Key factors influencing the reliability of trunk gas pipelines in the West Siberian North

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DECLARATION

This dissertation is the result of my own work unless otherwise stated and includes nothing which is the outcome of work done in collaboration. No part of this dissertation has been submitted for a degree or diploma or other qualification at any other university. It does not exceed the Department of Geography's 80,000 word limit (including footnotes and excluding appendices and references) as stated in paragraph 26 of the Memorandum to Graduate Students.

B. J. Seligma

Benjamin Seligman
October 1998

ABSTRACT

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For many years Russia has been the world's largest natural gas producer. Nearly 80% of total Russian production comes from three West Siberian enterprises of *RAO Gazprom*, Russia's monopolistic gas company. These gas fields are among the largest in the world and lie astride or just north of the Arctic Circle in the Nadym-Pur-Taz gas production complex (located in the Yamalo-Nenetskiy Autonomous District of Tyumenskaya Oblast'), several thousand kilometres from the major markets in the industrial regions of European Russia and in the "near" (other CIS countries) and "far" (eastern and western Europe) abroad.

The trunk pipelines which supply gas from these fields pass initially through a region of extreme and complex natural-climatic conditions, in particular permafrost, which present an array of problems for gas pipeline planning, construction and operation. Given that Russia depends so much upon the gas industry for hard currency revenues, notably through *Gazprom*'s exports to Europe, and that Russia, the rest of the CIS and Europe depend so much upon the company for energy supplies, *Gazprom* has a compelling interest in ensuring reliable gas transmission. The integrity of West Siberian trunk gas pipelines inspires little confidence in *Gazprom*'s ability to construct and reliably operate the northern section of the Yamal - Europe Gas Transmission System, the company's most ambitious pipeline project. The purpose of this thesis is to assess the extent to which such lack of confidence is justified.

The thesis examines two fundamental aspects of 30 years of trunk gas pipeline planning, construction and operation in the West Siberian North in order to provide a basis for assessing *Gazprom*'s capacity to meet the Yamal challenge. The first involves identification of the key issues relating to the integrity and reliability of buried trunk gas pipelines in this region. Research revealed that *Gazprom* lacks capacity to ensure pipeline reliability in permafrost conditions in two key respects: high quality planning and construction work backed up by a sound regulatory framework and appropriate product temperature regulation during operation. The second concerns whether there is evidence for or against the existence of a learning process with regard to the planning, construction and operation of northern trunk gas pipelines over the 30 year period. While evidence was found to support the existence of a learning process in some areas of these activities, for example in connection with the "Highly Reliable Pipeline Transport" programme founded in 1993, there are also strong indications of the industry's continuing failure to tackle fundamental problems in northern gas pipeline operations at their root. The thesis then provides an assessment of the technical preparedness of *Gazprom* for construction of the northern section of the Yamal - Europe Gas Transmission System in an area of even more complex natural-climatic conditions than those operating in the Nadym-Pur-Taz complex. We find that grounds remain for continuing lack of confidence in *Gazprom*'s competence to meet the Yamal challenge.

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ACRONYMS AND ABBREVIATIONS

b/d	barrels per day (oil).
Arktikneftegazstroy	Arctic Oil and Gas Industry Construction (of the former *Minneftegazstroy*).
AO	Autonomous Okrug (Autonomous District). Administrative subdivision based on nationality groups.
API	American Petroleum Institute.
ASME	American Society of Mechanical Engineers.
ASSR	Autonomous Soviet Socialist Republic. An administrative region of the Soviet Union whose boundaries were drawn up to give political recognition to an important nationality, often a minority.
AVO	Air Cooling Apparatus.
BCM	Billion Cubic Metres (gas).
BP	British Petroleum. Announced plans on August 11th 1998 to merge with Amoco to form BP-Amoco.
CIS	Commonwealth of Independent States.
COMECON	Economic Association of East European Countries (also known as CMEA, Council for Mutual Economic Assistance), dissolved in 1991.
CS	Compressor Station.
DEG	Diethylene Glycol.
DIN	German Institute for Norms (*Deutches Institut fur Normung*).
Energoset'proyekt	All-Russian Planning and Scientific-Research Institute for Energy Systems and Electricity Networks.
EBRD	European Bank for Reconstruction & Development.
ENI	An Italian oil & natural gas company.
FRG	Federal Republic of Germany (former West Germany).
Fundamentproyekt	State Institute for the Planning and Design of Bases and Foundations.
GANG	Gubkin State Oil & Gas Academy.
GDR	German Democratic Republic (former East Germany).
GIE	Gulf Interstate Engineering Co.
GCF	Gas-Condensate Field.
GF	Gas Field.
Giprogaztsentr	State Gas Industry Planning Centre.
Giprospetsgaz	State Institute for the Planning and Design of Trunk Pipelines and Special Construction for the Gas Industry (Subsidiary Company of *Gazprom*).
Giprotruboprovod	State Institute for the Planning and Design of Trunk Pipelines.
Glavinterneftegazstroy	Main Administration for International Oil & Gas Construction (no longer exists).
Glavsibtruboprovodstroy	Main Administration for Pipeline Construction in Siberia (no longer exists).
Glavsredazneftegazstroy	Main Administration for Oil & Gas Construction in Central Asia (no longer exists).
Glavtruboprovodstroy	Main Administration for Pipeline Construction (no longer exists).
Glavukrneftegazstroy	Main Administration for Oil & Gas Construction in the Ukraine (no longer exists).

Glavvostoktruboprovodstroy	Main Administration for Pipeline Construction in Siberia and the Far East (no longer exists).
Glavyamburgneftegazstroy	Main Administration for Oil & Gas Construction at the Yamburg Field (no longer exists).
Glavyuzhtruboprovodstroy	Main Administration for Pipeline Construction in the South (no longer exists).
Goskomarkhitektura	State Architecture Committee.
Gosplan	State Planning Committee of the Council of Ministers of the USSR (no longer exists).
Gosstroy	State Construction Committee.
GOST	State Standard.
GSTS	*Glavsibtruboprovodstroy* (Main Administration for Pipeline Construction in Siberia) (of the the former *Minneftegazstroy*).
GULAG	State Administration of Correctional-Labour Camps.
IPL	Integrated Production Line.
JV	Joint Venture.
kN	Kilonewton (force. 1 kN = 102 kg, or 224.8 lbs of force).
KomiNIPIstroy	Komi Scientific-Research and Planning Institute for Construction.
Kw	Kilowatt.
LenZNIIEP	Leningrad Scientific-Research and Planning Institute for Experimental Design of Residential and Public Buildings.
LPU	Linear-Production Administration. Manages gas transmission on specific sections of trunk gas pipelines.
LTS	Low-Temperature Separation.
MCM	Million Cubic Metres (gas).
MGU	Moscow State University.
Minenergo	Ministry of Energy and Electrification.
Mingazprom	Ministry of the Gas Industry (now *Gazprom*).
Minkhimmash	Ministry of Mechanical Engineering for the Petro-Chemical Industry.
Minmontazhspetsstroy	Ministry of Assembly and Special Construction Work.
Minneftegazprom	Ministry of the Oil & Gas Industry (no longer exists).
Minneftegazstroy	Ministry of Construction of Enterprises of the Oil & Gas Industry (now *Rosneftegazstroy*).
Minnefteprom	Ministry of the Oil Industry (no longer exists).
Mintransstroy	Ministry of Transport Construction.
Minuralsibstroy	Ministry of Construction for the Urals Region and Siberia.
Minvostokstroy	Ministry of Construction for the eastern regions of the USSR.
Minvuz	Ministry of Higher Education.
MISI	Moscow Engineering-Construction Institute named after V.V.Kuybyshev.
MPa	Megapascal (1 MPa = 142 pounds per square inch).
MT	Millions of Tons.
MYaB	Mastakh - Yakutsk - Bestyakh gas pipeline system.
NAGSS	Northern Autonomous Gas Supply System (Solenoye - Messoyakha - Noril'sk).
NIIOSP	Scientific-Research Institute for Foundations and Buried Structures.
NPT	Nadym-Pur-Taz Gas Production Complex (in the Yamalo-Nenetskiy AO).

NSM	Non-Woven Synthetic Material.
OGCF	Oil-Gas-Condensate Field.
OGF	Oil-Gas Field.
PechorNIPIneft'	Pechora Scientific-Research and Planning Institute for the Oil Industry.
PromstroyNIIproyekt	Scientific-Research Institute for Industrial and Construction Planning.
PNIIIS	Production and Scientific-Research Institute for Engineering Surveys and Construction.
R.	River.
RAO	Russian joint-stock company.
RAS	Russian Academy of Sciences.
RFE	Russian Far East.
RNGS	Russian Oil and Gas Construction joint-stock company (*Rosneftegazstroy*).
Rosneftegazstroy	Russian Oil and Gas Construction joint-stock company (successor to *Minneftegazstroy*).
r-o-w	right-of-way (for a pipeline).
SCC	Stress-corrosion cracking.
SDC	Stress-deformation condition.
SeverNIPIgaz	*Severgazprom*'s Scientific-Research and Planning Institute.
SGP	*Severgazprom.*
SN	Construction Norm.
SNiP	Construction Norms & Regulations.
SOG	Gas Cooling Station.
Soyuzgaztekhnologiya	All-Union Gas Technology Enterprise.
SPRI	Scott Polar Research Institute.
SRTO	Northern Regions of Tyumenskaya Oblast'.
Stroyizyskaniya	Construction and Survey Enterprise.
TEO	Feasibility Study.
TGP	*Tyumengazprom* (no longer exists).
TCM	Trillion Cubic Metres (gas).
TPFEC	Timano-Pechorskiy Fuel and Energy Complex.
TsNIIChM	Central Scientific Research Institute for Ferrous Metallurgy.
TsNIIS	Central Scientific-Research Institute for Transport Construction.
TTG	*Tyumentransgaz* (*Gazprom*'s largest gas transportation enterprise).
TU	Technical Requirements.
TyumenNIIgiprogaz	Tyumen Scientific-Research Institute for the Gas Industry (Enterprise of *Gazprom*).
UGSS	Unified Gas Supply System.
UKPG	Gas Processing Plant (located at a producing field).
Ukrgazproyekt	Ukrainain Planning Enterprise for the Gas Industry (successor to *Soyuzgazproyekt*).
UPPG	Plant for Preliminary Gas Processing (located at a producing field).
UralNITI	The Urals Scientific-Research Technical Institute.
Uraltruboprovodstroy	Urals Pipeline Construction Administration.
USA	United States of America.
USSR	Union of the Soviet Socialist Republics.
VNIIgaz	All-Russian Scientific-Research Institute for Natural Gases and Gas Technologies (Enterprise of *Gazprom*).
VNIIST	All-Russian Scientific-Research Institute for Construction of Trunk Pipelines.

VNIPIgazdobycha	All-Russian Scientific-Research and Planning Institute for Gas Production (Subsidiary Company of *Gazprom*).
VNIPItransgaz	All-Russian Scientific-Research and Planning Institute for Gas Transmission.
VSEGINGEO	All-Russian Scientific-Research Institute for Hydrogeology and Engineering Geology.
VSM	Vertical Support Member.
VSN	Departmental Construction Codes.
YEGTS	Yamal - Europe Gas Transmission System.
YuzhNIIgiprogaz	Southern Scientific-Research Institute for the Gas Industry.

GLOSSARY

Permafrost-related definitions are based upon those provided by van Everdingen (ed.) (1994). Indications are given of terms that are defined or examined in more detail in the text.

Cryogenic slope processes
A collective term used to describe processes involving the downslope movement of soils in regions of permafrost or seasonal freezing. Includes solifluction, creep and cryogenic landslides (for example, active-layer detachment failure). Discussed in chapter 5, subsection 5.2.2.3.

Cryopeg
Defined in the West as a layer of unfrozen ground that is perennially cryotic (forming part of the permafrost), in which freezing is prevented by freezing-point depression due to the dissolved-solids content of the pore water. Russian definitions differ. The distinction between western and Russian definitions of this term is made in chapter 5, subsection 5.2.2.4.

Cryotexture
The textural characteristics of frozen, fine-grained organic or mineral earth materials cemented together with ice. Russian geocryologists have identified up to ten cryotextures, including, for example, massive, lenticular, reticular, stratified and ataxitic.

Ice wedge
A massive, generally wedge-shaped body with its apex pointing downwards, composed of foliated or vertically banded, commonly white, ice.

Joule-Thomson effect
The change in temperature that occurs when a gas expands through a porous plug or into a region of lower pressure. For most real gases the temperature falls under these circumstances as the gas has to do internal work in overcoming the intermolecular forces to enable the expansion to take place. Discussed in chapters 4 and 5.

***Kray* (pl. *Kraya*)**
Region. A combination of *Oblast'* and republic whose boundaries have been laid out primarily for administrative purposes, but containing within it lesser political subdivisions that are based on nationality groups, for example autonomous districts (see "AO" in list of acronyms and abbreviations).

***Oblast'* (pl., *Oblasti*)**
Region. A purely administrative subdivision that contains no significant nationality group other than the titular nationality of the Russian Federation (see "ASSR" and "AO" in list of acronyms and abbreviations).

Permafrost
Ground that has remained at or below an annual average temperature of 0°C for at least two years, due to natural climatic conditions. Defined and examined in more detail in Appendix 1.

Polygonal peat bog
A peat bog with ice-wedge polygons.

***Rayon* (pl., *Rayony*)**
An *Oblast'*, *Kray* or Republic is divided into *rayony* which are small districts, similar in function to counties.

Solifluction
A cryogenic process involving the slow downslope movement of saturated unfrozen earth materials. Rates of flow vary widely and the term is often applied to processes operating in both seasonally-frozen ground and permafrost regions. Discussed in chapter 4, subsection 4.3.4 and chapter 5, subsection 5.2.2.3.

***Suglinok* (pl., *suglinoks*)**
Often referred to in the West as loam. A silt-like soil which contains some clay and sand but relaively more clay (10 - 30%) and less sand than *supes*. Discussed in chapter 4, subsection 4.3.2.2.

***Supes* (pl., *supeses*)**
Often referred to in the West as sandy loam. A silt-like soil which contains some clay (3 - 10%) and sand but mostly sand. Discussed in chapter 4, subsection 4.3.2.2.

Talik
A layer or body of unfrozen ground within an area of permafrost. They are most often associated with temperatures above 0°C (non-cryotic) but can also have temperatures below 0°C (cryotic), as in the case of, for example, a hydrochemical talik (see chapter 5, subsection 5.2.2.4). Typically they occur beneath large rivers and lakes in the permafrost zone because of the heat storage effect of the water. They may be described as "open" (penetrating the permafrost completely) or "closed" (isolated within the permafrost). Referred to throughout the thesis.

Thaw bulb
A more or less symmetrical zone of thawed ground in permafrost, below or surrounding a man-made structure maintained at temperatures above 0°C. Discussed in chapter 4, subsection 4.3.3.

Thermokarst
The cryogenic process by which characteristic landforms result from the thawing of ice-rich permafrost and subsequent thaw settlement. Such landforms include thermokarst lakes, *khasyreys* and *alases*. Discussed in chapter 4, subsection 4.3.3 and chapter 5, subsection 5.2.2.3.

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CHAPTER 1

INTRODUCTION

1.1 The Russian gas industry

The Russian gas industry was founded a little over half a century ago but by the late 1980s, due chiefly to Russian gas production, the Soviet Union had become the world's largest gas producer and exporter. Although Soviet oil and gas production had started in the Baku region of Azerbaijan in the 1870s and small-scale coal seam gas transportation was underway in the eastern Ukraine in the 1930s, it was not until 1943 that natural gas production and transportation really began to take off in Russia. Russia's first experience of gas pipeline construction came that year with the completion of a small line from Buguruslan to Kuybyshev (now Samara) in the Volga-Urals region, the same year that the Yelshanka gas field was discovered. This would become the source for the USSR's and Russia's first trunk gas pipeline, laid from Saratov (on the R.Volga) to Moscow. Also in 1943 the Soviet gas industry received its own autonomous directorate, named *Glavgaztopprom* (Kryukov & Moe, 1996, p.15). Its first major task was the construction and commissioning of the Saratov - Moscow trunk gas pipeline which was completed in 1946. Thus, the foundation of the gas industry is recognized as having taken place in 1946.

During the 1950s and 1960s the major gas-producing regions of the USSR were the western and eastern Ukraine, Krasnodarskiy and Stavropol'skiy Krays in the north Caucasus, Saratovskaya and Volgogradskaya Oblasts in the Volga-Urals region and Azerbaijan. In September 1965 the Ministry of the Gas Industry, forerunner of today's *Gazprom*, was founded in response to the discovery of significant gas fields in Uzbekistan and West Siberia in the late 1950s and early 1960s. During this period the network of trunk gas pipelines expanded rapidly. This pan-USSR network became known as the Unified Gas Supply System (UGSS). During the mid-1960s work began on the first trunk gas pipeline in West Siberia's Tyumenskaya Oblast', whose Yamalo-Nenetskiy Autonomous District (AO) has since become the cornerstone of Russian gas production. Work also began on the first gas pipeline in permafrost in Yakutiya in the Soviet Far East. From then on the focus of gas production began to shift to the sub-Arctic and then Arctic parts of the Yamalo-Nenetskiy AO. The first giant gas-condensate field (GCF) in Yamalo-Nenetskiy's Nadym-Pur-Taz production complex, Medvezh'ye (1.6 TCM of reserves initially), was commissioned in 1972. The UGSS began to expand at a tremendous rate as two other giant GCFs in this complex, Urengoy (7 TCM of reserves initially) and then Yamburg (5 TCM of reserves initially), were opened up in the late 1970s and mid-1980s respectively. While the Nadym-Pur-Taz complex is the dominant gas production region nowadays, significant gas output also comes from the Orenburg GCF in the Volga-Urals region.

Table 1.1 **Gas production totals for the world's top five producing countries (BCM), 1995 - 1997** (Source : *Nefte Compass*, 1998, p.9; *Petroleum Economist*, 1998b, p.130)

1997 Rank	**Country**		**Year**	
		1995	**1996**	**1997**
1	Russia*	594.9	600.3	569.2
	(*Gazprom*	559.5	564.7	533.8)
2	USA	526.6	538.2	536.9
3	Canada	158.7	164.1	169.0
4	UK	75.5	89.4	90.3
5	Netherlands	78.3	89.6	81.8

* Russia (and other CIS countries) measure gas volumes at 20°C rather than the 15°C used by most other countries. At 20°C gas volumes are 7% greater than at 15°C.

Today, Russia's proven gas reserves total roughly 50 TCM, with potential reserves of over 220 TCM. Russian gas production, roughly 95% of which comes from *Gazprom*, the Russian gas monopoly, is the largest in the world, as indicated in Table 1.1. This makes *Gazprom*, which accounts for 25% of the Russian federal budget, the world's largest gas production and transmission company. It operates the UGSS which is supplied by some 70 fields and is now almost 150,000 km in length, incorporating compressor stations, gas distribution stations and underground storage facilities. The majority of gas production now takes place in the inhospitable Arctic and sub-Arctic, notably at the Urengoy, Yamburg and Medvezh'ye GCFs, where new technologies for gas production and transmission have been introduced over the last 30 years. Most of the UGSS's major trunk gas pipelines originate at these three fields. A number of giant undeveloped fields lie in these regions of the Russian North, some of which are located on the now well-known Yamal Peninsula where proven gas reserves exceed 10 TCM. Yamal is expected to become a major new source of gas early in the next century. The major markets for this gas, as well as for some 20% of *Gazprom*'s current annual production, lie in western and eastern Europe.

1.2 Aims and justification of the thesis

1.2.1 Aims

Given the importance of Arctic and sub-Arctic fields in Russian gas production and hence the trunk pipelines that originate there, this thesis has three main aims:

1. to identify the most important issues with respect to buried (underground) trunk gas pipeline integrity and reliability in the permafrost regions of northern West Siberia;
2. having identified the key issues, to provide evidence of the existence of a learning process within the fields of northern trunk gas pipeline planning, construction and operation over the last 30 years;
3. finally, to assess the technical preparedness of *Gazprom* for construction of the northern section of the Yamal - Europe Gas Transmission System (YEGTS). The YEGTS is *Gazprom*'s most ambitious gas transmission project yet. YEGTS's northern section will be laid in even more complex natural conditions than those at Urengoy, Yamburg and Medvezh'ye.

1.2.2 Justification

There is tremendous interest amongst western oil majors in the oil and gas sectors of the Commonwealth of Independent States (CIS). The CIS, notably Russia, Kazakhstan, Turkmenistan, Uzbekistan and Azerbaijan, possesses huge oil and particularly gas reserves. Involvement in the these sectors through joint ventures, production-sharing agreements (PSAs) and strategic alliances with their former-Soviet counterparts, will allow western oil companies to make colossal additions of oil and gas to their portfolios and, because of the location of the CIS, improve and increase access to markets both in Europe and Asia. For the states of the CIS, the western companies bring with them much needed capital, without which they would be unable to develop their indigenous energy resources. In spite of the obvious attractions for both sides, investment by the western oil majors in the CIS oil and gas sectors continues to be slower than expected due to, most importantly, the unstable economic situation, lack of a stable tax system, slow passage of production-sharing and related legislation through the *Duma*. However, the recent spate of signings of strategic alliances, for example *Gazprom* with Shell and ENI, confirms that foreign participation is picking up.

This thesis focuses on Russia. Russia has attracted more attention since it possesses 85% of CIS proven gas reserves (34.4% of world proven gas reserves) and 73% of CIS proven oil reserves (4.7% of world proven oil reserves)[1]. As already indicated, a large proportion of these, notably the gas, lie in Russia's Arctic and sub-Arctic regions. In fact, in 1997, 499 BCM or 87.5% of Russia's gas was produced by *Gazprom*'s northern production enterprises, in descending order of output: *Urengoygazprom*, *Yamburggazdobycha*, *Nadymgazprom*, *Surgutgazprom*, *Severgazprom* and *Tyumentransgaz*. These enterprises operate in regions of the Russian North characterized by

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[1] Oil and gas reserve estimates are as of the end of 1996 and are taken from *Petroleum Economist*, 1998a, p.142.

extreme climatic conditions, often underlain by permafrost. Permafrost is defined briefly in the glossary but at this stage the reader is urged to refer to a more detailed summary of the phenomenon in Appendix 1. Permafrost occupies 49.7% (over 11,000,000 km²) of the land area of the CIS, or more than 50% (9,000,000 km²) of the land area of Russia. Trunk transportation of oil and gas by pipeline in Russia invariably involves crossing large expanses of permafrost. Nearly all of Russia's most important trunk gas pipeline systems, some of which exceed 4000 km in length, originate at Urengoy, Yamburg and Medvezh'ye, in the permafrost regions of northern West Siberia. The initial sections of these pipelines cross hundreds of kilometres of permafrost, followed by many hundreds more of bog. In the far northeastern part of European Russia, also a permafrost region, pipelines supply oil southwards from a number of large fields, including Ardalinskoye and Khar'yaginskoye.

With vast reserves of oil and gas in the Russian North we can anticipate the construction of many more pipeline systems within permafrost regions. Of these new transportation systems, several of the most ambitious ones are being planned by consortia or alliances consisting of both Russian and western oil companies. Examples of such international projects include:

1. the Irkutsk - China gas pipeline project in East Siberia, under development by Russia, China, Japan, South Korea and Mongolia. This ambitious project would involve the construction of a pipeline from the giant Kovyktinskoye GCF in Irkutskaya Oblast' through Mongolia to the Beijing region, for the supply of 20.5 BCM of gas per annum. Under the terms of a strategic alliance with *Sidanko*, BP acquired a 45% stake of *Sidanko*'s 60% stake in *Rusiya Petroleum* which holds the licence for development of Kovyktinskoye[2]. There are plans for the pipeline to be extended to South Korea and Japan at a later stage. Additional gas from Sakha-Yakutiya and Krasnoyarskiy Kray could be supplied to the system through spurs added much later;
2. the Zapolyarnoye - Urengoy pipeline will be laid to supply gas from the Zapolyarnoye oil-gas-condensate field (OGCF), located in the Yamalo-Nenetskiy AO. Part of Zapolyarnoye will be developed by a 50/50 joint development company formed under the terms of the *Gazprom*-Shell strategic alliance[3]. Production of liquids and gas is expected to start in 2003. In Krasnoyarskiy Kray Shell is involved with *Yeniseyneft'* in the planning of an oil pipeline from the Vankor field, via the Suzun field to a terminal at Dikson on the coast of the Kara Sea.

In spite of the involvement by western oil companies in Russian Arctic or sub-Arctic pipeline projects and extensive theoretical and experimental work on oil and gas pipeline operations in permafrost, they have little or no practical experience of construction and operation of oil or gas pipelines in permafrost conditions. Outside Russia there are only two operational oil pipelines in permafrost conditions; the Trans-Alaskan oil pipeline in the USA and the Norman Wells - Zama oil

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[2] BP bought 10% of the *Sidanko* integrated oil company under an agreement signed on November 17th 1997. Sidanko is controlled by *Uneximbank*.

[3] The *Gazprom*-Shell strategic alliance was signed in Moscow on November 17th 1997.

pipeline in Canada. But there are still no operational gas pipelines in permafrost outside Russia. Thus, as far as gas pipelines in permafrost are concerned, the focus of this thesis, the West has a great deal to learn from the Russian experience. Those western engineers planning and designing such pipelines for their own countries (Canada and USA, for example) or for Russia as part of the consortia and alliances mentioned above must build up an intimate knowledge of the complexities involved in developing pipelines for permafrost regions. The Russians have been unable to guarantee reliable gas pipeline operations in permafrost regions. Since their northern gas pipeline operations began 30 years ago, the Russians have encountered countless problems on these transmission systems. The origin of many of these problems lies in interactions between the pipelines and the extremely sensitive permafrost environment surrounding them.

After three decades of experience many of these problems remain unsolved. This must serve as a stark reminder to western specialists that gas pipeline operations in permafrost conditions are a great deal more complex than those in temperate zones. Furthermore, an understanding of these problems can only be achieved through close examination of the 30 year Russian experience. Only then can western specialists stand a chance of planning and designing reliable Arctic and sub-Arctic gas pipeline systems. Many problems now being encountered in Russia originate from the beginning of the development period. An historical examination is all the more important because of the influence Soviet policies had on oil and gas industry development during the 1970s and 1980s. This kind of approach also warrants broad coverage of many geocryological factors affecting gas pipeline reliability in the Russian North. Geocryology (a term derived from the Russian, *Geokriologiya*), the study of earth materials which have a temperature below 0°C, is clearly an essential element of any research into pipelines in permafrost conditions because it can offer explanations as to why, for example, displacements of northern pipelines occur unevenly over relatively small distances and over varying lengths of time. It tells us that we must recognize the diversity of natural and geocryological conditions not just from one permafrost region to another, but also within these regions at a very local scale. We will see that it took the Russians a long time to realise this. In essence, problems being experienced on Russia's northern gas pipelines are the result of a combination of many different natural, economic, historical and even social factors, the influence of which spans several decades. Both in Russia and in the West there is a tendancy to focus on specific factors (or sub-factors), giving one the false impression that any one factor being examined is solely responsible for gas pipeline unreliability. The thesis attempts to correct this misunderstanding.

There are also more far-reaching reasons for this research. The most important of these concerns security of gas supplies. Large sections of the UGSS have almost reached or exceeded their operational lifetime (33 years, according to the Russians). By 2005, the oldest parts of the UGSS in the Yamalo-Nenetskiy AO, notably the pipelines from Medvezh'ye, will have reached this threshold. It is thus important to gauge the operational reliability and condition of the northern gas pipelines as they approach the threshold, particularly since *Gazprom* proposes to carry out an extensive reconstruction programme on UGSS pipelines and compressor stations. *Gazprom* is developing an industry-wide diagnostics system, including the use of pigging equipment, which should be implemented in 1998 (Remizov, 1997, p.14). Secure supplies through reliable gas pipelines are critical since the Russian economy depends on *Gazprom* gas exports for such a large proportion of its total revenues. In 1996 the company exported 123.5 BCM to European markets (74.4 BCM to western Europe and 49.1 BCM to eastern Europe) which represented 49% of total European gas imports, the major recipients being Germany, Italy and France. Russia's closest competitor, the Netherlands, exported 45.8 BCM in total, all of which went to western European markets. With its massive reserves, *Gazprom*'s dominance of the European gas market is set to continue as demand increases. Long-term export contracts signed during the 12-month period up to July 1998 (the largest ones being with Turkey and Germany's Ruhrgas) have ensured that Russian gas exports will increase to a minimum of 150 BCM/year, possibly rising to 200 BCM/year. Ruhrgas, for example, has renewed its cooperation agreement with *Gazprom* which extends contracts for another 15 years. Linked to Russian gas exports is the existence of a gas industry equipment market for foreign companies. *Gazprom*'s access to this equipment market, particularly under barter terms, depends very much on its ability to provide uninterrupted gas supplies and this can only be ensured by reliable pipeline operations. This market will be particularly important as the UGSS reconstruction programme gains pace. Successful execution of the reconstruction programme and *Gazprom*'s largest current pipeline projects, the YEGTS and Blue Stream (Black Sea crossing), will require enormous international investment and lending. The same goes for projects only at the feasibility study stage, notably North Transgas, a *Gazprom*-Neste venture, in which Russian gas would be exported via Finland to northwest Europe.

Thus there are two clearly defined areas of justification for the thesis. First, that major western oil companies need to learn about trunk gas pipeline development in permafrost conditions, second, Russia's ability to maintain pipeline reliability and ensure security of product supplies.

1.3 Research methods

Two very different forms of investigation have been used in research for this thesis: field trips to various parts of the Russian North, and Moscow, and library-based research.

1.3.1 Field trips

Four major field trips have been undertaken since research began in January 1995. Each trip is outlined in brief below. Several other short visits have been made to Russia, generally to Moscow alone. These will not be described.

1.3.1.1 First field trip

A 3½ week trip to the Komi Republic (in Russia's European Northeast) was made in November-December 1995. This was the first trip to one of Russia's northern oil and gas production complexes. Komi's capital city, Syktyvkar, was used as the base. From there side-trips were made to Ukhta, where interviews were held at *Severgazprom* and *Komineft'* headquarters and the research institutes *SeverNIPIgaz*, *PechorNIPIneft'* and *KomiNIPIstroy*, and Vuktyl, the town supporting the Vuktyl'skoye GCF upon which *Severgazprom* has depended for gas production. The trip to Vuktyl included visits to the right-of-way (r-o-w) of the "Northern Lights" trunk gas pipeline (Punga - Vuktyl - Ukhta - Gryazovets) and to Vuktyl'skoye's gas processing plant (UKPG) No.8. A number of interviews were conducted with specialists in Syktyvkar, Ukhta and Vuktyl. Several days were spent in Moscow on the return journey where more interviews were held at *Rosneftegazstroy* (RNGS) and *PNIIIS*.

1.3.1.2 Second field trip

This was the main research field trip, lasting 25 weeks between March and September 1996. Roughly half that time was spent in the Komi Republic. Again, Syktyvkar was the base and two further side-trips were made to Ukhta. In Ukhta interviews were held at *SeverNIPIgaz*, *KomiNIPIstroy* and the Ukhta Industrial Institute. In June 1996 two weeks were spent in the Taymyrskiy AO (in East Siberia), visiting the headquarters of *Noril'skgazprom* in the Arctic city of Noril'sk, three GCFs (North and South Soleninskoye and Messoyakha) and the Northern Autonomous Gas Supply System (NAGSS), a small-scale trunk pipeline system which supplies gas from these GCFs to the Noril'sk mining-metallurgical combine. The trip to Taymyrskiy AO included visits to a full-scale large-diameter gas pipeline test section, at South Soleninskoye, and a pile test site on the outskirts of Noril'sk. Several weeks were spent in Moscow where interviews were held at *RNGS*, *VNIIgaz* (who organized the Taymyrskiy trip), *PNIIIS* and the Department of Geocryology of *MGU* (Moscow State University). Attendance was also possible at the First Conference of Russian Geocryologists, held at *MGU* from 3rd to 5th June.

1.3.1.3 Third field trip

A six week trip was made between February and April 1997. Much of this time was spent in Moscow, where interviews were held, but one week in early March was spent in Nadym thanks to an invitation from *Nadymgazprom*. Located in the Yamalo-Nenetskiy AO, Nadym is home to *Nadymgazprom* which operates the Medvezh'ye, Yubileynoye and Yamsoveyskoye GCFs. It is also carrying out preliminary development work at the Bovanenkovskoye and Kharasaveyskoye GCFs on the Yamal Peninsula. Several interviews were held at *Nadymgazprom* headquarters and also at the

Nadym Gas Production Administration, a subdivision of *Tyumentransgaz* (TTG) which operates the Kharvutinskoye GCF and is *Gazprom*'s and the world's largest gas transmission enterprise.

1.3.1.4 Fourth field trip

The final field trip lasted four weeks in March-April 1998. Two weeks were spent at the Yamburg GCF, the second largest producing gas field in Russia, thanks to an invitation from the Gubkin State Oil & Gas Academy (*GANG*) and *Yamburggazdobycha*. Yamburg is located north of Nadym in the Yamalo-Nenetskiy AO. The journey to Yamburg involved flying to Novyy Urengoy, the base settlement for the Urengoy GCF (operated by *Urengoygazprom*), Russia's largest producing field, and driving north from this large town to Yamburg through the Urengoy GCF. Several stops were made to conduct brief inspections of the Urengoy gathering line. At Yamburg visits were made to UKPG-1V and UKPG-2, wells, feeder lines and gathering lines. Interviews were held in various *Yamburggazdobycha* departments: administration, technical department, department of scientific-research production work (including geocryology laboratory) and the inter-field gathering line operations division. Ten days were spent in the settlement of Yamburg, which operates entirely by the shift method with workers being flown in and out regularly. The other two weeks were spent in Moscow, where several interviews (including data collection) were held at the Moscow branch of the Earth Cryosphere Institute and *GANG*.

1.3.1.5 Field trip difficulties

The intention had been to visit parts of the Yamalo-Nenetskiy AO, particularly Nadym and Novyy Urengoy, during the second (1996) field trip. Unfortunately permission was not forthcoming from the relevant *Gazprom* enterprises until 1997, when *Nadymgazprom* provided an invitation and then in 1998, when *Yamburggazdobycha* (via *GANG*) provided another. Even with these invitations the total amount of time spent in the Yamalo-Nenetskiy AO was only three weeks. This reflects the restrictions imposed by *Gazprom* upon the time spent by foreigners in centres of gas production, if indeed they receive permission at all. It should be noted that the invitation from *Nadymgazprom* was only made possible through a contact at *Gazprom* headquarters in Moscow. In addition, from mid-1997 many attempts were made to obtain permission from TTG to visit trunk gas pipelines and compressor stations in the Yamalo-Nenetskiy AO but without success. Thankfully, the short time spent in Yamalo-Nenetskiy did not affect data collection negatively since full visit and interview programmes were arranged by both *Nadymgazprom* and *Yamburggazdobycha*. But clearly a great deal of field trip data came from elsewhere within the *Gazprom* structure, for example *VNIIgaz*, *Severgazprom* and *SeverNIPIgaz*, as well as non-*Gazprom* sources such as RNGS, *GANG*, *MGU*, the Earth Cryosphere Institute and *Noril'skgazprom*.

1.3.2 Library-based research

Library-based research formed a very important part of the overall research effort given the difficulties in obtaining permission to visit selected field sites. Every attempt was made to make the broadest possible use of material in the Russian language. Full use was made of the SPRI library's extensive collection of Russian material, which is particularly strong in the field of geocryology. The Russian journals *Stroitel'stvo Truboprovodov* (Pipeline Construction) and *Gazovaya Promyshlennost'* (Gas Industry), crucial for a thesis of this nature, were available from the British Library. Numerous books, journals and other publications were obtained while in Russia, the majority of which are not available in the UK. Where western material has been used, it has in general been applied in order to reinforce similar Russian data. Papers written by westerners describing their participation in joint ventures or other projects in Russia have also been used.

1.3.3 Decision concerning the NAGSS

Following careful consideration, a decision was taken not to include case studies of the NAGSS in this thesis. The thesis focuses on the trunk gas pipelines of northern West Siberia which are part of *Gazprom*'s UGSS. The NAGSS however is a small-scale independent system operating within very different technical, economic and natural-climatic parameters. This issue is raised at various points in the thesis. Inclusion of the NAGSS case studies would have required extensive background sections in addition to those already required for the UGSS trunk lines, taking the thesis beyond its page limit. It would also detract from the key arguments of the thesis which concern UGSS trunk gas pipelines[4]. Nonetheless, where necessary, certain aspects of the NAGSS are used briefly for comparative purposes.

1.4 Thesis structure

The thesis takes the following form. Chapter 2 introduces the reader to the UGSS, including its early development. The majority of the chapter focuses on the system's northern component. The emergence of Tyumenskaya Oblast' as Russia's main gas producing region is the overriding theme. This is reflected in the detailed examination of the region's first trunk gas pipeline system, Igrim - Serov, followed by the more northerly multi-string pipeline systems that were built later from the Medvezh'ye, Urengoy and Yamburg GCFs. The Komi Republic's important role as a pipeline transit region is also recognized. Finally, chapter 2 assesses the influence of age on the UGSS. The longer the pipeline has been operational, the wider the variety of problems that face it.

Chapter 3 examines a set of peculiarly "Soviet" problems facing northern gas pipeline planners, designers and constructors. The chapter is therefore set very much in an historical context.

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[4] The author would like to add that the NAGSS will be the subject of a paper to be written subsequently. A large quantity of material concerning the NAGSS was gathered in June 1996 on the second field trip.

It starts by tackling the serious problem of deficiencies in the regulatory documents for pipeline planning and design. Having introduced them, a number of major criticisms of these documents by notable authorities are discussed. Then, problems facing Russia's leading pipeline planning and research institutes are examined with particular emphasis on the fall-out from the break-up of the Soviet Union. Construction practice, the next step in the pipeline development process, is addressed thereafter. Here, the impact of central planning, construction work organization and ways of accelerating assembly work on the largest trunk gas pipeline projects of the 1980s is assessed.

Chapter 4 is concerned with the pipeline operations phase. It focuses on the issue of "pipeline - permafrost" interactions and shows that the relationship between operational pipelines (in this case buried trunk gas pipeline systems) and the surrounding permafrost environment is a key factor in the short-, medium- and long-term reliability of northern product transmission systems. To demonstrate this, the chapter makes a detailed examination of the potentially harmful cryogenic processes of frost heave and thaw settlement which are influenced directly by the temperature of the product being transmitted through a pipeline. Alteration and activation of these processes has led to serious stability problems on buried trunk gas pipelines within the northern component of the UGSS. Another cryogenic process, thermal erosion, is considered in less detail. The chapter provides important evidence of the significant influence of product transmission temperatures upon pipeline reliability. Regulation of product temperature regimes is expensive and the Russians have not been able to introduce widespread regulatory mechanisms on their northern pipelines. Thus economic problems have had far-reaching effects on the reliability of pipelines in permafrost.

Chapter 5 focuses on the Yamal - Europe Gas Transmission System (YEGTS) project, a widely publicised and highly ambitious project which will see the construction of pipelines in even more challenging geocryological conditions than those already experienced in the Nadym-Pur-Taz gas production complex. Construction has begun on the southern (market) end of the system, but the source end on the Yamal Peninsula and just to the south of it, some 4000 km to the northeast, is not yet under way. The chapter tackles the issue of design of the northern section of the YEGTS. Given the experiences so far on operational UGSS pipelines, the environmental, particularly geocryological conditions in this region (which differ from those in Nadym-Pur-Taz), and the intended gas transmission temperature regime, the latter part of the chapter assesses the viability of solutions proposed so far to overcome specific engineering-geocryological problems on the YEGTS. It is found that a number of crucial problems have yet to be resolved. Special attention is given to the issue of using data from a separate pipeline system (in this case a pipeline test section) for the design of the YEGTS northern section, i.e. the transfer of data from one geocryological region to another. Conclusions are made about the current stage the YEGTS project has reached.

Finally, chapter 6 shows that the three fundamental aims posed in subsection 1.2.1 have been fulfilled. First, the key issues in buried trunk gas pipeline reliability in northern Russia are summarized. Then, evidence for and against the existence of a learning process is provided. As might be expected, significant progress has been made in some areas but not in others. Lastly, a critical assessment is made of the technical preparedness of *Gazprom* for construction of the northern section of the YEGTS. The wider implications of these conclusions are discussed in brief.

CHAPTER 2

DEVELOPMENT OF THE RUSSIAN TRUNK GAS PIPELINE SYSTEM IN INCREASINGLY HARSH NATURAL-CLIMATIC CONDITIONS

2.1 Introduction

This chapter examines the evolution of the Russian Unified Gas Supply System (UGSS), which is operated by *RAO Gazprom*[1]. A brief overview of the whole UGSS, including its early history, is given in section 2.2. Considerable detail will be provided in section 2.3 on the northern component of the UGSS which encompasses the West Siberian North (the Khanty-Mansiyskiy and Yamalo-Nenetskiy AOs of Tyumenskaya Oblast') and a large part of Russia's European North (the Komi Republic, in particular). Pipeline construction and operation conditions in these areas are complicated by the presence of permafrost and ground subject to cycles of intense seasonal freezing and thawing. The Komi Republic displays a widespread distribution of the latter type of ground condition, with a small zone of permafrost in its most northerly districts, while much of the north of Tyumenskaya Oblast' is characterized by continuous, discontinuous and island permafrost. This section follows the progress of construction of the northern part of the UGSS, starting with the Igrim - Serov pipeline, the first trunk gas pipeline laid in the northern conditions of West Siberia (subsection 2.3.1). It then moves on to the development further north of the vast pipeline corridors which transport gas from the Medvezh'ye and Urengoy GCFs in Yamalo-Nenetskiy's Nadym-Pur-Taz gas production complex (NPT) to western Russia, as well as abroad (subsection 2.3.2). More than 80% of Russia's gas is produced in the NPT where the largest gas pipeline corridors originate. This stage of pipeline development took place simultaneously with that in the Komi Republic, Komi being used mainly for pipeline transit. Thus, gas pipeline development in the European North is considered next (subsection 2.3.3). Section 2.4 focuses on the most recent large-scale developments of the UGSS northern section. This involved construction of trunk gas pipelines from the Yamburg GCF, Russia's second largest producing GCF. Yamburg lies further north than Medvezh'ye and Urengoy, in an area of the NPT which is geocryologically more complex. It thus serves as the best example of an area where large-diameter gas pipelines have been constructed and commissioned in the most challenging of geocryological environments. The section begins with a description of the field's development and current operations. Section 2.5 reviews some of the age-related problems

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[1] *RAO* is the transliteration of the Russian acronym for *Rossiyskoye Aktsionernoye Obshchestvo* (Russian Joint-Stock Company). *Gazprom* was established as a Russian joint-stock company by Presidential Decree No.1333 of November 5th 1992. It had previously been State Gas Concern *Gazprom*.

now being experienced on these pipelines and the frequency of accident occurrence. The chapter is concluded in section 2.6.

2.2 Overview and history of the UGSS

Virtually all the large-diameter high-pressure trunk gas pipelines in Russia are operated by *Gazprom* as a single entity known as the UGSS, shown in Fig.2.1. Fig.2.1 also shows three other trunk gas pipeline systems, though much smaller in scale, which are operated independently of *Gazprom* in East Siberia and the Russian Far East. These are; the NAGSS (Soleninskoye - Messoyakha - Noril'sk), Mastakh - Yakutsk - Bestyakh; Okha - Komsomol'sk-na-Amure. *Gazprom*'s 145,000 km UGSS traverses European Russia and West Siberia, of which 125,000 km have a diameter in excess of 1020 mm (Shmal' & Ivantsov, 1994, p.8; International Energy Agency, 1995), while 50,000 km are of the largest diameter 1420 mm pipe (Remizov *et al.*, 1996, p.247)[2]. By 1996, approximately 51% of the UGSS was composed of either 1220 mm or 1420 mm diameter pipelines (Ivantsov, 1997b). Tables 2.1 and 2.2 show the growth of the UGSS in the period 1958 - 1994, also demonstrating the growth in use of large-diameter pipe. The pipelines generally operate with a pressure greater than 5.5 MPa (798 psi or 56 kg/cm²). There are some 250 compressor stations in the system with a total fixed output of 40,200 Mw (Ivantsov, 1997b; Remizov, 1997, p.14). Twenty underground gas storage facilities have a working capacity of 45.6 BCM. Five more underground storage facilities are under construction.

Russia's remarkable gas industry has been active for half a century, celebrating its 50th anniversary in 1996. 1996 also marked the 50th anniversary of the commissioning of the first trunk gas pipeline, Saratov - Moscow. Plans for this 845 km gas pipeline, with a diameter of 325 mm (6.25 mm wall thickness) and for a design pressure of 5.5 MPa, were prepared in 1944 when the State Defence Committee took the decision to supply gas from the newly opened Yelshanka field near Saratov (on the R.Volga in Saratovskaya Oblast') to the industrial enterprises and population of the capital city (*Stroitel'stvo Truboprovodov*, 1996, p.2). The field was already linked to Saratov by a small pipeline which took one month to lay (Bokserman, 1996, p.54). The plan to go ahead with the Saratov - Moscow pipeline, despite an enormous shortage of materials and technical resources, marked the beginning of the Soviet gas industry and of development of the UGSS. It took some 18 months to lay the line, construction of which was carried out by *Mosgazstroy* and directed by Major-General Vasiliy Alekseyevich Pachkin of the engineering-technical office. *Mosgazstroy*, the predecessor of today's *Mostransgaz*, was the first enterprise in the USSR to undertake large-scale production and long-distance transmission of gas. On 11th July 1946, gas from Saratov arrived in

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[2] Strictly speaking, the UGSS extends throughout the CIS, comprising 220,000 km of trunk gas pipelines (Remizov *et al.*, 1996, p.247). For the purposes of this thesis, the term UGSS will be used in the Russian context only.

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Fig.2.1 Russia's trunk gas pipeline systems : UGSS, NAGSS, MYaB and Okha - Komsomol'sk (includes other CIS countries)

Moscow through the new pipeline. Annual throughput of the pipeline was supposed to be 500 MCM (*Petroleum Economist*, 1996a, p.64). The pipeline ran into problems later in 1946, due to hydrate accumulations in the pipe and Stalin himself ordered a report on its operation. In response to this, a special operations department for the Saratov - Moscow gas pipeline was set up on 9th December. Full capacity of the pipeline was achieved by August 1947 and this prompted Stalin to send his personal congratulations to the operations department headed by Yuliy Il'ich Bokserman. Bokserman was one of the founders of the Soviet gas industry and at the age of 86 continues working today at the Energy Research Institute (RAS).

Table 2.1 **Length of UGSS trunk gas pipelines, 1958 - 1994, 1000s of Km** (Sources : Shcherbina *et al.*, 1981, p.62, Table 1, p.64, Table 2; Batalin, 1983, p.2; *Gazprom*, 1995a, p.20)

Year	**Total length of gas p'lines**	**Growth in length (annual)**	**Gas pipeline diameter, mm (% of total length)**					
			<720	**720**	**820**	**1020**	**1220**	**1420**
1958	12.2	–	–	–	–	–	–	–
1960	21.0	4.5	–	–	–	–	–	–
1965	42.3	5.4	49.7	26.4	10.1	13.8	–	–
1966	47.6	5.3	–	–	–	–	–	–
1967	52.7	5.1	–	–	–	–	–	–
1968	56.1	3.4	–	–	–	–	–	–
1969	63.2	7.1	–	–	–	–	–	–
1970	67.5	4.3	44.2	19.1	7.5	23.5	5.7	–
1971	72.3	4.8	44.6	18.2	7.7	23.4	6.1	–
1972	78.7	6.4	43.1	17.6	7.1	22.8	8.2	1.2
1973	83.9	5.2	40.8	17.1	7.5	22.1	10.6	1.9
1974	91.5	7.6	39.3	15.8	7.4	21.5	13.2	2.8
1975	98.7	7.2	38.7	15.1	7.0	20.6	14.9	3.7
1976	103.0	4.3	36.7	15.6	6.9	20.0	16.6	4.2
1977	111.3	8.3	36.7	14.5	6.4	19.7	16.9	5.8
1978	117.7	6.4	34.9	14.6	6.1	19.3	16.5	8.6
1982	–	9.3	–	–	–	–	–	–
1992	137.6	–	–	–	–	–	17.2	35.0
1993	139.3	1.7	–	–	–	–	17.3	34.6
1994	140.8	1.5	–	–	–	–	17.2	34.3

Small gas pipeline systems of local significance had been built even earlier. The earliest recorded gas pipelines in the USSR were the 325 km of lines built between 1938 and 1940, the largest of which was the Dashava - L'vov pipeline (western Ukraine), 70 km long and with a diameter of 325 mm (*Stroitel'stvo Truboprovodov*, 1994, p.10). These supplied coal gas to towns and industrial plants in the Donbass coal basin. Also, a 160 km 325 mm diameter gas pipeline was laid between Buguruslan and Kuybyshev (now Samara) in the Volga-Urals region in 1943. Major aviation plants had been relocated to Kuybyshev in 1942, a critical year for Russia during World War II (Bokserman, 1996, p.54). The very first product pipeline of any description in the USSR was a 9 km oil pipeline built in 1878 in the area of Baku, Azerbaijan, where the Soviet oil industry has its origins. Over the next two decades, gas pipeline construction accelerated, the length and diameter of the lines increased as the industry developed. Between 1951 and 1955, 2548 km of gas pipelines were laid and in 1956, the first 720 mm diameter gas pipeline went into service between Stavropol' and Moscow over a distance of 1254 km. By the early 1960s, 820 mm and 1020 mm diameter lines were being put into service. A landmark event for Soviet gas pipeline construction was the commissioning of the first string of the Bukhara - Ural system in late 1963. This was 1961 km long (between the Gazlinskoye GCF in Uzbekistan and Chelyabinsk) with a diameter of 1020 mm and included the first pipeline suspension bridge crossing in the USSR over the R.Amu-Dar'ya in Uzbekistan. Eventually 19 compressor stations were built for the system's two strings (Shcherbina *et al.*, 1981, p.51-52).

Table 2.2 **Length of UGSS trunk gas pipelines in West Siberia*, 1966 - 1990** (Source : Krylov *et al.*, 1990, p.6, Table 1.1)

Year	**Total length of gas p'lines (km)**	**Growth in length over intervening period (km)**
1966	989	–
1970	1320.2	331.2
1975	4636.9	3316.7
1980	10,358.8	5721.9
1985	19,360.6	9001.8
1986	20,908.6	1548.0
1987	23,790.1	2881.5
1988	27,529.1	3739.0
1990 (plan)	31,340.5	3811.4

* <u>NOTE</u> : Up to 1970 pipelines in West Siberia were operated by *Tyumentransgaz* only. Since 1975 these pipelines have been operated by *Tyumentransgaz* and *Surguttransgaz*.

Construction of the USSR's and the world's first "northern" gas pipeline laid in an area of permafrost began in 1964. This was the Taas-Tumus - Yakutsk - Pokrovsk line in central Yakutiya in the Russian Far East, the original string of today's Mastakh - Yakutsk - Bestyakh system (MYaB)[3]. The lessons learnt from laying this pipeline in such complex and difficult conditions proved invaluable for the project to lay the first gas pipeline beyond the Arctic Circle. Construction of this line, the first string of the Messoyakha - Noril'sk pipeline system, was completed in the winter of 1969-70 in the Taymyrskiy AO of Krasnoyarskiy Kray in East Siberia. This string, now decommissioned, constitutes part of what is often referred to nowadays as the NAGSS. The first northern gas pipeline laid in the West Siberia's Tyumenskaya Oblast', Russia's oil and gas production centre, was the Igrim - Serov line, the planning and construction of which is described in detail in subsection 2.3.1. Soon after this, in the late 60s and early 70s, work began on construction of the heart of the modern-day UGSS, the vast multi-string (20 strings) systems laid over several thousand kilometres from the north of West Siberia to the western Russian border and beyond. Much of the pipe used in these systems is 1420 mm diameter for a pressure of 7.5 MPa[4]. These gas pipeline systems transmit the vast majority of Russia's gas production through some of the most inhospitable regions known to Man, including areas where permafrost and bogs extend for hundreds of kilometres continuously. While construction is complicated in both permafrost and boggy conditions, it is permafrost that presents some of the most serious problems for planners, many of which are to be addressed in the subsequent chapters of this thesis. Over 20,000 km of trunk pipelines have been laid in permafrost in Russia and several more pipeline systems are under construction in such harsh terrain, including two new strings from northern Tyumenskaya Oblast' (Ivantsov, 1997a). Construction should begin early next century on the northern section of the widely discussed YEGTS, to which chapter 5 of this thesis is devoted.

2.3 Overview of the northern component of the UGSS : gas pipelines in permafrost and ground subject to intense seasonal freezing and thawing

For the purposes of this thesis, a pipeline will be defined as being within the northern component of the UGSS if it lies within the Yamalo-Nenetskiy and Khanty-Mansiyskiy AOs of Tyumenskaya Oblast', the Nenetskiy AO of Arkhangel'skaya Oblast' or the Komi Republic. Together these administrative regions lie either side of the northern portion of the Ural Mountains. Permafrost, to varying degrees of continuity, is widespread.

As with *Transneft*'s oil pipeline network, the trunk gas pipelines of the northern component of the UGSS emanate from the largest fields of Tyumenskaya Oblast'. These giant GCFs, Yamburg, Urengoy and Medvezh'ye, and their satellites are located in the NPT, several hundred kilometres to the north of the Ob' Basin oil-production complex in Khanty-Mansiyskiy AO. From here, 20 pipeline

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[3] The history of development of this pipeline system has been described in detail by Seligman (1994).
[4] 1420 mm pipe was used for the first time on a 102 km section of the Medvezh'ye - Nadym - Punga gas pipeline, commissioned in 1972.

strings (1220 - 1420 mm diameter) transporting a total of 250 BCM per annum, proceed westwards or southwards towards the industrial heartlands of Russia (notably the Urals and Volga regions), continuing on to the Russian border with Belarus and the Ukraine and further, into the European gas pipeline network for export. Associated gas is also supplied from Khanty-Mansiyskiy AO southeastwards to the Kuzbass coal basin in Kemerovskaya Oblast'. The pipeline corridors are several thousand kilometres in length. The longest 1420 mm gas pipeline in the CIS is the so-called "Progress" line, which runs 4605 km between the Yamburg GCF in the northern sector of the NPT to the western Ukrainian border. NPT gas is moved to consumers along three main routes, as shown in Fig.2.1:

- via Punga, Vuktyl, Ukhta, Gryazovets, Torzhok and Minsk ("Northern Lights" pipeline system, northern route);
- via Pomary, Yelets, Kursk and Uzhgorod (central route);
- via Chelyabinsk, Povolzh'ye and eastern Ukraine (southern route).

The following section of the thesis charts the development of the northern sections of these routes, with particular emphasis placed upon the gradual progression northwards made by the UGSS during the last 30 years in West Siberia. This northward trend towards regions of increasingly complex natural-climatic conditions is demonstrated clearly by an examination of four components of the northern UGSS in the following chronological order : Igrim - Serov, Medvezh'ye - Centre, Urengoy - Centre, Yamburg - Centre[5]. The Komi Republic's role as a pipeline transit region, including for the YEGTS, is also examined.

2.3.1 Early development of trunk gas pipeline systems in West Siberia

2.3.1.1 Background

The development of the West Siberian gas industry, starting in the 1960s, took place in two major stages. The first stage was linked with the opening up of the Berezovskiy gas-bearing district (northwestern part of Khanty-Mansiyskiy AO, see Fig.2.1) in the early to mid-1960s. This includes the Punginskoye, Pokhromskoye, Severo-Igrimskoye and Yuzhno-Igrimskoye GCFs which, combined, had explored gas reserves of roughly 100 BCM at that time. This stage was characterized by relatively small levels of gas production from fields with small reserves (Orudzhev, 1981, p.50). However, development of these fields was carried out at accelerated rates. Annual gas production in respect to initial reserves came to 20 - 22% for the Severo- and Yuzhno-Igrimskoye GCFs and 10% for Punginskoye, while the national average was only 7%. The second stage of major development was linked with the opening up of the "unique" (giant) gas fields of the NPT, such as Medvezh'ye,

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[5] In this context "Centre" refers to the industrial and economic heartlands of European Russia.

Urengoy and Yamburg, which began in the late 1960s. More will be said about this second stage later in the chapter.

The development of the trunk gas pipeline system in West Siberia began in the mid-60s soon after the discovery of these enormous gas reserves. The need for developing them was determined by the growing needs of the economy and the decline of gas reserves at fields in the North Caucasus, Lower Volga and Eastern Ukraine.

Thus, the tasks laid down by the Communist Party and government for the gas industry required the accelerated development of gas production and transportation in this region, creating the necessity for constructing powerful high-capacity gas transmission systems over great distances. However, up to that time there had been no experience in building large gas pipeline systems in the complex natural-climatic conditions of West Siberia. Therefore, the only acceptable and, as practice showed, highly-effective solution was the construction and experimental-industrial commissioning of the region's first northern gas pipelines and the use of accumulated experience as a basis for the ensuing intensive development of northern trunk gas pipelines.

2.3.1.2 Igrim - Serov : the first northern gas pipeline in Tyumenskaya Oblast'

i) Introduction

The first northern trunk gas pipeline in Tyumenskaya Oblast' was the Igrim - Serov pipeline. With a diameter of 1020 mm, designed for an operational pressure of 5.4 MPa, it was put into experimental-industrial operation in 1966. On 4th February that year the following was written in the local Serov newspaper *Serovskiy Rabochiy* ("The Serov Worker"):

> *"Yesterday a long-expected guest arrived in our town - natural gas from the Igrimskoye field! More than 500 km through the taiga, swamps and crags, crossing the impetuous rivers of the Urals, the 'blue fuel' arrived. The gigantic effort of the constructors of the Igrim - Serov gas pipeline concludes a great victory."* (Zorin & Trutnev, 1987, p.58).

A full description of the planning and construction of this gas pipeline is provided by Ashot Kirillovich Dertsakyan in his book *The Construction of the Igrim - Serov Gas Pipeline* (1967). This was probably the first comprehensive description and analysis of gas pipeline planning and construction in Russia's northern conditions, although a number of short articles had been published prior to 1967 describing the planning of the Taas-Tumus - Yakutsk - Pokrovsk gas pipeline laid in central Yakutiya in the Russian Far East.

For this reason it is worth outlining here some of the major issues addressed by Dertsakyan. But firstly some background material. Of the 25,000 km of gas pipelines which were to be laid between 1960 and 1970, roughly 6000 km were earmarked for construction in conditions analogous to those of the route of the Igrim - Serov gas pipeline. Therefore, the experience of laying this pipeline would be of special interest to those engaged in planning and constructing other large-diameter gas pipelines in Tyumenskaya Oblast', the Komi ASSR and the North-West. This is the *raison d'être* for Dertsakyan's book.

ii) Development of gas fields in Berezovskiy rayon

Up to 1959 six GCFs had been opened up in Berezovskiy rayon of the Khanty-Mansiyskiy AO[6]. This provided the impetus for the planning of a trunk gas pipeline between these fields and Sverdlovsk (now Yekaterinburg) in the heart of the Urals industrial region. The opening of the Igrimskaya group of GCFs and the need for the accelerated use of cheap fuel for the industries of the Central Urals region required the laying of the Igrim - Serov trunk gas pipeline. It was proposed to join the Berezovskaya group of fields to the Igrimskaya group and to extend the pipeline southwards from Serov to Nizhniy Tagil and Sverdlovsk, the latter being where one of the largest gas pipelines in the country at that time, Bukhara - Ural, would link up to the Igrim - Serov line.

iii) Choosing the route of the pipeline

Giprospetsgaz, now *Gazprom*'s leading pipeline design institute based in St.Petersburg, carried out a study to determine the economic effectiveness of using Berezovskiy gas in the North, Central and Western Urals. The investigation was carried out together with representatives of the industrial enterprises of the Urals, members of regional planning committees and appropriate administrations of the Councils of the National Economy, and it again confirmed the expediency of the conversion of industries to gas fuel.

It also determined the direction the gas would travel. It was considered very important that the pipeline should transport the gas to Serov at reservoir pressure without intermediate compressor stations, hence the name "Igrim - Serov". However, at the very beginning it was planned to extend the pipeline to link up with the Bukhara - Ural system and to increase its capacity to 10 BCM per annum by means of commissioning compressor stations, both booster, i.e. at the source fields, and intermediate.

The Council of Ministers of the USSR, having examined the project in detail, approved the following parameters for the pipeline:

1. 1020 mm diameter pipe should be used;
2. there should be a primary capacity of 5.8 BCM per annum without the use of compressor stations, and subsequently 10 BCM per annum after the full development of the pipeline with the construction

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[6] Tyumenskaya Oblast's first gas discovery was made at Berezovo settlement on 21st September 1953 (Gurkov & Yevseyev, 1984, p.24-25; Zorin & Trutnev, 1987, p.15, 21).

of all stations. The decision was taken to plan and construct the Igrim - Serov gas pipeline following the direction Alta-Tump - Kartop'ya - Ivdel' - Serov.

The following changes were subsequently realized:

a. in line with the finalized project it had been proposed to locate the installations at the pipeline inlet in the vicinity of Alta-Tump, 40 km west of Igrim. However, with the commissioning of the Punginskoye GCF, located to the south of Igrim, the installations were subsequently switched to the vicinity of this field;

b. the outlet of the gas pipeline was switched from Kartop'ya to the vicinity of Komsomol'skiy (now Yugorsk), in the basin of the R.Ess, which reduced the overall length of the pipeline route by several kilometres.

The pipeline r-o-w would pass through Berezovskiy, Sovetskiy and Kondinskiy rayons of Khanty-Manskiyskiy AO (Tyumenskaya Oblast'), and Ivdel'skiy, Krasnotur'inskiy and Serovskiy rayons of Sverdlovskaya Oblast', as shown in Fig.2.2.

iv) Natural-climatic conditions of the fields and route of the pipeline

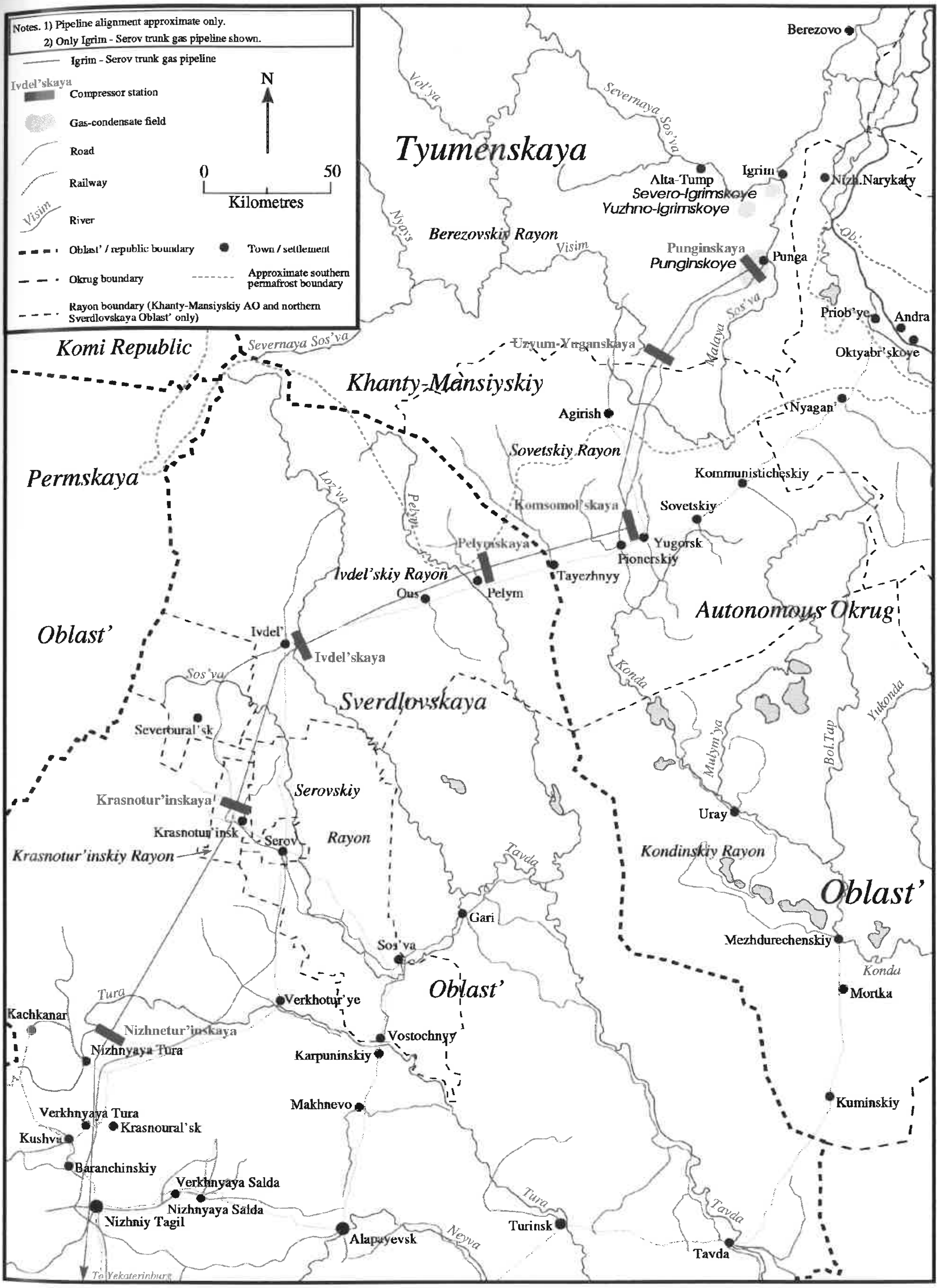
The Berezovskaya and Igrimskaya groups of fields are situated in the floodlands of the R.Ob' and its tributaries, such as the Malaya Ob' and Severnaya Sos'va. The surface of the floodlands is flat, but broken up by a large number of river channels and is covered by an almost unbroken blanket of bogs. The depth of the bogs reaches 4 - 5 m or more and during the period of floods, after snow melt, most of the GCFs are flooded to a depth of 2 - 3 m. The floods are protracted, the floodlands become free from water not earlier than late July-early August. In summer the area where the fields are located is practically impassable, but in winter it is possible to go in any direction using caterpillar cross-country vehicles and on new winter roads by wheeled-transport. Links between the fields and the outside world are by river in the navigation season, but in winter, by winter-road (*zimnik*, in Russian) in caterpillar- and wheeled-vehicles. Airlinks are maintained all-year round.

From the inlet installations, located at Punginskoye, to Ivdel' the route passes through the West Siberian plain, from Ivdel' it proceeds along the eastern slopes of the Urals. The whole route is covered by forest with a layer of moss 0.2 - 0.3 m thick. Significant areas of moss are encountered between Ivdel' and Serov.

The climate of the region is sharply continental, with temperatures ranging from +35°C in summer to -55°C in winter. The transition from winter to spring temperatures is abrupt and often leads to rapid snow melt and influences the river regimes. More detailed temperature data for the region are presented in Appendix 2.

The distribution of precipitation by season across the whole district is unfavourable for the development of effective drainage networks. Annual precipitation is roughly 440 mm. Eighty percent of this falls in the warm half of the year, April to October. In winter precipitation is minimal and the

Fig.2.2 The Igrim - Serov trunk gas pipeline



thickness of snow cover is relatively small. This promotes the development of thick ice on rivers and an increase in the depth of soil freezing.

According to Krylov *et al.* (1990, p.9) there are some 50 km of island and massive-island permafrost along the initial section of the r-o-w (the approximate position of the region's southern boundary of permafrost is shown in Fig.2.2). The maximum depth of seasonal freezing along the r-o-w fluctuates from 0.6 - 0.8 m in bogs to 2 - 2.2 m in exposed places with dry sandy soils.

In terms of hydrogeology and geological-lithological conditions, the route can be divided into two:

1. from the inlet installations to the foot of the Urals (Ivdel'). This portion of the route is characterized by the broad distribution of moraine and lacustrine-alluvial *suglinoks* and contemporary lacustrine-bog sediments. The soils are extremely damp in the warm period. Fluid/unstable and fluid-plastic consistencies are typical for *suglinoks*. In the spring-summer-autumn period the supporting capacity of soils of the first section is very low. Engineering studies showed that the supporting-capacity for saturated *suglinoks* equals 0.5 - 0.6 kg/cm², but for fine and dusty saturated sands - 1 kg/cm². Soil waters are encountered everywhere at depths from 1.8 m to the surface;
2. from Ivdel' to Serov. This portion passes along the foot of the eastern slope of the Urals, the relief of which is smooth with occasional hills, steep slopes and wide depressions. The section is not especially boggy. Under the deluvial cover, composed chiefly of detritus, lie poorly-fissured rocky soils that are 1 m thick (sometimes up to 3 m). The supporting-capacity of soils at depths of up to 1.8 m, is 0.5 - 2 kg/cm² for *suglinoks* (depending on the degree of dampness), and 5 - 15 kg/cm² for rocky soils. Soil waters on this section generally lie at a depth greater than 1.8 m.

Clearly, such harsh climatic conditions and complex geological conditions made construction planning and practice very awkward. The job was complicated further by the fact that this was the first time such operations had been carried out in West Siberia.

v) Construction of the Igrim - Serov gas pipeline

495 km of the pipeline were laid underground, often with concrete weights in saturated soils, as shown in Fig.2.3, while only 30 km were laid on-ground, generally in boggy and permafrost conditions. For a number of reasons, above-ground laying was deemed as being unacceptable for the Igrim - Serov gas pipeline. However, a number of above-ground solutions and proposals were of interest to engineers and it was suggested that they could be used as a basis for the development of support structures in permafrost conditions while planning other gas pipelines from Tyumenskaya Oblast' to the European part of the USSR and Urals.

Fig.2.3 Pipe and concrete weight laying operations on the Igrim - Serov r-o-w
(Source : Dertsakyan, 1967, p.97, Fig.21)

Note. The freezing of water in the trench made it impossible to lay the pipe at its planned position.

The Council of Ministers of the USSR approved the pipeline project in early 1963 and the order for its construction was issued simultaneously. However, the period of construction envisaged in the project - 3¼ years - could not be adhered to since construction completion was due by the end of 1965, and the beginning of work was delayed by 6 months. At the same time, the volume of work increased sharply due to the change in the diameter of the pipeline from 820 mm to 1020 mm.

The customer, the management group of the Bukhara - Ural gas pipeline, being occupied with the construction of that unique gas pipeline could not simultaneously devote the necessary attention to the organization of construction of Igrim - Serov. With their different geographical positions, the creation of an independent management group for the Igrim - Serov line was required.

The general contractor, *Tatnefteprovodstroy* trust of *Mingazprom*, failed to carry out much work between late 1962 and late 1963. Subsequently, Expedition Detachment No.2 of the Administration for Underwater-Technical Operations was commissioned to construct the R.Ivdel' crossing and to conduct a small amount of work on building a construction and accommodation base at Ivdel'. This and other circumstances accelerated the setting up of the independent pipeline construction management group which was officially due to start work in September 1963, with its base being in Ivdel' (later the management group was relocated to the construction centre at Komsomol'skiy).

Work rates increased somewhat with the appearance of this management group. By the end of 1963 construction divisions had been set up at Serov, Ivdel', Pelym and Komsomol'skiy. Construction of the R.Ivdel' crossing had been completed and preparatory work began on the R.Loz'va crossing; clearing of the r-o-w and the construction of roads on sleepers began. But it was only with the arrival of a new general contractor (*Mosgazprovodstroy*) in January 1964 that the concerned organizations sensed the real beginning of large-scale construction.

vi) Operation of the pipeline

The pipeline went into operation in February 1966. By 1980, with six compressor stations having been commissioned, gas was flowing through the Igrim - Serov - Nizhniy Tagil gas pipeline and its spurs to the major towns of Sverdlovskaya and Perm'skaya Oblasts. 10 BCM of gas was being supplied annually through the pipeline to the towns and industrial installations of the Urals, replacing roughly 6.1 MT of Kuzbass coal, 2.3 MT of weak-sulphureous fuel, 1.2 MT of sulphureous fuel, 1.5 MT of coke, coking products and 0.2 MT of peat.

2.3.1.3 After Igrim -Serov

The North-Urals Trunk Gas Pipeline Administration, predecessor of *Tyumentransgaz*, was founded on January 18th 1966. This administration succeeded the Igrim - Serov pipeline construction management group (Zorin & Trutnev, 1987, p.58). In these early years of development of the West Siberian gas field and transportation infrastructure, the first trunk gas pipeline compressor stations were built : Ivdel'skaya (1966), Krasntur'inskaya (1967), Nizhnetur'inskaya and Komsomol'skaya (1968), Pelymskaya (1970), Punginskaya (1971). With the Igrim - Serov pipeline already in operation with these new compressor stations, the next to be commissioned were the Pokhroma - Kazym and first string of the Kazym - Punga pipeline in 1971, supplying gas from the Pokhromskoye GCF which lies further north on the R.Ob' near the border between Khanty-Mansiyskiy and Yamalo-Nenetskiy AOs.

Experience gained from the construction and operation of the Igrim - Serov gas pipeline in particular, the first to be laid in the northern conditions of West Siberia, showed that gas pipelines could indeed be laid and operated successfully in an area of intense seasonal freezing and thawing of soils, widespread bogs and, more importantly, island permafrost. This offered encouragement to the gas industry in its quest for new gas reserves further north in regions of even more complex crossing and to conduct a small amount of work on building a construction and accommodation base at Ivdel'. This and other circumstances accelerated the setting up of the independent pipeline construction management group which was officially due to start work in September 1963, with its base being in Ivdel' (later the management group was relocated to the construction centre at Komsomol'skiy).

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2.3.2 Intensive large-diameter gas pipeline development from the Yamalo-Nenetskiy AO : the evolution of *Tyumentransgaz*

2.3.2.1 Background

Today, trunk gas transmission within Tyumenskaya Oblast' and northern Sverdlovskaya Oblast' is conducted almost exclusively by *Tyumentransgaz* (TTG), one of *Gazprom*'s 14 gas transmssion enterprises. It operates all the trunk gas pipelines in Tyumenskaya Oblast' other than the Urengoy - Surgut - Chelyabinsk system (two strings) which is operated by *Surgutgazprom* (formerly *Surguttransgaz*)[7]. It is in this respect that the organization of the gas industry in West Siberia differs from that in Russia's European North. Whereas in Tyumenskaya Oblast' gas transmission is carried out predominantly by TTG, an enterprise which was created for the sole purpose of gas transportation, in the European North (the Komi Republic in particular) this function is performed by *Severgazprom* whose main activity is gas production. The simple explanation for this is the difference in scale of gas industry activities in these two regions, with northern Tyumenskaya Oblast' producing well over 100 times more gas than the European North. Today, a single enterprise could not manage and run gas production and transportation in Tyumenskaya Oblast', where the majority of production is in any case conducted by three separate *Gazprom* enterprises : *Urengoygazprom*, *Yamburggazdobycha* and *Nadymgazprom*[8].

These enterprises and the initial sections of the major gas pipeline corridors, shown in Fig.2.4, operate in the continuous, discontinuous and island permafrost of the NPT, vast tracts of

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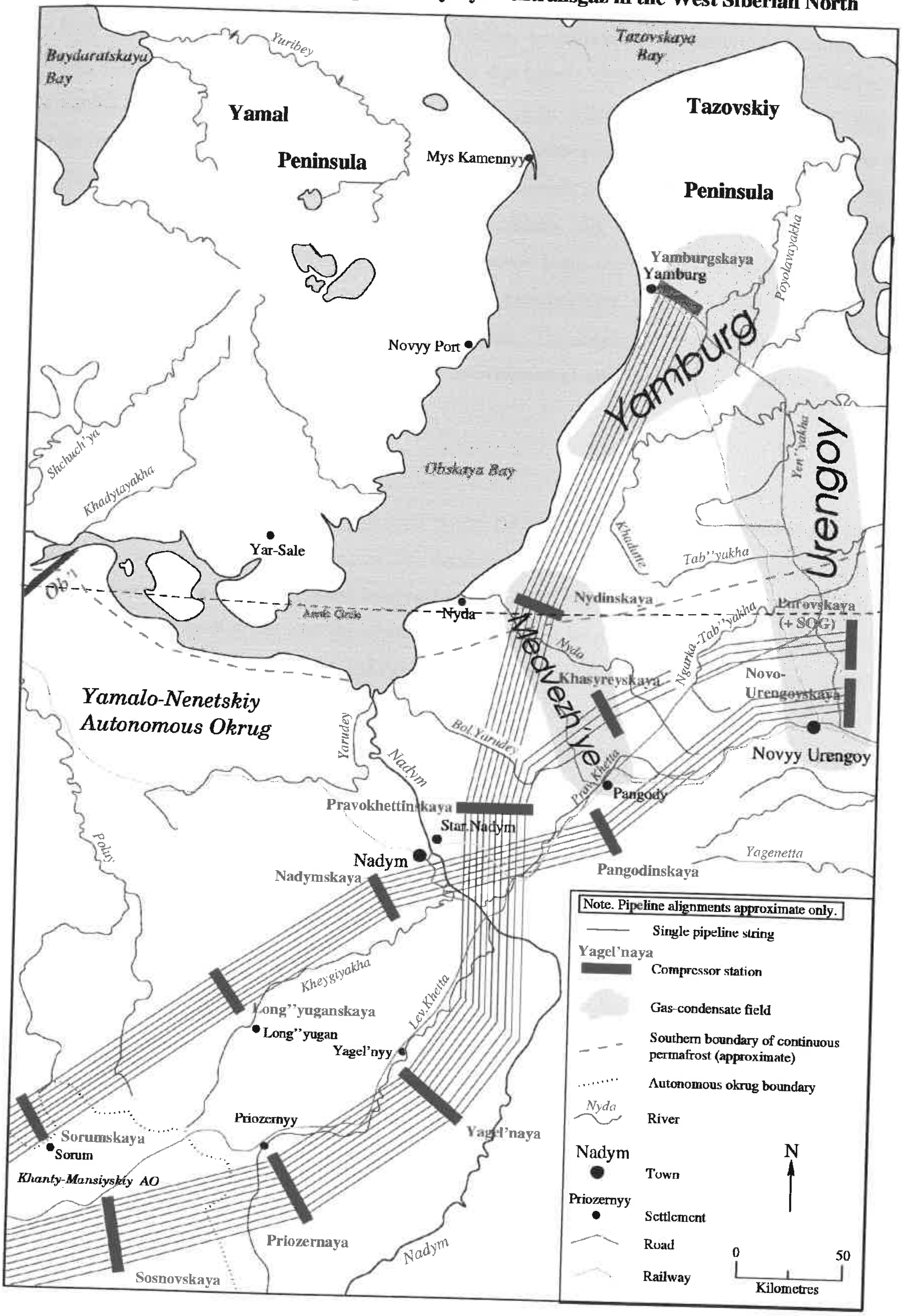
[7] A full history of *Surgutgazprom*'s predecessor *Surguttransgaz* can be found in : Zorin & Trutnev, 1993 "*Surgutskiy Variant*". Moscow, "*Nedra*".

[8] These three production enterprises were component parts of *Tyumengazprom* (TGP) which was formed in 1974 as an All-Union Industrial Association within the Ministry of the Gas Industry (*Mingazprom*) (Orudzhev, 1981, p.131; Kryukov & Moe, 1996, p.15). TGP also included the gas transportation enterprises TTG and *Surguttransgaz*, the latter being transformed into the gas production enterprise *Surgutgazprom* in 1989 (also in 1989, *Mingazprom* was transformed into State Concern *Gazprom*, under the leadership of Viktor Chernomyrdin). TGP was closed that year in dramatic circumstances for it was believed that the regional coordination provided by the association had become a threat to Moscow's control (Kryukov & Moe, 1996, p.18). The central ministerial apparatus preferred direct communication with individual production associations, such as *Urengoygazprom*, which were subsequently set up as separate organizations directly answerable to *Gazprom* in Moscow. Thereafter, there were no more significant changes to the component parts of *Gazprom*, although in November 1992 *Gazprom* itself was transformed into a Russian Joint-Stock Company by Presidential Decree (see Footnote 1). This decree laid down that the company would be partly privatized. It would also take over ownership of the UGSS and acquired all the property of the gas industry, whereas before it had only been the manager of a state-owned industry. *Gazprom*'s current chairman is Rem Vyakhirev.

Fig.2.4 Trunk gas pipelines operated by Tyumentransgaz in the West Siberian North



which become flooded in the summer months. Pipeline construction, operation and maintenance under such conditions are far more complex than in the Igrim - Serov pipeline's zone of influence further south, demanding complicated design and planning in order to minimize the risk of causing serious disturbances to fragile tundra, forest-tundra and northern *taiga* landscapes. Sadly, since the early 1970s, when the first 1420 mm pipelines were laid, significant environmental damage has been caused, having serious repercussions for pipeline operations. As will be illustrated, the pipeline construction programmes in the 1970s and 1980s required huge sections to be built as quickly as possible so that centrally planned production and transmission targets could be met. The environment played a very small role in such programmes. The major problems associated with gas pipeline construction and operation in such harsh environmental and economic conditions are to be examined in detail in subsequent chapters.

2.3.2.2 The Medvezh'ye GCF : the catalyst

The earliest stage of rapid pipeline construction in the NPT was linked with full commissioning in March 1972 of the first of the three giant GCFs : Medvezh'ye. Geologists discovered the gas-bearing structure which was subsequently named Medvezh'ye about 80 km northeast of Nadym in February 1966 in the basin of the R.Nyda and the right-bank tributaries of the R.Nadym (location shown in Fig.2.4)[9]. The field has an elongated appearance, stretched in the meridional direction (north - south), and lies within three natural zones : southern tundra, forest-tundra and northern *taiga*. For this reason the natural environment of the field, in particular geocryological conditions, is complex and heterogeneous. Climatic data for Medvezh'ye are presented in Appendix 2. In the north of the field permafrost is generally continuous (with lake and river taliks), whereas at the southern end of the field, 150 km away, soils are mostly unfrozen (Baulin *et al.*, 1984, p.3; Griva, 1997a). In terms of thickness, the picture is complicated by the presence of so-called "double-layered" or "unjoined" permafrost (defined in Appendix 1), especially in the southern part of the field. But where it is "joined", maximum thicknesses are 400 m. Soil temperatures vary from being positive or just below 0°C (highly unstable "warm" permafrost) in the south, to -3....-5°C in the north. Soil iciness increases from south to north, with 5 - 15% being normal for *suglinoks* in central parts of the field. The most common cryogenic processes are thermokarst, signs of which are most obvious in peatbogs, and frost heave, which produces frost mounds with ice cores developing directly below the peat. Polygonal peat bogs with ices wedges are found further north. In general, according to Baulin

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[9] The first discovery of gas in the NPT and the Yamalo-Nenetskiy AO as a whole was made in April 1962 in the region of Tazovskiy settlement. The daily productivity of the Cenomanian gas exceeded 1 MCM (Zorin & Trutnev, 1987, p.19). Tazovskiy lies 150-km north of Novyy Urengoy at the mouth of the R.Taz.

et al. (1984, p.23), the southern part of the field is extremely sensitive to anthropogenic disturbances on account of the presence of "warm" permafrost[10].

Table 2.3 **Gas production by *Nadymgazprom* (BCM), 1972 - 1997** (Sources : Orudzhev, 1981, p.55, Table 8; Sagers, 1992, p.208; *Nefte Compass*, 1998, p.9)

1972	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1985**	**1986**
2.0	9.1	18.6	29.9	41.5	60.2	71.4	70.4	71.0	73.8	73.7
1987	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
73.4	73.1	72.6	72.1	71.1	69.1	68.0	64.3	61.9	65.3	54.0

Medvezh'ye has 485 wells and, as is normal, is divided into a number of sub-fields (nine in all), each of which has an UKPG, booster compressor station (used to increase productivity) and a system of feeder lines. *Nadymgazprom*, the production enterprise operating the field (founded in 1974 and based in Nadym, a town of 48,000 inhabitants), reported that Medvezh'ye was producing 200 MCM per day by the second half of the 1970s. By then it had become the largest gas-production complex in the USSR and in 1977 it reached its planned production capacity of 65 BCM per annum, one year earlier than expected (Orudzhev, 1981, p.51). Table 2.3 shows *Nadymgazprom*'s gas production figures for 1972 - 1997. Today *Nadymgazprom* also operates the Yubileynoye GCF (commissioned in December 1992), the Yamsoveyskoye GCF (commissioned in 1996), both of which are satellites of Medvezh'ye, as well as the Bovanenkovskoye and Kharasaveyskoye GCFs on the Yamal Peninsula which have not yet entered their commercial production phases.

On April 28th 1972, the so-called "red-joint" was welded, linking the Medvezh'ye - Nadym and Nadym - Punga pipelines and on the eve of Victory Day (May 9th), Medvezh'ye gas entered the westward flow of Tyumen's "blue fuel" (Zorin & Trutnev, 1987, p.59).

2.3.2.3 Directions of gas flow from Tyumenskaya Oblast'

By 1980, four principal directions of gas flow from Tyumenskaya Oblast' to the central, western, southern and eastern regions of the country had taken shape:

1. Medvezh'ye - Nadym - Punga - Nizhnyaya Tura;
2. Urengoy - Nadym - Punga - Ukhta;

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[10] Key texts on geocryological conditions at Medvezh'ye are Baulin *et al.* (1984, p.3-24), Baulin (1985) and Goral'chuk *et al.* (1989, p.290-297).

3. Urengoy - Surgut - Chelyabinsk;
4. Nizhnevartovsk - Parabel' - Kuzbass (does not originate in the NPT).

The following is a summary of the development of the first three of these directions of gas flow, as outlined by Orudzhev (1981, p.78-80)[11].

i) Medvezh'ye - Nadym - Punga - Nizhnyaya Tura

The rapid development of this system was linked with the development of the Medvezh'ye GCF. The Medvezh'ye - Nadym - Punga pipeline (string 1), put into operation in 1972, covers a distance of nearly 700 km. Moreover, the section of pipeline between Medvezh'ye and Nadym (118 km) was the first to be laid using 1420 mm diameter pipe for a working pressure of 7.35 MPa (75 kg/cm^2). The section south of Punga (Igrim - Serov - Nizhnyaya Tura) was already in place. *Petroleum Economist* (1996a, p.70) reports that as early as 1969 there were plans to install two 5-km stretches of experimental 2500 mm diameter pipe, one of which would be in the vicinity of Nadym, while the other would be near Ukhta in the Komi Republic on the Ukhta - Torzhok pipeline. It was intended to lay the sections below, on and above ground to expose the pipe to different stresses. The article goes on to describe how the Ye.O.Paton Electro-Welding Institute (Ukraine) had developed a method for spirally welding this pipe, which had been manufactured in limited quantities at the Zhdanovskiy Metallurgical Plant in the Donbass. The author could not find any other references to the installation of this very large diameter pipe.

By 1972, the Medvezh'ye - Nadym - Punga, Igrim - Serov and Nizhnyaya Tura - Perm' gas pipelines were providing a supply of gas from Medvezh'ye to the major consumers in the Urals. In 1974, NPT gas first reached Moscow through the Perm' - Kazan' - Gor'kiy - Centre gas pipeline. With the construction of the Medvezh'ye - Nadym - Punga - Nizhnyaya Tura multi-string gas pipeline system, progressive technical solutions were introduced, such as the use of large diameter pipe for 7.35 MPa pressure, and gas-pumping units of high-unitary capacity. This allowed the accumulation of a wealth of experience in laying large-diameter pipelines in regions of permafrost and bogs and also across large water courses (for example, the R.Nadym and R.Ob').

The volume of gas transmitted through the Medvezh'ye - Nadym - Punga - Nizhnyaya Tura system exceeded 45 BCM per annum by the end of the 10th 5-Year Plan (1980). Gas supply in this direction was set to increase on account of the future commissioning of the next giant field in the NPT, Urengoy. On April 22nd 1978, Lenin's birthday, the first gas from Urengoy was transmitted

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[11] Sabit Atayevich Orudzhev was Minister of the Gas Industry between 1972 and 1981. *Urengoygazprom*, the *Gazprom* enterprise now responsible for operating the Urengoy GCF, was originally named "*Urengoygazdobycha* named after S.A.Orudzhev", in recognition of Orudzhev's important contribution to shaping the USSR's oil and gas industries in the 1970s and 1980s.

through Urengoy - Nadym string 1, at a volume of 11 BCM, and in 1979 this increased to 21.3 BCM per annum.

ii) Urengoy - Nadym - Punga - Ukhta

This system was developed to meet the increasing requirement for gas in the western and northwestern regions of European Russia. The first string of this system (Punga - Vuktyl) was laid in 1975 - 76. With the commissioning of string 2 in 1979, additional gas supplies to the west and northwest of the country through the simultaneously developed Vuktyl - Ukhta - Torzhok system (described in subsection 2.3.3) amounted to some 40 BCM.

In 1981, the construction of the Urengoy - Punga - Vuktyl - Ukhta - Gryazovets - Moscow Circle pipeline system was completed and in May that year it was put into operation (*Stroitel'stvo Truboprovodov*, 1986, p.24). This was the first of seven large-diameter TTG pipelines (one for export) to be completed from Urengoy. The length of this 1420 mm line with a design pressure of 7.35 MPa is 2800 km. It had been completed virtually within one year and most importantly reached planned capacity in the year of completion (Gurkov & Yevseyev, 1984, p.95).

iii) Urengoy - Surgut - Chelyabinsk

The resource-base of this system is the Urengoy and Vyngapurovskoye GCFs. This system includes two 1420 mm strings, laid in 1978 and 1979, with 7.35 MPa design pressure and a length of 1780 km. Unlike the other pipelines mentioned above which are operated by TTG, these two strings are operated by *Surgutgazprom*. In 1980, the North Priobskoye OGCF was earmarked for link-up to the system, from where stripped petroleum gas would be supplied. This system satisfies the gas requirement for the industrial enterprises of Tyumenskaya Oblast' and also the southern Urals and the Volga region. Considerable detail on the development of these two strings can be found in Zorin & Trutnev (1993).

Thus, by the early 1980s, the largest branching system of high-capacity trunk gas pipelines in the history of the development of the Soviet gas industry had been formed in West Siberia, which provided gas supplies to practically all the major consuming centres of the country and for export. By the beginning of the 11th 5-Year Plan (1981), the overall length of trunk transport arteries in this region exceeded 10,000 km (see Table 2.2), of which almost 7000 km was constructed using 1420 mm pipe. By this time, the length of new gas pipeline systems from Urengoy greatly exceeded 3000 km and construction work was progressing at tremendous rates.

In 1981, the 2730 km Urengoy - Petrovsk pipeline was completed earlier than planned, which included the construction of 24 compressor stations with a total capacity of 1.86 million Kw (*Stroitel'stvo Truboprovodov*, 1986, p.24: 1994, p.15). The use of progressive methods of assembly and the most advanced technology enabled the monthly completion by each Integrated Production Line[12] (IPL) of up to 25 - 30 km of pipeline on this route. The following year saw the completion of the Urengoy - Novopskov gas pipeline over a distance of 3571 km. IPLs were completing 1.5 km of pipeline every day and for the first time reinforced-concrete weights were used in the construction of a small river-crossing (*Stroitel'stvo Truboprovodov*, 1986, p.24). 1982 was also the year in which construction began on the second longest gas pipeline in the USSR : Urengoy - Pomary - Uzhgorod.

2.3.2.4 The Urengoy - Pomary - Uzhgorod export gas pipeline

Before describing the construction of the Urengoy - Pomary - Uzhgorod gas pipeline, it is essential to review some background material on its source of gas, the giant Urengoy GCF. Although much larger, the field bears many natural-climatic similarities to Medvezh'ye. Climatic data for the field are presented in Appendix 2. It lies within the southern tundra, forest-tundra and northern *taiga* subzones and possesses continuous, discontinuous and island permafrost. Permafrost tends to be "joined" in the north of the field, being up to 430 m thick, but "double-layered" in the south, where taliks between layers can be up to 200 m thick. Perennially-frozen soils (for example, *supeses* and *suglinoks* with interlayers of clays and dusty sands) are encountered almost directly beneath the surface in the north, but in some river valleys further south the permafrost table lies at a depth of 7 - 10 m. Soil temperatures at the depth of zero annual-average amplitude are as low as -6°C in peatbogs in the north (Yen"yakhinskaya area) (Chigir *et al.*, 1997a, p.28), although the average for the field is -3....-5°C (Remizov *et al.*, 1996, p.150). Soil iciness reaches 50% in peaty soils in the far north of the field at depths of less than 5 m. Dominant cryogenic processes at work in Urengoy are frost heave, thermal-contraction cracking (only in the far north), thermokarst and thermal erosion[13].

A small exploratory drilling brigade witnessed the first flow of gas from the field's well No. R-2 on 6th June 1966. The members of that drilling brigade could not have known at the time that Urengoy would become the largest producing field in the USSR, supporting the town of Novyy Urengoy which grew up around it (location shown in Fig.2.4). Novyy Urengoy, which lies 80 km south of the Arctic Circle in the southern part of the field, now has a population of approximately 90,000, making it one of the largest towns in the Russian Far North.

Urengoy went into production in April 1978. Urengoy now has 15 UKPGs (see Fig.2.5) for the processing of gas before it enters the gathering line system, with each one processing some 20 BCM of gas per annum. For the first time in Russian gas industry practice, some of these plants were equipped with cooling stations (SOG) where the gas is cooled before it enters the pipelines.

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[12] The IPL is examined in detail in chapter 3 subsection 3.4.3.

[13] Key texts on geocryological conditions at Urengoy are Baulin (1985), Sukhov *et al.* (1989, p.236-246), Goral'chuk *et al.* (1989, p.290-297) and Remizov *et al.* (1998).

This is done to preserve, to the greatest degree possible, the frozen state of permafrost both within

Fig.2.5 UKPG-11 at the Urengoy GCF

(Author's photograph, taken on 4th April 1998)

the field and in the area just south of it. Evidence suggests that this measure has not been as successful as originally anticipated, an issue to be discussed in considerable detail in chapter 4. In 1979 Urengoy produced 24.7 BCM of gas and in 1980, roughly 50 BCM. Orudzhev (1981, p.51) explains that Urengoy's production was expected to increase to 185 BCM per annum. In fact, in 1988, its peak year, production totalled 300 BCM. Table 2.4 shows the staggering increase in production at the field during the 1980s, followed by a slowing in the 1990s. The production peaks achieved after 1986 were not necessarily a good thing. As Gorst (1988, p.147) points out, Russian and western critics had suggested that production had been forced at Urengoy at the expense of the field's long-term future. But this forced production was probably linked to the delay in bringing the Yamburg GCF on stream for which Urengoy had to compensate.

Table 2.4 **Gas production by *Urengoygazprom* (BCM), 1979 - 1997** (Sources : Orudzhev, 1981, p.51; Shabad, 1984, p.356-357; Sagers, 1992, p.208; *Nefte Compass*, 1998, p.9)

1979	**1980**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	
24.7	50.0	156	210	258.2	296.0	298.0	300.0	
1989	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
288.3	287.9	295.1	287.6	262.8	249.4	239.6	242.2	226.7

Condensate production began at Urengoy in 1985 (drilling had been started in 1983). Three processing plants were completed at the field in 1985 from where the condensate, having undergone initial processing, is transmitted 725 km southwards to Surgut, in the centre of the Khanty-Mansiyskiy AO oil production complex, where further processing takes place. This stabilized condensate is then piped another 1450 km to the Minnibayevo processing plant at Al'met'yevsk in Tatarstan (Shabad, 1986, p.81).

Construction of the Urengoy - Pomary - Uzhgorod gas pipeline began in July 1982 (see Fig.2.6). The resource base for the pipeline would be the central part and northern dome of the Urengoy GCF, with the initial compressor station, Purovskaya, lying in the middle of the field to reduce the length of gathering lines (Mitsenmakher, 1983, p.5). This export pipeline is 4451 km in length and has a diameter of 1420 mm. During the first six months of construction roughly 2300 km of pipe had been welded together and 1850 km insulated and laid. Welding quality was greatly enhanced by the newly introduced "*Sever*-1" ("North-1") electro-contact welding apparatus. In the following year, after the construction of 794 lake/river-crossings (including crossings of the Ob', Volga, Don, Dnepr and Dnestr), the use of 130 million cubic metres of soil and the investment of 7.6 billion rubles (1983 prices) Urengoy - Uzhgorod was put into service six months ahead of plan. It had been completed three times faster than would have been possible at normal rates of construction. In addition, 120 km of permafrost had been crossed, in excess of 700 km of bogs, more than 2000 km of forest, 545 km of mountain ranges (the Urals and the Carpathians), and 417 road and railway crossings (L'vov, 1986, p.65-66). Three million tonnes of pipe were used in the construction of the pipeline and 26 million square metres of pipe surface were insulated to protect it from corrosion. Some 40 compressor stations were built to maintain the planned capacity of the system (32 BCM per annum). These are situated every 100 - 130 km along the pipeline. GTN-25 gas compression units, manufactured within the USSR, were used at the stations. It had been planned to import machinery

Fig.2.6 Construction of the Urengoy - Pomary - Uzhgorod trunk gas pipeline begins
(Source : Ivanov & L'vov, 1983, p.40-41)

Note : the red banner reads "An accelerated effort for the Urengoy - Uzhgorod export gas pipeline"; the white banner reads "The West Siberia - Western Europe gas pipeline begins here".

for the Pomarskaya compressor station from abroad, but US sanctions, discussed below, prevented this (Ivanov & L'vov, 1983, p.55). Each day during construction, 15 - 20 million rubles of investment were used up on the r-o-w. With the participation of 20,000 workers, it had taken 14 months to complete and more than 30 ministries and departments had participated in the construction and solution of various problems. Some 50 IPLs had been working at points along the r-o-w, each achieving on average 90 km of completed pipeline over a 12 month period. On average, 248 km of pipeline were laid per month.

The pipeline system was put into operation in stages, corresponding to the readiness of each section. Firstly, the Algasovo - Yelets section was commissioned, followed by Pomary - Algasovo, then the longest section Urengoy - Lyalinskaya compressor station, and finally the small sections Lyalinskaya - Pomary, Yelets - Barskaya and Barskaya - Uzhgorod (Batalin, 1983, p.4). Compressor stations were also commissioned in stages. Thus, as completion of the whole system drew nearer, the supply of Urengoy gas to the industrial regions of the Urals, Volga basin, centre, west and south of the USSR increased by tens of millions of cubic metres per day. The stage-by-stage commissioning of the pipeline allowed *Mingazprom* to utilize each complete section to maximum effect and to accumulate additional reserves in underground storage facilities for the winter peak demand. As Boris L'vov (1986, p.66) puts it in his book tracing the development of the West Siberian oil and gas industry:

> *"The* [Urengoy - Pomary - Uzhgorod] *export trunkline is not only a large-scale engineering structure, but it is at the same time an example of the optimal solution to an array of fundamentally new scientific-technical, economic and administrative problems linked with the organization of construction, gas production and transportation in varying natural-climatic zones. A tangible contribution has been made to the issue of future industrial-economic development of the northern regions of the country".*

The project also helped to strengthen economic cooperation between the USSR and the German Democratic Republic (GDR). More than a thousand workers from the GDR took part in the construction of the pipeline on the territories of Ivano-Frankovskaya and Zakarpatskaya (Trans-Carpathian) regions of western Ukraine. Bulgarian and Yugoslavian workers also played a part in the construction of the pipeline and compressor stations.

Perhaps one of the most significant points L'vov (*ibid*, p.71) makes in his description of the Urengoy - Uzhgorod pipeline project and related events (for example, the sanctions imposed by the Reagan administration) lies in the following:

> *"The achievement of our constructors is evidence of the resounding failure of the sanctions imposed by the US administration. The first of the six Siberian gas pipelines, Urengoy - Gryazovets - Moscow (2240 km) was completed within 22 months, Urengoy - Petrovsk (2726 km) within 25 months and Urengoy - Novopskov (3346 km) within 23 months. Meanwhile, the largest*

oil pipeline in the USA, Alaska - Centre [i.e. the Trans-Alaskan Oil Pipeline], *1280 km in length and with a much smaller diameter* [1220 mm] *than in the USSR, was completed more than three years after a six-year period of preparation for construction. There is yet another significant fact : the Urengoy - Novopskov gas pipeline, mentioned above, was constructed simultaneously with the Urengoy - Pomary - Uzhgorod pipeline, and in addition the laying of the two parallel Urengoy - Centre pipelines began. There was not another example* [of such feats] *in the practice of world pipeline construction".*

L'vov clearly takes great pleasure in comparing Soviet and American rates of pipeline construction. He uses this successfully to illustrate how the American sanctions failed[14].

2.3.2.5 After Urengoy - Uzhgorod

August 1984 and February 1985 saw the completion of the Urengoy - Centre 1 and Urengoy - Centre 2 gas pipelines respectively, each 3100 km long. The former went into operation six months ahead of schedule. As a result of an experiment conducted on one section of the Urengoy - Centre 2 pipeline, the use of spiral pipe with an ultimate strength of 650 MPa and a wall thickness of 15.1 mm was demonstrated successfully in the construction of these 1420 mm diameter gas pipelines (*Stroitel'stvo Truboprovodov*, 1986, p.24). 21st April 1984 was a significant date for the West Siberian gas industry since it marked the occasion of the transmission of the one trillionth cubic metre of gas through the expanding pipeline network. The second half of the 1980s was dominated by the development of the Yamburg GCF, the NPT's northernmost GCF, and its system of large-diameter pipelines. This new era of pipeline development is addressed in section 2.4.

Today, three decades after its founding, TTG employs more than 30,000 people and is the leading gas transmission enterprise of *Gazprom*, supplying more than 1.3 BCM of gas per day from the giant fields of the NPT to the industrial complexes and consumers in the Urals and European part of Russia, as well as abroad (*Tyumentransgaz*, 1996, p.2). Table 2.5 shows gas transmission figures for TTG between 1966 and 1991. As of 1995-96, TTG operated 27,000 km of trunk gas pipelines, ranging in diameter from 1020 mm to 1420 mm, with design pressures of between 5.5 and 7.5 MPa (55 and 75 bar) in the Yamalo-Nenetskiy AO, Khanty-Mansiyskiy AO and northern Sverdlovskaya Oblast'. Table 2.6 shows expansion of the overall length of TTG's pipeline network between 1966 and 1995. It operates 32 compressor stations with 1125 gas-compression units with a total capacity of 15,000 Mw. Table 2.7 shows the total power capacity of TTG compressor stations between 1966 and 1995. There are 20 different kinds of compression unit in use, produced both

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[14] These sanctions were an attempt to stop the supply of equipment and technology to the USSR's oil and gas industries. The Americans believed that this would indirectly hinder the strengthening of the Soviet military. More on these sanctions can be found in Gurkov & Yevseyev (1984, p.78-92).

Table 2.5 **Transmission figures for *Tyumentransgaz* (BCM), 1966 - 1991,** (Source : *Tyumentransgaz*, 1996, p.16)

1966	**1971**	**1976**	**1981**	**1986**	**1991**
0.558[a]	9.128	43.678	110.830	318.265	460.360
0.520[b]	8.705	41.750	105.652	299.811	437.819
0.027[c]	0.397	1.928	5.078	15.351	21.618

[a] : Receipt (applies to all columns).
[b] : Commercial gas (applies to all columns).
[c] : Own needs (applies to all columns).

Table 2.6 **Overall length of *Tyumentransgaz* trunk gas pipelines and spurs, 1966 - 1995** (Source : *Tyumentransgaz*, 1996, p.16)

Overall length, km
(figure in brackets is length of new pipeline put into operation that year)

1966	**1971**	**1976**	**1981**	**1986**	**1991**	**1995**
714 (714)	1226 (268)	5209 (756)	7658 (873)	17,059 (1521)	25,382 (588)	26,356 (77)

N.B. Each string is taken into account here.

Table 2.7 **Total power capacity of *Tyumentransgaz* compressor stations, 1966 - 1995, Mw** (Source : *Tyumentransgaz*, 1996, p.17)

1966	**1968**	**1970**	**1972**	**1974**	**1976**	**1978**	**1980**
21	93	113	185	564	978	1696	1856
1982	**1984**	**1986**	**1988**	**1990**	**1992**	**1994**	**1995**
3096	6241	8797	11,475	12,785	13,480	14,074	14,614

domestically and abroad, each with a capacity of between 5 and 25 Mw. Gas turbines come from the aviation or shipping industry[15].

In 1992 TTG began to diversify its activities. Its Nadym Gas Production Administration began development of the Kharvutinskoye GCF which lies at the southern end of the Yamburg GCF. This field has potential reserves of 700 BCM of Cenomanian gas. Production began in February 1996 (Lashin, 1997). Gas from Kharvutinskoye is piped to an UKPG at Yamburg, then to the Yamburgskaya compressor station for onward transmission[16].

2.3.3 The UGSS in Russia's European North - *Severgazprom*

The Komi Republic has become an important transit region for TTG pipelines. This transitional role will gain even more importance with the construction of later stages of the YEGTS across the republic. Although natural-climatic conditions in Komi are not as severe as in the NPT, the pipelines crossing its territory are laid in soils subject to intense seasonal freezing and thawing where boggy conditions prevail. Such conditions can be best compared to those of the Berezovskiy gas-bearing district which supplies the Igrim - Serov line. The first pipelines in these two regions were laid in the mid to late 1960s.

2.3.3.1 The Vuktyl'skoye GCF

In October 1964, exploration-well No.2, drilled not far from the bank of the R.Pechora in the central-eastern region of the Komi Republic, produced an industrial gas flow containing a high percentage of condensate (Podyuk, 1994, p.8). This particular flow was the forerunner of the large-scale development which was to take place at that site, subsequently becoming known as the Vuktyl'skoye GCF (location shown in Fig.2.1). After trials were held the following summer at wells No.3 and 21, this field was confirmed as being highly promising for the future of gas production in the European North of Russia. It also received the status of "unique", making it one of the largest fields discovered at that time, in terms of reserves[17]. The large reserves, high yield rates, the relative proximity of the field to the industrial complexes of the European North and the centre of the country and a serious fuel deficit all provided the necessary impetus for rapid development of Vuktyl'skoye.

Vuktyl'skoye lies within the Timano-Pechorskiy Fuel and Energy Complex (TPFEC), as shown in Fig.2.1. The TPFEC combines the oil- and gas-bearing regions of the Komi Republic and the Nenetskiy AO of Arkhangel'skaya Oblast', both in Russia's European Northeast. Some 375 BCM of gas has been produced in the TPFEC (Engesaeth & Muller, 1997, p.15), the vast majority of this

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[15] The reader might find it useful to compare the data in these tables with that provided by Krylov *et al.* (1990, p.6-8, Table 1.1). Table 1.1 in Krylov *et al.* includes data for both TTG and *Surguttransgaz*.

[16] An UKPG is under construction at Kharvutinskoye (Lashin, 1997).

[17] Vuktyl'skoye's recoverable gas reserves were estimated to be 388 BCM (Engesaeth & Muller, 1997, p.24).

having come from Vuktyl'skoye. In addition, 28 - 30 BCM of associated gas has been produced. Since 1975 (peak production year - 18 BCM) production of gas in the complex has fallen. Currently five GCFs in the TPFEC hold initial gas reserves of approximately 500 BCM (Vdovenko, Shelemey & Ilatovskiy, 1997, p.3). While 77% of Komi's gas reserves have been extracted already (Podyuk, 1996, p.44), negligible gas production has taken place in the Nenetskiy AO.

2.3.3.2 The Vuktyl - Torzhok gas pipeline

On May 10th 1967, the USSR Council of Ministers approved a special resolution for the organization of gas production at the Vuktyl'skoye GCF and the construction of a large-diameter (1220 mm) gas pipeline from the field, via Ukhta to Torzhok, the latter being 220 km northwest of

Fig.2.7 Sixteen kilometres south of Vuktyl on the r-o-w of the Punga - Vuktyl - Ukhta trunk gas pipeline

(Author's photograph, taken on 5th December 1995)

Moscow in Tverskaya Oblast'. The fulfilment of these plans was entrusted to *Mingazprom*, which was headed at that time by Aleksey Kirillovich Kortunov. Kortunov, who headed *Mingazprom* between 1965 and 1972, made Vuktyl'skoye a reality and, as Podyuk notes (1994, p.8), he was also responsible for the massive development of the UGSS and is credited as being one of the key figures in the development of the Soviet gas industry.

Soon a committee was formed, based in Ukhta, which would be responsible for opening up Vuktyl'skoye and other GCFs in the area. After only three months, in July 1967, the *Komigazprom* enterprise was established by *Mingazprom* in consultation with the committee. Soon the committee merged with *Komigazprom*, the latter taking over all responsibilities for field development and the construction of the 200 km Vuktyl - Ukhta section of the pipeline and headed initially by Nikolay Vasil'yevich Petlichenko. On November 18th 1967, *Mingazprom*'s resolution No.528 ordered the creation of an administrative body to organize construction of the linear section and compressor stations of the 1500 km Ukhta - Torzhok section of the pipeline, named *Severgaztsentr* and also based in Ukhta.

Natural gas from Vuktyl'skoye arrived in Ukhta in October 1968 after the completion of the Vuktyl - Ukhta section of pipeline (see Fig.2.7), during a particularly severe winter when gas reserves in Moscow fell to minimum levels. Given the unique and complex features of the Vuktyl - Torzhok pipeline construction project, the largest Russian pipeline project of the 1960s, *Mingazprom* presented *VNIIST* with the task of developing recommendations for the construction of the second stage, i.e. Ukhta - Torzhok, as stated in the ministry's protocol No.22 of 14th October 1968. At this time, specialists from *VNIIgaz*[18] and several other leading planning institutes (*Vostokgiprogaz*, *Giprogaz* and *YuzhNIIgiprogaz*) were working alongside *VNIIST* to suggest the most effective ways of developing the field itself. Construction of field installations and the pipeline was carried out by *Komigazstroy*, and subsequently *Glavkomigazneftestroy*, together with contractors and sub-contractors from other parts of the USSR.

It had taken a year and a half to construct the Vuktyl - Ukhta section, but in April 1969 the second stage to Torzhok was undergoing testing and by July gas from Vuktyl'skoye was being fed directly to the Cherepovetskiy Metallurgical Plant in Vologodskaya Oblast' to the south-west of Komi. 1220 mm pipe was used for the first time in Russia on this section (*Stroitel'stvo Truboprovodov*, 1994, p.12). Soon, the pipeline which became known as "Northern Lights" ("*Siyaniye Severa*") was supplying gas to the industrial complexes of Moscow and Leningrad via spurs from the main pipeline at Gryazovets.

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[18] In 1968, the Komi branch of *VNIIgaz* was founded in Ukhta to conduct research into gas industry development problems in the European North of Russia. It was re-formed in ca.1993, becoming the *SeverNIPIgaz* scientific-research and planning institute, a sub-division of *Severgazprom*.

2.3.3.3 Subsequent developments

The next stage of pipeline development in the region included the construction of two strings from Punga in Tyumenskaya Oblast', West Siberia, to Torzhok, via Vuktyl and Ukhta. Construction was carried out between 1975 and 1976. 1420 mm diameter pipe for a design pressure of 7.5 MPa was used, which increased throughput of one string twofold in comparison with the 1220 mm pipe used on the Northern Lights system's Vuktyl - Ukhta section (Vitova, 1993, p.10). Gas compression units from the aviation industry, GPA-Ts-63, were used for the first time, as were shipping industry GPU-10 units. Vitova (1993, p.10) suggests that the economic effectiveness of these units exceeded 10 million rubles (at mid-1970s rates).

By the 1980s two gas industry enterprises were operating in Ukhta : *Komigazprom* and *Ukhtatransgaz*. The latter, formed in 1974, operated the Punga - Vuktyl - Ukhta - Torzhok gas pipeline. Conflicting interests of the two enterprises concerning the productivity of the Vuktyl'skoye field eventually resulted in the two being merged to form *Severgazprom* (SGP) in 1986, headed initially by Bogdan Vladimirovich Budzulyak. It is now a so-called "daughter" enterprise of *RAO Gazprom* employing 16,000 people and is headed by A.A.Zakharov (who succeeded Vasiliy Grigor'yevich Podyuk in 1997)[19]. Through its 12 Linear-Production Administrations (known in Russian as *LPU*), SGP currently operates just over 8000 km of pipelines (720 mm to 1420 mm diameter) between Vuktyl in the northeast of Komi and the western parts of Vologodskaya and Yaroslavskaya Oblasts, This pipeline system, more than half of which is over 15 years old, transports approximately 80 BCM of gas annually[20]. Less than 5 BCM of this total is produced by SGP[21], the rest coming from the NPT via Punga (Shcherenkova, 1995, p.8). Thus the SGP pipeline network is used predominantly as a transit system for gas moving from West Siberia to western Russia and beyond. The majority of the pipelines are buried and insulated with bituminous tape wrapping and also secured by cathodic protection. Twelve compressor stations, the major ones being Vuktyl'skaya, Ukhtinskaya, Sindorskaya and Mikun'skaya, one booster station (294 gas-compression units with a total capacity of 2.4 million Kw) and 63 gas distribution stations are operational. In 1993 SGP performed repair-work on 113 compression units (Shcherenkova, 1995, p.9). SGP supplies gas to large customers, such as the Pechora, Syktyvkar and Sosnogorsk power

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[19] As of late 1997 Budzulyak and Podyuk were members of the Board of *Gazprom*.

[20] 1992 : 79.4 BCM; 1993 : 74.9 BCM; 1994 : 75.0 BCM (Shcherenkova, 1995, p.8-9); 1995 : 72.8 BCM (Podyuk, 1996, p.44).

[21] More than 90% of SGP's gas is produced at Vuktyl'skoye, 5% at Zapadno-Soplesskoye, the remainder at Pechorogorodskoye, Pechorokozhvinskoye, Yugidskoye, Zapadno-Tebukskoye, Voy-Vozh and other fields. The latter two (oil) fields produce associated gas. Since 1968, 336 BCM of gas has been produced at the Vuktyl'skoye GCF, with production having fallen since 1983. In its peak production year the field produced roughly 18 BCM of gas, in 1995 annual production had fallen to 3.2 BCM. SGP's total gas production in 1995 was 3.212 BCM (Podyuk, 1996, p.44).

stations, while small customers are supplied by *Komigaz*. SGP's customers lie within the republic itself, as well as Arkhangel'skaya, Vologodskaya and Yaroslavskaya Oblasts.

There are several other pipeline spurs operated by SGP within the Komi Republic and one in the Nenetskiy AO to the north, as shown in Fig.2.1. Komi's first gas pipeline and also the world's first "self-compensating" pipeline (325 mm diameter) runs for 130 km between the Nizhneomrinskoye OGF and the Ukhta oil refinery, via several other fields including Voy-Vozh from where the pipeline was originally laid in the early 1940s. The pipeline is suspended from wooden supports. According to Leonid Dimov, Director of *KomiNIPIstroy* in Ukhta, the patent for the supports of this pipeline was American. He says that owing to the pipeline's thick walls, low pressure and geometry, there have been few problems throughout its 50 or so years of operation (Dimov, 1996b). The pipeline was designed by *PechorNIPIneft'*, a research and planning institute based in Ukhta and part of the *Komineft'* (Komi's oil company) group of organizations. Its specialists were awarded the Stalin Prize and a special diploma for their outstanding work on the original Voy-Vozh - Ukhta gas pipeline. A gas pipeline from Vuktyl'skoye supplies Pechora in northern Komi, most of the gas going to its power station. Another runs from the Pashninskoye OGCF to the town of Nizhniy Odes in central Komi. There is also a single gas pipeline string between Pechora and the Vozeyskoye OGF in Komi's Far North, via Usinsk. This pipeline supplies gas from Vuktyl'skoye and other local fields to oil industry installations. Lastly, a short pipeline is marked on some maps between the Dzhebol'skoye GF and a point on the River Pechora, south of Troitsko-Pechorsk. The Nenetskiy AO has only one small operational gas pipeline at present. This supplies gas from the Vasilkovskoye GCF, which produces 0.1 - 0.2 BCM per annum (Manov & Kalinina (eds.), 1996, p.113), to Nar'yan-Mar.

A report produced by the Danish company NN&R A/S Consulting Engineers and Planners for the Komi Republic (NN&R, 1994) mentions that little information was available on the integrity of SGP's pipeline system but "*only minor leaks and valve wear were reported for the 25 year operation of the transmission pipelines*". The year after the report was written, a rupture caused a massive explosion on a 1420 mm diameter pipe section near Ukhta. The Russian authorities and SGP played down the incident, dismissing it as a routine problem even though the explosion had been witnessed by the crew and passengers of a Boeing 747 flying overhead at the time, en route to Japan. They reported seeing a huge fire beneath them and a fireball rising into the sky. Nobody can be sure of the number of unreported accidents that might have taken place while Russian airspace was closed to foreign aircraft and before the arrival of foreign oil companies participating in joint-venture oil production in the north of the republic and the Nenetskiy AO. SGP is served by two pipeline failure-restoration teams which are capable of conducting repair-preventative operations in the event of an accident (*Severgazprom*, 1994, p.6). Yakovlev, Kolotovskiy & Sharygin (1997, p.17-

18) describe SGP's policy for increasing reliability of their trunk gas pipeline system, characteristics of typical failures and monitoring efforts, including the use of pigging devices.

Condensate is produced at Vuktyl'skoye and Zapadno-Soplesskoye GCFs (more than 200,000 tonnes annually) and it is delivered by a separate condensate pipeline to the Sosnogorsk Gas Processing Plant (near Ukhta). Gas is also processed here and products of the plant include four types of so-called "technical carbon", resin, LNG, light hydrocarbons and stable condensate.

2.3.3.4 The future of trunk gas pipeline development in the European North

The future of gas pipeline development in Russia's European North depends primarily upon two major projects which will help to accelerate hydrocarbon production in the relatively untouched northern part of the TPFEC. The first project concerns the opening up of large GCFs in the Nenetskiy AO, particularly those of the Nar'yan-Marskiy gas-bearing district which has recoverable gas reserves of 449.4 BCM and 19.2 MT of condensate (Podyuk, 1996, p.45). Generally speaking, this gas differs from the free gas of Komi on account of its higher sulphur content (more than 0.0014%), whereas Komi gas is notable for its high ethane content[22] (8 - 12%) (Manov & Kalinina (eds.), 1996, p.106). The plan is to begin large-scale gas production at the Layavozhskoye OGCF, which has the largest gas and condensate reserves of any field in the TPFEC : 110.9 BCM of gas, 8.1 MT of condensate and 42.2 MT of oil (Podyuk, 1996, p.45; Vdovenko, Shelemey & Ilatovskiy, 1997, p.9). This would be linked subsequently by gathering lines to the neighbouring Vaneyvisskoye, Vasilkovskoye and Kumzhinskoye GCFs. Production from these fields, which could reach 9 BCM per annum, would be fed southwards to Pechora, via Usinsk, linking up with supply infrastructure there. Also, ethane-rich gas (though much of it coming from the Vuktyl'skoye GCF) would be supplied to the proposed gas-chemical plant to be built at Sosnogorsk. This would produce more than 200,000 tonnes of polyethylene annually (*Severgazprom*, 1994, p.13; Spiridonov (ed.), 1995, p.55)[23].

The second project is the construction and operation of the YEGTS. This is the largest project within Russia's gas industry development plan for the period 1990 - 2010 (*Severgazprom*, 1994, p.13). Already, the market-end of the pipeline system is under construction, but it is uncertain as to when construction will begin on the initial section, from the source at the Bovanenkovskoye

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[22] According to Manov & Kalinina (eds.) (1996, p.106) reserves ($A+B+C_1$) of ethane-containing gas in the Komi Republic amount to 148.6 BCM. Reserves ($A+B+C_1$) of sulphur-containing gas amount to 265.1 BCM in the Nenets AO and 17.6 BCM in the Komi Republic.

[23] A description of *Severgazprom*'s development plans for the Nenetskiy AO (including the Vasilkovskoye and Layavozhskoye GCFs) can be found in Vdovenko, Shemeley & Ilatovskiy, 1997, p.1-19.

GCF on the Yamal Peninsula (extreme north of Tyumenskaya Oblast')[24]. Current plans suggest that once construction begins from Yamal, a section in excess of 1000 km will be laid across Komi. The pipelines will enter Komi territory from the Yamalo-Nenetskiy AO (Tyumenskaya Oblast') at a point northeast of Vorkuta and will leave the republic southwest of Mikun', by that time following the "Northern Lights" corridor. The plan is for the construction of three 1420 mm diameter strings initially, and possibly three more later as and when demand requires it. Design pressure (Bovanenkovskoye - Torzhok section) is 7.4 MPa. Each string would transmit approximately 32 BCM of gas annually (Zorkal'tsev *et al.*, 1991, p.143) to domestic and foreign consumers. This large-scale transmission of gas through northern Komi will enable the gasification of the Vorkuta and Inta coal-producing districts and expansion of the Pechora power station. The northern section of the YEGTS will be examined in considerable detail in Chapter 5. Zorkal'tsev *et al.* (1991, p.146-151) also suggest that the Vuktyl'skoye GCF could be used eventually as an underground gas storage facility, because of the field's falling gas and condensate production, geographical proximity to the YEGTS, the presence of pipelines transmitting gas from the NPT via the field to western Russia (and abroad) and the developed social and production infrastructure which has grown up around the field since the late 1960s. The storage facility would be used to compensate for failure-related lower than normal delivery of gas and for regulating gas supplies both within and outside the Komi Republic. Thus, if failures occurred on the upstream side of the storage facility (i.e. Yamal - Ukhta or SRTO - Punga - Ukhta) gas would be extracted from the facility and supplied to consumers beyond Ukhta along the new YEGTS strings and the existing Ukhta - Torzhok and Ukhta - Vyatskaya strings. It is suggested that with the use of the facility additional annual gas transportation through the YEGTS could be roughly 0.6 BCM (Zorkal'tsev *et al.*, 1991, p.151). Research into the most effective ways of developing Vuktyl'skoye as a gas storage facility is being conducted by the *VNIIgaz* and *SeverNIPIgaz* institutes. Extending the field's life and the creation of a storage facility would also maintain the social infrastructure of the Vuktyl settlement which has a population of roughly 20,000.

Other gas pipeline projects within SGP's geographical zone of influence include the construction of a pipeline spur from the Nyuksenitskaya compressor station in eastern Vologodskaya Oblast' to Arkhangel'sk[25] and Severodvinsk. The first 720 mm diameter string (11 mm wall thickness) of the river-crossing under the Severnaya Dvina was completed in March 1996 (Mal'tsev & Rogatin, 1996, p.14). The crossing is located in Kholmogorskiy rayon of Arkhangel'skaya

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[24] *Severspetsburgaz*, a subdivision of SGP, is carrying out development drilling at the Bovanenkovskoye GCF. It drilled the first well at the field in 1975 (Kalinina, 1995). As of 1994, it had drilled 52 wells at the field (Podyuk, 1994, p.9).

[25] There are plans to construct a methanol export plant in Arkhangel'sk which would be fed by gas through this new spur (Remizov, 1997, p.14). It would be constructed in association with Ferrostahl of Germany.

Oblast', near the village of Tsenovets. Also, new strings of the SRTO - Torzhok and SRTO - Nechernozem'ye systems[26], are under construction. These pass through Komi and are part of the YEGTS project. Pipeline construction for these systems has been under way to the east of Vuktyl (Archegova, 1995; Kalinina, 1995). Within Komi 202 km of these new strings were completed in 1995, with another 65 km and 20 km in Tyumenskaya Oblast' under construction in 1996 (Podyuk, 1996, p.45). In fact, owing to non-payments affecting *Gazprom*, only 40 km were completed in 1996 and 20 km in 1997. By May 1998 only 11 km of the SRTO - Torzhok string had been laid (Kostina, 1998, p.10). It is intended that the new strings will allow an additional 12 - 14 BCM of gas transmission per annum.

Outside SGP's sphere of influence, but still within the European northwest, there are elaborate plans for the development of GCFs in the offshore Arctic. The Shtokmanovskoye GCF in the Barents Sea, 560 km north of Murmansk, is the current focus of attention. The project would require the construction of a system of subsea pipelines and a 1350 km system of onshore lines to transmit the gas southwards from the Murmansk area towards Volkhov.

2.4 Overview of development of the Yamburg GCF and trunk gas pipelines from Yamburg

2.4.1 Background and discovery of the Yamburg GCF

The opening up of the Yamburg GCF represented the third major stage of development in the NPT and a shift further north into more challenging natural-climatic conditions than those already experienced at Medvezh'ye and Urengoy. The pipeline corridor which was laid from Yamburg in the late 1980s, the northernmost part of the UGSS, marked the culmination of more than two decades of work on large-diameter gas pipeline construction in the Russian North. The section of corridor between Yamburg, which lies in the continuous permafrost zone, and Nadym will be examined in considerable detail in chapter 4. In this section, natural conditions of the field are reviewed briefly. This is followed by an account of the field's development history, as well as the trunk pipeline construction projects of the late 1980s.

Yamburg is located in the southern tundra subzone. Climatic conditions, which are extreme, are presented in Appendix 2. Permafrost at the field is generally continuous and of the "joined" type, with a maximum thickness of 560 m, coinciding with the centre of the field's geological dome. Seasonal thawing depths vary between 0.3 m for peaty soils to 1.5 - 2.0 m in mineral soils. Soil temperatures tend to be colder than at Urengoy or Medvezh'ye because of the minimal snow cover

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[26] In Russian, a gas pipeline system from the NPT to Torzhok, for example, that does not originate at a particular field, is known as "SRTO - Torzhok". SRTO is an acronym for "*Severnyye Rayony Tyumenskoy Oblasti*" or "Northern Regions of Tyumenskaya Oblast'". These pipelines generally originate at Nadym (Nadymskaya compressor station).

(little vegetation). At a depth of 2 m they range from -2 to -4°C; at 6 m from -5 to -6°C; at 10 - 12 m, -1....-7°C. The perennially frozen soils of Yamburg are represented chiefly by very fine low-temperature *supeses* (the temperature below the layer of annual thermal-ciculation reaches -7.2°C). These soils lose their supporting and gripping capability when they thaw. In the northern part of the field, the soils have a very high ice content, up to 80 - 90% in peats, and contain ice-wedges and layers of buried ice. Key cryogenic processes occurring at Yamburg include thermokarst, thermal erosion, thermal-contraction cracking and frost heave. Zakharov (1985, p.8), writing in 1985, reported that the geotechnical conditions of Yamburg had not been studied sufficiently at that time and the distributive regularities of geomechanical, thermal, hydrodynamic and geochemical interactions of gas production and transportation installations with frozen, unfrozen and freezing soils were not known. However, a permafrost laboratory now functions at Yamburg, as a subdivision of *Yamburggazdobycha*, the field's operating enterprise. Permafrost conditions are constantly monitored, particularly in relation to interactions with the field's gas production and transportation installations[27].

During the 12th Five Year Plan (1986-90), attention shifted to Yamburg from Urengoy. The field was discovered in 1969 in the central and western part of the Tazovskiy Peninsula (location shown in Fig.2.4), about 240 km north of the Urengoy GCF and 80 km northwest of Tazovskiy settlement, with reserves estimated at that time of approximately 4.4 TCM. Yamburg gas is concentrated predominantly in shallow Cenomanian dry-gas reservoirs, 1035 - 1210 m deep, but also in Neocomian (Valanginian) reservoirs which lie at depths of 2525 - 3200 m. Reserves of Cenomanian gas, which are practically pure methane, were initially 4.174 TCM (Salikhov, 1998). Neocomian gas reserves were estimated at 1.014 TCM and condensate reserves at 158 MT (*ibid.*).

The first tractor-sledge team arrived at Yamburg from Nadym in the winter of 1980 (Zorin & Trutnev, 1987, p.123), but development of Yamburg did not begin until January 1982, after the arrival from Pangody (the Medvezh'ye base settlement) of the first winter-road convoy consisting of 39 vehicles. The convoy, carrying the slogan "*Dayesh' Yamburg*" ("Let's Build Yamburg"), carried accommodation units, a boiler house, two compact generator units, a canteen and other necessities for these pioneers to consolidate their hold upon this new source of gas. The first production well, completed in summer 1983, provided fuel for the local boiler.

2.4.2 Development of Yamburg

In such harsh operating conditions, the plan was to speed up gas production, thus giving a projected lifetime of 20 rather than 25 years (25 years was normal for Soviet gas fields) (Shabad, 1986, p.81).

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[27] Key texts on geocryological conditions at Yamburg are Belopukhova *et al.* (1983, p.3-19), Dubikov *et al.* (1984, p.72-113), Baulin (1985) and Sukhov *et al.* (1989, p.236-246).

Production capacity was originally put at 100 BCM per annum, in 1980-81 (Shabad, 1984, p.358), but by 1985 the suggested capacity had been doubled to 200 BCM, close to that of Urengoy, the intention being for the 200 BCM output to be achieved within four years of commissioning the field (by 1989/90). Production was planned from 48 drilling islands in an 8500 km² area (*Arctic News Record*, 1986, p.10).

The delivery of field installations to Yamburg was revolutionized through the modularization of cargoes. Installations such as UKPGs would be assembled in Tyumen' city and shipped during the summer navigation season to Yamburg port, beginning in 1982. In winter these so-called "block-pontoons" were hauled across the frozen tundra surface to the required sites, only requiring final attachment to pre-installed piles. A railway was laid from Novyy Urengoy to Yamburg for further deliveries which is still fully operational. An airport was built too and this now handles large jet aircraft, such as the Tupolev 154.

There were no plans to build a large development settlement at Yamburg. Novyy Urengoy, the settlement built for the Urengoy GCF, would be the principal base during development of Yamburg. Fifteen hundred personnel were in place in temporary settlements in autumn 1985, but Shabad (1986, p.81) estimated that ultimately 15,000 - 25,000 would be needed. Dormitory settlements, accommodating 400 workers each, were to be scattered throughout the field. Shabad (1984, p.359) suggested that these could eventually accommodate 30,000 workers in total. In fact, things turned out differently from Shabad's expectations. The Yamburg GCF is unique in that it is operated entirely by shift workers most of whom are based in the settlement of Yamburg, 25 km west of the field, for periods of one to three months. The modern part of the settlement itself is composed of three-storey Finnish-made accommodation and administrative blocks, all built on piles. The compact shiftworker settlement, capable of accommodating up to 10,000 people, contains many of the facilities and services one would expect to find in a proper town, including shops and a large sports-culture complex. *Yamburggazdobycha* is based in the settlement with additional administrative offices in Novyy Urengoy and Moscow.

In 1985, the total development costs for Yamburg were estimated at 4.5 billion rubles (Ivantsov & Klyuchnikova, 1985, No.6, p.10). An earlier estimate (1982) had put the total at 3.5 billion rubles.

2.4.3 Gas production at Yamburg

2.4.3.1 Gas processing plants

Development in the period 1986-90 called for ten UKPGs, one for each sub-field. They were planned to be double the size of the Urengoy plants, and would be built in five years, compared to the eight years (1976-84) it took to complete 15 plants at Urengoy.

There are currently eight UKPGs and one UPPG for Yamburg's nine sub-fields (see Fig.2.8)[28]. Table 2.8 lists the currently operational field processing plants at Yamburg and the new UPPG, due to be commissioned in 1999. UKPG-2, the first, was put into operation on 26th September 1986 (*International Gas Report*, 1986b, p.416). By the time a fourth plant, UKPG-6, had been installed in mid-1988 (*International Gas Report*, 1988a, p.227) Yamburg was producing all of the USSR's incremental gas output.

Table 2.8 **Gas processing plants (UKPGs) currently operational and planned at the Yamburg GCF** (Source : Salikhov, 1998)

Name	**When commissioned**	**Type of product processed**	**Other details***
UKPG-2	26th September 1986	Cenomanian gas	DKS-2 commissioned in Feb.1997
UKPG-1	July 1987	Cenomanian gas	DKS-1 commissioned in June 1995
UKPG-5	January 1988	Cenomanian gas	
UKPG-6	September 1988	Cenomanian gas	DKS-6 commissioned in May 1996
UKPG-3	July 1989	Cenomanian gas	
UKPG-1V	March 1991	Valanginian gas and condensate	Also processes Valanginian products from UPPG-3V
UKPG-7	December 1991	Cenomanian gas	
UKPG-4	December 1994	Cenomanian gas	
UPPG-3V	October 1996	Valanginian gas and condensate	Product piped to UKPG-1V after preliminary processing
UPPG-2V	1999 planned	Valanginian gas and condensate	to employ same system as UPPG-3V

* NOTE : DKS is the Russian acronym for booster compressor station. Most plants now have or will soon have a DKS, but further commissioning details are unknown.

International Gas Report (1988b, p.334) reported a fire at UKPG-5 which caused serious damage and reduced production output. 2 BCM were lost during repair work. Fire burned fiercely for two hours, but luckily there were no fatalities. 500,000 rubles worth of damage was sustained to

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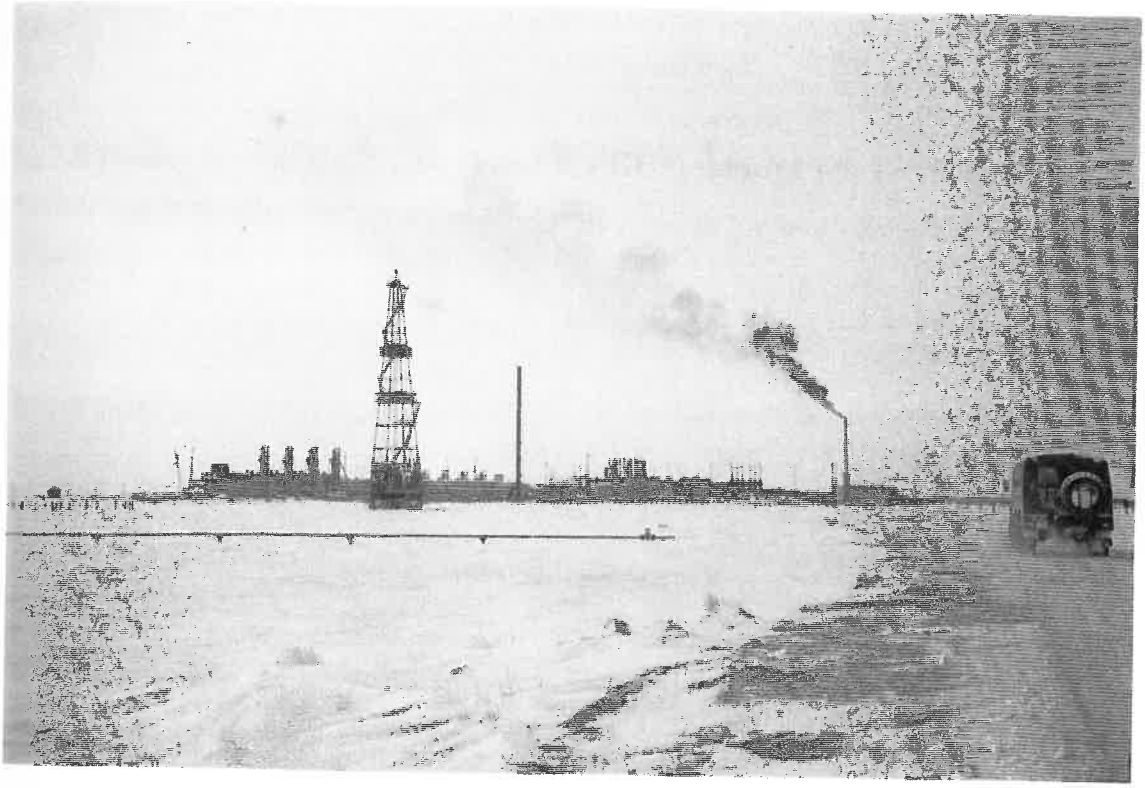
[28] UPPG is the Russian acronym for a plant conducting only preliminary processing of gas and/or condensate. Further processing occurs elsewhere.

UKPG-5. This accident drew attention to low quality work at Yamburg where workers were literally racing to raise production to 200 BCM per annum. At this stage Yamburg was producing 220 - 245 MCM per day of the USSR's 2.05 BCM per day.

Fig.2.8 UKPG-1V at the Yamburg GCF
(Author's photograph, taken on 8th April 1998)



The completion of the sixth plant, UKPG-1V, would make it possible to start extraction of condensate. Commercial condensate production from deeper Valanginian horizons began at Yamburg in March 1991, but the field had produced 15,200 tons of condensate in 1989, and 24,782 tons in 1990 [29].

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[29] Descriptions of the gas and condensate processing technologies used at Yamburg plants can be found in Klyusov & Yershov, 1995, p.31-32; Shinyayev & Voronin, 1995, p.38-39; Arabskiy & Zhukov, 1995, p.39-40.

2.4.3.2 Feeder and gathering lines at Yamburg

Formation gas is transmitted through feeder lines from well clusters within a particular sub-field to that sub-field's processing plant. For example, gas produced at sub-field 2 is processed at UKPG-2, gas-condensate produced at sub-field 1V is processed at UKPG-1V. The Yamburg GCF has approximately 900 km of feeder lines, up to 520 mm diameter, and all are laid above-ground on supports with single or double piles. Feeder lines are operated by a division belonging to the sub-field within which they transmit formation gas. Feeder line reliability is a serious problem at Yamburg. As much as 10% of the piles beneath feeder lines have been displaced by frost heave, thaw settlement and thermal erosion, and pile repairs or replacements are made annually (see Fig.2.9).

Fig.2.9 Feeder lines at UKPG-1V (Yamburg GCF) showing pile displacement
(Author's photograph, taken on 8th April 1998)

After processing at one of the plants, the gas is fed into Yamburg's system of gathering lines which transmit the product to one of two compressor station sections, Tul'skaya and Yeletskaya, which together comprise the Yamburgskaya initial compressor station (see Fig.2.10). There are 460 km of gathering line at Yamburg, with diameters of 1020 - 1420 mm. The entire gathering line system (see Fig.2.11) is divided into western and eastern corridors and is buried, except for crossings over streams. Officially, product temperature is usually in the range -2....-5°C (though positive temperatures are possible). This has resulted in minor displacement of some buried river crossings caused by frost heave in taliks. The system is operated and monitored by the Inter-field Gathering Line Operations Division of *Yamburggazdobycha*. When the gas reaches the two sections of the Yamburgskaya initial compressor station, it becomes the sole responsibility of TTG. After initial processing, unstable condensate is piped to Novyy Urengoy from UKPG-1V. The condensate is piped through 377 mm and 500 mm diameter lines at approximately -5°C. The Yamburg - Novyy Urengoy - Surgut condensate pipeline (500 mm diameter south of Novyy Urengoy) is operated by *Surgutgazprom*.

2.4.3.3 Gas output

By 1989, gas output from Yamburg stood at almost 130 BCM per annum. In 1990, Yamburg was producing 7 MCM per day above planned output (Sagers, 1991, p.410). That is a total of 2.5 BCM above the planned 1990 output. Table 2.9 shows the increase in natural gas production at the Yamburg GCF between 1985 and 1997. Currently, the Cenomanian horizon accounts for the vast majority of production (roughly 175 BCM per annum), while the Valanginian horizon produces around 5 BCM per annum (Klyusov & Yershov, 1995, p.31).

Table 2.9 **Gas production by *Yamburggazdobycha* (BCM), 1985 - 1997** (Sources : Sagers, 1992, p.208; *Nefte Compass*, 1997, p.9)

1985	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
0.1	3.1	40.0	85.0	128.9	158.8	167.9
1992	**1993**	**1994**	**1995**	**1996**	**1997**	
178.2	174.0	179.3	182.2	179.1	169.3	

Fig.2.10 Tul'skaya section of the

(Author's photographs, taken on 8

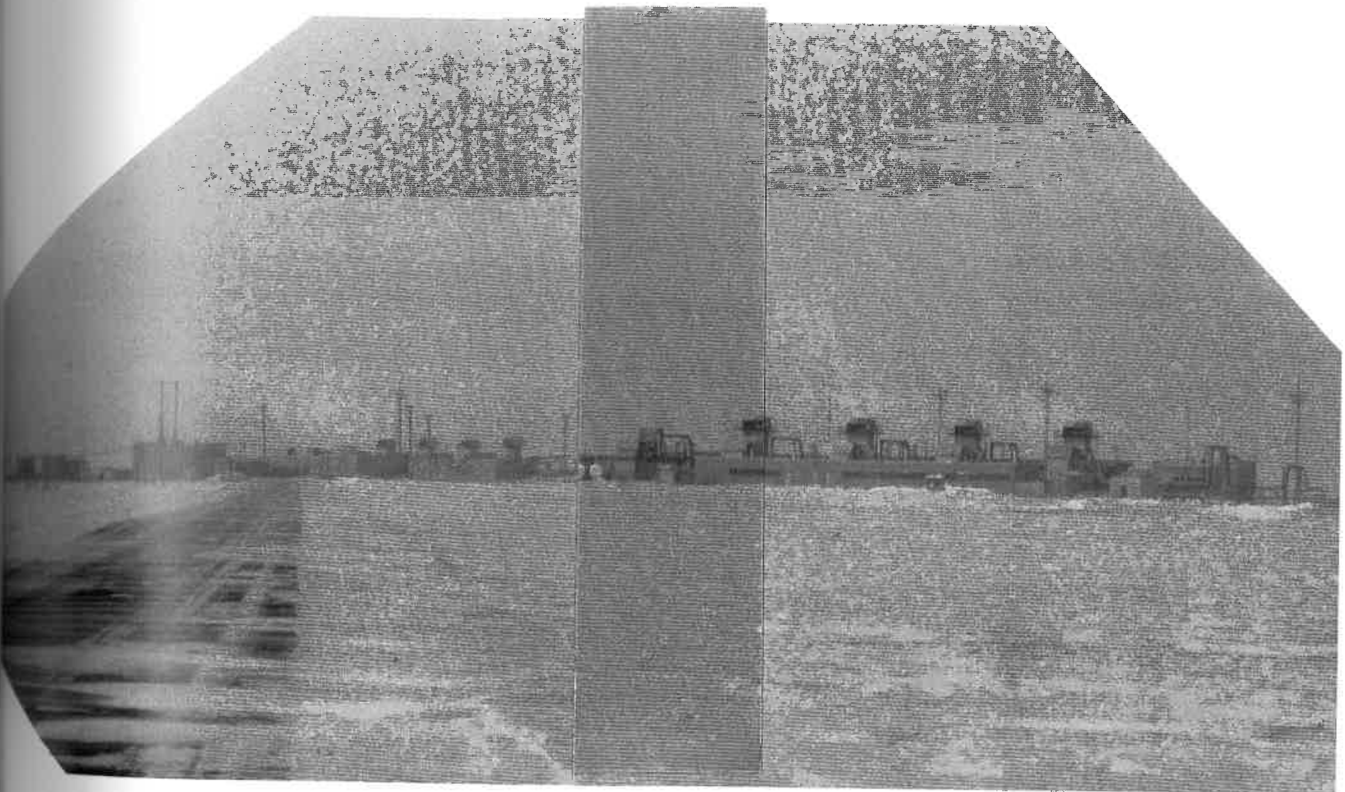
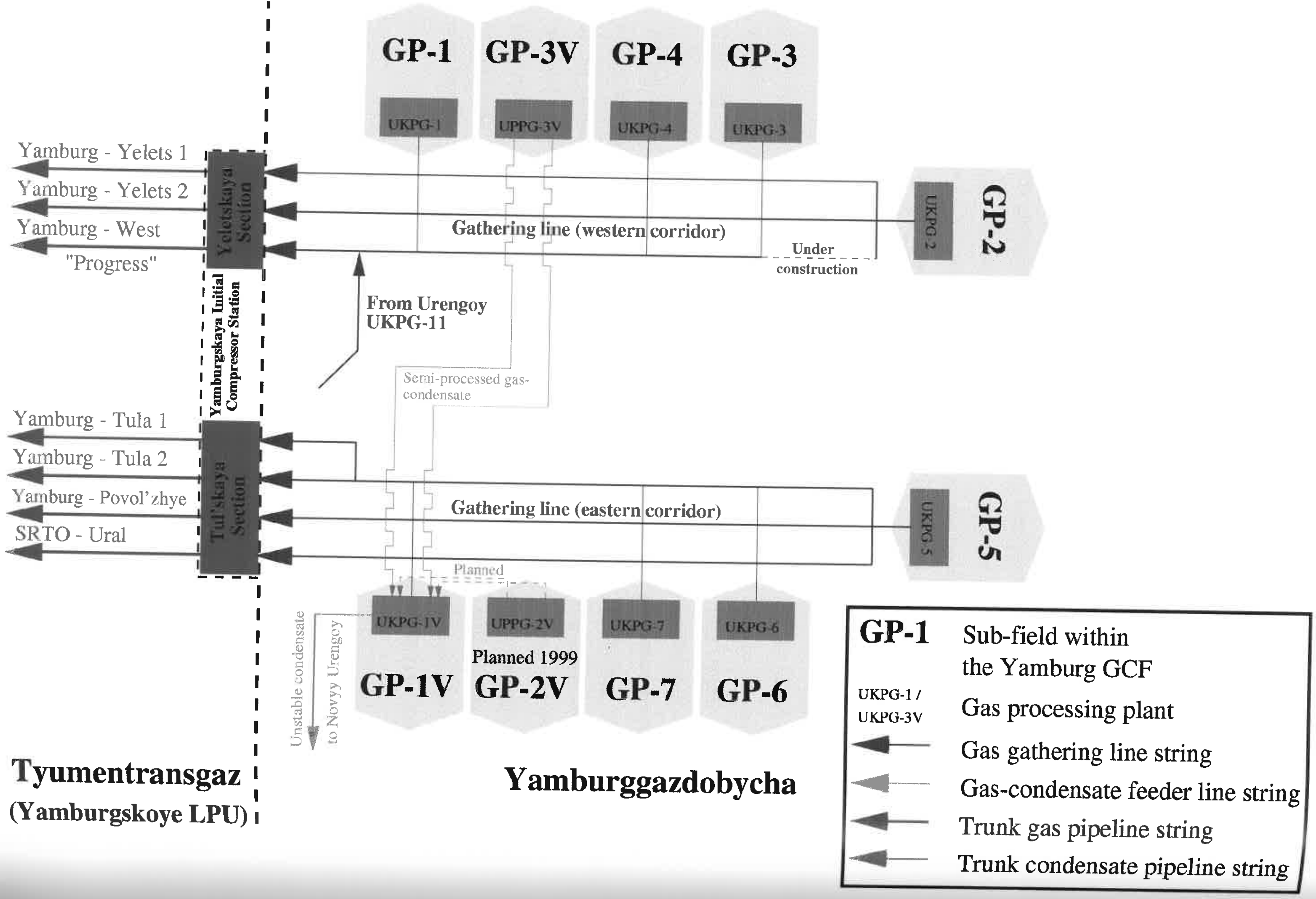


Fig.2.11 Diagram of the gas gathering line system at the Yamburg GCF (operated by Yamburggazdobycha)



2.4.4 Trunk pipeline development

Shabad (1986, p.82), citing *Stroitel'stvo Truboprovodov* (1985, No.1, p.3) writes that six pipeline strings, or a total of 23,000 km of 1420 mm diameter pipe, and 240 compressor units (known in Russian as GPA) would be required to transmit commercial gas from Yamburg. Each string would constitute 2.5 - 3 million tons of steel. The extreme climatic and complex geocryological conditions of the Tazovskiy Peninsula would pose new challenges for those designing and constructing the initial sections of the trunk pipelines from Yamburg. These conditions, many of which had not been encountered at either Medvezh'ye or Urengoy (for example highly icy soils) would also create complications for pipeline operations (addressed in chapter 4).

2.4.4.1 Yamburg - Yelets 1 and 2, Yamburg - Tula 1 and 2

Two domestic strings running to Yelets (a gas distribution centre, some 400 km south of Moscow in Lipetskaya Oblast'), the first to be completed in 1986, the second in 1987, were the first pipeline objectives. *Stroitel'stvo Truboprovodov* (1985b, p.9) mentions the initiative proposed by *Minneftegazstroy* and *Mingazprom* concerning the construction of the Yamburg - Yelets 1 pipeline. The two ministries stated that this pipeline would have to be completed ahead of schedule, by the beginning of the 27th session of the Communist Party in February 1986. The 1200 km section between the Pravokhettinskaya and Kungurskaya compressor stations had to be ready for gas transportation by 15th January 1986, with all intermediate stations ready.

Due to earlier than anticipated completion of six strings from Urengoy by 1985, construction crews got an early start on laying Yamburg - Yelets 1 (3150 km long). Since it was due to be completed before the Yamburg GCF was ready to produce, the string would need to be linked up to Urengoy UKPG No.11. The string would be extended through Kremenchug (Ukraine) and Tiraspol' (Moldova) to the Balkans (Romanian border) (*Oil & Gas Journal*, 1985a, p.46). According to *International Gas Report* (1986a, p.148) by April 1986 construction had finished on Yamburg - Yelets 1, having taken 17 months. *International Gas Report* (1986b, p.416) reported that Yamburg went onstream in September 1986, supplying gas for Yamburg - Yelets 1, and that it was expected to provide the entire increase in Soviet gas production during the 12th Five Year Plan. Eventually all Yamburg strings would carry 200 BCM per annum to the Soviet industrial heartlands and Eastern Europe.

600 km of the Yamburg - Yelets 2 gas pipeline was welded together in 1985, construction having begun in August that year (*Oil & Gas Journal*, 1985b, p.52), although the Communist Party had only anticipated the completion of 200 km of the pipeline. Yamburg's harsh climate slowed work at the new field, but testing was underway on Yamburg - Yelets 2 in early 1987 (*International Gas Report*, 1987, p.148).

In mid-1988 testing was completed on another line from Yamburg which terminates at Tula (170 km south of Moscow in Tul'skaya Oblast'), the Yamburg - Tula 1 pipeline (*International Gas Report*, 1988a, p.227). Construction on this line had been due for completion in the first quarter of 1988 (Krayzel'man, 1988, p.2). Yamburg - Tula 2 would be completed by the end of 1988.

Construction of these four lines from Yamburg had been conducted by the following pipeline construction associations : *Glavtruboprovodstroy, Glavsibtruboprovodstroy, Glavvostoktruboprovodstroy, Glavinterneftegazstroy, Glavyuzhtruboprovodstroy, Glavukrneftegazstroy* and *Glavsredazneftegazstroy*.

A fifth domestic string from Yamburg was laid to Saratov. It is known as the Yamburg - Volga Region (Povol'zhye) line and is 2755 km in length. A sixth string, known as SRTO - Ural, has also been laid from Yamburg to the Urals industrial region. *Pipe Line Industry* (1986, Vol.64, No.4, p.60) reported that a 4500 km line from Yamburg to Baku, Azerbaijan had been proposed for construction during the 12th Five Year Plan. This never materialized largely because of the larger than anticipated production capacity of the Astrakhanskoye GCF and the development of new fields in Azerbaijan.

2.4.4.2 The Yamburg - Western USSR Border gas pipeline : "Progress"

The seventh pipeline from Yamburg, an export string, known as "Progress", 4605 km long, was a joint-COMECON project to be completed in 1988, though *Arctic News Record* (1986, p.10) rather optimistically stated that this string, to Kremenchug in the Ukraine, was due for completion in April 1986. "Progress", the longest gas pipeline in the CIS, would be 1420 mm in diameter and have a capacity of 26.4 BCM per annum. "Progress" was to be equipped with exclusively Soviet turbine plants developed to replace embargoed US equipment on the Urengoy line. The 16-Mw compressor stations used successfully on the Urengoy export line, would be replaced by 25-Mw ones. The planning institute *YuzhNIIgiprogaz*, based in Donetsk in the Ukraine, designed the pipeline (*Stroitel'stvo Truboprovodov*, 1985a, p.9).

A brigade of East German welders welded the first joint on the "Progress" pipeline in mid-August 1986. The section from Yelets to the western USSR border was built mostly in the first half of 1988 (Krayzel'man, 1988, p.2). "Progress" was completed in mid-1988 for the export of 22 BCM per annum (*International Gas Report*, 1988a, p.227). The so-called "red-joint", the final welding operation to be conducted, was welded at the settlement of Bogorodchany near the Czechoslovak - Ukraine border (Khanzhenkov & Yashin, 1988, p.4).

2.5 The ageing UGSS

The commissioning of Yamburg in 1986 and the completion of the trunk lines from the field in 1988 marked the end of a gradual progression northwards by the Soviet gas industry spanning more than

20 years. In the 1960s, constructors had worked on the Igrim - Serov line, the first northern trunk gas pipeline in West Siberia, in some places laying it in island and massive-island permafrost. By the late 1980s, pipelines were being laid in continuous permafrost at Yamburg, more than 100 km north of the Arctic circle and more than 700 km northeast of Igrim and Punga. Today the Yamburg lines have been in operation for a decade, Medvezh'ye lines for more than two and the Igrim - Serov for more than three. These latter lines are approaching the 33 year threshold referred to in chapter 1 and they have been experiencing failures (leaks and ruptures) for a significant proportion of their operational lifetimes. Assessing the reliability of pipelines operating for so long in such harsh environmental conditions is all the more important.

More than 30% of the UGSS is more than 20 years old (15% of it is more than 30 years old and 2.5% is more than 40 years old) (Ivantsov, 1997a; Dinkov & Ivantsov, 1997a, p.17). The average age of pipelines within the UGSS is in excess of 16 years (Dinkov & Ivantsov, 1997a, p.17; Remizov, 1997, p.14). With an average pipeline design life of 33 years, much of the system is in urgent need of refurbishment or even replacement and many compressor stations need similar treatment. Ivantsov (1997b) says that 40,000 km of trunk gas pipeline have been in place for more than 33 years, i.e. about 27.5% of the whole UGSS. The effects of ageing on the gas pipeline network include a reduction of the effectiveness of their protective insulating coatings as well as a build up of defects in the pipe and at the welded joints, together with other metal ageing problems. Research into physical processes of deformation and damage in pipeline steel has defined the reduction in residual strength and crack resistance, and plastic and viscous properties of the steel, in relation to the period of operation. This research has been conducted by the *UralNITI* and *TsNIIChM* institutes. The results of this research have made it possible to estimate the residual operational reserve of gas pipelines on the basis of the condition of the pipe metal and the welded joints.

With regard to failures, one would expect a larger percentage on older pipelines than newer ones, and a relatively large number of failures during the so-called "running-in" period (the first six or so years). This was indeed the case until approximately 1991. From 1992 however, the number of failures occuring during the first six years of operation fell significantly, while the typical increase in failures with age continued. Dinkov & Ivantsov (1997a, p.17) say this can be explained by the much smaller volumes of trunk line construction in the 1990s as compared to the pipeline construction boom era of the late 1970s and 1980s. Another important trend lies in the fact that while the pipelines continue to age, according to official figures the overall number of failures on Russia's UGSS has been falling over the last ten years. Failure statistics for trunk gas pipelines are presented in Table 2.10. For comparison, some oil pipeline failure statistics are also given. In 1994-95 the gas pipeline accident rate was 0.21 per 1000 km (Ivantsov, 1996), down from 0.51 per 1000 km in 1985 (Shmal' & Ivantsov, 1994, p.11). According to Remizov (1997, p.14) the 0.2 per 1000 km rate had been maintained into early 1997. Within the UGSS, *Severgazprom*'s pipeline failure statistics, quoted for its individual *LPU*s, vary between 0.4 and 2.73 per 1000 km (Yakovlev, Kolotovskiy & Sharygin, 1997, p.17).

Table 2.10 **Failure statistics for Russian trunk gas pipelines** (Sources : Shmal' & Ivantsov, 1994, p.11; Ivantsov, 1996; Dinkov & Ivantsov, 1997a, p.17; Remizov, 1997, p.14; Shmal', 1998)

Year	**No. of failures per 1000-km of trunk gas pipeline**	**No. of failures per 1000-km of trunk oil pipeline**
1985	0.51	N/A
ca.1988	0.45 - 0.48	N/A
1990	N/A	0.27
1994 - 1995	0.21	N/A
1995 - 1996	0.21 - 0.23	0.18
1997	ca. 0.2	N/A

NOTE : This is the standard method of statistical representation of pipeline failures in the CIS.

As with trunk oil pipelines, trunk gas lines have been subject to defective installation, maintenance and repair work, all of which have contributed to high accident rates. Other causes of accidents include defective pipe and mechanical damage to operational lines. However, the most common cause of failures on trunk gas pipelines both in Russia as a whole and in West Siberia is internal and soil corrosion (Dinkov & Ivantsov, 1997a, p.18). This is shown clearly in Fig.2.12 and Table 2.11. Fig.2.12 shows that in most years between 1991 and 1996, corrosion was responsible for more than 20%, or in some cases more than 30%, of failures. Most of the large-diameter gas pipelines have anti-corrosion insulation created on-site using polymer tape. On-site application of polymer tape is linked to the largest number of corrosion-related incidents. Research into polymer tape on 120,000 km of gas pipelines has shown that repair work is needed on about 50% of this length (Ivantsov, 1997b). In the future, for example on the YEGTS, only factory-insulated pipe sections will be used (Dinkov & Ivantsov, 1997a, p.18; Shmal', 1998). Concern also surrounds the reliability of cathode protection of trunk gas pipelines, particularly those laid parallel to one another in corridors, as is the norm in northern Russia.

Table 2.11 **Causes of failures on trunk gas pipelines in West Siberia at 1993-94** (Source : Safonov et al., 1994a, p.179, Table 2)

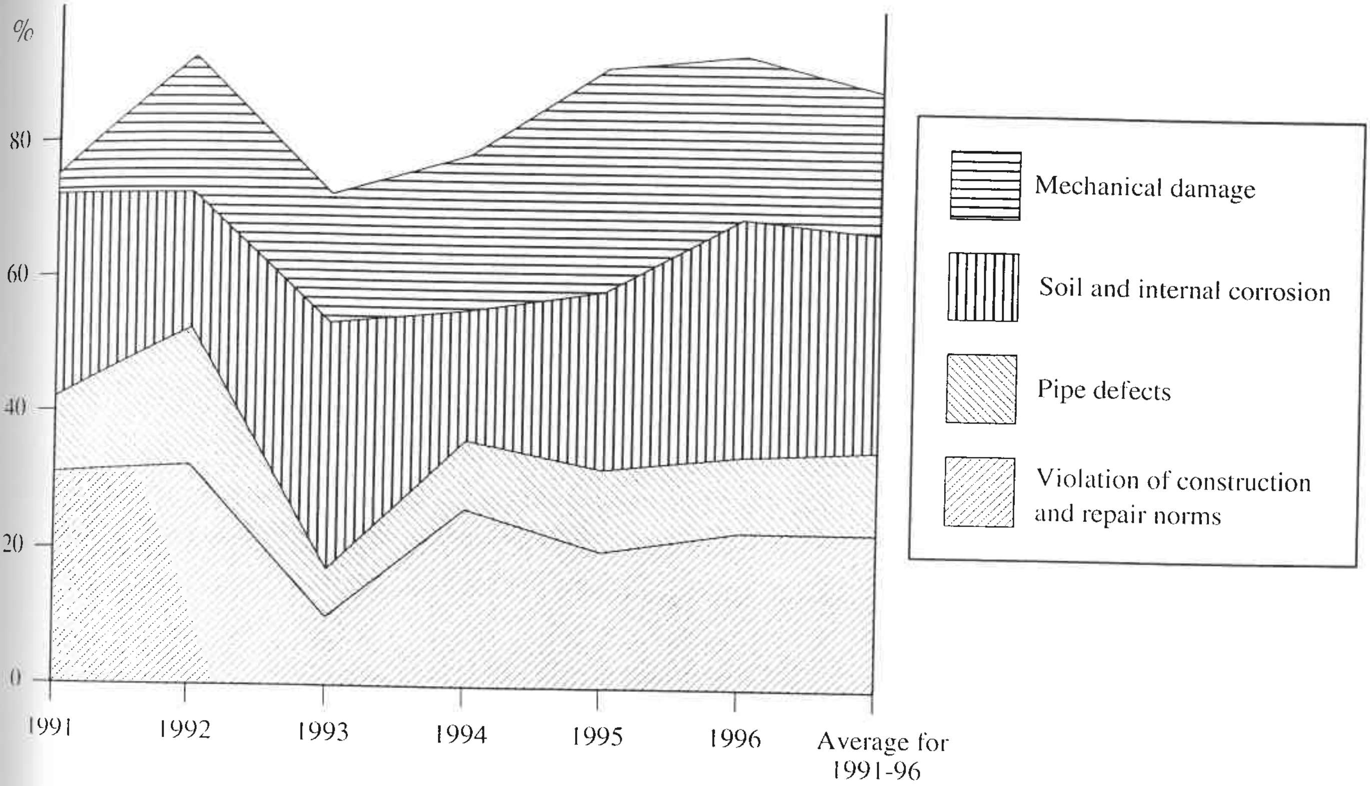
Cause of failure	**Failure classification**	
	Rupture	**Flaw, leakage**
% of all failures	12.5	87.5
Of which :		
Pipe defects	1.7	6.7
Defective welding	0.96	16.55
Defective construction-assembly work	0.96	6.95
Design errors	0.24	0
Violation of operation regulations	0	3.36
Internal corrosion	0.72	0.72
External/soil corrosion	5.52	45.83
Mechanical damage	2.16	4.58
Others	0.24	2.83

Serious concern has arisen in recent years about the number of incidents related to stress-corrosion cracking or SCC. Between 1990 and 1995, 13% of the total number of gas pipeline incidents were attributed to SCC. The uncertainty surrounding the occurrence of SCC in permafrost conditions will be discussed briefly in chapter 4.

In Arctic and sub-Arctic conditions there are the added factors of pipeline - permafrost interactions, extreme annual temperature ranges and strong winds. Construction takes place during winter, making it harder to ensure high quality assembly operations. However, the rate of soil corrosion is slower in the North. In Siberia and the polar regions it amounts to 0.23 - 0.30 mm per annum, whereas in the South it is 0.8 - 1.2 mm per annum (Dinkov & Ivantsov, 1997a, p.18). These and other issues pertaining to the peculiarities of gas pipeline construction and operation in northern Russia will be discussed in detail in the following chapters. One part of the UGSS which needs special attention in view of all these factors is located downstream of the Pravokhettinskaya compressor station in the NPT (location shown in Fig.2.4) where the 7-string corridor from the

Yamburg GCF intersects the 9-string corridor from Medvezh'ye and Urengoy. Any accident at this

Fig.2.12 **Principal causes of failures on trunk gas pipelines, 1991-96**
(Source : Dinkov & Ivantsov, 1997a, p.18, Fig.2)



high-risk point would cause severe disruption to a vast proportion of Russia's gas supplies and exports. A joint study of the UGSS recently carried out by *Gazprom*, the EBRD and 13 western firms made recommendations for work to increase the reliability of trunk gas transportation in Russia. They include the refurbishment of compressor stations in West Siberia, making provision for the use of internal defectoscopes on linear sections of West Siberian gas pipelines, installation of gas metering units, and the repair of a pipeline crossing under the R.Ob' (Rezunenko, 1996).

Another critical factor to consider when assessing the reliability of Russian trunk pipelines is the outdatedness of construction norms and regulations, known in Russian by their acronym SNiP. SNiPs are in urgent need of replacement. The severity of the problem regarding SNiP outdatedness will become apparent in chapter 3 which examines the issue from the point of view of design and planning of northern trunk pipelines. The peculiarities of designing and planning pipelines for permafrost conditions have traditionally received inadequate attention in SNiPs.

A unique situation has arisen regarding the age of the pipeline network which would not occur outside Russia. While on the one hand the UGSS is ageing rapidly, on the other there is a shortage of funds to carry out repair and replacement work. This is in no small part due to customer indebtedness to *Gazprom*. This is an important point to bear in mind when discussing the Russian trunk gas pipeline network and is one reason for Russia's increasing need for foreign investment.

2.6 Conclusion

The last 50 years has seen the development of the UGSS, the world's largest network of trunk gas pipelines, with expansion occurring intensively during the period 1970 - 1990. Depletion of gas reserves in the mid-1960s in the more accessible regions of southern Russia, namely the North Caucasus and the Lower Volga, and the eastern Ukraine required the opening up of newly discovered fields east of the Ural Mountains in Tyumenskaya Oblast' (the Berezovskiy gas-bearing district, Khanty-Mansiyskiy AO). This marked the beginning of large-scale gas industry development in northern Russia. Gas from the Berezovskiy rayon would be supplied to the large industrial enterprises of the Urals region, while soon afterwards the industries of Russia's Northwestern region would receive gas from the Komi Republic (the Vuktyl'skoye GCF) in Russia's European North. Local-scale development of gas fields and small pipeline systems took place independently of the UGSS at about this time in Yakutiya and the Taymyrskiy AO (Noril'sk mining-metallurgical complex).

While these early developments were relatively small and regional in scale, though still impressive by world standards, the discovery of gas further north in Tyumenskaya Oblast', in the NPT, enabled a rapid acceleration in the expansion of the pipeline network. The commissioning in 1972 of the first giant GCF of the Far North, Medvezh'ye, marked the beginning of the NPT's dominance in Russian gas production and the construction of multi-string large-diameter gas pipeline systems over thousands of kilometres through territories with complex natural-climatic conditions, making pipeline construction and operation much more challenging. After Medvezh'ye, Urengoy was opened up in more complex conditions, and later Yamburg, where permafrost is generally continuous and the climate still more severe. The future of gas pipeline construction in West Siberia will be even more challenging when work begins on the northernmost section of the YEGTS. The same can be said of offshore Arctic pipeline projects, such as Shtokmanovskoye.

A pattern has emerged in West Siberian gas pipeline development over the past three decades. Pipelines have been built progressively further north, reflecting the opening up of progressively larger GCFs in more complex natural-climatic conditions as one moves northwards. This northward trend continues today with the YEGTS and Arctic offshore projects. This progression northwards can be seen in the following chronological list of major trunk gas pipeline systems : Igrim - Serov (commissioned in 1966) ⇒ Medvezh'ye - Punga (from 1972) ⇒ Urengoy - Centre (from 1978) ⇒ Yamburg - Centre (from 1986) ⇒ YEGTS (ca.2005) ⇒ Shtokmanovskoye (post-2005). The move northwards has brought with it the need to overcome more complex and severe natural-climatic conditions. The two autonomous gas pipeline systems, MYaB (Yakutiya) and NAGSS (Taymyrskiy AO), developed under different circumstances in the mid-late 1960s. Large-scale industry in these regions of northern Russia, particularly in the case of Noril'sk, required a source of fuel from relatively nearby. Planners had little choice but to construct pipeline systems in continuous permafrost and very harsh climatic conditions.

The Komi Republic's role in northern Russian gas pipeline development has been somewhat different from that of Tyumenskaya Oblast'. While early pipeline development in the 1960s was necessary for the supply of its indigenous gas resources from Vuktyl'skoye, subsequent construction reflected the republic's increasingly important role as a transit region. NPT gas moves to consumers along the northern corridor of pipelines from the Yamalo-Nenetskiy AO and the "Northern Lights" system, via Komi, and in the future the YEGTS will likely cross the entire republic from northeast to southwest. This role will be further strengthened when the other administrative component of the TPFEC, the Nenetskiy AO, begins supplying its indigenous gas resources in the near future through pipelines linking up to the UGSS in Komi. The geocryological environment of Komi is also different. Unlike the centre and north of Tyumenskaya Oblast' where permafrost (to varying degrees of continuity) is widespread, Komi displays soils with intense seasonal freezing and thawing and very little permafrost, the latter being confined to the extreme north of the republic. Nonetheless, boggy conditions coincide with the r-o-ws of the trunk pipelines crossing the republic's territory.

The constraints imposed upon gas pipeline construction and operation in the northern section of the UGSS by the harsh climate and geography of the region are striking. The ways in which pipeline construction and operation are conducted depend to a great extent upon the specific kinds of natural-climatic conditions encountered along a pipeline's r-o-w. Nowhere is this more apparent than in the North. The presence of permafrost, as well as intense seasonal freezing and thawing of soils, has been, and remains, one of the most troublesome obstacles for those designing, constructing, operating and maintaining gas pipelines in the Russian North. For this reason, much of the thesis will examine the permafrost problem as it has been tackled in the past and how approaches to it have changed and might change in the future. To demonstrate this the following sections of pipelines will be examined in chapter 4: Nadym - Punga strings 1, 2, 3 and 4; Urengoy - Pangody - Nadym; Yamburg - Nyda; Urengoy gathering line, and in chapter 5: the YEGTS northern section. But prior to this another problem facing pipeline planners and constructors must be considered. This is the inadequacy and outdatedness of pipeline design and construction norms and regulations (SNiPs). This problem has traditionally been exacerbated by centralized policies of gas industry development, including the accelerated construction of trunk gas pipelines in West Siberia during the 1970s and 1980s. Chapter 3 tackles this peculiarly Soviet issue.

CHAPTER 3

PLANNING AND CONSTRUCTION REGULATIONS AND PRACTICE FOR TRUNK GAS PIPELINES IN THE RUSSIAN NORTH

3.1 Introduction

The number of failures on operational trunk gas pipelines in Russia, especially its northern regions, calls into question the entire process during which the pipelines are planned and constructed, as well as aspects of the subsequent operation and maintenance period. This chapter focuses upon the initial planning stage and the construction operations, including the regulations that govern them, in order to show the reader exactly how these activities were carried out and why they were carried out in that way during the period of accelerated pipeline construction from the early 1970s to the late 1980s, i.e. the 10th to 12th Five Year Plans. Pipeline operations in the North will be the subject of chapters 4 and 5. Having critically examined these activities it will be possible to draw some conclusions about the quality of the planning and construction activities and the extent to which particular aspects of these activities could have contributed to the current condition of the UGSS and pipeline failures.

Sections 3.2 and 3.3 concern the planning stage. 3.2 is a critical examination of norms and regulations governing trunk pipeline planning and construction in the CIS, known as SNiPs. SNiP is the acronym for *Stroitel'nyye Normy i Pravila*, translated as Construction Norms & Regulations. A brief history of SNiPs is given in subsection 3.2.2 and this is followed by a description of SNiP 2.05.06-85 "Trunk Pipelines", the normative document most relevant to planning pipelines, including those in northern conditions (subsection 3.2.3). Other SNiPs most often used in the planning and construction of northern trunk pipelines are reviewed in subsection 3.2.4. Subsection 3.2.5 provides the current major criticisms of the SNiPs in force today, with particular attention paid to those of Leonid Dimov, a respected authority on the subject who has contributed most to constructive criticism of the SNiPs. Recommendations for their improvement, replacement and harmonization with western norms are also provided. Some conclusions on the SNiP issue are given in subsection 3.2.6. Section 3.3 examines problems of a more general nature, concerning planning and research for northern trunk pipelines in specialized institutes. These problems are linked to the location of the institutes in the CIS (subsection 3.3.2) and the lack of competition in pipeline science, which includes financing (subsection 3.3.3).

Section 3.4 focuses on the construction stage within pipeline development and its relationship with planning, notably the SNiPs. Subsection 3.4.2 explains why pipeline construction in the 1970s and 1980s proceeded at extremely high rates and discusses how this was possible. One unusual way of achieving high rates of construction, discussed in subsection 3.4.3, was the Integrated Production Line (IPL), a system of work organization especially suited to the conditions of northern West Siberia. The function, organization and achievements of the IPLs which worked on the Urengoy - Pomary - Uzhgorod pipeline are discussed. Subsection 3.4.4 offers some conclusions about the likelihood of accelerated construction rates (including the technology and work organization which enabled this acceleration) being a major factor responsible for the current condition of the northern UGSS and pipeline failures.

The chapter is concluded in section 3.5.

3.2 Construction Norms and Regulations (SNiPs) for trunk pipelines in the Russian North

3.2.1 Introduction

The planning and construction of buildings and structures in Russia and other CIS member states are governed principally by normative documentation known as SNiPs, or Construction Norms and Regulations. These SNiPs in turn often refer the reader to other guidelines, or technical specifications (for steel types for example), such as GOSTs (State Standards), TUs (Technical Requirements) and VSNs (Departmental Construction Norms). Observance of SNiP guidelines is regarded as being crucial to the overall success of construction and represents the first stage in determining the eventual reliability and stability of the building or structure. By examining the relevant SNiPs we can see how important a factor design and construction regulations have been in

Table 3.1 **Major SNiPs for the planning and construction of trunk pipelines in northern conditions**

1. **SNiP 2.05.06-85 "Trunk Pipelines"**
Replaced SNiP II-45-75. (Referred to in text as SNiP 1)
2. **SNiP III-42-80 "Execution and Completion of Work. Trunk Pipelines"**
Replaced SNiP III-D.10-72. (Referred to in text as SNiP 2)
3. **SNiP 2.02.04-88 "Bases and Foundations in Permanently-Frozen Soils"**
Replaced SNiP II-18-76. (Referred to in text as SNiP 3)
4. **SNiP 1.02.07-87 "Engineering Surveys for Construction"**
Replaced SNiP II-9-78. (Referred to in text as SNiP 4)
5. **SNiP 2.02.01-83 "Foundations of Buildings and Structures"***
Replaced SNiP II-15-74 and SN 475-75. (Referred to in text as SNiP 5)

* NOTE : SNiP 5 does not apply to permafrost regions, but does apply to settling and heaving soils typical of regions immediately adjacent, for example much of the Komi Republic and Khanty-Mansiyskiy AO.

Table 3.2 **Other SNiPs, GOSTs, TUs and VSNs relevant to the planning and construction of trunk pipelines in northern conditions**

1. SNiPs

SNiP II-23-81 "Steel Structures"*

SNiP II-10-74

Used to determine distances between pipeline strings in technical corridors.

SNiP II-89-80 "Master Plans of Industrial Enterprises"*

Used to plan intersections between pipelines and other engineering structures, and minimum height (ground surface to pipe bottom) of above-ground pipelines.

SNiP II-8-78

Used to plan pipelines where mining operations are taking place.

SNiP II-6-74

Used to calculate loadings, influences upon pipelines and combinations thereof.

SNiP II-28-73

Used to determine requirements for the protection of concrete weights in aggressive environments (acidic soils, etc.)

SN 452-73 "Land Allocation for Trunk Pipelines"*

Used to determine minimum distances between underground pipeline strings.

* NOTE : These SNiPs are currently active. All other SNiPs listed here may have been replaced by updated versions.

2. GOSTs

GOST 2456-81 "Piles. Methods for Studies in Permanently-Frozen Soils".
GOST 1497-84 used for tension testing of pipe metal.
GOST 9454-78 used to determine impact strength of pipe metal.
GOST 9238-83 used for planning pipeline transits across railways.
GOST 25812-83 used with other documents in planning corrosion protection of pipelines.

(Point 13.42 of SNiP 2.05.06-85 lists five other GOSTs and fifteen TUs that specify which types of anti-corrosion coatings should be used on trunk pipelines).

3. TUs

TU 100-86 pipe specification.

4. VSNs

VSN 007-88 "Construction of Trunk and Field Pipelines. Structures and Ballasting".

This document was developed by *VNIIST* and approved by *Minneftegazstroy*. It is used as a guideline and its purpose should not be confused with that of the SNiP which is a state standard and must be used in planning and design (Aynbinder, 1997).

contributing to the deterioration of the condition of oil and gas pipelines in regions of permafrost. This examination will focus on the shortcomings of the SNiPs as pointed out by leading Russian authorities on the planning and design of pipelines for permafrost conditions.

Russia does not possess a SNiP dedicated to requirements for planning or constructing pipelines intended specifically for regions of permafrost. Instead, planners and constructors have to use several SNiPs which address various aspects of pipeline work in certain natural conditions. There are five SNiPs which apply most directly to trunk pipelines in the Russian North, while a number of other SNiPs contain small sections which are also relevant. The five important SNiPs are listed in Table 3.1. Yet more norms and regulations govern related activities, such as pipe welding and use of pipelaying machinery, with others, for example, for compressor station turbine blade quality and noise levels.

Other SNiPs and guidelines relevant to northern trunk pipeline planning and construction are listed in Table 3.2. These will not be discussed in this thesis.

The five important SNiPs listed in Table 3.1 are described and discussed below in subsection 3.2.3. But first, a brief history of the development of normative documentation in the northern context is provided.

3.2.2 Brief history of SNiPs for trunk pipeline planning and construction

The earliest normative documentation that the author found for pipeline planning in northern, i.e. permafrost conditions, is SN 353-66 "Instructions for the planning of population centres, enterprises, buildings and structures in the northern construction-climatic region", published in 1967 having been approved by *Gosstroy* (the USSR State Committee for Construction). A section on trunk pipelines was included in the document which had been based entirely upon research carried out for the planning of string 1 of the NAGSS (Zinevich *et al.*, 1985, p.14). Ironically this and other sections of SN 353-66 had been based upon research for various construction projects intended for regions of permafrost, not vice versa. Levin & Moryakov (1969, p.116) refer to an unspecified SNiP in respect of wall thickness calculation for the R.Yenisey crossing of NAGSS string 1. It is most likely that this SNiP is indeed SN 353-66.

Subsequently, say Zinevich *et al.* (1985, p.15), a set of normative documents which enveloped everything from the initial engineering surveys to the testing and operation of pipelines was developed, based upon NAGSS planning and early construction and operation experiences. Many scientific and technical solutions first put to use on the NAGSS were also implemented 15 years later during the construction of, for example, the Urengoy - Novopskov and Urengoy - Pomary - Uzhgorod trans-continental gas pipeline systems. It is important to note that the transfer of solutions from one pipeline project, namely the NAGSS, to others, such as lines from Urengoy, would be unacceptable today, particularly in this case since the NAGSS differs so much from the pipelines laid from Urengoy. This issue will be raised at various points in the current and subsequent chapters.

In 1976, SN 353-66's section on trunk pipeline planning was supplemented by *VNIIST's* "Provisional Instructions for the Planning, Construction & Operation of Oil & Gas Industry Installations in Permafrost Conditions". SNiP II-45-75 "Trunk Pipelines" then followed, making it the first SNiP for trunk pipeline planning exclusively, which in turn was replaced by SNiP 2.05.06-85, described below. SNiP III-D.10-72 was the first normative document exclusively for trunk pipeline construction and associated activities, succeeded later by SNiP III-42-80, described in subsection 3.2.4. This shows that even 30 years ago there were normative documents for construction in northern conditions. They would have been simple, but at least they existed. Nowadays however, such regulations for northern planning and construction, at least in respect of trunk pipelines, can only be found scattered throughout five principle SNiPs as well as parts of other less important SNiPs. While replacement SNiPs *are* actually being prepared, notably a successor to SNiP 2.05.06-85, surely both the planning and construction of northern pipelines require their own SNiPs or at the very least one SNiP covering both these activities?

3.2.3 SNiP 2.05.06-85 "Trunk Pipelines"

This is the principal SNiP to which all pipeline planners must refer during project development. SNiP 2.05.06-85 (hereafter referred to as SNiP 1) was elaborated by members of *VNIIST* (*Mintopenergo*'s pipeline construction research institute) with the participation of *YuzhNIIgiprogaz*, the State gas directorate, *VNIIgaz* (of *Mingazprom*), *Giprotruboprovod* (of *Minnefteprom*) and a scientific institute of *Minvuz*. SNiP 1 replaced its predecessor (SNiP II-45-75) on 1st January 1986 having been approved in Resolution No.30 of *Gosstroy* on 18th March 1985. SNiP 1 is based on officially approved technical specifications for steels (for example TU 100-86 for pipe specification) which are the starting point in the generation of standards and applies to :

> *"....the planning / design of new and rebuilt trunk pipelines and their spurs (built individually or in technical corridors) with a diameter of up to 1400 mm* [1] *and a working pressure of between 1.2 MPa and 10 MPa for the transmission of:*
>
> *a. oil, oil products (including stable condensate and benzine), natural, petroleum and artificial hydrocarbon gases from areas of production (fields) or storage to the location of the consumer;*
>
> *b. liquid petroleum gases of C_3 and C_4 fractions and their compounds, unstable benzine and condensate of petroleum gas and other liquid hydrocarbons with a saturated vapour pressure at a temperature of +40°C not higher than 1.6 MPa from areas of production (fields) or the initial pumping station to the location of the consumer;*

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[1] This is a rounded figure. Russia has no 1400-mm diameter pipelines and in fact 1420-mm is the largest diameter pipe used in Russia.

c. tank production at compressor or oil-pumping stations, underground storage facilities, booster compressor stations, gas distribution stations and gas discharge measurement units;

d. impulse fuel and start-up gas." (*Gosstroy*, 1985, p.1)

According to SNiP 1, the following pertain to the term "trunk pipeline" :

"a. A pipeline (from the point of departure from the field where the product was processed for onward transportation) with spurs and loops, valving, transits across natural and man-made obstacles, links to oil-pumping stations, compressor stations, gas discharge measurement units and gas reduction points, apparatus for the launch and receipt of cleaning devices, condensate gathering systems and methanol introduction devices.

b. Apparatus for electro-chemical protection of pipelines from corrosion, technical communications lines and structures, pipeline telemechanic facilities.

c. Electricity supply lines for pipeline maintenance and electricity supply devices and remote valving systems.

d. Fire-prevention facilities, pipelines anti-corrosion and protective structures.

e. Sites for storage and degassing of condensate, earth pits for accidental release of oil, oil products, condensate and liquid hydrocarbons.

f. Buildings and structures for the pipeline linear operation services.

g. Permanent roads and helicopter pads situated alongside the pipeline right-of-way and approaches to them and signalization of pipeline locations.

h. Initial and intermediate pumping stations, tank farms, compressor stations and gas distribution stations.

i. Underground gas storage facilities.

j. Oil and oil product heating points.

k. Markers and precautionary signs." (*Gosstroy*, 1985, p.1)

While SNiP 1 includes all trunk pipelines laid between the oil-gas-condensate fields and the points of consumption, it excludes those laid in towns and other population centres, offshore, within the fields and those pipelines due for refurbishment which show signs of corrosion and those cooled to temperatures below -40°C. Planners are told to refer to other SNiPs or normative documents in these cases.

There are two categories of trunk gas pipeline defined within SNiP 1 :

Class 1 : with an operational pressure above 2.5 MPa and up to 10.0 MPa inclusive.
Class 2 : with an operational pressure above 1.2 MPa and up to 2.5 MPa inclusive.

The structure of SNiP 1, laid out in Appendix 3, shows that there are only two small subsections (22 points) dedicated to planning pipelines in permafrost (this is only relevant to buried pipelines) and to electrochemical protection of pipelines in permafrost. However, there are other points throughout the SNiP which relate specifically to pipelines laid in permafrost, bogs and extremely low temperature conditions (24 points). That is still only 46 points out of the 362 total.

SNiP 1's comparable U.S. codes are ASME B31.4 "Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia and Alcohols" and ASME B31.8 "Gas Transmission and Distribution Piping Systems" (comparable German codes are DIN 2413 and DIN 2470). Also applicable is API Specification 5L-92 "Specification for Line Pipe", which is often referred to by ASME B31.4 and B31.8.

Recognizing the fundamental differences between Russian and U.S. pipeline engineering standards and the need for their harmonization with western standards, Gulf Interstate Engineering Co. (GIE), based in Houston, Texas, recently completed three man-years of work on a translation and interpretation of SNiP 1 and its comparison to the U.S. counterparts mentioned above (see for example, Aynbinder *et al.*, 1994, p.67-71 and Dalton *et al.*, 1994, p.52-58). Several members of the GIE team were Russian (some formerly members of *VNIIST* or *VNIIgaz*), including one former member (Alexander B.Aynbinder) of the Russian code committee which originally drew up SNiP 1. SNiP III-42-80 "Work Execution and Completion. Trunk Pipelines", described below, was also translated, interpreted and compared by GIE to equivalent U.S. codes.

The team paid particular attention to section 8 of SNiP 1 (Pipeline calculations for strength and stability). It is important to note that while the two standards are not entirely dissimilar, SNiPs use a design philosophy reflecting the USSR's legal and centralized economic system. The SNiPs are detailed, often dictating step-by-step instructions, whereas US codes are general in nature, written more as performance standards. In addition, whereas in the USA there are separate ASME codes for liquids and gas pipelines which outline the standards for design, installation, testing and operation, in Russia standards are comprised of one document for both oil *and* gas pipeline design (SNiP 1), then another for construction and pressure testing (SNiP III-42-80) and still others for operation.

The idea to translate these SNiPs began with a design and construction project for a 60 km oil pipeline in West Siberia which involved GIE and Benton Oil & Gas Co.[2] (*Pipeline & Gas Industry*, 1995b, p.51). The pipeline, laid from the North Gubkinskoye OGCF to the trunk oil pipeline system, is operated by the Geoilbent JV, hence the desire for its design to meet both CIS and US specifications. It has a capacity of 75,000 b/d (3,735,000 MT per annum) and was the first pipeline to be built to both CIS and western standards and specifications. The pipeline was completed in April 1993 (*Oil & Gas Journal*, 1993, Vol.91, No.15, p.1). GIE was also contracted by *Gazprom* to perform a feasibility study for the northern 492 km section of the first 1420 mm string of YEGTS (Bovanenkovskoye GCF to Vorkuta district, excluding the Baydaratskaya Bay crossing) in which their knowledge of Russia's normative documentation played a vital role. The

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[2] Benton Oil & Gas Co., based in California, holds a 34% stake in the Geoilbent JV which was set up in 1991 with *Purneftegaz* and *Purneftegazgeologiya* (both of which hold 33% stakes) to produce oil from two OGCFs (North Gubkinskoye and Prisklonovoye) in the Yamalo-Nenetskiy AO.

study was completed and submitted to *Gazprom* in 1994. Various elements of this feasibility study will be discussed in detail in chapter 5.

3.2.4 Other relevant SNiPs

3.2.4.1 SNiP III-42-80 "Work Execution and Completion. Trunk Pipelines"

SNiP III-42-80 (hereafter referred to as SNiP 2) replaced SNiP III-D.10-72 of the same name on 1st January 1981, having been approved in *Gosstroy* Resolution No.67 of 16th May 1980. The SNiP was developed by *VNIIST* with the assistance of the institutes *Giprotruboprovod* (of *Minnefteprom*) and *Giprospetsgaz* (of *Mingazprom*). It applies to the *construction* of new trunk pipelines and reconstruction of existing pipelines and their spurs, all of which have the same characteristics as those covered by SNiP 1.

Originally this SNiP *did not* apply to the construction of trunk pipelines in permafrost conditions, as stated in point 1.2. However, *Gosstroy* Resolution No.71 of 29th December 1986 approved a number of fundamental changes to SNiP 2 which came into force on 1st January 1987. These changes had been proposed by *Minneftegazstroy* who subsequently ordered *VNIIST* to prepare them. The following are the changes :

1. In point 1.2 after the words "*The regulations of this [SNiP] do not apply to the construction of feeder lines and also the construction of trunk pipelines in....*", exclude the words "*a zone of perennially-frozen soils,....*".

2. In point 4.28 after the sixth paragraph, add a seventh paragraph with the following content "*....of sections of pipelines described in points 6, 9, 10, 18, 20 and 23 of Table 3 of SNiP 2.05.06-85*".

3. In section 9 "Laying Pipelines in Special Natural Conditions" add the subsection "Laying pipelines in perennially-frozen soils". This new subsection contains four points (9.37 to 9.40).

Clearly, the first and third changes indicate that SNiP 2 actually became pertinent to pipelines constructed in perennially-frozen soils. But this begs the questions as to why pipelines in such conditions were omitted from the SNiP originally and why it took six years to make these changes? It would also appear that there is an error in the second change listed above since when one reads point 4.28 they will only find one paragraph, not six. The change must refer to another point and therefore one has to assume that 4.28 is actually a misprint.

SNiP 2 has 79 pages of instructions, but even when one takes these changes into account, there are only the four points mentioned above in the third change that relate specifically to the construction of pipelines in permafrost. There are also three points for pipelines laid in settling soils (points 9.29 to 9.31, p.53-54). One has to ask what did constructors for pipelines in permafrost use for guidelines prior to this change?

3.2.4.2 SNiP 2.02.04-88 "Bases and Foundations in Perennially-Frozen Soils"

SNiP 2.02.04-88 (hereafter referred to as SNiP 3) was developed by *NIIOSP* (of *Gosstroy*), *LenZNIIEP* (of *Goskomarkhitektura*), the institute *Fundamentproyekt* (of *Minmontazhspetsstroy*), *Krasnoyarskiy PromstroyNIIproyekt* (of *Minuralsibstroy*), the Yakut branch of *Zabaykalskiy PromstroyNIIproyekt* (of *Minvostokstroy*), *TsNIIS* (of *Mintransstroy*), *MISI* and Moscow State University. SNiP 3 replaced SNiP II-18-76 as of January 1st 1990, having been approved by *Gosstroy* Resolution No.252 of 21st December 1988. It applies to the planning of bases and foundations of buildings and structures built on permafrost. Beyond point 2.7, this SNiP does not apply to the bases of hydrotechnical structures, roads and railways built on earth, airport runways and associated surfaces, and the foundations of mechanisms with dynamic loadings.

3.2.4.3 SNiP 1.02.07-87 " Engineering Surveys for Construction"

SNiP 1.02.07-87 (hereafter referred to as SNiP 4) replaced SNiP II-9-78 and applies to the planning and implementation of survey work to be conducted prior to construction in order to select the optimal location or route of a particular structure, such as a pipeline. Such survey work would include, for example, the collection of detailed data on the physical-mechanical and thermophysical properties of permafrost in the region where the pipeline will be laid. It includes a sub-section within section 3 covering additional requirements for surveys in regions of perennially-frozen soil (points 3.95 to 3.116), as well as for surveys in regions of soils susceptible to subsidence (points 3.117 to 3.137), swelling (points 3.138 to 3.143), weak soils, such as peat (points 3.144 to 3.150), saline soils (points 3.151 to 3.159), eluvial soils (3.160 to 3.168) and artificial soils (3.169 to 3.177). Additional requirements are listed for surveys in regions of the following dangerous geological processes: karst (points 3.178 to 3.193), slope processes, such as landslides and solifluction (points 3.194 to 3.202), seasonal mountain torrents (points 3.203 to 3.210). The relevant sections mentioned above constitute 17 pages of SNiP 4.

3.2.4.4 SNiP 2.02.01-83 "Foundations of Buildings and Structures"

SNiP 2.02.01-83 (hereafter referred to as SNiP 5) replaced SNiP II-15-74 and SN 475-75 on 1st January 1985, after it was approved by a *Gosstroy* Resolution (No.211 or 311 [3]) of 9th December

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[3] The inside front cover of SNiP 5 quotes *Gosstroy* Resolution No.211 of 9th December 1985, whereas p.3 of the SNiP quotes Resolution No.311 of 9th December 1983.

1983. The norms presented in this SNiP must be observed in the planning of the foundations of buildings and structures. They do not extend to the planning of foundations of hydrotechnical structures, roads, aerodrome surfaces, structures laid in perennially-frozen soils, and also foundations of pile bases, deep supports and foundations under mechanisms with dynamic loadings. With relevance to this thesis, the norms do however cover the following aspects of planning foundations : peculiarities of planning foundations of structures laid in settling soils, saline soils and heaving soils.

SNiP 5 was prepared principally by *Gosstroy*'s *NIIOSP* institute (named after N.M.Gersevanov), together with the *Fundamentproyekt* institute (of *Minmontazhspetsstroy*), *Gosstroy*'s *PNIIIS* institute, the production enterprise *Stroyizyskaniya* (of *Gosstroy*), the *Energoset'proyekt* institute (of *Minenergo*) and *TsNIIS* (of *Mintransstroy*).

3.2.5 Criticisms of SNiPs

3.2.5.1 Introduction

The use of SNiPs represents the first stage in the development of any pipeline project. With a low quality project, in which calculations are flawed, it is impossible to produce a reliable installation, even if the subsequent construction stage maintains the highest possible standards. Likewise, poor quality construction can be the undoing of the most thoroughly prepared and accurately calculated project. Therefore, it can only be expected that SNiPs contain highly accurate information, free from errors, which is easily accessible. But there is much evidence to suggest that this is not always the case. Over the last five years in particular, a number of leading Russian authorities on northern pipeline planning and construction have pointed out where flaws lie in the relevant SNiPs. Their assessments have appeared in respected industry journals, such as *Gazovaya Promyshlennost'* and *Stroitel'stvo Truboprovodov* and can now be found in papers presented at international conferences worldwide. The flaws are not restricted to norms and regulations for northern pipelines. The diversity of these flaws lies in the fact that the SNiPs contain everything from insignificant misprints (for example, conflicting dates and *Gosstroy* resolution numbers, in the case of SNiP 5) to errors in equations (for example, in Appendix 5 of SNiP 3). The principle criticisms of SNiPs relate to four fundamental problems:

1. misleading information;
2. errors;
3. normative information is too widely dispersed (contained in too many documents);
4. lack of harmonization with western norms and regulations.

3.2.5.2 The criticisms of L.A.Dimov

One of the earliest and most revealing and critical assessments of the validity of these SNiPs was written by L.A.Dimov, director of the *KomiNIPIstroy* construction planning institute[4] (based in Ukhta, Komi Republic) and also director of Taleon, a private scientific-research firm for pipeline planning. It is fair to say that this marked the beginning of extensive and useful criticism of SNiPs. His assessment appeared in two parts in the leading Russian gas industry journal *Gazovaya Promyshlennost'* in 1993 (Dimov, 1993a, p.16-18; Dimov, 1993b, p.13-15). Dimov makes a number of criticisms of SNiPs 1, 3 and 4. The following is based upon the most important of these. In each case the relevant SNiP is given first, followed by the subject of the criticism.

SNiP 1

Stress-deformation condition (SDC) of pipelines

A number of significant problems related to pipeline operation in northern Russia can be attributed to weaknesses in the norms for pipeline planning and calculation of the so-called SDC of pipelines. Dimov considers that the calculation of the SDC is crucial to determine the reliability of a gas pipeline during operation and of its residual service-life. Unless the pipeline is tested for stresses, there are likely to be problems later on related to, for example, corrosion of the pipe wall. He focuses on the SDC issue in another article (Dimov, 1996a, p.67-70) in which he shows that insufficient attention has been paid to SDC calculation at the planning stage. A major reason for this, he says, is the inadequate coverage of this in SNiP 1. This problem clearly has far-reaching implications for pipelines laid in any conditions, permafrost or unfrozen ground. The only normative document which goes some way towards explaining the process of calculating the SDC of a gas pipeline is VSN 007-88 (full title given in Table 3.2) which, as pointed out earlier, is only a guideline.

