100 – 1000 t spill
d 3rd party vessel collision 1000 – 10,000 t spill
e 3rd party vessel collision > 10,000 t spill
f Pipe lay vessel collision
g DSV/Trench support vessel collision
h Rock dump vessel collision
i Pipe carrier/Supply vessel collision
j Anchor handler collision
k Shallow water pipe-lay vessel (C10) collision
l DP Pipe lay vessel (Solitaire) collision
m Pipe carrier/AHT/Supply vessel fire
n Rock dump vessel fire
o Pipe-lay vessel fire
p DSV/Trench support vessel fire
q Shallow water pipe-lay vessel fire
r DP Pipe lay vessel (Solitaire) fire
s Pipe carrier grounding
t Supply vessel grounding
u Rock dump vessel grounding
v DSV/Trench support vessel sinking
w Pipe carrier/AHT sinking
x Pipe-lay vessel sinking
y Rock dump vessel sinking
z Shallow water pipe-lay vessel sinking
aa DP pipe-lay vessel sinking
bb Bunkering operations – AHT
cc Bunkering operations – Pipe-lay vessel
dd Bunkering operations – Solitaire/C10

Figure 5.17 Risk Matrix - Environmental risks during construction

It can be seen that there are no high risk events but there are a number of medium risks which are listed below:

- 3rd party vessel collision resulting in a 100 – 1,000 t spill

- Pipe lay vessel collision
- Rock dump vessel collision

The environmental impact from vessel collisions relates to the potential for oil spills, with the largest potential size spills arising due to collisions involving oil tankers. Measures to manage these risks are discussed in **Section 5.6.2**.

5.4.4 Environmental Risks – Pipeline Operation

The environmental risks associated with gas releases from pinholes, holes and ruptures of the pipeline are described in terms of a location in the risk matrix presented previously in **Figure 5.3.** The environmental risk results for each country are presented in the following figures and tables; the significance of the results discussed in **Section 5.5.**

Failure Cause	**Gas release frequency per year**		
	Pinhole (A)	**Hole (B)**	**Rupture (C)**
Commercial Ship Traffic Interaction	7.1 E-8	7.1 E-8	4.0 E-6

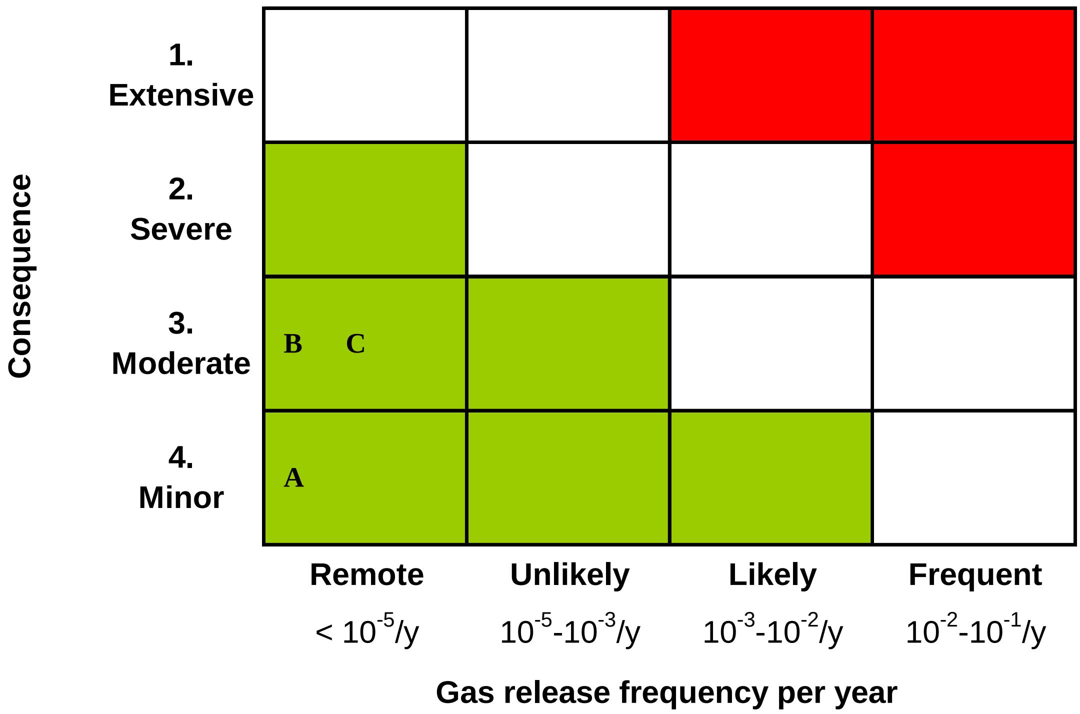

Figure 5.18 Environmental Risks – Russia

Failure Cause	Gas release frequency per year		
	Pinhole (A)	**Hole (B)**	**Rupture (C)**
Commercial Ship Traffic Interaction	2.5 E-7	2.5 E-7	3.5 E-5

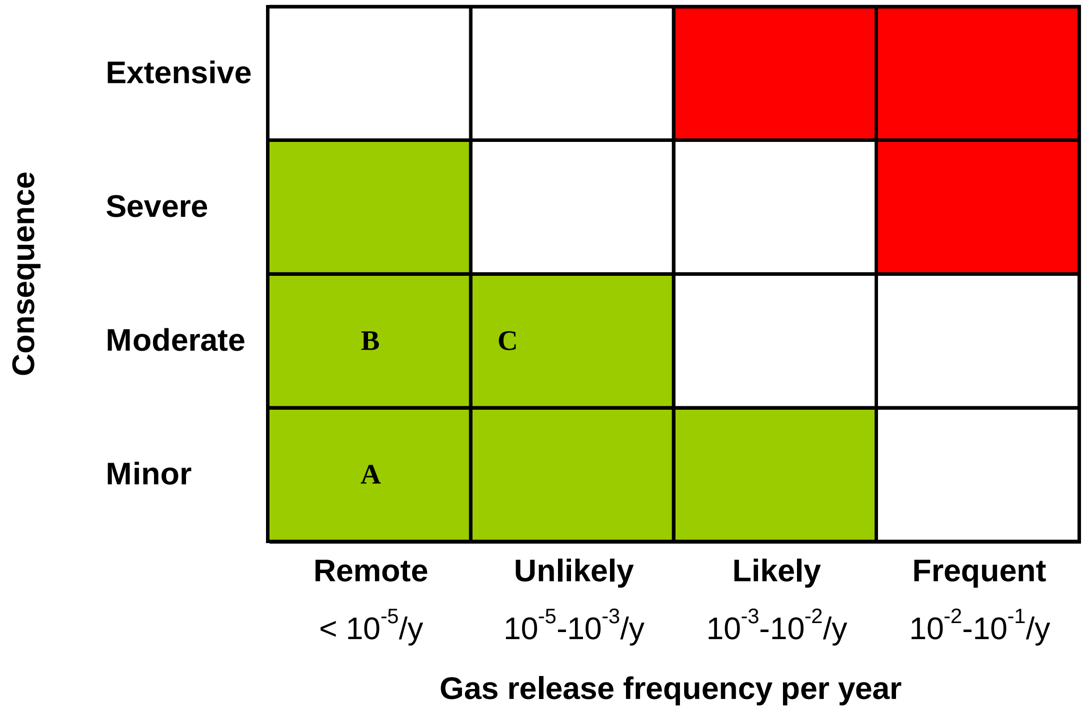

Figure 5.19 Environmental Risks – Finland

Failure Cause	Pinhole (A)	Hole (B)	Rupture (C)
Commercial Ship Traffic Interaction	2.1 E-8	2.1 E-8	3.4 E-6

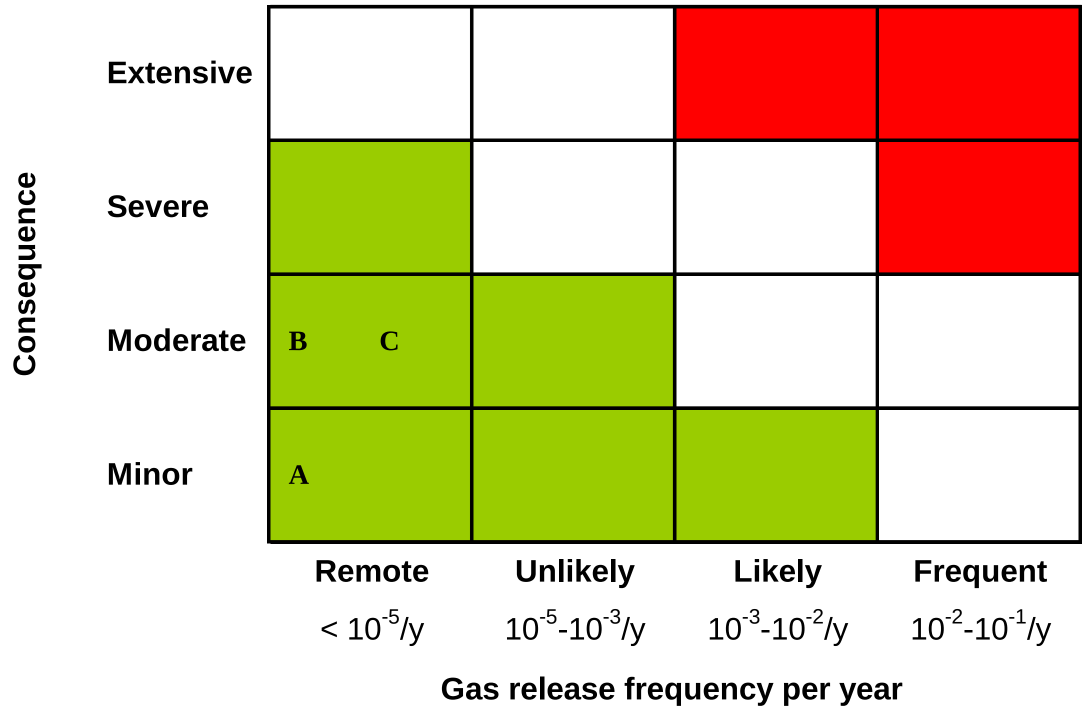

Figure 5.20 Environmental Risks – Sweden

Failure Cause	Gas release frequency per year		
	Pinhole (A)	Hole (B)	Rupture (C)
Commercial Ship Traffic Interaction	4.5 E-8	4.5 E-8	3.7 E-6

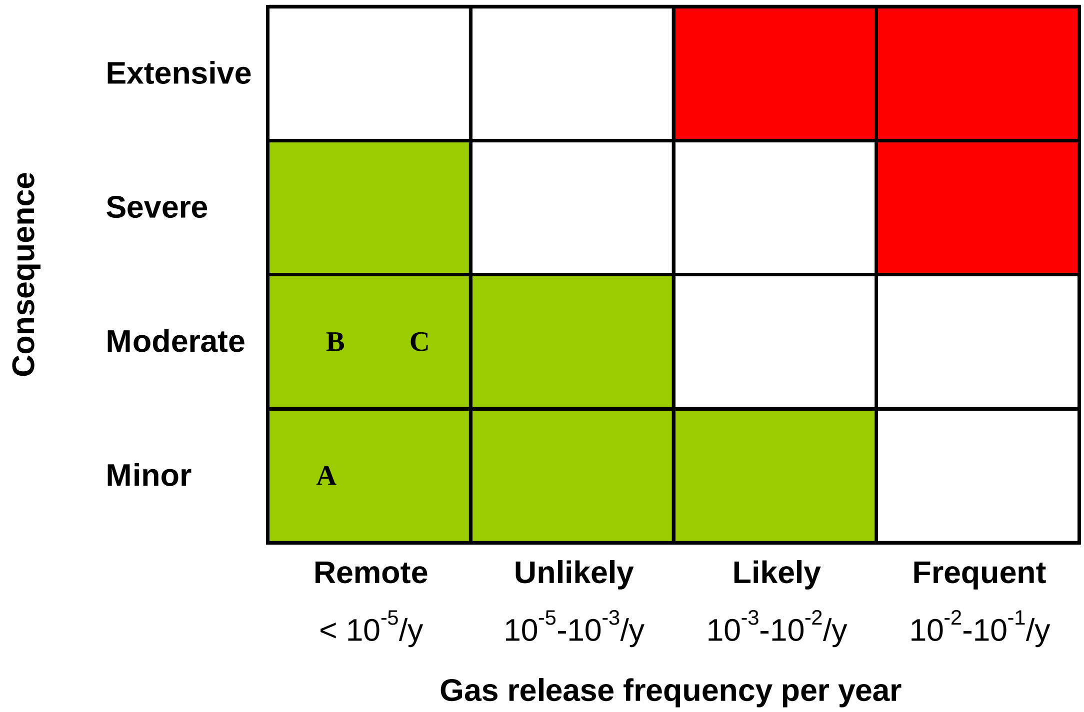

Figure 5.21 Environmental Risks – Denmark

Failure Cause	Gas release frequency per year		
	Pinhole (A)	Hole (B)	Rupture (C)
Commercial Ship Traffic Interaction	7.1 E-8	7.1 E-8	4.0 E-6

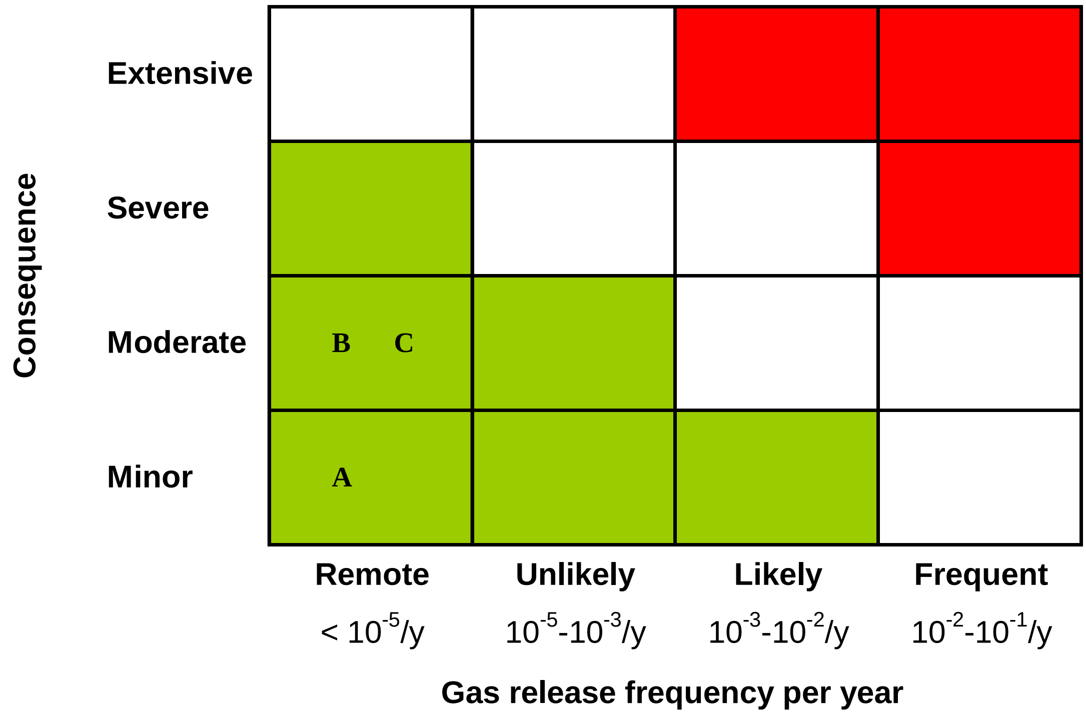

Figure 5.22 Environmental Risks – Germany

5.4.5 Global Warming Potential

Each Nord Stream pipeline will carry 27.5 billion cubic metres(1) of dry sweet natural gas each year between Russia and Germany. Considering all critical pipeline sections together, a full-bore pipeline rupture is estimated to occur once every 20,000 years, as described previously in **Section 5.4**; 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

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

of both the intake and offtake valves, after which the settle out pressure in the pipeline will be approximately 165 bar (as shown see **Figure 5.23**).

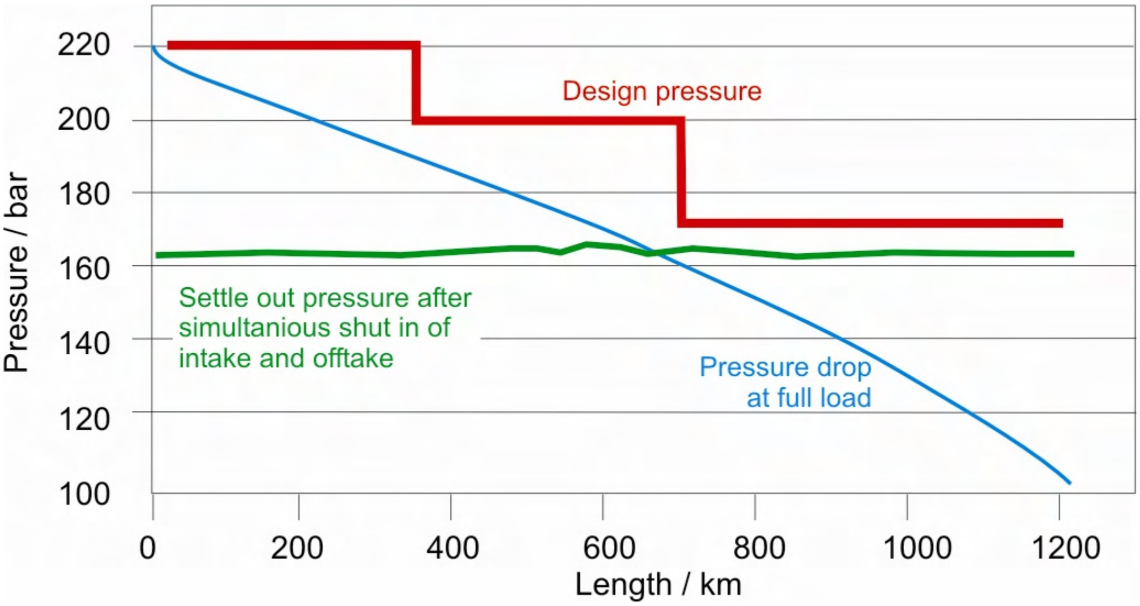

Figure 5.23 Methane Pressure in the Nord Stream pipeline(1)

From the pipeline dimensions given in the Project description(1) (internal diameter 1,153mm, length 1,220km) 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 methane varies with temperature; at one atmosphere pressure, methane has a density of 0.688 kg/m^3 at 20ºC and 0.717 kg/m^3 at 0ºC. According to the Swedish Meteorological Institute(2), the temperature at the bottom of the Baltic varies between 4ºC and 6ºC; at 5ºC the density of methane is 0.705 kg/m^3. Therefore the mass of gas in the pipeline (at 165 bar and 5ºC) 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, 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

(1) Nord Stream AG and Rambøll. 6 June 2008. Project Description. Work Paper for Danish Permit Application (Extract from Espoo Work Paper, May 2008).

(2) Swedish Meteorological and Hydrological Institute. SMHI's mission is to manage and develop information on weather, water and climate that provides knowledge and advanced decision-making data for public services, the private sector and the general public. http://www.smhi.se/cmp/jsp/polopoly.jsp?d=11122&l=sv (accessed August 2008).

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 5.15**), 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 5.15 National carbon dioxide emissions (2004)

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

Data from the Carbon Dioxide Information Analysis Centre published by the United National Statistics Division (http://milleniumindicators.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid=)

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(1), with tankers being the largest emitters, producing around 16 million tonnes of carbon dioxide (see **Table 5.16**).

Table 5.16 Carbon dioxide emissions from shipping in the Baltic Sea

Vessel type	Estimated CO_2 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

(1) Nord Stream AG & Ramboll. September 2008. Memo 4.3p - Air emissions and climate. Nord Stream Report No. G-PE-PER-EIA-100-43P00000.

Vessel type	Estimated CO_2 emissions. (thousand tonnes/yr)	Equivalent emissions from ruptured pipeline (%)
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 5.16** 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 (for all critical pipeline sections together, equivalent to approximately one failure every 20,000 years), the average annual mass released from a full bore rupture equates to 180 tonnes per year, or 0.00044% of the annual carbon dioxide emissions of shipping in the Baltic.

5.5 Discussion of the Risk Results

We all recognise that, as an inescapable fact of life, we are surrounded by hazards – all with a potential to give rise to unwanted consequences. No human activity is without risk. Some of the risks we face may be from naturally occurring hazards (e.g. earthquakes, lightning strikes), other arise as a results of industrial processes (e.g. refining fuel for use in vehicles), while others may arise from individual lifestyles and are risks we take willingly to secure some wanted benefits (e.g. driving or flying).

Risks need to be considered in the context of the benefits derived from taking the risk. When fully operational, the two pipelines will transport 55 billion cubic metres of gas per year from the gas fields of Russia to end markets in Europe, providing a source of energy for consumers and businesses for the next 50 years. One of Nord Stream’s main objectives is to design, build and operate the pipeline system safely, such that the benefits are delivered whilst ensuring the associated risks remain broadly acceptable.

To this end, the comprehensive risk analyses presented in the previous sections have appraised the risks to people and risks to the environment.

5.5.1 Risks to people

In this section the risk results are discussed in the context of the acceptance / tolerability criteria presented in **Section 5.1.4.**

Pipeline construction

Risks to third parties *onshore* during pipeline construction would only occur if non-construction personnel entered the landfall sites or approached inshore construction vessels. However the general public will be prevented from accessing these sites and vessels through the use of normal site security arrangements onshore and safety zones around the inshore vessels. The risk of injury or fatality to the general public is therefore considered to be very low.

There is only a remote possibility that unexploded munitions will be unearthed during onshore construction activities as the area has already been surveyed by magnetometer and metal detectors and no objects have been found. However, in the event that unexploded munitions were found during landfall preparations, an exclusion zone would implemented beyond the construction site if necessary to ensure no members of the general public would be in the potential blast area.

Offshore, the crews and passengers of passing vessels are exposed to the risks associated with collisions with construction vessels. The quantitative assessment has conservatively estimated the individual risks to such third party personnel to be as follows (per person per year):

- Cargo ship 4.0×10^{-6}
- Tanker 8.2×10^{-7}
- Passenger ship 1.7×10^{-8}

These levels of risks to third party personnel are well below the criterion value for risks to members of the public of 1.0×10^{-4} per person per year. The risk to passengers on the passing vessels is around 0.013% of the risk of being killed in a road accident (based on the average from **Table 5.1** presented previously). The risk for cargo ships crews is assessed as the greatest (equivalent to 3.1% of the road accident risk).

During construction a safety (exclusion) zone will be implemented around the construction vessels in addition to the normal navigational measures used by merchant shipping.

During the construction of line 2, line 1 will be operating and the risk assessment considered potential damage to the line from dropped pipe joints during 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 account will be taken of this in pipe loading operations in these areas.

Pipeline operation

The risks during operation arise as a result of damage to the pipeline, and the potential for gas release and ignition, caused by interactions with vessels in the Baltic. Potential interactions include dropped objects (e.g. containers from cargo vessels), dropped anchors, dragged anchors, sinking ships and grounding ships (close to the landfalls). There is also a risk of fishing gear becoming snagged on the pipeline, and in extreme cases of incorrect handling, to loss of a fishing vessel.

The analyses have shown that all critical section of the pipelines (i.e. areas of high shipping traffic) in all countries meet the agreed Project acceptance criterion of 10^{-4} failures/section/year. Therefore no additional protection of the pipeline is required.

The risks results shown in the *F-N* curves for each critical section of the pipeline (i.e. areas of high shipping traffic) also show that the level of risk is extremely low (i.e. the level of risk is considered 'broadly acceptable' in all cases when compared to the agreed risk tolerability criteria). In fact the *F-N* data can be summed for all critical pipeline sections in each country and plotted at the country level as shown in **Figure 5.24**.

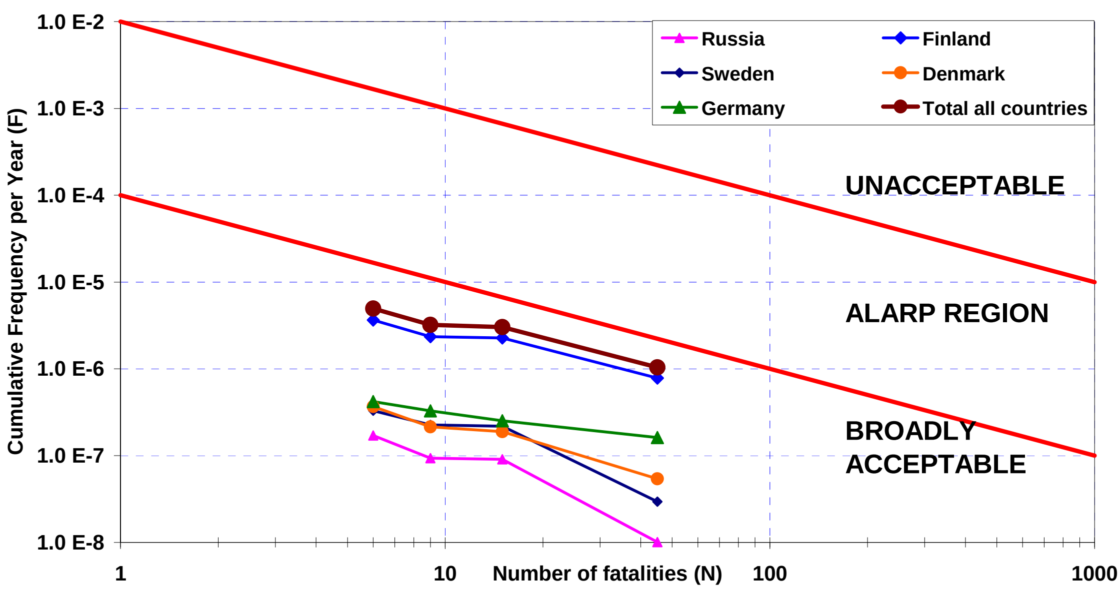

Figure 5.24 F-N results at the country level

It can be seen that the risk levels fall in the broadly acceptable regions in all cases.

The low level of risk is in part due to the design (and associated verification) of the pipeline. It will be designed and operated according to DNV OS-F101, *Submarine Pipeline Systems*, issued by Det Norske Veritas (DNV), Norway. This provides criteria and guidance on design, materials, fabrication, manufacturing, installation, pre-commissioning, commissioning, operation and maintenance of pipeline systems. The use of DNV design codes has been an established practice for offshore design houses for the last several decades - the code for submarine pipelines is currently used for all marine pipeline designs in the Danish and Norwegian North Sea oil and gas developments and is also being used extensively on a global basis.

The pipeline wall thickness varies between 26.8 mm and 41.0 mm, which together with the three-layer polyethylene anti-corrosion coating and concrete coating (60 to 110mm thick), means the pipeline can withstand the impacts of all but largest ships and dragged anchors. The pipeline is buried close to the landfalls such that the potential for failure by grounding ships is also minimised.

In the extremely unlikely event of a major sub sea gas release, the gas will be released to the water column and rise to the surface as a gas plume. On the surface there will be region where the gas disperses into the air. The size of this region will vary depending on the water depth of the release, the nature of damage and pipeline operating conditions at the time of damage. The extent of the gas cloud from a major gas release depends on the actual nature of the damage and the weather conditions (primarily wind speed and stability). No loss of buoyancy of a vessel should occur when passing over the gas plume[1].

Natural gas is much lighter than air and therefore will rise quickly. Therefore the risk that people onshore are affected by an offshore gas release is extremely low. Also there are no villages in the close vicinity of the areas where the pipelines reach the shore in Russia and Germany.

In general there are no permanent shipping restriction zones along the pipeline. The only exemption is the nearshore approach in Germany where the pipeline runs parallel to the shipping channel. Here a 200 m safety corridor has been established together with the German authorities, because there are frequent, regular maintenance works (ensuring sufficient depth of the shipping channel) in the shipping channel in the vicinity of the pipeline.

Trawling & risk to fishing vessels

The frequency of loss of a fishing vessel due to snagging and incorrect handling has initially been estimated to be very low, 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. The fishing assessment also suggested consideration should be given to establishing a fund from which to compensate fishermen for trawl gear damaged on the pipeline (as it would be safer for the fishermen and pipeline integrity to cut the trawl wires instead of trying to free the equipment).

(1) Vinnem, J. E. 2007. Offshore Risk Assessment Principles, Modelling and Applications of QRA Studies. ISBN: 978-1-84628-716-9.

Nord Stream is also considering mitigation measures as well as fishing restrictions in certain areas the pipeline might pose a risk to fishing vessels and their crew. This is being discussed at a national level.

Trawling & risk to pipeline

The analysis of trawling has shown the pipeline can withstand trawl gear interaction and the trawl gear would fail before any damage would be caused to the pipeline.

Munitions

Munitions screening surveys have been performed to establish that the pipeline corridor is clear of potentially unexploded munitions 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 **Chapter 8, Baseline Description** and the environmental impact associated with munitions and CWA is discussed in **Chapter 9, Impact Assessment and Mitigations Measures**.

The survey objectives are to:

- Identify and map targets that may represent potential munitions and may have the potential to influence pipeline design, installation and long term integrity
- Perform a visual inspection of targets and classification to identify potential munitions
- Integrate anomalies and objects identified and targets from previous investigations and correlation with public domain data

On the basis of such surveys, the pipeline has been routed to avoid munitions wherever possible; alternatively, to remove them. The ‘clearance corridor’ dimensions (25 m on either side of the route) are based on detailed analysis of the effects of underwater explosions(1) which address the propagation of the shock wave, the pipeline loading and the pipeline response (in terms of local and global deformation modes, strain of the pipe steel and the elasto-plastic behaviour of the concrete coating). The analysis is based on a theoretical 2000 kg charge (the largest actual unexploded ordnance ever found in the Baltic Sea is 935 kg charge weight and most are less than 300kg) and shows that such an explosion within 12 m of the pipeline would not result in a gas release. Saipem is contracted to lay the pipeline to a tolerance of +/- 7.5 m and hence this will ensure that any exploding munitions on the edge of the corridor could not damage the pipeline.

(1) Snamprogetti. 10 June 2008. Effects of Underwater Explosions. Nord Stream Report No. G-EN-PIE-REP-102-0072528-2.

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(1) and this risk is considered to be low.

Military exercises

Military exercises are carried out in the Baltic by NATO and a number of the Baltic States, including practice areas for bombing, minelaying practice or submarine exercises. A specific project study identifies the areas along the pipeline route where military exercises are undertaken(2). Nord Stream has established contact with the relevant national defence/naval authorities to inform them about the construction activities and subsequent operations. The intention is to agree that the length of pipelines that may be crossed by military vessels will be minimised, and more generally to agree arrangements to ensure any potential for military activities to impact the pipeline are minimised. The pipeline will be marked on the relevant nautical charts to ensure shipping in the vicinity of the pipeline is aware of its precise location.

Collisions with military vessels have not been specifically addressed in the quantitative risk assessment as the required data on these vessels is not readily available because they are not required to carry AIS (Automatic Identification System.). However, it is understood military vessel traffic is relatively small compared to the amount of commercial traffic and hence the addition of military vessels would not be expected to increase the ship pipeline interaction frequencies significantly. In addition military vessels generally have a higher level of manning and better developed watch-keeping than commercial vessels and are therefore less likely to be involved in collisions.

Chemical warfare agents

In 1947, after the end of World War II, chemical warfare agents (CWA) were dumped on the seabed, primarily in the Gotland dump site and Bornholm basin site. The concern in relation to these chemical warfare agents is the potential for them to be disturbed during construction and the agent impacting people or the marine environment.

Hence chemical warfare agents have been the subject of two specific studies by the National Environmental Research Institute (NERI) of Denmark(3,(4), which included interviews with

(1) Ramboll. March 1994. Report on Chemical Munitions Dumped in the Baltic Sea - Helcom.

(2) Nord Stream AG & Ramboll. October 4th, 2007. Memo no. 4.9-2. Military Practice Areas. Nord Stream Report No. G-PE-PER-EIA-100-49200000-01, Version 01.

(3) Sanderson, H. & Fauser, P. 20 June 2008. Risk screening of chemical warfare agents towards humans and the fish community resulting from sediment perturbation from construction of the planned Nord Stream offshore pipelines through risk area 3 (S-route) in the Baltic Sea. NERI report.

(4) Sanderson, H. & Fauser, P. 1 July 2008. Historical and qualitative analysis of the state and impact of dumped chemical warfare agents in the Bornholm basin from 1947-2008 NERI report.

interested stakeholder groups on Bornholm (e.g. the fishermen's association, Natural Conservation Society, deep-sea divers). In addition there has been comprehensive soil sampling and analysis of the sediment in the area of the pipeline route in the vicinity of the dump sites.

Whilst dumping killed fish stock in 1947 and fishermen have caught CWA since that time, there have been no reports of acute occupational accidents for at least the past decade in the Danish media. Much of the CWA material will have decayed to a harmless state since 1947, there are currently plenty of fish at the dump sites, and the studies showed that there are generally limited environmental concerns.

The laboratory results have not revealed any point sources of contaminants in the pipeline route. The results appear to give an indication of a diffuse low level background contamination given the history of the area. The detected concentrations are very low and below level of effects on the marine environment. The maximum concentration levels give no evidence of any existing conflict with pipe-laying in the route (which has specifically avoided known wrecks which may contain munitions and CWA).

However, as survey results show traces of trawling activity in the restricted areas, it has to be assumed that the remains of any munitions are spread widely.

5.5.2 Risk to the environment

Oil spills

The risk to the environment during construction arises from the potential for oil spills following a third party vessel collision with the construction vessels, or during refuelling of the construction vessels. In compliance with the MARPOL regulations(1) all vessels are required to carry a shipboard oil pollution emergency plan (SOPEP) which must be approved by a ship classification society. This includes procedures to control discharge and the reporting requirements in the event of an accidental spill. Oil spill response is included in the Nord Stream emergency notification procedure that will be in place for the construction phase.

In the event that the collision involves an oil tanker, clearly there is the potential for a relatively large spill. However, if an oil spill occurs, the oil spill response procedure would be implemented, which includes oil containment and dispersion/disposal, as a means of minimising the adverse impacts (see further discussion in **Chapter 9.10, Unplanned Events**).

(1) The MARPOL Convention is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

Gas release

There will be no release of gas to the environment during normal routine operations; this would only occur in the unlikely event of a pipeline leak/rupture. The total frequency of gas releases from all critical pipeline sections has been estimated to be 4.9 E-5 per year, equivalent to approximately one failure every 20,000 years. In such an event, the gas will rise to the water surface and disperse rapidly. Natural gas travelling through the water is not expected to have an impact on marine mammals, as it is not toxic; a local reduction of oxygen content in the water column would be very temporary. Once the gas has reached the sea surface it will disperse into the atmosphere and thus prevent any further impacts on marine mammals.

The risk of environmental impacts due a gas release leading to damage of a vessel resulting in release of hazardous cargo is also very low. For such a scenario to take place a combination of number of events will have to occur:

- The pipeline must be damaged to such an extent that a major gas release (full bore rupture) occurs – an extremely unlikely event
- A ship has to pass the gas cloud before information of gas release is distributed to the ship traffic (i.e. before ships can be warned to avoid the affected area)
- The gas cloud has to be ignited by the passing vessel
- The ship must be damaged to such an extent that a release of its cargo occurs (this is extremely unlikely in a flash fire scenario as no significant overpressures are generated)

It should be noted that the frequency of ship collisions with subsequent release of oil or other type of hazardous material is much higher than the estimated frequency of failure of the pipeline leading to a gas release.

Global warming

The total mass of methane in the pipeline is very large and methane has a global warming potential 25 times greater than carbon dioxide. However, given the very low expected frequency of methane release, the average annual mass released from a full bore rupture equates to 0.00044% of the annual carbon dioxide emissions of shipping in the Baltic in terms of global warming potential.

Spawning areas

Pipeline construction operations in spawning grounds could have a serious environmental impact and the possible need to restrict access during the spawning season has therefore been considered in the project planning. The potential impacts on spawning areas, and the measures necessary to minimise impacts are addressed in the Environmental Impact Assessment (EIA) in **Chapter 9**.

5.6 Risk Mitigation Measures

The various risk assessments that have been undertaken for the construction and operation of the Nord Stream pipeline have highlighted a number of specific risk mitigation measures that need to be maintained to ensure the risk to third parties and the environment remains at the tolerable levels estimated in the assessments. There are also other areas of best practice that have been highlighted in the studies that the project needs to adopt. These mitigation measures and area of best practice are summarised below under the headings of design, construction and operations (see also the risk control hierarchy in **Section 5.1.5**).

5.6.1 Design

- Pipeline pressure regulation and automatic pressure safeguarding system
- Pipeline leak detection (supervisory control and data acquisition system, automatic alarms and signals to the ESD system)
- Pipeline parameter monitoring (including pipeline temperature safeguarding)
- Fire and gas detection and protection
- Emergency shut down
- Minimising pipeline free spans on the seabed
- External corrosion protection
- Concrete coating which will provide additional protection against impact
- Rock placement over the pipeline in vulnerable areas
- Extensive surveys as a basis for clearing of any identified munitions.
- DNV and SGS/TÜV independent third-party verification of the quality of engineering work
- QA/QC and relevant inspections and testing at all project stages
- DNV final certification of compliance for the overall pipeline system

5.6.2 Construction

- Ship collision risk reduction measures including the use of:
  - Navigation warnings
  - Notice to Mariners
  - ARPA radar systems which automatically plot passing vessel trajectories and raise an alarm if a potential collision situation exists
  - AIS systems to assist with the identification of passing vessels and provide information on position, course and speed
  - Broadcasts on VHF
  - Experienced contractors/personnel[(1)]
  - Native speakers on the lay vessel in order to allow communication with local vessels
  - Emergency procedures for collision avoidance
- Emergency oil spill procedures and equipment on board all construction vessels
- Emergency response plans onboard all construction vessels and in the onshore sites in Russia and Germany
- A fisheries representative on one of the construction vessels to coordinate activities when required
- Visual and radar look out maintained on construction vessels at all times
- An exclusion zone enforced by a Guard Vessel around the pipe-lay vessel when considered necessary (e.g. in high shipping traffic areas)
- Security measures/fencing around landfall construction areas
- Use of designed support to safely cross subsea assets (cables/pipelines)
- Limitations to construction activities at critical times near spawning grounds

(1) The main contractor for the construction of the Nord Stream pipelines will be Saipem UK Ltd of the Eni Group. Saipem has in place a Health & Safety Executive Management System and its Quality Management System has been granted ISO 9001:2000 certification by Lloyd's Register Certification.

- Compliance with MARPOL requirements related to discharge of oil and waste products
- Use of bunds and double wall tanks for onshore fuel storage
- Use of oil transfer hoses fitted with self sealing couplings (which close the hose when they have been disconnected from the bunker points)
- Oil spill clean up kits kept on construction sites to address any local spills
- Munitions action plans for all countries for the clearance (i.e. lifting, disarmament, transportation and disposal) of any munitions discovered during construction; specialists will be utilised as required (e.g. the Russian Civil Defence Force will assist at the Russian landfall)
- Pull test on construction vessel anchors after they have been installed to minimise the possibility of a dragged anchor
- Weather forecasting to identify potential onset of unstable/poor weather conditions and criteria for suspending construction activities
- Minimisation of grounding through use of vessel navigation procedures, officer competence, pilotage during port movements and the preparation of passage plans
- Use of refuelling (bunkering) procedures for the pipe-lay and anchor handling tug (ensuring that hoses are checked, spill trays are in place, oil spill kit is in place, scuppers are blocked, communications are in place and that operations are closely monitored to ensure oil transfer spills are minimised)
- Seabed intervention works mitigation measures, including:
    - Separate storage of different soil types for backfilling (Germany, Natura 2000 area)
    - Onshore disposal of soil with high organic content (Germany, Natura 2000 area)
    - Backfilling at the respective extraction site after pipe-laying
    - Trenching carried out by a plough instead of jetting with a hydraulic jet sled (where possible)
    - Minimising sediment spreading during intervention works through use of silt screens and bubble screens where necessary

- Liaison with the relevant national defence/naval authorities to inform them about the construction activities and subsequent operations (aiming to minimise length of pipelines crossed by military vessels, relocate submarine practice areas etc. as necessary).

5.6.3 Operation

- Sacrificial anode consumption monitoring
- Pipeline marked on the relevant nautical charts
- Information and education of the fishing community
- Pipeline drying before initial use to prevent corrosion
- Pressure testing prior to gas filling
- Use of intelligent pigs for periodic inspection/monitoring
- Main control room permanently manned by one to two control room operators
- Full pipeline system parameter monitoring independently of the control room
- Pipeline emergency response plan
- Pipeline integrity management system (including for example regular surveying, erosion monitoring, span development monitoring)
- Planned maintenance and scheduled inspections carried out in accordance with manufacturers' requirements, statutory requirements, and recognised good industry practice

5.7 Summary & Conclusions

The results of the comprehensive analyses of the risks to people and the environment during the construction and operation of the Nord Stream pipelines show that *no risks are considered 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[1]; over 548,000 km of natural gas pipelines in the US[2]; 21,000 km of pipelines are used to transmit natural gas in Australi [3]; and there are many more kilometres of gas pipelines in Russia and Canada. Offshore pipelines have only minimal and temporary impact on the environment during installation and hardly any impact during operation. More than 6,000 km of pipelines are operated in the North Sea, some of which have been in operation since the 1970s, which indicates the feasibility and impact of the offshore pipeline.

During pipeline construction, the risk to third parties is limited to the crews and passengers of passing vessels that could collide with construction vessels; these risks are well below the criterion for risks to members of the public. The most significant risks to the environment during construction arise from the potential for oil spills as a result of tanker collisions with the construction vessels. The exclusion zones enforced around the construction 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, gas release and ignition, impacting people on vessels in the impacted area. 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 certain areas to prevent dragging anchors from leading to pipeline damage.

As noted previously in **Section 5.1.2**, there is always a degree of uncertainty in the risk estimates. However, the assessments discussed above show that the estimated levels of risk are significantly below the risk tolerability criteria agreed for the Project, and therefore even if the results were increased by an order of magnitude, they would remain broadly acceptable.

Unplanned events, such as a fuel/oil spill, the disturbance of conventional munitions and pipeline failure, have the potential to result in transboundary impacts (i.e. to impact upon resources/receptors in countries other than the country in which the event takes place). However, the total risk impact (which for pipeline operation is the sum total of all the national impacts), including the impact on the fishing industry and commercial shipping, has been shown to be low.

---

(1) European gas pipeline incident data group (EGIG). EGIG is a co-operation between a group of fifteen major gas transmission system operators in Western Europe and is the owner of an extensive gas pipeline-incident database. www.egig.nl (accessed August 2008).

(2) The US Central Intelligence Agency (CIA). The world factbook. https://www.cia.gov/library/publications/the-world-factbook/ (accessed August 2008).

(3) Australian pipeline industry association website. APIA is a national body representing the interests of Australia's high-pressure transmission pipeline sector. www.apia.net.au (accessed August 2008).

5.8 Reference List

Australian pipeline industry association website. APIA is a national body representing the interests of Australia's high-pressure transmission pipeline sector. www.apia.net.au (accessed August 2008).

Det Norske Veritas (DNV). January 2003. Risk Management in Marine and Subsea Operations. Recommended Practice, DNV-RP-H101.

Energy Institute. 2003. PARLOC 2001: The update of Loss of Containment Data for Offshore Pipelines. Report prepared by Mott MacDonald Ltd for The Health and Safety Executive, The UK Offshore Operators Association and The Institute of Petroleum. ISBN 0 85293 404 1.

European gas pipeline incident data group (EGIG). EGIG is a co-operation between a group of fifteen major gas transmission system operators in Western Europe and is the owner of an extensive gas pipeline-incident database. www.egig.nl (accessed August 2008).

Global Maritime. 22 September 2008. Nord Stream Pipeline Project Risk Assessment Construction Phase. Report No: GM-45190-0708-49203. Nord Stream Report No. G-GE-RSK-REP-126-GM-000049203.

Nord Stream AG. August 2007. Introduction to Health, Safety and Environmental (HSE) Management in Nord Stream AG. Nord Stream Report No. G-GE-HSE-PRO-000-000604L1.

Nord Stream AG and Snamprogetti. 3 January 2008. HSE Activities Management Plan. Nord Stream Report No. G-EN-HSE-REP-102-00085000.

Nord Stream AG and Rambøll. 6 June 2008. Project Description. Work Paper for Danish Permit Application (Extract from Espoo Work Paper, May 2008).

Nord Stream AG & Ramboll. September 2008. Memo 4.3p - Air emissions and climate. Nord Stream Report No. G-PE-PER-EIA-100-43P00000.

Nord Stream AG & Ramboll. 4 October 2007. Memo no. 4.9-2. Military Practice Areas. Nord Stream Report No. G-PE-PER-EIA-100-49200000-01. Version 01.

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

Sanderson, H. & Fauser, P. 20 June 2008. Risk screening of chemical warfare agents towards humans and the fish community resulting from sediment perturbation from construction of the planned Nord Stream offshore pipelines through risk area 3 (S-route) in the Baltic Sea. NERI report.

Sanderson, H. & Fauser, P. 1 July 2008. Historical and qualitative analysis of the state and impact of dumped chemical warfare agents in the Bornholm basin from 1947-2008 NERI report.

Snamprogetti. 28 March 2008. Seismic Design Basis, Snamprogetti report. Nord Stream Report No. G-EN-PIE-REP-102-00071738.

Swedish Meteorological and Hydrological Institute. SMHI's mission is to manage and develop information on weather, water and climate that provides knowledge and advanced decision-making data for public services, the private sector and the general public. http://www.smhi.se/cmp/jsp/polopoly.jsp?d=11122&l=sv (accessed August 2008).

Snamprogetti. 10 June 2008. Effects of Underwater Explosions. Nord Stream Report No. G-EN-PIE-REP-102-0072528-2.

UK Health and Safety Executive. 2001. Reducing Risks, Protecting People: HSE’s decision-making process. ISBN 0 7176 2151 0.

US Central Intelligence Agency (CIA): The CIA is an independent US Government agency responsible for providing national security intelligence to senior US policymakers. The world factbook https://www.cia.gov/library/publications/the-world-factbook/ (accessed August 2008).

Vinnem, J. E. 2007. Offshore Risk Assessment Principles, Modelling and Applications of QRA Studies. Springer. 2nd edition. ISBN 978-1-84628-716-9.