NORD STREAM -
PRE-COMMISSIONING

THE WORLD'S LARGEST OFFSHORE GAS PIPELINE

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1.0 ABSTRACT

As submarine gas pipelines get longer and more remote, the challenge of pre-commissioning becomes greater. No project demonstrates this better than the groundbreaking Nord Stream project comprising of 1,224 km x 48in twin gas transmission submarine pipelines running from Russia to Germany through the Baltic Sea - a delicate marine environment that needs to be protected and preserved.

In September 2011, the pre-commissioning of the Nord Stream Line 1 was completed ahead of schedule. Line 2 pre-commissioning was completed one year later.

This paper presents the challenges experienced during the planning, engineering and preparation for the pre-commissioning and the relevant field experience collected during execution. It also gives a summary of the schedule and lessons learnt.

2.0 PIPELINE DESIGN AND PRE-COMMISSIONING PHILOSOPHY

2.1 PIPELINE DESIGN AND CONSTRUCTION CONCEPT

Nord Stream comprises two 48in subsea pipelines running from Russia to Germany through the Baltic Sea. The total length of each pipeline is 1,224 km. These are the world's longest single-section offshore pipelines.

The Nord Stream pipelines are defined as the offshore system which exports gas from Vyborg, Russia, crossing the Gulf of Finland and the Baltic Sea, to a receiving terminal in Lubmin (Greifswald), Germany. In addition to crossing Russia and Germany, the pipelines also cross the Exclusive Economic Zones (EEZ) of Finland, Sweden and Denmark. Each pipeline has a capacity of 84 million Sm^3/day, with a total yearly capacity (for both pipelines) of 55 billion Sm^3.

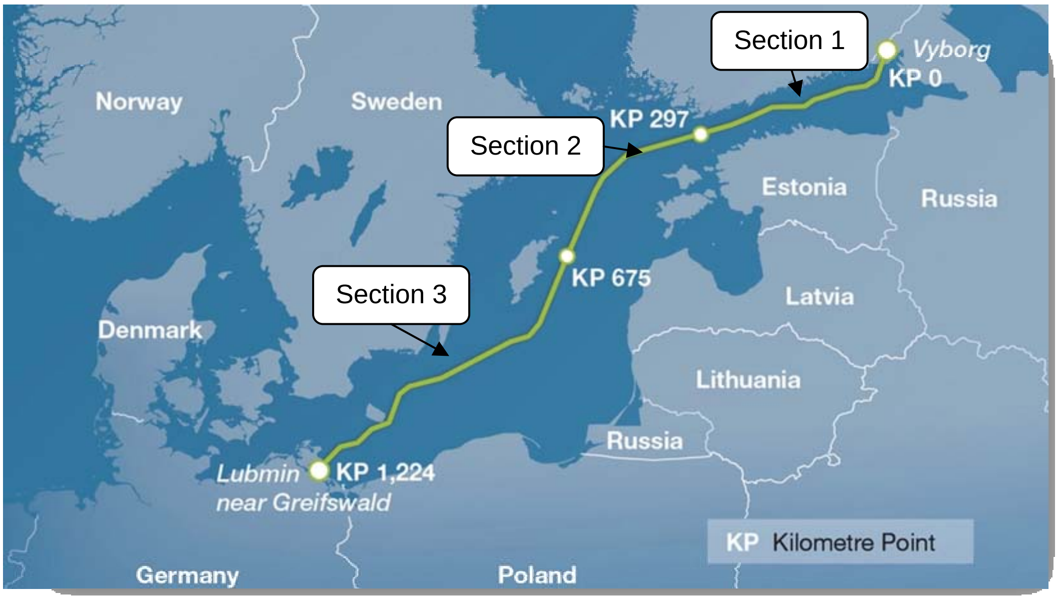


Fig. 1: *Nord Stream pipeline route*

The pipelines are designed with a segmented design pressure concept in accordance to the gas pressure profile along the route. The pipelines configuration is illustrated in **Fig. 2** below. There are no intermediate platforms along the route.

Each of the three sections was installed with offshore subsea terminations (laydown heads) designed for both the start-up/abandonment operations and subsequent pre-commissioning activities. This was required because each of the sections had to be pressure tested separately.

Subsequently, the sections were joined by hyperbaric tie-ins at KP 297 and KP 675 thus creating a single 1,224 km pipeline.

Fig. 2: *Nord Stream pipeline segmentation*

Saipem was selected as the contractor for construction activities, while Baker Hughes was the selected contractor for the pre-commissioning work. As further described below, the design and construction concept had a significant impact on the pre-commissioning execution.

2.2 PRE-COMMISSIONING CONCEPT

The initial concept was based on water filling from onshore to onshore, utilizing large-diameter crossovers at the sub-sea tie-in locations for flooding. High-pressure crossovers would then be installed for pressure testing. Thus, all three sections of the pipeline had to be laid before commencing pre-commissioning operations.
Since the German area consisted of an almost closed bay with very shallow water and low currents, flooding was to be performed from Russia to Germany with dewatering in the opposite direction. This plan required a water winning and injection spread to be installed at the Russian Landfall, with an air spread installed at the German Landfall.

In an effort to reduce the environmental impact of the water treatment as much as possible, caustic soda (NaOH) and sodium bisulphite ($NaHSO_3$) were initially selected as additives; the first to stifle anaerobic bacteria activity, the latter as Oxygen scavenger. The use of caustic soda generated significant concerns because of the possibility of precipitation of carbonates and blockage at crossover locations. Consequently, detailed water sampling and analysis trials were performed (these are described in section 3.2.7).

All pre-commissioning activities on the Nord Stream project were essentially "one-shot" operations that could not be repeated or reversed without major schedule impacts or affecting the permitting limitations for water disposal.

The pre-commissioning philosophy was further discussed and modified during the tendering phase with consultations between Nord Stream, Saipem and Baker Hughes.

The resulting adopted philosophy was based on subsea intervention at the wet end of the sections from a subsea construction vessel (SCV). This philosophy enabled each section to be completed independently of any other sections and enabled section 1 (closest to Russia) to be pre-commissioned earlier in the year while the sea at the Russian coast remained frozen and while section 3 pipe lay was still on-going. This resulted in significantly increased schedule flexibility. The final pre-commissioning concept was established as:

- Pre-commissioning spreads onshore were located in autonomous areas separate from the construction sites used for the permanent facilities.
- Pre-commissioning pigs for the subsea pipeline would not traverse the permanent pig traps or permanent valves.
- Flooding, cleaning, and gauging (FCG) were performed offshore onboard the SCV. All subsea handling was performed by ROV.
- Water was treated with sodium bisulphite ($NaHSO_3$) and ultra violet light (UV) only.
- Pressure test of sections 1 and 2 from SCV.
- Pressure test of section 3 from the receiving terminal in Germany (to reduce vessel time and risk from waiting on weather).
- De-watering from Germany with water discharge in Russia, after completion of subsea hyperbaric tie-in at KP 297 and KP 675.
- Drying from Germany to Russia.
- Nitrogen as a barrier between air and gas during commissioning of the pipelines.

The flooding, cleaning, gauging and pressure-testing spread were installed on-board the Saipem vessel “Far Samson” and included suction pumps, a water treatment system, flooding and pressure test pumps. In addition, pressure test pumps for section 3 were installed at the German landfall.

The Dewatering and Drying spread was located at German Landfall and included 15 x 760m^3 steel water tanks. The Russian landfall was developed as a water receiving facility, and included a settling pond and a temporary 16in floating discharge line.

The flooding, cleaning, and gauging (FCG) pig train was designed to ensure that the operation could be completed in a single pig run while providing contingency pigs to account for wet buckle scenarios during the pipe laying activities. For each section, four BIDI pigs were used. The pigs were back loaded into the subsea test head and installed on the sea bed up to one year before the operation.

The dewatering pig train was designed to ensure that water removal and desalination could be completed in a single pig run.

- The first batch of four pigs was separated by slugs of potable water designed to dilute the residual salt content remaining on the pipe wall to an acceptable level.
- The second batch of four pigs was separated by dry air – the function of these pigs was to pick up water remaining after the desalination pigs.
- The pig train was spaced so that the first four pigs could be received and removed before the arrival of the second set of four pigs.

2.3 KEY CHALLENGES AND CONSTRAINTS

The Nord Stream pre-commissioning work scope provided several key challenges because of its size, geographic location and environmental sensitivity. These challenges included:

Pipeline Size:

- **Pipeline length -** This was the world's longest offshore dewatering operation and the world's longest sealing tool run. Experience from the pre-commissioning team and the pig vendor was important in ensuring that pig integrity could be maintained along the full pipeline length.

  It was also essential to establish the location of possible events, particularly in case of gauge plate damage or stuck pigs. This required the development of a carefully managed pig tracking system.
- **Pipeline volume and water depth -** Each 48in pipeline had an internal volume of 1.3 million m^3. The maximum water depth, combined with losses, required a dewatering pressure of 29 barg. Therefore, a very large air compressor spread was necessary in Germany.
- **Vessel limitations –** Since also the flooding spread was large, the SCV had to comply with challenging criteria including deck space, accommodations, ROV's, cranes and power generators. The fitting of all necessary equipment for a safe operation required input from specialists and extreme attention to detail.

Geographic Location:

- **Weather -** Most of the Baltic Sea freezes in winter. This limits the operational window for the offshore operations. Water winning and water disposal could not be performed while the sea was frozen.

Environmental Sensitivity:

- **Water treatment -** The water treatment philosophy was refined to provide the most environmentally friendly approach, in compliance with the applicable international and local regulations, while maintaining corrosion protection and minimizing the possible formation of precipitates inside the pipeline.
- **Noise pollution -** Strict noise restrictions required the purchase of a custom air-compressor-spread to ensure compliance.
- **Diesel handling and storage -** Large diesel volumes for the compressor spread in Germany required custom diesel storage and handling system to receive and distribute 100 m3 of diesel per day with no containment loss.
- **Waste management -** A comprehensive waste management system was implemented to separate, track and manage all the waste produced during the project's execution.

3.0 PRE-COMMISSIONING AND EXECUTION

3.1 TIMELINE OVERVIEW

Tendering, Engineering and Procurement Activities

The contract for the Nord Stream pre-commissioning was awarded in August 2009.

Tendering commenced early, allowing sufficient time for multiple concepts to be considered before settling on the preferred concept upon which the pre-commissioning contract was based. The tender period ran for about nine months concurrently with other project approvals to allow for immediate commencement.

The engineering procedures prepared for pre-commissioning totalled some 110 documents over an 18-month period, and which required review and approval by both Saipem and Nord Stream. The 18-month period was necessary not only for the base scope engineering, but also for evaluating all possible options and changes thoroughly.

To meet the flow and pressure demands while achieving the strict environmental and noise targets set, a large percentage of the pre-commissioning equipment was procured new for the project. The early award afforded a 12-month period for equipment building, testing and delivery. Despite robust contracting strategies, some vendors did not meet their delivery schedules; however, the window allowed sufficient float for this to not affect the project's schedule.

Flooding, Cleaning, Gauging and Pressure Testing

The success and performance of the FCGT operations can be attributed to 100% contingency of critical equipment and full onshore spread function testing, including all interconnection piping. It took 41 days to complete pipeline 1 and 38 days to complete pipeline 2.

Dewatering, Drying and Nitrogen Injection

The success and performance of the dewatering, drying and nitrogen packing operations can be attributed to a combination of excellent pigs and reliable compressor spread performances.

In summary, the full pre-commissioning of each line was completed in less than 150 days, from commencement of Flooding, Cleaning, Gauging and Pressure Testing (FCGT) to the completion of nitrogen injection.

Summary

From the formation of the Nord Stream pre-commissioning team in early 2008, to the completion of pre-commissioning operations on line 2 in August 2012, the following details the key milestones achieved:

- RFQ issued for pre-commissioning operations	November 2008
- Pre-commissioning contract awarded to Baker Hughes	August 2009

- Engineering and procurement operations commenced	September 2009
- Contracts placed for all Wet Buckle Contingency (WBC) equipment	December 2009
- WBC equipment mobilized and function-tested	March 2010
- Contracts placed for all pre-commissioning equipment	June 2010
- Pre-commissioning FCGT equipment mobilized	February 2011
- Operational period for FCGT on Line 1	March to May 2011
- Dewatering and drying equipment mobilized	June 2011
- Operational period to dewater, dry and N2 pack Line 1	July to August 2011
- Line 1 gas in work completed	September 2011
- Operational period for FCGT on Line 2	March to May 2012
- Operational period to dewater, dry and N2 pack Line 2	July to August 2012
- Line 2 gas in work completed	September 2012
- Pre-commissioning sites reinstated	October 2012

3.2 SUPPORTING EQUIPMENT AND SERVICES

3.2.1 MAJOR EQUIPMENT SPREADS

Two major equipment spreads were required for the pre-commissioning of the pipelines; the FCGT spread offshore and the compressor spread onshore in Germany.

FCGT Spread

The FCGT spread was designed to provide filtered and treated seawater to propel the pig train within a speed range of 0.5 – 1.0 m/s. The FCGT pig train is designed to clean and gauge the pipeline while filling it with water for the pressure test.

This required the installation of 10,000 hp / 7,500 kW of diesel-driven pumping equipment and the use of 1000 hp / 750 kW of electrical power supplied from the SCV's on-board generators. The entire spread was installed, function-tested and certified in seven days while the vessel was in the port of Norrkoping, Sweden.

The spread was designed to pump water from 5 to 20m below the sea surface using electrical submersible pumps and forcing the water through two stages of filtration; primary filtration to 200 µm and final filtration to 50 µm.

After filtration, the water was treated with UV and then metered and treated with Sodium Bisulphate. Finally, the pressure was boosted through the flooding pumps and injected into the subsea test heads via twin 6in LFH downlines and 8in low pressure hot stabs. All subsea hose handling and connections were performed by Work Class Innovator ROV and supported by the vessel crane.

During the flooding operation, the flooding spread consistently achieved flow rates up to 2500 m^3/hr with no mechanical downtime.

Figs. 3 and 4: *Schematic and Photo of SCV at Operation Location*

<u>Equipment at Land Fall Germany</u>

The compressor spread was designed and installed to provide dry, “oil-free” air to push the pig train for dewatering and to subsequently dry the pipeline. The compressor spread was specifically built for the project. It was designed around primary compressors that delivered 34 barg of air and 34 barg dryers. The dewatering spread, with 24,000 hp/18,000 kW of power, ensured a minimum free air delivery of 30,000 scfm / 850 m^3/min was injected into the pipeline at better than -60^{o}C dew point.
The dryers also incorporated active carbon filtration to prevent oil carryover into the pipelines, as required by ISO 8573-1 class 2.

The compressor spread included a central diesel storage capacity of 200m^3 and a distribution system capable of handling 100 m^3 of diesel per day. In addition, facilities were installed to handle condensate from the air spread, with 100m^3 of storage. The systems for diesel and condensate were designed to ensure zero losses to the environment and were approved and certified by Technischer Überwachungs-Verein **(**TÜV).

In addition to the air spread, the German Landfall site also included 18,000m^2 of hard standing, 11,400m^3 of water storage capacity tanks and more than 1,500m of steel pipework. **Figs. 5** and **6** below give an overview of the site.

Figs. 5 and 6: *Landfall Germany Layout*

Equipment at LandFall Russia

The Russian landfall area was developed mainly as a receiving terminal for the pre-commissioning water. A 6000m^3 water storage pond was installed to allow any possible discolored water from the pipeline to settle and be appropriately disposed. **Fig. 7** below gives an overview of the site.

Fig. 7: *Landfall Russia Pre-commissioning Site*

Fig. 8: *Water Storage Pond*

A 20in, 1,200m long water disposal line was also installed comprising 600m of steel pipe onshore and 600m of floating pipe HDPE offshore. The water removed during dewatering was transported to its permitted discharge location (at a location with a water depth of more than 5 m) and released back into the sea via a dedicated diffuser system.

3.2.2 PIG TRAPS, SUB-SEA HEADS AND HOTSTABS

Pig Traps

The permanent pig launchers, pig receivers and all permanent valves were excluded from the pre-commissioning operations to avoid any damage. The temporary pig traps (see **Figs. 9** and **10**) were designed and built for the project and rated at 50 barg design pressure. They incorporated a 48in. ball valve, which allowed for the individual launching of the dewatering pigs from Germany. In Russia, the four FCG pigs, the eight dewatering pigs and the four sealing tools (inserted in the pipeline by the tie-in operator) were received in batches of four pigs.

Fig. 9: *Temporary Pig Trap: Russian Landfall*

Fig. 10: *Temporary Pig Trap: German Landfall*

Subsea Heads

Each subsea section termination required a sub-sea head that could either receive or launch the FCG pig train. It was also designed to be used during the execution of the pressure test. Despite their sizes (48in x 25 m) these heads had to be suitable to pass through the firing line on the pipe lay vessel.

The design, construction and testing of the subsea heads was tightly controlled with several stages of testing, validation and retesting to ensure the head integrity would be 100% during the deployment, flooding and pressure test operations.

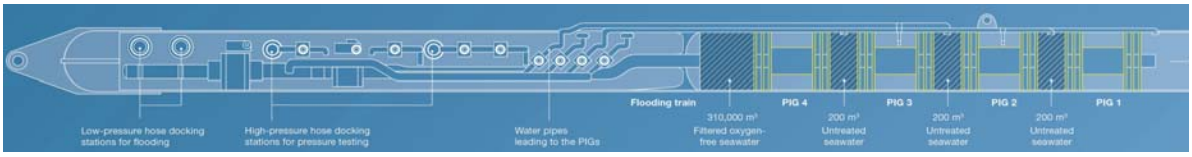


Fig. 11: *Subsea Launcher (typical)*

Hot stabs

Connection of the FCGT downlines to the subsea heads was done via ROV hot stabs. Three sizes were selected; 8in (low pressure) for flooding, 4in (high pressure) for pressure testing, and 1in (high pressure) for pressure test instrumentation.

The 8in and 4in hot stabs were inserted hydraulically into balanced T-design receptacles. These were selected out of several possible options for its low friction losses and the possibility of inserting the stab from either side of the sub-sea head. A hydraulic hot-stab extractor tool which could push out a locked stab was also developed.

Since the hot stabbing operation was critical, the project invested in dry trails and full-scale wet trials in a Norwegian fjord to confirm both the hot stabbing operation and hose deployment arrangement.

Fig. 12: *8-inch Low-Pressure Hot stab*

Fig. 13: *Subsea Head (typical)*

3.2.3 LAY-FLAT HOSES AND BREAKAWAY COUPLING

The use of lay flat hoses (LFH) was proposed by Baker Hughes based on previous experience using them on other projects in Asia – such hoses require far less deck space than hard-wall hoses.
Flooding operations utilized two 6in LFH hoses supported by steel downwires and suspended clump weights. During pressurization, the LFH expands, with the resulting internal bore comparable to that of an 8in hard-wall hose.

A system was developed to enable the SCV to disconnect quickly and safely from the subsea heads in the event of an emergency such as a dynamic positioning (DP) run away. The DP controller can release all the hoses and downwire from the vessel at the push of a single button. The hoses and downwire would remain attached to the subsea heads and suspended from buoys for subsequent reconnection.
In the event the disconnect system was activated, all pumps on-board would shut down while internal check valves ensured water from the pipeline would not be released.

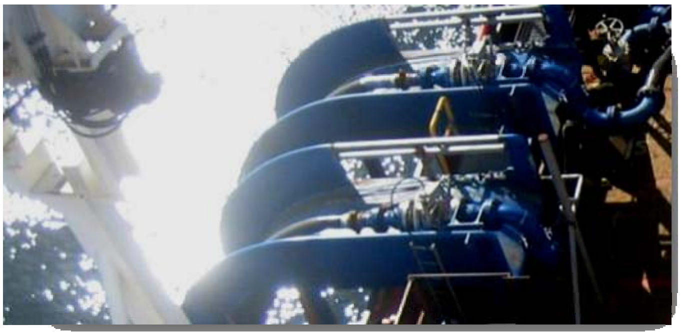


Fig. 14: *Chute and Subsea Hoses*

Fig. 15: *Breakaway Coupling Detail*

3.2.4 PIGS AND SEALING TOOLS

Correctly designed and fabricated pigs were key to the successful pre-commissioning operation on the world's longest single-section pipeline. All pigs were specifically designed and fabricated according to strict specifications and subject to stringent quality checks. They were not purchased as off-the-shelf products.

Market surveys and conceptual studies were initiated with three different pig vendors, with one vendor testing a prototype pig. Tests included pressures required for initiation, running, restarting forward and reverse, and flipping the discs. The resulting recommendations and proven field experience from earlier projects were the basis for the final pig selection. Several concepts were evaluated but later discarded, including light-weight pig bodies and the use of wheels.

During the production and assembly phase, each pig was subject to extensive quality checks. Before final delivery, each pig was again checked and measured to make certain they were delivered in accordance with the specifications.

Flooding, Cleaning and Gauging Pigs

The FCG pigs were designed to displace the air with water, ensuring an air content of less than 0.2% and to pass a 97% gauge plate through the pipeline without damage. In addition, they must be able to remove as much construction debris as possible from the pipeline.

The selected pig for flooding, cleaning and gauging was a conventional BIDI-type pig with four guiding discs, three sealing discs and one gauge plate on each pig. All pigs were also equipped with magnets and were designed to carry a transponder for tracking the pigs. For each pipeline section one pig was equipped with a "smart gauge plate". The smart gauge system facilitates annunciation of the gauging run without the need to physically remove the pigs from the head. Should gauge plate damage be observed, the system also provides the approximate pipeline location where the damage occurred. The pictures below show the two different pigs (different vendors) selected for the flooding, cleaning and gauging operation.

Figs. 16 and 17: *Flooding, Cleaning and Gauging Pigs*

Dewatering Pigs

The dewatering pigs were designed to separate the desalination slugs and remove as much water as possible prior to commencing the drying operation.

These pigs were the most important because they had to perform over a distance of more than 1,200 km. That had never been done before. The dimensions were carefully selected to make sure the discs did not wear out (stiff discs) during the distance or lose contact with the pipe wall (soft discs) because of aquaplaning. The discs needed to have correct hardness, wear properties, flexibility and contact forces with the pipe wall. Accumulated experience from earlier long distance pipelines was a key factor in the selection process.

The selected dewatering pig was also a BIDI type (see **Fig. 18**) with four guiding discs and four sealing discs. All pigs were equipped with rare earth magnets for "local" pig tracking and designed to carry a transponder for "global" pig tracking.

Sealing tools

Sealing tools are used during hyperbaric tie-ins to prevent water in the welding area. A minimum of one tool on each side of the weld is required. To provide a sufficient level of protection with respect to pressure variations (tidal variations, atmospheric pressure variations), the sealing tool must be able to hold a certain pressure without any movements.

This tool is a further development of the traditional spheres used in earlier projects. It contains two sealing elements (tyres) mounted on a BIDI-type pig with guiding discs. Its purpose is to obtain long-distance wear-resistance after completion of the tie-in.

The Nord Stream sealing tools (see **Fig. 19**) were designed with a nominal “break loose” pressure of 1.5 bar. They also had to be capable of travelling up to 675 km for their removal after the weld had been performed.

Fig.18: *Dewatering Pig*

Fig.19: *Sealing Tool*

3.2.5 SMART GAUGE

To annunciate any gauge plate damage and assist with the location of the defects within the pipeline sections, the third pig in each of the FCG pig trains was fitted with a smart gauge plate. The system, if activated, can be interrogated either subsea, while travelling through the pipeline, or when at rest in the receivers.

The smart gauge records the first damage event and communicates the time of event through the pipe wall when interrogated.

The smart gauge was only activated once in contact with water to extend the battery life after installation in the test head and subsea deployment.

3.2.6 PIG TRACKING

Accurate pig tracking is essential to confirm the location of the pigs when launched, received and in transit. This provides increased operational confidence and was required to accurately divert the any discoloured water in front of each pig into the settling pond.

Acoustic transponders were selected to provide “global” pig tracking when the pig train was moving or stationary. The magnets, included in all BIDI pigs, provided the ‘local’ pig tracking when passing magnetic pig detectors.
All FCG pigs and pigs 1-3 of the dewatering train were installed with active acoustic transponders. These allowed each pig to be individually identified and their distance from the pig tracking vessel to be the calculated.
Because of the duration of the pig runs and the time between the subsea deployments in the lay-down heads and the actual run, a long battery life and/or delayed start mechanism was also required. Acoustic transponders provided an excellent solution because they only emit an acoustic signal when they are requested and can be left in sleep mode for more than a year before being used.

In addition to the active acoustic transponders, magnets were used to activate magnetic detectors at subsea and onshore to confirm the passage of each of the pigs out of the launchers and into the receivers on each section.

A pig tracking vessel followed each pig train, checking both the smart gauge and pig position from launch to receipt on the FCG, sealing tools and dewatering pigs (see **Fig. 20** and **21**).

An additional method of tracking the dewatering train is to track the interface pig between water and air by plotting the velocity as measured at the discharge outlet in Russia. The water column in front of this pig will result in the outlet flow and velocity being proportional to the pipeline profile (height of liquid column) - see **Fig. 22**.

Fig 20: *Pig Tracking Vessel*

Fig. 21: *Acoustic Transponder*

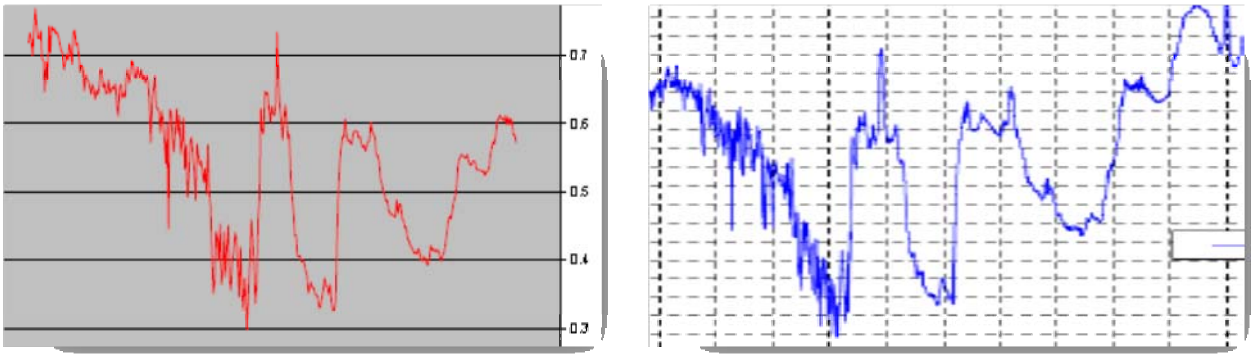


***Fig. 22:** Velocity Profile (red) and Pipeline Profile (blue)*

The interface pig will always be at the last plotted position on the velocity graph. By comparing it with the pipeline profile, the pig location can be identified.
This method is very accurate as long as the pig train is in a reasonably good condition; that is where little or no air has bypassed the pigs.

Should the velocity graph slowly trend away from the pipeline profile, this indicates that the pig train is losing sealing integrity because large amounts of air bypassing the pigs. This may also be used for pig train "quality control" as it progresses through the pipeline. This is important information to the receiving location because it helps them better prepare for what to expect at the receiving end (air in front of train, 2-phase flow etc.).

3.2.7 WATER TREATMENT

Given the significant volumes involved, sea water was the only practical option as a water source.
Sea water had to be adequately treated before injection into the pipelines; treatment had to take into consideration and satisfy two conflicting requirements, namely: line integrity (i.e. protect the inner surfaces of the pipelines), and compliance with international and local environmental standards for the direct discharge of pre-commissioning waters back into the sea.

The treatment approach and specifications were accurately balanced and tested to the maximum possible extent in laboratory and field tests prior to submittal to the Environmental Agencies for the release of the water discharge permit.

Nord Stream carried out studies on pre-commissioning water in two distinctive phases:

1. In preparation for the pre-commissioning operations, over a time period of approximately two years, to test and select the most appropriate treatment and obtain the discharge approval by the Agencies; and
2. During pre-commissioning, in particular during the FCG operations and during the dewatering of the pipelines, to monitor and document the results of the selected and approved treatment approach.

Treatment of sea water has a two-fold objective in terms of pipeline integrity, namely: avoid the oxygen induced corrosion (OIC) and minimize the risk of microbiologically induced corrosion (MIC). The first objective is achieved by adding oxygen depleting agents to the sea water ("oxygen scavengers"), typically sodium hydrogen sulphite (widely used as an anti-oxidant in the food industry, e.g. to preserve many wines during the aging period).

Several different methods are adopted in the off-shore industry for MIC control, ranging from the dosage of strong biocides, to the inhibition of bacterial activity by pH control of sea water, to Ultra Violet (UV) light treatment.

The Nord Stream project was subject to a few key constraints in the selection of the MIC control approach. The use of biocides was strongly discouraged by the Environmental Authorities. Also, pH control had to be carefully evaluated for the possible formation of precipitates, which might have proven problematic while the pigs were travelling during the dewatering phases.

Three alternative treatments of natural sea water were investigated, in particular:

1. Dosage of oxygen scavenger (OS)
2. Dosage of OS and pH control with caustic soda (NaOH); and
3. Dosage of OS and biocide (Gluteraldehyde - GTA), for comparison purposes only.

Natural seawater (without any treatment) was also subject to tests, as a "blank" for reference purposes.

The testing program was carried out between 2009 and 2010, in cooperation with the Finnish company, Ramboll OY, and included the following activities:

1. Seasonal seawater sampling and analysis at the locations intended for water uptake (KP297 and KP675), and at a location representing KP0;
2. Bench scale laboratory tests;
3. Pilot plant scale tests for precipitation potential of treatment option (b);
4. Laboratory scale medium and long-term corrosion tests (LCT), reproducing the anticipated conditions inside the pipelines and various residence times of the treated sea water in the lines (between 1 and 10 months); and
5. Full scale testing (FST), whereby sections of pipeline were filled with treated and non-treated sea water, deployed subsea and left on the sea bottom for time periods of six and 12 months (see figures below).

Fig. 23: *Full Scale Testing*

Fig. 24: *Laboratory*

FST and LCT were carried out on sea waters collected at KP0; results were then factored for sea water at KP297 and KP675, through scientific judgement based on the detailed knowledge acquired of the physical-chemical characteristics of the water at the three locations.

The extensive testing program allowed Nord Stream to reach the following conclusions:

1. The “no treatment” option was ruled out, based on observed significant localized corrosion and crevice corrosion in the LCT and FST tests;
2. The combination of OS dosage and pH control with NaOH proved not attractive, because:

   - It gave no advantage, in comparison with OS dosage only, for the planned residence time of the sea water in the pipelines during pre-commissioning operations (2 - 4 months); and
   - The pilot scale precipitation tests demonstrated that calcium carbonate precipitates inside the pipelines could result in increased risk because of the amounts of sludge to be moved along the pipelines during the dewatering operations.

In the end, the option of OS dosage only was selected for the treatment of sea water.
For added safety, UV light treatment was also added prior to filling water into the pipelines. This was based on the observation of comparatively high numbers of sulphates-reducing bacteria (SRBs) in the sea water sampled at KP297 and KP675 during Spring and Summer (SRBs can typically give way to MIC phenomena).

3.2.8 NOISE

The location in Germany has stringent noise emission limits of 65 dB (day) and 55 dB (night) at the closest dwelling. The local marina was located within 500m of the compressor spread.

To ensure the specification was met, all of the equipment supplied was sound-proofed to 76 dB at 7m. No additional special sound barrier was installed or required.

4.0 RESULTS

4.1 FLOODING, CLEANING, GAUGING AND PRESSURE TESTING

The subsea heads, the hot stabs and the pig tracking system worked flawlessly during the FCGT operations.

All the FCG pigs performed as expected and no damage was observed. The water filtration, additive system and pumping spread operated consistently at or above their specified duty. Success of the flooding operation was demonstrated during the pressure test where air content was confirmed to be well within the DNV requirement of less than 0.2%.

The cleaning operation removed less than 2 kg of construction debris in each section, supporting the belief that almost all the construction debris was removed. Some iron oxide and small amounts of sand and some red-colored dust were also removed.

The gauging plates confirmed the internal diameter to be within the design requirements. Out of six smart gauge runs, only one of them gave a damage indication (which was proved to be false).

The pressure test operations were all accepted after only hours of pressure stabilization prior to the mandatory 24-hour holding period. **Fig. 25** below shows a summary of the pressure test data for pipeline 1. Pipeline 2 had very similar results.

	Length (km)	Volume (m3)	Test Pressure (barg)	Pressurisation Duration (hrs)	Volume Added (m3)	Stabilisation Period (hrs)	Pressure Drop Over Test Period (%)
Section 1	297	310,098	248	36:33	4,823	2	0.048
Section 2	378	394,670	226	53:16	5,772	4	0.035
Section 3	548	572,167	201	40:68	7,596	6	0.102

***Fig. 25:** Pressure test operations data*

The main reason for the quick and successful pressure test was the favourable spring weather conditions, whereby the temperatures were similar at the surface and at the bottom of the Baltic Sea.

4.2 DEWATERING AND DRYING

The use of temporary onshore pig traps, together with temporary 48in valve resulted in a very smooth and controlled dewatering operation. This made it easier to control the operation and to keep water and air separated during the launching of the train. The train was launched with pig 4 as a “perfect” barrier between the desalination water and the air.

The compressor spread and dryers, as well as all support systems, met or exceeded their specified duties throughout the operation. As planned, air injections ceased when the dewatering pig train had travelled 60 % of the pipeline length, with the remaining pig travel driven by the expanding air. This was implemented to save fuel and to minimize the depressurization requirements after receipt of the pig train in Russia.
Throughout the dewatering operation, the pig tracking vessel followed the different pigs all the way to the Russian coast. First, the two sets of sealing tools (one set from KP 297 and one set from KP 675) arrived, and then the dewatering train. Such accurate pig tracking was necessary when diverting the water in front of each pig to the settling pond (see also section 4.5). The dewatering pressure and pig velocity are shown in **Fig. 26**. See also **Fig. 22** for further details with respect to pipeline profile and pig velocity

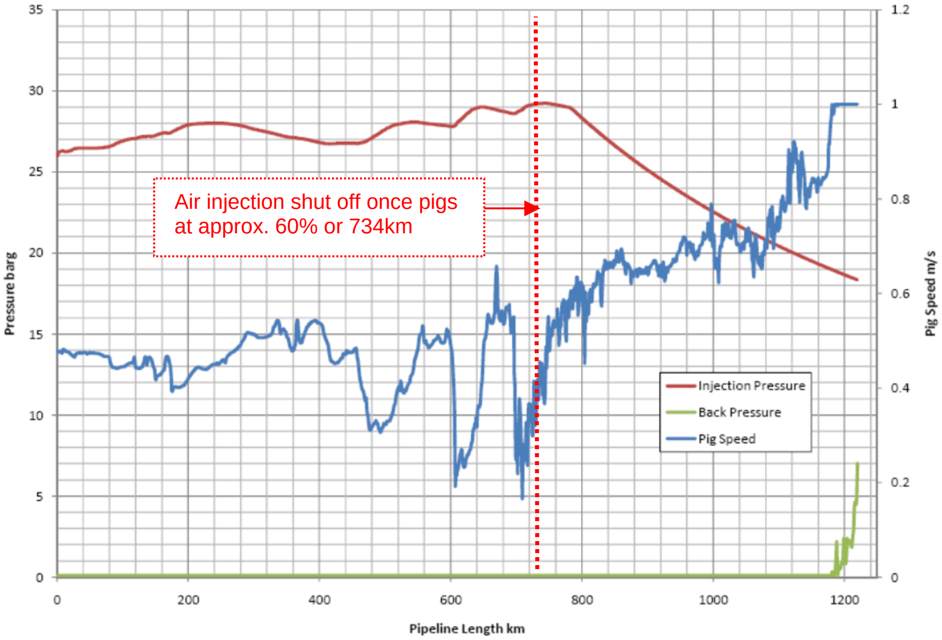


***Fig. 26:** Dewatering pressure and pig velocity*

During the receipt of the pig train, the desalination water was checked for chloride content. The analysis demonstrated that the final chloride content was well below the specified limit of 200 ppm. The amount of water received in front of the swabbing pigs was very small. Based on experience from pipeline 1 (very little water), the flow in front of the swabbing pigs was routed through the silencers for pipeline 2.

Based on calculations and observations, the amount of water in front of the swabbing pigs was less than 1 m^3. This is an impressive result and occurred because of good pigs, internal coating and very smooth operations (with only the use of the discharge control valve towards the end of the operation to maintain maximum 1 m/s velocity). **Fig. 27** below shows the wear observed on the dewatering pigs.

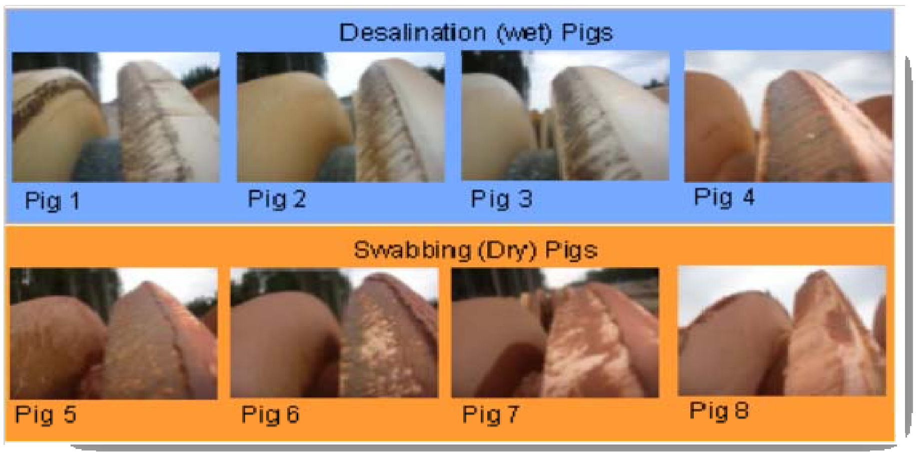


***Fig. 27:** Dewatering Pig Wear*

The desalination pigs showed little wear after travelling 1.224 km. The swabbing pigs show greater wear, but still maintained sealing integrity. That indicates that they have been running mostly dry and confirms the excellent results.

The drying operation for pipeline 1 was completed after 18 days, and included a soak period of 24 hours. An atmospheric water dewpoint of better than -35°C was achieved and confirmed by a 24-hour soak period. Based on this, pipeline 2 was dried to better than -35°C and accepted without a soak period.

During the drying, 4.5 m^3 of water was removed (calculated based on dew point readings and air volume). This corresponds to a water film thickness of 1 micron on the pipeline wall, and demonstrates the best dewatering results ever achieved (regardless of pipeline size and length). Dryness was also confirmed post-commissioning where gas dew point levels were recorded.

4.3 NITROGEN

To avoid explosive mixtures in the pipeline (as set out in DNV OS-F101) during commissioning (gas filling), there was a need to use an inert gas as a barrier between the air and the natural gas in the pipeline. For various reasons, nitrogen packing differed between lines 1 and 2:

1. Line 1 was completely filled with 99.9% pure nitrogen from Germany.
2. Line 2 was partially filled from Russia (gas filling end) using a 99.9% pure nitrogen batch equal to 10% of the pipeline volume.

For both pipelines, the mixing zone between air and nitrogen was approximately 1.5 km. The mixing zone between nitrogen and gas was approximately 2 to 3 km.

It was important to maintain the interface velocity above the critical minimum to obtain these results.

4.4 WATER TREATMENT

Treatment of the sea water was carried out on board the SCV where the sea water injection pumps were installed. Pre-commissioning water was pumped into the pipelines at KP297 and KP675.

The water treatment included the following steps:

1. Filtration through 200 µm and 50 µm cartridge filters,
2. On-line injection of oxygen scavenger (OS), a commercial solution of Sodium Bisulphite and iron-based catalyst, and
3. UV light treatment.

The key analytical parameters of sea water for the control of the treatment operations were obtained in a fully equipped laboratory installed on-board the SCV.

Metered amounts of OS were dosed and adjusted daily to match the measured oxygen concentrations of filtered sea water. Based on the results of the test program, the OS dosage rate was set at the stoichiometric value, equal to 6.5 mg OS/mg O_2.

Dissolved oxygen concentrations in the filtered sea water were generally at saturation values (over-saturation concentrations were also measured at times), ranging between 12.5 mg/l and 15.0 mg/l.

Special attention was given to the potential environmental impact of oxygen depleted water at the discharge location. A special water diffuser was designed and installed. The purpose was to achieve a high re-oxygenation effect in the immediate proximity of the discharge point. This was a requirement of the water discharge permit released by the Russian authorities. The effectiveness of the diffuser was confirmed by the field measurements carried out during dewatering.

A UV treatment unit was also installed on-board the pre-commissioning vessel. The unit had a design “killing rate” of more than 99% of the initial bacteria count at effective UV dosages of 40 ÷ 60 mj/cm^2. Bacteriological analysis was carried out in the laboratory on-board the SCV during the FCG operations for both total anaerobic and total aerobic bacteria before and after the UV package.
The calculated “killing rates” for anaerobic bacteria were generally in-line with expectations.

The results and observations confirmed the management of the water treatment achieved the project targets. There was no measurable impact on the marine environment at the discharge location and preservation of the integrity of the pipelines was confirmed.

4.5 ENVIRONMENTAL

Almost all of the water was discharged directly into the sea. The water treatment, as presented above, was acceptable for direct discharge into the sea. The discolored water in front of each pig had to be captured and settled before being discharged back to sea.

This water was diverted to the water settlement pond. Water stored in the pond was discharged to sea through filters after a minimum 24-hour settling period. All water discharged to sea was clean and contained no oxygen.

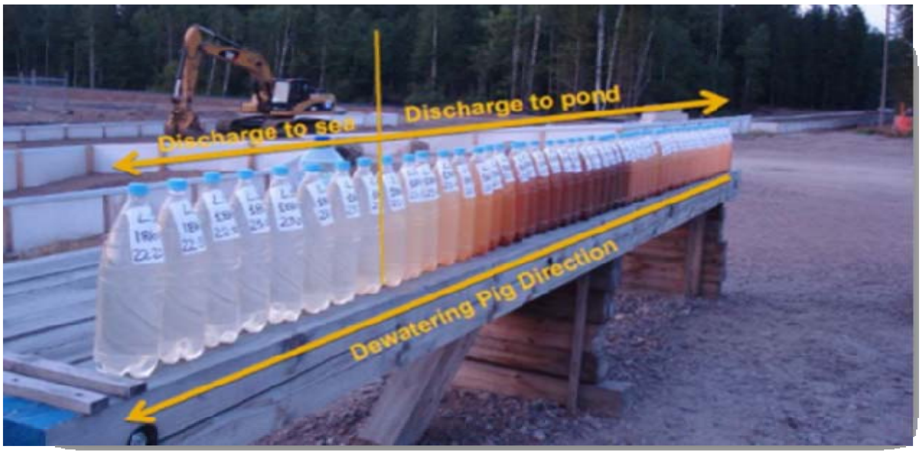


Fig. 28: *Water sampling during dewatering train receipt*

The discharge point was located 600m offshore and was fitted with a diffuser nozzle to ensure rapid oxygenation of the water.

The discharge water was continuously monitored by the environmental authorities and showed compliance with local and international regulations (oxygen levels were found greater than 7 ppm well within the 100m distance from the diffuser as required by the regulations). **Fig. 28** is showing the discoloured water as sampled during operations.

The noise generated in Germany was monitored by a third party. The compressor spread complied in full with the stringent noise limitations for the project.
The sound proofing of all individual units also improved the working environment for the operational personnel and improved safety as normal verbal communication was possible within the area of the compressor spread.

4.6 LEASSONS LEARNT

A summary of the lessons learnt during the execution of the work include:

1. Early identification and focus on long lead items (e. g. subsea heads)
2. Establish pre-commissioning concept early in the project
3. Early selection of main water source and water treatment regime
4. Early start of engineering and planning
5. Early involvement in permanent design work (identify pre-commissioning requirements)
6. Establish any additional local authority requirements early
7. Establish pre-commissioning environmental basis early
8. Identify risks early (e.g. pigs) and maintain focus
9. Maintain risk register with regular reviews and updates
10. Maintain focus on equipment and function tests
11. Carefully select key sub-contractors and suppliers
12. Careful and comprehensive follow up and control of critical supplies and suppliers
13. Procedures should be approved well in advance of commencement of field operations
14. Pig tracking was very useful for control of operation and for accurate information to stakeholders
15. Continuity of key personnel

5.0 CONCLUDING REMARKS

The pre-commissioning task on the Nord Stream pipelines was remarkably successful. Besides being concluded within budget and ahead of schedule, the technical achievements were impressive:

1. The world’s longest ever, single-section dewatering operation
2. The world’s longest travel distance for tie-in sealing tools

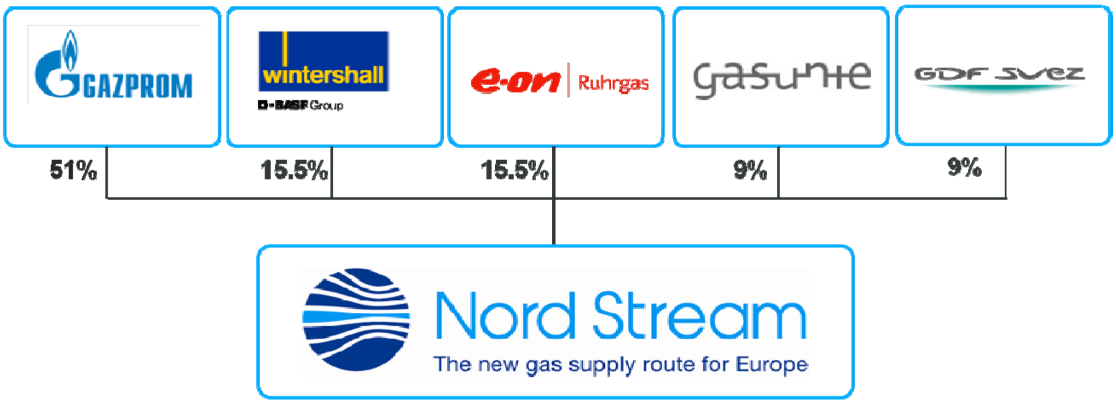
3. Combination of dewatering and sealing tool removal operation
4. Very effective dewatering operation confirmed by the quick-drying operation
5. Very quick and effective pressure test operations (favourable temperatures)
6. Very effective water pumping through two 6-in. LFH (2500 m^3/hr or 0.66m/s pig speed in 48” pipeline)
7. Effective cleaning and gauging operations
8. Very effective pigs which were specifically designed for the work
9. Successful pig tracking allowed good control and operational confidence
10. Effective water treatment concept with practically no effect on the environment

These results were obtained by experienced personnel working as a team and focusing on:

1. Early engineering and planning
2. Early involvement in pipeline design requirements
3. Early focus on long lead items (e.g. pipeline head)
4. High-quality equipment and experienced personnel
5. Continuous attention to safety, risk and environment
6. Correct procedures prepared early by involved personnel
7. Professional operational execution, monitoring and control

6.0 ACKNOWLEDGEMENT

The Nord Stream pipeline system is being designed, constructed and operated by Nord Stream AG on behalf of its shareholders. The shareholders are shown below:



A Special mention is made to the contribution from the Nord Stream pre-commissioning team:

Andrew Turnbull - Senior Project Engineer

Giuseppe Lopez - Senior Project Engineer

PIPE-LAY CONTRACTOR

PRE-COMMISSIONING CONTRACTOR