SNiP 1

Laying pipelines in permafrost

In SNiP 1 the section on laying pipelines in permafrost (points 5.43 to 5.56) contains virtually no concrete information. In point 5.43, the introduction to this section, the reader is told:

> *"The planning of pipelines intended for regions of permafrost should be carried out in accordance with the requirements of SNiP* [3], *special departmental normative documents approved by Minneftegazstroy* [now AO Rosneftegazstroy], *Mingazprom* [now RAO Gazprom] *and Minnefteprom* [no longer exists] *in accordance with Gosstroy SSSR* [now *Gosstroy Rossii*] *and additional instructions of the norms presented here."*

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[4] *KomiNIPIstroy* was formerly the Ukhta branch of *VNIIST*.

Rather than providing specific information about laying pipelines in permafrost, the reader is told to refer to other sources. The bodies which have approved these normative documents no longer exist, as indicated in the square brackets. In particular, nothing now remains of *Minnefteprom*, it having amalgamated with *Mingazprom* in 1989 to form *Minneftegazprom*, and currently the Russian oil sector is dominated by a handful of huge vertically integrated companies (such as *Lukoil, Yukos* and *Surgutneftegaz)* which emerged in 1992 (Kryukov & Moe, 1996, p.19, 25). The most surprising additional source is SNiP 3 since pipelines, by the very nature of their interaction with the soils in or on which they are laid, differ markedly from the foundations of buildings.

Further, point 5.47 says that the principle of using permafrost as a base for a pipeline must be accepted in accordance with the requirements of SNiP 3 depending on the method of laying the pipeline, i.e. below-, on-, or above-ground, its operational regime, engineering-geocryological conditions and the possibility of alteration of the soil characteristics of the base. But if one takes, for example, the choice of the pipeline laying method, the reader is told in point 1.1 that trunk pipelines ought to be laid underground, with on-ground and above-ground methods dismissed except for cases cited in a later section (point 7.1) where the above-ground method is acceptable (SNiP 1 provides no reasoning for this, although it is true that most specialists think underground pipelines are safer from the point of view of the explosion risk, particularly the so-called "cascade" or "avalanche" rupture).

SNiP 1's recommendation that the principal of using the permafrost as a base for a pipeline depends on the choice of the pipeline-laying method is misleading. In fact it should be the other way round. As Dimov says (1993a, p.16), the method of pipeline laying should be determined by the principle of using the permafrost, its engineering-geocryological conditions and possible alterations to the soil base.

SNiP 1

Cryogenic processes

Cryogenic processes (such as frost heave and thermal-contraction cracking, which are examined in chapters 4 and 5) and flooding are not addressed in any detail in SNiP 1. In section 8 (Pipeline calculations for strength and stability) there is only one small reference to heaving (point 8.27). It points out that for linear and flexible-curving pipeline sections (buried or on-ground in a berm), in order to avoid longitudinal and transverse displacements, subsidence and heaving, the maximum total longitudinal stresses resulting from the influence of wind, product temperature and pressure variations and flexible curves in the pipeline must be taken into account.

There is no data at all in either SNiP 1 or 3 concerning thermal-contraction cracking of pipe walls. This process can involve the development of fissures in the pipe wall. These are widened as meltwater which has accumulated in them in summer freezes in winter and expands (Ivantsov, 1995).

SNiP 3

Planning of bases and foundations in permafrost

In SNiP 3 point 1.3 stresses that the planning of bases and foundations without sufficient engineering-geocryological studies is unacceptable. But the term "sufficient" is vague and the statement is not backed up by specific requirements or recommendations.

SNiP 4

Engineering survey work for pipeline construction

Dimov's major criticism of SNiP 4 concerns point 1.9 in which it is said that the composition and volume of survey work for pipeline construction planning must be determined in accordance with departmental construction norms. However, no such norms exist. Consequently, engineering surveys are being conducted on the basis of the planners' own decisions. Such decisions are made subjectively and are based upon their particular experience, qualifications and their level of preparedness.

Since the publication of this assessment in 1993, Dimov has written several more articles for *Gazovaya Promyshlennost'* in which he makes further criticisms of these and other SNiPs, for example SNiP 5. These are discussed below.

SNiP 1

Laying pipelines in bogs and boggy conditions of northern Russia

In 1993 and 1994 two more articles, written together with Ye.M.Bogushevskaya of *SeverNIPIgaz*, were published focusing on laying gas pipelines through bogs and boggy terrain typical for many areas of the Russian North[5]. The norms for the planning of pipelines laid through bogs are set out in ten points of SNiP 1, points 6.21 to 6.30. In the first of these articles (Dimov & Bogushevskaya, 1993, p.12-14) the authors attempt to show that it is more reliable to lay a gas pipeline through a bog *on the surface* in a berm. This proposal is a challenge to SNiP 1, point 6.21 which says that:

> *"The laying of pipelines underground must be envisaged in bogs and boggy areas. As an exception, with the appropriate basing, it is acceptable to lay pipelines along the surface of the bog in a berm (on-ground laying)....".*

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[5] Ten years ago the *SeverNIPIgaz* institute was a branch of *VNIIgaz*, then it became a subsidiary of *Severgazprom*. The journal "*Region*", published in Syktyvkar, Komi Republic, reported recently (*Region*, 1998, p.11) that the institute has been returned to *VNIIgaz*, although 90% of its work is for *Severgazprom*.

They substantiate their argument by describing problems associated with trench digging, stability of backfill, ballasting, and calculation of the SDC for buried pipelines in bogs. The material provided in their argument shows that on-ground laying of gas pipelines in bogs is more reliable and more economical than underground laying. The authors also provide an account of a large-scale experiment with an 820 mm diameter gas pipeline laid in a berm on the surface of a type II bog near Ukhta[6]. Over two and a half years of tests (1990 - 92), during which time the pipeline section was in operation, the berm did not undergo appreciable alterations caused by erosion (water or wind), although it did lose its original trapezoidal form and was consolidated above the top of the pipe by 8 - 13 cm. The results of tests reinforce their argument. Dimov and Bogushevskaya conclude by saying that the categorical approval of underground laying of gas pipelines in bogs in point 6.21 of SNiP 1 should be removed, permitting planners to select the method of laying based upon a full technical-economic analysis and the expediency and effectiveness of specific construction operations on the r-o-w.

The second article written by Dimov and Bogushevskaya (1994, p.27-28) disputes point 6.23 of SNiP 1 which states:

> *"The laying of pipelines in bogs should be envisaged, as a rule, rectilinearly with a minimal number of bends".*

However, the authors maintain that although it is not difficult to plan the laying of a pipeline through a bog, it is practically impossible to lay a pipeline strictly rectilinearly. This is crucial in the context of the SDC since even the slightest deviation of the longitudinal axis of the pipe from the straight line will lead to a SDC which is considerably different from that planned. Furthermore, point 6.23 of SNiP 1 makes no distinction between pipe bends in the horizontal and vertical planes. A bend in the horizontal plane can be used to alter the course of the r-o-w, whereas one in the vertical plane may take the pipeline over an obstacle, such as a river or lake. In conclusion, Dimov and Bogushevskaya stress that the status of pipeline bends in bogs should be defined more clearly in the wording of any replacement to SNiP 1, with account taken of analyses of the condition of gas pipelines buried in weak soils.

SNiP 1

Pipeline - soil interaction

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[6] According to SNiP 2 (point 9.1) a type II bog is one completely filled with peat, over which the movement and operation of construction machinery is permitted only along boards or roads which guarantee a reduction of the unit (area) pressure on the surface of the bed to 0.01 MPa (0.1 kg/cm²). There are three types of bog according to SNiP 2, the type relates to the degree of accessibility for machinery.

Dimov (1995, p.33) questions the trustworthiness of mathematical dependencies used by the authors of SNiP 1 for specifying interactions between pipes and soils. He also disputes their methodology for computerized calculations of buried pipelines. However, when he wrote the article there were no other methodologies available that could be used reliably and widely by oil and gas industry planning institutes. Dimov explains that other work in this field, developed by institutes other than *VNIIST*, does exist, but in terms of soil - pipe interactions and the reaction of soil to longitudinal and transverse displacements of a pipeline, it is inferior to that represented by SNiP 1 which had been prepared principally by *VNIIST*. Nevertheless, *VNIIST* as the principle contributor to the preparation of SNiP 1 must be criticized constructively, says Dimov, even though he is unable to suggest an alternative source of improved, more trustworthy methods for making calculations for the linear part of buried pipelines which are backed up by experimental data and field observations. Here, Dimov has addressed another pressing problem bound up within the design and planning stage of pipeline projects. This lies in the fact that *VNIIST* has little competition from other planning institutes which could have developed cutting-edge design methodologies for pipelines in any conditions, but especially those of the Russian North. This issue is addressed in more detail in section 3.3.

SNiP 1 and SNiP 5

Computerized calculation methodology for buried pipelines

Further on in this article (Dimov, 1995, p.33-34), Dimov describes two flaws within the computerized calculation methodology for buried pipelines, as laid out in the "Manual for Automated Calculation for the Strength of the Linear Part of Pipelines" (R 499-83 / *VNIIST*. 1984. Moscow. 205 p.). Planners are referred, indirectly, to this manual in point 8.1 of SNiP 1 [7]. The first flaw relates to the calculation of a pipeline "*with an arbitrary contour of the axis in the vertical plane*", i.e. bend in the vertical direction. The value R (the calculated resistance of the soil foundation to, for example, displacement of the pipe within it) used in the computerized calculation is taken as being equal to the value R_0 (the calculated resistance of the soil, for preliminary determination of the dimensions of the foundations) which is used according to tables 1 - 4 in Appendix 3 of SNiP 5. However, in point 2.42 of SNiP 5 it is written that R_0 should be used for class III structures only. Buried pipelines, in accordance with the regulations for designating the level of importance of buildings and structures during their planning, are class I structures. In order to circumvent this flaw, Dimov proposes that for such structures, value R must be determined

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[7] This and other handbooks are not approved by state authorities and are therefore not official. They are based on the state standards and may be used as guidelines (Aynbinder, 1997).

according to formula (7) of point 2.41 in SNiP 5. All the coefficients in this expression are easily determined, none the less it is not used in the above-mentioned manual.

The second flaw relates to calculations of a pipeline "*with an arbitrary contour of the axis in the horizontal plane*", i.e. bend in the horizontal direction. Dimov describes the situation in this case as being worse still. The aforementioned manual recommends that another value Pr^{r}_{np} also be taken as equal to R_0. But in SNiP 5 the values R_0 do not have relations for the horizontal direction at all. Thus, the formulae used in this manual to which planners are referred in point 8.1 of SNiP 1 are, in Dimov's words, "very poor" and do not conform to solutions for the bases of buried structures.

Dimov stresses that in the development of replacements for SNiP 1, accompanied by VSNs and automated programs for the calculation of the linear part of pipelines, all solutions in those norms which relate to soil - pipe interactions should be completely revised. There needs to be a significant increase in the accuracy of calculations of the SDC of buried pipelines.

SNiP 1 and SNiP 5

Pipeline - soil interaction for "pure" and "secured" buried gas pipelines

One of the most recent articles in which Dimov criticizes SNiP 1, and others, was published in 1996 (Dimov, 1996a, p.67-70). Here he examines some ways of improving the planning and calculation of buried gas pipelines. After pointing out that the calculation of the SDC is not covered sufficiently in SNiP 1 (as already stated at the beginning of this subsection), Dimov explains that soil - pipeline interaction models in the standard literature for conducting calculations for buried pipelines fall well short of the quality of analogous models for the interaction between soil and the foundations of buildings and similar structures. This is especially the case for the large variety of weak soils and pipelines fixed at planned levels by weighting materials, anchors or non-woven synthetic materials (NSM) together with soil. The interactions between the soil foundation and these "secured" buried pipelines (as opposed to the "pure" unsecured pipelines) have been studied to a very limited extent. The calculation of the SDC can be improved with the help of soil mechanics and a better understanding of soil - pipeline interactions. It is to the issue of soil - pipeline interaction that Dimov pays special attention throughout the rest of the article, as well as improvements in planning and making calculations for the two aforementioned types of buried gas pipelines: "pure" and "secured".

Dimov explains that current computerized calculations do not possess a single non-linear model recognizing the non-linear characteristics of the "pure" gas pipeline which if taken into account, he stresses, would lead not only to a quantitative but also a qualitative change in the calculated SDC of the pipeline. But even those linear models used are themselves insufficiently developed. With this in mind, he once again outlines the shortcomings (through using Appendix 3 in SNiP 5) of the prescribed manner in which planners calculate the resistance of or permissible pressure on the soil in respect of pipe displacements. He emphasizes that the calculations for resistance in SNiP 5 are intended only for the vertical plane, and not the horizontal, for which the calculations are also used. Calculations for the vertical plane must be improved, while new ones for the horizontal plane must be developed.

In the context of "secured" gas pipelines, Dimov focuses upon those fixed by anchoring mechanisms in perennially-frozen soils, recognizing the peculiarities inherent in planning structures for permafrost regions. After pointing out that it is practically impossible to fulfil all the requirements for the planning and construction of lengthy pipeline systems in permafrost conditions (one of the best examples being the detailed surveys of geocryological properties of soils which must be conducted in accordance with SNiP 4), he identifies yet another flaw within section 8 of SNiP 1. In this case it is point 8.5:

> *"The values of the characteristics of soils of foundations should be accepted according to the data of engineering surveys, with account taken of the forecast of soil properties during operation* [of the pipeline]*".*

Dimov points out that the disparity in soil property data and the stratification of soils up to and after construction can be such that the intitial determination of the data becomes all but useless. Also, any approximate determination which takes into account changes in soil properties during pipeline operation will lead to a sharp reduction in the reliability of anchor mechanisms. These approximations, Dimov says, can be blamed indirectly for the many "floating" sections of northern gas pipelines which were initially secured by anchors. In his opinion, anchor structures, the most economic securing mechanism in terms of cost and labour-effectiveness, are at the same time the most unreliable mechanism precisely on account of the insufficiencies in forecasting soil - pipeline interactions. The fact that the character and regimes for loadings of anchors on gas pipelines have not been studied extensively aggravates the situation further. It is suggested that it is safer to opt for the more expensive but more reliable securing structures: weighting materials or NSM with imported soil, the loading capacity of which depends much less (or not at all) upon the condition of the soil surrounding the pipeline. Anchor structures are discussed again in chapters 4 and 5.

Dimov concludes with a call for the production of a handbook to SNiP 1, in which everything that has been achieved in an attempt to improve and facilitate trunk pipeline planning should be detailed, together with a list of the most urgent tasks for research in this field. Such a handbook has already been published to accompany SNiP 5.

3.2.5.3 Further criticism from other authorities

Other authorities in Russia have in many cases presented a rather more simplistic view of the issue of SNiP inadequacies. Nevertheless, although they do not go into the intricacies of the problem, pointing out the diversity of flaws that Dimov has noted over the last five or so years, they do stress that SNiPs relevant to pipeline planning and construction (notably SNiP 1) must be replaced. Some experts *do* however focus on specific areas in which the SNiPs fall short of what is required to ensure reliable planning and construction. We shall look at their observations first.

i) Specific SNiP problems

The specific problems discussed here will be presented, as before, according to the relevant SNiP and issue.

SNiP 1

Environmental protection

In one of the earliest criticisms of SNiPs, Ivantsov (1988, p.29) addressed the section on environmental protection in SNiP 1 (section 9). It was stated earlier in subsection 3.2.3 that pipeline planning in permafrost regions has very limited coverage in this SNiP. The same can be said of environmental protection which received less than one page (13 points) of coverage in the final version of the SNiP. What are needed, he emphasizes, are a set of norms dedicated to the ecological aspects of planning pipelines in northern conditions (permafrost, seasonally freezing and thawing soils, areas where soil heaving occurs, etc.). These must be drawn up to reflect the considerable experience of man's activities in the Arctic and sub-Arctic, particularly construction of trunk pipelines in permafrost and boggy conditions.

SNiP 1

Underwater pipeline crossings

In a collection of articles published by *VNIIgaz* in 1993, Sonninskiy & Levin focused on the complex question of laying underwater pipeline crossings (Sonninskiy & Levin, 1993, p.35-40). They were especially critical of point 6.17 of SNiP 1:

> *"If the width of the body of water at the low water level is 75 m or more at the point where the pipeline crossing is located, the laying of a reserve string should be envisaged."*

In their opinion a reserve string is unnecessary and undesirable on account of the additional volumes of work required, extra expenses and further environmental disturbance in the crossing zone. What is necessary is to increase the reliability of the planned operational strings. This can be achieved by making use of electro-welded pipes made from X-60 steel (carbon steel with added niobium (Nb), vanadium (V) and silicon (Si)) which, they say, possesses the best combination of all the necessary properties (for example, strength, impact elasticity, ease of welding)[8]. The authors of this research say that the use of even stronger steels, X-70 and X-80, is unnecessary because X-60 steel contains properties sufficient for a reliable crossing section of pipeline. This view probably has to do with the fact that X-70 and X-80 steels are still relatively unknown in the CIS. For example, Russian pipe sections with a diameter of between 1020 mm and 1220 mm are manufactured typically using X-60 category steel (Dalton *et al.*, 1994, p.55). This is reflected in SNiP 1 which was drawn up at a time when X-80 steel for example was not used by the Soviet Union. Reliability can be increased further with greater pipe wall thicknesses for crossing sections.

Given the above, it is recommended that an amendment be issued which either excludes point 6.17, or changes it to say that in an exceptional case, after the thorough substantiation of such a decision in the pipeline crossing project, a reserve string or strings can be acceptable.

Continuing the theme of underwater pipeline crossings, another article in the *VNIIgaz* collection looks at other recommendations to improve underwater pipeline crossing reliability (Sonninskiy, Levin & Al'bov, 1993, p.52-54). While making the case once more for the use of X-60 steel, recommending this be reflected in section 13 of SNiP 1 (the chemical composition of pipe steel is not addressed in detail in section 13), the authors indicate that calculations for underwater pipelines should be based upon the yield strength (as is the case in the USA and Germany), or, even better, upon the durability of the material. Given that pipeline damage can occur in the presence of small stresses, the ultimate strength is not the most representative strength characteristic for potentially unsafe sections of underwater gas pipeline transits. They call for appropriate amendments to section 8 of SNiP 1. This conjecture is based upon their claim that analysis of normative and actual characteristics of pipe steel used in the construction of underwater transits over the last 20 years shows that the quality of imported western pipes is higher than that for Russian pipes. Imported pipe steel surpasses Russian counterparts in terms of its energetic characteristics (impact elasticity, fibrous structure), indicating a higher capacity to resist damage. The yield strength versus ultimate strength issue reappears below in ii).

SNiPs 1 and 2

Pipe metal fatigue

Metal fatigue is something that both SNiP 1 and SNiP 2 fail to take into account and, according to Dr.Vladimir Kharionovskiy and other specialists from *VNIIgaz*, this is one of the main reasons for a reduction in the service life of gas pipeline structures (Kharionovskiy, Botov & Kurganova, 1993, p.19-20). They note that, among other deficiencies, there is an absence in the norms of requirements

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[8] Niobium improves the metal structure, while the addition of silicon allows a reduction of the carbon content in the steel, thus making the pipe sections easier to weld together.

and criteria for estimating the efficiency of assembled joints based upon fatigue strength, and strength calculations do not take into account active additional and, moreover, dynamic loadings on a pipeline.

SNiP 2

Construction-assembly work

Bolonov *et al.* (1996, p.55), members of *Yakutgazprom*, have written that based on an analysis of accidents on the MYaB, current SNiPs for the planning and construction of gas pipelines require significant improvement in order to accommodate a more complete recognition of complex northern conditions (permafrost, seasonal freezing zones, etc.), particularly in the context of large-diameter trunk gas pipelines. Their concern lies mainly in the area of construction-assembly work in the winter, notably poor-quality manual welding. They say that more than 50% of the accidents on this pipeline occurred at the circular joints on linear pipe sections which had been welded at low temperatures.

Low quality construction work in Arctic conditions is also criticized by Ivantsov & Kharionovskiy (1993, p.100). There is an absence of strict requirements for instrumental quality control for individual construction operations in SNiPs. This, they say, explains the current status of quality control in construction work.

The issue of construction work quality will be addressed in considerable detail in subsection 3.4.3.

SNiP 2

Pipeline testing

Ivantsov and Kharionovskiy (1993, p.101) also denounce the requirements for trunk pipeline testing, as laid out in section 11 (Testing of Pipelines) of SNiP 2. Apparently, current testing methods do not guarantee failure-free, reliable pipeline operation, even for a short period of time. One way they feel that testing standards could be improved is by harmonizing them with western norms, in particular by implementing specific requirements where they demand higher standards than those of existing Russian ones, such as the level of loadings on a pipeline which are imitated during tests. Ivantsov and Kharionovskiy (1993, p.103) claim that SNiP 2 was amended in 1982 to raise testing standards, but the author found no evidence of this in an acquired copy of this SNiP.

SNiP 3

Strength characteristics of frozen saline soils

In 1993 two articles appeared in the Russian journal *Osnovaniya, Fundamenty i Mekhanika Gruntov* (Bases, Foundations and Soil Mechanics) which were highly critical of SNiP 3. The authors of one of these articles (Trusov & Gorodetskiy, 1993, p.27-29) focus on the design values recommended by SNiP 3 for the strength characteristics of frozen saline soils. Their comments are substantiated by investigations (1989 - 1991) conducted by their institute, *NIIOSP* (Scientific-Research Institute for Foundations and Underground Structures, sometimes known as *NIIOsnovaniy*), into soils from the Bovanenkovskoye GCF on Yamal. *NIIOSP* investigated the construction properties of eight different soil types (various *suglinoks*, *supeses* and clays). As part of this study, the authors found that their design pressure onto frozen soil values *R* (resistance of frozen soil to normal pressure) differed considerably from those recommended by SNiP 3 (section 6), examples of which are shown in Table 3.3. This is because the calculations made for the SNiP design pressure values are based upon soils from Amderma (far northeastern part of the Nenetskiy AO, Arkhangel'skaya Oblast'), which have a marine salinity that is different from that of the Yamal type of marine salinity. The SNiP values are even more distinct from soils with a continental salinity, such as those found in central Sakha-Yakutiya. This demonstrates that soils of marine and continental origin have substantially different design pressure values, and such values can vary between soil types of even a single salinity since they have their own properties and design pressures inherent in the given region. Therefore, it is completely inadequate to have universal design pressure values based upon a single type of saline soil. SNiP 3 should contain a table listing values for several types of marine saline and continental saline soils from a wide variety of coastal and in-land sites.

Table 3.3 **Discrepancies in design pressure *R* on soil, KPa, based on various data sources** (Adapted from : Trusov & Gorodetskiy, 1993, p.67, Table 2)

Soil Designation	**Salinity (D_{sal}, %*)**	**Soil Temp. (°C)**	**Design pressure *R* on soil, KPa, according to data from :**			
			NIIOSP tests on Yamal	Yamal (other source)	Central Sakha-Yakutiya	SNiP 3 (Amder-ma)
Silty sand	0.47	-3.0	137	120	560	175
Supes	0.82	-3.0	210	–	–	300
Suglinok	0.84	-3.0	115	160	640	330
Suglinok	0.50	-2.0	240	120	400	350

*NOTE : % = grams of salt per 100 grams of dry soil.

Such discrepancies were also found in the case of values R_{af} (design shear resistance along the surface of freezing with the foundation). For soils of continental salinity from Sakha-Yakutiya, R_{af} exceeded the SNiP 3 normative value by a factor of more than two for some *suglinoks*. But

NIIOSP and other Yamal data fell below the normative values by up to 30%. Trusev and Gorodetskiy conclude their article by urging the results of their tests and others to be recommended as an addition to SNiP 3. Soil salinity and cryopegs within soils will be examined further in chapter 5 (notably subsection 5.2.2.4).

The second article relates chiefly to the construction of buildings, rather than pipelines, on permafrost but it still serves to point out the wide variety of shortcomings within SNiP 3. The authors (Mirenburg & Yanchenko, 1993, p.30-32), from the *PechorNIIproyekt* institute (Vorkuta branch of *Komigrazhdanproyekt*), make a number of criticisms of SNiP 3. The following four are a sample. In point 4.11 of SNiP 3 it is stated:

> *"With appropriate substantiation....it is acceptable to load the foundations when the soil temperatures exceed the calculated ones, but not with values higher than:* $T = T_{bf} - 0.5°C$*, for sandy soils containing large lumps, and* $T = T_{bf} - 1°C$*, for silty-clayey soils, where* T_{bf} *is the temperature at which soil freezing starts".*

However, SNiP 3 does not indicate to what temperature the text refers. In Mirenburg and Yanchenko's opinion, since the temperature of the frozen soil of a base during the design period can vary from 0°C to the design mean-annual T_0 or T_0' (where T_0 is the design mean-annual temperature of the permafrost, and T_0' is the design mean-annual temperature of the permafrost at its upper surface), T_0 or T_0' can be adopted as specific values here.

Further, in SNiP 3 the value of settlement due to thawing of the foundation under natural pressure $S_{th} = 0.0268$ m, whereas in SNiP 3's predecessor (SNiP II-18-76) $S_{th} = 0.372$ m. Settlement due to the thawing of ice inclusions alone is 0.3 m. There has been an underestimation of real settlement and this indicates the need for urgent correction of SNiP 3.

The authors then criticize SNiP 3's delimitation of soil state. The temperature of the soil base varies significantly with time and depth, and thus its state also varies. Hence, in SNiP 3 it is essential to determine the position in space and time of the soil standard from which the soil state is established for the design of bases. A unified method for delimiting this state should be adopted, or such a delimitation should be abolished.

The fourth point they pick up on is an error in equation (2) in Appendix 5 of SNiP 3. The authors do not specify what this error is, however.

SNiP 3

Frozen-in anchoring devices in frozen saline soils

Also in 1993, several articles were published in *Stroitel'stvo Truboprovodov* which had significant implications for SNiP 3. These articles focused upon the results of tests on frozen-in anchors (examined in chapters 4 and 5) in perennially-frozen saline soils which were conducted by *VNIIST*, under the leadership of R.M.Khafizov (*Soyuzgaztekhnologiya* and *Arktikneftegazstroy* also took part). The tests were carried out in 1990 at experimental test-site No.1 at the Bovanenkovskoye GCF on the Yamal Peninsula, with a view to using the results in the planning of feeder and gathering lines and other pipelines at and between such GCFs as Bovanenkovskoye, from where the YEGTS will begin, and Kharasaveyskoye (Khafizov *et al.*, 1993a, p.13). Khafizov *et al.* (1993b, p.31) note that although significant experience of using anchoring apparatus in trunk gas pipeline laying had been accumulated at the Yamburg GCF, tests had to be conducted on Yamal in conditions most representative of those typical for the r-o-w of the YEGTS' northernmost section because of the difference in soil conditions between these two regions of the West Siberian North. Initially tests were conducted in the period March - May in the presence of minimum seasonal soil temperatures at

Table 3.4 **Comparison of frozen-in anchor supporting capacity values (*VNIIST* and according to SNiP 3)** (adapted from : Khafizov *et al.*, 1993a, p.14, table)

Type of anchor	Dimensions of anchoring element (cm)	Distance between discs (cm)	Supporting capacity F_u (kN)					
			Calculated according to SNiP 3			From *VNIIST* tests		
			Discs	Rod	Total	Discs	Rod	Total
Group 1								
Finned	14.5	–	–	28	178	–	–	196
Single-disc	12	–	23	33	56	33	53	86
Quadruple-disc	12	40	93	33	126	90	53	143
Six-disc	12	24	139	33	172	119	53	172
Eight-disc	12	17	187	33	202	119	53	172
Triple-disc	12	40	69	33	102	74	53	127
Bar	2.8	–	–	33	33	–	53	53
Group 2								
Triple-disc, with sand in-fill	12	40	30	32	62	–	–	138
Triple-disc	12	40	30	32	62	–	–	134
Quadruple-disc, with movable discs	12	40	38	32	70	–	–	126
Soft, with three extensions	20×20	50	110	–	110	–	–	119

NOTE : Group 1 anchors submerged by the "drill-drop" method with a non-saline sandy mortar; Group 2 anchors submerged using the "drop" method.

depths from 2.5 m to 5 m [9] (average soil temperature : -5.6°C) to determine the supporting capacity of the bases of a variety of frozen-in anchor structures. The anchor structures themselves penetrate up to 5 m into the soil. However, further tests were made later in November and December that year, with maximum seasonal soil temperatures, since experience has shown that winter is the time of year when perennially-frozen soils have minimum values of resistance and cohesion.

The supporting capacity F_u of the anchor structures tested by Khafizov's team from *VNIIST* proved generally to be 10 - 20% higher than those calculated according to SNiP 3, as shown in Table 3.4, with the exception of eight-disc anchor structures which turned out to be lower.

The fact that the supporting capacity of the bases of the submerged anchors is considerably greater than that calculated according to SNiP 3 can be attributed to an under-estimation in this SNiP of the values of the calculated resistances of saline clayey soils and also to the imperfection of the methodology for the calculation of anchors sunk into permafrost (Khafizov *et al.*, 1993a, p.15).

Further tests were carried out at the Bovanenkovskoye test site during spring (March - April) of the following year (Khafizov *et al.*, 1993b, p.31-34). The resulting supporting capacity values achieved in these experiments were compared to those calculated according to VSN 007-88. For three of the five types of anchoring structures, the supporting capacity values F_u exceeded those of the values calculated according to the VSN. The authors of this article hasten to point out that the calculated resistances of saline frozen soils at temperatures below -4°C are absent from SNiP 3. The values of calculated resistances R_{af} shown in the SNiP are used only for a preliminary determination of the calculated supporting capacity of the base of frozen-in anchors. For this reason, these values require corrections and the results of the comparison should be seen as preliminary.

The fact that the actual supporting capacity of a single-disc revolving anchor exceeded by 1.6 times the calculated value (analogous results were observed on anchors at a test site at the Yamburg GCF) can initially be explained by the process of soil consolidation in front of the displaced anchor blade with the formation of soil cores which increase resistance to the displacement of the anchor. This phenomenon, which is not taken into account in the current normative documents, requires additional analytical study[10].

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[9] Cold winter temperatures take a number of months to penetrate the earth and will have reached depths of several metres by early summer. Likewise, warmth from the short summer will have reached several metres down by late autumn and early winter.

[10] A summary of the results from the studies on frozen-in anchors in saline permafrost (1990-1992) can be found in : Khafizov *et al.* 1993. *Izmeneniye nesushchey sposobnosti vmorazhivayemykh ankerov v zasolennom grunte pri povtornykh ispytaniyakh* [The change of the supporting capacity of frozen-in anchors in saline soil during repeated tests]. *Stroitel'stvo Truboprovodov*, No.5, p.32-35 (notably its table on p.33).

It should be further noted that due to the absence of normative documents to regulate studies of frozen-in anchors in permafrost conditions, these tests were conducted in accordance with GOST 2456-81 "Piles. Methods of Studies in Perennially-Frozen Soils" (Khafizov *et al.*, 1993b, p.31).

SNiP 4

Engineering-geocryological surveys

Kharionovskiy (1994, p.505) criticizes an unnamed SNiP (in fact he is referring to SNiP 4) which stipulates that two to three test holes per kilometre should be drilled as part of the engineering-geocryological survey of a pipeline route. It is well known that a change in soil composition may occur much more often and so initial planning data is often inaccurate. Test holes should be drilled as often as practically possible. In fact, apparently unknown to Kharionovskiy, SNiP 4 paragraph 3.108 says that along the routes of linear structures geophysical and other observations should be carried out at intervals of not more than 250 m., in certain cases at 50 m intervals.

Once more, SNiP 4 comes under fire from Loskutov (1996, p.33-34) of RNGS. He says that the normative documents, such as SNiP 4, which govern the execution of engineering surveys for trunk pipeline planning and construction are inadequate. The experience of constructing installations at Urengoy, Yamburg and other GCFs has highlighted the inadequacies of the surveys for examining engineering-ecological problems in permafrost conditions which are regulated by SNiP 4. The norms do not regulate the physical-mechanical influences upon the earth's surface or thermal influences on perennially-frozen soils which are so often associated with the passage of machinery and equipment during survey work. Yet it is these very influences which can alter the atmosphere-soil-permafrost thermal balance, leading to the initiation of serious industrial technogenesis, i.e. cryogenic processes such as thermokarst, thermal erosion, thermal abrasion and frost heave, and this disturbance is subsequently exacerbated during construction of installations such as pipelines. Landscapes in permafrost regions are the least stable under technogenic influence. As his response, Loskutov calls for the development of a system for the normalization of nature-protection planning for oil and gas industry installations in permafrost regions. Importantly, he notes that regional aspects, i.e. variations (macro-, meso- and micro-scale) in natural conditions between regions, must be taken into account when creating the regulatory documents.

ii) General views on SNiPs : replacements and harmonization

Secondly, there are those who have written simply that the SNiPs, particularly SNiP 1, must be replaced. For some time now several of Russia's most respected experts in the field of trunk pipeline planning, construction and operation in northern conditions have been saying that these SNiPs must be replaced by more thorough normative documents, reflecting the free-market system now emerging in the CIS, and each of them stresses that the replacements must be harmonized with those standards in force in the USA, Canada and Europe. This is the logical progression from the translation and interpretation of SNiPs by companies such as GIE. Harmonization is essential now that foreign investors and contractors are operating in the Russian pipeline market, and Russian organizations are involved overseas.

Over the last few years, two distinguished experts have presented papers at high-level international conferences, with parts of these papers being devoted to the necessity for replacement SNiPs. They have not published any papers addressing the SNiP issue specifically, the reason being that they are not planners *per se* but authorities on the whole range of relevant issues. Both of them now occupy some of the most senior posts in the field of pipeline development in Russia. This reflects their many years of involvement in the Soviet and now Russian pipeline industry. The two experts are:

1. Gennadiy Yusifovich Shmal' - General Director of *Rosneftegazstroy* (RNGS), formerly the Ministry of Construction of Enterprises of the Oil and Gas Industry (*Minneftegazstroy*).
2. Professor Oleg Maksimovich Ivantsov - Head of the Scientific-Technical Council, RNGS.

Shmal' and Ivantsov have presented papers each year at the annual international conference on oil and gas pipelines in the former Soviet Union, organized by the Adam Smith Institute, and in 1997 at the conference on oil and gas pipeline projects in Russia and the CIS, organized by IBC UK Conferences. But certainly by 1994 both of them had written that SNiP 1 and SNiP 2 were obsolete (Shmal' & Ivantsov, 1994, p.10). They emphasized that the SNiPs had to be replaced and required harmonization with Western standards and norms. In Dimov's earlier articles (1993a; 1993b) he reported that the experimental and theoretical research necessary for improvement and replacement of SNiPs had practically ceased. Perhaps this might be viewed by some as an overstatement, particularly in the context of the last four years, for as we shall see below there has of late been considerable effort made to improve and replace outdated SNiPs, codes and regulations. But in the pre-1993 context there is some degree of truth in Dimov's claim. As one example of the problem, Dimov (1993, p.14) reported that essential work needed to improve the soil models and methods for calculating weak, unstable soil - pipeline interactions was being conducted by his institute alone (*KomiNIPIstroy*, Ukhta). In the same article he even mentions a group of traditionalist planners who greet all new SNiP proposals with suspicion since they have grown accustomed to old normative documents and working within their framework of calculations and methodologies.

Returning to Shmal' and Ivantsov, we shall focus on the comments made in some of their most recent papers. Most importantly, it is revealed that an unspecified number of new SNiPs have already been drawn up, covering the design and construction of pipelines and these have been harmonized with foreign standards. They do not specify to which precise processes or types of pipelines these SNiPs apply, but Shmal' (1997a and 1997b) says that construction quality requirements have been tightened up and thresholds for reliability and safety, including ecological safety, have been raised. Shmal' (1998) states that RNGS and other organizations were finalizing the contents of a new SNiP for construction. During the development of these new SNiPs, new regulatory codes were produced to deal with the construction of a range of structures and facilities. For example, in 1997 *Gazprom* published its "Methodological Recommendations for Calculating the Structural Reliability of Trunk Gas Pipelines" (Kharionovskiy *et al.*, 1997). In an attempt to fill the gap in SNiP 1, the recommendations include several sections devoted to buried and above-ground pipelines laid in permafrost, including interactions between buried pipelines and frost mounds. As early as 1995, *Gazprom* also introduced new "Regulations for Fulfilment of Ecological Requirements in the Siting, Planning, Construction and Operation of Trunk Gas Pipeline Underwater Crossings" (Konvissar, Zuyev & Antipov, 1995). Shmal' (1997a) mentions that special regulations have been developed for the YEGTS, for which new technologies are suggested and organizational solutions are tailored to work on this new generation of pipelines. In 1997 *Gazprom* published its "Temporary Instructions for Technology and Organization of Loading and Unloading Operations, Storage and Transportation of Insulated 1420 mm Diameter, 18.3 m Long Pipes" (Potemkin *et al.*, 1997). These were drawn up specifically for pipe sections imported from Germany's Mannesmann to be used on the Torzhok - Belostok section of the YEGTS. Other new codes also make the use of horizontal-directional drilling mandatory in the construction of underwater pipeline crossings. Ivantsov (1997a and 1997b) adds that harmonization of these SNiPs with western standards has proved difficult due to differing conceptions lying at the base of analyses of pipeline strength and linear stability. This is where he breaks away from the norm of generalization and addresses a specific problem. The reasons for the difficulties are numerous, he explains, but the following example will serve to highlight the difficulties involved in harmonization. Strength analysis recognizes a structure, such as a pipeline, as being acceptable (reliable and safe) on the condition that the equivalent maximum stresses in the pipeline do not exceed the ultimate strength (according to Russian standards) or the yield strength (according to western standards) of the material, allowing for appropriate reserve coefficients[11]. Different methodological concepts produce markedly different results. But finding out which concept is closer to a more correct understanding of the nature of pipeline operations is complex and is something the Russian and western experts have not yet discussed together.

The new SNiPs, regulations and codes have been drawn up within the framework of the CIS inter-governmental scientific-technical programme "Highly Reliable Pipeline Transport", headed by

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[11] The reserve coefficient represents a form of safety factor. The safety factor is the ratio of yield strength over design strength. Thus, the design strength multiplied by the reserve coefficient gives the yield strength of the pipe metal.

Ivantsov, B.Ye.Paton and V.A.Dinkov. The programme was ratified by the governments of Russia and the Ukraine in November 1993, with the aim of increasing the reliability and safety of gas, oil and product pipeline systems in various regions of Russia, the Ukraine and other CIS states[12]. For this reason the programme must be seen as a turning-point in the history of Russian and post-Soviet era trunk pipeline development. It is the first such programme to be developed with the sole objective of improving pipeline reliability in the CIS. The harmonization of SNiPs with western standards is one of the principal objectives of the programme, which has not only seen the development of new regulatory codes, as stated above, but also the composition of a new GOST "Steel Pipelines. General Requirements for Protection from Corrosion" (*Stroitel'stvo Truboprovodov*, 1995, No.4, p.11). More should follow. In May 1995, at the working meeting of the CIS Inter-Governmental Oil and Gas Council (held in Minsk, Belarus), Azerbaijan, Armenia, Belarus, Georgia, Moldova, Kazakhstan, Uzbekistan and Turkmenistan took the decision to join the programme's accompanying association (which bears the same name) and to take part in financing of its work. Shmal' (1996) reports that at the same meeting it was decided to set up a unified system of standards covering the design and construction of pipelines and their repair, maintenance and reconstruction. This would take into account existing joint ventures in various projects in CIS states. Thus it would seem that Dimov's earlier fears have been to a considerable extent allayed.

Ivantsov (1996), who wrote an unpublished critique of SNiPs related to pipeline design and construction in the North, indicated that some new SNiPs might be introduced either in 1997 or 1998, although he added that judging from the past this was highly unlikely. His view is shared by Dr. Karl F. Ott (1997), Head of the Technical Department of TTG. Ott says that currently the new SNiPs are undergoing a lengthy review and editing, and it could be some time before they are enforced. No one, it seems, can be sure of when the new generation of SNiPs will come into effect. Unfortunately, this is not the only cause for concern regarding the new SNiPs. Ivantsov & Kharionovskiy (1993, p.94) reported that in the draft of a replacement for SNiP 2, the requirements for welding quality are not differentiated in terms of static and dynamic loadings. Such a differentiation would help to determine the requirements for external weld reinforcement.

One should also criticize the way in which all SNiPs too often tell the reader to refer to the requirements of other SNiPs. It is something Dimov (1993a) has pointed out. The authors of the SNiPs dispatch the readers elsewhere, indicating that they have failed to compile the necessary data themselves.

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[12] Founder members of the programme are : *Gazprom, Transneft', Rosneft', Rosneftegazstroy* (RNGS), *Ukrgazprom* and *Ukrneft'*.

3.2.6 Conclusion

By no means all the shortcomings of relevant SNiPs have been identified here, but clearly, with such fundamental weaknesses, immediate improvement and reworking of these and many other SNiPs must be carried out. As Dimov puts it, "Now we are living with 'old baggage' based on work carried out in the 1980s" (Dimov, 1993b, p.14). It is also important to bear in mind that many of the aforementioned criticisms apply not only to the planning of pipelines in permafrost, but to the planning of pipelines in general, for example calculating the SDC for any pipeline.

The SNiPs, particularly SNiP 1, do not appear to have taken into account the diversity of natural conditions within the vast expanse of the Russian North. Even the most basic of delineations, such as the continental and maritime distinction, have not received consideration. Such distinctions are crucial, as has been demonstrated through the example of the calculation of design pressure values R in different parts of northern Russia where saline soils of either the continental or maritime type are found. While it is essential that all the criticisms outlined in subsection 3.2.5 are considered while drawing up the replacements, it is also crucial that the whole range of issues, environmental to engineering, concerning pipeline design and planning for northern (permafrost and boggy) conditions be included within one document. The norms necessary for northern pipeline project work must be consolidated and not spread out in several separate SNiPs as is the case today. Consolidation can only improve and expedite the whole design and planning process. It would also reduce the likelihood of unnecessary duplication of normative material. *Stroitel'stvo Truboprovodov* (1989, p.23) reported that in 1989 47 VSN documents were replaced by just nine in an effort to reduce duplications and inconsistencies. The same line should be taken for SNiPs, particularly since they are official, unlike the VSNs which are guidelines only.

Not all the recommendations for changes to SNiPs are ideal. For example, the reasoning behind suggestions made by Sonninskiy & Levin (1993, p.35-40) in the context of reserve strings, requires a more "market economics" approach. They fail to recognize that in market economies the economics for a pipeline could not work without guarantee that the pipeline would be in full use at a later stage. One could argue that reserve strings are a legitimate issue for unique projects such as the Baydaratskaya Bay crossing for the YEGTS. Reserves have been incorporated in accordance with SNiP 1 (*Pipeline & Gas Industry*, 1995a, p.57). In the future, projects for similar crossings could acknowledge the successes and, in the event of them, failures associated with this project and this might allow planners to safely omit reserve strings from their designs. Reserve strings on subsea systems are not so unusual in the West. A good example is the dual string (812 mm diameter) gas pipeline system from the Frigg gas field in the North Sea (on the UK sector and Norwegian sector boundary) to St.Fergus, just north of Aberdeen. However, the second string was laid partly for security of supply but chiefly to be able to increase capacity (Palmer, 1997). The two Black Sea strings of the Blue Stream project will be laid sequentially, not simultaneously, for similar reasons.

From an economic point of view, additional strings can only be installed if it is absolutely certain that this extra capacity will be utilized at a later stage. Clearly, reserve strings are an important consideration for the planning of lengthy subsea pipeline crossings in the Arctic, but on non-Arctic subsea crossings and river crossings of several hundred metres in length money would be better spent on ensuring the safety and reliability of fully operational strings. The amendment to SNiP 1 should reflect this as being an issue of reserve capacity rather than reserve string in the event of pipeline failure.

However, the creation and development of the "Highly Reliable Pipeline Transport" programme, the chief objectives of which are to increase the reliability of pipeline transport and to develop a new generation of SNiPs, is a very encouraging step forward, giving reason for optimism. But, there are signs that some of these new SNiPs are inadequate (as noted above). Such inadequacies must be avoided and perhaps this is indicative of the influence that the old guard still maintains; some of them wish to continue living with the "old baggage", working within a familiar but unfortunately wholly inadequate framework. The same can be said of the fact that it is taking so long for the ratification and enforcement of new SNiPs. The traditionalists may be holding up their passage towards enforcement. The whole SNiP system, from generation to enforcement to amendment, needs to be governed by a new regulatory body which brings the system more in line with the western approach and enforces improvement when needed. Inspectors from this body could also inspect sites of failures to determine the culpability of various parties, in particular to monitor adherence to SNiPs. The body would be a department of *Gosstroy*, the government construction committee, whose current job it is only to enforce SNiPs. Nonetheless, *Gazprom* is gradually introducing its own new codes for pipeline design calculations which do take into consideration the complexities of planning pipelines in permafrost conditions. New codes have also been drawn up with the YEGTS project in mind. *Gazprom* has compiled these new codes in cooperation with other organizations, such as RNGS. Thus it would appear that the gas giant is taking matters into its own hands, recognizing that without some form of alternative regulations, the absence of replacement SNiPs could jeopardize the reliability and safety of the latest pipeline design and planning efforts.

3.3 Planning and research institutes

3.3.1 Introduction

In this section a number of more general problems affecting the planning of trunk gas pipelines for northern conditions are considered. These problems relate to the way in which planning and research was organized during the Soviet era and to how this planning structure has been affected by the break-up of the Soviet Union.

3.3.2 The location of leading planning institutes : yesterday at home, today abroad

3.3.2.1 The problem

One of the most serious problems facing pipeline planning today stems from the location of the main planning centre for all of the largest trunk gas pipelines from the Russian North : *YuzhNIIgiprogaz*. The *YuzhNIIgiprogaz* institute, together with subcontractors, is responsible for having designed installations for the Medvezh'ye and Yamburg GCFs and the major trunk gas pipeline systems from the Yamalo-Nenetskiy AO, including the Yamburg - Western USSR border or "Progress" gas pipeline system. *YuzhNIIgiprogaz* (together with *Giprospetsgaz*) also compiled the feasibility study for the construction of the YEGTS, completed in 1993. Generally speaking, *YuzhNIIgiprogaz* has been the leading planner of gas pipelines originating east of the Ural Mountains, i.e. in West Siberia, while *Giprospetsgaz* has traditionally been more closely associated with the gas pipeline systems of European Russia (Griva, 1997b), including today's Shtokmanovskoye project, although it too designed a number of trunk gas pipelines from Urengoy and Yamburg GCFs and of course the original West Siberian line, Igrim - Serov.

YuzhNIIgiprogaz is located in the industrial city of Donetsk in the heart of the Donbass coal basin of the eastern Ukraine. Its origins go right back to the birth of the Soviet gas industry and since then its members have helped to shape Soviet and Russian trunk gas pipeline development. It was in the Donetsk mining institute in the early 1930s that a group of students, including a founding father of the Soviet gas industry, Yuliy Il'ich Bokserman, prepared the gasification project for Donetsk, based on coal gas (*Petroleum Economist*, 1996b, p.32). Gasification of the first town in the Donbass took place in 1934. Bokserman graduated from the mining institute in the same year with a degree in gas engineering, and soon afterwards became head of a gas research team. This team formed the basis of what soon became *YuzhNIIgiprogaz* and it planned the first pipelines, no more than 20 km in length, for delivery of coal gas to towns and plants in the Donbass. Evidently, the location of *YuzhNIIgiprogaz* is the result of the birth of the Soviet gas industry which emerged from the coal industry of the eastern Ukraine.

Roughly 70% of all of the former *Mingazprom* trunk pipeline planning work was carried out by *YuzhNIIgiprogaz*, with *VNIPItransgaz* and *Ukrgazproyekt* (formerly *Soyuzgazproyekt*) (Kovalenko, 1992, p.2), the latter two smaller institutes being based in Kiev, capital of the Ukraine, while institutes based in Russia were mainly subcontractors. Dimov (1993b, p.13) describes the Russian institutes as being given certain sections of the major trunk pipelines to design, mainly those in the central or southern regions, whereas *YuzhNIIgiprogaz* determined the overall line of planning, principle technical solutions and scientific innovations. There was a continuous flow of planning documentation and leading specialists between Donetsk and remote parts of West Siberia, where the constructors were laying 1420 mm pipe sections from Medvezh'ye, Urengoy and Yamburg. The geographical paradox is obvious. Donetsk lies more than 3000 km from these GCFs. The institute's closest links have been with *VNIIST* (Moscow), which is where policy (i.e. normative documentation) for pipeline planning and construction has been developed[13], and *VNIIST*'s former northern branch in Ukhta, now *KomiNIPIstroy*. Between the two of them, the newest solutions for gas pipeline calculation, ballasting, laying in permafrost, etc. were devised, or *VNIIST* would do the research, while *YuzhNIIgiprogaz* would implement the results of this research in its various planning projects. So an exchange of scientific data took place continuously between Moscow and Donetsk. Thus, over three decades, a highly-qualified group of planners emerged in Donetsk who played the leading roles in northern gas pipeline planning. Yet, as Dimov adds, many of them had never actually encountered permafrost, let alone seen the consequences of cryogenic processes such as frost heave.

Therein lies one of the problems - vast distances between the gas source and the planners who were based thousands of kilometres away from the nearest permafrost. But a serious blow to the gas pipeline planning fraternity came in 1991 with the breakup of the Soviet Union. Russia and the Ukraine now had separate governments as well as different aspirations and interests. The unusual situation arose whereby the major gas fields lay in northern Russia, while the leading planning institute was now located abroad in the Ukraine. This posed a complex question: should the previous relationship between Donetsk and Moscow be maintained or should priority be given to Russia's own leading planning institutes, for instance *Giprospetsgaz* (St.Petersburg), *VNIPIgazdobycha* (Saratov), *Giprogaztsentr* (Nizhnyy Novgorod) and *TyumenNIIgiprogaz* (Tyumen')? It would seem that the relationship between the planning institutes, notably *YuzhNIIgiprogaz* and the Russian institutes, remained virtually unchanged. This is certainly the opinion of *YuzhNIIgiprogaz*'s deputy general director, Anatoliy V.Miroshnichenko (1998). The activities and division of labour of the main institutes remain the same, even though while *Giprospetsgaz* is a subsidiary company of *Gazprom*, *YuzhNIIgiprogaz* is now a fully independent joint-stock company, depending only on shareholder decisions[14]. Both have played leading roles in planning and design of the YEGTS (for example, its feasibility study) as well as the new SRTO - Torzhok trunk gas pipeline system which will be linked into the YEGTS before the Yamal GCFs themselves. Nonetheless, relations between the leading institutes are competitive, though business-like.

3.3.2.2 A solution to the distance problem

Dimov (1993b, p.13-14) suggested that one solution to the distance problem could be the founding of a large scientific-technical and planning-research centre for pipeline construction in the Russian

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[13] *VNIIST*'s role should not be confused with that of a planning institute. It is the leading pipeline construction research institute where policy is developed and research into all aspects of pipeline construction is conducted.

[14] *Gazprom* owns more than 50% of *Giprospetsgaz*.

North, the basis of which would be two or three of the existing leading institutes. He presents the following justification for such a centre:

1. the need for an intellectually robust planning centre which could evolve on the basis of close links with Russian science and be geared towards the priority interests of Russia. The centre would be occupied with the enormous tasks of Russia's northern gas industry;
2. the lack of such a centre in the North itself. Such a centre would have to be located as near to the North as reasonably possible, to reduce transport costs and to save time;
3. the main enterprises of *Gazprom* have their own scientific-planning institutes or departments within their structure which tackle solutions to their own "local" problems. For example, *Severgazprom* relies on *SeverNIPIgaz*, while *Nadymgazprom* has its Scientific-Technical Centre and *Yamburggazdobycha* has its Centre for Scientific-Research Production Work. But as has been indicated in chapter 2, not all *Gazprom*'s enterprises are occupied with trunk gas transmission. Thus, the *Nadymgazprom* and *Yamburggazdobycha* centres are only occupied with questions concerning commissioning of new fields, particular problems at producing fields and on their feeder and gathering lines. Research concerning gas transmission through existing trunk gas pipelines in Tyumenskaya Oblast' would be the task of *Tyumentransgaz*'s Technical Department and also *TyumenNIIgiprogaz*. While research and planning carried out by these organizations at the local scale is important for a better understanding of particular problems (e.g. laying pipelines in the weak boggy soils of Komi), the pooling of all such information within one main centre would be invaluable for the planning of future trans-continental pipeline systems.

As Dimov puts it, this centre would address tasks of a more "global" or large-scale nature in the interests of Russia. The issues it would study, such as improving calculations for pipelines in northern conditions, corrosion and stress, are beyond the scope of the smaller regional institutes. Dimov (1993b, p.14) goes on to say that this centre would set the standard for normative documentation and, consequently, the quality of planning in all institutes of the gas industry. In essence, the centre would become the so-called "general" planner of Russia's northern gas pipelines and be responsible for the technical quality and reliability of all planning solutions. A suitable name for this new centre might be the Scientific-Research and Planning Centre for the Construction of Northern Gas Pipelines.

In terms of its location, St.Petersburg would have been first choice if it had been in the European northeast, rather than northwest, since that is where *Giprospetsgaz* is based. Dimov also mentions that the transfer of *Giprospetsgaz* to Moscow, where *VNIIST* and *VNIIgaz* are based, would be another option, but less attractive. The displacement of *Giprospetsgaz* to Ukhta or Nadym, two ideal locations, is certainly unrealistic. Nonetheless, Dimov says that if the centre was eventually

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The centre's membership would initially and ideally come from *Giprospetsgaz*, *VNIIST* and *VNIIgaz* (the best sources of planners and scientists in Russia). But scientific-technical links with the three Ukrainian institutes, especially *YuzhNIIgiprogaz*, must be maintained, irrespective of the membership and location of the centre. Relationships with other specialized institutes involved in oil and gas industry design and planning, such as the Ye.O.Paton Electric Welding Institute of the Ukrainian Academy of Sciences, must also be preserved. A reasonable way of harnessing the strongest planning potential of such institutes would be the distribution of certain planning work between Russian and Ukrainian, as well as foreign institutes and organizations on a competitive basis.

3.3.2.3 Sources of new talent in the field of pipeline planning and research

Another potential problem facing the future of pipeline planning and research in Russia and the development of a new planning centre concerns the declining sources of talented young scientists who could become involved in this field. As Dimov explains (1993b, p.14), many university graduates are seeking higher salaries and living standards than are possible in the field of pipeline planning, while some are going a step further and leaving Russia for brighter opportunities overseas. Established experts in the field also moved overseas during the last 20 or so years, many, for example, going to the USA to find jobs with multinational oil companies based in Texas. Of course, emigration from the CIS is a generic problem, not something peculiar to the oil and gas industry. Those experts who have been left behind in Russia are nearing retirement, and with the absence of an influx of large numbers of young scientists there is the risk of a breach in the succession of generations, the so-called "scholar-pupil" link could be severed. Dimov also observed a lack of conferences organized with younger scientists and specialists in mind. However, as in the case cited earlier in which *Gazprom* has tackled the SNiP problem by introducing its own codes, the company is also attempting to muster new talent amongst Russia's youth. For example, October 1997 saw the

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[15] *Komineft'* is expected to transfer its headquarters from Ukhta to Usinsk, the latter being located much nearer to Komi's producing oil fields.

second All-Russian Conference for Young Academics, Specialists and Students on the Problems of the Russian Gas Industry, the first having been held in September 1995. Both were organized by *Gazprom*, the Gubkin State Oil & Gas Academy and the Ministry of General & Professional Education. The second conference, which saw 255 oral presentations and 298 posters, included a section entitled "Planning, construction and operation of gas transportation and storage systems" (Amiyan, 1997). The conferences brought together young members of 42 *Gazprom* enterprises and students from 15 higher education institutions, while at both conferences a number of prizes were conferred upon the authors of the best papers by the organizing committee. *Gazprom* has also recently concluded an agreement with the Gubkin State Oil & Gas Academy for the training of young specialists (*RAO Gazprom*, 1997, p.16). While *Gazprom* may succeed in recruiting all the young people it needs, other oil and gas industry organizations, such as RNGS and *VNIIST*, may not find it so easy.

3.3.3 Lack of competition in pipeline science

While Dimov's concerns about a lack of research and graduate recruitment have been somewhat quelled through the efforts of the "Highly Reliable Pipeline Transport" programme and *Gazprom*, he is fully justified in expressing anxiety about the lack of competition between scientific institutes in the development of new ideas, trends and schools of thought (Dimov, 1993b, p.15). As indicated above, there are two outstanding scientific institutes in the field of pipeline engineering : *VNIIST* and *VNIIgaz*. *VNIIST* in particular does not receive serious competition from any other organization and consequently it remained, certainly in 1993, the only centre for the study of SDC calculation for pipelines. The absence of competitors to *VNIIST* and *VNIIgaz* can be explained by a shortage of financing for research work. Smaller institutes cannot realize their research potential without financing. *VNIIST* itself is short of funds, so perhaps *VNIIgaz* (under the *Gazprom* umbrella) is fairing best nowadays. What is worrying is that this monopolization of research, for whatever reason, leads to stagnation and decreasing standards in the work conducted. With this in mind, questions arise concerning the quality of the work being conducted within the "Highly Reliable Pipeline Transport" programme. It is all very well to have the research necessary for SNiP replacements taking place, but what about its quality? Ivantsov & Kharionovskiy (1994, p.94) have already expressed concerns about this, as indicated earlier in subsection 3.2.5.3 ii). Another problem here is that although *VNIIgaz* research remains relatively well funded by *Gazprom*, its research covers a wide variety of gas-related issues (as suggested by its full name), not just pipeline construction and operation, whereas *VNIIST* is occupied solely with pipeline issues, yet is suffering financially[16]. *VNIIST*'s shortage of finances has much to do with it now being a component of *Mintopenergo*. *VNIIST* also lost some of its most outstanding "pipeline in permafrost" specialists to other organizations owing to certain policy changes made with the arrival of a new director. It is also overrun by bureaucrats in administrative positions, rather than research posts. The institute now has nine deputy directors (Khrenov, 1998).

3.4 Construction practice

3.4.1 Introduction

During the late 1970s and 1980s, the rates of pipeline (oil, gas and product of all diameters) construction in the USSR reached unprecedented levels, unheard of in world practice. These rates of construction, reaching 22,000 km to 25,000 km per annum at their peak, were achieved in response to central directives from *Gosplan* which in turn stemmed from the desire and need to swiftly increase gas supplies to domestic heavy industry and exports to the West. However, the high rates were not supported by the necessary scientific and technical capabilities or the social and economic conditions needed for construction on such a scale. As a result, say Ivan Mazur (1996, p.102), now Chairman of RNGS, and Borodavkin (*Petroleum Economist*, 1990, p.76), of *GANG*, the majority of pipeline construction projects did not comply with world standards. Other authorities, for example Dinkov & Ivantsov (1997a, p.20) make the point that one cannot always link high construction rates with low quality assembly work. Of course this is true, but they do later acknowledge that, in general, opinions such as Mazur's are valid.

It was not the first time that politics had taken precedence over science, society and economics. The situation described by Mazur is somewhat reminiscent of Stalin's ill-fated attempt in the early 1950s to lay a 4500 km railway across northern Russia from the Urals to Chukotka. Although the reasons for his desire to lay the railway were very different and the labourforce consisted of tens of thousands of prisoners based in the infamous *GULAG* labour camps, the final decisions about rates of construction and where to construct came not from the engineers familiar with the natural conditions of the North, but from Stalin himself. Needless to say, of the 500 km of track that was actually laid, much became deformed and displaced by a variety of cryogenic processes initiated by the activities of the labourers. Some have even suggested a further similarity between Stalin's infamous railway project and the largest pipeline construction projects of the 1980s. Two articles published by western journals in 1982 alleged that forced labour had been used on a massive scale during the construction of the Urengoy - Pomary - Uzhgorod gas pipeline (*The Oil Daily*, 1982, p.8; *Petroleum Economist*, 1982, p.431). Neither article provided any evidence for

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[16] *VNIIgaz*'s financial position is epitomized by the multi-storey research building with new laboratories under construction next to the original building in Razvilka village (on the outskirts of Moscow).

their claims and it seems highly unlikely that the Soviets would have used forced labour on projects of such national importance. History has shown that projects using forced labour almost always fail. These claims were likely to have been part of US propaganda at the time of the Reagan sanctions mentioned in chapter 2.

This section explains why such rapid rates of pipeline construction were needed and shows how the Soviets were able to lay trunk pipelines faster than anyone else.

3.4.2 Central Planning : rapid construction required by production-driven policies

In chapter 2 it was shown that the largest trunk gas pipeline projects (Urengoy - Pomary - Uzhgorod and the "Progress" line from Yamburg) were realised with a view to exporting tens of billions of cubic metres of gas per annum to countries of western, central and eastern Europe. For example, according to the contracts signed in the early 1980s some 40 BCM would be supplied annually by the USSR to those western European countries that had agreed to deliver pipe and equipment for the pipeline system from Urengoy (Gurkov & Yevseyev, 1984, p.10). This included 10.5 BCM to the FRG (West Germany), where the gas would be used in every sector, household to industry. Italy would receive 8.5 BCM per annum and France 8 BCM per annum. Gurkov & Yevseyev examine some of the major reasons why western European countries chose Soviet gas to meet their energy requirements (1984, p.79-92). But suffice it to say that in spite of US calls for a veto on industrial cooperation with the USSR, western Europe could not realistically afford to ignore Soviet gas. Projections of the falling share of oil in the western European primary energy market, the long lead times involved with developing new coal mines and building new nuclear power stations, the expected production decline of the Dutch Groningen field, hold ups in development of North Sea gas, and job creation related to East-West trade all meant that western European countries had strong incentives to look towards such giant sources of gas as Urengoy.

The need for the rapid development of huge trunk pipeline systems was clear. But the gas would not just benefit foreigners. Boris Shcherbina, Minister for Construction for the Oil and Gas Industry (i.e. *Minneftegazstroy*) in the early 1980s, pointed out that West Siberia had come to play such an important role in the country's economy that not one large-scale national economic objective could be attained without its active involvement[17] (Gurkov & Yevseyev, 1984, p.94).

With the need to provide the national economy and foreign markets with a reliable supply of natural gas, a number of vast gas pipeline construction projects were needed. Not only were tens of thousands of kilometres of pipe necessary to transport huge volumes of gas, but the pipe had to be

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[17] At the time of Gurkov and Yevseyev's interview with Shcherbina 93% of Soviet iron and steel was being manufactured using gas.

laid as rapidly as possible. The rates of construction of individual pipeline systems from the NPT (including Urengoy and Yamburg) are indicated in chapter 2, but perhaps these words of Shcherbina best express the scale of the task that faced *Minneftegazstroy* and its subdivisions:

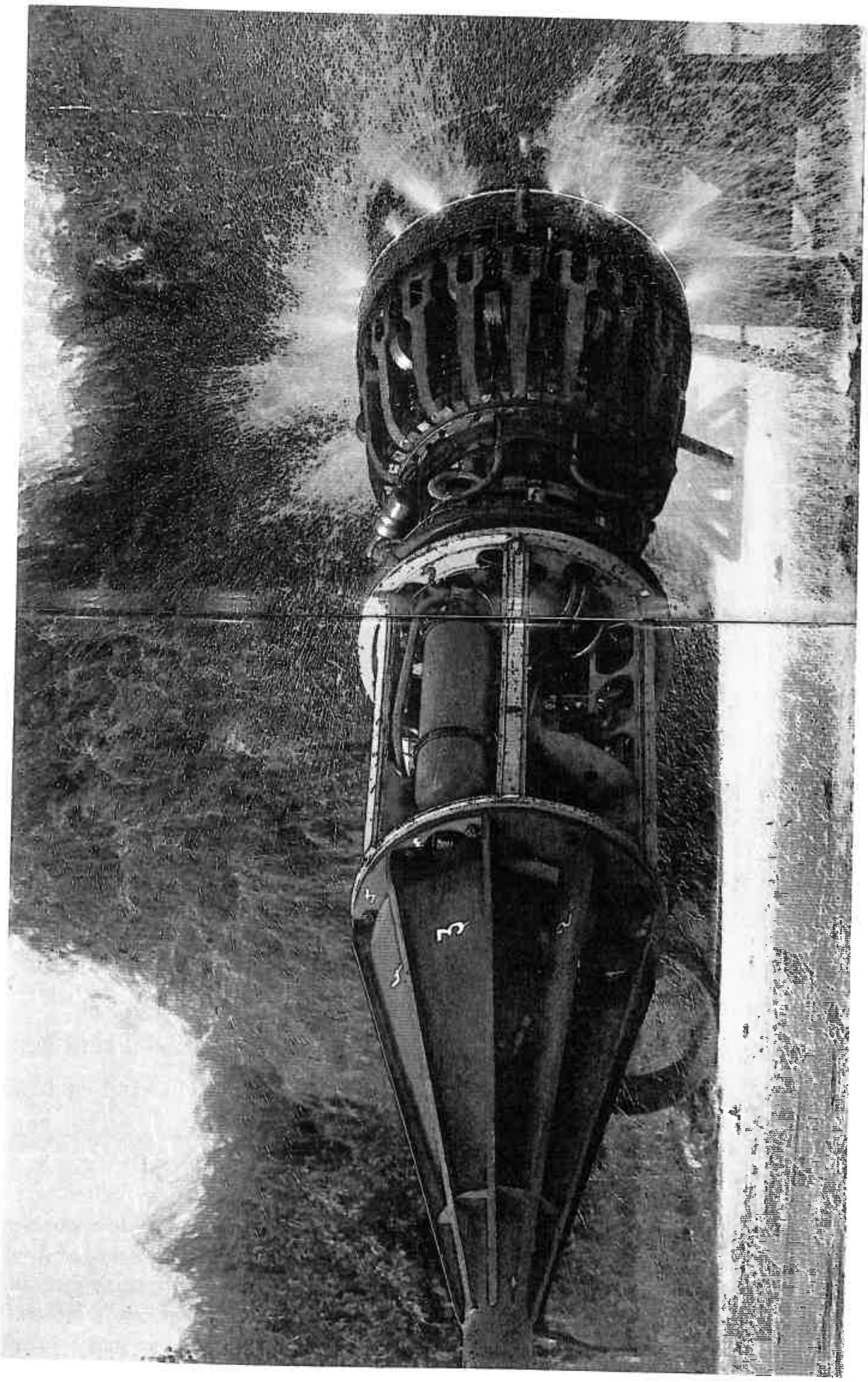
> *"The 1970s saw high, unprecedented rates of pipeline construction.... The length of pipelines has doubled while their capacity has grown fourfold. Underground piping now transports more than two-thirds of the total fuel. Soviet pipelines could circle the earth at the equator more than three times. Like blood arteries in a living body, the pipelines branch out into all the union republics forming the most ramified gas supply system in the world. The scope and rates of pipeline construction for the 11th Five-Year Plan (1981-1985) are such that the equator could be circled twice in a short period of time. As to the Urengoy - Uzhgorod pipeline along which West Siberian gas will flow to Europe, we intend to complete it and put it into operation before the deadline laid down in the contracts."* (Gurkov & Yevseyev, 1984, p.95).

Indeed, in 1983 the pipeline was commissioned six months ahead of schedule, having taken 14 months to construct. All the other pipeline systems from Urengoy, such as Urengoy - Gryazovets - Moscow Circle, completed in 1981, boast similar statistics.

As to the length of the rapidly expanding UGSS, the USSR could have ended up with much greater distances of trunk pipelines. The Soviets avoided more construction by increasing the diameter of the lines. Diameters of 1220 mm and 1420 mm became necessary for the new pipeline systems of the 1980s which needed greater transmission capacities. Nevertheless, the length of trunk gas, oil and product pipelines in the USSR increased annually by 12 - 15,000 km during the early to mid 1980s (L'vov, 1986, p.26). The peak trunk gas pipeline construction year in Russia was 1987 when 10,400 km of line were laid (Wilson, 1995, p.4), but for the USSR as a whole it was 1985 with 12,500 km laid. In addition the average distance over which gas was transported increased four times between 1960 and 1985 (Remizov *et al.*, 1996, p.117), reflecting the opening up of new GCFs in more remote regions such as West Siberia.

In order to maintain these unprecedented rates of construction a whole range of new construction machinery was developed in the early 1980s, for example the *Sever*-1 resistance welding apparatus, shown in Fig.3.1, developed jointly by *Minneftegazstroy* and the Ye.O.Paton Electric Welding Institute of the Ukrainian Academy of Sciences (Kiev). New excavating machinery capable of removing perennially-frozen soil at accelerated rates appeared. Also, new means of securing pipelines in boggy conditions were introduced, notably anchoring devices to replace inefficient reinforced-concrete weights. Just as important as the machinery that took part in the construction process were the new forms of work organization that had been developed with these trunk gas pipeline projects in mind. The most significant of these systems of construction work organization was the Integrated Production Line (IPL), already mentioned in chapter 2. The IPL,

Fig.3.1 ***Sever*-1 resistance welding apparatus for 1420 mm diameter pipe**
(Source : Ivanov & L'vov, 1983, p.46-47)



which relied heavily upon the manpower of the *Komsomol* (Young Communist League)[18], will be examined in more detail in the following subsection.

3.4.3 Integrated Production Line (IPL) construction

The scale of the pipeline construction projects which began in the 1970s and the rate at which they had to be completed were such that a large workforce and a highly organized system of construction and assembly operations had to be put into effect. *Minneftegazstroy* and its various subdivisions devised a system whose workforce was capable of easily meeting, if not undercutting deadlines. But questions remain about the quality of work that was fulfilled in such volumes and in such short periods of time. Some might wonder how thousands of young volunteers from the *Komsomol* could possibly perform such demanding tasks at the highest standards, even though they had received vocational training before departure to the construction sites in West Siberia. The efficiency of the new system and the quality of work conducted within it will be discussed below.

The IPL (known in Russian as *Kompleksniy Tekhnologicheskiy Potok* or *KTP*) is a construction unit which uses highly integrated and efficient forms of organization and mechanization to carry out pipeline assembly work and related activities such as pipe welding, insulating and laying. The IPL was preceeded by the so-called Production Line-High Speed construction method. This had been devised in the early 1970s by *Glavsibtruboprovodstroy* (GSTS), a West Siberian division of *Minneftegazstroy* based in Tyumen', as an alternative to the forms of labour organization which were the norm for the central part of the USSR, the Urals and Central Asia, but which were unsuitable for the natural-climatic conditions of West Siberia and for accelerated construction rates. The production line-high speed method was first used during the construction of the gas pipeline from the Nizhnevartovsk gas processing plant to the Surgut electric power station in the winter of 1973/74 (Shabanov, 1985, p.14). A double-shift operation was organized for the fulfilment of such tasks as supply of pipe sections to the r-o-w, welding, pipe insulating and trench digging. By the following winter season there were two high speed construction units at work, each containing some 300 workers. Welding operations, involving the use of electrodes with cellulose coating, were accelerated significantly but the success of these units lay in the fact that they were formed on the basis of the welding-assembly divisions to which insulating-pipe laying subdivisions were transferred

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[18] The *Komsomol* was a mass organization of Soviet youth founded in October 1918 which had a membership of more than 42 million by 1988 (Yegorov, 1988, p.5). It played a very significant role in large construction projects within Siberia and the Soviet Far East. The Far Eastern city of Komsomol'sk-na-Amure, built by *Komsomol* members in the early 1930s, was named after the organization. It made great contributions to priority construction projects in West Siberia in the 1970s and 1980s such as the Tobol'sk Petrochemical complex, the city of Nizhnevartovsk, the Tyumen' - Nizhnevartovsk and Surgut - Urengoy railways and the development of the Medvezh'ye GCF. (See : Yegorov, V.Ye. 1988. *70 Years of the Soviet Komsomol*. Moscow, Novosti, and, Il'inskiy, I.M. 1978. *What is the Komsomol?* Moscow, Novosti, for more on this organization).

and during the construction period special operations (trench digging, pipe and ballast deliveries) were also attached. With such a management structure the average seasonal productivity of such a unit rose from 47 km to 115 km. The enlargement of welding-assembly brigades enabled a reduction in their overall numbers. In 1974 there were 80 welding-assembly brigades in GSTS containing 465 welders but by 1984 there were 960 welders working in just 31 brigades. The development of brigades for all types of operations allowed a shift towards introducing low levels of self-financing, but this payment method was complicated by the fact that some specialized brigades fell within other administrative structures and received their pay there. This problem led to the creation of the IPL which was capable of conducting independently all the main activities. Shcherbina described the IPL, each of which contained more than 300 workers, as "a factory moving on wheels and tracks with a single production goal leaving welded, insulated piping, laid in the trench and ready for operation behind it" (Gurkov & Yevseyev, 1984, p.101). These IPLs were administered by new specialized pipeline construction trusts[19] (other trusts were created for compressor station construction). The creation of these trusts, which are subdivisions of GSTS, allowed a reduction in the number of organizations occupied with construction, increased efficiency and moved the administrative organs nearer to the installations under construction. Being to a great extent self-contained, the trusts did not have to be supplied regularly from afar. 1982 saw the beginning of construction of multi-string gas pipeline systems within a single corridor in West Siberia and this meant that the boundaries between different trusts and their respective IPLs and brigades could be easily delineated. In addition, dormitory settlements, welding bases and ballast-manufacturing teams for each trust could be located at optimal sites arranged linearly along the corridor. Since the construction teams had to work on several parallel pipeline strings within the corridor over many months, they would lead a much more settled life, remaining in one climatic zone, favourably influencing their work, rather than being displaced after the completion of one string. With the ability to conduct construction operations on several pipelines simultaneously rates of assembly were accelerated notably. Rates were further increased when construction work began to take place in the short summers, for which the trusts had to build year-round roads using NSM, thermosyphons and wood chippings. It must be remembered that construction during summer months should generally be avoided since, for example, this can initiate melting of bodies of buried ice exposed during the digging of trenches or the like. This has implications not just for the natural state of the geocryological environment but also for the stability of structures laid within it. Thus one could say that acceleration by means of introducing summer construction would probably have had the additional effect of disturbing permafrost conditions and threatening the stability of engineering structures.

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[19] This is the Soviet usage of the term "trust" (*trest* in Russian). Soviet trusts comprised a group of industrial or commercial enterprises with centralized direction.

Another means of accelerating construction rates and reducing commissioning periods, in a manner that was peculiar to the Soviet Union, was known as the Socialist Emulation or Competition (*Sotsialisticheskoye Sorevnovaniye*, in Russian)[20]. All trusts, IPLs and brigades took part in what amounted to a competition encouraging workers to perform as quickly and effectively as possible within their brigades. The brigades competed against each other to lay as much pipeline as possible in one season. This would boost construction statistics for their particular trust, which was in turn competing with other trusts within GSTS. The competition at various levels within GSTS would, it was hoped, place the company high up in the rankings of Soviet oil and gas industry construction enterprises. The results of the competition, such as lengths of pipeline laid in a season by individual brigades and IPLs, were published regularly in GSTS's newspaper devoted to the emulation, "*Za Tempy i Kachestvo*" ("For Speed and Quality"), on posters, news flashes (known as "*Molnii*") and other easily accessible sources of information. It was intended that these results would inspire the workers, instilling within them a competitive spirit. In fact, it was impossible to avoid the emulation in all its guises. But this blanket-coverage of results served its purpose most effectively. GSTS repeatedly occupied the highest places in the "class lists" for commissioning pipeline installations ahead of schedule in the 11th Five Year Plan (1981-85). According to P.P.Shabanov of GSTS, its trusts were classed 31 times and 43 workers were awarded government prizes in the 1984-85 construction season alone (Shabanov, 1985, p.15). In that season the trusts *Severtruboprovodstroy*, *Komsomol'sktruboprovodstroy* and *Kazymtruboprovodstroy* performed best. Two IPLs of *Severtruboprovodstroy*, the outstanding performers, laid 123 km and 150 km. Shabanov also notes that of the 16 IPLs operating within GSTS at that time, nine crossed the 100-km mark.

One must also bear in mind the conditions in which the workers lived, conditions which would have to have been made as comfortable as possible in order to maintain worker productivity in such a harsh climate. There are several accounts of life in the r-o-w construction site dormitory settlements, one of which (L'vov, 1986) is described below, and they all paint a very rosy picture of conditions, such that morale amongst workers was always high. In these descriptions propaganda should not be ignored and one should question the descriptions of conditions in worker settlements provided by authors such as L'vov. However, the settlements did indeed possess a reasonable array of amenities. GSTS had 32 dormitory settlements within its trusts during the mid 1980s, equipped

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[20] The Socialist Emulation was initiated in 1929 and based upon the ideas of Lenin. Initially it took the form of a competition between factory brigades to produce as much of a particular product as possible. The competition was quickly introduced into the coal industry in 1932 in the form of the Stakhanov Movement (*Stakhanovskoye Dvizheniye*, in Russian) and then into other industrial sectors, such as vehicle and rolling stock-manufacture, textiles, forestry, and agriculture. Taking part in the competition often involved overfulfilment of the targets set within the Five Year Plan. The intention of the competition was simple - to fulfil or overfulfil production targets and to guarantee the continuous growth in labour productivity, but by instilling such a competitive spirit within the workers that the quality of the product often suffered.

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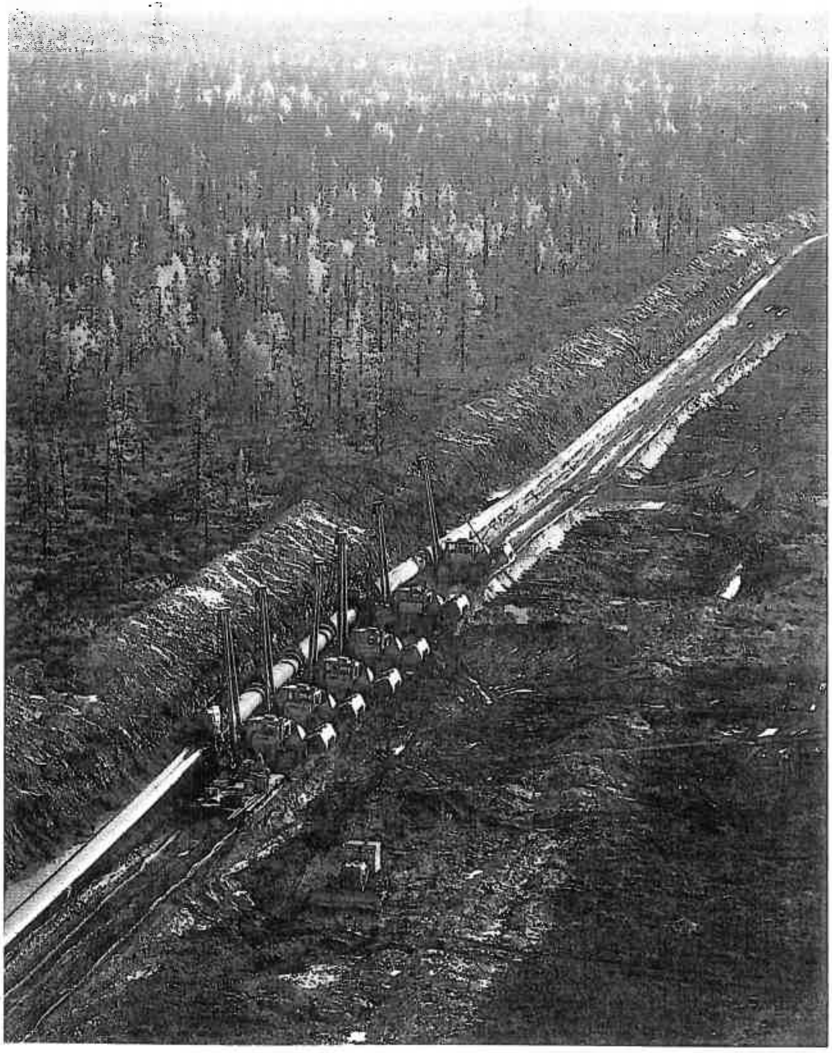
with everything from medical centres to theatres, and several of them (Molodezhniy, Priozerniy and Khetta of *Severtruboprovodstroy*; Yubileyniy of *Priob'truboprovodstroy*; Oktyabr'skiy and Verkhne-Kazymskiy of *Kazymgazpromstroy*) were frequently voted the most comfortable and best in the oil and gas industry. Workers' children were also sent away during the summer months on trips to pioneer camps on the Black Sea coastline.

Fig.3.2 Pipe insulating operations on the r-o-w of the Urengoy - Pomary - Uzhgorod trunk gas pipeline

(Source : Ivanov & L'vov, 1983, p.53)



The involvement of the IPL method was crucial in order to maintain the very rapid rates of construction on such projects as Urengoy - Pomary - Uzhgorod. Batalin (1983, p.3-5), Kryukova (1983, p.9) and Sudobin *et al.* (1985, p.12-13) describe the IPL construction method used so effectively on this vast project. In all 49 IPLs from the three main pipeline construction contractors of *Minneftegazstroy* (GSTS, *Glavvostoktruboprovodstroy* and *Glavtruboprovodstroy*) were used during the construction of this pipeline (Shmal', 1996b). Sudobin *et al.* describe a number of progressive forms of IPLs used for a variety of operations such as welding, earth-removal, insulating-laying, ballasting and delivery of equipment to the r-o-w (see Fig.3.2). The construction schedules for the IPLs were governed by daily and weekly tasks for fulfilment, covering all operations from the beginning of construction right through to completion. Among other things the schedules enabled the synchronization of the activities of all the numerous participants in the construction project. The improvements to the organization of construction allowed an increase of the average-daily use of machinery to 12 hours, 20% higher than for previous projects (Sudobin *et al.*, 1985, p.13). The level of automation of operations in the Urengoy - Pomary - Uzhgorod construction project was unprecedented, helping to increase the level of quality and rates of work. The power of the machinery for a single IPL was to reach on average 13,700 Kw. The energy output of a single worker on the project reached 67 - 69 Kw (*Stroitel'stvo Truboprovodov*, 1996, No.4-5, p.2; Shmal', 1997b), but more often amounted to 54 Kw which was still 8% higher than for previous projects (Sudobin *et al.*, 1985, p.13). According to Shmal' (1997b), the average monthly rate of gas pipeline construction by IPLs on this project amounted to 11.8 km but in some months they delivered 20 - 25 km of ready pipeline. Batalin (1983, p.4) says that GSTS's 12 IPLs averaged 26 km of construction during March 1983. The average length of pipe completed in a 12-month period was 90 km, though some achieved considerably more than this.

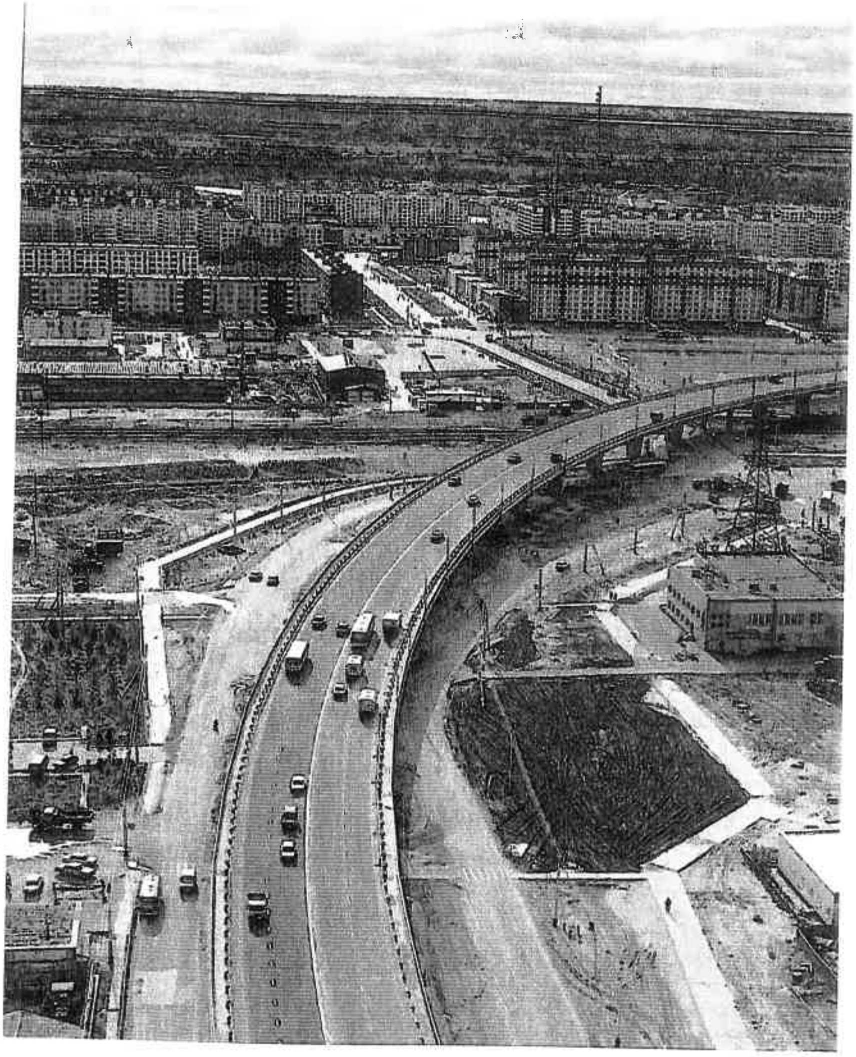
The Socialist Emulation also played a significant role in motivating workers involved in the Urengoy - Pomary - Uzhgorod project. Batalin (1983, p.3) and Sudobin *et al.* (1985, p.13) confirm this in stating that the emulation had a great influence by way of accelerating construction of the pipeline. The competition appears to be what most encouraged workers to meet the daily and weekly schedules of tasks laid down. Nonetheless, even with the most attractive of incentives, living conditions still had to be conducive to hard work. As mentioned above, the conditions in which the workers lived had to be made as comfortable as possible to maintain high levels of productivity. This was particularly so for those based in dormitory settlements, or what L'vov called *polevyye gorodki*, literally "field townlets", 53 of which sprung up along the r-o-w of the Urengoy - Pomary - Uzhgorod pipeline to house workers from the three construction contractors (Ivanov & L'vov, 1983, p.34-35; L'vov, 1986, p.142). Boris L'vov stayed in one such settlement on the remote West Siberian section of the pipeline during winter, not far from Novyy Urengoy. He describes (1986, p.142-144) how great attention had been paid to drinking-water sources, prevailing winds, ground-water level and natural beauty in choosing the location of these settlements and he manages convincingly to make the workers' accommodation, known as the *dom-bochka* or barrel-house, shown in Fig.3.3, sound remarkably comfortable. These simple accommodation units were used throughout the development of the NPT, including Yamburg. Each barrel-house, a standardized cylindrical living unit on wheels, is resilient to the strongest of West Siberian blizzards and equipped with everything from heating, hot water and clothes driers to TVs, radios and record players. The occupants of these barrel-houses would rarely be bored, he says, principally because this particular settlement possessed its own well-stocked library, to which new books were regularly added by those passing through by helicopter. He describes the workers and their children, many of whom were taking middle school correspondence courses, as being content with life, enjoying the facilities and events organized by the settlement council, in spite of winter temperatures below -40°C. He was even invited to attend the wedding of two constructors who met having been sent to the settlement under the terms of the *Komsomol* duty schedule. He puts the number of young men and women assigned to the Urengoy - Pomary - Uzhgorod project by the *Komsomol* at 12,000.

Fig.3.3 Dom-bochki at a "field townlet" on the Urengoy - Pomary - Uzhgorod r-o-w
(Source : Ivanov & L'vov, 1983, p.35)

L'vov's description does manage to persuade the reader that conditions even in the remotest of field townlets were indeed conducive to hard work, helping to realize accelerations in construction rates through increases in labour productivity. However, it is unlikely that all the townlets came up to the standards described by L'vov. And what of conditions in the main towns of the Yamalo-

Nenetskiy AO at that time? Conditions in the town of Novyy Urengoy, shown in Fig.3.4, which serves the Urengoy GCF and to some extent Yamburg and described as Nadym's "younger brother", appear to have been just as good, if not better, even in 1978 when hundreds of *Komsomol* workers were still arriving, ready to take part in the construction of what was to become one of the largest towns in the Russian North[21]. In their book "Tapping Siberian Wealth : The Urengoy Experience" (1984), Gurkov and Yevseyev describe these conditions on trips they made to the town in its early days. Somewhat ironically, they recount that several of these young workers had told their families how disappointed they were to find proper houses and separate sleeping quarters, even multi-storey

Fig.3.4 A view of Novyy Urengoy
(Unspecified source)



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[21] In 1978 Novyy Urengoy had 8000 residents, today the number is just over 90,000.

apartment blocks being built at that time in Novyy Urengoy. They had gone to this fledgling town, which lies just 80 km south of the Arctic Circle, under the impression that they would live in tents, struggling against the elements. With these sorts of conditions they would be quite content, for they aspired to the role of pioneers of the West Siberian North.

But allegedly good living conditions and a regular supply of keen *Komsomol* units are in themselves not enough to ensure high-quality work in specialized activities such as pipe welding and insulation or even other operations that might require less qualified workers. Sociological accounts of West Siberian gas industry development (the best examples of which include; Gurkov & Yevseyev (1984) and L'vov (1986)) may well convey the message that good working conditions equals high quality work, but, with a decade having passed, one really must question their supposition. This is certainly not an attempt to denegrate the heroic efforts of all those who took part in the construction of the West Siberian trunk gas pipeline systems and associated infrastructure. Indeed, there are few other feats that deserve comparison. But at the time these accounts were written these trunk pipeline systems were still under construction and even the first line from Urengoy (Urengoy - Nadym 1, commissioned in 1978) had only been operating for some five years. It is well-known that problems arising from defective assembly work can take a number of years to reveal themselves. Work that might have appeared faultless then could actually have contained undetectable flaws which in turn would initiate stress fractures in the steel and so on. The number of pipeline failures whose causes originate from the construction stage, as indicated in chapter 2, section 2.6, suggests that either the descriptions of Gurkov & Yevseyev, L'vov and others are inaccurate, indeed amounting to little more than propaganda, or the reason(s) for such failures lie elsewhere, outside the construction workers' sphere of influence. Such a reason could be defective pipe and associated components. In fact, both sorts of reasons apply here. According to Shmal' & Ivantsov (1994, p.11, Table 1) the percentage of all failures on trunk gas pipelines caused by defective construction-assembly work was 9.1% between 1981 and 1985, rising to 13.9% from 1986 to 1990 and reaching 30.2% in 1991[22]. Damage caused by construction devices accounted for 6.0% of failures (1981-85), 9.8% (1986-90) and 2.3% (1991). Batalin (1983, p.6), first deputy minister of construction of enterprises of the oil and gas industry in the 1980s, reported that in the period 1981-82 more than 50% of failures occurred at special welded joints (for example, backlash, incised and repaired joints), which themselves accounted for only 5% of all types of welded joints at that time. He goes on to say that some welders possessed insufficient qualifications and discipline for welding work. Thus, with Batalin's information, it appears that while the drive to work rapidly may well have been there, the quality of the work must have suffered through a combination of low qualifications

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[22] The authors do not make it clear as to whether construction-assembly work includes welding.

and discipline, and the necessity to complete pipe sections as rapidly as possible[23]. According to Table 2 of Shmal' & Ivantsov (1994, p.11), of the 25 failures on trunk gas pipelines in 1992, five were caused by defective construction-assembly work (20%) and three by defective welding work (12%). Defective pipe sections accounted for another five failures (20%) in 1992. In both tables the failures are for the whole USSR and are not broken down by region but the figures show that there was a significant number of failures arising from shortcomings at the construction stage during the period 1980-1992. According to data from Safanov *et al.* (1994, p.179, Table 2), displayed in Table 2.11, defective welds and construction work account for roughly 15% of serious gas pipeline ruptures, i.e. major incidents (12.5% of all incidents) in West Siberia and for some 27% of flaws and leaks, i.e. minor incidents (87.5% of all incidents) on these lines.

Perhaps it is unjust to question the quality of *all* work fulfilled by welders, insulation layers and pipe layers who would not stop even in temperatures of -40°C accompanied by wind speeds of 7 m/s or more. N.N.Khrenov (1998), who has worked in the Russian pipeline sector for more than 30 years, acknowledges that construction quality was not always good, but defends welding quality. Many workers had accumulated experience from earlier pipeline construction projects, some admittedly, like Messoyakha - Noril'sk, on a much smaller scale. In addition, Gurkov & Yevseyev (1984, p.166) report that checks were made of all welded joints and X-ray pictures of them were stored away in archives with the welder's name attached. Such measures, if fully implemented, would surely have had some effect in terms of raising work quality. Undoubtedly, such measures did not reach full implementation. The welders and their fellow IPL workers were doing a job upon which the national economy depended with the added pressure of having to meet targets set not just by *Gosplan*, but also by competing IPLs. Nonetheless, substandard construction-assembly work was and still remains a major factor contributing to pipeline failures, and not just those on West Siberian lines.

But should we not also be pointing our fingers at the SNiPs here? It appears that the workers performed their operations in accordance with normative and regulatory documentation that, as we have seen, is flawed and outdated, documentation that reflected the Soviet centralized economy suiting, with its step-by-step instructions, rapid pipeline construction on a large scale.

3.4.4 Conclusion

The Soviet trunk gas pipeline construction projects of the 1970s and 1980s were unique in terms of their scale and the rate at which they were realised, but the condition of the pipelines today and the statistics of failures are to a significant extent testimony to finished products that were flawed and

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[23] The high percentage of failures occurring at manually welded joints during the early 1980s prompted a gradual transfer to automatic submerged arc welding thereafter (Shmal', 1996b).

would not operate reliably throughout their given life-span in the complex natural conditions of northern Russia. The literature of the 1980s describing the completion of the pipelines portrays many thousands of willing workers, the majority of whom were youthful *Komsomol*, who lived in relative comfort, and who thus should have been able, and reportedly were, to work efficiently and rapidly within the IPL system of construction organization, performing to the standards as laid down within the SNiPs. It is highly unlikely that all the work was of the quality described by the authors of books and articles at that time, even with inspections. Nonetheless, as Dinkov & Ivantsov (1997a, p.20) have said, it would be inaccurate and too simplistic to say that high construction rates were in themselves responsible for low-quality construction-assembly work. It is more accurate to say that systems of work organization and fulfilment were ideally suited to rapid rates of construction but not to production of a fully reliable finished pipeline. Only the passing of time would reveal the true quality of the construction-assembly work in the operational and failure characteristics of the pipelines over several decades.

It is probably most fair to say that while construction-work organization and living conditions were in general satisfactory, the quality of the work fulfilled was influenced negatively to a smaller degree by the desire and need to maintain high work rates and by minor shortcomings in *Komsomol* training programmes, but perhaps to a greater degree by the fact that everyone was working in accordance with inadequate SNiPs riddled with flaws and intended to favour massively accelerated construction rates.

3.5 Conclusion

This chapter has shown that at the planning-construction stage the single greatest factor contributing to the unacceptably high number of failures on northern Russian trunk gas pipelines is the SNiP. The problem lies in the fact that those SNiPs governing trunk pipeline planning and construction in the CIS and especially northern Russia contain inadequacies which reflect the oil and gas industry policies of the Soviet era, especially the period approximately 1970 to 1990. This was a period when pipeline construction was greatly accelerated in order to provide increases in gas supplies to both domestic and foreign consumers. The SNiPs were devised with centralized policies in mind and, to a much lesser extent, the long-term reliable operation of the pipeline systems. The intention was to supply as much gas as possible as quickly as possible by whatever means possible and the SNiPs had to accommodate this principle. They should enable planning and construction to proceed rapidly with specific instructions governing all steps of these activities laid down and not act simply as guidelines that would require much additional planning work. But there were a number of contradictions to this concept, for example in SNiP 1 the referral of planners to many other SNiPs. This would have slowed planners down. What is even more worrying is that the same SNiPs enforced at that time are still active nowadays, at a time when the Soviet Union has been more or less consigned to the history books. Market principles are being nurtured in Russia and other CIS member states, principles which are not compatible with the outdated SNiPs. Replacements are being developed, but not without problems, and nobody can be sure when these might be put into effect. Another concern must be that even if much improved replacement SNiPs are introduced in the near future, how will they be enforced? What guarantee is there that planning and design institutes will adhere to them meticulously and that standards will be observed during construction and assembly of pipelines? Current failure rates, though falling, will hopefully serve as a stark reminder of the price paid for failing to adhere to higher standards maintained by western nations. These crucial matters must be tackled by a regulatory body to ensure swift action at all stages of the SNiP development process. The Russians can go a long way towards ensuring pipeline reliability if SNiPs are adhered to strictly. Meanwhile, in an attempt to redress the balance, *Gazprom* is introducing its own codes for pipeline design, developed with RNGS and other organizations, which it will enforce.

The difficulties facing pipeline planners and those engaged in pipeline research today, not just those caused by the SNiPs but also by the breakup of the Soviet Union and the current economic and educational predicament of the CIS, must also be borne in mind when considering the current state of the northern section of the UGSS. If future pipeline systems are to be planned and constructed economically and with the long-term reliability of the piplines as a priority, the present planning and research apparatus of Russia (organization and distribution of work amongst institutes) must be renovated, uniting the best aspects of the past, such as the skills of specialists from institutes such as *Giprospetsgaz*, with the innovations and market/competitive principles of the present.

If one was to take at face value the technical and organizational methods of accelerating pipeline construction put into use during the 1970s and 1980s it might have been reasonable to suggest that they too have contributed directly and significantly to the problems being experienced on the northern UGSS today. But by looking at them in some detail, it appears that the new technologies for welding for example (irrespective of the skills of those using the equipment) and the IPL system of labour organization functioned effectively. In fact they led indirectly to problems later because of adherence to inadequate regulations, most notably from the point of view of long-term structural reliability of the pipelines. Worker error did cause some problems but these would have been largely undetectable at the time of construction and assembly work without the kinds of diagnostic equipment in use today. This might explain some of the claims concerning high work quality and standards made soon after the completion of construction projects in the 1980s.

This chapter has covered those problems and issues relevant to the planning and construction stage of pipeline development in the Russian North. In the following chapter, attention turns to the operation stage. Thus, more emphasis will be placed upon the natural, or more specifically geocryological, dimension to northern trunk gas pipeline development.

CHAPTER 4

GEOGRYOLOGICAL AND ASSOCIATED PROBLEMS ON WEST SIBERIAN TRUNK GAS PIPELINE SYSTEMS

4.1 Introduction

This chapter examines interactions between operational buried trunk gas pipelines and the perennially-frozen soils surrounding them. These are known as "pipeline - permafrost" interactions[1].

Before one can approach the issue of pipeline - permafrost interactions there must be a firm understanding of the temperature regimes of northern Russian trunk gas pipelines. This issue is the subject of section 4.2. The temperature regime of any pipeline, whether it be for the transportation of oil, gas or other products, will have a significant influence upon the surrounding soil in which a pipeline is buried or even upon the soil in which the piles of raised pipelines are submerged. In soils which are susceptible to development of potentially harmful cryogenic processes, such as frost heave and thaw settlement, the influence of pipeline product transmission temperature regimes must be such that these processes are at least kept to a minimum, if not excluded. Normally, this would mean keeping product temperature as close as possible to that of surrounding soils by means of temperature regulation (subsections 4.2.1, 4.2.2 and 4.2.3). If unsuitable product temperature regimes are in use, a pipeline could be exposed to potentially dangerous stresses initiated by such cryogenic processes (section 4.3) as frost heave (subsection 4.3.2) and thaw settlement (subsection 4.3.3), leading perhaps to displacement, deformation and eventually a rupture. Case studies illustrating the influence of these cryogenic processes upon trunk gas pipelines in the NPT are provided. While frost heave and thaw settlement are widely recognized as being the major causes of loss of stability of a pipeline in such conditions, another cryogenic process, thermal erosion (subsection 4.3.4), closely associated with thaw settlement, can exacerbate the problem. It must also be noted that in both natural and technogenic circumstances the intensity and magnitude of cryogenic processes vary considerably and depend upon local physical-geographical conditions, notably soil conditions and moisture availability. In the technogenic circumstances under consideration in this thesis, pipeline construction and operation methods also play a critical role.

The chapter is concluded in section 4.4.

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[1] Interactions between the piles of on-ground or raised pipelines and soils are not considered here.

4.2 Temperature of transmitted gas

4.2.1 Temperature regulation

The temperature of gas transmitted through trunk pipelines in permafrost regions can be either unregulated or artificially regulated.

4.2.1.1 Unregulated

Firstly, the use here of the term "unregulated" indicates that transmitted gas temperatures undergo no *intentional* cooling or warming, thus the gas can still be subject to some artificial warming or cooling influence. For example, gas being transmitted through pipeline systems several thousand kilometres in length is warmed as a result of compression at intermediate compressor stations.

The transmitted temperature of gas depends either upon ambient temperatures to which the pipeline is directly exposed if laid above-ground, or upon the temperature of soils (which if near the earth's surface are influenced by the prevailing climatic conditions) surrounding a buried pipeline or one laid in a berm on the ground. As indicated above, on lengthy pipeline systems such as those laid from West Siberia, transmitted gas temperatures will be altered by compression at intermediate compressor stations, usually placed 100 km to 150 km apart along the pipeline r-o-w. Compressed gas temperatures are much higher than in an uncompressed state, but temperatures will fall naturally as the compressed gas expands along the pipeline downstream of a compressor station. This is known as the Joule-Thomson effect (or in Russian, *drosselirovaniye*, translated as throttling). There are no trunk gas pipeline systems in northern Russia which operate without compressor stations. Therefore, gas is always subject to a certain amount of warming at some stage along a trunk gas pipeline system, for example on the UGSS. The NAGSS however, albeit a small independent system, possesses only one compressor station. It is also the only trunk gas pipeline system in northern Russia whose transmitted gas temperatures are almost totally unregulated. It's single compressor station, located at the South Soleninskoye GCF, provides some artificial warming influence. But between this station and Noril'sk, a distance of 305 km, transmitted gas temperatures in the three above-ground pipeline strings are influenced by nothing other than ambient temperatures, except for very small sections (2 - 3 km) of pipeline buried below rivers and floodlands where localized temperature regulation occurs intentionally. One would therefore expect a great annual range of gas temperatures in the NAGSS as a whole. Table 4.1 shows the average-daily temperature of transported gas and hydrocarbon condensate recorded throughout 1985 at the Messoyakha GCF, the location of which is shown Fig.2.1 [2]. If one takes the minimum figure of -52.5°C (February 14th) and the maximum figure of +26°C (June 12th), the maximum range is 78.5°C. The lowest gas

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[2] Messoyakha lies 40 km east of South Soleninskoye and 265 km west of Noril'sk.

Table 4.1 **Average-daily temperature (°C) of transmitted gas and hydrocarbon condensate at Messoyakha on the NAGSS in 1985** (Source : Borovkov, 1996)

Date	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	-46	-40	-33	-23	-2	+6	+6.5	+12.6	+4.5	-1	-31	-26
2	-24	-39	-29	-31	-6	+11	+8	+13.8	+3.5	-2	-31	-25.5
3	-33	-34.8	-13.5	-31	-8	+1	+18.5	+13	-0.2	-2.5	-34	-18
4	-43	-40	-16	-31	-5	+5	+22.1	+17.3	+2	-4	-29	-20.5
5	-46	-41.4	-27	-25.2	-5	+5	+11	+12.5	+0.5	-5	-16.7	-24
6	-47	-39.6	-23	-23	-1	+12	+11	+12.5	+1.2	-4	-7	-21
7	-39	-28.5	-17	-11	-6	+19	+6	+12	+3.9	-4	-9	-22
8	-39	-38	-19	-5	-13	+23.5	+5	+17.4	+4.9	-6	-9	-22
9	-38	-35	-20	-4.1	-4	+18	+6	+18.7	+5.3	-8	-5.2	-20
10	-33	-39.7	-15	-10.9	-8	+16	+11	+15.6	+1	-6	-9.9	-14
11	-25	-42.8	-11	-4.7	-4	+17	+12	+16	-5.2	-1.9	-13.3	-11
12	-30	-39.3	-13	0	-6	**+26**	+11	+15	+1	-2.4	-17.5	-16
13	-29	-42.5	-15	-1.5	-6	+11	+7	+10.7	+2.9	-1.3	-14.8	-21
14	-18	**-52.5**	-14	+3.8	-4	+8	+7	+13.2	+5	-7.8	-19.2	-23
15	-20	-31	-15	+2.5	-1.5	+5	+15	+13.9	+3.9	-3.8	-13.5	-30
16	-21	-18	-22	-4	+3	+11	+17	+13.8	+3.3	-1.8	-10.3	-37
17	-27	-30	-26	-7.8	+1	+12	+24	+6	+8.3	-1	-10.6	-30
18	-27	-33	-31	-12	+6	+20	+11	+14	+8	0	-18	-19
19	-32	-35	-27	-11	-1	+20	+9	+10	+13.3	-3	-20	-26
20	-36.5	-23	-27	-3	-5	+25	+10	+14	+8.9	-3.1	-29	-29
21	-39.3	-26	-30	-7	-2	+23.5	+12	+10	+6.8	-3	-32.5	-17.4
22	-39	-18	-26	-15	0	+12	+13.5	+7	+5	-3.2	-31	-13.5
23	-21.5	-12.5	-18	-13	+1	+13	+18	+6	+7.3	-6	-34	-22
24	-35	-22	-26	-7	+2	+16.5	+12	+7	+9.4	-6	-30.5	-35
25	-41	-27	-33	-8	+6	+18	+25	+9	+7.4	-18	-24	-36
26	-33	-28	-26	-14	+10	+12.5	+25.3	+10	+5.6	-17	-22	-41
27	-26	-29	-27	-11	0	+13.5	+18.4	+9	+3	-19	-28	-40
28	-29	-36	-26	-23	+2	+14.8	+17	+4	0	-18.7	-38	-41
29	-31		-29	-6	+10	+12.9	+15	+5	-1.5	-18.8	-38	-39.5
30	-38		-30	-1	+12	+6	+12.4	+5	+1	-24	-37.5	-37.5
31	-32		-26		+11		+12.4	+4		-25.4		-33.3
Average-monthly temp.	-38.8	-32.6	-22.9	-10.8	-0.8	+13.8	+13.2	+11.2	+4.1	-7.3	-22.1	-26.2

Average 1985 temp. = -9.4; coldest temp. =-52.5 (February 14th); warmest temp. = +26 (June 12th); annual temp. range = 78.5

temperature ever recorded on the NAGSS was -56°C and the highest +35°C, giving a maximum long-term range of 91°C (Borovkov, 1996). One should also note that the proximity of these figures to their respective air temperatures on any given day is likely to be very close indeed. Some Russian pipeline specialists, such as Ivantsov & Kharionovskiy (1993a, p.48), apply the term "cold" pipeline to the NAGSS since transmitted gas temperatures are below 0°C for much of the year (approximately 7.5 months)[3]. The annual average temperature of gas transmitted through Messoyakha is approximately -9.5°C. Although a detailed discussion of NAGSS failures is beyond the scope of this thesis, it should be noted that this pipeline system, especially the few sections buried below rivers and floodlands, has experienced numerous ruptures, the causes of which are directly related to its "cold" product transmission regime which favours the development and dominance of frost heave.

4.2.1.2 Regulated

In permafrost regions gas may be cooled artificially, and intentionally, after compression in order that gas which has only just been compressed will nevertheless have a temperature at or near to that of surrounding soils downstream of the compressor station. This is considered desirable where warm compressed gas might cause thawing and subsequent settlement of frozen soils surrounding a buried pipeline and ultimately of the pipeline itself. However, the final temperature of the gas after cooling should not be too far below that of soils surrounding a buried pipeline, in particular those frost-susceptible soils whose temperature is only slightly below 0°C since additional cooling could initiate secondary or continuing frost heave of the soils and of the buried pipeline (discussed later in subsection 4.3.2.2). Therefore, as Levin & Zelenov (1983, p.10) point out, it is not simply a question of cooling the gas, but of regulating its cooling.

Ideally, soil conditions (composition, temperature, moisture content, iciness, etc.) in permafrost regions would be homogeneous along the entire length of a pipeline system, or at least between individual compressor stations. In this case, gas temperatures could be maintained artificially at temperatures at or as close as possible to those of the soils surrounding the pipeline and hence there would be little concern for potentially dangerous pipeline - permafrost interactions caused by warm gas thawing frozen soils or even chilled gas freezing unfrozen soils. But in reality soil conditions vary markedly from place to place, perhaps even being heterogeneous over very short distances. Significant differences in iciness, strength of frost heave and other geocryological properties of soils can be observed even over distances of several centimetres. Thus, it is wholly unreasonable to think that the cooling of gas at compressor stations in permafrost regions will permit

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[3] The terms "cold" and "warm" gas pipelines are used widely in Russian texts to describe pipelines through which predominantly negative (below 0°C) and positive temperature (above 0°C) products are transmitted.

pipeline operations to proceed permanently without the appearance of any pipeline - permafrost interactions whatsoever. Nonetheless, it is accepted that in most cases gas cooling will indeed cause some cooling of unfrozen or frozen soils and even freezing of surrounding unfrozen soils. Alternatively, uncooled gas might thaw the surrounding frozen soil. Significant frost heave or thaw settlement may not occur in areas where the soils in question are coarser textured, such as sands, because they are not noted for their high frost susceptibility. Also, any soils that have a low ice-content will not be so susceptible to serious deformation in the event of frost heave or thaw settlement. Fine soils however, such as clays, silts, peats and admixtures thereof, including sand, and highly icy soils are frost-susceptible to varying degrees. In essence, gas cooling will be considered essential only if a gas pipeline might otherwise be subject to stresses that could cause its rupture. Such stresses are likely to occur in conditions where the pipeline will be displaced significantly in a non-uniform manner over relatively short distances. Such uneven displacements would be caused by "differential" (uneven) settlement or frost heave of soils that are heterogeneous in terms of composition, temperature, moisture content and iciness. Simple cooling or cooling of gas below the temperature at which local soils heave must therefore be avoided if those soils are likely to be susceptible to significant differential heave. If, on the other hand, warming or cooling of non-frost susceptible soils is likely or insignificant amounts of non-differential settlement or heave of both soils and the pipeline may occur over some distance, then the costly task of gas cooling is probably unnecessary.

In a region where such soils occur, the random distribution of highly icy frost-susceptible soils over short distances is of great concern to those planning a gas pipeline. Gas cooling stations would most likely be considered essential. However, in Russia there is a distinct lack of such installations in the permafrost regions, including those areas of West Siberia where these hazardous soil types are found. Reasons for this might include an absence of the financial resources for gas cooling. It is also likely to have been thought that the installation of cooling stations would slow down the rate of construction and commissioning of gas pipeline systems in the 1970s and 1980s. But it was certainly not thought simply that cooling was unnecessary.

Some degree of gas cooling is essential, even in the absence of permafrost. Hot gas that could be at temperatures of +80....+100°C after compression is undesirable for the following reasons (Savkin, 1987, p.25):

1. damages many types of anti-corrosional insulation;
2. causes undesirable thermal stresses in gas pipelines;
3. lowers gas pipeline productivity;
4. increases the aggressive influence of harmful admixtures within the transported product, for example hydrogen sulphide;
5. intensifies both external and internal pipe corrosion;

6. leads to thawing of frozen soils in permafrost regions.

Gas cooling systems were used for the first time in the USSR during the 1960s (*ibid.*, p.25). The cooling system used water with traditional cooling towers and shell-and-tube heat exchange apparatus. Use of this water cooling system proved inefficient in the northern regions, hence the transfer to air cooling apparatus (*Apparat Vozdushnogo Okhlazhdeniya* in Russian, or AVO) which took place in the early to mid-1970s.

Currently, there are two separate means of cooling gas that is to be transmitted through trunk pipelines in the permafrost regions of West Siberia: AVO and gas cooling stations (*Stantsiya Okhlazhdeniya Gaza* in Russian, or SOG). These are described below.

4.2.2 Air Cooling Apparatus (AVO)

What the Russians call "the intensification of pipeline transport", or increasing throughput of gas, can be achieved not only by keeping the interior pipe surface free from liquid and solid obstructions or increasing the average pressure of the gas, perhaps by reducing distances between compressor stations[4], but also by reducing its temperature. The gas temperature in a large-diameter gas pipeline can exceed +80°C. Such temperatures can make it difficult to maintain the planned position and stability of a pipeline once operational, and also complicates protection from corrosion. In the USSR, it was well known by the late 1970s that with the increasing diameter and operating pressure of the new trunk gas pipeline systems the natural cooling capacity of a pipeline between compressor stations would be reduced and the heating of gas during compression would not be compensated for by cooling (Joule-Thomson effect) between compressor stations (Orudzhev, 1981, p.97). It was calculated that for a 1020 mm diameter gas pipeline temperature equilibrium in the pipeline could only be achieved with a distance between compressor stations well in excess of 150 km. This is unacceptable if high throughput of gas is to be maintained since compressor stations would have to be closer together, thus AVO became necessary at compressor stations throughout the USSR, including Central Asia. Shcherbina *et al.* (1981, p.99) explained how compressor stations on the large trunk gas pipeline systems operational at the end of the 1970s were equipped with AVO which permitted a slight decrease in the initial gas temperature[5]. Those AVOs used so-called zig-zag configured apparatus for a conditional pressure of 6.27 MPa with a heat exchange surface of 5300 m^2 per unit to cool gas on 1220 mm diameter trunk gas pipelines operating at a pressure of 5.4

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[4] This method was used on several sections of the Vyngapurovskoye - Chelyabinsk gas pipeline, which originates at Urengoy (Shcherbina *et al.*, 1981, p.99).

[5] It should also be noted that AVO is used at UKPGs (and their booster compressor stations) at all gas fields, including those in the north. Ignat'yev (1997, p.36) provides an account of AVO operations at the Medvezh'ye GCF booster compressor stations, which incidentally do not function effectively as the gas is not cooled sufficiently, resulting in thawing of soils around the foundations of the units and the formation of hydrates in the apparatus piping.

MPa. Orudzhev (1981, p.98) also described the AVG-1-75 air cooling apparatus, new at that time, which had a heat exchange surface in excess of 20,000 m² and a pressure of 7.4 MPa.

Table 4.2 **Recommended and actual winter-time (November to March) gas temperatures after compression and AVO cooling at selected compressor stations in the NPT** (Sources : Recommended data received direct from the respective compressor station *LPU* and telephoned in to Nadym Gas Production Enterprise (TTG) on 13th March 1997; Actual data : Galiullin *et al.*, 1996, p.129-136)

Compressor station, incl. type : ICS or CS (and for which trunk gas pipeline)*	**Recommended gas temperature after compression and AVO (°C)**	**Actual gas temperature after compression and AVO (°C)**	**Permafrost continuity at compressor stn.**
Novourengoyskaya, ICS (Urengoy - Nadym 1)	+4....+8	+9	Discontinuous/Massive-island
Pangodinskaya, CS (Urengoy - Nadym 1)	+8....+10	+16	Island
Nadymskaya, CS (Nadym - Punga)	+8....+10	No data	Massive-island
Purovskaya**, ICS (Urengoy - Uzhgorod)	+2....+6	+11	Continuous/Discontinuous
Khasyreyskaya, CS (Urengoy - Uzhgorod)	No data	+12	Island
Yamburgskaya**, ICS (Yamburg - Yelets 2)	0	-1	Continuous
Nydinskaya, CS (Yamburg - Yelets 2)	+4....+8	+12	Discontinuous
Pravokhettinskaya, CS (Yamburg - Yelets 2)	ca.+8	No data	Massive-island

* ICS - Initial compressor station, the first one on a pipeline system, usually located at the source field. CS - a compressor station located at an intermediate point along the pipeline system.

** The Purovskaya compressor station possesses a fully operational SOG, but it is not in use during winter. Yamburgskaya also has a SOG but it has not yet been commissioned.

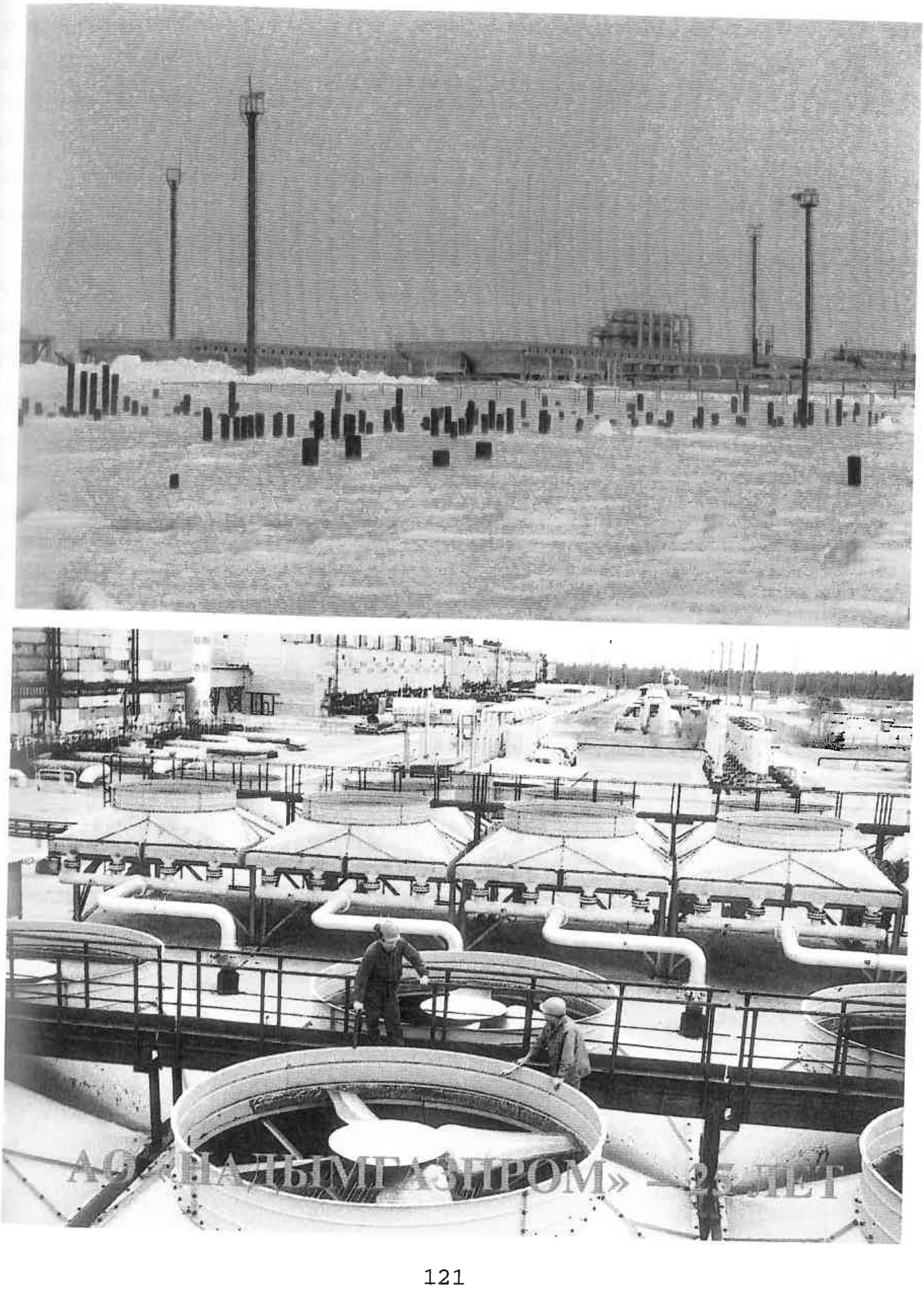
Each compressor station or UKPG has up to 40 seperate AVO units, as shown in Fig.4.1, and in winter fewer than 10 units are required to maintain gas temperatures at recommended levels

Fig.4.1 Two views of AVO units at compressor stations in the NPT

(Sources : top. Author's photograph, taken 8th April 1998; bottom. *Nadymgazprom*)

Top. AVO units at the Tul'skaya section of the Yamburgskaya initial compressor station

Bottom. AVO units at the Nadymskaya compressor station



(Demushkin, 1998; Peters, 1998). In the early 1980s Orudzhev (1981, p.97) and Shcherbina *et al.* (1981, p.99) pointed out however that at its most effective AVO can only cool the gas to 10....12°C above that of the temperature of the surrounding air. This is especially unsatisfactory for summer time gas pipeline operations in northern West Siberia, where air temperatures can reach +20°C or more in July. This would give a post-AVO gas temperature of more than +30°C. AVO in use today are slightly more efficient than those used in the early 1980s and it is now standard practice at compressor stations in West Siberia to use all available AVO units during summer, perhaps the full complement of 40, but even this does not allow cooling of gas below +20°C. Soil temperatures are of course still below freezing in many parts. Therefore, the use of AVO alone cannot cool gas to year-round temperatures of for example -2....-6°C.

Table 4.2 shows recommended winter-time average gas temperatures after compression and AVO cooling at selected compressor stations in the NPT (see locations on Fig.2.4). Actual average winter gas temperatures can be expected to be +/-0.5°C from these figures, says Lashin (1997) of TTG. But in reality, figures much higher than these are possible. Actual winter-time gas temperatures after compression and AVO at the first two compressor stations on these strings have been included in Table 4.2. The real situation is also demonstrated by Fig.s 4.2, 4.3 and 4.4. These show actual average winter and summer time (1993) gas temperatures before and after compression and after AVO cooling at the Novourengoyskaya, Purovskaya and Yamburgskaya stations (also after SOG cooling in the case of Purovskaya summer operations), as well as along the linear part of the pipeline string initial sections on which they operate : Urengoy - Nadym 1, Urengoy - Pomary - Uzhgorod and Yamburg - Yelets 2.

4.2.3 Gas Cooling Stations (SOG)

In order to maintain year-round temperatures of transmitted gas within a range -2....-6°C additional cooling is required. SOGs were being installed for the first time in northern Russia to provide this additional cooling at the beginning of the 1980s on Urengoy - Nadym 1, but these used gas-engine compressors and were considered uneconomical and not powerful enough (Orudzhev, 1981, p.98-99). At about that time the Russians were developing more powerful turbo-compressors which could lower gas temperatures to -10°C. *Mingazprom* gave *Minkhimmash* the task of developing the ATP5-8/1 and ATP5-16/1 turbo-compressor units with cold productivity of 8 and 16 million kcal/hour respectively. Initially it was planned to drive the compressors electrically, later gas turbines from the aviation industry would be used. There was also mention of the use of turbo-expanders (*ibid.*, p.99). Between December 1982 and September 1983 six imported SOGs were delivered to the Urengoy GCF (*Pétrole Informations*, 1987, p.83). These stations (components provided by Creusot Loire-Framatome and Hispano-Suiza as part of an agreement signed in late 1981 by the Creusot Loire

Fig.4.2 Seasonal change of gas temperature after compression, AVO cooling and along the initial section of the Urengoy - Nadym 1 trunk gas pipeline, 1993 (Source : Galiullin et al., 1996, p.130, Fig.2)

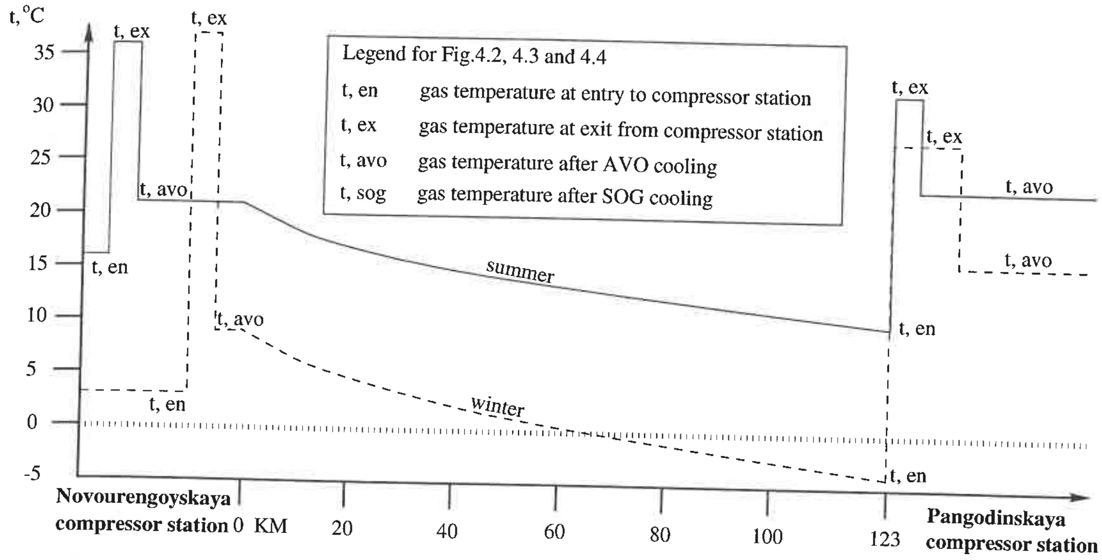


Fig.4.3 Seasonal change of gas temperature after compression, AVO and SOG cooling and along the initial section of the Urengoy - Uzhgorod trunk gas pipeline, 1993 (Source : Galiullin et al., 1996, p.131, Fig.3)

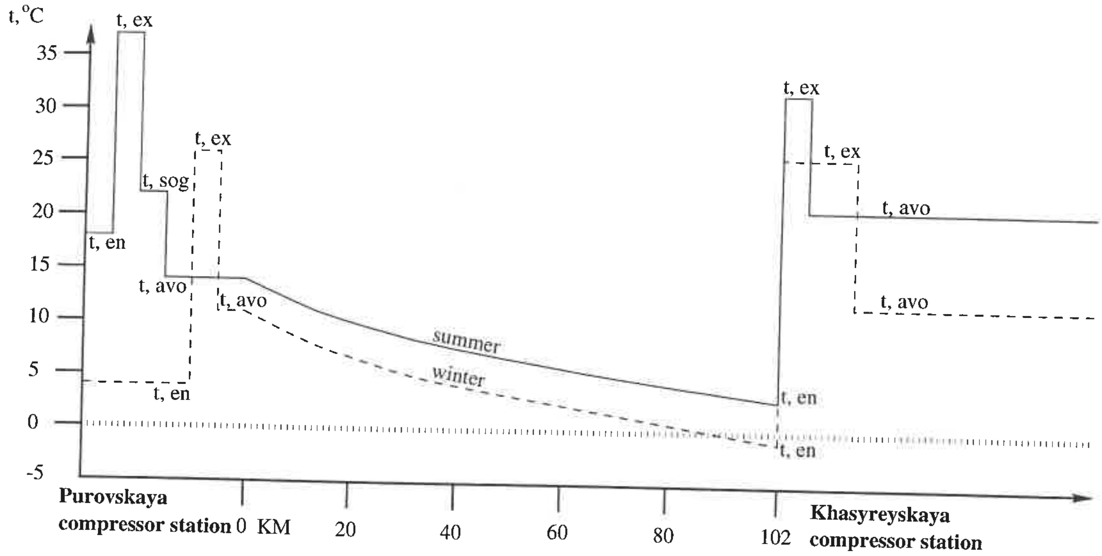
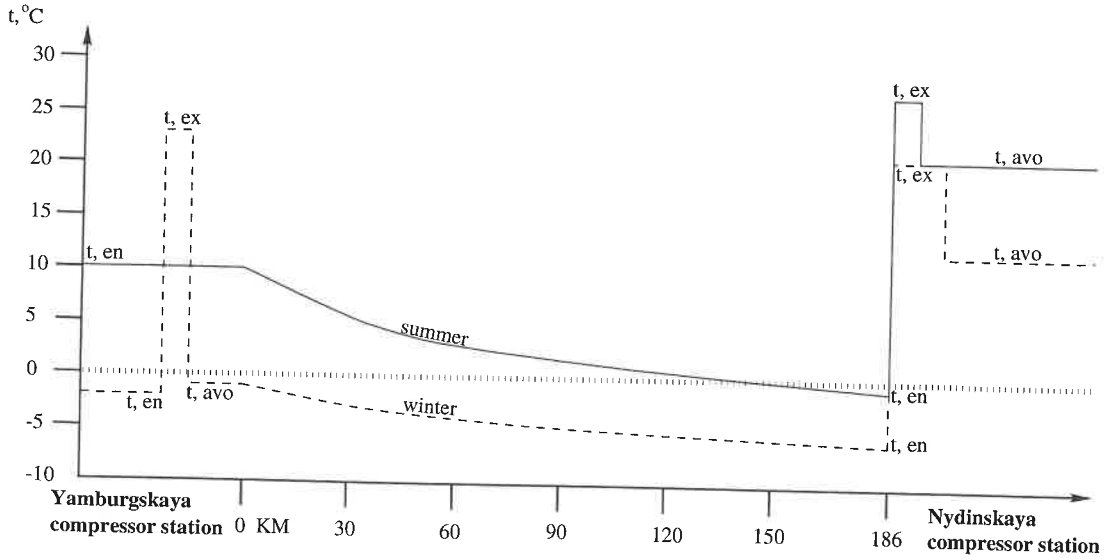


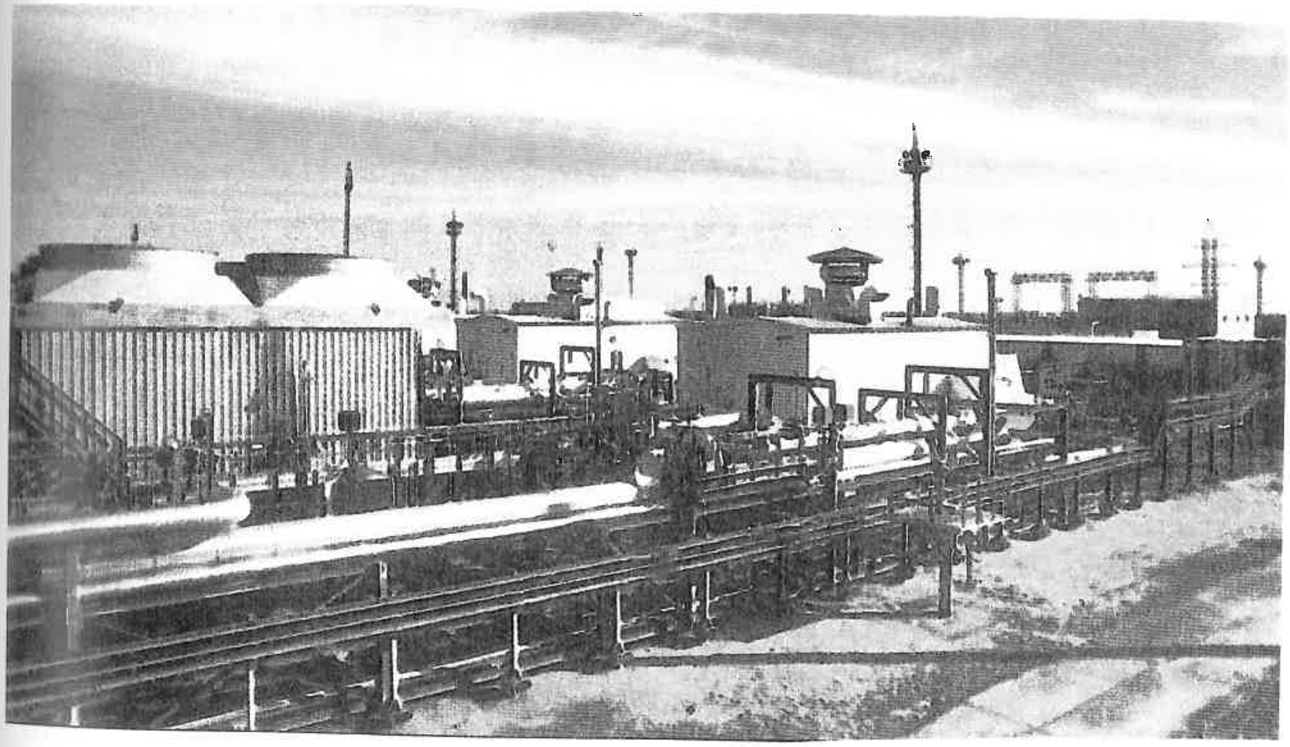
Fig.4.4 Seasonal change of gas temperature after compression, AVO cooling and along the initial section of the Yamburg - Yelets 2 trunk gas pipeline, 1993 (Source : Galiullin et al., 1996, p.132, Fig.4)



Sofregaz consortium and the Soviet *Mashinoimport* purchasing agent) use propane evaporation to produce the cold. The evaporated propane is compressed in a turboblower driven by a gas turbine and then condensed in an air-cooled condenser[6]. The facilities were not started up until 1987, although full operations were not expected to begin until 1988 (*ibid.*, p.82). According to Karl Ott (1997), head of TTG's Production-Technical Department, one SOG at the Purovskaya compressor station was not commissioned until the early 1990s. The SOG at Purovskaya is used only in summer-time when AVO can cool post-compression gas to around +22°C. SOG cooling brings the temperature down to +14°C before it is fed into the trunk pipeline, as shown in Fig.4.3. A photograph of a SOG at the Urengoy GCF is shown in Fig.4.5.

Fig.4.5 A SOG at the Urengoy GCF

(Source : *Petroleum Economist*, 1994)



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[6] More detail on these SOGs (main characteristics of gas turbines in the SOGs, etc.) is provided in *Pétrole Informations*, No.1638, October 1987, p.82-83.

Table 4.3 **Temperature of cooled gas transmitted from SOGs in the Yen"yakhinskaya area of the Urengoy GCF** (Source : Chigir *et al.*, 1997, p.29)

SOG location	**Start-up year**	**Temperature (°C) of gas (summer*)**	**Temperature (°C) of gas (winter**)**
UKPG-11	1989	+3.0	+3....+5
UKPG-12	1991	+3.0	+3....+5
UKPG-13	1993	+3....+5	+20 (SOG shut down)

NOTES :
* summer is the period second half of May to end of September.
** winter is the period beginning of October to first half of May.

Chigir *et al.* (1997, p.29) mention that three SOGs were commissioned at UKPG-11, -12 and -13 in the northern part of the Urengoy GCF between 1989 and 1993, but it is unclear whether these were part of the same consignment delivered under the above-mentioned contract. These three SOGs are used to cool gas being pumped from the UKPGs into Urengoy's gas gathering line system (1420 mm diameter). The cooling of gas at the UKPGs also permits the use of energy from excess reservoir pressure of the gas, thereby improving the economic performance of the field (Levin & Zelenov, 1983, p.10). The primary reason for installing the SOGs was the instability of certain sections of the gathering line strings caused by the development of thaw bulbs around them and the displacement of the strings away from their design position in both the horizontal and vertical planes. This problem is examined in detail later in this chapter. The seasonal temperatures of cooled gas transmitted from these SOGs are given in Table 4.3.

The figures shown in Table 4.3 seem unusually high, given the fact that soils in the areas of these stations have temperatures well below 0°C. Perhaps it was originally thought that limited melting of soils would not result in serious soil settlement and disturbance to the pipeline strings because the soils have a low ice content. Gas temperatures in the range +6...0°C (for Urengoy UKPG-11, UKPG-12 and UKPG-13) or as high as +14°C (for the Purovskaya compressor station in summer), although post-SOG, would still be enough to cause melting, so one should ask, why use expensive propane or butane SOGs?

The Yamburgskaya compressor station, located at the head of all trunk gas pipelines laid from the Yamburg GCF, has a Russian-built SOG which uses a propane-butane mixture to the cool the gas. However, the SOG has not yet been commissioned due to a lack of finances (Khrenov, 1998). Consequently, the temperature of gas transmitted from Yamburgskaya is often well above 0°C, as shown in Fig.4.4. But note that Fig.4.4 shows only the average temperatures for summer and winter 1993. Odishariya (1996) says that the temperature of gas transmitted from Yamburg is most often in the range +5....+12°C. Warm gas transmission from Yamburg has caused considerable thawing of soils surrounding the strings, a process which will be put into context later in this chapter (subsection 4.3.3.3), and many lengthy pipe sections are now floating in water-filled trenches, as shown in Fig.4.6. As a concession to the permafrost, albeit too late, gas is transmitted from Yamburg without compression in summer, but this results in a reduction of throughput at that time of year. The commissioning of the Yamburgskaya SOG as soon as possible is essential. According to calculations made by Galiullin *et al.* (1996, p.136), the commissioning of the SOG, permitting average-annual gas temperatures of -2°C, would result in total restoration of permafrost under the Yamburg - Nydinskaya compressor station section of the Yamburg - Yelets 2 trunk gas pipeline after only the third year of operations. This rapid restoration is explained by the relatively mild existing temperature regime and the small depths of thawing under the pipe strings (3 m, as opposed to 8 - 10 m beneath the parts of Urengoy - Nadym 1). Such a rapid restorative measure might be better than that suggested by Odishariya (1996) whose view is that once a cooling station has been commissioned it is essential to cool the gas very gradually over a number of years, letting the soils refreeze very slowly. This slow, protracted freezing could cause increased frost heave in fine soils.

In theory the SOG would only be needed during summer, when AVO cooling could not reduce the transmitted gas temperature far enough on its own. During winter, AVOs at Yamburgskaya cool post-compression gas to -1°C, as shown in Fig.4.4. The mere presence of an operational SOG at Yamburgskaya will allow increased gas output since this additional cooling will permit compression operations in summer without the problem of soil thawing downstream of the station[7].

While SOGs using compressed propane, butane or freon machinery are effective, they are also expensive to install and operate, as are turbo-expanders. Savkin (1987, p.29) says that a single SOG using propane or freon at a compressor station cost more than 20 million old rubles and approximately 5 million old rubles per annum for operating costs, clearly a great deal of money. Savkin goes on to propose new methods of cooling gas both effectively and cheaply in the far north. He proposes that the logical sources of refrigerants in the far north are cold water from rivers and the sea, thawed man-made glaciers, subterranean water, snow and in certain cases solid carbon

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[7] There are however some SOGs, such as those at Urengoy UKPG-11 and UKPG-12, which run year-round. These SOGs have the additional role of increasing gas output.

Fig.4.6 Trunk gas pipeline strings floating in melt water pools
(Sources : top. Rouganskiy, 1994; bottom. Khrenov, 1997)
Top. Two strings crossing the Yubileynoye GCF (between Urengoy and Medvezh'ye GCFs)
Bottom. One string of the Urengoy - Surgut line, ca.60 km south of Novyy Urengoy

dioxide. He wrote a second article on this issue more recently, in which he describes plans for a modernized SOG consisting of three interconnected systems (Savkin, 1997, p.27-28). The first cooling system is known as "modernized air cooling apparatus" (MAVO) and comprises vertical or inclined heat exchanger sections. The second system comprises modernized irrigation coolers into which are fed cold air and water for the intensification of heat exchange. The third would be an auxilliary system for cooling circulated water consisting of a man-made or artificial glacier, a system of large-diameter pipes submerged in the soil and water storage tanks. The cooling would be carried out as follows:

1. after the gas has been processed in the UKPG and compressed in the compressor station, it is fed into the first cooling system where cooling takes the temperature of the gas from +100....+120°C to +10°C in winter (200 - 220 days per annum), or to +30....+60°C in spring, summer and autumn;
2. the gas then proceeds to the second system where it is cooled in the spring-summer-autumn period from +30....+60°C to +6....+8°C;
3. in the spring-summer-autumn period final cooling to -6....-8°C would be achieved using propane cooling.

Five or six reserve AVO units would be maintained as back-up cooling systems. The use of this new technology in the spring-summer-autumn period will allow a reduction in numbers of AVO units, as well as reduction (by more than 30%) of the use of expensive propane cooling systems since the lowering of the temperature from +30....+60°C to +6....+8°C takes place using water and air, while only the reduction from the latter temperature to -6....-8°C uses propane. Savkin (1997, p.28) concludes by saying that this technology can provide an economy of capital investment and operational costs of more than 1 trillion old rubles for a single gas pipeline string. Khrenov (1998) however criticises Savkin's cooling proposal. He claims that such natural sources of cold would not be sufficient to create enough cold to cool large volumes of gas. He also points out that propane and butane are produced anyway from Valanginian horizons at fields such as Yamburg and are therefore logical cooling agents for SOGs[8].

4.3 Geocryological problems

4.3.1 Introduction

The r-o-ws of northern trunk gas pipelines are characterized by highly complex natural conditions, such as the presence of bogs, widespread zones of flooding, and perennially-frozen soils. The extent of such conditions is shown in Table 4.4. Such conditions on the r-o-w complicate considerably and raise the price of pipeline operations, fufilment of repair work, and require special technical solutions

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[8] Valanginian gas at Yamburg contains 2.5 - 3% propane and 1.5 - 2% butane (Klyusov & Yershov, 1995, p.32).

to guarantee the stability and reliability of pipelines in soils susceptible to a loss of supporting capacity.

Table 4.4 **Length of sections of selected trunk gas pipeline systems with bogs and permafrost** (Source : Krylov *et al.*, 1990, p.16)

Pipeline system	**Overall length in Tyumenskaya Oblast' (km)**	**Length of section with bogs (km)**	**Length of section with permafrost (km)**
SRTO (Nadym) - Ural (string-3)	1181	554	28.3
Urengoy - Nadym	235	17	75
Urengoy - Chelyabinsk	1780	412	49
Urengoy - Pomary - Uzhgorod	1522	500	120

The problem of ensuring the high reliability of the linear part of gas pipelines operating in boggy and flooded localities, where the soils have a low gripping capability (adhesion forces), is particularly important. Longitudinal displacements of pipelines caused by variations in the temperature of the gas (seasonal or linked with a change of the regime) will disturb ballasting, causing a loss of stability, and damage anti-corrosion insulation. In some cases distortions will lead to plastic deformation (the development of corrugations) and to a failure situation.

The operation of northern sections of gas pipelines is complicated further by the presence of perennially-frozen soils. Disturbances occurring during construction and operation of linear structures and installations with redistribution of heat can lead to warming of the permafrost and the freezing of unfrozen soils, with consequent displacement of the installation.

Studies of interactions between gas pipeline systems and perennially-frozen soils have been conducted by *VSEGINGEO*, the Earth Cryosphere Institute (Siberian Branch of RAS), Moscow State University, the Mel'nikov Institute of Permafrost Studies (Siberian Branch of RAS), *Giprospetsgaz*, *TyumenNIIgiprogaz*, *VNIIgaz*, *VNIIST* and other organizations. The earliest work was carried out on the gathering lines of the Medvezh'ye GCF and the trunk gas pipeline systems Medvezh'ye - Nadym, Urengoy - Pangody - Nadym. Thermometric stations for the measurement of soil temperatures in the gas pipelines' zones of influence, heave-measurement stations and levelling apparatus for measurement of horizontal and vertical soil and pipe displacements were installed on these installations. The Medvezh'ye - Nadym - Punga gas pipeline (part of which is examined in subsection 4.3.2.3), being the oldest component of the UGSS in the NPT, is the best studied stretch of trunk gas pipeline in West Siberia, having been in operation for roughly 25 years. But, as Chigir *et al.* (1997, p.28) have noted, studies of operational northern trunk pipelines have diminished drastically over the last 15 years. This has a great deal to do with financial constraints. Thankfully nowadays, with contracts from *Gazprom* enterprises (for example *Urengoygazprom*), small stretches of trunk gas pipelines and gathering lines are undergoing extensive diagnostic investigations. Some of these investigations will be examined in detail later (subsection 4.3.3.6).

Krylov *et al.* (1990, p.17) note that the trunk gas pipelines mentioned above (Table 4.4) are located in generally favourable engineering-geocryological conditions, in predominantly unfrozen soils with islands of permafrost, and small zones of flat peatbogs containing individual frost mounds. The exception, they add, is the pipeline corridor Urengoy - Pangody, where of 123 km of r-o-w, 72 km are composed of permafrost. In general, zones of soils which are relatively susceptible to settlement are encountered along the r-o-w; the soil iciness on account of icy inclusions amounts to 3% (infrequently 10% in peatbogs). Relative settling with thawing amounts to 0.015 - 0.03 (very occasionally 0.08). The calculated heaving pressure reaches 0.0784 MPa. Krylov *et al.* do not mention the more problematic sections of trunk gas pipeline further north coming out of Yamburg or the gathering line of northern Urengoy where, in both cases, permafrost is continuous, soil iciness is high and other complicating factors are rife. Pipeline construction on the Yamal Peninsula will be even more challenging in this respect.

Currently, gas is too often transmitted at positive temperatures in zones of permafrost, or the temperature is variable from one season to the next, i.e. positive in summer, negative in winter. This leads to a degradation of the permafrost, disturbance of natural equilibrium and undesirable influences on the gas transmission installation. The depth of thawing of perennially-frozen soils after several years of gas pipeline operations with a positive temperature has reached 8.4 m on Urengoy - Nadym string 1 (Galiullin *et al.*, 1996, p.133). Pipe displacements linked with seasonal thawing and resulting thaw settlement (*osadka pri ottaivanii*, in Russian) have often been observed within the range 15 - 25 cm, but magnitudes can be much greater. Bog development and thermal erosion (*termoeroziya*, in Russian) have been noted in zones of thawing. Significant settlement of linear valve units on thawing sections has taken place. Owing to compressor station operations, the transmission of gas with a constant negative temperature is an unknown phenomenon, at least in the NPT, although the construction of gas cooling stations on all northern UGSS pipelines is planned. However, if unregulated, cooled gas transmission can initiate or accelerate undesirable cryogenic processes, notably frost heave (*moroznoye pucheniye*, in Russian), and consequently pipe deformations in zones of unfrozen soils and in the active layer in or below which a pipeline is buried.

The frost heave problem is addressed in the next subsection, followed by thaw settlement and thermal erosion.

Two other processes are of growing concern to those planning pipelines for operation in permafrost conditions. Thermal-contraction cracking (*morozoboynoye rastreskivaniye*, in Russian), sometimes known as cryogenic or frost cracking (*kriogennoye, moroznoye rastreskivaniye*), is a cryogenic process involving the development of tensile fractures from thermal stresses in frozen ground. The growth of frost cracks in the ground can cause the build-up of additional stresses in a pipe wall (Grechishchev & Sheshin, 1983, p.142; Badu *et al.*, 1989, p.429). It has not been a problem on NPT pipelines, for example the Gathering Line Operations Division of *Yamburggazdobycha* reports no failures caused by thermal-contraction cracking (Kondrat'yev, 1998), but the process in its natural form occurs intensively in many parts of the Yamal Peninsula and thus will be examined in chapter 5 only in the context of the YEGTS. The second process, stress-corrosion cracking (SCC) (*korrozionnoye rastreskivaniye pod napryazheniem (KRN)* or *stress-korroziya*, in Russian), begins with the development of small cracks, invisible to the eye, which are often found in "colonies" with all the cracks oriented parallel to the pipe's longitudinal axis. Over some years these cracks lengthen and deepen, merging together to form longer cracks. When these cracks are large enough the pipeline may leak or rupture (Ott, Surkov & Rybalko, 1992, p.523; National Energy Board of Canada, 1996, p.ix). The process takes place under the influence of the corrosional environment surrounding a buried pipeline and external tensile stresses. SCC is a common problem on pipelines worldwide and is fairly well known to pipeline designers. Although the phenomenon was first identified in the 1950s it remains poorly understood, and in the meantime the number of SCC-related pipeline failures shows no sign of decreasing both in the West and in Russia. Considerable uncertainty surrounds SCC in permafrost and whether or not it actually occurs in such conditions. Some northern pipeline specialists claim that SCC does not occur at all in permafrost. For example, Remizov et al. (1997a, p.24) and Khrenov (1998) hold the view that natural conditions necessary for development of SCC are absent in permafrost, in particular their field study location in the Urengoy GCF. The winters are too long, the water is too clean and the soils are too pure, says Khrenov. But it shall be seen that many "warm" gas pipelines float for several months each year in pools of meltwater surrounded by thawed soils, thus obscuring Khrenov's picture of an "inactive" environment. Indeed, as Ivantsov (1993, p.56) points out, a so-called "corrosional microclimate" develops around such pipelines. It is true that in the north rates of corrosion are much slower than in the south, 0.23 - 0.30 mm/year as opposed to 0.8 - 1.2 mm/year (Dinkov & Ivantsov, 1997a, p.18), but it does nevertheless occur there and so surely conditions do exist for development of SCC. Pipeline failures in the NPT have not been attributed to SCC and so it cannot be discussed further in this thesis, but clearly the uncertainty surrounding its occurrence in permafrost conditions justifies a serious research effort in the NPT or on the Yamal Peninsula.

4.3.2 Frost heave

4.3.2.1 Introduction

Frost heave is considered to be one of the most serious problems facing gas pipeline operations in northern regions. Heave occurs when there is a movement of water towards the point in the soil where freezing is occurring. Water migration occurs due to the thermodynamics of freezing in porous media, so-called water suction or cryosuction. This causes a volume increase in addition to the 9% volume increase always associated with the freezing of water. The increase in the soil's volume through the accumulation of this additional water accounts for most of the heaving. Heaving of course occurs naturally, but the influence of Man's activities, such as pipeline operations, upon natural conditions can induce and/or accelerate this process. The nature of this thesis only permits a detailed examination of the influences of pipeline construction and operation upon frost heave, without going into the process in its natural form.

4.3.2.2 Technogenic frost heave

The uniform heaving of a pipeline over a substantial distance would not be considered particularly dangerous for a pipeline, but in reality the diversity of natural conditions even over a small distance means that heaving never takes place in an entirely uniform manner. So, where there are variations in soil texture uniformity, moisture availability and permafrost continuity (thermal transition), heaving will occur differentially, as has been the case on certain buried sections of gas pipelines in the Russian North, and it is to this process that pipeline planners need to pay a great deal of attention. Some of the most important experimental investigations into differential heaving under conditions of soil texture variability (silt and sand) were conducted outside the former-USSR by a team of French and Canadian scientists led by Professor Peter Williams of Carleton University, Ottawa, Canada, between 1982 and 1989. A series of experiments using a test-section of pipe, with chilled gas being passed through it, showed that where there is a transition between soil types with marked variations in frost susceptibility (silt is more frost-susceptible than sand), a pipeline will be exposed to dangerous deformation caused by differential frost heave, as shown in Fig.4.7. The same test-section of pipe was used to investigate the effects of differential heaving at the boundary between frozen and non-frozen silt soil. The build up of strain on the pipe in these experiments (1990-93) was more rapid than in the earlier soil-type transition investigations[9].

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[9] More detail on the French-Canadian experiments can be found in the following documents:

Williams, P.J. (ed.). 1993. Gas Pipelines, Oil Pipelines and Civil Engineering in Arctic Climates. Proceedings of a seminar held in Caen and Paris, France. Ottawa, Carleton University, GSL.

Williams, P.J. *et al.* 1992. The France-Canada joint study of deformation of an experimental pipeline by differential frost heave. In: Triantafyllou, M.S. *et al.* (eds.). *Proceedings of the 2nd (1992) International*

Fig.4.7 Graph showing pipe displacement in the France-Canada soil transition experiment
(Source : Williams et al., 1992)

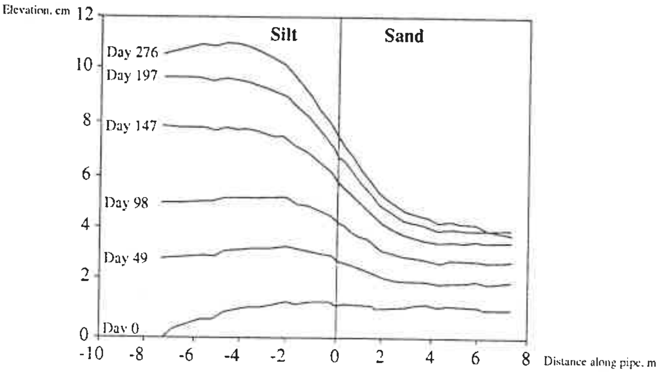
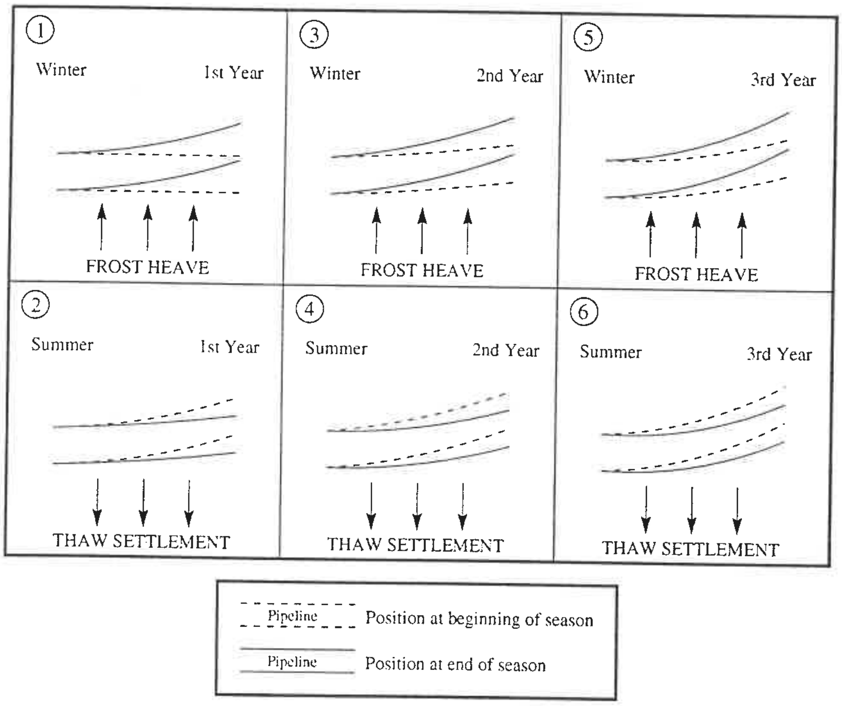


Fig.4.8 Pipeline jacking in permafrost conditions



Offshore & Polar Engineering Conference. San Francisco, USA, 14-19 June 1992. Golden, Colorado, The International Society of Offshore & Polar Engineers, p.40-45.

Riseborough, D.W. *et al.* 1993. Pipelines buried in freezing soil: a comparison of two ground-thermal conditions. Reprint from: Yoon, M. *et al.* (eds.). *Proceedings of the 12th International Conference on Offshore Mechanics & Arctic Engineering*. Book No.G00681. American Society of Mechanical Engineers, p.187-193.

More references can be found on the GSL website: http://www.carleton.ca/GSL/

Also of great concern is the process known as secondary or continuing heave, in which heaving occurs in already-frozen soil because of the migration of water which remains liquid below 0°C. Uncertainty still surrounds the band of sub-zero temperatures at which heaving will occur. Professor Williams suggests that this process is unlikely to occur below -2°C to any significant extent, although others (for example, Parmuzin, 1980, p.135) believe that it could occur down to -5°C. It would therefore seem that secondary heaving is most likely to take place in so-called "warm" (relict) permafrost, which is normally warmer than -2°C. If this process occured differentially it could also be dangerous for a pipeline, although the magnitude of such heave is small over a long time and engineers are still unsure about how sensitive pipelines are to this process. In general, rates of heaving in secondary heave are slower than for ordinary heaving (non-frozen to frozen state). Another very important heaving process is known as frost jacking (*moroznoye vypuchivaniye* or *vymorazhivaniye*, in Russian). A pipeline may be heaved up in winter in the active layer but, the following summer when some thaw settlement takes place, the pipe section will not return to its original pre-heave position. Over a number of years, the cumulative result is that the pipeline is jacked up, as shown in Fig.4.8.

In the frost heave context, mixed sand and clay soils, such as *supes* and *suglinok*, are problematic for those planning pipelines for the Russian North. According to Oswell *et al.* (1995, p.574), *supes* is a silt-like soil having some clay (3 - 10%) and sand, but mostly sand. *Suglinok* is also a silt-like soil which has clay and sand, but relatively more clay (10 - 30%) and less sand than *supes*. While the sand element is highly permeable, the clay element exerts great suction forces, drawing in water from adjacent areas. Such soils, particularly *suglinok* and wet *supes*, can be described as highly frost-susceptible and if heaving can be induced within them, i.e. where the temperature is warmer than -2°C, represent a real threat to cooled-gas pipeline operations in such conditions. The buried sections of the NAGSS which were displaced due to frost heave passed through *supes* and *suglinok* soils and an investigation carried out in 1974 on a buried section of the MYaB (529 mm diameter, winter gas temperature is approximately -7°C, summer - slightly above 0°C) revealed that frost heaving had pushed the pipe up by 20 - 50 cm in some localities with such soils (Turbina, 1980, p.32).

4.3.2.3 A case study of trunk gas pipeline heaving and jacking

i) Case study methodology

There are three ways of approaching case studies concerning the problem of trunk gas pipeline stability in permafrost conditions. These approaches are just as applicable to cases of thaw settlement and other cryogenic processes leading to pipeline instability.

1) Using engineering-geocryological research already completed (published openly in books, journals, special reports, or acquired through specialists working for gas industry companies, such

as *Gazprom*) which describes studies conducted on operational pipeline systems and which provides accounts of what has happened to that particular system under the influence of cryogenic processes over an extended period of time. This simply involves describing what has already been studied, followed by one's own analysis.

2) Making predictions (what the Russians called "*prognoz*") about possible pipeline - permafrost interactions given the local geocryological conditions which have already been described. This can be subdivided into:

i. making predictions for pipelines that are already operational but for which no known studies have been carried out investigating pipeline - permafrost interactions and current integrity;

ii. making predictions for pipelines which are planned. Preferably, design details for the planned pipeline would be known. Details on local geocryological conditions would also be known.

3) Conducting one's own field work in the region in question and either investigating local geocryological conditions, then taking the approach of 2), or, if possible, also studying the condition of operational pipeline systems in a known geocryological environment, then taking an approach similar to 1).

This thesis has had to make use of 1) and 2) because new fieldwork in regions such as the NPT was impossible given constraints imposed on foreign scientists by Russian authorities and gas companies. In any event, the latter still makes 1) and 2) relatively difficult. The following case study and the one in 4.3.3.6 reflect these approaches.

ii) The case study : string 1 of the Nadym - Punga gas pipeline

In order to estimate the parameters of seasonal heave and their variations in the presence of industrial development, monitoring of heave was organized by *VSEGINGEO* at 17 heave-measurement sites in the northern *taiga* and forest tundra subzones of the NPT (Nevecherya, 1983a, p.131; Nevecherya, 1983b, p.156). These include some of the longest running northern gas pipeline monitoring efforts in Russia, initiated in autumn 1971. Each site incorporates two or three profiles situated in parallel, 5 - 10 m apart. On each profile, 10 heave-measurement markers were placed at 5 - 10 m intervals. Such a number of markers enabled the team to collect data in a quantity sufficient for statistical analysis. In autumn, before freezing, and in spring, before thawing, levelling of the markers occured from the depth reference point which was not subject to heaving. It should be noted that the devices used for measurement were crude and unlikely to have produced results as accurate as those possible today.

In order to estimate the variation of parameters of frost heave during industrial development at three of the northern *taiga* sites, in each case one of the profiles was located on a pipeline r-o-w (Nadym - Punga strings 1, 2, 3 and 4), the second parallel to it in natural conditions. The third consisted of markers installed on a section of string 1 (1220×20 mm diameter). Natural characteristics of the three sites, located approximately 40 km south of Nadym, are given in Table 4.5. The sites are located in the zone of massive-island distribution of high temperature ("warm") permafrost (Moskalenko, 1996, p.399).

Table 4.5 **Natural characteristics of northern West Siberian heave-measurement sites located in the northern *taiga* natural-territorial complex on the right bank of the R.Kheygiyakha (Yamalo-Nenetskiy AO) to measure natural and technogenic heave** (Source : Nevecherya, 1983a, p.134)

Site	**Geomorphological level**	**Local characteristics of the natural-territorial complex**
1	Third lacustrine-alluvial plain	Hummocky surface with very sparse larch-spruce-cedar trees. Seasonally-freezing layer composed of *suglinok*, *supes* and dusty sand.
2	Third lacustrine-alluvial plain	Flat surface with spruce-birch-cedar open woodland. Seasonally-freezing layer composed of *suglinok*, *supes* and dusty sand.
3	Third lacustrine-alluvial plain	Flat drained surface with larch-pine woods. Seasonally-freezing layer composed of dusty sand, *supes* and less often *suglinok*.

The following was noted at site 1 regarding frost jacking of the 1220×20 mm diameter pipe section. This pipe was laid in the trench and backfilled with local soil. As shown in Fig.4.9, the total magnitude of heaving of the soil surface along the r-o-w varied from 26 mm to 147 mm in the winter of 1972-73 and from 3 mm to 72 mm in the winter of 1973-74. Frost heave of the pipe amounted to 32 - 61 mm and 16 - 86 mm respectively, which is comparable with the total heave of the surrounding soil. As is evident from Fig.4.9, soil heaving on profile 1 along the r-o-w is highly variable. The pipe was heaved up without serious deformation, which is explained by the pipe's rigidity. However, uniform jacking up of the pipe did not occur. Additional deformation of the pipe took place in the winter of 1972-73 in the order of 29 mm over the length of a 36.3 m curving section of the pipe and in the following winter it attained 86 mm over a 61.3 m curving pipe section. It should be noted that the considerable displacement of the pipe occurred because of the tangential forces of the heaving. Soil thawing at site 1 allowed the pipe to revert to its initial position, this is to say no residual jacking was recorded. At site 2 the pipe had been laid on the ground and covered

Fig.4.9 Heave of soil and pipe on profile 1 of heave-measurement site No.3 on the right-bank of the R.Kheygiyakha, Yamalo-Nenetskiy AO.
(Source : Nevecherya, 1983a, p.140, Fig.IV.10)

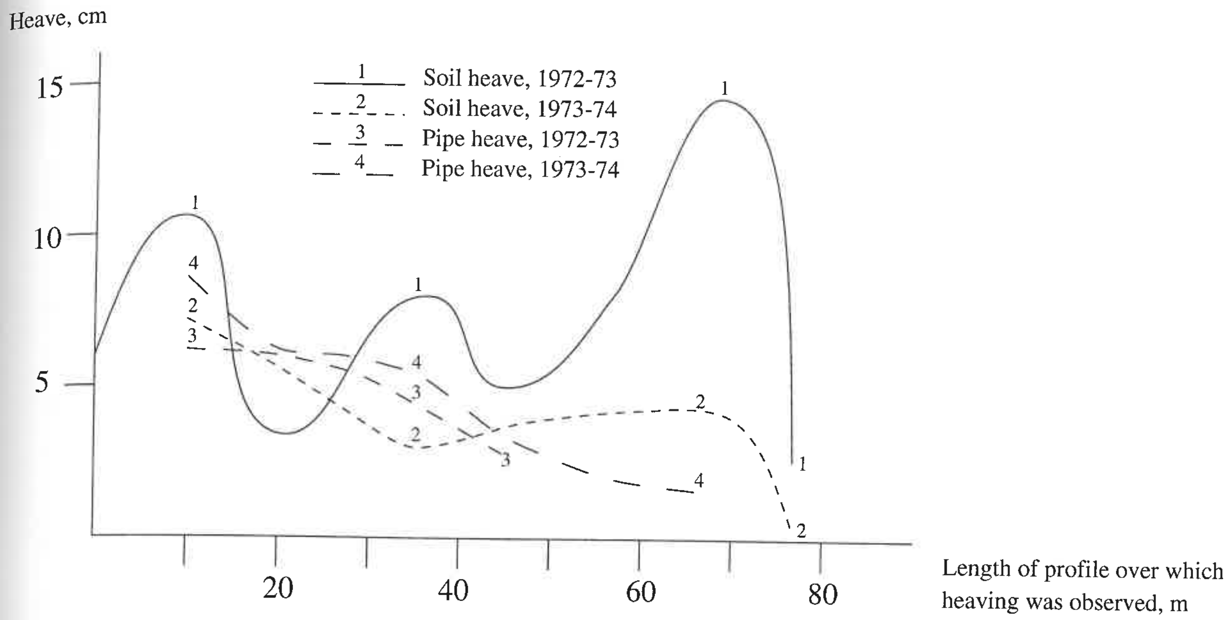
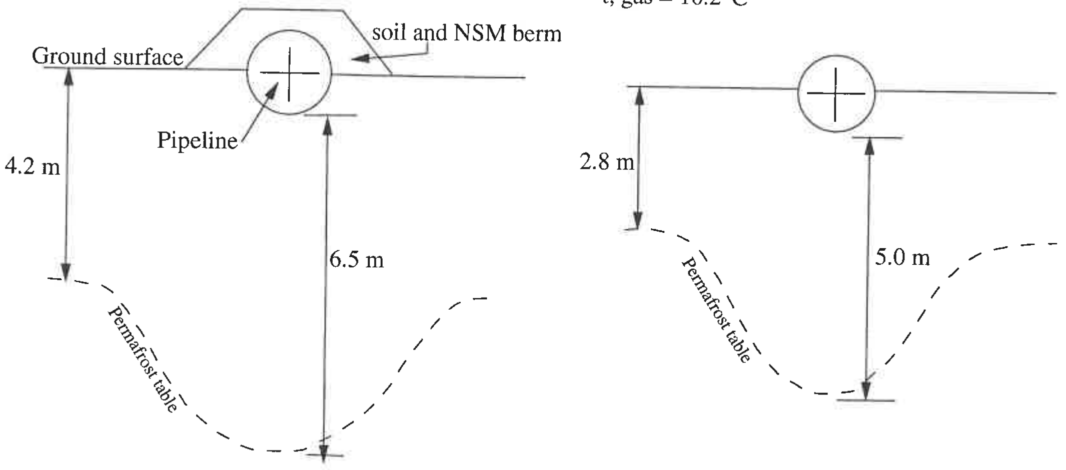


Fig.4.10 Thaw bulb dimensions beneath the Urengoy - Nadym 1 trunk gas pipeline in summer 1984 at various distances from the Novourengoyskaya compressor station
(Source : Galiullin et al., 1996, p.132, Fig.5)

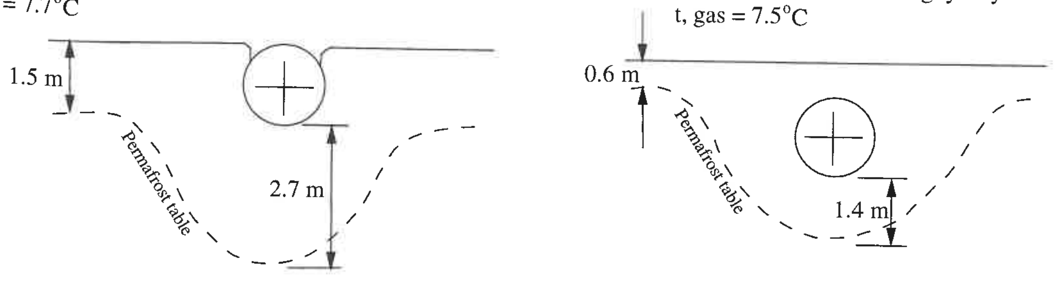
Location: 5 km from Novourengoyskaya compressor station
t, gas = 13.3°C

Location: 28 km from Novourengoyskaya compressor station
t, gas = 10.2°C



Location: 47.8 km from Novourengoyskaya compressor station
t, gas = 7.7°C

Location: 50 km from Novourengoyskaya compressor station
t, gas = 7.5°C



with sand. Jacking of the pipe with freezing of the soil base took place in an almost uniform fashion. At site 3 in the area where the seasonally-thawing layer is composed of dusty *suglinoks*, with the depth of thawing gradually increasing, the total magnitude of heave and the magnitude of pipe jacking increases. The heave of the soil and jacking up of the pipe reached respectively 30 mm and 42 mm in the winter of 1972-73 and 76 mm and 68 mm in the following winter. In the following summer the pipe not only returned to its original position, it actually settled below this level due to settlement of the soil as a result of the increased depth of seasonal thawing.

Thus the magnitude of jacking up of pipelines laid below and on-ground proved, in this case, to be comparable to that of heave on the r-o-w. However, due to the rigidity of the pipe, it deformed in the vertical plain more evenly than the heaving of the r-o-w's soil. The length of individual deformations of the 1220 mm pipe reached 60 - 80 m, while the dimensions of individual heave mounds (caused by soil heaving of the seasonally-freezing layer) on the r-o-w did not exceed 10 m.

The territory studied, especially its higher geomorphological levels, is characterized by intensive heave of soils of the seasonally-thawing -freezing layers. Industrial development, including pipeline construction and operation, caused a sharp increase in the total magnitude of heaving at most sites (by 2 - 3 times with heaving of the seasonally-thawing layer and by 1.5 - 2 times with heaving of the seasonally-freezing layer), and consequently an increase in the irregularity of heaving by area (differential heave) and also the seasonal pulsation and residual jacking up of various structures, notably pipelines (cooled or transporting products whose temperatures vary seasonally) (Nevecherya, 1983a, p.140-142; Badu *et al.*, 1989, p.429).

That technogenic frost heave actually took place on this section of Nadym - Punga 1 presents us with the question of why and how it could have occurred. The answer to this question might well lie chiefly in the fact that at the time of these field observations the Nadymskaya compressor station had not yet been commissioned. This station, known locally also as "kilometre-0", was built in the 1976-77 winter season and commissioned soon afterwards. The following are likely contributary factors:

1. in winter the gas transmitted from the Medvezh'ye GCF (commissioned in 1972) could have been cooled by AVO to temperatures of approximately +12°C after compression at the Pangodinskaya compressor station;
2. this gas would cool further on expansion (Joule-Thomson effect) during transmission through the pipeline. This cooling process would have occurred extensively on the 120 km section between the Pangodinskaya compressor station (commissioned in 1973) and the approximate area of these heave-measurement stations south of Nadym;
3. as mentioned above, the Nadymskaya station, which is now located between 13 km and 30 km upstream of the measurement sites, did not then exist. Its warming influence (compression) on the gas was therefore not an issue in the early 1970s;

4. soils in the area just south of Nadym are frost-susceptible *supeses*, *suglinoks* and dusty sands. The *suglinoks* are highly icy. Soil temperatures would not have been much below 0°C, if at all, in this part of the NPT. In fact, the annual average soil temperatures in the area lie in the range -3....+1°C (Moskalenko, 1997, p.89).

Conditions therefore existed for some technogenic frost heave to occur. With the commissioning of Nadymskaya in 1977, the picture changed dramatically on this pipeline section. Evidence of significant changes downstream of Nadymskaya is provided in subsection 4.3.3.3. The installation and commissioning of compressor stations in the NPT marked the beginning of the evolution of a so-called "thaw ⇒ freeze-thaw" process, the development of which will be addressed in subsections 4.3.3.5 and 4.3.3.6. But in terms of frost heave, it is likely that pipeline ruptures did not occur because the magnitude of the heave itself was not great, reflecting the relatively low soil iciness and the large diameter pipes with thick walls were rigid enough to withstand the effects of the heaving forces. Heaving in icy or highly icy soils, typical further north in parts of the Tazovskiy and especially Yamal peninsulas, would be more dangerous since the magnitude of frost heave in such soils is generally much greater.

4.3.2.4 Conclusion

Differential heaving has occurred on a well-studied section of the buried Nadym - Punga 1 apparently without serious repercussions, such as ruptures. Although no ruptures on this pipeline have been attributed directly to frost heave, the investigations conducted in the Nadym area allow us to demonstrate that without the influence of a compressor station nearby, frost heave will be the dominant cryogenic process at work. Heave has also taken place in frost-susceptible *suglinoks* and *supeses*. Such soils are also common on buried sections of the NAGSS (although this pipeline system has a different annual temperature regime of surrounding soils and of transported gas), where there have been a large number of ruptures. That ruptures are far more common on the NAGSS than on the examined stretch of the UGSS is most probably a reflection of the differing annual range of gas transmission temperatures and pipe rigidity of the respective pipeline systems. The NAGSS buried sections vary between 325 mm and 529 mm in diameter (wall thickness : ca.10 mm), whereas Nadym - Punga 1 is 1220 mm diameter (wall thickness : 20 mm). Nevecherya (1983a, p.139) makes the point that the rigidity of Nadym - Punga 1 is responsible for more uniform deformation of the pipe in the vertical plain than the soil heave observed in the pipeline's r-o-w. The rigidity of pipelines in the buried floodlplain sections of the NAGSS is far less and thus much more susceptible to ruptures caused by uneven (differential) heaving.

Frost heave related ruptures of gas pipelines seem to be much more prevalent on small-diameter pipelines such as the NAGSS, as opposed to most parts of *Gazprom*'s UGSS northern section. This must be connected with the absence of numerous compressor stations on the NAGSS and thinner pipe walls. As shall be seen in the following subsection (4.3.3), thaw settlement related problems on the UGSS are serious, due in no uncertain terms to the functioning of numerous compressor stations. Therefore, a major conclusion here could be that in the context of trunk gas pipeline operations in the Russian North today, settlement-related pipeline ruptures are associated with lengthy pipeline systems that need compressor stations, whereas heave-related ruptures are associated more with shorter systems that require few compressor stations or none at all.

4.3.3 Thaw settlement

4.3.3.1 Introduction

Thaw settlement is the cryogenic process of subsidence caused by the thawing of excess ice (segregated and bedded ice) in the ground due to natural or anthropogenic (and technogenic) changes of heat exchange at the earth's surface. It is one of the most widespread cryogenic processes in northern West Siberia, together with frost heave. Characteristic landforms resulting from thaw settlement in this part of the Russian North, generally resembling depressions in the earth's surface, include thermokarst lakes and *khasyreys*. Thaw settlement in its natural undisturbed form and the relief features typical of it are not described in this thesis, while technogenic thaw settlement resulting from pipeline operations is examined below.

4.3.3.2 Technogenic thaw settlement

Taken on its own, thaw settlement, resulting from the melting of ice-rich soils, does not represent a serious threat to the reliability and safety of pipeline operations. While differential settlement is of more concern, it still does not pose the kinds of problems indicative of differential heaving. Ordinary or differential settlement are passive processes resulting in the loss of support or bearing-capacity of the soils, whereas differential heave implies very powerful forces, acting within a confined area (a few metres), pushing a pipeline upwards.

Nevertheless, the initiation of thaw settlement can bring with it a set of related problems, including the subsequent development of thermal erosion, and in combination with other factors (such as corrosion and cryogenic processes characteristic of winter time, for example frost heave) it has contributed to many pipeline displacements and ruptures in northern Russia. Some oil pipeline ruptures, such as those experienced on the Vozey - Usinsk oil gathering line (325 mm diameter) in the vicinity of the Vozeyskoye OGF in the Komi Republic's far north, have been attributed in part to differential settlement of soils (Seligman, 1996, p.42). It is possible that without the presence of cracks formed as a result of corrosion, these ruptures would not have taken place, that is to say thaw settlement on its own is unlikely to have led to such ruptures.

Thaw settlement has been a very serious problem in the NPT. As in the case of the Vozey - Usinsk oil pipeline ruptures referred to above, thaw settlement is not the sole cause of accidents on the NPT large-diameter gas pipelines. However, thaw settlement can be defined as the major factor contributing to, or initiating, the overall reduction of reliability and safety of these pipelines. The following section provides an insight into the current situation in the NPT.

4.3.3.3 Trunk gas pipeline - permafrost interactions associated with thaw settlement in the NPT

i) The root of the problem:

In the opinion of RNGS's Oleg Ivantsov (1995) and Guram Odishariya (1996), a senior member of the *VNIIgaz* research institute who specializes in the study of pipeline - permafrost interactions, perhaps the single most important factor contributing to the deterioration in the condition of trunk gas pipeline strings operating in permafrost (especially in the NPT) is the lack of temperature regulation of transported gas. It can best be described as the "root" of the overall problem. Not only has this led to unreliable and unsafe pipeline operations, but there has also been a great deal of environmental damage associated with it. Hereafter, this thesis will be concerned predominantly with the former, but studies concerning the latter, namely alterations to the geocryological environment which do not necessarily result in pipeline displacement, can be found in works such as Moskalenko (1996, p.399-407; 1997, p.88-94).

As discussed in section 4.2, if the post-compression gas temperature is not regulated artificially it will be determined by ambient temperature patterns on a day-to-day basis. Thus, the gas will have a temperature well above 0°C in summer and well below 0°C in winter. This is the case most notably with the NAGSS. The temperature of gas transported through buried trunk pipelines in the NPT is often above +20°C in summer and below 0°C in winter, made possible through the use of AVO. With high temperatures in summer a thaw bulb develops around the pipeline which, after five to seven years, may reach a depth of 7 m or more below the pipe. The pipeline may subside to varying degrees as a result of thaw settlement associated with the development of this thaw bulb. But the extent of thaw settlement also depends upon the iciness of the soils. For instance, settlement in zones of ice wedges occurs very intensively. Over two to three years ice wedges can thaw completely, leaving the r-o-w dissected by a network of gullies. Ivlev *et al.* (1989, p.406) describe an unspecified section of pipe which had settled by a maximum of 77 cm over seven years. Where the settlement occurred unevenly, an 86 mm flexure of the pipe developed. The settlement of a gas pipeline is likely to be followed by its upward floatation. A gas pipeline, which is in any case buoyant, will float up once the soils around it have lost their bearing capacity and the area has become waterlogged and boggy, especially if ballasting or anchoring is absent or ineffective. However, oil pipelines will, as a rule, settle in such circumstances because they are heavier.

Thawing immediately downstream of a compressor station -

It is recognized that the most serious thawing takes place immediately downstream of a compressor station, since the temperature of transmitted gas is higher here than further along the pipeline. According to Ivantsov (1996a) in summer the temperature of gas as it enters a trunk pipeline after compression can in exceptional cases reach +45°C if, for example, there are problems with the AVO. The following example demonstrates the problem. In the early 1980s *VNIIgaz* and *VNIIST* carried out field-studies of thawing at the base of buried 1220 mm and 1420 mm diameter strings 15 km downstream of the Nadymskaya station on the Nadym - Punga gas pipeline corridor (Ivantsov & Kharionovskiy, 1993a, p.51). Soils in this area are mainly *supeses* and dusty sands (22 - 27% moisture content) overlain by a 0.8 m layer of peat and have an average annual temperature from 0°C to -0.9°C. After the commissioning of the Nadymskaya compressor station in early 1977, the average annual gas temperature of strings 2 and 3 of the pipeline corridor increased from +3.2°C to +22°C. This in turn led to a considerable increase in the depth of thawing, figures for which are provided in Table 4.6, and even to the cessation of seasonal freezing. The depth of thawing continues to deepen. Rivkin (1997, p.166) reports that the thaw bulbs beneath strings 2 and 3 are now 10 m and 15 m deep respectively. These are deeper than any thaw bulbs reported beneath the initial sections of pipeline from Yamburg and Urengoy. It should be noted that this stretch of the Nadym - Punga corridor is the same (bar a few kilometres) as that subject to the heave measurement observations conducted since the early 1970s and described in subsection 4.3.2.3. The difference now being the presence of a compressor station.

Table 4.6 **Increase in depth of soil thawing 15 km downstream of the Nadymskaya compressor station, 1976-80** (Source : Ivantsov & Kharionovskiy, 1993a, p.51)

Year	**Term of operation (years)**	**Nadym - Punga pipeline corridor**		
		String 2	**String 3**	**String 4**
		Depth of thawing (m)		
1976	3	1.6		
	1		1.8	1.8
1977	4	2.6		
	2		2.9	6.5
1980	7	3.8		
	5		6.3	–

Is the situation much different for pipelines transmitting gas cooled by AVO and further by SOG? SOGs at selected UKPGs and the Purovskaya compressor station at the Urengoy GCF cool the gas to temperatures usually not much higher than +10°C (see Fig.4.3). Nevertheless, such a temperature is easily high enough to cause thaw related problems on the initial stretch of trunk pipelines after SOG cooling at Purovskaya. In fact, 20 km from Purovskaya twenty thermal stabilizers have been installed in a peatbog either side of one pipeline string and these use propane as a refrigerant (Lashin, 1997). These work on the same principle as the so-called heat pipes within VSMs on the Trans Alaska Oil Pipeline which use anhydrous ammonia as a refrigerant. The stabilizers and heat pipes prevent heat from the warm product being conducted down into the ground. The combination of the Purovskaya SOG and these thermal stabilizers seems to have had a positive effect on the Urengoy - Pangody section of trunk gas pipelines. These are apparently stable (*ibid.*).

In spite of the as yet reliable operation of most trunk gas pipelines in the NPT, there is an important message that comes out of the discussion above. It appears that SOGs are not being used effectively. Financial constraints are restricting the levels of cooling. Gas is not being cooled to temperatures below 0°C and thaw-related problems are still occuring downstream of the operational Purovskaya SOG. The same conclusion can be drawn from the operation of SOGs at UKPG-11, -12 and -13 at the Urengoy GCF. These particular SOGs, already referred to earlier in subsection 4.2, are discussed later in the context of thaw bulb development around two strings of Urengoy's gathering line.

Thawing further downstream -

We have established that thawing is problematic immediately downstream of compressor stations, with or without SOGs, in the NPT. We must now examine the dynamics of thawing along a whole section of pipeline, that is to say between two compressor stations, to compare thawing near and far from compressor stations. Firstly, we shall take the Novourengoyskaya - Pangodinskaya section of Urengoy - Nadym 1. Fig.4.10 shows the dimensions of thaw bulbs beneath the Urengoy - Nadym 1 pipeline string in four separate locations : 5 km, 28 km, 47.8 km and 50 km downstream from the Novourengoyskaya compressor station. The thaw bulb at 5 km is much deeper than that at 50 km, partly reflecting the falling gas temperature the further away one gets from the station. These measurements were taken in summer 1984. However, Galiullin *et al.* (1996, p.133) report that maximum thaw depths at the time of writing were 8 - 10 m, as opposed to the 6.5 m shown in the diagram. In addition, the diagram shows that nearer Novourengoyskaya the pipeline has floated up and broken through the surface. In fact, in 1993 there were 72 km of these so-called "defective" sections of pipeline within the Novourengoyskoye *LPU* (*ibid.*, p.133). Repair work on these sections began in 1990. This involved covering the exposed pipe with sheets of NSM, followed by a soil prism or berm on top, as shown in Fig.4.10 (5 km mark). The repair work has apparently stabilized such sections (*ibid.*, p.136). The Purovskoye *LPU* possessed only 26 km of such pipe sections in

1993, this smaller total being indicative of the effectiveness of the SOG at the Purovskaya compressor station. The problem of buried gas pipelines breaking through the surface will be examined further below.

The dynamics of thawing between two compressor stations are also clearly demonstrated on the Yamburg - Nyda section of pipeline corridor. According to Lashin (1997) 9 m diameter thaw bulbs have formed around some stretches of pipeline strings. The thaw bulbs are particularly prevalent beneath the first 150 km of pipeline corridor from the Yamburg GCF. Throughout this section of corridor, transmitted gas temperatures are above 0°C in summer, as shown in Fig.4.4. Beyond the 150 km mark, gas temperatures are generally sub-zero year-round. Likewise, the majority of "defective" sections are located on the first 100 km from Yamburg. Some strings from Yamburg have been displaced by 40 cm from their design position over tens of kilometres, but Lashin does not consider this magnitude of displacement to be of great concern. This section of corridor presents us with another important fact. The thaw bulbs reach only 3 m in depth below Yamburg - Yelets 2 (Galiullin *et al.*, 1996, p.133). These are not as deep as those beneath Urengoy - Nadym 1 because of the relatively cooler temperature regime on strings from Yamburg (often sub-zero). Thus, it is inaccurate to say that the largest thaw bulbs will be downstream of compressor stations without operational SOGs (the SOG at Yamburgskaya has not yet been commissioned). The shallower thaw bulbs and cooler temperature regime will permit restoration of permafrost after only three years of year-round gas transmission at -2°C when the SOG is finally commissioned, as opposed to 12 years for the Urengoy - Nadym 1 (*ibid.*, p.134-136).

Evidence of deeper thawing further south is provided by separate investigations on pipelines from Medvezh'ye and Urengoy, some of which are referred to by Ivlev *et al.* (1989, p.401). They showed that on one semi-submerged pipeline string through which gas was transported at a constant temperature of 15 - 17°C, the soil temperature at a depth of 10 m beneath the pipe base increased by 0.5....0.6°C, as shown in Fig.4.11, between 1975 and 1982, and the permafrost table fell to more than 10 m. Such an increase in soil temperatures at a depth of 10 m was observed between 1978 and 1984 on a different pipeline transmitting gas at more variable temperatures (-5....+14°C). Both these temperature regimes are more extreme than that of the Yamburg - Nyda corridor.

It is not simply the linear part of NPT trunk gas pipeline systems that is seriously affected by unregulated gas transmission temperatures. In the opinion of Vladislav Lashin (1997), Leading Engineer at the Nadym Gas Production Enterprise of TTG, one trunk gas pipeline component that is susceptible to the thermal influences of poorly regulated gas transmission is the T-joint between the

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Fig.4.11 Temperature change of frozen soils with depth under the warming influence of a gas pipeline
(Source : Ivlev et al., 1989, p.400, Fig.120v)

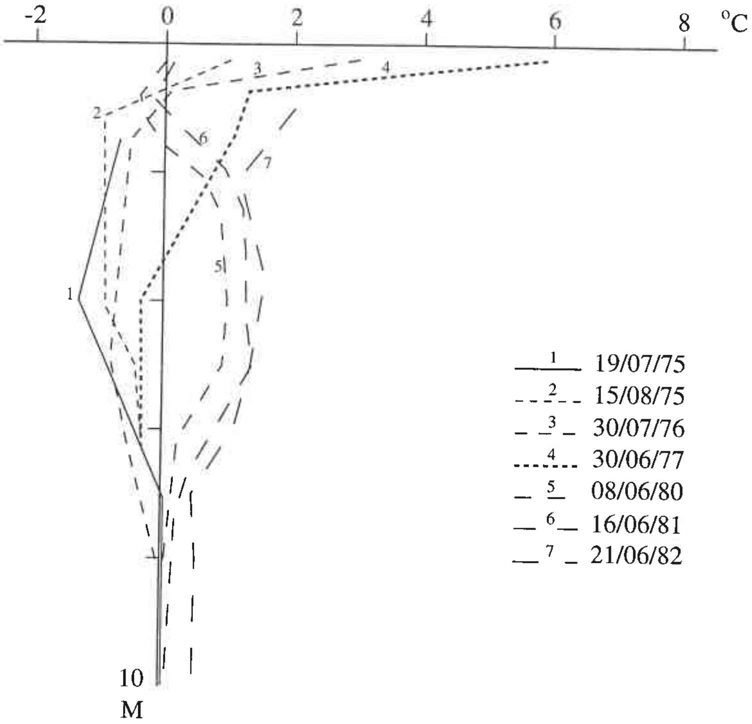
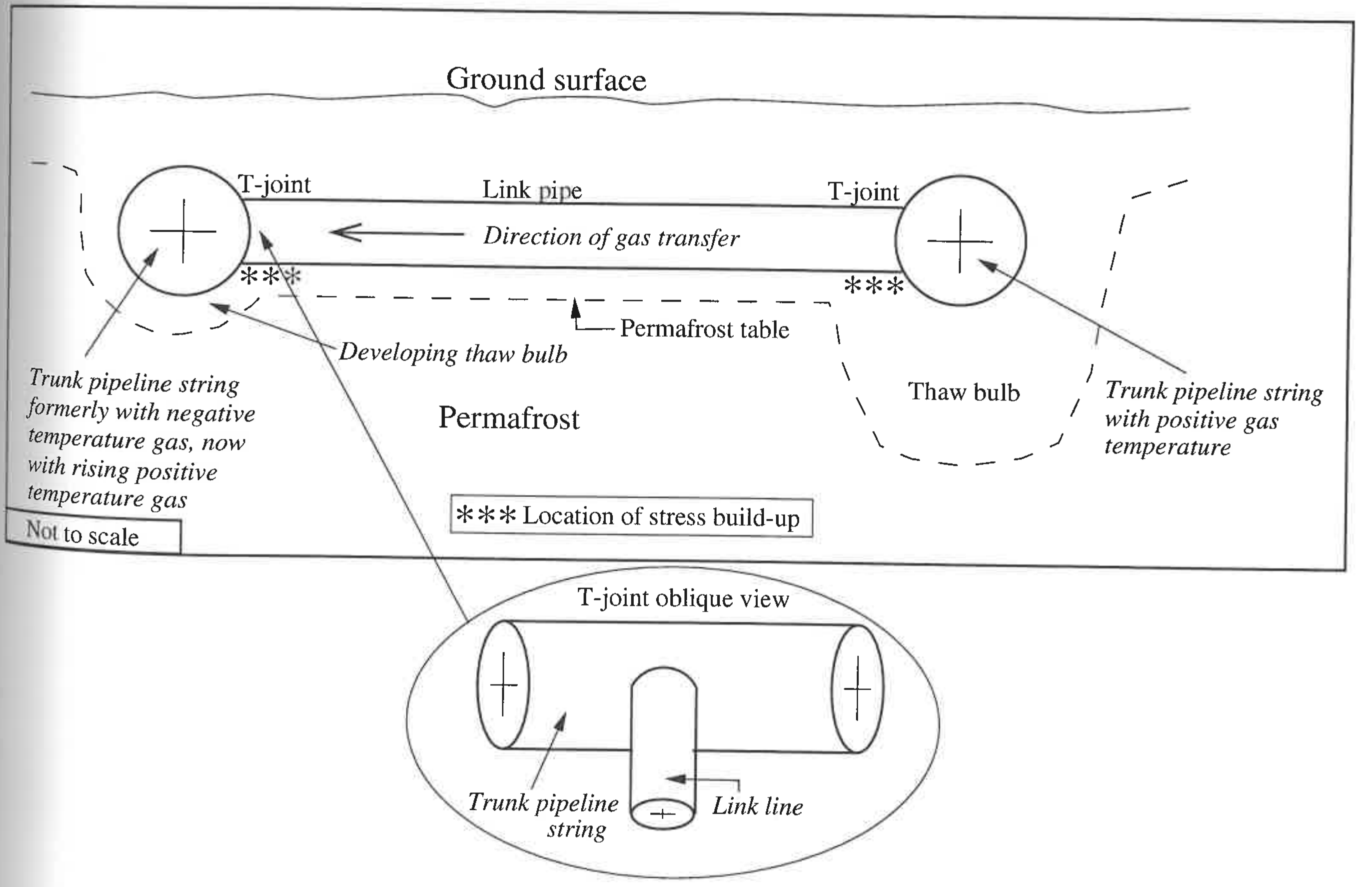


Fig.4.12 Stress build-up in link line T-joints caused by gas transfer between adjacent trunk pipeline strings (profile view)



trunk pipeline itself and a pipe section linking it to an adjacent pipeline, known as a link line[10]. The problem lies in the following. The temperature of gas transmission varies from string to string within the same corridor at any time of year. If one string transmitting gas with a positive temperature must be shut down and its gas transferred to an adjacent string which transmits gas at cooler, even negative temperatures, stresses will build up around the joints of the trunk and link pipes as shown in Fig.4.12, and a thaw bulb will develop around the receiving string as warm gas penetrates it. The pipes will perhaps become unstable, losing their original position due to the loss of supporting capacity of surrounding soils as they thaw and stresses build up. Concern about this problem has led *VSEGINGEO* to initiate remote sensing of these link sections to monitor thermal fields around pipelines in the NPT.

ii) "Floating up" and deformation of gas pipelines:

As a result of the annual thawing of soils around pipeline strings in the NPT, channels have developed through thermal erosional processes with soils being washed away by meltwater during the summer months (thermal erosional processes are described in more detail in subsection 4.3.4). The subsequent loss of soil load-bearing capacity and inadequate ballasting means that the pipelines sometimes lose longitudinal stability and "float" upwards, as shown in Fig.4.6.

There are currently 400 km of "floating" gas pipelines in northern Russia (Ivantsov, 1996b and 1998), but in spring 1988 there were 2000 km of pipelines affected in this way and between 1981 and 1987 more than 50 cases of associated buckled pipeline were repaired by TGP alone (*ibid*; Dinkov & Ivantsov, 1997c, p.29). The curvature of these buckled sections reached 5 m or more, with seasonal fluctuations in the range 0.5....0.7 m.

The phenomenon of pipe buckled in this way is also a common problem outside the permafrost zone, in boggy regions composed of peat which are inundated by floodwaters during the spring thaw and where seasonal freezing is intense. Such regions include much of the Komi Republic, Khanty-Mansiyskiy AO and more southerly parts of West Siberia. Some studies, such as those carried out by *Uraltruboprovodstroy*, *YuzhNIIgiprogaz* and *PNIIIS* have shown that a thorough hydrogeological survey of a pipeline r-o-w can determine whether in certain cases it is possible to use local soils as a ballasting material for the pipeline, enabling a reduction in the amount of costly reinforced-concrete weights or anchor structures. This approach was used in the planning of the Omsk - Novosibirsk 1220×12/14.3 mm diameter gas pipeline which lies well south of the permafrost zone (Kulagin, 1993, p.28). The results of many studies have shown that one of the main causes of damage to trunk gas pipelines in southern West Siberia is buckling (Klyuk, Stoyakov &

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[10] In this context, a link line (*peremychka*, in Russian) is used to transfer gas supplies between strings in the event of emergencies when a string/s must be shut down but transmission levels must be maintained through other strings. They are located every 40 - 50 km along the trunk pipeline corridors (Lashin, 1997).

Timerbulatov, 1994, p.4). Buckling of gas pipelines with an 8 m sag bend and a 150 - 250 m length buckled section have been observed. In such cases, the longitudinal stresses can exceed the design values and in the event of certain combinations of longitudinal and hoop stresses the pipe can be damaged and rupture.

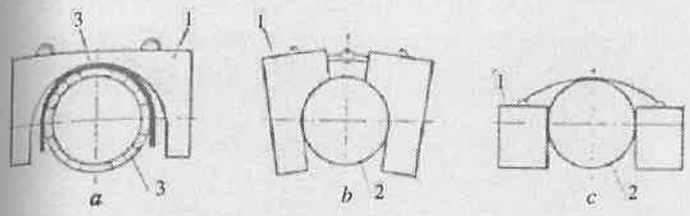
Returning to the permafrost context, there is another important factor contributing to the rising up of buried gas pipelines which helps to explain why they break through the surface. Again, this is frequently exacerbated by thermal erosion. The problem here lies in the massive difference between the temperature in winter, the only time when pipelines are laid in permafrost conditions and when the new pipe could be exposed to temperatures of -30°C or lower, and that in summer, after commissioning, when the gas could be at +15 or +20°C. Ivantsov has emphasized this phenomenon in many articles (for example, Ivantsov 1993a, p.56 and 1998), adding that the maximum calculated temperature range can reach 80 - 100°C in extreme cases. It is this range of temperatures that causes substantial thermal expansion and this in turn gives rise to huge axial forces which can be in the order of 2500 tonnes for a 1420 mm diameter pipe section. This causes the pipe to arch upwards, sometimes over a distance of 2.5 km, and break through the ground surface. Conventional ballasting, such as reinforced-concrete loading or simple anchoring devices, will not keep the pipeline in its design position under such circumstances, as shown in Fig.4.6b.

4.3.3.4 Gas pipeline ballasting and anchoring in permafrost

This is a logical point at which to describe the variety of ballasting and anchoring devices used over the last 20 or so years in the NPT and other parts of West Siberia where bogs are widespread. Early accounts of pipeline ballasting and anchoring principles and mechanisms tell us that the most important objective for those taking part in pipeline construction was to increase commissioning rates of pipeline system sections, something discussed in detail in chapter 3. While only the occasional reference is made by Blinov (1980, p.23) to increasing the quality of ballasting, he makes much more of the fact that his construction division, *SU-11* of the *Severtruboprovodstroy* trust based in Nadym, had achieved ballasting rates of 1 - 1.2 km per day. Blinov says that such rates were only possible through a whole set of measures ranging from improved worker conditions during construction on the pipeline r-o-w, to improved ballasting technology.

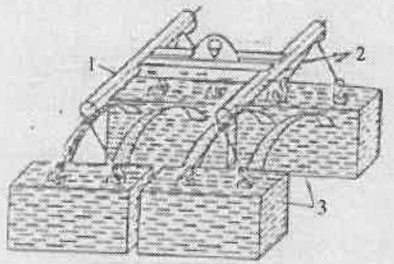
The earliest forms of ballasting included concrete and reinforced-concrete weights of up to four tons each (Shcherbina *et al.*, 1981, p.108). These would be in the form of a saddle, hinged or belt-like, as shown in Fig.4.13a. Orudzhev (1980, p.86-87) suggested that the hinged and belt weights were the most reliable since they were less likely to tip off the pipe thus reducing the likelihood of displacement through upward floatation.

Fig.4.13 Ballasting and anchoring mechanisms for trunk gas pipelines in permafrost



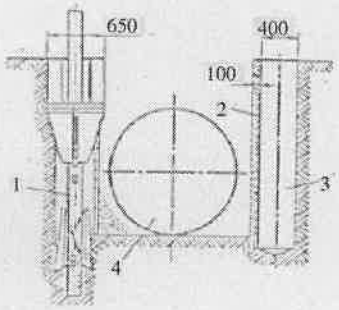
4.13a

Types of ballasting mechanism - a. saddle; b. hinged; c. belt.
1. reinforced-concrete weight; 2. pipeline; 3. protective element.
(Source : Orudzhev, 1981, p.87, Fig.22)



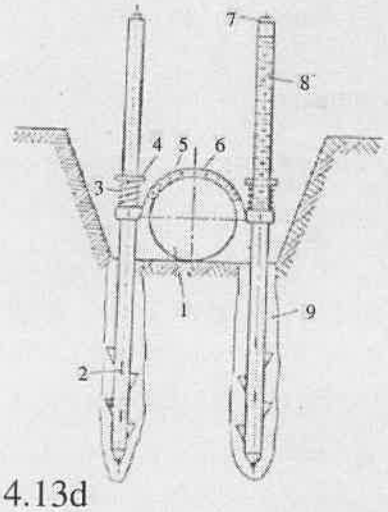
4.13b

UBO weighting compound.
1. cross-member; 2. slings; 3. UBO weights.
(Source : Blinov, 1980, p.24, Fig.2)



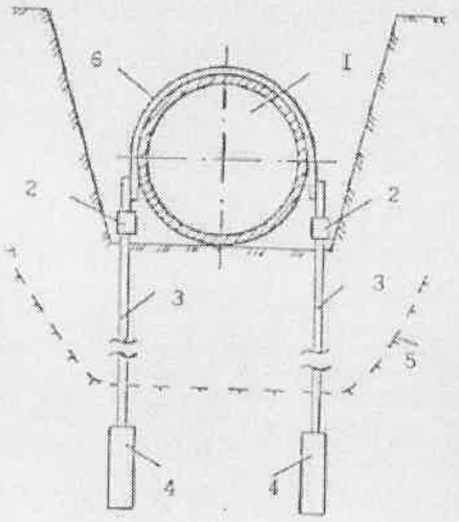
4.13c

AR-401 exposable anchor.
1. AR-401 anchor; 2. link-piece between borehole and trench;
3. borehole; 4. pipeline.
(Source : Blinov, 1980, p.22, Fig.1)



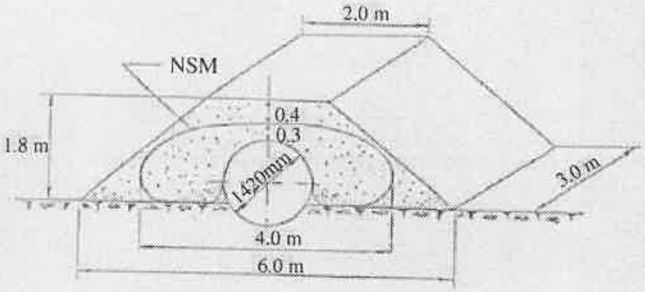
4.13d

Thermo-anchor
1. Pipeline; 2. thermo-anchor; 3. shock-absorber;
4. supporting washer; 5. belt; 6. fettling mat; 7. plug;
8. kerosene; 9. zone of permafrost warmed by steam needles.
(Source : Blinov, 1980, p.24, Fig.3)



4.13e

Frozen-in anchor.
1. pipeline; 2. load limiter; 3. anchor link; 4. anchor (multi-disc, perforated and similar); 5. permafrost table; 6. belt.
(Source : Ivantsov & Kharionovskiy, 1993a, p.74, Fig.28)



4.13f

Berm with NSM.
(Source : Galiullin et al., 1996, p.136, Fig.11)

The replacement of saddle weights by weighting compounds of the UBO type, belt-like, as shown in Fig.4.13b, permitted more reliable ballasting of a pipeline and an increase of work quality. With the so-called group method of ballasting earth work volumes could be reduced by using both weighting compounds and screw anchors. Two brigades within *SU-11* used these ballasting methods widely. To increase the rate of ballasting work, a cross-beam could be used with which two UBO weighting compounds can be installed simultaneously, as shown in Fig.4.13b.

Blinov (*ibid.*, p.23-24) describes another method to secure a gas pipeline: the AR-401 exposable anchor. Its introduction enabled ballasting rates to be raised and the quantity of weights reduced. AR-401 exposable anchors, as shown in Fig.4.13c, were used by *SU-11* to ballast pipelines in trenches dug by rotor excavators. With this method of pipeline ballasting, 400 mm diameter initial boreholes are drilled at the sides of the trench and a 100 mm wide link-piece between the borehole and the trench incorporated. The anchor is installed in one initial borehole so that the upper pair of blades are directed parallel to the trench. As the anchor is driven in, the link-piece between the initial borehole and the trench is disturbed by this pair of blades. After opening the blades a securing belt is installed. The amount of necessary earth work associated with this method of ballasting is reduced by more than two times.

Prior to 1980, pipelines had been secured with the use of AS-4p-40 screw anchors with which holes in the frozen soil layer or ice were drilled by hand by four workers. By 1980, the VAG-202 installation was being used which could drill holes in ice for several sets of anchors.

Blinov (*ibid.*, p.24-25) goes on to say that so-called thermo-anchors had been proposed for use in perennially-frozen soils where previously only weighting compounds had been used. These would be made from 9 m sections of 168 mm diameter pipe, as shown in Fig.4.13d. Initially, with the help of a mobile steam-making installation (using steam needles), the frozen soil is thawed to a depth of 5 - 6 m below the trench into which the anchors are driven. A belt with shock-absorbers is then installed which prevents damage to the belt in the event of frost heave. The cavity of each anchor is filled with kerosene and in winter this allows the release of warmth from the soil into the atmosphere which leads to intense cooling of soils around these anchors. Therefore, although the anchor has a small cross-section, considerable forces are required to displace it from its position. In order to exclude the thermal influence of the pipeline on the soil under the pipe, thermal insulation rugs are laid in the location of the anchor units. Blinov expected that the economic effect of introducing such anchors would amount to a saving of roughly 500,000 old rubles per kilometre of ballasting but the economic effect would be greater still if rotor excavators were used to prepare the trench.

While the cooling of gas through the installation of costly SOGs has been shown to reduce rates of thawing near the Purovskaya compressor station, the Russians have also experimented with so-called frozen-in anchors to secure pipe sections laid in soils which have a low load-bearing capacity. Frozen-in anchors were installed in the late-1980s on the Yamburg - Yelets gas pipeline (string 2), north of Nadym, as shown in Fig.4.13e. The pipeline is secured using anchors buried in permafrost to which discs have been fitted. The anchors consist of a 28 mm diameter rod with 120 mm diameter discs attached to them. Normally, frozen-in anchors are installed at intervals of 10 m for 1420 mm diameter pipelines, using steam needles ("drop" method) or excavators ("drill-drop" method) or a combination of both ("combined" method) (Telegin *et al.*, 1995, p.23-25). Pull-out tests involving loads of 10 - 12 tons have shown that such devices are only effective where processes such as thaw settlement and frost heave do not occur in a widespread fashion. Mazur (1993, p.13) stresses that the use of frozen-in anchors is based on the principle that the soil around each anchor remains permanently frozen. The gas temperature should be as close to the surrounding soil temperature as possible to prevent frost heaving (if too cold) or settlement (if too warm). In practice (Yamburg - Yelets string 2 often has positive temperature gas transmission) there have been cases where, as a result of thawing in ice-rich fine-grained dusty soils, the anchors were displaced vertically by 100 - 300 mm and the pipe travelled with the anchor or parted from it (Ivantsov & Kharionovskiy, 1993a, p.74-75). According to Lashin (1997) this has happened about 70 km south of the Yamburg GCF. However, on some sections of Yamburg - Yelets string 2 the pipeline was successfully bound since the depth at which the anchor discs were located, approximately 6 m, was deeper than the maximum depth of thawing of permafrost below the pipe, which is 3 m. Shmal' (1993, p.13) endorses the use of frozen-in anchors since they are cost-effective compared with more traditional ballasting devices, such as those made from reinforced concrete.

Other economic ways of ballasting include the use of earth ballast and NSM. This is a common method of dealing with the problem of buckled pipe sections which have broken through the surface, as already indicated in subsection 4.3.3.3. The affected pipe section can either be relaid in a new trench or a soil berm (prism) is laid over the top without reburying it. Sheets of NSM are laid within the soil as shown in Fig.4.13f.

Nowadays reinforced-concrete weights (UBO or UBK types), frozen-in anchors and NSM with mineral soils are the three standard methods of securing trunk pipelines in the Far North (Telegin *et al.*, 1995, p.23). But none of these ballasting and anchoring methods is 100% effective. The problem is that they do not tackle the problem at its root. These are all ameliorative measures designed for conditions of warm gas transmission in permafrost conditions. The cooling of gas, helping to reduce the annual range of gas transmission temperatures, must be seen as a key way of improving the situation because it reaches the root of the problem - it lessens the chances of "floating up" and therefore the need for ballasting and anchoring can be to some extent reduced.

4.3.3.5 The role of thaw settlement in the wider context of reduced gas pipeline reliability

In the long winters which follow the brief summers (during which thaw settlement, thermal erosion and other cryogenic processes take place if positive temperature gas is being transmitted), a seasonal freezing zone will develop around the same pipelines as the gas transmission temperature drops. This drop will occur as a result of effective winter time AVO cooling. However, some older gas pipelines will have floated up towards the earth surface due to lost longitudinal stability through bog development in that area over some years and small parts of the affected section of pipeline may have become fully uncovered and exposed to ambient air temperatures. In such cases the winter time gas transmission temperature will be reduced further. So instead of having "warm" gas being transmitted almost year-round through a buried pipeline which is shielded from very low winter air temperatures by vegetation, snow cover and a 2 m or so layer of soil, the gas temperature will be cooled significantly in winter (well below 0°C) because that shield no longer exists. The pipeline is thrust into a very dangerous predicament.

Whether or not the pipeline remains underground or is displaced upwards, perhaps even exposed, it will be subject to varying degrees of frost heave and perhaps jacking (depending on local soil conditions, the proximity of the pipe to the surface and presence or absence of vegetation and snow cover above). But in the case of a floating or exposed pipeline the problem is compounded because of the larger annual range of gas temperatures resulting from exposure to ambient air temperatures. An exposed section of pipe could also be susceptible to thermal-contraction cracking in the pipe walls, a process to be examined in chapter 5. Thus, such a pipeline has become susceptible to a different set of cryogenic processes which would not have been the case, at least to such a great extent, had the gas originally been cooler and not initiated thawing of surrounding soils and subsequent upward floatation.

It is therefore reasonable to say that such a pipeline will have been transferred from a buried environment in which thawing processes are dominant to a surficial one in which both thawing and freezing processes, but mainly the latter, are taking place. We can call this phenomenon the "thaw ⇒ freeze-thaw" process. This phenomenon characterizes those gas pipeline systems in the NPT which traverse large areas of icy frost-susceptible soils, particularly in the Yamburg and north Urengoy areas (central and southern Tazovskiy Peninsula). It is important to recognize that the origin of this process is associated directly with large-scale usage of compressor stations with inadequate gas transmission temperature regulation. The following case study (subsection 4.3.3.6) from the northern part of the Urengoy GCF will demonstrate this process. Evidence of the process can also be seen in other parts of the NPT but the field work at Urengoy represents perhaps the only clear evidence of the two separate stages of the process, based on material published in the last two or so years.

4.3.3.6 Case study of the "thaw ⇒ freeze-thaw" process

i) Introduction

The gas pipeline to be examined here is the Urengoy gathering line, shown in Fig.4.14. Although it is not a trunk pipeline it can for the purposes of this thesis be included within the "trunk" category because of its large diameter (1420 mm), the distance it covers and volume of gas it transports. It is in its own way a trunk line delivering processed gas from several northern and central sub-fields to Urengoy's initial compressor stations. There is no analagous gathering line in the West with similar characteristics because there are no producing fields of Urengoy's size in the West. The line consists of a number of separate pipeline strings running in two corridors (eastern and western), the combined length of which totals 1100 km, including 887 valve units. The 1420 mm strings, made from imported steel, are in both buried and semi-buried configurations, making a large number of underwater and aerial transits across water bodies (Lanchakov *et al.*, 1995b, p.53-54; Remizov *et al.*, 1997a, p.21). The majority of the gathering line has been in operation for more than 15 years.

It has already been indicated that the number of organizations conducting field studies along the r-o-ws of trunk gas pipelines in northern Russia has fallen dramatically over the last 15 years (Chigir *et al.*, 1997a, p.28). However, the most active of the few currently engaged in such research is the firm "*Ekotekh*", directed by N.N.Khrenov, which functions within the Gubkin State Oil & Gas Academy. Together with Moscow State University, the Gubkin State Oil & Gas Academy and *Urengoygazprom*, the latter being the "client", "*Ekotekh*" has in recent years been working intensively in the northern part of the Urengoy GCF, specifically the Yen"yakhinskaya and Severourengoyskaya areas (delineated in Fig.4.14). The former, the geocryological conditions of which are described by Chigir *et al.* (1997a, p.28), contains three sub-fields which were commissioned between 1985 and 1986 and these are centred around their own UKPGs (UKPG-11, -12 and -13). The latter contains a single sub-field, commissioned in 1987, centred around UKPG-15.

Before examining the work of "*Ekotekh*" and its collaborators, it is important to note that traditionally feeder and gathering lines, no less important than trunk pipelines, have received little diagnostic attention (Lanchakov *et al.*, 1995b, p.53). Gathering lines such as Urengoy's are due more than just a cursory glance for several reasons. Firstly, many feeder and gathering lines at northern GCFs are in a critical condition[11]. Secondly, these pipelines are the link between the UKPGs and the trunk pipelines and therefore must be maintained at the highest level of reliability and subject to frequent and full diagnostic inspections. Thirdly, Urengoy is the cornerstone of *Gazprom*, producing some 43% of the company's total output annually (242.2 BCM in 1996, see also Table 2.5).

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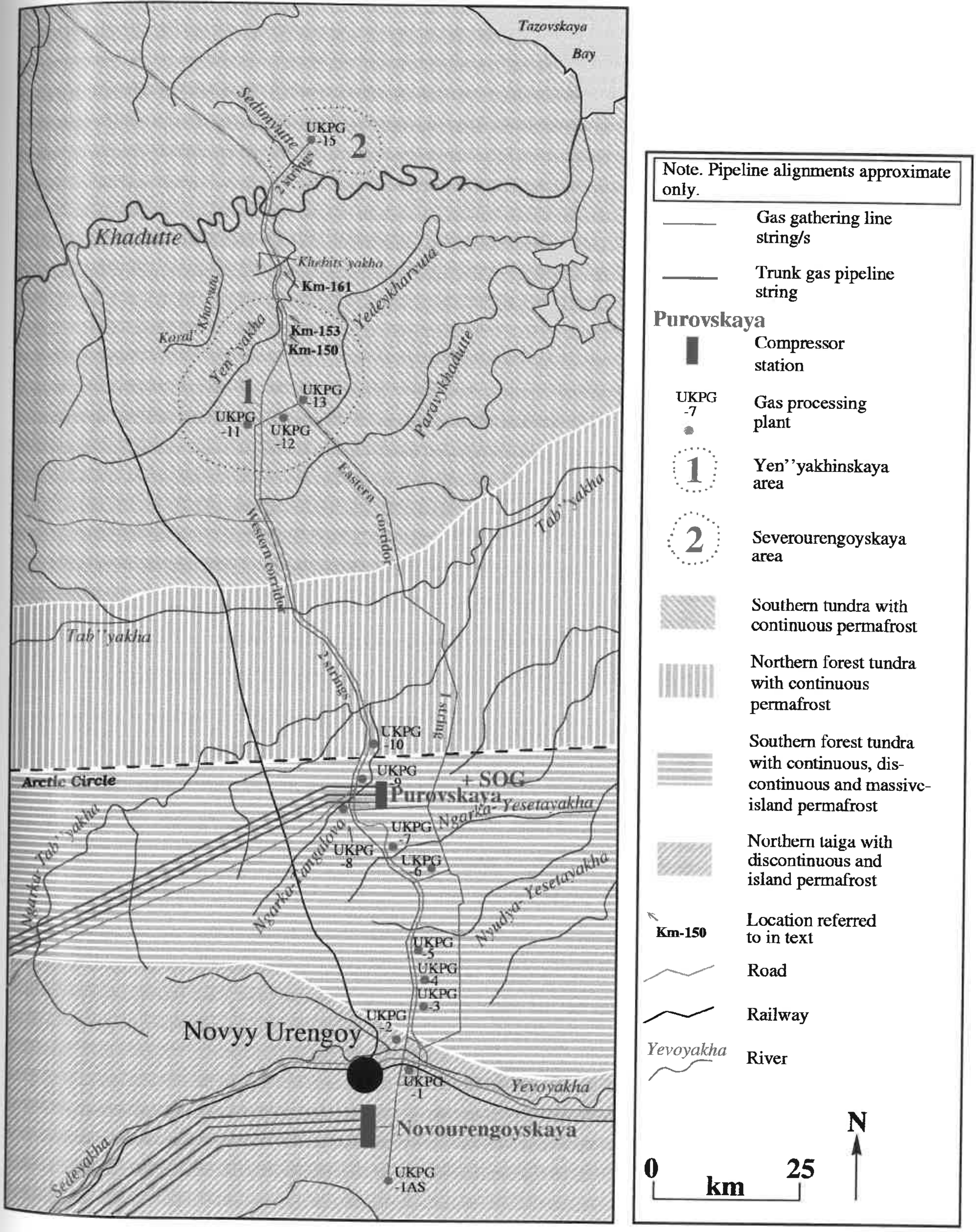
[11] While parts of Urengoy's gathering line are in poor condition, up to 10% of the 100,000 piles supporting Yamburg's feeder lines have been displaced by cryogenic processes (see Fig.2.9).

Fig.4.14 The Urengoy GCF and gathering line system (operated by Urengoygazprom)



Gazprom should therefore give priority to a gathering system which feeds such vast volumes of gas into the UGSS, so crucial to Russian domestic and export supplies.

ii) The problem at Urengoy

There are currently two major problems concerning researchers of the Urengoy gathering line. First, the seasonal dynamics of thaw bulbs which developed under the fields' gathering line strings during their first few years of operation. Second, the displacement by erosion and frost jacking of pile supports of "beam-transits" (aerial transits) across small water courses[12]. Here we shall only address the first issue, which has been examined in considerable detail by Chigir *et al.* (1997a, p.28-31). The problem lies in the following. Between 1985 and 1989/1990 gas was being transmitted through the gathering line at approximately +20°C. This was coupled with a sharp increase of the summer heat-exchange in the soils surrounding the buried gathering line strings which was caused by serious disturbance of the heat-insulating soil-top peat, moss and moss-lichen cover during construction of the strings and their soil berms[13]. Thus, up to 1990, thaw bulbs formed under the strings of the gathering line and 2 - 3 m to each side of them in the perennially-frozen soils. Data from the Urengoy branch of *TyumenNIIgiprogaz* gathered between 1985 and 1990 showed that in the area of UKPG-11 (Yen"yakhinskaya area) the permafrost table, normally at a depth of 0.4 - 2.0 m depending on soil type, fell to 4 - 5 m along the 1000 mm diameter link lines[14]. Over the first kilometre of the 1420 mm diameter gathering line heading to UKPG-10 the table fell to 5 - 6 m. In these cases the thaw bulbs in *supes-suglinok* soils were 1 m deeper than those in peatbogs. In the zone of UKPG-13 (Yen"yakhinskaya area) the permafrost table fell to depths of only 2.0 - 2.5 m in all along the link lines. A thaw bulb was recorded at approximately this depth along the UKPG-13 - UKPG-12 section of the gathering line string 1.

The development of these thaw bulbs was accompanied by upward floatation of the link lines and gathering lines in bogs, particularly within *khasyreys*. This was caused by widespread flooding or moistening in the soils of the pipeline corridors, discussed by Remizov *et al.* (1997b, p.17), which can be attributed on the one hand to the obstruction of slope surface and supra-permafrost slope drainage by trenches during construction, and the blocking or damming of this drainage by the pipelines and their berms on the other. Settlement of the surface along the pipelines as a result of the degradation of the upper iciest horizons of the permafrost intensified this floating up process. Thus, progressive development of bogs led to the floating up of the majority of the

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[12] Erosion and frost jacking of pile supports beneath beam-transits are examined by Remizov *et al.* (1997a and 1997b).

[13] A soil berm (*obvalovka* or *obvalovaniye*, in Russian) lies on top of semi-buried or on-ground pipeline sections or it can be used in an attempt to ballast sections that have been displaced upwards (floated up).

[14] In this context, a link line (*gazoprovod podklyucheniya*, in Russian) connects the UKPG to the gathering line strings.

pipelines and catastrophic damage to their berms. According to data from *Urengoygazprom*'s *LPU*, shown in Table 4.7, nearly 55 km of berms were destroyed in this way in the northern part of Urengoy in 1989.

Data from "*Ekotekh*", compiled using aerial photography (scale 1 : 10,000) of the Urengoy GCF, showed that by 1994 50 - 60% of the berms of gathering line string 1 and 60 - 70% of the berms of string 2 between UKPG-13 and UKPG-15 had been destroyed. By 1994 the berms of link lines at UKPG-11, -12 and -13 had been almost totally destroyed. However, the berms at UKPG-11 were repaired in the winter period 1995-96. UKPG-12 and -13 link lines remain without berms due to a shortage of finances (Khrenov, 1998).

Table 4.7 **Length of berms destroyed on strings 1 and 2 of the Urengoy gathering line in the Yen"yakinskaya and Severourengoyskaya areas in 1989, based on data from the *Urengoygazprom LPU*** (Source : Chigir *et al.*, 1997a, p.29)

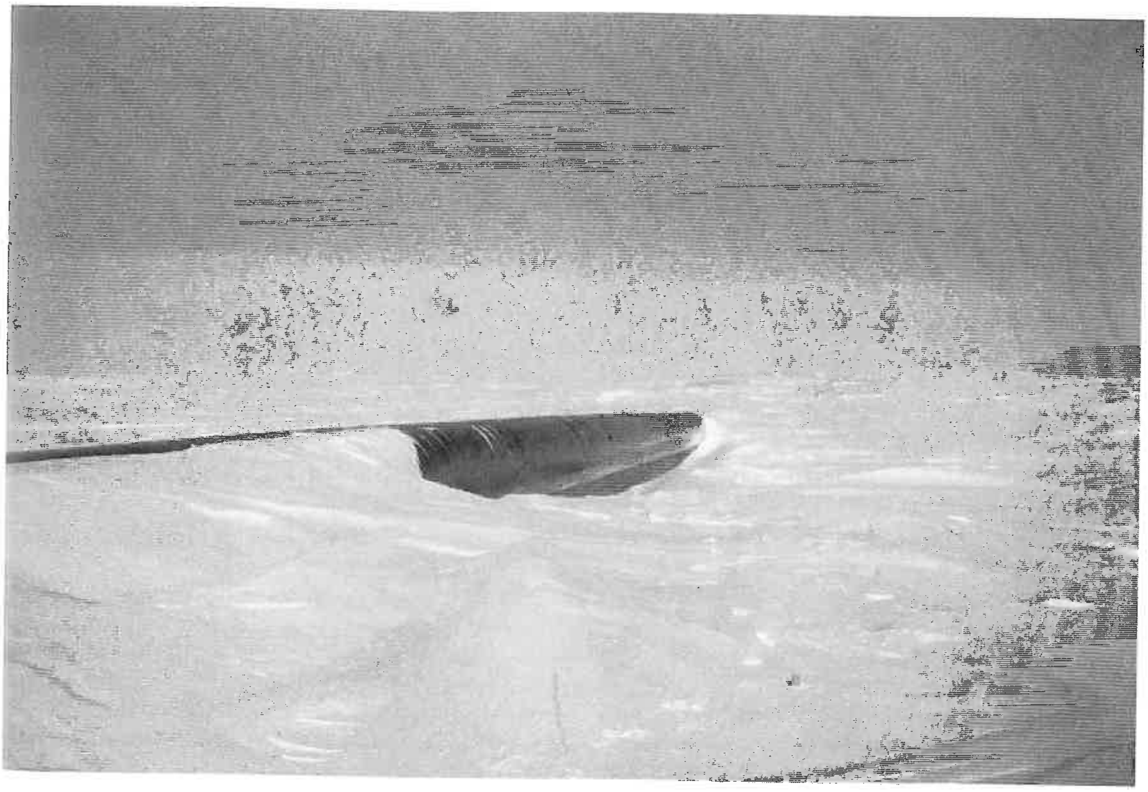
Section of gathering line	Total length of string (km)	Length of berms destroyed (km)
UKPG-13 - UKPG-15		
String 1	58	12
String 2	55	26
UKPG-11 - UKPG-13		
String 1	11	7.8
String 2	11	8.3

The development of thaw bulbs and surface settlement was accompanied by an increase of zones of disturbance and the substitution of rootless mosses and lichens by rooted grass-sedge-cotton grass associations. Nonetheless, the transpiration of these new vegetation associations could not prevent the progressive development of bogs on the gathering line corridor or the formation of temporary and permanent water courses which flow into adjacent erosional channels. The situation is complicated by the presence of gathering line "beam-transits", such as that shown in Fig.4.15 (which, as indicated earlier, have themselves been subject to erosion and frost jacking).

These processes, ultimately causing loss of stability of the gathering line strings, led to a decision to install SOGs at UKPG-11, -12 and -13 between 1989 and 1993, as already discussed in subsection 4.2.3. "*Ekotekh*" subsequently carried out reconnaissance studies of the depths of the thaw bulbs on 21 transverse profiles at the end of September 1996. More than 200 measurements of the depth of soil thawing were made using a submerged 1 cm diameter steel probe in both disturbed (along the pipelines) and natural conditions. Probing was also carried out with a "sonar" device.

Fig.4.15 Summertime and wintertime views of beam-transit displacement at km-161 (R.Khebits'yakha) on the Urengoy gathering line

(Sources : top. Remizov *et al.*, 1997a, p.24, Fig.3; bottom. Author's photograph, taken on 4th April 1998)



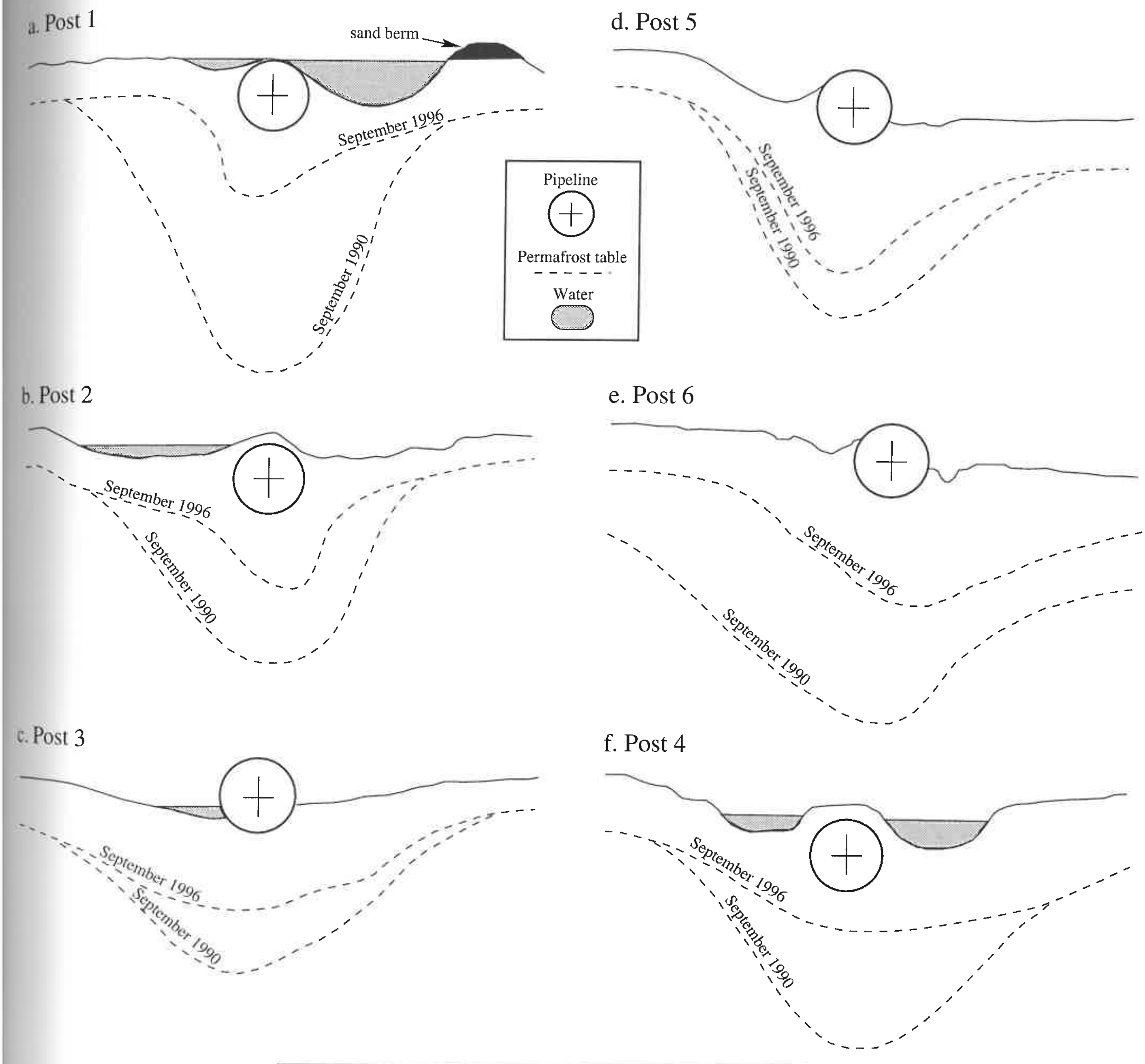
Analysis of the data yielded some surprising results. These are shown in Table 4.8 and in Fig.4.16. At 2 - 3 m either side of the pipe sections, the thickness of the seasonally-thawing layer was found to be equivalent to the natural value for the boggy grassy-sedge associations (1.2 - 1.5 m) which replaced peat, moss and lichen covers. Within disturbed peatbogs the thickness of this layer exceeds that of the undisturbed localities by approximately 2.5 times, of disturbed shrub-lichen-moss cover by 1.5....2 times, of disturbed shrub-moss-lichen cover by only 1.2....1.5 times.

Table 4.8 **Results of investigations conducted by "*Ekotekh*" in September 1996 on link and gathering line strings in the Yen"yakhinskaya area of the Urengoy GCF** (Source : Chigir *et al.*, 1997a, p.29-30)

Zone of the Yen"-yakhinskaya area	**Link line (LL) or gathering line (GL) strings**	**Depth of permafrost table (m)**	
		from ground surface	**from pipe base**
UKPG-11			
Observation posts 1 and 2 (see Fig.4.16a, b)	LL	1.5....2.0	0.5....0.7
Observation posts 3, 5 and 6 (see Fig.4.16c, d, e)	GL (string-1)	1.5....2.0	0.5....1.0
Observation post 4 (see Fig.16f)	GL	1.5....2.0	0.5
UKPG-12 valve units	LL	1.5....2.0	0.7....1.0
UKPG-13 valve units	LL	1.5....2.0	1.0
UKPG-13	GL	–	2.0
UKPG-13 - UKPG-15	GL (string-2)	1.5....2.0	1.0....1.5
UKPG-13 - UKPG-12	GL (string-2)	1.5....2.0	1.0....1.5
UKPG-13	GL (string-3, eastern corridor)	1.5	1.0
UKPG-13	GL (string-1)	2.8	–

Fig.4.16 Permafrost table displacement between 1990 and 1996 on the Urengoy gathering line, also showing displacement of pipeline strings

(Source : Chigir et al., 1997a, p.30-31, Fig.2 and Fig.3)



Note. For depths of permafrost tables see Table 4.8.

Chigir *et al.* (1997a, p.30) reach a fascinating and ironic conclusion about the cause of these reductions of thaw bulbs observed under link lines and gathering line strings within the Yen"yakhinskaya area. In all probability, they say, the reduction is linked not so much with the operation of the SOGs as with the destruction of the pipeline berms. Over eight months of the year when air temperatures are sub-zero, gas is fed at a temperature of +3....+5°C from the UKPGs into the link lines which are completely or 50% devoid of berms. Without berms, the pipe strings are exposed directly to the freezing winter air which cools the gas to sub-zero temperatures. The gas in turn exerts a cooling influence on the soils beneath the pipelines, rather than a warming influence. As a result, the thaw bulbs observed in September 1996 have a seasonal character.

The freezing of pipe metal to the soil of the berms and even to snow was observed in late May 1996 everywhere on the gathering line near UKPG-11 and also in the zones of beam-transits on the western corridor (UKPG-13 to UKPG-15 section) across a stream (kilometre-151 on the road) and across the R.Khebits"yakha (kilometre-161 on the road) (locations shown in Fig.4.14). Thus, even in the second half of May, gas with a negative temperature is transmitted through the pipes on these sections. Perhaps several kilometres of exposed pipe, free from soil and snow, is sufficient for gas in pipes in this part of the southern tundra zone to have a negative temperature. From the results of measurements of the permafrost table along the link lines of UKPG-11, -12 and -13 it is reasonable to assume that this occurs over the first few kilometres from the AVO. The cold gas, slightly below 0°C, has a cooling influence upon the soils surrounding the gas pipelines at a considerable distance from the northern (Yen"yakhinskaya area) sections of the gathering line whose berms are often more than 50% destroyed. The exposed pipe sections of the Yen"yakhinskaya area therefore fufil an unusual role in that they act as "SOGs" for the more southerly sections of the Urengoy gathering line, predetermining the seasonal character of the thaw bulbs. This means, say the study's authors, that it is more correct to talk of a peculiar technogenic variety of seasonally-thawing layer, rather than of thaw bulbs.

The results of this study have raised many new questions. For example, the character of interactions between this seasonally-thawing layer and the gathering line. But it is also possible to say that the pipes in this region of the Urengoy GCF are subject to seasonal frost heave and settlement which results in the jacking up of the pipes (Chigir *et al.*, 1997a, p.31; Remizov *et al.*, 1997b, p.18). Frost jacking of pipes occurs especially intensively on sections which have a tendency to float up. However, this jacking up of some sections is accompanied by the pressing down of others into the soil. Such sections, for instance string 1 near UKPG-11, appear to be "sinking" into the bogs. Pipe sections with concrete weights are subject to intensive frost jacking and the weights are easily displaced, freeing the pipe beneath and allowing it to float up. This is accompanied by the destruction of berms on such "floating" sections of the gathering line. But sections whose weights have been freed from their fastening units where the berm *is* still intact, often observed on floating sections, cannot be explained without the involvement of seasonal frost heave (Chigir *et al.*, 1997a, p.31).

The following conclusions can be made from this study:

1. crucially, Chigir *et al.*'s study provides in addition compelling evidence of the second stage of the previously mentioned "thaw ⇒ freeze-thaw" process. This evidence lies in the fact that jacking up of sections of the gathering line is most intensive on those parts of the pipeline system which have floated up. Being nearer the earth's surface, these sections are more susceptible to significant frost heave in winter and thaw settlement in winter. Therefore, this stage also demonstrates considerable seasonal variations in active cryogenic processes, but the net result is upward displacement of the pipe
2. SOGs are not suitable for all conditions in permafrost regions and should not be regarded as a universal way out of soil thawing problems in such complex conditions, where for example, soil berms over pipelines have been partially or totally destroyed;
3. in the transitional zone from frozen to thawed soil, thaw bulb sizes must be fixed and regulated. Frost heave must not be allowed to begin in the presence of developing thaw bulbs;
4. while the researchers who took part in this study are now familiar with the influence of thawing on a pipeline in these conditions, they know very little about what takes place with freezing (particularly taking into account soil composition irregularities), in so far as they do not yet have the experience. This type of research is essential since the rigid frozen foundation of a pipeline is potentially more dangerous than a thawed one.

iii) Additional factors complicate the problem

The problems being experienced on the Urengoy gathering line do not simply owe their existence to warm gas transmission leading to thaw bulb development. Those studying the gathering line have suggested that planning errors made not while designing the line, but actually at an earlier stage in the field's development could be making things worse. Some very important lessons can be learnt from these errors which are of particular relevance to the opening up of new northern oil and gas fields, including those on the Yamal Peninsula.

As Yegurtsov *et al.* (1996, p.23-24) and Remizov *et al.* (1997a, p.22) have pointed out, the condition of Urengoy's gathering line, as with any northern gas pipeline, is determined first and foremost by the dynamics of its interactions with the geological environment. A pipeline laid in permafrost is uniquely bound to its environment and together they form a "geotechnical system". The term "geotechnical system" is applied to pipelines and other linear communications systems laid in complex environments, such as permafrost or bogs, in which interactions between the structure and its surrounding environment determine the integrity of both components of the system. Permafrost (cryogenic) and erosional processes are what they call the "controlling or dominating" factors within this northern geological environment. Furthermore, the planning of any linear structure in northern latitudes, particularly a pipeline system, must take into account the significant variations in the reactions of such a structure to similar influences along its entire length. The reason for this is illustrated clearly through the example of Urengoy's gathering line. The Urengoy GCF stretches 180 km from north to south, constituting some 1.5° of latitude. At this latitude, such a distance covers several types of natural-territorial complex including the southern tundra and northern forest tundra subzones in the far north of the field (Yen"yakhinskaya area) and the southern forest tundra and northern *taiga* subzones in the south[15]. Each subzone contains diverse geocryological and erosional conditions and, as has been noted by Remizov *et al.* (1996, p.150), Urengoy has two distinct permafrost zones; one characterized by joined and continuous permafrost (north) and the other by the unjoined and discontinuous/massive-island type (south). Thus, say Yegurtsov *et al.* (1996, p.23):

> *"....we have here a number of the most important natural boundaries literally cutting through the territory of the field.... The differentiation of natural conditions inevitably leads to significant variations in the mechanisms of interaction of the pipeline - environment system on sections which traverse different zones."*

Yegurtsov *et al.* have studied these zonal variations and the influences of particular natural-territorial complexes upon the gathering line, allowing them to compile a map of these zonal variations in the territory through which the gathering line passes. These variations are discussed in detail throughout Remizov *et al.* (1998). In 1994 a complex inspection of the Urengoy gathering line was conducted (Lanchakov *et al.*, 1995b, p.54). Their on-ground inspection (as opposed to their separate analysis based on remote sensing, details of which are also given in Lanchakov *et al.*, 1995b, p.54) of some 30 sections of the gathering line, which were assigned to them under a contract from *Urengoygazprom*, revealed "*a considerable number of defective sections which represent a potential danger for the reliable functioning of the gathering line*" (Yegurtsov *et al.*, 1996, p.23). Even so, they stress that the amount of on-ground work determined by the contract was insufficient for a complete assessment of the situation[16].

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[15] It should be noted that even the smaller Medvezh'ye GCF displays such a diversity of natural-territorial complexes (as noted in chapter 2).

[16] On-ground investigations included the following techniques and instrumentation:
a. geodesic measurements of the spatial position of the gathering line;
b. measurements of SDC parameters using a magnetic device, the Stresskan-500 device, which records stress magnitude data;
c. measurements of long-term changes of SDC parameters using strain gauges. The strain gauges were stuck onto metallic plates 0.2-mm thick which were welded onto the pipe using the spot welding method. In each case, three gauges were aligned in the longitudinal direction, circular and at an angle of 45° on the pipe, while two gauges were installed on the metal plate, one as compensation, the other as a control;
d. visual inspections of pipe walls;

One explanation offered by the investigators for the unsatisfactory condition of the gathering line fits in well with the above-mentioned consideration which is so important for planners of northern pipelines. Those who planned the route for the Urengoy gathering line failed to observe the zonal variations of the field's natural-territorial complexes. Instead, the gathering line's r-o-w was pre-determined by the location of previously built UKPGs, i.e. when the UKPGs were planned and built the future routing of the gathering line was not considered (Lanchakov *et al.*, 1995b, p.54; Yegurtsov *et al.*, 1996, p.24 and Remizov *et al.*, 1997a, p.25-26). As it turned out, the line proceeds through many areas which are unfavourable for its reliable operation, crossing a large number of water courses. But, as is evident from any map of this part of the NPT, streams, rivers and lakes form a very dense network of obstacles that are virtually impossible to avoid. The close proximity of the Novyy Urengoy - Yamburg service road to the line has also had a negative impact. Owing to the construction of road bridges, the widths of water courses crossing floodlands have been significantly narrowed, thereby raising the levels of spring floods (the majority of the field is subject to floodwater influence) and the base of erosion. In addition, in crossing an elevated part, the gathering line intercepts the surface and soil drainage of water which flows in the general direction of the R.Pur, thereby protecting the road. Field work conducted on the R.Khadutte (for example, Chigir & Yegurtsov, 1994; Lanchakov *et al.*, 1995a, p.16-17), R.Yen"yakha (for example, Chigir *et al.*, 1997b, p.5-7) and other rivers which cross the Urengoy GCF has also allowed researchers to conclude that a different engineering approach must be applied to the construction of pipeline river crossings (known as *dyukers*, in Russian) in the tundra zone from that used in the forest tundra and northern *taiga* zones. The studies revealed that in the past planners had failed to take into account the natural dynamics of tundra rivers (notably the R.Khadutte and R.Yen"yakha) and their potential response to technogenic influences. Serious damage was caused to the *dyukers* beneath these two tundra rivers, resulting in the need for costly repairs[17]. This has serious implications for the construction of trunk gas pipelines and gathering lines on the Yamal Peninsula.

The investigations carried out in 1995 on the northern section of the gathering line's western corridor between UKPG-13 and UKPG-15 established the dependence of the technical condition of the pipeline upon the peculiarities of different natural-territorial complexes, most of all upon relief and cryolithological conditions of landscapes. Given the accumulated data, Yegurtsov *et al.* (1996,

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e. estimation of condition of pipe insulation, ballasting and berms;
f. temperature measurements;
g. evaluation of cryogenic processes. Observation posts were set up which were equipped with vibrating wire transducers to measure pipe displacements, frost heave forces, stresses, soil and pipe wall temperature;
h. video and photographic observations;
i. samples of pipe metal were taken for analysis of their condition.
Further information on diagnostic instrumentation can be found in Remizov *et al.* (1997a, p.23-25).

[17] Khrenov (1998) reported that the R.Khadutte crossing was repaired in 1996 at a cost of US$6 - 8 million and the R.Yen"yakha crossing is presently awaiting repairs due to a shortage of finances.

p.25) and Remizov *et al.* (1997a, p.25) propose that natural-territorial complexes be ordered in the following manner in terms of the danger posed for the gathering line (in descending order of hazard for pipelines):

small water courses ⇒ small river and stream floodlands ⇒ terraces of river valleys and *khasyreys* ⇒ peat bogs with polygonal wedge ice ⇒ peatbogs without polygonal wedge ice, but with developing technogenic thermokarst ⇒ shrub-lichen-moss tundra ⇒ shrub-moss-lichen tundra

The investigations also revealed a number of defective and potentially dangerous sections, of which the most worrying are those sections located in the area of kilometre-150, -153 of the service road, R.Khebits'yakha (km-161 of the road), R.Yen"yakha, R.Khadutte, R.Sedimyutte, the locations of which are shown in Fig.4.14.

4.3.3.7 Conclusion

The two case studies of the Nadym - Punga trunk gas pipeline corridor, one pre-commissioning of compressor station (subsection 4.3.2.3), and the other post-commissioning (subsection 4.3.3.3), provide us with the evidence required for the first major conclusion. Ivantsov & Kharionovskiy (1993a, p.51) describe thawing beneath three strings (2, 3 and 4) of the Nadym - Punga pipeline corridor, 15 km downstream of the Nadymskaya compressor station (commissioned in 1977). There was a considerable increase in the depth of thawing, even a cessation of seasonal freezing. These particular observations began in 1976. However, jacking up of Nadym - Punga string 1 was observed between 1972 and 1974 by Nevecherya (1983a, p.130-142). String 1 was put into operation in 1972, five years before the commissioning of the Nadymskaya compressor station. The influence of compressor station operations was significant in that the pumping of warm compressed gas into the section downstream of the station led to the cessation of seasonal freezing and dramatic increases in depths of seasonal thawing on a section of the corridor where heaving and jacking up of string 1 had been observed several years before. Thus, the absence or presence of compressor stations can determine which categories of cryogenic processes (freeze or thaw) will be dominant.

The Urengoy gathering line case study (subsection 4.3.3.6) provides the basis for the second major conclusion. Through the initiation of thaw processes, as stated above, compressor station operations without adequate gas cooling are responsible for initiation of a more complex and long-term phenomenon, which we have called the "thaw ⇒ freeze-thaw" process. This long-term process demonstrates that the initiation of soil thawing can eventually lead to pipelines becoming susceptible to other more harmful cryogenic processes such as frost heave and jacking after they have floated up towards the earth's surface. It has been shown that current methods of ballasting and anchoring are largely incapable of preventing upward pipeline displacement, thus favouring the more or less uninterrupted development of the "thaw ⇒ freeze-thaw" process. The Urengoy gathering line case study has also demonstrated that SOGs are not necessarily fully effective if introduced several years after pipeline operations have begun, i.e. when the thawing problems have already arisen. SOGs should be installed as part of an initial development plan, along with the compressor stations and the pipeline itself, and their operation should result in effective gas temperature regulation from the moment the pipeline is commissioned. The case study also showed that pipeline planners must consider the zonal variations of a region's natural-territorial complexes when selecting a r-o-w and designing the pipeline itself.

4.3.4 Thermal erosion

Thermal erosion is considered at this point since it is closely associated with the process of thaw settlement along trunk gas pipeline corridors in the NPT. As mentioned above, after frozen soils surrounding a warm gas pipeline have thawed, resulting in varying degrees of settlement, conditions exist in the trench for loose soil to be eroded and washed away during the short summers. The affected section of pipe will be exposed, subsequently floating up as ballasting structures may be dislocated.

Natural thermal erosion occurs most actively in the far north of West Siberia (Yamal, Gydanskiy and Tazovskiy peninsulas) in connection with the activity of temporary water courses. In essence, it is the erosion of ice-rich permafrost by the combined thermal and mechanical influence of running water. It manifests itself extremely unevenly throughout this region in the form of gullies and erosional channels on different geomorphological levels (Andrianov *et al.*, 1989, p.143). In northern West Siberia the process is characterized by a clearly expressed zonal variation[18]. Unlike the tundra zone, where they are found not only along side large rivers but also beside small rivers, streams, lakes and on watersheds, these thermal erosional gullies are practically absent in the forest tundra and *taiga* zones further south. The southern boundary of the zone of prevalent thermal erosion is accepted as being the latitudinal line joining the mouths of the region's major rivers: R.Ob', R.Nadym, R.Pur and R.Taz (Voskresenskiy & Zemchikhin, 1986, p.134). The widespread development of gullies in the tundra zone, where their size and volume are greatest, can be explained by the intensive surface drainage that is caused by the shallow lying impermeable permafrost table which acts as a conduit for up to four months of rain each year. The lower the soil temperature during snow melt, the less will be the loss of meltwater into the ground, and the higher the discharge.

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[18] Voskresenskiy & Zemchikhin (1986, p.132-134 and Fig.2) have broken down northern West Siberia into regions according to volumes of material displaced by thermal erosion in its natural form. The NPT is characterized mainly by a slight degree of thermal erosional modification, although some parts of the Tazovskiy Peninsula (including areas of the Yamburg GCF) are included in the group of moderate degree of modification. The Yamal Peninsula falls into the groups of moderate (central Yamal) and severe (northern Yamal) modification.

Opinions on the role played by spring thaw water in gully development are mixed. Some say that they play no role, while others say that these thaw waters are responsible for not less than 75% of the annual growth of gullies. However, it is reasonable to suggest that a major factor in the thermal erosion is the length of the period of snow melt. The shorter it is, the higher the discharge of meltwater and thus the higher its erosive potential *(ibid.*, p.134). Therefore, the erosive potential of the Arctic tundra (northern Yamal Peninsula, for example), where the period of snow melt is some 48 hours, is much greater than in the forest tundra, where the figure is 240 hours. In addition, the rarity and sparseness of vegetation in the tundra zone promotes thermal erosion. Where lichen cover for example has been disturbed, gully development is usually generated. In the tundra zone also, fine and dusty sands are widely distributed, especially within contemporary geological rises, and such soils are the most susceptible to erosion (as opposed to clays and *suglinoks*). Further, according to field studies conducted by V.K.Dan'ko, thawed soils are eroded 10 - 15 times more intensively than unfrozen soils. Erosion is intensified with increasing soil moisture content and, in the case of clayey soils, with stratified and reticular (as opposed to massive) cryogenic textures. This high iciness is what distinguishes the geocryological factors which are most favourable for gully development on the Tazovskiy and Yamal peninsulas.

Andrianov *et al.* (1989, p.144-145) also point out that other geological processes assist thermal erosion in the development of gullies, for example, thermal-contraction cracking (examined in chapter 5), thermokarst in areas of wedge ice, aeolian processes (deflation), lateral erosion of rivers and thermal abrasion along coastlines, and especially slope processes (such as solifluction). Slope processes cause an annual 6 m or more of widening of gullies in central parts of the Tazovskiy Peninsula. In addition, the overwhelming majority of actively developing gullies coincide with positive tectonic structures, such as the Yamburg rise, where hydrographic networks are dense, elevations are greater and easily eroded sands are predominant. In the western (domed) part of the Yamburg rise, the density of gully networks amounts on average to 1.0 - 1.2 km/km², though increasing locally to 2.5 km/km². On lower relief and peripheral areas of the rise, the gully networks are much less dense; 0.1 - 0.3 km/km². This western part of the rise corresponds roughly with the western and central parts of the Tazovskiy Peninsula. Overall, 10 - 15% of the area of the peninsula is occupied by gully networks developing under the influence of thermal erosion, aeolian processes and solifluction (Sukhov *et al.*, 1989, p.246). Initially, thermal erosional gullies grow at a rate of 5 - 10 m (length) and 2 - 6 m (width) per annum. They can be up to 1 km in length, 20 - 30 m deep and 30 - 50 m wide at the top.

Given the above-mentioned characteristics of thermal erosion in northern West Siberia, it would be expected that the most intensive manifestation of the technogenic form of these processes, initiated by the construction and operation of not just pipelines but also UKPGs and other installations, would be in the zone of the Yamburg GCF and on the initial stretch of trunk pipelines from the field in the central and western parts of the Tazovskiy Peninsula. Indeed, aerial and land-based photographic evidence from this area of the peninsula shows much evidence particularly of the mechanical (hydraulic transport) element of thermal erosion along the Yamburg trunk gas pipeline corridor, where the pipeline strings, especially the older ones, are now floating in lengthy pools of water in the trenches in which they were laid, as shown in Fig.4.6. The trenches and the warm pipelines themselves act as highly efficient conduits, or artificial gullies, for sediments being moved by melt water, thereby accelerating the whole process of pipeline displacement. Erosion is intensified due to the redistribution and concentration of surface drainage. Ivlev *et al.* (1989, p.405) say that on one section of an unspecified pipeline r-o-w, but most likely near Yamburg, gullies 3.5 m deep, 7 m wide and 300 m long formed over three years adjacent to the pipeline trenches. This is precisely what is shown in Fig.4.17, though on a slightly smaller scale. Settlement of Ivlev *et al.*'s pipe section caused by thermal erosion reached 1046 mm over five years, while an additional sag amounted to 700 mm over a distance of 39 m. Erosion on one side of the trench foundation caused lateral displacement of the pipe[19].

Fig.4.17 Thermal erosional gullies developing adjacent to a pipeline string floating in melt water (south of Yamburg)
(Source : Amoco, 1991)

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[19] Gully development on parts of the NAGSS r-o-w (raised pipeline sections) has led to pile displacement.

4.4 Conclusion

The northern section of *Gazprom*'s UGSS (in the NPT) is not subject to a clear-cut annual cycle of intensive and diverse (i.e. freeze and thaw associated) cryogenic processes. Several decades of experience in the NPT have shown that gas transmission temperatures in fully buried pipelines whose backfill and berms remain in tact (newer lines) are rarely, if ever, below zero and will be more constant, within a small annual temperature range. Artificial temperature regulation (cooling) measures at compressor stations (and UKPGs), including SOGs which are in any case still a rarity, have been inefficient. This explains the origin of stability and reliability problems. Thawing associated with positive temperature gas transmission throughout the year, with small variations in positive temperatures in winter and summer months associated with AVO and seasonal SOG operations, lead to thaw settlement and eventually the loss of soil supporting capacity (adhesion forces) with the buried pipeline subsequently floating up. Thermal erosional processes in summer wash away backfilled soils leaving the affected pipe section exposed and perhaps free of its berms (as in the case of the Urengoy gathering line and Yamburg trunk lines). Many pipe sections are photographed in summer in this condition, floating in trenches of meltwater. Once the pipeline is in this state, it and the transmitted gas will be subject to direct winter cooling (and summer warming) from ambient air temperatures. Gas temperatures on such sections will thus be much more variable throughout the year, being below 0°C in winter and well above 0°C in summer. Heaving of thawed soils will occur in winter as a result of the cooling influence of the gas and pipeline. Over a series of summer and winter periods, the pipeline could be jacked up even further out of the ground. The exposed pipe could also be subject to thermal-contraction cracking in the pipe wall itself. Exposure to winter air temperatures could lead to a reduction of thaw bulbs, as has been observed on the Yen"yakhinskaya section of the Urengoy gathering line. Thus, thawing is the origin of the pipeline reliability problem in the NPT, whilst later individual pipeline strings become subject to both thaw and frost related processes.

Depending on their length of operation, individual pipeline strings in the NPT are at different stages of subjection to this long-term "thaw ⇒ freeze-thaw" process. Newer strings will still be subject to the thawing process only (thaw stage), as they remain buried. Strings commissioned some 15 - 20 years ago will now be exposed and subject to both thawing and freezing influences (freeze-thaw stage). Fig.4.18 demonstrates the stage that individual pipes in the same corridor have reached in this process. Five parallel strings are visible in this photograph taken in 1991 just south of the Yamburg GCF. It is clear that the string in the foreground is the oldest since it is fully exposed and floating in a trench of melt water. The strings beyond it are younger, with patches of exposed floating pipe only, while most of the pipe remains below the surface.

However, the fact remains that so far apparently fewer accidents have occured on the northern UGSS per kilometre than on the independent NAGSS. This must have a great deal to do with pipeline diameter, wall thickness and rigidity. When accidents do occur on the UGSS, gas supplies are re-routed without problem through adjacent strings in the pipeline corridor and the damaged section of pipe is replaced as quickly as possible, often within a day or two, as in the case of the rupture on one string of the "Northern Lights" corridor near Ukhta (Komi Republic) in April 1995. The damaged pipe section was replaced within 48 hours and the affected string was then put into operation again immediately. Gas was diverted through an adjacent string during replacement. The favoured practice of replacing pipe sections after rupture, while being conducted extremely efficiently, is a dangerous and uneconomical approach to take to pipeline operations. Before refurbishing the UGSS and planning new pipelines, *Gazprom* must refocus on the task of making sure such ruptures do not occur in the first place.

Fig.4.18 Yamburg - Nyda trunk gas pipeline corridor (5 strings visible) showing older lines in foreground and newer lines in background
(Source : Amoco, 1991)

Nonetheless, many buried trunk gas pipelines in the NPT have inevitably been subject to varying degrees of stress as a result of a variety of cryogenic processes, notably frost heave and settlement. This is a reasonable assumption given the vast amount of engineering-geocryological research carried out in the West Siberian North over many decades which indicates the susceptibility of many parts of the NPT to destructive cryogenic processes (differential heave and settlement, thermal-contraction cracking, solifluction in areas comprising clays, *suglinoks*, dusty *supeses* and sands overlain by peat). The pipelines have not ruptured as they are large diameter with fairly thick walls, increasing their rigidity. Nadym - Punga string 1 was jacked up by differential heaving only a year after commissioning but did not deform markedly because of its rigidity. But perhaps we should rephrase that and say that these pipelines in the NPT have not ruptured *yet*. It is likely that minute stress fractures and the like have built up in the walls of NPT trunk gas pipelines over the last 25 years or so (in the case of the oldest pipes, such as Medvezh'ye - Nadym - Punga string 1) and in the next decade we could see a sharp rise in the number of ruptures caused by corrosion for example (perhaps even SCC) or combinations of cryogenic stress which develop in a concealed fashion over many years. Diagnostic studies of Medvezh'ye - Nadym - Punga string 1, the oldest trunk line in the NPT, should be intensified over the next decade as it approaches the end of its design operational lifetime, with attention paid to minute fracture build up and the possibility of SCC.

Frost heave related problems are characteristic of the NAGSS, where gas temperatures are in general much colder than on the UGSS because of the absence of multiple compressor stations and gas transmission temperature regulation. But on the UGSS northern section, thaw settlement seems to be the over-riding factor, in other words the initial cause, in combination with other factors, since gas is warm after compression. The influence of the Soviet policy of producing gas quickly and in vast volumes necessitated the installation of many compressor stations to keep throughput high and effective and SOGs were too expensive, hence the origin of thaw related problems. Such policies did not influence the NAGSS since its purpose has always been to supply gas to the Noril'sk industrial region (mining-metallurgical combine) and its supporting settlements, rather than being an export line. Therefore, only one small compressor station was deemed as being necessary. Hence:

> Soviet accelerated gas supplies (for domestic use and export) from West Siberia + many compressor stations and very few SOGs = thaw settlement and possibly "thaw ⇒ freeze-thaw" process (northern UGSS or NPT)
>
> Domestic supplies alone + very few or no compressor stations = frost heave (NAGSS)

One needs also to bear in mind distances. West Siberia to Europe is some 4000 km, making compressor stations essential. Conversely, Messoyakha to Noril'sk is a mere 265 km, and so compressor stations are not totally necessary but if this had been an export route, the installation of one intermediate compressor station midway between Messoyakha and Noril'sk would have been very likely.

This chapter has also shown that it is essential to acknowledge the diversity of soil types and conditions in the Russian North, and, crucially for pipeline operations, the diversity of pipeline -

permafrost interations likely under such circumstances. In areas where average-annual soil temperatures are very low, for example -7.5°C in the central part of the Yamburg GCF (for example, R.Poyolavayakha basin), chilled gas pipeline operation would not be a cause for concern since secondary frost heave does not occur at temperatures so far below zero. However, if the gas is not chilled sufficiently, leading eventually to thawing of icy soils, there could be significant settlement of the pipeline. But as Sukhov *et al.* (1989, p.246) point out, the relatively low soil temperatures of some parts of the Tazovskiy Peninsula predetermine the fairly high stability of such soils under technogenic influence. Conversely, where average-annual soil temperatures are only just below zero, in the range 0....-2°C, in so-called "warm" permafrost, chilled gas pipeline operations could still lead to secondary heave or alternatively warm gas could very quickly warm the soil sufficiently to cause settlement in icy soils. Thus, areas with clays, *suglinoks* and dusty *supeses*, especially overlain by peat, whose temperatures are only just below 0°C, are most susceptible to technogenic activation or intensification of cryogenic processes that could lead to deformation and rupture of a pipeline. However, with natural conditions varying significantly over a relatively small area, planners are never faced with the simple task of planning a whole pipeline system for homogeneous natural conditions. The great length of most trunk pipeline systems makes the chance of encountering highly diverse natural conditions along its length an absolute certainty.

Buried trunk gas pipelines in permafrost regions are part of a geotechnical system which is highly susceptible to change. This change can be brought about by a variety of technogenic disturbances ranging from construction work to the implementation of inappropriate gas transmission temperature regimes and misplaced river crossings, possibly upsetting the system's equilibrium. By no means therefore can such a pipeline be considered separately from the surrounding geocryological environment. The separation of the two components, consideration of one without taking into account the other, at any stage of pipeline development will dramatically increase the chances of failure situations.

CHAPTER 5

ADEQUACY OF PROPOSED RESPONSES TO GEOCRYOLOGICAL PROBLEMS POSED BY THE YAMAL - EUROPE PIPELINE

5.1 Introduction

Having examined in chapter 4 the condition of operational trunk gas pipelines in the West Siberian North, notably the NPT, we must now turn our attention to northern gas pipeline projects currently under development. Chapter 4 also showed how the Russians have traditionally approached pipeline geocryological and associated problems, or "pipeline - permafrost" interactions. Invariably they do not tackle the problem at its roots and are left with the difficult task of implementing "damage limitation" measures, by which time the affected section of pipeline has become dangerously unreliable. An examination of a new major northern gas pipeline project will permit an assessment of the degree to which Russian pipeline specialists, planners and designers have altered their approach to overcoming these problems which, as has been demonstrated, so often affect the integrity and reliability of pipelines operating in permafrost conditions. Just as important is the question of the level of technical preparedness for the new generation of northern gas pipeline projects. An examination and appraisal of the research work conducted for such projects to date will provide an indication as to whether they can be implemented effectively and whether or not the outcome will be a reliable pipeline system.

There are currently two so-called mega-projects for northern gas pipeline systems under development by *Gazprom*, along with several smaller scale projects. The YEGTS and Shtokmanovskoye projects will each involve the supply of more than 50 BCM per annum from new GCFs to domestic and foreign consumers. Of the two, only the YEGTS will be considered in this chapter. Part of the YEGTS is already under construction and the overall project has received much more attention than Shtokmanovskoye. Shtokmanovskoye, which has a development consortium, is still some way off from being realized, reflecting in part a lack of finances and the technical difficulties involved in planning and design of offshore gas production and transmission facilities in the Arctic. In geocryological terms the YEGTS, almost entirely onshore, has more in common with existing northern trunk gas pipelines in Russia.

Section 5.2 considers the whole question of design of the northern section of the YEGTS. The YEGTS project is introduced in subsection 5.2.1. As the name Yamal - Europe suggests, the pipeline will be laid from the West Siberian Arctic through western Russia and on to the markets of western Europe. Therefore, only a relatively small section of the pipeline will operate in permafrost conditions. This section, known as the northern section (subsection 5.2.2), is introduced and described in 5.2.2.1 and 5.2.2.2, with particular attention paid to natural and geocryological conditions of the section's proposed r-o-w which is divided into four subregions (5.2.2.3). High soil salinity and cryopegs, not previously encountered by those designing northern trunk gas pipelines, are given special consideration in 5.2.2.4. Having established the environmental conditions, subsection 5.2.3 examines the proposed gas compression and, where appropriate, cooling regimes for the northern section. Subsection 5.2.3.2 focuses on gas cooling by SOG at one particular compressor station. The linear part of the northern section is the focus of subsection 5.2.4, in which measures so far proposed to minimize the risk of harmful pipeline - permafrost interations are examined. Consideration is given to the configuration of the pipeline, above-, on- or below-ground (5.2.4.2) and solutions to eliminate, or at least minimize, potentially dangerous cryogenic processes initiated by pipeline construction and operation (5.2.4.3). Proposed solutions to other associated problems (corrosion, pipeline hydraulic effectiveness and monitoring) are discussed in 5.2.4.4.

Planning is clearly a crucial stage in the development of any pipeline project and whether or not the pipeline will operate reliably can be determined at this point. This part of a project is simplified if the planners can use the results of tests conducted on experimental pipeline sections, or pipeline components (anchors and piles for example), in field conditions. This is the subject of section 5.3. YEGTS planners were able to glean important data from two tests sites in particular, one a frozen-in anchor test site actually located on the Yamal Peninsula and near the proposed r-o-w of the northernmost part of the pipeline, the other a full-scale pipeline test section located in an adjacent region (the Gydanskiy Peninsula) and attached to the NAGSS. These test sites are considered in subsections 5.3.2 and 5.3.3 respectively. Most importantly, we need to assess the extent to which results from these tests are appropriate for, and can be applied to, the YEGTS. This is achieved by taking stock of differences between certain conditions, notably geocryological and technical, of the objects under test and the object being planned.

The chapter is concluded in section 5.4.

5.2 The Yamal - Europe Gas Transmission System (YEGTS) : solutions to old and new problems

5.2.1 Introduction

The YEGTS will be 4120 km long up to the Polish-German border, with 31 compressor stations, passing through the territories of Russia, Belarus and Poland whereas in the past all of the USSR's export lines were laid further south through the Ukraine. According to the feasibility study (known as the *TEO* in Russian) carried out by *Giprospetsgaz* and *YuzhNIIgiprogaz* in 1993-94, under a contract from *Gazprom*, it will be 5800 km long, but this figure includes an extensive network of new pipelines to be laid in Germany which will transmit gas from a variety of sources other than

Table 5.1 **Technical characteristics of the YEGTS (excluding German lines)** (Sources : *Gazprom*, 1995b, p.16-17; Izak, 1995, p.15-16; *Gazovaya Promyshlennost'*, No.11-12, 1996, p.9; *Nefte Compass*, June 5th 1997, p.12; *Oil & Gas Journal*, August 25th 1997, p.36; Rezunenko, 1997, p.15-16)

Russian section (Bovanenkovskoye GCF to Russian-Belarus border)

Corridor length : 2875 km
Compressor stations : 21
Including:

1. Bovanenkovskoye GCF - Torzhok
Corridor length : 2475 km (including 75 km offshore)
No. of strings (onshore) : three 1420×21 mm diameter (with up to three additional strings)
No. of strings (offshore/Baydaratskaya Bay) : four 1220×27 mm diameter (with up to four additional strings)
No. of compressor stations : 17 (Bovanenkovskaya, Baydaratskaya, Yarynskaya, Gagaratskaya, Vorkutinskaya/Seydinskaya, Intinskaya, Syninskaya, Kadzheromskaya, Sosnogorskaya, Zheleznodorozhnaya, Novourdomskaya, Novoprivodinskaya, Novonyuksenitskaya, Novoyubileynaya, Novogryazovetskaya, Myshkinskaya, Kiverichiskaya)
Compressor unit types : GPA-Ts-16L, GPA-Ts-16A, GPU-16A, GPA-Ts-25, GPA-Ts-76
No. of SOGs : 2 (Bovanenkovskaya, Yarynskaya)
Pressure : 7.4 MPa

2. Torzhok - Russian-Belarus border
Corridor length : 400 km
No. of strings : two 1420×21 mm diameter (additional strings possible)
No. of compressor stations : 4 (Torzhokskaya, Rzhevskaya, Kholm-Zhirkovskaya, Smolenskaya)
Pressure : 8.3 MPa

Belarus section

Corridor length : 575 km
No. of strings : two 1420×21 mm diameter (additional strings possible)
Compressor stations : 5 (Orshanskaya, Krupskaya, Minskaya, Nesvizhskaya, Slonimskaya)
Pressure : 8.3 MPa
Annual capacity : 68 BCM

Polish section

Corridor length : 670 km
No. of strings : two 1420×21 mm diameter (additional strings possible)
No. of compressor stations : 5
Pressure : 8.3 MPa
Completion : first string 1998, second string post-2000
Annual capacity : 65 BCM

Totals

Length : 4120 km
No. of compressor stations : 31

Yamal (Izak, 1995, p.15-16). The pipeline can be sub-divided into three sections, the technical characteristics of which are presented in Table 5.1. Its route from source to market is shown in Fig.5.1.

The reserve base of the Yamal GCFs is truly vast. Proven reserves exceed 10 TCM, much of which is concentrated in two of the twenty-five or so discovered fields on the peninsula; these two fields are Bovanenkovskoye (with 4.4 TCM) and Kharasaveyskoye (with 1.2 TCM). *Gazprom* has been planning to develop these fields since the early 1980s and to transport the gas to western Russia, and eastern and western Europe. For example, an article written in 1988 in the journal *Stroitel'stvo Truboprovodov* describes *Mingazprom*'s intention to start supplying gas from Yamal by the end of 1991, if not before (Veselyy, 1988, p.6). Writing in 1987, Ivantsov (1987, p.12-16) described detailed plans for design of the northern section of the YEGTS and mentions the "Yamal" scientific-technical programme which was set up to tackle problems concerning the development of the two GCFs and the trunk pipelines. As early as spring 1987 freight supplies were being delivered to Bovanenkovskoye via Murmansk and the R.Mordyyakha on the peninsula's west coast for development of the field's infrastructure.

A decade has passed but, owing to several factors, the project continues to be delayed. Initially the delay was caused primarily by concerns for the indigenous Nentsy people. It was feared that construction of the pipeline system around Baydaratskaya Bay on the initial Bovanenkovskoye GCF - Vorkutinskaya/Seydinskaya compressor station section would cause severe environmental damage and interfere with traditional economic activities, such as reindeer herding. As shown in Fig.5.2, this corridor would follow the route of the Chum - Obskaya - Bovanenkovo railway, the northern part of which is still under construction. Subsequently, an alternative shorter (by 100 km) initial section was proposed which would take the corridor *across* Baydaratskaya Bay instead of around it. Some experts, for example Vladimir Feygin (1996) of *VNIIEgazprom*, believed as late as 1996 that the final decision to go ahead with this alternative route had not yet been taken. The circum-bay route would be preferable for maintenance since it would follow the route of the railway, making it fully accessible along its entire length (Ivantsov & Kharionovskiy, 1993a, p.25). North of the Gagaratskaya station on the newer route there will be no railway access. This is another reason why a final decision has still not been taken on the routing of the YEGTS initial section. More recent indications are that the initial section of the pipeline corridor will cross Baydaratskaya Bay[1] (Mikhailov, 1996, p.40; Ivantsov, 1997b), however, one should not assume that this will be the chosen route since alternatives are still under consideration.

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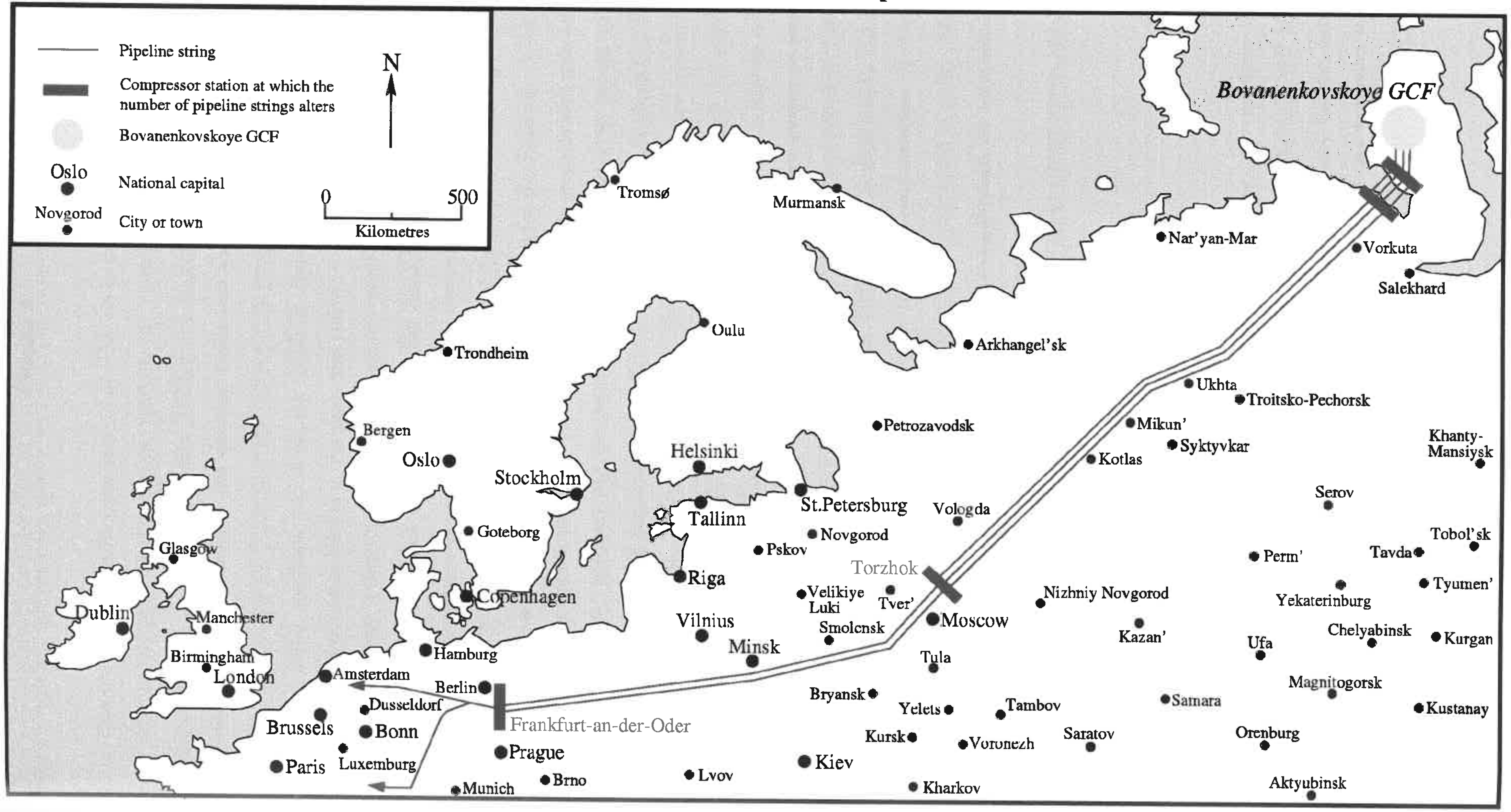
[1] Ivantsov (1997b) says that the shorter route across Baydaratskaya Bay would reduce the permafrost section of the YEGTS by 125 km. It will cut required pipe steel volumes by 400,000 tons and reduce gas consumption for the YEGTS by 0.43 BCM.

Fig.5.1 Route of the Yamal - Europe Gas Transmission System from Yamal to European markets



Construction of the Russian section of YEGTS is delayed for other reasons. Currently, the lack of foreign and particularly domestic markets for Yamal gas does not justify the US$40 billion needed to realise the whole project. Stern (1995, p.xv) suggested that unless Russian demand reaches 1990 levels and exports double, the existing fields and satellites in the NPT can meet demand without the development of Yamal or other frontier-style projects until at least 2005. Indeed, initially gas from the NPT satellites will feed the YEGTS through two separate strings now under construction on the routes SRTO - Torzhok and SRTO - Nechernozem'ye which incorporate 18 compressor stations (*Gazovaya Promyshlennost'*, No.11-12, 1996, p.9; Ivantsov, 1997b; Rezunenko, 1997, p.15). Lack of finances had also been a problem but the construction of the YEGTS will now take place in several stages to meet incremental demand for gas, thereby lowering financial risks as reinvestment helps to fund later stages of the project. A banking consortium, led by Dresdner Bank AG and Crédit Lyonnais, is organizing funding for the Torzhok - West section in the form of a US$3 billion syndicated loan. Revenues gained from share sales will also be used to fund the YEGTS but many technical and environmental questions concerning design of the northern section of the YEGTS remain unanswered and these will be discussed throughout this chapter.

Once operational, the YEGTS should carry 70 - 80 BCM of gas per annum which will be consumed primarily in Germany and Poland but the system will be linked to the western European pipeline network via the German Midal and Stegal systems, so many other countries will also benefit from Yamal gas. It should be noted that the YEGTS is being built from market to source, therefore gas from other parts of Russia can be delivered through existing pipelines which will be connected to the western (Belarus-Poland-Germany) section of the YEGTS. This section will be completed well in advance of the northern part of the pipeline corridor. In fact several stretches of this section have already been completed or are under construction. So, while construction is going ahead on Yamal, gas from elsewhere in Russia, notably the NPT, can be flowing through the completed opposite end of the system.

Full-scale production at Bovanenkovskoye was due to start in 1997 but this has been pushed back, probably well into the next century, and not before 2005.

5.2.2 The northern section of the YEGTS

5.2.2.1 Introduction

The YEGTS project as a whole was described briefly above. Here, the northern section of the YEGTS, often referred to in Russian as the "main section" (*golovnyy uchastok*), will be examined in considerable detail. This is a 492 km section of pipeline corridor which, for the purposes of this thesis, excludes the 75 km sub-sea crossing of Baydaratskaya Bay. As indicated in Fig.5.2, the northern section originates at km-1 at the Bovanenkovskaya booster compressor station at the

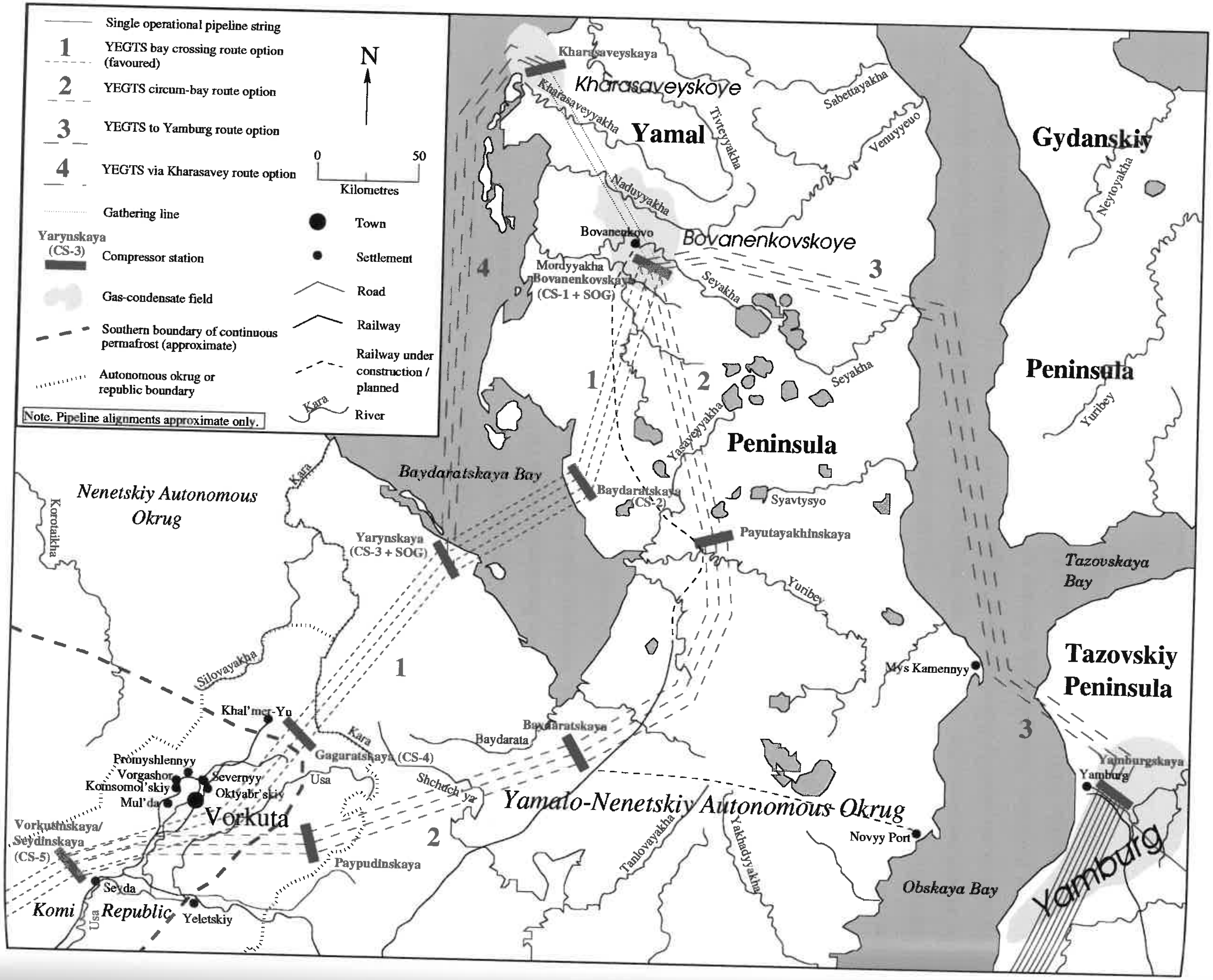


Fig.5.2 Northern section of the Yamal - Europe Gas Transmission System (including route options)

Bovanenkovskoye GCF. Bovanenkovskoye is located in the central western part of the Yamal Peninsula, in Yamal'skiy rayon of the Yamalo-Nenetskiy AO[2]. The field lies in the R.Mordyyakha - R.Naduyyakha interfluve. The northern section will terminate at the Vorkutinskaya/Seydinskaya compressor station, near the settlement of Seyda and some 65 km southwest of the Vorkuta coal-mining centre in the Komi Republic. It will include five compressor stations (Bovanenkovskaya booster, Baydaratskaya, Yarynskaya, Gagaratskaya, Vorkutinskaya/Seydinskaya) and two SOGs (Bovanenkovskaya and Yarynskaya). The reasons for selecting this particular stretch of the YEGTS for detailed examination will be made clear hereafter, but in essence this is the section where continuous permafrost is widespread, engineering-geocryological conditions are extremely complex, some of which have not been encountered in the NPT or NAGSS zone, and consequently new approaches to specific problems and new solutions are called for to improve reliability of pipeline operations, thereby ensuring uninterrupted supplies of gas. Also, this particular route could well be the one chosen by *Gazprom*. The journals *Stroitel'stvo Truboprovodov* and *Gazovaya Promyshlennost'* focus only on this route and most of all on the Yamal Peninsula component (the first 134 km), reflecting the extremely complex engineering-geocryological conditions of that part of the pipeline system. As Dr.Ivan Mazur, Chairman of *Rosneftegazstroy*, has pointed out (1989, p.8), despite the relative proximity of the Bovanenkovskoye GCF to Yamburg (250 to 350 km), natural conditions are very different. However, this focus of attention upon Yamal itself often gives the impression that the rest of the northern section has been neglected. While engineering-geocryological conditions south of the peninsula may well be more like those of the NPT for example, they will possess their own peculiarities and therefore still require full consideration with full coverage in the relevant journals.

5.2.2.2 Recent background to development of the YEGTS northern section

On 1st October 1992 the scientific-technical council of *Gazprom* and the expert council of RNGS held a joint meeting to determine parameters for gas production in the first stage of development on the Yamal Peninsula and for construction of the YEGTS (Ivantsov & Kharionovskiy, 1993b, p.25; Stepanov, 1994, p.2). The impetus behind this meeting came from Presidential Decree No.539 "*On the urgent measures for opening up new large gas fields on the Yamal Peninsula, in the Barents Sea and on the shelf of Sakhalin Island*", signed on 1st June 1992. The meeting addressed a whole range of problems, from planning delivery of freight and equipment to the peninsula, to technical solutions for the YEGTS northern section. Many of these questions had already been broached in 1987 at a similar meeting, when the interests of the indigenous peoples of the peninsula and

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[2] Eventually a 100 km spur will be laid in a northwesterly direction from Bovanenkovskoye to the Kharasaveyskoye GCF. This will not be considered here.

surrounding areas, the Nentsy, were to some extent heeded - the route of the pipeline corridor was altered to save thousands of hectares of reindeer pastures. The journal *Severnyye Prostory* (Northern Expanses) covered much of this highly contentious issue in 1988 and 1989.

As already indicated there has been considerable debate surrounding the routing of the initial section of the YEGTS (Bovanenkovskoye GCF - Vorkutinskaya/Seydinskaya compressor station). In addition to the two routes already mentioned, at least two others are apparently under consideration, as indicated in Fig.5.2 (route options 3 and 4).

Apart from the routing debate, many technical and environmental questions, associated predominantly with the northern section of the YEGTS, remain unanswered. Indeed, the journal *Stroitel'stvo Truboprovodov* (1995, p.38) reported that a meeting of the scientific-technical committee of the Interdepartmental Commission for Arctic and Antarctic Affairs (held in November 1994) had found evidence of flaws in technological, engineering-ecological, normative and organizational proposals made in the *TEO* for the Yamal fields and the YEGTS which had been completed earlier in 1994. This chapter will address the most important of these in respect of the YEGTS. The pipelines will be crossing extremely difficult terrain, especially on Yamal itself where there are abundant ice-rich saline soils, including cryopegs (cryopegs will be examined in subsection 5.2.2.4). In addition to the Yamal Peninsula, they will also traverse a 400 km zone of permafrost south of the Baydaratskaya Bay crossing. The bay crossing is, in its own right, a unique and complex construction project involving the construction of up to eight 1220 mm diameter strings. Beneath the bay the soil is mainly unfrozen and therefore gas will not require cooling after passing through the Baydaratskaya compressor station (bay crossing inlet). However, a SOG will be installed immediately downstream of the Yarynskaya CS (bay crossing outlet) to protect the permafrost. While all the appropriate solutions have not yet been elaborated, a great deal of research, by both Russian and western firms and design institutes, has gone into investigating ways of minimizing potential problems that might result from interactions between the pipelines and the surrounding permafrost and unfrozen soils both on- and off-shore. The Yamal Field and Yamal Transport scientific-technical programmes, and a separate programme for the bay crossing, are attempting to overcome some of these problems (Mikhailov, 1996, p.40).

Activity on Yamal currently involves experimental gas and condensate production at the two GCFs, the construction of the 508 km railway from Obskaya (near Salekhard) to Bovanenkovo settlement, construction of port facilities at Cape Kharasavey, infrastructure development at both GCFs (for example, road and bridge construction) and basic preparatory work for pipeline construction[3]. Mikhailov (1996, p.40) has described these activities in more detail. In May 1995

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[3] Construction of the Obskaya - Bovanenkovo railway, designed by *Lengiprotrans*, began in 1986 and so far the first 240 km section has been completed, including the Payuta station (Malkova, 1997, p.55). It will be used for the delivery of freight and equipment needed in the development of the Bovanenkovskoye GCF and

condensate was shipped by an icebreaking tanker from the Tambeyskoye GCF (northeast Yamal) to Finland. It was the first export of petroleum from the Russian North through winter ice (*Arctic News Record*, 1995, p.6). *Gazprom* also intends to export LNG direct from Yamal year-round as well as transporting oil and condensate by tankers (Gritsenko, 1996, p.viii).

5.2.2.3 Natural conditions of the YEGTS northern section

Natural conditions (climatic and geocryological) of the YEGTS northern section are extremely diverse and complex. Geocryological conditions are particularly complicated on the Yamal Peninsula, representing a significant hazard for the development of gas industry infrastructure. The main features of the region's geocryological conditions will be described briefly below, with the YEGTS northern section being divided into four subregions. Climatic data are provided in Appendix 2. Greater detail on all geocryological characteristics, cryogenic processes and phenomena and climatic data for these subregions has been provided in numerous papers, articles and books over the last 35 years, the most important of which are included in footnotes at the end of each subregional description.

i. The Bovanenkovskoye GCF

Bovanenkovskoye is located in the western central part of the Yamal Peninsula, in the R.Mordyyakha - R.Naduyyakha interfluve. The R.Seyakha (Mutnaya) flows directly through the field and the relief is terraced and broken up by numerous lakes, the largest being 7 km² in area.

Permafrost is continuous, with continuity being broken only by occasional closed taliks (rarely open) and on floodlands rarely exceeds 150-m in thickness. Perennially-frozen soils, which lie directly beneath a 0.3 - 1.5 m thick active layer, are *supeses*, *suglinoks*, clays and sands with iciness being up to 80%. Soils are to varying degrees saline, often containing cryopegs, about which more will be said in subsection 5.2.2.4. Annual average soil temperatures vary in the range 0....-8°C.

A number of cryogenic processes occur actively within the field. Thermal-contraction cracking, together with its characteristic recurring ice wedges, is common, while frost heave is not so widespread. Thermokarst lakes and *khasyreys* in various stages of development are widespread, although little thermokarst is developing currently. Solifluction on slopes of varying steepness occurs throughout the field, especially in *supes-suglinok* soils and thermal erosion occurs actively on sandy slopes. Sukhodol'skiy *et al.* (1984, p.42-72) describe slope processes, combining displacements of seasonally-thawing slope sediments with thawing of relict ice beds, as being the most significant of all the physical-geological processes within the field. Massive ice is encountered frequently, lying

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the initial section of the YEGTS, as well as to transport liquids from the field southwards. A Payuta - Novyy Port section may also be added in the future to assist the development of the Novoportovskoye OGCF (see Fig.5.2).

just below the active layer in places and exceeding 20 m in thickness. Cryogenic landslides (for example, active layer detachment failure) are also prolific (Leibman, 1995, p.262)[4].

ii. Bovanenkovskoye GCF to Baydaratskaya Bay east coast

This subregion, the geocryological conditions of which have been described by Dubikov, Boykova & Minkin (1989, p.209-218), lies between the R.Mordyyakha in the north and Viktoriya, on Baydaratskaya Bay's south east coast, the site of a hydrometeorological station and the proposed Baydaratskaya compressor station (CS-2). Again, lakes are widespread, most of thermokarst origin.

Permafrost is also continuous, with maximum and minimum depths of 450 m and 50 m respectively. Open taliks are found beneath large lakes, such as L.Yambuto. Sandy-clayey soils are typical with annual average temperatures of -1....-8°C. Seasonal thawing depths lie in the range 0.5....1 m. Iciness is also high (up to 40%), especially in epigenetic soils which contain ice streaks and massive ice. Soils can also be saline, containing cryopegs (see subsection 5.2.2.4).

Thermal-contraction cracking, frost heave, thermokarst and solifluction are widespread cryogenic processes in this area of Yamal. A regionalization of these processes on the peninsula has been made in the appendices of Trofimov (ed.) (1975). Polygonal wedge ice formed by thermal-contraction cracking is very common throughout the subregion, although active development of these features occurs mainly in its northern part. Differential heaving is caused by the development of thermal-contraction cracks which complicate the configuration of the freezing front. Earth circles, small mound microrelief and perennial and seasonal frost mounds are found here. Thermokarst processes are common, especially in syngenetic polygonal wedge ice and gully networks develop as a result of thermal erosion after these wedges have thawed[5].

iii. Baydaratskaya Bay west coast to Vorkuta

This subregion lies between Yary, on the west coast of the bay, the site of the Floks hydrometeorological station and the proposed Yarynskaya compressor station (CS-3) and SOG, and Vorkuta in northeastern Komi Republic.

Three different geocryological regions are included within this territory; the Baydaratsko-Yuribeyskaya (described by Vasil'chuk *et al.*, 1989, p.218-226), the Ural (described by Oberman & Borozinets, 1988, p.301-324) and the Malo-Bol'shezemel'skaya Tundra (described by Kaznacheyeva *et al.*, 1988, p.275-301), the latter two being the larger regions by area. Permafrost is continuous in

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[4] Key texts on local geocryological conditions are Trofimov (ed.) (1975), Sukhodol'skiy *et al.* (1984, p.42-72), Dubikov, Boykova & Minkin (1989, p.209-218), Agalakov (1993, p.112-124), Kuznetsova & Chernyad'yev (1996, p.381-388) and Baulin *et al.* (1996).

[5] Key texts on local geocryological conditions are Trofimov (ed.) (1975), Parmuzin & Sukhodol'skiy (1983, p.38-52), Platov, Trofimov & Korobanova (1985, p.40-48), Dubikov, Boykova & Minkin (1989, p.209-218), Vasil'chuk *et al.* (1989, p.218-226) and Brushkov, Lepinskikh & Nikolayev (1990, p.115-120).

the north, while it has a discontinuous or massive-island distribution further south, with annual average soil temperatures generally not falling below -5°C, but can be above 0°C in the south. The permafrost is up to 700 m thick in the R.Kara area, and as little as 100 m or even less. Soils are, in general, highly icy and in the Yary coastal region saline where cryopegs are found in sandy soils (see subsection 5.2.2.4).

Cryogenic processes have played a major role in shaping the mountainous northern part of this subregion, up to the R.Kara. Frost heave leads to the development of a variety of features, including stony earth circles and migrational and intrusive frost mounds. Thermal-contraction cracking is widespread and icings are a common occurrence on the lower parts of slopes. Cryogenic slope processes, for example solifluction, are prolific. Thermokarst, thermal erosion and coastal thermal abrasion also occur. Oberman & Borozinets (1988, p.322-324) state that engineering-geocryological conditions become more complex as one moves northwards into the continuous permafrost zone north of the R.Kara. The most common cryogenic phenomena south of the R.Kara, towards Vorkuta and passing the Gagaratskaya compressor station (CS-4), are seasonal and perennial frost mounds, thermokarst and thermal erosional forms and polygonal relief[6].

iv. Vorkuta

The Vorkuta coal-bearing basin is located in the northeastern part of the Komi Republic, some 65 km north of the site proposed for the Vorkutinskaya/Seydinskaya compressor station (CS-5).

Permafrost in this area is continuous, discontinuous, massive-island and island in distribution. It can be up to 300 m thick and as little as 10 m, with soil temperatures lying in the range -6....+4°C.

Widespread evidence of the following cryogenic processes can be found around Vorkuta; frost heave (perennial and seasonal peat or peat-mineral frost mounds, earth circles, moundy microrelief), thermal-contraction cracking (ice wedges), thermokarst and solifluction (Uvarkin & Zhukova, 1964, p.165-186)[7].

Having considered these geocryological characteristics it is reasonable to suggest that the sections of pipeline in the Yamal-Nenetskiy AO, i.e. between the Bovanenkovskoye GCF and the Baydaratskaya compressor station (east coast of Baydaratskaya Bay), together with the coastal zone of the west coast of the Bay, will be the most complicated. Russian geocryologists provide sound endorsements

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[6] Key texts on local geocryological conditions are Yevseyev (1976, p.95-159), Ivanova, Kondrat'yeva & Sukhodol'skiy (1985, p.11-20), Kaznacheyeva *et al.* (1988, p.275-301), Oberman & Borozinets (1988, p.301-324) and Vasil'chuk *et al.* (1989, p.218-226).

[7] Key texts on local geocryological conditions are Uvarkin & Zhukova (1964, p.165-186), Kaznacheyeva *et al.* (1988, p.275-301) and Kakunov (1994, p.121-138).

of this assumption (for example, Dubikov, Boykova & Minkin, 1989, p.218; Baulin & Chekhovskiy, 1994, p.815-820; Kuznetsova & Chernyad'yev, 1996, p.381-388). The reasons for the extreme complexity of these sections are as follows:

1. Soil iciness is highly variable in terms of scale and area. But in general soils of Yamal are highly icy (up to 80%). The upper layer of Quaternary syngenetically frozen soils are highly icy (40 - 60%) mainly due to the presence of segregated ice within them. This upper layer can be up to 20 m thick on alluvial and marine terraces. Epigenetically frozen soils, which lie beneath, are typically not so icy. High iciness results in the most part from the occurrence of wedge ice in areas such as floodlands and low supra-floodland terraces. Thick wedge ice is encountered. Ice wedges can be 5 m wide at the surface and 15 m deep in *suglinoks* and clays. They can also be encountered in peatlands.

