Nord Stream AG

Offshore pipeline through the Baltic Sea

Memo 4.3s
Materials

February 2009

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Table of contents

List of abbreviations and definitions

3LPE	three-layer polyethylene (an anticorrosion coating system)
Al	aluminium
BCM	billion cubic metres
Cd	cadmium
EEZ	exclusive economic zone
EAC	environmental assessment criteria
EIA	environmental impact assessment
Espoo Convention	Convention on Environmental Impact Assessment in a Transboundary Context
EPA	Environmental Protection Agency
EU	European Union
FBE	fusion-bonded epoxy
HELCOM	Helsinki Commission. Convention on the Protection of the Marine Environment of the Baltic Sea Area
HDPE	high-density polyethylene
HERA	Human and Environmental Risk Assessment
IPCS	International Programme on Chemical Safety
KP	kilometre post
LC_{50}	lethal concentration where 50% of the test population is killed
Log K_{OW}	the logarithmic octanol-water partition coefficient (a measure of a compounds' solubility in water)
µg/l	microgram (10^{-6} g) per litre (the concentration of a compound per litre of water)
OSPAR	Oslo and Paris Convention on the Protection of the Marine Environment of the North East Atlantic
Pb	lead
PBT/vPvB	persistent, bioaccumulative, toxic / very persistent, very bioaccumulative
PE	polyethylene
PEC	predicted environmental concentration
PNEC	predicted no-effect concentration
pig/pigging	pipeline inspection gauges for cleaning, inspecting the pipeline without stopping flow of gas in the pipeline
ppm	parts per million
PU	polyurethane
SES	Saipem Energy Services
TEN-E	Trans-European Energy Network
TW	territorial water
US	United States
WT	wall thickness
Zn	zinc

1. Introduction

1.1 The Nord Stream Project

Nord Stream is a natural gas pipeline transmission system from Russia to Germany with connections to onshore transmission systems in these two countries. The system will consist of two almost parallel 48-inch steel pipelines and is to be built by Nord Stream AG. It will pass through the exclusive economic zones (EEZs) of five countries: Russia, Finland, Sweden, Denmark and Germany, and the territorial waters of Russia, Germany and Denmark. At full capacity it will provide 55 billion cubic metres (bcm) of natural gas per year to western European consumers. The European Union's institutions, recognizing the need to encourage the construction of new import routes, have designated Nord Stream a 'project of European interest' as part of the Trans-European Networks - Energy (TEN-E).

The shareholders of Nord Stream AG are:

- OAO Gazprom,
- Wintershall AG (a BASF subsidiary)
- E.ON Ruhrgas AG (an E.ON subsidiary)
- NV Nederlandse Gasunie

Nord Stream AG is based in Zug, Switzerland, with a branch office in Moscow, Russia. The company was established for the planning, construction and subsequent operation of the new offshore pipelines across the Baltic Sea.

1.2 Materials and chemicals assessment

As basis for the environmental impact assessment (EIA), several background memos have been prepared.

As the different types of materials used for the Nord Stream pipelines will be exposed to the Baltic Sea marine environment during the pipelines' expected lifetime of 50 years, there is a risk that these materials may degrade and that some of their constituents will leak into the water column.

This memo assesses the potential environmental impacts of the materials used for the Nord Stream pipelines by identifying the total inventory of materials to be used for the pipelines and subsequently evaluate their potential ecotoxicological effects.

2. Summary

The Nord Stream pipelines will be constructed of individual 12.2 m steel line pipes that will be welded together in a continuous laying process. The line pipes will be internally coated with an epoxy-based material to reduce the hydraulic friction.

An external three-layer polyethylene coating will be applied over the line pipes to prevent corrosion. Further corrosion protection will be achieved by incorporating sacrificial anodes of aluminium and zinc. A concrete weight-coating containing iron ore will be applied over the line pipe's external anti-corrosion coating.

A field joint coating will be applied over the welded joints. The field joint coating will consist of a heat shrink sleeve applied directly over the joint. Polyurethane foam will be sprayed through a hole in a former mounted over the concrete gap in order to fill the annulus between the concrete coatings on either side of the joint.

The total material consumption for the Nord Stream Project will be:

- Approx. 2,140,415 tonnes carbon steel
- Approx. 2,447 tonnes epoxy paint for internal coating
- Approx. 50,822 tonnes PE for external anticorrosion coating
- Approx. 2,451,006 tonnes weight coating (70% iron ore, 30% cement)
- Approx. 6,222 tonnes aluminium and 5,644 zinc alloy for sacrificial anodes
- Approx: 1,003 tonnes PE and 8,653 tonnes PU for field joint coating

Potential impacts during construction of the pipelines are related to the waste generation onboard the pipe-laying vessels and the overall management of waste by the Project. All waste will be collected and transported to shore for appropriate disposal and will therefore not lead to any impacts on the Baltic Sea environment.

Potential impacts during pre-commissioning of the pipelines are related to the possible discharge of small amounts of epoxy dust/scraps with the test water. Only very negligible impacts are expected due to the very small amount of debris that may be present in the pipelines after cleaning.

Potential impacts during the expected 50 years of operation of the pipelines are related to the possible migration of harmful substances from the pipeline to the marine environment.

Based on an ecotoxicological evaluation it is assessed that the potential impacts caused by migration of compounds from the internal epoxy coating, the external three-layer anticorrosion coating, the concrete coating and the field joint coating to the water phase will be minor or nonexistent, even in a worst case scenario. This is mainly due to the coatings either being very durable or not containing compounds that may have negative effects on the marine environment.

The sacrificial anodes are designed to release a small amount of material to the water to sustain the cathodic protection of the pipeline in case of damage to the external coating and exposure of the bare pipe. The release of metal will impact the biota living directly on the pipeline, but this is only expected to occur in the shallower parts of the pipeline route. It has been calculated that the concentration of zinc will be larger than the predicted no-effect concentration in a distance of < 3 m from the individual anodes. However, this is only assessed to be a minor impact on the environment, since only few receptors will be living so close to the pipeline. In total, the sacrificial anodes are expected to contribute approximately 90.3 tonnes of zinc and 99.5 tonnes of aluminium to the Baltic Sea per year during the lifetime of the pipelines.

Once the pipelines have reached the end of their design life or economic life they may be shut down. Decommissioning will take place according to industry standards at that point in time. In case the pipeline is left on the seabed after decommissioning, the materials will slowly decompose and the materials will be spread in the Baltic Sea.

3. Methodology

3.1 Content of the memo

The scope of this study is the upstream pipeline system, which is defined as the two Nord Stream pipelines that will run from Portovaya Bay near the town of Vyborg, north of St. Petersburg, Russia, across the Gulf of Finland and the Baltic Sea to landfall at Lubmin in the Greifswald area in Germany. The pipeline route is depicted in Figure 3.1.

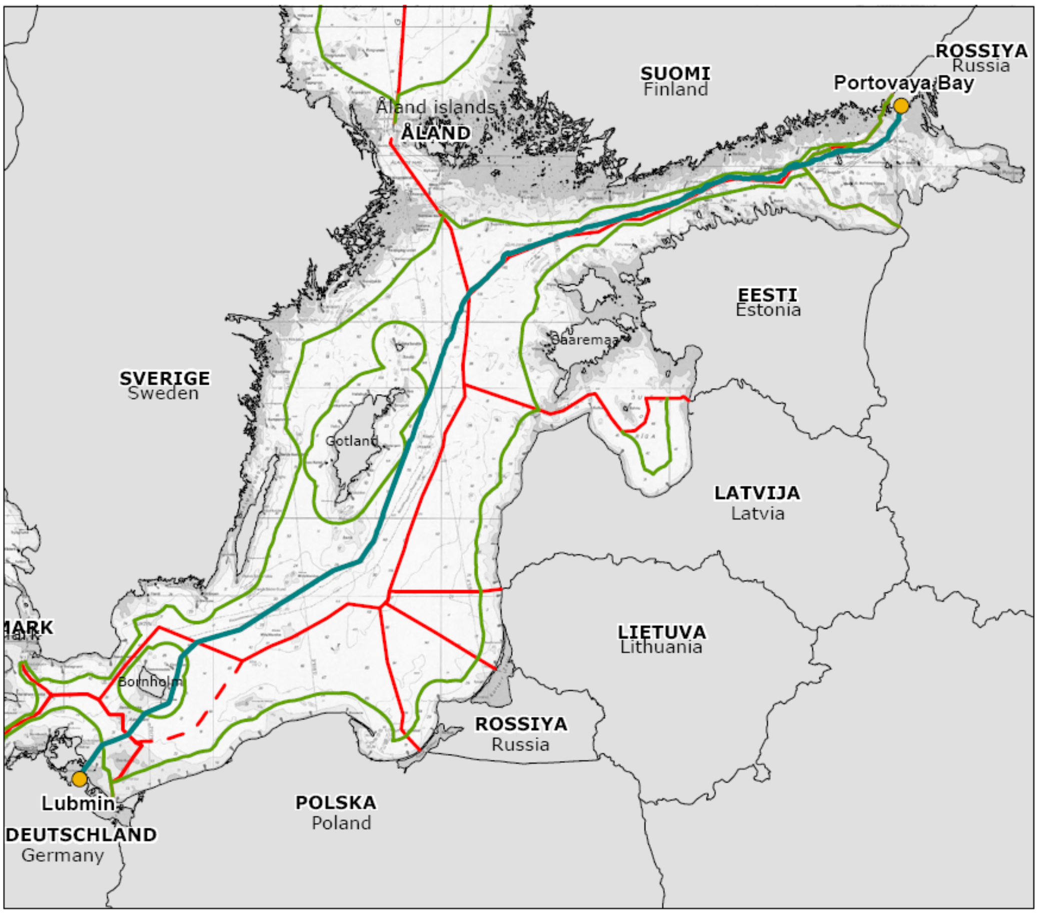

Figure 3.1: The Nord Stream pipeline route through the Baltic Sea. The dark green line indicates the pipeline route. The red lines indicate the exclusive economic zones of the countries around the Baltic Sea, and the green lines indicate the limit of the territorial waters. The dotted red line indicates the midline between Denmark and Poland.

The Nord Stream pipeline will consist of two 48-inch steel pipelines with a capacity of transporting 55 bcm per year in total. The pipelines are referred to as the 'north-west' and 'south-east' pipelines to distinguish their orientation relative to each other.

Each pipeline has a total offshore length of about 1,222 km. Landfall facilities in Russia and Germany will connect the two pipelines to the Russian and European gas networks.

This memo identifies and quantifies the total inventory of materials to be used for the offshore part of the Nord Stream pipeline system. Where applicable, the ecotoxicological impact on the marine environment of these materials is evaluated.

The inventory of materials is presented in Chapter 4, an assessment of the potential environmental impacts in the different stages of the Nord Stream pipeline project is presented in Chapter 5 and a summary of the impacts in a transboundary context is given in Chapter 6.

3.2 Collection of data

The data used for quantification of the material demand is based on the technical documentation for the pipeline design provided by Nord Stream AG and the design contractor Saipem Energy Services[1] (SES, former Snamprogetti S.p.A.).

The typical chemical composition of the coating materials has been obtained from data sheets provided by potential or already selected suppliers. The majority of this data is confidential and is therefore not directly mentioned or referred to in this study.

The environmental properties for the substances are found by searching in acknowledged databases and resources such as the US EPA ECOTOX Database /1/, IPCS INCHEM[2] /2/, Danish EPA /3/ and HERA[3] Risk Assessment /4/. For most compounds it was possible to find data in these resources but in a few cases the data origin from producers of chemicals, e.g. from material safety data sheets.

3.3 Field data

No field data has been used for this study.

3.4 Methodology

The impact assessment is hierarchically based. First the constituents of the different materials have been identified and quantified. Then it has been researched whether any of these compounds are potentially harmful and if they are able to leak into the water column. Finally the concentrations of the potentially harmful substances in the water column have been estimated (the so-called predicted environmental concentration, PEC) and compared to the concentration below which unacceptable

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[1] SES is an engineering contractor of the Eni Group based in Italy. The company has been mandated by Nord Stream AG to perform the task of detailed design engineering of the Nord Stream pipelines.

[2] IPCS is a joint programme of WHO, ILO and UNEP. INCHEM provides access to internationally peer reviewed information on chemicals.

[3] HERA is a European voluntary risk assessment initiative between manufacturers of household cleaning products and suppliers of the raw materials.

effects on organisms will most likely not occur (the so-called predicted no-effect concentration, PNEC).

In cases of exceedance of the PNEC value, the risk of effects on the marine environment has been assessed. The risk depends on the concentration, speciation and harmful characteristics of the substance in question and the time and physical range of the exposure of the marine environment to the elevated concentrations.

The impact assessment methodology principle is shown in Figure 3.2

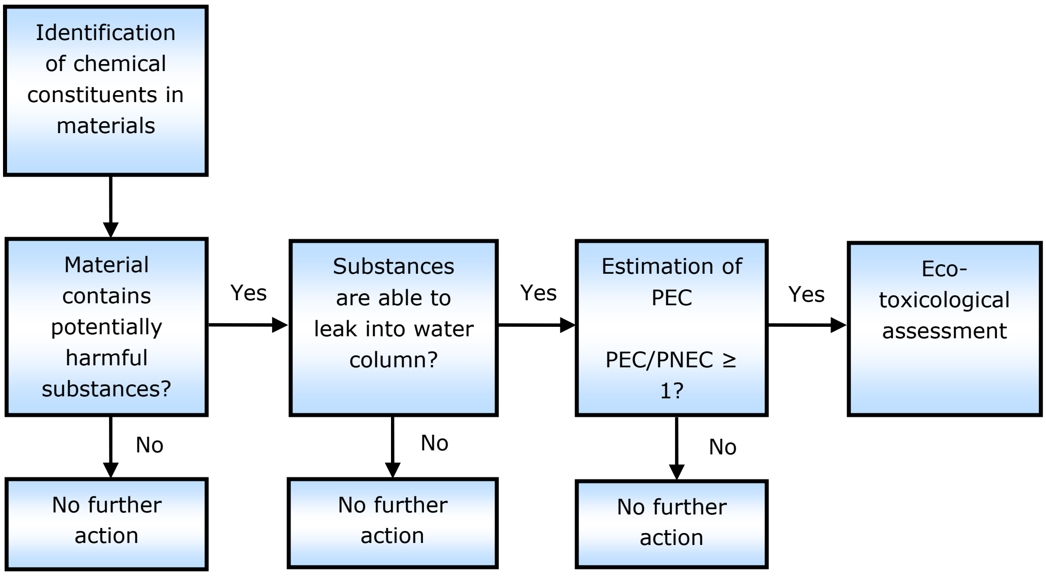

Figure 3.2: Schematics of the assessment methodology.

3.4.1 Identification of harmful properties of a substance

The material constituents have, where possible, been individually assessed with respect to their environmental properties, that is, persistence, bioaccumulation potential and toxicity towards aquatic organisms (PBT). Degradation pathways and the risk of formation of more harmful substances are assessed where possible. For some compounds laboratory data are limited (e.g. for log K_{OW}). In these cases calculated values are used were possible.

When searching for data, emphasis has been on finding data for the standard set of tests for toxicity performed on freshwater/saltwater organisms: Algae, crustacean and fish. In case of lacking data, other results may be included. According to the EU Technical Guidance Document on Risk Assessment /5/ freshwater and saltwater data are usually comparable. This assessment is based on the lowest values found in order to consider the compounds for the most sensitive organisms.

The assessed environmental properties for each compound within its PBT-characteristics are summarized using the following designation:

- : Assessed as not being of concern for the aquatic environment

(+): Assessed as a possible or minor concern for the aquatic environment

+: Assessed as a concern for the aquatic environment

Notice that these assessments are valid for compounds that are unbound and found in the water phase, whereas all chemicals found in the internal and external coatings, the heat shrink sleeve and the PU foam filling are to a very high extent chemically fixed in macromolecular, inert and insoluble complexes.

Different means of release of compounds from the pipeline are identified:

- Degradation/corrosion exerted by organisms (e.g. bacteria)
- Mechanical stress
- Breakdown products from degradation
- Diffusion

The dominant release is assessed to be diffusion. Generally, the release of compounds will be a very slow process – the coatings are intended to sustain a barrier against the harsh conditions found on the bottom of the Baltic Sea and are therefore designed to be resistant against deterioration and degradation. If there is any release of chemical compounds from the pipeline it will not be a point source, but a diffuse release.

The compounds assessed are those found on safety data sheets from the manufacturers. The individual compounds' names, CAS-numbers etc. are concealed and made anonymous here according to confidentiality agreement with producers – all data are compiled in a background document.

3.4.2 Calculation of PEC

The PEC of potentially harmful substances is estimated based on the following assumptions and criteria:

- The pipelines are assumed to be freely exposed on the seabed, i.e. not buried.

- The pipelines have been designed for an operational life of 50 years. The rate of release of substances is assumed to be constant throughout the design life.

- Approx. 40% of the anode material will be sacrificed during the 50 years design life (based on industry experience from anodes in the North Sea).

- The initial dilution of a material that is released from the pipeline will occur in a 1 m layer around the pipeline.

- The potential environmental risks asociated with a release of materials are assumed to be at a local scale.

- Spreading of compounds in the water phase is assumed to be by advection-dispersion, i.e. governed by water flow and molecular diffusion.

- Water current velocity is set at a low level of 0.01 m/s. The modelled mean sea bottom current at six different locations along the pipeline route was between 0.01 and 0.06 m/s /6/.

The PEC values have also been compared to measured background values obtained from HELCOM /7/ and water quality criteria. Since no specific water quality criteria exist for the Baltic Sea, the OSPAR Ecotoxicological Assessment Criteria (EAC) for the North Sea has been used /8/. The EAC is defined as the concentration level of a substance above which concern for ecotoxicological effects is indicated.

4. Inventory of materials

The following section contains an inventory of the materials that will be used for the Nord Stream pipelines. The inventory is based on present (January 2009) status specifications and design. These may be subject to further optimisation during final detailed design.

4.1 Length of the pipelines

The Nord Stream Route passes through the exclusive economic zones (EEZs) of Russia, Finland, Sweden, Denmark and Germany. In Russia, Denmark and Germany the pipeline also passes through territorial waters (TWs). Reference is made to Table 4.1 and Table 4.2 for the length of the pipelines in the five countries. The kilometre post (KP) refers to the location along the pipeline length starting from the Russian landfall at KP 0.

Table 4.1 Details of lengths of the north-west pipeline in the countries of origin. Lengths are approximate and subject to final optimisation.

North-west line	Classification	Section length [km]	National length [km]	Cumulative kilometre point [km]	Dry/wet section
Russia	Dry section	1.5	1.5		1.5
	TW	121.8	123.2	123.2	1223.1
	EEZ	1.4			
Finland	EEZ	375.3	375.3	498.5	
Sweden	EEZ	506.4	506.4	1004.9	
Denmark	EEZ	49.4	137.1	1142.0	
	TW	87.7			
Germany	EEZ	31.2	81.1	1223.1	
	TW	49.9			
	Dry section	0.5	0.5		0.5

Table 4.2 Details of lengths of the south-east pipeline in the countries of origin. Lengths are approximate and subject to final optimisation.

South-east line	Classification	Section length [km]	National length [km]	Cumulative kilometre point [km]	Dry/wet section
Russia	Dry section	1.5	1.5		1.5
	TW	122.5	123.7	123.7	1222.2
	EEZ	1.2			
Finland	EEZ	374.3	374.3	498.0	
Sweden	EEZ	506.1	506.1	1004.1	
Denmark	EEZ	49.5	137.1	1141.2	
	TW	87.6			
Germany	EEZ	31.2	81.0	1222.2	
	TW	49.8			
	Dry section	0.5	0.5		0.5

4.2 Materials, components and manufacturing

The Nord Stream pipelines will be constructed of individual 12.2 m steel line pipes that will be welded together in a continuous laying process. The line pipes will be internally coated with an epoxy-based material. The purpose of the coating is to reduce hydraulic friction, thereby improving the flow conditions.

An external three-layer polyethylene coating will be applied over the line pipes to prevent corrosion. Further corrosion protection will be achieved by incorporating sacrificial anodes of aluminium and zinc. The sacrificial anodes are a dedicated and independent protection system in addition to the anticorrosion coating.

A concrete weight-coating containing iron ore will be applied over the line pipe's external anti-corrosion coating. While the primary purpose of the concrete coating will be to provide on-bottom stability, the coating will also provide additional external protection against foreign objects, such as impacts by fishing gear.

When the pipes are welded together on the lay vessel a field joint coating will be applied over the joints. The field joint coating will consist of a heat shrink sleeve applied directly over the joint. Polyurethane foam will be used to fill the annulus between the concrete coatings on either side of the joint. The foam will be sprayed through a hole in a former, which will be mounted over the concrete gap. The formers will be made of either polyethylene or carbon steel.

The present status (January 2009) of the specifications for the above-mentioned materials and the expected quantities required for the construction of the Nord Stream pipelines are outlined below. These specifications may be subject to further optimisation during detailed design.

4.2.1 Line pipe

The pipelines will be constructed of steel line pipes with a length of 12.2 m that are welded together. The line pipes will be submerged arc, single seam, longitudinally welded SAWL 485 I FD[4] grade carbon steel line pipe, as per DNV OS-F101 /9/, with a nominal diameter of 48" (~ 1,219.2 mm) and a constant internal diameter of 1,153 mm.

The wall thickness of the steel pipes is based on maximum allowable operation pressure and therefore varies in four thicknesses between 26.8 – 41.0 mm. The wall thickness will be distributed as indicated in Table 4.3 and Table 4.4.

[4] Designation for the pipeline material specification: SAWL = process of manufacture (submerged-arc welding, one longitudinal weld seam); 485 = specified minimum yield stress (SMYS), in MPa; I = level of non-destructive testing (I = level I); FD = supplementary requirements (F = fracture arrest properties, D = enhanced dimensional requirements)

Table 4.3 North-west pipeline wall thickness (WT) distribution. Lengths are approximate and subject to final optimisation.

From KP [km]	To KP [km]	Length [km]	Pipe WT [mm]
0.0	0.5	0.5	41.0
0.5	300.0	299.5	34.6
300.0	675.0	375.0	30.9
675.0	1222.6	547.6	26.8
1222.6	1223.1	0.5	30.9

Table 4.4 South-east pipeline wall thickness (WT) distribution. Lengths are approximate and subject to final optimisation.

From KP [km]	To KP [km]	Length [km]	Pipe WT [mm]
0.0	0.5	0.5	41.0
0.5	300.0	299.5	34.6
300.0	675.0	375.0	30.9
675.0	1221.7	546.7	26.8
1221.7	1222.2	0.5	30.9

The density of the carbon steel that will be used for the line pipe will be 7,850 kg/m^3. The material composition of the steel and the corresponding weight is displayed in Table 4.5 below.

Table 4.5 Chemical composition of SAWL 485 I FD carbon X70 graded steel.

Element	Maximum contents [weight %]
Carbon (C)	0.080
Manganese (Mn)	1.750
Silicon (Si)	0.350
Phosphorus (P)	0.015
Sulphur (S)	0.003
Nitrogen (N)	0.010
Aluminium (Al)	0.035
Nickel (Ni)	0.425
Molybdenum (Mo)	0.300
Chromium (Cr)	0.300
Copper (Cu)	0.300
Vanadium (V)	0.080
Niobium (Nb)	0.060
Titanium (Ti)	0.030
Calcium (Ca)	0.004
Arsenic (As)	0.003
Tin (Sn)	0.005
Iron (Fe)	96.25
Total	**100**

4.2.2 Buckle arrestors

To minimise the risk of pipe collapse during installation, buckle arrestors (pipe reinforcement) will be installed at specific intervals in susceptible areas. The buckle arrestors will be welded into the pipelines in those areas that are susceptible to propagation buckling, i.e., deeper sea areas. Risk of collapse is during installation only.

The buckle arrestors will be made of the same steel alloy as the line pipes and will be equal in length to the line pipes. However, these pipes will have a greater wall thickness, with machined thinner wall ends to match the adjoining line pipe, as illustrated in Figure 4.1.

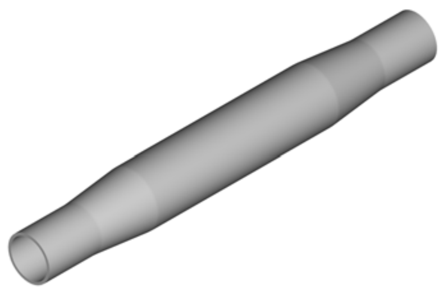

Figure 4.1 Buckle arrestor principle. The buckle arrestor has a greater wall thickness than the adjacent section of pipeline.

Buckle arrestors will be used along a 305 km stretch of the pipeline, more specifically from KP 420 to KP 520, from KP 550 to KP 610, from KP 675 to KP 800 and from KP 1000 to KP 1020. The spacing between the buckle arrestors will be 927 m (equal to 76 line pipes).

4.2.3 Welding of line pipe

Welding consumables similar and compatible to the composition of the line-pipe material will be used. The weld properties will have a minimum steel grade equal to that of the line pipe. No other materials will be added during welding.

4.2.4 Internal antifriction coating

The line pipes will be internally coated with an antifriction coating to increase flow capacity of the pipeline system. The internal coating of a line pipe is illustrated in Figure 4.2. The coating will be an epoxy-based red-brown, high-gloss paint.

The epoxy will be comprised of the following components:

- Epoxy base (epoxy resin, pigments, extenders, additives and organic solvent)
- Curing agent (aliphatic/cycloaliphatic amine or polyamide)

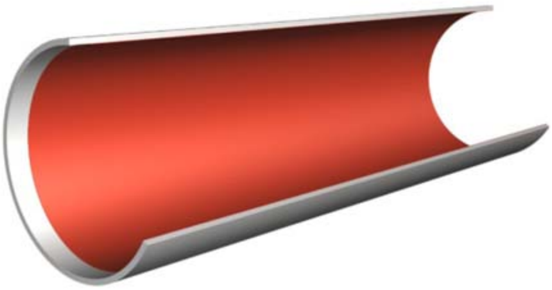

Figure 4.2 Internal line pipe coating will be an antifriction, epoxy-based coating.

The coating will have a thickness of ~90 to 150 μm and cover the entire line pipe length, except for an internal cutback of ~50 mm at the pipe ends to allow for heat transfer during welding. This cutback will remain uncoated after welding.

About 1 kg of epoxy coating will be required per m of pipeline. The coating will be applied at the line pipe manufacturing site.

4.2.5 External anticorrosion coating

An external coating will be applied over the line pipes to prevent corrosion. The external anticorrosion coating will be a three-layer polyethylene (3LPE) coating. The coating principle is illustrated in Figure 4.3 below.

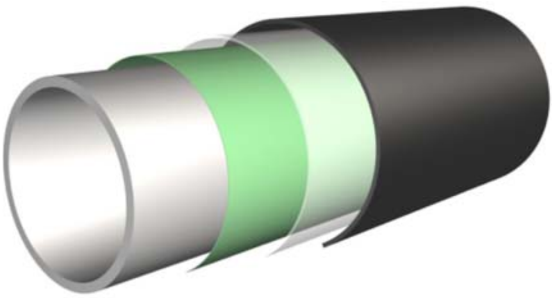

Figure 4.3 Three-layer polyethylene (3LPE) external anticorrosion coating principle. The coating consists of an inner layer of fusion-bonded epoxy (dark green), an adhesive layer in the middle (light green) and a top layer of polyethylene (black).

The 3LPE external anticorrosion coating will comprise of:

- Inner layer: fusion-bonded epoxy with a thickness of 0.15 - 0.30 mm
- Middle layer: adhesive with a thickness between 0.2 - 0.4 mm.
- Outer layer: high density polyethylene base with additives.

The minimum overall thickness of the coating will be 4.2 mm and cover the entire line pipe length, except an external cutback of approximately 200-250 mm at the pipe ends, which will be kept free of coating to facilitate welding and inspection.

About 20 kg of 3LPE coating will be required per m of pipeline. The coating will be applied at the pipe manufacturing site.

4.2.6 Concrete weight coating

The line pipes also will be externally coated with concrete. The concrete coating will be applied over the anticorrosion coating, as shown in Figure 4.4, and will give the pipelines sufficient weight to remain stable on the seabed, both during the installation phase and during the operation of the pipelines.

Both ends of the line pipes will be kept free of concrete coating to allow for welding of the joints at the lay vessel. After welding, these joints will be protected against corrosion (refer to Section 4.2.7 on field joint coating).

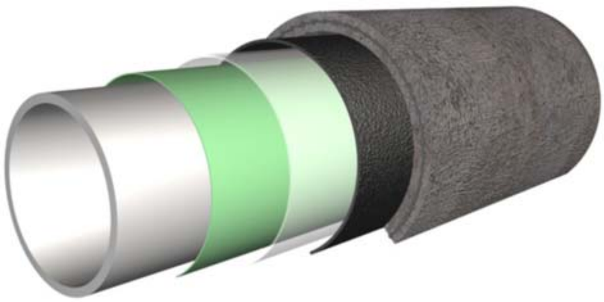

Figure 4.4 Concrete coating on top of the three-layer anticorrosion coating.

The concrete comprises of a mix of cement, water and aggregate (inert solid material such as crushed rock, sand, gravel). The concrete coating will be reinforced by steel bars welded to cages with a minimum bar diameter of 6 mm. Moreover, iron ore aggregate will be added to increase the density of the weight coating. The coating process is illustrated in Figure 4.5.

The cement used for the concrete will be a Portland cement suitable for marine use. The Portland cement will be specified in accordance with ASTM C 150 Type II. No additives will be used in the concrete mixture, but silica fume[5] may be added up to 10% of the cement weight. The maximum chloride in the mix will be less than 0.4%. No admixtures or curing membranes will be used.

The concrete coating will have a thickness of 60-110 mm and a density of maximum 3,040 kg/m^3. Iron ore constitutes 70% of the weight of the coating. The remaining 30% is concrete (cement and aggregate).

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5 Silica fume (or microsilica) is a by-product of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. Silica fume is also collected as a by-product in the production of other silicon alloys such as ferrochromium, ferromanganese, ferromagnesium and calcium silicon.

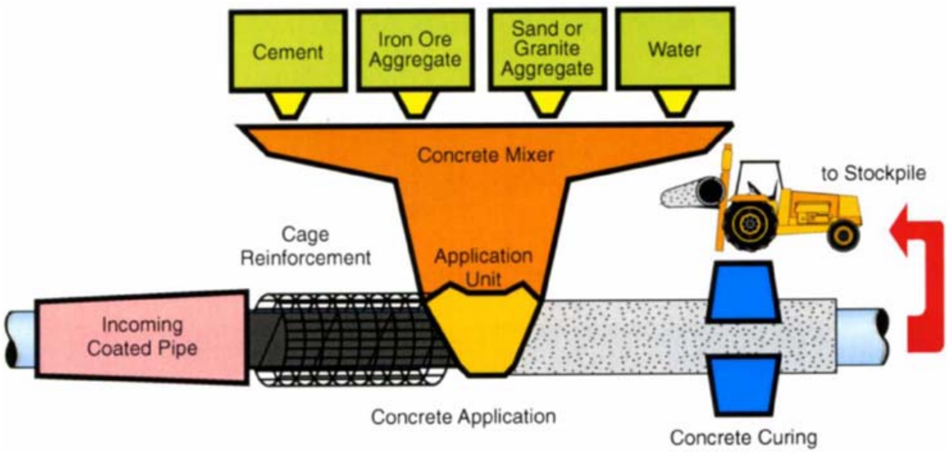

Figure 4.5 Concrete-coating process.

The concrete coating will be applied by an impingement process at weight-coating plants. A pre-defined number of line pipes will have anodes attached during the concrete coating process (see Section 4.2.8 on cathodic protection).

The thickness of the concrete coating can be seen in Table 4.6 and Table 4.7.

Table 4.6 Details of coating of the north-west pipeline in the countries of origin. Numbers are approximate and subject to final optimisation.

From KP [km]	To KP [km]	Section length [km]	Wall thickness [mm]	Concrete thickness [mm]	Concrete density [kg/m^3]
0.0	0.5	0.5	41.0	60	3040.00
0.5	78.6	78.1	34.6	60	3040.00
78.6	296.8	218.2	34.6	80	3040.00
296.8	297.3	0.5	34.6	80	3040.00
297.3	407.6	110.3	30.9	90	3040.00
407.6	415.6	8.0	30.9	80	3040.00
415.6	417.6	1.9	30.9	60	3040.00
417.6	438.3	20.8	30.9	80	3040.00
438.3	523.3	85.0	30.9	60	3040.00
523.3	570.4	47.1	30.9	80	3040.00
570.4	620.6	50.2	30.9	60	3040.00
620.6	668.2	47.6	30.9	80	3040.00
668.2	675.5	7.3	30.9	60	3040.00
675.5	676.0	0.5	30.9	60	3040.00
676.0	762.8	86.8	26.8	70	3040.00
762.8	808.1	45.3	26.8	100	3040.00
808.1	962.6	154.5	26.8	110	3040.00
962.6	1138.5	175.9	26.8	90	3040.00
1138.5	1212.4	73.9	26.8	100	3040.00
1212.4	1222.3	9.9	26.8	90	3040.00
1222.3	1222.8	0.5	30.9	60	3040.00

Table 4.7 Details of coating of the south-east pipeline in the countries of origin. Numbers are approximate and subject to final optimisation.

From KP [km]	To KP [km]	Section length [km]	Wall thickness [mm]	Concrete thickness [mm]	Concrete density [kg/m³]
0.0	0.5	0.5	41	60	3040.00
0.5	79.5	79.0	34.6	60	3040.00
79.5	296.9	217.4	34.6	80	3040.00
296.9	297.4	0.5	34.6	80	3040.00
297.4	413.3	115.9	30.9	90	3040.00
413.3	415.3	2.0	30.9	80	3040.00
415.3	417.8	2.4	30.9	60	3040.00
417.8	438.6	20.8	30.9	80	3040.00
438.6	523.0	84.4	30.9	60	3040.00
523.0	570.2	47.1	30.9	80	3040.00
570.2	620.3	50.1	30.9	60	3040.00
620.3	667.2	47.0	30.9	80	3040.00
667.2	675.0	7.8	30.9	60	3040.00
675.0	675.5	0.5	30.9	60	3040.00
675.5	763.0	87.5	26.8	70	3040.00
763.0	806.6	43.6	26.8	100	3040.00
806.6	962.2	155.6	26.8	110	3040.00
962.2	1138.0	175.8	26.8	90	3040.00
1138.0	1212.2	74.2	26.8	100	3040.00
1212.2	1221.8	9.6	26.8	90	3040.00
1221.8	1222.3	0.5	30.9	60	3040.00

4.2.7 Field joint coating

Concrete-coated line pipes will be transported to the lay vessel, where they will be welded together. Before the lay-down procedure takes place, a field joint coating will be applied externally around the welded pipe joints to fill in the remaining space between the concrete coating on each side of the field joint and to protect the joint against corrosion.

The field joint coating will have a length of about 0.8 m [6], representing approximately 7% of the overall pipeline length. Figure 4.6 (overleaf) shows a field joint prior to coating.

The field joint coating system will comprise a heat-shrink sleeve made of high-density polyethylene. The welded field joint will be heated prior to application of the heat-shrink sleeve. The heat-shrink sleeve is formulated to be cross-linkable, which gives it elastic properties and enables it to fit tightly around the steel pipe joint. Because of the cross-linking, the material will contract to its original length when cooling down, thereby fitting closely around the field joint preventing any voids.

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6 The length of the field joints will vary in areas with lay down heads and buckle arrestors.

Figure 4.6 A typical field joint before coating. The three-layer polyethylene anticorrosion coating and the concrete coating are visible on the line pipes.

Since the heat-shrink sleeve is not thick enough to fill the entire annulus between the concrete at either side of the field joint, a carbon steel sheet or a polyethylene former will be installed around the field joint. The carbon steel sheet or the polyethylene former will overlap the concrete coating and be permanently secured by carbon steel straps (for the carbon steel sheets) or welded polyethylene (for the polyethylene formers). Two-component polyurethane foam will be injected into the void between the heat-shrink sleeve and the steel sheet former through a port created on top of the former. The foam will rise and cure to fill the joint volume. The foam is able to withstand fishing trawl impact.

Figure 4.7 shows the fitting of the infill former in the field joint coating station at the lay vessel along with a field joint after coating.

Figure 4.7 Fitting of the infill former in the field joint coating station (left) and a typical field joint after coating (right). The infill former and the concrete coating are approximately flush and aligned.

The heat-shrink sleeve will be approximately 2 mm thick and have a density of about 900 kg/m^3. The polyurethane foam will have a density of approximately 160 kg/m^3 when in place. The field joint coating will be flush with the concrete.

4.2.8 Cathodic protection

To ensure the integrity of the pipelines over their design operational life, secondary anticorrosion protection will be provided by sacrificial anodes of a galvanic material. This secondary protection will be an independent system that will protect the pipelines in case of damage to the external anticorrosion coating.

The design of the cathodic protection system takes into account various parameters specific to the Nord Stream pipeline – such as pipeline installation operations, lifetime of the pipeline and possible increased coating degradation due to Baltic Sea environmental characteristics – to ensure that the required amount of protection current for the entire pipeline design life is provided.

The performance and durability of different sacrificial alloys in Baltic Sea environmental conditions has been evaluated with dedicated tests conducted by DNV (Section for Failure Investigation and Corrosion Management).

The tests showed that the salinity of seawater has a major effect on the electrochemical behaviour of aluminium alloys. In particular it was observed and reported that low salinity concentrations in seawater dramatically decreased the electrochemical performance of tested samples. During testing, no major effect on electrochemical performance due to H_2S (i.e., oxygen-free conditions) was reported. H_2S is present in the sediment as well as in the sea water in certain parts of the Baltic Sea through which the pipeline will traverse.

In the light of the test results zinc alloy has been selected for parts of the pipeline route with very low average salinity. This is the case in parts of the Russian, Finnish and Swedish exclusive economic zones. For all other sections indium-activated aluminium will be used. The materials composition of the two alloys is outlined in Table 4.8.

Metals	Indium-activated aluminium [weight %]	Zinc [weight %]
Aluminium (Al)	Remainder	0.10 - 0.50
Cadmium (Cd)	0.002	0.007
Copper (Cu)	0.003	0.005
Indium (In)	0.016 - 0.020	-
Iron (Fe)	0.06	0.005
Lead (Pb)	-	0.005
Silicon (Si)	0.08 - 0.12	-
Zinc (Zn)	4.75 - 5.75	Remainder
Others	0.02 each	0.02 each
-: metal not present in anode material		

Table 4.8 Composition of aluminium and zinc alloy for anodes.

The cathodic protection system will thus comprise of:

- Zinc and indium-activated aluminium bracelet anodes (two half-shells per anode)
- Anode electrical continuity cables (two cables per half shell)
- Cartridge/materials necessary to perform the cable welding between anodes and pipes

Figure 4.8 shows a typical anode mounted on a pipeline.

Figure 4.8 A sacrificial anode is mounted in a gap in the concrete coating and directly attached to the pipe.

The dimensions of the anodes depend on various parameters, such as the pipeline dimension, the thickness of the concrete weight coating, the design life of the pipeline, the type of coating, the environment characteristics and the anode material.

It is intended that there will be seven different designs of aluminium anodes and four different designs of zinc anodes. The thickness of the aluminium anodes will vary between 50 - 100 mm, the length will vary between 400 - 520 mm and the weight will vary between 199.9 – 459.9 kg per anode. The zinc anodes will have a thickness varying between 50 - 100 mm, a length varying between 408 - 494 mm and a weight varying between 529.2 – 1,177.7 kg per anode.

Besides the aluminium and zinc the anodes will also contain small amounts of other metals and impurities. Both types of anodes will contain cadmium (<0.01%) and the zinc anodes will additionally contain lead (<0.01%).

The number of anodes to be installed in each country of origin and the corresponding quantities of aluminium and zinc alloy is listed in Table 4.9. The anodes will be spaced 5-12 line pipes apart.

Table 4.9 Number of anodes to be installed in the five countries of origin. Quantities are approximate and subject to final optimisation.

Type	Unit	Russia	Finland	Sweden	Denmark	Germany
Aluminium	[no]	58	2,980	8,326	2,457	1,773
Zinc	[no]	2,206	3,111	891	0	0

4.3 Summary of material amounts

The expected material consumption required for the pipeline sections in each of the five countries of origin is summarised in Table 4.10 below.

Table 4.10 Summary of material consumption in the countries of origin. Quantities are approximate and subject to final optimisation.

Material	Russia	Finland	Sweden	Denmark	Germany	Total
Total length of 2 pipelines (km)	246.9	749.7	1,012.4	274.1	162.1	**2,445.2**
Steel (t) (incl. buckle arr.)	250,530	715,275	833,810	213,800	127,000	**2,140,415**
Internal epoxy coating (t)	247	749	1,014	274	163	**2,447**
External 3LPE coating (t)	5,162	15,615	21,006	5,672	3,366	**50,822**
Concrete weight coating (t)	193,755	714,064	1,042,494	289,531	211,162	**2,451,006**
Anodes Aluminium (t) Zinc (t)	 14 1,673	 1,011 2,845	 3,436 1,126	 936 0	 825 0	 **6,222** **5,644**
Field joint coating Layer 1: HSS (t) Layer 2: PU (t)	 101.2 698.4	 307 2,522	 415 3,716	 112 1,044	 67 673	 **1,003** **8,653**

5. Description of environmental impacts

This chapter contains an assessment of the impact on the marine environment in the Baltic Sea caused by the materials to be used for the Nord Stream pipelines. Environmental impacts from the Nord Stream pipelines are described with respect to the different stages of the project:

- Construction
- Pre-commissioning
- Operation and maintenance
- Decommissioning

Impacts on the onshore environment or impacts due to onshore processes are outside the scope of this study. Only impacts on the offshore marine environment, i.e., from landfall to landfall, are assessed.

Assessment of the environmental impacts from extraction of raw materials and production of chemicals and intermediate products for the pipeline is also outside the scope of this study. However, requirements to the contractor to exercise environmental care are/will be incorporated in the tender documents.

5.1 Impact during construction

The environmental impacts during construction of the Nord Stream pipelines related to the use of materials are described in Chapter 5.1.1. The impacts can be the result of:

- Waste generation and management

5.1.1 Waste generation and management

The pipe-laying processes may generate waste that is different from the typical onboard waste such as food waste, deck sweepings, etc. The typical types of waste that are specific to lay vessels are:

- End millings from the pipe end bevelling process
- Flux from the welding process
- Heat-shrink-sleeve cut-offs
- Polyurethane infill from field joint coating
- Concrete
- Oils (from machinery etc.)

Just before welding, the bare line pipe ends will be bevelled to create a profile for welding, which will produce metal scraps. During welding, flux will be added to prevent oxidation of the base and filler materials. Examples of metal scraps from bevelling and typical containers for collecting and storage are shown in Figure 5.1. The waste will be secured in the containers by strap down covers.

Based on the pipe-lay contractors' experience from a previous project concerning a similar-sized pipeline, approximately 115 tonnes of metal scraps and 25 tonnes of waste oil and sludge is expected to be generated per month of pipe-laying. Pipe-laying for the Nord Stream pipeline will take 11 months for the north-west pipeline and 14 months for the south-east pipeline. It is therefore expected that a total of approximately 2,875 tonnes of metal scraps and 625 tonnes of waste oil will be generated during installation of the pipelines.

The heat-shrink sleeves will be ordered to a specific length for the Nord Stream project. Therefore, apart from the protection sheet, which is removed from the adhesive layer prior to installation, there will be minimal waste from the heat-shrink sleeve itself.

Also, the polyurethane infill has hardly any spills.

Figure 5.1 Metal scraps from the bevelling process (left) and typical containers (right).

All waste produced by the lay vessels will be handled and disposed of in accordance with MARPOL 73/78 and HELCOM requirements. According to these requirements, the Baltic Sea has special area status, meaning that any dumping or discharge of waste into the sea is prohibited.

All waste produced on the lay vessels will be separated and sent to shore to be properly disposed of by a licensed waste disposal contractor. The disposal will take place in compliance with applicable internationally recognised standards and procedures in conjunction with local legislation. Organic and biodegradable waste may be incinerated at site before being sent to shore for controlled disposal.

The processing facilities where the waste will be delivered depend on the geographical location where the pipe-laying vessel is operating. In any case, when applicable, the contractors will make use of the ports already selected to support the Nord Stream project logistics.

Waste generation and management is thus not assessed to have any impact on the marine environment.

5.2 Impact during pre-commissioning

After installation of the pipelines, pre-commissioning and under water tie-ins will be performed before the pipeline system can enter into operation. Pre-commissioning activities will include: flooding, cleaning and gauging of the pipelines, a system pressure test, underwater tie-ins and dewatering and drying of the pipelines.

The pipelines will be flooded with filtered seawater taken in at the Russian landfall. In total, 1,270,000 m^3 of seawater per pipeline will be used. A temporary pumping system will pump the water into a supply line at a depth of 10 m. This system will also be used for the discharge of water during the dewatering operation.

The environmental impacts during pre-commissioning of the Nord Stream pipelines related to the use of materials are described in Chapter 5.2.1 to 5.2.2 . The impacts can be the result of:

- Release of compounds from the internal coating and subsequent discharge of with the test water
- Discharge of internal coating scrap

5.2.1 Release of compounds from the internal coating

As described in section 4.2.4, the Nord Stream pipelines will be internally coated with an epoxy-based paint. It has been considered whether any of the coating constituents may diffuse into the test water and be discharged along with it, since the pipelines may be flooded for some time. The entire process of pre-commissioning each pipeline, including tie-ins, will take approximately five months. This comprises two months for flooding, cleaning and gauging the pipeline, 1.5 months for testing and underwater tie-in and 1.5 months for dewatering and drying the pipeline.

The internal coating is epoxy-based and mainly consists of:

- Epoxy base (epoxy resin, pigments, extenders, additives and organic solvent
- Curing agent (aliphatic/cycloaliphatic amine or polyamide)

Furthermore, the two-component system contains additives in smaller amounts, e.g. solvents).

Two different formulations for the epoxy base will be used. The composition of the base and curing agent in the two formulations is comparable, but additives may be different and amounts of the individual components vary.

When the two components are mixed, the resin base is polymerized to form a protective coating inside the pipe. The reaction between the epoxy base and the curing agent results in strong chemical bindings that are very resistant towards degradation, including impact from salt water and chemicals which will be the case during pre-commissioning.

After reaction and formation of the cured epoxy it is insoluble in water; it is a thermosetting plastic meaning it will not melt or change state until the decomposition temperature is reached. Thus, epoxy products are extremely durable materials, practically being non-degradable in the environment.

The findings regarding the environmental properties of chemical constituents found in the internal coating are summarized in Table 5.1 to Table 5.3 below.

Table 5.1 Summary of PBT-properties, internal coating, epoxy base.

	Epoxy resin	Solvent 1	Solvent 2	Epoxy monomer
Persistent	+	-	(+)	+
Bioaccumulative	(+)	-	-	-
Toxic	(+)	+	(+)	(+)

Table 5.2 Summary of PBT-properties, internal coating, curing part.

	Solvent 1	Solvent 2	Amine 1	Amine 2	Amine 3	Amine 4
Persistent	-	-	-	(+)	(+)	-
Bioaccumulative	-	-	-	(+)	-	-
Toxic	-	-	-	(+)	-	-

Table 5.3 Summary of PBT-properties, internal coating, thinner.

	Solvent 1	Solvent 2	Solvent	Solvent 4
Persistent	-	-	-	(+)
Bioaccumulative	-	-	-	-
Toxic	+	-	-	(+)

The tables show that some of the constituents in the coatings may be problematic in the environment since they have PBT properties. However, as described above the internal coating will be very resistant to degradation and release of compounds to the test water is assessed to be insignificant. Moreover, epoxy in hardened condition has no impact on the aquatic environment and is also approved for in-situ lining of water mains /10/, /11/, /12/.

Impacts from the pre-commissioning activities including discharge of coating substances with the test water is described in detail in the background memo on pre-commissioning /13/. The memo concludes that some discoloration from the internal coating may be washed out of the pipeline with the test water.

5.2.2 Discharge of internal coating scrap

Liquid epoxy coating systems require a clean and dry surface. To ensure the cross linking between the epoxy and the curing agent the right ratio base and hardener has to be respected. Improper mixing can theoretically leave epoxy powder components unhardened. This, however, is unlikely to happen, because the epoxy paint is sprayed on with two-component pumping systems and strict specifications have been set for preparation and check of compliance with established coating standards. Also, repair of the coating is not allowed as per project specifications. It is therefore unlikely that uncured epoxy material will be present in the pipelines.

Nonetheless, it is considered whether other occurrences of the discharge of coating scraps will be discharged during cleaning of the pipeline interior. Flooding of the pipeline will be combined with cleaning and gauging by means of 'pigs'. Examples of pigs are shown in Figure 5.2.

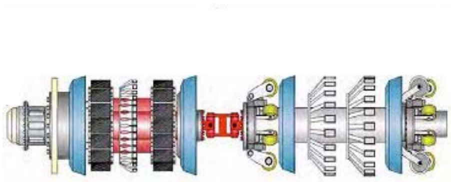

Figure 5.2 Examples of 'pigs'. A gauge pig being pushed into a pig launcher (left) and drawing of a typical intelligent pig for internal inspection (right).

The pig is sent down the pipeline from pig launchers and propelled by the pressure of the water (or gas during operation) in the pipeline. The pigs will be arranged in a 'pig train' that will include at least four cleaning and gauging pigs (high seal, bi-di type without brushes). Some water will be introduced ahead of the first cleaning pig to wash away debris.

The debris will consist of dust that has collected in the pipeline during construction. Besides some epoxy coating scraps the majority of the dust will be comprised of rust (iron oxide) from corrosion of the uncoated pipe at the joints. Also some occasional welding flux from the joint welding and cement dust from the lay vessel may be present. The amount of debris is expected to be only a few cubic metres.

The pigs will push this debris into pig traps/pig receivers, from which it will be collected and then properly disposed of onshore and no environmental impact on the marine environment is therefore expected. Cleaning pigs will be sent down the pipelines until the amount of debris received in front of the last pig is ≤ 5 litres. Even though this indicates that the pipelines are very clean there is a possibility that some small amount of remaining debris (≤ 5 litres) may be discharged with the test water. This small amount of debris that potentially may be discharged is not assessed to cause any environmental impacts.

Impacts from the pre-commissioning activities including discharge of scraps with the test water is also described in the background memo on pre-commissioning /14/.

5.3 Impact during operation and maintenance

The environmental impacts during operation and maintenance of the Nord Stream pipelines related to the use of materials are described in Chapter 5.3.1 to 5.3.6. The impacts can be the result of:

- Release of compounds from the pipeline, external anticorrosion coating, concrete coating, field joint coating and sacrificial anodes to the marine environment

5.3.1 Line pipe and buckle arrestors

The Nord Stream pipelines will be constructed of long carbon steel line pipes that will be welded together.

It is not expected that any of the compounds in the pipeline steel will be released to the marine environment during the lifetime of the pipelines, as they are designed with no corrosion allowance.

5.3.2 External anticorrosion coating

External coating will be applied over the pipelines to prevent corrosion. The external anticorrosion coating will be a three-layer polyethylene (3LPE) anti-corrosion coating.

The 3LPE external anticorrosion coating will consist of:

- Inner layer: fusion bonded epoxy (FBE)
- Middle layer: adhesive
- Outer layer: high density polyethylene (HDPE) base with additives

The outer HDPE layer constitutes the vast majority of the coating. It is stated that the minimum overall thickness of the 3LPE coating will be 4.2 mm. The minimum thicknesses of the three layers in the 3LPE coating will be:

- Inner layer = 0.30 mm
- Middle layer = 0.40 mm
- Outer layer = 3.50 mm

This means that more than 83% of the 3LPE corrosion coating layer is HDPE. Several studies have focused on migration of additives from PE, e.g. for PE pipes used for water pipes and the results from such studies have been used in the assessment.

HDPE is a polymer made of carbon and hydrogen (-CH_2). Typically, thousands of CH_2-groups are combined in a molecule and molecular weight above 100,000 is not unusual. Higher molecular weight (long-chained molecules) means increase in the mechanical characteristics of the HDPE (ultimate strength). Polyethylene is manufactured by polymerization of ethylene - the residual monomer left in the polyethylene is typically less than 1 ppm.

HDPE is used in numerous products, e.g. food packaging, furniture, bags, natural gas pipes, water pipes and bottles. Many studies have been conducted on this material, e.g. by the Danish EPA. It has been found that additives may migrate from the HDPE.

Also, it is known that polyethylene in time will deteriorate and decompose due to light exposure and oxygen /15, 16/. Decomposition will increase when the temperature is increased and new chemical compounds will be formed during the decomposition. Typically, oxygen will be a part of these chemical compounds.

Environmental properties for the 3LPE anti-corrosion coating are summarized in Table 5.4 to Table 5.6 below. The designations for the HDPE layer 1, 2 and 3 do not necessarily reflect the order of the three layers in the coating. Notice that the assessment is made for unbound dissolved chemicals and that they are in fact bound in a complex.

Table 5.4 Summary of PBT-properties, HDPE layer 1.

	Polymer	**Anti-oxidant 1**	**Anti-oxidant 2**	**Acid scavenger**	**UV-Stabilizer 1**	**UV-Stabilizer 2**	**Pigment**
Persistent	+	+	+	+	+	+	+
Bioaccumulative	-	-	(+)	-	(+)	(+)	-
Toxic	-	-	-	-	-	-	-

Table 5.5 Summary of PBT-properties, HDPE layer 2.

	Polymer	**Antioxidant 1**	**Antioxidant 2**	**Acid scavenger**	**UV-Stabilizer**
Persistent	+	+	+	-	+
Bioaccumulative	-	-	(+)	-	-
Toxic	-	-	-	-	(+)

Table 5.6 Summary of PBT-properties, HDPE layer 3.

	Polymer 1	**Polymer 2**	**Antioxidant 1**	**Antioxidant 2**
Persistent	+	+	+	+
Bioaccumulative	-	-	-	(+)
Toxic	-	-	-	-

The tables show that many of the compounds present in the 3LPE coating will be persistent in an aquatic environment, and some compound may also display either biocaccumulability or toxicity. However, the compounds are not expected to migrate into the marine environment.

One reason is that the coating is applied to the pipeline in order to prevent corrosion, thus it has been made with the intention to be stable and sustain a protective barrier around the steel pipe for many years.

Also, decomposition of the coating will inevitably happen over the course of time, however, the decomposition rate of HDPE is expected to be extremely low under the aquatic conditions present where the pipeline will be located due to the following reasons:

- Low temperature
- Little oxygen present
- Very little light present
- The HDPE has been stabilized with antioxidants
- HDPE is covered by a thick layer of concrete coating

It is thus emphasized that migration of additives and degradation of the PE are slow processes and that the compounds being released will be found in small very small concentrations probably below detection limits. Migration is mainly expected if the concrete coating is damaged and the HDPE coating is exposed. No environmental impacts are expected from the 3LPE coating.

5.3.3 Concrete weight coating

No additives or hazardous compounds will be used in the concrete. It is therefore assessed to have no negative impact on the marine environment.

5.3.4 Field joint coating

As described in section 4.2.7, the selected field joint coating system consists of a heat-shrink sleeve made of high density polyethylene (HDPE). A steel sheet or a polyethylene former will be installed around the field joint, overlapping onto the concrete coating and permanently secured by carbon steel straps (for the steel sheets) or welded polyethylene (for the polyethylene formers). Two-component polyurethane (PU) foam will be injected into the void between the heat-shrink sleeve and the steel sheet former. The PU filling expands and fills the void thus hindering intrusion of water and subsequent corrosion of the steel.

It is possible that some of these steel or PE sheets will be damaged and fall off during the lifetime of the pipeline. Should this happen, the PU infill and ultimately the HDPE heat shrink sleeve will be exposed to the marine environment.

The HDPE heat shrink sleeve mainly consists of an insoluble polymer. A few additives (e.g. pigment and antioxidant) are also found in the PE. The adhesive layer on the heat shrink sleeve consists of various chemicals, e.g. resins, asphalt, pigment and antioxidant.

PU foam consists of a resin (polyols) and a hardener (isocyanides).

The environmental properties of the heat shrink sleeve and PU foam are summarized in Table 5.7 and Table 5.8 below. It should be noted that the assessment is made for unbound dissolved chemicals and that they are in fact bound in a complex.

Table 5.7 Summary of PBT-properties, heat shrink sleeve.

	Polymer 1	Antioxidant 1	Resin 1	Butyl rubber		Naphtha
Persistent	+	+	+	+		+
Bioaccumulative	-	(+)	-	-		-
Toxic	-	-	-	-		-
	Polymer 2	**Antioxidant 2**	**Resin 2**	**Wax**	**$CaCO_3$**	**Pigment**
Persistent	+	+	+	-	-	+
Bioaccumulative	-	(+)	-	-	-	-
Toxic	-	-	-	-	-	-

Table 5.8 Summary of PBT-properties, PU foam.

	Polyol	Amino alcohol	Isocyanate
Persistent	-	+	+
Bioaccumulative	-	-	-
Toxic	-	(+)	-

Degradation and a potential loss of residual polymer from the HDPE sleeve to the water body from such a polymer in the conditions found here is unlikely to result in an environmental impact. The PE is protected against UV light and oxygen meaning that degradation factors are virtually not present. Small pieces or fractions of solid PE may be released at some time e.g. due to mechanical stress but free monomers are unlikely. The additives (e.g. pigment and antioxidant) are bound in the structure and any release will be very slow. The adhesive layer on the heat shrink sleeve consists of various chemicals, e.g. resins, asphalt, pigment and antioxidant. The resins in the adhesive layer are cured via polymerization and are subsequently heavily bound, making bioavailability unlikely. The additives are also expected to be bound in the material. In case of diffusion to the water phase, the additives are not acute toxic and/or are insoluble in water, meaning bioavailability is diminished. /15, 16/

The polyol and the isocyanate of the PU foam will be processed with a mixing ratio of 1:1. The processing is performed using a stoichiometric iso-index meaning that after foaming the number of free reactive NCO-groups is negligible. The isocyanate is highly reactive and after reaction with the resin compound it is heavily bound in a insoluble and inert complex. Any residual monomers migrating from the PU to the surrounding water is not expected to result in exposure for the aquatic organisms, since the reactivity of the monomer will presumably lead to binding of MDI to abiotic dissolved or particulate organic material before interaction with biota. The complexes are typically not bioavailable and no exposure takes place /17/. Any diffusion of residual polyol is not assessed problematic, since they are only slightly toxic towards aquatic organisms and/or biodegradable. /18/

5.3.5 "Worst case" consideration: The case of the heat shrink sleeve

The heat shrink sleeve and the PU foam are the material regimes that are most likely to be exposed to the marine environment (if steel sheets or PE sheets fall off). Therefore, a worst case consideration regarding migration of compounds from the materials to the water phase is made for the heat shrink sleeve and the PU foam.

For the heat shrink sleeve, an Antioxidant 1 is chosen: It is persistent and bioaacumulative and labelled with R50/53 by the EU. The proportion of antioxidant is unknown , but studies have shown that antioxidants in PE pipes typically are in the range 0.0007-0.5% /19/. As a conservative estimate, is it assumed that the antioxidant is present as 0.5% (by mass). The potential release of additives from PE has been evaluated in several studies regarding rub off from drinking water pipes to the water. These studies have emphasized on the concentrations found in the water, whereas the total potential for release is unknown. Here, a released fraction of 20% is used. This is assessed to be *very* conservative.

Table 5.9 Properties for heat shrink sleeve.

Total amount of heat shrink sleeve (kg)	1,003,000
Antioxidant 1 content (%)	0.5
Fraction released (%)	20
No. of pipe joints (-)	200,410

Thus, a total amount of 5,015 kg Antioxidant 1 is used for the two pipelines. Assuming that 20% is released (via diffusion) within a month after a carbon steel or PE sheet falls off the pipeline, and knowing the dimension of the heat shrink sleeve a diffusive flux of approximately 122 $mg \cdot m^{-2} \cdot h^{-1}$ is found. Supposing equilibrium with the surrounding water body is reached within 24 h in a circular layer of 1 m water around the heat shrink sleeve with an exchange rate of 0.5 hours, it will result in an average concentration in the water body of 0.038 mg/l. This is below the NOEC values found for crustacean (0.74 mg/l, 48 h) and algae (0.63 mg/l, 72 h) and well below the NOEC for fish (5 mg/l, 96 h). The same calculation for polyol found in the PU foam results in an average concentration of 30 mg/l (lowest NOEC found is 8590 mg/l for crustacean).

The calculations and results are assessed to be very conservative because:

- Less than 20% is likely to be released
- It will occur during much longer time, probably years

Thus, the actual concentration that is expected around the heat shrink sleeve will be magnitudes lower, if even measurable. Furthermore, compounds that may migrate into the water phase are in many cases biodegradable or insoluble in water. However, the calculation illustrates that even an unlikely, extreme worst case scenario does not give reason to environmental concern regarding the chemicals found in the anti-corrosion coating.

5.3.6 Sacrificial anodes

To minimize external corrosion, cathodic protection of the offshore pipelines will be based upon sacrificial anodes of a galvanic material. This type of corrosion protection is also used on e.g. ships and in harbours.

As mentioned in Chapter 4.2.8 both indium-activated aluminium alloy and zinc alloy will be used as anode material. The zinc anodes are required where salinity levels are low, i.e. in some parts of the Russian, Finnish and Swedish waters.

The potential environmental impacts from pipeline anodes are related to the release of metal ions from the anode material, which will seep to the marine environment during the lifetime of the pipeline. The release rate of metal ions from the anodes depends on the total amount of anode material and the release rate of metals from the anodes.

The total mass of anode material required for both pipelines is 6,222 tonnes of aluminium alloy and 5,644 tonnes of zinc alloy. Apart from aluminium and zinc, the alloys comprise small quantities of other metals. Both the zinc and aluminium anodes contain traces of cadmium (< 0.01%). Moreover, the zinc anodes contain traces of lead (< 0.01%). The anodes will be spaced 5 to 12 line pipes apart, corresponding to a distance between the anodes of 61 to 146.4 m.

A screening of the release of metals from the anodes based on the initial dilution in the first 1 m of water around the anode has been made. In the screening, the PEC values for the most problematic metals (either due to their concentration or due to their environmental properties) has been compared to general background levels in the Baltic Sea /7/. The PEC values have also been compared to water quality criteria and to PNEC values. The results are seen in Table 5.10. The PEC is shown as a min to max range due to the different sizes of anodes that will be used along the pipeline.

Specific water quality criteria have not been established for the Baltic Sea, instead water quality criteria for the North Sea have been used, the so-called OSPAR Environmental Assessment Criteria (EAC) values /20/ /21/ where available, for the remaining compounds PNECs derived in the earlier EU TNO Report has been used /22/. No background value has been found for aluminium, neither have EAC or PNEC values been established. According to the US EPA ECOTOX database /23/ the most sensitive method of toxicity of aluminium in sea water yields a LC_{50} of 120 µg Al/l for water.

The screening showed that zinc from the zinc anodes is the only compound where the predicted environmental concentration (PEC) is higher than the predicted no-effect concentration (PNEC), whereas the release of zinc from the aluminium anodes is predicted to be within the acceptable EAC level and below PNEC values. The releases of cadmium from the aluminium and zinc anodes and the release of lead from the zinc anodes will be so low that they will fall below the EAC quality criteria and PNEC values. The release of aluminium from the aluminium anodes will result in a high concentration of dissolved aluminium (similar range as that of zinc), but since aluminium is generally not considered problematic for the aquatic environment it is not further assessed.

Table 5.10 Max. metal ion concentrations from aluminium and zinc anodes in the water column 1 m from the pipeline compared to background concentrations, water quality criteria and PNEC values.

Metals	**Metal content (% mass)**	**Release rate (mg/hr)**	**PEC 1 m from the pipeline (µg/l)**	**Background concentration /7/ (µg/kg water)**	**Accep-table level at sea /24/ (µg/l)***	**PNEC /20/,/21/ (/22/) (µg/l)**
Aluminium anode						
Aluminium	94.57	327	15.92-45.75	-	-	-
Zinc	5.25	18	0.88-2.54	0.6-1.0	0.5-5	7.8 (0.56)
Cadmium	0.002	0.07	0.0003-0.001	0.012-0.016	0.01-0.1	0.19 (0.115)
Zinc anode						
Aluminium	0.30	3	0.17-0.35	-	-	-
Zinc	99.68	832	55.48-115.37	0.6-1.0	0.5-5	7.8 (0.56)
Cadmium	0.007	0.06	0.004-0.008	0.012-0.016	0.01-0.1	0.19 (0.115)
Lead	0.005	0.04	0.003-0.006	0.012-0.020	0.5-5	(0.1)

For assessment of the potential environmental impact of the zinc metal concentration in the water column, the $PEC_{MIN-MAX}$ has been calculated using a simplified advection-dispersion transport model as seen in Figure 5.3 overleaf.

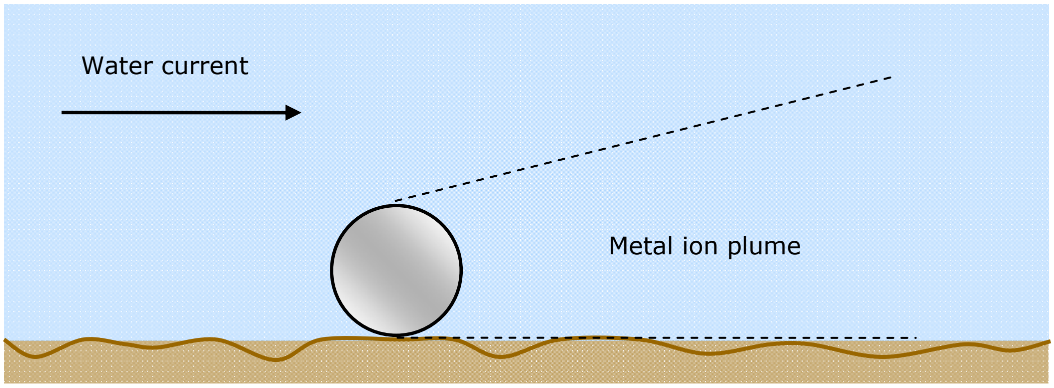

Figure 5.3 Principle in the simplified advection-dispersion model used for estimation of the spreading of zinc from the anodes.

In the model the concentration of released metals from the anodes depends on molecular diffusion and mechanical dispersion and thus is a function of the water velocity, the distance from the anode and the lateral and vertical spreading of the plume. The model uses the following assumptions:

- The initial area is set as the max outer height of the pipeline (approx. 1.5 m) times the width of the anode (approx. 0.5 m).
- The plume slope factor is set at 0.2 (for both vertical and lateral spreading).
- The water velocity is set at 0.01 m/s, which is the lowest mean value derived from long-term measurements of bottom water current velocities in the Baltic Sea /25/.

The expected concentration of metal ions in the water column (the predicted environmental concentration, PEC) immediately around the anode has been calculated and compared to the acceptable levels within the marine environment and background concentrations (see Table 8.16).

Advection-dispersion calculations have shown that the distance from the zinc anodes where elevated zinc concentrations may be found (PEC>PNEC) is only about 3 m from the largest anode type as seen in Figure 5.4 overleaf. The figure shows that zinc is quickly diluted in the sea.

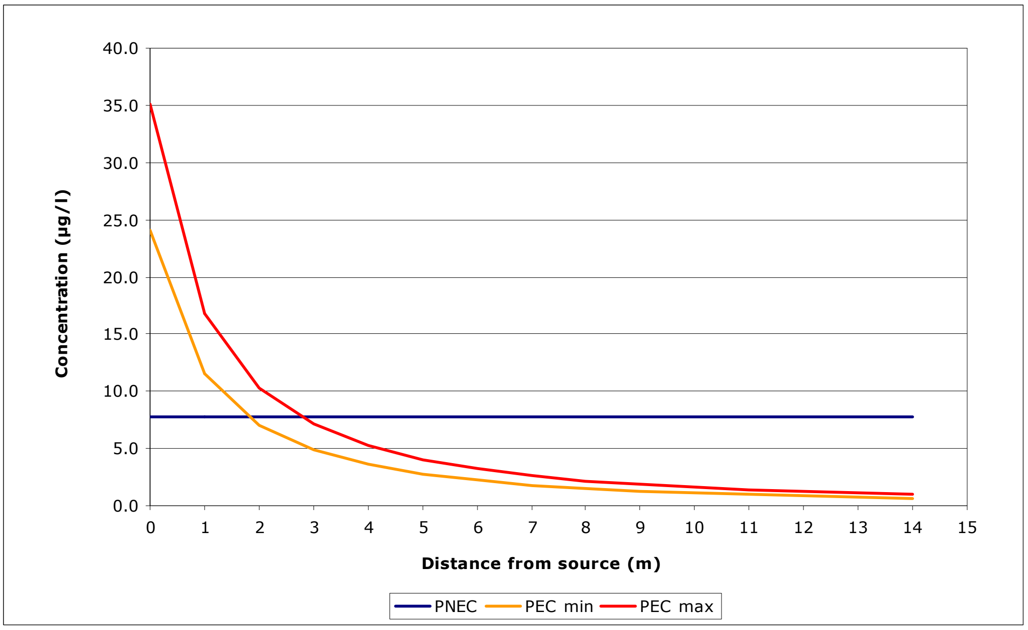

Figure 5.4 Relationship between PEC and PNEC for zinc released from a zinc anode.

In the view of measured background values, it appears that the zinc emission from the anodes will contribute only with a small increase to the background concentration.

The release of aluminium from the aluminium alloy anodes is expected to result in a concentration of approximately ~30 µg/l, a factor of 300 higher. However, this concentration is only expected in close proximity to the individual anodes and due to the effect of currents and water exchange this concentration will quickly be reduced.

Zinc anodes will primarily be used in the Gulf of Finland. The amount of zinc that will be sacrificed per year from the zinc anodes, and be added to the marine environment of the Gulf of Finland is approximately 8% of the external waterborne input to the Gulf of Finland in 2000, and 0.75% of the total waterborne input to the Baltic Sea in 2000 /26/.

From model simulations carried out in ref. /27/ it has been calculated that the annual deposition of zinc into the Baltic Sea area is around 400 tons. The amount of zinc from anodes compared to waterborne and atmospheric loads of zinc to the Baltic Sea area will be 0.66%, based on ref. /26/ and ref. /27/. It should here be noticed that release of zinc to the Gulf of Finland from anodes in connection with harbour installations, vessel and from discharge of ballast water have not been included in the calculations of ref. /26/.

The amount of zinc that will be brought into suspension with sediment during a 10 year storm (by using mean value of zinc in surface sediments from the Nord Stream field study carried out by FIMR in 2007) has been calculated to be around 865 tons, and so the amount of zinc from anodes will correspond to around 2.7% of the load from a 10 year storm.

In seawater and brackish water part of the zinc from the anodes will be found in dissolved form as inorganic and organic complexes. Near the seabed where concentrations of suspended particles often are greater, part of the zinc will be adsorbed to suspended particles/sediment. Zinc associated with suspended sediment will be deposited with flocculated particles, where it will accumulate particularly in anaerobic sediments, as is often the case in the deeper parts of the Gulf of Finland.

The ratio between soluble and precipitated zinc from zinc anodes has been investigated in ref. /28/. In laboratory experiments (carried out in estuarine water) designed to determine the influence of biofilms on the dissolution and environmental fate of zinc, was the concentrations of zinc in solution and zinc as solids analysed /28/ . The results showed that the majority of corrosion products formed during cathodic protection by zinc anodes in estuarine water is insoluble, and that zinc precipitated as carbonates, sulphide and phosphate, with the soluble fraction of zinc varying from 3.7% – 41.6%. Experiments carried out with biofilm on the anodes showed soluble zinc varying from 3.7% - 17.0%, while anodes without biofilm showed soluble zinc varying between 2.7% for normal protection, and 41.6% for overprotection with excess of anodes.

Based on the calculations above, the amount of toxic compounds released is generally very low and it is concluded that there is only a small risk posed by the release of compounds from the anodes, and this is only in the close proximity to the anodes. As such, the significance of the impacts on the water column can be stated to be minor impacts.

5.4 Impact during decommissioning

International obligations concerning decommissioning of offshore installations have their origins in the United Nations Convention of the Law of the Sea (UNCLOS). The convention stipulates that 'installations or structures which are abandoned or disused shall be removed to ensure safety of navigation …Such removal shall have due regard to fishing, the protection of the marine environment and the rights and duties of other states.'

There are no specific international regulations or guidelines on the decommissioning of offshore pipelines. Pipeline decommissioning will have to consider individual circumstances, such as comparative decommissioning options, removal or partial removal in a way that causes no significant adverse effects on the environment, the likely deterioration of the material involved, as well as its present and future effect on the marine environment.

If the pipelines are left on the seabed, they will deteriorate over time and all materials will eventually be spread in the Baltic Sea. The sum of materials can be seen in Table 4.10. The degradation will happen over a long period of time and is therefore not expected to cause any significant or acute impacts, however it is recognised that the pipeline materials will contribute to the general level of pollution in the Baltic Sea.

Complete removal of the pipeline can be performed as a reverse lay and would have environmental impacts similar to those for installing the pipeline; however the actual impact would depend on practice and technology available at the time of the decommissioning.

Since no impacts related to the use of materials are foreseen during construction, the same will be expected for decommissioning by removal.

6. Description of transboundary impacts

The Espoo Convention on Environmental Impact Assessment in a Transboundary Context stipulates the obligations of parties to assess the environmental impact of certain activities at an early stage of planning. It also lays down the general obligation of states to notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries.

The very nature of the Nord Stream project – a 1,222 km long offshore nature gas transmission pipeline system – gives rise to transboundary environmental impacts among the countries where the pipelines shall be built. Transboundary environmental impacts to third parties (only affected parties) also may occur.

Therefore, the EIA authorities in Germany, Denmark, Sweden, Finland and Russia unanimously concluded at a meeting on 19 April 2006 that the Nord Stream project falls under Article 3 of the Espoo Convention on Environmental Impact Assessment in a Transboundary Context.

6.1 Transboundary impacts

Based on the assessments presented in this memo, it can be concluded that there will be no transboundary impacts from the use of materials.

6.2 Summary of environmental impacts on the nine countries

6.2.1 Russia

No impact on the marine environment will be caused by the pipeline steel or concrete coating, nor are there impacts assessed from the internal coating, external anticorrosion coating or field joint coating.

A conservative estimate of the load of metals that will be released to the Russian EEZ waters from the anode material is approximately 0.23 tonnes aluminium and 27 tonnes zinc per year. This has been assessed to cause a minor impact on the marine environment.

6.2.2 Finland

No impact on the marine environment will be caused by the pipeline steel or concrete coating, nor are there impacts assessed from the internal coating, external anticorrosion coating or field joint coating.

A conservative estimate of the load of metals that will be released to the Finnish EEZ waters from the anode material is up to approximately 16 tonnes aluminium and 45 tonnes zinc per year. This has been assessed to cause a minor impact on the marine environment.

6.2.3 Estonia

It is assessed that materials used for the Nord Stream pipelines will have no impact on the Estonian marine environment.

6.2.4 Sweden

No impact on the marine environment will be caused by the pipeline steel or concrete coating, nor are there impacts assessed from the internal coating, external anticorrosion coating or field joint coating.

A conservative estimate of the load of metals that would be released to the Swedish EEZ waters from the anode material is up to approximately 55 tonnes aluminium and 18 tonnes zinc per year. This has been assessed to cause a minor impact on the marine environment.

6.2.5 Denmark

No impact on the marine environment will be caused by the pipeline steel or concrete coating, nor are there impacts assessed from the internal coating, external anticorrosion coating or field joint coating.

A conservative estimate of the load of metals that would be released to the Danish EEZ waters from the anode material is up to approximately 15 tonnes aluminium per year. This has been assessed to cause a minor impact on the marine environment.

6.2.6 Germany

No impact on the marine environment will be caused by the pipeline steel or concrete coating, nor are there impacts assessed from the internal coating, external anticorrosion coating or field joint coating.

A conservative estimate of the load of metals that would be released to the German EEZ waters from the anode material is up to approximately 13 tonnes aluminium per year. This has been assessed to cause a minor impact on the marine environment.

6.2.7 Lithuania

It is assessed that materials used for the Nord Stream pipelines will have no impact on the Lithuanian marine environment.

6.2.8 Latvia

It is assessed that materials used for the Nord Stream pipelines will have no impact on the Latvian marine environment.

6.2.9 Poland

It is assessed that materials used for the Nord Stream pipelines will have no impact on the Polish marine environment.

7. Methods for avoiding/reducing impacts

In the following sections measures to avoid or minimise the environmental impacts on the marine environment from the materials used for the Nord Stream pipelines are listed.

7.1 Construction

No impacts are expected in this phase and therefore no mitigation measures are suggested.

7.2 Pre-commissioning

Impacts from pre-commissioning can be caused by residue of the epoxy-based internal coating or by coating compounds ending up in the test water. The main part of the debris will be collected and discharged of onshore, and will therefore not have any impact on the marine environment. There is a potential that a very small part of the debris will be left in the pipelines after cleaning and therefore will be discharged to the sea with the test water. The potential impacts are expected to be negligible and no therefore no mitigation measures are suggested.

Detailed analyses of the performance and degradation of the coating material have been performed to ensure that the most durable alternative have been selected.

7.3 Operation and maintenance

Though assessed minor, the potential impacts on the environment during the operation and maintenance phase will be related to seepage of metals ions from the anodes.

Detailed analyses of the performance and degradation of the coating and anode materials have been performed to ensure that the most durable alternatives have been selected.

It should be mentioned that from an environmental perspective the aluminium anodes are the preferred alternative to the zinc anodes. The requirement for anode material is approximately 2½ times larger for zinc than for aluminium. Moreover, the zinc anodes contain cadmium and lead. Both compounds are included in both the Helsinki Commission (HELCOM) list of hazardous substances for immediate priority action /29/ and the EU list of priority substances in the field of water policy /30/. The aluminium anodes have a low content of cadmium, but otherwise have no content of toxic metals.

Zinc anodes are only used where necessary due to the environmental conditions; otherwise the more environmentally sound aluminium alloy will be used.

8. Proposal for monitoring programme

The most significant impact from materials used for the Nord Stream pipelines will be the seepage of metal ions from the sacrificial anodes to the water phase. A monitoring programme can therefore include a logging of the concentration of zinc ions around selected zinc anodes in order to make sure that the sacrifice of the anode material is not happening too fast and that concentrations of zinc will not be higher than calculated. Also monitoring and maintenance of the pipeline exterior is crucial, since the anodes mainly sacrifices ions if the pipeline coating has been damaged and bare pipe has been exposed.

9. Missing information

No important information was missing at the time of writing. It should however be noted that the chemical compositions of several of the coatings are only typical examples. The reason that specific information for the coatings to be used on the Nord Stream pipelines is not used is mainly due to the fact that few contracts have yet been awarded to suppliers. Only products approved for sale and use within the EU will be chosen for the Nord Stream pipelines.

10. References

/1/ United States Environmental Protection Agency (US EPA), **2008,** "ECOTOX Database", http://cfpub.epa.gov/ecotox/ , Date accessed: 2008-11-1.

/2/ International Programme on Chemical Safety (IPCS), **2008,** "INCHEM Database", http://www.inchem.org/ , Date accessed: 2008-11-1.

/3/ Danish Environmental Protection Agengy (Danish EPA), **2009,** "Vejledende liste til selvklassificering af farlige stoffer", http://www.mst.dk/Kemikalier/Stoflister+og+databaser/Vejledende+liste+til+selvklassificering+af+farlige+stoffer/ , Date accessed: 2008-11-1.

/4/ Human and Environmental Risk Assessment (HERA), **2009,** "HERA Risk Assessment Database", http://www.heraproject.com/RiskAssessment.cfm , Date accessed: 2008-11-1.

/5/ European Chemicals Bureau (ECB) and Institute for Health and Consumer Protection, **2003**, "Technical Guidance Document (TGD) on Risk Assessment, Part II - Environmental Risk Assessment", (Ed: European Commission).

/6/ Nord Stream AG and Ramboll, **2007**, "Memo 4.3a-1 - Hydrodynamical model setup for the Baltic Sea", Nord Stream AG, Zug, Switzerland.

/7/ Pohl, C. and Hennings, U., **2006**, "Trace metal concentrations and trends in Baltic surface and deep waters, 1993-2006", (Ed: HELCOM), HELCOM, Helsinki, Finland.

/8/ OSPAR Commission, **2000**, "Regional QSR II - Greater North Sea, Chapter 4 - Chemistry", London.

/9/ Det Norske Veritas DNV, **2000**, "Code DNV OS-F101, Submarine Pipeline Systems with January 2003 reprints/amendments".

/10/ Water Bylaws Scheme, **1998,** "Items which have passed Full Test of Effects on Water Quality"

/11/ UK Drinking Water Inspectorate, **2001,** "Drinking Water 1999 - A report by the Chief Inspector Drinking Water Inspectorate"

/12/ WRc-NSF Ltd., **2007,** "The Long Term Migration of Substances from In-situ Applied Epoxy Resin Coatings - Final Report to the Drinking Water Inspectorate"

/13/ Nord Stream AG and Ramboll, **2007**, "Memo 4.3t - Assessment of pre-commissioning", Nord Stream AG, Zug, Switzerland.

/14/ Nord Stream AG and Ramboll, **2007**, "Memo 4.3t - Assessment of pre-commissioning", Nord Stream AG, Zug, Switzerland.

/15/ Rambøll/Teknologisk Institut, **2008**, "Nedbrydning af stabilisatorer i PEH-kapperør", in *Projekt nr. 2004-02, Dansk Fjernvarmes F&U-konto*.

/16/ Frees, N. and Knudsen H. H., **2005**, "Baggrundsdokument for Miljøvejledning for fjernvarmerør".

/17/ Danish Environmental Protection Agengy (Danish EPA), **2001**, "Environmental and Health Assesment of Alternatives to Phthalates and to flexible PVC, Environmental Project No. 590".

/18/ Plastindustrien i Danmark, Sektionen for polyurethanplast, **2006**, "Materialeinformationsblad. Polyurethan-plast og polyurethan-elastomere".

/19/ Danish Environmental Protection Agengy (Danish EPA), **2006**, "Health and environmental aspects of plastic materials, Environmental Project No. 1103".

/20/ Netherlands Organization for Applied Scientific Research (TNO) and the National Institute of Public Health and Environment (RIVM), **2008**, "European Union Risk Assessment Report, Zinc Metal, Final Report, Part 1, Environment", prepared for the European Commission Joint Research Centre, Institute for Health and Consumer Protection, Consumer Products & Quality (CPS&Q) Unit.

/21/ Federal Public Service Health, Food Chain Safety and Environment, **2007**, "European Union Risk Assessment Report, Cadmium Metal, Final Report, Part 1, Environment", prepared for the for the European Commission Joint Research Centre, Institute for Health and Consumer Protection, Consumer Products Safety & Quality (CPS&Q) Unit.

/22/ K.I.E Holthaus, N. H. B. M. Kaag R. G. Jak M. G. D. Smit, **2004**, "TNO Report, R2004/243, Update of an evaluation of PNEC values for water produced water according to the revised marine EU-TGD", TNO, The Netherlands.

/23/ United States Environmental Protection Agency (US EPA), **2008,** "ECOTOX Database", http://cfpub.epa.gov/ecotox/ , Date accessed: 2008-11-1.

/24/ OSPAR Commission, **2000**, "Regional QSR II - Greater North Sea, Chapter 4 - Chemistry", London.

/25/ Nord Stream AG and Ramboll, **2007**, "Memo 4.3a-1 - Hydrodynamical model setup for the Baltic Sea", Nord Stream AG, Zug, Switzerland.

/26/ HELCOM, **2004**, "The fourth Baltic Sea pollution load compilation (PLC-4). Environment Proceedings No. 93", in *Environment Proceedings No. 93*.

/27/ Sofiev, M, Petersen, G, Kr¨ger, O, Schneider, B, Hongisto, M and Jylha, K, **2001**, "Model simulations of the atmospheric trace metals concentrations and depositions over the Baltic Sea", *Atmospheric Environment*, Vol. *35*, pp. 1395- 1409.

/28/ Wagner, P, Little, B, Hart, K, Ray, R, Thomas, D, Trzaskoma-Paulette, P and Lucas, K, **1996**, "Environmental fate of Sacrificial Zinc Anodes and Influence of a Biofilm", *International Biodeterioration & Biodegradation*, Vol. *PII: S0964-8305(96)00013-3*, pp. 151- 157.

/29/ HELCOM, **2007,** "Selected substances for immediate priority action (Rec. 19/5, Attachment, Appendix 3)", http://www.helcom.fi/environment2/hazsubs/action/en_GB/list/ , Date accessed:

/30/ European Parliament and European Council, **2001**, "Decision No 2455/2001/EC of the European Parliament and of the Council of 20 November 2001 establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC".