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Burns and Roe Enterprises, Inc.

BUSINESS PLAN for DELIVERY ORDER No. 19 Northwest Region Power Investment Plan - Nadvoitsky Aluminum Plant Electrolyzers Upgrade Project

RUSSIA

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Table of Contents

PREFACE 3

1 0 PROJECT SUMMARY 4

1 1 General 4
1 2 Summary of Results 4
1 2 1 Savings 4
1 2 2 Project Financing and Economics 5
1 2 3 Sensitivity Analysis and Risk Assessment 6

2 0 INTRODUCTION TO THE BUSINESS 6

2 1 General 6
2 2 Current Condition 7
2 3 Power Supply and Consumption 7
2 4 Raw Material Sources 8
2 5 Major Consumers 8
2 6 Current Financial Status 8

3 0 NATURE OF THE PROJECT 9

3 1 General 9
3 2 Past Rehabilitation Experience 10
3 3 Project Objectives 11
3 4 Project Implementation 11
3 5 Renovation Impacts 11
3 6 Risk Assessment 12
3 7 Project Support 14
3 8 Project Ratios 14

4 0 BENEFITS 15

4 1 Energy Savings/Environmental Improvements 15
4 2 Export Promotion 15

5 0 MARKET ANALYSIS 16

5 1 World Market 16
5 2 Russian Aluminum Market 16

6 0 FINANCIAL PLAN ASSUMPTIONS AND PROJECT COSTS 17

6 1 General Project Assumptions 17
6 2 Interest and Discount Rates 18
6 3 Capital Investment Schedule and Loan Structure 19

7 0 CASHFLOW PROJECTIONS AND FINANCIAL VIABILITY 19

7 1 Taxation 19
7 2 Cash flow Projections 21
7 3 Assessment of the Sensitivity Calculation Results 25

APPENDIX 27

Preface

This preliminary business plan for the OSC Nadvoitsky Aluminum Works Electrolyzers Upgrade Project has been prepared by Burns and Roe Enterprises, Inc (BREI) and its Russian subcontractors with funding from the U S Agency for International Development (USAID) under the NIS Energy Efficiency and Market Reform Project- Northwest Region Power Investment Plan, Delivery Order No 19 - Electrical Energy Efficiency Improvements Task

This information has been carefully compiled using the most accurate information and data available Much of the information was provided by the staff of OSC Nadvoitsky Aluminum Works (NAW), Region of Karelia, Russia Estimates found in the business plan include elements of the authors' subjective judgments and analyses Accurate data needed to support critical elements of the business plan are often difficult to obtain No liability is assumed for the correctness or completeness of the information included in this document Burns and Roe Enterprises, Inc and its subcontractors disclaim all liability for possible errors and omissions in the business plan

The business plan does not include all information required for a complete evaluation of the proposed project by a prospective lender or investor Rather prospective lenders and investors are strongly encouraged to undertake their own assessments based on the information provided in this document The technical renovation needs of Nadvoitsky Aluminum Works are constantly changing, thus, details of the project, including costs described herein, will also change

The authors would like to express their appreciation to the staff of Nadvoitsky Aluminum Works for their willingness to provide the data and information required to complete this business plan and their support of the BREI team

All data, evaluations, plans and conclusions presented are as of May of 1998 and are based on coordinated opinions of the project development participants

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1 0 Project Summary

The public joint stock company Nadvoitsky Aluminum Works (NAW), located in the Republic of Karelia, township Nadvoitsky, Zavodskaya Street, 1, is providing this application for the funding of the *Electrolyzers Upgrade Project*

1 1 General

The project is to be implemented in 1999-2001 and includes the replacement of 84 electrolyzers that have lateral current supply by electrolyzers with baked anodes installed together with the computerized control system The technological part of the project is based on the common world-wide practice for the aluminum industry and includes proven methods for such operation

Major objectives of the proposed project include electric power savings, lower emissions of contaminants, and improvement of major technical and economic factors of aluminum production The upgrading of the electrolysis production is a part of a Energy Efficiency Regional Program set by the Government of the Republic of Karelia

The financial and economic factors of the project have been calculated in accordance with The Methodological Recommendations for Evaluating Investment Projects Efficiency and Selecting Projects for Financing approved by the State Construction Department of the Russian Federation, the Ministry of Economy of the Russian Federation, the Ministry of Finance of the Russian Federation and the State Committee for Industry of the Russian Federation (March, 1994), and the Guide to Energy Efficiency Bankable Proposals (June 1997) Unless otherwise stated, all reference to rubles are for denominated rubles or those in circulation at a time of this writing

1 2 Summary of Results

1 2 1 Savings

Table 1-1 summarizes the benefits of the proposed project, including energy savings, output increase, and emissions decrease

Table 1-1

Category	Amount Saved	Cost Savings (in million of rubles)
Energy Savings	42 7 million kWh/year (15%)	4 32/year
Output Increase	2468 tons/year	23 45/year
Emissions Decrease	1065 3 tons/year	--

1 2 2 Project Financing and Economics

The proposed project should be implemented within a three-year period during 1999-2001 The schedule assumes that contractors and consultants will be brought in to support project implementation Note, any necessary legal and institutional preparatory work is not included in the implementation period

Table 1-2 provides an overview of the assumed loan characteristics for the proposed project

Table 1-2 Loan Structure

Loan amount	61 million rubles ($9 94 million)
For	All capital investments
Term	Five years including the grace period
Grace Period	Two years (construction time)
Construction Begins	1999
Construction Completed	2001

The results of the economic analysis for the base case scenario are presented in Table 1-3 The cost of the project includes all local taxes

Table 1-3 Financial Analysis of the Energy Efficiency Upgrade

Category	Amounts
Net Present Value	7,420,600 rubles
Payback Period	3 7 years
Discount Rate	10 %
Profitability Index	1 135
Internal Rate of Return	17 7 %

The project internal rate of return (IRR) is 17 7%, and is above the requirements of all multilateral development banks Given the project's good economics, Russian commercial banks may be willing to provide a portion of the required investments

1 2 3 Sensitivity Analysis and Risk Assessment

The base case scenario provides a satisfactory IRR value of 17 7 % Three sensitivities were looked at

- Case 2 - Interest Rate is 20%, Base cost of aluminum, Increase in inflation, Higher currency exchange rate This case provides IRR of 22 5%
- Case 2(a) - Interest Rate is 20%, Lower cost of aluminum, Increase in inflation, Higher currency exchange rate In this case the project has a negative NPV
- Case 3 - Interest Rate is 10%, Higher cost of aluminum, Decrease in inflation, Base currency exchange rate This case provides IRR of 26 1%

Case 2(a) is the only case where the IRR is below the acceptable limit if the described conditions described are sustained

The *financial risk* existing in most projects in the Former Soviet Union is primarily related to loan repayment However, property guarantees of the NAW have been offered as a financial risk mitigation mechanism for this project The amount of investments in the project constitutes about 16% of the NAW total assets The *political risk* for this project is lower than on average across Russia The political and ethnic situation in the Republic of Karelia has been stable for many years and does not have the potential for severe social conflicts and confrontations The *technical and managerial risks* related to project implementation are also minimal due to the common technology proposed for this project

2 0 Introduction to the Business

2 1 General

Nadvoitsky Aluminum Works (NAW) was commissioned in 1954 The present organizational and legal form of ownership is that of a public joint stock company with 28 4 million rubles of equity The state owns 20% of the shares while the remainder of the shares are held by the public

Contact Information

NAW·

General director	Nechaev Gennady Pavlovich
Technical director	Lukin Nikolay Anatolyevich
Telephone	814-31-39-230

Moscow representative office

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NAW's major product include aluminum in the form of ingots (15 kg/piece) and slabs (up to one ton/piece) Silumin, aluminum powders and dusts are also produced in small amounts Oxygen and heat generated by the NAW boiler house are supplied to consumers of the Nadvoitsky township as a by-product of the technological process

Over the past three years NAW sales (in million of rubles) amounted to

1995	280 282
1996	308 501
1997	325 656

NAW is considered to be a small enterprise in size Its annual output of raw aluminum is significantly lower than the output of the major Bratsk and Krasnoyarsk aluminum plants in Russia

2 2 Current Condition

Most of the production lines at NAW have outdated electrolyzers, except for one experimental production line, with self-baking anodes Much of the equipment is physically old, which results in excessively high electric power consumption In 1997, specific electric power consumption per one ton of aluminum amounted to 16,470 kWh Power to NAW is supplied by AO "Karelenergo"

Discharge and exhaust emissions are also higher than in modern plants and lead to considerable contamination of the production premises and the outside environment

2 3 Power Supply and Consumption

Until recently, a high electric power tariff (0 204 rubles/kWh in 1997, which is 3-4 times higher than the tariff set for other major Russian aluminum plants) was typical for NAW and other aluminum plants in the North-West region The high electric power tariff resulted in very high production costs Electricity costs contributed more than 51% to the

aluminum production costs A tariff reduction was implemented in March 1998 reducing the cost of electricity by over 50%

2 4 Raw Material Sources

50% of raw material comes from the Pikalevsky aluminum plant located about 70 km from NAW The rest is imported from Western Europe through the Murmansk port

2 5 Major Consumers

Close proximity to European countries and satisfactory transportation methods contribute to the fact that about 95% of the NAW products are sold outside NIS in Western Europe Major foreign consumers include

- Glencore International (Switzerland)
- Trans-World (Aluminium) Limited (Great Britain)
- Hunter Douglas Metals B V (Netherlands)
- Metallgesellschaft (Germany)
- AB Electrolux, Group Global Purchasing (Sweden)

2 6 Current Financial Status

Over the past three years NAW incurred significant losses Based on 1997 performance, losses accounted for 92 342 million rubles This is primarily related to extremely high electricity tariffs and outdated equipment

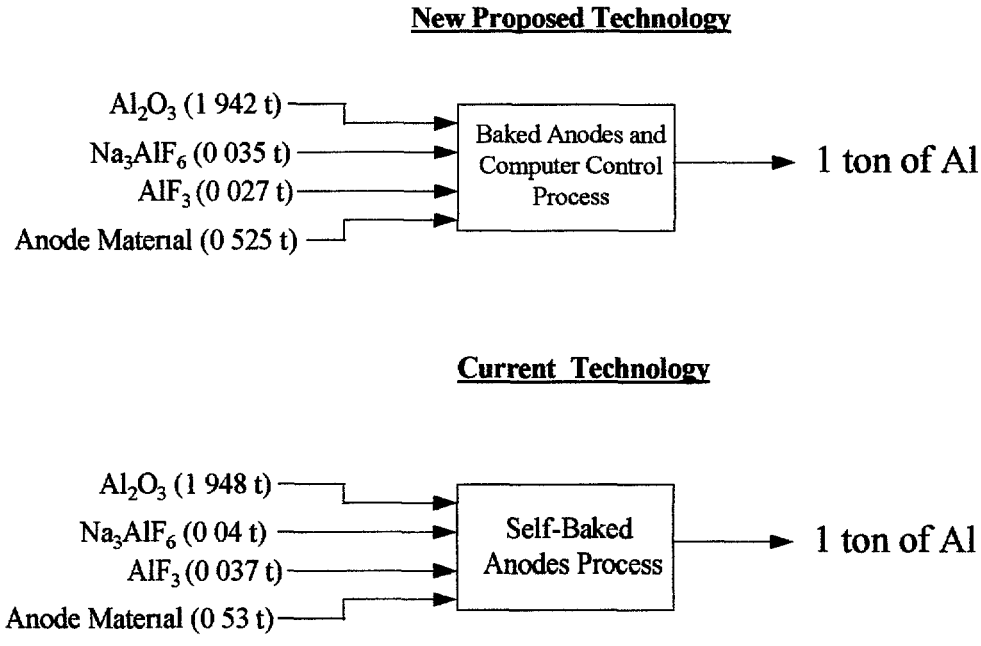
In March 1998, a long-term power purchase contract (the contract terminates January 1, 2004) signed between NAW and AO Karelenergo under the aegis of the regional energy commission The new tariff is 0 101 rubles/kWh (1 6 cents/kWh) The new tariff is 50 5% lower than the one in 1997 The power purchase contract is planned to be extended for another 4-5 years in 2004 The current wholesale market tariff for the North-West region is 0 149 rubles/kWh This will result in a decrease of NAW production costs

3.0 Nature of the Project

3 1 General

The production of raw aluminum is a multi-stage process that includes raw material processing, the production of aluminum by electrochemical method and casting blanks for further processing This project primarily deals with aluminum production at the electrolysis stage Exhibit 3-1 provides the details of aluminum production process

Exhibit 3-1 - Process Diagrams



NAW's electrolysis production stage consists of 356 electrolyzers (baths) installed in four buildings, each containing 80-90 electrolyzers The buildings form two production blocks with two buildings in each block The post-electrolysis stage includes a thermal shop that produces Silumin in mixers, and a shop that produces aluminum powder as well as auxiliary products (oxygen, wastes recycling, and process steam) More than 90% of electric power required for the process is consumed in the electrolysis production stage Exhibits 3-2 and 3-3 provide general layouts for the electrolyzers with baked anodes (new proposed technology) and self-baked anodes (currently used technology)

Exhibit 3-2 - Baked Anodes (New Proposed Technology)

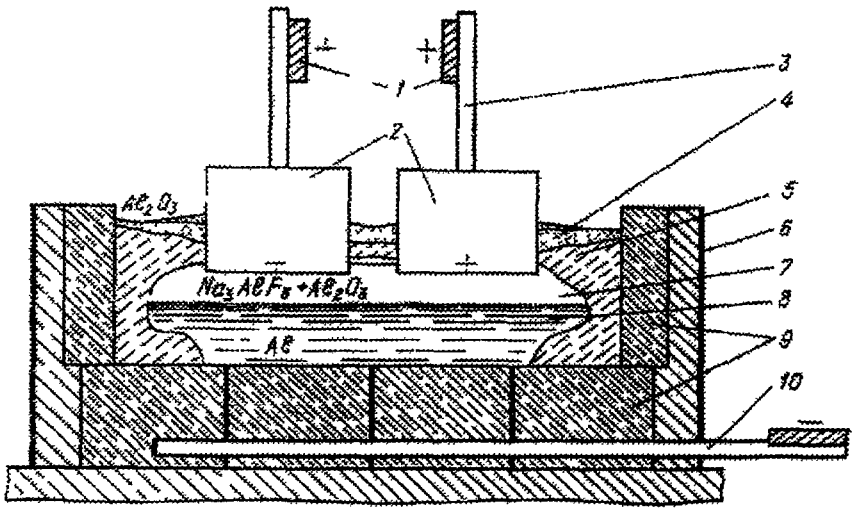
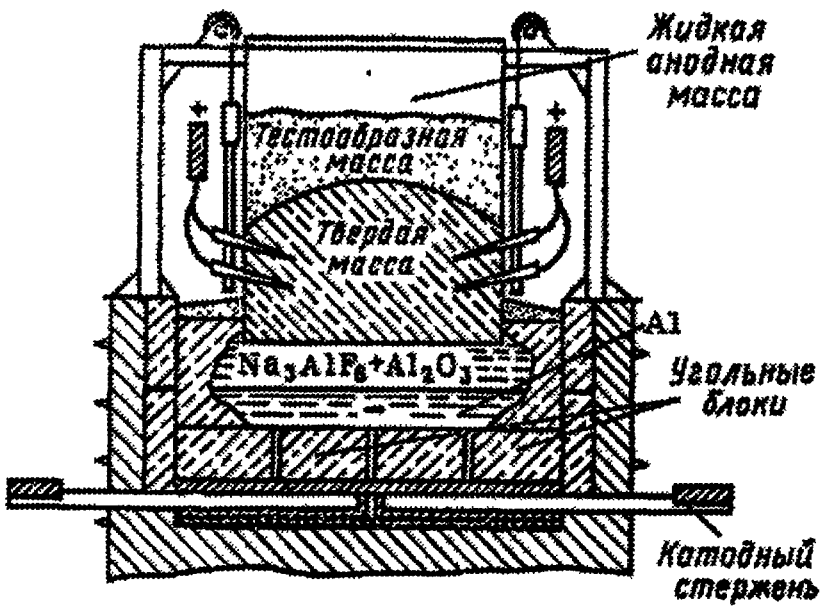


Exhibit 3-3 - Self-Baking Anodes (Currently Used Technology)



3 2 Past Rehabilitation Experience

An experimental shop with 12 rehabilitated electrolyzers with baked anodes has been operating successfully over the past three years The project was performed by the Kaiser Corp (USA) The company supplied baked anodes and provided general rehabilitation supervision A number of local personnel and management participated in this project and received valuable experience in the form of operations training

3 3 Project Objectives

The main objective of the proposed project is a technical upgrade of outdated equipment in the aluminum production building No 1 to achieve the following major targets

1) Lower electric power consumption in aluminum production at the NAW
2) Create conditions for aluminum production intensification and increasing electrolyzers efficiency
3) Contribute to the improvement of environmental conditions in the region by reducing emissions and discharges into the environment

3 4 Project Implementation

The project is planned to be implemented in the following three stages

	Rehab Starts	Amount of replaced electrolyzers, units	Planned annual raw Aluminum output, tons
Stage 1	1999	20	4272
Stage 2	2000	32	6835
Stage 3	2001	32	6835

At the same time, each batch of electrolyzers will be installed within a year, in turn obtaining the full effect of installation the following year Please note that the production levels do not decrease during the rehabilitation process

Project Importance

The management of the plant is interested in lowering aluminum production costs by decreasing their electric power consumption and in reducing the emission of fine dust particles The proposed project will improve the working conditions of the personnel during the electrolysis production process In addition to this, increased product output is expected, leading to higher revenues

3 5 Renovation Impacts

The replacement of electrolyzers together with the installation of the Computerized Control System of Production Processes (CCS PP) will improve major characteristics of the aluminum electrochemical production at the NAW The implementation of the project will allow the following projected results to be obtained

	Quantity	in mil of rubles
(a) Electric power savings - 15%	42 75 ml kWh/yr	4 32
(b) Higher metal yield, - 9 5% given current efficiency	1814 tons/yr	17 23
(c) Increase in metal yield by increasing magnitude of current	654 tons/yr	6 21
(d) Lower emissions of contaminants, including	1065 3 tons/year	not estimated
dust	96 3 tons	
tarry substances	400 8 gr	
fluoride	15 7 tons	
anhydrous hydrogen fluoride	22 4 tons	
sulfur oxides	8 60 tons	
carbon oxides	521 5 tons	

The proposed project will also increase the electrolyzers' service life from 4 25 years to 6 years

3 6 Risk Assessment

Political and Geographic Risks

The political risk for the proposed project may be considered to be lower than on average across Russia The political and ethnic situation in the Republic of Karelia is characterized by tranquillity and lack of social conflicts and confrontation that occur in other Russian regions In addition to that, Karelia is located outside the natural disaster zone in Russia Earthquakes, typhoons, and other natural disasters are not common in that region

Technical and Managerial Risks

These risks are estimated to be minimum for the proposed projects The upgrading of the production line by installing electrolyzers with preliminary baked anodes and computerized controls for electrolyzer systems is not a technical innovation Around 700 electrolyzers with baked anodes are already operating in Russia At NAW, an experimental shop with 12 new electrolyzers has been operating successfully since 1995

The financing of the experimental shop upgrading was conducted by the plants internal funds The current operation of this shop provides reliable technological and industrial economics data used in this proposal Major benefits of the proposed system include

- The scope of proposed work does not require any additional production premises, except for an anode and installation shop (AIS)
- NAW has been operating for more than 40 years, and has significant production experience, highly skilled managerial personnel and workers that are familiar with current and newly proposed systems

Financial and Economic Risks

To reduce the risk related to loan repayment, property guarantees of the NAW can be used as a mechanism of financial and economic risk regulation The amount of investments in the proposed project is only 16% of current NAW assets

Risk related to profitability of the NAW is quite low, seen as though in the near future the larger part of the plant products (more than 95%) will be exported to the Western European market Any growth in the share of Russian consumers will primarily depend on the ability of Russian consumers to pay for the NAW products

Two external risks related to the production costs are also possible They are

- A possible increase in the price of raw materials due to an increase in customs duties, leading to an increase in production costs by another 3-5% This case is considered in the sensitivity analysis for this project

- A possible increase in the price of electric power due to the termination of the power purchase contract signed with power supplier AO Karelenergo (# 0001, dated March 23, 1998), or changes in its terms

The first risk can be assessed with a probability of 0 1, and the second one with a probability of 0 2, if the contract is terminated The weight of the first risk can be assessed by a factor of 0 4, and that of the second one by a factor of 0 6, depending on conditions

The total number of risk points obtained as a total of the products of specific risks by their weights is assessed in this case to be 0 16, which is within acceptable limits

This risk probability figures are based on the risk analysis methodology provided by the Russian Academy of Sciences Energy Research Institute

Additional Benefits

In addition to the risks mentioned above, the proposed project evaluation should take into consideration some factors that can potentially stabilize project performance and diminish the above mentioned implementation risks They include the following

The project provides quick (within three years) upgrading of only 84 out of existing 356 electrolyzer units This provides the possibility to implement upgrading without lowering the plant output and, and consequently, without decreasing NAW sales

Better labor conditions and increased automation will also contribute to the plant productivity

3 7 Project Support

Support of the Project By the Government

The upgrading project is a part of the Federal Program for Technical Upgrading and Development of Russia's Metallurgy Sector for 1993-2000 (Resolution of the Russian Federation Government # 41, dated January 23, 1994) The proposed project has been included into the Regional Program for Energy Efficiency of the Republic of Karelia (Resolution of the Government of the Republic # 154, dated August 6, 1997)

3 8 Project Ratios

Four integral factors have been calculated to show project profitability These factors are as follows (base scenario)

Repayment period (the number of years during which revenues from the production activity conducted by the enterprise will cover costs related to investments)	3 3 years
Discounted period of repayment (at 10%)	3 7 years
Net present (discounted) value (NPV) The sum of net discounted cash revenues minus discounted investment costs	7420 6 thousand rubles
Investment profitability index Profitability index is a relative factor that characterizes a level of revenues per unit of costs	1 135
Internal rate of return (IRR) shows expected profitability of the project	17 7%

4 0 Benefits

4 1 Energy Savings/Environmental Improvements

Following energy savings and environmental improvements are foreseen for the proposed project

		Value in mil of rubles
(a) Electric power savings - 15%	42 75 ml kWh/year	4 32
(b) Higher metal yield, - 9 5% given current efficiency	1814 tons/year	17 23
(c) Increase in metal yield by increasing magnitude of current	654 tons/year	6 21
(d) Lower emissions of contaminants including	1065 3 tons/year	not estimated
dust	96 3 tons	
tarry substances	400 8 g	
fluoride	15 7 tons	
anhydrous hydrogen fluoride	22 4 tons	
sulfur oxides	8 60 tons	
carbon oxides	521 5 tons	

Proposed project will also increase electrolyzers service life from 4 25 years to 6 years

4 2 Export Promotion

Currently, about 95% of the product is sold to the Western European market Table 4-1 presents the projected increase in total sales and increase of corresponding export share

Table 4-1 - Projected Sales Increase

Market Sales (x1000 tons)	1999	2000	2001	2002	2003	2004
Foreign	57 000	57 570	58 190	58 190	58 190	58 814
Domestic	3 000	3 000	3 000	3 000	3 000	3 000
Total	61 814	61 190	61 190	61 190	60 570	60 000

5 0 Market Analysis

5 1 World Market

World production of aluminum increased slightly in 1997, as compared to 1996 Total world inventories of aluminum were relatively unchanged - an increase in London Metals Exchange (LME) inventories was balanced by a decline in producer inventories

Table 5-1 provides details of primary aluminum production by major producers in the world

Table 5-1 - Major Primary Aluminum Production (in tons)

	Russia	Australia	Canada	European Union	Norway	United States
1995	***2,724,378***	1,296,941	2,171,992	2,063,917	846,794	3,375,075
1996	***2,874,236***	1,371,633	2,283,210	2,198,920	863,002	3,577,222
1997	***2,906,020***	1,494,840	2,327,188	2,229,697	918,558	3,603,362
1998*	***480,124***	257,755	377,856	370,257		589,198

* 1998 figures are based on January and February data only
Source USGS - Minerals Information

The LME cash price for high-grade primary aluminum ingot followed the same general trend as the U S market price during the last few years The monthly average U S market price of primary aluminum metal, as reported by Platt's Metals Week, fluctuated during the last few years but followed a general downward trend before recovering near the end of 1996 Table 5-2 below represents U S Market spot average aluminum prices for 1992-96

Table 5-2 - U S Aluminum Prices (spot price in average cents per pound)

	1992	1993	1994	1995	1996
U S. Market	57 5	53 3	71 2	85 9	71 3

Source USGS - Minerals Information

5 2 Russian Aluminum Market

Eleven aluminum plants are currently in operation in Russia Five major plants are located in Siberia, one is operating in the Urals, and three are operating in the North-West region Currently, about 90% of the products produced by these plants are exported to the foreign market

The Russian market is characterized by a decrease in demand for aluminum But a local price for it amounts to around 1800 dollars/ton, which is equivalent to the average price at

the London Commodity Exchange (LCE) taking into account the cost of exported aluminum delivery from Russia Price fluctuations by specific plants are in the 17-18% range and primarily depend on the costs of electric power and raw materials delivery

NAW provides a quality of aluminum[1] that is quite comparable with the quality of this metal produced by other Russia's plants and plants worldwide

Given the established links and potential consumers, the sales and price of aluminum produced by NAW are projected in Table 5-3

Table 5-3 - Sales and Price Forecast for NAW

	Sales (in 1000 tons)			**Price**			**Revenues** (in 1000 rubles)		
	Foreign Market	Local Market	Total	Foreign Market (US$/ ton)	Foreign Market (1000 rubles)	Local Market (1000 rubles)	Foreign Market	Local Market	Total
1999	57 0	3 0	60 0	1500	9 5	12	542	36	578
2000	57 6	3 0	60 6	1500	9 6	12	553	36	589
2001	58 2	3 0	61 2	1520	9 9	12	576	36	612
2002	58 2	3 0	61 2	1540	10 2	12	594	36	630
2003	58 2	3 0	61 2	1560	10 4	12	605	36	641
2004	58 8	3 0	61 8	1570	10 7	12	629	36	665

6 0 Financial Plan Assumptions and Project Costs

6 1 General Project Assumptions

The following assumptions were made while preparing input data for calculating the base scenario of the financial plan

The beginning of the project	January 1, 1999
The duration of the project	5 years
Project currency	ruble

The tariff for electric power supplied to the aluminum plant is assumed to be 0 016 US$/kWh for the whole period Other general economic parameters used in the financing plan are presented in Table 6-1

[1] Aluminum produced by NAW has been registered at the London Metal Exchange and passed all necessary expertise

Table 6-1 - General Economic Parameters						
	Years					
	1999	2000	2001	2002	2003	2004
	Annual inflation, % (*)					
Maximum	6 3	5 2	4 6	4 3	4 0	3 7
Base	5 7	4 7	4 2	3 9	3 7	3 5
Minimal	5 1	4 2	3 7	3 5	3 4	3 2
	Exchange rate, rubles per dollar (*)					
Maximum	6 42	6 63	6 81	6 98	7 15	7 31
Base	6 3	6 4	6 5	6 6	6 7	6 8
Minimal	6 1	6 1	6 15	6 2	6 25	6 3
	Aluminum price (dollars per ton)					
Maximum (**)	1500	1500	1520	1540	1560	1570
Base	1460	1480	1500	1510	1530	1530
Minimal	1420	1420	1420	1420	1420	1420

(*) Forecast submitted by Russia's Ministry of Economy
Inflation for payroll has been assumed with a constant coefficient 1 08 to industrial inflation (based on data submitted by the pro-rector of the Higher Economic University, E E Gavrilenkov, Moscow)
Dollar exchange rate – oofficial forecast of Russia's Ministry of Economy (May 1998) till the year 2001, after that year the data is estimated Current (May 1998) rate is 1 USD = 6 14 rubles
(**) Forecast submitted by the NAW

6 2 *Interest and Discount Rates*

The following interest rates were used

- Worst case scenario 20%
- Base case scenario 15%
- Best case scenario 10%

The discount rate is 10% These figure was discussed and verified with EBRD representatives in Moscow and Helsinki

6 3 Capital Investment Schedule and Loan Structure

The total investment required for the proposed project is estimated to be 61 million rubles

Estimated structure of investments by project implementation stages is presented in Table 6-2 (million rubles)

Table 6-2 - Investment Schedule (in mil. of rubles)

Project Activity	Total Amount of Investment Required	Equipment		Materials, Construction and Installation
		Electrolyzers	Controls	
Stage 1	15	2 2	2 0	10 8
Stage 2	23	3 5	2 3	17 2
Stage 3	23	3 5	2 3	17 2

The project is to be financed with the proceeds of a 5-year loan

The loan repayment schedule is as shown in Table 6-3

Table 6-3 - Loan Principal Amount Repayment Schedule

	1999	2000	2001	2002	2003
Repayment (in millions of rubles)	--	--	13 0	23 0	25 0

7 0 Cash flow Projections and Financial Viability

7 1 Taxation

Taxes, presented in Table 7-1 are used in the cash flow calculations Land tax is not used Its value is negligible and does not impact the calculations in any way Tax rates are assumed to be constant for the duration of the project

Table 7-1 - Taxes (%)

	Overhead	Profit Tax
Pension fund	28	
Social security	5 4	

Employment fund	1 5	
Medical insurance	3 6	
Life insurance	1 0	
Property tax		2 0
Profit tax		35 0
Housing tax		1 5
Roads tax		3 0
Local tax		1 0

7 2 Cash flow Projections

The financial performance of the project is presented in the following tables

Table 7-2 - Profit and Loss Balance
Table 7-3 - Cash Flow
Table 7-4 - Balance Sheet
Table 7-5 - Ratios

Table 7-2
Profit and Loss Balance
(in x1000 of rubles if not stated otherwise)

	1999	2000	2001	2002	2003
Aluminum output, (x1000 tons)		4 272	11 107	17 942	17 942
Price of aluminum ($/ton)	1,460	1,480	1,500	1,510	1,530
Price of aluminum (1000 rubles/ton)	9,198	9,472	9,750	9,966	10,251
Revenues (x1000 rubles)		40,464 4	108,293 3	178,810	183,923 4
Production costs					
Raw and auxiliary materials		19,531 6	52,914 0	88,809 7	92,095 6
Electricity		6,124 3	16,171 8	26,525 5	26,927 4
Salary and fringes		1,168 0	3,036 7	4,905 3	4,905 3
Other direct costs		491 3	1277 3	2,063 3	2,063 3
Total direct costs		27,315 2	73,399 8	122,303 8	125,991 7
Overheads		255	255	255	255
Depreciation		2,504 3	6,344 4	10,184 6	10,184 6
Other fixed costs		17 1	44 4	71 8	71 8
Total fixed costs		2,776 4	6,643 8	10,511 3	10,511 3
Loan interest		2,250	5,700	7,200	3,750
Taxable profit		8,122 86	22,549 63	38,794 81	43,670 42

	1999	2000	2001	2002	2003
Profit tax		2,843 00	7,892 37	13,578 18	15,284 65
Other taxes		1,973 93	4,468 80	6,584 30	6,737 70
Net profit		3,305 93	10,188 47	18,632 33	21,648 07
Cumulative net profit		3,305 93	13,494 39	32,126 72	53,774 8

Table 7-3
Cash Flow
(in x1000 of rubles if not stated otherwise)

	1999	2000	2001	2002	2003
Investments	-15000	-23000	-23000	0	0
Cumulative investments	-15000	-38000	-61000	-61000	-61000
Discounted investment	-15000	-20,909 1	-19,008 3	0	0
Cumulative discounted investment	-15000	-35,909 1	-54,917 4	-54,917 4	-54,917 4
Investments in working capital	0	0	0	0	0
Revenues	0	40464 4	108293 3	178810 0	183923 4
Direct costs		27315 2	73399 8	122303 8	125991 7
Fixed costs		2776 4	6643 8	10511 3	10511 3
Loan interest		2250	5700	7200	3750
Taxable profit		8122 86	22549 63	38794 81	43670 42
Profit tax		2843 00	7892 37	13578 18	15284 65
Net profit		3305 93	10188 47	18632 33	21648 07
Net cash revenues		5810 19	16532 89	28816 91	31832 65
Cumulative net cash revenues		5810 19	22343 08	51159 99	82992 64
Discounted net cash revenues		5,282 0	13,663 6	21,650 4	21,742 0
Ccumulative discounted net cash revenues		5,282 0	18,945 6	40,596 0	62,338 0
Equity	0	0	0	0	0
Payment of dividends	0	0	0	0	0
Long-term loan	15000	23000	23000		
Loan repayment			13000	23000	25000
Balance	15000	23000	10000	-23000	-25000
Cumulative balance	15000	38000	48000	25000	0
Balance of accrued funds	0	5810 2	3532 9	5816 9	6832 7
Cumulative balance of accrued funds	0	5810 2	9343 1	15160 0	21992 6

Table 7-4
Balance Sheet
(in x1000 of rubles if not stated otherwise)

	1999	2000	2001	2002	2003
Fixed (off-current) assets	15000	38000	61000	61000	61000
Depreciation		-2504 3	-8848 7	-19033 3	-29217 8
Total depreciated cost	15000	35495 7	52151 3	41966 7	31782 2
Current (operational) assets		5810 2	9343 1	15160 0	21992
Total assets	15000	41305 9	61494 4	57126 7	53774 8
Equity	0	0	0	0	0
Retained profit	0	3305 9	13494 4	32126 7	53774 8
Total equity		33059	13494 4	32126 7	53774 8
Long-term liabilities	15000	38000	48000	25000	0
Current liabilities		0	0	0	0
Total liabilities	15000	41305 9	61494 4	57126 7	53774 8

Table 7-5
Ratios

Repayment period, years	3 3
Repayment period with discounting, years	3 66
Net present value (NPV), x1000 rubles	7420 6
Investment profitability index	1 135
Investment efficiency ratio	92%

7 3 Assessment of the Sensitivity Calculation Results

Table 7-6 presents a comparison of all ratios under different sensitivities reviewed

Table 7-6 - Sensitivity Analysis

	SCENARIOS (Refer to Table 6-1)			
Sensitivities descriptions	**Case 1 - Base Case**	**Case 2**	**Case 2a**	**Case 3**
Interest Rate	15%	20%	20%	10%
Aluminum Price	Base	Base	Minimal	Maximum
Inflation	Base	Maximum	Maximum	Maximum
Dollar Exchange Rate	Base	Maximum	Base	Base
Repayment period, years	3 3	3 2	3 8	3 1
Repayment period years, with discounting	3 7	3 5	4 3	3 35
NPV, 1000 rubles	7420 6	12,531 0	-5 651 5	15822 6

Profitability index	1 135	1 228	-	1 29
IRR, %	17 7	22 5	-	26 1

The base scenario is characterized positively in terms of all factors of the project Case 2 (20% interest rate, maximal inflation rate and a dollar exchange rate, aluminum base price), is also acceptable The best results are achieved when the most favorable values of input data are combined together (Case 3)

In case when all input data is unfavorable (scenario 2a), project factors become significantly worse However, the probability of the worst combination of all input parameters is not very high and is estimated at the level of less than 5% (according to ERI methodology)

The assessment of the probability of the reviewed scenarios occurrence, as per ERI methodology, is as follows (a) Case 1 - 0 6, Case 2 - 0 15, Case 2a - 0 05, and Case 3 - 0 25

The findings presented in Table 7-6 above provide evidence of high reliability and stability of the project

To perform a more detailed sensitivity analysis, additional calculations have been conducted in order to determine the impact of major production costs items on project efficiency The following categories were reviewed raw material costs fluctuations, and electricity consumption increase

The conducted analysis shows that the project will still be economically viable if

- raw material costs and material costs go up another 21 % from the base value
- electric power costs go up another 45% from the base value

APPENDIX

(1995-97 NAW Financial Reports)

Burns and Roe Enterprises, Inc.

BUSINESS PLAN for DELIVERY ORDER No. 19
Northwest Region Power Investment Plan - Volkhovgypsum Natural Drying Upgrade Project

RUSSIA

August 1998

Submitted by:	Burns and Roe Enterprises, Inc.
Submitted to:	U.S. Agency for International Development
Contract No.:	CCN-0002-Q-00-3154-00 Energy Efficiency and Market Reform Project - Nothwest Region Power Investment Plan Delivery Order No. 19 Volkhovgypsum Natural Drying Upgrade Project

28

Table of Contents

PREFACE 3

1 0 PROJECT SUMMARY 4

1 1 GENERAL 4
1 2 SUMMARY OF RESULTS 4
1 2 1 Improvements 4
1 2 2 Project Financing and Economics 5
1 2 3 Sensitivity Analysis and Risk Assessment 5

2 0 INTRODUCTION TO THE BUSINESS 6

2 1 GENERAL 6
2 2 RAW MATERIAL SOURCES 7
2 3 MAJOR CONSUMERS 7
2 4 CURRENT FINANCIAL STATUS 7

3 0 NATURE OF THE PROJECT 7

3 1 GENERAL 7
3 2 PROJECT OBJECTIVES 8
3 3 PROJECT IMPLEMENTATION 9
3 4 RENOVATION IMPACTS 9
3 5 RISK ASSESSMENT 9
3 6 PROJECT RATIOS 11

4 0 BENEFITS 12

4 1 ENERGY SAVINGS/ENVIRONMENTAL IMPROVEMENTS 12
4 2 EXPORT PROMOTION 12

5 0 MARKET ANALYSIS 12

5 1 GENERAL 12
5 2 COMPETITION 13
5 3 GYPSUM DEMAND AND PRICE 13

6 0 FINANCIAL PLAN ASSUMPTIONS AND PROJECT COSTS 14

6 1 GENERAL PROJECT ASSUMPTIONS 14
6 2 INTEREST AND DISCOUNT RATES 15
6 3 CAPITAL INVESTMENT SCHEDULE AND LOAN STRUCTURE 15

7 0 CASH FLOW PROJECTIONS AND FINANCIAL VIABILITY 16

7 1 TAXATION AND INFLATION 16
7 2 CASH FLOW PROJECTIONS 16
7 3 ASSESSMENT OF THE SENSITIVITY CALCULATION RESULTS 20

Preface

This preliminary business plan for the Volkhovgypsum Industrial Wastes Recycling Factory has been prepared by Burns and Roe Enterprises, Inc (BREI) and its Russian subcontractors with funding from the U S Agency for International Development (USAID) under the NIS Energy Efficiency and Market Reform Project- Northwest Region Power Investment Plan, Delivery Order No 19 - Electrical Energy Efficiency Improvements Task

This information has been carefully compiled using the most accurate information and data available Much of the information was provided by the staff of the Volkhovgypsum Industrial Wastes Recycling Factory, Leningrad Region, Russia Estimates found in the business plan include elements of the authors' subjective judgments and analyses Accurate data needed to support critical elements of the business plan are often difficult to obtain No liability is assumed for the correctness or completeness of the information included in this document Burns and Roe Enterprises, Inc and its subcontractors disclaim all liability for possible errors and omissions in the business plan

The business plan does not include all information required for a complete evaluation of the proposed project by a prospective lender or investor Prospective lenders and investors are strongly encouraged to undertake their own assessments based on the information provided in this document The technical renovation needs of Volkhovgypsum Factory (VF) are constantly changing, thus, details of the project, including costs described herein, will also change

The authors would like to express their appreciation to the staff of Volkhovgypsum Factory for their willingness to provide the data and information required to complete this business plan and their support of the BREI team

All data, evaluations, plans and conclusions presented are as of May 1998 and are based on coordinated opinions of the project development participants All ruble values are stated in "denominated rubles" as of 1998, unless other wise noted

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1 0 Project Summary

The public joint stock company Industrial Wastes Recycling Factory Volkhovgypsum, located in the Leningrad Region, town of Volkhov, Kirovsky Prospect, 29, is providing this application for the funding of the *Natural Drying Upgrade Project*

1 1 General

The project is to be implemented in 1999 and includes the introduction of natural preliminary drying of phosphogypsum in the raw materials warehouse This project is not considered to be technically-complex, and it does not require any innovative technological improvements

The major objectives of the proposed project include electric power and natural gas savings, increase of recycling process, utilization of existing landfill products in the process, stabilization of gypsum quality The upgrading of the Volkhovgypsum Factory is included in the priority list of projects in the Leningrad Region

The financial and economic factors of the project have been calculated in accordance with The Methodological Recommendations for Evaluating Investment Projects Efficiency and Selecting Projects for Financing approved by the State Construction Department of the Russian Federation, the Ministry of Economy of the Russian Federation, the Ministry of Finance of the Russian Federation and the State Committee for Industry of the Russian Federation (March, 1994), and the Guide to Energy Efficiency Bankable Proposals (June 1997) Unless otherwise stated, all reference to rubles are for denominated rubles or those in circulation at the time of this writing

1 2 Summary of Results

1.2 1 Improvements

Table 1-1 summarizes the benefits of the proposed project, including energy savings, fuel savings, and Gypsum production increases

Table 1-1 - Project Benefits

Category	Amount Saved	Notes
Energy Savings	4 2 million kWh /year 2003 (60%)	Energy consumption decreases from 230 kWh/ton to 90 kWh/ton
Fuel Savings (Natural gas)	2 200 tons spec fuel/year 2003 (46%)	Fuel consumption decreases from 160 kg spec fuel/ton to 86 kg spec fuel/ton
Output Increase	up to 20-30 thousand tons/yr	Long term (2006) increase of output is

	increase in 2002-2003	estimated at 100 thousand tons/yr

Other benefits include gypsum quality improvements, factory staffing increase, and environmental improvements in the region

1 2 2 Project Financing and Economics

The proposed project should be implemented within a one-year period beginning 1999 The schedule assumes that contractors and consultants will be brought in to support project implementation Note, any necessary legal and institutional preparatory work is not included in the implementation period

Table 1-2 provides an overview of the assumed loan characteristics for the proposed project

Table 1-2 Loan Structure

Total Project Cost	10 Million Rubles ($1 63 million)
Loan amount*	7 million rubles ($1 14 million)
For	30% - Equipment, 30% - Labor and materials
Term	Five years including the grace period
Grace Period	Two years (construction time)
Construction Begins	1999
Construction Completed	2000

*Remaining 3 million dollars are covered by Volkhovgypsum Factory resources

The results of the economic analysis for the base case scenario are presented in Table 1-3 The cost of the project includes all local taxes

Table 1-3 Financial Analysis of the Energy Efficiency Upgrade

Net Present Value	2,391,100 rubles
Payback Period	3 3 years
Discount Rate	10 %
Profitability Index	1 239
Internal Rate of Return	19 %

The project's internal rate of return (IRR) is 19%, and is normally above the requirements of the multilateral development banks Given the project's reliable economic features, Russian commercial banks may be willing to provide a portion of the required investments

1 2 3 Sensitivity Analysis and Risk Assessment

The base case scenario provides a satisfactory IRR value of 19 % Three sensitivities were looked at

- Case 1(a) - Similar to the base case, but includes additional investments This case provides IRR of 18 5%
- Case 2 - Interest Rate is 20%, Lower cost of gypsum, Increase in inflation This case provides IRR of 13%
- Case 3 - Interest Rate is 10%, Higher cost of gypsum, Decrease in inflation This case provides IRR of 23 1%

Case 2 provides for the most unfavorable conditions and still provides IRR of 13 percent However, according to the risk assessment methodology developed by the Energy Research Institute of the Russian Academy of Sciences (ERI), the probability of Case 2 is low, between 1-3%

The *financial risk* existing in most projects in the Former Soviet Union is primarily related to loan repayment However, property guarantees of the Volkhovgypsum Factory as well as guarantees of the Leningrad Region and Volkhov municipality have been offered as a financial risk mitigation mechanism for this project In addition, Volkhovgypsum Factory is planning to invest 30% of the required amount from their own capital The *political risk* for this project is lower than on average across Russia The political and ethnic situations in the Leningrad Republic have been stable for many years The region does not have the potential for severe social conflicts and confrontations The *technical and construction risks* related to project implementation are also minimal due to the well-proven technology proposed for this project

2 0 Introduction to the Business

2 1 General

Industrial Wastes Recycling Factory Volkhovgypsum was commissioned in 1990 The present organizational and legal form of ownership is that of a public joint stock company with 2 5 million rubles of equity (1997) The state owns 43% of the shares while the remainder of the shares are held by the public Volkhovgypsum Factory currently employs about 70 workers

Contact Information

General director	Oleg I Ivanov
Telephone	812-632-7838
Fax	812-631-3774

Gypsum binder (gypsum) is Volkhovgypsum Factory's major product Silumin, gypsum powders and dusts are also produced in small amounts

In 1997 Volkhovgypsum Factory production was 4,000 tons of gypsum and amounted to 2,503 thousand rubles 1998 projection is approximately 5,000 tons of gypsum

Volkhovgypsum Factory is considered to be a small enterprise in size, but there is a prospective to expand the production capabilities in the near future

2 2 Raw Material Sources

Enterprise uses a relatively simple technology for the production of gypsum The factory operates on the basis of wastes recovered from the neighboring aluminum production plant and the reserves of raw materials are practically inexhaustible (the cost of wastes recovery is around 25 rubles per 1 ton) At the same time a wider use of existing wastes has a positive impact in the area of local environmental improvements The Volkhovgypsum factory has a wide market for its products both in the Northwest region of Russia and in neighboring Republic of Belarus

Presently, about 25 million tons of phosphogypsum have been accumulated at the landfill located about 1 5 km from Volkhovgypsum Factory This impacts local water bodies, such as Volkhov river, Ladoga Lake and even the Baltic sea with phosphates, fluorides and sulfites run-offs Accounting for the industrial output of 90 thousand tons per year (2005) existing storage can provide raw materials for more than 150 years of gypsum production at Volkhovgypsum Factory (1 6 tons of gypsum is consumed to produce one ton of the gypsum binder)

2.3 Major Consumers

Close proximity to St Petersburg (120 km) and to Petrozavodsk (270 km) and satisfactory transportation methods available contribute to the lower cost of transportation to the consumers in the Northwest and Central Regions of Russia and in the Republic of Belarus

2 4 Current Financial Status

Volkhovgypsum Factory does not have any long-term debts The share of energy consumption in the production costs amounted to 29% in 1997

3 0 Nature of the Project

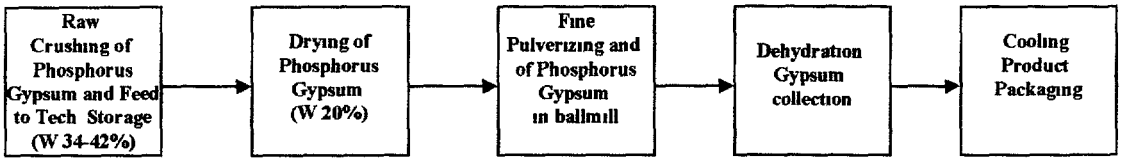
3 1 General

The production of gypsum binder is a two-step process which includes pulverizing and dehydration of phosphogypsum The project proposed will introduce a new natural preliminary drying component The process will take place in the technological warehouse Exhibit 3-1 provides the details of gypsum production process

34

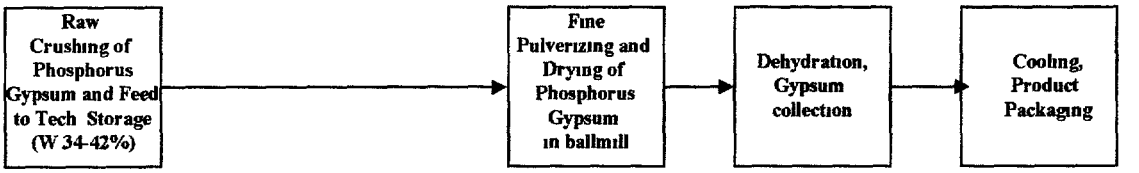
Exhibit 3 1 Process Diagram

Proposed Natural Preliminary Drying Configuration



Energy Consumption = 90 kWh/ton of product, Natural Gas Consumption = 86 kg spec fuel/ton of product

Existing Configuration



Energy Consumption = 230 kWh/ton of product, Natural Gas Consumption = 160 kg spec fuel/ton of product

Presently, the moisture content of phosphogypsum transported to the production lines is up to 42-44% This causes disruptions in the supply of materials and the formation of debris in the processing equipment In addition, this leads to the increased power consumption at the dehydration stage of the process

The proposed natural preliminary phosphogypsum drying stage (three-weeks of open air drying) would bring moisture content of the material down to 25-30% In addition to a higher gypsum quality, this will provide a decrease in electric power consumption by 60% and gas consumption by almost 50% This leads to the potential for the increase of product output

3 2 Project Objectives

The main objective of the proposed project is an upgrade of gypsum production technology process to achieve the following major targets

- Reduce energy component of the gypsum binder production costs
- Increase the volume of gypsum production
- Improve gypsum quality
- Improve environmental conditions of the Town of Volkhov, Volkhov River, Ladoga Lake and the Baltic Sea

35

3 3 Project Implementation

The project is planned to be implemented during a 1 year period beginning in 1999 The total investment need is 10 million rubles Thirty percent of this amount will be covered by Volkhovgypsum Factory resources The remaining 70% will come from the requested loan

The proposed project is included in the Catalogue of Investment Proposals for the Leningrad Region It is supported by Solid Waste Law in the Leningrad Region which is still under review in the Legislative Assembly This law will support the exemption of the waste treatment facilities from regional taxes

3.4 Renovation Impacts

The implementation of the project will allow to obtain the following results

a) Energy savings - up to 60% Energy consumption per one ton of the product is reduced from 230 to 90 kWh, saving up to 4 2 million kWh/year (2003)
b) Fuel savings - up to 46% Natural gas consumption will be reduced from 160 to 86 kg of specific fuel per one ton of the product, saving up to 2 2 thousand tons of specific fuel per year (2003)
c) Gypsum quality improvements
d) 5-6 times increase of gypsum production (up to 20-30 thousand tons/year by 2002-2003) can be expected

Estimated forecast of the gypsum binder production by year is presented below

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Gypsum production (1000 tons)	6	15	20	30	70	90

e) Other effects

- Approximately 130 additional jobs will be created at the factory This is a benefit in the given the current situation on the Russia job market
- Gypsum recycling will be intensified, clearing about 0 5 hectares of the city territory per year
- Provisions for the chemical contamination reduction of Volkhov River, Ladoga Lake and the Baltic Sea

3 5 Risk Assessment

Political and Geographic Risks

The political risk for the proposed project may be considered to be lower than on average across Russia The political and ethnic situation in the Leningrad Region is characterized by tranquillity and lack of social conflicts and confrontation that occur in certain other Russian regions In addition to that, Leningrad Region is located outside the natural disaster zone in Russia Earthquakes, typhoons, and other natural disasters are not common in that region

Technical and Managerial Risks

These risks can also be considered minimal Recycling currently used and the upgrade proposed are not technically complex and have been proven to be reliable This technology is also protected by Russian Federation Patent No 1794925 All necessary documentation, including licenses, certificates, regulations, permits have been approved A certificate (issued by the USSR Ministry of Foreign Economic Relations on September 17, 1991) states that the enterprise has been included into a state register of foreign economic relations and can implement export-import transactions Factory's managerial staff and a skilled team of technical specialists in the field of the phosphogypsum recycling have been working at the factory for many years

The technology for natural preliminary phosphogypsum does not require sophisticated equipment and is limited to commonly available industrial equipment items, such as, bucket cranes, conveyer belts and a clay plow The equipment installation and control of the process are considered routine operations for the factory staff

Financial and Economic Risks

Risk related to demand, supply of the product and deliveries of raw material to Volkhovgypsum Factory is low The Volkhovgypsum Factory has a steady market with good prospects for future expansion Residential housing construction in the North-West region (primarily in St Petersburg and the Leningrad Region) is projected to increase in the near future This will result in a higher demand for gypsum The raw material is located nearby, and the quantity is virtually unlimited

Risk related to loan repayment should be considered However, property guarantees of the factory have been adopted to decrease this risk In addition, the guarantee of the Government of Leningrad, one of the most developed regions of the country, and the guarantee of Volkhov municipal office have been also provided State guarantees of the Leningrad region Government and those of the town of Volkhov have been provided in the form of financial liabilities The Volkhovgypsum Factory is ready to commit 30% of the project cost out of their own resources

Some factors can be considered a reserve (back-up) that will further reduce the above mentioned risks These factors are

- A possibility of gypsum price increase based on a higher quality of the product obtained as a result of the proposed project implementation
- The calculations did not take into account a tax relief provided under Instruction of the State Tax Authority of the Russia Federation # 37, dated August 10, 1995 This instruction states that during the loan repayment period the tax on profits is reduced in the amount of not more that 50% of the tax amount calculated without taking into account a tax relief As a preferential profit tax is set for the Leningrad region (31%), this additional relief allows to reduce tax liabilities by 13 5%
- There is a possibility of additional tax relief for the waste handling enterprises This law is currently being developed by the Legislative Assembly of the Leningrad Region
- The land that is cleared from phosphogypsum in the Town of Volkhov costs about 1,123 rubles per m_2 and can potentially be reclaimed and utilized

Risk Probabilities

- Risk related to loan repayment is estimated to be less than 0 1%
- A probability of demand risk is less than 0 1%

These risk probability figures are based on the risk analysis methodology provided by the Energy Research Institute of the Russian Academy of Sciences

3 6 Project Ratios

Four integral factors have been calculated to show project profitability These factors are as follows (base scenario)

Repayment period (the number of years during which revenues from the production activity conducted by the enterprise will cover costs related to investments)	2 8 years
Discounted period of repayment (at 10%)	3 3 years
Net present (discounted) value (NPV) The sum of net discounted cash revenues minus discounted investment costs	2,391 1 thousand rubles
Investment profitability index Profitability index is a relative factor that characterizes a level of revenues per unit of costs	1 239
Internal rate of return (IRR) shows expected profitability of the project	19%

4 0 Benefits

4 1 Energy Savings/Environmental Improvements

Following energy savings and other benefits are foreseen for the proposed project

Savings and Benefits		
Category	**Amount Saved**	**Notes**
Energy Savings	4 2 million kWh /year 2003 (60%)	Energy consumption decreases from 230 kWh/ton to 90 kWh/ton
Fuel Savings (Natural gas)	2,200 tons spec fuel/year 2003 (46%)	Fuel consumption decreases from 160 kg spec fuel/ton to 86 kg spec fuel/ton
Output Increase	up to 20-30 thousand tons/yr increase in 2002-2003	Long term (2006) increase of output is estimated at 100 thousand tons/yr

Other benefits include gypsum quality improvements and environmental benefits for the Region

4 2 Export Promotion

Currently, all product is sold within in Russia and other countries of Commonwealth of Independent States (CIS) There is a possibility of Western European market penetration because of Volkhovgypsum Factory's competitive pricing and convenient location (close proximity to ports and major railroads) Table 4-1 presents the projected increase in total sales

Table 4-1 - Projected Sales

Year	2000	2001	2002	2003	2004	2005
Annual Increase in Sales	-	9	5	10	40	20
Total Sales (x1000 tons)	6	15	20	30	70	90

5 0 Market Analysis

5.1 General

Volkhovgypsum Factory has a reliable market for selling its product It is determined by the combination of three factors

- High demand for gypsum Gypsum pricing is currently more attractive than other constructions materials, for example cement

- Low availability of gypsum for new construction in Northwest Russia and the Republic of Belarus
- Low production costs at the Volkhovgypsum Factory This helps to preserve a competitive pricing as compared to other factories in Russia

Today, the consumption of gypsum in Russia is 5% of the cement consumption (6% in Central Russia, and only 4% in Northwest Russia) The average worldwide consumption of gypsum is about 30% of cement consumption

In the developed countries, the share of gypsum binder in the housing construction amounts to 80-85% of total amount of binders utilized At the same time, the price for gypsum is comparable to the cement price

The Russian and Belarusian pharmaceutical industries can be considered stable consumers of gypsum Currently, about 30% of Volkhovgypsum factory product is sold to the pharmaceutical companies in these countries

While profitability of cement factories in Russia is 20%, profitability of the gypsum binder production is about 40% Energy costs for gypsum binder production are only one fourth those of cement production The Volkhovgypsum Factory estimates that current demand for gypsum binder in the Northwest region is more than 600 thousand tons per year

5 2 Competition

Kolpino factory is the main competitor of Volkhovgypsum Factory in the Northwest region It produces around 120 thousand tons of gypsum binder per year

Voskresensk factory in the Central region produces a special kind of gypsum (alfagypsum) the demand for which does not exceed 3% of the total gypsum consumption in Russia This plant can not be considered to be a competitor to the Volkhovgypsum Factory

5 3 Gypsum Demand and Price

An increasing demand for gypsum binder in the Northwest region today is not satisfied Gypsum is imported from the Central region and outside Russia in the form of dry mixtures (from Germany, Sweden, Finland, Norway, Poland) Volkhovgypsum Factory has a reason for future expansion to increase sales of gypsum in the Northwest region of Russia and the Republic of Belarus

Due to the cheap raw material (55 rubles per one ton in 1997 including transportation costs), Volkhovgypsum Factory can sell its product at the price of 600 rubles per ton Competitors price is around 820 rubles per ton In case the proposed project can be implemented, Volkhovgypsum Factory can decrease the product price to 500 rubles/ton by the year 2005

6.0 Financial Plan Assumptions and Project Costs

6 1 General Project Assumptions

The following assumptions were made while preparing input data for calculating the base scenario of the financial plan

The beginning of the project	January 1, 1999
The duration of construction	1 year
Project currency	ruble

The tariff for electric power supplied to the gypsum plant is assumed to be 0 246 US$/kWh in 1999 Other general economic parameters used in the financing plan are presented in Table 6-1

Table 6-1 - General Economic Parameters

Annual inflation, % (*)

Year	1999	2000	2001	2002	2003	2004
Maximum	6 3	5 2	4 6	4 3	4 0	3 7
Base	5 7	4 7	4 2	3 9	3 7	3 5
Minimal	5 1	4 2	3 7	3 5	3 4	3 2

Gypsum Binder Price, rubles/ton(**)

Year	1999	2000	2001	2002	2003	2004
Maximum		800	790	765	730	700
Base		800	780	755	650	600
Minimal		800	770	670	600	550

Electricity Tariff (without inflation), ruble/kWh (***)

Year	1999	2000	2001	2002	2003	2004
Base	0 246	0 238	0 237	0 236	0 235	0 234

Natural Gas Tariff, ruble/ton of specific fuel (***)

Year	1999	2000	2001	2002	2003	2004
Base	350	355	360	365	370	380

(*) Forecast submitted by Russia's Ministry of Economy Inflation for payroll has been assumed with a constant coefficient 1 08 to industrial inflation (based on data submitted by the pro-rector of the Higher

41

Economic University, E E Gavrilenkov Moscow) Dollar exchange rate – official forecast of Russia's Ministry of Economy (May 1998) till the year 2001, after that year the data is estimated Current (May 1998) rate is 1 USD = 6 14 rubles
(**) Forecast submitted by the Volkhovgypsum Factory
(***) Energy Efficiency and Demand Group forecast, Energosetproject, Moscow

6 2 Interest and Discount Rates

The following interest rates were used

- Worst case scenario 20% per annum
- Base case scenario 15% per annum
- Best case scenario 10% per annum

The discount rate is 10% per annum These figure was discussed and verified with EBRD representatives in Moscow and Helsinki

Dividends are paid at 10% for base and best cases and 5% for worst case scenario

The equipment to be housed in the warehouse structure is assumed to have a 10 year useful life The useful life for trucks life is expected to be 5 years, as per Volkhovgypsum Factory experience records

6 3 Capital Investment Schedule and Loan Structure

The total investment required for the proposed project is estimated to be 10 million rubles 30% of this amount will be covered by Volkhovgypsum Factory using their own funds The remaining 70% will be financed with the proceeds of a 5-year loan

The loan repayment schedule (in x1000 of rubles) is as shown in Table 6-2

Table 6-2 - Loan Principal Amount Repayment Schedule

Year	1999	2000	2001	2002	2003
Loan draw down	7000				
Debts as of the beginning of the year	7000	7000	7000	4000	2000
Loan repayment			3000	2000	2000
Debt as of the end of the year	7000	7000	4000	2000	0

7.0 Cash flow Projections and Financial Viability

7 1 Taxation and Inflation

Taxes, presented in Table 7-1 are used in the cash flow calculations Land tax is not used Its value is negligible and does not impact the calculations in any way Tax rates are assumed to be constant for the duration of the project

Table 7-1 – Tax Rates (%)

Basis	Overhead*	Profit Tax
Pension fund	28	
Social security	5 4	
Employment fund	1 5	
Medical insurance	3 6	
Life insurance	1 0	
Property tax		2 0
Profit tax		31 0
Housing tax		--
Roads tax		3 0
Local tax		--

* - Land tax is excluded

Inflation rate with the breakdown by specific costs components is presented in the following table 7-2 for the base scenario (% per year)

Table 7-2 - Inflation rate

Year	1999	2000	2001	2002	2003	2004
Total costs	5 7	4 7	4 2	3 9	3 7	3 5
Payroll costs	6 2	5 1	4 5	4 2	4 0	3 8

7 2 Cash flow Projections

The financial performance of the project is presented in the following tables

Table 7-3 - Profit and Loss Balance
Table 7-4 - Cash Flow
Table 7-5 - Balance Sheet
Table 7-6 - Ratios

43

Table 7-3 Profit and Loss Balance
(1000 of rubles if not stated otherwise)

Year	**1999**	**2000**	**2001**	**2002**	**2003**
Gypsum output, 1000 tons		6	15	20	30
Price per ton		800	780	755	650
Revenues, 1000 rubles		4,800	11,700	15,100	19,500
Production costs					
Raw and aux materials		330	859	1,190	1,852
Electric power		134	333	441	658
Natural Gas		191	483	652	989
Payroll with overheads		690	1,725	2,300	3,450
Other direct costs		480	1,200	1,600	2,400
Total, direct costs		1,826	4,601	6,184	9,350
Depreciation		700	700	700	700
Other fixed costs		365	920	1,236	1,870
Total, fixed costs		1,065	1,620	1,937	2,570
Taxable profit		1,908	5,477	6,978	7,579
Profit tax		592	1,698	2,163	2,350
Other taxes		237	409	494	604
Net profit		1,080	3,370	4,321	4,625
Cumulative net profit		1,080	4,450	8,771	13,396

44

Table 7-4 - Cash Flow
(1000 of rubles if not stated otherwise)

Year	1999	2000	2001	2002	2003
Investments	-10,000				
Cumulative investments	-10,000	-10,000	-10,000	-10,000	-10,000
Discounted Investments	-10,000				
Discounted Cumulative investments	-10,000	-10,000	-10,000	-10,000	-10,000
Revenues, 1000 rubles	0	4,800	11,700	15,100,0	19,500
Direct costs		1,826	4,601	6,184	9,350
Fixed costs		1,065	1,620	1,936	2,570
Taxable profit		1,908	5,477	6,978	7,579
Profit tax		591	1,698	2,163	2,349
Net profit		1,079	3,370	4,320	4,625
Net cash revenues		1,779	4,070	5,020	5,325
Cumulative net cash revenues		1,779	5,849	10,870	16,195
Discounted net cash revenues		1,547	3,077	3,301	3,044
Cumulative discounted net cash		1,547	4,625	7,926	10,971
Equity	3,000				
Dividend payment				300	300
Balance of stock holding activity	3,000	0	0	-300	-300
Cumulative balance of stock holding	3,000	3,000	3,000	2,700	2,400
Long-term loan	7,000	0	0		
Loan repayment			3,000	2,000	2,000
Interest rate on the loan		1,050	1,050	600	300
Balance	7,000	-1,050	-4,050	-2,600	-2,300
Cumulative balance	7,000	5,950	1,900	-700	-3,000
Balance of accrued funds	0	729	20	2,120	2,725
Balance of cumulative accrued funds	0	729	749	2,870	5,596

45

Table 7-5 - Balance Sheet
(1000 of rubles if not stated otherwise)

Year	1999	2000	2001	2002	2003
Fixed (off-current) assets	10,000	10 000	10,000	10,000	10,000
Depreciation		-700 0	-1,400 0	-2,100 0	-2,800 0
Total depreciated cost	10,000	9,300	8,600	7,900	7,200
Current (working) assets		729	749	2,870	5,596
Total assets	10,000	10,029	9,349	10,770	12,796
Equity	3,000	3,000	3,000	3,000	3,000
Dividends			0	-300	-300
Cumulative dividends			0	-300	-600
Retained profit	0	1,079	4,449	8,770	13,396
Total equity	3,000	4 079	7,449	11,470	15,796
Long-term liabilities	7,000	5,950	1,900	-700	-3,000
Current liabilities		0	0	0	0
Total liabilities	10,000	10,029	9,349	10,770	12,796

Table 7-6
Ratios (Base Case)

Repayment period, years	2 8
Repayment period with discounting, years	3 3
Net present value (NPV), x1000 rubles	2,391 1
Investment profitability index	1 239
IRR	19 %

7 3 Assessment of the Sensitivity Calculation Results

Table 7-7 presents a comparison of all ratios under different sensitivities reviewed Note For scenario descriptions refer to Table 6-1)

Table 7-7 - Sensitivity Analysis

Case	1 (Base)	1(a)*	2	3
Interest Rate	15%	20%	20%	10%
Gypsum Price	Base	Base	Low	High
Inflation	Base	Base	High	Low
Repayment period, years	2 8	3 1	3 1	2 8
Repayment period, with discounting	2 8	3 1	3 1	2 8
NPV, 1000 rubles	2391	1409	750	3694
Profitability index	1 24	1 13	1 08	1 37
IRR, %	19 0	18 5	13 0	23 1

*** - Base with additional investment costs**

The base scenario is characterized positively in terms of all factors of the project Case 1(a) (20% interest rate, maximal inflation rate and a dollar exchange rate, gypsum base price), is also acceptable The best results are achieved when the most favorable values of input data are combined together (Case 3)

In case when all input data is unfavorable (scenario 2), project factors become worse However, the probability of the worst combination of all input parameters is not very high and is estimated at the level of 1-3% (according to ERI methodology)

The assessment of the probabilities of the reviewed scenarios occurrences, as per ERI methodology, is as follows

Case 1	Case 1(a)	Case	Case 3
0 6	0 18	0 02	0 2

The findings presented above provide evidence of high reliability and stability of the project

To perform a more detailed sensitivity analysis, additional calculations have been conducted in order to determine the impact of major production costs items on project

efficiency The following categories were reviewed raw material costs fluctuations, and electricity consumption increase

The conducted analysis shows that the project will still be economically viable if

- raw material costs and material costs go up another 20 % from the base value
- electric power costs go up another 18% from the base value
- salary goes up 37%

48

APPENDIX

(1995-97 Volkhovgypsum Factory Financial Reports)

NORTH-WEST REGION POWER INWESTMENT PLAN

Prefeasibility Study of

SOSNOVY BOR NUCLEAR POWER PLANT

2 x VVER-640

July 1998

50

Contents

1 INTRODUCTION 3
2 PROJECT BACKGROUND 3
3 DESCRIPTION OF THE EXISTING CONDITIONS 3
4 ALTERNATIVE PLANT CONCEPTS 4
5 TECHNICAL EVALUATION OF THE PLANT CONCEPT 5
5 1 General description *5*
5 2 Brief Description of Main Systems and Equipment of the Reactor Plant *11*
5 2 1 Reactor Core 12
5 2 2 Main Circulation Pump (MCP) 12
5 2 3 Pressurizer 12
5 2 4 Steam Generator (SG) 12
5 2 5 Safety systems 12
5 3 Processing and Handling of Liquid Radioactive Substances and Wastes *13*
5 4 Systems and Equipment of the Turbine Plant *13*
5 5 Fuel Handling *14*
5 6 Electrical Plant *14*
5 7 I&C Systems *15*
5 8 Major Features of the Approach to Safety *16*
5 8 1 Regulatory Requirements 16
5 8 2 Safety Concept 18
6 ENVIRONMENTAL ASPECTS 20
7 PROJECT COSTS AND O&M COSTS 24
8 ECONOMIC ANALYSIS 26
9 FINANCING 28
10 PROJECT IMPLEMENTATION PLAN 28
10 1 Project organisations *28*
10 2 Time schedule *29*
10 3 Project risks *30*

1 Introduction

General purposes of this study are expressed in the Terms of References and in the Work Plan of the Project for North-West Region Power Investment Plan This study report provides information on technical and safety features and economic aspects of the proposed construction of a new nuclear power plant comprising two VVER-640 units in Sosnovy Bor The aim of the study was to evaluate if the planned project is feasible alternative from technical, economic and safety point of view to be taken into consideration in planning investments to the north-western energy systems within the time frame till year 2010 defined for the study

The need to study alternatives for new power generation cpacity arises from the fact that four nuclear power units in the north west Russia with total generation capacity of 2880 MW are planned to be decommissioned in years 2003 - 2005 Necessity to conduct an analysis of the energy investment alternatives to continued operation of nuclear plants is expressed in the agreement between Russian government and EBRD/NSA

This study on implementation of new nuclear capacity in Sosnovy Bor was conducted by the Russia-Finnish joint team Partisipants were from Russia side - RRC "Kurchatov Institute, Sankt-Peterburg Institute Atomenergoproekt and concern "Rosenergoatom", from Finnish side - Finnish Energy Conservation Group (FECG) All technical and economic data used in this study were collected from the Russian sources Review of the data and comparision with corresponding western experience was done by FECG

2 Project background

Nuclear industry in Russia is primarly based on PWR technology of VVER-440 and VVER-1000 types and grafit moderated channel reactors of type RBMK Both VVER-440 and RBMK reactors present technology from sixtees VVER-1000 is yunger design, but neither it is a reactor type for the future The development and realization of new nuclear power plant (NPP) projects with improved technical and economic parameters is an urgent necessity for the development of nuclear power (NP) as part of the Russian energy system and a priority task of Russia's MINATOM

New rector types with passive safety features are under development in the design institutes Design of the medium power NPP, called VVER-640, with electric output of 645 MW is at the moment ready enough for consideration of a demonstration plant project The site of the nuclear facilities in the city of Sosnovy Bor has been selected for the site of first VVER-640 The regulatory body Gosatomnazor (GAN) has awarded permission for construction of that plant in 1996

The AO Lenenergo has energy surplus at the moment but due to decommissioning of first units of Leningrad NPP, there will be need for new generation capacity in the area during the analysed period till 2010 In this study a new nuclear power project with two VVER-640 units is considered

3 Description of the existing conditions

The existing Leningrad NPP In Sosnovy Bor has four RBMK reactors of 1000 MW electric output each Design service life of 30 years of the units will end and they will be shut down as follows

Unit 1	2003
Unit 2	2005
Unit 3	2009
Unit 4	2011

The nuclear generation capacity in the area will decrease by 3000 MW in years 2003 2009 There is at the moment energy surplus in the area of AO Lenenergo, and it is supplying power through many connections to the neighbouring energy systems in Russia and abroad Some new generation capacity is however expected to be required during the considered period till 2010 to compensate the decommissioned nuclear plants Rather large energy surplus in the area allows to consider replacing capacity not equivalent to the decomissioned one The required new capacity is evaluated in detail in the report of the Planning and Modelling Team taking into account forcasted deveopment in demand of electricity, existing power plants, new power plants under construction or decided, planned new projects, export and import

The new nuclear power plant is planned to be located in Sosnovy Bor in area of the scientific institute NITI, which is conducting experimental studies for verification the design and safety features of VVER-640 concept Due to the existing Leningrad power plant with four RBMK reactors in the vicinity of the planned new site, there are ready infrastructere for construction, operation and maintenance of a nuclear power plant The main designer of the power plant concept is Sankt Petersburg Atomenergoproekt (SPAEP) in Sankt Petersburg, not far from the proposed site of the demonstration plant Also the suppliers of the main components are in the Leningrad region The fact that of all those organisation important for implementation of the project are located near to Sosnovy Bor makes it a most suitable place for construction of the demonstration plant from project management point of view

The new power plant is proposed to be located in the area not far away from the site of the existing Leningrad NPP Connections with the electric network, raw water source, railway, etc do not need long new structures

Both the need to find a site for construction of a demonstration plant of reactor concept VVER-640, suitability of Sosnovy Bor site for that purpose and demand to erect new generation capacity in the area because of decommissioning of first units of Leningrad NPP, support the proposal to construct a VVER-640 plant in Sosnovy Bor

4 Alternative plant concepts

For selection of the type of new nuclear power plant for Sosnovy Bor an international evaluation of proposed options was organised in Sankt Petersburg in 1992 The proposed reactor concepts were VVER-91, VVER-92 and VVER-640 (called at that time NP-500) The evaluation team recommended VVER-640 for the next power plant in Sosnovy Bor

VVER-640 is a medium power NPP with gross electric output of 640 MW Sankt Petersburg Atomenergoproekt (SPAEP) has been the main designer in development of this power plant concept OKB Gidropres from Podolsk is main designer of the reactor installation The primary and secondary side processes of the energy production and their components do not include much new innovations Reactor pressure vessel and most of the other main components are either a copy or a modification of the components used in VVER-1000 The safety systems include totally new innovations having more passive features than the older reactor generations

VVER-91 concept is an evolutionary development of the standard Soviet VVER-1000 power plant VVER-91 utilizes the main components of standard VVER-1000 and also elsewhere the design is based on proven solutions Main areas of improvements compared with standard VVER-1000 are economy and safety

The engineering and design work of VVER-91 was done by Sankt Petersburg Atomenergoproekt and IVO Power Engineering Ltd (former IVO International Ltd) acting as consult VVER-91 was developed as an option for Kola 2 power plant and later for competition on third nuclear unit of Finland Neither of those projects realized, but at the moment there is a project to deliver to China a nuclear power plant based on VVER-91 concept

VVER-92 was developed by Moscow Atomenergoproektt It is also based on VVER-1000, but has more "revolutionary" new solutions than VVER-91 This concept was not designed as ready as VVER-91 It participated in selection of reactor type both for Kola 2 and Sosnovy Bor There is no projects based on that technology, and its development work has been cancelled

In Russia there is under development also a large power NPP called VVER-1500, with electric output of 1500 MW gross Considerations to replace the units of Leningrad NPP by that type of reactors are preliminary assessments only Development and design of VVER-1500 are still in conceptual phase and it is not available within the timeframe to be considered in the North-West region power investment plan

5 Technical evaluation of the plant concept

5.1 General description

VVER-640 nuclear power plant project with the V-407 reactor is developed in accordance with the Russian Federal Programme "Environmentally Clean Power" The main goal of development was to create the design of a competitive, medium-power nuclear power plant with enhanced safety features The design is based on more than 30 years experience in the construction of nuclear power plants with pressurized water reactors (PWR) in Russia and abroad Mostly technologies and systems proven during design, construction and operation of the proceeding NPP generations are used The safety systems are comprised of both traditional systems, such as the sprinkler systems and systems of forced circulation with emergency power supply from diesel generators, and passive systems of residual heat removal to the ultimate heat sink that allow to undergo design accidents without external power supply

The main design parameters of the VVER-640 power plant unit is given in table 5-1 The lay out of the main buildings is shown in Figure 5-1 and unit cross-section by the reactor and turbine plants in Fig 5- 2 Figure 5-3 gives the principal scheme of main systems

The unit includes a V-407 reactor installation and one turbine in a two-circuit design The primary circuit contains the VVER-640 (V-407) thermal reactor, four main circulation loops, steam pressurizer and auxiliary equipment located within a containment Each loop includes a horizontal steam generator (SG), main circulation pump (MCP), main DU620 pipeline made of stainless steel

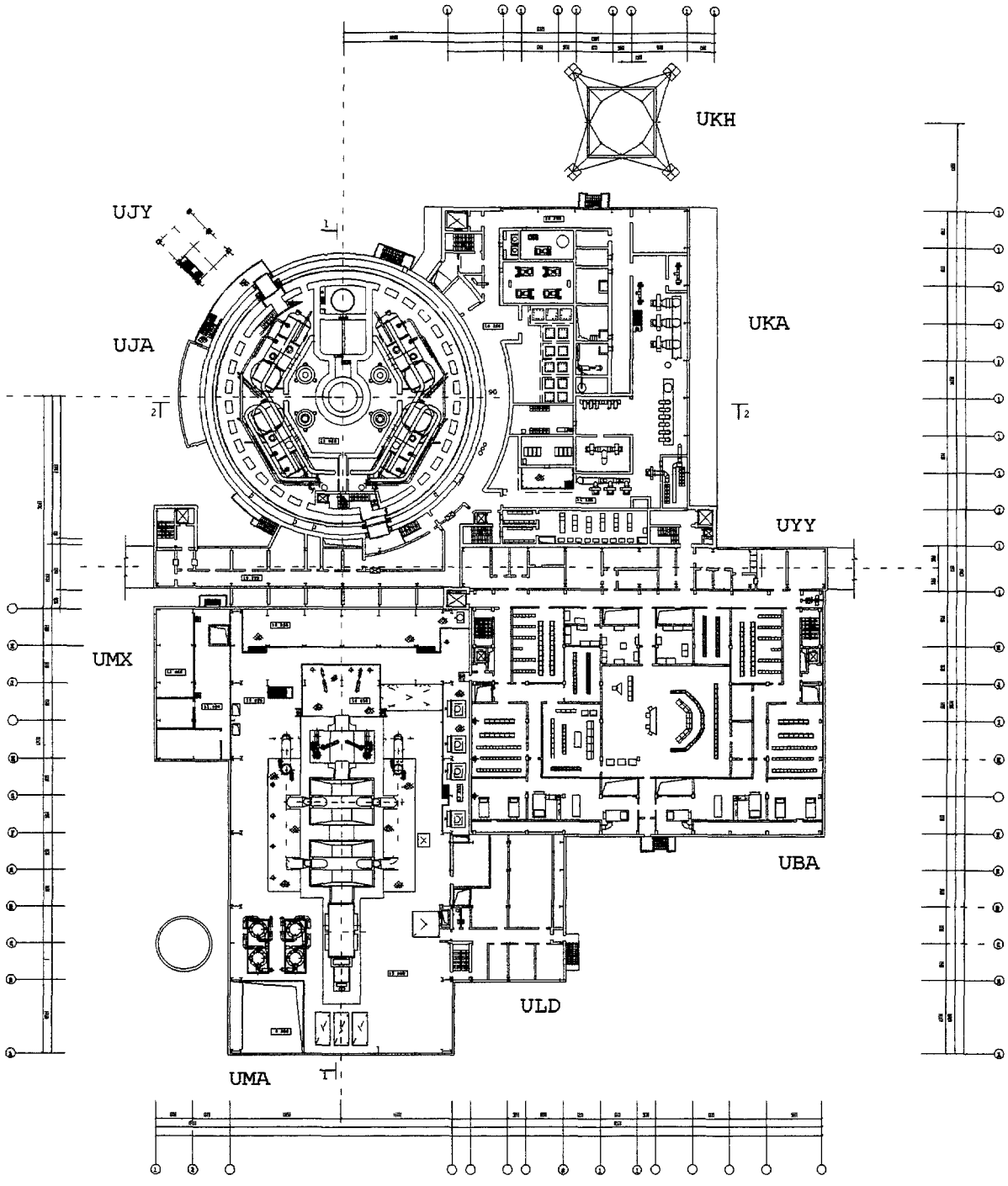
The secondary circuit is comprised of the steam side of the SGs, main steam lines, the turbine, deaeration systems, regeneration and feedwater systems and auxiliary equipment The turbine is of a one-shaft type with one high and medium pressure cylinder (HMPC), and two two-stream low pressure cylinders (LPC) For the last turbine step a 1200 mm blade is used

The generator has a complete water cooling system and it does not require hydrogen In-house electricity consumers are fed by AC current circuits of 6 kV, 0 4 kV and 220 V

Complying with national safety standards, the unit concept corresponds in general to the international trends in the development of nuclear power The unit corresponds to the class of evolutionary projects with the use of passive safety systems An combination of active and passive elements in the safety systems, use of equipment and systems well-proved in the national practice, the use of such solutions as a double containment, pool cooling of the core etc are used to increase the safety and reliability of the plant

Table 1 1

Main Characteristics of the VVER-640 Reactor Plant	
Reactor type	V-407 (PWR)
Thermal rated power, MW	1 800
Number of loops	4
Pressure in the reactor at outlet of the core, MPa	15 7
Temperature of coolant in the reactor °C - at outlet - at inlet	 323 3 293 7
Fuel loading, tons of U	68 64
Average enrichment of fresh fuel, %	3 45
Averagedischarge burn-up, MW day/kgU	39 6
Average specific energy density of the core, KW/l	64 5
Steam generator type	horizontal
Steam generation, tons/h	3576
Steam pressure in the steam generator, MPa	7 06
Turbine	K-600-6 9/50 (LMZ)
Number of turbines per unit	1
Rated power of the turbine, MW	645
Rotation frequency, rpm	3,000
Parameters of steam upstream from the turbine - pressure, MPa - temperature, °C - degree of dryness	 6 9 284 5 0 995
Pressure in the condenser, kPa	4 9
Generator	TZV-630-2UZ
Unit net efficiency, %	33 3
Design life time, years	50



UJA - Reactor building

UMA - Turbine building

ULD - Condensate treatment plant

UKA - Auxiliary building

UBA -Control building

Figure 5-1 Layout of the Main Unit Buildings

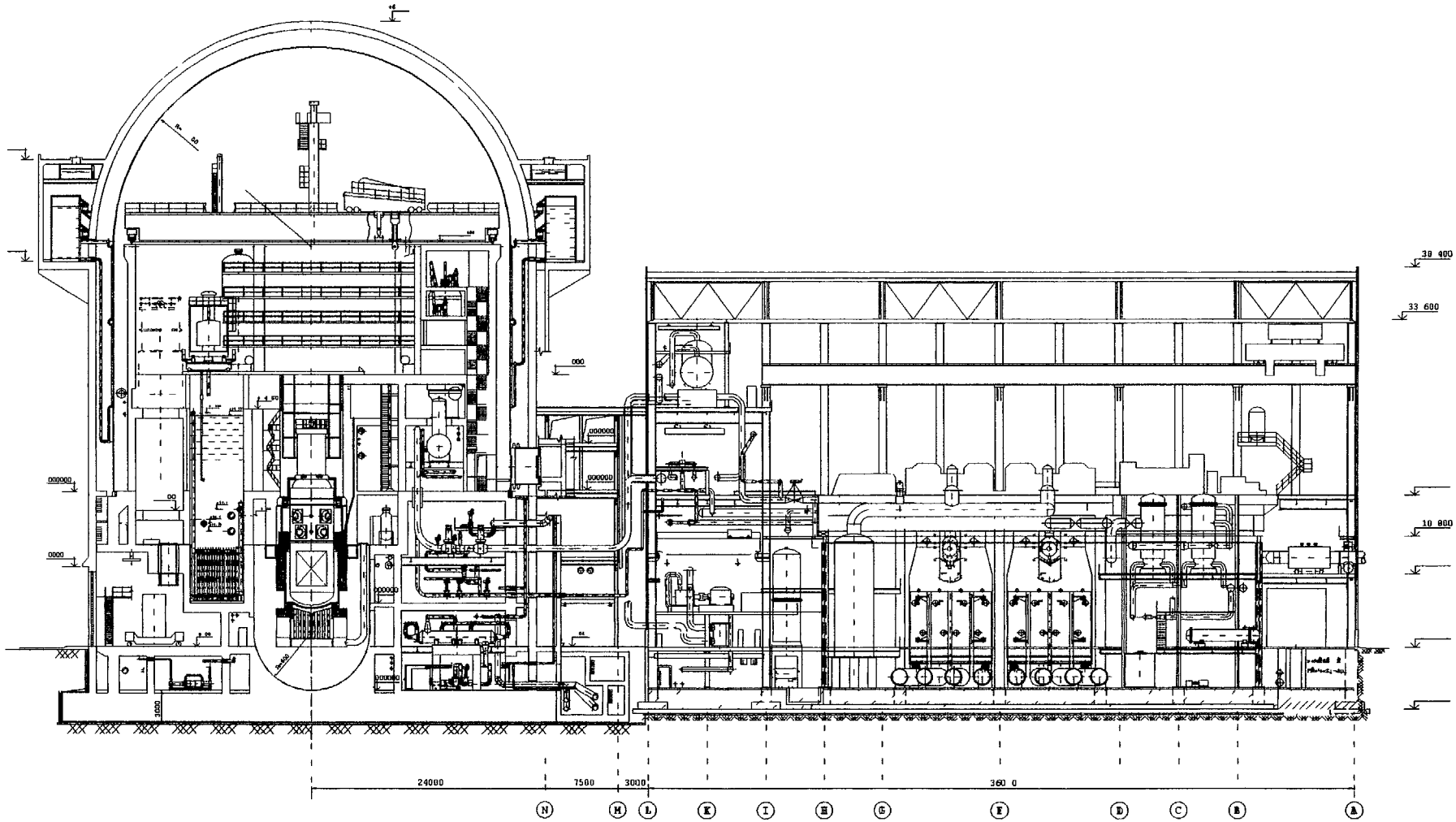


Figure 5-2 Unit Cross-section by the Reactor and Turbine Plant.

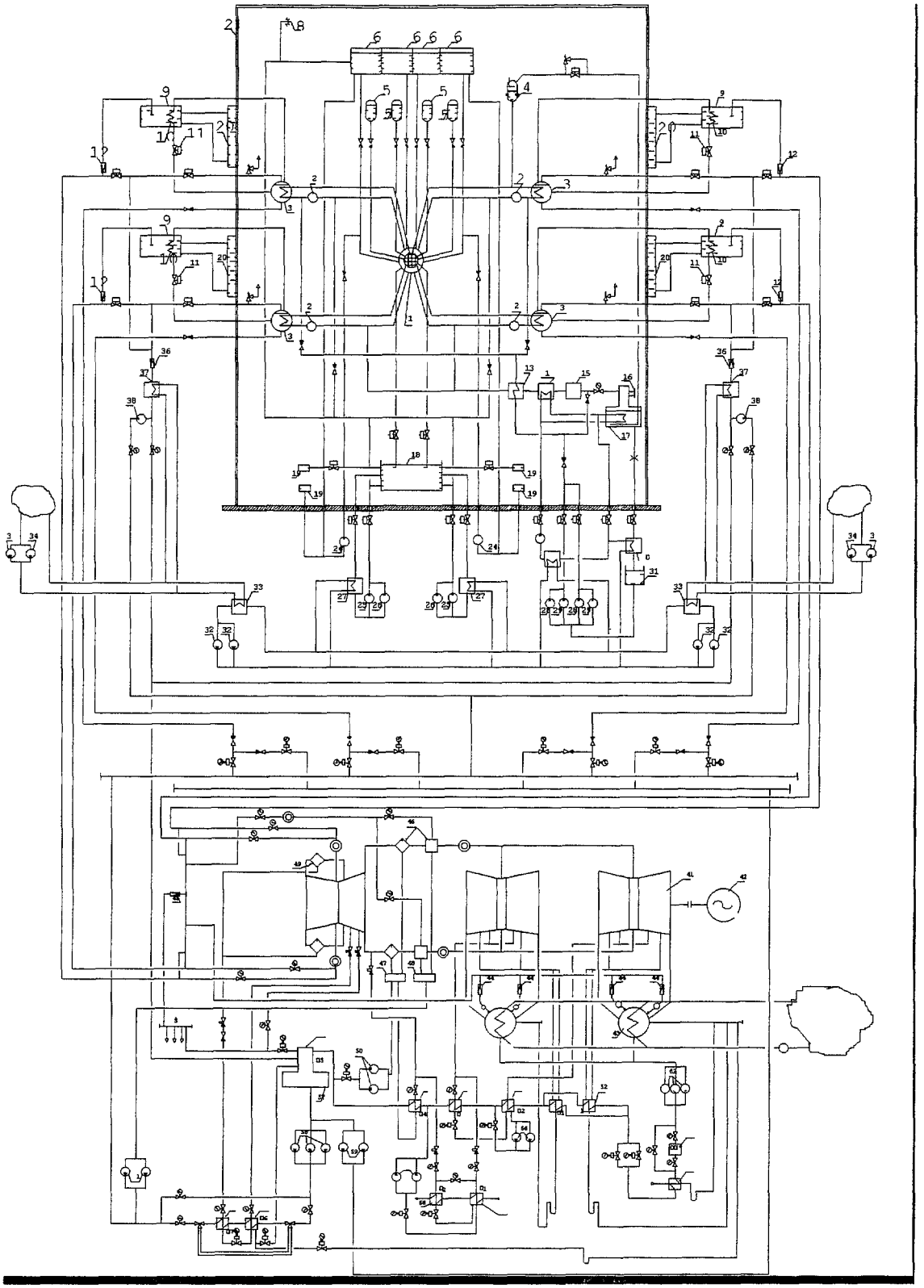


Figure 5-3 Principle Scheme of Main Systems

List of components in Figure 5-3

1 Reactor
2 Primary coolant pump
3 Steam generator
4 Pressurizer
5 H p ECCS accumulator tank
6 ECCS tank
8 Sprinkler
9 Chemically demineralized water storage tank
10 heat exchanger of passive heat removal system
11 Startup valve of passive heat removal system
12 Quick-acting pressure reducing plant
13 Regenerative heat exchanger of primary circuit makeup-blowdown system
14 Aftercooler of primary circuit makeup-blowdown system
15 Coolant treatment plant
16 Protective membrane
17 Bubbler-degasser
18 Fuel pond
19 Screen filter
20 Cooler of passive heat removal from containment
21 Containment
24 Pump of emergency cooling
25 Fuel cooling system pump
26 Fuel cooling system pump
27 Fuel cooling system heat exchanger
28 Primary circuit makeup-blowdown system pump
29 Primary circuit makeup-blowdown system pump
30 Coolant removal heat exchanger
31 Damper tank of the primary circuit makeup-blowdown system
32 Pump for the reactor building consumer intermediate cooling circuit
33 Heat exchanger for the reactor building consumer intermediate cooling circuit
34 Reactor building cooling water system pump
36 Pressure reducing plant
37 Heat exchanger for reactor heat removal
38 Pump for reactor heat removal
41 Steam-driven turbine
42 Generator
43 Condenser
44 Quick-acting pressure reducing plant of steam discharge into condenser
45 Quick-acting pressure reducing plant of steam supply for auxiliaries
46 Moisture separator-reheater (SR)
47 SR separated moisture collecting tank
48 SR condensate collecting tank
61 H p heater No7
62 Condensate pump
63 Condensate pump of unit water demineralization plant
49 First-stage separator
50 SR separated moisture pump
51 SR condensate pump
52 L p heater No1
53 L p heater No2
54 L p heater No3
55 L p heater No4
56 Deaeration column
57 Deaerator tank
58 Feed water pumps
59 Auxiliare feed water pump
60 H p heater No6
64 Condensate treatment plant
65 Heater
66 Drain pump of l p heater 12
67 Network main heater
68 Network peak-load heater

5 2 Brief Description of Main Systems and Equipment of the Reactor Plant

NPP with VVER-640 is designed for electricity generation in the base load mode A possibility of heat supply to external customers is provided, but not concidered in this study The equipment is designed with due regard of the possibility of electricity

generation in the daily load-following mode Estimates are made for the reliability of operation of the reactor core and unit systems that showed the sufficiency of design solutions for power maneuvering

Layout and cross section drawings of the reactor plant and pictures of the main components are in Appendix 1

5 2 1 Reactor Core

The reactor core of V-407 contains 163 fuel assemblies (FA) that are used also for the placement of control rods and unmovable burnable absorbers

As fuel, slightly enriched uranium dioxide is used as in VVER-1000 and VVER-440 reactors The fuel campaign in the stationary mode is 298 effective days The average discharge burup of fuel is 39 6 MWd/kgU The maximum average burnup of a fuel assembly is 45 5 MWd/kg U, the maximum average burnup of a fuel rod is 49 0 MWd/kg U, the maximum average burnup of a fuel pellet is 54 1 MWd/kg U

5 2 2 Main Circulation Pump (MCP)

The multi-year experience of design and operation of MCPs for NPPs with VVER reactors was taken into account in the design of the MCP as well as results of research and development studies with long-term verification of the lifetime of major components

5 2 3 Pressurizer

The well-proved and currently used VVER-1000 pressurizer is used

5 2 4 Steam Generator (SG)

The SG is a one case device of horizontal type All construction materials that are used for SG manufacturing have been tested in operation of NPPs with VVER-1000 and VVER-440, they are certified and approved by GAN RF

5 2 5 Safety systems

In case of full black-out accidents (loss of in-house needs power and unit diesel generators) a system of passive heat removal from the SGs is activated for the cooling of the reactor and heat transfer to the reservoirs of emergency heat removal

In accidents with the loss of coolant in the primary circuit boron solution is supplied to the reactor from the reservoirs of the emergency core cooling system (ECCS) The activation pressure of the ECCS reservoirs is 4 0 MPa In case of further pressure reduction in the primary circuit the flooding of the core from ECCS reservoirs follows The coolant leaving the reactor from the break is collected on the containment floor in the emergency cooling pool

To guarantee water supply from ECCS reservoirs, in case of pressure decrease to 0 6 MPa there occurs an automatic opening of release valves that connect the reactor with the fuel loading pool As the primary circuit, emergency reservoirs and reservoirs of ECCS become empty, the water level in the emergency pool exceeds the reactor outlets

and a natural circulation circuit is created that contains the core - release valve above the core - fuel loading pool - release valve under the core - the core

Heat removal from the fuel loading pool is provided by the evaporation of some part of the coolant with subsequent steam condensation at the walls and within the metal containment and the return of the condensate to the emergency pool Water supply to the fuel loading pool is provided from the emergency pool through a connection valve

Heat removal from the containment is provided through the wall to the water of the system of containment cooling by natural circulation between the reservoir of emergency cooling and containment cooling channels The quantity of water in the reservoir is designed for cooling for at least 24 hours, the single failure principle taken into account

In accordance with the safety concept, it is assumed that after 24 hours the residual heat is removed with the systems of normal operation important for safety that have a permanent source of cooling water and reliable power supply from unit diesel generators

5 3. Processing and Handling of Liquid Radioactive Substances and Wastes

A number of technical solutions are implemented in the project in order to minimize the amount of liquid radioactive substances (LRS) and decrease the degree of salt contents

- separate collection of LRSs depending on the activity with reuse of low-active mediums,
- maximum use of no-waste technologies,
- use of low-waste deactivation methods,
- renunciation of the regeneration of low-salt water filters,
- use of cleaned circuit water only for feeding the primary circuit

Under the condition of strict observance of operation procedures by NPP staff the design amount of waste waters is 8000 m^3/year per unit, only 10% or less with the salt content of 1 5 g/l and higher

Technical solutions for the systems of collection and processing of LRSs result in the absence of LRS release beyond NPP limits due to the organization of closed water circuits with the reuse of cleaned water in the NPP cycle

5 4. Systems and Equipment of the Turbine Plant

Turbine plant K-600-6,9/50 is of a one-shaft type with one high and medium pressure cylinder (HMPC), and two two-stream low pressure cylinders (LPC) The structural arrangement is HMPC + 2LPC + Generator The LPCs are unified with the currently used K-1000-60/3000 turbine

The steam condensing plant K-600-6,9/50 without regulated steam take-outs, with intermediate steam separation and one-step steam superheater is designed for direct rotation of an alternate current generator of the TZV type with full water cooling and the power of 645 MW, with the rotation frequency of 3000 rot/min, and for heat supply with the intensity up to 250 Gcal/hour for centralized heat supply to industrial and non-industrial customers in the temperature range of 150/70 °C

The principal thermal scheme includes 4 low pressure heaters (LPH), deaerator of increased pressure (1 3 MPa abs) that operates at changing pressure in transient modes, and 2 high pressure heaters (LPH)

5 5 Fuel Handling

The transportation and technological part for fuel handling at the NPP ensures

- receipt and storage of fresh nuclear fuel,
- fuel preparation for loading into the reactor,
- fuel reloading in the reactor core,
- fuel unloading from the reactor core,
- intermediate storage of spent nuclear fuel up to 5 years,
- temporary storage of spent nuclear fuel (after the intermediate storage) in universal transportation containers before sending in a car-container train to the regeneration plant (a "dry" storage technique is implemented),
- transportation of fresh and spent nuclear fuel in the NPP territory,
- sending of spent nuclear fuel (after the intermediate storage) to the regeneration plant,
- biological protection of the staff at all phases of reloading, transportation and storage of nuclear fuel

The works for receiving fresh nuclear fuel at the NPP and for sending spent nuclear fuel after temporary storage from the NPP are performed at a railway terminal with all necessary equipment

Receipt, storage and preparation of fresh fuel before the loading into the reactor are performed in the fresh fuel storage facility

The reloading of nuclear fuel in the reactor and storage of spent nuclear fuel in the reloading pool are performed in the reactor building of the unit

Storage (temporary storage) of spent nuclear fuel in the reactor building is performed in the reloading pool for not less than 3 years, the storage volume of the reloading pool being sufficient for storage (temporary storage) of spent nuclear fuel during 5 years

Storage of spent nuclear fuel after the temporary storage in the reactor building and before the shipment to the reprocessing plant is performed in the spent fuel storage facility that is an intermediate storage facility of the container type Upon request of the client, storage of nuclear fuel can be provided up to the time of NPP decommissioning

5.6. Electrical Plant

By design, NPP is comprised of several power units with VVER-640 reactors and generators of the power of 645 MW

Use of synchronized generator of the TZV-630-2 type is assumed with the following parameters nominal power 645 MW, voltage 20 kV, rotation speed 3000 rot/min with full water cooling, the

internals filled in with air under quasi-atmospheric pressure, use of fire-resistant liquid OMTI in the bearing lubrication system is possible

The TZV-630-2 generator is explosion- and fire-safe and complies with equipment requirements for the equipment of group "B" of explosion- and fire-hazard

For operation with the TZV-630-2 generator a unit transformer of the power 800 MVA is foreseen which is a three-phase, two-coil increasing transformer

For ensuring in-house needs redundancy the installation of two reserve in-house needs transformers with the power of 63 MVA is foreseen

The following systems for power supply to in-house consumers are provided

- system of normal operation,
- system of reliable power supply for normal operation of the systems important for safety including unit diesel generators,
- system of emergency power supply including emergency diesel generators

5 7 I&C Systems

The design assumes the following hierarchical structure of the control of technological processes at the NPP

- power plant level, where strategic objectives of NPP control and automatic control of common plant systems and facilities are combined,
- unit level, where the control of the unit as a whole is implemented,
- control sub-systems that supervise the operation of technological equipment and systems for various functions and modes,
- sensors, execution units and simplest control algorithms (the level of individual control directly linked with the object of the control)

The base technical means of the I&C of thermal processes are

- modular system of collection and output of data that includes micro-process controller MK-3, memory device MZU-1, internal communication system MVS-3 and a number of modules for measurement transformation and control modules,
- failure-resistant calculation complex using the method of majoritary redundancy and comprised of the following modules SN (synchonizer), PRC (processor), OZU (operation memory), SZU (system memory), BIF MCVO (interface unit of the data collection system), BIF IRPS (unit for device connection), BIF LS (interface unit of the communication line),
- color displays with functional key-boards,
- DEC Micro VAX-3900 as the power unit computer,
- stream-line network communication means with redundancy that provide for information transfer among various hierarchical levels of the control system,

- sensors, execution devices etc

Automatic protections are divided into two categories

group I - automatic protections of unit safety systems (reactor emergency protection, control of safety systems),

group II - automatic protections of the systems of normal operation that are in turn divided into

- protections that switch off devices and components,
- protections that limit the power of a given device,
- protections that perform local operations

Only the emergency signalization and signals of essential failures in the schemes of operation of emergency protections are duplicated in full

5 8 Major Features of the Approach to Safety

5 8 1 Regulatory Requirements

The project of a unit with VVER-640 is being developed in accordance with Russian regulatory requirements that are in force at the moment of issuing the documentation The major safety documents of GOSATOMNADZOR of the Russian Federation (GAN RF) are unconditionally observed and all deviations from these documents are substantiated and defended in GAN RF

The main regulatory documents that define safety criteria at the design of VVER-640 unit are

- "General Rules for the Safety of NPPs (OPB-88)"
- "Rule of Nuclear Safety for the Reactors of NPPs", PBA RU AC-89

In addition to the national regulatory documentation listed in the "List of Main Regulations and Norms in Force in the Area of Atomic Power under GAN RF's Responsibility" (P-01-01-92), international standards and IAEA materials related to the design of NPPs were considered such as "Regulations for the Safety of NPPs", "Design of NPPs N50-C-D (Rev 1)", IAEA Safety Guidelines N50-CG-D1 D14, Main Principles of the Safety of Atomic Power Stations N75-INSAG-3, "The Safety of Nuclear Power", INSAG-5 (draft)

Radiological safety of the environment is based on the regulations currently in force in Russia (OPB-88, NRB-76/87, SPAS-88, OSP-72/87, PNAE G-03-33-93) and ICRP publications

In accordance with the regulatory documentation in force the classification of the buildings and facilities of the NPP in accordance with their safety function was performed as well as the classification of major systems and equipment by safety, seismic resistance and fabrication quality Special attention was given to the reliability of the systems of normal operation because, on one hand, they ensure the reliability of electricity

generation and the limits of safe operation and, on the other hand, provide safety increase for overcoming accident processes and participate in after-accident measures Accordingly, the systems that ensure water supply to systems of the reactor plant, heat removal from the reactor, supply of boron solution to the reactor and electricity generation on site are made with enhanced quality requirements for fabrication and installation and, if necessary, with additional redundancy

According to the estimates made for the project, the level of radiological impact on the population and the environment is below the established regulations and it is kept and a reasonably achievable low level with due regard to social and economic aspects In addition, during NPP normal operation and design incidents regulations for the emissions and contents of radioactive substances in the environment are not exceeded, and in case of beyond design accidents the regulations on the release of most hazardous radioactive nuclides are observed

The project applies the following principles to ensure fullfillment of the radiation safety requirements

- consistent implementation of the principle of defense-in-depth based on the use of a system of barriers at the potential pathways of radiation and radioactive substances into the environment,
- system of technical and organizational measures aimed at the protection of the barriers and their efficiency,
- system of technical and organizational measures directly aimed at the protection of the population and the environment

The system of technical and organizational measures directly aimed at the protection of the population includes

- design conservatism,
- quality assurance at all phases of the design, construction and operation of the NPP,
- NPP site selection,
- establishment of an NPP general protection zone,
- preparation of plans for emergency measures for population protection in case of beyond-design accidents

The protection from all types of radiation that may affect the plant staff and the population during NPP operation is based on the following criteria

- during normal operation the share of additional radiation from the NPP in the equivalent population doze must be significantly below the background level,
- in case of design accidents, technical means provided by the design must ensure the complete protection of the population beyond the NPP site without the implementation of organizational measures in accordance with the "Criteria for decision making on population protection measures in case of nuclear reactor accident",

- in case of beyond-design accidents, technical and organizational means should provide the means of accident management, so that the estimated probability of the maximum release would not exceed 10^{7} per reactor-year

In addition to the requirements of PBA RU AC-89, the project ensures the compliance with the operational design limit of fuel rod damages that is defined as 0 1% of the fuel rods with gas releases and 0 01 % with direct contact between the fuel and the coolant

In case of design accidents, including the break of the main circulation pipeline, the functionality of accident protection and emergency cooling is ensured independently from the availability of alternative current sources (the system of in-house needs, unit diesel generators and cooling water for at least 24 hours Accordingly, the project includes safety systems based mainly on the principle of passive operation and qualities of "inherent safety" such as self-regulation, thermal capacity, thermal conductivity, thermal convection, gravitation, energy of compressed gas and other natural processes For systems of normal operation their safety efficiency for use in post-accident measures has been demonstrated Technical solutions minimize effects of human errors on safety in all design modes

Information on the performed safety analyses, main safety regulations and the assessment of the impact of technological processes at the unit on the environment in all operation modes including normal operation, incidents, design accidents and beyond-design accidents is presented in "Preliminary Reports on Safety Substantiation" that are prepared for every specific site

In the framework of design activities level 1 probabilistic safety assessments (PSA-1) according to the IAEA terminology were performed for the estimation of the probability of severe damage to the reactor core of an NPP with VVER-640

The results of these studies show that the project of an NPP of medium power with VVER-640, which is based on the use of technical solutions for major equipment proved during long experience of operation of NPPs with VVER reactors and complemented with modern requirements for the application of multi-barrier defense, combination of active and passive safety systems, complies with the current safety criteria for NPPs and allows to diminish the level of the impact on the environment

5 8 2 Safety Concept

General

Safety concept of NPP with VVER-640 determines criteria and principles of safety and design approaches to their implementation based on national regulatory requirements, IAEA recommendations and experience in the development and approval of NPPs with VVERs of earlier generations The concept considers the impacts on barriers and their protection, methods to ensure the compliance with the criteria and principles of safety at the design phase, and also some aspects related to the site selection, equipment manufacturing, construction and operation

The concept was developed with the following objectives

- to determine the necessary calculational analyses and safety programs,

- to assess the safety of design solutions for NPP protection barriers,
- to determine technical means for NPP safety,
- to develop and substantiate the limits and conditions of safe operation,
- to develop procedures for safe NPP operation

Main Safety Principle

The safety concept of NPP with VVER-640 is based on the defense-in-depth principle that assumes application of a system of barriers at the potential paths of radiation and radioactive substances into the environment and a system of technical and organizational measures in order to protect the barriers and ensure their efficiency and to protect the population

In accordance with the defense-in-depth principle an NPP is designed, built and operated in such a way that radioactive materials are encircled by a number of physical barriers The system of barriers of an NPP with VVER-640 includes

- the fuel matrix,
- fuel rod cladding,
- primary circuit coolant boundary,
- system of hermetic compartments

Main Design Principles

The main design principles of technical and special technical means in the safety concept of NPP with VVER-640 are formulated in accordance with the requirements of current regulatory documents (OPB-88, PBA RU-89) and with due regard of IAEA recommendations ("Summary of Regulations for the Safety of Atomic Power Stations NPP Design", IAEA, Vienna, 1990 Safety Series, [1] 50-Ñ-D Rev 1) These principles define

Redundancy	Increase in system reliability by the application of structural, functional, informational and time redundancy in respect of the minimum that is necessary and sufficient for the functionality of the system
Principle of single failure	Principle that requires that the system fulfills its functions at any initial activating event and at any failure, independent of the initial event, of one of the active or passive elements with moving mechanical parts
Diversity	Increase in system reliability by the application of different means or of similar means but based on different action principles in different systems (or in different channels within one system) for the fulfillment of a given function
Independence	Increase in system reliability by the application of functional

	and/or physical separation of channels (component), for which the failure of one channel (component) does not lead to a failure of another channel (component)
Safe Failure	When practically possible, the "safe failure" principle is used in the design of systems and components necessary for NPP safety that requires that in case of a component or system failure the plant remain at the initial protection "level" without a need of initiation any actions
Common cause failure	Measures minimizing common cause failures are implemented in the design as possible
Consideration of "internal" and "external" events	Consideration of events in the design of technical and special technical means in the safety concept of NPP with VVER-640 is implemented, internationally accepted approaches and with due regard to NPP site specificity

The consideration of "external" events includes

1) Seismic events
2) Aviation crashes
3) Blast wave
4) Squalls (hurricane)
5) Extreme air temperatures
6) Tornado hazard
7) Impact of the inundation
8) Impact of nearby transportation lines
9) Impact of nearby industrial facilities
10) Diversions (subversive activity)

6 Environmental aspects

The regulatory requirements of the proposed power plant are more destricting regarding release limits of radioactivity during normal operation and in postulated accident conditions than those applied to the existing power plants in the area Design of the systems for handling and treatment of the radioactive water is improved to meet those requirements

For units of medium power, Table 6-1 gives a comparison of main radiation parameters that characterize NPP impact on the environment and population in the near-by region Prognosticated releases of radioactive gases into the environment during normal operation are presented (for operating units data of actual operation are given) Also, releases for the most serious design accident and for a heavy accident with fuel damage (risk of 10^{-7} 1/year for VVER-640) are given For the VVER-640 unit two options of the most serious design accident are estimated with power supply and without power supply for 24 hours

For comparison, data for NPPs of medium power with VVERs are given unified VVER-440 project (2nd stage of the Kola NPP, the Paks NPP, B-2 stage of the Bohunice plant, the Dukhovany NPP, the Rovno NPP, Loviisa project 1,2)

Additionally, operational data for accidents in 1986 and 1992 at the Leningrad and Chernobyl NPPs are presented that show extremely low radiation impact on the environment of accidents at the VVER-640, including beyond-design accidents with fuel melting

The prognosticated releases of radioactive gases and aerosols into the atmosphere from the VVER-640 unit during normal operation is redused by

- guarantees of the manufacture-plant on the increase in the density of fuel rods during unit operation at power,
- increase in the requirements for the sealing of major equipment and the corresponding reduction in non-controlled and controlled leakages of radioactive mediums,
- decrease in the volume of coolant take-out during regulation due to the reduction in the scope of boron regulation,
- creation of a closed gas circuit for temporary storage of "clean" and "dirty" coolant,
- renunciation of permanent operation of the exhaust system of the ventilation of the hermetic volume with partial vacuum in the circle gap between shells

Table 6-2 presents a comparison of the condition of the main barriers that hinder the proliferation of radioactive substances into the environment during normal operation Table 6-3 gives a comparison of the condition of the main barriers that prevent uncontrolled release of radioactive substances into the environment

Table 6-1 Comparison of Radiological Impact on the Environment of NPP units of Various Generations

Unit condition	National regulations for maximum radioactive releases[1]	Radioactive release (% of the maximum)		
		Operating NPPs		NPPs under design
		RBMK-1000	VVER-440	VVER-640
Normal operation, operational incidents	Allowable release, Ci/day GWe	Chernobyl NPP, units 3, 4	Kola NPP units 3, 4	
	IRG- 500	50 - 100	1 - 2	0 04
	Iodine-131 - 0 01	3 - 100	< 1	0 05
	LLN - 0 015	0 2	< 1	0 04
		Zone of radiological impact		Controlled zone
Design accidents	Release that necessitates informing regulatory bodies, Ci	Leningrad NPP accident of 30 03 92	Estimation of DA consequences	
	IRG- 15000	33	< 100	<0 001 /0 05
	Iodine-131 - 0 3	800	7400	< 5 /10
	LLN - 0 45	-	1000	<0 01 / 2
	Zone of radiological impact	up to 3 km	up to 3 km	site
Severe accidents (probability for VVER-640 10^{7} 1/year)	Accident release that requires immediate implementation of the plan of protection measures (for units of earlier generations), Ci	Chernobyl NPP, accident of April-May 1986	Estimation of the consequences of severe accident	
	Iodine-131 - 30000	25000	analysis does not exist	< 2
	Cs-137 - 3000	30000		<0 03
	Zone of radiological impact	more than 100 km		1 5 êì

[1] IRG - inert radioactive gases, LLN - long-lived nuclides, DA - most serious design accident, doses are in Ci 1 Ci = 37 GBq

Table 6-2 Comparison of Main Barriers in the Mode of Nominal Operation

Barrier	Barrier Condition	NPP Design	
		VVER-440	VVER-640
Fuel Cladding	Operation unsealing limit, (%)		
	gas	1	0 1
	contact with fuel	0 1	0 01
	Unsealing limit of safe operation, (%)		
	gas	1	1
	contact with fuel	0 1	0 1
Main Equipment of First Circuit	Circuit dehermetization, (V/year) allowable level of circuit unsealing (operational limit)	9	4 0
	coolant take-out		
	boron regulation	67	4 3
	unit shutdown	3	0 3
Hermetic Zone (hermetic compartments of main equipment)	Unsealing, (% V/day)	144	<<0 1[2]

Table 6-3 Comparison of the Design Bases Efficiency of Main Barriers in Case of Main Circulation Pipeline Break for the Most Severe Design Accident

Barrier	Barrier Condition	NPP Design	
		VVER-440	VVER-640
Fuel Cladding	Unsealing, (%)	100	1
Hermetic Zone (hermetic compartments of main equipment)	Unsealing, (% V/day)	1	0 1
	Design pressure, (MPa)	0 15	0 4

The barrier principle and other safety aspects are described by the designer are given more in detail in Appendix 2 Licensing activities with GAN and other authotities are listed in Appendix 3

[2] Support of partial vacuum in the hermetic zone of the exhaust ventilation system

72

For storage safety, liquid radioactive wastes in the design of VVER-640 are solidified by the cementation method with the creation of a product, resistant to leaching and complying with the requirements of safe storage The use of pressing and milling reduces the amount of solid wastes

Table 6-4 presents a comparison of the volumes and parameters of plant radioactive wastes with medium size units (averaged for unit) It is shown that a significant reduction of waste volume is expected in the design of NPP with VVER-640 as compared with operating NPPs with VVER-440

Table 6-4 Comparison of Volumes and Parameters of Radioactive Wastes for Medium Size NPP Units of Different Generations

Type and category of NPP wastes	Operating NPPs		NPP with VVER-640
	Kola units 3,4	Loviisa units 1,2	
Liquid wastes, m^3/year unit			
- salt concentrate for 400 g/l of ion exchange	416	40	22
- materials	32	8	15
Packages with solidified wastes, per year-unit			
- metal casks with bitum compound of the volume of 0 2 m^3	solidification facility at the design phase	no data	
- concrete protection containers of[3] 2 6 m^3			37[4]
Solid wastes, m^3/year-unit			
group I	100 - 200	}25 - 35[5]	46[5]
group II	10 - 30		14[5]
group III	1 - 2	no data	0 5[5]

Appendix 4 presents data on the cleaning and use of industrial sewage waters of the system of condensate

7 Project costs and o&m costs

The total cost of the VVER-640 reactor plants has been estimated using both the Russian and EEDB methodologies The major factors influencing the cost of the VVER-640 plant are the research and development program, detailed engineering, reactor buildings, reactor plant components including state-of-the-art reactor instrumentation and controls, turbine generator and auxiliaries, construction

[3] The container volume calculated with the external dimensions

[4] For one unit, 13 containers with solidified wastes (from the special laundry) are added

[5] With pressing

and field services, and a contingency to address the first–of–a–kind engineering necessary to develop the detail design for the plant The R&D cost is not include in present estimate Construction of the NPP in the natural and climate conditions of the North-West region of Russia on soft soils, with a closed system of technical water supply and cooling towers, with automobile transportation is considered A cost break down of a power plant with two NP-640 units is given in the table 7-1

Table 7-1, Capital costs of proposed power plant 2 x VVER-640

BASE CONSTRUCTION COSTS, million USD	1884
Materials	386
Equipment	791
Labor	254
Contingency + ownwer's	452
SPECIFIC CAPITAL COCST, USD/kWe	1460
FIRST FUEL LOAD COST PER UNIT, million USD	53 5
FUEL LOAD COST USD/kWe	83

The presented nominal costs USD 1460 per kWe is slightly higher than the higher estimate of in JPNAS and clearly higher than values given in ERI-JEAS referred in JPNAS

In the used methodology the costs were evaluated first in rubels of 1991, and then converted to USD of today using conversion factors The work costs was evaluated using salaries of today This methodology has some risks related to correctness of conversion factors of cost levels and currency exchance rates in 1991 and now In this study that methodology was however used that the results were comparable with the results done by other groups using same standard Russian methodology

There are some factors difficult to evaluate at the moment Real manufacturing costs are not based on real contracts or offers of the suppliers or recent corresponding contracts Thera are big changes in the conditions compared to those when last coresponding project was implemented Regulatory requirements, e g quality assurance requirements, are more strict and and the regulatory body has more power and is more independent than earlier

Operating and maintenance costs and fuel and waste management costs including fuel cycle back end are given in table 7-2

Table 7-2, Operating and maintenance costs	
FIXED NON-FUEL O&M COSTS, million USD/year	68

74

including - materials without fuel, water and soil - salaries of THE own staff and contractors - depreciation	 25 8 3 2 39 0
TOTAL NUMBER OF PERSONNEL (incl contractors)	552
SALARY, USD/man year	6080
FUEL COSTS + WASTE MANAGEMENT, USD/Kwh	0 005

8 Economic analysis

For economic assessments of the investment requirements for NPP projects with VVER-640 the "Atomenergo-invest" program package was used that is developed joint by a Research Consulting Company "Alt" and by Institute Atomenergoproekt of St -Petersburg This package was selected in accordance with "Methodological recommendations for assessment of the efficiency of investment projects and their selection for financing" that were approved by Gosstroy of Russia, Ministry of Economics of RF, Ministry of Finance of RF, Gosprom of Russia N7-12/47 as of 31 March 1994, as well as in accordance with the recommendation of the group of planning and modelling The calculation algorithm takes into account the tax environment of the current period

The assessment of economic parameters is done for Sosnovy Bor plant with two VVER-640 units is based on the data given in the previous chapters Following additional data and assumptions are used

The annual use of installed capacity is assumed to be 7000 hours/year corresponding capacity factor of 80%

The in-house electricity consumption is calculated for the average loading of major equipment according and amounts to 7 05% of the electricity generated

- Discount rate 10%, In the sensitivity analysis a discout rate of 8% was concidered
- Social charges, charges for the employment fund, medical insurance etc amount to 39% of the annual salary fund
- The liquidation reserve or reserve for the NPP decommissioning fund is defined as 1 3% from the production cost
- Charges for the extra-budgetary R&D fund are 1 5% of the total production cost[6]
- Charges for the special regional investment fund for financing social construction in the 30-km NPP protection zone are 1% of the total production cost[6]
- Charges in an insurance reserve on liqidation of emergency consequences from objects of nuclear power 1% of the total production cost
- Land cost is not taken into account in this case, because the exact territory has not been defined yet (to be determined by local authorities)

[6] Federal low ' About financing especially of dongerous manufactured and units ' adopted 02 21 96, article 3

75

- For the NPP equipment was taken into account, that the finaces for indemnification of the value added tax (VAT) become covered at the expense of finaces from VAT, showed for payment to consumers of power production VAT on civil and erection works is not compensated
- The calculations do not take into account directly the costs of decommissioning that appear for VVER-640 after 50 years of service life of the first unit Decommissioning costs are indirectly accounted for by the charges for the "Liquidation reserve"
- In estimations the electric power tariff was assumed constant during the whole service life NPP The accounts were carried out for two values 45 mills/kWh and 60 mills/kWh
- The step of account is equal to 1 year Production from each unit is taken into account beginning since the next year after start-up of the appropriate block
- Construction time is 7 years and the dirbursement schedule as follows

year	unit 1	unit 2
1	3 4%	0 0%
2	16 %	7%
3	19 %	19 %
4	26 %	20 %
5	22 %	22 %
6	10 %	17 %
7	3 6%	11 %
8		8 %

- Construction time is 8 years and the dirbursement schedule as follows

year	unit 1	unit 2
1	3 4%	0 %
2	11 %	5 %
3	19 %	10 %
4	22 %	19 %
5	19 %	22 %
6	12 %	18 %
7	10%	12 %
8	3 6%	10 %
9		4 %

Results of account of commercial effectivness are submitted in appendix 7, as the diagrams of set parameters

Table 8-1 Results of economic estimation of Sosnovy Bor NPP construction (8 years construction / 7 years construction)

	Discount rate	
	8 %	10 %
	Tariff, mills/kW h	Tariff, mills/kW h

	45	60	45	60
Simple payback period, year	16 3 / 15 3	14 0	16 3 / 15 3	14 0
Discounted payback period, year	>60 / 43 2	23 4	>60 / >60	41 6
Net present value, M $	-5 2 / 54	491	-314 / -270	39 2
Profitability Index	1 0 / 1 04	1 36	0 75 / 0 79	1 03
The internal rate of return, %	8 0 / 8 3	10 2	8 0 / 8 3	10 2
Average production cost of the electric power, mills/kw h	20 2 / 20 0	20 1	20 2 / 20 0	20 1

9 Financing

According to Russian laws all nuclear power plants are owned by the government Financing can not be based on implementation of IPP type or any other model where some other investor than the government will come a shareholder of the plant

Most of the financing will be from Russian sources Direct governmental financing represents the own capital of the power utility Most probably additional financing of the Russian delivery and work will be credits from Russian banks Western financing may be available up to the amount of western deliveries, if in addition of the guarantee of Russian government the export credit guaranteed by the state institutions of the exporting country is given

In the economic analysis the following percentage of financing from different sources with the indicated rate of interest was assumed

- Governmental financing, about 40 %
- Loans from Russian banks, about 40%, real interest rate 7 8% for longterm loans and 9 8% for shortterm loans
- Loans from western banks, about 20%, real interest rate 5 8%

10 Project implementation plan

10 1 Project organisations

The system of project management is based on IAEA recommendations ("Nuclear Power Project Management" Tech Rep Series [1] 279) and Russian regulations

The following organizations are responsible for the design and realization of NPP with VVER-640 in accordance with Russian law and regulations

⇒ Institute "Atomenergoproject" of St -Petersburg (SPBAEP),

Leading designer - Architect engineer of the NPP

⇒ OKB "Gidropress" (OKB GP),

Architect engineer of the reactor plant

⇒ RRC "Kurchatov Institute",

Scientific leader

For I&C systems elements and components developed for VVER-1000s in cooperation with Siemens will be used

Fabrication of major equipment components is provided by Russian industries Traditionally, the following enterprises are supplier of major NPP components

- "Izhorsky plant" company reactor, pressurizer, hydraulic reservoirs of the ECCS, main circulation pipeline, protection cylinder for reactor internals, racks of the fuel storage pool, heat transfer equipment, containment,
- Kirovsky plant MCP and major pump equipment,
- Podolsky plant SGs, heat transfer equipment,
- "Metal plant" the turbine plant,
- "Electrosila" generator,
- "Atommash" the fuel loading machine and transportation and service equipment for the reactor plant

In accordance with a Framework Agreement on Cooperation in Design and Construction of NPPs with VVER-640/407 reactors between the Ministry of the Russian Federation on Atomic Energy and Siemens AG, KWU Department signed in Moscow on May 15, 1995 it is determined that Siemens AG will take part in the following areas of the implementation of the project of NPP with VVER-640

- design, supply, assembling and start-up of certain I&C systems,
- design, supply, assembling and start-up of certain electrical components and equipment, including the emergency diesel generator,
- design, supply, assembling and start-up of certain components and equipment of technological and ventilation systems

10.2 Time schedule

Preliminary time schedule of the project is in Appendix 5 The construction time is expected to be 7 to 8 years It is not realistic to consider shorter time of implementation when the present conditions of economy and industry are taken into account and the fact that the project is based on new type of power plant without previous experience

The readines of design describes Appendix 6 listing stages of basic design works and the examinations of the design documentation

Construction works will be started in 1999 and will be execute simultaneously with the experimental studies at the test facilities at the scientific centre NITI in Sosnovy Bor are completed with positive results The tests of containment systems at the KSM-1 facility are scheduled scheduled for years 1999 - 2001

10 3 Project risks

For such a specific object as an NPP, there are additional specific risks radiation risk and "political" risk, in addition to usual risks (technical, economic, social) Radiation risk can be, in principle, regarded as economic risk, because it is related to the possibility of severe accidents with the destruction of the reactor and release of substantial amounts of radioactive substances beyond the safety barriers and further into the environment and, as a consequence, with a possible loss of the unit This risk (or the probability of a sever accident) is estimated by calculation techniques According to the regulations that are followed in the project design the probability of such accidents should be minimal and amount to ~ 10-6 - 10-7 1/reactor-year Strict adherence to regulations and rules during construction and operation, fulfillment of technological requirements, "safety culture" are first priority measures for diminishing the NPP radiation risk

Social opposition to NPP construction under the influence of "green movements" or of the fear appeared after the Chernobyl accident is an additional aspect of the social risk This risk can be reduced by information campaigns with comparisons of conventional and nuclear power plants as energy sources for the population, experts and decision makers

Possible sources for the risk called "political" are both competing energy producers (the Gasprom concern, foreign companies interested in the market for their products such as gas-turbine plants, combined-cycle plants etc) and "anti-nuclear" groups, maybe even at high power levels, that are against nuclear power in principle In this case, independent economic policy of a given region that decided to develop nuclear power on its territory can serve as a guarantee

Appendix 8 presents a qualitative analysis of some risk categories as well as of possible counter-measures in order to reduce them

NORTH-WEST REGION POWER INVESTMENT PLAN

Prefeasibility Study of
KOLA-2 NUCLEAR POWER PLANT

3 x VVER-640

July 1998

80

Contents

1 INTRODUCTION 3
2 PROJECT BACKGROUND 3
3 DESCRIPTION OF THE EXISTING CONDITIONS 4
4 ALTERNATIVE PLANT CONCEPTS 4
5 TECHNICAL EVALUATION OF THE PLANT CONCEPT 5
5 1 General description 5
5 2 Brief Description of Main Systems and Equipment of the Reactor Plant 11
5 2 1 Reactor Core 11
5 2 2 Main Circulation Pump (MCP) 11
5 2 3 Pressurizer 11
5 2 4 Steam Generator (SG) 11
5 2 5 Safety systems 11
5 3 Processing and Handling of Liquid Radioactive Substances and Wastes 12
5 4 Systems and Equipment of the Turbine Plant 12
5 5 Fuel Handling 13
5 6 Electrical Plant 13
5 7 I&C Systems 14
5 8 Major Features of the Approach to Safety 15
5 8 1 Regulatory Requirements 15
5 8 2 Safety Concept 17
6 ENVIRONMENTAL ASPECTS 19
7 PROJECT COSTS AND O&M COSTS 23
8 ECONOMIC ANALYSIS 25
9 FINANCING 27
10 PROJECT IMPLEMENTATION PLAN 28
10 1 Project organizations 28
10 2 Time schedule 29
10 3 Project risks 29

81

1 Introduction

General purposes of this study are expressed in the Terms of References and in the Work Plan of the Project for NorthWest Region Power Investment Plan This study report provides information on technical and safety features and economic aspects of the proposed construction of a new nuclear power plant comprising three VVER-640 units near town Polarny Zori in Murmansk region The aim of the study was to evaluate if the planned project is feasible alternative from technical, economic and safety point of view to be taken into consideration in planning investments to the north-western energy systems within the time frame till year 2010 defined for the study

The need to study alternatives for new power generation capacity arises from the fact that four nuclear power units in the north west Russia with total generation capacity of 2880 MW are planned to be decommissioned in years 2003 - 2005, two of which are units 1 and 2 of Kola NPP Necessity to conduct an analysis of the energy investment alternatives to continued operation of nuclear plants is expressed in the agreement between Russian government and EBRD/NSA

This study on implementation of new nuclear capacity in Sosnovy Bor was conducted by the Russia-Finnish joint team Participants were from Russia side - RRC "Kurchatov Institute, St Petersburg Institute Atomenergoproekt and concern "Rosenergoatom", from Finnish side - Finnish Energy Conservation Group (FECG) All technical and economic data used in this study were collected from the Russian sources Review of the data and comparison with corresponding western experience was done by FECG

2 Project background

The existing Kola NPP near the suggested new site has four VVER-440 reactors with total electric generation capacity 1760 MW Design service life of 30 years of the units will expire and they will be shut down as follows

Unit 1	2003
Unit 2	2004
Unit 3	2011
Unit 4	2014

At the present time energy balance of the AO "Kolenergo" has surplus and there are limitations for using full Kola NPP capacity There is energy export to Karelia and also some to Scandinavian countries During the considered period till 2010 the nuclear generation capacity in the region will decrease by 880 MW in years 2003 and 2004 Today's surplus of energy may chance to deficit of energy after 2006, if the decommissioned nuclear generation capacity will not be compensated The required new capacity is evaluated in detail in the report of the Planning and Modeling Team taking into account forested development in demand of electricity, existing power plants, new power plants under construction or decided, planned new projects, and export The regulatory body Gosatomnazor (GAN) has awarded permission for construction of that plant in 1996

Taking into account difficulties to deliver coal and oil to the Kola peninsula, and also uncertainty of time when natural gas is available and of cost of natural gas, it is extremely expedient to estimate economic efficiency of Kola-2 NPP project as replacing capacity Kola NPP is central part of the energy system of Kola Peninsula Replacement of its decommissioned capacity by similar baseload power plant in the same area has minimal secondary influence on the energy system and the network

3. Description of the existing conditions

The new nuclear power plant is planned to be located on the same neck of land between open lakes of Imandra as the existing Kola NPP, but on the opposite side of it, about 10 km from Kola NPP The site is almost untouched wilderness without any industrial facilities Cooling water is planned to be taken from the lake Imandra, like now for Kola NPP Town Polarny Zori, where most of the staff of Kola NPP live, is about 15 km from the site Murmansk, the principal town of Kola Peninsula, is about 200 km northward from the site It has some 500 000 inhabitants

The new power plant is planned to be a green field plant located near the site of existing Kola NPP Connections with the existing infrastructures need some 5 to 15 km new roads, railway track and transmission and telephone lines depending of final routing of them Water will be taken from Lake Imandra The power plant will have own water treatment plant and sewage system

4 Alternative plant concepts

For selection of the type of new nuclear power plant for Kola 2 project, a competition between potential alternatives was organized in 1993 The proposed reactor concepts were VVER-91 and VVER-92 The evaluation team recommended VVER-91 Later on that decision was canceled, because 1000 MW plant was considered to bee to big unit in the energy system of Kola peninsula, that has only 300 MW connection with other energy systems The new nuclear power plant project was proposed to be based on VVER-640 concept

VVER-640 is a medium power NPP with gross electric output of 640 MW Saint Petersburg Atomenergoproekt (SPAEP) has been the main designer in development of this power plant concept OKB Gidropres from Podolsk is main designer of the reactor installation The primary and secondary side processes of the energy production and their components do not include much new innovations Reactor pressure vessel and most of the other main components are either a copy or a modification of the components used in VVER-1000 The safety systems include totally new innovations having more passive features than the older reactor generations

VVER-91 concept is an evolutionary development of the standard Soviet VVER-1000 power plant VVER-91 utilizes the main components of standard VVER-1000 and also elsewhere the design is based on proven solutions Main areas of improvements compared with standard VVER-1000 are economy and safety

The engineering and design work of VVER-91 was done by Saint Petersburg Atomenergoproekt and IVO Power Engineering Ltd (former IVO International Ltd) acting as consult VVER-91 was developed as an option for Kola 2 power plant and later for competition on third nuclear unit of Finland Neither of those projects realized, but at the moment there is a project to deliver to China a nuclear power plant based on VVER-91 concept

VVER-92 was developed by Moscow Atomenergoproekt It is also based on VVER-1000, but has more "revolutionary" new solutions than VVER-91 This concept was not designed as ready as VVER-91 It participated in selection of reactor type both for Kola 2 and Sosnovy Bor There is no projects based on that technology, and its development work has been canceled

In Russia there is under development also a large power NPP called VVER-1500, with electric output of 1500 MW gross Considerations to replace the units of Leningrad NPP by that type of reactors are preliminary assessments only Development and design of VVER-1500 are still in

82

conceptual phase and it is not available within the timeframe to be considered in the NorthWest region power investment plan

5 Technical evaluation of the plant concept

5 1 General description

VVER-640 nuclear power plant project with the V-407 reactor is developed in accordance with the Russian Federal Program "Environmentally Clean Power" The main goal of development was to create the design of a competitive, medium-power nuclear power plant with enhanced safety features The design is based on more than 30 years experience in the construction of nuclear power plants with pressurized water reactors (PWR) in Russia and abroad Mostly technologies and systems proven during design, construction and operation of the proceeding NPP generations are used The safety systems are comprised of both traditional systems, such as the sprinkler systems and systems of forced circulation with emergency power supply from diesel generators, and passive systems of residual heat removal to the ultimate heat sink that allow to undergo design accidents without external power supply

The main design parameters of the VVER-640 power plant unit are given in table 5-1 The lay out of the main buildings is shown in Figure 5-1 and unit cross-section by the reactor and turbine plants in Fig 5-2 Figure 5-3 gives the principal scheme of main systems

The unit includes a V-407 reactor installation and one turbine in a two-circuit design The primary circuit contains the VVER-640 (V-407) thermal reactor, four main circulation loops, pressurizer and auxiliary equipment located within a containment Each loop includes a horizontal steam generator (SG), main circulation pump (MCP), and main DU620 pipeline made of stainless steel

The secondary circuit is comprised of the steam side of the SGs, main steam lines, the turbine, deaeration systems, regeneration and feed water systems and auxiliary equipment The turbine is of a one-shaft type with one high and medium pressure cylinder (HMPC), and two two-stream low-pressure cylinders (LPC) For the last turbine step a 1200-mm blade is used

The generator has a complete water cooling system and it does not require hydrogen In-house electricity consumers are fed by direct current circuits of 6 kV, 0 4 kV and 220 V

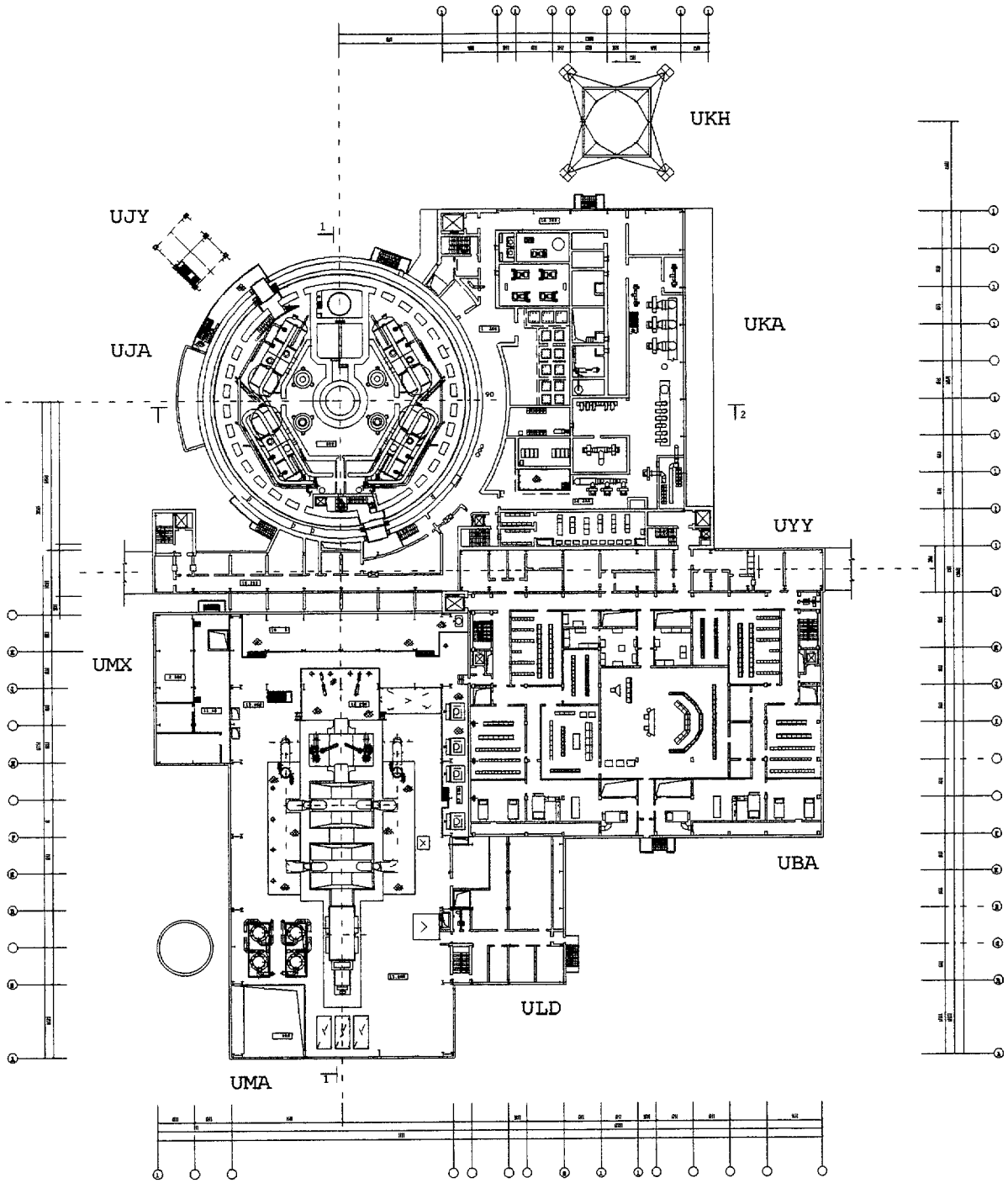
Table 1 1.

84

Main Characteristics of the VVER-640 Reactor Plant	
Reactor type	V-407 (PWR)
Thermal rated power, MW	1 800
Number of loops	4
Pressure in the reactor at outlet of the core, MPa	15 7
Temperature of coolant in the reactor °C - at outlet - at inlet	 323 3 293 7
Fuel loading, tons of U	68 64
Average enrichment of fresh fuel, %	3 45
Average discharge burn-up, MW day/kgU	39 6
Average specific energy density of the core, KW/l	64 5
Steam generator type	horizontal
Steam generation, tons/h	3576
Steam pressure in the steam generator, MPa	7 06
Turbine	K-600-6 9/50 (LMZ)
Number of turbines per unit	1
Rated power of the turbine, MW	645
Rotation frequency, rpm	3,000
Parameters of steam upstream from the turbine - pressure, MPa - temperature, °C - degree of dryness	 6 9 284 5 0 995
Pressure in the condenser, kPa	4 9
Generator	TZV-630-2UZ
Unit net efficiency, %	33 3
Design life time, years	50

Complying with national safety standards, the unit concept corresponds in general to the international trends in the development of nuclear power The unit corresponds to the class of evolutionary projects with the use of passive safety systems An combination of active and passive elements in the safety systems, use of equipment and systems well-proved in the national practice, the use of such solutions as a double containment, pool cooling of the core etc are used to increase the safety and reliability of the plant

85



UJA - Reactor building

ULD - Condensate treatment plant

UBA -Control building

UMA - Turbine building

UKA - Auxiliary building

Figure 5-1 Layout of the Main Unit Buildings

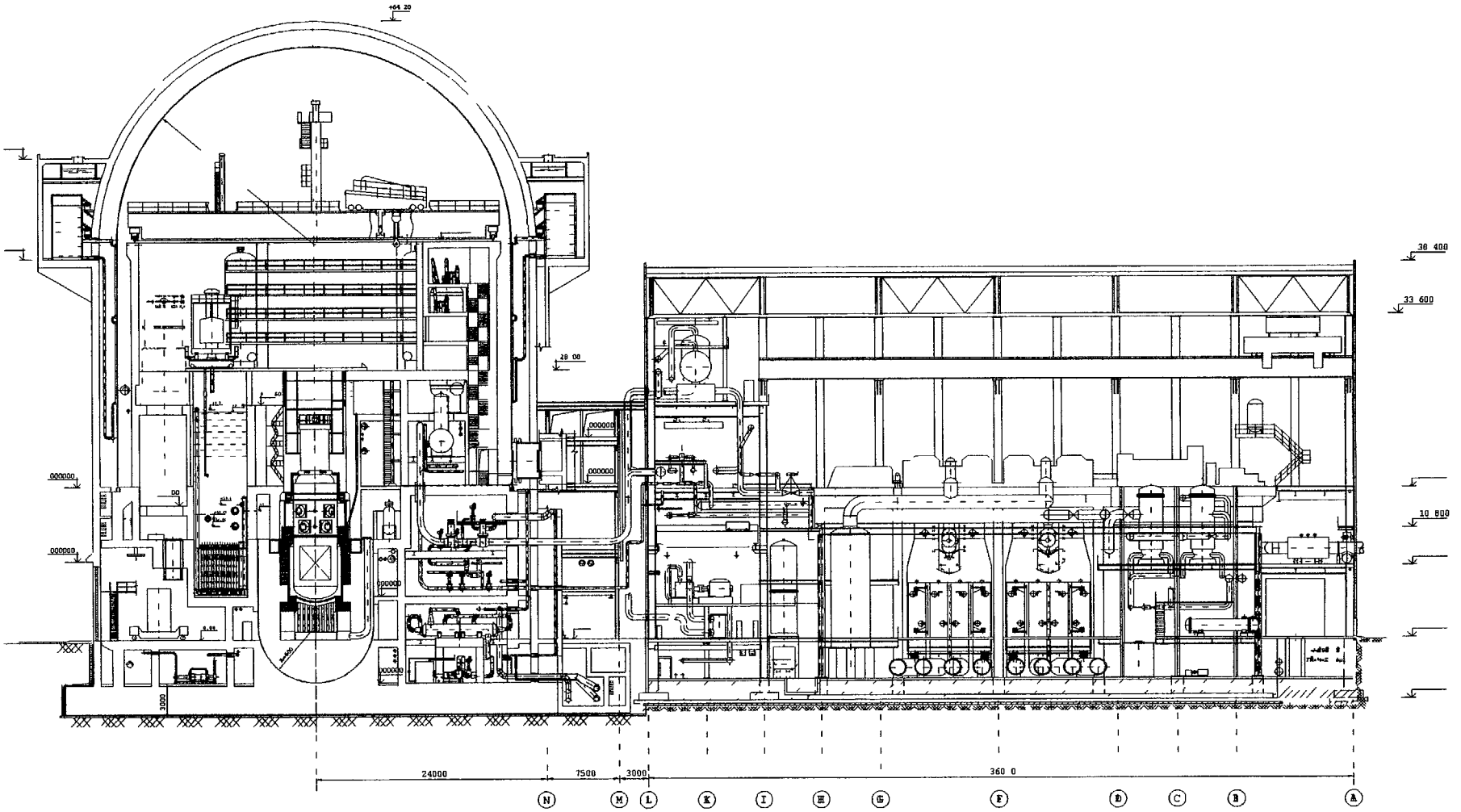


Figure 5-2 Unit Cross-section by the Reactor and Turbine Plant

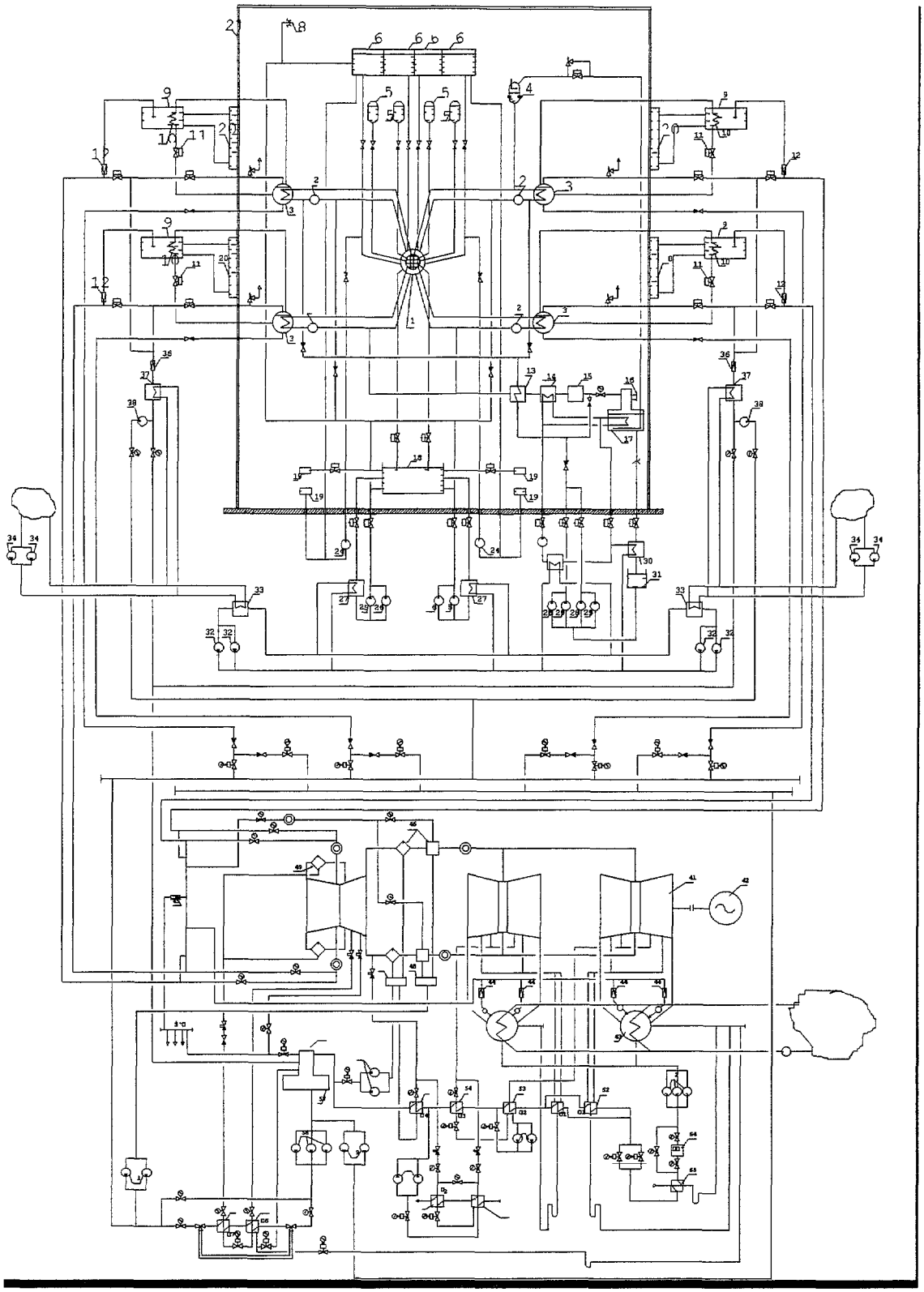


Figure 5-3 Principle Scheme of Main Systems

List of components in Figure 5-3

1 Reactor
2 Primary coolant pump
3 Steam generator
4 Pressurizer
5 H p ECCS accumulator tank
6 ECCS tank
8 Sprinkler
9 Chemically demineralized water storage tank
10 heat exchanger of passive heat removal system
11 Startup valve of passive heat removal system
12 Quick-acting pressure reducing plant
13 Regenerative heat exchanger of primary circuit makeup-blowdown system
14 Aftercooler of primary circuit makeup-blowdown system
15 Coolant treatment plant
16 Protective membrane
17 Bubbler-degasser
18 Fuel pond
19 Screen filter
20 Cooler of passive heat removal from containment
21 Containment
24 Pump of emergency cooling
25 Fuel cooling system pump
26 Fuel cooling system pump
27 Fuel cooling system heat exchanger
28 Primary circuit makeup-blowdown system pump
29 Primary circuit makeup-blowdown system pump
30 Coolant removal heat exchanger
31 Damper tank of the primary circuit makeup-blowdown system
32 Pump for the reactor building consumer intermediate cooling circuit
33 Heat exchanger for the reactor building consumer intermediate cooling circuit
34 Reactor building cooling water system pump
36 Pressure reducing plant
37 Heat exchanger for reactor heat removal
38 Pump for reactor heat removal
41 Steam-driven turbine
42 Generator
43 Condenser
44 Quick-acting pressure reducing plant of steam discharge into condenser
45 Quick-acting pressure reducing plant of steam supply for auxiliaries
46 Moisture separator-reheater (SR)
47 SR separated moisture collecting tank
48 SR condensate collecting tank
49 First-stage separator
50 SR separated moisture pump
51 SR condensate pump
52 L p heater No1
53 L p heater No2
54 L p heater No3
55 L p heater No4
56 Deaeration column
57 Deaerator tank
58 Feed water pumps
59 Auxiliary feed water pump
60 H p heater No6
61 H p heater No7
62 Condensate pump
63 Condensate pump of unit water demineralization plant
64 Condensate treatment plant
65 Heater
66 Drain pump of l p heater 12
67 Network main heater
68 Network peak-load heater

5 2 Brief Description of Main Systems and Equipment of the Reactor Plant

NPP with VVER-640 is designed for electricity generation in the base load mode A possibility of heat supply to external customers is provided, but not considered in this study The equipment is designed with due regard of the possibility of electricity generation in the daily load-following mode Estimates are made for the reliability of operation of the reactor core and unit systems that showed the sufficiency of design solutions for power maneuvering

Layout and cross section drawings of the reactor plant and pictures of the main components are in Appendix 1

5 2 1 Reactor Core

The reactor core of V-407 contains 163 fuel assemblies (FA) that are used also for the placement of control rods and unmovable burnable absorbers

As fuel, slightly enriched uranium dioxide is used as in VVER-1000 and VVER-440 reactors The fuel campaign in the stationary mode is 298 effective days The average discharge burnup of fuel is 39 6 MWd/kgU The maximum average burnup of a fuel assembly is 45 5 MWd/kg U, the maximum average burnup of a fuel rod is 49 0 MWd/kg U, the maximum average burnup of a fuel pellet is 54 1 MWd/kg U

5 2 2 Main Circulation Pump (MCP)

The multi-year experience of design and operation of MCPs for NPPs with VVER reactors was taken into account in the design of the MCP as well as results of research and development studies with long-term verification of the lifetime of major components

5 2 3 Pressurizer

The well-proved and currently used VVER-1000 pressurizer is used

5 2 4 Steam Generator (SG)

The SG is a one case device of horizontal type All construction materials that are used for SG manufacturing have been tested in operation of NPPs with VVER-1000 and VVER-440, and they are certified and approved by GAN RF

5 2 5 Safety systems

In case of full black-out accidents (loss of in-house needs power and unit diesel generators) a system of passive heat removal from the SGs is activated for the cooling of the reactor and heat transfer to the reservoirs of emergency heat removal

In accidents with the loss of coolant in the primary circuit boron solution is supplied to the reactor from the reservoirs of the emergency core cooling system (ECCS) The activation pressure of the ECCS reservoirs is 4 0 MPa In case of further pressure reduction in the primary circuit the flooding of the core from ECCS tanks The coolant leaving the reactor from the break is collected on the containment floor in the emergency cooling pool

To guarantee water supply from ECCS reservoirs, in case of pressure decrease to 0 6 MPa there occurs an automatic opening of release valves that connect the reactor with the fuel loading pool As the primary circuit, emergency reservoirs and reservoirs of ECCS become empty, the water level in the emergency pool exceeds the reactor outlets and a natural circulation circuit is created that contains the core - release valve above the core - fuel loading pool - release valve under the core - the core

Heat removal from the fuel loading pool is provided by the evaporation of some part of the coolant with subsequent steam condensation at the walls and within the metal containment and the return of the condensate to the emergency pool Water supply to the fuel loading pool is provided from the emergency pool through a connection valve

Heat removal from the containment is provided through the wall to the water of the system of containment cooling by natural circulation between the reservoir of emergency cooling and containment cooling channels The quantity of water in the reservoir is designed for cooling for at least 24 hours, the single failure principle taken into account

In accordance with the safety concept, it is assumed that after 24 hours the residual heat is removed with the systems of normal operation important for safety that have a permanent source of cooling water and reliable power supply from unit diesel generators

5.3 Processing and Handling of Liquid Radioactive Substances and Wastes

A number of technical solutions are implemented in the project in order to minimize the amount of liquid radioactive substances (LRS) and decrease the degree of salt contents

- separate collection of LRSs depending on the activity with reuse of low-active mediums,
- maximum use of no-waste technologies,
- use of low-waste deactivation methods,
- renunciation of the regeneration of low-salt water filters,
- use of cleaned circuit water only for feeding the primary circuit

Under the condition of strict observance of operation procedures by NPP staff the design amount of waste waters is 8000 m^3/year per unit, only 10% or less with the salt content of 1 5 g/l and higher

Technical solutions for the systems of collection and processing of LRSs result in the absence of LRS release beyond NPP limits due to the organization of closed water circuits with the reuse of cleaned water in the NPP cycle

5 4 Systems and Equipment of the Turbine Plant

Turbine plant K-600-6,9/50 is of a one-shaft type with one high and medium pressure cylinder (HMPC), and two two-stream low-pressure cylinders (LPC) The structural arrangement is HMPC + 2LPC + Generator The LPCs are unified with the currently used K-1000-60/3000 turbine

The steam condensing plant K-600-6,9/50 without regulated steam take-outs, with intermediate steam separation and one-step steam superheater is designed for direct rotation of an alternate current generator of the TZV type with full water cooling and the power of 645 MW, with the rotation frequency of 3000 rot/min , and for heat supply with the intensity up to 250 Gcal/hour for

91

centralized heat supply to industrial and non-industrial customers in the temperature range of 150/70 °C

The principal thermal scheme includes 4 low-pressure heaters (LPH), deaerator of increased pressure (1 3 MPa abs) that operates at changing pressure in transient modes, and 2 high pressure heaters (LPH)

5 5 Fuel Handling

The transportation and technological part for fuel handling at the NPP ensures

- receipt and storage of fresh nuclear fuel,
- fuel preparation for loading into the reactor,
- fuel reloading in the reactor core,
- fuel unloading from the reactor core,
- intermediate storage of spent nuclear fuel up to 5 years,
- temporary storage of spent nuclear fuel (after the intermediate storage) in universal transportation containers before sending in a car-container train to the regeneration plant (a "dry" storage technique is implemented),
- transportation of fresh and spent nuclear fuel in the NPP territory,
- sending of spent nuclear fuel (after the intermediate storage) to the regeneration plant,
- biological protection of the staff at all phases of reloading, transportation and storage of nuclear fuel

The works for receiving fresh nuclear fuel at the NPP and for sending spent nuclear fuel after temporary storage from the NPP are performed at a railway terminal with all necessary equipment

Receipt, storage and preparation of fresh fuel before the loading into the reactor are performed in the fresh fuel storage facility

The reloading of nuclear fuel in the reactor and storage of spent nuclear fuel in the reloading pool are performed in the reactor building of the unit

Storage (temporary storage) of spent nuclear fuel in the reactor building is performed in the reloading pool for not less than 3 years, the storage volume of the reloading pool being sufficient for storage (temporary storage) of spent nuclear fuel during 5 years

Storage of spent nuclear fuel (after the temporary storage in the reactor building) before the shipment to the reprocessing plant is performed in the spent fuel storage facility that is an intermediate storage facility of the container type Upon request of the client, storage of nuclear fuel can be provided up to the time of NPP decommissioning

5 6 Electrical Plant

By design, NPP is comprised of several power units with VVER-640 reactors and generators of the power of 645 MW

Use of synchronized generator of the TZV-630-2 type is assumed with the following parameters nominal power 645 MW, voltage 20 kV, rotation speed 3000 rot/min with full water cooling, the internals filled in with air under quasi-atmospheric pressure, use of fire-resistant liquid OMTI in the bearing lubrication system is possible

The TZV-630-2 generator is explosion- and fire-safe and complies with equipment requirements for the equipment of group "B" of explosion- and fire-hazard

For operation with the TZV-630-2 generator a unit transformer of the power 800 MVA is foreseen which is a three-phase, two-coil increasing transformer

For ensuring in-house needs redundancy the installation of two reserve in-house needs transformers with the power of 63 MVA is foreseen

The following systems for power supply to in-house consumers are provided

- system of normal operation,
- system of reliable power supply for normal operation of the systems important for safety including unit diesel generators,
- system of emergency power supply including emergency diesel generators

5 7 I&C Systems

The design assumes the following hierarchical structure of the control of technological processes at the NPP

- power plant level, where strategic objectives of NPP control and automatic control of common plant systems and facilities are combined,
- unit level, where the control of the unit as a whole is implemented,
- control sub-systems that supervise the operation of technological equipment and systems for various functions and modes,
- sensors, execution units and simplest control algorithms (the level of individual control directly linked with the object of the control)

The base technical means of the I&C of thermal processes are

- modular system of collection and output of data that includes micro-process controller MK-3, memory device MZU-1, internal communication system MVS-3 and a number of modules for measurement transformation and control modules,
- failure-resistant calculation complex using the method of majority redundancy and comprised of the following modules SN (synchronizer), PRC (processor), OZU (operation memory), SZU (system memory), BIF MCVO (interface unit of the data collection system), BIF IRPS (unit for device connection), BIF LS (interface unit of the communication line),
- color displays with functional key-boards,
- DEC Micro VAX-3900 as the power unit computer,

- stream-line network communication means with redundancy that provide for information transfer among various hierarchical levels of the control system,
- sensors, execution devices etc

Automatic protections are divided into two categories

group I - automatic protections of unit safety systems (reactor emergency protection, control of safety systems),

group II - automatic protections of the systems of normal operation that are in turn divided into

- protections that switch off devices and components,
- protections that limit the power of a given device,
- protections that perform local operations

Only the emergency signalization and signals of essential failures in the schemes of operation of emergency protections are duplicated in full

5.8 Major Features of the Approach to Safety

5 8 1 Regulatory Requirements

The project of a unit with VVER-640 is being developed in accordance with Russian regulatory requirements that are in force at the moment of issuing the documentation The major safety documents of GOSATOMNADZOR of the Russian Federation (GAN RF) are unconditionally observed and all deviations from these documents are substantiated and defended in GAN RF

The main regulatory documents that define safety criteria at the design of VVER-640 unit are

- "General Rules for the Safety of NPPs (OPB-88)"
- "Rule of Nuclear Safety for the Reactors of NPPs", PBA RU AC-89

In addition to the national regulatory documentation listed in the "List of Main Regulations and Norms in Force in the Area of Atomic Power under GAN RF's Responsibility" (P-01-01-92), international standards and IAEA materials related to the design of NPPs were considered such as "Regulations for the Safety of NPPs", "Design of NPPs N50-C-D (Rev 1)", IAEA Safety Guidelines N50-CG-D1 D14, Main Principles of the Safety of Atomic Power Stations N75-INSAG-3, "The Safety of Nuclear Power", INSAG-5 (draft)

Radiological safety of the environment is based on the regulations currently in force in Russia (OPB-88, NRB-76/87, SPAS-88, OSP-72/87, PNAE G-03-33-93) and ICRP publications

In accordance with the regulatory documentation in force the classification of the buildings and facilities of the NPP in accordance with their safety function was performed as well as the classification of major systems and equipment by safety, seismic resistance

94

and fabrication quality Special attention was given to the reliability of the systems of normal operation because, on one hand, they ensure the reliability of electricity generation and the limits of safe operation and, on the other hand, provide safety increase for overcoming accident processes and participate in after-accident measures Accordingly, the systems that ensure water supply to systems of the reactor plant, heat removal from the reactor, supply of boron solution to the reactor and electricity generation on site are made with enhanced quality requirements for fabrication and installation and, if necessary, with additional redundancy

According to the estimates made for the project, the level of radiological impact on the population and the environment is below the established regulations and it is kept and a reasonably achievable low level with due regard to social and economic aspects In addition, during NPP normal operation and design incidents regulations for the emissions and contents of radioactive substances in the environment are not exceeded, and in case of beyond design accidents the regulations on the release of most hazardous radioactive nuclides are observed

The project applies the following principles to ensure fulfillment of the radiation safety requirements

- consistent implementation of the principle of defense-in-depth based on the use of a system of barriers at the potential pathways of radiation and radioactive substances into the environment,
- system of technical and organizational measures aimed at the protection of the barriers and their efficiency,
- system of technical and organizational measures directly aimed at the protection of the population and the environment

The system of technical and organizational measures directly aimed at the protection of the population includes

- design conservatism,
- quality assurance at all phases of the design, construction and operation of the NPP,
- NPP site selection,
- establishment of an NPP general protection zone,
- preparation of plans for emergency measures for population protection in case of beyond-design accidents

The protection from all types of radiation that may affect the plant staff and the population during NPP operation is based on the following criteria

- during normal operation the share of additional radiation from the NPP in the equivalent population doze must be significantly below the background level,
- in case of design accidents, technical means provided by the design must ensure the complete protection of the population beyond the NPP site without the implementation of organizational measures in accordance with the "Criteria for

95

decision making on population protection measures in case of nuclear reactor accident",

- in case of beyond-design accidents, technical and organizational means should provide the means of accident management, so that the estimated probability of the maximum release would not exceed 10^{7} per reactor-year

In addition to the requirements of PBA RU AC-89, the project ensures the compliance with the operational design limit of fuel rod damages that is defined as 0 1% of the fuel rods with gas releases and 0 01 % with direct contact between the fuel and the coolant

In case of design accidents, including the break of the main circulation pipeline, the functionality of accident protection and emergency cooling is ensured independently from the availability of alternative current sources (the system of in-house needs, unit diesel generators and cooling water for at least 24 hours Accordingly, the project includes safety systems based mainly on the principle of passive operation and qualities of "inherent safety" such as self-regulation, thermal capacity, thermal conductivity, thermal convection, gravitation, energy of compressed gas and other natural processes For systems of normal operation their safety efficiency for use in post-accident measures has been demonstrated Technical solutions minimize effects of human errors on safety in all design modes

Information on the performed safety analyses, main safety regulations and the assessment of the impact of technological processes at the unit on the environment in all operation modes including normal operation, incidents, design accidents and beyond-design accidents is presented in "Preliminary Reports on Safety Substantiation" that are prepared for every specific site

In the framework of design activities level 1 probabilistic safety assessments (PSA-1) according to the IAEA terminology were performed for the estimation of the probability of severe damage to the reactor core of an NPP with VVER-640

The results of these studies show that the project of an NPP of medium power with VVER-640, which is based on the use of technical solutions for major equipment proved during long experience of operation of NPPs with VVER reactors and complemented with modern requirements for the application of multi-barrier defense, combination of active and passive safety systems, complies with the current safety criteria for NPPs and allows to diminish the level of the impact on the environment

5 8 2 Safety Concept

General

Safety concept of NPP with VVER-640 determines criteria and principles of safety and design approaches to their implementation based on national regulatory requirements, IAEA recommendations and experience in the development and approval of NPPs with VVERs of earlier generations The concept considers the impacts on barriers and their protection, methods to ensure the compliance with the criteria and principles of safety at the design phase, and also some aspects related to the site selection, equipment manufacturing, construction and operation

76

The concept was developed with the following objectives

- to determine the necessary calculational analyses and safety programs,
- to assess the safety of design solutions for NPP protection barriers,
- to determine technical means for NPP safety,
- to develop and substantiate the limits and conditions of safe operation,
- to develop procedures for safe NPP operation

Main Safety Principle

The safety concept of NPP with VVER-640 is based on the defense-in-depth principle that assumes application of a system of barriers at the potential paths of radiation and radioactive substances into the environment and a system of technical and organizational measures in order to protect the barriers and ensure their efficiency and to protect the population

In accordance with the defense-in-depth principle an NPP is designed, built and operated in such a way that radioactive materials are encircled by a number of physical barriers The system of barriers of an NPP with VVER-640 includes

- the fuel matrix,
- fuel rod cladding,
- primary circuit coolant boundary,
- system of hermetic compartments

Main Design Principles

The main design principles of technical and special technical means in the safety concept of NPP with VVER-640 are formulated in accordance with the requirements of current regulatory documents (OPB-88, PBA RU-89) and with due regard of IAEA recommendations ("Summary of Regulations for the Safety of Atomic Power Stations NPP Design", IAEA, Vienna, 1990 Safety Series, ¹ 50-C-D Rev 1) These principles define

Redundancy	Increase in system reliability by the application of structural, functional, informational and time redundancy in respect of the minimum that is necessary and sufficient for the functionality of the system
Principle of single failure	Principle that requires that the system fulfills its functions at any initial activating event and at any failure, independent of the initial event, of one of the active or passive elements with moving mechanical parts
Diversity	Increase in system reliability by the application of different means or of similar means but based on different action principles in different systems (or in different channels within one system) for the fulfillment of a given function
Independence	Increase in system reliability by the application of functional and/or physical separation of channels (component), for

97

	which the failure of one channel (component) does not lead to a failure of another channel (component)
Safe Failure	When practically possible, the "safe failure" principle is used in the design of systems and components necessary for NPP safety that requires that in case of a component or system failure the plant remain at the initial protection "level" without a need of initiation any actions
Common cause failure	Measures minimizing common cause failures are implemented in the design as possible
Consideration of "internal" and "external" events	Consideration of events in the design of technical and special technical means in the safety concept of NPP with VVER-640 is implemented, internationally accepted approaches and with due regard to NPP site specificity

The consideration of "external" events includes

1) Seismic events
2) Aviation crashes
3) Blast wave
4) Squalls (hurricane)
5) Extreme air temperatures
6) Tornado hazard
7) Impact of the inundation
8) Impact of nearby transportation lines
9) Impact of nearby industrial facilities
10) Diversions (subversive activity)

6 Environmental aspects

The regulatory requirements of the proposed power plant are more districting regarding release limits of radioactivity during normal operation and in postulated accident conditions than those applied to the existing power plants in the area Design of the systems for handling and treatment of the radioactive water is improved to meet those requirements

For units of medium power, Table 6-1 gives a comparison of main radiation parameters that characterize NPP impact on the environment and population in the near-by region Prognosticated releases of radioactive gases into the environment during normal operation are presented (for operating units data of actual operation are given) Also, releases for the most serious design accident and for a heavy accident with fuel damage (risk of 10^{-7} 1/year for VVER-640) are given For the VVER-640 unit two options of the most serious design accident are estimated with power supply and without power supply for 24 hours

For comparison, data for NPPs of medium power with VVERs are given unified VVER-440 project (2nd stage of the Kola NPP, the Paks NPP, B-2 stage of the Bohunice plant, the Dukhovany NPP, the Rovno NPP, Loviisa project 1,2)

Additionally, operational data for accidents in 1986 and 1992 at the Leningrad and Chernobyl NPPs are presented that show extremely low radiation impact on the environment of accidents at the VVER-640, including beyond-design accidents with fuel melting

The prognosticated releases of radioactive gases and aerosols into the atmosphere from the VVER-640 unit during normal operation is reduced by

- guarantees of the manufacture-plant on the increase in the density of fuel rods during unit operation at power,
- increase in the requirements for the sealing of major equipment and the corresponding reduction in non-controlled and controlled leakages of radioactive mediums,
- decrease in the volume of coolant take-out during regulation due to the reduction in the scope of boron regulation,
- creation of a closed gas circuit for temporary storage of "clean" and "dirty" coolant,
- renunciation of permanent operation of the exhaust system of the ventilation of the hermetic volume with partial vacuum in the circle gap between shells

Table 6-2 presents a comparison of the condition of the main barriers that hinder the proliferation of radioactive substances into the environment during normal operation Table 6-3 gives a comparison of the condition of the main barriers that prevent uncontrolled release of radioactive substances into the environment

Table 6-1 Comparison of Radiological Impact on the Environment of NPP units of Various Generations

Unit condition	National regulations for maximum radioactive releases[1]	Radioactive release (% of the maximum)		
		Operating NPPs		NPPs under design
		RBMK-1000	VVER-440	VVER-640
Normal operation, operational incidents	Allowable release, Ci/day GWe	Chernobyl NPP, units 3, 4	Kola NPP, units 3, 4	
	IRG- 500	50 - 100	1 - 2	0 04
	Iodine-131 - 0 01	3 - 100	< 1	0 05
	LLN - 0 015	0 2	< 1	0 04
		Zone of radiological impact		Controlled zone
Design accidents	Release that necessitates informing regulatory bodies, Ci	Leningrad NPP accident of 30 03 92	Estimation of DA consequences	
	IRG- 15000	33	< 100	<0 001 /0 05
	Iodine-131 - 0 3	800	7400	< 5 /10
	LLN - 0 45	-	1000	<0 01 / 2
	Zone of radiological impact	up to 3 km	up to 3 km	site
Severe accidents (probability for VVER-640 10^{7} 1/year)	Accident release that requires immediate implementation of the plan of protection measures (for units of earlier generations), Ci	Chernobyl NPP, accident of April-May 1986	Estimation of the consequences of severe accident	
	Iodine-131 - 30000	25000	analysis does not exist	< 2
	Cs-137 - 3000	30000		<0 03
	Zone of radiological impact	more than 100 km		1 5 km

[1] IRG - inert radioactive gases, LLN - long-lived nuclides, DA - most serious design accident, doses are in Ci 1 Ci = 37 GBq

Table 6-2 Comparison of Main Barriers in the Mode of Nominal Operation

Barrier	Barrier Condition	NPP Design	
		VVER-440	VVER-640
Fuel Cladding	Operation unsealing limit, (%)		
	gas	1	0 1
	contact with fuel	0 1	0 01
	Unsealing limit of safe operation, (%)		
	gas	1	1
	contact with fuel	0 1	0 1
Main Equipment of First Circuit	Circuit dehermetization, (V/year) allowable level of circuit unsealing (operational limit)	9	4 0
	coolant take-out		
	boron regulation	67	4 3
	unit shutdown	3	0 3
Hermetic Zone (hermetic compartments of main equipment)	Unsealing, (% V/day)	144	<<0 1[2]

Table 6-3 Comparison of the Design Bases Efficiency of Main Barriers in Case of Main Circulation Pipeline Break for the Most Severe Design Accident

Barrier	Barrier Condition	NPP Design	
		VVER-440	VVER-640
Fuel Cladding	Unsealing, (%)	100	1
Hermetic Zone (hermetic compartments of main equipment)	Unsealing, (% V/day)	1	0 1
	Design pressure, (MPa)	0 15	0 4

The barrier principle and other safety aspects are described by the designer are given more in detail in Appendix 2 Licensing activities with GAN and other authorities are listed in Appendix 3

For storage safety, liquid radioactive wastes in the design of VVER-640 are solidified by the cementation method with the creation of a product, resistant to leaching and complying with the requirements of safe storage The use of pressing and milling reduces the amount of solid wastes

[2] Support of partial vacuum in the hermetic zone of the exhaust ventilation system

Table 6-4 presents a comparison of the volumes and parameters of plant radioactive wastes with medium size units (averaged for unit) It is shown that a significant reduction of waste volume is expected in the design of NPP with VVER-640 as compared with operating NPPs with VVER-440

Table 6-4 Comparison of Volumes and Parameters of Radioactive Wastes for Medium Size NPP Units of Different Generations

Type and category of NPP wastes	Operating NPPs		NPP with VVER-640
	Kola units 3,4	Loviisa units 1,2	
Liquid wastes, m^3/year unit			
- salt concentrate for 400 g/l of ion exchange	416	40	22
- materials	32	8	15
Packages with solidified wastes, per year-unit			
- metal casks with bitumen compound of the volume of 0 2 m^3	solidification facility at the design phase	no data	
- concrete protection containers of[3] 2 6 m^3			37[4]
Solid wastes, m^3/year-unit			
group I	100 - 200	}25 - 35[5]	46[5]
group II	10 - 30		14[5]
group III	1 - 2	no data	0 5[5]

Appendix 4 presents data on the cleaning and use of industrial sewage waters of the system of condensate

7 Project costs and O&M costs

The total cost of the VVER-640 reactor plants has been estimated using both the Russian and EEDB methodologies The major factors influencing the cost of the VVER-640 plant are the research and development program, detailed engineering, reactor buildings, reactor plant components including state-of-the-art reactor instrumentation and controls, turbine generator and auxiliaries, construction and field services, and a contingency to address the first–of–a–kind engineering necessary to develop the detail design for the plant The R&D cost is not included in present estimate Construction of the NPP in the natural and climate conditions of the NorthWest region of Russia on soft soils, with a

[3] The container volume calculated with the external dimensions

[4] For one unit 13 containers with solidified wastes (from the special laundry) are added

[5] With pressing

closed system of technical water supply and cooling towers, with automobile transportation is considered A cost break down of a power plant with two NP-640 units is given in the table 7-1

Table 7-1 Capital costs of proposed power plant 3 x VVER-640

BASE CONSTRUCTION COSTS, million USD	3820
Materials	783
Equipment	1394
Labor	726
Contingency + owner's	917
SPECIFIC CAPITAL COST, USD/kWe	1974
FIRST FUEL LOAD COST PER UNIT, million USD	53 5
FUEL LOAD COST USD/kWe	83

The presented nominal costs USD 1974 per kWe is clearly higher than higher estimate of in JPNAS and values given in ERI-JEAS referred in JPNAS Main reason is that in JENAS a plant in central region of Russia was considered Especially labor costs, but also other costs, are higher in the Murmansk region

In the used methodology the costs were evaluated first in rubles of 1991, and then converted to USD of today using conversion factors The work costs was evaluated using salaries of today This methodology has some risks related to correctness of conversion factors of cost levels and currency exchange rates in 1991 and now In this study that methodology was however used that the results were comparable with the results done by other groups using same standard Russian methodology

There are some factors difficult to evaluate at the moment Real manufacturing costs are not based on real contracts or offers of the suppliers or recent corresponding contracts There are big changes in the conditions compared to those when last corresponding project was implemented Regulatory requirements, e g quality assurance requirements, are stricter and the regulatory body has more power and is more independent than earlier

Operating and maintenance costs and fuel and waste management costs including fuel cycle back end are given in table 7-2

Table 7-2. Operating and maintenance costs

FIXED NON-FUEL O&M COSTS, million USD/year including - materials without fuel, water and soil - salaries of the own staff and contractors - depreciation	146 3 56 3 9 7 80 3
TOTAL NUMBER OF PERSONNEL (incl contractors)	828

SALARY, USD/man year	12160
FUEL COSTS + WASTE MANAGEMENT, USD/kWh	0 005

8 Economic analysis

For economic assessments of the investment requirements for NPP projects with VVER-640 the "AtomEnergo-invest" program package was used that is developed joint by a Research Consulting Company "Alt" and by Institute Atomenergoproekt of St -Petersburg This package was selected in accordance with "Methodological recommendations for assessment of the efficiency of investment projects and their selection for financing" that were approved by Gosstroy of Russia, Ministry of Economics of RF, Ministry of Finance of RF, Gosprom of Russia N7-12/47 as of 31 March 1994, as well as in accordance with the recommendation of the group of planning and modeling The calculation algorithm takes into account the tax environment of the current period

The assessment of economic parameters is done for Sosnovy Bor plant with two VVER-640 units is based on the data given in the previous chapters Following additional data and assumptions are used

The annual use of installed capacity is assumed to be 7000 hours/year corresponding capacity factor of 80%

The in-house electricity consumption is calculated for the average loading of major equipment according and amounts to 7 05% of the electricity generated

- Discount rate 10%, In the sensitivity analysis a discount rate of 8% was considered
- Social charges, charges for the employment fund, medical insurance etc amount to 39% of the annual salary fund
- The liquidation reserve or reserve for the NPP decommissioning fund is defined as 1 3% from the production cost
- Charges for the extra-budgetary R&D fund are 1 5% of the total production cost[6]
- Charges for the special regional investment fund for financing social construction in the 30-km NPP protection zone are 1% of the total production cost[6]
- Charges in an insurance reserve on liquidation of emergency consequences from objects of nuclear power 1% of the total production cost
- Land cost is not taken into account in this case, because the exact territory has not been defined yet (to be determined by local authorities)
- For the NPP equipment was taken into account, that the finances for indemnification of the value-added tax (VAT) become covered at the expense of finances from VAT, showed for payment to consumers of power production VAT on civil and erection works is not compensated

[6] Federal law "About financing especially of dangerous manufactured and units adopted 02 21 96 article 3

104

- The calculations do not take into account directly the costs of decommissioning that appear for VVER-640 after 50 years of service life of the first unit Decommissioning costs are indirectly accounted for by the charges for the "Liquidation reserve"
- In estimations the electric power tariff was assumed constant during the whole service life NPP The accounts were carried out for two values 45 mills/kWh and 60 mills/kWh
- The step of account is equal to 1 year Production from each unit is taken into account beginning since the next year after start-up of the appropriate block
- Construction time is 7 years and the disbursement schedule as follows

year	unit 1	unit 2	unit 3
1	3 4%	0 0%	0 %
2	16 %	7 %	0 %
3	19 %	19 %	7 %
4	26 %	20 %	19 %
5	22 %	22 %	20 %
6	10 %	17 %	20 %
7	3 6%	11 %	18 %
8	0 %	8 %	11 %
9		0 %	5 %

Results of account of commercial effectivness are submitted in appendix 7, as the diagrams of set parameters

Table 8-1 Results of economic estimation of Kola-2 NPP construction (7 years construction)