2. Salinity of frozen soils of different origins and ages varies widely, thus their phase composition and the temperatures at which they freeze also vary greatly. Saline negative-temperature pressurized waters are found within the frozen soils at varying depths in the form of hydrochemical taliks and cryopegs. Hydrochemical taliks lie from the surface downwards, whereas cryopegs are found deeper and never at the surface. Large cryopegs are encountered near Baydaratskaya Bay. However, they are generally found at depths well below the normal level at which a pipeline would be buried, unlike hydrochemical taliks. In exceptional cases, cryopegs encountered close to the bay lie at a depth of as little as 1.2....2 m which is relatively shallow compared to the norm. The dense concentration of cryopegs here is a result of proximity to the bay. Cryopegs may even contain water unfrozen at temperatures between -7°C and -10°C. Cryopegs and saline soils, together with their implications for pipeline construction and operation, are examined in subsection 5.2.2.4.

3. Massive ice is widespread. As Baulin & Chekhovskiy (1994, p.816) have stressed, signs of massive ice are not apparent at the surface, except in cases of thermokarst leading to surface subsidence down to the level of the ice bed. Nonetheless, the upper surface of this massive ice may be only 1 - 2 m below the surface. Massive ice may be up to 30 - 40 m thick, extending horizontally for as little as 10 - 20 m or as much as several kilometres. It occurs in the upper 50 m horizon of the permafrost.

4. Cryogenic and slope processes are manifest. Thermokarst, thermal erosion, solifluction, landslides, thermal-contraction cracking and frost heave are all common. Thermokarst processes are not developing significantly nowadays due to the thermal stability of frozen soils (soil temperatures of -8°C are found on Yamal), but the influence of warm gas transmission could upset this stability.

Thermal-contraction cracking must also be considered in pipeline design. High soil iciness, the presence of massive ice (including wedge ice) and the partitioning of relief by water courses, create conditions favourable for slope processes. Solifluction and landslides occur even on slopes with the shallowest of inclines.

5. Disturbance of natural conditions can lead to a 1 - 2°C variation in the annual-average temperature of frozen soils. Thermokarst processes can be activated with an increase in temperatures and thermal-contraction cracking of soils with a reduction. Generally, the seasonally-thawing layer can be deepened by 0.2 - 0.3 m and seasonal heaving initiated. However, on well-drained, partitioned relief composed of *supes*-sandy soils, the seasonally-thawing layer can be deepened by 0.8 m. Dubikov, Boykova & Minkin (1989, p.218) consider this type of terrain is the most challenging in engineering-geocryological terms since it is subject to intense thermal erosion, slope processes, thermokarst and potentially irreversible damage to the surface layer.

Thus engineering-geocryological conditions of Yamal, notably its southwest coast, are extremely complex. A number of specialists, such as Baulin & Chekhovskiy of *PNIIIS* (1994, p.815), have emphasized that it these very conditions (1-5 above) that distinguish the Yamal Peninsula from other parts of the West Siberian North, notably the NPT, making it a truly challenging area in which to construct and operate buried trunk gas pipelines. Badu & Firsov (1975, p.263) conclude that during industrial development of the Yamal Peninsula special attention must be given to the dynamics and forecasting of thermal-contraction cracking (and associated wedge ice development), as well as thermokarst in all types of ground ice since the influence of these processes could lead to catastrophic consequences on sections where pipelines have been laid and are operational.

As a result, experiences from the past three decades in the NPT, while contributing greatly to the learning process, cannot be relied upon to provide all the answers to the engineering-geocryological problems that confront pipeline planners on the peninsula. The same can said of the experiences from the NAGSS and its test section at the South Soleninskoye GCF (to be discussed in section 5.3). This is yet further confirmation of sharp regional variations in engineering-geocryological conditions throughout the Russian permafrost zone. It can only be hoped that those participating in the elaboration of new SNiPs have taken stock of these variations.

In view of such extreme natural conditions, the vulnerability of such an environment and its inability to rehabilitate itself, it must always be remembered that disturbances caused by pipeline construction and operation will not only affect the integrity of the pipeline itself but also initiate serious long-term environmental damage.

5.2.2.4 Saline soils and cryopegs : making the YEGTS northern section so challenging

There are few geocryological peculiarities that Russian pipeline planners have not encountered somewhere in the NPT, Komi Republic or NAGSS zone over the last three decades, but one that is new to them is the presence of highly saline soils and cryopegs, features in most cases associated with proximity to the sea (though not always, for example inland cryopegs in Sakha-Yakutiya). Their significance for pipeline planners, in the context of freezing-point depression and pipeline corrosion for example, is considerable. For these reasons cryopegs and their geotechnical significance will be examined here.

i. Definition of a cryopeg

There seems to be a fundamental difference between the Russian definition of a cryopeg and that accepted outside. Russian hydrologists and geocryologists (for example, Kononova *et al.*, 1971, p.75; Tolstikhin, 1973, p.29; Orlyanskiy, 1985, p.24; Yershov, 1990, p.386; Dubikov & Ivanova, 1990, p.8; Romanovskiy, Konishchev & Rosenbaum, 1992, p.5; Streletskaya, Ivanova & Rivkin, 1996, p.149 and others) maintain that cryopegs are lenses of negative temperature "cryosaline" waters (cooled brines) found within saline frozen and cryotic soils. In the west however, accepted definitions, such as those put forward by Harris *et al.* (1988, p.22) and Van Everdingen (1994, p.10-11), state that a cryopeg is a layer of unfrozen ground that is perennially cryotic (forming part of the permafrost), in which freezing is prevented by freezing-point depression due to the dissolved-solids content of the pore water. This definition should not be confused with that for a hydrochemical talik which is a cryotic talik in which freezing is prevented by mineralized groundwater flowing through it, perhaps from a sub-permafrost aquifer to a saline spring (Harris *et al.*, 1988, p.81; Van Everdingen, 1994, p.59). Thus, the disparity in the cryopeg definitions relates to what is at a temperature below 0°C. For the Russians it is the water, for the westerners it is the soil. Streletskaya (1994, p.801), a specialist on soil salinity based at *PNIIS*, does however acknowledge both definitions:

> *"Cryopegs are bodies of liquid saline water associated with permafrost, and may also imply ice-free permafrost with saline pore water."*

The term "cryopeg" for negative temperature waters comes from the Greek words "cryos", meaning "cold, ice" and "peg", meaning "cold water" (a spring), and appears to have been used in the Soviet Union as early as 1933 by O.K.Lange in his book "A Short Course in General Hydrogeology" (full reference, see footnote[8]). Tolstikhin (1941, p.104) mentions that in 1933 the hydrogeologist P.M.Kozlov had described negative temperature (-3°C) saline water at depths of 130 m on one of the

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[8] O.K.Lange. 1933. *Kratkiy Kurs Obshchey Gidrogeologii*. Moscow, *Gorgeonefteizdat*.

Russian Arctic islands. Indeed, it was during the 1930s and 1940s that discoveries of saline waters at temperatures below -10°C cast doubt upon the established belief that the thickness of a frozen soil section could be determined by knowledge of the depths at which positive temperatures were revealed by drilling towards the base of the frozen zone (Tolstikhin, 1973, p.29).

Kononova *et al.* (1971, p.75) divide cryopegs into two types:

1. surface cryopegs, found in the oceans, seas or mineral lakes;
2. underground cryopegs, found above, within or under permafrost, i.e. supra-, intra- and sub-permafrost cryopegs.

Sub-permafrost cryosaline waters (sub-permafrost cryopegs, by the Russian definition), or what western specialists might call basal cryopegs (e.g. Harris *et al.* and Van Everdingen), can be pressurized and are in contact with the frozen soils above them (Dostovalov & Kudryavtsev, 1967, p.317; Yershov, 1990, p.386). Intra-permafrost cryopegs, of the Russian definition, correspond to the western definition of isolated cryopegs. The supra-permafrost cryopeg presents a problem since such cryopegs, by western definition, generally occur above sub-sea permafrost, yet these are described by Kononova et al. as surface cryopegs. Western definitions call these marine cryopegs. Perhaps Kononova et al.'s supra-permafrost cryopeg occurs in immediate proximity to the sea or ocean, i.e. they could be found in *laydas* which are influenced directly by tides[9].

Lenses of cryopegs can be found within saline frozen soils which occupy a significant part of the Russian permafrost zone[10]. Dubikov & Ivanova (1990, p.5) point out, perhaps unsurprisingly, that greater detail on saline frozen soils exists for northern West Siberia and this allowed them to compile a map of frozen soil salinity in this region which shows not only the distribution of saline and non-saline frozen marine Paleogenic and Quaternary soils, but also types and degrees of salinity.

Streletskaya (1994, p.802) explains that the mechanism for the formation of cryopegs varies considerably. At Bovanenkovskoye, for example, one group of cryopeg lenses developed syngenetically when saturated marine sediments froze, another group was formed by the differentiation of salts and water when massive ice was generated by sea water, while a third group, still forming nowadays, results from the freezing of taliks (containing soluble sea salt) beneath lakes

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[9] *Layda* - a Russian term used to describe a coastal boggy water meadow on the low-lying coastlines of Russia's northern seas (Arctic Ocean), which are flooded by high tides. They can be several kilometres wide (Spiridonov (ed.), 1980, p.221).

[10] According to GOST 25100-82, the term "saline" is applied to those frozen soils in which the soluble salt content exceeds 0.05 - 0.10% in sands, 0.15% in *supeses*, 0.20% in *suglinoks* and 0.25% in clays (Dubikov & Ivanova, 1990, p.3, footnote 1; Baulin & Chekhovskiy, 1994, p.816). At Bovanenkovskoye, for example, frozen soil salinity varies from 0.03% to 2 - 3% (Baulin & Chekhovskiy, 1994, p.816; Streletskaya, 1994, p.801-802). Minimum values are noted in the soils of the low river terraces and floodlands and salinity tends to increase with depth within the upper 20 m soil layer.

In Russia it is common practice to express water salinity in grams per litre (g/l) and soil salinity in grams per 100 grams of dry soil (%).

and rivers as they are drained. A fourth group develops annually when the saline soil temperature increases (for example due to climatic changes) together with the volume of non-freezing water. Some of this water accumulates amongst impermeable layers of soils.

Of concern to us are the cryopegs of the second type (Kononova *et al.*'s underground cryopegs). In the Russian Arctic underground cryopegs, from now on referred to simply as cryopegs, are distributed chiefly in the west and east Siberian Arctic and sub-Arctic regions, notably along the coast of the Arctic Ocean. In general, they are observed along the coasts of the Kara and Laptev seas, between the mouth of the R.Pechora in the Nenetskiy AO in the west and the mouth of the R.Lena in Sakha-Yakutiya in the east, but also in the soils of the Arctic islands. According to Kononova *et al.* (1971, p.80) the coldest known cryopegs in the former USSR at that time were located in the eastern flank of the Khatangskiy artesian basin, in the area of Nordvik (on the border of Taymyrskiy AO and Sakha-Yakutiya), where their temperatures lie in the range 0....-12°C.

ii. Distribution and characteristics of cryopegs in the region of the YEGTS northern section

Space precludes a detailed account of cryopeg distribution and characteristics in the western part of the Yamal Peninsula and the coastal part of the Russia's European Northeast[11]. However, it must be noted here that cryopegs are found not only around Baydaratskaya Bay and all the way up the peninsula's Kara Sea coast, but also inland, including within the Bovanenkovskoye GCF.

iii. Implications of cryopegs and saline soils for pipeline operations on Yamal

Cryopegs and associated saline soils present a number of complications for pipeline operations. Pipeline planners must take into account the corrosive potential of these phenomena, the strength of saline frozen soils, the possibility of frost heave initiation in cryotic saline soils and of blow outs if pressurized cryopegs are pierced during drilling operations.

Corrosion is of great concern to the YEGTS planners, particularly on the section between Bovanenkovskaya and Baydaratskaya compressor stations. YEGTS corrosion research has focused on this part of the pipeline system since the mid 1980s, but essential elements of it have been adversely affected by financial problems. To date, research both in the laboratory and in the field has shown that soil and water salinity levels on Yamal vary significantly and can be very high indeed (in

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[11] Accounts of cryopeg distribution and characteristics can be found in the following:
Yamal Peninsula - Kononova *et al.* (1971, p.79); Trofimov & Badu (1975, p.151); Yunak (1977, p.129); Lakhtina *et al.* (1983, p.88-101); Orlyanskiy (1985, p.24-34); Vasil'chuk *et al.* (1989, p.224); Ivantsov & Kharionovskiy (1993a, p.20 & 115); Streletskaya (1994, p.801-804); Baulin & Chekhovskiy (1994, p.816); Dubikov, Figarov & Tsourikov (1994, p.846-48); Streletskaya, Ivanova & Rivkin (1996, p.149-153); Krylov, Bobrov & Seguin (1997, p.133-145).
European Arctic - Kononova *et al.* (1971, p.79); Orlyanskiy (1985, p.26-27); Kaznacheyeva *et al.* (1988, p.277); Oberman & Borozinets (1989, p.321); Mel'nikov & Spesivtsev (1995, p.109).

excess of 100 g/l for some waters), but corrosional activity is not considerable, although corrosion of pipe steel has reached 0.2 mm/year in the active layer at the Bovanenkovskoye GCF (Ivantsov & Kharionovskiy, 1993, p.115). Corrosion of concrete and reinforced-concrete must also be considered. Of course, research results come from selected sites on the peninsula and are not representative of the whole of the r-o-w between the first two compressor stations, particularly since it is well known that salinity levels are so diverse. Krylov, Bobrov & Seguin (1997, p.134) have emphasized the corrosive properties of Yamal's saline permafrost, as have Streletskaya *et al.* (1996, p.149-153), Polozov, Sanzharovskaya & Voytsekhovskaya (1988, p.20-21) and Polozov (1996, p.43-46). What is apparent from past and current research material concerning water and soil salinity on Yamal is that there has been a clear bias towards investigations in the vicinity of Kharasaveyskoye and Bovanenkovskoye GCFs, while very little appears to have been done further south, towards Baydaratskaya Bay. Cryopegs exist here in close proximity to the bay, as Vasil'chuk *et al.* (1989, p.224), Dubikov, Figarov & Tsourikov (1994, p.846) and Mel'nikov & Spesivtsev (1995, p.109, 117) have shown. However, in spite of the studies at the two GCFs, cryopegs still remain the least studied cryogenic phenomenon (Streletskaya, Ivanova & Rivkin, 1996, p.149). A map of cryopeg distribution for the r-o-w as far as the west coast of Baydaratskaya Bay, similar to the 1 : 25,000 cryopeg map being produced for the Bovanenkovskoye GCF, would be extremely useful for planners. Without such a map planners will find it difficult to determine the optimal (low corrosion risk) locations for installations. The corrosion issue, in particular corrosion prevention for the YEGTS northern section, is covered further in subsection 5.2.4.4.

Frost heave initiation in cryotic saline soils must be another concern, potentially more dangerous than corrosion. Freezing of saline water and soils could occur with cooled gas transmission at temperatures below the freezing point of the particular body of saline water or soil in question. On the Yamal Peninsula this could be at around -1....-5°C. It should be noted that Evans & Taksa say that gas transmitted from CS-1 would be at -3°C in winter and -7°C in summer. It would be colder near to CS-2 on account of the Joule-Thomson effect and heat exchange. These sorts of temperatures could surely cause the freezing of some saline soils which would result in frost heave. In the context of cryopegs, it should also be noted that when saline water freezes it is only pure water, not the dissolved salts, that actually freeze. The salts are either pushed ahead of the freezing front or concentrated in tiny, even microscopic, pockets which are locked into the ice as the water freezes around them. But there is uncertainty as to the extent to which these minute salt pockets form. From the perspective of corrosion, it is important to determine whether or not such pockets could exist in close proximity to, or even against, the side of a pipe wall.

Cryopegs also impede the freezing of piles to surrounding soils, thus reducing the supporting capacity of supports, for raised pipelines for example (Streletskaya, Ivanova & Rivkin, 1996, p.149).

When drilling and a cryopeg is pierced there is also the risk of a blow out. The presence of artesian water has been known to cause blow outs in non-permafrost conditions.

Another important area of research which has not received enough attention recently is the strength of saline frozen soils. Some investigations have been carried out in relation to the construction of the Obskaya - Bovanenkovo railway (see, for example, Brushkov, Lepinskikh & Nikolayev, 1990, p.115-120). Strength charateristics of saline *suglinoks* taken from near the Tyurinto permafrost monitoring station (near Cape Kharasavey) have been investigated by Brushkov, Lepinskikh & Nikolayev (*ibid.*), but they emphasized that much more work was needed in this area of engineering-geocryological research.

5.2.2.5 Conclusion

That the engineering-geocryological conditions of the YEGTS northern section are among the most diverse and complex yet encountered by pipeline planners is undisputed. Complexity and diversity are the two factors that have presented the greatest challenge to the YEGTS planners. On the one hand the YEGTS will cross areas with highly icy soils containing massive ice, saline frozen and cryotic soils containing lenses of unfrozen saline water (cryopegs) and soils susceptible to slope processes such as solifluction and cryogenic landslides, while on the other there will be areas of saline unfrozen and noncryotic soils under Baydaratskaya Bay and areas further south where zones of continuous, discontinuous, massive-island and island permafrost lie in close proximity to each other. It is fair to say that the engineering geocryological conditions of the Yamal Peninsula section of the pipeline system are the greatest challenge because conditions comparable to these have not been encountered elsewhere. Experience from the Tazovskiy Peninsula (pipelines from Yamburg) and the southern Gydanskiy Peninsula (NAGSS and its test section, to be discussed in subsection 5.3.3) can only be of limited use to the YEGTS planners since these areas of the Russian North only possess certain similarities to Yamal, for example fairly icy soils with wedge ice. Hence, more attention will be paid to the Yamal Peninsula section of the YEGTS in the rest of this chapter. It is now time to turn to the design solutions proposed so far for the YEGTS northern section. Perhaps most importantly, we need to look for signs of a consensus on these solutions among specialists from all sections of the Russian gas industry. It must be remembered that numerous organizations and their subdepartments have taken part in planning and designing the YEGTS. Particular attention should be paid to the solutions proposed by *Gazprom* (and its subsidiaries such as *VNIIgaz*, *Giprospetsgaz*), RNGS and *VNIIST*, without forgetting independent organizations such as *YuzhNIIgiprogaz* and the Earth Cryosphere Institute (RAS).

5.2.3 Gas compression and cooling on the YEGTS northern section

5.2.3.1 Distribution of compressor stations and SOGs

Fig.5.2 shows the proposed compressor station locations, of which Baydaratskaya (CS-2), Yarynskaya (CS-3) and Gagaratskaya (CS-4) were included in the feasibility study performed by GIE (Evans & Taksa, 1995), already referred to in chapter 3 (subsection 3.2.3). These stations will each house four gas turbine-driven GPA-Ts-16L compressor units.

There will be two SOGs on the northern section, one at the Bovanenkovskaya booster compressor station (CS-1), and one at the Yarynskaya station (CS-3). GIE's feasibility study included the determination of the most technically and economically feasible gas cooling method for the SOG at CS-3 only (discussed in detail in subsection 5.2.3.2). The study took into account the maximum number of strings planned for the YEGTS northern section; six 1420 mm strings on land and eight 1220 mm strings for the Baydaratskaya Bay crossing. Details on segments of the YEGTS northern section, between compressor stations, are given below:

Bovanenkovskaya CS-1 - Baydaratskaya CS-2 :
Distance = 134 km. Pipeline pressure = 7.4 MPa.
The SOG at CS-1 will cool the gas to approximately -3°C in winter and to -7°C in summer to prevent the thawing of surrounding highly icy soils[12]. A much lower temperature is required during summer to keep the icy soils around the buried pipeline strings frozen while air temperatures are well above 0°C. By the time the gas has reached the Baydaratskaya compressor station (CS-2) it will be much cooler as a result of the Joule-Thomson effect and heat exchange between frozen soils and the buried pipeline strings. Ivantsov (1987, p.12-14) described in considerable detail the proposed gas temperature regime for the initial section of the YEGTS, as per its original routing *around* Baydaratskaya Bay. With an initial temperature of -7°C, calculations showed that by the time the gas reaches the next compressor station (which in this case would have been Laborovskaya, 440 km south of Bovanenkovskaya), it will be at -20....-22°C in winter and in summer at -13....-14°C since some warmth from the soils will reduce the influence of the Joule-Thomson effect. Ivantsov & Kharionovskiy (1993, p.129) quoted exactly the same figures six years later, but by this time the original circum-bay route had virtually been rejected. These figures might have been useful for comparison but instead they are used evidently, and very misleadingly, for the Bovanenkovskaya - Baydaratskaya leg of the now favoured bay crossing route. This distinction should have been made clear in the text of the more recent publication. However, one can conclude from this that by the time the gas reaches Baydaratskaya, its temperature will not be as cold as -20....-22°C because the

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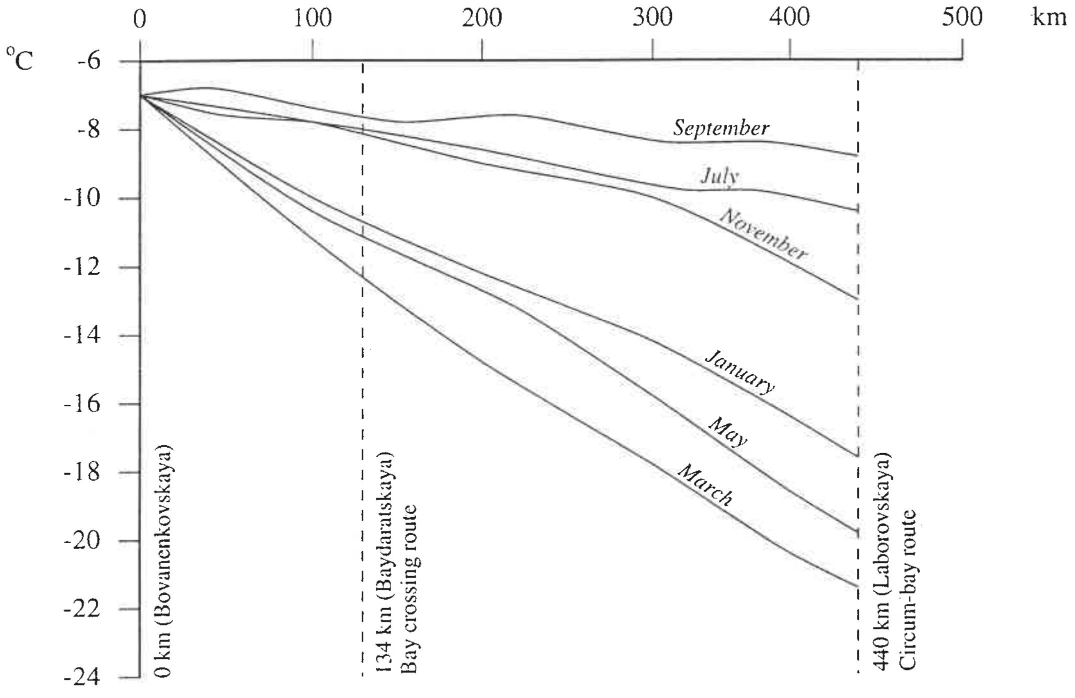
[12] Kubanov, Suleymanov & Turevskiy (1994, p.8) quote figures of -2....-5°C in winter and -5....-7°C in summer. Ivantsov & Kharionovskiy (1993b, p.28) quote -2°C for winter and -7°C for summer. Stepanov (1994, p.4) quotes figures of -3°C and -7°C respectively.

distance between the two stations is only 134 km, as opposed to 440 km for the original Bovanenkovskaya - Laborovskaya leg. This is illustrated in Fig.5.3. Although the parameters used to produce this graph would not all apply to the bay crossing route, it still permits us to assume that the gas temperature after 134 km would not be much below -12°C at any time of year. According to Kubanov (1996, p.94) gas temperature at Baydaratskaya will not fall below -17°C (and pressure not below 5.3 MPa).

Fig.5.3 Change of average-monthly temperatures of gas transmitted along the YEGTS (Yamal Peninsula section)
(Source : Ivantsov, 1987, p.13, Fig.1)



Baydaratskaya CS-2 - Yarynskaya CS-3 (Baydaratskaya Bay crossing) :
Distance = 75 km. Pipeline pressure = 7.4 MPa.
At the inlet to the crossing the gas temperature will be +16°C (winter) or +12.7°C (summer) and at the outlet -0.4°C (winter) and +1.6°C (summer) (*VNIIgaz & Eko-Sistema*, 1997, p.1.1.8). The GIE study says that there will be no need for a SOG at CS-2 because the soils are unfrozen beneath Baydaratskaya Bay. This is inaccurate, for according to Dubikov, Figarov & Tsourikov (1994,

p.845) there is relict permafrost beneath the bay at temperatures of -0.5....-2.0°C. It should be noted that although some soils are indeed unfrozen, they are at the same time cryotic (i.e. at a temperature below 0°C). Freezing-point depression, which has occurred as a result of soil salinity, prevents soils from freezing (or thawing) until their temperature reaches -2°C or lower. Hence, there is no contemporary development of permafrost. Localised thawing of isolated zones of frozen soils would not cause considerable settlement according to the GIE study. But Dubikov *et al.* (1994, p.849) have shown that thaw settlement in these soils can be as much as 120 cm after 10 years of pipeline operation with gas transmission temperatures in the range +12....3.6°C. They say that the inclusion of polyurethane coatings around the pipeline strings will not prevent progressive thaw settlement. It is therefore recommended that the gas outlet temperature (after CS-2) be lowered by laying small-diameter (up to 325 mm) cooling pipes alongside the main pipeline strings in the shoreline zone downstream from CS-2. This form of cooling, in combination with insulation around the subsea strings, will prevent the development of thaw bulbs around pipe sections, precluding thaw settlement. This recommendation demonstrates that there is disagreement in the conclusions of GIE and Dubikov *et al.* regarding the thaw settlement hazard on this section of the pipeline.

Yarynskaya CS-3 - Gagaratskaya CS-4 :
Distance = 131 km. Pipeline pressure = 7.4 MPa.
The SOG at CS-3, the study of which is described below (subsection 5.2.3.2), will cool gas to approximately -2.2°C to prevent thawing of ice-rich soils.

Gagaratskaya CS-4 - Vorkutinskaya/Seydinskaya CS-5 :
Distance = 152 km. Pipeline pressure = 7.4 MPa.
Gas from CS-4 will not require SOG cooling because soils downstream are not susceptible to severe settlement after thawing (Evans & Taksa, 1995). AVO cooling is sufficient. This would suggest that the perennially-frozen soils here are probably sandy and gravely and, unlike on Yamal, do not contain significant volumes of excess ice[13]. This lack of susceptibility to serious settlement has been indicated using GIE's geothermal predictions of two-dimensional thaw settlement over a number of years carried out by computer modelling. GIE used soil temperature data studied by *Gazprom* and *YuzhNIIgiprogaz* for their predictions, an example of which is shown in Fig.5.4.

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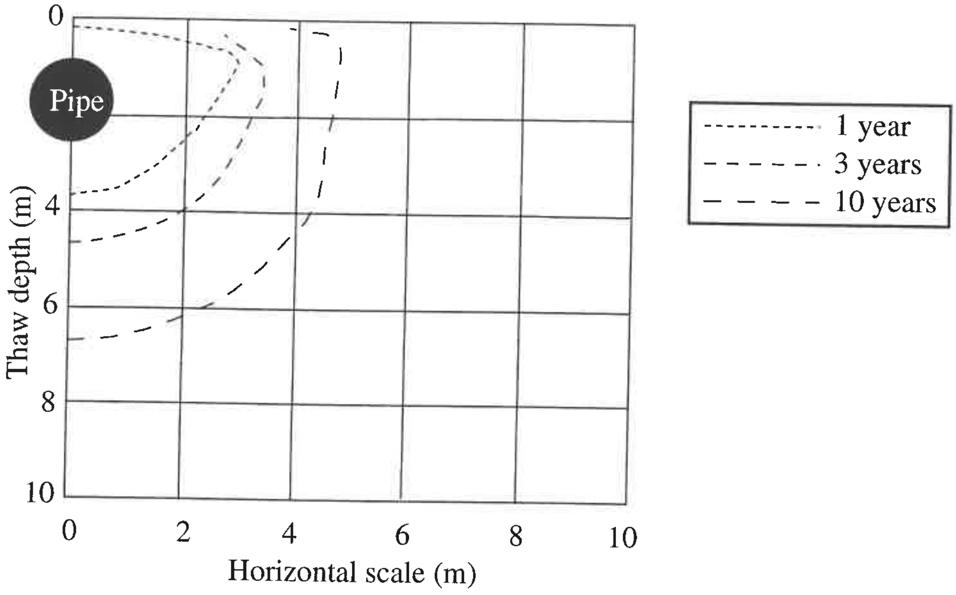
[13] Excess ice is the volume of ice in the ground which exceeds the total pore volume that the ground would normally have under natural frozen conditions. Upon thawing, a soil containing excess ice will settle under its own weight until it attains its consolidated state (van Everdingen (ed.), 1994, p.18).

Fig.5.4 Predicted thaw bulb beneath warm buried pipe near the Gagaratskaya compressor station (CS-4)

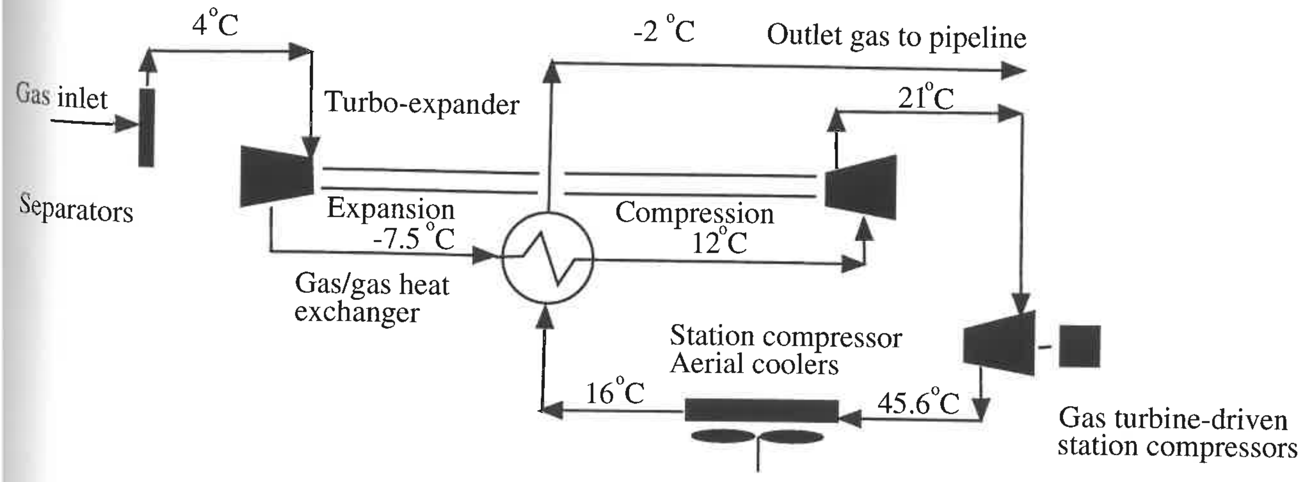
(Source : Evans & Taksa, 1995)



Note. 1420 mm pipe, mean pipe temperature = 6.5 °C, mean ground temperature = -1 °C, thaw bulb shown at year end.

Fig.5.5 Low pressure turbo-expander for the SOG at the Yarynskaya compressor station (CS-3)

(Source : Evans & Taksa, 1995)



5.2.3.2 Gas cooling by SOG at the Yarynskaya compressor station (CS-3)

For six to seven months per year ambient air temperatures in the CS-3 region are too high to achieve cooling of compressed gas to temperatures of -2.2°C by AVO alone. Therefore, GIE carried out investigations for SOG facilities using propane refrigerant plants and turboexpanders. Three gas cooling alternatives were investigated:

1. propane refrigeration;
2. high pressure turboexpander;
3. low pressure turboexpander.

Three different operating regimes for CS-3 were used in the investigations:

1. normal - all eight bay crossing strings are operational;
2. emergency - one bay crossing string is out of service;
3. extreme emergency - two bay crossing strings are out of service.

The use of regime 3 in winter would result in the lowest suction pressure, the maximum compressor horsepower and the maximum heat of compression for gas entering CS-3. CS-3 will be equipped to handle the maximum requirements of this regime. In all cases for regime 3, all four compressor units were required to be in operation to provide total compression requirements[14]. Computer modelling was used to perform heat, material balance and horsepower calculations for the compressors at CS-3 for the three cooling alternatives and operating regimes, for both summer and winter. In all cases, gas cooling equipment was assumed to be shutdown and bypassed during a six-month winter period each year. Only AVO is required to cool compressed gas to -2.2°C in winter.

Evans and Taksa concluded that a low pressure turboexpander, as shown in Fig.5.5, operating on the suction side of the station compressors would be the most technically and economically efficient gas cooling method for CS-3. Costs of gas cooling alternatives and the factors used to calculate these costs can be found in Appendix 4. The capital and operating costs of the cooling equipment are substantial and will contribute significantly to the overall costs of transporting the gas to consumers. However, the high initial capital outlay and operating costs associated with gas cooling equipment operations will ensure greater pipeline integrity and consequently a more reliable supply of gas to consumers.

5.2.4 Solutions for the linear part of the YEGTS northern section

5.2.4.1 Definition

The linear part of a trunk pipeline system comprises the pipeline sections between compressor stations. The lengths of these sections have been indicated in subsection 5.2.3.1.

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[14] Each of the four compressor sets was assumed to have an ISO rating of 20,500 Bhp.

5.2.4.2 To lay the pipeline above-, on- or below-ground

The available literature and results of discussions with specialists suggest that the YEGTS northern section will be laid in general underground. As noted above, gas will be transmitted at temperatures below 0°C year-round on the Yamal Peninsula (CS-1 - CS-2) and between CS-3 and CS-4. However, with particular relevance to the Yamal Peninsula, Stepanov (1994a, p.4-5) says that where buried massive ice and shallow-lying cryopegs are encountered, the on-ground method of pipeline laying is favoured. He adds that consideration should be given to laying pipeline strings under rivers at depths greater than normal and without insulation, but it is unclear whether he is referring to sections of pipe carrying cooled or uncooled gas. Pipe burial would be acceptable within small river taliks where the likelihood of dangerous differential frost heave is remote, but Mel'nikov (1995) adds that on- or above-ground configurations must be considered in areas of extensive river crossings where large taliks exist below the river in which frost heave could be initiated by a buried cooled gas pipeline. Yet others (for example, Griva, 1997a) have proposed that the pipelines could still be laid as *dyukers*, underground within river taliks on the condition that special heating devices be installed around the pipe strings to prevent the freezing of talik soils. This heating system would function in the same way as the one in use on the NAGSS *dyukers* buried beneath the R.Yenisey. These heating systems work on the same principal as the cooling pipes proposed by Dubikov, Figarov & Tsourikov (1994, p.849-850) for the underground shoreline section of the YEGTS just before it crosses Baydaratskaya Bay (as described above in subsection 5.2.3.1). This measure has been proposed for the opposite effect - to prevent warm gas from thawing frozen soils around the subsea strings[15]. Such temperature regulation would only be considered necessary and economical for crossings beneath wide rivers, where freezing of taliks could lead to serious frost heave problems. For comparison, *Yamburggazdobycha* considered it uneconomical to install heaters alongside gathering line *dyukers* transmitting gas at -4°C through taliks beneath small rivers. Although heave has occurred in places it has never been enough to rupture the pipe (Kondrat'yev, 1998). This attitude of investing in preventative measures only in the face of imminent rupture conforms very much to *Gazprom*'s belief in replacing pipe after rupture, not preventing rupture (described in chapter 4, section 4.4) and should be discouraged.

5.2.4.3 Ways of minimizing the risk of dangerous cryogenic processes

i) Introduction:

Ivantsov & Kharionovskiy (1993b, p.26) have identified two cryogenic processes which in their opinion require most attention in the context of the YEGTS initial section on the Yamal Peninsula -

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[15] Refrigerant lines were installed on an 11 km section of the Trans Alaska Oil Pipeline to reduce the warming effect on surrounding ice-rich soils (Williams, 1986, p.55 and Fig.4.4).

frost heave and thermal-contraction cracking. In actual fact, the cryogenic process to which the YEGTS northern section is potentially most susceptible is thaw settlement, hence the great importance attached to gas cooling and SOGs. As indicated in subsection 5.2.3, gas at the Bovanenkovskaya compressor station will be cooled in winter to approximately -3°C and in summer to -7°C. At the Yarynskaya station gas will be cooled year-round to -2.2°C. As Evans & Taksa (1995) have indicated, the cooling is needed since both these legs of the YEGTS northern section are considered to be located in regions susceptible to potentially dangerous levels of thaw settlement.

The article in which Ivantsov & Kharionovskiy emphasize the importance of frost heave and thermal-contraction cracking is at times even more misleading in that there are many references to the NAGSS and its pipeline test section near the South Soleninskoye GCF, together with suggestions as to how solutions used there can be applied to the YEGTS. These have little relevance for much of the YEGTS northern section since the NAGSS and its test site loop (ironically enough intended for YEGTS, gathering and feeder line research and development) transport gas at unregulated temperatures. This issue will be taken further in subsection 5.3.3 below. The NAGSS is subject to a unique combination of cryogenic processes which has developed largely on account of its gas transmission temperature regime (absence of regulation by cooling). A pipeline system transmitting cooled gas below 0°C year-round, as in the case of onshore YEGTS strings up to CS-4, will be subject to a very different set of cryogenic processes and temperature stresses. Ivantsov and Kharionovskiy do nevertheless acknowledge the intended gas transmission temperature regime for the Bovanenkovskaya SOG which is that during winter the gas will be maintained at -2°C and in summer at -7°C.

ii. Ballasting : is it necessary?

There are currently two contrasting opinions on the ballasting issue. In order to prevent floating up of the pipeline caused by melting of ice-rich permafrost, Stepanov (1994a, p.4), speaking for *Gazprom*, states that frozen-in anchors are to be used on sections where the gas is cooled by SOGs (research conducted into frozen-in anchor performance on the Yamal Peninsula will be examined below in subsection 5.3.2.2). This represents the more traditional approach to pipeline construction in northern Russia, which can also be interpreted as an acknowledgement that some thawing will take place, even though it is known perfectly well that the intention is to cool the gas on much of the northern section. Others have suggested, somewhat ironically, that there would be no need for this sort of ballasting if thawing of frozen soils could be prevented and this principle lies at the heart of the other opinion. Professor Oleg Ivantsov of RNGS (1987, p.13, p.14; 1993, p.56; 1995; Ivantsov & Kharionovskiy, 1993b, p.28) has made the radical suggestion that ballasting and the use of frozen-in anchors would not be necessary at all with the condition that the gas is cooled reliably (its temperature is maintained year-round at surrounding soil temperature), that construction of the pipeline is completed within one winter season, backfill must be of low moisture content to increase the soil's compression strength, and commissioning must occur before the onset of summer. It would be fair to say that Ivantsov's suggestion has only received serious consideration because of his stature within the Russian pipeline industry, but naturally the renunciation of anchors would represent a significant economic benefit. That Stepanov has revealed *Gazprom*'s intention to use frozen-in anchors indicates that perhaps the above conditions will not be met. Judging from past experience it is very likely that temperature regulation will not take place reliably and some melting might well occur. In such a case, the anchors would be crucial for stabilizing the affected pipeline strings. But deep thawing could render the anchors useless if the frozen soils around the bases of the anchor structures are also melted. It is pointed out that any delay in supplying the cooled gas through the new pipe strings will mean that by summer a ballasting berm must be laid above the buried strings some 1 - 1.2 m above the border of seasonal thawing. This would require the berm to be roughly 0.5 m in height (i.e. above ground level) since seasonal thawing depths in this area of the peninsula in general lie in the range 0.5 - 1.0 m (Dubikov, Boykova & Minkin, p.217). The question of duration of construction remains unanswered. On the one hand, it is reported that the scientific-technical and expert councils of *Gazprom* and RNGS envisage completion of pipeline and SOG construction by the onset of the first summer (Ivantsov & Kharionovskiy, 1993b, p.28), whereas the GIE feasibility study says that construction will take two winter seasons, or 19 months in total (Evans & Taksa, 1995). Whatever the outcome, it would seem that the designers have two options:

1. to install more reliable and powerful SOGs (more expensive), but enabling the exclusion of anchors and ballasting;
2. to install cheaper and less efficient SOGs, but with the likelihood of thawing problems and the pipeline floating up. In this case anchors and ballasting would be essential but still might not prevent floating up.

Preference must be given to the first option, with construction completed within one winter season if at all possible. But if anchors and ballasting are excluded in the end, the cooling regime of the SOG must be maintained at all costs so that the pipeline is retained within frozen soil. Any upset in this regime could eventually lead to irreversible thawing of soils around the pipeline strings and possibly even the initiation of the "thaw ⇒ freeze-thaw" process. It would seem that *Gazprom* will nonetheless install anchors and so the company needs also to bear in mind the comments made by Leonid Dimov of *KomiNIPIstroy*, as discussed in chapter 3, subsection 3.2.5.2. In his opinion, voiced as recently as 1996, much more research is required to ensure reliable functioning of anchor structures. His opinion is shared by Telegin *et al.* (1995, p.23), in spite of tests conducted at the Bovanenkovskoye GCF during the early 1990s (discussed below). But experiences with frozen-in anchors on Yamburg - Yelets 2 near the Yamburg GCF, examined in chapter 4, subsection 4.3.3.4, are testimony to their lack of reliability. Irrespective of these concerns, there remain two factors influencing the reliability of anchor structures. Firstly, the design of the structures themselves, including calculations of their interaction with frozen soil; and secondly, the effectiveness of gas cooling operations. The latter, as already noted, is crucial, since no matter how well designed the anchors may be, they will not function reliably in the presence of "warm" gas temperatures which cause deep melting of frozen soils.

Continuing with the ballasting theme, Stepanov (1994a, p.4) states that for sections transmitting uncooled gas (CS-4 - CS-5, for example), reinforced-concrete weights are to be used to ballast the pipeline strings. But practice in the NPT (for example just south of Yamburg) has shown that such weights are unreliable (they are not frost-resistant and are often damaged during installation) and it is hoped that they would never be considered for pipe sections surrounded by saline soils where corrosion would be a major problem, as Polozov *et al.* (1988, p.20) and Telegin *et al.* (1995, p.26) have warned. Soil together with NSM is also cited by Stepanov for use as ballast and as protection for soil berms from erosion. This is more in line with Telegin *et al.*'s recommendation that such materials be used in combination with so-called soil-filled container weights (*ibid.*). The containers would be made from industrial fabric and the weight unit, comprising two containers, one each side of the pipe, would have a volume of 3.5 m^3 and a mass of roughly 5.5 tons.

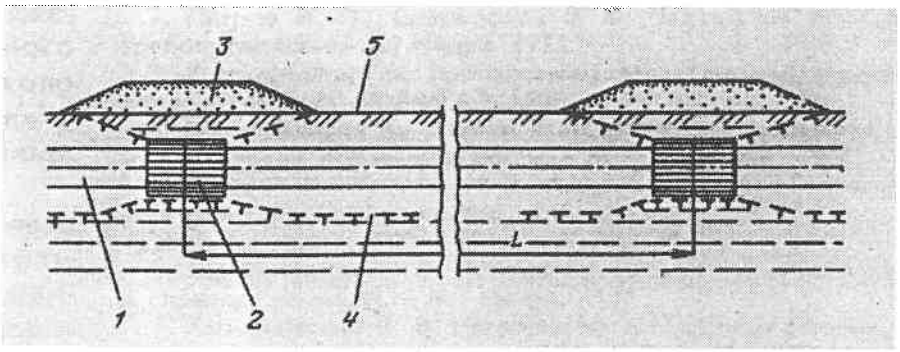
iii. Anti-frost heave measures:

As far as counteracting frost heave is concerned, Ivantsov & Kharionovskiy (1993b, p.27-28) also describe the short-term heating of the pipeline at points where it passes through extensive river taliks, as mentioned above in subsection 5.2.4.2. They go on to describe construction of trenches transverse to the pipeline axis which are filled with non-frost susceptible soil. Another solution to the problem involves the installation of so-called "frozen support masses" (*merzlyye opornyye massivy*), as shown in Fig.5.6. The manner in which these masses function is described in detail by Ivantsov & Kharionovskiy (1993b, p.27-28). However, this measure presupposes unregulated gas transmission temperatures, i.e. positive in summer, which makes it irrelevant to most of the YEGTS northern section. But perhaps it is being considered in any case as a precautionary measure in the event of gas cooling problems.

Pipelines should not be laid at the base or on lower parts of slopes since water and moisture accumulate which, in natural conditions, is favourable for the development of intrusive (injected ice) frost mounds and hydrolaccoliths. Frost heave and jacking would be serious here with such high moisture availability. The heave (if differential) could not only displace the pipeline strings, but also damage the coatings around the pipeline, thus exposing sections of the pipe wall to corrosion.

Much more work must be done on the frost heave problem, particularly in relation to heave in saline cryotic soils and cryopegs caused by very low gas transmission temperatures. Gas temperatures could be as low as -12....-17°C at the end of the Bovanenkovskaya - Baydaratskaya section of the YEGTS, in a coastal area where saline cryotic soils and cryopegs are abundant.

Fig.5.6 Structure of a buried pipeline with frozen support masses
(Source : Ivantsov & Kharionovskiy, 1993b, p.27, Fig.3)



1. Pipeline; 2. thermal insulation; 3. berm; 4. border of permafrost; 5. Ground surface.

iv. Measures to counteract thermal-contraction cracking of soils:

Ivantsov & Kharionovskiy (1993b, p.28) also stated that thermal-contraction cracking of soils must be considered very seriously in the planning of the YEGTS, as indicated in chapter 4, subsection 4.3.1. Polygonal cracks have been observed in exposed sections of buried gas pipelines where the snow cover is minimalized by winds. According to studies such as Kharionovskiy & Tsymbal (1990, p.50-58), stresses in pipe walls can reach 130 - 140 MPa in the region of a thermal-contraction crack, but there is an additional 25 MPa precisely where the crack is located. These stresses are higher than those that Grechishchev & Sheshin (1983, p.155, Table IV.16) calculated in earlier research into the influence of thermal-contraction cracking on pipe walls. The cracking has a significant influence upon stress and this must be taken into account in calculations. The thermal-contraction cracking issue requires much more research in the context of the YEGTS section CS-1 to CS-2 where phenomena resulting from the process, such as recurring ice wedges, are common. Where gas temperatures will be below -10°C, perhaps upstream of the Baydaratskaya compressor station, Baulin & Chekhovskiy (1994, p.820) have suggested that pipeline strings be wrapped in insulating "shells" in order to protect them from additional stresses caused by frozen soil cracking.

v. Thermal-contraction cracking in pipe steel:

Very little is known about the origin and dynamics of thermal-contraction cracks on the surface of some pipe walls. According to Ivantsov (1995), this is a newly identified problem. Cracks appear in the exposed surfaces of pipe walls, in which water accumulates in summer. This water freezes in winter, expanding and widening the cracks over several years. Again, this is something that needs greater attention in the context of the YEGTS northern section chiefly because year-round negative-temperature gas transmission is envisaged.

vi. Anti-thermal erosion measures:

Solutions to the serious problem of thermal erosion, even if they exist, have received negligible coverage in key industry journals. Thermal erosion will be an important consideration for the YEGTS northern section even if the gas cooling regime is adhered to. For example, if construction activities proceed without the use of sand work pads on the Yamal Peninsula, as Evans & Taksa (1995) have pointed out, thermal erosion could be initiated, rapidly worsening on account of the thawing of wedge ice and consequently posing a threat to reliable pipeline operation. Any upset in the gas cooling regime which promotes the initiation of thawing of icy soils would very likely result in the origin of thermal erosion. According to the classification of Voskresenskiy & Zemchikhin (1986, p.130-138) the Yamal Peninsula, especially the central and northern part, is either moderately or highly susceptible to thermal erosion (see chapter 4, subsection 4.3.4).

A solution to the thermal erosion problem has been proposed by Karl F.Ott, Head of the Technical Department, TTG [16]. As Fig.5.7 shows, the aim of this proposal is to lay a pipeline across the gentlest slopes above river floodlands so that the pipeline actually follows the course of the river, but without changing the local natural erosion regime or obstructing the path of temporary water courses which arise during the spring thaws (Ott, 1997). In line with this, the pipeline must be laid within a single geomorphological level and not perpendicular to the river, i.e. crossing the river valley. As shall be explained below, this has important implications for the YEGTS northern section. While the pipeline is laid in gentle slopes above the floodlands it must also be laid above maximum flood level, but below the first suprafloodland terrace. Fig.5.7 shows also that the pipeline must be laid in a "zig-zag" fashion in that above-ground transits are used to cross the river from one gentle slope to another, always avoiding the steep slopes which link the first supra-floodland terrace to the floodlands.

This proposal once again throws open the question of the routing of the YEGTS northern section r-o-w, but in this case the alternative r-o-ws proposed by Ott differ significantly from the two main ones already under consideration (the Baydaratskaya Bay crossing and the circum-bay routes). Ott suggests that in order to avoid thermal erosional problems on the Yamal Peninsula, gas gathering lines from Bovanenkovskoye and Kharasaveyskoye GCFs and the YEGTS itself should follow the

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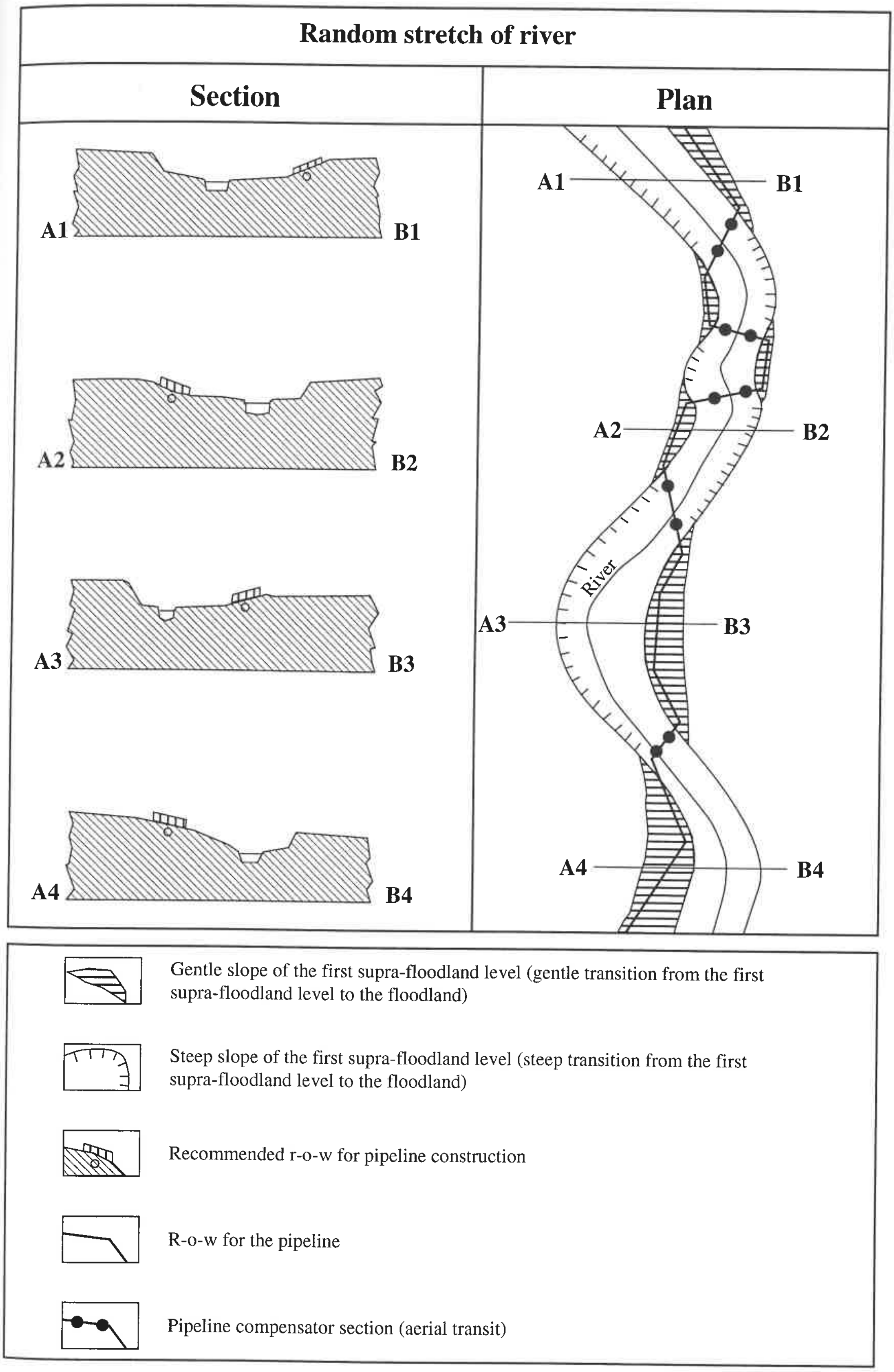
[16] This proposal has been patented by the Russian Federation Committee of Patents and Trade Marks.

Fig.5.7 Method suggested by K.F.Ott (Tyumentransgaz) to counteract thermal erosion on the Yamal Peninsula
(Source : Ott, 1997)



courses of river systems (west-east orientation), rather than cutting across them (north-south orientation) as would be the case with better known route options (1 and 2). This is indicated in Fig.5.2, in which route option 3 is shown heading eastwards from Kharasaveyskoye and Bovanenkovskoye to Yamburg, which would incorporate an underwater transit across Obskaya Bay off Yamal's east coast. Evidently, these lines would link up with the existing trunk gas pipeline system at Yamburg. Another r-o-w, route option 4, would lie off Yamal's west coast, running underwater from Cape Kharasavey to the Yarynskaya compressor station. Gathering lines would feed gas to the subsea trunk pipeline which would be more than 250 km in length.

Clearly, these are radical route proposals, the main inspiration for which in this case stems from the desire to minimize the risk of thermal erosion along the r-o-ws of trunk gas pipeline strings. However, thermal erosion is far from being the key factor promoting alternative route proposals. The thermal erosion issue on its own would not justify an entirely new set of feasibility studies and design projects, but according to Ott and Khrenov (1998) these r-o-ws, in particular the west-east route to Yamburg, are under serious consideration by *YuzhNIIgiprogaz*, one of the design institutes involved in the original *TEO* for the YEGTS, and *Gazprom* itself. The west-east route is particularly attractive because of the very much shorter length of new pipeline required to reach Yamburg and all the associated economic and environmental benefits. Given that the Yamburg GCF has approximately 15 years left of production at current levels of output (Salikhov, 1998), Yamal gas could gradually replace Yamburg gas in the existing trunk pipelines heading southwestwards from the field. Appraisals of these alternatives can only serve to delay further the selection of the route for the YEGTS northern section. Nonetheless, it is encouraging to see that all possible options are being explored.

5.2.4.4 Other solutions

i. Corrosion prevention and the "with or without" debate:

As already discussed in subsection 5.2.2.4, YEGTS corrosion specialists have the added complication of cryopegs, which in some cases do not freeze at -7°C or even as low as -10°C, and saline frozen and cryotic soils.

Traditionally, the importance of corrosion has been underestimated by both industry and government in Russia. Extreme wear and deterioration of pipeline systems occurred chiefly because corrosion control was not made a priority (Vorob'yeva & Legezin, 1993, p.32-34). The sheer scale of pipeline construction in the 1970s and 1980s resulted in numerous violations of the SNiP regulations for corrosion control (Stepanov, 1994b, p.64). The present condition of the Russian oil and gas pipeline networks has driven corrosion control high up in the list of research priorities. Here, we examine corrosion in the context of the YEGTS. But one must not forget SCC, already referred to in chapter 4 (subsection 4.3.1), which is of particular concern nowadays, while very little is known about the process in northern conditions. It is therefore crucial that some research work focuses on SCC in northern conditions as part of the Yamal pipeline development programme.

The service life and reliability of gas pipelines depend largely on protection against soil corrosion. While there has been a general decrease in related failures since 1990, Ivantsov (1996b) describes corrosion as the Achilles heel of Russian pipelines, as was shown in chapter 2, section 2.5. Corrosion has been a particular problem for small-diameter gathering lines at the Medvezh'ye and Vyngapurovskoye GCFs on which corrosion pits reach 2 - 4 mm in depth. Specialists at the *GiproTyumenneftegaz* institute have determined that pipeline corrosion rates are between 0.1 and 0.85 mm per annum in the Ob' Basin (Khanty-Mansiyskiy AO) (Ivantsov & Kharionovskiy, 1993a, p.114). Northern Russian gas pipelines display two forms of corrosion protection; (1) passive protection (coatings, such as thermo-plastic powders, polymer tapes and bitumen) and (2) active protection (electro-chemical/cathode). These have been described in considerable detail by Ivantsov & Kharionovskiy (1993a, p.113-130).

As far as corrosion prevention strategies for the YEGTS northern section are concerned, an unusual situation has arisen in the debate surrounding exactly which strategy should be employed. It would appear that two approaches to corrosion prevention are being considered, both very different, one being more traditional and the other one far more radical even though it has been under consideration for at least a decade. However, much of the available literature does not give one the impression that there are two sides to the debate. In a situation very much reminiscent of the ballasting debate described in subsection 5.2.4.3, ii., specialists from RNGS, namely Professor Ivantsov, are on one side of this debate, while those from *Gazprom*'s corrosion department and *VNIIST* lie on the other.

Gazprom's Department of Corrosion Protection, having analysed the technical and economic characteristics of cathode protection systems incorporating insulating flanges, considers that the use of such a combination for the YEGTS will guarantee a significant reduction of both capital and operational costs and will lead to the attainment of a high level of corrosion protection and operational reliability (Pritula & Tychkin, 1995, p.18). This conforms more to the traditional approach. In fact, Tychkin & Petrov (1997) confirm that *Gazprom* considers a combination of both active and passive protection to be the optimal form of corrosion protection of buried pipelines in permafrost conditions. It would seem that *Gazprom* is pursuing this strategy for the YEGTS northern section. Most components of both cathode and coating protection systems are currently being redeveloped by *Gazprom* and *VNIIgaz* to take into consideration those factors listed in Table 5.2.

VNIIgaz and Gaz de France have already developed the Minerva 3000 automatic transducer and rod galvanic anodes which have been designed with full consideration of the factors listed in Table 5.2 (*ibid.*).

Table 5.2 **Main factors driving *Gazprom*'s redevelopment of cathode (active) and coating (passive) corrosion prevention systems for gas pipelines operating in permafrost conditions, including the YEGTS** (Source : Tychkin & Petrov, 1997)

Cathode Protection

1. Thick layers of perennially-frozen soils require correction of protection parameter calculations.
2. Pipeline strings laid within a single "technological" corridor - older strings have less negative potentials and act as cathodes to the newer strings.
3. The need to create stable and continuous protection (polarization) potential required development of automatic transducers which:
    a. exclude cathodic hydrogeneration;
    b. compensate partially for errors in protection parameter calculations;
    c. stabilize protection during seasonal changes in soil resistivity, soil thawing, flooding, etc.
4. Protection of transducers and power lines from extreme natural-climatic conditions of the north.
5. Remoteness of power supply sources.
6. Seasonal variations in current distribution along pipeline strings.
7. Potential damage to cathode cables.
8. Soil heterogeneity.
9. Need for new telemetry and telecontrol of cathode transducers.

Coating Protection

1. Desire to use triple-layered coatings.
2. Methods of trench excavation to minimize damage to pre-coated pipe sections.
3. Need for anticorrosive soil backfill.
4. Pipe storage - pipes must not be exposed to cyclic temperature differences.

On the other hand, Ivantsov & Kharionovskiy (1993a, p.129) refer to a corrosion prevention system called "*Kholod*" ("Cold") which they say had been suggested for use on the YEGTS northern section. Ivantsov wrote about the *"Kholod"* system as early as 1987. The principle behind the system is in line with that for ballasting and anchoring, as discussed above in subsection 5.2.4.3 ii. As with ballasting, Ivantsov proposed that if the gas were cooled to a sufficiently low temperature, in this case to -8°C, cathode protection could be excluded entirely (Ivantsov, 1987, p.15-16; Ivantsov & Kharionovskiy, 1993a, p.129). At critical temperatures all phase transitions in a soil electrolyte cease and the majority of it acquires a crystalline state, while a small part remains unfrozen. Phase transitions were shown to cease at -5°C in soils possessing minimal salinity. The formation of a crystalline framework in the frozen soil almost completely cuts off access by free oxygen to the corrodable surface and considerably reduces its depolarization. The rate of corrosion is slowed significantly (to about 0.1 mm per year). Ivantsov goes on to say that in order to slow corrosional

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7. Potential damage to cathode cables.
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However, soils in the Bovanenkovskoye GCF can have salinity levels of at least 1.0%, depending on the soil type (Streletskaya, 1994, p.804, Table 4.1). Ivantsov noted in 1987 that further research was being conducted to develop correlations between temperature of cooling and the rate of pipe steel corrosion in soils with different salinity, composition and moisture content which are typical for the YEGTS corridor on Yamal. These were conducted within the gas industry's "Corrosion" programme. While these correlations have not been forthcoming, other associated research offers an insight into the corrosive activity of Yamal's soils and waters and the performance of anti-corrosion coatings under their influence. Anatoliy Polozov, formerly of the northern branch of *VNIIST* in Ukhta (now *KomiNIPIstroy*), led studies into pipeline corrosion during the 1980s, as part of the Yamal development programme (Polozov, Sanzharovskaya & Voytsekhovskaya, 1988, p.20-21; Polozov, 1996, p.43-46). Research was conducted in both laboratory and field conditions. Corrosion stations were established in 1986-87 at the Bovanenkovskoye and Kharasaveyskoye GCFs which comprised steel samples covered with a waterproof material[17]. Polozov's research group concluded that soil salinity in the study region is very heterogeneous with the quantity of dissolved salts generally lying in the range 0.09....42.76 g/l. Waters capable of causing metal corrosion are surface waters (minimal corrosive component content), supra-permafrost waters (fairly acidic, pH 5.0 - 6.4) and lenses of intra-permafrost waters in marine sediments (cryopegs)[18]. The latter are highly saline (85 g/l is typical, exceeding that of the Kara Sea by six times) and do not freeze at temperatures of -8°C. While these are generally found at depths of 4 - 10 m, one lense was discovered near the settlement of Bovanenkovo at 1.2....7.0 m, the depth at which a buried pipeline would lie. Although salinity was not more than 43 g/l in this case, corrosive activity was noted. The research also showed that rates of corrosion for Bovanenkovskoye (0.005....0.012 mm per year) and Kharasaveyskoye (0.002....0.025 mm per year) are average or low in perennially-frozen soils, although they are higher in the active layer and with the movement of surface water (up to 0.3 mm per year). Lower corrosion rates can be explained by their high moisture content, low temperatures and low concentrations of corrosive components in water (such as Cl + SO).

It must be noted that water salinity levels well in excess of 85 g/l have been found on Yamal, for example up to 150 g/l in cryopegs in the coastal *layda* west of Bovanenkovskoye (Streletskaya, 1994, p.804, Table 1). Much depends on the sites chosen for field tests, but this variability helps to

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[17] Observations at these stations recently ceased due to a shortage of funds (Polozov, 1996, p.45).

[18] Unusually, Polozov does not use the term cryopeg to describe these lenses, but according to the recognized Russian definition this term should be applied here.

demonstrate the extreme diversity of soil and water salinity in the central western part of the Yamal Peninsula, while corrosive activity of such soils and waters need not be high. Given the relatively low corrosive activity of these soils and waters, the Russian-made bitumen-polymer coatings used to protect the experimental steel samples at the corrosion stations proved effective. These coverings were also shown to be frost resistant and Polozov and his team thus recommended the use of GT-760IN, GTP-821 and GTP-900 coatings (Polozov, 1996, p.46). However, this recommendation was approved by *Glavyamburgneftegazstroy* in 1987, only months after the experiments began and it was aimed specifically at protection of steel piles (for gas feeder lines) rather than for buried trunk gas pipelines.

While the results of these tests are nonetheless significant, from the point of view of pipe coatings, we are still no less uncertain about the "*Kholod*" system which would supposedly permit the exclusion of cathode protection. Without more data on the gas cooling temperature - rate of corrosion correlations it is impossible to make any firm conclusions as to its possible performance in respect of the YEGTS northern section. Other than Ivantsov & Kharionovskiy's brief discussion in 1993 there have been no other references to "*Kholod*" since Ivantsov posited the idea in his 1987 paper. Whether or not this is an indication of the system's demise, in favour of a more traditional approach using cathode protection as well as coatings, we cannot be sure. All the indications are that *Gazprom* and *VNIIST* are currently pursuing the cathode protection with pipe coatings approach. This must, under no circumstances, be perceived by *Gazprom* as *carte blanche* for cheaper gas cooling operations at the two SOGs, especially at Bovanenkovskaya, in which gas temperatures could be permitted, even periodically, to exceed the -2....-7°C design figures. Experience in the past has shown for example that pipe coatings have been damaged during laying operations and power cuts have rendered cathode stations useless (Ivantsov & Kharionovskiy, 1993a, p.123, p.127; Stepanov, 1994b, p.64). In such cases, higher gas temperatures would result in significant corrosive activity. SOG operations must achieve the design temperature levels in order to prevent the development of a "corrosional microclimate" around the pipes, with cathode and protection functioning as additional security.

That Ivantsov is proposing the *Kholod* corrosion prevention system as well as the exclusion of anchors and ballasting, suggests that he must also be a proponent of the effective cooling of the CS-1 to CS-2 leg of YEGTS, which would allow considerable savings given that cathode stations, electricity lines, anchors and other forms of ballasting could be excluded from the design. However, this is certainly the riskier of the two options.

ii. Increasing the hydraulic effectiveness of the Bovanenkovskaya - Baydaratskaya section of the YEGTS:

Since 1986, members of *VNIIgaz* (Kubanov, Suleymanov & Turevskiy, 1994, p.8-10; Tolstov & Kashchitskiy, 1995, p.3-5; Kubanov, 1996, p.94-100; Istomin & Yakushev, 1996, p.56-58), *YuzhNIIgiprogaz* (Sumskiy & Yelistratov, 1996, p.89-94) and *Urengoygazprom* have developed new low-temperature gas treatment technologies to prevent the build up of a liquid phase, or gas hydrates, in gas pipelines[19]. *VNIIgaz* scientists carried out calculations of the thermohydraulic operational regimes of the Bovanenkovskoye GCF - Baydaratskaya compressor station section (134 km) of the YEGTS in order to determine the requirements for low-temperature separation (LTS) of gas. This process should ensure single-phase gas transmission, i.e. without the accumulation of a liquid phase or hydrates in the pipelines. Hydrates build up in pipelines in the form of dense hydrate plugs (Makogon, 1994, p.124). A so-called "dry" operational regime must be ensured so that the likelihood of reduced hydraulic effectiveness is minimized.

Currently, the most widely used method of preparation of Cenomanian gases for transportation is absorption dehydration. This process is carried out in the UKPGs located at the fields. Heavy hydrocarbons (C_3 + higher) are fed into a pipeline where they condense on account of a lowering of the pipeline's pressure and temperature. Condensation of the hydrocarbons and of the absorbents (diethylene glycol, known as DEG) which are carried away within the gas from the absorbers leads to a reduction of the hydraulic effectiveness of the gas transmission system. This phenomenon occurs on the initial sections of trunk pipelines from Yamburg and Urengoy (Sumskiy & Yelistratov, 1996, p.90). In addition, the *VNIIgaz* studies have shown that the use of absorption dehydration in combination with a SOG and separation for Aptian-Cenomanian gas at the Bovanenkovskoye GCF will not guarantee a dry operating regime for the initial 130 km of the YEGTS. Five different variants for gas preparation were used in the *VNIIgaz* calculations. A year-round dry operating regime along the whole 130 km section can be achieved only by implementing LTS at -35°C with a removal value of 2 mg/m³. Hydraulic effectiveness reaches 95% under such conditions (the figure accepted in the calculations was only 90%). LTS has been recommended for use at Bovanenkovskoye and Kharasaveyskoye GCFs by *Gazprom* (*ibid.*, p.91; Kubanov, 1996, p.100).

iii. Airborne and satellite monitoring of the YEGTS northern section:

Since the 1980s remote sensing from space has dramatically improved monitoring and therefore, indirectly, the reliability of Russian gas industry installations, particularly trunk and gathering gas pipelines in the north of West Siberia (Khrenov & Yegurtsov, 1997, p.68). Satellites have been used

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[19] Gas hydrates, also known by their chemical name of "clathrates", are ice-like compounds of natural gas (mainly methane) and water which are stable at very low temperatures and high pressures. They also occur naturally in permafrost regions and in the deep ocean. They are increasingly being seen as a major source of gas reserves for the future (Istomin & Yakushev, 1996, p.56).

in conjunction with fixed-wing aircraft and helicopters equipped with various forms of photographic apparatus to monitor northern trunk gas pipelines since the mid 1970s [20]. For example, aerial monitoring of the Nadym - Punga gas pipeline began in 1975, details of which can be found in Borodavkin, Khrenov & Yegurtsov (1990, p.87-91). The data provided by these types of monitoring makes it possible to gauge the relationship between a pipeline and the surrounding environment (pipeline - permafrost interactions) over time making it possible to assess changes in this relationship. Results also help to improve pipeline management practices and to reduce monitoring costs as compared with land-based methods. The most important applications of pipeline remote sensing are as listed in Table 5.3.

Table 5.3 **Key applications of pipeline monitoring by remote (air, space) sensing** (Source : Khrenov & Yegurtsov, 1997, p.67)

1. Evaluation of pipeline condition - spatial position and movement, identification of sections under stress, assessment of cause(s), leak detection, location of damage to pipeline banking, ballast weights.
2. Evaluation of interations between pipelines and environment - location of environmental disturbances along r-o-w and potential disturbances.
3. Environmental assessment - detection of escaping pollutants.
4. Thematic mapping of regions crossed by pipelines.
5. Develop recommendations for pipeline repair and upgrade schedules.
6. Supervision of pipeline repair and construction.
7. Assists in the planning of new pipelines - identification of potentially dangerous or difficult sections.
8. Forms an integral part of large-scale pipeline surveys in conjunction with land-based methods.
9. Allows the reinterpretation of older surveys conducted without remote sensing methods.

The founding of the firm "*Ekotekh*" in 1988 marked the beginning of a new era in remote sensing of gas pipeline systems and surrounding environments in northern West Siberia. The firm was set up specifically to provide remote sensing and land-based survey support for gas pipeline and environment monitoring in West Siberia. It's aim is to evaluate and, where possible, predict the condition of the pipelines and landscapes through which they pass. Over almost one decade "*Ekotekh*" has conducted surveys of 15,000 km of trunk or gathering gas pipelines including the northern sections of the following systems: Yamburg - Yelets, Urengoy - Nadym, Nadym - Punga, Urengoy - Surgut - Chelyabinsk, Urengoy - Pomary - Uzhgorod, Nizhnevartovsk - Parabel' trunk gas pipelines, Urengoy GCF gathering line and Yamburg - Urengoy, Urengoy - Surgut condensate

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[20] N.N.Khrenov is recognized as the founding father of trunk pipeline monitoring by remote sensing. His work in this field began in the mid 1970s at *VNIIST* (Khrenov & Yegurtsov, 1996, p.47).

pipelines (Khrenov & Yegurtsov, 1996, p.66; Khrenov & Yegurtsov, 1997, p.68). Full descriptions of monitoring work on both gas and oil pipelines conducted from 1975 up to and after the founding of "*Ekotekh*" can be found in Khrenov & Yegurtsov (1996, p.66-87).

Aerial photography of Yamal began in 1977, when photographs (scale of 1 : 2000 and 1 : 50,000) were taken of gas fields there. They would be used in the planning of the optimal routing for the YEGTS northern section r-o-w. These were analyzed with the help of ground-based data collected by *Giprospetsgaz* on the planned r-o-w of the YEGTS Bovanenkovskaya (CS-1) - Baydaratskaya (CS-2) section (*ibid.*, p.67). A decade passed before the next stage of aerial photography on a more extensive section of the proposed YEGTS r-o-w. In 1987 two stages of surveying were conducted on the section Bovanenkovskaya (CS-1) - Gagaratskaya (CS-4), in conjunction with surveys of operational trunk gas pipelines in the NPT. Photographs were taken from modified AN-30 and TU-134 aircraft flying in mid July, immediately after snow melt, and in mid September, by which time maximum melting of permafrost had taken place and before the first snow falls in order to obtain data on soil moistening (*ibid.*, p.73-74).

Together with a new generation of internal diagnostic equipment, both airborne and satellite surveying will play a crucial role in the monitoring of the whole operational YEGTS[21]. The experience already gained from "*Ekotekh*" in northern West Siberia will have allowed specialists to refine their methods of monitoring new northern pipelines, notably the YEGTS northern section which will pass through some of the most hazardous and complex landscapes in the Russian North. In 1994-95 for example, the Gubkin State Oil & Gas Academy (*GANG*) set out guidelines and recommendations for remote sensing practices, including the processing and analysis of data from airborne and satellite monitoring (*ibid.*, p.64; Khrenov & Yegurtsov, 1997, p.68).

5.3 Test sites for the planning of the YEGTS northern section

5.3.1 Introduction

There has been a tendency, although it is now decreasing, for Russian pipeline planners to place too much emphasis upon experiences from other oil and gas provinces within the Russian Federation when developing design solutions for new northern pipeline projects. In doing so they fail to take into full consideration the fact that natural-climatic (geocryological, hydrological, etc.) conditions vary markedly within the vast territory of the Russian North. There are significant differences in such conditions both between and within the main oil and gas producing provinces. Experiences from past

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[21] Internal diagnostics is becoming common on the UGSS, particularly in the form of cooperative operations between *Gazprom* daughter enterprises and western diagnostics firms. For example, in 1995 the German firm Pipetronix conducted ultrascan diagnostics of Urengoy - Centre string 1 within the Krasnortur'inskoye and Lyalinskoye *LPU*s of TTG in order to locate stress-corrosion cracks (Khoroshikh, Dolgov & Orlyanitskiy, 1996, p.85-90).

development of gas fields and pipeline construction in other gas-bearing provinces do undeniably provide important lessons for planned projects elsewhere, but the danger lies in relying too much upon those experiences. What might be appropriate for one geocryological area may well be inappropriate for another. So far this thesis has indicated many of the regional variations in geocryological conditions within the Russian North, for example differences in soil type, moisture availablity, soil iciness and salinity. These differences have crucial implications for the structural design of an installation and, in the case of pipelines, the temperature at which the product should be transmitted. This point cannot be emphasized enough in pipeline planning.

Ideally, to ensure the reliable functioning of any installation it is essential to base design solutions both upon past experiences from other regions (for elaboration of the main type of solution) and upon detailed large-scale field investigations of experimental pipeline sections constructed at the site of the planned installation (to tailor the final design solutions to local natural-climatic conditions). These investigations would be an important addition to the standard engineering-geocryological surveys carried out as part of the first stage of planning in accordance with SNiP 1.02.07-87.

Three decades ago pipeline planners used experiences from the original Taas-Tumus - Yakutsk section of the MYaB to design string 1 of the NAGSS. Admittedly, the NAGSS planners had no other pipeline experience from permafrost regions upon which to base their solutions, but at the same time natural-climatic conditions in central Sakha-Yakutiya and the Taymyrskiy AO vary significantly. The lack of any full-scale pipeline testing in the Noril'sk area prior to construction put the planners at an immediate disadvantage when drawing up the final design solutions for NAGSS string 1. Several years later, the early experiences from NAGSS were used in the design of the first 1220 mm and 1420 mm diameter strings from the Medvezh'ye GCF in the NPT. The operation of these large-diameter strings from the NPT, commissioned in the early 1970s, provided essential data for the planning of the next generation of trunk gas pipeline strings from Urengoy and Yamburg in the 1980s. Although these latter pipelines were all laid within the same gas producing province of northern West Siberia, natural-climatic conditions still vary considerably from field to field, and within fields, each one being located at a different corner of the NPT "triangle". Small experimental feeder line and gathering line sections were installed and tested by *VNIIST* and other planning institutes at Urengoy (1985-86) and Yamburg (1986-88), but these would have been of little use to trunk pipeline development which had by that time already started at these fields.

As has been shown in chapter 4, geocryological conditions in the NPT, even permafrost continuity, are highly variable. The opening up of Yamal marks the beginning of development of another new gas producing province with its own local geocryological peculiarities not encountered elsewhere. In some respects central Yamal bears greater similarity to the southern part of the Gydanskiy Peninsula than the NPT, at least in climatic and geocryological terms, but even those similarities are limited. Thus, for the YEGTS designers to produce the most effective solutions for trunk pipeline construction and operation in the new Yamal gas province, as well as in regions further south (up to Vorkuta), they would ideally have been able to use results from full-scale pipeline test sections built on Yamal and perhaps also near Vorkuta, where geocryological conditions are very different. Currently, there is only one such test section in the Russian Far North, this being the 1420 mm diameter test section on the NAGSS at the South Soleninskoye GCF (southern Gydanskiy Peninsula), results from which have been used for the planning of YEGTS. South Soleninskoye had the advantage of an existing fully operational trunk gas pipeline system (720 mm diameter) onto which the test section could be attached and more will be said about this test section in subsection 5.3.3. The Yamal Peninsula and Vorkuta region have no operational trunk gas pipelines so test sections were ruled out from the start, but even a small scale test section linked to the feeder lines transmitting gas from the first wells at Bovanenkovskoye would have provided some crucial insight into pipeline operations in the precise conditions that the initial section of the YEGTS will operate. Krasulin, Gekhman & Stepanova (1989, p.22) mention that there were plans to construct an experimental 720 mm diameter pipeline to investigate the structural reliability of above-ground pipes (feeder lines) at Bovanenkovskoye but there is no evidence of this ever having been built.

While a pipeline test section has never been built on Yamal, test sites were set up for investigations into specific aspects of feeder and gathering line construction and of general development on the peninsula, no less important than those concerning trunk pipeline (YEGTS) operation. These test sites are described in subsection 5.3.2.

5.3.2 Test sites on the Yamal Peninsula

5.3.2.1 Introduction

With its considerable experience in conducting field investigations related to pipeline research in permafrost conditions, *VNIIST* was given the task of directing the development of test sites on the Yamal Peninsula. These would be used to test and then assess the reliability of solutions to a variety of problems recommended by the planning institutes. Two test sites were proposed, both of which are located in different geomorphological and engineering-geocryological conditions at the Bovanenkovskoye GCF. Characteristics of the two sites are presented in Table 5.4.

A plan view of test site No.1 is shown in Fig.5.8. According to Krasulin, Gekhman & Stepanova (*ibid.*), test site No.1 would be used for investigating:

1. the supporting capacity of piles for the field's above-ground gas feeder lines and gathering line;
2. the supporting capacity of frozen-in anchors in different soil types;
3. methods for consolidating soil backfill;
4. structures of winter roads and methods of protecting them during summer;

Fig.5.8 Test site No.1 at the Bovanenkovskoye GCF
(Source : Krasulin, Gekhman & Stepanova, 1989, p.22, Fig.3)

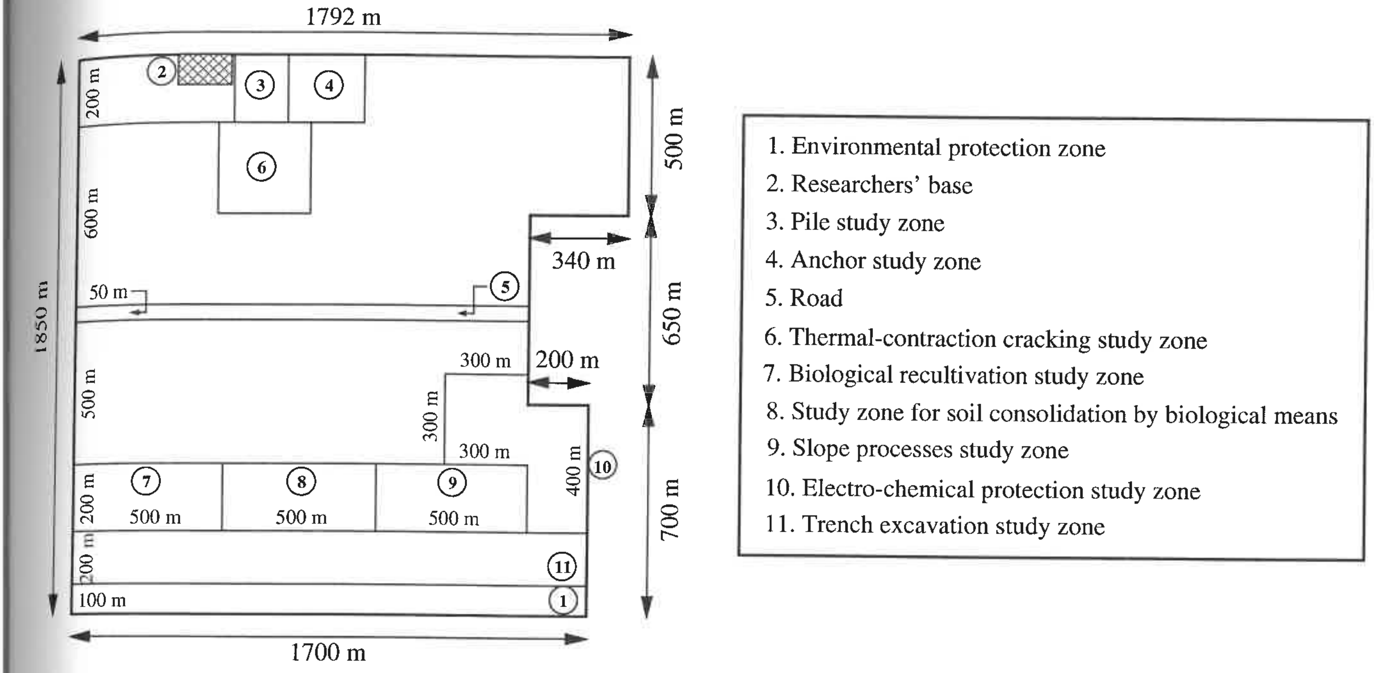
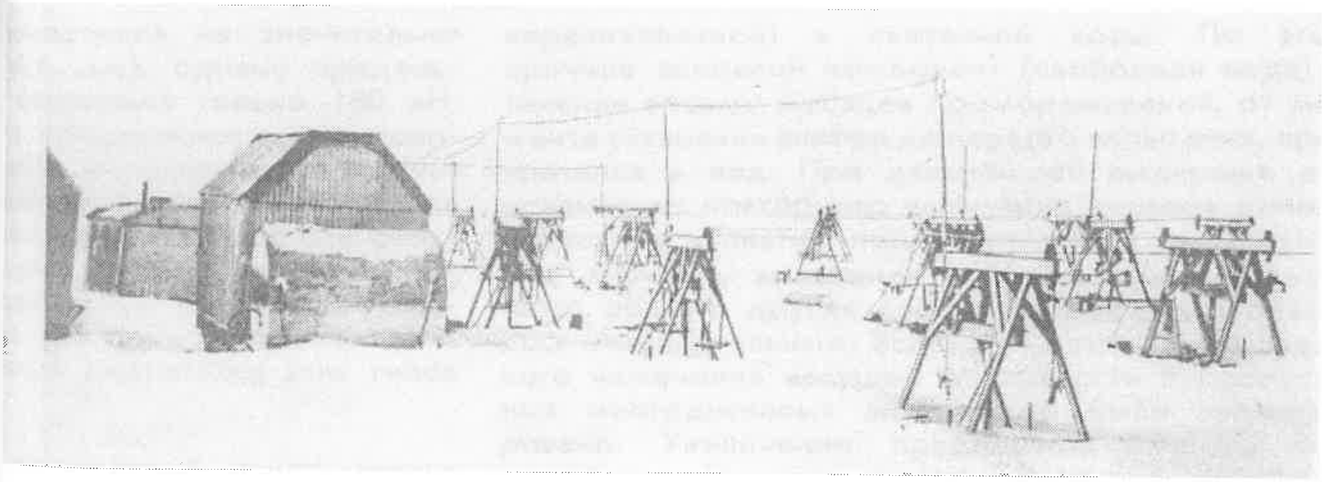


Fig.5.9 Frozen-in anchor field at test site No.1, Bovanenkovskoye GCF
(Source : Khafizov, Il'yasov & Pomazanov, 1993, p.32, Fig.1)



5. methods of installing piles, pipeline insulation, digging trenches;
6. methods of assembling and installing special protection devices in areas of cryopegs;
7. thermal-contraction cracking and slope processes on very gentle inclines;
8. methods of recultivating disturbed or badly damaged moss tundra.

Table 5.4 **Natural and geocryological conditions at the Bovanenkovskoye GCF test sites** (Source : Krasulin, Gekhman & Stepanova, 1989, p.22-23)

Test Site No.1 - R.Mordyyakha floodlands, adjacent to road and gas feeder line.

Elevation above sea level (m)	**Surface features**	**Soil types**	**Average annual soil temperature (°C)**	**Seasonal thawing depth (m)**	**Soil salinity (% *)**
14	flat, practically unpartitioned (no gully networks), boggy, few small lakes	*supeses*, dusty sands, *suglinoks* (interbedded)	-2.2....-4.2	0.2....0.4 (peatbogs), 0.6....0.8 (mineral soils)	0.2....0.7

Test Site No.2 - gentle slope of the R.Seyakha - R.Yunetayakha interfluve (terraces and coastal-marine plain) with L.Tibeyto on the southwestern side.

Elevation above sea level (m)	**Surface features**	**Soil types**	**Average annual soil temperature (°C)**	**Seasonal thawing depth (m)**	**Soil salinity (% *)**
10....25	heavily eroded, partitioned by gullies and small streams, slope surface favourable for formation of solifluction terraces and lobes	sands, *supeses*, *suglinoks*, clays (buried massive ice at 1.5....5.2 m)	-3.6....-5.5	0.6....1.2 (mineral soils, beneath a 10 cm moss-vegetation cover)	No data

* NOTE : % is grams of salt per 100 grams of dry soil.

While *VNIIST* is the main investigative organization, other organizations such as *VSEGINGEO*, the northern branch of *NIIOSP* and the Siberian Division of RAS have participated in analysing the results of tests conducted at the two sites.

5.3.2.2 Frozen-in anchor investigations at test site No.1 (Bovanenkovskoye GCF)

The most widely published results of the investigations have been from the frozen-in anchor component which has been directed by R.M.Khafizov of *VNIIST*. Fig.5.9 shows a view of the frozen-in anchor field at test site No.1. Several articles were published in 1993, some already referred to in chapter 3, subsection 3.2.5.3 (part i), describing the results of these studies (Khafizov *et al.*, 1993a, p.13-16; Khafizov, Il'yasov & Pomazanov, 1993, p.32-35; Khafizov, 1993, p.28-32; Khafizov *et al.*, 1993b, p.31-34). Background and results of the frozen-in anchor tests conducted in 1990 have already been examined in chapter 3. Further tests were also conducted in 1991 and 1992.

Frozen-in anchors are used to prevent a buried gas pipeline from being displaced upwards, away from the original position of the pipeline. Such displacements could lead to the build-up of dangerous stresses in the pipe walls, possibly leading to rupture. Such cases have already been examined in chapter 4, subsection 4.3.3.4. Upward displacements could be caused by combinations of thaw settlement (summer) and frost heave (winter), resulting in jacking, if the gas is transmitted at temperatures above and below 0°C depending upon the time of year. Alternatively, a pipeline could eventually float up after a number of years of predominantly positive temperature gas transmission, as has been the case in the NPT. However, frozen-in anchors are rendered useless if their frozen soil foundations thaw as a result of excessive warming to considerable depths (5 m or more). It is therefore essential that gas cooling by SOGs is effective and gas temperatures should not rise far above 0°C at any time of year, especially summer. If the soil foundations of the anchors remain frozen, some thawing just below the underside of the buried pipeline is acceptable since upward displacement will still be prevented.

The attention given to the frozen-in anchor investigations at test site No.1 would indicate that this form of stabilization of buried trunk gas pipelines is heavily favoured (at least by *Gazprom* as indicated earlier) for the YEGTS section on the Yamal Peninsula which will include SOG cooling. The precise location of these tests within site No.1 was particularly important since geocryological conditions, notably frozen soil salinity levels, had to be representative of those along the planned YEGTS r-o-w on the peninsula. Khafizov *et al.* (1993b, p.31) have acknowledged that experiences from the Yamburg test site and actual trunk gas pipeline operation with frozen-in anchors (Yamburg - Yelets 2) would not be sufficient grounds upon which to base YEGTS anchoring designs due to significant differences in soil conditions. A principal difference is the presence of saline frozen soils at Bovanenkovskoye. These are not found at Yamburg. The use of results obtained at test site No.1 should therefore ensure a more reliable design for frozen-in anchors to be used on the YEGTS (Bovanenkovskaya compressor station to Baydaratskaya).

Khafizov *et al.* (1993b, p.34) show that the frozen-in anchors tested at site No.1 between 1990 and 1992 can sustain considerable extraction loadings (*vydergivayushchiye nagruzki*) even in saline frozen clayey soils: finned anchors - 160 kN, quadruple-disc anchors - 180 kN, single-element rotating anchors - 170 kN and quadruple-element rotating anchors - 180 kN [22]. The tests showed that the actual supporting capacity (120.5 kN) of the soil foundations of single-disc anchors was 1.66 times higher than that calculated using construction norm VSN 007-88 (72.4 kN), while for quadruple-disc anchors it was 1.2 times higher (154.5 kN as opposed to 128.9 kN). Given these results, together with the experiences from anchor tests at Yamburg (described by Gumerov *et al.*, 1989, p.23-24), they recommend that buried trunk gas pipelines on Yamal should be secured using finned and quadruple-disc anchors. These must be used in combination with SOG cooling at the Bovanenkovskaya compressor station.

Analysis of the structural solutions of the frozen-in anchors and the technology for submerging them in frozen saline (less than 0.25%) soils showed that the so-called "drop" method (*opusknoy sposob*) of submergence should be used. Soil salinity is decreased considerably by using this method since a large amount of fresh water is injected resulting from the condensation of heated steam[23]. Decreased salinity of the frozen clayey soil adjacent to the anchors helps to increase its supporting capacity, bringing it closer to those values for non-saline *suglinoks* and *supeses*, as calculated in accordance with normative documentation.

According to data from Khafizov (1993, p.32) and Khafizov *et al.* (1993b, p.34) the anchors were submerged in soils with only 0.2% salinity, but elsewhere on the YEGTS r-o-w salinity will be higher. This is indicated by research conducted by, for example, Streletskaya (1994), as discussed earlier in this chapter (subsection 5.2.2.4). Additional tests could have been conducted to investigate the supporting capacity of soils with a higher salinity. At the very least it would be important to ascertain how effective the "drop" method of anchor submergence would be in more saline soils. Perhaps the injection of steam would serve to reduce this higher salinity sufficiently to create conditions for acceptable soil supporting capacity values.

The existence of the two Bovanenkovskoye test sites shows that the planning and design institutes, such as *VNIIST*, recognize the importance of obtaining results from investigations carried out over several years in geocryological conditions very similar to those of the planned pipeline system. Moreover, the test sites are located within the *same* geocryological region as the planned initial section of the proposed pipeline. There has been little evidence of such forethought in previous trunk gas pipeline planning and design projects. Nonetheless, the installation of a full-scale pipeline test section would have been even more useful for the planners. Frozen-in anchors could

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[22] 1 kN (kilonewton) = 102 kg (force) or 224.8 lb (force).

[23] The sink method of anchor submergence involves thawing the permafrost by using heated steam which is injected under pressure through a steam needle. After thawing the anchor is submerged into the soil mass (Khafizov, 1993, p.32).

have been tested in the manner that they should be used - to secure a pipeline, and not simply submerged in the ground individually with loadings applied.

5.3.3 The South Soleninskoye 1420 mm diameter pipeline test section (NAGSS)

5.3.3.1 Introduction

With the absence of far northern gas pipeline experiences which could be applied to pipeline development on the Yamal Peninsula, notably the YEGTS northern section, proposals were put forward in 1986 by *VNIIgaz*, *VNIIST* and *Giprospetsgaz* to construct a 1420 mm diameter pipeline experimental test section[24] (Kharionovskiy, 1991, p.3). Two major considerations were used in determining where the section would be located:

1. natural-climatic conditions had to be as similar as possible to those of central western Yamal;
2. the test section would have to be attached to an existing gas pipeline system, if for no other reason than to reduce costs.

With little else to choose from, a section of the NAGSS just north of the South Soleninskoye GCF was selected (see location in Fig.2.1), onto which the test section could be attached. The test section should not be regarded as an autonomous pipeline system; gas is fed into it directly from the NAGSS. This test section is known by some (for example Konstantinov, 1990, p.103) as the "Yamal" test site. The 5 km test section of pipe has provided invaluable data particularly for planners designing concepts for feeder and gathering lines at Yamal GCFs, as well as for the northern section of the YEGTS, but the results should be valuable for any gas pipeline project planned for an area of continuous permafrost.

This subsection demonstrates that although South Soleninskoye was, under these circumstances, the most appropriate site for the "Yamal" test section, the results of the observations conducted there have a more limited usage for YEGTS planners than might have been hoped. This stems firstly from the fact that geocryological conditions of the two regions (test site and western Yamal) are not identical and secondly because the gas transmission temperature regime of the test pipeline, and the NAGSS, does not match that intended for use on the YEGTS northern section, particularly the Yamal Peninsula section (CS-1 - CS-2). In connection with the latter, test site results are in fact more appropriate for the planning and design of the Bovanenkovskoye GCF feeder lines. Results of the test section observations will be described briefly.

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[24] At that time of course, production at Urengoy had not yet peaked and Yamburg had barely begun producing gas, let alone supplying it. Also, the Russians were fully aware of pipeline test sites in the Alaskan and Canadian North, for example Kharionovskiy (1993, p.30-35) examines those at Prudhoe Bay, Norman Wells, Inuvik, Lake Kluane (Yukon) and Sen Salt (100 km north of Norman Wells). But these sites are not comparable to the Yamal Peninsula in engineering-geocryological terms.

5.3.3.2 Natural conditions of the test section region

From 1986, under a contract from *VNIIgaz*, the northern expedition of *MGU*'s Geography Faculty and the firm *Sevzapaderogeodeziya* carried out geocryological surveys of a 50 km² area to determine the most appropriate location for the test site and also for planning and design of the pipeline test section (Konstantinov, 1990, p.103; Kharionovskiy, 1993, p.33). Surveying continued until 1990, after commissioning of the section, in order to monitor the pipeline's influence on the surrounding permafrost. Konstaninov (1990, p.103-112; 1991, p.43-51) describes the natural conditions of the area (before construction) as follows. Climatic data for the region are provided in Appendix 2.

The test section is situated within the southern tundra subzone (grass-shrub lichen-moss tundra) in the R.Taz - R.Yenisey interfluve, at an elevation of 45 - 70 m. One metre high alder thickets can be found on the upper parts of slopes, mossy *yerniks* at the foot of slopes and osiers in stream basins. Shrubs reach a maximum height of 1.5 m. Roughly 10 - 15% of the area of the test site is occupied by polygonal peat bogs with both boggy sedge-cotton grass-sphagnum outcrops and dry areas occupied by shrub-moss-lichen associations. Soils in the upper 10 m soil section are late Quaternary and Holocene thinly/finely dispersed (*tonkodispersnyye*) lacustrine-alluvial and glacial-marine. Medium grained (0.25 - 0.5 mm) Kazantsevsk sands lie at the base of this section, although they can be found at the surface in places. *Supes-suglinoks* in general lie above the sands at the surface (1.0....4 - 5 m thick). 3 - 4 m thick peat layers are encountered occasionally. In climatic terms, the test section region is subject to slightly more extreme conditions than Yamal GCFs.

5.3.3.3 Geocryological conditions of the test section region

The South Soleninskoye GCF is situated in the northern part of the Taz-Khetsko-Yeniseyskaya geocryological region, which has been described in considerable detail by Vasil'chuk & Kudryashov (1989, p.260-264). Geocryological conditions are in some respects similar to those of the Bovanenkovskoye GCF, but it is misleading to suggest, as some have done (for example, Ivantsov & Kharionovskiy, 1993a, p.79), that they are practically identical. One striking difference is the lack of saline permafrost and cryopegs at the test section. Nonetheless, South Soleninskoye is much more appropriate than the NPT where geocryological conditions are very different.

Permafrost at the site is continuous and exceeds 400 m in thickness, though deep closed taliks exist beneath large lakes. Average annual soil temperatures at the depth of zero annual amplitude (10 - 12 m) vary within the range -7....-2°C. The lowest temperatures are typical for the peaks of hills from where snow is blown away by winds. The highest temperatures are found in the bottoms of *khasyreys* and stream basins where snow depths often exceed 1.5 m. But soil temperatures are most often in the range -4.5....-5.5°C where there are gentle slopes and the snow cover is 0.2....0.6 m deep. In the period August - October the temperature of the upper 1.5 m soil horizon, or active layer, is less than -1°C (plastic-frozen state), whereas in winter their temperature is -10....-15°C (hard-frozen state).

Seasonal thawing depths range from 0.3 m to 1.5 m. Variations in depths of the seasonally-thawing layer are caused by the heterogeneous lithology and iciness of soils, different levels of moisture availability and diversity of vegetation type, continuity and height. Soil thawing begins in late June, with maximum intensity of thawing in June - July, and ceases in mid-September. Freezing of the layer then commences and is complete by early December. The deepest active layers (1.2....1.5 m) are typical where osiers grow and where sands are found at the surface. Thinly dispersed soils under temporary water courses thaw a little less deeply (1.0....1.2 m). Minimum thawing depths (0.3....0.5 m) are noted in peatbogs where the moss cover is some 20 cm thick. For 80% of the test site's territory, where *suglinoks* and *supeses* are found at the surface, thawing depths are 0.6....0.9 m.

Since the soils of the active layer contain significant amounts of dusty soil particles which are highly icy they are very susceptible to frost heave during freezing. Observations revealed heaving magnitudes of 5 - 7 cm in a 0.6 - 0.9 m thick active layer. The disturbance and removal of the vegetation cover by pipeline construction and operation has led to considerable increases in the depth of seasonal thawing, which in icy thinly dispersed soils has led to the development of thermokarst and thermal erosion.

Within the test section region there are four types of soils which differ in terms of cryogenic structure and iciness:

1. sandy upper Quaternary soils : they have a massive cryotexture and a low moisture content of 15....25%;
2. thinly dispersed soils of the ground surface soil complex : these are the dusty *supes-suglinok* soils which are noted for their high iciness and diverse cryotextures. High iciness levels of 40....60% (0.4....0.6) are the norm in the upper section (1 - 3 m thick) of the perennially frozen soils. The surveys have revealed a close relationship between cryogenic structure, thickness of the highly icy horizon and landscape conditions. Maximum thicknesses (3 m) of the highly icy horizon are found beneath the lower parts of slopes in the hummocky shrub-moss tundra. Here stratified, lenticular and reticular cryotextures are common, with 5....20 cm thick ice interlayers. The thickest ice streaks often lie immediately beneath the active layer.

Similar cryotextures and high levels of iciness (greater than 50%) are typical for the upper soil horizons in slopes occupied by spotted/mottled (*pyatnistaya*) tundra. Ataxitic cryotextures are encountered often in *supeses* in such tundra. The minimum thicknesses of highly icy soils near the surface are found in the upper parts of slopes covered with alder thickets, where stratified and reticular cryotextures have developed with 1 - 2 cm thick streaks situated at 3 - 4 cm intervals. Iciness in such areas lies within the range 25....35% (0.25....0.35);

3. lacustrine-boggy Holocene *supeses* and *suglinoks* : these coincide with depressions in relief and typically they have lenticular-stratified and reticular cryotextures. Ice streaks are 0.5 - 1 cm thick. Moisture content does not exceed 30....40%;
4. polygonal peatbogs with recurring ice wedges: while these Holocene features are very limited in extent they require special attention because of their engineering-geocryological complexities, in particular the presence of recurring wedge ice within them. The peat is 3 - 5 m thick with polygons reaching 10 - 15 m. Ice wedges lie at depths of 0.3 - 0.5 m and can be 5 m in height, 0.3 - 1 m wide. Massive cryotextures are normal for frozen peat with lenses and pockets of ice. Moisture content occasionally exceeds 200....300%.

Given the above, Konstantinov (1990, p.111) concludes that the main peculiarity of the cryogenic structure of the test section region is the presence of a horizon of high iciness which lies directly under the seasonally-thawing layer. This elevated iciness is also emphasized by Sharapova (1990, p.112). The presence of highly icy soils in the surface soil complex and of recurring wedge ice in peatbogs create ideal conditions for the development of thermokarst and rapid solifluction initiated by disturbances of surface conditions during pipeline construction and operation. In addition, areas with high annual average soil temperatures and deep thawing (osier beds) are awkward since even a slight increase in snow cover depth could lead to the development of taliks and a loss of stability for pipelines. Natural conditions in the region demonstrate that geocryological conditions can vary significantly even within a small area, this being another reason for the precise location of the site. In terms of the YEGTS, the high iciness of soils (with the presence of recurring ice wedges, ice lenses and pockets) provides welcome opportunities for the study of pipeline operations in such unfavourable geocryological conditions, conditions which are rarely found in other permafrost regions where gas pipelines operate.

5.3.3.4 Observations of pipeline - permafrost interactions at the test section

Design of the test section was carried out by *Giprospetsgaz* and construction, carried out by *Noril'sktruboprovodstroy*, took place in winter 1988 (Sharapova, 1990, p.114). Technical characteristics are shown in Table 5.5.

The following research work has been conducted on the test section, as outlined by Kalyavin (1990, p.141, 143) and Kharionovskiy (1993, p.33-34):
1. instrumental investigation of the strength and stability of various pipeline configurations (above, on, under ground) with a variable gas transmission temperature regime and diverse geocryological conditions;
2. study of vibrations and vibration strength of an above-ground pipeline with varying spans of pipe sections;
3. analysis of gas pipeline strength with non-stationary regimes (start up, shut down);

Table 5.5 **Technical characteristics of the South Soleninskoye pipeline test section, Yamalo-Nenetskiy AO** (Source : Kalyavin, 1990, p.138-144; Vinogradov, 1993, p.46-51; Kharionovskiy, 1993, p.31, p.33)

Location
69°05' N, 81°35' E.
Ca.2 km upstream (north) of the NAGSS compressor station at the South Soleninskoye GCF. Attached to string 1 of the North Soleninskoye - South Soleninskoye - Messoyakha gathering line.

Pipeline steel characteristics
Diameter and wall thickness : 1420×18.7 mm (supplied by Nippon Steel Corp., Japan)
Ultimate strength : not less than 60 kg/mm^2
Yield strength : not less than 47 kg/mm^2
Impact strength : 9.7 kg.m/cm^2 (at -20°C); 7.6 kg.m/cm^2 (at -30°C); 6.3 kg.m/cm^2 (at -40°C)
Design minimum temperature of gas : -60°C

Design operational pressure
7.5 MPa (4.0....5.5 MPa normally)

Pipeline configuration and length
A. Above-ground : 1517 m
Divided into :
1. A 656 m "temperature block" (including a 150.8 m trapezoidal compensator section)
2. A 772 m "temperature block" (including a 266.8 m trapezoidal compensator section)
3. An 89 m self-compensating section

Fixed supports I, II and III (using "*komponor*" synthetic anti-friction material between support cross-beam and pipe wall surface)
B. On-ground : 1068 m
Comprises one "Temperature block" with the pipeline laid on surface supports or "sleepers"
Includes one trapezoidal compensator section
Fixed low-lying supports IV and V (using "*komponor*" synthetic anti-friction material between support cross-beam and pipe wall surface)
C. Buried : 2415 m
Includes :
1. Transverse anti-heaving sections of trenches with gravel fill
2. Anchor-supports or "wooden sleepers" to prevent floating up of the pipe section
3. Hinged weights
4. Trench plugs which hinder pipe displacement and erosion
5. An 800 m semi-submerged section laid in a berm
6. Water drainage chutes to prevent erosion

Pile supports for above-ground component
longitudinal-mobile (anti-heaving)
free-mobile (anti-heaving)

4. evaluating frost heave forces and their transfer to the pipeline;
5. analysis of pipeline strength in the presence of thermal-contraction cracking;

6. measurement of settlement and heave of surface supports in the case of on-ground configuration;
7. conducting seasonal and long-term measurements of temperature fields around the pipeline, displacements and deformation of the pipeline caused by variable pressure and temperature of gas;
8. analysis of the influence of snow drifting against the pipeline and its displacement, stress state and wall temperature;
9. observations of solifluction, slope erosion, gully development and study over several seasons of soil composition and properties on sections with varying pipeline configurations;
10. analysis of thermal erosion in the pipeline zone and forecasting its development;
11. study of new pile support structures, compensator sections, thermopiles, anti-heaving piles, anchor structures and weights;
12. development of observation methods for the Far North, taking into account requirements for continuity, remoteness and automation.

In order to monitor the condition of the pipe section over several years, a number of devices (resistance strain gauges, displacement recorders, heave measurement gauges, geodesic markers and thermometers) were installed at various points along the pipeline. Some of the instrumentation is shown in Fig.5.10.

Five years of observations at the test site (1988-1993) allowed the principal researchers from *VNIIgaz*, led by Dr.V.V.Kharionovskiy, to make the following conclusions. The prevailing message is that the above- and on-ground components were much more successful (stable) than the buried part (Ivantsov and Kharionovskiy, 1993a, p.87; Kharionovskiy, 1993, p.34-35). The on- and above-ground components demonstrated the effectiveness and economy of the low-lying (reducing wind loadings) piles together with "*komponor*" anti-friction material on the cross-beams of fixed supports[25]. Cryogenic processes disturbing the ground surface were initiated to a limited extent, although some thawing around the bases of piles was noted. However, lack of backfill integrity and thermal erosion, floating up and heaving proved to be serious problems for the buried component. Just two years after construction this component had floated up in many places and the pipeline was exposed, with thermal erosion and thermokarst occurring along the r-o-w. This is illustrated clearly in Fig.5.11. The mechanism for development of these problems is described in detail by Sharapova

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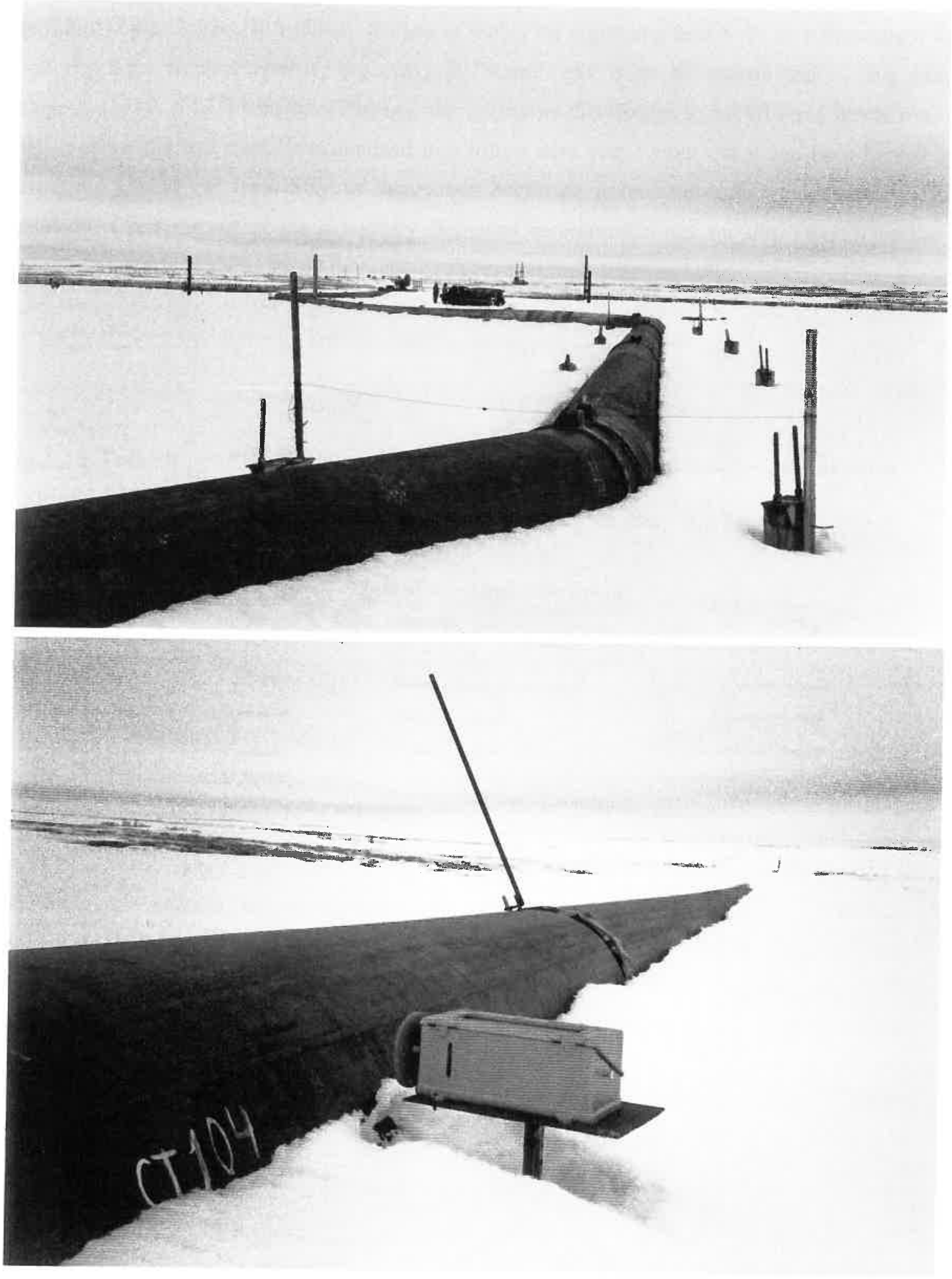
[25] Detailed examinations of different aspects of the on- and above-ground components of the pipeline test section can be found in the following papers written by members of the *VNIIgaz* research team : Vinogradov, 1993, p.46-51 (general); Kharionovskiy & Vinogradov, 1993, p.10-12 (general); Ivantsov & Kharionovskiy, 1993a, p.81-85 (general); Filippskiy & Degtyarev, 1990, p.144-147 (supports and piles); Podkol'zin, 1990, p.155-158 (temperature fields around piles); Vinogradov, 1991, p.55-59 (vibrations).

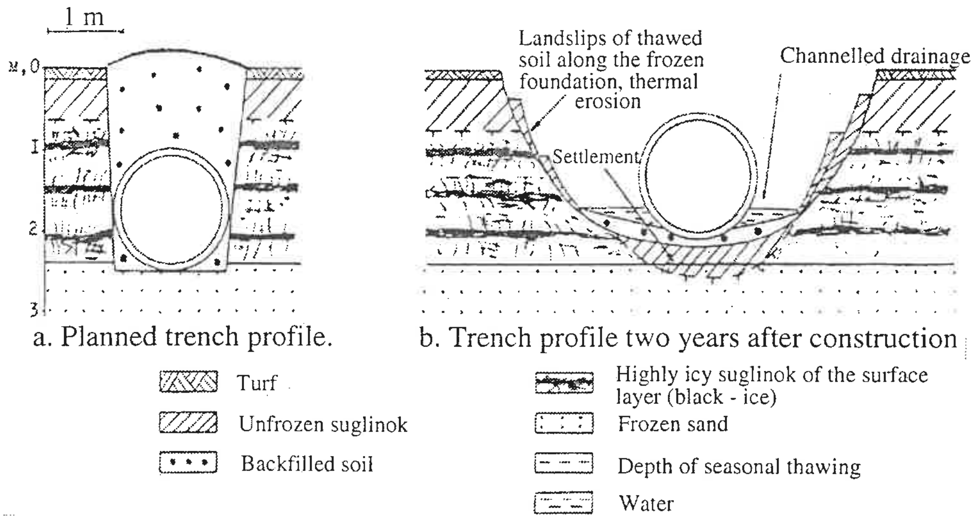
Results from investigations of anti-heaving piles (cheaper than, for example, the piles with heat pipes used on the Trans Alaska Oil Pipeline) at a test site 5 km from Noril'sk can be found in : Kharionovskiy & Shilin, 1993, p.23-25 and Ivantsov & Kharionovskiy, 1993a, p.88-91. The test site is a joint project between *VNIIgaz* and Nippon Kokan Corporation (NKK), Japan.

Fig.5.10 Instrumentation used at the South Soleninskoye test section
(Author's photographs, taken on 6th June 1996)
Top. Device used to measure displacement of pipe by cryogenic processes.
Bottom. Gas pressure and temperature gauge.



(1990, p.114-121) and Ivantsov & Kharionovskiy (1993a, p.85-87). The buried component had been jacked up due to cumulative effects of settlement in summer (warm gas transmission) and heaving in winter (cool gas transmission). This should not happen on the YEGTS northern section if gas cooling works effectively. The manifestation of these processes, leading to the floating up of the pipe, destruction of the berm and exposure, revealed the importance of installing suitable backfill material after pipe laying. In addition, the use of highly icy *supes-suglinok* soils as a foundation for buried pipelines is unacceptable, especially if "warm" gas is to be transmitted at any time. Sharapova (1990, p.121) concludes that in order to prevent disturbance to backfill and berms over a buried pipeline the soil must be maintained in a frozen state year-round which can be achieved by transmitting cooled gas from May to September, beginning immediately after construction. This conclusion is reminiscent of the previously discussed recommendations for the YEGTS northern section, particularly the views held by Ivantsov as regards the ballasting issue.

Fig.5.11 Trench profile of a buried section of the South Soleninskoye test section
(Source : Sharapova, 1990, p.115, Fig.1)



a. Planned trench profile.

b. Trench profile two years after construction

5.3.3.5 Conclusion : how appropriate is the South Soleninskoye test section for the YEGTS?

It is essential at this stage to point out fundamental differences between the NAGSS with its test section and the YEGTS northern section:

1. NAGSS and test section gas transmission temperature is unregulated, whereas YEGTS gas will be cooled on Yamal (CS-1 - CS-2) and on the section CS-3 - CS-4;
2. NAGSS is largely above-ground (meaning exposure to ambient temperature extremes and winds), whereas the YEGTS will be in general buried;
3. diameters of the two pipeline systems differ: 720 mm (NAGSS) and 1420 mm (YEGTS), although the Soleninskoye test section is 1420 mm;
4. geocryological conditions vary. No saline soils and cryopegs in NAGSS area. (But both areas have highly icy soils);
5. climatic conditions vary - NAGSS zone slightly more extreme than Yamal west coast.

Given these characteristics, the test section and NAGSS itself would provide useful experience and data for development of Yamal GCFs' feeder and gathering lines, the former in particular since they will be above-ground and smaller in diameter than the YEGTS, transmitting uncooled gas.

i) Significance for Yamal GCF feeder lines : as Vinogradov (1993, p.46) says, the test section is also intended for research into design solutions for above-ground 1420 mm gas pipeline operations at Yamal GCFs (as stated, the test section includes an above-ground component). Vinogradov is referring to the feeder lines at Bovanenkovskoye and Kharasaveyskoye[26]. Since gas transmitted in feeder lines from the wells to UKPGs will not be temperature regulated, the NAGSS test section (above-ground component) will have provided a very useful insight into such pipeline operations - its gas temperature is not regulated either. The pipe structures used for the above-ground component appeared to have performed well and this will certainly be encouraging for those designing Yamal GCF above-ground feeder lines.

ii) Significance for Yamal GCF gathering lines : the test section, even the buried component, is less appropriate for Yamal gathering lines. Experience from other GCFs (Urengoy, Yamburg) has shown that while these do tend to be buried, their temperature *is* often, though not always, regulated (for example SOGs at northern Urengoy UKPGs). Gathering lines on Yamal, very likely to be buried, will have to transmit cooled gas to avoid potentially significant settlement in highly icy soils containing massive ice. The same can be said for the trunk gas pipeline strings of the YEGTS, but

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[26] According to Sonninskiy (1990, p.96) there are to be approximately 1000 km of gas feeder lines at the Bovanenkovskoye GCF (500 km : 530 mm diameter; 250 km : 720 mm diameter; 250 km : 1020 mm diameter). Safonov *et al.* (1994b, p.184) quote a figure of 800 km of 300 - 500 mm diameter feeder lines at the field.

the test section has provided clear evidence of the undesirable consequences of using unsuitable backfill and of transmitting uncooled gas through a pipeline buried in highly icy soils.

iii) Significance for the YEGTS and generally : the variable temperature regime of the test section does not match that intended for the YEGTS but it will be useful in that YEGTS temperature regulation by cooling may not always function as planned, as has been the case at Urengoy. It is reasonable to expect that when operational the YEGTS sections CS-1 - CS-2 and CS-3 - CS-4 will never function consistently within the planned temperature regimes. It is to be hoped that the lessons from the South Soleninskoye test section will have driven home the painful reality of uncooled gas transmission through pipelines buried in highly icy soils.

The test section has been most useful for Yamal GCF feeder line project development and has been less useful for gathering line and YEGTS project development. However, some questions remain unanswered, such as those concerning gas transmission through pipelines in saline permafrost. Even more critical for the YEGTS is that no one yet knows if the consequences of gas transmission at negative temperatures year-round through pipelines laid in such complex soil conditions could be undesirable, reducing operational reliability and safety. One should not forget that the traditional gas transmission temperature regimes in other parts of the Russian North (namely the NPT) have a lot to answer for in this respect.

The availability of material on different aspects of the South Soleninskoye test section indicates that much more work has been done on the above-ground (pile) section, rather than the buried section. This could be interpreted as further evidence of results of the tests being used more for the Yamal GCF feeder lines and to some extent gathering lines, rather than for the YEGTS.

5.4. Conclusion

One only has to read a very limited selection of literature to discover that the engineering-geocryological conditions of the Yamal Peninsula, particularly those in which the first 134 km of the YEGTS are likely to be laid, are extremely complex and diverse. No other trunk pipeline system in Russia, or the world, has been laid in such conditions. The high iciness of the soils, which contain massive ice (including wedge ice and buried ice), and the high salinity of soils and lenses of water (cryopegs), which display different magnitudes of corrosive activity, are the outstanding complications for planners. In this respect, it is surprising that the GIE feasibility study described by Evans & Taksa (1995) did not focus on these issues which were conspicuous by their absence. The extreme diversity of soil and water salinity levels in the central western part of the peninsula also highlight the degree to which natural conditions can vary within a relatively small geographical area. Encouragingly, there are indications that this natural diversity has been taken into account, for example in the positioning of the two test sites at the Bovanenkovskoye GCF. However, full recognition of this diversity should have prompted the creation of a test site near the location of the

Baydaratskaya (CS-2) or Yarynskaya (CS-3) compressor stations in order to investigate engineering-geocryological conditions in a coastal zone where salinity and cryopeg distribution are less clearly understood. In defence of Russian pipeline research, one should not jump to the conclusion that the shortage of test sites testifies to ignorance or dismissal of natural diversity. Financial problems have always plagued such research, particularly in recent years, prohibiting the continuation or initiation of field investigations. There is the added complication on the peninsula of cryogenic slope processes such as solifluction and cryogenic landslides which occur at different velocities even on slopes of very shallow inclines. Perennially-frozen soil temperatures vary considerably (-8....0°C). The obvious disadvantage of such extreme conditions is the challenge they represent for the YEGTS planners. But less obvious is the fact that they have eclipsed, at least in the literature, the less extreme (relatively speaking), though still complex conditions of the region to the south of Baydaratskaya Bay. For example, soil and water salinity will still be a significant factor in the region of and some way south of the Yarynskaya compressor station (CS-3).

The impression one gets from the available research material is that numerous solutions devised to create a stable and reliable pipeline system are being considered, but it is not clear as to which solutions will actually be incorporated into the final designs. The solutions proposed so far sometimes reflect both unregulated and regulated gas transmission temperature regimes, yet the planners know that a stable and reliable pipeline system buried in highly icy soils susceptible to significant settlement can only result from strict regulation (by cooling) of gas transmission temperatures. Therefore, one must presume that planners, most notably *Gazprom*, are preparing for the worst case scenario in which the cooling will not always be effective and certain pipe sections will eventually be in thawed soils, perhaps restrained by frozen-in anchors, so long as the thawing has not reached the base of the anchor structures. It is essential that gas is cooled effectively and this should go hand in hand with rapid though efficient construction over one winter season and backfilling with non-frost susceptible soils with a low moisture content. Some might say that it would be advisable for ballasting measures to be included as a precautionary measure, since preventing a bouyant pipe string from floating up would eliminate other problems, many of which have been examined in chapter 4, and keep costs down.

The question of which route will be selected for the northern section remains unanswered. On the surface it appears that there are only two variants in the running, with the Baydaratskaya Bay crossing route heavily favoured. But proposals such as that offered by Ott (1997), namely the much shorter west-east route to Yamburg, confirm that other variants are under consideration, even radical ones such as this. This is perhaps the clearest evidence of *Gazprom*'s lack of technical preparedness for full implementation of the northern section. But we have seen that markets are not yet ready for Yamal's gas and so the route-debate can continue, though not indefinitely, before crucial decisions need to be taken.

As has been demonstrated, the lack of consensus extends to other areas of the YEGTS project. In terms of design solutions for specific components of the pipeline's northern section, there are several examples of specialists taking different approaches to the inherent problems. The divergence of opinions on such issues as ballasting by frozen-in anchors and corrosion prevention is clear evidence of this. On the one hand *Gazprom* is employing a traditional approach, with the application of certain modifications, whereas on the other RNGS has suggested some radical and riskier solutions to these questions, apparently motivated by the possibility of economizing. In areas such as the crucial question of duration of pipeline construction operations, *Gazprom* and RNGS both agree that the process should be completed within one winter season. However, this is contradicted by the GIE study which said that construction would be conducted over two winters.

There is also disunity over the issue of whether to lay the pipeline strings through lengthy river taliks (buried) or above them. The former approach is the riskier of the two with the danger of differential frost heave if the heating system failed. Buried river crossings (*dyukers*) have proved to be some of the most troublesome sections of northern gas pipeline systems, for example on the NAGSS and Urengoy gathering line. The heating system approach, if selected for use, must function reliably.

These disputed issues need further investigation before final decisions are taken regarding design solutions for the YEGTS northern section. The same can be said for those issues which are not necessarily disputed but which have simply undergone less research. Thermal-contraction cracking, frost heave (particularly in saline cryotic soils), continuing or secondary frost heave and cryopeg freezing around pipes fall into this category. Thermal-contraction cracking, both in soils and within the walls of pipes themselves, requires particularly close attention in the context of pipeline operations on the Yamal Peninsula because of the considerable stresses involved. The process was reportedly investigated both at test site No.1 (Bovanenkovskoye GCF) and at the South Soleninskoye pipeline test section, but almost nothing has been published concerning results of observations. There is still considerable uncertainty surrounding Ivantsov & Kharionovskiy's "*Kholod*" corrosion prevention system and unless this proposal receives further investigation, it is likely that the traditional coatings and cathode protection approach will be selected for the northern section. Significant research efforts are being directed towards SCC, but almost no research has been conducted in a northern context, especially in northern West Siberia. This must change. There is also urgent need for research into other questions which lie beyond the scope of this thesis, for example environmental remediation during and after construction, and the impact of global warming on permafrost, particularly in the context of Yamal's retreating coastlines. The shortfall in YEGTS research is linked directly to the problems discussed in chapter 3, section 3.3, particularly the economic and structural-administrative problems facing institutes such as *VNIIST*.

The above-mentioned would suggest that there is a lack of consensus on design solutions for practically every component of the YEGTS northern section. Thankfully, there seems to be no disagreement over the proposed use of low-temperature separation (LTS) of gas at Bovanenkovskoye's UKPGs. This process will replace traditional absorption dehydration in order to produce a year-round dry operating regime for the trunk pipelines on Yamal, thereby improving their hydraulic effectiveness. *VNIIST*'s frozen-in anchor research at test site No.1 has proven the effectiveness of using finned and quadruple-disc anchors submerged by the so-called sink method. Unfortunately, as already noted, there still remains the question of whether or not these anchors will be used at all. *Gazprom* can also be confident about their airborne and satellite monitoring practices. The establishment of "*Ekotekh*" marks a major step forward in the development of monitoring northern gas pipelines.

The lack of consensus on so many issues has also revealed the different approaches to problems taken by those involved in the YEGTS project. From its inception in the early 1980s, Ivantsov and *Rosneftegazstroy* have taken a "use the permafrost as an ally, not an enemy" approach to the YEGTS northern section. This is best exemplified by the ballasting and corrosion prevention issues, both of which have already been examined. However, although RNGS are of the opinion that by using the permafrost and gas cooling in the right way it is possible to exclude both ballasting and cathode protection of buried YEGTS sections (the *"Kholod"* system), others from *VNIIST* and *Gazprom* have written recently about the use of coatings and cathode protection in combination with insulating flanges (Pritula & Tychkin; Tychkin & Petrov) and the use of frozen-in anchors and reinforced-concrete weights (Stepanov). *Gazprom*'s approach to these issues is again one of applying contingency measures, rather than tackling the root of the problem through implementing effective gas cooling at the beginning of a pipeline project.

It would appear from the few articles available from the late 1980s (notably Ivantsov, 1987, p.12-16) that considerable research had been conducted early on in the evolution of the Yamal development project, albeit fairly general at times. Of course this is a good thing since ideas and concepts can be developed and fine-tuned over time. But it is unsettling to see Ivantsov giving exactly the same gas cooling statistics in his 1993 book (co-authored with Kharionovskiy) as he had described in 1987, yet this original article concerned an entirely different corridor route for the northern section of the YEGTS (circumventing Baydaratskaya Bay) with a much greater distance between the first and second compressor station, 440 km, compared to 134 km for the current plan which is part of a new corridor route. The application of cooling data from the original route proposal to the new one is unacceptable given the differences in natural-climatic, engineering-geocryological conditions and distances between compressor stations. Application of data in this manner cannot be condoned.

In the YEGTS project, *Gazprom* must free itself from the traditional approach to pipeline reliability of applying ameliorative measures only after problems arise. Notable examples in the past include the installation of SOGs at several UKPGs in the Urengoy GCF (Yen"yakhinskaya area) after thawing of soils around buried gathering line strings, as discussed in chapter 4 (subsection 4.3.3.6). Most major reliability problems stemming from pipeline - permafrost interactions can be avoided by cooling gas effectively, according to a specified year-round cooling regime suited to a particular stretch of pipeline. As a number of authorities have emphasized in relation to the YEGTS northern section, the gas cooling regimes at the Bovanenkovskaya and Yarynskaya SOGs must be put into operation immediately after the commissioning of the new pipeline strings to minimize thaw-related pipeline displacements and possibly the subsequent development of the "thaw ⇒ freeze-thaw" process. In the same way, strict maintenance of the gas cooling regimes at the two SOGs can reduce the corrosive activity of soils surrounding the pipeline strings. While this might be the case, cathode protection of the strings should almost certainly be included in designs, opposing Ivantsov's proposal to exclude it. Protective coatings, for example the bitumen-polymer coatings suggested by Polozov, cannot be relied upon on their own, nor should ballasting and frozen-in anchors (the latter in certain locations only) be renounced in the hope that SOGs will function as planned throughout their operational lifespans. Much of the necessary research into these and other technologies has been conducted, or it is still in progress. This must not be wasted on the assumption that the SOGs on their own can ensure the smooth functioning of the YEGTS. In essence, the RNGS minimalist and radical approach is certainly the more economical, but from past experiences it would not be reliable. Even a minor upset in the cooling regime could trigger thawing and all that follows. If effective cooling *could* be guaranteed, this approach would undoubtedly be the best option but it is more realistic to think in terms of a compromise between the RNGS and *Gazprom* approaches, that is to ensure effective cooling combined with contingency measures such as frozen-in anchors. This represents a very significant initial investment but will ensure more reliable pipeline operations with fewer ruptures and less repair work, making the pipeline more economical in the long-term.

Furthermore, two patterns have emerged in the coverage of planning and design of the YEGTS northern section in Russia's leading gas industry and pipeline journals, particularly *Stroitel'stvo Truboprovodov* and *Gazovaya Promyshlennost'*. Firstly, there is an obvious shortage of papers examining solutions to potential geocryological problems on the YEGTS northern section. In fact, one could say that coverage of any aspect of the YEGTS is sparse. Could this be a reflection of the lack of research currently in progress? It is not easy to say. The Baydaratskaya Bay crossing section has received attention in western journals, reflecting foreign involvement in its feasibility study (*Petergaz* JV) and in construction of the first two strings across the bay. Secondly, within the limited coverage that the northern section does receive, the emphasis is placed almost entirely upon the first 134 km of the pipeline system, i.e. Bovanenkovskaya (CS-1) - Baydaratskaya (CS-2). This is understandable in view of the complex geocryological conditions there and new solutions are required to cope with them. But, as indicated earlier, the fact that conditions south of Baydaratskaya Bay are less complex does not mean that they are any less worthy of discussion and analysis in journals or elsewhere. The same goes for pipeline design for this part of the northern section. It is hoped that the area between CS-3 and CS-5 will receive coverage before final designs are approved.

All things considered, we can draw the following conclusion on the project for the YEGTS northern section (CS-1 to CS-5). Not only is it premature to construct this section of the YEGTS (there is no immediate demand from domestic and foreign markets for Yamal gas), but also *Gazprom* is not realistically in a position to construct it. The level of technical preparedness falls far short of what is required to construct a reliable trunk gas pipeline system in such complex permafrost conditions. A great deal more research is necessary in order to answer a number of crucial questions related to the routing of the r-o-w and design solutions for various components of the pipeline system. Effective gas cooling by SOG holds the key to reliable operation of the YEGTS northern section. Thus, the hardest decision will be whether or not to accept RNGS's economically attractive proposal that frozen-in anchors and cathode protection can be excluded. If *Gazprom* seriously intends to maintain a reliable pipeline system, they will have to reject the RNGS approach and incorporate these components. New research must receive broader coverage in relevant industry journals so that the academic, planning and design communities can offer constructive criticism with the aim of developing the most reliable and economical solutions to these problems.

CHAPTER 6

CONCLUSION

6.1 Summary

The principal message conveyed by this thesis is that the temperature of gas transmitted through a pipeline (notably a buried one) in permafrost conditions is a key factor in determining both the short-term and long-term stability and reliability of the pipeline. Chapters 4 and 5 in particular show this. In the case of a gas pipeline made from the highest quality steel, assembled and laid according to the appropriate norms and to the highest standards, it would be fair to label product temperature as *the* key factor influencing reliability. However, as chapter 3 in particular has shown, there are a number of other important factors involved in the Russian context, namely archaic constructions norms and regulations, low quality construction and pipe steel and others. Collectively these can be grouped under the heading "construction quality". It is impossible to say which of these two factors has most influenced the reliability of northern gas pipeline networks in Russia - construction quality or product transmission temperature - because none of these gas pipelines have ever been subject to a constantly regulated product temperature regime throughout their period of operation. Although SOGs have been commissioned at three Urengoy UKPGs and the Purovskaya initial compressor station, they have not dramatically improved the reliability or stability of the pipelines to which they are connected. In order to be effective, i.e. ensure maximum stability of the pipeline on account of minimizing melting of permafrost, SOGs must be commissioned at the same time as the pipeline, not several years later, as was the case at Urengoy. Once operational, the YEGTS could provide us with some clues as to the individual importance of these two factors. If the YEGTS northern section is constructed to the highest standards, significantly surpassing those of the last 30 years, the role of SOGs and their influence on northern gas pipeline reliability will be much easier to distinguish. Conversely, if the SOGs operate effectively from the start, the construction quality factor will play a more decisive role. Both construction quality and SOG operations must meet the highest possible standards.

In section 6.2 factors that have contributed to the deterioration of the condition of northern trunk and gathering gas pipelines in Russia will be reviewed and the reliability of these lines will be assessed. With such a variety of factors involved, many of which originated more than a decade or two ago, we must ask the question: what evidence exists of a learning process? Bearing in mind current financial constraints, have there been indications in recent years that the Russians are avoiding the errors of the past in certain areas of northern trunk gas pipeline development? The learning process issue is addressed in section 6.3. Finally, section 6.4 considers *Gazprom*'s technical preparedness for construction of the YEGTS northern section. Technically speaking, is the gas giant really in a position to start construction?

6.2 Condition of the northern section of the UGSS

Having described and analysed a wide variety of historical and contemporary issues in northern trunk gas pipeline reliability in the previous chapters, we can conclude that the current poor condition of the northern section of the UGSS has much to do with the two key factors mentioned in section 6.1: construction quality, which is an historical and broad-based factor, and insufficient gas transmission temperature regulation, also an historical factor, but one which continues to play a major role today in determining the reliability of all northern pipeline systems.

6.2.1 Construction quality

The following are based upon the findings of chapter 3.

6.2.1.1 Production-driven construction policy

The policy of rapidly accelerating construction rates in order to increase gas supplies for domestic consumption and export dominated the gas industry during the 1970s and 1980s. Evidence of the policy lies in the following:

i) the structure and composition of SNiPs such as SNiP 1 were designed to favour accelerated construction rates;

ii) the direct result of i) is poor quality assembly work. This resulted from inadequate SNiPs, the use of poorly qualified workers (notably welders), and the general desire to increase construction rates through, for example, the Socialist Emulation or Competition.

6.2.1.2 Flawed system of generating normative documentation

Another factor lies in the way early normative documentation was drawn up. Prior to the introduction of SNiP II-45-75 (later replaced by SNiP 1), some of the earliest normative documents, compiled in the early 1970s and introduced alongside the already active SN 353-66, were drawn up based purely upon experiences from the planning, construction and operation of NAGSS strings 1 and 2. This is understandable given that the first two strings of NAGSS were the latest northern gas pipelines at that time. We now know that it is unacceptable to, for example, plan a pipeline in the NPT using norms devised according to pipeline development in an entirely different geocryological setting. Indeed, we are also told by Zinevich *et al.* (1985, p.15) that some of the design solutions used on several trunk lines laid from Urengoy did not, as one might have expected, come from the Medvezh'ye - Nadym - Punga lines laid eight to ten years earlier in the same gas-production complex. They actually came from the NAGSS designed 15 years earlier. Not only are geocryological conditions in these two regions very different, but the Urengoy lines and the NAGSS differ significantly in terms of configuration (Urengoy lines are buried, NAGSS is above-ground), gas transmission temperature regimes, diameter and use of compressor stations. This would indicate that during the 1970s and early 1980s the Russians did not fully understand that different geocryological conditions have very different implications for pipeline design, and that buried and raised pipelines of different diameters will perform very differently in similar geocryological conditions (on account of different gas transmission temperature regimes). The fact remains that norms were drawn up and Urengoy lines partly designed based on the limited experiences from NAGSS operations. This would undoubtedly have resulted in some detrimental effects upon operation of those pipelines. But why were these Urengoy lines not designed to some extent using the experiences from the Medvezh'ye trunk lines which bear more similarities to the Urengoy lines than the NAGSS, in both geocryological terms (both systems are in the NPT) and technical terms (diameter, configuration - buried)? Perhaps they viewed the longer operational period of the NAGSS as more important for design purposes than the similar geocryological conditions of Medvezh'ye.

If new replacements for the currently active SNiPs are prepared thoroughly, taking into account *all* criticisms and recommendations made by authorities such as Dimov, and they are strictly adhered to, many of the problems described in chapter 4 could be minimized or avoided altogether. In particular, the replacement SNiPs concerning all aspects of northern pipeline construction would be contained within the minimum possible number of separate documents. In fact, one document covering all these pipeline issues would be best. Issues that have received negligible coverage in the currently active SNiP 1, such as measures to counteract dangerous cryogenic processes and environmental issues, must be incorporated. These and other matters must be addressed within the "Highly Reliable Pipeline Transport" programme, the creation of which surely marked a positive turning point in the development of the post-Soviet oil and gas industries.

6.2.2. Insufficient gas transmission temperature regulation

Both historically and today, northern Russian trunk and gathering gas pipelines have been subject to, at best, insufficient product transmission temperature regimes and in many cases no regulation whatsoever. The Russians know that temperature regulation, notably in the form of SOG cooling in addition to AVO cooling, is essential to safeguard the permafrost, thus providing a stable foundation for the pipelines laid within it. A lack of finance has prevented a more widespread introduction of SOGs at both UKPGs and compressor stations. In the case of the Yamburgskaya station, a SOG has been built, but it has not been commissioned. This has meant that during summer the compressor station is shut down to keep the gas temperture lower, reducing the impact on permafrost. The result is that during summer gas output is low.

Fig.6.1 **Diagram showing the main stages in operations of the northern UGSS trunk gas pipeline systems over 30 years - a geocryological perspective**

1. Pre-1976-77 (before commissioning of the Nadymskaya compressor station). No upstream compressor station means gas is cool in Nadym region on the Medvezh'ye - Punga pipeline. Therefore, freeze-related cryogenic processes, e.g. frost heave, are dominant.

⇓

2. Post-1976-77 (after commissioning of the Nadymskaya compressor station). Operational compressor station with insufficient cooling means gas is much warmer on this section of pipeline. Seasonal thawing increases dramatically, seasonal freezing ceases. Initiation of the gradual "thaw ⇒ freeze-thaw" process would occur at this stage in some other locations, e.g. Urengoy and Yamburg.

⇓

3. Depending on local geocryological conditions, some northern UGSS pipelines float up (Urengoy - Nadym string 1, Yamburg - Yelets string 2, Urengoy gathering line, etc.). Ballasting and anchoring methods are ineffective ameliorative measures. Gas cooling by SOG either absent or insufficient. This is the transition from the thaw stage to the freeze-thaw stage.

⇓

4. Pipes fully exposed. Full development of freeze-thaw stage of "thaw ⇒ freeze-thaw" process. Pipes now exposed to both freeze and thaw cryogenic processes.

The influence of insufficient gas transmission temperature regulation can be summed up in the flow diagram Fig.6.1, based upon the findings from chapter 4. It shows from a geocryological perspective the main stages in the 30 year operations of the northern UGSS trunk gas pipelines. The geocryological approach emphasizes the influence of product transmission temperature.

Product transmission temperature regimes for northern pipelines should also be regulated by norms and standards. These should be strictly enforced on operational pipelines. However, enforcing them would be hard as *Gazprom* could try to make the case that SOG cooling is too expensive. If such product transmission temperature standards were adhered to, together with new SNiPs, a much safer situation would result on newer and new gas pipeline systems operating in northern conditions. But all of this would come too late for much of the existing northern trunk gas pipeline network, although adherence to the standards would help to some degree. Thus, all new gas pipelines under development should be planned in accordance with such new SNiPs and product transmission temperature standards.

6.2.3 Other factors

In simple terms, more effective SNiPs with regulation and more effective product transmission temperature regimes should result in more reliable northern pipelines. Having outlined the two key factors above, Fig.6.2 summarizes these and other important factors that have contributed to the reduction of northern trunk gas pipeline reliability within the period ca.1970 - the present day.

Fig.6.2 **Principal factors contributing to deterioration of trunk gas pipeline reliability in northern Russia, ca.1970 - present day**

Rapid production-driven gas industry development
+
ineffective Soviet SNiPs
+
poor working conditions
+
planning problems
i. Lack of finances
ii. Break-up of USSR leads to
dispersion of leading planning and design institutes
iii. Lack of youth development for pipeline engineering

⇓

Poor quality but rapid construction (IPL)
in complex engineering-geocryological conditions

⇓

Pipeline susceptibility to natural external influences
e.g. pipeline - permafrost interactions

⇓

<u>UNRELIABLE PIPELINES</u>

⇑

Ineffective engineering-geocryological surveys (SNiPs)
in complex engineering-geocryological conditions
+
Ineffective gas transmission temperature regulation

Given the above, another issue emerges. It is hard to see how pipeline failure statistics, for example, 36% of failures due to construction defects, etc., can be compiled in such a simplistic manner. The reasons for failures are very diverse and complex, especially in the context of northern pipeline operations in Russia. Evidently, failures on Russia's northern pipelines, oil, gas or product, small or large diameter, buried, on-ground or raised, arise from a combination of causes. We need to be aware of all these possible causes so that pipeline planners and designers can avoid such problems in future pipeline planning and design projects.

6.2.4 Reliability of the UGSS northern section

Failures on trunk gas pipelines within the northern UGSS, as with the rest of the UGSS, are still too common, although their frequency has fallen in recent years. *Gazprom*'s attitude to pipeline failures can be summed in the following three types of approach:

1. re-route gas and replace damaged pipe : *Gazprom* has been too content to pass off failures, even serious ones such as that near Ukhta in 1995, as "routine". It is too easy for the company to re-route supplies through adjacent strings in the pipeline corridors if a pipe section has to be shut down for repairs. This kind of operational philosophy must change, if only because under the market principles of the new Russia, *Gazprom* will not be able to afford the reserve capacity of multiple string corridors on future pipeline systems;
2. apply preventative measures when a rupture is imminent : simply because pipe deformation has not yet reached critical levels is no excuse for failure to install heaters on buried pipelines transmitting cooled gas through a talik. This approach taken by *Yamburggazdobycha* amounts to a considerable risk, jeopardizing the reliability of its gathering line system;
3. installation of frozen-in anchors : *Gazprom*'s measure of installing frozen-in anchors would not be necessary if effective gas cooling could be guaranteed. Past experience has shown that such a guarantee cannot be made, hence the company's willingness to incorporate anchors into designs. The inclusion of anchoring devices therefore reinforces the assertion that *Gazprom* is incapable of ensuring effective cooling regimes on its northern trunk gas pipelines.

As many of the NPT trunk lines approach the end of their design lifetimes there must be concern that the reliability of the UGSS and thus supply security will deteriorate. Monitoring (remote and internal) will play an increasingly important role, while the refurbishment programme, and the funding of it, must be implemented swiftly. Clearly, dealing with this programme and any new problems on existing lines is going to be a huge task, without the worries of constructing new pipeline systems such as the YEGTS northern section.

6.3 What evidence of a learning process ?

With such a large number of factors contributing to the deterioration of northern gas pipeline systems over the last three decades one would expect the Russians to have made inroads into rectifying the situation, at least in the recent past. What evidence for or against such efforts can be derived from the content of this thesis?

6.3.1. Evidence for the learning process

1. Founding of the "Highly Reliable Pipeline Transport" programme : The creation of this programme in 1993 was a turning-point in the history of Soviet and post-Soviet trunk pipeline development. As the name suggests, its main purpose is to improve the reliability and safety of gas, oil and product pipelines throughout the CIS member states. It should therefore be considered as outstanding evidence for the existence of a learning process. The break-up of the Soviet Union is likely to have been a catalyst for its founding since without such a programme it would be extremely difficult to develop policy for the reliable functioning of pipeline systems now lying within several independent states. So it could be said that the demise of the Soviet Union brought with it a unique opportunity to create a programme not simply to deal with post-Soviet issues, but also to develop new approaches to long-standing reliability problems.

2. Recognition of variations in natural-geocryological conditions : The selection of locations for test sites No.1 and No.2 at the Bovanenkovskoye GCF. Conditions vary at both sites and were selected for being as similar as possible, in geocryological terms, to the r-o-w of the trunk pipeline strings. As noted in chapter 3, subsection 3.2.5.3 i), Khafizov *et al.* (1993b, p.31) emphasized that while experiences from Yamburg will be useful, tests had to be conducted on Yamal in conditions most representative of those on the r-o-w. This signifies that the Russian planners and scientists are fully aware that in order to design a reliable pipeline for permafrost conditions, tests (results from which will be used for design) must be conducted in representative conditions wherever possible. This is important since soil-geocryological conditions vary so much from region to region and within regions in northern Russia. Recognition of such variations in natural conditions must also be incorporated into new SNIPs, as Loskutov (1996, p.33-34) has stressed. This contemporary situation is in stark contrast to the practices of the 1970s and 1980s, when trunk gas pipelines from the NPT (Medvezh'ye and Urengoy GCFs) were to some extent constructed to design solutions that had been incorporated into the NAGSS. During the 1970s at least, the Russians had to rely on the long-term, though small-scale experience of NAGSS operations. As we know the NAGSS operates in very different geocryological conditions from those found in the NPT.

3. Pipeline construction stage-by-stage : During the 1970s and 1980s the Russians showed how to increase rates of construction, both in terms of new machinery (e.g. *Sever*-1 welding technology) and work organization (Integrated production lines / IPLs). Many articles and books published in Russia place considerable emphasis upon the accelerated pipeline construction rates achieved over the last 30 years, while very few ever acknowledge any impact this may have had on construction quality. The Russians also knew that in order to maximise throughput of gas, sections of trans-continental pipeline systems, such as Urengoy - Pomary - Uzhgorod, completed early had to be commissioned at once and not left empty until the entire system was complete. This concept has been modified to take into account market principles and applied to the YEGTS. Speed of construction is not the key to economic success today. Instead, construction of the YEGTS is occuring in stages to meet incremental gas demand. While this method of pipeline construction may also reflect the fact that Russia cannot afford to purchase enough pipe and equipment to build the whole pipeline system, it does mean that the quality of assembly work is likely to be much higher chiefly because there is no need to accelerate construction operations in this case.

4. Airborne and satellite monitoring of trunk and gathering gas pipelines in the West Siberian North : The increased use of airborne and satellite monitoring (remote sensing) methods since the 1980s has contributed, indirectly, to the gradual improvement in the reliability of trunk and gathering gas pipeline systems in the West Siberian North. The emergence of specialist pipeline monitoring and diagnostic organizations, for example "*Ekotekh*", has enabled rapid progress in this important field. Remote sensing methods will play a crucial role in the monitoring of the entire YEGTS and other pipeline systems in the future.

5. Design of selected pipelines to both Russian and Western standards and the preparation of new SNiPs : An oil pipeline laid from the North Gubkinskoye OGCF in the Yamalo-Nenetskiy AO, operated by the Russian-American Geoilbent JV, was designed to both Russian and US norms. Construction was completed in 1993. This project required the translation of all relevant SNiP documentation (SNiPs 1 and 2) into English. This at least allowed some exposure of the Soviet era SNiPs to western engineers and thus some interaction between both parties in suggestions for SNiP replacements. All Russia's noted pipeline authorities (Shmal', Ivantsov, Kharionovskiy and Dimov, to name only the leaders in their field) acknowledge that currently active SNiPs are obsolete and replacements are essential to ensure that the new generation of trunk pipelines, particularly those in permafrost conditions, operate reliably. New SNiPs are indeed being prepared and reportedly harmonized with western standards, as was indicated in chapter 3. These have not yet been introduced. We cannot expect to see significant improvements in pipeline construction quality, and thus operational reliability, until these replacements are approved and, just as importantly, enforced.

The latter begs the question; how will the new norms be enforced both in the planning and design institutes and during construction?

6. *Gazprom*'s new codes : Recognizing the outdatedness of the currently active normative documentation and the threat this poses for the development of reliable pipeline planning and design projects in the near future, *Gazprom* has been compiling new codes which address specific issues not covered adequately in the ageing SNiPs. In particular, some of the codes (for example, "Methodological Recommendations for Calculating the Structural Reliability of Trunk Gas Pipelines", code RD 51-4.2.-003-97) pay close attention to permafrost and individual cryogenic processes such as frost heave. Within the "Highly Reliable Pipeline Transport" programme new regulatory standards have been drawn up specifically for design and construction organization in the YEGTS project.

7. Increased efforts, especially by *Gazprom*, to get youth interested in the gas industry : *Gazprom* realises that the future of the gas industry and, notably, the reliability of the UGSS depends on today's youth and future generations. The company is making a considerable effort to attract young people to the industry. This is a much harder task today because of the appeal of new, highly-paid careers in other disciplines. Since 1995 *Gazprom*, the Gubkin State Oil & Gas Academy and the Ministry of General & Professional Education have organized the annual All-Russian Conference for Young Academics, Specialists and Students on the Problems of the Russian Gas Industry.

6.3.2. Evidence against the learning process

1. Failure to tackle pipeline problems at their roots : A profound problem which lies firmly entrenched within the Russian oil and gas industries is that the Russians have traditionally not tackled pipeline problems at the root. They have been left with the task of performing "damage limitation" measures well after signs of potential pipeline damage are discovered or even after failures have occurred, ranging from minor releases of gas to catastrophic explosions. Leonid Dimov of *KomiNIPIstroy*, the ardent critic of currently active SNiPs whose concerns were discussed in chapter 3, sums up this situation well in the following quote (Dimov, 1991, p.15):

> *"Do we give much attention to the quality of calculation and design of such a complex linear structure as a pipeline? Definitely not enough and that is why the practice of* [pipeline] *operation punishes us with accidents and endless repairs."*

This dire situation has a great deal to do with the Soviet production-driven, rapid development of the gas industry during the period 1965-90. This went hand in hand with accelerated pipeline construction rates. There was little or no desire to consider possible problems on the pipelines, even to some extent during the planning and design phase. The issue of reliability was far outweighed by the will to produce as much gas as possible, as quickly as possible. The same can be said of the oil sector. The situation has not been helped by the fact that pipeline accidents sometimes do not affect supplies on the UGSS, with gas designated for the affected string being diverted through an adjacent line in the corridor.

The following are key examples of action being taken too late, once the pipeline strings had become dangerously unreliable. Often the action taken would prove ineffective and further ameliorative measures would have to be implemented.

i) Installation of SOGs at selected UKPGs at the Urengoy GCF

Between 1989 and 1993 SOGs were installed at three UKPGs (11, 12 and 13) in Urengoy's Yen"yakhinskaya area in an effort to stabilize gathering line strings around which thaw bulbs had developed due to positive temperature gas transmission. By 1996 the thaw bulbs had deteriorated, i.e. shrunk, but ironically this was not attributed to the operation of SOGs. In fact, the greatest contribution to thaw bulb reduction was made by the widespread destruction of the berms, exposing the pipelines, as was indicated in chapter 4 (subsection 4.3.3.6). These berms are being repaired at great cost. Cold ambient air temperatures (below 0°C for more than eight months annually) cooled the gas through the fully exposed sections of the gathering line and the soils of the thaw bulbs directly below the pipeline. This "unintentional" cooling had a much greater effect than the SOGs. Thus, ironically, the thaw bulbs were reduced because of earlier damage to berms which left the pipeline strings exposed, not by the intended ameliorative measure of SOG cooling.

ii) Repairs to *dyuker* transits under tundra rivers

Failure to take into account the natural dynamics of tundra rivers and their potential response to technogenic influences resulted in the need for expensive repair work on the *dyuker* transits under the R.Khadutte (Yen"yakhinskaya area of the Urengoy GCF), as demonstrated in chapter 4 (subsection 4.3.3.6). Other transits, such as that under the R.Yen"yakha, await repairs due to a shortage of funding.

2. Choosing the cheaper option : This is linked very closely to 1. On certain trunk gas pipelines laid from Yamburg, for example, frozen-in anchors were installed in an effort to stabilize buried pipeline strings (Yamburg - Yelets string 2). In the late 1980s this was seen as being cheaper than the construction and commissioning of a SOG at the Yamburgskaya compressor station. As shown in chapter 4, the frozen-in anchor programme has not been totally successful. Meanwhile, a SOG has been built but it remains out of service. Ironically, the decision to economize by installing anchors rather than a fully functional SOG has led to the need for considerable subsequent expenditure. Far

more money will have been spent on installation of inefficient anchors, creating the urgent need for construction and commissioning of a SOG, than if the SOG had been built and commissioned right at the beginning. Furthermore, the pipeline would probably have been in a more stable condition now had finances been used to commission the SOG rather than to install hundreds of anchors. Such principles should also have been applied in the case of the two examples given in 1.

6.3.3 Conclusion

Certainly throughout the 1980s and even into the early 1990s the Russians had shown few if any signs of learning and correcting mistakes of the past. But the post-Soviet "Highly Reliable Pipeline Transport" programme and one of its beneficiaries, the YEGTS project, are the first serious indications of a real step forward.

While the collapse of the Soviet Union was followed by these signs of progress, the event has brought with it a new set of problems. Financial constraints are seriously hindering implementation of certain measures, e.g. SOG construction and commissioning, giving the impression that the learning process is far less well developed than it really is. Financial issues were of little concern to the Soviet oil and gas industries but they are a serious problem now and are likely to remain a major obstacle to the improvement of the reliability of CIS trunk pipeline systems. The research, planning and design institutes, notably *VNIIST*, are particularly affected by this financial crisis. Furthermore, the "Highly Reliable Pipeline Transport" programme could take the learning process much further by developing regulatory bodies for SNiPs and product transmission temperatures.

6.4 Is *Gazprom* technically prepared for construction of the YEGTS northern section?

6.4.1 "Yes" or "no", and why

The simple answer to this question is a resounding "no". This assumption is based upon the evidence presented in chapter 5. This evidence can be summarized as follows:

1. A lack of consensus among specialists (notably the opposing approaches being taken by *Gazprom* and RNGS) on many design solutions, such as the necessity for ballasting by frozen-in anchors and cathode protection on pipeline sections transporting cooled gas.

2. Indecision surrounding which route should be selected for the northern section r-o-w. The following routes have been proposed:

    i) Baydaratskaya Bay crossing (considered by many to be the front-runner);

ii) around Baydaratskaya Bay;
iii) across the Yamal Peninsula (latitudinally), across Obskaya Bay to link up to the trunk gas pipeline system at Yamburg on the Tazovskiy Peninsula;
iv) offshore, from Cape Kharasavey to the Yarynskaya compressor station.

3. A lack of research conducted into several important technical issues. The key issues requiring significant further investigation include:

i) the floating up of pipelines in both permafrost and boggy conditions. Ivantsov (1998) says that this problem remains unsolved;
ii) the effect of thermal-contraction cracking of soils on buried trunk gas pipelines and thermal-contraction cracking in pipe walls;
iii) frost heave in saline cryotic soils;
iv) the effect of cooled gas transmission through a cryopeg, resulting in its freezing. Distribution of dissolved salts after freezing of water;
v) SCC of gas pipelines in permafrost conditions;
vi) the effectiveness of the "*Kholod*" corrosion prevention system proposed by Ivantsov.

4. The need for more widespread coverage of these key unresolved technical issues in industry journals, namely *Gazovaya Promyshlennost'* and *Stroitel'stvo Truboprovodov*. This will assist greatly in the quest for answers to problems within these issues. The last article focusing on the range of key issues in the construction and operation of the YEGTS northern section appeared in February 1993 (Ivantsov & Kharionovskiy, 1993b, p.24-28) and even this did not go far enough, often discussing the pipeline as if gas cooling would not be included.

Closely related to this problem is that of the wide gulf separating engineers and geocryologists in Russia. For example, *MGU* has leading specialists in pure geocryology, based at the university's Department of Geocryology, whereas other organizations such as *VNIIgaz* and *VNIIST* possess pure pipeline engineers. Admittedly some other institutions do contain a few specialists who have bridged the gap between both disciplines. *PNIIIS* is a good example of engineers and geocryologists coming together and to no small degree influencing developments in pipeline design for permafrost regions. But institutions such as the Earth Cryosphere Institute of the Siberian Branch of RAS (based in Tyumen'), although containing highly respected permafrost engineers such as Vladimir P.Mel'nikov and Yevgeniy S.Mel'nikov, seem to have been marginalised, due to financial constraints. But in *VNIIST*, policy changes, the departure of leading pipeline-in-permafrost experts and administrative problems are also affecting research capabilities. Clearly, a convergence of the pipeline engineer and geocryologist schools would help improve research into pipeline - permafrost interactions, particularly important for investigations related to any new pipeline test facility and indeed the YEGTS itself[1].

6.4.2 A full-scale pipeline test section on the Yamal Peninsula

Russia has taken too long to consider a variety of options for technical solutions to the YEGTS northern section. If the "stalemate" associated with certain technical solutions persists, it is highly likely that another five years or more would be needed to come to a concensus on the key solutions discussed in chapter 5 and listed above in subsection 6.4.1. However, this further delay should not be regarded as a bad thing *per se*. There is clearly a need for the construction of a full-scale pipeline test section on the Yamal Peninsula in the conditions of the future r-o-w, data from which can be used for the elaboration and selection of final design solutions. But, even the development of this test site itself could be delayed since the precise location of the site ideally should not be determined until the r-o-w of the YEGTS northern section has been finalised. Construction of such a test site need not take a few months, but would cost a considerable amount of money. It will take several years to accumulate the results required for incorporation into YEGTS final design. The more time available to accumulate results and data, the better. Useful data could be returned as soon as one year after tests begin on the experimental pipeline section, but cumulative results over several years would reveal important data on patterns in seasonal and annual dynamics of cryogenic processes, stresses in pipe steel, corrosion rates and the like. Thus, some funds should be allocated as soon as possible to finance the development of this pipeline test section. Given that the Bovanenkovskaya CS - Baydaratskaya CS route is the most likely choice, the test section could be located either at the Bovanenkovskoye GCF or 130 km to the south near Viktoriya, the site of the Baydaratskaya CS. But irrespective of which r-o-w is chosen, the YEGTS *will* originate at Bovanenkovskoye. Therefore, a test site could be set up at Bovanenkovskoye whenever funds are available, even before a final decision has been taken about the r-o-w. In addition, supply of materials to the field would be easier than to Viktoriya, on Yamal's southwest coast, where infrastructure is extremely limited and access is more complicated.

Such a test site must bear results before final decisions are made concerning measures to counteract such cryogenic processes as thermal-contraction cracking and how to resolve the ballasting and cathode protection dispute. In essence, the time that elapses due to the delay of full-scale development of Yamal GCFs can be spent wisely in the development of a new test site on the Yamal Peninsula. This is essential for the selection of design solutions based on tests conducted in natural conditions fully representative of those on the pipeline system's intended r-o-w. This in itself will go some way towards ensuring a more reliable gas transmission system.

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[1] Academics (geocryologists) and industrial engineers tend also to be "split" in North America.

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[1] Academics (geocryologists) and industrial engineers tend also to be "split" in North America.

Funding for the test site would possibly have to come from a non-Russian source. Rem Vyakhirev, Chairman of *Gazprom*, indicated recently that spending on Arctic gas development in 1998 would be one third of the 1997 level. It is possible that the Japanese could contribute to the funding of such a pipeline test section since it is in their interests to learn more about large-diameter gas pipeline operations in complex permafrost conditions in preparation for any trunk pipeline development from the RFE (Irkutskaya Oblast' and Sakha-Yakutiya) to China and beyond. Naturally, they would acknowledge the significant differences in the permafrost conditions of Yamal and the RFE. The Japanese have already invested considerable amounts in the South Soleninskoye test section, for which Nippon Steel provided the pipe sections, and in the anti-heaving pile test site near Noril'sk, funded in part by Nippon Kokan Corporation (NKK). While the recent financial turmoil in Asia has naturally made the Japanese draw the purse strings tighter, their preparations for RFE pipeline projects continue in earnest.

6.4.3 A lengthy delay

We know that currently there is not the demand, both internally and abroad, for Yamal gas. This throws considerable weight behind the argument that the northern section of YEGTS should not be constructed for a number of years. From a technical perspective, this thesis, notably chapter 5, has provided further reinforcement to this argument. Given the above, it makes complete sense that *Gazprom* should in the near future shift its focus to some extent southwards. As mentioned above, *Gazprom*'s investment in Arctic gas development has been cut. It is likely that in fact Mr.Vyakhirev was referring to Yamal development in particular. It is uncertain to what extent development in the NPT (notably satellite fields) will be affected. It is expected that work will get under way at the Zapolyarnoye OGCF through the newly formed alliance between the Russian gas monopoly and Shell, but the emphasis at this field will be upon liquids and production is not expected to begin until 2003. The other strategic alliance formed by *Gazprom* with Italian ENI will focus initially on hydrocarbon production at several fields in Astrakhanskaya Oblast' in the far south of Russia. This is also a mainly liquids project, although the Astrakhanskoye GCF contains huge gas reserves[2]. *Gazprom* is also pushing ahead with plans for a gas pipeline to Turkey crossing the Black Sea, the so-called "Blue Stream". So there are signs of *Gazprom* increasing activities in southern Russia. This is certainly the impression gained from articles such as those published in the Russian newspaper *Nezavisimaya Gazeta* in early 1998 (for example, *Nezavisimaya Gazeta*, Tuesday 17th February, 1998, p.4). In spite of indications of a shift southwards, *Gazprom* must in the meantime do all it can to ensure that research for the YEGTS project continues.

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[2] The *Gazprom* - ENI strategic alliance was signed on February 11th 1998 in Rome.

Unfortunately, the painful reality is that whether or not the Japanese or others assist the Russians financially in the development of a new test section, there will be other aspects of the YEGTS project which will go unfunded for the time being, for example feasibility studies for alternative routes and further research into unanswered technical questions. The delay in full-scale development of Yamal could therefore be longer than we expect.

6.5 Conclusion

Russia possesses the world's largest network of trunk gas pipelines, the majority of which are part of *Gazprom*'s UGSS, and many of these pipelines originate in permafrost regions where the country's largest GCFs are located. In 1997 *Nadymgazprom*, *Urengoygazprom* and *Yamburggazdobycha* accounted for 84.3% of *Gazprom*'s production or 79.0% of the Russian total. At the beginning of its journey southwards this gas passes through pipelines laid in permafrost. The long-term reliability of these pipelines was jeopardized during the Soviet rush to boost gas production, and reliable operations of similar pipelines in the future can only be contemplated through a firm understanding of the pipeline - permafrost geotechnical system. Most importantly, interactions between the two components of this system need to be understood, taking them fully into account when planning and designing pipelines for permafrost environments. Those involved must acknowledge the numerous peculiarities of permafrost, their regional variations and the consequences of pipeline construction and operation in such conditions.

Many more trunk gas, oil and product pipelines are likely to be constructed in the Russian Arctic and sub-Arctic and some of these new northern pipelines will be realised with the participation of western oil companies and contractors. These companies will bring with them much needed capital which can be used to implement crucial projects within the gas industry, notably the commissioning of efficient gas cooling systems (SOGs) in the North. At the same time, some of these companies have had negligible experience of operating in Russia, let alone the Russian North, and therefore it is especially important for them to familiarize themselves with Russia's permafrost regions and the inherent geotechnical issues. Other circum-polar nations, particularly the USA (Alaska) and Canada, have much to learn from Russia's experiences of gas pipeline development in permafrost. There are no Arctic trunk gas pipelines in either Alaska or Canada, only the Trans-Alaska and Norman Wells - Zama oil pipelines, but there are plans for large-scale gas production in the Mackenzie Delta region of Canada's Northwest Territories and in the Alaskan North for which new trunk gas pipelines will be needed.

Russia must ensure that its pipeline systems, notably the initial sections in the north, are reliable and capable of transmitting uninterrupted supplies to domestic customers and, just as importantly, as exports increase, to foreign consumers. Security of gas supplies is particularly important for Russia since it has the world's largest portfolio of gas export contracts upon which it relies for a substantial percentage of its hard currency revenues. In the meantime, as major northern trunk pipeline systems approach the end of their design lifetimes and while the likelihood of ruptures remains strong, *Gazprom* must step up its monitoring programme and find ways to improve the gas cooling regimes currently in use. As regards future pipeline projects, *Gazprom* must for the time being think in terms of combining RNGS' and its own approaches to design, that is the inclusion of SOGs and contingency measures such as anchoring devices in case of inconsistencies in cooling regimes. But *Gazprom* must strive to guarantee effective cooling regimes in the future.

APPENDIX 1

PERMAFROST AND ITS DISTRIBUTION WITHIN THE CIS

A1.1 Introduction

This appendix provides an explanation of the term "permafrost" (A1.2), followed by a decription of the distribution of permafrost within the CIS (A1.3), in particular Russia (A1.3.1) and northern West Siberia (A1.3.2). A1.3.2 also includes a short list of key texts on the general geocryology of northern West Siberia.

A1.2 What is Permafrost?

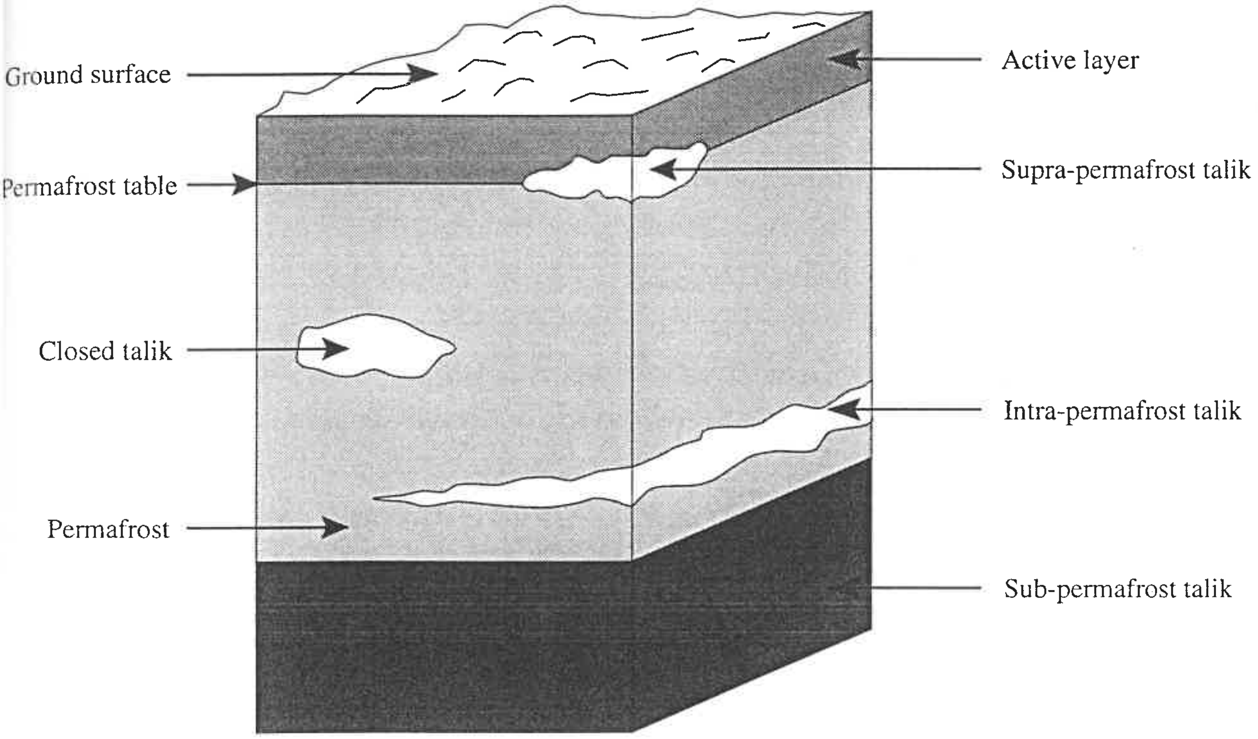
Those parts of the world in which frost-action and related processes dominate are known as periglacial. A wide range of cold, non-glacial conditions are experienced here. In such regions a layer of frozen ground that does not thaw completely in summer forms as a result of the long winter period and the relatively short period of summer thaw. This perennially frozen ground is termed "permafrost" (French, 1996, p.51). The earliest known scientific investigations of permafrost were carried out in Yakutsk by the Russian scientist A.F. von Middendorf between 1844 and 1846. Today the Siberian branch of the Russian Academy of Sciences maintains its largest permafrost research institute (*Institut Merzlotovedeniya*, in Russian) in Yakutsk.

Traditionally, permafrost has been defined on the basis of temperature; that is, soil or rock that remains at or below a mean annual temperature of 0°C for at least two consecutive years. However, permafrost may not necessarily be frozen since the freezing point of included water may be depressed by several degrees below 0°C. Therefore, to differentiate between temperature and state (frozen and unfrozen permafrost conditions) the terms cryotic and non-cryotic have been proposed which refer solely to the temperature of the material. Thus, cryotic soils have a temperature below 0°C but may in fact not be frozen because of freezing-point depression. Depression may result from soil salinity for example. Perennially cryotic ground is therefore synonymous with permafrost and permafrost may be frozen, partly frozen or unfrozen, depending on the ice/water content.

Fig.A1.1 shows a section of permafrost, including the most important terminology. The permafrost table marks the boundary between the upper surface of the permafrost and the supra-permafrost layer. The active layer is that part of the supra-permafrost layer which freezes in winter and thaws during summer, making it seasonally frozen ground. Below this layer seasonal influences are generally not felt (although thermal expansion and contraction may occur seasonally) and the soil or rock is truly perennially frozen. Unfrozen zones within and below permafrost are known as taliks.

Such zones may be unfrozen for a variety of reasons, for example, freezing-point depression or the heat-sink effect of large bodies of water such as rivers and lakes.

Fig.A1.1 Relationship between permafrost, the permafrost table, the active layer and supra-, intra- and sub-permafrost taliks



The growth of permafrost reflects a negative heat balance at the earth's surface. Thus, if one year the ground freezes to a depth of 60 cm over one winter but this frozen layer only thaws to a depth of 55 cm the following summer, a 5 cm layer of permafrost will have been formed by the second year. If such climatic conditions are repeated year after year the layer of permafrost will thicken and grow downwards from the base of the seasonal frost. Eventually, a layer of permafrost several hundred metres thick will have formed.

Many of the problems posed by permafrost are related both directly and indirectly to the water and/or ice content of the permafrost. French (1996, p.54) divides these into three categories:

1. the freezing of water in the active layer at the beginning of winter generally results in so-called frost heave (the technogenic variety is examined in detail in chapter 4, subsection 4.3.2). This

process poses a considerable threat to objects buried in permafrost, notably pipelines. The magnitude of the frost heave depends on the amount and availability of moisture present in the active layer and the frost susceptibility of the soil. Poorly drained silty soils usually have the highest water or ice contents and are highly "frost-susceptible" and tend to heave more than other soil types. As will be discussed in 4.3.2, frost heave may occur differentially, in the form of differential heaving, and below 0°C as so-called secondary or continuing heaving;

2. permafrost, particularly unconsolidated sediments, often contains large quantities of ground ice. The amount of ice held in the ground frequently exceeds the natural water content of that sediment in an unfrozen state and when the permafrost thaws settlement or subsidence of the ground will result (the technogenic variety is examined in chapter 4, subsection 4.3.3). A natural process associated with permafrost degradation is termed thermokarst;

3. the hydrological characteristics of permafrost are markedly different from those of unfrozen terrain. The infiltration of water into the ground is prevented by the presence of perennially or seasonally frozen ground. In certain cases water can penetrate the active layer. However, subsurface water flow is restricted to zones of taliks which often display a high level of mineralization because of the restriction of water flows and the concentration of dissolved solids in the unfrozen ground.

In terms of continuity by area, permafrost is usually described as being continuous (*sploshnoye rasprostraneniye*, in Russian) or discontinuous (*preryvistoye rasprostraneniye*, in Russian). In zones of continuous permafrost, the ground is frozen in all localities except for localized thaw areas and taliks existing beneath large rivers or lakes. In a zone of discontinuous permafrost (less than 80% continuity), bodies of frozen ground are separated by areas of unfrozen ground. To the south of the discontinuous zone is an area where permafrost is isolated to "islands" which typically occur beneath peaty organic sediments. Russian geocryologists recognize two types of "island" permafrost; massive-island (*massivno-ostrovnoye rasprostraneniye*, in Russian), with less than 50% permafrost continuity, and island (*ostrovnoye rasprostraneniye*, in Russian), with less than 20% continuity. In the West, island permafrost is generally referred to as sporadic permafrost. However, contrary to popular belief, there are no clearly defined boundaries between these zones and it is essential to recognize that transitions between these zones are gradual. In terms of vertical continuity, permafrost can exist as separate layers. The phenomenon of so-called "unjoined" permafrost is common in parts of northern West Siberia (for example, at the Urengoy and Medvezh'ye GCFs). "Unjoined" permafrost takes the form of two or more layers of permafrost separated by layers of unfrozen soil between them[1]. Formation is likely to have occurred as follows: a layer of unfrozen soils will have formed as a result of the Climatic Optimum during which a once continuous layer of permafrost, many hundreds of metres thick, could have thawed down to a depth

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[1] Permafrost in two layers is often known as "double-layered" permafrost (*dvukhsloynaya merzlota*, in Russian).

of perhaps 300 m [2]. This stage would be followed by a colder period in which a new layer of permafrost formed but did not reach the top of the "relict" permafrost layer (see below), thus leaving a layer of unfrozen soils in between. This process could be repeated several times, resulting in many layers of frozen and unfrozen soils. Hence the term "unjoined permafrost" (*neslivayushchayasya merzlota*, in Russian). It is therefore possible to apply the term "joined" to permafrost that is continuous vertically (*slivayushchayasya merzlota*, in Russian).

As stated above, so-called "relict" permafrost (*reliktovaya merzlota*, in Russian) is an important feature in permafrost regions. This type of permafrost owes its existence not to present but past climatic conditions. Permafrost with thicknesses in excess of 180 m can be found near the southern limits of permafrost in Siberia, where the mean annual air temperatures may be above 0°C. Such permafrost would have formed when climatic conditions in these areas were markedly colder and evidence suggests that such relict permafrost originated during the Pleistocene (the first epoch of the Quaternary). Where this permafrost exists in the presence of positive mean annual temperatures, it would be degrading.

A1.3 Permafrost within the CIS

A1.3.1 CIS and Russian permafrost

According to French (1996, p.56) permafrost can be divided into four categories defined by geographical area:

1. polar or latitudinal permafrost;
2. alpine permafrost (permafrost occurring in mountainous regions);
3. plateau permafrost (such as that occurring in the Tibetan Plateau);
4. subsea permafrost.

The CIS possesses the first, second and fourth types of permafrost.

Twenty-four percent of the earth's surface is underlain by permafrost, the majority of which occurs in the northern hemisphere, as shown in Table A1.1. The CIS (primarily Russia) possesses the largest area of permafrost[3]. The distribution and thickness of permafrost within the CIS and mean annual soil temperature data is illustrated in Fig.A1.2. Permafrost occupies 49.7% (over 11,000,000 km²) of the total area of the CIS, or more than 50% (9,000,000 km²) of the total area of Russia. It lies mostly east of the Ural Mountains, within West and East Siberia and the Russian Far East.

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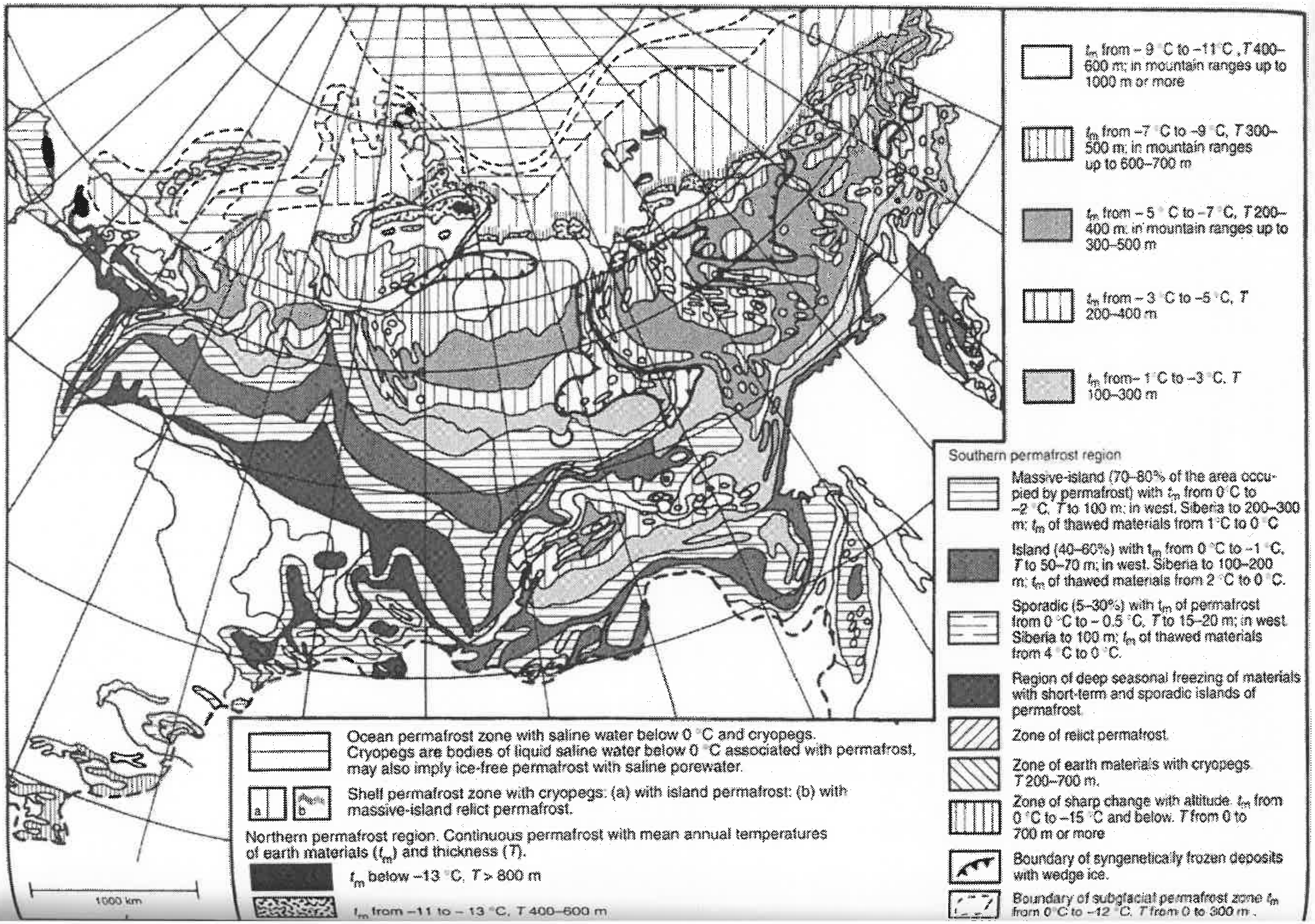
[2] The Climatic Optimum, known better as the Atlantic Period, occurred between 7500 and 5200 years ago in the post-glacial stage (Flandrian) of the Quaternary.

[3] Russian geocryologists often refer to the area occupied by permafrost as the "cryolithozone".

Fig.A1.2 Distribution and thickness of permafrost within the CIS, including mean annual soil temperature data
(Source : French, 1996, p.60, Fig.5.6)



Appendix 1

Table A1.1 **Global Distribution of Permafrost** (Source : French, 1996, p.56)

Northern Hemisphere (million km^2)		**Southern Hemisphere** (million km^2)	
CIS	11.0	Antarctica	13.5
Mongolia	0.8		
China	2.1		
North America			
Alaska	1.5		
Canada	5.7		
Greenland	1.6		
TOTAL	22.7		13.5
Total for both hemispheres :	36.2		
Total land area for both hemispheres :	149		
Area occupied by permafrost :	24%		

In the continuous permafrost zone the permafrost increases from approximately 300 m in depth at the southern limit to more than 600 m along the coast of the Arctic Ocean. Inland, thicknesses in excess of 500 m are common in the Republic of Sakha-Yakutiya (Russian Far East), with the thickest known permafrost occurring in the north of the republic. Here, sub-zero temperatures were recorded in a drill-hole at a depth of 1450 m in the Markha River Basin (Mel'nikov & Pavlov, 1982, p.163).

Discontinuous permafrost is encountered in limited areas in the European part of Russia, i.e. the Kola Peninsula and in the tundra and *taiga* (boreal forest) zones which lie between the White Sea and the Ural Mountains. East of the Urals, a broad zone of discontinuous permafrost exists in West and East Siberia. In these regions an approximate border between continuous and discontinuous permafrost coincides with the northern boundary of the *taiga* and is accompanied by a sharp increase in the thickness of the permafrost. For example, thicknesses of 25 - 30 m are common in the boreal forest discontinuous zone, whereas in the continuous zone of the tundra thicknesses of 400 m are common.

West Siberia, particularly Khanty-Mansiyskiy AO, possesses large areas of massive-island and island permafrost.

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West Siberia, particularly Khanty-Mansiyskiy AO, possesses large areas of massive-island and island permafrost.

In all parts of Russia's permafrost zones there are areas where permafrost is not encountered, most notably under the largest rivers, for example, the Ob', Yenisey and Lena, and lakes.

The permafrost of Siberia is greater than the North American permafrost in terms of extent, thickness and coldness. This reflects a number of factors, the most important of which is the difference in the history of continental glaciations in these two land masses. In Siberia during the Pleistocene, localized ice sheets formed only in the major mountain belts, leaving the lowland plains largely free of ice. Deep and continuous permafrost developed in response to the very low air temperatures to which the ground was exposed and low snowfall resulted in a lack of glaciation. This was in stark contrast to the ice sheets that covered much of North America.

Alpine permafrost is encountered in the mountainous regions of Central Asia, for example in the Tien Shan Mountains of Kyrgyzstan. Large areas of subsea permafrost are encountered in the Kara, Laptev and East Siberian seas.

A1.3.2 Distribution of permafrost in northern West Siberia

Perennially-frozen soils have developed over a vast area within West Siberia, amounting to more than 1 million km². They extend from the Beliy and Vil'kitskiy islands in the Far North of West Siberia down to 60°30'N at their southern limit, approximately the latitude of Surgut (Baulin, 1985, p.17). Others, such as Trofimov *et al.* (1980, p.29), say that perennially-frozen soils extend only as far south as 61°N, although they add that such soils are encountered further south in isolated patches[4].

According to the three-zone permafrost regionalization of West Siberia, proposed by V.V.Baulin and other geocryologists in 1967, the Urengoy and Medvezh'ye GCFs fall within the central zone in which discontinuous epigenetic permafrost is typical[5]. Perennially-frozen soils are not encountered continuously through the vertical plane in this zone, with many taliks beneath wooded areas. Soil temperatures do not exceed -1°C and permafrost here is double-layered. The Yamburg GCF lies in the southern subzone of the northern zone where continuous epigenetic permafrost is the norm. Soil temperatures increase southwards from -6°C to -1°C (Kritsuk, 1983, p.85; Remizov *et al.*, 1996, p.149). Permafrost distribution by area is determined by the joint influence of zonal, regional and local factors of heat exchange between soils and the atmosphere and as a result of the significant heterogeneity of the latter, distribution proves to be highly complex.

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[4] Seasonal freezing in West Siberia to the south of 60°30'N is described in detail in : Gilichinskiy, D.A. 1986. *Sezonnaya Kriolitozona Zapadnoy Sibiri* [The Seasonal Cryolithozone of West Siberia]. Moscow, "*Nauka*".

[5] Epigenetic permafrost was formed after the deposition of the earth material in which it occurs. Syngenetic permafrost was formed simultaneously with the deposition of the earth material in which it occurs.

Appendix 1

The considerable length of the territory in the longitudinal direction (ca.350 km) causes a well-pronounced latitudinal zonality in permafrost distribution. The area occupied by permafrost decreases from north to south and the area of unfrozen soils increases. At the same time the role of various factors of heat-exchange in the formation of permafrost changes.

Kritsuk (1983, p.85) states that north of the R.Ngarka-Tab"yakha (in the northern and southern forest tundra subzones) permafrost is continuous. While Trofimov *et al.* (1980, p.31) maintain that continuous permafrost is not encountered quite so far south but only above the middle course of the R.Tab"yakha (see Figs.2.4 and 4.14). South of the Arctic Circle in the southern forest tundra (the upper reaches of the R.Ngarka-Tab"yakha and R.Nyda), the area of unfrozen soils increases, giving way to areas of discontinuous and island permafrost. In the northern *taiga* subzone (in the valleys of the R.Nadym, R.Pur and their largest tributaries such as the R.Kheygiyakha, R.Pravaya Khetta, R.Levaya Khetta, R.Yamsovey and R.Yevoyakha) perennially-frozen soils still have a wide distribution. For example, states Kritsuk (1983, p.87), in the floodlands of the R.Nadym and its tributaries such soils occupy between 20-30 and 50-60% of the area, that is island and massive-island permafrost. This supposition is in sharp contrast to the conclusions of other geocryologists who maintain that the floodlands of all rivers and streams in the northern *taiga* are in an unfrozen state.

As Baulin (1985, p.19) emphasizes, the key factor influencing the development of permafrost in any region is snow cover. Where there are extensive unwooded areas, typical in the northern and southern forest tundra subzones, either side of the Arctic Circle, the snow cover will usually be less than 50 cm and permafrost will have developed in both mineral and peaty soils. Further south, where snow cover accumulates in well-vegetated and wooded terrain, permafrost will only develop in a few unwooded areas with peaty soils. Permafrost will almost never be encountered in sandy soils. Baulin states that snow cover determines the distribution of permafrost down to 62°N latitude, i.e. well into Khanty-Mansiyskiy AO.

The following are key texts on general geocryology of the West Siberian North.

Mel'nikov, Ye.S. (ed.). 1983. *Geokriologicheskiye Usloviya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Conditions of the West Siberian Gas-Bearing Province]. Novosibirsk, "*Nauka*".

Belopukhova, Ye.B., N.A.Tikhomirova & A.G.Sukhov. 1984, *Merzlotnyye usloviya Nadym-Purovskogo mezhdurech'ya i doliny R.Pur* [Permafrost conditions of the Nadym-Pur interfluve and the valley of the R.Pur]. In: *Geokriologicheskiye Usloviya i Prognoz Ikh Izmeneniya v Rayonakh Pervoocherednogo Osvoyeniya Severa (Sbornik Nauchnykh Trudov)* [Geocryological Conditions

and Forecasting Their Changes in Regions of Immediate Development in the North (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.157-178

Baulin, V.V. 1985. *Mnogoletnemerzlyye Porody Neftegazonosnykh Rayonov SSSR* [Perennially-Frozen Soils of the Oil and Gas-Bearing Districts of the USSR]. Moscow, "*Nedra*".

Yershov, E.D. (ed.) 1989. *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*".

APPENDIX 2

CLIMATIC DATA FOR RUSSIA'S EUROPEAN, WEST & EAST SIBERIAN NORTH

Location	**Nadym/ Medvezh'ye (NPT, W.Sib.)**	**Urengoy (NPT, W.Sib.)**	**Yamburg (NPT, W.Sib.)**	**Bovanenkovskoye/ Viktoriya (YEGTS, W.Sib.)**	**Yary/ Khal'mer-Yu (YEGTS, W.Sib./N.Eur.)**	**Vorkuta (YEGTS, N.Eur.)**
Average annual air temp. (°C)	-7.7	-7....-9	-7....-11	-6.5....-12	-6.3	-6
Average annual air temp. range (°C)	42	40	40....45	29	31	33
Average Jan air temp. (°C)	-28	-26	-24....-30	-23	-21	-21
Absolute min. air temp. (°C)	-50	-50	-55	-52	-52	-52
Average July air temp. (°C)	+14	+14	+13	+6	+10	+12
Absolute max. air temp. (°C)	N/A	N/A	+32	+30	+30	+31
Average annual precip. (mm)	485	450	350....430	300	N/A	517
Max. snow depth (cm)	100	50....60	40....50	40....50	N/A	150+

(continued)

Average annual wind speed (m/s)	3	3....5	N/A	7....9	N/A	5.5
Maximum wind speed (m/s)	20	24	30	25....35	40....45	40

Location	**Noril'sk (NAGSS, E.Sib.)**	**South Soleninskoye (NAGSS, E.Sib.)**	**Punga - Komsomol'skiy (Igrim - Serov, W.Sib.)**	**Komsomol'skiy - Ivdel' (Igrim - Serov, (W.Sib.)**	**Ivdel' - Serov (Igrim - Serov, W.Sib.)**
Average annual air temp. (°C)	-10.7	-8....-13	-3.4	-1.7	-0.5
Average annual air temp. range (°C)	42	42	38	36	34
Average Jan air temp. (°C)	-30	-33	-22	-20	-18
Absolute min. air temp. (°C)	-53	-57	-51	-48	-45
Average July air temp. (°C)	+12	+9	+16	+16	+16
Absolute max. air temp. (°C)	+32	+38	31.5	+33	+35
Average annual precip. (mm)	N/A	350....450	423	446	432

(continued)

Max. snow depth (cm)	70	150....200	70	N/A	N/A
Average annual wind speed (m/s)	N/A	5.5....5.8	3.6	N/A	N/A
Maximum wind speed (m/s)	40	40	N/A	N/A	N/A

Sources: Firsov *et al.*, 1989, p.284-285 (Nadym/Medvezh'ye); Remizov *et al.*, 1996, p.128 (Nadym, Urengoy); Chigir, 1995, p.3 (Urengoy); Krayzel'man & Klyuchnikova, 1985, p.6 (Yamburg); Sukhov *et al.*, 1989, p.236 (Yamburg); Kurbatov & Gabelaya, 1990, p.492 (Yamburg); Skubitskaya, 1996, p.475 (Yamburg); Evans & Taksa, 1995 (Bovanenkovskoye/Viktoriya, Yary/Khal'mer-Yu); Baulin *et al.*, 1996, p.10-12 (Bovanenkovskoye/Viktoriya); *VNIIgaz & Eko-Sistema*, 1997, p.C.3 (Yary/Khal'mer-Yu); Archegova *et al.*, 1991, p.5 (Vorkuta); Kakunov, 1994, p.123-124 (Vorkuta); Prikhod'ko, Stepanov & Dedeyev, 1994, p.8 (Vorkuta); Repalov & Kharionovskiy, 1994, p.28 (Noril'sk); Konstantinov, 1990, p.104-105 (South Soleninskoye); Konstantinov, 1991, p.44 (South Soleninskoye); Dertsakyan, 1967, p.18-19 (Punga - Komsomol'skiy, Komsomol'skiy - Ivdel', Ivdel' - Serov); Zakharov & Khasanov, 1981, p.9-10 (Punga - Komsomol'skiy).

APPENDIX 3

CONTENTS OF SNiP 2.05.06-85 "TRUNK PIPELINES"

The 50-page SNiP is divided into the following sections. The number of pages (approximately), subsections (and their titles), points and tables are indicated for each section :

1. Introduction
   ½ page
   8 points.

2. Classification and categories of trunk pipelines
   2½ pages
   3 points
   3 tables

3. Basic requirements for the pipeline route
   9½ pages
   27 points
   5 tables

4. Structural requirements for pipelines
   2½ pages
   2 subsections - i. General (11 points)
   ii. Placing of valve and other fixtures on pipelines (11 points)

5. Laying buried pipelines
   4 pages
   5 subsections - i. General (13 points)
   ii. Laying pipelines in mountainous conditions (9 points)
   iii. Laying pipelines in areas of mining operations (8 points)
   iv. Laying pipelines in seismically-active areas (12 points)
   v. Laying pipelines in perennially-frozen soils (14 points)

6. Pipeline transits across natural and man-made obstacles
   3½ pages
   3 subsections - i. General (1 point)
   ii. Underwater pipeline transits across water-bodies (29 points)
   iii. Buried pipeline transits beneath railways and roads (7 points)

7. Laying raised pipelines
   1 page
   10 points

8. Pipeline calculations for strength and stability
   12 pages
   9 subsections - i. General (1 point)
   ii. Calculation characteristics of materials (4 points)

iii. Loadings and influences (16 points)
iv. Determination of pipeline wall thickness (1 point)
v. Verification of strength and stability of buried and on-ground (in a berm) pipelines (10 points)
vi. Checking of strength & stability of raised pipelines (14 points)
vii. Compensators (6 points)
viii. Peculiarities of calculations for pipelines laid in seismically-active areas (10 points)
ix. Pipeline joint details (2 points)

10 tables

9. Environmental protection
1 page
13 points

10. Pipeline corrosion protection
1½ pages
5 subsections - i. General (2 points)
ii. Protecting pipelines from soil corrosion using protective coverings (2 points)
iii. Protecting raised pipelines from atmospheric corrosion (5 points)
iv. Electro-chemical protection of pipelines from soil corrosion (13 points)
v. Electro-chemical protection of pipelines in regions of perennially-frozen soils (8 points)

11. Technological communication lines of pipelines
3 pages
26 points
1 table

12. Planning liquefied petroleum gas pipelines
2½ pages
30 points
1 table

13. Materials and parts
4½ pages
5 subsections - i. General (2 points)
ii. Pipes and joining fixtures (26 points)
iii. Parts for securing pipelines against uprising (7 points)
iv. Materials used for pipeline anti-corrosion coatings (1 point)

4 tables

Appendix : Graph for determining the coefficient of the supporting capacity of T-joints
1 page
1 graph

APPENDIX 4

COMPARISON OF TOTAL NET PRESENT VALUE COSTS OF GAS COOLING FOR ONE 1420 MM DIAMETER PIPELINE STRING AT THE YARYNSKAYA COMPRESSOR STATION (YEGTS)

(Source : Evans & Taksa, 1995)

Gas cooling alternative	Total Net Present Value Cost (US$ Millions)
Propane Refrigeration	102.0
High Pressure Turboexpander	96.2
Low Pressure Turboexpander	89.3

NOTES

1. If six 1420 mm strings are laid, the savings for a low pressure turboexpander relative to propane refrigeration would be US$72 million and relative to a high pressure turboexpander US$42 million.

2. Factors considered in the economic evaluation of each gas chilling alternative were:
    a. Capital costs of all major chilling equipment, including capital costs of all installed aerial coolers.
    b. Capital costs including labour, maintenance and overhaul.
    c. Fuel costs for all station and propane refrigerant gas turbine-driven compressors.
    d. Electricity costs for fan motors of all aeriel coolers.
    e. Station and propane refrigerant gas turbine-driven compressor fuel efficiencies.
    f. Gas cooling equipment in each case operates only during a six-month winter period each year.
    g. A 20-year operating life for each case.
    h. A 6% present value interest rate.

REFERENCES

Agalakov, S.Ye. 1993. *Nekotoryye osobennosti stroyeniya kriolitozony Bovanenkovskogo mestorozhdeniya* [Some peculiarities of the structure of the cryolithozone at the Bovanenkovskoye GCF]. In: Tsibul'skiy, V.P. (ed.). *Yamal - Problemy Razvitiya* [Yamal - Problems of Development]. Tyumen', Institute of Problems of the North (*IPOS*), Siberian Branch of RAS, p.112-124.

Amiyan, K. 1997. *Vtoraya vserossiyskaya konferentsiya molodykh uchenykh, spetsialistov i studentov* [The 2nd All-Russian Conference of Young Academics, Specialists and Students]. *Gozovaya Promyshlennost'*, No.11, p.6-7.

Anan'yeva, G.V. & N.G.Ukraintseva. 1996. *Osobennosti rastprostraneniya podozernykh talikov na territorii Bovanenkovskogo mestorozhdeniya* [Peculiarities of the distribution of lake taliks in the territory of the Bovanenkovskoye field]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 1. Moscow, Moscow State University, p.80-92.

Andrianov, V.N. *et al.* 1989. *Usloviya razvitiya i rasprostraneniye kriogennykh geologicheskikh protsessov i yavleniy* [Conditions of development and distribution of cryogenic geological processes and phenomena]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.135-155.

Arabskiy, A.K. & I.Ye.Zhukov. 1995. *Rezultaty nachal'nogo etapa vnedreniya vibrodiagnosticheskogo kompleksa na predpriyatii "Yamburggazdobycha"* [Results of the initial stage of introducing a vibration diagnostics system in the enterprise "*Yamburggazdobycha*"]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.39-40.

Archegova, I.B. 1995. Personal communications with Inna Borisovna Archegova, Department of Plant Cover Restoration, Institute of Biology, Komi Science Centre, Urals Branch, RAS. Held in Syktyvkar, 30th November 1995.

Archegova, I.B. *et al.* 1991. *Ekologicheskiye Osnovy Upravleniya Produktivnost'yu Agrofitotsenozov Vostochnoyevropeyskoy Tundry* [Ecological Principals of Managing the Productivity of Agricultural Zones of the East European Tundra]. Leningrad, "*Nauka*".

Arctic News Record. 1986. Progress at Yamburg. *Arctic News Record*, Winter-Spring, Vol.5, No.1, p.10.

Arctic News Record. 1995. Gas condensate through winter ice. *Arctic News Record*, Vol.11, No.3, p.6.

Aynbinder, A. 1997. Personal communications with Alexander Aynbinder, Fluor Daniel, Sugar Land, Texas, USA. Fax of September 22nd 1997.

Aynbinder, A. *et al.* 1994. FSU pipeline design code compared to US codes. *Oil & Gas Journal*, Vol.92, No.10, March 7th, p.67-71.

REFERENCES

Agalakov, S.Ye. 1993. *Nekotoryye osobennosti stroyeniya kriolitozony Bovanenkovskogo mestorozhdeniya* [Some peculiarities of the structure of the cryolithozone at the Bovanenkovskoye GCF]. In: Tsibul'skiy, V.P. (ed.). *Yamal - Problemy Razvitiya* [Yamal - Problems of Development]. Tyumen', Institute of Problems of the North (*IPOS*), Siberian Branch of RAS, p.112-124.

Amiyan, K. 1997. *Vtoraya vserossiyskaya konferentsiya molodykh uchenykh, spetsialistov i studentov* [The 2nd All-Russian Conference of Young Academics, Specialists and Students]. *Gozovaya Promyshlennost'*, No.11, p.6-7.

Anan'yeva, G.V. & N.G.Ukraintseva. 1996. *Osobennosti rastprostraneniya podozernykh talikov na territorii Bovanenkovskogo mestorozhdeniya* [Peculiarities of the distribution of lake taliks in the territory of the Bovanenkovskoye field]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 1. Moscow, Moscow State University, p.80-92.

Andrianov, V.N. *et al.* 1989. *Usloviya razvitiya i rasprostraneniye kriogennykh geologicheskikh protsessov i yavleniy* [Conditions of development and distribution of cryogenic geological processes and phenomena]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.135-155.

Arabskiy, A.K. & I.Ye.Zhukov. 1995. *Rezultaty nachal'nogo etapa vnedreniya vibrodiagnosticheskogo kompleksa na predpriyatii "Yamburggazdobycha"* [Results of the initial stage of introducing a vibration diagnostics system in the enterprise "*Yamburggazdobycha*"]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.39-40.

Archegova, I.B. 1995. Personal communications with Inna Borisovna Archegova, Department of Plant Cover Restoration, Institute of Biology, Komi Science Centre, Urals Branch, RAS. Held in Syktyvkar, 30th November 1995.

Archegova, I.B. *et al.* 1991. *Ekologicheskiye Osnovy Upravleniya Produktivnost'yu Agrofitotsenozov Vostochnoyevropeyskoy Tundry* [Ecological Principals of Managing the Productivity of Agricultural Zones of the East European Tundra]. Leningrad, "*Nauka*".

Arctic News Record. 1986. Progress at Yamburg. *Arctic News Record*, Winter-Spring, Vol.5, No.1, p.10.

Arctic News Record. 1995. Gas condensate through winter ice. *Arctic News Record*, Vol.11, No.3, p.6.

Aynbinder, A. 1997. Personal communications with Alexander Aynbinder, Fluor Daniel, Sugar Land, Texas, USA. Fax of September 22nd 1997.

Aynbinder, A. *et al.* 1994. FSU pipeline design code compared to US codes. *Oil & Gas Journal*, Vol.92, No.10, March 7th, p.67-71.

Badu, Yu.B. & N.G.Firsov. 1975. *Sovremennyye ekzogennyye geologicheskiye protsessy i yavleniya* [Contemporary exogenic geological processes and phenomena]. In: Trofimov, V.T. (ed.). *Poluostrov Yamal (Inzhenerno-Geologicheskiy Ocherk)* [The Yamal Peninsula (Engineering-Geological Sketch)]. Moscow, Moscow University Press, p.257-268.

Badu, Yu.B. & V.T.Trofimov. 1975. *Rasprostraneniye mnogoletnemerzlykh i talykh porod* [Distribution of perennially-frozen and unfrozen soils]. In: Trofimov, V.T. (ed.). *Poluostrov Yamal (Inzhenerno-Geologicheskiy Ocherk)* [The Yamal Peninsula (Engineering-Geological Sketch)]. Moscow, Moscow University Press, p.78-81.

Badu, Yu.B. *et al.* 1989. *Prognoz izmeneniya geokriologicheskikh usloviy pri razlichnykh tipakh tekhnogennikh narusheniy* [Forecasting change of geocryological conditions under the influence of different types of technogenic disturbances]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.407-432.

Baglay, R.D., O.Ye.Trofimov & N.N.Khrenov. 1989. *Osobennosti vzaimodeystviya truboprovoda s merzlym gruntom* [Peculiarities of the interaction of a pipeline with frozen soil]. *Stroitel'stvo Truboprovodov*, No.7, p.37-39.

Batalin, Yu.P. 1983. *Uspeshno zavershit' gazoprovod Urengoy - Pomary - Uzhgorod - serdtsevinnuyu stroyku 1983 g. i odinnadtsatoy pyatiletki* [Concluding the Urengoy - Pomary - Uzhgorod gas pipeline successfully - the core construction project of 1983 and the eleventh five-year plan]. *Stroitel'stvo Truboprovodov*, No.4, p.2-7.

Baulin, V.V. 1985. *Mnogoletnemerzlyye Porody Neftegazonosnykh Rayonov SSSR* [Perennially-Frozen Soils of the Oil and Gas Bearing Regions of the USSR]. Moscow, "*Nedra*".

Baulin, V.V. & A.L.Chekhovskiy. 1994. Engineering and geocryological problems of development in the north of Yamal. In: Smith, D.W. & D.C.Sego (eds.). *Proceedings of the 7th International Cold Regions Engineering Specialty Conference*, March 7th to 9th, 1994, Edmonton, Alberta. Montreal, Canadian Society for Civil Engineering, p.815-820.

Baulin, V.V. *et al.* 1984. *Merzlotnyye usloviya Medvezh'yego gazovogo mestorozhdeniya i ikh prognoz pri osvoyenii territorii* [Permafrost conditions of the Medvezh'ye gas field and forecasting them during development of the territory]. In: *Geokriologicheskiye Usloviya i Prognoz Ikh Izmeneniya v Rayonakh Pervoocherednogo Osvoyeniya Severa (Sbornik Nauchnykh Trudov)* [Geocryological Conditions and Forecasting Their Changes in Regions of Immediate Development in the North (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.3-24.

Baulin, V.V. *et al.* 1996. *Geokriologicheskiye Usloviya Osvoyeniya Bovanenkovskogo Mestorozhdeniya* [Geocryological conditions of development of the Bovanenkovskoye field]. *Inzhenerno-Geologicheskiy Monitoring Promyslov Yamala, Tom II* [Engineering-Geological Monitoring of Yamal Fields, Volume II]. Tyumen', Institute of Problems of Development of the North (Siberian Branch, RAS) & *PNIIIS*.

Belopukhova, Ye.B. *et al.* 1983. *Inzhenerno-geokriologicheskoye rayonirovaniye Tazovskogo poluostrova* [Engineering-geocryological regionalization of the Tazovskiy Peninsula]. In: *Voprosy Regionalnoy i Inzhenernoy Geokriologii* [Questions of Regional and Engineering Geocryology]. Moscow, *Stroyizdat* and *PNIIIS*, p.3-19.

Blinov, M.A. 1980. *Ballastirovka truboprovodov v usloviyakh Kraynego Severa* [Pipeline ballasting in the Far North]. *Stroitel'stvo Truboprovodov*, No.10, p.23-25.

Bokserman, Yu.I. 1996. From the Saratov - Moscow gasline to the Era of Methane. *Petroleum Economist*, May, Vol.63, No.5, p.54-56.

Bolonov, V.Ye. *et al.* 1996. *Ekspluatatsiya magistral'nykh gazoprovodov v usloviyakh Kraynego Severa* [Operation of trunk gas pipelines in the Far North]. *Gazovaya Promyshlennost'*, No.3-4, p.55-56.

Borodavkin, P.P., N.N.Khrenov & S.A.Yegurtsov. 1990. *Diagnostika truboprovodnykh geotekhnicheskikh sistem v slozhnykh fiziko-geograficheskikh usloviyakh* [Diagnostics of pipeline geotechnical systems in complex physical-geographical conditions]. *Obzornaya Informatsiya. Seriya: Transport i Podzemnoye Khraneniye Gaza*. Moscow, *VNIIEgazprom.*

Borovkov, V.A. 1992. *Povysheniye Nadezhnosti Gazoprovodov, Ekspluatatsiruyemykh v Mnogoletnemerzlykh Gruntakh* [Increasing the Reliability of Gas Pipelines Operating in Perennially-Frozen Soils]. Dissertation for the degree of Candidate of Technical Sciences. Moscow, *VNIIgaz.*

Borovkov, V.A. 1996. Personal communications with Vladimir Aleksandrovich Borovkov, Chief of Industrial-Technical Department, *Noril'skgazprom*. Held in Noril'sk, 5th to 14th June 1996.

Borovkov, V.A. & V.V.Kalyavin. 1991. *Povysheniye ekspluatatsionnoy nadezhnosti uchastkov gazoprovodov v puchinistykh gruntakh* [Increasing the operational reliability of sections of gas pipelines in heaving soils]. In: *Problemy Nadezhnosti Gazoprovodnykh Konstruktsiy (Sbornik Nauchnykh Trudov)* [Problems of Reliability of Gas Pipeline Structures (Collection of Research Papers)]. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.27-32.

Brushkov, A.V., G.V.Lepinskikh & A.A.Nikolayev. 1990. *O prochnosti merzlykh zasolennykh gruntov p-ova Yamal* [On the strength of frozen saline soils of the Yamal Peninsula]. In: Vyalov, S.S. (ed.). *Zasolennyye Merzlyye Grunty Kak Osnovaniya Sooruzheniy* [Saline Frozen Soils As Foundations of Structures]. Moscow, "*Nauka*", p.115-120.

Chigir, V.G. *et al.* 1997a. *Mnogoletnyaya evolyutsiya i sezonnaya dinamka oreolov protaivaniya mnogoletnemerzlykh porod pod gazoprovodami Kraynego Severa* [Many-year evolution and seasonal dynamics of thaw bulbs of perennially-frozen soils under gas pipelines in the Far North]. *Stroitel'stvo Truboprovodov*, No.2, March-April, p.28-31.

Chigir, V.G. *et al.* 1997b. *Dinamika geotekhnosistem i diagnostika sostoyaniya gazoprovodov severa* [Dynamics of geotechnical systems and diagnostics of the condition of gas pipelines in the north]. *Stroitel'stvo Truboprovodov*, No.3, May-June, p.5-7.

Chigir, V.G. & S.A.Yegurtsov. 1994. *Predlozheniya po povysheniyu nadezhnosti perekhodov MPK i vodozabora Khadutte* [Proposals to increase the reliability of gathering line crossings and the water draw-off of the R.Khadutte]. Moscow, *Ekotekh.*

Dalton, P. *et al.* 1994. Knowing design codes essential for making, specifying FSU pipe. *Oil & Gas Journal*, Vol.92, No.28, July 11th, p.52-58.

Demushkin, V.V. 1998. Personal communications with Valeriy Vasil'yevich Demushkin, Head of Gas Processing Plant UKPG-2, *Yamburggazdobycha*. Held in Yamburg, 9th April 1998.

Dertsakyan, A.K. 1967. *Stroitel'stvo Gazoprovoda Igrim - Serov* [Construction of the Igrim - Serov Gas Pipeline]. Moscow, "*Nedra*".

Dimov, L.A. 1991. *Povysit' nadezhnost' truboprovodov v slabykh gruntakh* [Increasing the reliability of pipelines in weak soils]. *Stroitel'stvo Truboprovodov*, No.11, p.14-15.

Dimov, L.A. 1993a. *Problemy proyektirovaniya truboprovodov na severe Rossii* [Problems of planning pipelines for the north of Russia]. *Gazovaya Promyshlennost'*, No.3, p.16-18.

Dimov, L.A. 1993b. *Problemy proyektirovaniya truboprovodov na severe Rossii (prodolzheniye)* [Problems of planning pipelines for the north of Russia (conclusion)]. *Gazovaya Promyshlennost'*, No.7, p.13-15.

Dimov, L.A. 1995. *O primenenii osnovnykh polozheniy gruntov k raschetu podzemnykh truboprovodov* [On the use of the basic state of soils for the calculation of underground pipelines]. *Gazovaya Promyshlennost'*, No.5, p.33-34.

Dimov, L.A. 1996a. *Osnovnyye napravleniya sovershenstvovaniya proyektirovaniya i rascheta podzemnykh gazoprovodov* [Main ways to improve the planning and calculation of underground gas pipelines]. *Gazovaya Promyshlennost'*, No.5-6, p.67-70.

Dimov, L.A. 1996b. Personal communications with Leonid Aleksandrovich Dimov, Director of *GP "KomiNIPIstroy"* and *NPF "Taleon"*. Held in Ukhta, 5th May 1996.

Dimov, L.A. & Ye.M.Bogushevskaya. 1993. *Prokladka gazoprovodov na bolotakh i zabolochennykh uchastakh* [Laying gas pipelines on bogs and boggy sections]. *Gazovaya Promyshlennost'*, No.4, p.12-14.

Dimov, L.A. & Ye.M.Bogushevskaya. 1994. *Proyektirovaniye podzemnykh gazoprovodov na bolotakh* [Planning underground gas pipelines on bogs]. *Gazovaya Promyshlennost'*, No.1, p.27-28.

Dinkov, V.A. & O.M.Ivantsov. 1997a. *Vremya novomu pokoleniyu gazoprovodov* [Time for a new generation of gas pipelines]. *Gazovaya Promyshlennost'*, No.8, p.16-20.

Dinkov, V.A. & O.M.Ivantsov. 1997b. *Vremya novomu pokoleniyu gazoprovodov* [Time for a new generation of gas pipelines]. *Gazovaya Promyshlennost'*, No.9, p.12-16.

Dinkov, V.A. & O.M.Ivantsov. 1997c. *Vremya novomu pokoleniyu gazoprovodov* [Time for a new generation of gas pipelines]. *Gazovaya Promyshlennost'*, No.10, p.26-30.

Dubikov, G.I. *et al.* 1984. *Merzlotnyye usloviya Yamburgskogo podnyatiya* [Permafrost conditions of the Yamburg Rise]. In: *Geokriologicheskiye Usloviya i Prognoz Ikh Izmeneniya v Rayonakh Pervoocherednogo Osvoyeniya Severa (Sbornik Nauchnykh Trudov)* [Geocryological Conditions and Forecasting Their Changes in Regions of Immediate Development in the North (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.72-113.

Dubikov, G.I. *et al.* 1985. *Novyye rezultaty issledovaniy plastovykh l'dov na Yamale* [New results of research into massive ice on Yamal]. In: Sukhodol'skiy, S.Ye. & M.M.Koreysha (eds.). *Regional'nyye Geokriologicheskiye Issledovaniya (Sbornik Nauchnykh Trudov)* [Regional Geocryological Research (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.27-37.

Dubikov, G.I., I.M.Boykova & M.A.Minkin. 1989. *Mordyyakha-Khoyskaya oblast'* [The Mordyyakha-Khoyskaya region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.209-218.

Dubikov, G.I. & N.V.Ivanova. 1990. *Zasolennyye merzlyye grunty i ikh rasprostraneniye na territorii SSSR* [Saline frozen soils and their distribution within the USSR]. In: Vyalov, S.S. (ed.). *Zasolennyye Merzlyye Grunty Kak Osnovaniya Sooruzheniy* [Saline Frozen Soils As Foundations of Structures]. Moscow, "*Nauka*", p.3-9.

Dubikov, G.I., N.Figarov & A.Tsourikov. 1994. Subsea permafrost and gas pipeline construction of the Baydaratskaya Bay crossing in Siberia, Russia. In: Smith, D.W. & D.C.Sego (eds.). *Proceedings of the 7th International Cold Regions Engineering Specialty Conference*, March 7th to 9th, 1994, Edmonton, Alberta. Montreal, Canadian Society for Civil Engineering, p.843-864.

Engesaeth, S. & R.Muller. 1997. *Neftegazovaya Deyatel'nost' na Severo-Zapade Rossii - Status i Budushchiye Transportnyye Resheniya* [Oil & Gas Activity in the Northwest of Russia - Status and Future Transport Solutions]. *Bellona Working Document*, No.1, January 27th 1997. Oslo, Bellona.

Evans, H.D. & B.G.Taksa. 1995. Feasibility study : initial section of the Yamal - Centre pipeline system. In: *The 3rd International Conference on the Distribution of Oil & Gas in the Former Soviet Union. Pipeline Transmission Systems.* 22nd to 23rd March. Vienna, Austria. London, Adam Smith Institute.

Feygin, V.I. 1996. Personal communications with Vladimir Isaakovich Feygin, Leading Researcher, *VNIIEgazprom*, Moscow. Held in Beijing, China, 22nd to 23rd September 1996.

Filippskiy, A.Kh. & V.I.Degtyarev. 1990. *Analiz opor dlya truboprovoda ø 1420 mm* [Analysis of supports for a 1420 mm diameter pipeline]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.144-147.

Firsov, N.G. *et al.* 1989. *Ust'purovsko-Tazovskaya oblast'* [The Ust'purovsko-Tazovskaya region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.247-251.

French, H.M. 1996. *The Periglacial Environment.* 2nd Edition. Harlow, Longman.

Galiullin, Z.T. *et al.* 1996. *Optimal'nyye temperatury perevoda golovnykh uchastkov gazoprovodov Urengoy - Nadym i Yamburg - Nyda na rezhim okhlazhdeniya gaza* [Optimal temperatures for the transfer of initial sections of the Urengoy - Nadym and Yamburg - Nyda gas pipelines to a gas cooling regime]. In: *Yubileynyy Sbornik Trudov. 50 Let Gazoprovodu Saratov - Moskva. Tom 3*

[Jubilee Collection of Papers. For 50 Years of the Saratov - Moscow Gas Pipeline. Volume 3]. Moscow, *RAO Gazprom*, *VNIIgaz* and *IRTs Gazprom*, p.129-136.

Gazovaya Promyshlennost'. 1996. *Krasnyy styk supergigantskoy arterii* [The red joint of the supergiant artery]. *Gazovaya Promyshlennost'*, No.11-12, p.9.

Gazprom. 1995a. Annual Report 94. Moscow, *RAO Gazprom*.

Gazprom. 1995b. *The Yamal-Europe Project*. Moscow, *RAO Gazprom*.

Goral'chuk, M.N. *et al.* 1989. *Nadym-Purovskaya oblast'* [The Nadym-Purovskaya region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.290-297.

Gorst, I. 1988. Continuing gas boom. *International Gas Report*, May, p.147-149.

Gosstroy. 1985. *Magistral'nyye Truboprovodov. SNiP 2.05.06-85* [Trunk Pipelines. SNiP 2.05.06-85]. Official Publication. Moscow, *Gosstroy*.

Grechishchev, S.Ye. & Yu.B.Sheshin. 1983. *Prognoz kriogennogo rastreskivaniya gruntov i vyzyvayemykh im usiliy v podzemnykh truboprovodov* [Forecasting thermal-contraction cracking of soils and the forces which arise on account of it in buried pipelines]. In: Grechishchev, S.Ye. (ed.). *Geokriologicheskiy Prognoz Dlya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Forecasting for the West Siberian Gas-Bearing Province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.142-155.

Gritsenko, A.I. 1996. Exports all year round from planned LNG plant (*Gazprom* sponsored supplement). In: *Gas in the CIS. A Special Report*. London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.viii-x.

Gritsenko, A.I. *et al.* 1996. The Vuktyl field's potential for peak-shaving gas supply. In: *Gas in the CIS. A Special Report*. London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.10.

Griva, G.I. 1997a. Personal communications with Gennadiy Ivanovich Griva, Head of Ecological Monitoring Laboratory, Scientific-Technical Centre, *Nadymgazprom*, Nadym. Held in Nadym, 10th to 17th March 1997.

Griva, G.I. 1997b. Personal communications with Gennadiy Ivanovich Griva, Head of Ecological Monitoring Laboratory, Scientific-Technical Centre, *Nadymgazprom*, Nadym. Formerly of *YuzhNIIgiprogaz*, Donetsk, Ukraine. Held in Cambridge, 14th to 15th July 1997.

Gumerov, R.R. *et al.* 1989. *Vmorozhivayemyye ankery novoy konstruktsii* [Frozen-in anchors with a new structure]. *Stroitel'stvo Truboprovodov*, No.3, p.23-24.

Gurkov, G & V.Yevseyev. 1984. *Tapping Siberian Wealth : The Urengoy Experience*. Moscow, Progress Publishers. Translation of : *I Togda Mir Uslyshal : Urengoy!*

Harris, S.A. *et al.* 1988. *Glossary of Permafrost and Related Ground-Ice Terms.* Ottawa, Ontario, National Research Council of Canada. Associate Committee on Geotechnical Research. Permafrost Subcommittee.

Ignat'yev, M.P. 1997. *Opyt ekspluatatsii apparatov vozdushnogo okhlazhdeniya na dozhimnykh kompressornykh stantsiyakh v usloviyakh severnykh mestorozhdeniy gaza* [Experience of operation of air cooling apparatus at booster compressor stations in the conditions of northern gas fields]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.36.

International Energy Agency. 1995. *Energy Policies of the Russian Federation : 1995 Survey.* Paris, OECD.

International Gas Report. 1986a. Soviet Union. *International Gas Report*, April, p.148.

International Gas Report. 1986b. Giant gas field starts up. *International Gas Report*, November, p.416.

International Gas Report. 1987. Soviet Union. *International Gas Report*, April, p.148.

International Gas Report. 1988a. Soviet Union. *International Gas Report*, August, p.277.

International Gas Report. 1988b. Fire at Yamburg gasfield. *International Gas Report*, October, p.334.

International Gas Report. 1990. Soviet Union. *International Gas Report*, September, p.44.

Istomin, V.A. & V.S.Yakushev. 1996. Gas hydrates in Russia : meeting the challenge. In: *Gas in the CIS. A Special Report.* London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.56-58.

Ivanov, V. & B.L'vov. 1983. *Gazoprovod Urengoy - Uzhgorod* [The Urengoy - Uzhgorod Gas Pipeline]. Moscow, "*Planeta*".

Ivanova, T.F., K.A.Kondrat'yeva, S.Ye.Sukhodol'skiy. 1985. *Spetsial'noye geokriologicheskoye rayonirovaniye Yevropeyskogo severo-vostoka* [Special geocryological regionalization of the European north-east]. In: Sukhodol'skiy, S.Ye & M.M.Koreysha (eds.). *Regional'nyye Geokriologicheskiye Issledovaniya (Sbornik Nauchnykh Trudov)* [Regional Geocryological Research (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.11-20.

Ivantsov, O.M. 1987. *Vzyat' v soyuzniki vechnuyu merzlotu* [Make permafrost an ally]. *Stroitel'stvo Truboprovodov*, No.6, p.12-16.

Ivantsov, O.M. 1988. *Ekologiya i praktika* [Ecology and practice]. *Stroitel'stvo Truboprovodov*, No.7, July, p.28-32.

Ivantsov, O.M. 1993. Reliability of northern gas pipelines. *Oil & Gas Russia, Central Asia and the Caucasus*, Vol.2, No.1, p.51-58.

Ivantsov, O.M. 1995. Personal communications with Professor Oleg Maksimovich Ivantsov, Head of Scientific-Technical Council, *AO Rosneftegazstroy*, Moscow. Held in Moscow, 13th December 1995.

Ivantsov, O.M. 1996a. Personal communications with Professor Oleg Maksimovich Ivantsov, Head of the Scientific-Technical Council, *AO Rosneftegazstroy*, Moscow. Held in Moscow, 31st May 1996.

Ivantsov, O.M. 1996b. Reliability and safety of gas transport systems. In: *The 4th International Conference on the Distribution of Oil & Gas in the Former Soviet Union. Pipeline Transmission Systems, 25th to 26th April 1996, Moscow*. Documentation. London, Adam Smith Institute.

Ivantsov, O.M. 1997a. The reliability and ecological safety of Russia's main pipelines. In: *Oil & Gas Pipeline Projects in Russia & the CIS*. Documentation. 13th to 14th February 1997, Moscow. London, IBC UK Conferences Ltd.

Ivantsov, O.M. 1997b. Reliability on the Yamal - Europe gas pipeline network. In: *The 1997 International Conference on Oil & Gas Pipelines in the Former Soviet Union*. Documentation. 26th to 27th February 1997, Vienna. London, Adam Smith Institute.

Ivantsov, O.M. 1998. Technical problems on new pipeline projects. In: *The 1998 International Conference on Oil & Gas Pipelines in Russia and CIS Republics, 5th to 6th March 1998, Vienna*. Documentation. London, Adam Smith Institute.

Ivantsov, O.M. & L.P.Klyuchnikova. 1985. *Nauchno-tekhnicheskomu progressu - vysokiye tempy* [For scientific-technical progress - high rates]. *Stroitel'stvo Truboprovodov*, No.6, p.8-11.

Ivantsov, O.M. & V.V.Kharionovskiy. 1993a. *Arctic Gas Pipelines in Russia*. Moscow, *Neftegazstroyinformreklama*.

Ivantsov, O.M. & V.V.Kharionovskiy. 1993b. *Predlozheniya po sooruzheniyu gazoprovodov na Yamale* [Proposals for construction of gas pipelines on Yamal]. *Stroitel'stvo Truboprovodov*, No.2, p.24-28.

Ivlev, A.Yu. *et al.* 1989. *Kharakteristika izmeneniy geokriologicheskikh usloviy na osnove obobshcheniya opyta khozyaystvennogo osvoyeniya* [Characteristics of changes of geocryological conditions based on a generalization of the experience of economic development]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.397-407.

Izak, L.L. 1995. *Gazoprovod "Yamal-Yevropa". Razrabotka tekhniko-ekonomicheskogo obosnovaniya* [The "Yamal-Europe" gas pipeline. Development of the technical-economic feasibility study]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.15-16.

Kakunov, N.B. 1994. *Merzlotno-gidrogeologicheskiye usloviya Vorkutskogo geologo-promyshlennogo rayona* [Permafrost-hydrogeological conditions of the Vorkuta geological-industrial district]. In: Dedeyev, V.A. & Yu.V.Stepanov (eds.). *Vorkutskiy Uglenosniy Geologo-Promyshlenniy Rayon* [The Vorkuta Coal-Bearing Geological-Industrial District]. Syktyvkar, *RAN*, Urals Branch, Komi Science Centre, Institute of Geology, p.121-138.

Kalinina, A.A. 1995. Personal communications with Al'bina Aleksandrovna Kalinina, senior research fellow, Institute of Energy, Komi Science Centre, Urals Branch, RAS. Held in Syktyvkar, 30th November 1995.

Kalyavin, V.V. 1990. *Otrabotka tekhnicheskikh resheniy gazoprovodnykh konstruktsiy na poligone kraynego severa* [Development of technical solutions for gas pipeline structures at a test site in the far north]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.138-144.

Kanaykin, V.A. 1996. *Analiz prichin razryva trub MG* [Analysis of causes of the rupture of trunk gas pipeline pipes]. *Gazovaya Promyshlennost'*, No.11-12, p.28-29.

Kaplyanskaya, F.A. 1982. *Plastovyye zalezhi podzemnykh l'dov v lednikovykh otlozheniyakh na zapadnom poberezh'ye p-ova Yamal i pos. Kharasavey* [Massive beds of buried ice in glacial sediments on the west coast of the Yamal Peninsula and Kharasavey settlement]. In: Popov, A.I. (ed.). *Plastovyye L'dy Kriolitozony* (Massive Ice of the Cryolithozone). Yakutsk, *Akademiya Nauk SSSR*, p.71-80.

Kaznacheyeva, I.A. *et al.* 1988. *Malo-Bol'shezemel'skiy region* [The Malo-Bol'shezemel'skiy region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Yevropeyskaya Territoriya SSSR* [Geocryology of the USSR. European Territory of the USSR]. Moscow, "*Nedra*", p.275-301.

Khafizov, R.M. 1993. *Analiz konstruktivnykh resheniy vmorozhivayemykh ankerov i tekhnologii ikh pogruzheniya v vechnomerzlyye grunty s zasolennost'yu meneye 0.25%* [Analysis of structural solutions for frozen-in anchors and technology for submerging them in perennially frozen soils with a salinity of less than 0.25%]. *Stroitel'stvo Truboprovodov*, No.7, p.28-32.

Khafizov, R.M., S.S.Il'yasov & V.P.Pomazanov. 1993. *Izmeneniye nesushchey sposobnosti vmorazhivayemykh ankerov v zasolennom grunte pri povtornykh ispytaniyakh* [The change of the supporting capacity of frozen-in anchors in saline soil during repeated tests]. *Stroitel'stvo Truboprovodov*, No.5, p.32-35

Khafizov, R.M. *et al.* 1993a. *Rezultaty ispytaniy vmorazhivayemykh ankerov pri maksimal'noy sezonnoy temperature vechnomerzlogo zasolennogo grunta* [Results of tests of frozen-in anchors in the presence of the maximum seasonal temperature of permanently-frozen saline soil]. *Stroitel'stvo Truboprovodov*, No.4, p.13-16.

Khafizov, R.M. *et al.* 1993b. *Rezultaty ispytaniy opusknykh ankerov v vechnomerzlom zasolennom grunte* [Results of tests of movable anchors in permanently-frozen saline soil]. *Stroitel'stvo Truboprovodov*, No.8, p.31-34.

Khanzhenkov, V.A. & I.I.Yasin. 1988. *Uspekh internatsional'noy stroyki* [Success of the international construction project]. *Stroitel'stvo Truboprovodov*, No.9, p.4.

Kharionovskiy, V.V. 1991. *Nauchnoye obespecheniye konstruktivnykh resheniy gazoprovodov kraynego severa* [Scientific substantiation of structural solutions for gas pipelines of the far north]. In: *Problemy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Problems of Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.3-12.

Kharionovskiy, V.V. 1993. *Poligonnyye issledovaniya truboprovodov kraynego severa* [Test site research of pipelines in the far north]. *Stroitel'stvo Truboprovodov*, No.1, p.30-35.

Kharionovskiy, V.V. 1994. Distinguishing features of pipeline construction in Arctic regions. In: *Proceedings of Polartech '94. International Conference on the Development & Commercial Utilization of Technologies in Polar Regions*. 22nd to 25th March 1994, Luleå, Sweden. Luleå, Coldtech & Luleå University of Technology, p.504-520.

Kharionovskiy, V.V. 1996a. Problems of service life in the construction of gas pipelines. In: *The 4th International Conference on the Distribution of Oil & Gas in the Former Soviet Union. Pipeline Transmission Systems, 25th to 26th April 1996, Moscow*. Documentation. London, Adam Smith Institute.

Kharionovskiy, V.V. 1996b. Gas transport in Russia: reliability and failures. A section of the Gazprom sponsored supplement "The Russian Gas Industry". In: *Energy in the Former Soviet Union Yearbook 1996*. London, Petroleum Economist Ltd. and *Rosneftegazstroy*, p.i-x.

Kharionovskiy, V.V. *et al.* 1982. *Opredeleniye nesushchey sposobnosti nadzemnogo gazoprovoda na naledeopasnykh uchastkov* [Determining the supporting capacity of a raised gas pipeline on icing-prone sections]. *Stroitel'stvo Truboprovodov*, No.6, p.28-29.

Kharionovskiy, V.V. & A.B.Tsymbal. 1990. *Raschet truboprovodov pri moroznom rastreskivanii gruntov* [Pipeline calculations for thermal-contraction cracking of soils]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.50-58.

Kharionovskiy, V.V. & A.N.Shilin. 1993. *Naturnyye ispytaniya svay dlya truboprovodov v merzlykh gruntakh* [Field studies of piles for pipelines in frozen soils]. *Stroitel'stvo Truboprovodov*, No.5, p.23-25.

Kharionovskiy, V.V. & S.V.Vinogradov. 1993. *Opyt sooruzheniya i issledovaniy nadzemnykh gazoprovodov kraynego severa* [Experience of constructing and research of above-ground gas pipelines in the far north]. *Stroitel'stvo Truboprovodov*, No.4, p.10-12.

Kharionovskiy, V.V., V.M.Botov & I.N.Kurganova. 1993. *Novyy podkhod k otsenke kriteriyev ekspluatatsionnoy nadezhnosti magistral'nykh gazoprovodov* [A new approach to estimating the criteria of operational stability of trunk gas pipelines]. In: *Voprosy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Questions of the Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz*, p.17-21.

Kharionovskiy, V.V. *et al.* 1997. *Metodicheskiye Rekomendatsii Po Raschetam Konstruktivnoy Nadezhnosti Magistral'nykh Gazoprovodov* [Methodological Recommendations for Calculating the Structural Reliability of Trunk Gas Pipelines]. RD 51-4.2.-003-97. Moscow, *RAO Gazprom*, "Highly Reliable Pipeline Transport" Association, *VNIIgaz* and *IRTs Gazprom*.

Khoroshikh, A.V., I.A.Dolgov & N.I.Orlyanitskiy. 1996. *Diagnosticheskoye obsledovaniye magistral'nogo gazoprovoda diametrom 1420 mm snaryadom-defektoskopom "ul'traskan" na predpriyatii "Tyumentransgaz"* [Diagnostic inspection of a 1420 mm diameter trunk gas pipeline using "ultrascan" inspection equipment in the enterprise "*Tyumentransgaz*"]. In: *6th International Business Meeting "Diagnostics-96" (papers and reports).* Yalta, April 1996. Moscow, *RAO Gazprom, DAO Orgenergogaz & IRTs Gazprom*, p.85-90.

Khrenov, N.N. 1998. Personal communications with Nikolay Nikolayevich Khrenov, Gubkin State Oil & Gas Academy and Director of "Ekotekh". Held in Moscow, 26th March to 17th April 1998.

Khrenov, N.N. & S.A.Yegurtsov. 1996. *Primeneniye Aerokosmicheskikh Metodov dlya Diagnostiki Truboprovodnykh Geotekhnicheskikh Sistem i Monitoringa Okruzhayushchey Sredy* [The Use of Air and Space Methods for Diagnostics of Pipeline Geotechnical Systems and Environmental Monitoring]. Moscow, *RAO Gazprom & IRTs Gazprom.*

Khrenov, N.N. & S.A.Yegurtsov. 1997. Air and space monitoring of gas pipelines in western Siberia. In: *Gas in the CIS and Eastern Europe*. London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.67-68.

Klyuk, B.A., V.M.Stoyakov & G.N.Timerbulatov. 1994. *Prochnost' i Remont Uchastkov Magistral'nykh Truboprovodov v Zapadnoy Sibiri* [Strength and Repair of Sections of Trunk Pipelines in West Siberia]. Moscow, "*Mashinostroyeniye*".

Klyusov, V.A. & A.A.Yershov. 1995. *Opyt raboty tekhnologicheskogo oborudovaniya sistem podgotovki gaza na Yamburgskom gazokondensatnom mestorozhdenii* [Experience of operation of technological equipment of gas processing systems at the Yamburg gas-condensate field]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.31-32.

Kondrat'yev, S.D. 1998. Personal communications with Sergey Dmitriyevich Kondrat'yev, member of Permafrost Scientific-Research Laboratory, Centre for Scientific-Research Production Work, *Yamburggazdobycha*. Held in Yamburg settlement, 9th April 1998.

Kononova, R.S. *et al.* 1971. *Kriopegi - otritsatel'notemperaturnyye vody zemli* [Cryopegs - negative temperature waters of the earth]. *Merzlotnyye Issledovaniya*, No.XI, p.75-88.

Konstantinov, S.A. 1990. *Geokriologicheskiye usloviya opytno-promyshlennogo poligona "Yamal"* [Geocryological conditions of the "Yamal" experimental-industrial test site]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.103-112.

Konstantinov, S.A. 1991. *Verkhniy gorizont merzlykh porod v rayone opytno-promyshlennogo uchastka gazoprovoda na yuge Poluostrova Gydan* [The upper horizon of frozen soils in the region of the experimental-industrial section of a gas pipeline in the south of the Gydan Peninsula]. In: *Problemy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Problems of Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.43-51.

Konvissar, G.P., O.S.Zuyev & G.A.Antipov. 1997. *Reglament Vypolneniya Ekologicheskikh Trebovaniy Pri Razmeshchenii, Proyektirovanii, Stroitel'stve i Ekspluatatsii Podvodnykh Perekhodov Magistral'nykh Gazoprovodov* [Regulations for Fulfilment of Ecological Requirements in the Siting, Planning, Construction and Operation of Trunk Gas Pipeline Underwater Crossings]. RD 51-2-95. Moscow, *RAO Gazprom*, Gas Industry Ecological-Analytical Centre and *IRTs Gazprom*.

Koreysha, M.M. *et al.* 1982. *Plastovyye kompleksy podzemnykh l'dov oz. Neyto (p-ov Yamal)* [Massive complexes of buried ice near Lake Neyto (Yamal Peninsula)]. In: Popov, A.I. (ed.). *Plastovyye L'dy Kriolitozony* (Massive Ice of the Cryolithozone). Yakutsk, *Akademiya Nauk SSSR*, p.42-51.

Koreysha, M.M., A.N.Khimenkov & G.S.Bryksina. 1983. *Usloviya zaleganiya i stroyeniye plastovykh zalezhey podzemnogo l'da rayona oz. Neyto (p-ov Yamal)* [Conditions of bedding and structure of massive beds of buried ice in the region of Lake Neyto (Yamal Peninsula)]. In: *Voprosy Regional'noy i Inzhenernoy Geokriologii (Sbornik Nauchnykh Trudov)* [Questions of Regional and Engineering Geocryology (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.73-88.

Kostina, N. 1998. *Novyy niti gazovogo polotna* [New threads of the gas web]. *Region*, No.5 (12), p.9-10.

Kovalenko, M.P. 1992. *Gazovaya promyshlennost' Ukrainy : sovremennyye prioritety razvitiya* [The Ukrainian gas industry : current development priorities]. *Gazovaya Promyshlennost'*, No.12, p.2-3.

Krasulin, I.D., A.S.Gekhman & S.G.Stepanova. 1989. *Chtoby sokhranit' prirodu kraynego severa i sozdat' nadezhnyye truboprovody (naturnyye issledovaniya na Yamale)* [To protect the nature of the far north and to develop reliable pipelines (field studies on Yamal)]. *Stroitel'stvo Truboprovodov*, No.8, p.20-23.

Krayzel'man, A.M. 1988. *Vazhneyshiye stroyki tret'ego goda pyatiletki* [The most important construction projects of the third year of the Five-Year Plan]. *Stroitel'stvo Truboprovodov*, No.1, p.1-4.

Krayzel'man, A.M. & L.P.Klyuchnikova. 1985. *Yamburg - perspektivy i problemy* [Yamburg - perspectives and problems]. *Stroitel'stvo Truboprovodov*, No.1, p.6-8.

Kritsuk, L.N. 1983. *Osobennosti formirovaniya geokriologicheskikh usloviy* [Peculiarities of the formation of geocryological conditions]. In: Mel'nikov, Ye.S. (ed.). *Geokriologicheskiye Usloviya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Conditions of the West Siberian Gas-Bearing Province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.85-140.

Krylov, G.V. *et al.* 1990. *Gazotransportnyye Magistrali Zapadnoy Sibiri* [Gas Transport Mainlines of West Siberia]. Moscow, "*Nedra*".

Krylov, S., N.Bobrov & M.-K. Seguin. 1997. *Application des méthodes électromagnétiques à la délimitation du pergélisol salin dans la Péninsule de Yamal, secteur nord-ouest de la Sibérie* [Application of electromagnetic methods in delimiting saline permafrost on the Yamal Peninsula, northwestern sector of Siberia]. *Permafrost & Periglacial Processes*, Vol.8, p.133-145.

Kryukov, V. & A.Moe. 1996. *Gazprom. Internal Structure, Management Principles and Financial Flows*. London, Royal Institute of International Affairs.

Kryukova, L.P. 1983. *Obespechit' dosrochnyy vvod v deystviye eksportnogo gazoprovoda* [Guaranteeing the early commissioning of the export gas pipeline]. *Stroitel'stvo Truboprovodov*, No.4, p.8-11.

Kubanov, A.N. 1996. *Osobennosti ispol'zovaniya protsessa NTS dlya podgotovki k transportu "toshchikh" gazov mestorozhdeniy poluostrova Yamal* [Peculiarities of using the LTS process for preparing "lean" gas of Yamal Peninsula fields for transportation]. In: *Analiz Raboty Modernizirovannogo Oborudovaniya na Deystvuyushchikh Promyslakh i Ispol'zovaniye Sovremennykh Tekhnologiy i Oborudovaniya na Novykh Mestorozhdeniyakh Zapadno-Sibirskogo Regiona* [Analysis of Performance of Modernized Equipment at Active Fields and Using Current Technologies and Equipment for New Fields of the West Siberian Region]. Material of the Scientific-Technical Council of *RAO Gazprom*. Held in Saratov, October 1995. Moscow, *RAO Gazprom*, p.94-100.

Kubanov, A.N., V.A.Suleymanov & Ye.N.Turevskiy. 1994. *Analiz variantov podgotovki gaza Bovanenkovskogo GKM i usloviy ekspluatatsii gazoprovoda* [Analysis of variants for gas processing at the Bovanenkovskoye GCF and operational conditions of the gas pipeline]. *Gazovaya Promyshlennost'*, No.3, p.8-10.

Kulagin, V.P. 1993. *Ballastirovka gazoprovodov* [Ballasting of gas pipelines]. *Stroitel'stvo Truboprovodov*, No.7, p.26-28.

Kurbatov, N.I. & Gabelaya, R.D. 1990. Technology of pipeline construction on the Yamburg gas condensate field. In: *Polartech 90. International Conference on Development & Commercial Utilization of Technologies in Polar Regions*. 14th - 16th August 1990, Copenhagen, Denmark. Copenhagen, Danish Society for Arctic Technology, p.492-502.

Kuznetsova, Ye.G., I.B.Archegova & N.S.Kotelina. 1993. *Kharakteristika rastitel'nogo i pochvennogo prokrovov vdol' trassy gazoprovodov Yamal - Tsentr* [Characteristics of vegetation and soil covers along the route of the Yamal - Centre gas pipeline]. In: Mosunova, L.P. (ed.). *Gazoprovod Yamal - Tsentr : Prognoz Izmeneniy i Priyemy Vosstanovleniya Prirodnoy Sredy* [The Yamal - Centre Gas Pipeline : Forecast of Changes and Methods of Restoration of the Natural Environment]. Syktyvkar, *RAN*, Urals Branch, Komi Science Centre, p.24-35.

Kuznetsova, I.L. & V.P.Chernyad'yev. 1996. *Rayonirovaniye territori po stepeni riska razvitiya kriogennykh protsessov pri razmeshchenii inzhenernykh sooruzheniy (na primere Bovanenkovskogo mestorozhdeniya p-va Yamal)* [Regionalization of a territory according to the degree of risk of development of cryogenic processes in relation to the location of engineering structures (based on the example of the Bovanenkovskoye field, Yamal Peninsula)]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 1. Moscow, Moscow State University, p.381-388.

Lakhtina, O.V. *et al.* 1983. *O zasolennosti chetvertichnykh otlozheniy zapadnoy chasti poluostrova Yamal* [On the salinity of Quaternary sediments in the western part of the Yamal Peninsula]. In: *Voprosy Regional'noy i Inzhenernoy Geokriologii (Sbornik Nauchnykh Trudov)* [Questions of Regional and Engineering Geocryology (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.88-101.

Lanchakov, G.A. *et al.* 1995a. *Podvodnyye perekhody rek tundrovoy zony* [Underwater transits across rivers in the tundra zone]. *Gazovaya Promyshlennost'*, No.11, p.16-17.

Lanchakov, G.A. *et al.* 1995b. *Diagnostika mezhpromyslovogo kollektora v slozhnykh usloviyakh* [Diagnostics of a gathering line in complex conditions]. *Gazovaya Promyshlennost'*, No.12, p.53-54.

Lashin, V.V. 1997. Personal communications with Vladislav Viktorovich Lashin, Leading Engineer, Nadym Gas Production Administration, *Tyumentransgaz*. Held in Nadym, 12th to 13th March 1997.

Leibman, M.O. 1995. Cryogenic landslides on the Yamal Peninsula, Russia: preliminary observations. *Permafrost & Periglacial Processes*, Vol.6, p.259-264.

Levin, S.I. & Yu.F.Moryakov. 1969. Particulars of crossing the Yenisey River on the route of Messoyakha - Noril'sk gas pipeline. *Stroitel'stvo Truboprovodov*, No.1, p.12-14. Reprinted in English in: "*A Survey of Soviet Pipeline Construction Techniques and Related Activities in West Siberia*". ca.1970. Williams Brothers Co., p.113-118.

Levin, Ya.A. & V.V.Zelenov. 1983. *Okhlazhdeniye gaza transportiruyemogo iz severnykh mestorozhdeniy* [The cooling of gas transported from northern fields]. *Gazovaya Promyshlennost'*, No.2, p.10-12.

Loskutov, V.K. 1996. *Ekologicheskoye obespecheniye neftegazovogo stroitel'stva na etape gidrogeologicheskikh i geokriologicheskikh izyskaniy* [Ecological provision for oil and gas construction at the stage of hydrogeological and geocryological surveys]. *Stroitel'stvo Truboprovodov*, No.4-5, p.33-34.

Lur'ye, I.S. 1975. *Klimat* [Climate]. In: Trofimov, V.T. (ed.). *Poluostrov Yamal (Inzhenerno-Geologicheskiy Ocherk)* [The Yamal Peninsula (Engineering-Geological Sketch)]. Moscow, Moscow University Press, p.17-20.

L'vov, B.L. 1986. *Trassy Cherez Meridiany* [Routes across the Meridians]. Moscow, "*Mysl'*".

Makogon, Yu.F. 1994. Russia's contribution to the study of gas hydrates. In: Dendy Sloan, Jr., E., J.Happel & A.Hnatow (eds.). *International Conference on Natural Gas Hydrates*. Annals of the New York Academy of Sciences, Vol.715. New York, The New York Academy of Sciences.

Malkova, G.V. 1997. *Ekzodinamicheskiye protsessy na stroyashcheysya trasse zheleznoy dorogi "Obskaya - Bovanenkovo"* [Exodynamic processes on the route of the railway "Obskaya - Bovanenkovo" currently under construction]. *Izvestiya Russkogo Geograficheskogo Obshchestva*, Vol.129, No.5, p.55-59.

Mal'tsev, V.S. & V.I.Rogatin. 1996. *Podvodnyy perekhod gazoprovoda cherez Severnuyu Dvinu* [Underwater gas pipeline transit across the Severnaya Dvina]. *Stroitel'stvo Truboprovodov*, No.3, p.14-16.

Manov, N.A. & A.A.Kalinina. (eds.) 1996. *Energeticheskaya Strategiya Respubliki Komi (Osnovnyye Napravleniya Razvitiya Sistem Elektro-, Teplo- i Toplivosnabzheniya)* [Energy Strategy of the Komi Republic (Main Development Trends of Electricty, Heat and Fuel Supply)]. Syktyvkar, Komi Science Centre, Urals Branch, RAS.

Mazur, I.I. 1989. *Puti resheniya ekologicheskikh i sotsial'nykh voprosov Yamala* [Ways of solving the ecological and social problems of Yamal]. *Stroitel'stvo Truboprovodov*, No.6, p.7-10.

Mazur, I.I. 1993. Learning to respect the Arctic. *Oil & Gas Russia, Central Asia and the Caucasus*, Vol.2, No.2, p.11-16.

Mazur, I.I. 1996. Russian oil and gas pipelines - reliability and environmental impact. In: *Energy in the Former Soviet Union Yearbook 1996*. London, Petroleum Economist Ltd. and *AO Rosneftegazstroy*, p.102-105.

Mel'nikov, P.I. & A.V.Pavlov. 1982. Study of permafrost in the USSR: scientific and practical problems. *Cold Regions Science and Technology*, Vol.6, No.2, p.163-171.

Mel'nikov, Ye.S. 1995. Personal communications with Yevgeniy Sergeyevich Mel'nikov, Head of the Moscow Branch of the Institute of the Earth's Cryosphere, RAS. Held in Moscow, 13th August 1995.

Mel'nikov, Ye.S. & A.V.Pavlov. 1994. Experience of preliminary engineering-geocryological investigations in the oil and gas bearing regions in the north of Russia. In: Smith, D.W. & D.C.Sego (eds.). *Proceedings of the 7th International Cold Regions Engineering Specialty Conference*, March 7th to 9th, 1994, Edmonton, Alberta. Montreal, Canadian Society for Civil Engineering, p.793-799.

Mel'nikov, V.P. & V.I.Spesivtsev. 1995. *Inzhenerno-Geologicheskiye i Geokriologicheskiye Usloviya Shel'fa Barentseva i Karskogo Morey* [Engineering-Geological and Geocryological Conditions of the shelf of the Barents and Kara Seas]. Novosibirsk, "*Nauka*".

Mikhailov, N.V. 1996. Developing the Yamal gasfields. In: *Gas in the CIS. A Special Report.* London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.40.

Mirenburg, Yu.S. & O.M.Yanchenko. 1993. Discussion of SNiP 2.02.04-88 Norm "Bases and Foundations on Permafrost Soils". *Osnovaniya, Fundamenty i Mekhanika Gruntov*, No.2, March-April, p.30-32. English translation.

Miroshnichenko, A.V. 1998. E-Mail communication with Anatoliy V.Miroshnichenko, First Deputy Director of JSC *YuzhNIIgiprogaz*, Donetsk, Ukraine. 19th February 1998.

Mitsenmakher, V.M. 1983. *Osnovnyye proyektnyye resheniya magistral'nogo gazoprovoda Urengoy - Uzhgorod* [The main project solutions for the Urengoy - Uzhgorod trunk gas pipeline]. *Stroitel'stvo Truboprovodov*, No.1, p.5-7.

Moscow News. 1998. Gazprom's new project. *Moscow News*, No.25 (3829), July 2 - 8, p.7.

Moskalenko, N.G. 1996. *Vliyaniye prokladki gazoprovodov na geosystemy kriolitozony zapadnoy sibiri*. [Influence of laying gas pipelines upon geosystems of the West Siberian cryolithozone]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 2. Moscow, Moscow State University, p.399-407.

Moskalenko, N.G. 1997. *Prognoz dinamiki kriogennykh geosistem severotayezhnoy zony Zapadnoy Sibiri* [Forecasting the dynamics of cryogenic geosystems of the northern taiga zone of West Siberia]. In: Mel'nikov, Ye.S. (ed.). *Itogi Fundamental'nykh Issledovaniy Kriosfery Zemli v Arktike i Subarktike. Materialy Mezhdunarodnoy Konferentsii, Pushchino, 23 - 26 Aprelya 1996 g. Sbornik Nauchnykh Trudov* [Results of Fundamental Research of the Earth's Cryosphere in the Arctic and Sub-Arctic. Documentation of the International Conference, Pushchino, 23 - 26 April 1996. Collection of Research Papers]. Novosibirsk, "*Nauka*", Siberian Branch of RAS, p.88-94.

National Energy Board of Canada. 1996. *Public Inquiry Concerning Stress Corrosion Cracking on Canadian Oil and Gas Pipelines*. Report of the Inquiry No.MH-2-95. National Energy Board of Canada.

Nefte Compass. 1997. Gazprom strikes deal to fund Polish leg of Yamal Gasline. *Nefte Compass*, June 5th, Vol.6, No.23, p.12.

Nefte Compass. 1998. Gas leak. *Nefte Compass*, 5th February, Vol.7, No.6, p.9.

Nevecherya, V.L. 1983a. *Prognoz kriogennogo pucheniya pri sezonnom promerzanii gruntov* [Forecasting of cryogenic heaving with the seasonal freezing of soils]. In: Grechishchev, S.Ye. (ed.). *Geokriologicheskiy Prognoz Dlya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Forecasting for the West Siberian Gas-Bearing Province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.130-142

Nevecherya, V.L. 1983b. *Kriogennoye pucheniye gruntov* [Cryogenic heaving of soils]. In: Mel'nikov, Ye.S. (ed.). *Geokriologicheskiye Usloviya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Conditions of the West Siberian Gas-Bearing Province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.155-170.

Nevecherya, V.L. 1983c. *Naledeobrazovaniye* [Icing development]. In: Mel'nikov, Ye.S. (ed.). *Geokriologicheskiye Usloviya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Conditions of the West Siberian Gas-Bearing province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.179.

Nezavisimaya Gazeta. 1998. *Zimnyaya gazovaya politika* [Winter gas policy]. *Nezavisimaya Gazeta*, Tuesday 17th February 1998, No.26 (1597), p.4.

NN&R. 1994. The Republic of Komi. Komi Energy Plan. Identification Report - Volume 1. Draft. Nellemann, Nielsen & Rauschenbeger A/S.

Oberman, N.G. & V.Ye.Borozinets. 1988. *Ural* [The Urals]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Yevropeyskaya Territoriya SSSR* [Geocryology of the USSR. European Territory of the USSR]. Moscow, "*Nedra*", p.301-324.

Odishariya, G.E. 1996. Personal communications with Guram Erastovich Odishariya, Senior Member, *VNIIgaz*, Moscow. Held in Moscow, 3rd April and 23rd May 1996.

Oil & Gas Journal. 1985a. USSR plans major gas pipeline extension. *Oil & Gas Journal*, Vol.83, No.13, p.46.

Oil & Gas Journal. 1985b. Transportation. International Briefs. *Oil & Gas Journal*, Vol.83, No.34, p.52.

Oil & Gas Journal. 1997. Wingas starts work on Yamal gas link. *Oil & Gas Journal*, August 25th, Vol.95, No.34, p.36.

Orlyanskiy, V.V. 1985. *Kriogalinnyye vody (kriopegi) na poberezh'yakh Karskogo i Pechorskogo morey* [Cryosaline waters (cryopegs) on the coasts of the Kara and Pechora seas]. In: Anisimova, N.P. (ed.). *Kriogidrogeologicheskiye Issledovaniya* [Cryohydrogeological Investigations]. Yakutsk, Institute of Permafrost Studies, *SO AN SSSR*, p.24-34.

Orudzhev, S.A. 1981. *Goluboye Zoloto Zapadnoy Sibiri* [Blue Gold of West Siberia]. Moscow, "*Nedra*".

Osokin, A. 1997. Personal communications with Alexey Osokin, Department of Engineering-Ecological Monitoring, Laboratory of Ecological Monitoring, Scientific-Technical Centre, *Nadymgazprom*, Nadym. Held in Nadym, 10th to 17th March.

Oswell, J.M. *et al.* 1995. A comparison of CIS and ASTM soil classification systems. In: *Preprint of Proceedings of 48th Canadian Geotechnical Conference, September 1995, Vancouver, Canada*, p.573-581.

Ott, K.F. 1993. *Stress-korrozionnaya povrezhdayemost' gazoprovodnykh trub* [Susceptiblity of gas pipeline pipes to stress-corrosion]. *Gazovaya Promyshlennost'*, No.1, p.20-22.

Ott, K.F. 1997. Personal communications with Dr.Karl Fridrikhovich Ott, Head of the Technical Department, *DP Tyumentransgaz*, Yugorsk, Khanty-Mansiyskiy AO. Held in Oxford, 18th July 1997.

Ott, K.F., Yu.P.Surkov & V.G.Rybalko. 1992. Some features of the operational failure of pipe steels. *The Physics of Metals and Metallography*, Vol.73, No.5, p.523-526.

Palmer, A.C. 1997. Personal communications with Andrew Palmer, professor of Petroleum Engineering, University of Cambridge. Held in Cambridge, September 1997.

Parmuzin, O.Yu. 1980. Cryogenic texture and some characteristics of ice formation in the active layer. *Polar Geography & Geology*, Vol.4, No.3, July-September, p.131-152. [Translation of an article in: *Problemy Kriolitologii*, 1978, No.7, p.141-164.]

Parmuzin, S.Yu. & S.Ye.Sukhodol'skiy. 1982. *Plastovyye l'dy srednego Yamala i ikh rol' v formirovanii rel'yefa* (Massive ice in middle Yamal and its role in the formation of relief). In: Popov, A.I. (ed.). *Plastovyye L'dy Kriolitozony* (Massive Ice of the Cryolithozone). Yakutsk, *Akademiya Nauk SSSR*, p.51-61.

Parmuzin, S.Yu. & S.Ye.Sukhodol'skiy. 1983. *Morfologicheskiye osobennosti krupnykh zalezhey podzemnykh l'dov srednego Yamala* [Morphological peculiarities of large beds of buried ice in middle Yamal]. In: *Voprosy Regional'noy i Inzhenernoy Geokriologii (Sbornik Nauchnykh Trudov)* [Questions of Regional and Engineering Geocryology (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.38-52.

Paton, B.Ye. & O.M.Ivantsov. 1993. *Novoye v stroitel'stve i povyshenii nadezhnosti magistral'nykh gazoprovodov* [News on the construction and increase of reliability of mainline gas pipelines]. *Stroitel'stvo Truboprovodov*, No.7, p.4-8.

Peters, V.Ya. 1998. Personal communications with Valeriy Yakovlevich Peters, Head of Gas Processing Plant UKPG-1V, *Yamburggazdobycha*. Held in Yamburg, 8th April 1998.

Pétrole Informations. 1987. Gas cooling stations in Siberia. *Pétrole Informations*, No.1638, October, p.82-83.

Petroleum Economist. 1982. Untitled. *Petroleum Economist*, Vol.49, No.10, October, p.431.

Petroleum Economist. 1990. Pipelines in disrepair. *Petroleum Economist*, Vol.57, No.3, p.76.

Petroleum Economist. 1996a. Reporting Russia's gas industry. *Petroleum Economist*, Vol.63, No.5, p.64-78.

Petroleum Economist. 1996b. Gas in the Stalin era. *Petroleum Economist*, Vol.63, No.9, p.31-34.

Petroleum Economist. 1998a. Statistics. In: *Energy in the CIS & Eastern Europe*. London, *Petroleum Economist* & *Rosneftegazstroy* (RNGS), p.136-142.

Petroleum Economist. 1998b. World oil and gas production. *Petroleum Economist*, June, Vol.65, No.6, p.130.

Pipe Line Industry. 1986. Sharp decline in Soviet pipe line construction under new 5-year plan. *Pipe Line Industry*, Vol.64, No.4, p.56-60.

Pipeline & Gas Industry. 1995a. Staff Report. Construction to start on dual lines across NW Siberian bay. *Pipeline & Gas Industry*, Vol.78, No.1, p.57-62.

Pipeline & Gas Industry. 1995b. Western firm translates FSU pipe line codes to English. *Pipeline & Gas Industry*, Vol.78, No.7, p.51.

Platov, N.A., B.T.Trofimov & I.G.Korobanova. 1985. *Inzhenerno-geologicheskaya kharakteristika solifluktsionnykh gruntov (p-ov Yamal)* [Engineering-geological characteristics of solifluction soils (Yamal Peninsula)]. In: Sukhodol'skiy, S.Ye. & M.M.Koreysha (eds.). *Regional'nyye Geokriologicheskiye Issledovaniya (Sbornik Nauchnykh Trudov)* [Regional Geocryological Research (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.40-48.

Podkol'zin, V.P. 1990. *Naturnyye issledovaniya temperaturnykh poley merzlykh gruntov u svay na opytno-promyshlennom uchastke* [Field studies of temperature fields of frozen soils around the piles of the experimental-industrial section]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.155-158.

Paton, B.Ye. & O.M.Ivantsov. 1993. *Novoye v stroitel'stve i povyshenii nadezhnosti magistral'nykh gazoprovodov* [News on the construction and increase of reliability of mainline gas pipelines]. *Stroitel'stvo Truboprovodov*, No.7, p.4-8.

Peters, V.Ya. 1998. Personal communications with Valeriy Yakovlevich Peters, Head of Gas Processing Plant UKPG-1V, *Yamburggazdobycha*. Held in Yamburg, 8th April 1998.

Pétrole Informations. 1987. Gas cooling stations in Siberia. *Pétrole Informations*, No.1638, October, p.82-83.

Petroleum Economist. 1982. Untitled. *Petroleum Economist*, Vol.49, No.10, October, p.431.

Petroleum Economist. 1990. Pipelines in disrepair. *Petroleum Economist*, Vol.57, No.3, p.76.

Petroleum Economist. 1996a. Reporting Russia's gas industry. *Petroleum Economist*, Vol.63, No.5, p.64-78.

Petroleum Economist. 1996b. Gas in the Stalin era. *Petroleum Economist*, Vol.63, No.9, p.31-34.

Petroleum Economist. 1998a. Statistics. In: *Energy in the CIS & Eastern Europe*. London, *Petroleum Economist* & *Rosneftegazstroy* (RNGS), p.136-142.

Petroleum Economist. 1998b. World oil and gas production. *Petroleum Economist*, June, Vol.65, No.6, p.130.

Pipe Line Industry. 1986. Sharp decline in Soviet pipe line construction under new 5-year plan. *Pipe Line Industry*, Vol.64, No.4, p.56-60.

Pipeline & Gas Industry. 1995a. Staff Report. Construction to start on dual lines across NW Siberian bay. *Pipeline & Gas Industry*, Vol.78, No.1, p.57-62.

Pipeline & Gas Industry. 1995b. Western firm translates FSU pipe line codes to English. *Pipeline & Gas Industry*, Vol.78, No.7, p.51.

Platov, N.A., B.T.Trofimov & I.G.Korobanova. 1985. *Inzhenerno-geologicheskaya kharakteristika solifluktsionnykh gruntov (p-ov Yamal)* [Engineering-geological characteristics of solifluction soils (Yamal Peninsula)]. In: Sukhodol'skiy, S.Ye. & M.M.Koreysha (eds.). *Regional'nyye Geokriologicheskiye Issledovaniya (Sbornik Nauchnykh Trudov)* [Regional Geocryological Research (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.40-48.

Podkol'zin, V.P. 1990. *Naturnyye issledovaniya temperaturnykh poley merzlykh gruntov u svay na opytno-promyshlennom uchastke* [Field studies of temperature fields of frozen soils around the piles of the experimental-industrial section]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.155-158.

Podyuk, V. 1994. *Severgazpromu - 25 let : flagman gazovoy promyshlennosti Respubliki Komi* [To *Severgazprom* - 25 years old : leader of the gas industry of the Komi Republic]. *Neftyanik*, No.11-12, p.8-10.

Podyuk, V.G. 1996. *Severgazprom - opornaya baza otrasli* [*Severgazprom* - supporting base of the branch]. *Gazovaya Promyshlennost'*, No.9-10, p.44-47.

Polozov, A.Ye. 1996. *Korrozionnonaya aktivnost' gruntov p-ova Yamal* [Corrosional activity of the soils of the Yamal Peninsula]. *Stroitel'stvo Truboprovodov*, No.4-5, p.43-46.

Polozov, A.Ye., S.F.Sanzharovskaya & L.N.Voytsekhovskaya. 1988. *Korrozionnaya aktivnost' gruntov i prirodnykh vod Yamala* [Corrosional activity of the soils and natural waters of Yamal]. *Stroitel'stvo Truboprovodov*, No.2, p.20-21.

Potemkin, G.A. *et al.* 1997. *Vremennaya Instruktsiya po Tekhnologii i Organizatsii Pogruzochno-Razgruzochnykh Rabot, Skladirovaniyu i Transportirovke Izolirovannykh Trub Diametrom 1420-mm, Dlinoy 18.3-m* [Temporary Instrictions for Technology and Organization of Loading-Unloading Operations, Storage and Transportation of Insulated 1420-mm Diameter and 18.3-m Long Pipes]. Moscow, *RAO Gazprom* and *IRTs Gazprom.*

Prikhod'ko, Yu.N., Yu.V.Stepanov & V.A.Dedeyev. 1994. *Obshchiye svedeniya o Vorkutskom geologo-promyshlennom rayone* [General information on the Vorkuta geological-industrial district]. In: Dedeyev, V.A. & Yu.V.Stepanov (eds.). *Vorkutskiy Uglenosniy Geologo-Promyshlenniy Rayon* [The Vorkuta Coal-Bearing Geological-Industrial District]. Syktyvkar, *RAN*, Urals Branch, Komi Science Centre, Institute of Geology, p.6-24.

Pritula, V.V. & Tychkin, I.A. 1995. *Primeneniye izoliruyushchikh flantsev na gazoprovodakh Yamal-Zapad* [Using insulating flanges on the Yamal-West gas pipelines]. *Gazovaya Promyshlennost'*, No.3, p.17-18.

Proskurnina, O. 1997. Norilsk Nickel makes debt deal. *Moscow News*, No.42 (3794), October 23-29, p.8.

RAO Gazprom. 1997. *RAO Gazprom v Rossii i Mire* [RAO Gazprom in Russia and the World]. Moscow, *RAO Gazprom* and *IRTs Gazprom.*

Region. 1998. *Uchenyye spasayut Vuktyl* [The scholars are saving Vuktyl]. *Region*, No.5 (12), p.11-12.

Remizov, V.V. 1997. Gazprom's science and technology policy through 2015. In: *Gas in the CIS and Eastern Europe.* London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.13-14.

Remizov, V.V. *et al.* 1996. *Geologo-Tekhnicheskiye Printsipy Osvoyeniya Neftegazokondensatnykh Mestorozhdeniy Tyumenskogo Severa* [Geological-Technical Principles of Developing the Oil, Gas and Condensate Fields of the Tyumen North]. Moskva, *Nedra.*

Remizov, V.V. *et al.* 1997a. *Obespecheniye nadezhnoy ekspluatatsii mezhpromyslovogo kollektora na mnogoletnemerzlykh gruntov* [Guaranteeing the reliable operation of a gathering line in permafrost]. *Gazovaya Promyshlennost'*, No.8, p.21-26.

Remizov, V.V. *et al.* 1997b. *Tekhnogennyye pucheniye i osadka porod na trassakh severnykh truboprovodov : prakticheskiye rezultaty* [Technogenic frost heave and settlement of soils on the right-of-ways of northern pipelines : practical results]. *Gazovaya Promyshlennost'*, No.11, p.17-20.

Remizov, V.V. *et al.* 1998. *Diagnostika sostoyaniya gazotransportnykh sistem Kraynego Severa. Tekhnogeoekologicheskiy analiz sostoyaniya territoriy trass gazoprovodov* [Diagnostics of the condition of gas transportation systems in the Far North. Techno-geo-ecological analysis of the condition of territories of gas pipeline corridors]. *Gazovaya Promyshlennost' Na Rubezhe XXI Veka* [The Gas Industry at the Border of the 21st Century]. Moscow, *RAO Gazprom* and *IRTs Gazprom.*

Repalov, V.I. & V.V.Kharionovskiy. 1994. *Analiz nadezhnosti severnoy avtonomnoy sistemy gazosnabzheniya* [Analysis of the reliability of the northern autonomous gas supply system]. *Stroitel'stvo Truboprovodov*, No.5, p.27-30.

Rezunenko, V.I. 1996. Results of research on possibilities for reconstructing the Russian Unified Gas Supply System. In: *The 4th International Conference on the Distribution of Oil & Gas in the Former Soviet Union. Pipeline Transmission Systems.* Documentation. 25th to 26th April 1996, Moscow. London, Adam Smith Institute.

Rezunenko, V.I. 1997. New Gazprom projects will diversify Russian exports. In: *Gas in the CIS and Eastern Europe.* London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.15-16.

Rivkin, F.M. 1997. *Rezultaty issledovaniy emissii metana vdol' gazoprovoda Nadym - Punga* [Results of research into methane emissions along the Nadym - Punga gas pipeline]. In: Mel'nikov, Ye.S. (ed.). *Itogi Fundamental'nykh Issledovaniy Kriosfery Zemli v Arktike i Subarktike. Materialy Mezhdunarodnoy Konferentsii, Pushchino, 23 - 26 Aprelya 1996 g. Sbornik Nauchnykh Trudov* [Results of Fundamental Research of the Earth's Cryosphere in the Arctic and Sub-Arctic. Documentation of the International Conference, Pushchino, 23 - 26 April 1996. Collection of Research Papers]. Novosibirsk, "*Nauka*", Siberian Branch of RAS, p.165-168.

Romanovskiy, N.N., V.N.Konishchev & G.E.Rosenbaum. 1992. *Russian - English Glossary of Geocryology Terms.* IPA Permafrost Terminology Working Group. [No publisher given].

Safanov, V.S. *et al.* 1994a. *Predvaritel'naya otsenka riska ekspluatatsii gazotransportnoy sistemy "Yamal - Tsentr"* [Preliminary estimation of the risk of operating the "Yamal - Centre" gas transport system]. In: Belov, N.S. (ed.). *Osnovnyye Napravleniya v Reshenii Problemy Ekologicheskogo Riska Toplivno-Energeticheskogo Kompleksa* [Main Directions in Solving the Ecological Risk Problem of the Fuel-Energy Complex]. Moscow, *VNIIgaz*, p.171-183.

Safonov, V.S. *et al.* 1994b. *Kompleksnaya otsenka riska ekspluatatsii tekhnologicheskikh ob"yektov krupnogo gazokondensatnogo mestorozhdeniya v usloviyakh kraynego severa* [Complex risk assessment of technological installations of a large gas-condensate field in the conditions of the far north]. In: Belov, N.S. (ed.). *Osnovnyye Napravleniya v Reshenii Problemy Ekologicheskogo Riska Toplivno-Energeticheskogo Kompleksa* [Main Directions in Solving the Ecological Risk Problem of the Fuel-Energy Complex]. Moscow, *VNIIgaz*, p.184-206.

Sagers, M.J. 1991. Review of the Soviet gas industry in 1990. News Notes. *International Geology Review*, Vol.33, No.4, p.408-411.

Sagers, M.J. 1992. Review of natural gas industry of the Former Soviet Union in 1991. News Notes. *International Geology Review*, Vol.34, No.2, p.207-212.

Salikhov, Z.S. 1998. Personal communications with Zul'far Salikhovich Salikhov, Chief Engineer, *Yamburggazdobycha*. Held in Yamburg settlement, 9th April 1998.

Savkin, P.S. 1987. *Kakiye sistemy okhlazhdeniya sleduyet stroit' na kompressornykh stantsiyakh v severnykh rayonakh strany?* [Which cooling systems should be built at compressor stations in the northern regions of the country?]. *Stroitel'stvo Truboprovodov*, No.9, p.25-27.

Savkin, P.S. 1997. *Novyye sistemy okhlazhdeniya prirodnogo gaza* [New systems for cooling natural gas]. *Gazovaya Promyshlennost'*, No.2, p.27-28.

Seligman, B.J. 1994. *Zhidkoye Zoloto? Environmental Aspects of Natural Gas Transportation from the Sakha Republic*. Master of Philosophy thesis. University of Cambridge.

Seligman, B.J. 1996. *An Investigation of Gas and Oil Pipeline Construction and Operation in the Permafrost Regions of Russia*. Final Report submitted to Nippon Steel Corporation on November 30th 1996.

Severgazprom. 1994. *Severgazprom* [*Severgazprom*]. Ukhta, *Severgazprom*.

Shabad, T. 1984. Soviet Arctic oil and gas developments. News Notes. *Polar Geography & Geology*, Vol.8, No.4, p.352-359.

Shabad, T. 1986. Soviet Arctic gas developments. News Notes. *Polar Geography & Geology*, Vol.10, No.1, p.80-82.

Shabanov, P.P. 1985. *Skorostnyye metody sooruzheniya truboprovodonykh sistem iz Zapadnoy Sibiri* [High speed methods of constructing pipeline systems from West Siberia]. *Stroitel'stvo Truboprovodov*, No.1, p.14-15.

Sharapova, T.A. 1990. *Podzemnaya prokladka gazoprovoda v sil'nol'distykh gruntakh* [Underground laying of a gas pipeline in highly icy soils]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.112-121.

Shcherbina, B.Ye. *et al.* 1981. *Otechestvennyy Truboprovodnyy Transport* [Domestic Pipeline Transport]. Moscow, "*Nedra*".

Shcherenkova, O.A. 1995. *Analiz proizvodstvennoy deyatel'nosti DP "Severgazprom"* [Analysis of the production activity of DP "*Severgazprom*"]. *Gazovaya Promyshlennost'*, No.2, p.8-10.

Sheshin, Yu.B. & N.G.Ukraintseva. 1983. *Kriogennoye rastreskivaniye i rost povtorno-zhil'nykh l'dov* [Cryogenic cracking and the growth of recurring wedge ice]. In: Mel'nikov, Ye.S. (ed.). *Geokriologicheskiye Usloviya Zapadno-Sibirskoy Gazonosnoy Provintsii* [Geocryological Conditions of the West Siberian Gas-Bearing province]. Novosibirsk, "*Nauka*", *Sibirskoye Otdeleniye*, p.170-174.

Shinyayev, S.D. & V.I.Voronin. 1995. *Issledovaniye korrozii oborudovaniya na UKPG Yamburgskogo gazogo mestorozhdeniya* [Research into corrosion of equipment at gas processing plants of the Yamburg gas field]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.38-39.

Shiyatov, S.G. & V.S.Mazepa. 1995. *Klimat* [Climate]. In: Ponomareva, A.I. (ed.). *Priroda Yamala* [The Nature of Yamal]. Yekaterinburg, "*Nauka*", p.32-68.

Shmal', G.I. 1993. Piping down the valleys wild. *Oil & Gas Russia, Central Asia and the Caucasus*, Vol.2, No.3, p.12-16.

Shmal', G. 1996. Modern technologies and techniques for building pipeline systems. In: *The 4th International Conference on the Distribution of Oil & Gas in the Former Soviet Union. Pipeline Transmission Systems*. Documentation. 25th to 26th April 1996, Moscow. London, Adam Smith Institute.

Shmal', G. 1997a. Construction technology for new pipeline projects. In: *Oil & Gas Pipeline Projects in Russia & the CIS*. Documentation. 13th to 14th February 1997, Moscow. London, IBC UK Conferences Ltd.

Shmal', G. 1997b. Construction technologies for new pipeline projects. In: *The 1997 International Conference on Oil & Gas Pipelines in the Former Soviet Union*. Documentation. 26th to 27th February 1997, Vienna. London, Adam Smith Institute.

Shmal', G.I. 1998. Participation by Rosneftegazstroy in plans to build new generation main pipelines. In: *The 1998 International Conference on Oil & Gas Pipelines in Russia and CIS Republics, 5th to 6th March 1998, Vienna*. Documentation. London, Adam Smith Institute.

Shmal', G.I. & O.M.Ivantsov. 1994. *Nadezhnost' magistral'nykh nefteprovodov i gazoprovodov v Rossii* [Reliability of trunk oil pipelines and gas pipelines in Russia]. *Stroitel'stvo Truboprovodov*, No.1, p.6-14.

Skubitskaya, M.G. 1996. *Prognoz razvitiya ovrazhnoy erozii s uchetom merzlotno-gruntovykh usloviy Yamburgskogo mestorozhdeniya* [Forecasting the development of gully erosion taking into account permafrost-soil conditions of the Yamburg field]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 2. Moscow, Moscow State University, p.475-483.

Sonninskiy, A.V. 1990. *Opory nadzemnykh teploizolirovannykh gazoprovodov* [Supports of above-ground thermally insulated gas pipelines]. In: *Nadezhnost' Gazoprovodnykh Konstruktsiy* [Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.96-103.

Sonninskiy, A.V. & S.I.Levin. 1993. *Novaya konseptsiya na sooruzheniye podvodnykh perekhodov gazoprovodov cherez vodnyye pregrady* [New concepts for the construction of underwater gas pipeline transits across bodies of water]. In: *Voprosy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Questions of the Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz*, p.35-40.

Sonninskiy, A.V., S.I.Levin & I.N.Al'bov. 1993. *Truby dlya podvodnykh perekhodov magistral'nykh gazoprovodov, normativnyye trebovaniya k materialu i raschetam u nas i za rubezhom* [Pipes for underwater trunk gas pipeline transits. Normative requirements for material and calculations in Russia and abroad]. In: *Voprosy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Questions of the Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz*, p.52-54.

Spetsivtsev, V.I. 1996. *Singeneticheskiye plastovyye l'dy v pribrezhno-morskikh otlozheniyakh Baydaratskoy Guby* [Syngenetic massive ice in the coastal-marine sediments of Baydaratskaya Bay]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 1. Moscow, Moscow State University, p.279-282.

Spiridonov, A.I. (ed.). 1980. *Chetyrekh"yazychnyy Entsiklopedicheskiy Slovar' Terminov po Fizicheskoy Geografii* [Four Language Encyclopaedic Dictionary of Physical Geographical Terms]. Moscow, *Izdatel'stvo "Sovetskaya Entsiklopediya".*

Spiridonov, Yu.A. (ed.). 1995. *Respublika Komi* [Komi Republic]. Syktyvkar, Komi Republic Centre for Research into International and Inter-regional Socio-economic Problems, Komi Branch, Russian Geographical Association.

Stepanov, S. 1994a. *Samyy severnyy proyekt* [The northernmost project]. *Gazovaya Promyshlennost'*, No.1, p.2-5.

Stepanov, S. 1994b. Scientific approaches to corrosion control. In: *Gas in the Former Soviet Union. A Special Report*. London, Petroleum Economist Ltd. & *Gazovaya Promyshlennost'*, p.62-66.

Stern, J.P. 1993. *Oil and Gas in the Former Soviet Union : the Changing Foreign Investment Agenda*. Post-Soviet Business Forum. London, Royal Institute of International Affairs.

Stern, J.P. 1995. *The Russian Natural Gas 'Bubble'. Consequences for European Gas Markets*. London, Royal Institute of International Affairs Energy and Environment Programme.

Streletskaya, I.D. 1994. Formation, distribution and dynamics of cryopegs, and associated problems of construction north-west Yamal Peninsula, Russia. In: Smith, D.W. & D.C.Sego (eds.). *Proceedings of the 7th International Cold Regions Engineering Specialty Conference*, March 7th to 9th, 1994, Edmonton, Alberta. Montreal, Canadian Society for Civil Engineering, p.801-804.

Streletskaya, I.D., N.V.Ivanova & F.M.Rivkin. 1996. *Kartirovaniye territorii Bovanenkovskogo GKM po usloviyam rastprostraneniya kriopegov (poluostrov Yamal)* [Mapping conditions of cryopeg distribution on the territory of the Bovanenkovskoye GCF (Yamal Peninsula)]. In: *Materialy Pervoy Konferentsii Geokriologov Rossii* [Documentation of the First Conference of Russian Geocryologists]. Book 1. Moscow, Moscow State University, p.149-153.

Stroitel'stvo Truboprovodov. 1985a. *"Progress" nachnetsya s Yamburga* ["Progress" is starting from Yamburg]. *Stroitel'stvo Truboprovodov*, No.5, p.9.

Stroitel'stvo Truboprovodov. 1985b. *Dlya dosrochnogo zavresheniya vazhneyshey stroyki* [For the completion ahead of schedule of the most important construction project]. *Stroitel'stvo Truboprovodov*, No.9, p.9.

Stroitel'stvo Truboprovodov. 1986. *Letopis' vazhneyshikh stroyek* [Chronicle of the most important construction projects]. *Stroitel'stvo Truboprovodov*, No.2, p.24.

Stroitel'stvo Truboprovodov. 1989. *Novyye normativnyye dokumenty, utverzhdennyye Minneftegazstroyem SSSR* [New normative documents approved by Minneftegazstroy of the USSR]. *Stroitel'stvo Truboprovodov*, No.8, p.23-24.

Stroitel'stvo Truboprovodov. 1994. *Stranitsy istorii* [Pages of history]. *Stroitel'stvo Truboprovodov*, No.5, p.10-16.

Stroitel'stvo Truboprovodov. 1995a. *Mezhvedomstvennaya Komissiya po delam Arktiki i Antarktiki - nauchno-tekhnicheskiy sovet* [Interdepartmental Commission for Arctic & Antarctic Affairs - scientific-technical council]. *Stroitel'stvo Truboprovodov*, No.1, p.38.

Stroitel'stvo Truboprovodov. 1995b. *Mezhgosudarstvennaya nauchno-tekhnicheskaya programma "Vysokonadezhnyy Truboprovodnyy Transport"* [The inter-state scientific-technical programme "Highly Reliable Pipeline Transport"]. *Stroitel'stvo Truboprovodov*, No.4, p.10-12.

Stroitel'stvo Truboprovodov. 1996. *Pervomu magistral'nomu gazoprovodu Saratov - Moskva - 50 let* [To the first trunk gas pipeline Saratov - Moscow - 50 years]. *Stroitel'stvo Truboprovodov*, No.4-5, p.2-3.

Sudobin, G.N. *et al.* 1985. *Potochno-skorostnoy metod stroitel'stva transkontinental'nogo gazoprovoda Urengoy - Pomary - Uzhgorod* [The production-line high-speed method of constructing the Urengoy - Pomary - Uzhgorod trans-continental gas pipeline]. *Stroitel'stvo Truboprovodov*, No.2, p.12-13.

Sukhodol'skiy, S.Ye. *et al.* 1984. *Osobennosti merzlotno-inzhenerno-geologicheskikh usloviy Bovanenkovskoy struktury (Sredniy Yamal)* [Peculiarities of the permafrost-engineering-geological conditions of the Bovanenkovskaya structure (Middle Yamal)]. In: *Geokriologicheskiye Usloviya i Prognoz Ikh Izmeneniya v Rayonakh Pervoocherednogo Osvoyeniya Severa (Sbornik Nauchnykh Trudov)* [Geocryological Conditions and Forecasting Their Changes in Regions of Immediate Development in the North (Collection of Research Papers)]. Moscow, *Stroyizdat* and *PNIIIS*, p.42-72.

Sukhov, A.G. *et al.* 1989. *Tazovskaya oblast'* [The Tazovskaya region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.236-246.

Sumskiy, B.A. & V.I.Yelistratov. 1996. *Ispol'zovaniye opyta proyektirovaniya i ekspluatatsii mestorozhdeniy i gazotransportnykh sistem Kraynego Severa pri osvoyenii gazokondensatnykh mestorozhdeniy poluostrova Yamal* [Using the experience of planning and operating fields and gas transmission systems in the Far North for the development of gas-condensate fields of the Yamal Peninsula]. In: *Analiz Raboty Modernizirovannogo Oborudovaniya na Deystvuyushchikh Promyslakh i Ispol'zovaniye Sovremennykh Tekhnologiy i Oborudovaniya na Novykh Mestorozhdeniyakh Zapadno-Sibirskogo Regiona* [Analysis of Performance of Modernized Equipment at Active Fields and Using Current Technologies and Equipment for New Fields of the

West Siberian Region]. Material of the Scientific-Technical Council of *RAO Gazprom*. Held in Saratov, October 1995. Moscow, *RAO Gazprom*, p.89-94.

Surkov, Yu.P. *et al.* 1994. Corrosion crack initiation in gas pipelines. *The Physics of Metals and Metallography*, Vol.78, No.1, p.102-104.

Tarlinskiy, V.D. & A.S.Bolotov. 1993. *Metallurgicheskoye kachestvo trubnykh staley i problema korrozionnogo ractreskivaniya pod napryazheniyem* [Metallurgical quality of pipe steel and the problem of stress-corrosion cracking]. *Gazovaya Promyshlennost'*. No.11, p.27-28.

Telegin, L.G. *et al.* 1995. *Sooruzheniye Magistral'nykh Truboprovodov v Usloviyakh Kraynego Severa* [Construction of Trunk Pipelines in the Far North]. Moscow, *RAO Gazprom* & *IRTs Gazprom*.

The Oil Daily. 1982. Soviets invite pipeline inspection. *The Oil Daily*, Wednesday, November 10th, p.8.

Tolstikhin, N.I. 1941. *Podzemnyye Vody Merzloy Zony Litosfery* [Subterranean Waters of the Frozen Zone of the Lithosphere]. Moscow, Leningrad, "*Gosgeolizdat*".

Tolstikhin, O.N. 1973. *Kriopegi - kholodnyye vody zemli* [Cryopegs - cold waters of the earth]. *Chelovek i Stikhiya*, No.II, p.29-30.

Tolstov, V.A. & Yu.A.Kashchitskiy. 1995. *Sozdaniye novogo tekhnologicheskogo oborudovaniya dlya obustroystva mestorozhdeniy poluostrova Yamal* [Creating new technological equipment for development of the fields of the Yamal Peninsula]. *Khimicheskoye i Neftyanoye Mashinostroyeniye*, No.12, p.3-5.

Trofimov, V.T. (ed.). 1975. *Poluostrov Yamal (Inzhenerno-Geologicheskiy Ocherk)* [The Yamal Peninsula (Engineering-Geological Sketch)]. Moscow, Moscow University Press.

Trofimov, V.T. 1977. *Zakonomernosti prostranstvennoy izmenchivosti inzhenerno-geologicheskikh usloviy zapadno-sibirskoy plity* [Regularities of the spatial variability of engineering-geological conditions of the West Siberian plate]. Moscow, Moscow State University Press.

Trofimov, V.T. & Yu.B.Badu. 1975. *Gidrogeologicheskiye usloviya* [Hydrogeological conditions]. In: Trofimov, V.T. (ed.). *Poluostrov Yamal (Inzhenerno-Geologicheskiy Ocherk)* [The Yamal Peninsula (Engineering-Geological Sketch)]. Moscow, Moscow University Press, p.144-157.

Trofimov, V.T. *et al.* 1980. *Kriogennoye Stroyeniye i L'distost' Mnogoletnemerzlykh Porod Zapadno-Sibirskoy Plity* [Cryogenic Structure and Ice Content of Perennially-Frozen Soils of the West Siberian Platform]. Moscow, Moscow University Press.

Trusov, Ye.N. & S.E.Gorodetskiy. 1993. Design values of strength characteristics of frozen saline soils. *Osnovaniya, Fundamenty i Mekhanika Gruntov*, No.2, March-April, p.27-29. English translation.

Turbina, M.I. 1980. *Izmeneniye prirodnykh usloviyakh na odnom iz uchastkov deystvuyushchego gazoprovoda (Tsentral'naya Yakutiya)* [Change in natural conditions on one of the sections of an operating gas pipeline (Central Yakutiya)]. In: Pavlov, A.V. & I.A.Nekrasov (eds.). *Merzlotnyye Issledovaniya v Osvaivayemykh Rayonakh SSSR* [Permafrost Studies in Regions of the USSR Under Development]. Novosibirsk, "Nauka", p.31-36.

Tychkin, I.A. & N.A.Petrov. 1997. Corrosion protection of oil and gas pipelines in the north of Russia. In: *Oil & Gas Pipeline Projects in Russia & the CIS*. Documentation. 13th to 14th February 1997, Moscow. London, IBC UK Conferences Ltd.

Tychkin, I.A. *et al.* 1997. *Otsenka korrozionnoy opasnosti gazotransportnykh sistem otrasli na baze dannykh vnutritrubnoy defektoskopii (VTD) i kompleksnykh elektrometricheskikh obsledovaniy (KEO) gazoprovodov* [Estimating the corrosional danger of the industry's gas transport systems based on data from internal flaw detection and complex electrometric observations of gas pipelines]. In: *O Korrozionnom Sostoyanii Magistral'nykh Gazoprovodov Otrasli i Metodakh Otsenki ikh Ostatochnogo Resursa* [On the Corrosional Condition of the Industry's Trunk Gas Pipelines and Methods for Estimating their Life Expectancy]. *Materialy Nauchno-Tekhnicheskogo Soveta RAO Gazprom.* Moscow, *Gazprom* & *IRTs Gazprom.*

Tyumentransgaz. 1996. *Tyumentransgaz* XXX [*Tyumentransgaz* XXX]. Yugorsk, *Tyumentransgaz.*

Uvarkin, Yu.T. & A.I.Zhukova. 1964. *Kriogennyye i postkriogennyye obrazovaniya* [Cryogenic and post-cryogenic formations]. In: Bobov, N.G. & L.A.Brattsev (eds.). *Geokriologicheskiye Usloviya Pechorskogo Ugol'nogo Basseyna* [Geocryological Conditions of the Pechora Coal Basin].Moscow, "*Nauka*", p.165-186.

van Everdingen, R.O. (ed.). 1994. *Multilanguage Glossary of Permafrost and Ground-Ice Related Terms.* Draft. Calgary, Canada, International Permafrost Association Terminology Working Group.

Vasil'chuk, Yu.K. *et al.* 1989. Baydaratsko-Yuribeyskaya oblast' [The Baydaratsko-Yuribeyskaya region]. In: Yershov, E.D. (ed.). *Geokriologiya SSSR. Zapadnaya Sibir'* [Geocryology of the USSR. West Siberia]. Moscow, "*Nedra*", p.218-226.

Vdovenko, V.L., S.V.Shelemey & Yu.V.Ilatovskiy. 1997. *Deyatel'nost' gazovogo kompleksa na territorii Nenetskogo avtonomnogo okruga i ego vliyaniye na ekonomicheskoye razvitiye* [Gas complex activity in the territory of the Nenets autonomous district and its influence on economic development]. Report to the 2nd International Conference "Arctic Town & Environment", held in Nar'yan-Mar, September 1997. Ukhta, *SeverNIPIgaz, RAO Gazprom.*

Veselyy, N.N. 1988. *Yamal i ego problemy* [Yamal and its problems]. *Stroitel'stvo Truboprovodov*, No.2, p.6-9.

Vinogradov, S.V. 1991. *Naturnyye issledovaniya kolebaniy gazoprovoda bol'shego diametra* [Field studies of vibrations of a large diameter gas pipeline]. In: *Problemy Nadezhnosti Gazoprovodnykh Konstruktsiy* [Problems of Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov.* Moscow, *VNIIgaz* and *Soyuzgaztekhnologiya*, p.55-59.

Vinogradov, S.V. 1993. *Naturnyye issledovaniya nadzemnykh gazoprovodov kraynego severa* [Field studies of above-ground gas pipelines in the far north]. In: *Voprosy Nadezhnosti*

Gazoprovodnykh Konstruktsiy [Questions of the Reliability of Gas Pipeline Structures]. *Sbornik Nauchnykh Trudov*. Moscow, *VNIIgaz*, p.46-51.

Vitova, L.I. 1993. *Severgazpromu - chetvert' veka* [To *Severgazprom* - quarter of a century]. *Gazovaya Promyshlennost'*, No.11, p.10.

VNIIgaz & *Eko-Sistema*. 1997. *Prirodnyye Usloviya Baydaratskoy Guby. Osnovnyye Rezultaty Issledovaniy Dlya Stroitel'stva podvodnogo Perekhoda Sistemy Magistral'nykh Gazoprovodov Yamal - Tsentr* [Natural Conditions of Baydaratskaya Bay. Main Results of Research for Construction of the Underwater Transit of the Yamal - Centre System of Trunk Gas Pipelines]. Moscow, *VNIIgaz* & *Eko-Sistema*.

Vorob'yeva, R.A. & N.Ye.Legezin. 1993. *Protivokorrozionnaya zashchita neftegazovogo sooruzheniya* [Anti-corrosion protection of an oil and gas installation]. *Gazovaya Promyshlennost'*, No.1, p.32-34.

Voskresenskiy, K.S. & V.Ye.Zemchikhin. 1986. Thermal erosion in the north of Western Siberia. *Polar Geography & Geology*, Vol.10, No.2 (April-June), p.130-138. [Translation of an article in: *Geomorfologiya*, 1986, No.1, p.41-46].

Williams, P.J. 1986. *Pipelines & Permafrost. Science in a Cold Climate*. Carleton University Press.

Williams, P.J. & M.W.Smith. 1989. *The Frozen Earth. Fundamentals of Geocryology*. Cambridge, Cambridge University Press.

Wilson, D.C. 1995. The Russian gas industry in 1994. In: *Gas in the Former Soviet Union*. London, Petroleum Economist & *Gazovaya Promyshlennost'*, p.4-8.

Yakovlev, A.Ya., A.N.Kolotovskiy & V.M.Sharygin. 1997. *Obespecheniye ekspluatatsionnoy nadezhnosti MG Severgazproma* [Ensuring the operational reliability of *Severgazprom*'s trunk gas pipelines]. *Gazovaya Promyshlennost'*, No.9, p.17-18.

Yegorov, V.Ye. 1988. *70 Years of the Soviet Komsomol*. Moscow, Novosti.

Yegurtsov, S.A. *et al.* 1996. *Polevyye obsledovaniya sostoyaniya severnogo uchastka mezhpromyslovogo kollektora Urengoyskogo GKM* [Field investigations of the condition of the northern section of the gathering line of the Urengoy gas-condensate field]. *Stroitel'stvo Truboprovodov*, No.3, May-June, p.21-25.

Yershov, E.D. 1990. *Obshchaya Geokriologiya* [General Geocryology]. Moscow, "*Nedra*".

Yershov, E.D. 1998. *General Geocryology*. Cambridge, CUP. [In Press.]

Yevseyev, V.P. 1976. *Migratsionnyye bugry pucheniya severo-vostoka Yevropeyskoy chasti SSSR i Zapadnoy Sibiri* [Migratory frost mounds of the northeastern European part of the USSR and West Siberia]. In Popov, A.I. (ed.). *Problemy Kriolitologii* [Problems of Cryolithology]. Issue 5. Moscow, Moscow University Press, p.95-159.

Yunak, R.I. 1977. *Mnogoletnyaya merzlota* [Permafrost]. In: Sisko, R.K. (ed.). *Yamalo-Gydanskaya Oblast' (Fiziko-Geograficheskaya Kharakteristika)* [The Yamalo-Gydanskaya Region (Physical-Geographical Characteristics)]. Leningrad, *Gidrometeoizdat*, p.123-137.

Zakharov, Yu.F. 1985. *Inzhenerno-geologicheskiye problemy obustroystva Yamburgskogo mestorozhdeniya* [Engineering-geological problems in the development of the Yamburg field]. *Stroitel'stvo Truboprovodov*, No.1, p.8-9.

Zakharov, Yu.F. & M.F.Khasanov. 1981. *Inzhenerno-Geologicheskiye Usloviya Neftegazonosnykh Rayonov Severnogo Zaural'ya* [Engineering-Geological Conditions of the Oil and Gas-Bearing Districts of the Northern Trans-Urals Region]. Moscow, "*Nauka*".

Zinevich, A.M. *et al.* 1985. *Kompleks sooruzheniy po nadezhnomy gazosnabzheniyu Noril'skogo gorno-metallurgicheskogo kombinata* [The set of structures for the reliable supply of gas to the Noril'sk mining-metallurgical combine]. *Stroitel'stvo Truboprovodov*, No.2, p.14-15.

Zorin, L.Z. & A.N.Trutnev. 1987. *Tyumenskoye Uskoreniye* [Tyumen Acceleration]. *Peredovyye Kollektivy* [Advanced Teams]. Moscow, "*Nedra*".

Zorin, L.Z. & A.N.Trutnev. 1993. *Surgutskiy Variant* [The Surgut Variant]. Moscow, "*Nedra*".

Zorkal'tsev, V.I. (ed.) 1991. *Timano-Pechorskiy TEK : Strategii Razvitiya i Puti Povysheniya Effektivnosti* [The Timano-Pechorskiy Fuel-Energy Complex : Development Strategies and Ways of Increasing Effectiveness]. Syktyvkar, Komi Science Centre, Urals Branch, AS SSSR.