	Discount rate			
	8 %		10 %	
	Tariff, mills/kW h		Tariff, mills/kW h	
	45	60	45	60
Simple payback period, year	18 9	15 2	18 9	15 2
Discounted payback period, year	>60	33 8	>60	>60
Net present value, M $	-590	292	-1034	-380
Profitability Index	0 78	1 11	0 59	0 85
The internal rate of return, %	6 4	8 7	6 4	8 7
Average production cost of the electric power, mills/kW h	25 6	24 2	25 6	24 2

9 Financing

According to Russian laws all nuclear power plants are owned by the government Financing can not be based on implementation of IPP type or any other model where some other investor than the government will become a shareholder of the plant

Most of the financing will be from Russian sources Direct governmental financing represents the own capital of the power utility Most probably additional financing of the Russian delivery and work will be credits from Russian banks Western financing may be available up to the amount of western deliveries, if in addition of the guarantee of Russian government the export credit guaranteed by the state institutions of the exporting country is given

In the economic analysis the following percentage of financing from different sources with the indicated rate of interest was assumed

- Governmental financing, about 40 %
- Loans from Russian banks, about 40%, real interest rate 7 8% for long-term loans and 9 8% for short-term loans
- Loans from western banks, about 20%, real interest rate 5 8%

10 Project implementation plan

10.1 Project organizations

The system of project management is based on IAEA recommendations ("Nuclear Power Project Management" Tech Rep Series [1] 279) and Russian regulations

The following organizations are responsible for the design and realization of NPP with VVER-640 in accordance with Russian law and regulations

⇒ Institute "Atomenergoproject" of St -Petersburg (SPBAEP),

Leading designer - Architect engineer of the NPP

⇒ OKB "Gidropress" (OKB GP),

Architect engineer of the reactor plant

⇒ RRC "Kurchatov Institute",

Scientific leader

For I&C systems elements and components developed for VVER-1000s in cooperation with Siemens will be used

Fabrication of major equipment components is provided by Russian industries Traditionally, the following enterprises are supplier of major NPP components

- "Izhorsky plant" company reactor, pressurizer, hydraulic reservoirs of the ECCS, main circulation pipeline, protection cylinder for reactor internals, racks of the fuel storage pool, heat transfer equipment, containment,
- Kirovsky plant MCP and major pump equipment,
- Podolsky plant Sags, heat transfer equipment,
- "Metal plant" the turbine plant,
- "Electoral" generator,
- "Atomic" the fuel loading machine and transportation and service equipment for the reactor plant

In accordance with a Framework Agreement on Cooperation in Design and Construction of NPPs with VVER-640/407 reactors between the Ministry of the Russian Federation on Atomic Energy and Siemens AG, KWU Department signed in Moscow on May 15, 1995 it is determined that Siemens AG will take part in the following areas of the implementation of the project of NPP with VVER-640

- design, supply, assembling and start-up of certain I&C systems,
- design, supply, assembling and start-up of certain electrical components and equipment, including the emergency diesel generator,
- design, supply, assembling and start-up of certain components and equipment of technological and ventilation systems

10 2 Time schedule

Preliminary time schedule of the project is in Appendix 5 The construction time is expected to be 7 to 8 years It is not realistic to consider shorter time of implementation when the present conditions of economy and industry are taken into account and the fact that the project is based on new type of power plant without previous experience

The readiness of design describes Appendix 6 listing stages of basic design works and the examinations of the design documentation

Construction works will be started in 2001 after finished simultaneously with the experimental studies at the test facilities at the scientific center NITI in Sosnovy Bor are completed with positive results

10 3. Project risks

For such a specific object as an NPP, there are additional specific risks radiation risk and "political" risk, in addition to usual risks (technical, economic, social) Radiation risk can be, in principle, regarded as economic risk, because it is related to the possibility of severe accidents with the destruction of the reactor and release of substantial amounts of radioactive substances beyond the safety barriers and further into the environment and, as a consequence, with a possible loss of the unit This risk (or the probability of a sever accident) is estimated by calculation techniques According to the regulations that are followed in the project design the probability of such accidents should be minimal and amount to ~ 10-6 - 10-7 1/reactor-year Strict adherence to regulations and rules during construction and operation, fulfillment of technological requirements, "safety culture" are first priority measures for diminishing the NPP radiation risk

Social opposition to NPP construction under the influence of "green movements" or of the fear appeared after the Chernobyl accident is an additional aspect of the social risk This risk can be reduced by information campaigns with comparisons of conventional and nuclear power plants as energy sources for the population, experts and decision-makers

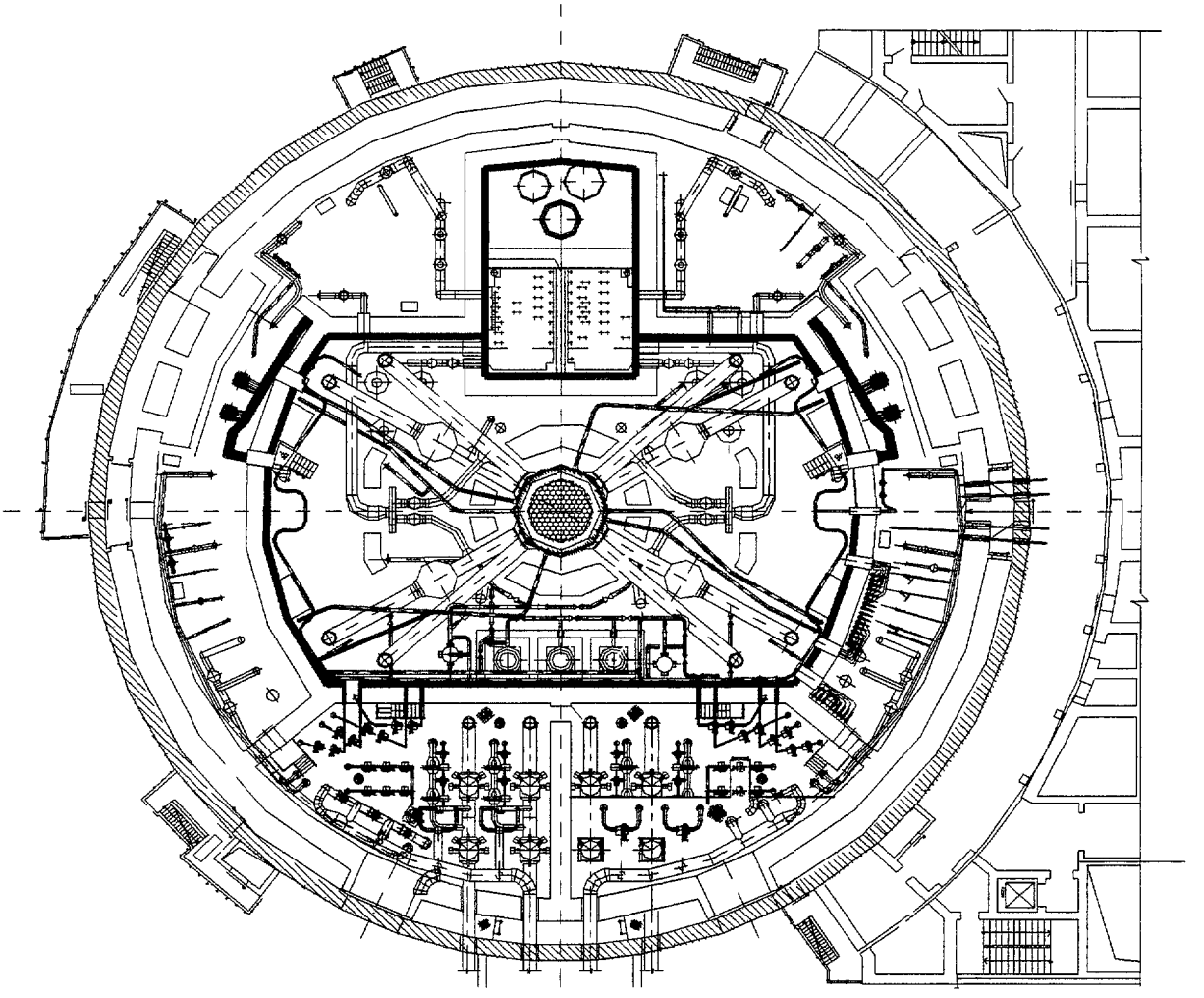
Possible sources for the risk called "political" are both competing energy producers (the Gasprom concern, foreign companies interested in the market for their products such as gas-turbine plants, combined-cycle plants etc) and "anti-nuclear" groups, maybe even at high power levels, that are against nuclear power in principle In this case, independent economic policy of a given region that decided to develop nuclear power on its territory can serve as a guarantee

Appendix 8 presents a qualitative analysis of some risk categories as well as of possible counter-measures in order to reduce them

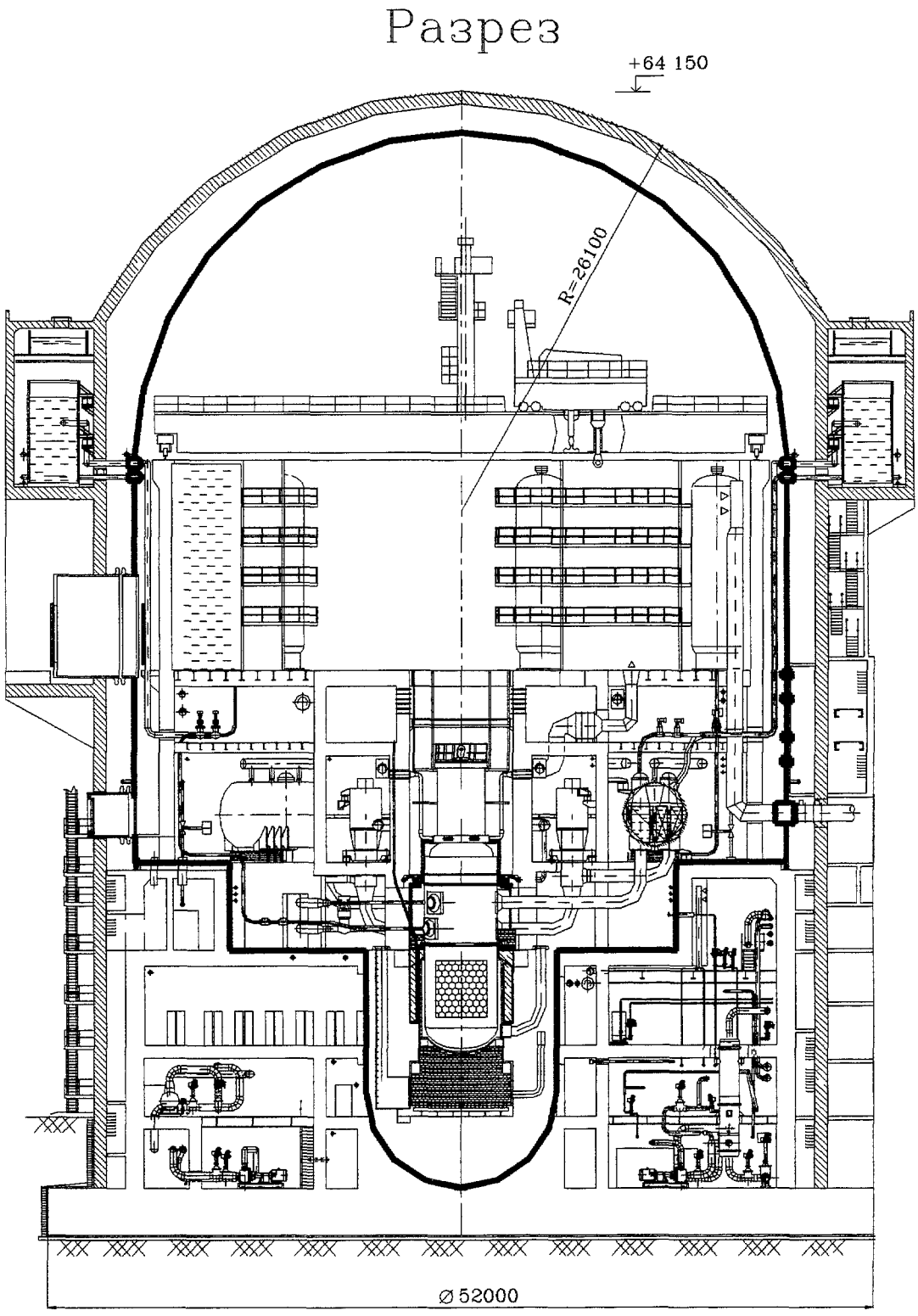
DRAWINGS

1	Layout of the reactor plant
2	Cross section of the reactor plant
3	Reactor
4	Main circulation pump
5	Steam generator

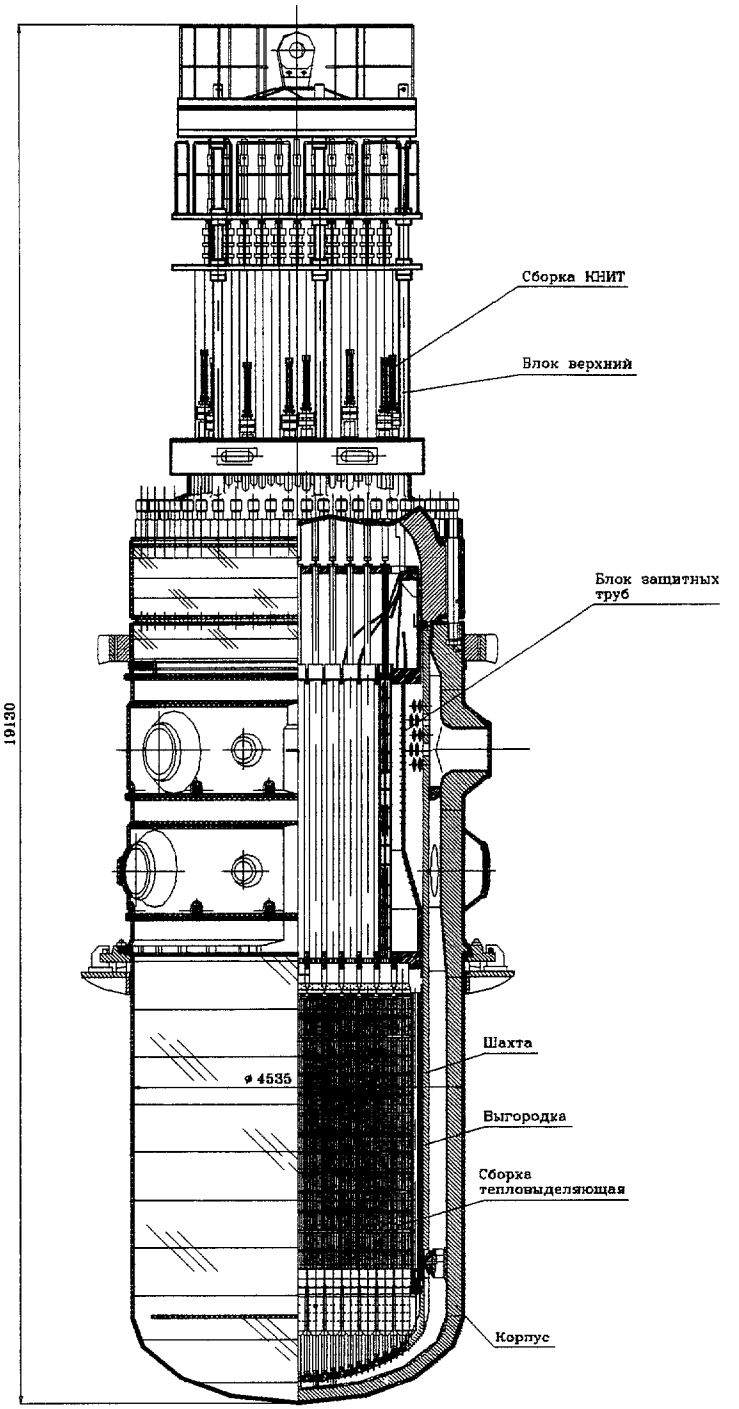
План на отметке 10 0



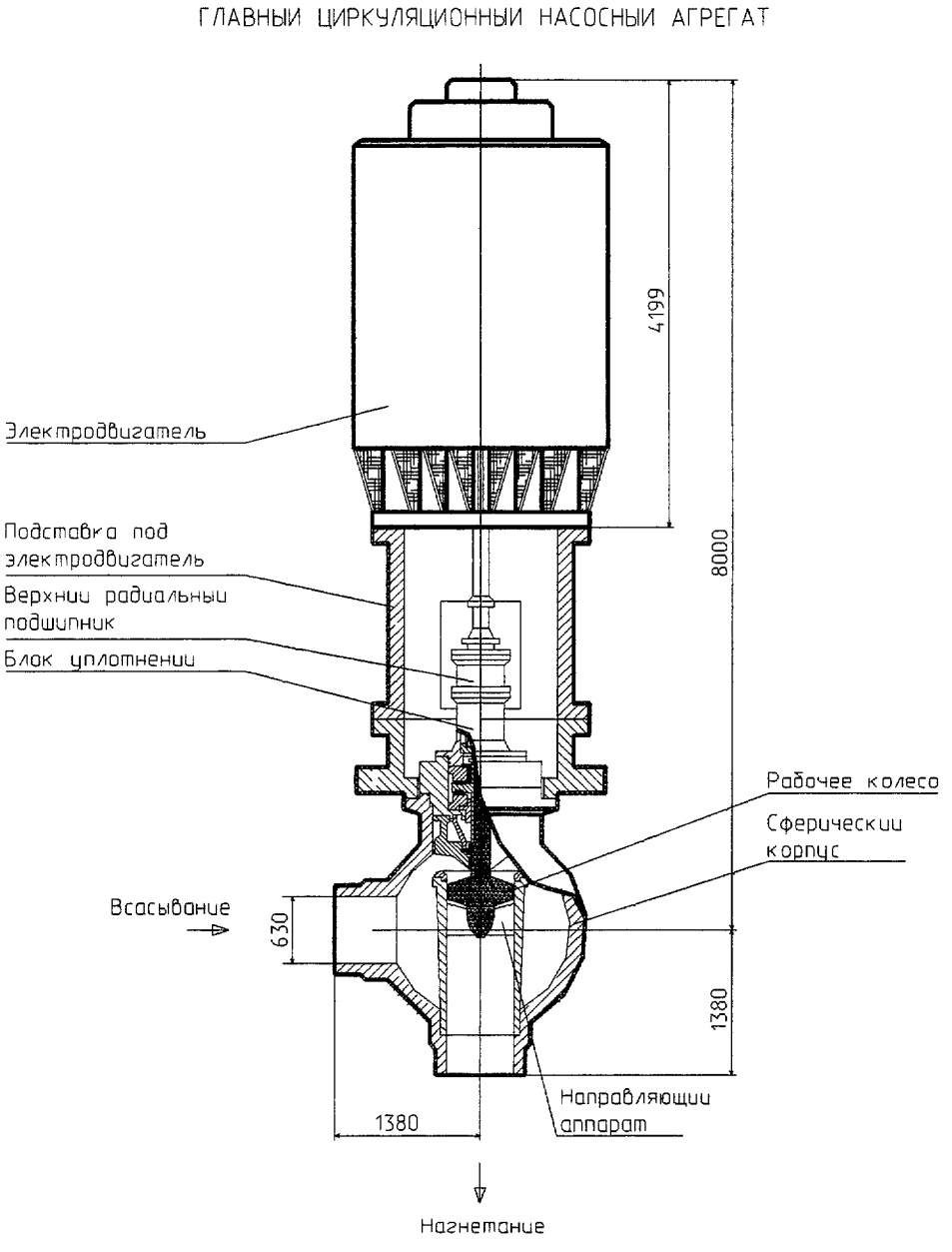
Lay out of the reactor plant on level +10 m



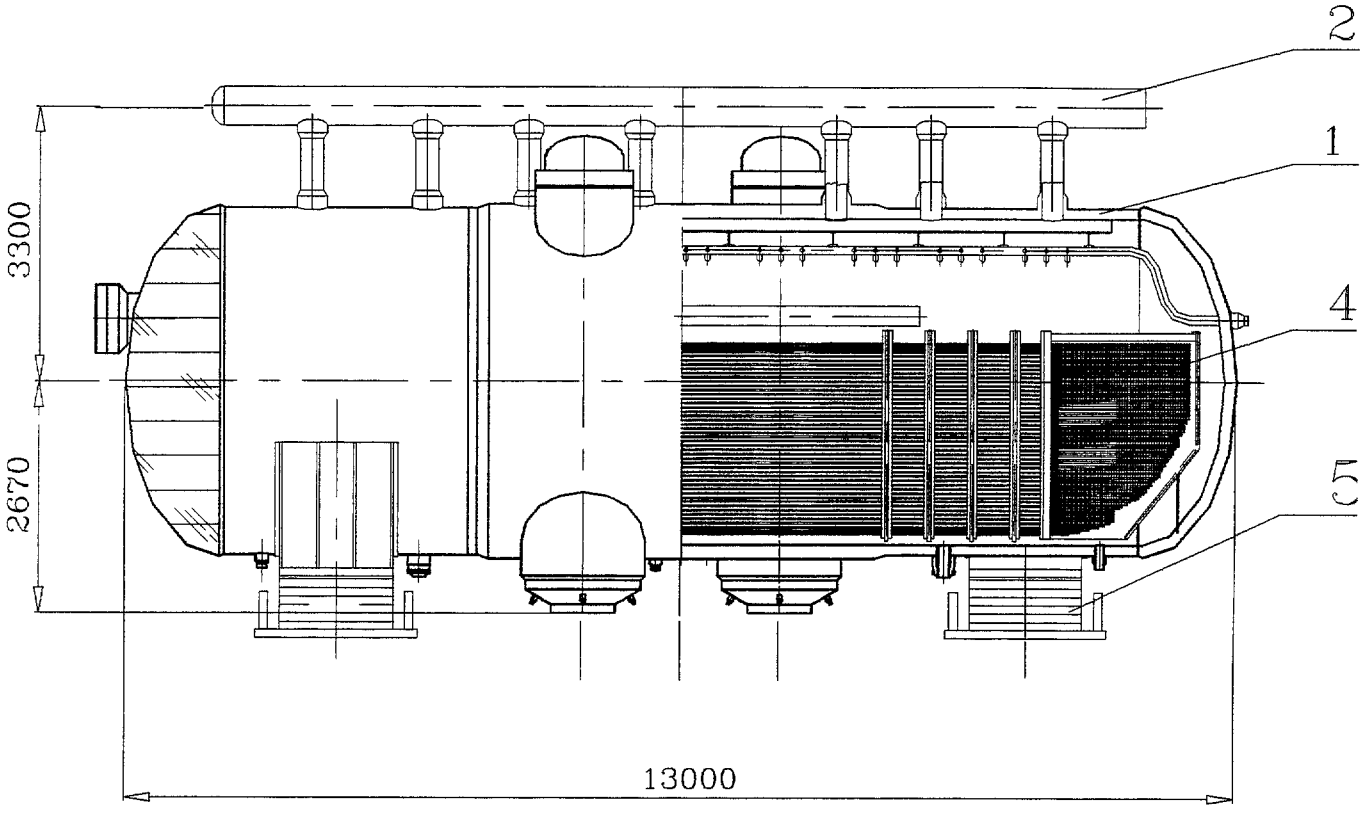
The reactor plant


Сборка КНИТ
Блок верхний
Блок защитных труб
19130
Шахта
ø 4535
Выгородка
Сборка тепловыделяющая
Корпус

Reactor



The main circulation pump



Steam generator

SAFETY ASPECTS OF VVER-640

1 General

The VVER-640 is designed to meet the following Russian regulatory limits
For routine operation and accidents, the limits for damage to fuel elements are 0 1% of fuel elements will develop gas non-tightness defects and 0 01% of fuel elements will develop direct contact of fuel with the coolant

The probability of significant damage to fuel (i e , melting of the fuel) is less than 10^{-5}/reactor-year, and the probability of exceeding the threshold values for release of radioactivity necessitating population evacuation beyond the distances determined by regulatory requirements for nuclear power plant placement is less than 10^{-7}/reactor-year

The reactivity is affected by two independent systems based on different principles of operation (diversity of operation)

- Control rod system, with mechanically actuated control rods in the reactor core
- System for modifying the boric acid concentration in the coolant

In all the design modes, the activation of the mechanical CRS system only (even with the failure to actuate of the most effective control rod) is sufficient for fast suppression of reactivity and for maintaining the reactor in a subcritical state The system of boron solution regulation is sufficiently effective to provide for a slow transfer of the reactor to a subcritical state and for maintaining the reactor in such a state An additional measure for increasing the reliability of ensuring reactor subcriticality in accidents is the use of boron solution in the safety systems that supply cooling water into the reactor and into the spent fuel cooling pond In beyond-design accidents, the transfer of the reactor to the subcritical state is effected by joint operation of all the operable reactivity regulating systems

For accidents not involving the depressurization of the primary circuit, emergency shutdown of the reactor is accomplished by introducing negative reactivity by means of gravity insertion of the control rod clusters into the core Reactor cooldown and removal of residual heat is by operation of normal systems having built-in redundancy of their actuating components and the availability of electrical power supply from a backup diesel-generator unit

In the event of a complete loss of power supply (station blackout), the system for passive heat removal (SPHR) from the steam generators shall be activated, which will provide for the cooldown of the reactor unit, and also for long-term decay heat removal Natural circulation in the primary circuit and the SPHR transfer the residual heat from the core to the heat removal tank for accidents

For loss of coolant accidents from the primary circuit and loss of flow accidents, the response of the automatic protection system and the drop of the coolant pressure will be followed by feeding into the reactor a boric acid solution from

hydraulic accumulators, at an initial pressure of 4 0 MPa Subsequent reduction of the pressure will be accelerated due to heat removal through the SPHR Then, in the event that adequate functioning of the pumping means is not supported for proper makeup to the primary circuit, the core will be flooded from the leveling tanks that hold an emergency supply of the boric acid solution The leveling tanks are located inside the containment The leaking coolant from the ruptured primary circuit will accumulate on the floor of the containment in a specifically partitioned area (the emergency heat removal pool) As the primary circuit, emergency hydraulic tanks and leveling tanks gradually empty, the level in the pool will rise above the level of the outlet pipes of the reactor When the reactor pressure decreases to a preset point, valves will open to form a natural circulation circuit pool to lower mixing chamber of the reactor to core to upper mixing chamber of the reactor and back to the pool Heat will be removed from the pool by partial evaporation of the coolant, with subsequent condensation of steam on the walls and in the interior of the metal shell and with the condensate returning to the pool

From the metal shell, heat will be removed through its wall to the water of the system for heat removal from the sealed shell (SHR SE) To ensure an adequate level in the pool for emergency heat removal, all penetrations through the metal shell are positioned at levels above the required fluid level in the pool If the temperature, pressure, or radioactivity of the atmosphere inside the containment exceeds preset values, the sealed shell is isolated by the closure of the isolation valves on the piping of routine operation systems

According to the probabilistic risk assessment (PRA) results, the safety systems have been designed to preclude severe damage to the core, with a probability of such damage well below 10^{6}/reactor-year However, to follow the present-day trends of expanding in-depth protection, provisions for containing the melt inside the reactor vessel and beyond its confines are now being worked out, and also for protecting against exceeding the maximum allowable pressure value inside the sealed protective shell with the use of a spray system

It is intended that the potential for reaching an explosion-hazardous concentration of hydrogen in the steam-and-gas mixture will be limited by controlled combustion of hydrogen inside the containment

In addition to passive methods, electrical controls are provided for safety system management Control of safety systems in design accidents, including the actuation of the emergency protection of the reactor, emergency cooling of the reactor, prolonged removal of residual heat, localization of the containment, and provision of conditions allowing for the presence and work of the personnel is achieved through a twin-set safety control system Each safety control system set includes two subchannels simultaneously initiating according to the "either/or" pattern, one actuating mechanism for the systems built on a 2x100% pattern, or each channel affecting its own actuating mechanism for systems built on a 4x50% pattern Logic is stored in read-only-memory which cannot be reprogrammed

Each safety control system set provides automatic control of the safety systems,

data for the on-line personnel on the block control board (BCB) and the stand-by control board (SCB) The safety control system is protected from external effects

The containment consists of an internal metal shell and an external concrete shell In the space between the inner and outer shells, a small vacuum is maintained with the effluent air passing through filters into the ventilation duct

Inner diameter 41 m
Full volume 60,000 m^3
Design pressure 0 5 MPa
Design temperature 150°C

The design leak rate from the sealed shell is 0 2 % of the sealed volume for 24 hours The concrete shell is designed to withstand the external effects of an airplane crash, shock wave, and seismic effects

2. Barrier system description

Four systems of barriers are traditionally considered

	Barrier	Description
1	Fuel matrix	As fuel for fuel rods is used low enrichment of uranium dioxide used now in NPP with VVER-1000 and VVER-440 reactors The use of uranium dioxide allows to limit an release of gaseous radioactive fusion products from a fuel matrix
2	Fuel rod clad	The barrier represents a pipe with final detail's from zirconium alloy, fulfilled with dioxide uranium tablets VVER-640 fuel rod with comparison of existing VVER-1000 fuel rod, has the improved parameters because of perfecting production process of tablets and fuel rods, implementation of more effective of monitoring methods, strengthens of tolerances during manufacturing, improving of assemblage quality
3	The primary circuit coolant boundary	The primary circuit coolant represents a circuit, on which the coolant circulates through the core and consists from reactor vessel, main circulating pipeline consisting of four circulating loops Each loop includes steam-generator and main circulation pump Besides its the system of pressuriser and some other systems concerns to the primary circuit As a basic constructional material of barriers, based on operation experience of the previous NPP generations, the stainless steel is selected
4	Containment systems	The containment is a barrier which content the main equipment of reactor unit, and also a spent fuel pit The containment includes a steel containment, tight liner concrete constructions, isolation devices, personal air lock and manholes, penetrations The steel containment is the smooth cylindrical envelope with hemispherical top from low-alloy steel fixed on a bottom in concrete array of interior pedestal

3 Description of NPP safety levels

The first level	THE GOAL maintenance of NPP safety by means of operation reliability and by preservation of barriers effectiveness and ensuring of able to work of staff by means of technical and organizational measures stipulated for normal operation
The second level	THE GOAL of NPP safety by means of restriction of normal operation, down to its shutdown and preservation of barriers effectiveness and ensuranse of able to work of staff by means, including means specially stipulated for reactor shutdown and maintaining it in undercritical state
The third level	THE GOAL maintenance of NPP safety by means of reliable shutdown by work of means specially stipulated for reactor shutdown and maintaining it in undercritical state, both protection of barriers and ensuring of able to work of staff by specially intended means
The fourth level	THE GOAL maintenance of NPP safety by means of transferring of reactor island to undercritical state and keep it in this condition, protection of barriers and ensuranse of able to work of staff by any accessible means, and also additional means intended for control of beyond design basis accidents

4 System of engineering measures

System of engineering measures is intended for

- Protection of barriers with the goal of preservation of barriers properties protective effectiveness
- Mitigation of accidents consequences with the goal of reduction actions of radioactive impact to the staff, population and environment

The system of engineering measures includes a choice of barriers constructional materials, design of barriers and choice of means and special means for barriers protection from actions at each of safety level

The choice of materials and barriers design determines of operation life of barriers with allowance for that the selected engineering and special means ensure restriction of influence of coupled actions to barriers by means of maintaining of each actions performances in baudares, appropriate to each NPP safety level limits The choice of materials both design of barriers and engineering and special means in the project of NPP with VVER-640 is carried out on the base of maximum use of NPP with VVER development and operation experience with account for term NPP raises of design operation until 50 years

The protection of barriers is carried out by means stipulated in the project engineering measures or special means for each NPP safety level

The basis of choice for engineering measures and special means in the NPP project with VVER-640 is the analysis of actions issues to barriers, accepted technological and radiation criterions and the requirement including

- Basic design principles,

- "Interior" and "exterior" actions,
- Ensuranse of NPP defense in the power supply,
- Ensuranse of NPP defense in control and monitoring and et al

5 The Electrosupply systems

The electrosupply systems are intended for maintenance of operation of engineering and special means for ensuranse of barriers effectiveness at each "level" of the NPP defense

The following electrosupply systems are provided

- Electrosupply system for means of normal operation,
- Reliable electrosupply system for means of normal operation including a block diesel - generator and battery,
- Emergency electrosupply system for special means including an emergency diesel - generator and storage batteries
-

6 The control and monitoring system

The monitoring control system has an hierarchical structure appropriate to the NPP defense "levels" The controlling means of a lower hierarchies have priority bear a relation to tools of a higher hierarchy The NPP monitoring and control system is subdivided into four basic functional areas

1 Functional area of systems for normal operation,
2 Functional area of systems for normal operation, important for safety,
3 Functional area of safety systems,
4 Functional area for monitoring of radiating situation and major NPP parameters

The concept of safety NPP with VVER-640 provides three posts of control both for monitoring of a barriers condition and for engineering and special means

1 The main control room (MCR) - is the basic control console, with which is carried out monitoring and control NPP at the all defense "levels"
2 The reserve control room (RCR) - is the additional control post physically separated from MCR, on which enough of instrumentation and controlling means is placed, so that it was possible to stop reactor and to support it in undercritical condition, to remove residual heat and to monitor major parameters of NPP
3 The spare control post for antiaccident operations control - this emergency control post is physically separated from MCR and RCR, hear is placed minimum necessary amount of tools for monitoring of the important NPP parameters and radiating situation at the NPP and in the immediate proximity from it, with the purpose of actuating of protective measures plan

7. A system of structure measures

The system of structure measures includes

- Choice of a site for the nuclear power plant arrangement
- NPP operation in the correspondence with the regulatory normative - by the justified operational rules and instructions, including commissioning, guiding for normal operation, emergency operational guidings, guiding on a radiating safety
- Quality assurance
- Safety assessment

LICENSING

	1 Licensing works (For implementation of design to concrete site the base project of NPP with VVER-640 is developed, the necessary R&D are carry out and the notes and sentences of examinations are obtained which ensure deriving solutions on construction of concrete NPP)			
N	**The name of basic stages of the project realization and conducted works**	**Solutions, inference and examination**	**Time expended on realization of works and examination** Development Examination	**Brief content of inferences, sentences and recommendations**
1	Solution under the safety assessment (MINATOM of Russia and GAN of Russia) Are prepared and discussed the basic solutions on licensing procedures (hereinafter by GAN of Russia are prepared RD-04-07-94 and other appropriate documents)	Is authorized by V N Mikhaylov both Y G Vishnevsky 12 10 92		MINATOM represents into GAN of Russia " the Report on the NPP Safety Assessment" (SAR) at the base of RG 1 70 (US NRC)
2	"New generation medium power unit with reactor plant V-407 (VVER-640) The preliminary report on NPP safety" SPb AEP OKB GIDROPRESS (OKB GP) NRC KI 1992 N 70581 (Ref MINATOM of Russia N 04-2 from 14 04 92) To issue the PSAR have proceeded joint works of the conducting developers and experts of GAN of Russian Federation during three years Under the judgment of the developers, represented materials, confirming safety are sufficient for deriving the license to the beginning of civil work, with allowance for the experience of development and operation of a great many of the prototypes (NPP with VVER reactors)	Inference of GAN of Russian Federation N 14-09/347 from 17 12 92 Inference GRS (GERMANIUM) GRS -A-2130	10 months 8 months	The report is considered by the experts TC NRC Central district of GAN of Russian Federation
3	"New generation medium power unit with reactor plant V-407 (VVER-640) The preliminary report on NPP safety" The project of unit basic buildings SPb AEP, 1992 N 71120		6 months 3 months	Study of NPP and reactor plant design solutions to the substantiation of safety and for account of technical-economical indexes
4	Meeting on preparation of materials under the safety assessment which necessary for deriving, (license) on construction of New generation medium power unit with reactor plant V-407 (VVER-640)	The protocol of GAN of Russian Federation and MINATOM of Russian Federation from 19-23 10 1992 (The Sosnoviy Bor)		GAN of Russia has marked under condition of addition to PSAR for materials of chapter 2 PSAR can be by the substantiation for a choice of a site for NPP construction
5	"New generation medium power unit with reactor plant V-407 (VVER-640)" The project of SPb AEP 1993 No-72224	Inference MINATOM of Russia from 30 04 95	10 months 10 months	The leading organizations of MINATOM of Russian Federation have marked the correspondence to the modern requirements
6	Evaluation of probability indexes of NPP safety with reactor plant VVER-640 The main report of SPb AEP No -71646	The examination together with item 3 1 is provided	6 months 6 months	

2 Package of base design materials on NPP (the Base design materials are developed and carried out all necessary examinations in structure of the design documentation on the sites of Kola NPP-2 and Far East NPP, and also take into account the recommendations of inferences from GRS and SIEMENS (Germanium), carried out in a phase 1993-1994 years Now by results of examinations the adjustments are conducted which allow to ensure unification of engineering solutions to reduce the time of expenditures and realization of examinations on other sites and ensure a possibility of rigorous participation in the tenders for NPP construction in Russia and abroad)

N	The name of basic stages of the project realization and conducted works	Solutions, inference and examination	Time expended to realization of works and examination Development Examination	Brief content of inferences, sentences and recommendations
1	"New generation medium power unit with reactor plant V-407 (VVER-640)" The project NP-00-01 SPb AEP, OKB GP NRC KI	Conference including of interests	12 months 12 months	The given stage is carried out within the framework of works by section 3 of the given table
2	"New generation medium power unit with reactor plant V-407 (VVER 640) PSAR" The reports " The Concept of NPP safety " and " An Evaluation of probability indexes of safety" SPb AEP OKB GP NRC KI (June 1996)	Inferences of interests	6 months	The given stage is carried out within the framework of works on section 3 of the given table

3 Design works on NPP site (as an example the works by deriving a solution to construction of VVER-640 unit at a site of NORTHWEST SCIENTIFIC - industrial CENTRE of Nuclear Engineering in Sosnoviy Bor are represented)

N	The name of basic project stages realization and conducted works	Solutions, inference and examination	Time expended on realization of works and examination Development Examination	Brief content inferences, sentences and recommendations
1	NORTHWEST scientific - industrial Center of Nuclear Engineering PSAR of New generation medium power unit with reactor plant V-407 (VVER-640) (first edition) SPb AEP OKB GP NRC KI April, 1993 (Ref NITI N 4-23/3490 from 28 04 93) The materials are prepared for the first stage of deriving of a solution to construction (endorsing of a site)	Is considered of GAN of Russian Federation (N 14-09/493 from 29 12 93)	6 months 8 months	GAN of Russia has produced "A preliminary inference on a site for construction "
2	NORTHWEST scientific - industrial center of Nuclear Engineering The feasibility report for construction The report "An Evaluation of environmental impact" POKAS (O) and POKAS (VP) SPb AEP January, 1994	Is agreed by Minzdrav GAN of Russian Federation Commission of State ecological examination and expert council of Minpriroda Control of state expert Appraisals of the Projects of MINATOM of Russian Federation	36 months 12 months Including about 30 months Surveys and observations	The coordination at a regional level in 15 organizations

3	NORTHWEST scientific - industrial center of Nuclear Engineering The preliminary report (PSAR) of a new generation with reactor VVER-640 (altenation 1) SPb ASP, SKB SP NRC KI March, 1994 The materials are prepared for final stage of construction solution deriving	The MINATOM judgment of Russia from 30 04 95 on design materials and SAR of NPP with VVER-640 The materials of SAR are considered by NRC KI N 32-19/77 From 16 05 94 also N 32-32/95 From 16 05 95	12 months 12 m (common with item 4)	**25 06 96 GAN of Russian Federation is given a temporal solution for construction of the pilot unit with VVER-640 at the Sosnoviy Bor site N 02/013-01-03**
4	Additional materials represented on examination for deriving of NPP construction solution The report " Safety Concept of NPP with VVER-640 " N 73031 The report " Evaluation of probability indexes of NPP safety" N 73080 POKAS (P) POKAS (RU) and POKAS (R) N NPC-89-002 SPb AEP OKB GP NRC KI March - August 1994	Is considered bv GAN of Russian Federation for deriving a temporal solution on NPP construction	(See item 3)	

USE OF INDUSTRIAL WASTE WATER OF WATER TREATMENT SYSTEM IN COMPONENT COOLING WATER SYSTEM

1 Main engineering solutions

The system, stipulated in the project for clearing of a turbines condensate / hereinafter - the condensate clearing system/ is one of the source of formating the industrial waste water, appearing as an outcome of filters regeneration - hereinafter - regenerationing waters

Regenerationing waters are subdivided to sour and alkaline mineralized waters, washing waters and waters of filters loosening

Regenerationing waters are collected in control tanks for check of a radionuclides content in them and for solution of questions of their further clearing It is provided installation of a tank for sour waters, tank for alkaline waters, tank for washing waters and tank for filter loosing waters

The scheme stipulates a possibility of feeding of regenerationing waters into a radioactive water treatment system with availability of activity in them

Regenerating waters of condensate clearing system which containing the radionuclides in an amount less then tolerable concentration are transferring in a GCP water treatment system for further joint processing

To reuse are subject the waters of filters washing, of condensate treatment system and water regenerater loosening The washing waters after monitoring of its radioactivity are used to loosening of filters-regeneraters The loosening waters containing corrosion products after monitoring on activity are defended, for want of it the inradioactive clarified water is used repeatedly together with washing water, and inradioactive pulp water are processed jointly with pulp waters of water treatment system

Stipulated separate gathering of sour and alkaline waters, and also separate gathering of waters of filters washing and filters loosening allow to reduce volume of wastes and enable to use repeatedly in a water treatment cycle of waters from washings and loosening

Thus, only mineralized waters (the sour and alkaline waters) are exposed to further processing

With the purposes of reliability raise of the gathering scheme for regenerationing waters of the water treatment system the reservation of the most important equipment is provided

In all cycles of waters gathering and processing the monitoring processes with duplication of automated monitoring by laboratory analyzers is stipulated A foundation for a choice of regeneration waters processing method are the results of the full chemical analysis of the fluids which have arrived in gathering tanks

1 2 Description and volume of rehenerated waters of water treatment system

Mineralized waters contain

- The salts extracted from a condensate, which have arrived in a working fluid due to the penetration of cooling water,
- Regenerationing solutions used in filters-regeneraters for restoring of resin exchange ability,

- Chemical reagents which used for water-chemical mode correction in the second circuit, and which extracted by filters from a condensate

Chemical structure of alkaline waters

- The salt content (chlorides, sulfates, silicate acid) - 3740 mg/liter,
- Content of free NaOH - 6470 mg/liter

Chemical structure of sour waters

- The salt content (calcium, magnesium, ammonia) - 5700 mg/l,
- Content of a free sulfuric acid - 3905 mg/l

Flow rate of alkaline waters from one regeneration operation - 40 m^3, flow rate of sour waters from one regeneration - 45 m^3

Pulp waters contain

- Corrosion products of constructional materials from an equipment and pipelines of the second circuit,
- Destruction products of resin materials

Content of iron oxides in pulp waters is 5-10 g/l, content of small-sized non-working resin fractions per the first year of operation - is 3 7 g/l, per consequent years - 2 g/l Flow rate of pulp waters from loosing operation and hydro-overload of one filter - 70 m^3

The number of regeneration actions of a mixed bed demineralizer filters, servings for desolination and deferrization of a turbine condensate, depends on quality of cooling water in turbines condensers At cooling water the salt content up to 1000 mg/l the calculated amount of regenerations for each filter will make 4 time/year, for the whole unit - 16 time/year As to binding of plant to a concrete water-supply source the frequency of filters regeneration of water treatment system and the volumes of regenerating waters are subject to an improvement

2 Component cooling water system

For the cooling of components in reactor and turbine plants is provided one-through scheme with use for cooling systems devises which ensures uninterrupted work of an NPP heat exchange equipment

Below in appropriate sections the basic measures on a drop of probable negative influence of hydraulic engineering buildings of a component cooling water system on an environment in a phase of construction and operation are represented

2.1 Water-supply systems in NPP site

In the correspondence with assigning and parameters of heat exchange equipment three autonomous systems of cooling are stipulated

- Basic system of cooling (RA), ensuring a heat removal from condensers and part of auxiliary turbine equipment which have not of contact to greasing systems The RA cooling system of cooling RA is a system of normal operation which is not influencing to safety
- Auxiliary system of cooling (RS), ensuring a heat removal from intermediate circuit of

auxiliary turbine equipment which have a contact to greasing systems, from refrigerating machines and from of general site customers The RS system is a system of normal operation which is not influencing to safety

- System of cooling RE, ensuring a heat removal from basic intermediate cooling circuit of customers located in reactor and auxiliary unit parts, building of electromechanical devices and diesel-generators building The RE system is a system of normal operation, important for safety

2 2 Brief Description of a water-supply systems

The cooling water is bringed immediately on a unit site with the help of the open bringing channel The drain water after of heat exchanger equipment from all cooling systems is dumped in the common open assigning channel The channels capacity for one unit is ~ 35 m^3/sec

The dumping of the heated up water in a water-supply source is decided at the time of NPP arrangement in a specific construction conditions in an association from an accepted intake construction and cooling ability of a water-supply source

1 The basic system of cooling (RA) is designed on uniflow scheme The nominal flow rate of cooling water for one unit is

- For the turbine condensers 98000 m^3/hr,
- For a part of auxiliaries 1500 m^3/hr

In the cooling scheme of a RA system the block variant of feeding by cooling water to the condenser is stipulated - on each half of condenser group its pipeline and pump is accepted

1 The auxiliary system of cooling (RS) is designed on uniflow scheme The nominal flow rate of cooling water in a system for one unit is

- 3100 m^3/hr for cooling an equipment in a normal operational conditions, including 1000 m3/hr for cooling the refrigerating machine,
- 1200 m^3/hr for cooling a part of auxiliaries of the turbine and of general site customers working in a turbine stopping conditions

2 The system of cooling (RE), intended for cooling of basic intermediate circuit, is designed on uniflow scheme

The nominal flow rate of cooling water is ~ 3000 m^3/hr

The cooling basic intermediate circuit (system KAA) is produced by through the group of heat exchangers, placed in a building of basic intermediate circuit

The water temperature differences which past through heat exchanger equipment of cooling systems, is

- For a RA system - 10-12 °C,
- For a RS system - 4- 5 °C,
- For a RE system - 5- 6 °C

In a specific NPP site arrangement conditions it is necessary to execute a complex of R&D works with the purpose of clearing of influence of damp warm NPP waters to a reservoir ecological

system of and to put in the project appropriate compensatory measures

BASIC WORKS READINESS UNDER THE DESIGN DOCUMENTATION, CARRIED OUT ON NPP WITH VVER-640

1 Readines of engineering

1 NPP Engineering project	The base project is carried out "New generation medium power unit with reactor plant V-407 (VVER-640) The project NP-00-01 " SPb AEP, OKB GIDROPRESS (OKB GP), NRC KI
1 1 Engineering project of reactor plant 1 2	The engineering project readiness is about 80 %
1 3 Engineering project of turbine plant 1 4	The engineering project is carried out
1 3 Engineering projects of auxiliaries	The equipment unified on 60% with VVER-1000 one
2 Reports of the safety assessment (PSAR)	Is carried out Base PSAR at a modern level in the correspondence with US NRC Guide 1 70 Only the finishing of chapter 2 and appropriate sections under the requirements from a leg of a site is required on cooling water, grounds and atmosphere (PSAR has passed examination in GAN of Russian Federation, because of which temporal solutions on units construction are obtained in NSI CNE and KNPP-2)
3 Probability safety analyses	The report "Probability analysis of safety A level 1" is carried out
4 Concept of NPP safety	The report "Concept of safety NPP with VVER-640" is carried out
5 Evaluation of action on an environment	The report "An Evaluation of environment impact " is carried out

2 Examinations of design materials

FEDERAL ORGANS

25 06 96 GAN of Russian Federation has issued a temporal solution to construction of a pilot unit with VVER-640 in structure of NSI CNE in Sosnoviy Bohr N 02/013-01-03

GAN of Russian Federation - Summary experts' report on a site (N F-16407)
GAN of Russian Federation - Preliminary inference on a site (ref N 02/004-01-01 from 13 10 94)

General staff of Russian Federation Army Forces (ref N 312/1/16NS from 19 01 94)
Ministry of Extremely Situations (MChS) of Russian Federation (ref N 22-435-8 from 18 03 94)

State Supervision Ministry of Public Health of Russian Federation (ref N 94-06 from 26 05 94)

State fire-prevention service Ministry of Internal Affairs (MVD) of Russian Federation (ref N 20/5/741 from 28 10 94)

Ministry of Nature of Russian Federation - Summary inference of a commission of experts of State Ecological Examination (SEE) (from 25 10 94)

Ministry of Nature of Russian Federation -solution of SEE Council (from 05 12 94 N 19)

MINATOM of Russian Federation - inference of Department of Project Examination (commission inference from 29 12 94)

MINATOM of Russian Federation -statement of the feasibility REPORT (protocol N 66/80 from 29 12 94)

Commission of Expertsof Department of Nuclear Powwer Development of MINATOM of Russia (from July 20, 1994 N6)

REGIONAL And DEPARTMENTAL ORGANS

North-West regional department of an air transport (ref N 4 16 40 from 01 06 93)

Road committee of Leningrad region (ref N 177 from 23 03 93)

Department of the October railway (ref N NOKS-14 from 10 06 93)

Administration of Sosnoviy Bohr (Protocol N 50/7-94 from 20 04 94)

"North-West regional department" Ministry of fishing Indusrty of Russian Federation (ref N 86-PG from 14 06 94)

Neva-Ladoga Basin Water-Supply Department of Roscomvod (ref N 71 from 30 12 94)

Government of Leningrad region (ref N 3 32/835 from 29 07 94)

State Expert Department of Leningrad region (Lenoblgosexpertiza) (ref N 7/1 from 04 04 94)

Inference of utility organization (NITI), of MINATOM Main department-16 (Dep of science and engeneering) and Main department-26 by materials of the feasibility REPORT (ref N 66/49 from 30 06 94)

Experts' report of VNIIAES (ref N 2132-15/4683 from 09 11 93)
Commission of experts of NRC KI (ref N 32-32/95 from 16 05 95)

The solution of the scientific-engineering council of St -Petersburg institute "AEP" (is authorized by the Minister of MINATOM of Russia, V N Michaylov, 10 10 95)

REVIEWINGS and EXAMINATIONS of DESIGN MATERIALS by FOREIGN ORGANIZATIONS

Commission of International competition "Energy" on a new generation NPP(St - Petersburg 1992)

German company on nuclear reactor - GRS (Berlin - Cologne - Moscow - St - Petersburg, 1994)

US DOE, Bruchavien National Laboratory (BNL), Raytheon Engineers and Constructors" - report "Joint Parallel Steady of an Alternatives of Development of a Nuclear Power Engineering in Russia" (Washington - Philadelphia - Moscow, 1994)

US DOE, BECHTEL, Argonne National Laboratory, BATTELLE Pacific Northwest Laboratory - report "Research of Possibilities of Substitution with Use of Nuclear Potencies for Seversk (Tomsk-7) and Geleznogorsk (Krasnojarsk-26) " (Washington - St -Petersburg -Moscow, 1995)

RISKS OF A NPP PROJECT

Risks of a preparatory stage

Aspect of risk	Influence to profit	Counter-measures
Remoteness from transport turnpikes	Additional expenditures to creation of access roads	Are not required, since all entrances available The risk is not present
Relation of a local authority	Possibility of introduction by them of additional restrictions	Are not required, since the relation of an authority are positive
Engineering security	Expenditures to supply of the electric power, water, heat	The expenditures are minimum, since the basic communications available
Availability of the contractors	Danger of overestimate of works cost	The tenders on the most capital-intensive works

In a preparatory stage the risk of the project is minimum, as both as the basis and the resources in region in a enough either are present, or can be supplied

Risks of a building stage

Aspect of risk	Influence to profit	Counter-measures
Unexpected expenditures - inflationary - rise in prices	Magnification of loan funds	The factors of risk need to be taken into account when compiling of the expense budget, the additional emission of the shares or bonds is possible
Delayed realization of terms of works	Magnification of the production start time	The risk is reduced by organizational measures and monitoring
Delayed preparation of technical personnel	Magnification of term of design volume service achievement	The risk is reduced by organizational measures and monitoring
Delayed realization of starting-up and adjustment works for safety ensuring	Distance of term of NPP accreditation in a system	The risk is reduced by economic sanctions to the contractors and organizational measures
Unconscientiousness of the contractors	Magnification of terms of building and installation works	The risk is reduced at the stage of the contracts, by monitoring and sanctions

Taking into account that fact, that for supply of basic building needs accommodating ready

territories in industrial zone of operating NPP is necessary, the main measure of the given aspect of risk drop, the coordination of civil and erection works with the common program of works in industrial zone, and further use of precise monitoring for the schedule will be

Funding-economic risk

Aspect of risk	Influence to profit	Counter-measures
Instability of demand	Falling of demand with a rise of production prices	The risk is insignificant, since the demand is conditionally constant, the expenses are by the cost of an energy consumer
Emerging of an alternate vield	Drop of demand	To services NPP the alternative on a Kola peninsula is not present
Price cut by the competitors	Price cut and income	NPP is a form of legal monopoly because of licensing agreements with the state
Growth of the taxes	Diminution of a net profit	The risk has a common character, it can be reduced by a local authority
Insolvency of customers	Falling of sales	The customer is various, such risk is not characteristic only of export
Growth of prices on materials, repairing parts etc	Drop of the profit	The consumption of materials, equipment and others Is appreciable
Shortage of circulating assets	Magnification of the credits	The circulating assets has a character of constants costs, and are independent of scales of a turnover
Large time of payments passing	Diminution of the profit	Taking into account rather seller's price of single service, it is possible to organize specially accounts

The funding-economic risks of NPP creation and development are appreciable, but it can be inspected, that allows to organize matter with a reducing of risks to minimum at any stages of the project development

Social risks

Aspect of risk	Influence to profit	Counter-measures
Lack of the qualified laborers	Magnification of expenditures on complectation	In region there are special enterprises, that facilitates acquisition
Relation of local authorities	Additional expenditures on realization of their requirements	Relations with authorities and system of the mutual obligations should be installed legally precisely on a pioneering stage
Insufficient wage level	Turnover of the stuff, drop of production	The risk of a similar type is insignificant, taking into account a labor market position in region
Low qualification of staff	Magnification of accidents, reject, drop of production quality	The risk is reduced by inevitability of tutoring of staff during accreditation and introduction in the state register
Social infrastructure	Unexpected expenditures	The social infrastructure of territory is rather stablis

The social risks of the project are appreciable, but are less significant, than other aspects of risks, and are also under control at all stages of NPP creation and of the program development

Engineering risks

Aspect of risk	Influence to profit	Counter-measures
Wear and tear of an equipment engineering resources, idle times	Expenditures to repair	Equipment is new and science fulfilled, the system of quality assuring and metrological certification are the warranty of the risk minimization
Insufficient reliability of a process engineering	Magnification of expenditures to elimination of accidents and maintaining of production quality	The process engineering for measurements is rigidly given by the standards, maintaining of quality of NPP work - is one of the mandatory conditions for recognizing of the project as a whole

It is represented, that the greatest risk is the risk of delay of the work beginning of and lack of a synchronization with the program of region development

CONTENTS

1 INTRODUCTION **3**

2 PROJECT BACKGROUND **3**

3 DESCRIPTION OF EXISTING CONDITIONS **4**

3 1 MAIN PLANT DATA 4
3 2 PLANT PERFORMANCE 6
3 2 1 Process Description *7*
3 2 2 Operating Modes *8*
3 3 INFRASTRUCTURE 8
3 3 1 Location and site *8*
3 3 2 Connections *9*
3 3 3 Fuels *9*
3 3 4 Water *9*
3 3 5 Personnel *9*

4 IDENTIFICATION AND REVIEW OF ALTERNATIVE PLANT CONCEPTS **9**

4 1 PROCESS OPTIMISATION METHODS 9
4 2 PROCESS OPTIMISATION 10
4 2 1 New CHP plant with GT *11*
4 2 2 New combined -cycle power plant *11*
4 2 3 Two combined-cycle power plants *11*

5 COSTS **12**

5 1 INVESTMENT COSTS 12
5 1 1 Other fixed costs *12*
5 1 2 Variable costs *12*

6 TECHNICAL OPTIMISATION OF ALTERNATIVE PLANT CONSEPTS **13**

6 1 BASIC DATA 13
6 1 1 Energy demand and production *13*
6 1 2 Outdoor temperature *14*
6 2 FUEL PRICES AND TAXES 15
6 3 HEAT AND ELECTRICITY 15
6 4 RESERVE POWER 15
6 5 ENERGY SUPPLY OPTIMISATION METHODS 15
6 6 ENERGY SUPPLY OPTIMISATION 16

7 ECONOMIC ANALYSIS **18**

7 1 TECHNICAL DATA AND PRESENTATION OF THE SELECTED CONCEPT 20
7 2 SENSITIVITY ANALYSIS 21

8 ENVIRONMENTAL ASPECTS **23**

9 PROJECT COSTS **24**

134

1 INTRODUCTION

Prefeasibility study for the project North-West Region Power Plant Investment Plan in Russia provides technical and economic feasibility information regarding the proposed St Peterburg heat and power plant extension The project will comprise an extension of 240 MW_e of installed capacity The project is one of the projects developing the extension of power plants in the North-West Region of Russia After both the Finnish and the Russian in-depth analyses St Petersburg heat and power plant was selected because of its viability

This study will present the project background and describe the existing conditions in greater detail After this general alternative plant concepts are discussed Specific methods for technical optimisation of the plant concepts are thereafter discussed with emphasis on the programs developed by Ekono Energy Ltd of Finland Environmental aspects along with economic and financial considerations of the projects are also discussed Finally, the discussion leads to the project implementation plan

2 PROJECT BACKGROUND

The Nuclear Safety Account (NSA) of the EBRD has agreed with the Russian Government to conduct an analysis of the energy investment alternatives to continued operation of nuclear plants in the Centre and North-West Russia The government of Finland and USAID have agreed to support that analysis by financing a study for North-West Russia

The aim of the thermal and hydropower study is to identify and evaluate potential thermal & hydro investment projects to be included in the North-West Region Power Investment Plan until the year 2010 of which St Petersburg is among the selected cases

The objective of the project is to increase the present capacities of 240 MW for electrical output and 280 Gcal/h for district heat output taking into account the feasibility and environmental aspects of the project The study reviews the present situation of the emissions and the expected development

The area of St Petersburg will benefit from the extension of the heat and power plant from the economic point of view This will at least include the expenditure of funds for construction materials, construction labour, and transportation and shipping costs This will lead to an economic ripple effect through the economy as funds are used for materials, transportation and services This ripple effect continues to the personal level, too, as each worker has personal needs concerning, for instance, housing and food The economy of the area is expected to be positively effected by the increased

demand for goods and services Moreover, the extension of the power plant will make it possible to ensure the requisite reliability of the supply of electric and heat power in the region

Of the social aspects may be mentioned the following ones in the case of the implementation of the project

- improved comfort level and quality of life for the residential of St Petersburg
- allows more buildings to be built in the area served by the plant
- decreased heat and electricity tariffs and subsidy payments

3 DESCRIPTION OF EXISTING CONDITIONS

3 1 Main plant data

Power Plant No 5 is owned by the JSC "Lenenergo", and it serves the heat load in the residential sector The total load from the users amounts to 1396 MW (1200 Gcal/h) With consideration for heating of the plant itself (40 Gcal/h) and the leakages of the district heating network (20 Gcal/h), the total load will be 1465 MW (1260 Gcal/h) The total heat sales in 1997 was some 2500 Tcal

The existing power plant consists of 3 steam turbines, 6 steam boilers and 2 hot water boilers The total electricity production capacity of the plant is 69 MW However, the plant is old, and for this study it is assumed, that the basic equipment installed in the existing main building, will be decommissioned So, all calculation are based on the new units The first unit consisting a steam boiler and a steam turbine is now under construction and it should be completed next year (1999) This new unit will be handled as "an existing plant" since it is already under construction and therefore not anymore the object of a pre-feasibility study

The new unit will be a conventional steam power plant with a steam boiler and a steam turbine The main fuel will be natural gas Technical plant data in greater detail is presented in Chapter 3 2

In addition to the new power plant unit the hot water boiler house will be expanded with six new boilers - four hot water boilers and two saturated steam boilers

New basic equipment in the main building and in the hot water boiler house is being installed at the site No 2 situated beyond the Dalnevostochy Prospect

At the moment (spring 1998) construction works and installation of equipment in the main building are being completed, hence, any essential change in the layout of the basic equipment is no longer possible

The nominal capacities of the main equipment and the total nominal capacity of the plant are presented in the following tables

Table 3-1 Main data of the power plant unit (rated values)

Steam boiler		
- unit number	1	
- type	E_n-670-140	
- fuel (main/back-up)	natural gas/HFO	
- maximum live steam flow	670	t/h
	(186,1	kg/s)
- live steam pressure	137	bara
- live steam temperature	545	°C
- reheat steam pressure	27	bara
- reheat steam temperature	545	°C
- steam output [1)]	507	MW
Steam turbine		
- unit number	1	
- type	T-180/120-130	
- electrical output	180	MW
(maximum capacity	210	MW)
- district heat output	280	Gcal/h
	(326	MW)
- live steam flow	656	t/h
	(182,2	kg/s)
- live steam pressure	127,5	bara
- live steam temperature	540	°C
- reheat steam pressure	24,9	bara
- reheat steam temperature	540	°C
- ultimate back-pressure	0,0865	bara

1) Calculated

According to nominal values plant's gross efficiency will be 89,8 % (based on the boiler efficiency of 90 %) Plant's own consumption of electricity is estimated to be 6 % of the gross electricity production plus 20 kWh/Gcal for the district heat production This means a total net efficiency of 86,9 %

Table 3-2 Main data of the heat only boilers

Steam boilers		
- type	E-160-24	
- number of boilers	2	
- fuel (main/back-up)	natural gas/HFO	
- steam flow	160	t/h
	(44,4	kg/s)
- steam pressure	24	bara
Water boilers		
- type	KVGM-100	
- number of boilers	4	
- fuel (main/back-up)	natural gas/HFO	
- district heat output	100	Gcal/h
	(116,3	MW)

The new unit is running first to meet the district heat demand Hot water boilers are used during the district heat peak demand period and during the maintenance shut down periods of the power units

The number of the annual running hours of unit 1 will be very high since the district heat production capacity of unit 1 will cover only 20 - 30 % of the peak demand

Emissions to atmosphere through the stack of the unit 1 are based purely on the boiler construction and the burner technology since the boiler will not be equipped with SO_x- or NO_x -removal facilities However, comparing to the recent years, the SO_x -emission level will decrease significantly due to decommissioning of 40 small boiler houses The estimated emission levels concerning NO_x-emissions will be 120 mg/Nm^3 (40 mg/MJ) with natural gas firing and 250 mg/Nm^3 (80 mg/MJ) with heavy fuel oil firing This is in accordance with the Russian standard GOST P 50831-95 "Boiler units Thermal engineering equipment General specifications"

3 2 Plant Performance

The turbine will be an extraction condensing turbine and will be started up in 1999

The main parameters of the turbine are shown in Table 3-2, and the main flow diagram in Figure 3-1

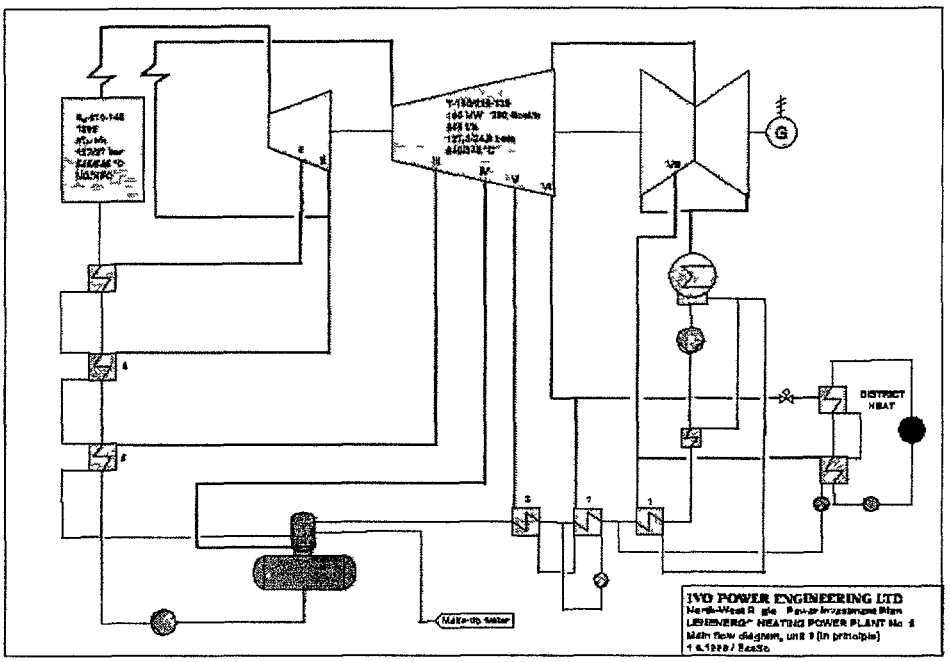


Figure 3-1 Main flow diagram unit 1 (in principle)

3 2 1 Process Description

The feedwater is preheated by extraction steam up to the boiler inlet temperature of about 250 °C For this, the condensing line has in the flow direction, after the condensing and leak steam condensers, 3 LP-preheaters, after that a mixer-preheater (feedwater tank with deaerators - 6,58 bara, 162 °C) and in the feedwater line 3 HP-preheaters Steam for deaeration is taken from extraction IV

The HP-section of the steam turbine has two extractions The outgoing steam is led to the reheater in the boiler The IP-section has four and the LP-section has one extractions Steam to district heat exchangers is taken from the IP- and LP-sections trough controlled exctractions

Makeup water is taken into the feedwater tank

The rated values of extractions at turbine plant 1 are presented in Table 3-3)

Table 3-3 Rated values of turbine plant 1

Extractions	t/h	kg/s	bara	°C
- inlet steam	656,0	182,2	127,5	540
- I	31,6	8,8	41,2	386
- II	49,9	13,9	27,2	333
- III	17,9	5,0	12,6	447
- IV, deaerator	31,7	8,8	6,6	360
- V	22,0	6,1	2,6	249
- VI	8,0	2,2	1,0	152
- VII	1,9	0,5	0,49	98
- exhaust			0,087	

The control limits of the district heat extractions are 0,49-1,47 bara at the lower pressure extraction and 0,59-1,96 bara at the upper pressure extraction

Main cooling system is based on a cooling tower

3 2 2 Operating Modes

The power plant unit can be operated in an almost pure back-pressure operation, when only the minimum steam flow needed for cooling the condensing turbine blades, flows into the condenser Other operating modes are condensing mode, combined back-pressure and condensing mode and reduction mode

3 3 Infrastructure

3 3 1 Location and site

Power plant No 5 is located about 20 km north-east from the historic centre of St Petersburg, and it covers the district heat demand of the surrounding residential areas

There is enough free space on the site for the expansion of the power plant The new unit, which is under construction, is located next to the existing main building

3 3 2 Connections

It is assumed in this study, that no new major district heat pipelines nor high voltage transmission lines are needed for the new power plant units - that is no major investments are expected

3 3 3 Fuels

The future operation of the power plant is based on the utilisation of natural gas In this study it is assumed that the required capacity of natural gas will be available on the site almost through the year Only in winter 10 % of the fuel consumption is assumed to be heavy fuel oil while 90 % is natural gas

3 3 4 Water

Major part of the make-up water goes to district heating network So, the consumption is not expected to increase significantly due to power plant extension, and therefore no major investments to new water treatment facilities is assumed in this studv

3 3 5 Personnel

The present number of the plant personnel is about 600 This is estimated to be sufficient also after the extension of the plant As a matter of fact, due to new technology in the new power plant unit(s), there is need for the reduction of the operation personnel

4 IDENTIFICATION AND REVIEW OF ALTERNATIVE PLANT CONCEPTS

4 1 Process optimisation methods

Tursim is a modelling programme designed for steady state simulation of power plants It can be used to model different kinds of steam turbine, gas turbine and combined cycle plants in both design and off-design conditions It is based on physical process quantities and component models and applies a graphic user interface

The applied mathematical models profit from Ekono Energy's extensive experience in power plant process calculation The implementation uses the latest PC technology, making it to user-friendly professional tool The programme internal solving method is equation based, enabling calculation and input in any desired order This means flexibility in choice of fixed parameters The same plant model can thus be used to simulate any situation at a

141

given power output, fuel input, heat output etc and also in situations, where a specific process parameter must be achieved

One of the program's useful special features is its optimisation function It chooses an optimally efficient value for free variables, if the model contains degrees of freedom This enables easy determination of an optimal operation method or dimensioning

4 2 Process optimisation

The prefeasibility study is based on an assumption that district heat demand will increase up to 1500 MW The following concepts have been studied to cover the shortage of district heat

1) Existing situation with 60 MW gas turbine unit The existing case have been studied with a gas turbine unit which is planned to be build beside the existing CHP plant

2) New CHP plant with 60 MW gas turbine The new plant would be the exact copy of the first alternative

3) New combined-cycle power plant The combined-cycle power plant is equipped with ABB 13E2 gas turbine unit, heat recovery boiler and steam turbine unit

4) Two combined-cycle plants The combined-cycle plants are similar to concept 3

The process values of the first two alternatives have been given by the Russian partners The combined-cycle plant has been designed and simulated with Tursim process simulation tool

The main technical values of the power plants are presented in Table 4-1 in outdoor temperature 0°C

Table 4-1 Electric and heat outputs of alternatives in outdoor temperature 0°C

Power plant	Fuel input, MW	Electricity (net), MW	Heat, MW	Overall efficiency, %
Existing situation	757	240	326	74 7
New CHP with GT unit	757	240	326	74 7
Combined cycle plant	490	230	195	87 0
Two combined cycle	980	460	390	87 0

plants				

4 2 1 New CHP plant with GT

One alternative is to build a CHP plant with a gas turbine The plant would be exact copy of the existing system Exhaust gases pass through air reheater into air duct The electricity output is about 240 MW and the heat output is 326 MW

For the new unit two different flow charts have been proposed The more detailed description of the alternatives is given in Appendix 2 The flow diagrams of the alternatives are presented in Appendix 1 1 (Figure 2 1 and 2 2)

4 2 2 New combined -cycle power plant

The other alternative is a condensing combined-cycle plant with extractions The power plant consists of a gas turbine unit with electricity output of 170 MW, a heat recovery boiler and a steam turbine The total electricity output is 233 MW and the heat output 195 MW in the back-pressure mode The maximum electricity output is 250 MW in the condensing mode

A power output diagram and flow diagrams of the combined cycle power plant are shown in Appendix 1 2 A simple gas turbine cycle, consisting of air compressor, combustion chamber, and gas turbine is used with the turbine exhaust gas going to heat-recovery boiler to generate superheated steam That steam is used in a standard steam cycle, which consists of turbine, district heat exchanger, pump and feedwater heaters The heat-recovery boiler consists of an district heat exchanger, economiser, boiler, steam drum and superheater The gas leaves the heat recovery boiler to the stack Both gas and steam turbines drive electric generators The more detailed plant description is presented in Appendix 2

4 2 3 Two combined-cycle power plants

The alternative of two combined-cycle power plants have also been studied Both power plants are based on ABB 13E2 gas turbine units The total electricity output of the units in the back-pressure mode is 466 MW and the heat output is 390 MW The plant concepts are described in greater detail in Appendix 2

5 COSTS

5 1 Investment costs

Investment costs consist of investment costs and connection costs to power, heat and gas network Due to the increased heat load investments for heat only boilers are also needed Heat only boiler investments are included in all the alternatives to cover the shortage between the need of 1500 MW and the power plant capacity The price of the heat only boilers have estimated to be 35 USD/kW Investment costs for each concept have been collected to Table 5-1 The investment cost have also been directed to the existing situation because the power plant is still under construction and so it will be more comparable with other alternatives

There are no (or only minor) connection costs to the power, heat and gas network They will not be taken into consideration

Table 5-1 Investment costs of each power plant

Concept	Power plant, million USD	Heat only boilers, million USD
Existing situation	120	41
CHP with GT	120	30
Combined-cycle plant	123	34
Two combined-cycle plants	246	27

5 1 1 Other fixed costs

Other fixed costs are costs of personnel in the power plant and fixed maintenance costs

The average yearly salary cost for personnel in power plants is 3000 USD/person, a The present number of the plant personnel is 600 This is estimated to be sufficient also after the extension of the plant

Fixed maintenance costs have been evaluated to be yearly 2 % of the investment cost of the power plant

5 1 2 Variable costs

Variable costs include the electricity and heat production costs and variable maintenance Also the usage of heavy fuel oil during gas supply interruptions is considered here

Electricity and heat production costs are calculated with Copsim simulation program

Variable maintenance costs are presented in Table 5-2 Due to the different plant concepts also the variable costs differ The maintenance cost have been estimated according to the Ekono Energy's experience

Table 5-2 Variable maintenance costs of the power plants

Concept	Maintenance costs, USD/MWh$_f$
Existing situation	0 73
CHP plant with gas turbine unit	0 73
Combined-cycle plant	0 91
Two combined-cycle plants	0 91

In this study the gas and oil prices are considered as a variable cost

6 TECHNICAL OPTIMISATION OF ALTERNATIVE PLANT CONSEPTS

6 1 Basic data

6 1 1 Energy demand and production

Heat demand is only demand for hot water

Due to the uncertainties in heat consumption in the future the studies have been made with yearly load demand of 4000 GWh/a No increase in yearly load demand will be taken into account The estimated load demand will be used for the whole operation period of the power plant

The yearly load demand curve is presented in Figure 6-1

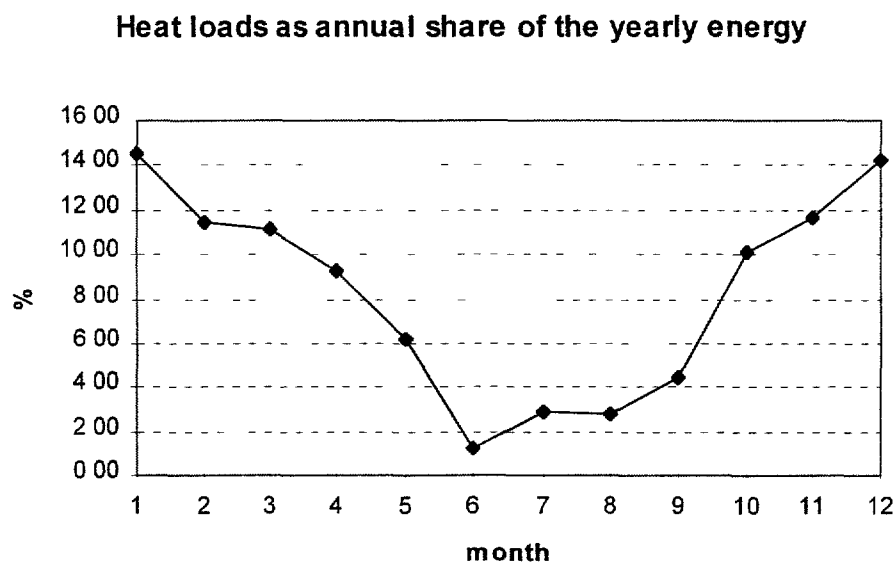


Figure 6-1 Monthly heat loads as an annual share of energy

Heat load variation curve is formed according to variations in a similar Finnish town

The annual heat production is estimated to cover the heat demand The electricity load is assumed to be infinite The produced electricity amount is based on the heat load All the produced electricity is estimated to be sold

6 1 2 Outdoor temperature

Performance of outdoor temperatures in St Petersburg is presented in Figure 6 2 The temperature variation curve has been made with the daily averages of the similar Finnish city which daily temperature variation is known

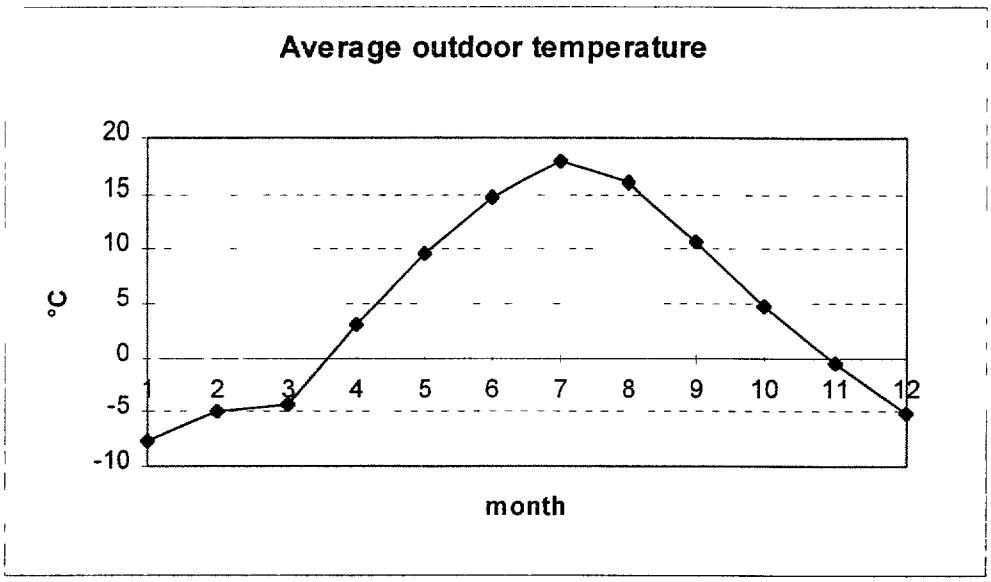


Figure 6-2 Monthly average temperatures in St Petersburg

6 2 Fuel prices and taxes

The calculations have been made without VAT

The calculations have been made with gas price of 7 27 $/MWh The storing costs of the reserve fuel have expected to be included in the gas price

Heavy fuel oil is reserve fuel for the power plant

6 3 Heat and electricity

Since actual price information was not available the prices have been estimated by Ekono Energy

Heat have expected to be sold with the price of 9 USD/MWh The price covers the costs of heat production

Electricity has expected to sold with the price of 24 5 USD/MWh The price has been chose so that the alternatives are viable

6 4 Reserve power

In the study no costs for reserve power have been identified

6 5 Energy supply optimisation methods

The energy supply has been simulated using the Copsim energy optimisation program developed by Ekono Energy

Copsim is an optimisation program for analysing and simulating a utility's energy production and purchase over the year on an hourly basis With the program it is possible to determine the least cost alternative for an energy utility's heat and power production and purchase mix between plants available

The calculation can be carried out based on the real heat and power load patterns on hourly basis If the real load patterns are not available, typical forecasts for heat and power consumption on hourly basis can be formed for example using monthly energy supply and some typical daily load pattern as basic data

Copsim calculates the operating costs based on turbine characteristics, capacities and efficiencies of each plant taking fuel prices, energy tariffs and maintenance periods into account

As a results a large variety of reports are generated including for example operating costs energy production of each plant and energy purchase on an hourly basis as well as duration and variation curves

6 6 Energy supply optimisation

The operation of each power plant is simulated when hourly heat and power load curves are given for the whole year The power plants are modelled to the Copsim-simulation program based on the characteristics of the plant The results of the Copsim-simulation program are the variable production costs of heat and power and the optimal operation of the power plants

The daily variations in power and heat outputs for heat load 4000 GWh are presented in Appendix 3 Total heat and power generation for each concept is given in Table 6-1 The more detailed specification of the outputs and fuel consumption of the power plants is given in Appendix 4

Table 6-1 The heat and electricity generation in each alternative

Power plant	Existing, MWh	CHP + GT, MWh	Combined-cycle, MWh	2 x combined-cycle, MWh
Electricity	**1951**	**3961**	**3862**	**5807**
Back-pressure	1702	2846	3151	4249
Condensing	249	1015	711	1559
Heat	**4586**	**4586**	**4586**	**4586**
Combined production	2348	3963	3437	4144
Heat only boilers	2237	623	1149	442

The electric power capacity in the back-pressure and condensing mode of each alternative is presented in Figure 6-3

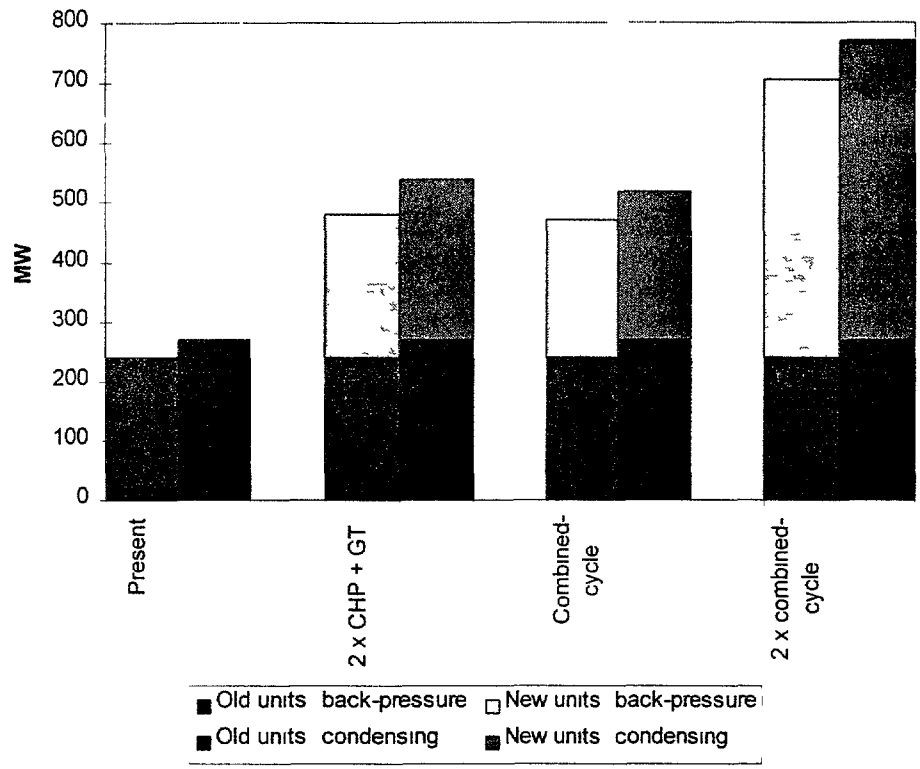
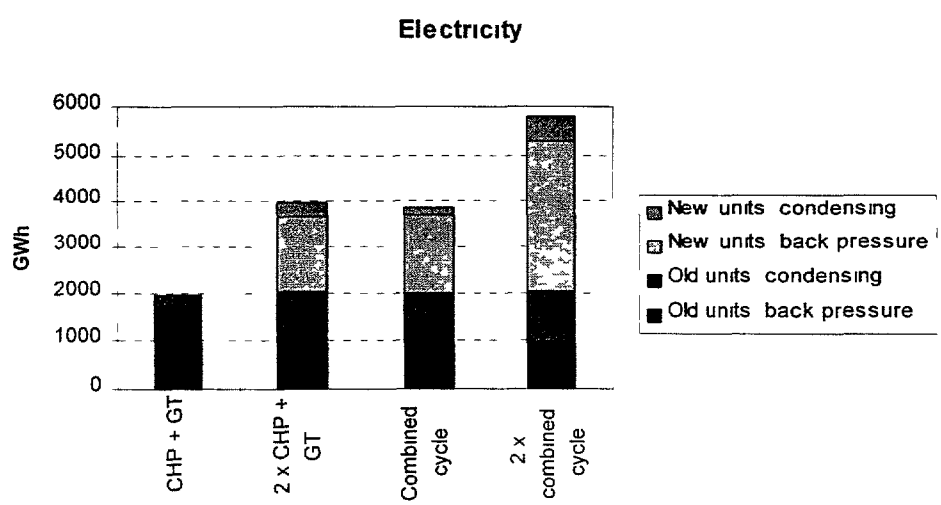


Figure 6-3 The electricity supply of each alternative

The yearly electric energy output of each alternative is presented in Figure 6-4 The figure shows that with combined-cycle power plants it is possible to produce the most electricity in back-pressure operation



149

Figure 6-4 The supplied electricity in each alternative

The heat outputs and yearly energies of each alternative are presented in Figures 6-5 and 6-6

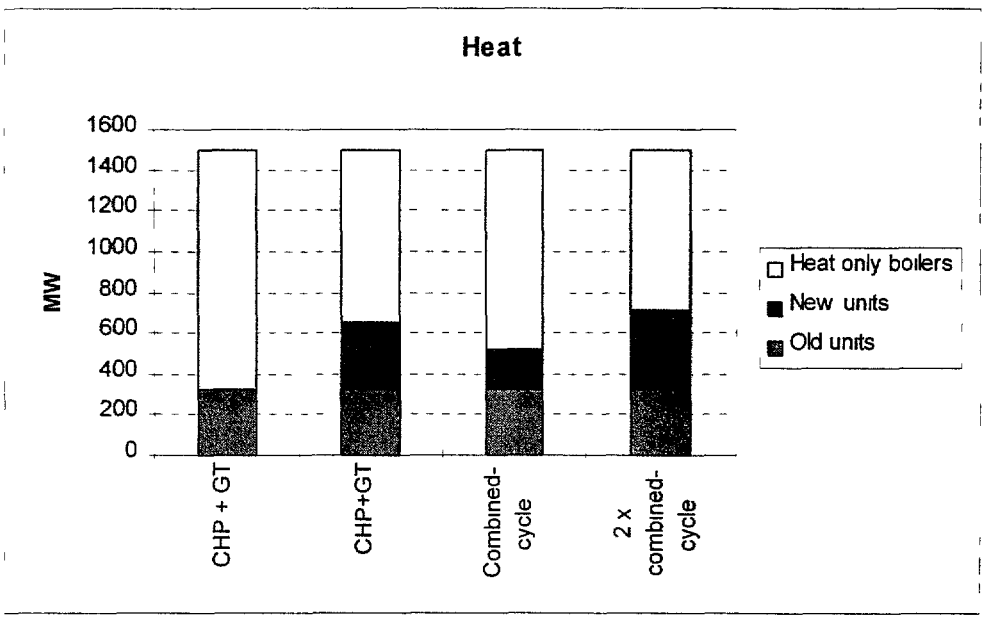


Figure 6-5 The heat outputs of alternatives

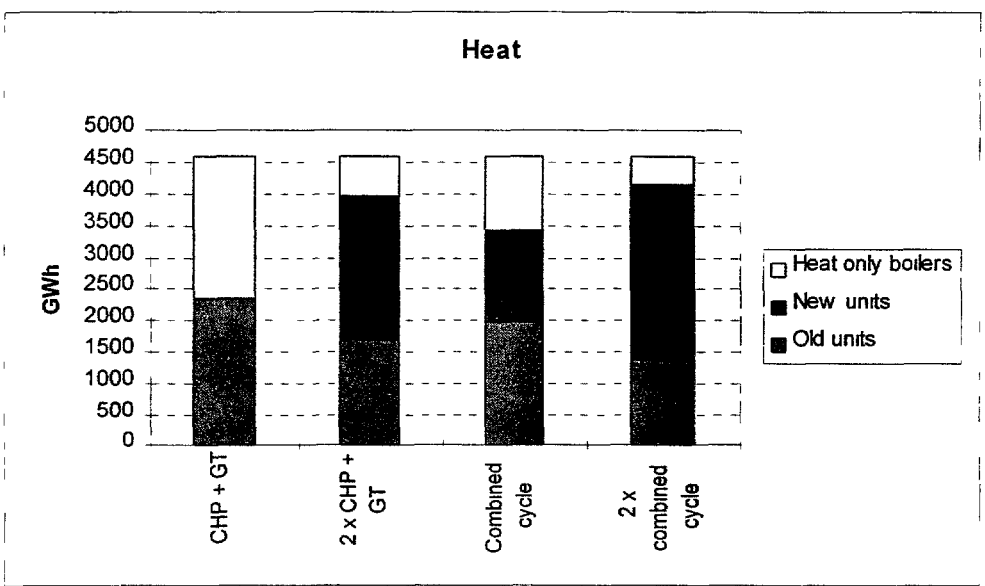


Figure 6-6 The heat energies of each alternative

7 ECONOMIC ANALYSIS

Each concept is calculated in a base case to find out, which power plant is the most viable

A base case is formulated on next assumptions A new power plant is scheduled to operate as a base load plant to maximise the amount of electricity in cogeneration mode Old capacity is used as controlling power

The feasibility calculations are based on the following assumptions

- technical life time of the power plant is 25 years
- real interest rate is 8%

The customer price of heat and electricity is based on assumptions of Ekono Energy because no actual price information was available The price of electricity has been determined so that the extension of the existing system becomes viable The spreadsheet calculations with results are given in Appendix 5

The key figures of the feasibility of the alternatives are shown in Table 7-1 The feasibility have been calculated with the heat demand of 4000 GWh/a

Table 7-1 Key figures of the alternatives

Concept	KEY FIGURES		
	Net present value, million USD	Pay-pack time, a	IRR, %
Present situation	107	9 3	15 2
CHP with GT	225	8 2	16 8
Combined-cycle	263	7 5	18 0
2 x combined-cycle	337	8 0	17 1

The result show that all the alternatives are viable Although, the most viable alternatives are the combined-cycle power plants This is because in combined-cycle power plants the electricity is produced with high efficiency as a result of good heat to power ratio

The concept of one combined-cycle power plant is the most profitable though it requires quite large investments in heat only boilers and the amount of heat produced in HOBs is relatively high The good viability is a consequence of large amount of inexpensive back-pressure electricity

The feasibility calculations have also been calculated in case that no condensing power will be produced The key figures of these calculations are presented in Table 7-2

Table 7-2 Key figures of the alternatives in the back-pressure production

Concept	KEY FIGURES		
	Net present value million USD	Pay-pack time, a	IRR, %
Present situation	88 9	10 4	14 0
CHP with GT unit	146	10 5	13 9
Combined-cycle	216	8 5	16 3
2 x combined-cycle	231	10 0	14 4

The internal rates of the alternatives are also presented in Figure 7-1

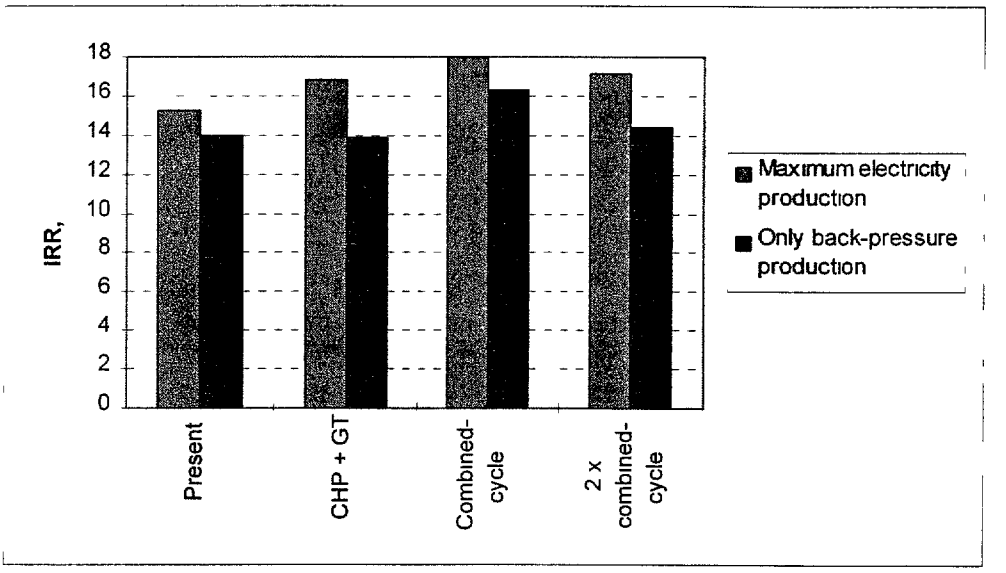


Figure 7-1 Internal rates of return of each alternative

Table 7-2 and Figure 7-1 show that the concepts of present situation and combined-cycle power plant are the least sensitive to the condensing production

7 1 Technical data and presentation of the selected Concept

The concept of one combined-cycle power plant seems to be the most profitable It has quite short pay-back time and the internal rate of return is good

It is technically possible to connect the new combined-cycle plant to the existing units The combined-cycle plant is based on a gas turbine with power output of 170 MW The total electricity output in back-pressure

mode is 233 MW and the district heating output 195 MW In the condensing mode the electricity output is 250 MW and the district heat production is from 0 to 50 MW The plant capacity curve and schematic flow diagram are presented in Appendix 1 2 The plant data is as follows

Gas turbines	One, rated at 170 MW at 0°C
Turbine exhaust	522°C
Heat recovery boiler	Two pressure (63 4 bar and 6 5 bar) Forced recirculation in boiler section
Feedwater	110°C at economiser inlet
Steam	60 bar, 497°C, 65 kg/s
Steam turbine	One high pressure, one low pressure and one condensing, nonreheat, rated at 81 7 MW
Fuel	Natural gas

The combined-cycle power plant has operational flexibility The gas and steam turbine may be started, controlled, and loaded independently from a centralised control room The gas turbine may be operated with or without the heat recovery boiler

7 2 Sensitivity analysis

The changes in profitability of the combined-cycle plant have been studied in cases of different interest rates and the changes in prices of gas, heat, electricity and investment costs The results are shown in Table 7-3

Table 7-3 Sensitivity analysis of the combined-cycle power plant

Combined-cycle power plant	KEY FIGURES		
	Net present value, million USD	Pay-pack time, a	IRR, %
Basic case	263	7 5	18 0
Real interest 5%	437	6 6	18 0
Real interest 10%	182	8 3	18 0
Real interest 12%	120	9 5	18 0
Investment cost +10%	235	8 6	16 2
Investment cost -10%	290	6 5	20 1
Electricity price +10%	364	6 0	21 5
Electricity price -10%	162	10 1	14 3
Heat price +10%	307	6 8	19 5
Heat price -10%	219	8 4	16 4
Gas price +10%	183	9 4	15 1
Gas price -10%	343	6 3	20 8

Table 7-3 shows that the feasibility of the combined-cycle power plant is not very sensitive to the variation of the real interest rate, investment costs or heat price The changes in rates or prices have only an impact of few years on the pay-back time This is a good defence towards uncertainties of inflation rate and changes in investment costs

The feasibility of the combined-cycle plant depends a little more on the prices of electricity and gas However, the power plant is still viable when the prices change ± 10 % The changes of feasibility are presented in Figure 7-2 as a function of internal rate of return

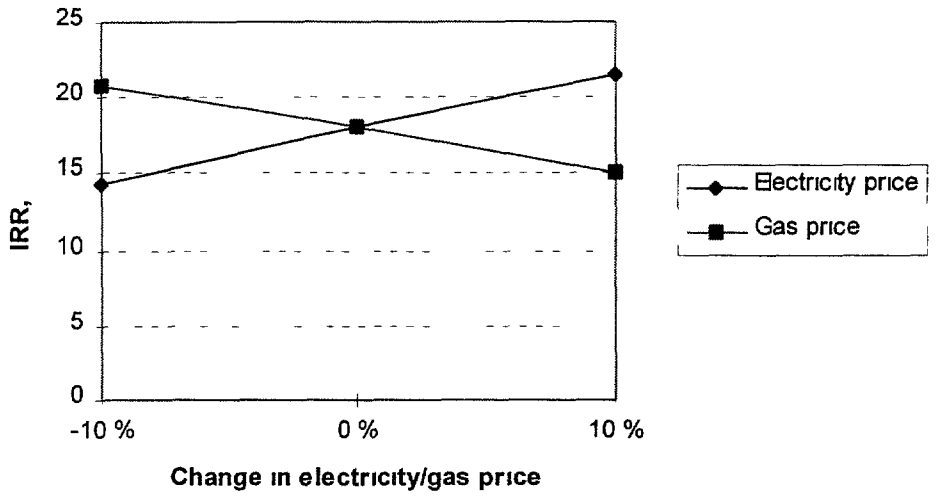


Figure 7-2 Changes in internal rate of return when gas and electricity prices are varied

8 ENVIRONMENTAL ASPECTS

All the power plants are natural gas or heavy fuel oil fired Estimates of emission amounts are based on an assumptions that only natural gas is fired in the power plants

The characteristics of natural gas is expected to be as follows

methane	98 99 %
ethane	0 1 %
oxygen	0 01%
nitrogen	0 96%
carbon dioxide	0 04%

Calculated heat value of natural gas is 8490 kcal/Nm^3 35,55 MJ/Nm^3

Annual NO_x emissions of Lenenergo's power plant No 5 are presented in Table 6-1 Emission factor for combined cycle is estimated based on gas turbine manufacturers' guarantee values for NO_x emissions Other emission factors are accordance with the Russian standards GOST 27510-87 for water boilers and GOST P 50831-95 for boiler units Emission factors are as follows

HOB	50 mg/MJ$_{fuel}$
existing unit	40 mg/MJ$_{fuel}$
CHP with GT	40 mg/MJ$_{fuel}$
Combined cycle	60 mg/MJ$_{fuel}$

155

Table 6-1 Annual NO_x emissions of Lenenergo's power plants (tons per year)

Concept	HOB	Old unit	New unit	Total
Present situation	445	720	0	1165
CHP with GT	125	720	720	1565
Combined-cycle	230	720	870	1820
2 x combined-cycle	90	720	1740	2550

Annual CO_2 emissions are presented in Table 6-2 Emission factor for CO_2 is 55 g/MJ

Table 6-2 Annual CO_2 emissions of Lenenergo's power plants (1000 tons per year)

Concept	HOB	Old unit	New unit	Total
Present situation	487 5	991 5	0	1479
CHP with GT	136	988 5	991 5	2116
Combined-cycle	250 5	991 5	800	2042
2 x combined-cycle	96 3	991 5	1600 2	2668

Specific emissions per produced energy unit are lowest in present situation (new unit and HOBs under construction) because of high efficiency of new HOBs On the other hand, much more electricity is generated in the other alternatives Therefore, if different value of electricity and heat is taken into consideration, the situation will change

9 PROJECT COSTS

The total investment cost of the combined-cycle power plant is estimated to be approximately 120 million USD The rough estimate for the distribution of the investment costs is presented in Figure 9-1

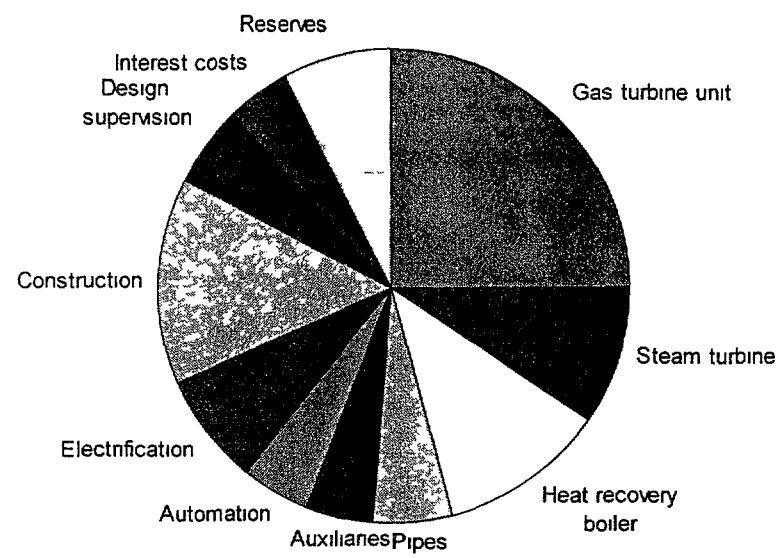


Figure 9-1 The estimate for the distribution of investment costs

The costs will be divided between Russia and Western countries It has been estimated that the steam turbine unit and electrification as well as construction work would be Russian Part of the piping work, design and supervision is also planned to be Russian The estimated division of the costs is presented in Figure 9-2

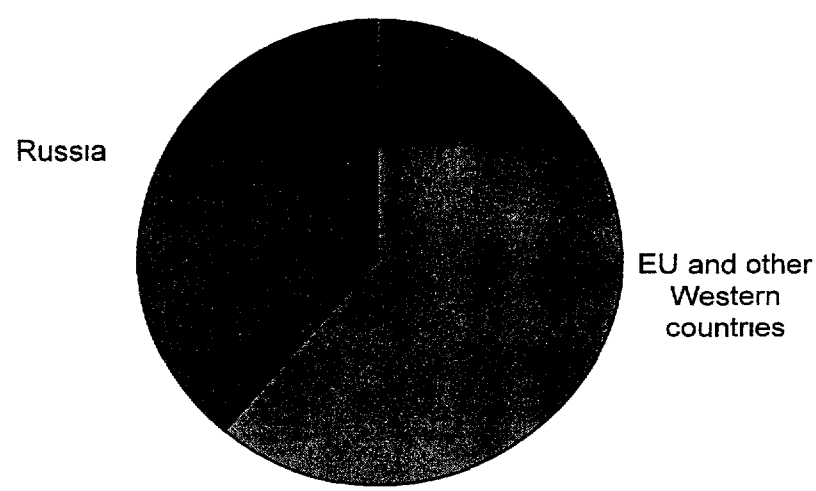


Figure 9-2 Estimated division of costs

10 FINANCING

The most likely possibilities that may be available in financing the St Petersburg heat and power plant project are as follows

10 1 Equity investments and guarantees

10 1 1 Equity investments

When an investment is associated with a major capital outlay as for a power station, an equity investment is always required Owners are generally required to give up some ownership to the new investors Usually lenders require one third equity of the total costs Local companies should be included in their consortia to reduce the political risk

An equity investment may be undertaken in a variety of forms, including subscriptions to ordinary shares or preference shares Quasi-equity investments ranging from subordinated loans, debentures and income notes to redeemable preference shares are also offered When a Multilateral Investment Bank, the EBRD for instance, takes an equity stake it expects an appropriate return on its investment It will have a clear exit strategy and will only take a minority position

In the case of the EBRD as an investor, it may also underwrite a share issue by a public or a privately owned enterprise

The EBRD will consider financing the transfer of shares in existing enterprises only in the case of privatisation where such a transfer will definitely improve efficiency, for example through better management, rehabilitation or expansion under new ownership, or synergy with the acquirer's operations

The terms and conditions of the EBRD's investment in a particular project will depend on the risks and prospective returns of the project, as well as on the characteristics of the entity serving as a vehicle for the investment, for example the joint-stock company

The EBRD does not seek long-term investments or take a controlling interest in or direct responsibility for managing enterprises Where the EBRD can, it will encourage other co-financiers to participate in funding a project These potential co-financiers could include commercial banks and international financial institutions, export credit agencies, and further official sources such as government development assistance programmes Most of these potential co-financiers may also on their own take part in the funding of the investment

Co-financing benefits both lenders and borrowers For borrowers co-financing can

- facilitate a flow of resources from various financiers
- catalyse the flow of additional resources from official and private institutions
- help in meeting large resource requirements for projects too big to be handled by one funding agency

Co-financing can also help in mobilising resources which are sometimes provided on equal or better terms than those available from the leading bank's own funds Co-financing thus offers expanded business opportunities together with greater security and lower costs Usually the leading bank organises co-financing arrangements

10 1 2 Guarantees

Guarantees are a very effective instrument especially for debt and project financing Guarantees from Multilateral Development Banks and the Export Credit Agencies are available against losses from currency transfer or inconvertability, expropriation, breach of contract and war and civil disturbance

Through the EBRD, for instance, various types of guarantees are available, ranging from all-risk guarantees to partial risk-specific contingent guarantees, but in all cases the maximum exposure must be known and measurable and the credit risk must be acceptable

10 2 Project financing by sources and terms

Project financing is the model generally applied by Multilateral Development Banks for projects in CEE and NIS The lender finances the project proper Crucial for an investment decision is that the project can in its business plan show an anticipated cash flow sufficient to repay the loan, pay interest and also give a sufficient accumulation of earnings at the borrower Assets, contracts and cash flow of the project are used as a collateral in the event of a default In project financing for larger projects the banker plays an important role in forming the financial plan of the project, in organising and implementing the syndicate funding

Credits by Multilateral Development Banks such as the EBRD and the World Bank have been traditionally excluded from sovereign debt reschedulings and have therefore enjoyed preferred creditor status Banks that participate in loans to private sector borrowers made by the development banks, where the Multilateral Development Banks remain the lender of record, may share in the benefit of this preferred creditor status

159

10 2 1 International Financing Institutions

EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT (EBRD)

Lending Operations

EBRD activities in the energy sector involve upgrading the power sector, with the introduction of more efficient technology, the reduction of transmission and distribution losses, and the completion of conventional power plants

In financing power plant projects, the trend in EBRD financing has been to shift from public sector projects towards privately owned and run projects, the IPP's (Independent Power Producers) In these cases, the financing is structured on project-finance basis, i e non-recourse, with completion guarantees, off-take agreements, etc

Government ownership does not, as such, exclude a power project from the bank's lending programme, but more and more, EBRD projects are designed to transfer power utilities from public to private ownership In public sector power projects there either needs to be a sovereign guarantee, or in case of project risk being assumed, the project should be ring-fenced to look financially like a private sector project, i e it should have its own cash-flows separate from government expenses and revenues

As regards the minimum size of an EBRD-financed power project, loans in practice tend to be more than MUSD 20 or more and equity investments at least MUSD 10 Through global loans, where a local bank acts as a financial intermediary, even very small power projects can be financed Loan financing may in these cases be supplemented with risk capital from venture funds where EBRD has invested

The EBRD provides loans which are tailored to meet the particular requirements of the project The credit risk may be taken entirely by the EBRD or partly syndicated to the market A loan may be secured by a borrower's assets and/or it may be converted into shares or be equity-linked The Bank lends in any hard currency, and it has started to fund or facilitate loans in certain local currencies When lending to private commercial enterprises the EBRD does not normally require guarantees from the host government and loans are typically without recourse to foreign sponsors, once a project is up and running The basis for providing a loan is the cash flows of the investment and the ability of the investment to repay that loan over the agreed period

The terms of the EBRD loans are as presented in table 9 1

Table 9 1 Terms of the EBRD loans

Rates	• margin over market benchmark (normally Libor) • variable rate or fixed rate
Terms	• loan maturities from 5 to 10 years
Fees	• front-end fee at signing • annual commitment fees
Expenses	• reimbursements of out-of-pocket expenses from sponsors to the EBRD
Recourse	• not required to a sponsor
Insurance	Funded companies or entities shall have • insurance against normally insurable risks (e g theft of assets) • *no* insurance against political risk • *no* insurance against non-convertibility of the local currency
Security	Security of loan with *project assets* of companies or entities • mortgage on fixed assets (e g land) • mortgage on movable assets (e g equipment) • assignment of company's hard currency and domestic currency earnings • pledge of sponsor's shares in company • assignment of company's insurance policy and other contractual benefits
Covenants	Finance covenants • limiting indebtedness • certain financial ratios • other issues

WORLD BANK

The World Bank, founded more than 40 years ago, has a role of a lender-donor institution It has provided more than 200 billion USD in financial and technical assistance to developing countries to stimulate economic growth and stability Russia became a member of the Bank in 1992 The Bank consists of four closely associated institutions the International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the International Finance Corporation (IFC), and the Multilateral Investment Guarantee Agency (MIGA) In this context we concentrate only on the IBRD because of the nature of the project and the country

The IBRD lends funds, most of which it raises through the sale of AAA-rated bonds in international capital markets, creditworthy developing countries These countries shall be able to pay near-market interest rates Loans

are made only to governments, government agencies, or institutions that can obtain a guarantee from their government Goods, works and services financed by these loans are procured in accordance with procedures stipulated by the Bank The IBRD also provides partial risk or partial credit guarantees (with a counter-guarantee from their government) to private lenders on development projects

In table 9 2 the main terms of the World Bank loans are presented

Table 9 2 Terms of the IBRD loans

Loans	• currency pool loan • single currency loan • Libor-based single currency loan
Rates	• rate reset semi-annually (currency pool loan) • Libor-based or fixed-rate (single currency loan) • six-month Libor
Repayment	• 12-15 years
Grace period	• 3-5 years
Borrowers	• governments and • agencies that can obtain a guarantee from the government

The World Bank finances, on average, about 40% of the total cost of a project, which in turn stimulates further funding by the borrowing countries and by other agencies and commercial banks that co-finance with the World Bank If the World Bank agrees to fund the project, perhaps RAO and the Energos may request a long term, soft loan (i e low interest) for approximately 1/2 (one-half) of the project costs

NORDIC INVESTMENT BANK (NIB)

NIB is a multilateral financing institution founded in 1976 and owned by the five Nordic countries (Finland, Sweden, Norway, Denmark and Iceland) The Bank's authorised capital has been subscribed to in proportion to the member countries' GNP

In order to have the possibility to finance a Russian investment the Petrozavodsk heat and power plant extension shall have positive environmental impacts In addition to this it has to be ensured that the borrower can pay back the loan, i e covenants are required from the borrowers In the case that either RAO or one of the energos is the borrower one requirement is that the Russian Ministry of Finance gives a security In the case of the Nordic Investment Bank as a lender it is required a Nordic interest, i e

162

- the project has positive effects on employment and business in the Nordic countries
- the project is carried out in one Nordic country by the combined efforts of that country and a non-Nordic country
- foreign investments in the Nordic countries can involve greeenfield investments, as well as expanding production in an existing subsidiary
- NIB's participation should be in reasonable proportion to the size of the project and the anticipated benefit for the Nordic countries

However, high priority is given to lending for cross-border investments that promote Nordic economic integration, stronger growth and high employment on a long-term basis

In table 9 3 are presented the principle terms of the Nordic Investment Bank loans In addition to loans, NIB offers also guarantees

Table 9 3 Terms of the NIB loans

Rates	• fixed • floating
Repayment	• 5-20 years
Grace period	• up to 7 years
Terms	• all costs related to a project can be financed • maximum 50% of the total project costs

NIB's lending consists to 20% of international loans (borrowers outside the Nordic countries) The international loans increases more than the Nordic loans

TACIS PROGRAMME

Ownership

The Tacis programme is a technical assistance programme, which provides grant finance for know-how to support the process of transformation to market economies and democratic societies

The know-how is delivered by providing policy advice, consultant teams, studies and training, by developing and reforming legal and regulatory frameworks, institutions and organisations, and by setting up partnerships, networks, twinnings and pilot projects

Tacis partner countries comprise Russia and the New Independent States (Armenia, Azerbaidzan, Belarus, Georgia Kazakhstan, Kyrgystan, Moldova, Turkmenistan, Tajikistan, Ukraine, Uzbekistan) and Mongolia

The Tacis programme is funded from the EU budget and operates under its rule The budget is fixed annually by the European Parliament and the Council of the European Union The yearly budget provided for Tacis is then divided up between each country based on criteria such as population, gross domestic product, commitment to the reform process etc

A new Tacis regulation was approved by the Council in June 1996 The new regulation permits a limited amount of the allocation to be used for small-scale infrastructure projects in the context of cross-border cooperation In addition, the regulation states that the Tacis programme will support the establishment of joint ventures through the funding of equity investment in small and medium-sized enterprises

Programming process

Indicative Programmes are prepared by the European Commission in coordination with the partner countries and cover a four-year period (presently 1996-1999) Indicative programmes take each individual country's reform priorities and economic circumstances into account and establish the basic objectives and strategy for the Tacis programme in that country Indicative programmes may also include financial estimates

National Action Programmes are prepared every second year (except in Russia and Ukraine every year) and they comprise individual projects and activities, which support the sector objectives established in the Indicative programmes Action programmes also allocate the funding available for each sector

Financial proposals are based on the Action Programmes where projects are described and budgeted They outline the contracts available for tender and are submitted for the opinion of the Tacis Committee Once the Tacis Committee has delivered a favourable opinion and subsequently the Commission has formally approved the financing proposals, the corresponding budget commitments are made

Funding Operations

The different TACIS programs that can assist the energy sector reform in Russia are

- Tacis Action Programme for Russia 1998
- Tacis Inter-State Programme

- Tacis Cross-Border Cooperation
- Nuclear Safety Programme
- The Joint Venture Programmes

Project Cycle

Ordinarily, a proposal to include a project in one of the Tacis financed programmes, may only be made by a national or local organisation from a Tacis partner country and should correspond to objectives identified by the Indicative Programmes for that country

The project is then submitted to the Coordinating Unit in that country The Coordinating Unit will assess the proposal and may, after a pre-selection, submit it to the European Commission for further consideration either via the Commission's Delegation in that country or directly to the DG 1 in Brussels

If the project is then selected in an Action programme, the corresponding contracts are put out to tender in the normal way It should be noted that Action programmes do not always automatically retain selected projects as originally proposed

THE NORDIC PROJECT EXPORT FUND (NOPEF)

Ownership

The Nordic Project Export Fund was established in 1982 and operates under the Nordic Council of Ministers Its shareholders are the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)

Nopefs annual budget is approximately ECU 3 5 million

The Board of Directors constitutes of two representatives from each Nordic country

Operational Structure

The main priority of NOPEF is to foster and develop Nordic cooperation The concept of Nordic interest is also a priority for all activities of NOPEF NOPEF's target is to strenghten the Nordic companies international competitive advantage by offering attractive financing for feasibility studies and business planning activities This fosters the internationalisation of Nordic companies and their participation in international projects

NOPEF cooperates with the NIB, NEFCO and the Nordic Development Fund (NDF) to strengthen the Nordic profile

Target Sectors/Restrictions

NOPEFs target region is the neighboring region and NOPEF has also during the last few year focused on small and medium sized Nordic companies, which today stand for 75% of the total amount of companies seeking financing from NOPEF

During the last years 80% of NOPEF's activities have been in Central and Eastern Europe, and especially in the Baltic States North-West Russia has taken the place of Asia as an increasingly important region outside the neighboring region

Most of the projects financed during 1996 have represented the forestry, energy, production and the construction industries New important areas of operation are the information technology, data service and wholesale sectors The environmental sector is also an interesting sector and in this sector NOPEF usually works in close cooperation with the NIB and NEFCO

Loans

NOPEF gives interest-free loans to finance pre-feasibility and feasibility studies in the Baltic states and in the North-West Russia.

The loan can cover 50% of the feasibility study costs

Project Cycle

The initial contact to NOPEF can be taken by telephone or fax After discussing the project with one of the NOPEF project consultants, application papers can be received

The project consultants evaluates the project and forwards the application, if it fulfills the requirements made by NOPEF, to the Board of Directors

THE NORDIC ENVIRONMNET FINANCE CORPORATION (NEFCO)

Ownership

The Nordic Environment Finance Corporation (NEFCO) is a risk capital institution financing environmental projects (including investments in single energy production plants) in Central and Eastern Europe NEFCO was

106

established in 1990 by the five Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)

NEFCOs capital (doubled in 1996) is ECU 80 million, with the intention to invest the capital in some 50 projects up to year 2001 Denmark shall subscribe ECU 18 3 million, Finland ECU 14 9 million, Iceland ECU 880 000, Norway ECU 15 6 million and Sweden ECU 30 4 million

All powers of the Corporation are with the Board, which may to the extent it sees acceptable, delegate power to the Managing Director and/or to the Nordic Investment Bank Financial decisions are made by the Board The Board approval for a project is usually obtained in two steps (1) the project is given an indication of interest, which means that it falls within the field of NEFCO's operations (2) the project undergoes full appraisal to confirm its viability in NEFCO's opinion

NEFCO is situated in Helsinki, together with the Nordic Investment Bank

Operational Structure

Projects eligible for financing from NEFCO must fill the following criteria

1) The project should be carried out in one of NEFCO's countries of operation in Central and Eastern Europe Priority is given to the Baltic Sea region and the Barents region

2) The project should have relevant environmental effects Priority is given to projects that have substantial environmental effects on the Nordic region, i e projects that lead to reduction of pollution in the Baltic Sea and the Barents Sea or reduction of transboundary airborne pollution

3) The project is based on long-term cooperation through investments in enterprises, primarily through the formation of joint venture companies or corporate acquisitions

4) The project has a Nordic company or institution as business partner

5) The project is economically financially institutionally and technically viable

A Nordic partner should take part in the project on a long-term basis Generally this implies participation in an enterprise also acquisitions and joint ventures are typical, but long-term cooperation may also be based, for example, on a twinning arrangement The Nordic partner is also required to have sufficient experience of the business The environmental, technical,

institutional, economical and financial feasibility of the project should be demonstrated, normally through a feasibility study

NEFCO aims at participating as an active investor In practice this usually means that NEFCO requests the right to nominate a representative in the Board of project companies, at least in the early phase of a project

Subscribing of equity and shares

Facilitating mobilisation of necessary equity base for a project NEFCO can then participate as a partner in the project NEFCO will not accept a majority ownership or a dominating position for itself

Medium and long-term loans and guarantees

Provided on market terms In some cases subordinated loans and loans with equity features may be provided Often the loans are extended in addition to NEFCO's equity participation in the projects

NEFCO's participation in projects for equity investments is generally in the range of 25-35% of the total financing Loans on market terms, loans with equity features, subordinated loans or mezzanine financing normally is in the range of 25-50% of total loan financing

In large projects the proportion would be smaller According to present policy the maximum commitment for one project is approximately ECU 4 million A commitment under ECU 125,000 will be considered by NEFCO only under special conditions, for example in the case of environmentally significant demonstration projects

NEFCO regularly co-finances projects with other financial institutions and with the Nordic countries bilateral environmental assistance programs for the neighbouring region

10 2 2 Suppliers Credit

The project may also be announced under a turnkey arrangement with the successful contractor responsible for obtaining the financing from export credit agencies The procurement under this scenario will be done on an international competitive basis The maturity of the loans from export credit agencies is likely to be for about 7-8 years, and will require guarantees from RAO and the Russian government Approximately 70% of the estimated costs to complete the project can be financed in this manner, with the rest of the funds coming from commercial banks

168

10 2 3 Commercial Banks

Based upon the balance sheets of RAO and the energos and with the appropriate guarantees from the Government, some of the Western commercial banks may be interested in financing the project The interest rates for such loans, however, are likely to be higher

10 3 Grant funds

10 3 1 EBRD and other development banks

In addition to the EBRD's and other development banks' capital paid in by the shareholder countries, many member countries have lodged special funds with the Banks to assist in preparing projects Such grant funds are available to employ consultants to carry out feasibility studies for projects and to cover other preparation costs Thus, the grant funds do not cover the financing in the investments

10 4 Risks

Financiers have the requirement that risks connected with their participation in a project are kept at a low level A structured and comprehensive approach to risk management is thus essential

Risks are usually divided in two types

a) project risks and

b) global risks

Project risks include development risk (planning, bidding), construction risk (design, completion, etc), operational risk (defects, management, economics of operation), financial risk (foreign exchange, interest, cash flow) and revenue risk (demand, rates)

Global risks include political risks (expropriation, force majeure, fiscal changes, etc), legal risks (changes in law and regulation during concession period), commercial risks (escalation of costs of raw materials, convertibility, devaluation) and environmental risks

All risks must be carefully scrutinised and evaluated The most important thing is that each risk should be clearly identified and appropriately allocated and that responsibilities are clearly defined in the contract

10 5 Summary of financing

In figure 9 1 there is presented the basic structure of the international project financing

The privately financed projects are characterised with an emphasis on the follow-up of revenue flows arising from the project to service the loans and to provide the return on the equity which has been invested The funders to make this follow-up can be insurers, lenders, investors or donors

The insurers decide on the insurance policy In practice this usually means that the lenders have certain requirements for the insurances which the insurers apply In most cases the insurance requirements are set only against normally insurable risks such as outbreak of fire

The lenders cover a large group including among others international development banks, commercial banks and export credit agencies All the lenders have their general regulations on lending and specific regulations which differ from one area to other The common terms include the rates of interest which are normally set at a margin over a market benchmark The loan maturities for example for the EBRD loans generally range from 5 to 10 years The maturities of the export credit agencies follow the same tendency

The investors are dealing with equity investments and guarantees The biggest investors in this area are the Multinational Development Banks The Banks' equity investments are provided for assisting the initial stage of the project and the Banks will only take a minority position

The banks are generally handling the guarantees if the bank's customer fails to meet certain commitments, such as loan repayment In this way the banks may help borrowers gain access to financing a project

The donor institutions are usually at the same time the lenders The grants are generally provided for feasibility studies not for investments Thus, this alternative is not viable for this project financing

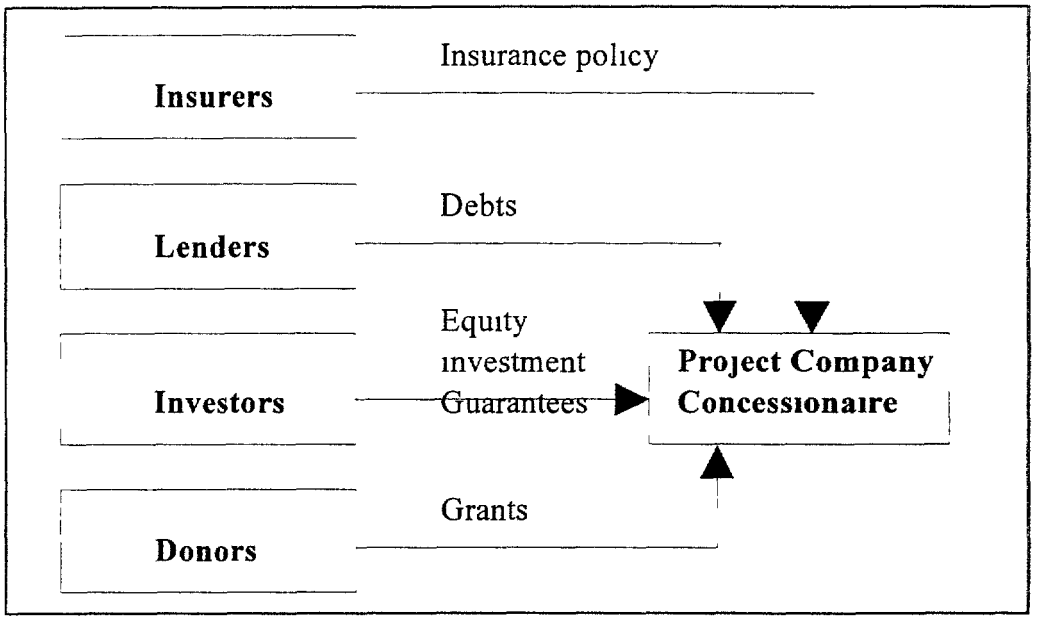


Figure 10-1 Summary of project financing

10 6 Conclusions

Whether the World Bank, for instance, would fund the becoming investment in the case that RAO and the energos would be the borrowers of a long-term soft loan the basis could be as follows

- The Russian electric sector requires capital that is not available from within Russia
- Energos and RAO are willing to invest a substantial amount of their own funds for the project
- The project will be environmentally sound and will save natural gas, oil, coal and nuclear fuel which are finite natural resources
- The region should have a reliable long term power investment plan the objective of which would be to lead the region to self-sufficiency in generation capacity

11 PROJECT DEVELOPMENT AND IMPLEMENTATION

11 1 Alternative Project Development Options

Text under the paragraph 10 1 Alternative Project Development Options is based on the findings presented in the Financial Appraisal Report - Hydro Team March 1998 of the TACIS Project Development of Local Energy Resources of Karelia, Project No ERUS 9504

There are basically two different ways to carry out the proposed project These are

(1) Development by an Independent Power Producer (IPP)

The IPP builds and operates the station selling power to a power procurer on the basis of a Power Purchase Agreement (PPA)

(2) Development by Lenenergo

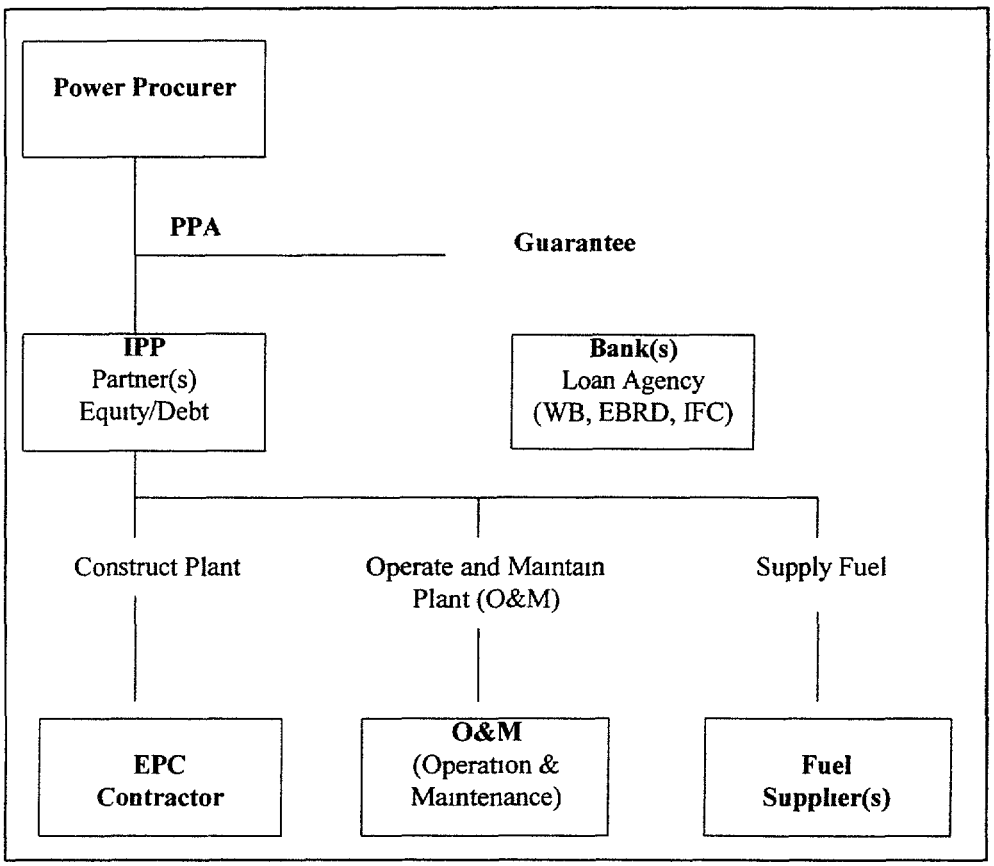
In this case Lenenergo would build and operate the plant

11 1 1 Development by Independent Power Producer (IPP)

Structure

An IPP normally comprises a consortium which often typically involves an international electricity company, engineering, procuring and contracting suppliers (i e engineering, procuring and contracting Contractor) and financiers Typical structural models are

Model 1

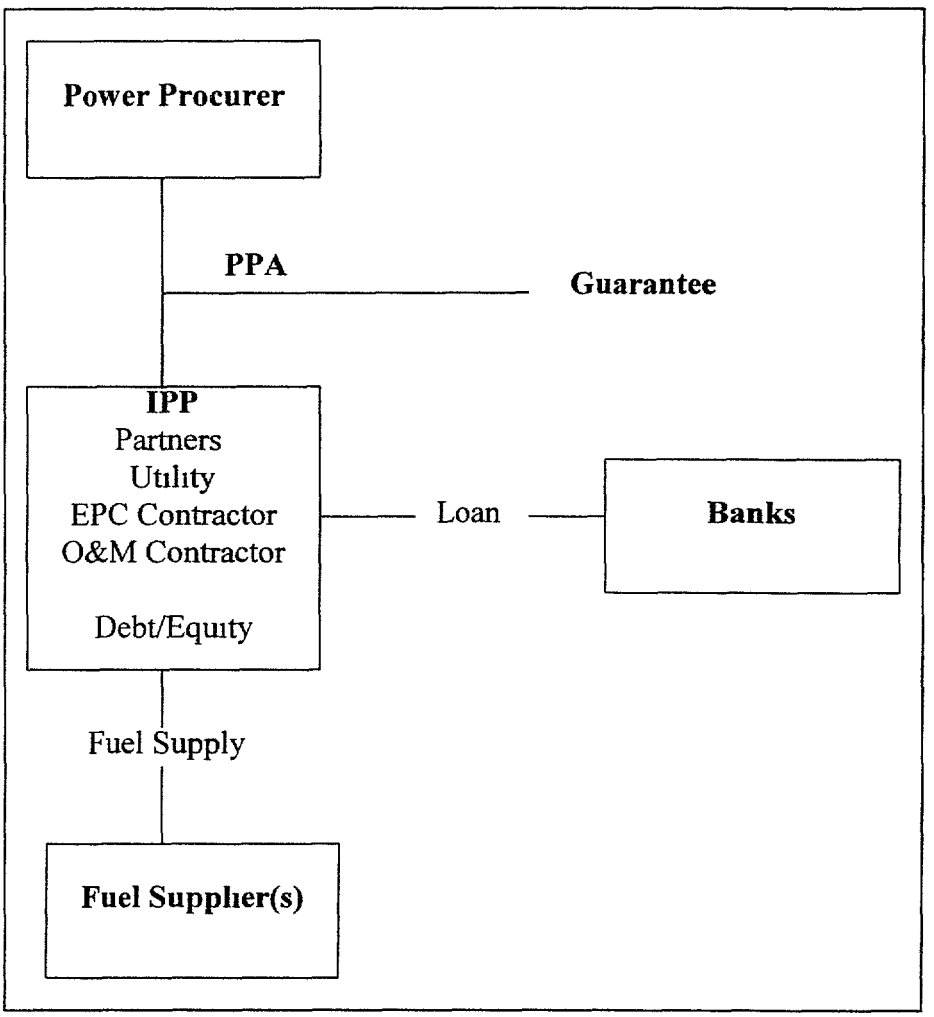


PPA = Power Purchase Agreement, EPC = Engineer, Procure and Construct

WB = World Bank, EBRD = European Bank for Reconstruction and Development

IFC = International Finance Corporation

Model 2



Under Model 1 the plant operation and maintenance contractors are not partners in the IPP while in Model 2 they are In Model 1 the following subsidiary contracts are required in addition to the main PPA

1 Construct Contract

2 Operation and Maintenance Contract

3 Fuel Supply Contract

Major international lending agencies may favor Model 1 as its structure is more geared to accommodating competitive tendering and procurement

If the financial position of Lenenergo is weak any IPP will most likely require RAO to guarantee all payments due by Lenenergo to the IPP

Formation of an IPP

The impetus would have to come from either Lenenergo or RAO or both as the power procurer The power procurer would develop a draft or outline PPA This would determine the size and fuel type of any future IPP Invitations to bid would then be issued in newspapers, technical and trade journals both within Russia and throughout Europe A wide circulation of the invitation to bid is probably necessary if it is to attract international lending agencies An alternative approach would be initially to target potential investors and invite them to an investment workshop at which the power procurer's requirements would be revealed

Power Purchase Agreements (PPA)

In the event of an IPP development a PPA would have to be drawn up between the IPP and either Lenelenergo or RAO This power purchase agreement would be the legal basis governing the long term sale of firm electric capacity and associated energy

Funding for IPP Development

This would obviously depend on the successful consortium Three possible options are conceivable namely

- Totally foreign based consortium
- Totally Russian consortium
- Joint venture

Totally foreign based consortium

Two pertinent facts immediately present themselves

- The combined cycle gas turbine development is likely to be financially attractive
- The political and economic environment in St Petersburg area is positive towards foreign investment

These factors indicate that a totally foreign owned consortium may be a feasible way to develop an IPP It would have the advantage of enabling the consortium to raise the necessary debt and equity finance on western capital markets However a significant disadvantage could arise from the lack of local contact and knowledge arising from the non involvement of a Russian(s) partner

Totally Russian consortium

There could be significant disadvantages with this approach because of

175

- Difficulty of raising required level of equity capital given the small scale of stock markets in Russia
- Relative scarcity of long term debt in Russia
- Lack of experience of operating in a competitive generating environment using PPAs
- Possible financing difficulties may be a real barrier to procuring the most advanced technology

For these reasons a solely Russian consortium is unlikely to be the preferred option

Joint Venture

This could involve foreign and Russian involvement both as equity holders and debt financiers Equity involvement could be either through direct investment or through, for example, the fuel supplier or the operations and maintenance contractor taking payment partially in the form of equity In the case of debt the financing could be provided by foreign banks and Russian banks with in all probability the bulk of the debt financing coming from foreign banks

The advantages of this approach is that it allows access to the most advanced technology and western capital and at the same time have Russian involvement in the ownership, management and financing of the IPP In this way permanent knowledge transfer is guaranteed with long term economic benefits From a short term perspective local participation may be advantageous from an administrative and legal point of view

11 1 2 Development by Lenenergo

The second development option is for Lenenergo to undertake the development For this to be a realistic option two conditions must be present

1 Lenenergo, as the borrower, must be commercially attractive to lending institutions

2 The projects must be economically viable in their own right (which appears to be the case for combined cycle gas turbine)

Requirements of Banks to Finance Lenenergo

Before banks will lend they will need reassurance that the borrower can meet the loan interest and capital repayments While banks may require the

loan to be guaranteed (e g by RAO) they view such guarantees as a protection of last resort and will not lend unless they are reasonably certain that the borrower has the financial capacity to contractually meet debt service payments From a financial viewpoint before concluding a loan agreement banks will require the following

- Proof of current financial soundness

- Evidence of future continuing financial soundness

Financial statements prepared in accordance with internationally accepted accounting standards and properly audited accounts are used to establish the current financial position Financial projections prepared using computerised financial models and based on realistic assumptions would be used as indicators of the future financial position

11 2 Project Implementation Plan

The principle implementation plan of the project is presented in Figure 11-1 The more detailed schedule is presented in Appendix 6

Task name	Year				
	1	2	3	4	5
Feasibility study	----------				
General planning		---------- -			
Plant design			----------		
Architectural design			------		
Procuring of GT		-------	----------	----------	--
Procuring of HRB		-----	----------	----------	--
Procuring of ST		-------	----------	----------	--
Pipes			----------	------	
Auxiliaries			---------	------	
Automation			----------	----	
Electrification		---	---	--------	
Construction			----------	-------	
Connections				-	
Test runs					---

Figure 11-1 The principle schedule

The total time of construction is 4 5 years including feasibility study and pre-design The feasibility study contains the final selection of the plant concept and preliminary design of the plant General design and plant design consists of final power plant layout and preparing and sending the tender documents as well as authorisations

The procurement of gas and steam turbines as well as heat recovery boiler contains the order, manufacturing time, assembly, implementation and test runs of the parts

Pipes auxiliaries and electrification contains the deliveries, assemblies and implementation of different equipment These parts and work would be

mainly Russian Automation system and equipment would be for the most part Western

Construction consists of earth moving and pile work, foundations, construction and regional works The connection to electricity, district heat, water and natural gas networks is expected to be a minor work

The anticipated division of working time between Russia and Western countries has been presented in Figure 11-2

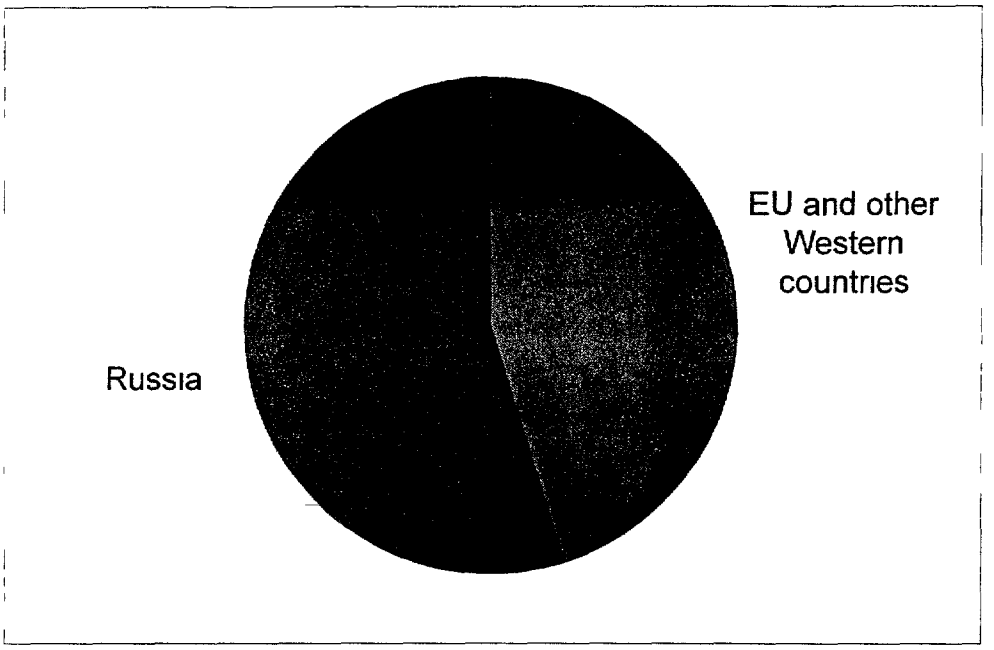


Figure 11-2 The anticipated division of working time

12 SUMMARY

In this prefeasibility study four different power plant concepts have been compared present situation with a 60 MW gas turbine unit, cogeneration plant with 60 MW gas turbine unit, combined-cycle power plant and two combined-cycle power plants All the alternatives are natural gas fired There is also a need for new heat only boiler investments in all the alternatives to cover the shortage of district heat Heat only boilers will be used during district heat peak demand periods and during maintenance

The viability of each concept is quite good and near each other When the amount of electricity production is an important point concepts based on heat and power co-production are the most interesting choices Furthermore to maximise the electricity production, combined-cycle power plant based concepts should be considered because of their high heat to power ratio

The concept of one combined-cycle power plant was the best alternative according to pay-back time and internal rate of return The feasibility of the combined-cycle power plant is based on a large amount of back-pressure production The power plant is also very flexible with heat and power production so it suits easily to the variation of heat and electricity load demands

The feasibility of the concept of two combined-cycle power plant units is not so good as a concept based on one combined-cycle plant This is due to the increased amount of electricity production in condensing mode In the most viable concept 3150 GWh of electricity was produced in cogeneration mode and 710 GWh in condensing mode Respectively the figures for a concept with two combined-cycle plants are 4250 GWh and 1560 GWh Thus the potential for extra cogeneration is obvious So it might be worth considering to study the unit of even larger combined-cycle plant than the one in this study The investment costs per unit will decrease when the unit size increases, so the larger combined-cycle power plant might be even more profitable than the studied one

Sensitivity analysis of the combined-cycle power plant showed that the viability is not very sensitive to the variations of internal rates, investment costs or changes in prices The viability of the power plant is a bit more sensitive to the variations of gas and electricity prices For a more exhaustive feasibility study a more accurate information about gas, heat and electricity prices as well as heat demand in future is needed

According to the results of this study the combined-cycle power plant is very profitable and worth investing We recommend that the planning will be continued with the concept of a combined-cycle plant

1 NEW CHP PLANT WITH GAS TURBINE

1 1 Description of plant operation

The alternative is a steam turbine process with gas turbine Atmospheric air via air inlet comes into gas turbine's compressor, pressurises and comes into combustion chamber Combustion product gases are led into gas turbine, expand and rotate turbine with compressor and electrical generator After gas turbine combustion products go into the boiler In boiler the oxygen of the combustion gases is used in boiler's burning process It's possible to mix some excess air in the exhaust The high pressure steam generated in the boiler expands in the steam turbine and rotates the generator to produce electricity

After the steam turbine there is a condenser The district heating network water is heated in two steam extractions

There are two optional flow diagrams, which differ slightly as follows The flow diagrams of these two cases are presented in Appendix 1

In heat flow chart in Figure 2 1 there is a cogeneration cycle power plant with gas turbine exhausting in the boiler furnace without displacement of regenerative extraction of the steam turbine and with retention of a regenerative air heater The heat flow chart does not provide for reheat of auxiliary air, thus ensuring decrease in gas temperature at the boiler inlet For the recovery of heat of flue gases, air-to-water heat exchanger is used for the reheat of make-up water of the heat supply network by heat of excess air At the next stage, the complication of the heat flow chart is possible, by means of using air-to-water heat exchanger for re-heating make-up water or condense, as a result, economical efficiency in the condensation mode will increase

In Figure 2 2 there is a classical heat flow chart of a cogeneration cycle power plant with gas turbine exhausting in the boiler furnace, in accordance with such flow chart, provision is made for the replacement of regenerative air heater by gas-to-water heaters of high and low pressures, installed in the flue gas path of the boiler after the economiser and coupled to the water mains in parallel with the systems of regenerator of high and low pressures of the steam turbines The implementation of such flow chart involved the necessity of restriction of steam flow for the turbine defined by limited throughput of the seventh stage of the intermediate pressure cylinder (about 585 t/h) In the independent mode, air reheat is ensured by condense (the first stage) and cold-reheat steam (the second stage)

For both versions, the layout of the basic and auxiliary equipment in the main building of the cogeneration plant remains without any changes

1 2 Main design parameters of the power plant (outdoor temperature 0°C)

The basic design point is maximum heat load Outdoor temperature is 0°C and corresponding power is about 240 MW_e / 326 MW_{th}

The characteristic performance parameters for the gas turbine unit are

Electricity output, net	60	MW
Efficiency	34 3	%
Exhaust temperature	557	°C
Exhaust flow	184	kg/s

Characteristic parameters of the steam cycle are

Electricity output, net	180	MW
Pressure	128	bar
Temperature	540	°C
Steam flow	182	kg/s

Performance characteristics of the power plant performance are as follows The outdoor temperature is 0°C, district heating supply water temperature 90°C and return water temperature 50°C

Electricity output, net		
back-pressure	240	MW
condensing	270	MW
District heat output	326	MW
Pressure	128	bar
Temperature	540	°C
Steam flow	182	kg/s
Total efficiency	74 8	

1 3 Description of mechanical equipment

1 3 1 Boiler unit

Boiler Ep-670-13,7 is a circulation drum boiler Boiler consists of furnace and convection parts including steam re-heater, extraction steam re-heater and economiser Boiler is gas/oil-fired

Partial upgrading of the boiler unit will be required to the following extent

- partial upgrading of burning devises
- coupling of the exhaust gas duct to the boiler
- the same - in accordance with the system of exhaust of excess gases to the area of an economiser

- installation of air-to-water heat exchanger and coupling to the air and water mains
- partial upgrading of gas-air ducts of the boiler unit

Boiler unit includes steam drum, convection surfaces, air-blow and exhaust gas equipment, burners, framework, stairs, stages, piping, fitting, control and safety automation, casing, insulation ect

1 3 2 Steam turbine unit

Steam turbine is a back pressure turbine with intermediate steam reheat and condensing unit Network water is heated with extraction steam in two steps

The steam turbine plant consists of

- steam turbine and auxiliary equipment
  - back pressure steam turbine
  - district heat exchangers
  - principal control device and protective system
  - developed regeneration system
- generator
- sound insulating hoods for the steam turbine and generator

1 3 3 Automation

It has been planned that "ASU TP" automation control system will be used It provides technology for process control, data collection, saving and indication, protection as well as technical diagnoses, technical and economical indicators calculation, saving and processing

System includes computers with software, sensors, cables and other equipment

1 3 4 Electrical equipment

Electrical equipment includes all electrical equipment of power plant, including transformers, internal power plant switchyards for 0,4 and 6 kV, accumulators, switchyard, buses, power cables, electrical drivers ect

1 3 5 Other equipment

Fuel handling facilities

A compressor station for gas pressure raising from 12 bar to 25 bar is planned Also installing gas pipelines from main gas pipeline to compressor station and from compressor station to gas turbine unit including fittings, control and safety automation The volume of compressor station building is about 4000 m^3

An existing oil supply system is used The oil system requires small reconstruction Volume of the oil tank is 50 000 m^3 It is enough for 10 days use of the power plant

Reserve for diesel oil is not planned In case of the cut of gas supply power plant will operate in steam/power mode

Water treatment equipment

Primary water is supplied by city water line For leakage compensation (about 5% of steam production) water will be treated in a demineralisation plant

District heating water is not treated Cooling towers will be used in closed-loop condensing water cooling

Annual make-up water demand is about 25 10^6 m^3/a

Piping

CHP plant includes all pipeline system with shut-off control and safety fittings The volume of piping is sufficient for reliable operation of power plant

Auxiliary equipment

Auxiliary equipment are as follows feed water pumps, district heating pumps condensate and other pumps, lifts, cranes, tanks, heat exchangers, backup boiler, pneumatic appliances, spear engine and maintenance workshop equipment and tools

Infrastructure

Existing district heating pipelines, electric networks and water supply network will be utilised

1 4 Construction works

Outside the power plant site the existing district heating pipes and water supply pipes will be used The main building of the power plant consists of machine room, de-aeration stack, boiler room, open type regenerative air heater as well as air blow and exhaust gas units The framework of the main building is made of steal

2 COMBINED CYCLE POWER PLANT

The combined cycle power plant is a condensing power plant with extractions The net output is 233 MW_e / 195 MW_{th} This natural gas fired combined cycle is based on LMZ's GTE-60 gas turbine process

Exhaust gases from the gas turbine are led to heat recovery boiler In heat recovery boiler the heat of the hot exhaust gases are used to generate steam for a steam turbine The electric power of the plant is produced in two generators Thermal energy for district heating is obtained on the heat exchangers of the steam turbine extractions and steam generator convection surfaces There is a condenser after the steam turbine The process values and flow diagram are presented in Appendix 1 2

The power plant can be run in two modes the back pressure operation and condensing operation When district heat load is in its maximum, thermal energy is obtained on both, the heat exchangers of the steam turbine extractions and boiler convection surfaces When district heat is not needed, the power plant runs in condensing mode and thermal energy is obtained only in heat recovery boiler convection surfaces The extraction steam is used in electric power production by condensing all the steam

2 1 Main design parameters of the power plant (outdoor temperature 0°C)

The basic design point is maximum heat load Outdoor temperature is 0°C and corresponding power is about 233 MW_e / 195 MW_{th}

The characteristic performance parameters for the combined power cycle with GTE-60 are

Net power, electrical	233	MW
Efficiency	87 0	%
Exhaust temperature	522	°C
Exhaust flow	549	kg/s

Characteristic parameters for the live steam from the steam generator are

Pressure	60	bar
Temperature	497	°C
Steam flow	65	kg/s
Feed water temperature	110	°C

Performance characteristics of the power plant are shown in Table 1 The outdoor temperature is 0°C, district heating supply water temperature 90°C and return water temperature 50°C

Table 1 Performance parameters of the combined cycle power plant

		Max back pressure operation	Max condensing operation
Electrical output, gross	MW	236	252
District heat output	MW	195	50/0
Fuel consumption	MW	492	492
Total efficiency	%	87 0	60 9

2 2 Description of mechanical equipment

2 2 1 Boiler unit

The boiler plant includes one boiler, which consists of five adjacent heat exchanger packages From hotter to cooler exhaust gases the heat exchangers are as follows two superheaters, evaporator economiser and district heat exchanger

The expenses of the boiler plant include the steam drum, circulating pumps and steel chimney and their framework and foundations

2 2 2 Steam turbine unit

The steam turbine is a condensing turbine with three extractions The district heating water for is heated with two steam extractions On of the extractions is used for de-aeration

The steam turbine plant consists of

- steam turbine and auxiliary equipment
  - condensing steam turbine
  - district heat exchangers
  - principal control device and protective system
- generator

- sound insulating hoods for the steam turbine and generator

2 2 3 Gas turbine unit

One gas turbine type of ABB GT 13E2 is included in the power plant Natural gas is the main fuel, but also light fuel oil can be used as a reserve fuel The gas turbine unit consists of

- the gas turbine with axial compressor
- auxiliary equipment
- generator
- turbine control system
- air intake system
- sound insulating hoods for the steam turbine and generator

Sulphur is not a problem as a contaminant, when burning natural gas The emission level of NO_x is reduced onto level 60 $mgNO_2/MJ$ by using low-NO_x burners

2 2 4 Automation

Automation includes measuring instruments and control and monitoring devices installed It also includes the cable works and the operator's room equipment Power plant data processing equipment and software are included as well

2 2 5 Electrical equipment

Electrification costs include all electrification related to the process, such as power transformers, switchboards, buses, high-voltage power cables, electrical motor for feed water pump and switchyard

2 2 6 Other equipment

Fuel handling facilities

In the pressure reduction station the pressure of gas is reduced to 22 bars for gas turbine and to 5 bars for auxiliary burners Gas is led from the pressure reduction station to the gas turbine and auxiliary burners in stainless steel pipe

The reserve fuel is light fuel oil For fuel storing there's a fuel reservoir tank in the power plant area

Water treatment equipment

Power plant process water from the public water distribution network is used as feed water It is treated in the demineralisation plant The water treatment equipment include also a condensate polishing plant and district heating water treatment equipment

In the steam generator there is a water loss of 2% of live steam stream The existing cooling towers will be used in closed-loop condensing water

Piping

Piping includes the high and low pressure steam pipes, natural gas pipes, insulation and fixtures Also district heating networks and the connection to the present system are included

Auxiliary equipment

Auxiliary equipment are as follows feed water pumps, district heating pumps, condensate and other pumps, lifts, cranes, tanks, heat exchangers, backup boiler, pneumatic appliances, spear engine and maintenance workshop equipment and tools

Infrastructure

Existing district heating pipelines, electric networks and water supply network will be utilised

2 3 Construction works

Construction works include foundation, construction works with all material and lightning needed, water supply and sewer system, fire alarm and sprinkler system as well as a telecommunications network

The main building of the power plant is made of steel constructions The building includes the boiler room, turbine room, control room, electrical equipment room, water treatment room and condense treatment rooms and condense pumping plant The office premises, rooms for personal, repair-shop and store-house are located in the present buildings

Earth-removing costs include excavation and earth removing, rain water sewerage, drain work road and yard constructing, asphalt and grass work, fences and power plant yard area lightning

2 4 Design and supervision

2 4 1 Design

Design includes power plant site geological study and general-, process-, architectural-, electrical-, automation- and mechanical construction planning and design Contract document arrangements and cost-, time schedule and delivery supervision are also included

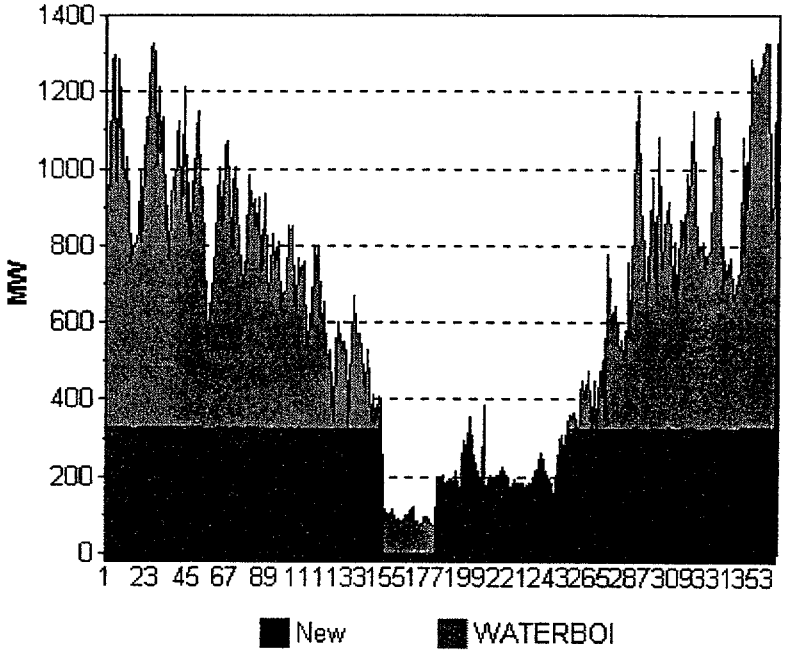
2 4 2 General and site costs

Site costs include supervision of construction work and installation of equipment general management of construction site, time schedules, maintenance during construction works, electric and heat supply of the site and melioration works Supervision of temporary buildings and construction is included as well

General costs include project management costs, settlement of orders, licences of the authorities and public relations during construction works Acceptance and testing of the power plant are also included

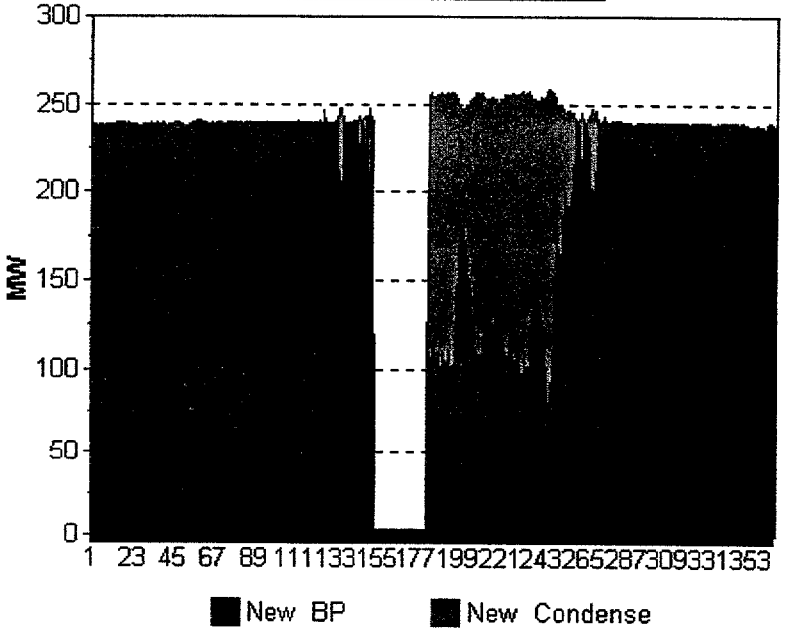
VARIATION CURVE OF HEAT

Existing situation, heat load 4000 GWh



VARIATION CURVE OF POWER

Existing situation, heat load 4000 GWh



Summary of power and heat production
Total heat load 4000 GWh

	Existing CHP + GT	2 x CHP + GT	Combined cycle	2 x combined-cycle
Capacity				
- power back pressure MW	240	480	473	706
- power condensing MW	270	540	520	770
- district heating, back pressure MW	326	652	521	716
Power production				
Old units				
- back pressure, GWh	1702 3	1204 5	1418 7	980 8
- condensing, GWh	248 6	805 7	565 5	1056 8
- total, GWh	1950 9	2010 2	1984 2	2037 6
New unit				
- back pressure GWh	0	1641 3	1732 6	3267 9
- condensing GWh	0	309 8	145 3	501 7
- total GWh	0	1951 1	1877 9	3769 6
Total, GWh	**1950 9**	**3961 3**	**3862 1**	**5807 2**
Extra production GWh		2010 4	1911 2	3856 3
back pressure GWh	1702 3	2845 8	3151 3	4248 7
- extra production GWh		1143 5	1449	2546 4
District heat production GWh				
Old units	2348 2	1689 3	1976 2	1387 8
New unit	0	2273 3	1460 3	2755 9
HOB	2237 4	623 1	1149 1	441 9
Total	**4585 6**	**4585 7**	**4585 6**	**4585 6**
Fuel cost USD/MWh	7 27	7 27	7 27	7 27
Fuel GWh/a				
HOB	2461 1	685 4	1264 0	486 1
Old units	5006 6	4992 7	5007 0	5006 9
New units	0 0	5006 9	4039 5	8080 2
Fuel, total GWh	**7467 7**	**10685 0**	**10310 5**	**13573 2**
Fuel, back pressure GWh/a				
HOB	2461 1	685 4	1264 0	486 1
Old units	4459 7	3187 9	3717 7	2597 4
New units	0 0	4309 8	3602 1	6763 2
Fuel, back pressure, GWh/a	**6920 8**	**8183 2**	**8583 8**	**9846 7**

Heat production costs	M$/a	36 3	36 1
Variable maintenance costs	M$/a	5 4	7 8
Variable costs together	*M$/a*	*59 7*	*85 4*
TOTAL COSTS	**M$/a**	**63 9**	**92 0**
INCOME			
Heat selling			
Heat capacity fee income	M$/a	0 0	0 0
Heat energy income	M$/a	41 3	41 3
Heat sales altogether	*M$/a*	*41 3*	*41 3*
Electricity selling			
Electricity capacity fee income	M$/a	0 0	0 0
Electric energy income	M$/a	47 8	97 1
Electricity sales altogether	*M$/a*	*47 8*	*97 1*
TOTAL INCOME	**M$/a**	**89 1**	**138 3**
PROFIT	**M$/a**	**25 2**	**46 3**
NET PRESENT VALUE	**M$**	**107 5**	**224 6**
PAY-BACK TIME	**a**	**9 3**	**8 2**
INTERNAL RATE OF RETURN	**%**	**15 16%**	**16 82%**

36 9	37 4
3 7	7 3
78 6	*106 0*
85 3	**115 1**

0 0	0 0
41 3	41 3
41 3	*41 3*

0 0	0 0
94 6	142 3
94 6	*142 3*
135 9	**183 5**

50 6	**68 4**
262 7	**337 2**
7 5	**8 0**
17 95%	**17 06%**

YEARLY COSTS AND INCOME

Power plant		Present	New CHP with GT
- electricity output (yearly average)	MW	239 6	239 6
- heat output (yearly average)	MW	326 0	326 0
- fuel input (+0 C outdoor temp)	MW	825 0	825 0

Input data			
Power plant life time	year	25	25
Real interest	%	8%	8%

Energies and production costs			
- fuel input energy	GWh	7467 2	10685 2
- fuel costs	$/MWh	7 3	7 3
- heat energy	GWh	4584 3	4585 6
- heat energy production cost	$/MWh	7 9	*7 9*
- electricity	GWh	1950 9	3961 4
- electricity production cost	$/MWh	9 2	*10 5*

Prices

Heat			
- capacity fee	$/MW,a		
- energy price	$/MWh	9 0	9 0
Electricity			
- capacity fee	$/MW,a		
- energy price	$/MWh	24 5	24 5

COSTS

Investments			
Power plant investment	M$	120	240
Connection costs	M$	0	0
Heat only boilers	M$	41	30
investment costs together	*M$*	*161*	*270*
Fixed costs			
Personnel costs	M$/a	1 8	1 8
Fixed maintenance costs	M$/a	2 4	4 8
Fixed costs together	*M$/a*	*4 2*	*6 6*
Variable costs			
Electricity production costs	M$/a	18 0	41 6

CC	2 x CC
233 2	466 4
195 0	390 0
492 0	984 0

25	25
8%	8%

10311 6	13573 8
7 3	7 3
4585 6	4585 6
8 1	*8 2*
3862 1	5807 0
9 9	*10 5*

9 0	9 0

24 5	24 5

243	366
0	0
34	27
277	*393*

1 8	1 8
4 9	7 3
6 7	*9 1*

38 1	61 2

6 1 INTRODUCTION

Plan in Russia provides technical and economic feasibility information regarding the proposed St Peterburg Prefeasibility study for the project North-West Region Power Plant Investment heat and power plant extension The project will comprise an extension of 240 MW_e of installed capacity The project is one of the projects developing the extension of power plants in the North-West Region of Russia After both the Finnish and the Russian in-depth analyses St Petersburg heat and power plant was selected because of its viability

This study will present the project background and describe the existing conditions in greater detail After this general alternative plant concepts are discussed Specific methods for technical optimisation of the plant concepts are thereafter discussed with emphasis on the programs developed by Ekono Energy Ltd of Finland Environmental aspects along with economic and financial considerations of the projects are also discussed Finally, the discussion leads to the project implementation plan

6 2 PROJECT BACKGROUND

The Nuclear Safety Account (NSA) of the EBRD has agreed with the Russian Government to conduct an analysis of the energy investment alternatives to continued operation of nuclear plants in the Centre and North-West Russia The government of Finland and USAID have agreed to support that analysis by financing a study for North-West Russia

- The aim of the thermal and hydropower study is to identify and evaluate potential thermal & hydro investment projects to be included in the North-West Region Power Investment Plan until the year 2010 of which St Petersburg is among the selected cases

The objective of the project is to increase the present capacities of 240 MW for electrical output and 280 Gcal/h for district heat output taking into account the feasibility and environmental aspects of the project The study reviews the present situation of the emissions and the expected development

The area of St Petersburg will benefit from the extension of the heat and power plant from the economic point of view This will at least include the expenditure of funds for construction materials, construction labour, and transportation and shipping costs This will lead to an economic ripple effect through the economy as funds are used for materials, transportation and services This ripple effect continues to the personal level, too, as each worker has personal needs concerning, for instance, housing and food The economy of the area is expected to be positively effected by the increased demand for goods and services Moreover, the extension of the power plant will make it possible to ensure the requisite reliability of the supply of electric and heat power in the region

Of the social aspects may be mentioned the following ones in the case of the implementation of the project

- improved comfort level and quality of life for the residential of St Petersburg
- allows more buildings to be built in the area served by the plant
- decreased heat and electricity tariffs and subsidy payments

6 3 DESCRIPTION OF EXISTING CONDITIONS

6 3 1 Main plant data

Power Plant No 5 is owned by the JSC "Lenenergo", and it serves the heat load in the residential sector The total load from the users amounts to 1396 MW (1200 Gcal/h) With consideration for heating of the plant itself (40 Gcal/h) and the leakages of the district heating network (20 Gcal/h), the total load will be 1465 MW (1260 Gcal/h) The total heat sales in 1997 was some 2500 Tcal

The existing power plant consists of 3 steam turbines, 6 steam boilers and 2 hot water boilers The total electricity production capacity of the plant is 69 MW However, the plant is old, and for this study it is assumed, that the basic equipment installed in the existing main building, will be decommissioned So, all calculation are based on the new units The first unit consisting a steam boiler and a steam turbine is now under construction and it should be completed next year (1999) This new unit will be handled as "an existing plant" since it is already under construction and therefore not anymore the object of a pre-feasibility study

The new unit will be a conventional steam power plant with a steam boiler and a steam turbine The main fuel will be natural gas Technical plant data in greater detail is presented in Chapter 3 2

In addition to the new power plant unit the hot water boiler house will be expanded with six new boilers - four hot water boilers and two saturated steam boilers

New basic equipment in the main building and in the hot water boiler house is being installed at the site No 2 situated beyond the Dalnevostochy Prospect

At the moment (spring 1998) construction works and installation of equipment in the main building are being completed, hence, any essential change in the layout of the basic equipment is no longer possible

The nominal capacities of the main equipment and the total nominal capacity of the plant are presented in the following tables

Table 3-1 Main data of the power plant unit (rated values)

Steam boiler		
- unit number	1	
- type	E_n-670-140	
- fuel (main/back-up)	natural gas/HFO	
- maximum live steam flow	670	t/h
	(186,1	kg/s)
- live steam pressure	137	bara
- live steam temperature	545	°C
- reheat steam pressure	27	bara
- reheat steam temperature	545	°C
- steam output [1)]	507	MW
Steam turbine		
- unit number	1	
- type	T-180/120-130	
- electrical output	180	MW
(maximum capacity	210	MW)
- district heat output	280	Gcal/h
	(326	MW)
- live steam flow	656	t/h
	(182,2	kg/s)
- live steam pressure	127,5	bara
- live steam temperature	540	°C
- reheat steam pressure	24,9	bara
- reheat steam temperature	540	°C
- ultimate back-pressure	0,0865	bara

1) Calculated

According to nominal values plant's gross efficiency will be 89,8 % (based on the boiler efficiency of 90 %) Plant's own consumption of electricity is estimated to be 6 % of the gross electricity production plus 20 kWh/Gcal for the district heat production This means a total net efficiency of 86,9 %

Table 3-2 Main data of the heat only boilers

Steam boilers		
- type	E-160-24	
- number of boilers	2	
- fuel (main/back-up)	natural gas/HFO	
- steam flow	160	t/h
	(44,4	kg/s)
- steam pressure	24	bara
Water boilers		
- type	KVGM-100	
- number of boilers	4	
- fuel (main/back-up)	natural gas/HFO	
- district heat output	100	Gcal/h
	(116,3	MW)

The new unit is running first to meet the district heat demand Hot water boilers are used during the district heat peak demand period and during the maintenance shut down periods of the power units

The number of the annual running hours of unit 1 will be very high since the district heat production capacity of unit 1 will cover only 20 - 30 % of the peak demand

Emissions to atmosphere through the stack of the unit 1 are based purely on the boiler construction and the burner technology since the boiler will not be equipped with SO_x- or NO_x -removal facilities However, comparing to the recent years, the SO_x -emission level will decrease significantly due to decommissioning of 40 small boiler houses The estimated emission levels concerning NO_x-emissions will be 120 mg/Nm^3 (40 mg/MJ) with natural gas firing and 250 mg/Nm^3 (80 mg/MJ) with heavy fuel oil firing This is in accordance with the Russian standard GOST P 50831-95 "Boiler units Thermal engineering equipment General specifications"

6 3 2 Plant Performance

The turbine will be an extraction condensing turbine and will be started up in 1999

The main parameters of the turbine are shown in Table 3-2, and the main flow diagram in Figure 3-1

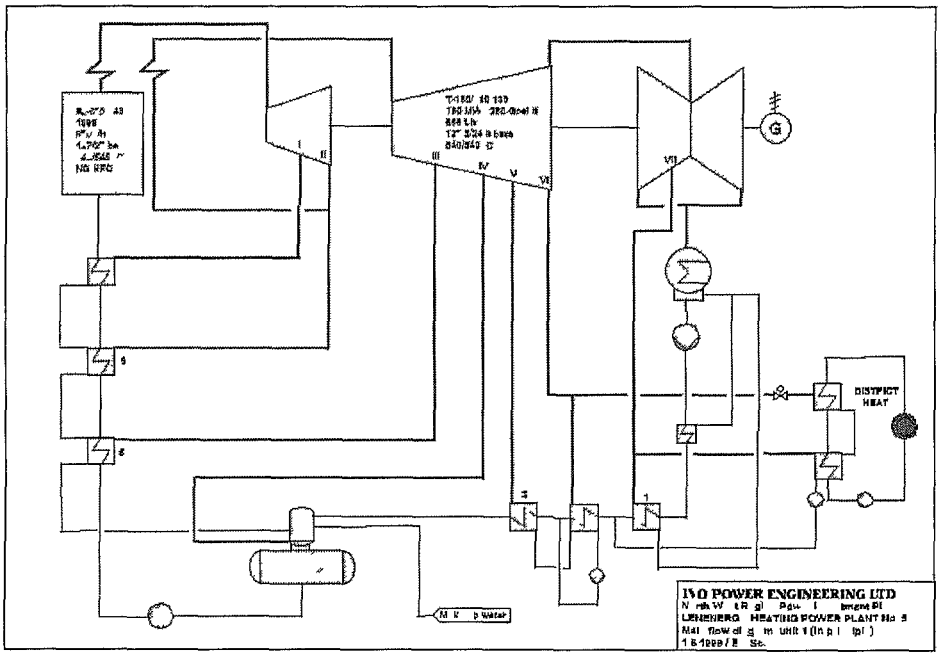


Figure 3-1 Main flow diagram, unit 1(in principle)

6 3 2 1Process Description

The feedwater is preheated by extraction steam up to the boiler inlet temperature of about 250 °C For this, the condensing line has in the flow direction, after the condensing and leak steam condensers, 3 LP-preheaters, after that a mixer-preheater (feedwater tank with deaerators - 6,58 bara, 162 °C) and in the feedwater line 3 HP-preheaters Steam for deaeration is taken from extraction IV

The HP-section of the steam turbine has two extractions The outgoing steam is led to the reheater in the boiler The IP-section has four and the LP-section has one extractions Steam to district heat exchangers is taken from the IP- and LP-sections trough controlled exctractions

Makeup water is taken into the feedwater tank

The rated values of extractions at turbine plant 1 are presented in Table 3-3)

Table 3-3 Rated values of turbine plant 1

Extractions	t/h	kg/s	bara	°C
- inlet steam	656,0	182,2	127,5	540
- I	31,6	8,8	41,2	386
- II	49,9	13,9	27,2	333
- III	17,9	5,0	12,6	447
- IV, deaerator	31,7	8,8	6,6	360
- V	22,0	6,1	2,6	249
- VI	8,0	2,2	1,0	152
- VII	1,9	0,5	0,49	98
- exhaust			0,087	

The control limits of the district heat extractions are 0,49-1,47 bara at the lower pressure extraction and 0,59-1,96 bara at the upper pressure extraction

Main cooling system is based on a cooling tower

6 3 2 2 Operating Modes

The power plant unit can be operated in an almost pure back-pressure operation, when only the minimum steam flow, needed for cooling the condensing turbine blades, flows into the condenser Other operating modes are condensing mode, combined back-pressure and condensing mode and reduction mode

6 3 3 Infrastructure

6 3 3 1 Location and site

Power plant No 5 is located about 20 km north-east from the historic centre of St Petersburg, and it covers the district heat demand of the surrounding residential areas

There is enough free space on the site for the expansion of the power plant The new unit, which is under construction, is located next to the existing main building

6 3 3 2 Connections

It is assumed in this study, that no new major district heat pipelines nor high voltage transmission lines are needed for the new power plant units - that is no major investments are expected

6.3 3 3Fuels

The future operation of the power plant is based on the utilisation of natural gas In this study it is assumed that the required capacity of natural gas will be available on the site almost through the year Only in winter 10 % of the fuel consumption is assumed to be heavy fuel oil while 90 % is natural gas

6 3 3 4Water

Major part of the make-up water goes to district heating network So, the consumption is not expected to increase significantly due to power plant extension, and therefore no major investments to new water treatment facilities is assumed in this study

6 3 3 5Personnel

The present number of the plant personnel is about 600 This is estimated to be sufficient also after the extension of the plant As a matter of fact, due to new technology in the new power plant unit(s), there is need for the reduction of the operation personnel

6 4 IDENTIFICATION AND REVIEW OF ALTERNATIVE PLANT CONCEPTS

6 4 1 Process optimisation methods

Tursim is a modelling programme designed for steady state simulation of power plants It can be used to model different kinds of steam turbine, gas turbine and combined cycle plants in both design and off-design conditions It is based on physical process quantities and component models and applies a graphic user interface

The applied mathematical models profit from Ekono Energy's extensive experience in power plant process calculation The implementation uses the latest PC technology, making it to user-friendly professional tool The programme internal solving method is equation based, enabling calculation and input in any desired order This means flexibility in choice of fixed parameters The same plant model can thus be used to simulate any situation at a given power output, fuel input, heat output etc , and also in situations, where a specific process parameter must be achieved

One of the program's useful special features is its optimisation function It chooses an optimally efficient value for free variables, if the model contains degrees of freedom This enables easy determination of an optimal operation method or dimensioning

202

6 4 2 Process optimisation

The prefeasibility study is based on an assumption that district heat demand will increase up to 1500 MW The following concepts have been studied to cover the shortage of district heat

1) Existing situation with 60 MW gas turbine unit The existing case have been studied with a gas turbine unit which is planned to be build beside the existing CHP plant

2) New CHP plant with 60 MW gas turbine The new plant would be the exact copy of the first alternative

3) New combined-cycle power plant The combined-cycle power plant is equipped with ABB 13E2 gas turbine unit, heat recovery boiler and steam turbine unit

4) Two combined-cycle plants The combined-cycle plants are similar to concept 3

The process values of the first two alternatives have been given by the Russian partners The combined-cycle plant has been designed and simulated with Tursim process simulation tool

The main technical values of the power plants are presented in Table 4-1 in outdoor temperature 0°C

Table 4-1 Electric and heat outputs of alternatives in outdoor temperature 0°C

Power plant	Fuel input MW	Electricity (net) MW	Heat, MW	Overall efficiency, %
Existing situation	757	240	326	74 7
New CHP with GT unit	757	240	326	74 7
Combined cycle plant	490	230	195	87 0
Two combined cycle plants	980	460	390	87 0

6 4 2 1New CHP plant with GT

One alternative is to build a CHP plant with a gas turbine The plant would be exact copy of the existing system Exhaust gases pass through air re-heater into air duct The electricity output is about 240 MW and the heat output is 326 MW

For the new unit two different flow charts have been proposed The more detailed description of the alternatives is given in Appendix 2 The flow diagrams of the alternatives are presented in Appendix 1 1 (Figure 2 1 and 2 2)

6 4 2 2New combined -cycle power plant

The other alternative is a condensing combined-cycle plant with extractions The power plant consists of a gas turbine unit with electricity output of 170 MW, a heat recovery boiler and a steam turbine The total electricity output is 233 MW and the heat output 195 MW in the back-pressure mode The maximum electricity output is 250 MW in the condensing mode

A power output diagram and flow diagrams of the combined cycle power plant are shown in Appendix 1 2 A simple gas turbine cycle, consisting of air compressor, combustion chamber, and gas turbine is used with the turbine exhaust gas going to heat-recovery boiler to generate superheated steam That steam is used in a standard steam cycle, which consists of turbine, district heat exchanger, pump and feedwater heaters The heat-recovery boiler consists of an district heat exchanger, economiser, boiler, steam drum and superheater The gas leaves the heat recovery boiler to the stack Both gas and steam turbines drive electric generators The more detailed plant description is presented in Appendix 2

6.4 2 3Two combined-cycle power plants

The alternative of two combined-cycle power plants have also been studied Both power plants are based on ABB 13E2 gas turbine units The total electricity output of the units in the back-pressure mode is 466 MW and the heat output is 390 MW The plant concepts are described in greater detail in Appendix 2

6 5 COSTS

6 5 1 Investment costs

Investment costs consist of investment costs and connection costs to power, heat and gas network Due to the increased heat load investments for heat only boilers are also needed Heat only boiler investments are included in all the alternatives to cover the shortage between the need of 1500 MW and the power plant capacity The price of the heat only boilers have estimated to be 35 USD/kW Investment costs for each concept have been collected to Table 5-1 The investment cost have also been directed to the existing situation because the power plant is still under construction and so it will be more comparable with other alternatives

There are no (or only minor) connection costs to the power, heat and gas network They will not be taken into consideration

Table 5-1 Investment costs of each power plant

Concept	Power plant, million USD	Heat only boilers, million USD
Existing situation	120	41
CHP with GT	120	30
Combined-cycle plant	123	34
Two combined-cycle plants	246	27

6 5 1 1 Other fixed costs

Other fixed costs are costs of personnel in the power plant and fixed maintenance costs

The average yearly salary cost for personnel in power plants is 3000 USD/person, a The present number of the plant personnel is 600 This is estimated to be sufficient also after the extension of the plant

Fixed maintenance costs have been evaluated to be yearly 2 % of the investment cost of the power plant

6 5 1 2Variable costs

Variable costs include the electricity and heat production costs and variable maintenance Also the usage of heavy fuel oil during gas supply interruptions is considered here

Electricity and heat production costs are calculated with Copsim simulation program

Variable maintenance costs are presented in Table 5-2 Due to the different plant concepts also the variable costs differ The maintenance cost have been estimated according to the Ekono Energy's experience

Table 5-2 Variable maintenance costs of the power plants

Concept	Maintenance costs, USD/MWh_f
Existing situation	0 73
CHP plant with gas turbine unit	0 73
Combined-cycle plant	0 91
Two combined-cycle plants	0 91

In this study the gas and oil prices are considered as a variable cost

6 6 TECHNICAL OPTIMISATION OF ALTERNATIVE PLANT CONSEPTS

6 6 1 Basic data

6 6 1 1Energy demand and production

Heat demand is only demand for hot water

Due to the uncertainties in heat consumption in the future the studies have been made with yearly load demand of 4000 GWh/a No increase in yearly load demand will be taken into account The estimated load demand will be used for the whole operation period of the power plant

The yearly load demand curve is presented in Figure 6-1

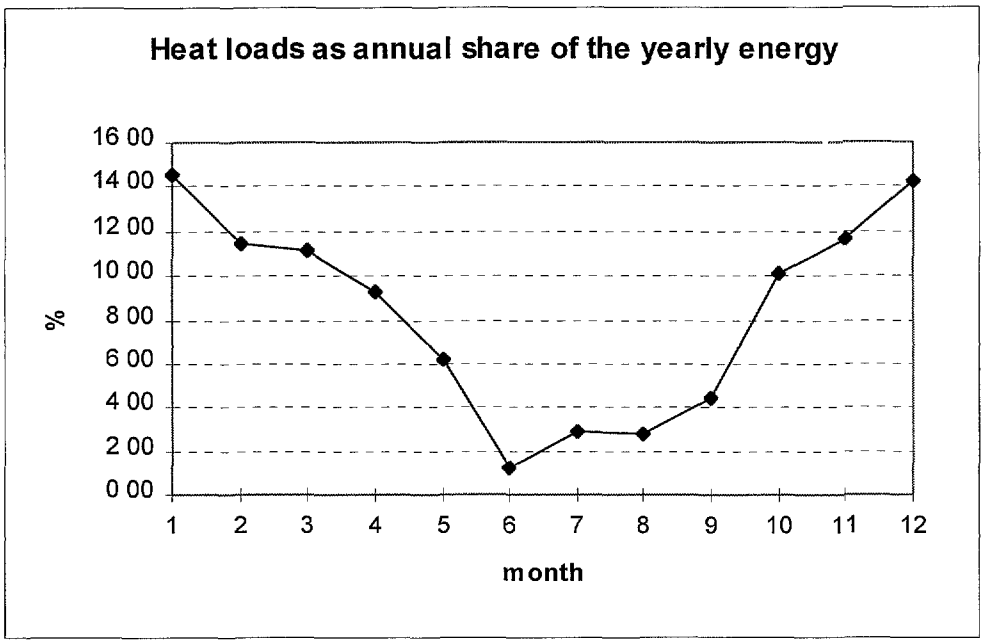


Figure 6-1 Monthly heat loads as an annual share of energy

Heat load variation curve is formed according to variations in a similar Finnish town

The annual heat production is estimated to cover the heat demand The electricity load is assumed to be infinite The produced electricity amount is based on the heat load All the produced electricity is estimated to be sold

6 6 1 2Outdoor temperature

Performance of outdoor temperatures in St Petersburg is presented in Figure 6 2 The temperature variation curve has been made with the daily averages of the similar Finnish city which daily temperature variation is known

207

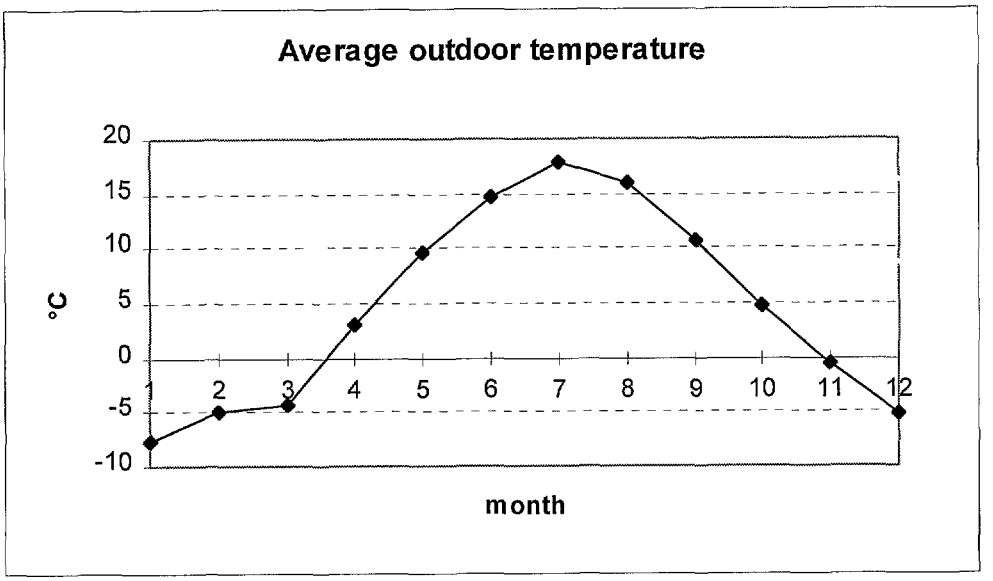


Figure 6-2 Monthly average temperatures in St Petersburg

6 6 2 Fuel prices and taxes

The calculations have been made without VAT

The calculations have been made with gas price of 7 27 $/MWh The storing costs of the reserve fuel have expected to be included in the gas price

Heavy fuel oil is reserve fuel for the power plant

6 6 3 Heat and electricity

Since actual price information was not available the prices have been estimated by Ekono Energy

Heat have expected to be sold with the price of 9 USD/MWh The price covers the costs of heat production

Electricity has expected to sold with the price of 24 5 USD/MWh The price has been chose so that the alternatives are viable

6.6 4 Reserve power

In the study no costs for reserve power have been identified

208

6 6 5 Energy supply optimisation methods

The energy supply has been simulated using the Copsim energy optimisation program developed by Ekono Energy

Copsim is an optimisation program for analysing and simulating a utility's energy production and purchase over the year on an hourly basis With the program it is possible to determine the least cost alternative for an energy utility's heat and power production and purchase mix between plants available

The calculation can be carried out based on the real heat and power load patterns on hourly basis If the real load patterns are not available, typical forecasts for heat and power consumption on hourly basis can be formed for example using monthly energy supply and some typical daily load pattern as basic data

Copsim calculates the operating costs based on turbine characteristics, capacities and efficiencies of each plant taking fuel prices, energy tariffs and maintenance periods into account

As a results a large variety of reports are generated including for example operating costs, energy production of each plant and energy purchase on an hourly basis as well as duration and variation curves

6 6 6 Energy supply optimisation

The operation of each power plant is simulated when hourly heat and power load curves are given for the whole year The power plants are modelled to the Copsim-simulation program based on the characteristics of the plant The results of the Copsim-simulation program are the variable production costs of heat and power and the optimal operation of the power plants

The daily variations in power and heat outputs for heat load 4000 GWh are presented in Appendix 3 Total heat and power generation for each concept is given in Table 6-1 The more detailed specification of the outputs and fuel consumption of the power plants is given in Appendix 4

Table 6-1 The heat and electricity generation in each alternative

Power plant	Existing, MWh	CHP + GT, MWh	Combined-cycle, MWh	2 x combined-cycle, MWh
Electricity	**1951**	**3961**	**3862**	**5807**
Back-pressure	1702	2846	3151	4249
Condensing	249	1015	711	1559
Heat	**4586**	**4586**	**4586**	**4586**
Combined production	2348	3963	3437	4144
Heat only boilers	2237	623	1149	442

The electric power capacity in the back-pressure and condensing mode of each alternative is presented in Figure 6-3

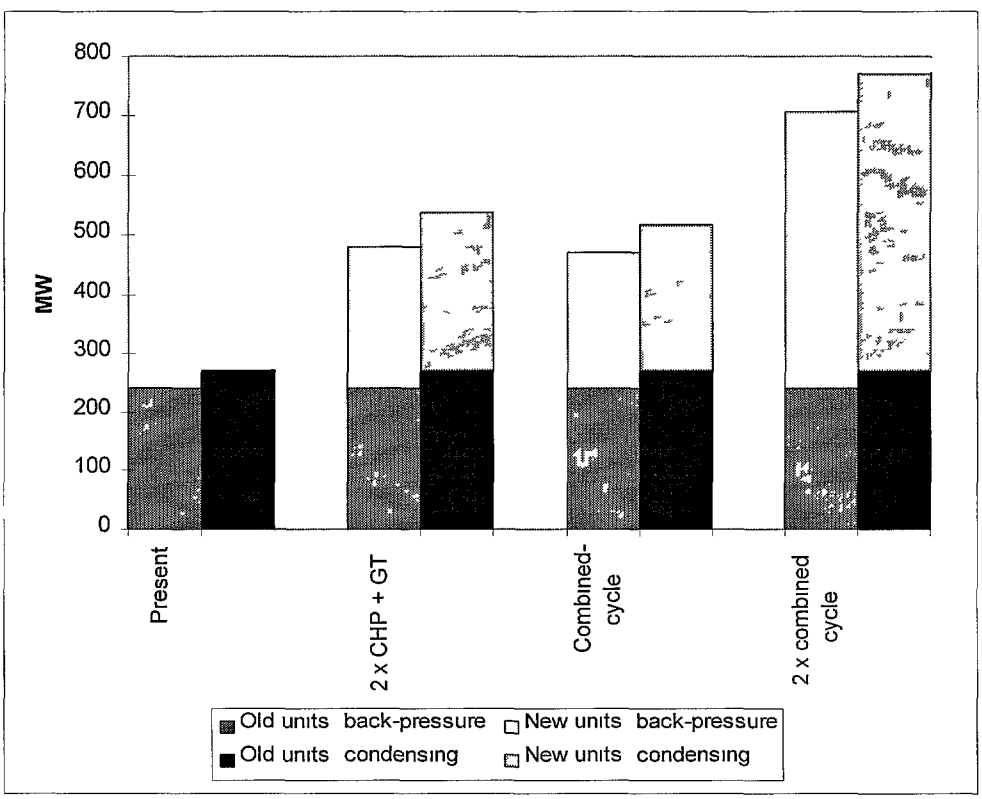


Figure 6-3 The electricity supply of each alternative

210

The yearly electric energy output of each alternative is presented in Figure 6-4 The figure shows that with combined-cycle power plants it is possible to produce the most electricity in back-pressure operation

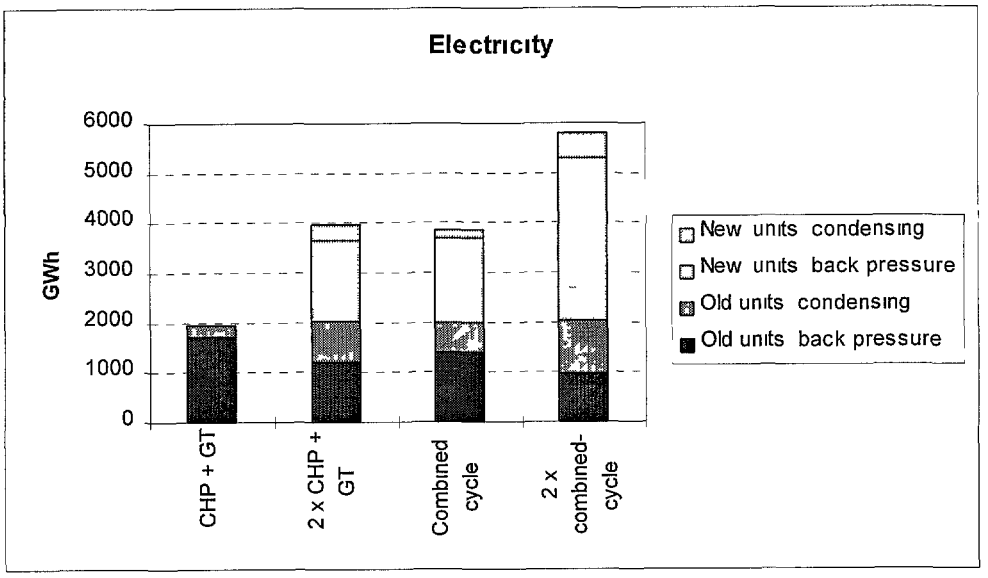


Figure 6-4 The supplied electricity in each alternative

The heat outputs and yearly energies of each alternative are presented in Figures 6-5 and 6-6

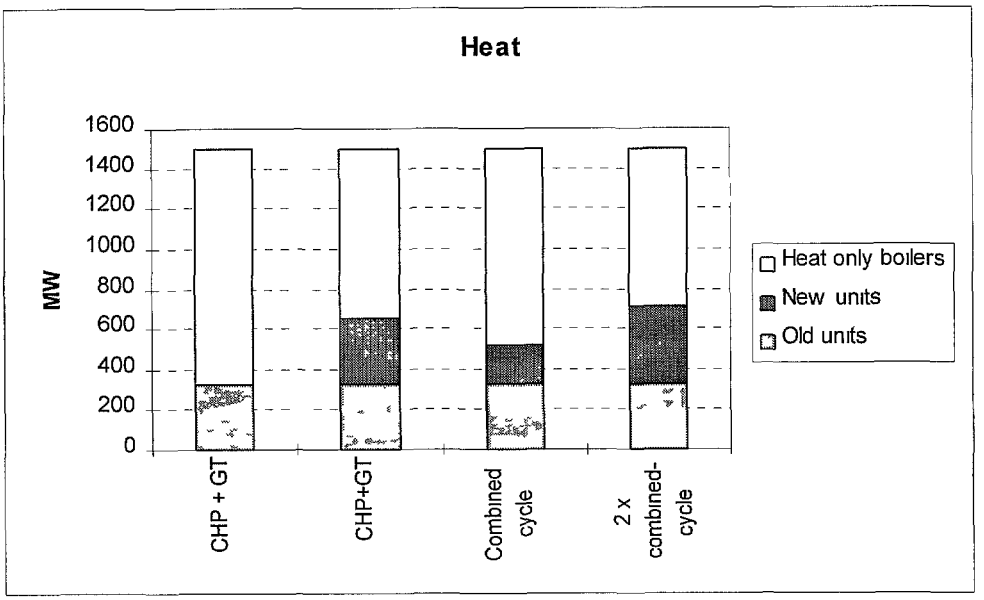


Figure 6-5 The heat outputs of alternatives

211

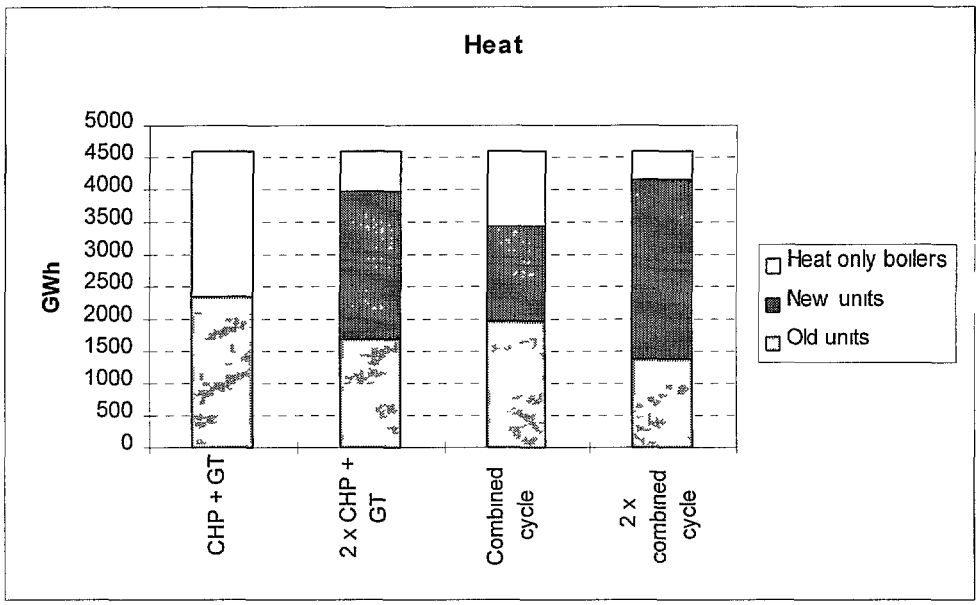


Figure 6-6 The heat energies of each alternative

6 7 ECONOMIC ANALYSIS

Each concept is calculated in a base case to find out, which power plant is the most viable

A base case is formulated on next assumptions A new power plant is scheduled to operate as a base load plant to maximise the amount of electricity in cogeneration mode Old capacity is used as controlling power

The feasibility calculations are based on the following assumptions

- technical life time of the power plant is 25 years
- real interest rate is 8%

The customer price of heat and electricity is based on assumptions of Ekono Energy because no actual price information was available The price of electricity has been determined so that the extension of the existing system becomes viable The spreadsheet calculations with results are given in Appendix 5

The key figures of the feasibility of the alternatives are shown in Table 7-1 The feasibility have been calculated with the heat demand of 4000 GWh/a

212

Table 7-1 Key figures of the alternatives

Concept	KEY FIGURES		
	Net present value, million USD	Pay-pack time, a	IRR, %
Present situation	107	9 3	15 2
CHP with GT	225	8 2	16 8
Combined-cycle	263	7 5	18 0
2 x combined-cycle	337	8 0	17 1

The result show that all the alternatives are viable Although, the most viable alternatives are the combined-cycle power plants This is because in combined-cycle power plants the electricity is produced with high efficiency as a result of good heat to power ratio

The concept of one combined-cycle power plant is the most profitable though it requires quite large investments in heat only boilers and the amount of heat produced in HOBs is relatively high The good viability is a consequence of large amount of inexpensive back-pressure electricity

The feasibility calculations have also been calculated in case that no condensing power will be produced The key figures of these calculations are presented in Table 7-2

Table 7-2 Key figures of the alternatives in the back-pressure production

Concept	KEY FIGURES		
	Net present value, million USD	Pay-pack time, a	IRR, %
Present situation	88 9	10 4	14 0
CHP with GT unit	146	10 5	13 9
Combined-cycle	216	8 5	16 3
2 x combined-cycle	231	10 0	14 4

The internal rates of the alternatives are also presented in Figure 7-1

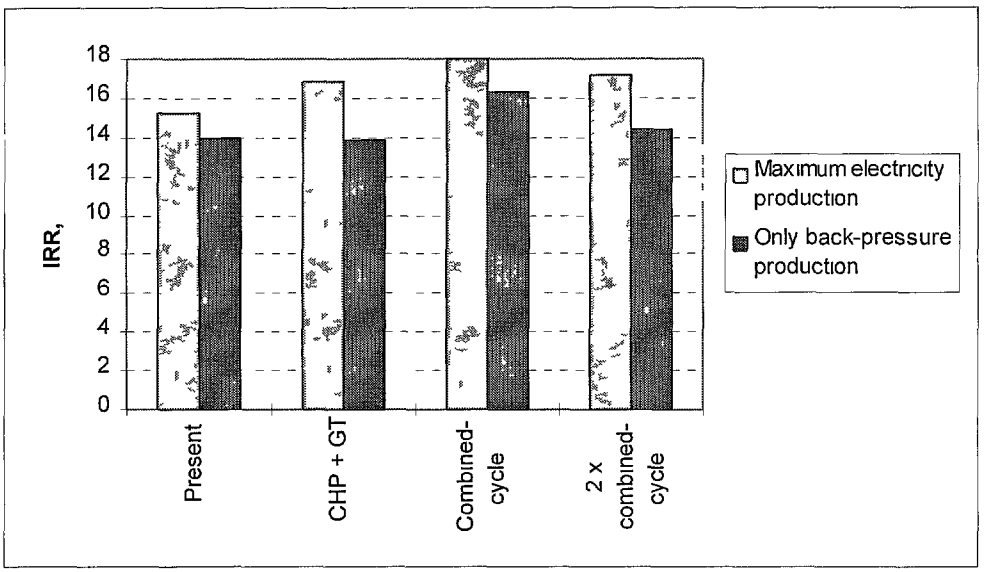


Figure 7-1 Internal rates of return of each alternative

Table 7-2 and Figure 7-1 show that the concepts of present situation and combined-cycle power plant are the least sensitive to the condensing production

6 7 1 Technical data and presentation of the selected Concept

The concept of one combined-cycle power plant seems to be the most profitable It has quite short pay-back time and the internal rate of return is good

It is technically possible to connect the new combined-cycle plant to the existing units The combined-cycle plant is based on a gas turbine with power output of 170 MW The total electricity output in back-pressure mode is 233 MW and the district heating output 195 MW In the condensing mode the electricity output is 250 MW and the district heat production is from 0 to 50 MW The plant capacity curve and schematic flow diagram are presented in Appendix 1 2 The plant data is as follows

One, rated at 170 MW at 0°C

aust 522°C

ry boiler Two pressure (63 4 bar and 6 5 bar) Forced recirculation in boiler section

110°C at economiser inlet

60 bar, 497°C, 65 kg/s

e One high pressure, one low pressure and one condensing, nonreheat, rated at 81 7 MW

214

Natural gas

The combined-cycle power plant has operational flexibility The gas and steam turbine may be started, controlled, and loaded independently from a centralised control room The gas turbine may be operated with or without the heat recovery boiler

6 7 2 Sensitivity analysis

The changes in profitability of the combined-cycle plant have been studied in cases of different interest rates and the changes in prices of gas, heat, electricity and investment costs The results are shown in Table 7-3

Table 7-3 Sensitivity analysis of the combined-cycle power plant

Combined-cycle power plant	KEY FIGURES		
	Net present value, million USD	Pay-pack time, a	IRR, %
Basic case	263	7 5	18 0
Real interest 5%	437	6 6	18 0
Real interest 10%	182	8 3	18 0
Real interest 12%	120	9 5	18 0
Investment cost +10%	235	8 6	16 2
Investment cost -10%	290	6 5	20 1
Electricity price +10%	364	6 0	21 5
Electricity price -10%	162	10 1	14 3
Heat price +10%	307	6 8	19 5
Heat price -10%	219	8 4	16 4
Gas price +10%	183	9 4	15 1
Gas price -10%	343	6 3	20 8

Table 7-3 shows that the feasibility of the combined-cycle power plant is not very sensitive to the variation of the real interest rate, investment costs or heat price The changes in rates or prices have only an impact of few years on the pay-back time This is a good defence towards uncertainties of inflation rate and changes in investment costs

The feasibility of the combined-cycle plant depends a little more on the prices of electricity and gas However, the power plant is still viable when the prices change ± 10 % The changes of feasibility are presented in Figure 7-2 as a function of internal rate of return

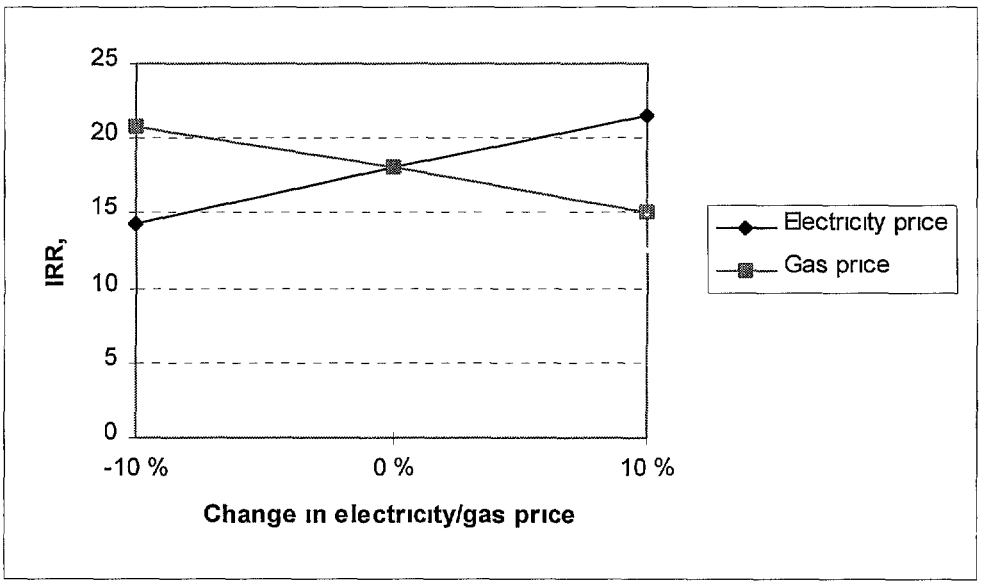


Figure 7-2 Changes in internal rate of return when gas and electricity prices are varied

6 8 ENVIRONMENTAL ASPECTS

All the power plants are natural gas or heavy fuel oil fired Estimates of emission amounts are based on an assumptions that only natural gas is fired in the power plants

The characteristics of natural gas is expected to be as follows

ne	98 99 %
	0 1 %
n	0 01%
n	0 96%
dioxide	0 04%

Calculated heat value of natural gas is 8490 kcal/Nm^3 35,55 MJ/Nm^3

Annual NO_x emissions of Lenenergo's power plant No 5 are presented in Table 6-1 Emission factor for combined cycle is estimated based on gas turbine manufacturers' guarantee values for NO_x emissions Other emission factors are accordance with the Russian standards GOST 27510-87 for water boilers and GOST P 50831-95 for boiler units Emission factors are as follows

	50 mg/MJ$_{fuel}$
nit	40 mg/MJ$_{fuel}$

GT 40 mg/MJ_{fuel}
ined cycle 60 mg/MJ_{fuel}

Table 6-1 Annual NO_x emissions of Lenenergo's power plants (tons per year)

Concept	HOB	Old unit	New unit	Total
Present situation	445	720	0	1165
CHP with GT	125	720	720	1565
Combined-cycle	230	720	870	1820
2 x combined-cycle	90	720	1740	2550

Annual CO_2 emissions are presented in Table 6-2 Emission factor for CO_2 is 55 g/MJ

Table 6-2 Annual CO_2 emissions of Lenenergo's power plants (1000 tons per year)

Concept	HOB	Old unit	New unit	Total
Present situation	487 5	991 5	0	1479
CHP with GT	136	988 5	991 5	2116
Combined-cycle	250 5	991 5	800	2042
2 x combined-cycle	96 3	991 5	1600 2	2668

Specific emissions per produced energy unit are lowest in present situation (new unit and HOBs under construction) because of high efficiency of new HOBs On the other hand, much more electricity is generated in the other alternatives Therefore, if different value of electricity and heat is taken into consideration, the situation will change

6 9 PROJECT COSTS

The total investment cost of the combined-cycle power plant is estimated to be approximately 120 million USD The rough estimate for the distribution of the investment costs is presented in Figure 9-1

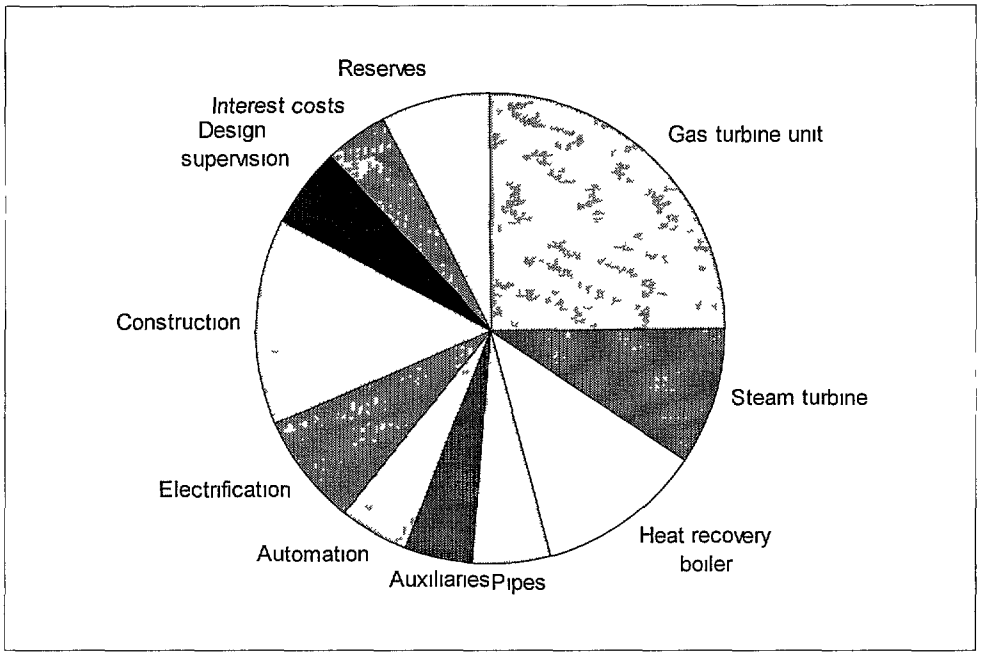


Figure 9-1 The estimate for the distribution of investment costs

The costs will be divided between Russia and Western countries It has been estimated that the steam turbine unit and electrification as well as construction work would be Russian Part of the piping work, design and supervision is also planned to be Russian The estimated division of the costs is presented in Figure 9-2

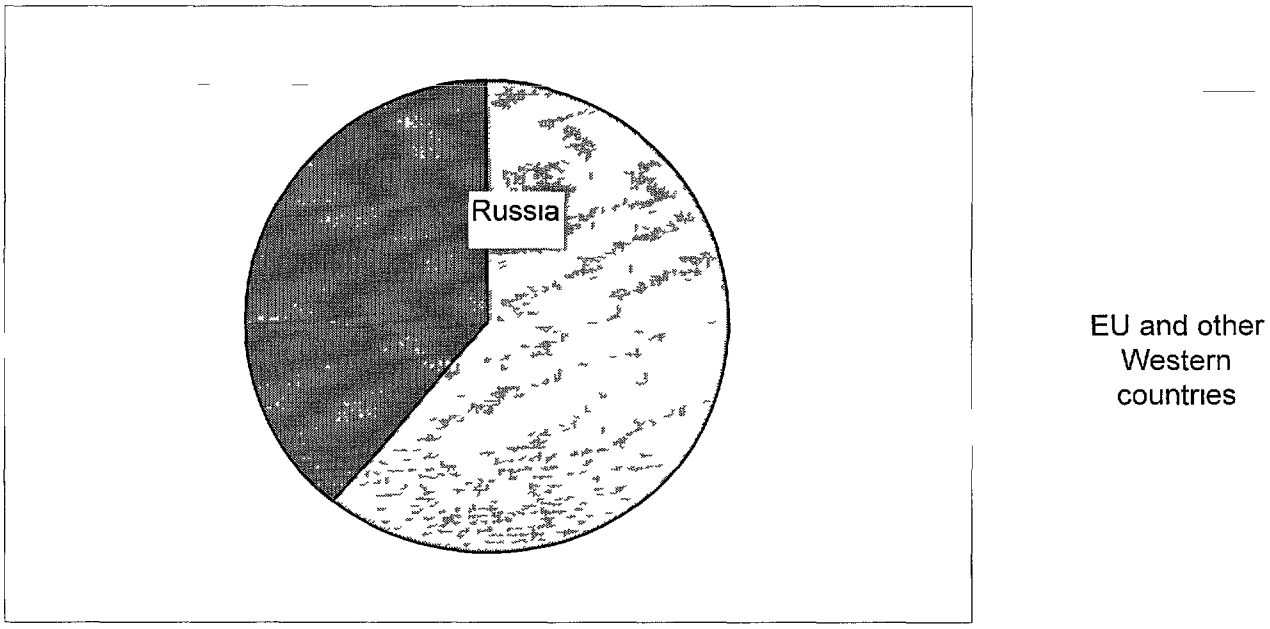


Figure 9-2 Estimated division of costs

6 10 FINANCING

The most likely possibilities that may be available in financing the St Petersburg heat and power plant project are as follows

6 10 1 Equity investments and guarantees

6.10 1 1Equity investments

When an investment is associated with a major capital outlay as for a power station, an equity investment is always required Owners are generally required to give up some ownership to the new investors Usually lenders require one third equity of the total costs Local companies should be included in their consortia to reduce the political risk

An equity investment may be undertaken in a variety of forms, including subscriptions to ordinary shares or preference shares Quasi-equity investments ranging from subordinated loans, debentures and income notes to redeemable preference shares are also offered When a Multilateral Investment Bank, the EBRD for instance, takes an equity stake it expects an appropriate return on its investment It will have a clear exit strategy and will only take a minority position

In the case of the EBRD as an investor, it may also underwrite a share issue by a public or a privately owned enterprise

The EBRD will consider financing the transfer of shares in existing enterprises only in the case of privatisation where such a transfer will definitely improve efficiency, for example through better management, rehabilitation or expansion under new ownership, or synergy with the acquirer's operations

The terms and conditions of the EBRD's investment in a particular project will depend on the risks and prospective returns of the project, as well as on the characteristics of the entity serving as a vehicle for the investment, for example the joint-stock company

The EBRD does not seek long-term investments or take a controlling interest in or direct responsibility for managing enterprises Where the EBRD can, it will encourage other co-financiers to participate in funding a project These potential co-financiers could include commercial banks and international financial institutions, export credit agencies, and further official sources such as government development assistance programmes Most of these potential co-financiers may also on their own take part in the funding of the investment

Co-financing benefits both lenders and borrowers For borrowers co-financing can

- facilitate a flow of resources from various financiers
- catalyse the flow of additional resources from official and private institutions

- help in meeting large resource requirements for projects too big to be handled by one funding agency

Co-financing can also help in mobilising resources which are sometimes provided on equal or better terms than those available from the leading bank's own funds Co-financing thus offers expanded business opportunities together with greater security and lower costs Usually the leading bank organises co-financing arrangements

6 10 1 2Guarantees

Guarantees are a very effective instrument especially for debt and project financing Guarantees from Multilateral Development Banks and the Export Credit Agencies are available against losses from currency transfer or inconvertability, expropriation, breach of contract and war and civil disturbance

Through the EBRD, for instance, various types of guarantees are available, ranging from all-risk guarantees to partial risk-specific contingent guarantees, but in all cases the maximum exposure must be known and measurable and the credit risk must be acceptable

6 10 2 Project financing by sources and terms

Project financing is the model generally applied by Multilateral Development Banks for projects in CEE and NIS The lender finances the project proper Crucial for an investment decision is that the project can in its business plan show an anticipated cash flow sufficient to repay the loan, pay interest and also give a sufficient accumulation of earnings at the borrower Assets, contracts and cash flow of the project are used as a collateral in the event of a default In project financing for larger projects the banker plays an important role in forming the financial plan of the project, in organising and implementing the syndicate funding

Credits by Multilateral Development Banks such as the EBRD and the World Bank have been traditionally excluded from sovereign debt reschedulings and have therefore enjoyed preferred creditor status Banks that participate in loans to private sector borrowers made by the development banks, where the Multilateral Development Banks remain the lender of record, may share in the benefit of this preferred creditor status

6 10 2 1International Financing Institutions

EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT (EBRD)

Lending Operations

EBRD activities in the energy sector involve upgrading the power sector, with the introduction of

more efficient technology, the reduction of transmission and distribution losses, and the completion of conventional power plants

In financing power plant projects, the trend in EBRD financing has been to shift from public sector projects towards privately owned and run projects, the IPP's (Independent Power Producers) In these cases, the financing is structured on project-finance basis, i e non-recourse, with completion guarantees, off-take agreements, etc

Government ownership does not, as such, exclude a power project from the bank's lending programme, but more and more, EBRD projects are designed to transfer power utilities from public to private ownership In public sector power projects there either needs to be a sovereign guarantee, or in case of project risk being assumed, the project should be ring-fenced to look financially like a private sector project, i e it should have its own cash-flows separate from government expenses and revenues

As regards the minimum size of an EBRD-financed power project, loans in practice tend to be more than MUSD 20 or more and equity investments at least MUSD 10 Through global loans, where a local bank acts as a financial intermediary, even very small power projects can be financed Loan financing may in these cases be supplemented with risk capital from venture funds where EBRD has invested

The EBRD provides loans which are tailored to meet the particular requirements of the project The credit risk may be taken entirely by the EBRD or partly syndicated to the market A loan may be secured by a borrower's assets and/or it may be converted into shares or be equity-linked The Bank lends in any hard currency, and it has started to fund or facilitate loans in certain local currencies When lending to private commercial enterprises the EBRD does not normally require guarantees from the host government and loans are typically without recourse to foreign sponsors, once a project is up and running The basis for providing a loan is the cash flows of the investment and the ability of the investment to repay that loan over the agreed period

The terms of the EBRD loans are as presented in table 9 1

Table 9 1 Terms of the EBRD loans

Rates	margin over market benchmark (normally Libor) variable rate or fixed rate
Terms	loan maturities from 5 to 10 years
Fees	front-end fee at signing annual commitment fees
Expenses	reimbursements of out-of-pocket expenses from sponsors to the EBRD
Recourse	not required to a sponsor
Insurance	Funded companies or entities shall have

	insurance against normally insurable risks (e g theft of assets) *no* insurance against political risk *no* insurance against non-convertibility of the local currency
Security	Security of loan with *project assets* of companies or entities mortgage on fixed assets (e g land) mortgage on movable assets (e g equipment) assignment of company's hard currency and domestic currency earnings pledge of sponsor's shares in company assignment of company's insurance policy and other contractual benefits
Covenants	Finance covenants limiting indebtedness certain financial ratios other issues

WORLD BANK

The World Bank, founded more than 40 years ago, has a role of a lender-donor institution It has provided more than 200 billion USD in financial and technical assistance to developing countries to stimulate economic growth and stability Russia became a member of the Bank in 1992 The Bank consists of four closely associated institutions the International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the International Finance Corporation (IFC), and the Multilateral Investment Guarantee Agency (MIGA) In this context we concentrate only on the IBRD because of the nature of the project and the country The IBRD lends funds, most of which it raises through the sale of AAA-rated bonds in international capital markets, creditworthy developing countries These countries shall be able to pay near-market interest rates Loans are made only to governments, government agencies, or institutions that can obtain a guarantee from their government Goods, works and services financed by these loans are procured in accordance with procedures stipulated by the Bank The IBRD also provides partial risk or partial credit guarantees (with a counter-guarantee from their government) to private lenders on development projects

In table 9 2 the main terms of the World Bank loans are presented

Table 9 2 Terms of the IBRD loans

Loans	currency pool loan single currency loan

	Libor-based single currency loan
Rates	rate reset semi-annually (currency pool loan) Libor-based or fixed-rate (single currency loan) six-month Libor
Repayment	12-15 years
Grace period	3-5 years
Borrowers	governments and agencies that can obtain a guarantee from the government

The World Bank finances, on average, about 40% of the total cost of a project, which in turn stimulates further funding by the borrowing countries and by other agencies and commercial banks that co-finance with the World Bank If the World Bank agrees to fund the project, perhaps RAO and the Energos may request a long term, soft loan (i e low interest) for approximately 1/2 (one-half) of the project costs

NORDIC INVESTMENT BANK (NIB)

NIB is a multilateral financing institution founded in 1976 and owned by the five Nordic countries (Finland, Sweden, Norway, Denmark and Iceland) The Bank's authorised capital has been subscribed to in proportion to the member countries' GNP
In order to have the possibility to finance a Russian investment the Petrozavodsk heat and power plant extension shall have positive environmental impacts In addition to this it has to be ensured that the borrower can pay back the loan, i e covenants are required from the borrowers In the case that either RAO or one of the energos is the borrower one requirement is that the Russian Ministry of Finance gives a security In the case of the Nordic Investment Bank as a lender it is required a Nordic interest, i e

- the project has positive effects on employment and business in the Nordic countries
- the project is carried out in one Nordic country by the combined efforts of that country and a non-Nordic country
- foreign investments in the Nordic countries can involve greeenfield investments, as well as expanding production in an existing subsidiary
- NIB's participation should be in reasonable proportion to the size of the project and the anticipated benefit for the Nordic countries

However, high priority is given to lending for cross-border investments that promote Nordic economic integration, stronger growth and high employment on a long-term basis

In table 9 3 are presented the principle terms of the Nordic Investment Bank loans In addition to loans, NIB offers also guarantees

Table 9 3 Terms of the NIB loans

Rates	fixed floating
Repayment	5-20 years
Grace period	up to 7 years
Terms	all costs related to a project can be financed maximum 50% of the total project costs

NIB's lending consists to 20% of international loans (borrowers outside the Nordic countries) The international loans increases more than the Nordic loans

TACIS PROGRAMME

Ownership

The Tacis programme is a technical assistance programme, which provides grant finance for know-how to support the process of transformation to market economies and democratic societies

The know-how is delivered by providing policy advice, consultant teams, studies and training, by developing and reforming legal and regulatory frameworks, institutions and organisations, and by setting up partnerships, networks, twinnings and pilot projects

Tacis partner countries comprise Russia and the New Independent States (Armenia, Azerbaidzan, Belarus, Georgia, Kazakhstan, Kyrgystan, Moldova, Turkmenistan, Tajikistan, Ukraine, Uzbekistan) and Mongolia

The Tacis programme is funded from the EU budget and operates under its rule The budget is fixed annually by the European Parliament and the Council of the European Union The yearly budget provided for Tacis is then divided up between each country based on criteria such as population, gross domestic product, commitment to the reform process etc

A new Tacis regulation was approved by the Council in June 1996 The new regulation permits a limited amount of the allocation to be used for small-scale infrastructure projects in the context of cross-border cooperation In addition, the regulation states that the Tacis programme will support the establishment of joint ventures through the funding of equity investment in small and medium-sized enterprises

Programming process

Indicative Programmes are prepared by the European Commission in coordination with the partner countries and cover a four-year period (presently 1996-1999) Indicative programmes take each individual country's reform priorities and economic circumstances into account and establish the basic objectives and strategy for the Tacis programme in that country Indicative programmes may also include financial estimates

National Action Programmes are prepared every second year (except in Russia and Ukraine every year) and they comprise individual projects and activities, which support the sector objectives established in the Indicative programmes Action programmes also allocate the funding available for each sector

Financial proposals are based on the Action Programmes where projects are described and budgeted They outline the contracts available for tender and are submitted for the opinion of the Tacis Committee Once the Tacis Committee has delivered a favourable opinion and subsequently the Commission has formally approved the financing proposals, the corresponding budget commitments are made

Funding Operations

The different TACIS programs that can assist the energy sector reform in Russia are

- Tacis Action Programme for Russia 1998
- Tacis Inter-State Programme
- Tacis Cross-Border Cooperation
- Nuclear Safety Programme
- The Joint Venture Programmes

Project Cycle

Ordinarily, a proposal to include a project in one of the Tacis financed programmes, may only be made by a national or local organisation from a Tacis partner country and should correspond to objectives identified by the Indicative Programmes for that country

The project is then submitted to the Coordinating Unit in that country The Coordinating Unit will assess the proposal and may, after a pre-selection, submit it to the European Commission for further consideration either via the Commission's Delegation in that country or directly to the DG 1 in Brussels

If the project is then selected in an Action programme, the corresponding contracts are put out to tender in the normal way It should be noted that Action programmes do not always automatically retain selected projects as originally proposed

THE NORDIC PROJECT EXPORT FUND (NOPEF)

Ownership

The Nordic Project Export Fund was established in 1982 and operates under the Nordic Council of Ministers Its shareholders are the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)

Nopefs annual budget is approximately ECU 3 5 million

The Board of Directors constitutes of two representatives from each Nordic country

Operational Structure

The main priority of NOPEF is to foster and develop Nordic cooperation The concept of Nordic interest is also a priority for all activities of NOPEF NOPEF's target is to strenghten the Nordic companies international competitive advantage by offering attractive financing for feasibility studies and business planning activities This fosters the internationalisation of Nordic companies and their participation in international projects

NOPEF cooperates with the NIB, NEFCO and the Nordic Development Fund (NDF) to strengthen the Nordic profile

Target Sectors/Restrictions

NOPEFs target region is the neighboring region and NOPEF has also during the last few year focused on small and medium sized Nordic companies, which today stand for 75% of the total amount of companies seeking financing from NOPEF

During the last years 80% of NOPEF's activities have been in Central and Eastern Europe, and especially in the Baltic States North-West Russia has taken the place of Asia as an increasingly important region outside the neighboring region

Most of the projects financed during 1996 have represented the forestry, energy, production and the construction industries New important areas of operation are the information technology, data service and wholesale sectors The environmental sector is also an interesting sector and in this sector NOPEF usually works in close cooperation with the NIB and NEFCO

Loans

NOPEF gives interest-free loans to finance pre-feasibility and feasibility studies in the Baltic states and in the North-West Russia

The loan can cover 50% of the feasibility study costs

Project Cycle

The initial contact to NOPEF can be taken by telephone or fax After discussing the project with one of the NOPEF project consultants, application papers can be received

The project consultants evaluates the project and forwards the application, if it fulfills the requirements made by NOPEF, to the Board of Directors

THE NORDIC ENVIRONMNET FINANCE CORPORATION (NEFCO)

Ownership

The Nordic Environment Finance Corporation (NEFCO) is a risk capital institution financing environmental projects (including investments in single energy production plants) in Central and Eastern Europe NEFCO was established in 1990 by the five Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)

NEFCOs capital (doubled in 1996) is ECU 80 million, with the intention to invest the capital in some 50 projects up to year 2001 Denmark shall subscribe ECU 18 3 million, Finland ECU 14 9 million, Iceland ECU 880 000, Norway ECU 15 6 million and Sweden ECU 30 4 million

All powers of the Corporation are with the Board, which may to the extent it sees acceptable, delegate power to the Managing Director and/or to the Nordic Investment Bank Financial decisions are made by the Board The Board approval for a project is usually obtained in two steps (1) the project is given an indication of interest, which means that it falls within the field of NEFCO's operations (2) the project undergoes full appraisal to confirm its viability in NEFCO's opinion

NEFCO is situated in Helsinki, together with the Nordic Investment Bank

Operational Structure

Projects eligible for financing from NEFCO must fill the following criteria

1) The project should be carried out in one of NEFCO's countries of operation in Central and Eastern Europe Priority is given to the Baltic Sea region and the Barents region

2) The project should have relevant environmental effects Priority is given to projects that have

substantial environmental effects on the Nordic region, i e projects that lead to reduction of pollution in the Baltic Sea and the Barents Sea or reduction of transboundary airborne pollution

3) The project is based on long-term cooperation through investments in enterprises, primarily through the formation of joint venture companies or corporate acquisitions

4) The project has a Nordic company or institution as business partner

5) The project is economically, financially, institutionally and technically viable

A Nordic partner should take part in the project on a long-term basis Generally this implies participation in an enterprise, also acquisitions and joint ventures are typical, but long-term cooperation may also be based, for example, on a twinning arrangement The Nordic partner is also required to have sufficient experience of the business The environmental, technical, institutional, economical and financial feasibility of the project should be demonstrated, normally through a feasibility study

NEFCO aims at participating as an active investor In practice this usually means that NEFCO requests the right to nominate a representative in the Board of project companies, at least in the early phase of a project

Subscribing of equity and shares

-
Facilitating mobilisation of necessary equity base for a project NEFCO can then participate as a partner in the project NEFCO will not accept a majority ownership or a dominating position for itself

Medium and long-term loans and guarantees

-
Provided on market terms In some cases subordinated loans and loans with equity features may be provided Often the loans are extended in addition to NEFCO's equity participation in the projects

NEFCO's participation in projects for equity investments is generally in the range of 25-35% of the total financing Loans on market terms, loans with equity features, subordinated loans or mezzanine financing normally is in the range of 25-50% of total loan financing

In large projects the proportion would be smaller According to present policy the maximum commitment for one project is approximately ECU 4 million A commitment under ECU 125,000 will be considered by NEFCO only under special conditions, for example in the case of environmentally significant demonstration projects

NEFCO regularly co-finances projects with other financial institutions and with the Nordic

countries bilateral environmental assistance programs foi the neighbouring region

6 10 2 2Suppliers Credit

The project may also be announced under a turnkey arrangement with the successful contractor responsible for obtaining the financing from export credit agencies The procurement under this scenario will be done on an international competitive basis The maturity of the loans from export credit agencies is likely to be for about 7-8 years, and will require guarantees from RAO and the Russian government Approximately 70% of the estimated costs to complete the project can be financed in this manner, with the rest of the funds coming from commercial banks

6 10 2 3Commercial Banks

Based upon the balance sheets of RAO and the energos and with the appropriate guarantees from the Government, some of the Western commercial banks may be interested in financing the project The interest rates for such loans, however, are likely to be higher

6 10 3 Grant funds

6 10 3 1EBRD and other development banks

In addition to the EBRD's and other development banks' capital paid in by the shareholder countries, many member countries have lodged special funds with the Banks to assist in preparing projects Such grant funds are available to employ consultants to carry out feasibility studies for projects and to cover other preparation costs Thus, the grant funds do not cover the financing in the investments

6 10 4 Risks

Financiers have the requirement that risks connected with their participation in a project are kept at a low level A structured and comprehensive approach to risk management is thus essential

Risks are usually divided in two types

a) project risks and

b) global risks

Project risks include development risk (planning, bidding), construction risk (design, completion, etc), operational risk (defects, management, economics of operation), financial risk (foreign exchange, interest, cash flow) and revenue risk (demand, rates)

Global risks include political risks (expropriation, force majeure, fiscal changes, etc), legal risks (changes in law and regulation during concession period), commercial risks (escalation of costs of raw materials, convertibility, devaluation) and environmental risks

All risks must be carefully scrutinised and evaluated The most important thing is that each risk should be clearly identified and appropriately allocated and that responsibilities are clearly defined in the contract

6 10 5 Summary of financing

In figure 9 1 there is presented the basic structure of the international project financing

The privately financed projects are characterised with an emphasis on the follow-up of revenue flows arising from the project to service the loans and to provide the return on the equity which has been invested The funders to make this follow-up can be insurers, lenders, investors or donors

The insurers decide on the insurance policy In practice this usually means that the lenders have certain requirements for the insurances which the insurers apply In most cases the insurance requirements are set only against normally insurable risks such as outbreak of fire

The lenders cover a large group including among others international development banks, commercial banks and export credit agencies All the lenders have their general regulations on lending and specific regulations which differ from one area to other The common terms include the rates of interest which are normally set at a margin over a market benchmark The loan maturities for example for the EBRD loans generally range from 5 to 10 years The maturities of the export credit agencies follow the same tendency

The investors are dealing with equity investments and guarantees The biggest investors in this area are the Multinational Development Banks The Banks' equity investments are provided for assisting the initial stage of the project and the Banks will only take a minority position

The banks are generally handling the guarantees if the bank's customer fails to meet certain commitments, such as loan repayment In this way the banks may help borrowers gain access to financing a project

The donor institutions are usually at the same time the lenders The grants are generally provided for feasibility studies not for investments Thus, this alternative is not viable for this project financing

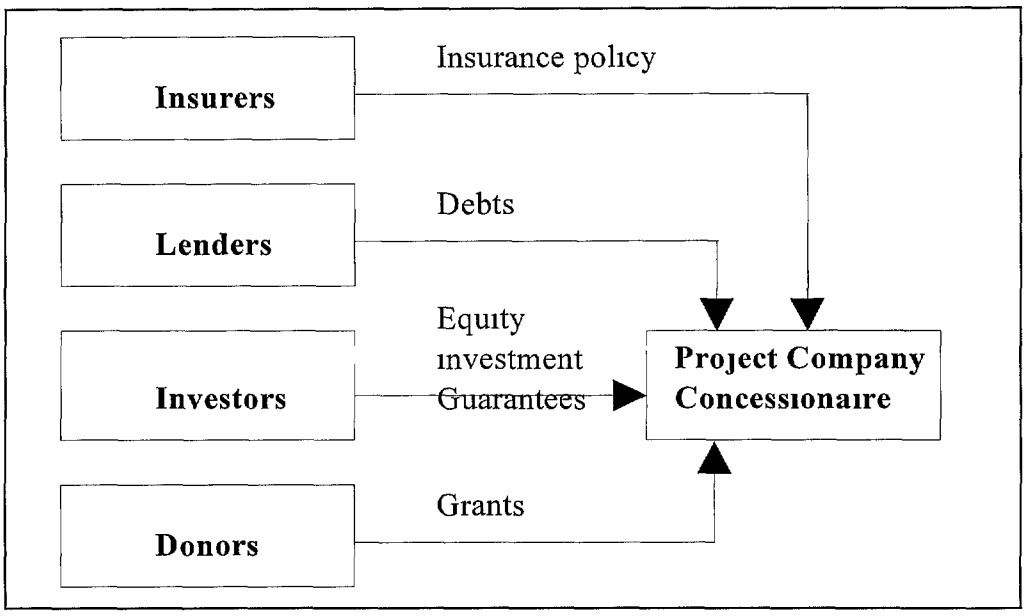


Figure 10-1 Summary of project financing

6.10 6 Conclusions

Whether the World Bank, for instance, would fund the becoming investment in the case that RAO and the energos would be the borrowers of a long-term soft loan the basis could be as follows

- The Russian electric sector requires capital that is not available from within Russia
- Energos and RAO are willing to invest a substantial amount of their own funds for the project
- The project will be environmentally sound and will save natural gas, oil, coal and nuclear fuel which are finite natural resources
- The region should have a reliable long term power investment plan the objective of which would be to lead the region to self-sufficiency in generation capacity

6 11 PROJECT DEVELOPMENT AND IMPLEMENTATION

6.11 1 Alternative Project Development Options

Text under the paragraph 10 1 Alternative Project Development Options is based on the findings presented in the Financial Appraisal Report - Hydro Team March 1998 of the TACIS Project Development of Local Energy Resources of Karelia, Project No ERUS 9504

There are basically two different ways to carry out the proposed project These are

(1) Development by an Independent Power Producer (IPP)

The IPP builds and operates the station selling power to a power procurer on the basis of a Power Purchase Agreement (PPA)

(2) Development by Lenenergo

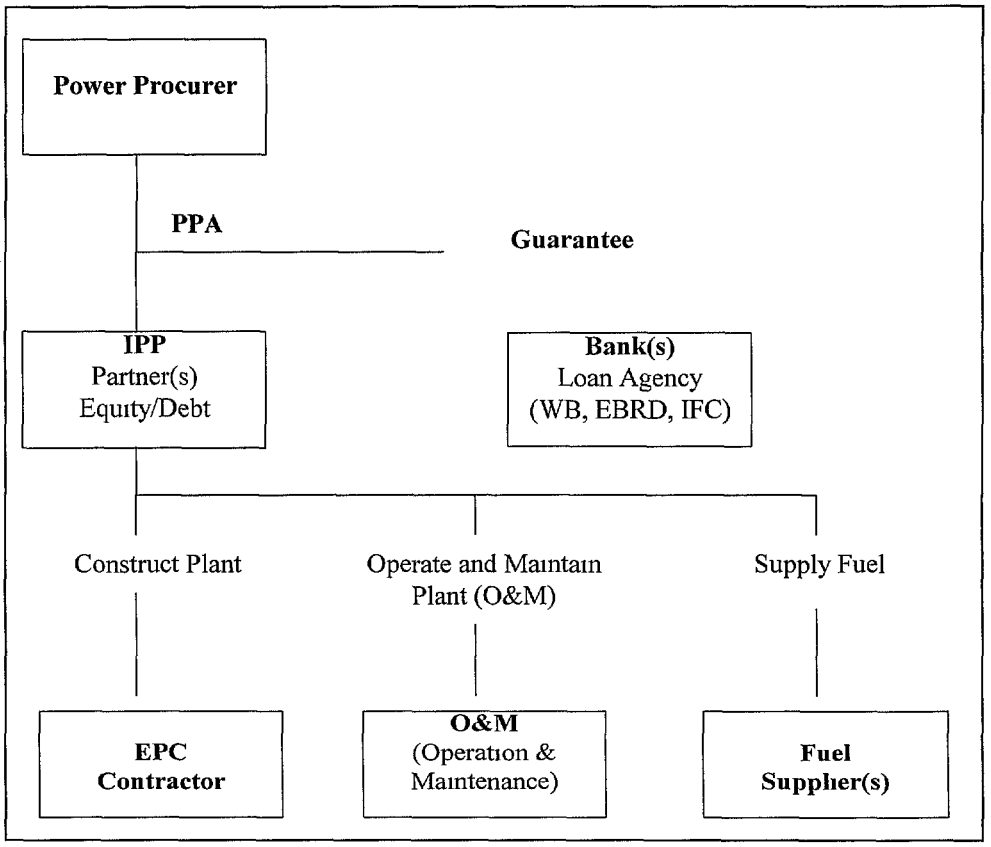
In this case Lenenergo would build and operate the plant

6 11 1 1Development by Independent Power Producer (IPP)

Structure

An IPP normally comprises a consortium which often typically involves an international electricity company, engineering, procuring and contracting suppliers (i e engineering, procuring and contracting Contractor) and financiers Typical structural models are

Model 1

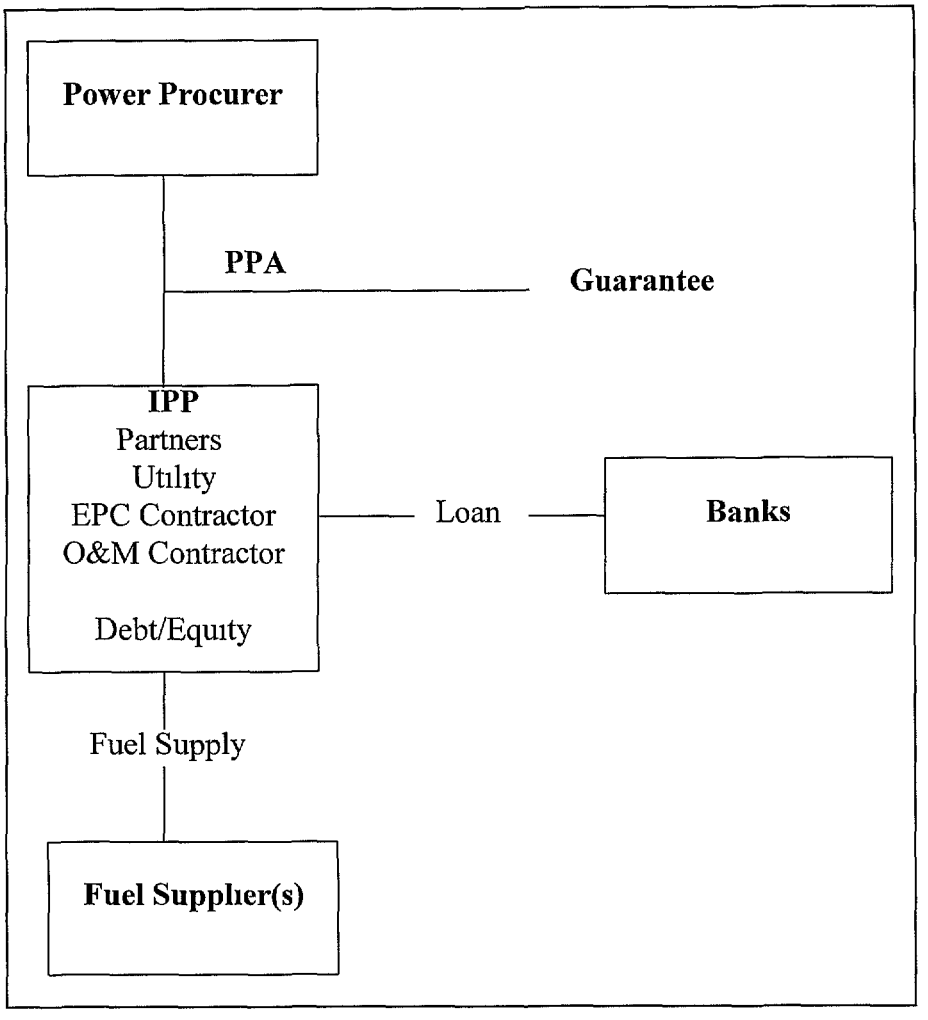


PPA = Power Purchase Agreement, EPC = Engineer, Procure and Construct

WB = World Bank, EBRD = European Bank for Reconstruction and Development

IFC = International Finance Corporation

Model 2



Under Model 1 the plant operation and maintenance contractors are not partners in the IPP while in Model 2 they are In Model 1 the following subsidiary contracts are required in addition to the main PPA

1 Construct Contract

2 Operation and Maintenance Contract

3 Fuel Supply Contract

Major international lending agencies may favor Model 1 as its structure is more geared to accommodating competitive tendering and procurement

If the financial position of Lenenergo is weak any IPP will most likely require RAO to guarantee all payments due by Lenenergo to the IPP

Formation of an IPP

The impetus would have to come from either Lenenergo or RAO or both as the power procurer The power procurer would develop a draft or outline PPA This would determine the size and fuel type of any future IPP Invitations to bid would then be issued in newspapers, technical and trade journals both within Russia and throughout Europe A wide circulation of the invitation to bid is probably necessary if it is to attract international lending agencies An alternative approach would be initially to target potential investors and invite them to an investment workshop at which the power procurer's requirements would be revealed

Power Purchase Agreements (PPA)

In the event of an IPP development a PPA would have to be drawn up between the IPP and either Lenelenergo or RAO This power purchase agreement would be the legal basis governing the long term sale of firm electric capacity and associated energy

Funding for IPP Development

This would obviously depend on the successful consortium Three possible options are conceivable namely

- Totally foreign based consortium
- Totally Russian consortium
- Joint venture

Totally foreign based consortium

Two pertinent facts immediately present themselves

- The combined cycle gas turbine development is likely to be financially attractive
- The political and economic environment in St Petersburg area is positive towards foreign investment

These factors indicate that a totally foreign owned consortium may be a feasible way to develop an IPP It would have the advantage of enabling the consortium to raise the necessary debt and equity finance on western capital markets However a significant disadvantage could arise from the lack of local contact and knowledge arising from the non involvement of a Russian(s) partner

Totally Russian consortium

There could be significant disadvantages with this approach because of

- Difficulty of raising required level of equity capital given the small scale of stock markets in Russia
- Relative scarcity of long term debt in Russia
- Lack of experience of operating in a competitive generating environment using PPAs
- Possible financing difficulties may be a real barrier to procuring the most advanced technology

For these reasons a solely Russian consortium is unlikely to be the preferred option

Joint Venture

This could involve foreign and Russian involvement both as equity holders and debt financiers Equity involvement could be either through direct investment or through, for example, the fuel supplier or the operations and maintenance contractor taking payment partially in the form of equity In the case of debt the financing could be provided by foreign banks and Russian banks with in all probability the bulk of the debt financing coming from foreign banks

The advantages of this approach is that it allows access to the most advanced technology and western capital and at the same time have Russian involvement in the ownership, management and financing of the IPP In this way permanent knowledge transfer is guaranteed with long term economic benefits From a short term perspective local participation may be advantageous from an administrative and legal point of view

6 11 1 2Development by Lenenergo

The second development option is for Lenenergo to undertake the development For this to be a realistic option two conditions must be present

1 Lenenergo, as the borrower, must be commercially attractive to lending institutions

2 The projects must be economically viable in their own right (which appears to be the case for combined cycle gas turbine)

Requirements of Banks to Finance Lenenergo

Before banks will lend they will need reassurance that the borrower can meet the loan interest and capital repayments While banks may require the loan to be guaranteed (e g by RAO) they view such guarantees as a protection of last resort and will not lend unless they are reasonably certain that the borrower has the financial capacity to contractually meet debt service payments From a financial viewpoint before concluding a loan agreement banks will require the following

- Proof of current financial soundness

- Evidence of future continuing financial soundness

Financial statements prepared in accordance with internationally accepted accounting standards and properly audited accounts are used to establish the current financial position Financial projections prepared using computerised financial models and based on realistic assumptions would be used as indicators of the future financial position

6 11 2 Project Implementation Plan

The principle implementation plan of the project is presented in Figure 11-1 The more detailed schedule is presented in Appendix 6

Task name	Year				
	1	2	3	4	5
Feasibility study	----------				
General planning		---------- -			
Plant design			----------		
Architectural design			------		
Procuring of GT			------- ----------	---------- --	
Procuring of HRB			----- ----------	---------- --	
Procuring of ST			------- ----------	---------- --	
Pipes			--- -------	------	
Auxiliaries			--------	------	
Automation			---------	----	
Electrification		---	---	--------	
Construction			----------	-------	
Connections				-	
Test runs					---

Figure 11-1 The principle schedule

The total time of construction is 4 5 years including feasibility study and pre-design The feasibility study contains the final selection of the plant concept and preliminary design of the plant General design and plant design consists of final power plant layout and preparing and sending the tender documents as well as authorisations

The procurement of gas and steam turbines as well as heat recovery boiler contains the order, manufacturing time, assembly, implementation and test runs of the parts

Pipes, auxiliaries and electrification contains the deliveries, assemblies and implementation of different equipment These parts and work would be mainly Russian Automation system and equipment would be for the most part Western

Construction consists of earth moving and pile work, foundations, construction and regional works The connection to electricity, district heat, water and natural gas networks is expected to be a minor work

The anticipated division of working time between Russia and Western countries has been presented in Figure 11-2

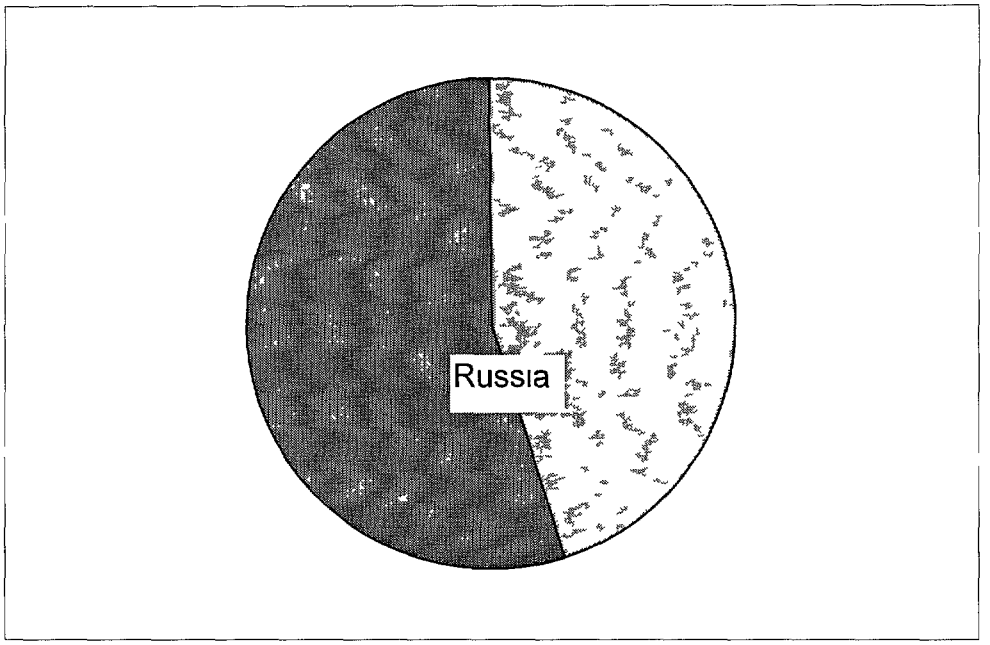


Figure 11-2 The anticipated division of working time

6 12 SUMMARY

In this prefeasibility study four different power plant concepts have been compared present situation with a 60 MW gas turbine unit, cogeneration plant with 60 MW gas turbine unit, combined-cycle power plant and two combined-cycle power plants All the alternatives are natural gas fired There is also a need for new heat only boiler investments in all the alternatives to cover the shortage of district heat Heat only boilers will be used during district heat peak demand periods and during maintenance

The viability of each concept is quite good and near each other When the amount of electricity production is an important point concepts based on heat and power co-production are the most interesting choices Furthermore to maximise the electricity production, combined-cycle power plant based concepts should be considered because of their high heat to power ratio

The concept of one combined-cycle power plant was the best alternative according to pay-back time and internal rate of return The feasibility of the combined-cycle power plant is based on a large amount of back-pressure production The power plant is also very flexible with heat and power production so it suits easily to the variation of heat and electricity load demands

The feasibility of the concept of two combined-cycle power plant units is not so good as a concept based on one combined-cycle plant This is due to the increased amount of electricity production in condensing mode In the most viable concept 3150 GWh of electricity was produced in cogeneration mode and 710 GWh in condensing mode Respectively the figures for a concept with two combined-cycle plants are 4250 GWh and 1560 GWh Thus the potential for extra cogeneration is obvious So it might be worth considering to study the unit of even larger combined-cycle plant than the one in this study The investment costs per unit will decrease when the unit size increases, so the larger combined-cycle power plant might be even more profitable than the studied one

Sensitivity analysis of the combined-cycle power plant showed that the viability is not very sensitive to the variations of internal rates, investment costs or changes in prices The viability of the power plant is a bit more sensitive to the variations of gas and electricity prices For a more exhaustive feasibility study a more accurate information about gas, heat and electricity prices as well as heat demand in future is needed

According to the results of this study the combined-cycle power plant is very profitable and worth investing We recommend that the planning will be continued with the concept of a combined-cycle plant

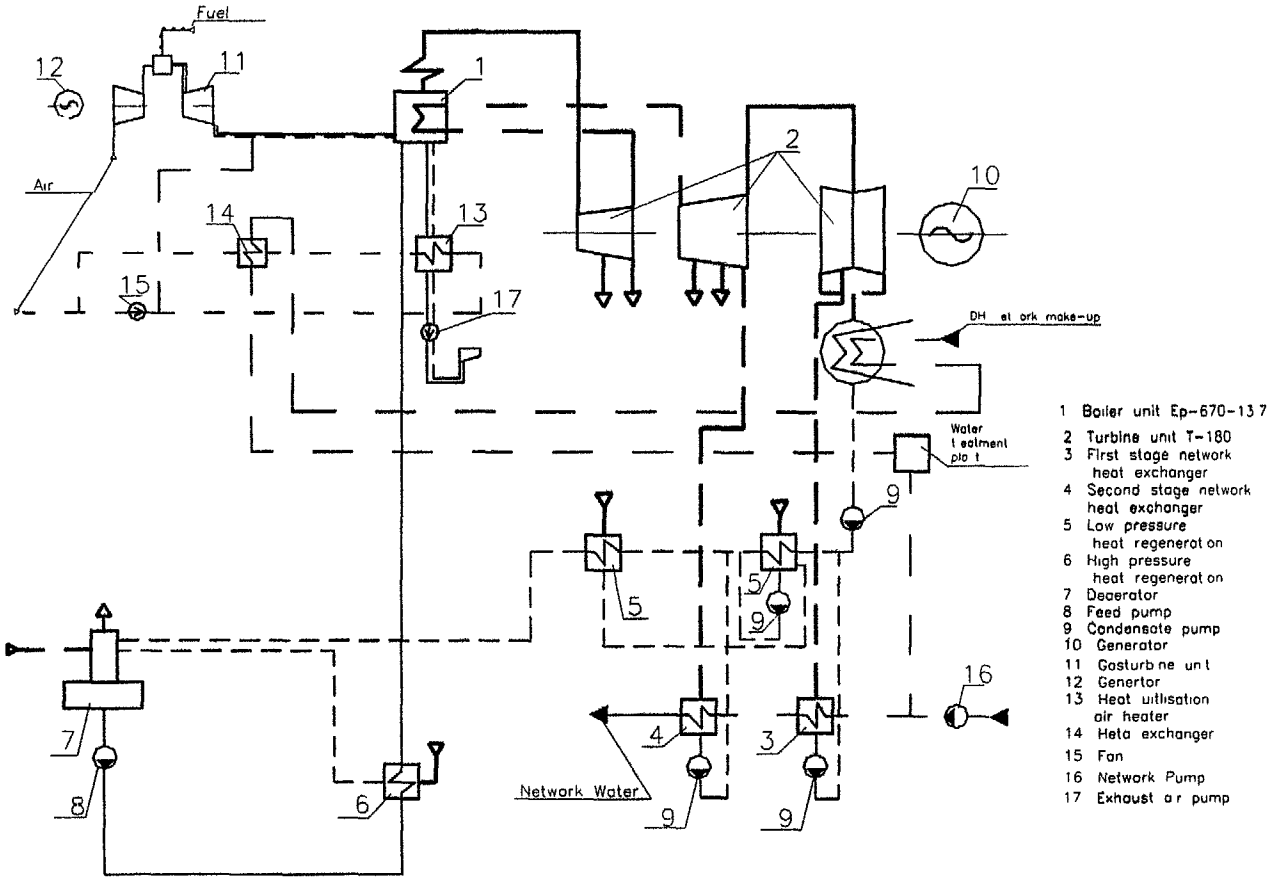


Figure 2.1 Schematic of Unit 1 of TETs-5 of AO "Lenenergo"

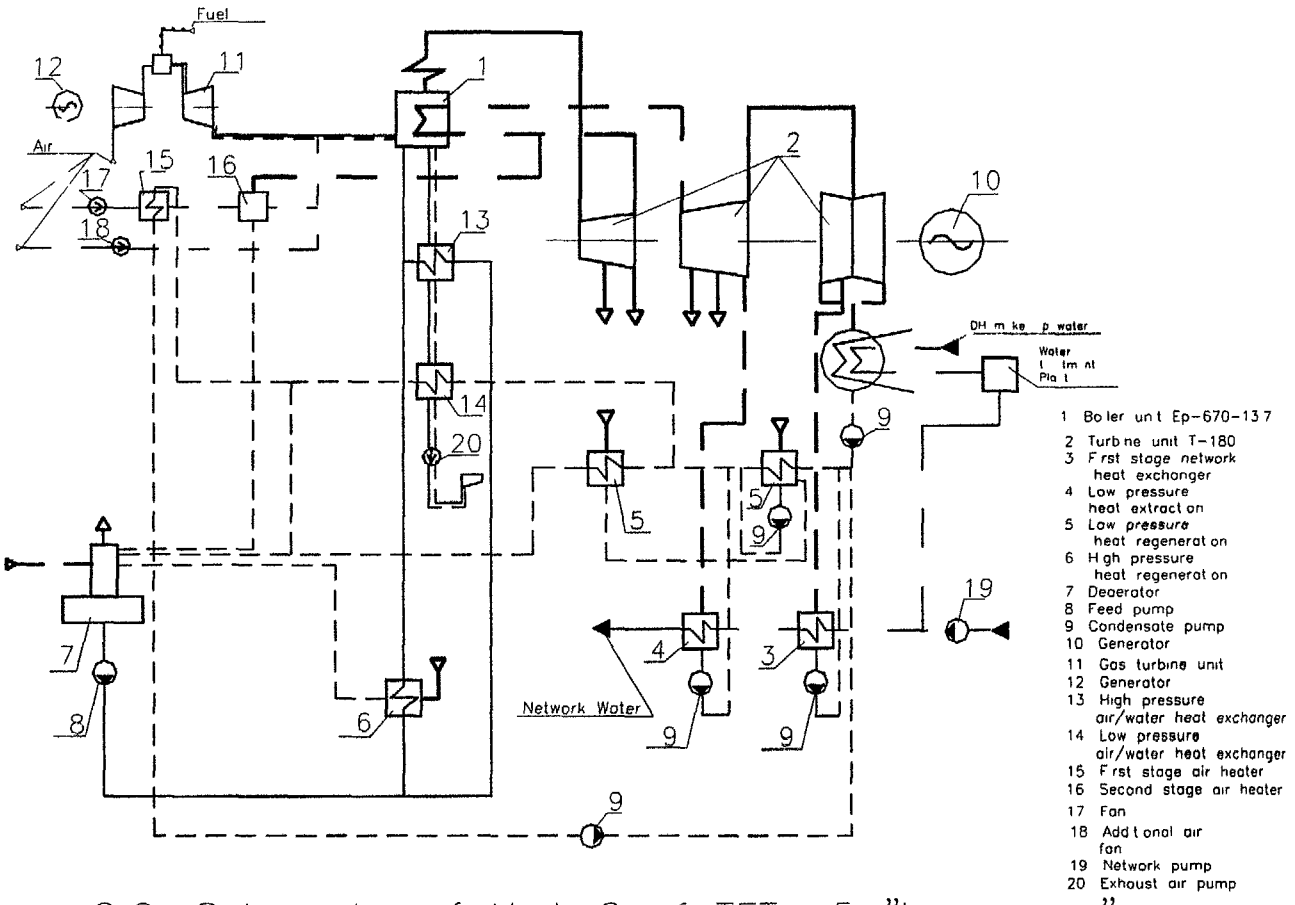


Figure 2 2 Schematic of Unit-2 of TETs-5 "Lenenergo"

1 NEW CHP PLANT WITH GAS TURBINE

1 1 Description of plant operation

The alternative is a steam turbine process with gas turbine Atmospheric air via air inlet comes into gas turbine's compressor, pressurises and comes into combustion chamber Combustion product gases are led into gas turbine, expand and rotate turbine with compressor and electrical generator After gas turbine combustion products go into the boiler In boiler the oxygen of the combustion gases is used in boiler's burning process It's possible to mix some excess air in the exhaust The high pressure steam generated in the boiler expands in the steam turbine and rotates the generator to produce electricity

After the steam turbine there is a condenser The district heating network water is heated in two steam extractions

There are two optional flow diagrams, which differ slightly as follows The flow diagrams of these two cases are presented in Appendix 1

In heat flow chart in Figure 2 1 there is a cogeneration cycle power plant with gas turbine exhausting in the boiler furnace without displacement of regenerative extraction of the steam turbine and with retention of a regenerative air heater The heat flow chart does not provide for reheat of auxiliary air, thus ensuring decrease in gas temperature at the boiler inlet For the recovery of heat of flue gases, air-to-water heat exchanger is used for the reheat of make-up water of the heat supply network by heat of excess air At the next stage, the complication of the heat flow chart is possible, by means of using air-to-water heat exchanger for re-heating make-up water or condense, as a result, economical efficiency in the condensation mode will increase

In Figure 2 2 there is a classical heat flow chart of a cogeneration cycle power plant with gas turbine exhausting in the boiler furnace, in accordance with such flow chart, provision is made for the replacement of regenerative air heater by gas-to-water heaters of high and low pressures, installed in the flue gas path of the boiler after the economiser and coupled to the water mains in parallel with the systems of regenerator of high and low pressures of the steam turbines The implementation of such flow chart involved the necessity of restriction of steam flow for the turbine defined by limited throughput of the seventh stage of the intermediate pressure cylinder (about 585

t/h) In the independent mode, air reheat is ensured by condense (the first stage) and cold-reheat steam (the second stage)

For both versions, the layout of the basic and auxiliary equipment in the main building of the cogeneration plant remains without any changes

1 2 Main design parameters of the power plant (outdoor temperature 0°C)

The basic design point is maximum heat load Outdoor temperature is 0°C and corresponding power is about 240 MW_e / 326 MW_{th}

The characteristic performance parameters for the gas turbine unit are

Electricity output, net	60	MW
Efficiency	34 3	%
Exhaust temperature	557	°C
Exhaust flow	184	kg/s

Characteristic parameters of the steam cycle are

Electricity output, net	180	MW
Pressure	128	bar
Temperature	540	°C
Steam flow	182	kg/s

Performance characteristics of the power plant performance are as follows The outdoor temperature is 0°C, district heating supply water temperature 90°C and return water temperature 50°C

Electricity output, net		
back-pressure	240	MW
condensing	270	MW
District heat output	326	MW
Pressure	128	bar
Temperature	540	°C
Steam flow	182	kg/s
Total efficiency	74 8	

242

1 3 Description of mechanical equipment

1 3 1 Boiler unit

Boiler Ep-670-13,7 is a circulation drum boiler Boiler consists of furnace and convection parts including steam re-heater, extraction steam re-heater and economiser Boiler is gas/oil-fired

Partial upgrading of the boiler unit will be required to the following extent

- partial upgrading of burning devises
- coupling of the exhaust gas duct to the boiler
- the same - in accordance with the system of exhaust of excess gases to the area of an economiser
- installation of air-to-water heat exchanger and coupling to the air and water mains
- partial upgrading of gas-air ducts of the boiler unit

Boiler unit includes steam drum, convection surfaces, air-blow and exhaust gas equipment, burners, framework, stairs, stages, piping, fitting, control and safety automation, casing, insulation ect

1 3 2 Steam turbine unit

Steam turbine is a back pressure turbine with intermediate steam reheat and condensing unit Network water is heated with extraction steam in two steps

The steam turbine plant consists of

- steam turbine and auxiliary equipment
  - back pressure steam turbine
  - district heat exchangers
  - principal control device and protective system
  - developed regeneration system
- generator
- sound insulating hoods for the steam turbine and generator

1 3 3 Automation

It has been planned that "ASU TP" automation control system will be used It provides technology for process control, data collection, saving and indication, protection as well as technical diagnoses, technical and economical indicators calculation, saving and processing

System includes computers with software, sensors, cables and other equipment

1 3 4 Electrical equipment

Electrical equipment includes all electrical equipment of power plant, including transformers, internal power plant switchyards for 0,4 and 6 kV, accumulators, switchyard, buses, power cables, electrical drivers ect

1 3 5 Other equipment

Fuel handling facilities

A compressor station for gas pressure raising from 12 bar to 25 bar is planned Also installing gas pipelines from main gas pipeline to compressor station and from compressor station to gas turbine unit including fittings, control and safety automation The volume of compressor station building is about 4000 m^3

An existing oil supply system is used The oil system requires small reconstruction Volume of the oil tank is 50 000 m^3 It is enough for 10 days use of the power plant

Reserve for diesel oil is not planned In case of the cut of gas supply power plant will operate in steam/power mode

Water treatment equipment

Primary water is supplied by city water line For leakage compensation (about 5% of steam production) water will be treated in a demineralisation plant

District heating water is not treated Cooling towers will be used in closed-loop condensing water cooling

Annual make-up water demand is about 25 10^6 m^3/a

Piping

CHP plant includes all pipeline system with shut-off control and safety fittings The volume of piping is sufficient for reliable operation of power plant

Auxiliary equipment

Auxiliary equipment are as follows feed water pumps, district heating pumps, condensate and other pumps, lifts, cranes, tanks, heat exchangers, backup boiler, pneumatic appliances, spear engine and maintenance workshop equipment and tools

Infrastructure

Existing district heating pipelines, electric networks and water supply network will be utilised

1 4 Construction works

Outside the power plant site the existing district heating pipes and water supply pipes will be used The main building of the power plant consists of machine room, de-aeration stack, boiler room, open type regenerative air heater as well as air blow and exhaust gas units The framework of the main building is made of steal

2 COMBINED CYCLE POWER PLANT

The combined cycle power plant is a condensing power plant with extractions The net output is 233 MW_e / 195 MW_{th} This natural gas fired combined cycle is based on LMZ's GTE-60 gas turbine process

Exhaust gases from the gas turbine are led to heat recovery boiler In heat recovery boiler the heat of the hot exhaust gases are used to generate steam for a steam turbine The electric power of the plant is produced in two generators Thermal energy for district heating is obtained on the heat exchangers of the steam turbine extractions and steam generator convection surfaces There is a condenser after the steam turbine The process values and flow diagram are presented in Appendix 1 2

The power plant can be run in two modes the back pressure operation and condensing operation When district heat load is in its maximum, thermal energy is obtained on both, the heat exchangers of the steam turbine extractions and boiler convection surfaces When district heat is not needed, the power plant runs in condensing mode and thermal energy is obtained only in heat recovery boiler convection surfaces The extraction steam is used in electric power production by condensing all the steam

2 1 Main design parameters of the power plant (outdoor temperature 0°C)

The basic design point is maximum heat load Outdoor temperature is 0°C and corresponding power is about 233 MW_e / 195 MW_{th}

The characteristic performance parameters for the combined power cycle with GTE-60 are

Net power, electrical	233	MW
Efficiency	87 0	%
Exhaust temperature	522	°C
Exhaust flow	549	kg/s

Characteristic parameters for the live steam from the steam generator are

Pressure	60	bar
Temperature	497	°C
Steam flow	65	kg/s
Feed water temperature	110	°C

Performance characteristics of the power plant are shown in Table 1. The outdoor temperature is 0°C, district heating supply water temperature 90°C and return water temperature 50°C

Table 1 Performance parameters of the combined cycle power plant

		Max back pressure operation	Max condensing operation
Electrical output, gross	MW	236	252
District heat output	MW	195	50/0
Fuel consumption	MW	492	492
Total efficiency	%	87 0	60 9

2 2 Description of mechanical equipment

2 2 1 Boiler unit

The boiler plant includes one boiler, which consists of five adjacent heat exchanger packages From hotter to cooler exhaust gases the heat exchangers are as follows two superheaters, evaporator, economiser and district heat exchanger

The expenses of the boiler plant include the steam drum, circulating pumps and steel chimney and their framework and foundations

2 2 2 Steam turbine unit

The steam turbine is a condensing turbine with three extractions The district heating water for is heated with two steam extractions On of the extractions is used for de-aeration

The steam turbine plant consists of

- steam turbine and auxiliary equipment

  - condensing steam turbine
  - district heat exchangers
  - principal control device and protective system
- generator
- sound insulating hoods for the steam turbine and generator

2 2 3 Gas turbine unit

One gas turbine type of ABB GT 13E2 is included in the power plant Natural gas is the main fuel, but also light fuel oil can be used as a reserve fuel The gas turbine unit consists of

- the gas turbine with axial compressor
- auxiliary equipment
- generator
- turbine control system
- air intake system
- sound insulating hoods for the steam turbine and generator

Sulphur is not a problem as a contaminant, when burning natural gas The emission level of NO_x is reduced onto level 60 $mgNO_2/MJ$ by using low-NO_x burners

2 2 4 Automation

Automation includes measuring instruments and control and monitoring devices installed It also includes the cable works and the operator's room equipment Power plant data processing equipment and software are included as well

2 2 5 Electrical equipment

Electrification costs include all electrification related to the process, such as power transformers, switchboards, buses, high-voltage power cables, electrical motor for feed water pump and switchyard

2 2 6 Other equipment

Fuel handling facilities

In the pressure reduction station the pressure of gas is reduced to 22 bars for gas turbine and to 5 bars for auxiliary burners Gas is led from the pressure reduction station to the gas turbine and auxiliary burners in stainless steel pipe

The reserve fuel is light fuel oil For fuel storing there's a fuel reservoir tank in the power plant area

Water treatment equipment

Power plant process water from the public water distribution network is used as feed water It is treated in the demineralisation plant The water treatment equipment include also a condensate polishing plant and district heating water treatment equipment

In the steam generator there is a water loss of 2% of live steam stream The existing cooling towers will be used in closed-loop condensing water

Piping

Piping includes the high and low pressure steam pipes, natural gas pipes, insulation and fixtures Also district heating networks and the connection to the present system are included

Auxiliary equipment

Auxiliary equipment are as follows feed water pumps, district heating pumps, condensate and other pumps, lifts, cranes, tanks, heat exchangers, backup boiler, pneumatic appliances, spear engine and maintenance workshop equipment and tools

Infrastructure

Existing district heating pipelines, electric networks and water supply network will be utilised

2 3 Construction works

Construction works include foundation, construction works with all material and lightning needed, water supply and sewer system, fire alarm and sprinkler system as well as a telecommunications network

The main building of the power plant is made of steel constructions The building includes the boiler room, turbine room, control room, electrical equipment room, water treatment room and condense treatment rooms and condense pumping plant The office premises, rooms for personal, repairshop and store-house are located in the present buildings

Earth-removing costs include excavation and earth removing, rain water sewerage, drain work, road and yard constructing, asphalt and grass work, fences and power plant yard area lightning

2 4 Design and supervision

2 4 1 Design

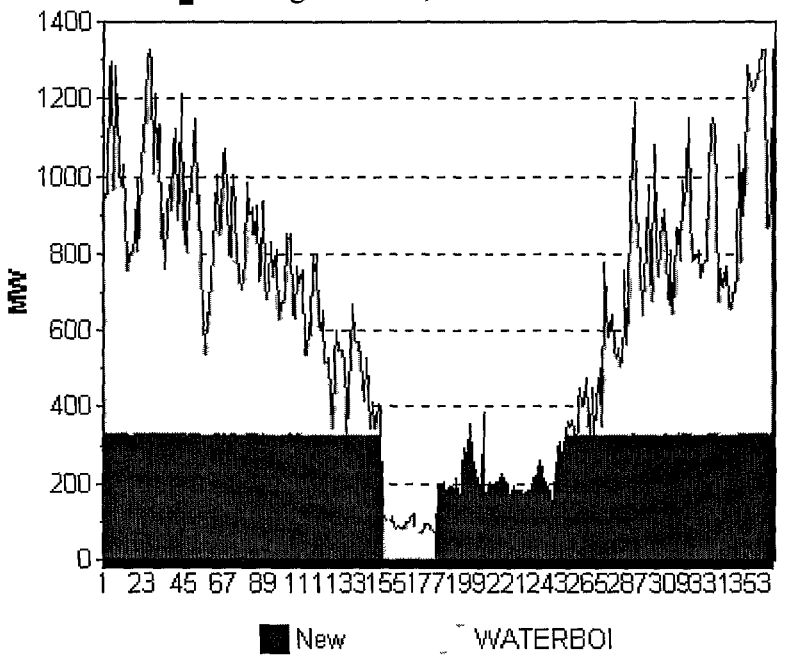
Design includes power plant site geological study and general-, process-, architectural-, electrical-, automation- and mechanical construction planning and design Contract document arrangements and cost-, time schedule and delivery supervision are also included

2 4 2 General and site costs

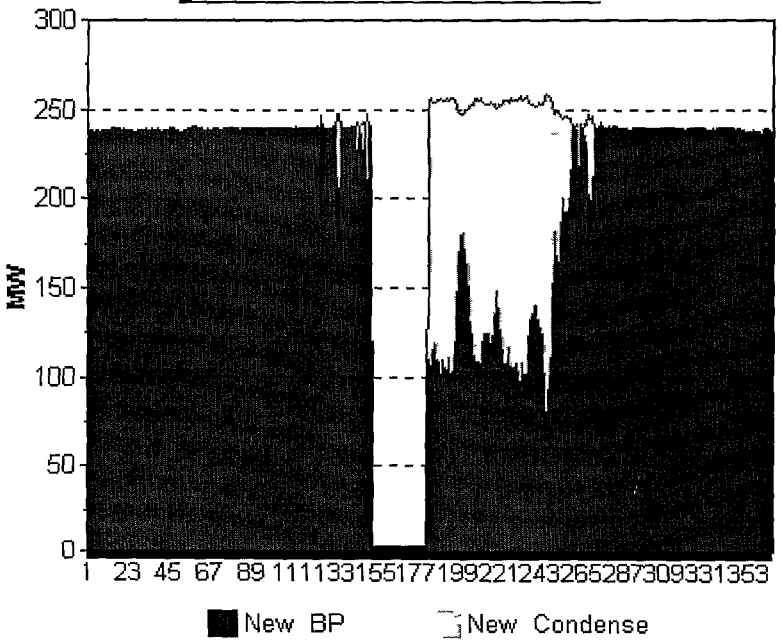
Site costs include supervision of construction work and installation of equipment, general management of construction site, time schedules, maintenance during construction works, electric and heat supply of the site and melioration works Supervision of temporary buildings and construction is included as well

General costs include project management costs, settlement of orders, licences of the authorities and public relations during construction works Acceptance and testing of the power plant are also included

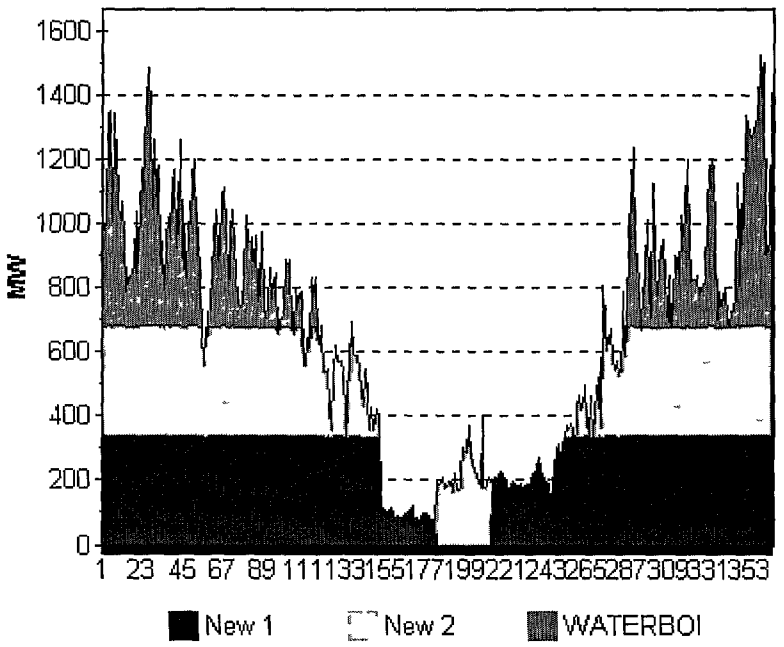
VARIATION CURVE OF HEAT
Existing situation, heat load 4000 GWh



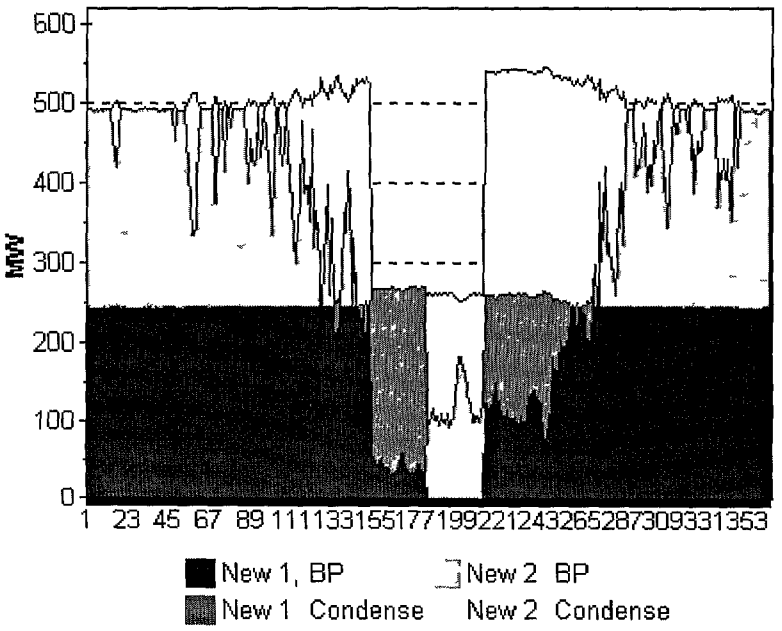
VARIATION CURVE OF POWER
Existing situation, heat load 4000 GWh



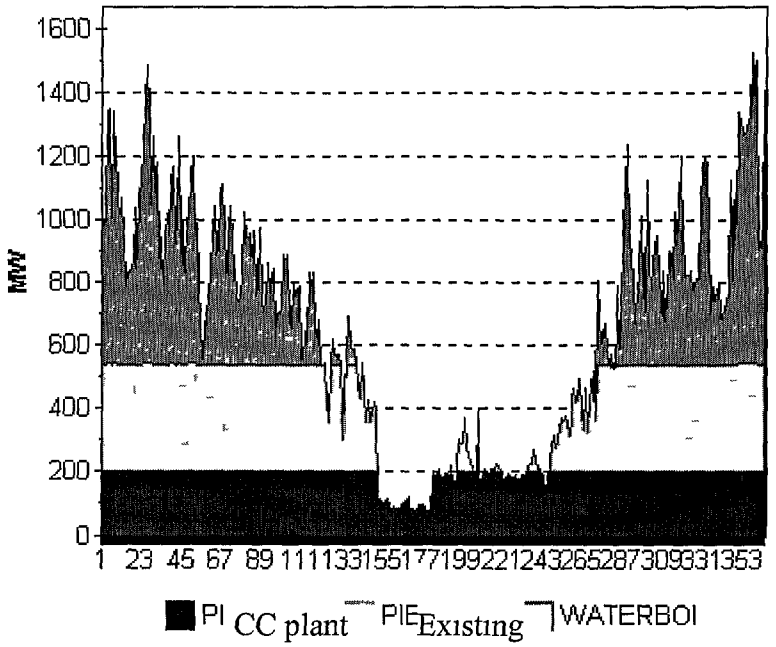
VARIATION CURVE OF HEAT
CHP + GT 249/330 MW, heat load 4000 GWh



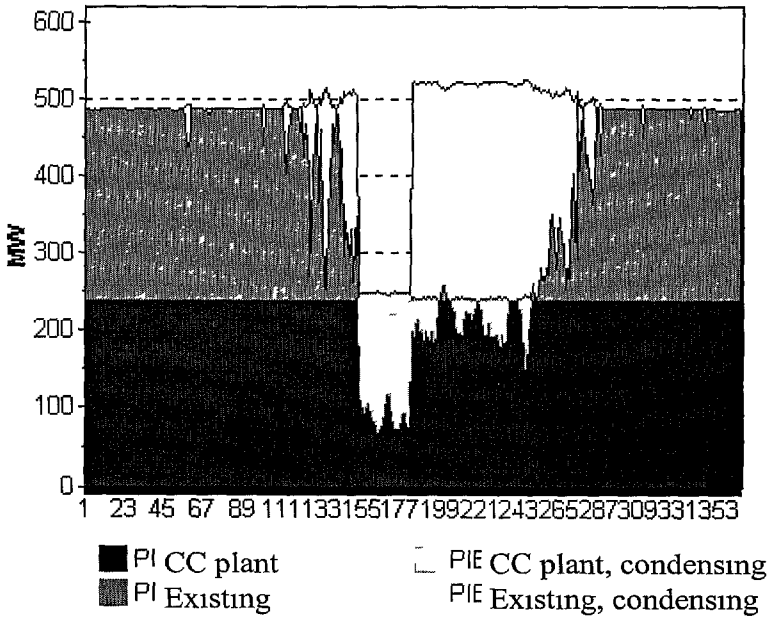
VARIATION CURVE OF POWER
CHP + GT 249/330 MW, heat load 4000



VARIATION CURVE OF HEAT
Combined-cycle, heat load 4000 GWh

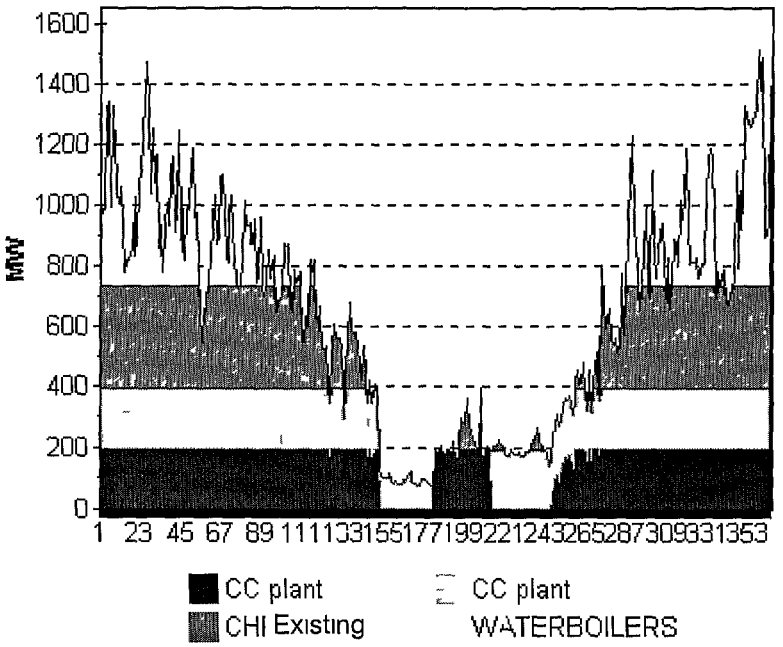


VARIATION CURVE OF POWER
Combined-cycle, heat load 4000 GWh



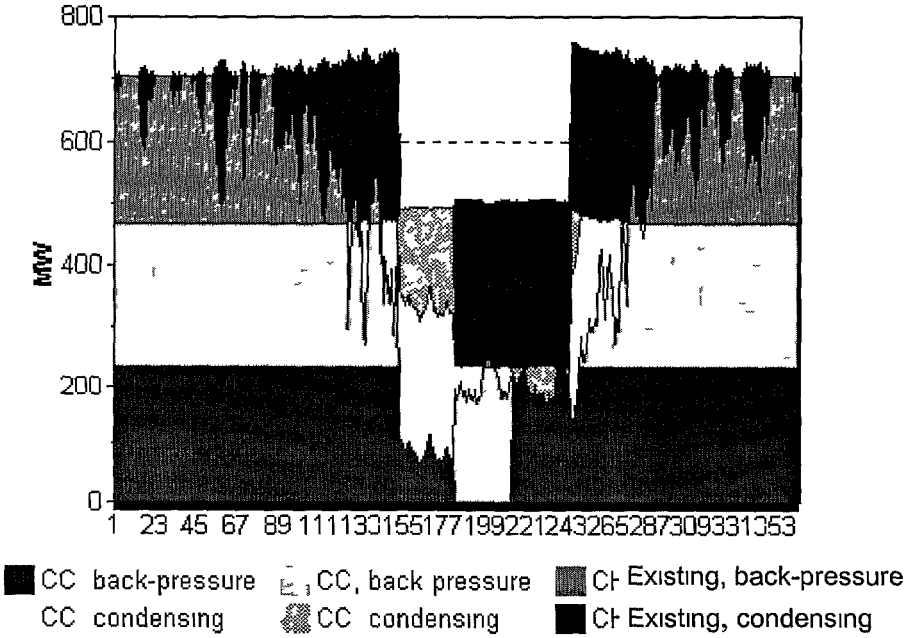
VARIATION CURVE OF HEAT

2 x combined-cycle, heat load 4000 GWh



VARIATION CURVE OF POWER

2 x combined-cycle, heat load 4000 GWh



Summary of power and heat production
Total heat load 4000 GWh

	Existing CHP + GT	2 x CHP + GT	Combined cycle	2 x combined-cycle
Capacity				
- power, back pressure MW	240	480	473	706
- power, condensing, MW	270	540	520	770
- district heating back pressure, MW	326	652	521	716
Power production				
Old units				
- back pressure GWh	1702 3	1204 5	1418 7	980 8
- condensing GWh	248 6	805 7	565 5	1056 8
- total, GWh	1950 9	2010 2	1984 2	2037 6
New unit				
- back pressure, GWh	0	1641 3	1732 6	3267 9
- condensing GWh	0	309 8	145 3	501 7
- total GWh	0	1951 1	1877 9	3769 6
Total, GWh	**1950 9**	**3961 3**	**3862 1**	**5807 2**
Extra production GWh		2010 4	1911 2	3856 3
back pressure, GWh	1702 3	2845 8	3151 3	4248 7
- extra production, GWh		1143 5	1449	2546 4
District heat production GWh				
Old units	2348 2	1689 3	1976 2	1387 8
New unit	0	2273 3	1460 3	2755 9
HOB	2237 4	623 1	1149 1	441 9
Total	**4585 6**	**4585 7**	**4585 6**	**4585 6**
Fuel cost, USD/MWh	7 27	7 27	7 27	7 27
Fuel, GWh/a				
HOB	2461 1	685 4	1264 0	486 1
Old units	5006 6	4992 7	5007 0	5006 9
New units	0 0	5006 9	4039 5	8080 2
Fuel, total GWh	**7467 7**	**10685 0**	**10310 5**	**13573 2**
Fuel, back pressure, GWh/a				
HOB	2461 1	685 4	1264 0	486 1
Old units	4459 7	3187 9	3717 7	2597 4
New units	0 0	4309 8	3602 1	6763 2
Fuel, back pressure, GWh/a	**6920 8**	**8183 2**	**8583 8**	**9846 7**

YEARLY COSTS AND INCOME

Power plant		Present	New CHP with GT	CC	2 x CC
- electricity output (yearly average)	MW	239 6	239 6	233 2	466 4
- heat output (yearly average)	MW	326 0	326 0	195 0	390 0
- fuel input (+0 C outdoor temp)	MW	825 0	825 0	492 0	984 0

Input data

Power plant life time	year	25	25	25	25
Real interest	%	8%	8%	8%	8%

Energies and production costs

- fuel input energy	GWh	7467 2	10685 2	10311 6	13573 8
- fuel costs	$/MWh	7 3	7 3	7 3	7 3
- heat energy	GWh	4584 3	4585 6	4585 6	4585 6
- heat energy production cost	$/MWh	7 9	*7 9*	*8 1*	*8 2*
- electricity	GWh	1950 9	3961 4	3862 1	5807 0
- electricity production cost	$/MWh	9 2	*10 5*	*9 9*	*10 5*

Prices

Heat					
- capacity fee	$/MW,a				
- energy price	$/MWh	9 0	9 0	9 0	9 0
Electricity					
- capacity fee	$/MW,a				
- energy price	$/MWh	24 5	24 5	24 5	24 5

COSTS

Investments

Power plant investment	M$	120	240	243	366
Connection costs	M$	0	0	0	0
Heat only boilers	M$	41	30	34	27
investment costs together	*M$*	*161*	*270*	*277*	*393*

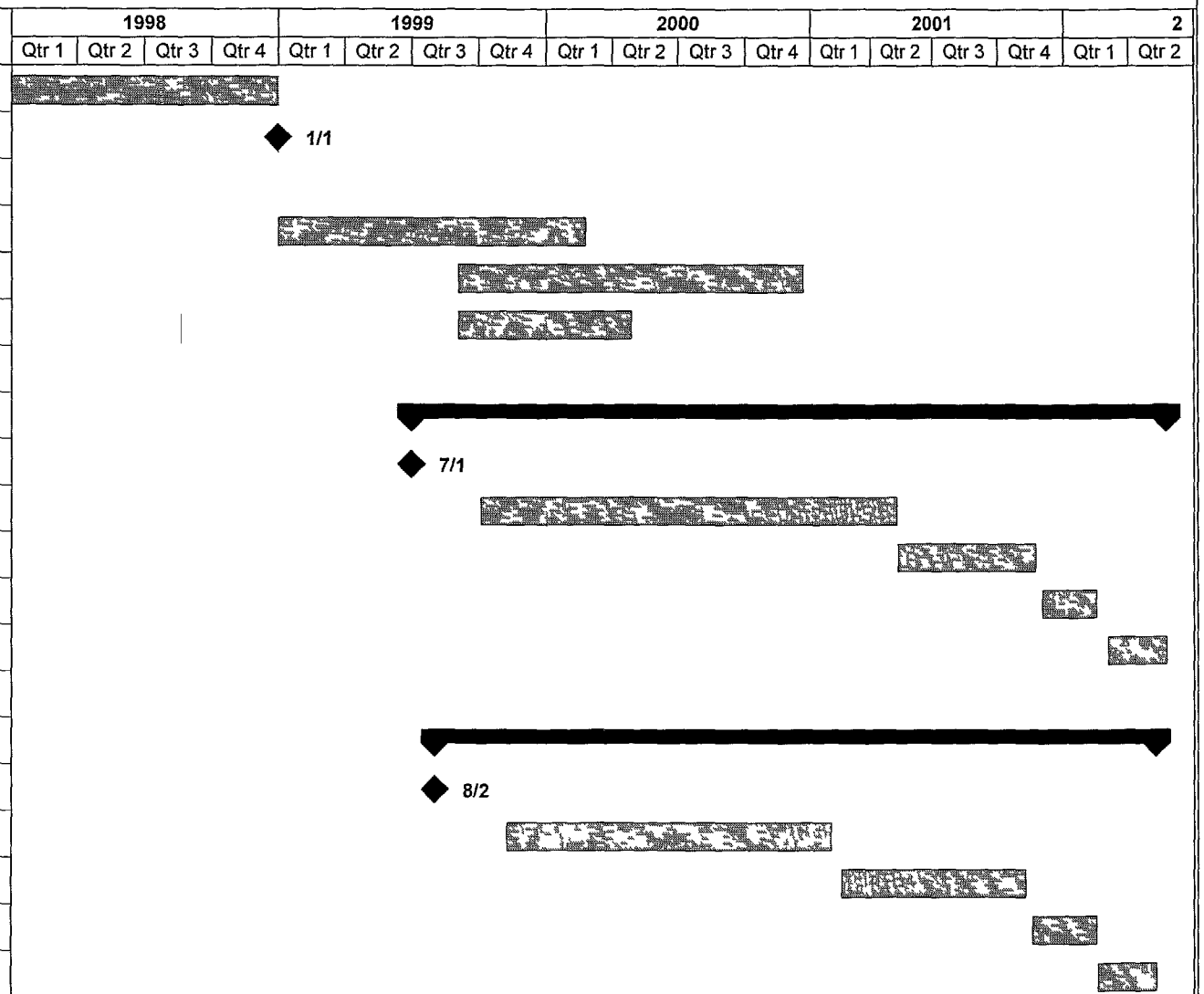
Fixed costs

Personnel costs	M$/a	1 8	1 8	1 8	1 8
Fixed maintenance costs	M$/a	2 4	4 8	4 9	7 3

Fixed costs together	*M$/a*	*4 2*	*6 6*	*6 7*	*9 1*
Variable costs					
Electricity production costs	M$/a	18 0	41 6	38 1	61 2
Heat production costs	M$/a	36 3	36 1	36 9	37 4
Variable maintenance costs	M$/a	5 4	7 8	3 7	7 3
Variable costs together	*M$/a*	*59 7*	*85 4*	*78 6*	*106 0*
TOTAL COSTS	**M$/a**	**63 9**	**92 0**	**85 3**	**115 1**
INCOME					
Heat selling					
Heat capacity fee income	M$/a	0 0	0 0	0 0	0 0
Heat energy income	M$/a	41 3	41 3	41 3	41 3
Heat sales altogether	*M$/a*	*41 3*	*41 3*	*41 3*	*41 3*
Electricity selling					
Electricity capacity fee income	M$/a	0 0	0 0	0 0	0 0
Electric energy income	M$/a	47 8	97 1	94 6	142 3
Electricity sales altogether	*M$/a*	*47 8*	*97 1*	*94 6*	*142 3*
TOTAL INCOME	**M$/a**	**89 1**	**138 3**	**135 9**	**183 5**
PROFIT	**M$/a**	**25 2**	**46 3**	**50 6**	**68 4**
NET PRESENT VALUE	**M$**	**107 5**	**224 6**	**262 7**	**337 2**
PAY-BACK TIME	**a**	**9 3**	**8 2**	**7 5**	**8 0**
INTERNAL RATE OF RETURN	**%**	**15 16%**	**16 82%**	**17 95%**	**17 06%**

Power Plant Extension of St Petersburg
Implementation Plan

ID	Task Name
1	**Feasibility study and pre-design**
2	**Implementation decision**
3	
4	**General planning**
5	**Plant design**
6	**Architectural design**
7	
8	**Procuring of gas turbine**
9	Purchase order
10	Manufacturing
11	Assembly
12	Implementation, GT + HRB
13	Test runs
14	
15	**Procuring of HRB**
16	Purchase order
17	Manufacturing
18	Assembly
19	Implementation
20	Test runs

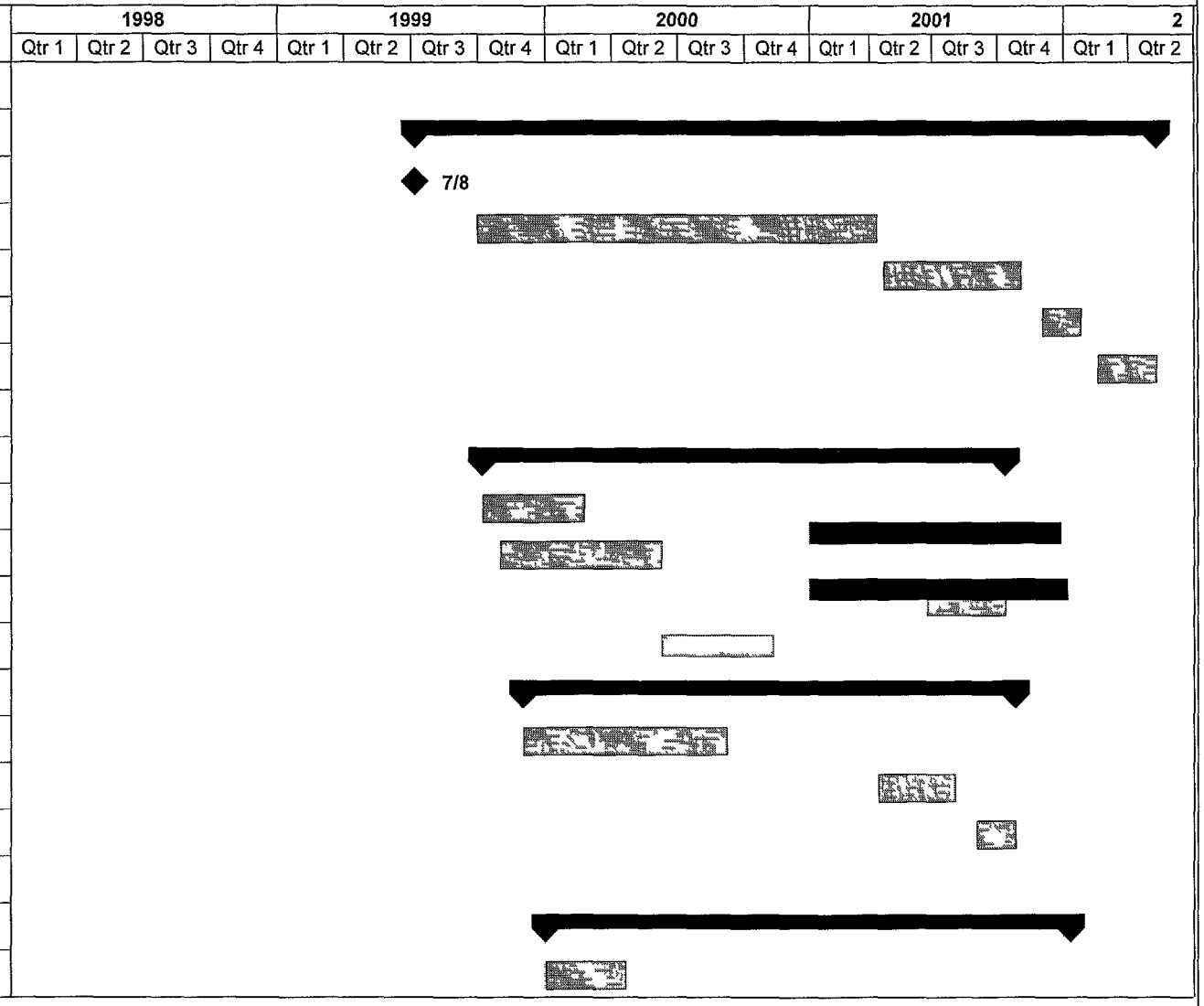


Project Append6 MPP
Date Fri 7/24/98

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

Power Plant Extension of St Petersburg
Implementation Plan

ID	Task Name
21	
22	**Procuring of steam turbine**
23	Purchase order
24	Manufacturing
25	Assembly
26	Implementation of CC plant
27	Test runs
28	
29	**Pipes**
30	Valves
31	Pipes
32	Insulation
33	
34	**Auxiliaries**
35	Deliveries
36	Assemblies
37	Implementations
38	
39	**Automation**
40	Automation system



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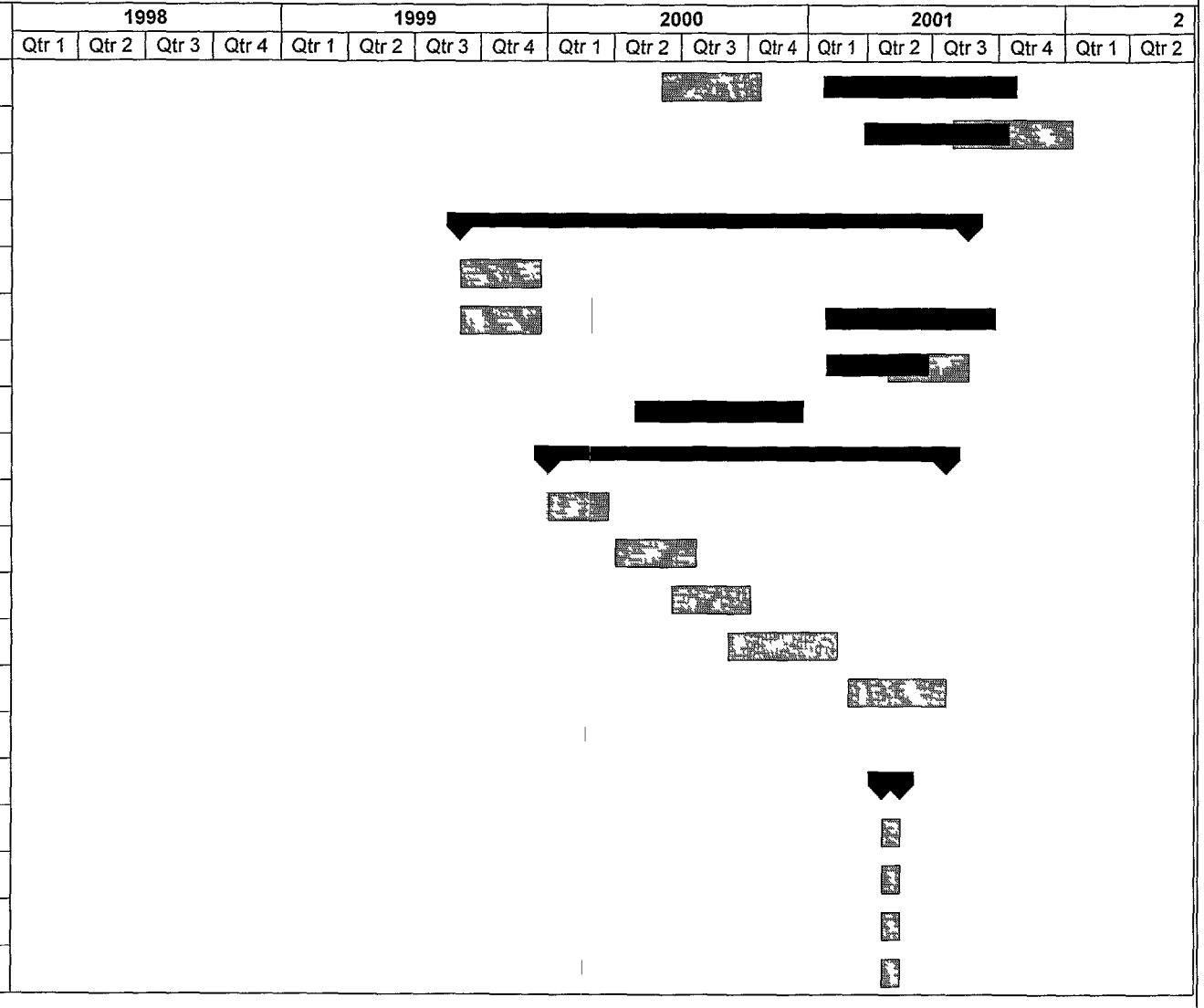
Date Fri 7/24/98

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

Power Plant Extension of St Petersburg
Implementation Plan

APPENDIX 6

ID	Task Name
41	Equipment
42	Test and implementation
43	
44	**Electrification**
45	Transformers and gear plant
46	High voltage eqipments
47	Electrification and cable
48	
49	**Construction**
50	Earth moving and pile work
51	Foundation
52	Foudations for equipments
53	Construction
54	Regional works
55	
56	**Connections**
57	Electricity
58	District heating network
59	Water
60	Natural gas



Project Append6 MPP
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Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress