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Performance analysis of WWER-440/230 nuclear power plants

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FOREWORD

The performance of nuclear power plants is a very important subject which involves various fields: safety, economics, service rendered to the electrical system, environmental impact, radiological protection and personnel safety.

Much of the debate in the past few years on the nuclear power sector in eastern Europe and the former Soviet Union has centered on safety and little attention has been paid to the apparent excellent reliability of some of the designs.

This report examines one particular design, the WWER-440/230, the first generation of commercial WWERs, essentially comparable to the western PWR. This design was installed widely in eastern Europe with a total of 16 units being completed in what are now Armenia, Bulgaria, Germany (the former German Democratic Republic) the Slovak Republic and Russia. The plants in Armenia and Germany (the former German Democratic Republic) have been closed down, but particularly in Bulgaria and to a lesser extent the Slovak Republic the remaining plants supply a significant proportion of the electricity of the country and decisions to close them could not be taken lightly.

The aim of this report is twofold: first to determine whether the impression given by these good overall performance indicators is confirmed using more detailed indicators covering a wide range of factors; second, to see to what extent good performance can be attributed to the industrial and institutional environment in which these plants were designed, built and operated. Particular attention is paid to identifying factors that may impact the quality of the service provided, especially those factors under management control which can be strongly influenced by current and future policy changes and those factors that are beyond the plant management control but could have influenced the performance of the power plants. Issues concerning the safety of these plants are of considerable importance, but they remain outside the scope of this report. Conclusions and recommendations formulated by the IAEA related to WWER safety are contained in the series of reports prepared in the framework of the Extrabudgetary Programme on WWER Safety. A programme progress report was published in 1994 (IAEA-TECDOC-773).

Extensive use of the IAEA Power Reactor Information System (PRIS) has been made to determine the availability of the nuclear power plants and the major causes of unavailability.

For the countries of eastern Europe and the former USSR, the information in this report is intended to allow skills which have proved valuable and systems which have proved effective to be identified and preserved. For the western European countries, North America and Japan, this is intended to allow programmes of assistance to be directed where they are most needed. There may be also lessons which can be learned which will improve the economic and technical performance of future plants worldwide.

This report serves as a starting point that can be developed and extended to other plants in this region and to other sets of plants in different regions, with the aim of identifying where assistance can be most effective to ensure that existing strengths are not lost and to help identify areas to reinforce.

This TECDOC is the result of a series of advisory and consultants meetings held by the IAEA in Vienna in 1991-1994. It was prepared with the participation and contributions of experts from Bulgaria, Finland, France, Germany, Hungary, Italy, the Russian Federation, the Slovak Republic, the United Kingdom and the United States of America.

Special thanks are due to R. Mussapi of ENEA/ANPA, Italy, and S. Thomas of the University of Sussex, UK, who edited the report. Ms. R. Spiegelberg-Planer from the Nuclear Power Engineering Section, IAEA, is the officer responsible for preparing this report.

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SUMMARY

The WWER-440/230 was the first commercial model of the Soviet WWER design of nuclear power plant. A total of 16 plants of this design were constructed, installed in Russia, the former Czechoslovakia, Bulgaria, Armenia and the former German Democratic Republic. While this design has attracted adverse comment because of the absence of some safety features considered essential, simple analyses of operating performance has suggested that they continue to be highly effective as reliable generators of power.

This report has two main objectives: first to establish whether the conclusions of the simple performance analyses are confirmed by more detailed and wide-ranging analyses; and second to determine what factors, particularly those related to the industrial and institutional structure that underpinned their development, were important in determining their success. This will help to identify skills and structures with valuable features which should be taken account of in programmes of assistance to the former Soviet Union and eastern Europe. Issues surrounding the safety of these plants are of considerable importance, but they remain outside the scope of this publication. Conclusions and recommendations formulated by the IAEA related to WWER safety are contained in the series of reports prepared in the framework of the Extrabudgetary Programme on WWER Safety. A Programme progress report was published in 1994 (IAEA-TECDOC-773) including a comprehensive list of references.

The development of civil nuclear power in the former Soviet Union was driven by the need to provide an additional source of primary energy for electricity generation. The provision of adequate supplies of electricity to the whole of the Council for Mutual Economic Assistance (CMEA) region was seen as an essential element in ensuring the economic success of the region, particularly in the east European countries which had limited fossil fuel resources. This incentive was sharpened by the first oil crisis which seemed to demonstrate the need to reduce dependence on fossil fuels.

Nuclear power technology was also seen as part of the technological competition with the West[1]. Thus, while there are major differences between US and Soviet nuclear technology, significant events in the West seemed to have echoes in the former Soviet Union. For example, the completion of the Shippingport reactor, the order for Oyster Creek and the growth of safety regulations in the 1970s in the USA were paralleled by comparable events in the former Soviet Union. The ultimate former Soviet Union's objective may have been to develop a technology which could be sold on world markets.

The nuclear programme was presented as a venture in which the whole of the CMEA region could participate and this was reflected in the proliferation of international committees and commissions. In practice however, all key developments in terms of research and development and design took place within the republics of the former Soviet Union, primarily in Russia. Only when the technology had been fully proved were the east European partners allowed any role. Amongst the former Soviet Union's east European partners, there was variation in the extent to which they could participate. For example, the former Czechoslovakia which has a long tradition of power engineering was able to manufacture some components and could specify minor design features, while Bulgaria could do little more than choose the sites. Despite this limited role, in the east European countries with nuclear power programmes, nuclear became a more significant component of electricity generation than in the former Soviet Union.

Development of the WWER was only one part of an overall strategy in which two types of reactor, the WWER and the RBMK were initially developed with an expectation, shared in the West,

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[1]The term "West" is used in this publication to denote countries outside the former CMEA region.

that the fast reactor, which was much less dependent on the exploitation of large reserves of uranium, would take over. Again, as in the West, the technologies chosen had military origins, marine propulsion in the case of the WWER and plutonium production in the case of the RBMK.

Initial development of the WWER was slower than for the RBMK, mainly for practical reasons such as the difficulty of transporting large WWER components and the ease of fabricating RBMK components. However, the military sensitivity of RBMK technology meant that the WWER was much more suitable for export to the east European partners. In addition, the increasing dominance of the PWR in the West may have also served to increase attention on the similar WWER.

In the development of the WWER, the key site was Novovoronezh, where nearly all the prototypes and first-of-a-series plants were built. Novovoronezh was also a centre of WWER expertise with the training centre being located there.

The system for R&D, design and construction was highly centralized around the key Soviet ministry, Minenergo - the various reorganizations and renamings did little to weaken this structure. The key research institutes reported directly to this ministry which not only owned and operated the plants, but was also in a position to specify the manufacturing facilities required. This situation was in contrast to most countries in the West where plant developers, designers and manufacturers were generally remote from each other and from the final user. The central role of the users may have led to a design that was more closely oriented towards the needs of the user and may have increased the extent to which operating experience could be built on.

The centralization through Minenergo (in its various guises), that is a strong feature of the other aspects of the Soviet nuclear power programme, is also reflected in the day-to-day management of the plant. Any important events are fed directly to the centre for dissemination to other plants. Clear objectives and goals on performance and costs are set in consultation with the central authorities and performance in meeting these goals is rigorously evaluated.

Soviet-designed nuclear power plants, specially those in the former Soviet Union, are very much more labour intensive than those in the West and all have required the construction of large towns, under the control of the nuclear power plant management, just to support them. The dependence of this community on the plant places a particular responsibility on the plant staff to operate the plant effectively.

A detailed analysis of performance using a range of performance indicators and comparing the plants with other relevant groups of nuclear power plants largely confirms the conclusions of previous analyses that the WWER-440/230 compares favourably with other groups of nuclear power plants worldwide. The absence of any decline in performance following the Chernobyl accident and the opening up of plant in this region to western scrutiny, suggests that high availability was not made possible simply by low safety standards in the area. There is little evidence that performance is yet being adversely affected by ageing.

A distinctive feature of the performance of these plants as compared to those in the West is the high proportion of down-time that is accounted for by planned rather than unplanned events. Other performance indicators, such as those developed by WANO, are not available in sufficient detail and for long enough time periods for any strong conclusions to be drawn.

The main factors that emerge which seem to explain the high performance of the WWER-440/230 plants are centralization and the strong powers granted to those involved in the development, construction and operation of this type of plant and the high priority that the former Soviet Union attached to the successful development of nuclear power at the time of its design.

These two factors meant that highly qualified personnel could be attracted and retained for all important tasks and high quality materials were made available. Centralization also led to a system in which there were few institutional barriers to the collection and dissemination of operating experience. However, centralization also led to a lack of plurality which meant that plant designers were able to carry through their design vision with little need to make compromises to accommodate the views of others. Whilst this gave good results with the first generation of WWERs, the dangers in such a strategy were illustrated by the failure to act on the design weaknesses inherent in the RBMK.

The impact of two other factors, standardization, and size and complexity is less clear cut. Centralization inevitably tended to lead to some degree of standardization although this was not carried through to the same extent as with the French nuclear power programme. Nevertheless, the uniformity of performance levels achieved, despite the fact that the plants were installed in several countries, does suggest that standardization was a significant force in improving standards of design, manufacturing and construction. The impact of size and complexity is an issue that is unresolved for the West. The observation in the West, that smaller earlier designs of plant work better than larger newer ones is repeated in the former Soviet Union and eastern Europe. However, it is still not clear to what extent this arises because the plants are small, or they are less complex, because they incorporated fewer engineered safety systems. In addition, early plants might perform better because when they were designed, nuclear power was a new exciting technology able to attract the best resources for their design and manufacture.

1. INTRODUCTION

The performance of nuclear power plants is a very important subject. It has relevance to safety, economics, service rendered to the electrical system, environmental impacts, radiological protection and personnel safety. This report examines the performance of the first generation of the Soviet designed PWR, the WWER-440/230. The main objectives are to determine how well this group of plants has performed and to identify factors that have contributed to this. While the analyses may be able to contribute in part to reviews of their safety and their economics, it must be emphasized that no attempt is made in this report to draw conclusions on these subjects.

Sixteen plants of the WWER-440/230 design were built, completed between 1972 and 1982. These are located in the former Soviet Union (in Russia and Armenia), the former GDR, the former CSFR (the Slovak Republic) and Bulgaria. The plants in the former GDR were closed in 1989 and 1990, respectively, and are not analyzed in detail in this report. A successor design, the WWER-440/213, of the same size was produced, the first entering service in 1981 in the former Soviet Union, differing mainly in the safety systems it had (for example, it included a more developed confinement structure and a full-scope emergency core cooling system). A further 14 plants of this later design have been placed into service, in the former Soviet Union (in Russia and the Ukraine), the former CSFR (the Czech Republic and the Slovak Republic) and Hungary.

Two further plants using the basic WWER-440 design, but with western designed containment and instrumentation, were built in Finland entering service in 1977 and 1981. These are not strictly of either the WWER-440/230 or the WWER-440/213 design but since they represent a modification and updating of the model 230, for the purposes of analysis, they are categorized as of the model 213 type.

The Chernobyl accident, involving a RBMK reactor type, and weaknesses in the operation and maintenance of some of these plants identified during IAEA missions has given all nuclear power plant in eastern Europe and the former Soviet Union a poor reputation in the West. There has been particular concern about the safety of the first generation design of WWER and, in some cases, pressure to close these plants because their safety provisions do not correspond with those usually found in western plants.

However, much less well-known is that early analyses of the operating performance examining the energy availability of the WWER-440/230 plants based on data relating to a few years from 1987 onwards showed that they compared very favorably with plants in the West. This high level of performance was maintained and sometimes exceeded in plants of the second generation design (model 213) and also those installed in Finland.

The analysis described in this report therefore has three main aims:

- to describe fully the performance of the WWER-440/230 plants over a longer period, from commissioning to the end of 1992, than was previously possible using as wide a range of indicators as can be gathered;

- to review the industrial and institutional structure, and the political background in which these plants were designed, built and operated;

- and to determine how and to what extent this institutional environment influenced the levels of performance achieved.

Particular attention is paid to identifying which factors are under management control and which can be strongly influenced by current and future policy changes and those factors that are not under management control because they are intrinsic to the design or were determined by the construction process or by earlier operation.

In order to do this, the IAEA's PRIS database has been used, adding data from early years that have not been previously published. Internationally accepted performance indicators, such as those used by WANO, provided by each operator of WWER-440/230 plants to the IAEA under the auspices of the expert group involved in this research, have also been used. Information on the institutional structure has been assembled from a review of published sources widely available in the West and from the expert group comprising representatives from the relevant countries with first-hand experience of the operation, regulation and management of these plants.

From this analysis it is hoped to establish whether earlier analyses based on a restricted sample of data, which showed good operating performance, are confirmed over a longer period and with a wider range of indicators. In addition to establishing the overall long-term values of these indicators, it has been examined how major contemporary events have affected the way the plants have been operated and whether these changes have influenced operating performance. Such events include changes during the last decade in the political situation in eastern Europe and the former Soviet Union culminating in the dissolution of CMEA and the Warsaw Pact, the Chernobyl accident, the worsening economic situation of the countries and the opening up of the plants to western scrutiny.

It has proved difficult to build a complete and widely agreed picture of the evolving institutional structure because of the long period of time examined and the lack of complete and freely available documentation. Nevertheless, an attempt was made to identify the strengths and weaknesses of the structure. Particularly for the factors that are under management control, this should allow attempts to assist these countries to be carefully targeted so that existing strengths can be maintained and built upon and any weaknesses remedied.

The structure of the report is as follows. In the following chapter, the energy policy context is described. Chapter 3 examines in greater detail the strategies adopted for the three main nuclear technologies developed by the former Soviet Union, the RBMK, the fast reactor and particularly the WWER. Chapter 4 looks at the industrial infrastructure that was deployed to design, build and operate the plants. Chapter 5 examines the operating procedures at the plant looking especially at how and where key decisions were taken and how significant information on operating experience was dealt with.

Chapter 6 presents the detailed analysis of operating performance, placing the performance of the WWER-440/230 plants in the context of the closely related WWER-440/213 and of nuclear power plants world-wide. It also identifies whether there are any major time trends, perhaps related to external events or to ageing in the performance data. Chapter 7 attempts to draw connections between the institutional and political background and the analysis of operating performance in order to identify the main factors that have contributed to the operating performance achieved.

This report has relevance to a number of groups. For WWER-440/230 plant management, it allows the performance of their plant to be put in perspective with the performance of the other plants of this design and of nuclear power plants world-wide. From this it may be possible to determine which aspects of plant operating policy are already strong and to identify opportunities to improve performance.

For policy-makers in eastern Europe and the former Soviet Union and also for those in the West trying to direct assistance to these plants, the analysis may help identify where assistance can be most effectively placed to ensure that existing strengths are not lost in any organizational changes and to help identify areas that can usefully be reinforced.

More generally, the work should have relevance to any countries that possess or hope to launch nuclear power programmes. There is still wide variability in the success with which nuclear power programmes are carried through and uncertainty as to why this variability arises. This work may help to reduce this uncertainty by identifying skills and functions that are of key importance, and features of institutional structures that have proved effective in meeting these needs.

The analysis of the operating performance of nuclear power plants is a difficult and sometimes controversial subject. Performance indicators are multi-dimensional, the data set is small and the institutional structure too complex for normal statistical analyses that would give very firm evidence for causal links to be used. This research must therefore be regarded as a starting point that can be developed and extended, perhaps applying the methodology to other plants in this area and to other sets of plants in different regions.

2. ENERGY CO-OPERATION IN THE EASTERN EUROPEAN COUNTRIES (1955-1991)

This chapter is intended to highlight the energy resources context and the development of the nuclear area in the former Soviet Union and eastern European countries. The final objective is to outline the general background that, along with the information of the following chapters should complete the picture against which the nuclear reactors' performance has been analysed.

2.1. ENERGY RESOURCES

Among the Council for Mutual Economic Assistance (CMEA)[2] member States only the former Soviet Union could found its economic development on its own energy resources. In fact the former Soviet Union had at its disposal about half the coal resources of the world, and great reserves of oil and gas able to allow the country to be energy independent and to cover almost all the CMEA partners' needs. This extremely advantageous condition was partially counter balanced by other less favourable characteristics such as: location, quality and transportability of energy resources. In the medium and long term, this gave some economic advantage to nuclear power at least west of the Urals.

The energy base for all the other countries of the Council, with the exception of Romania, was indigenous coal/lignite deposits complemented at first by oil and later by gas imported from the former Soviet Union, while the role of hydropower remained generally insignificant. Soviet energy supplies succeeded in providing almost 80% of the import requirements of CMEA countries for oil, practically all of the requirements for natural gas and more than 70% of the requirements of coal.

The position of Poland and Romania was, at the beginning, that of net energy exporters because of their respective surpluses of coal and oil but, later on, as Romania's own internal need grew it became a net energy importer while Poland was throughout a hydrocarbon importer.

On the other hand the four countries which based their industrialisation drive on Soviet fuel (Bulgaria, the former CSFR, the former GDR and Hungary) were also, and not by coincidence, those most involved in the nuclear sector of the Council while the role of the other two partners remained marginal.

There is no complete, reliable information regarding the former Soviet Union, and generally CMEA, uranium resources and exploitation. From the available data it seems that the former Soviet Union did not have large reserves, at least not enough to cover both civil and military needs. As a result, a general agreement was signed by all CMEA countries - with the exception of Romania - to deliver all exploited minerals to the former Soviet Union. The Soviets, on their own, provided fresh fuel assemblies and received the spent fuel.

The CMEA primary energy situation can be summarised as follows. While energy supplies were abundant, they were neither cheap nor environmentally clean, so that particular care was paid by the Council to the energy sector and more precisely to electric power generation which was considered, in compliance with the socialist faith in technological and scientific development, the driving force of economic development.

Another related issue of major concern for its strategic relevance was the establishment of a regional Energy Complex including pipelines (both oil and gas), electric transmission lines and power plants, to be considered somehow as an extension of the enormous Soviet Energy Complex and able to serve the allies' needs. An important part of this long term strategy was, since the introduction in the former USSR of civil nuclear power in the 1950s, the development of a nuclear programme on a

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[2]The CMEA is described in Annex G.

multinational basis, a programme that fully integrated all of its allies. The CMEA member States pursued this policy with varying degrees of success for a period of about three decades, and the existing and operating energy infrastructure bears witness to the success and limits of past patterns (see Tables 2.1 and 2.2).

2.2. THE NUCLEAR DEVELOPMENT

In a situation characterised by almost complete isolation, the origin and development of Soviet or, generally, of the eastern Europe civilian nuclear power took place in a substantially autonomous manner, sometimes along very different lines to those pursued, at the same time, in western countries.

The history of this development can be split in two major phases, a pioneering period from 1955 to 1971 and a commercial period from 1971 onwards.

The pioneering period started with the agreement signed by the former Soviet Union and the former CSFR, in 1955, for the construction in Bohunice of an experimental gas cooled, natural uranium fuelled reactor prototype. This remains the only attempt to develop such a reactor type in eastern Europe. It ended in 1971, the year in which the Comprehensive Program for the Development of Socialist Economic Integration, a major milestone for CMEA energy co-operation, was signed.

In this period the basic infrastructure was laid, scientific and technical levels were improved in all the countries by means of several agreements for research on nuclear energy and the development of equipment for the nuclear power industry, and also by means of dedicated institutions like the Joint Institute of Nuclear Research (JINR) of Dubna (Moscow).

By the end of the 1960s, the former Soviet Union had a full capability in pressurized water reactor technology, the first two units of the unified model WWER-440/230 were under construction at Novovoronezh and eight reactors of this type had been ordered by the former GDR, the former CSFR, Bulgaria and Hungary (the Hungarian contract was modified in 1973 to four WWER-440/213 units).

The first oil crisis, with the subsequent rise in the price of fossil fuels sharpened interest in nuclear power generation, which seemed the only economic long-term source of power. Great nuclear programmes were launched in the former USSR and in former Czechoslovakia and, to a lesser degree, in almost all the other States. In this period, multilateral international specialisation, co-productionand reciprocal supplies of equipment for nuclear power plants, under the aegis of the international organisations and particularly of Interatomenergo, took place.

Considerable importance was attached, by all member States, to the reduction of construction times, and to the improvement of operation and of techno-economic performance indicators of nuclear power plants. The reduction of construction time and, generally, of capital costs of NPPs was pursued and achieved by means of: constructing several, generally two or more units per site, unification and/or replication of general layout along with reduction to a minimum of post-construction design changes and increasing the size per unit. From 1980, the trend for WWER stations was to install at least two 1000 MW reactors per site.

Since the very beginning, in conjunction with the nuclear programme, great effort was devoted to establishing an effective electric interconnection between the Soviet European Power System and that of the European partners. The purpose of the interconnection was to allow both the optimisation of power exchanges, taking advantage of the different time zones in member countries and the consequent different peak time, and direct electric power export from the former Soviet Union hence reducing the corresponding fossil fuel export.

TABLE 2.1. ELECTRICITY PRODUCTION IN EASTERN COUNTRIES (GW.h)

	Thermal Production (GW.h)			Hydro Production (GW.h)			Nuclear Production (GW.h)			Share of Nuclear Electricity (%)		
	1975	1980	1990	1975	1980	1990	1975	1980	1990	1975	1980	1990
Bulgaria	20 230	24 957	25 598	2 453	3 713	1 878	2 554	6 165	13 496	11.47	19.76	32.94
Former CSFR	55 274	63 446	58 048	3 816	4 763	3 959	187	4 523	22 954	0.35	6.90	27.02
Former GDR	80,493	85 261	103 500	1 272	1 658	1 992	2 740	11 889	11 800	3.59	10.77	11.10
Hungary	20 311	23 764	14 502	161	112	178	0	0	12 892	0.00	0.00	46.76
Former USSR	892 415	1 037 068	1 319 584	125 987	183 938	233 000	20 205	72 922	211 500	0.48	1.48	3.55

TABLE 2.2. ELECTRICTY CAPACITY IN EASTERN COUNTRIES (MW)

	Thermal Capacity (MW)			Hydro Capacity (MW)			Nuclear Capacity (MW)			Share of Nuclear Capacity (%)		
	1975	1980	1990	1975	1980	1990	1975	1980	1990	1975	1980	1990
Bulgaria	4 387	5,622	6 396	1 793	1 868	1 973	880	1 320	2 760	12.46	14.98	24.80
Former CSFR	11 273	12 647	14 993	1 588	2 136	3 042	114	852	3 520	0.88	5.45	16.33
Former GDR	14 546	16 505	19 736	715	1 496	1 844	950	1 836	1 830	5.86	9.26	7.82
Hungary	3 875	4 934	4 901	46	46	48	0	0	1 654	0.00	0.00	25.05
Former USSR	172 071	201 907	240 822	40 515	52 311	64 973	4 898	12 492	37 875	2.25	4.68	11.02

In 1959, the first step towards establishment of the regional interconnection, called MIR, was decided. In 1962, the Central Dispatch administration was set up in Prague to operate the grid. The final part of this project was almost completed in the mid-1980s with the construction of the high voltage lines from the Khmelnitski nuclear power plant to Poland and from the South Ukraine nuclear power plant to Bulgaria (see Figure 2.1). While the level of interconnection, between CMEA member States, has steadily improved, by contrast the east/west Europe grids have remained as yet physically separated, apart from local power exchange in the North (the former USSR-Finland) and in central area (the former Czechoslovakia-Austria).

In the mid-1980s, two factors led to dramatic changes and the end of the isolation period:

- in March 1985, Gorbachev became the Secretary of the Communist Party of the former Soviet Union and adopted the policies of "perestrojka" (restructuring) of the economy and policy and "glasnost" (freedom of expression).

- in April 1986, the Chernobyl accident.

The situation in the CMEA member States at the time of Chernobyl can be summarised as follows:

- *Bulgaria*: four WWER-440 units in operation and two more units WWER-1000 units under construction at the Kozloduy site. The Bulgarian government had planned four further 1000 MW(e) units at the Belene site;

- *Hungary*: two WWER-440 units in operation and two more WWER-440 under construction at Paks. Two new sites for future nuclear plants had already been selected;

- *the former GDR*: four WWER-440 units in operation and four more WWER-440 units under construction at the Griefswald site. The Stendal nuclear power plant with four 1000 MW(e) was under construction;

- *the former CSFR*: four WWER-440 units in operation at Bohunice, one WWER-440 in operation and three more units under construction at Dukovany, four WWER-440 units under construction at Mochovce. The Temelin nuclear power plant with two WWER-1000 units was also under construction;

- *the former USSR*: the following plants were in operation; ten WWER-440 units at the Novovoronezh, Kola, Armenia and Rovno nuclear power stations; five units with WWER-1000 reactors at the Novovoronezh, South Ukraine, Kalinin and Zaporozhe sites; twelve 1000 MW(e) units with RBMK reactors, a 1500 MW(e) RBMK at Ignalina station; the BN-350 and BN-600 fast neutron reactors and other smaller stations. Further development was planned through the expansion of the existing nuclear stations and the construction of new ones, such as those at the Rostov, Balakovo, and Crimea sites. The capacity at each site would be 4000-6000 MW(e);

- *Romania*: one CANDU reactor was under construction and four more units were planned at the Cernovoda site. According to a Romanian-Soviet agreement a second station (Moldava), to be equipped with three WWER-1000, was planned;

- *Cuba*: two WWER-440 were under construction at the Juragua site;

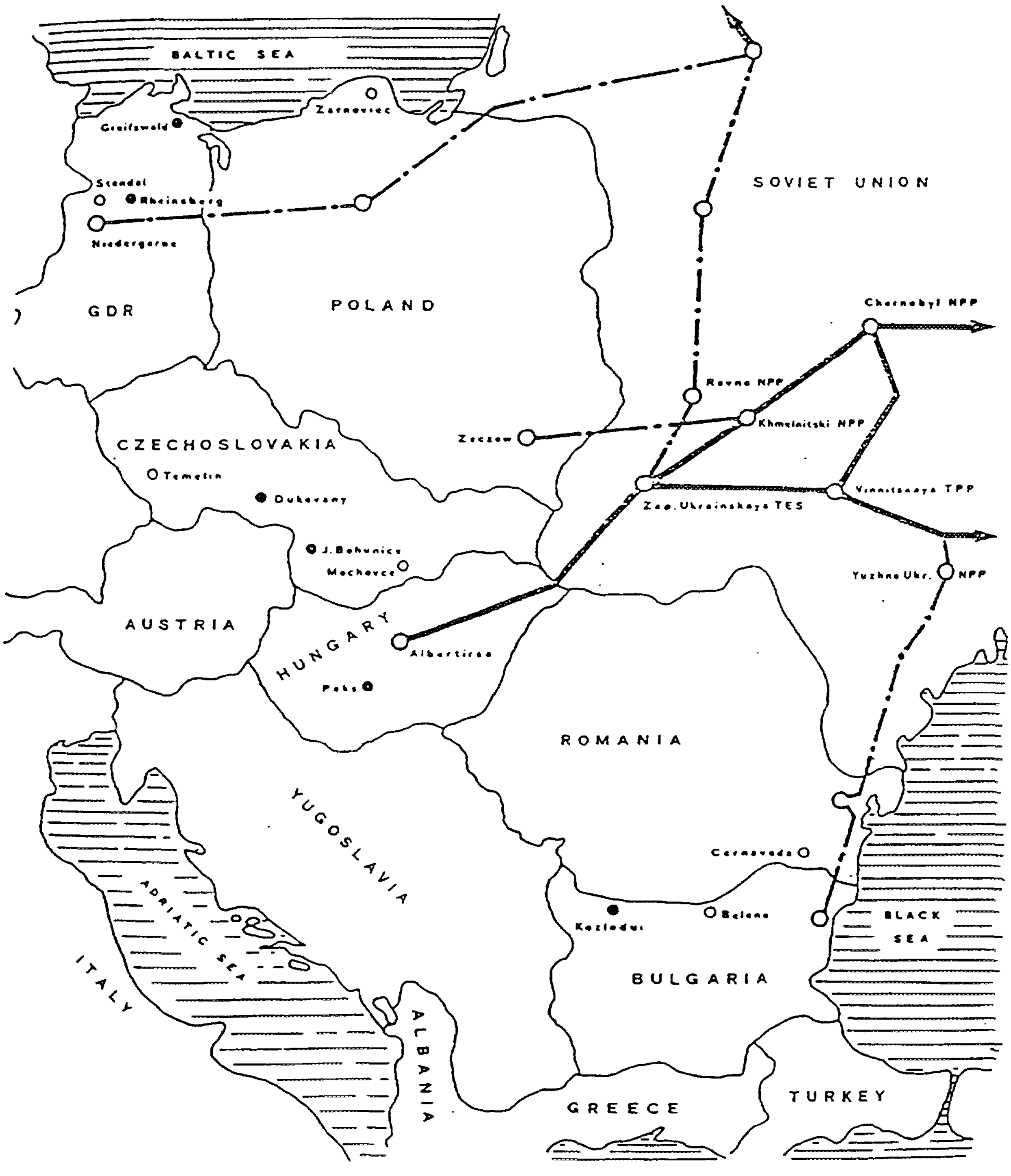

FIG. 2.1. Part of the interconnection grid in the former CMEA countries.

- *Poland*: two WWER-440 were under construction at the Zarnowiec station and more two units were envisaged for the same site; a second site, Kujawy, had already been selected for further developments.

After a series of political changes in the region, in 1990 the GDR ceased to exist and in 1991, WTO and CMEA were officially disbanded. In the CMEA area, in the period 1971-1991, sixteen WWER-440/230 model, fourteen (plus two plants in Finland) WWER-440/213 units and nineteen WWER-1000 MW(e) units were built [3] (see Table 3.3).

The impact of the Chernobyl accident was enormous. In September 1986 in Vienna, 62 countries signed two conventions under the auspices of the IAEA: the Early Notification of a Nuclear Accident and the Assistance in the Case of Nuclear Accident or Radiological Emergency. In December 1988, for the first time an international mission (Operational Safety Assessment Review Team, OSART) was invited to examine a Soviet reactor (Rovno 3). In September 1989, the Extrabudgetary Nuclear Safety Project on the Safety of Old Reactors was launched in Vienna.

A feature of both phases of nuclear development, was the clear willingness of the Soviet authorities to counter any proliferation risk by means of strict, direct, control of the entire sector, the type of technology transferred (limited to the pressurised water type) and finally establishing the whole fuel cycle within Soviet territory.

As a consequence of Soviet leadership, and by means of the CMEA Standing Commissions and Organisations, Soviet standards and regulations were enforced in all other member States; the highest level engineers, researchers and technicians could receive education and training in Soviet universities and training centres promoting the Soviet approach to nuclear technology.

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[3] Seventeen RBMKs were built in the Soviet Union.

3. DEVELOPMENT OF WWER TECHNOLOGY IN THE FORMER SOVIET UNION

Tthis chapter examines how WWER technology was developed in the former Soviet Union. It describes the technology development of this type of reactor and the steps in its development to commercial application. Particular attention is paid to the development of the first commercial design of Soviet PWR, the WWER-440/230. In addition, some information regarding the other reactor types developed in the former Soviet Union is given.

3.1. THE WWER

Three generations of civilian WWER (where WWER is the acronym of **Vodo-Vodyanoy Energetichesky Reaktor,** Water Cooled Water Moderated Power Reactor) reactors have been designed and built. The prototypes of this type were three small reactors, each 90 MW(th), built for the propulsion system of the "Lenin" ice-breaker during the period 1956-1959. The first commercial prototype (model 210) was unit 1 of Novovoronezh, a site on the Don riverside. The main characteristics of the model 210 can be summarized as follows:

- Thermal power 760 MW(th) and electric power 210 MW(e),
- 6 cooling loops operating with water at 100 at,
- 3 turbines (70 MW(e) each), plus a supplementary one of 75 MW(e), moved by saturated steam at 29 at.

Several changes implemented during the first operating period, 1964-1969, (power density, burn-up, boron in the moderator) permitted power increases from the original 210 up to 240 in 1966 and 280 MW(e) in 1969.

A second prototype, smaller than the previous one, was built at Rheinsberg, in the former German Democratic Republic. The main characteristics of this prototype are the following:

- Thermal power 265 MW(th) and electric power 70 MW(e),
- 3 cooling loops operating with water at 100 at,
- 1 turbine, moved by saturated steam at 32 at.

The third prototype, designated model 365, was built, also at Novovoronezh Nuclear Power Station, and had several changes as compared with the model 210:

- Thermal power 1320 MW(th) and electric power 365 MW(e),
- 8 cooling loops operating with water at 105 at,
- 5 turbines (73 MW(e) each one) moved by saturated steam at 29 at.

The most important nuclear changes were: a better flux shape (obtained by introduction of regions with different U enrichment in the core and decreasing the number of control rods from the original 73 to 37), and a reduced external fuel rod diameter.

The experience gained from these three units allowed the design and construction of a "standard" reactor, the **WWER-440/230,** the first examples of which were Novovoronezh units 3 and 4 (sometimes referred to as model 179) whose construction started in 1967. The main characteristics of this design (see Table 3.1), which apply to all units, are summarized in Annex A. The WWER-440/230s were built in modules of two units: both reactors are in a common reactor hall and share some frequently used operational systems, but have independent and separate safety systems. All the reactors are equipped with two 220 MW(e) turbine systems.

TABLE 3.1. MAIN CHARACTERISTICS OF THE WWER-440/230

COUNTRY	SITE	UNIT NUMBER	CONSTRUCTION START	COMMERCIAL OPERATION	SHUTDOWN
RUSSIA	NOVOVORONEZH	3	1967	1972	
		4	1967	1973	
	KOLA	1	1970	1973	
		2	1973	1975	
	ARMENIA*	1	1973	1979	1989
		2	1975	1980	1989
GERMANY	GREIFSWALD**	1	1970	1974	1990
		2	1970	1975	1990
		3	1972	1978	1990
		4	1972	1979	1990
SLOVAK REPUBLIC	BOHUNICE	1	1974	1981	
		2	1974	1981	
BULGARIA	KOZLODUY	1	1970	1974	
		2	1970	1975	
		3	1973	1981	
		4	1973	1982	

* Both reactors were closed following a disastrous earthquake which happened in the region in 1988.

** The reactors were closed after the re-unification of the country, because they did not meet the west German safety requirements especially regarding containment function.

The key mechanical equipment could be considered as being of a standardized design and was produced with standardized manufacturing procedures but the reactors have been defined, by the Russians themselves, as "unified type" rather than "standardized type". These units were designed using normal industrial standards and codes, only the reactor equipment was designed and manufactured according to special requirements.

Two peculiar characteristics of the first generation reactors are important and these concern the power rating and the confinement. The designers, during the early design phase, 1960-1970, had to keep in mind a fundamental constraint regarding vessel dimension and hence the reactor power: the dimension of components that could be moved by rail. An additional limiting condition at that time in designing the reactor arose from small local grid dimensions, that were unable to support large power plants. It is interesting to note that the dimensions of the main vessel for the WWER-1000 dimensions could not be increased much over those of the 440 MW(e) design due to continuing railway freight limits.

The lack of western style containment was the consequence of an analysis in which a peculiar boundary condition played an important role along with economic evaluations. The probability of a major accident at a nuclear power plant was perceived, at least during the early phase, as less of concern in the former USSR than in western countries. Excellence of design, high-quality in manufacture and reliability of equipment, implementation of preventive measures and operating procedures, and well-qualified personnel were supposed by the Russian designers to prevent release of radioactivity in the environment. The so-called Maximum Planned Accident, assumed to be a LOCA, was the rupture of a 100 mm pipe of primary circuit, but the use of a flow reducer meant they could assume that the effective diameter of such a rupture was only 32 mm. On this assumption, their analysis of such an event suggested that there was no need for the reactors to have special (redundant) ECCSs. What is more distance was considered an additional barrier to tackle any incident/accident by reducing the radiological consequence. This additional barrier was implemented by requesting that nuclear power plants should not be located "close" to cities with more than 100.000 inhabitants.[4] On this basis, a containment structure was seen, at least up to 1980, as a costly and superfluous precaution.

The second generation of WWERs was designed, roughly, in the early seventies. These reactors, generally designated as model 213 or **WWER-440/213**, were designed according to common industrial standards and rules and to the safety requirements of "General Safety Regulations for Nuclear Power Plants during Design, Construction and Operation" (OPB-73). This second generation comprises 16 reactors. Two other units of the basic WWER-440 design are in operation in Finland and are best considered as part of the 213 series (see Table 3.2).

TABLE 3.2. MAIN CHARACTERISTICS OF THE WWER-440/213

COUNTRY	SITE	UNIT NUMBER	CONSTRUCTION START	COMMERCIAL OPERATION
CZECH REPUBLIC	DUKOVANY	1	1978	1985
		2	1978	1986
		3	1978	1987
		4	1978	1988
FINLAND	LOVIISA	1	1971	1977
		2	1972	1981
HUNGARY	PAKS	1	1974	1983
		2	1974	1984
		3	1979	1986
		4	1979	1987
RUSSIA	KOLA	3	1977	1982
		4	1976	1984
SLOVAK REPUBLIC	BOHUNICE	3	1976	1985
		4	1976	1985
	MOCHOVCE	1	1983	
		2	1983	
		3	1985	
		4	1985	
UKRAINE	ROVNO	1	1976	1981
		2	1977	1982

Some WWER-440/213s are still under construction, including the four reactors in Mochovce (Slovak Republic). The construction of some other reactors, such as Greifswald 5-8 (former GDR) and Juragua 1 and 2 (Cuba), has been abandoned, while the four planned reactors of Zarnowiec (Poland) were canceled by the Polish government due to a fierce public opposition.

The second generation presents a number of changes related mainly to the safety systems and confinement structure, but as "power producers" are quite similar to the previous WWER-440/230 reactors. The Finnish reactors differ from the others as regards the safety systems and I&C, and

[4] It has been stated that such stations must be at least 6 miles from populated places, and 20 miles from major towns. To date (1980), none has been built closer than about 25 miles from any major urban centre. Plants constructed more recently, such as those at Kursk and Smolensk, have been located no closer than 22 miles from major city (L. Dienes, T. Shabad).

because they adopted a Westinghouse type containment building. The quality requirements for equipment and system design, manufacture and construction were set out in special documentation covering reactor equipment.

The first two WWER generations (WWER-440/230 and 213) can probably be considered - in accordance with some experts opinions - as "experimental installations" useful to accumulate operating experience, to identify optimum reactor size and to optimize the whole fuel cycle and the production structure. At the end of the 1970s it was decided there was a "necessity for standardization and unification of the principal units and mechanisms". This resulted in the "standard" model 1000 MW(e), with an option for a two loop, 500 MW(e) reactor where the main dimensions remained almost unchanged. A similar effort was made to standardise steam generators, turbine-generators and other conventional systems.

This third generation of WWERs, which is generally designated as WWER-1000, was designed in the period 1971-1985 mostly according to standards set out in OPB-73, and to subsequent updates Nuclear Safety Regulations for Nuclear Power Plants, PBYa-04-74, and General Safety Regulations of Nuclear Power Plants during Design, OPB-82, and to "Radiation protection norms" (NRB-76). These reactors have a containment building and a primary circuit with four cooling loops and, with the exception of the prototype of Novovoronezh 5, all have only one turbine system. Some five units of this 1000 MW(e) reactor type belong to the so-called "small" series :

- Novovoronezh 5 (Russian Federation), *model 187* in operation since 1981;
- South Ukraine 1 (Ukraine), *model 302* in operation since 1983;
- Kalinin 1 and 2 (Russian Federation), in operation since 1985 and 1987 respectively, and South Ukraine 2 (Ukraine) in operation since 1985 are *model 338.*

All other units in operation, and particularly the units under construction at Temelin (Czech Republic) and the two in operation at Kozloduy (Bulgaria) are of "standard" type 320 model. The latest design, the so-called model 392 type was planned for the Novovoronezh and Kola sites, but has not yet been built. At present there are 19 WWER-1000 units in operation (see Table 3.3).

The design of the "pilot unit", Novovoronezh 5, started in 1971 and was mainly developed according to common industrial rules, standards and regulations valid in that period; but the issuing of OPB-73 and PBYa-04-74 required the introduction of some modifications to the design.

A similar situation arose during the development of the WWER-1000/320 series design. Design of the "pilot unit" (Zaporozhe 1 in Ukraine) started in 1978 but in the process of design development, some measures to meet the new requirements OPB-82 were implemented.

3.2. OTHER NUCLEAR DESIGNS

Two other reactor designs, the RBMK (where RBMK stands for Reaktor Bol'shoi Moshchnosty Kanal'nyi/Kipiashchii - High Power Channels/Boiling Reactor) and the fast reactor or BN (where BN stands for Bystryi Neitroni), have been developed extensively.

3.2.1. The RBMK

In December 1946, the first research reactor, Fl (Fizicheskii-Pervii, Uranium - graphite type), was run at the Kurchatov Institute (in that period it was simply Laboratory N 2 of the USSR Academy of Science). The small U-graphite, water cooled, prototype AM-1 (5 MW(e)) produced electricity for the first time at the Institute of Physics and Power Engineering of Obninsk, in 27 June 1954.

TABLE 3.3. MAIN CHARACTERISTICS OF THE WWER-1000

COUNTRY	SITE	UNIT NUMBER	CONSTRUCTION START	COMMERCIAL OPERATION
BULGARIA	KOZLODUY	5	1980	1988
		6	1984	1993
CZECH REPUBLIC	TEMELIN	1	1984	
		2	1985	
RUSSIA	BALAKOVO	1	1980	1986
		2	1981	1988
		3	1982	1989
		4	1984	1993
		5	1987	
		6	1988	
	BASHKIR	1	1983	
		2	1983	
	KALININ	1	1977	1985
		2	1982	1987
		3	1985	
		4	1986	
	NOVOVORONEZH	5	1974	1981
	ROSTOV	1	1981	
		2	1983	
		3	1989	
	TATAR	1	1987	
		2	1988	
UKRAINE	KHMELNITSKI	1	1981	1988
		2	1985	
		3	1986	
		4	1987	
	ROVNO	3	1981	1987
		4	1986	
	SOUTH-UKRAINE	1	1977	1983
		2	1979	1985
		3	1985	1989
		4	1987	
	ZAPOROZHE	1	1980	1985
		2	1981	1985
		3	1982	1987
		4	1984	1988
		5	1985	1989
		6	1986	

The first "demonstration unit", 100 MW(e), was built in 1958 at the Siberian Nuclear Power Station[5] at Troitsk. Five other reactors of the same type went into operation, at the same site, in the period 1958-1963. The fuel cycle of these dual purpose reactors was prevalently oriented to plutonium production for military purposes.

The two reactors - 100 and 200 MW(e) respectively - built at Beloyarsk Nuclear Power Station were a further development (1962-1969). The second one could produce superheated steam with characteristics comparable to those of thermal power station steam. Drawing on experience with conventional plants, these nuclear reactors were used for heating in nearby industrial buildings and homes.

Variations on the theme were the four small reactors - each 12 MW(e) - built at Bilibino[6] located in the far north-east of Siberia. These reactors - characterized by natural coolant circulation - could supply steam to the local gold mines and the village heating system.

The first commercial RBMK reactor, Leningrad 1, situated about 45 miles west of St. Petersburg, Russian Federation, went critical in 1973 and has been in commercial operation since November 1974. Leningrad units 1 & 2 (also known as Sosnovy Bor), Kursk units 1 & 2 (in the Russian Federation) and Chernobyl units 1 & 2 (in Ukraine) constitute the first generation of RBMK reactors. Within a short time, this was followed by a second one.

The culmination of this type of plant was reached with the two reactors - 1500 MW(e) each one - built at Ignalina (today Republic of Lithuania), in commercial operation since 1984 and 1987. A further scaling up of this reactor type was also considered. A RBMK-P-2000/2400, with an electrical output of about 2000 MW(e), characterized by superheated steam was studied in the early 1970s, but development was not completed.

Compared with other reactor types but especially with the pressurized one, the RBMK had some distinctive characteristics:

- no requirement to produce large reactor pressure;
- capability to increase power by adding modular elements;
- on-line refuelling;
- flexibility in fuel cycle characteristics (with the consequent possibility to vary the amount of plutonium produced).

3.2.2. Fast Reactors

Since the very beginning of the Soviet nuclear era, the experts had judged that indigenous uranium resources were insufficient to support a massive reliance on slow neutrons reactors. Hence, in their continuous effort to maintain the strategic energy independence of the country, the Soviet planners identified the development of fast neutrons reactors as the logical solution to cover the country's electrical base-load demand and to close rationally the fuel cycle in the long term.

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[5]The Russians generally name their NPPs by means of abbreviation/acronym in which the first letter stands for the geographical area of the nuclear site: e.g. the Siberian Nuclear Power Station is mentioned as SAES: Sibirskaya Atomnaya ElektroStantsia.

[6]Dual purpose nuclear power plants (electric power and heating) are named ATET and hence for Bilibino NPP the acronym is BiATET.

The earliest studies in this field date from 1949. A series of research reactors (namely BR-1 - Bystryi Reactor - and BR-2 in 1955, BR-5 in 1959) led to the construction of a first prototype, the BOR 60 in 1968, at Dimitrovgrad (NIIAR in the Russian Federation).

In July 1973 the so-called BN-350, a dual purpose reactor able to produce 150 MW(e) and about 120.000 ton/day of desalinated water, entered into operation at Shevchenko (Kazakhstaan) beside the Caspian Sea. Eight years later, in November 1981, the first demonstration unit (BN-600 - three loop, pool design) at Beloyarsk (Russian Federation) started commercial operation. The first commercial unit should have been an 800 MW(e) reactor whose construction started, but has not been completed, again at Beloyarsk.

The fast reactor, like the RBMK, was developed only in the former USSR and not exported to any other CMEA country.

3.2.3. Nuclear Heat Supply

Great importance was attached in the former Soviet Union to the development of nuclear energy as a heat source. This was due to a wish to replace the extensive use of fossil fuels as a source of crude heat because of the harsh climate and the large amount of thermal power required by some industries - 40% of fossil fuel produced during the XIth Five Year Plan was used for this purpose.

Thermal power from a nuclear power station can be produced by direct steam withdrawal, using an ad-hoc dual purpose reactor, or from a special nuclear boiler. Utilization of direct steam withdrawal was achieved for the first time in the world, at Beloyarsk Nuclear Power Plant (Russian Federation). Afterwards steam withdrawal was implemented at Leningrad, Kursk, Novovoronezh and Kola in the Russian Federation and at Chernobyl in Ukraine and a number of other nuclear power plants in all other CMEA member States. The Bilibino Nuclear Power Plant (Russian Federation) could be considered the first nuclear dual purpose facility, but it was not followed by other units.

Several studies were performed in order to evaluate the optimum size and reactor type for heat production. A natural circulation PWR was chosen with a thermal power of 500 MW (ACT- 500) able to supply about 430 Gcal/h, to be located near, roughly 2 km, from the area to be supplied. In 1986, construction of two ACT prototypes was started, but has not been finished, at Gorkiy and Voronezh.

3.2.4. Other Reactor Prototypes

To complete this review, it should be noted that in several scientific institutes, research was carried out regarding other reactor types.

VK-50 - On December 1965, in the Scientific Research Institute of Dimitrovgrad, the VK-50 reactor was completed. It was a light water cooled and moderated, boiling water reactor whose principal characteristics were: thermal power 150 MW; electric power 50 MW, steam production 220 t/h at 60 at. In 1974, a slight modernization made it possible to increase its thermal power to 250 MW and its electric power to 65 MW.

ARBUS - Under the programme of research devoted to the development of reactors for heating purpose, at Dimitrovgrad, in 1963, a small prototype - 5 MW(th) - cooled with an organic fluid, hydrostabilised gasoil - was completed.

TES -3 - At the research Institute of Obninsk a small - 1.5 MW(e) - pressurized reactor was developed. This reactor - which went critical in 1961 - was assembled along with its turbo-alternator on four trucks (tractors) to become the only mobile reactor in the world.

4. INDUSTRIAL SYSTEM FOR THE DEPLOYMENT OF WWER TYPE REACTORS IN THE FORMER SOVIET UNION

In this chapter, the main industrial concerns that have been involved in the design and manufacture of the WWER design of nuclear power plant are identified; plant construction and ownership along with some information regarding Regulations and the Regulatory Body are also presented to complete the picture.

4.1. RESEARCH AND DEVELOPMENT, DESIGN AND ARCHITECT ENGINEER

Ever since the pioneering period, the Soviet Research and Development (R&D) programme has benefitted from huge resources and the highest priority. The State Committee for Utilisation of Atomic Energy (GKAE) was responsible for financing and supervising R&D activities, and for scientific and technical contacts with other east European countries and International Agencies (mainly the IAEA). Two scientific centres have shared the major responsibilities for WWER technology R&D:

- the *Institute of Atomic Energy I.V. Kurchatov* (IAE or Kurchatov Institute); in close co-operation with several other institutes and organisations, the Kurchatov Institute carried out the design and development of the WWER reactor type from the beginning with the prototype reactors of the Lenin icebreaker;

- the *All Union Scientific Research Institute of Instrument Manufacture* (SNIIP); SNIIP was set up in 1953 and was in charge of solving problems and questions in the field of designing facilities and instruments for dosimetric, radiometric and spectrometric equipment, and monitoring equipment of reactors. An interesting landmark in the activities of SNIIP was the construction of a radiometric complex for the nuclear icebreakers Lenin, Arktika and Sibir. In recent years, SNIIP has produced a large assembly of equipment for the monitoring, control and safety of reactors.

R&D, Design and Architect Engineer activities were organised and performed by an unusual structure composed of government institutes rather than industrial companies. The most important members were:

- the Kurchatov Institute (Moscow). As noted above, this was mainly responsible for R&D and design in the following areas: reactor physics and core design, control and protection systems. The Institute also acted as Scientific Manager.

- the OKB Gidropress (near Moscow). This institute was the main designer of the primary thermo-hydraulic systems, the ECCSs. OKB was initially under the control of the Ministry of Heavy, Power and Transport Machine Building, and only later in the eighties did control pass to the GKAE.

- the Atomenergoproject. This institute is based in Moscow but has branches in St. Petersburg, Kiev and Kharkov. It fulfilled the role of Architect-Engineer, that is, it was responsible for designing the general plant layout. Atomenergoproject was originally under the control of Minenergo (Ministry of Power and Electrification, see Section 4.3) and, in the late 1980s, it was divided into two organisations. One, Teploenergoproject, performs power plant project engineering and remained under Minenergo. The other, retaining the original name, was transferred to the Ministry of Atomic Energy and continued to perform the nuclear power plant project engineering function.

This Soviet triumvirate represents the direct link between designer and client that allowed Minenergo, taking advantage of the less formal Soviet position on nuclear safety in that period, to drive the WWER-440 design towards that "production oriented layout", that may have contributed to the good operating performance of the first generation of reactors.

This concentrated structure was a powerful force in promoting the Soviet learning process.[7] It was able to collect and analyse technical information on all the important aspects of the process including design, manufacture and operating experience directly from the plants and the manufacturers.

This structure was also responsible for approving any plant (system) modification or backfit not only for reactors in the Soviet Union but also for those in other east European countries. Here, in spite of the existence of National Authorities, its final approval to any changes has almost always been required.

4.2. MANUFACTURERS AND INDUSTRIAL SUPPORT SYSTEM

Vendors, in the western sense, did not exist in the former USSR; but several hundred specialised manufacturers/factories worked under the control and supervision of several Ministries, particularly the Ministry of Heavy Power and Transport Machine Building.

The most important among them were:

- the Izhorskij Zavod (St. Petersburg), supplier of vessels, internals, control rod drive mechanisms, pressurizers and other pressurized components for the first two WWER generations (WWER-440/230 and WWER-440/213). During the 1980s the leading position passed to Atommash (Volgodonsk). In 1988 these two factories were jointly able to produce 13 vessels per year (WWER-1000) - three at Izhorskij and ten at Atommash;

- the Podolsk Mechanical Engineering Plant (Moscow), supplier of steam generators - along with Atommash;

- the KhTZ (Kharkov) along with LMZ (St. Petersburg) supplier of turbines;

- the Taganrog Boiler Building, supplier of de-aerators and preheaters.

In 1989 general co-ordination of these and other manufacturers was placed under the control of the new special Ministry for Atomic Power Industry (MAPI).

A special co-ordination unit called Soyuzatomenergo was established within the ministerial structure (Minenergo) to co-ordinate the production rate of components and spare parts. It decided on their distribution to the power plants according to their needs as presented by Site Directors, and as perceived by Soyuzatomenergo. In this regard each Site Director (WWER & RBMK) was responsible to Soyuzatomenergo for plant management and the achievement of production goals. This system was excessively bureaucratic and contained no direct link between plants and industry. These failings gave rise to delays in component supply and constraints on plant operation.

The whole fuel cycle was under the control of the Ministry of Medium Machine Building. Since this Ministry was also responsible for a number of military activities, virtually no information is available on its activities. According to some sources about 600 000 tons of uranium were produced between 1945 and 1990 in the CMEA countries, 300 000 of which were reserved for the Soviet military. There is no evidence that shortages in the provision of front-end fuel cycle services created

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[7] "Defined as any process whereby the experience of designing, producing or using is utilised to improve design, production or use of the product", S.D. Thomas, The realities of nuclear power, Cambridge University Press, 1988.

problems for plants or in any way affected plant performance. Indeed, Soviet fuel cycle facilities were able to support all the needs of the CMEA countries and had sufficient excess separative work unit capacity to enter the western European market in the mid-1970s. In July 1989 the Ministry of Medium Machine Building became a major part of the new Ministry for Atomic Power and Industry.

4.3. PLANT CONSTRUCTION AND OWNERSHIP

Before Chernobyl, the Ministry of Power and Electrification (Minenergo) acted as owner and operator of almost all the power plants (it controlled about 90% of total former USSR installed capacity) and was also responsible for plant construction. This Ministry, by means of its design branch, the so called Atomenergoproject, participated from the first stages - Beloyarsk and Novovoronezh - in designing both main reactor types (RMBK & WWER) thereby creating the foundations for that "intimate co-operation" that became the rule in nuclear development and an example for other technological areas.

After the Chernobyl accident, the new Ministry of Atomic Energy (Minatomenergo) assumed the function of owner-operator for almost all the nuclear power plants. The Soyuzatomenergo and Atomenergoproject were also placed under the new ministry, while responsibility for plant construction remained with Minenergo. In July 1989 a special Ministry for Atomic Power and Industry (MAPI) was established, re-uniting the short-lived Minatomenergo and the Ministry of Medium Machine Building. MAPI was responsible for the design, siting, construction and operation of nuclear power plants and nuclear fuel cycle facilities, so reuniting and finally rationalising the whole nuclear sector.

4.4. REGULATIONS AND REGULATORY BODY

In the former Soviet Union, as in some western countries, the first steps in nuclear technology were taken when there were no specific nuclear laws (i.e. laws clearly defining and separating roles, responsibilities and duties of the main parties concerned with nuclear power). Nevertheless, the process of development and enforcement of standards and regulations, mainly dealing with specific safety issues, started at the dawn of the nuclear era.

In 1970, in the course of designing the two WWERs for Finland, a formal set of requirements for safety of nuclear power plants was formulated for the first time. On this basis "Nuclear Safety Regulations for Nuclear Power Plants" (PBYa-04-74) was issued in 1974. These Safety Regulations contained regulations associated with safety and control, engineering and organisational requirements related to nuclear systems during design, construction and operation of Nuclear Power Plants. They stated, inter alia, the Plant Management's responsibility for implementation of the Regulations and for monitoring their observance. Plant inspection and supervision depended upon the Inspectorate for Nuclear Safety (during that period part of GKAE). Limits and conditions of plant safety operation were defined by and agreed with the Scientific Manager (the Kurchatov Institute) and Project Chief (the Atomenergoproject).

The State Committee on Radiation Protection (part of the Ministry of Public Health) issued in 1976 "Radiation Safety Standards" (NRB -76) based on ICRP recommendations. Three years later, this State Committee issued another document (SP-AES-79) to expand and complete the previous NRB-76 as regards specifically siting, layout and shielding of nuclear power plants.

A new key document "General Safety Regulations of Nuclear Power Plants during Design, Construction and Operation" (OPB-82) was issued in 1982. According to OPB-82, plant inspections and supervision were to be carried out by: the USSR State Committee for Supervision of Nuclear

Power Safety (Gosatomenergonadzor)[8] and the Ministry of Public Health[9]. An updated document (OPB-88) containing more specific regulations was issued officially in 1988.

As previously mentioned, during the 1970s, several organizations participated in nuclear power plant inspections, this situation was simplified by the establishment in May 1984, of the Gosatomenergonadzor. Moreover this new Regulatory body (acting with the scientific support of the Kurchatov Institute) could enforce the regulations by means of an organized network of resident inspectors.

The Ministry of Public Health maintained responsibility for issuing radiation protection standards and for the correlated inspections, while GKAE performed surveillance on the environment and people surrounding the power stations. Finally, in April 1990, the previous Authority was re-organized as the USSR State Committee for the Supervision of Safety in Industry and Nuclear Power.

Due to the complex situation previously described, it is fairly difficult to evaluate Authority/Plant interactions and the correlated effects on plants performance. The generally accepted view, as regards safety aspects, is that set out in chapter 3 of "The Safety of WWER-440 model 230 Nuclear Power Plants", IAEA, Vienna 1992. Nevertheless, the interaction between Authority and Plant could be defined as an other aspect of that "intimate co-operation" oriented towards the achievement of production goals previously mentioned.

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[8]More exactly two bodies were mentioned but these two, one year later, were reunited in the Gosatomenergonadzor.

[9]A further body Gosgorteknadzor was in charge of preparation of regulations and for carrying out inspections of pressurized components (vessel and main pipelines).

5. PLANT MANAGEMENT AND POLICY

This chapter describes plant management and policy, paying particular attention to the Novovoronezh NPP, the reference plant for WWERs and particularly for the 230 model.

5.1. GENERAL PLANT POLICY

The operation of nuclear power plants in the former Soviet Union was highly regulated and centrally controlled. MAPI was responsible to the Council of Ministers of the Soviet Union for conducting and regulating all activities related to nuclear power in accordance with the laws of the country. MAPI, and previously Minenergo, had a complex organizational structure with many vertical and horizontal reporting relationship. The WWER reactors came under the jurisdiction of a section of the Nuclear Power Plant Operating Department with the operation of other reactors such as RBMKs coming under the jurisdiction of a different section in the same Department.

In addition to exerting strong control over all financial matters related to the operation of nuclear power plants, the Operating Department had also established a broad set of goals related to their operation. Many of these goals placed a high priority on issues related to the safe operation of nuclear power plants. The Operating Department appointed all nuclear site directors, issued directives, made technical decisions and personnel policy, including hiring, training and rates of pay, was largely governed by centralized government decisions.

Novovoronezh nuclear power plant is headed by a Site Director who is responsible for the management and administration of six departments - the safe operation of the three units on the site, economics, security, capital construction, transport and supply services and personnel matters. The city of Novovoronezh is also under the administrative control of the Site Manager. The station has approximately 4,500 employees, whereas the city of Novovoronezh has about 35,000 inhabitants, but most of these are either directly or indirectly involved in the operation and administration of the NPPs.

The Chief Engineer is responsible for the day to day operation of the nuclear power plants, with seven operating departments reporting to him: Operation of units 3 and 4, Operation of unit 5, Engineering, Maintenance, Reliability and Safety, Labor Protection and Services, Training (see Fig. 5.1). His daily duties include checking plant status and then sending a status report to MAPI in Moscow and holding a telephone conference call with each department head who reports the status and significant events.

Every year a statement of Novovoronezh Nuclear Power Plant goals and objectives, the so-called Order No. 1, is issued by the plant management. This document contains a summary of the previous year's performance in meeting objectives and the list of goals and objectives for each section in the NPP. There are 18 separate areas. Goals and objectives with appropriate data, references and costs are well defined for each area. Every three months the document is reviewed and updated if necessary.

The Special Operating Regime under which Novovoronezh NPP units 3 and 4 is presently being operated, requires that an Annual Safety Report be submitted to the regulatory agency. This Safety Report must contain data which indicates plant status and performance. This data should be used by the plant management to develop performance indicators.

5.2. OPERATIONS

The Operations Division has seven departments and is headed by the Chief Engineer. Two departments control operational activities: one for units 3 and 4 and one for unit 5; the other departments provide a range of special technical support and interface directly with Operations Departments. Some of the specialist departments are subdivided into a number of sections which therefore creates a complex matrix organization.

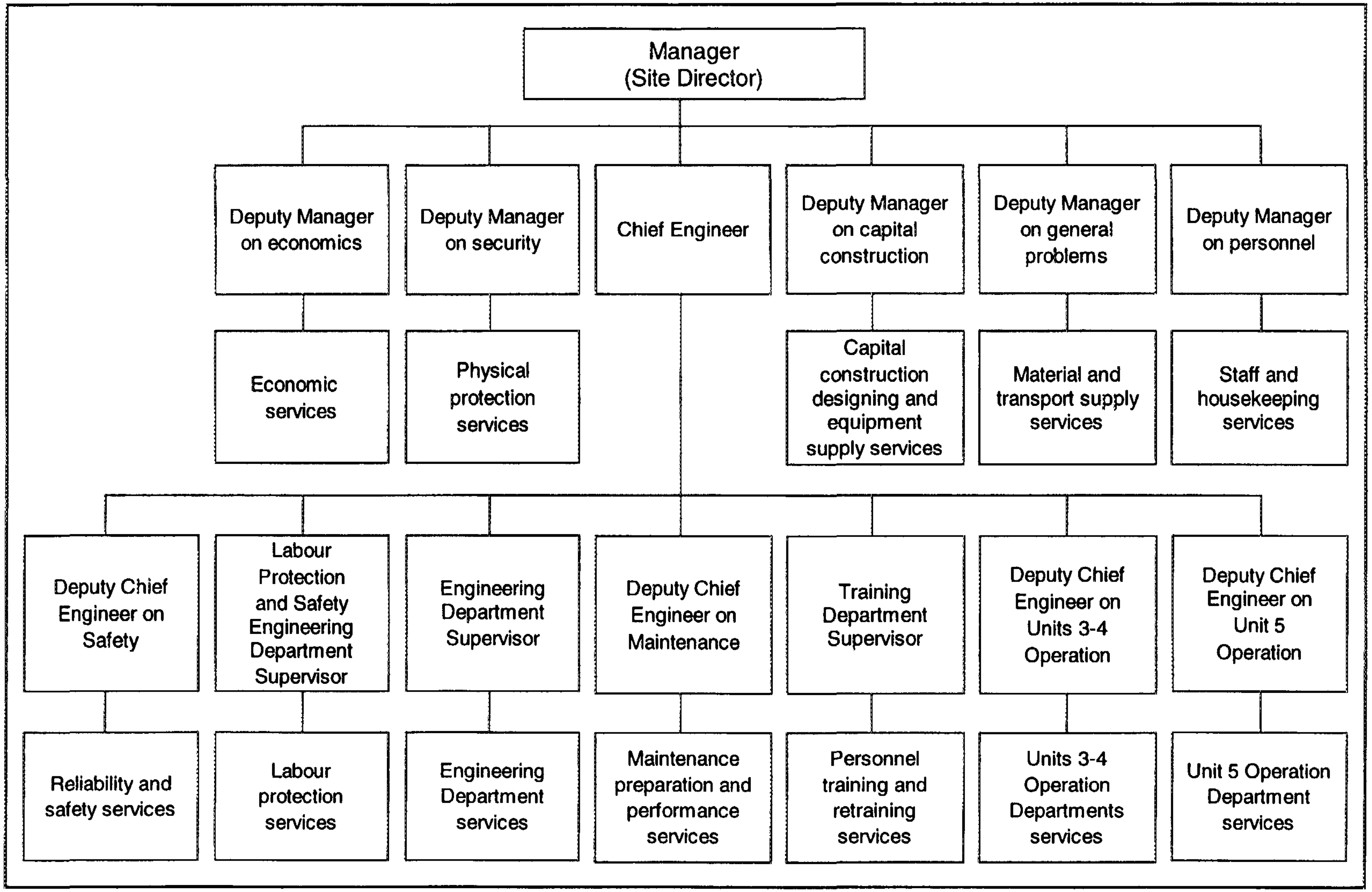

FIG. 5.1. Organizational Structure of Plant Management

The Deputy Chief Engineer of units 3 and 4 heads the shift operations department, which carries out all operational activities. Five of seven available shift teams are allocated to supporting the 24 hours of operations activities. Each shift team is headed by the Shift Supervisor and formed from two principal groups of staff: one group is defined as the Operating Control group and are the staff of the two separate unit control rooms, the second one is defined as the Technical Support group who forms five separate sections within the shift (see Figure 5.2).

Day to day activities are coordinated by the Chief Engineer at the office intercom conference. All Deputy Chief Engineers and Supervisors contribute to this meeting and the activities of the previous 24 hours are discussed and actions agreed. All operational activities are recorded in chronological order in the many log-books of supervisors and unit control room staff.

The Deputy Chief Engineer visits each unit control room twice per day, authorizes the daily work programme at the Shift Supervisor's office. During special activities all levels of management will have cause to attend at the plant. Generally for unusual events, a full investigation is completed by the Chief Engineer.

The Technical Regulation document contains the main rules and methods for unit operation, general sequence of operation as well as limits and conditions of safe operation. Under fault or emergency situations the operator relies entirely upon experience, his memory of the emergency procedures and training.

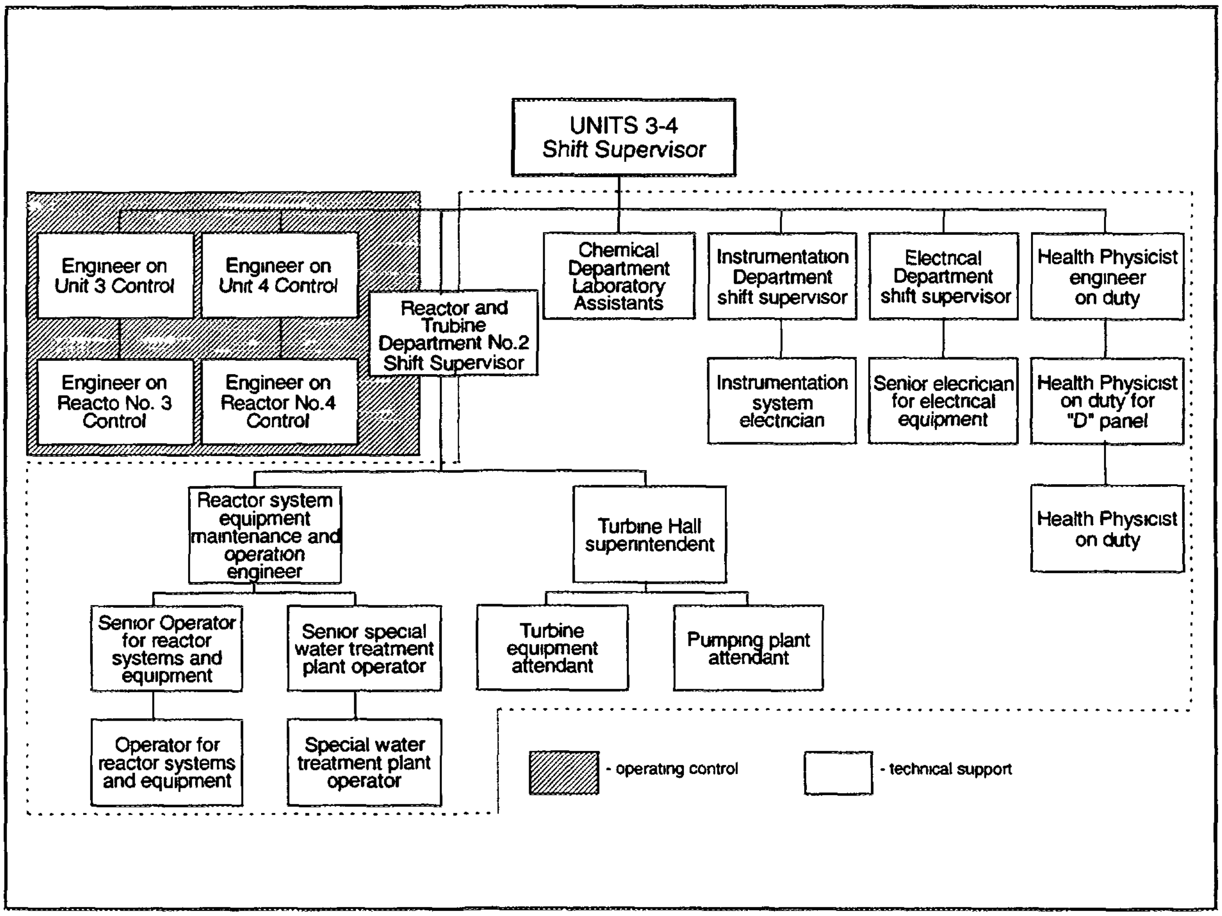

FIG. 5.2. Organizational structure of shift operating personnel.

5.3. SAFETY POLICY AND REGULATIONS

The regulatory agency, Gosatomenergonadzor responsible to the council of Ministers, was established relatively late, in 1984, for a country with a large nuclear program. In addition to a central office in Moscow there were five regional offices. Novovoronezh was under the direction of the South western regional office in Kiev. The regulatory body was responsible for the development and enforcement of nuclear safety codes and standards at all stage, from site selection to decommissioning, in a nuclear power plant project.

At Novovoronezh there were 5 resident inspectors. Currently, Novovoronezh units 3 and 4 do not meet present nuclear safety and licensing requirements. Therefore the present strategy is to take appropriate measures, including design modifications, and strictly enforced special operating rules known as the Special Operating Regime to enable operation up to the end of their design lifetime in 2001 and 2002. This special regime places considerable emphasis on high standards of human performance, development of procedures and training. It also requires that a safety analysis report be prepared and reviewed by the Regulator.

Industrial safety policy within the former Soviet Union was regulated through numerous codes and standards, mainly issued by MAPI. Each nuclear power plant also had its own policy and procedures which were based on the MAPI policy. At Novovoronezh there is a Labor Protection and Safety Engineering Department which reports to the Chief Engineer. This department in also responsible for radiation protection. Each year, the Novovoronezh nuclear power plant statement goals and objectives - Order No. 1 - is updated with respect to industrial safety, radiation safety and labor protection improvements. Security was governed by directives issued by three Ministries: MAPI, the Ministry of Interior and the KGB. All security guards were military personnel from the Ministry of Interior.

5.4. TRAINING AND QUALIFICATION

Training at the site is provided by two distinct and separate organizations: the plant's own Training Department and the Novovoronezh Nuclear Training Center. The Novovoronezh Nuclear Training Center is operated primarily as a centralized training facility for WWER plant operations staff throughout the former USSR, eastern Europe and Cuba. Extensive training for CMEA operators has been conducted at this Training Center. However there has been a steady decrease in the number of foreign students trained since 1983. The Training Center is managed independently of the plant. The Training Center is equipped with three simulators: model 230, Novovoronezh Unit 5, and the model 320 (WWER-1000).

The position of reactor control operator requires applicants to already have a University degree. Candidates must also pass a comprehensive psychological and physiological evaluation prior to enrollment into training. At the completion of training and examinations, the Examination Commission assign the trainee to an observation period in the control room. When the Deputy Chief Engineer for Operations is satisfied with his performance, the Chief Engineer is requested to authorize the individual for independent operations.

5.5. OPERATING EXPERIENCE

Internal plant operating experience is applied by the following means:

- investigation reports and Plant Manager orders are issued after all incidents at the plant, they are distributed to the departments of the plant for execution, including discussion with personnel;

- annual reviews of plant operating disturbances are produced, including analysis of causes and recommendations for prevention of such disturbances in future, such reviews being sent to all plant departments;

- annual reports are distributed between plant departments;

- operating experience is used for preparation and conduct of training sessions for operating personnel at the Plant Training Department and at the Training Center simulator.

Operating experience from other nuclear power plants, in the Soviet Union is officially used at the plant in the following way:

- information on incidents which occurred at other stations which comes via MAPI is discussed with plant personnel;

- plant supervisory and management personnel is informed about incidents which occurred at other stations during the daily morning telephone meeting (this information also comes via MAPI);

- organizational and technical measures are developed and implemented on the basis of information about incidents which occurred at other stations;

- plant and departmental management personnel study monthly operating reports from other similar nuclear power plants (such as Kola and Rovno) and use them for the preparation of training sessions for operating personnel at the Training Department;

- plant and departmental management personnel, Training Department instructors and plant shift supervisors analyse the operating disturbances reports and nuclear power plant components reliability assessments which come from MAPI and its organizations (VNIIAES, Soyuzatomtenergo, and manufacturers);

- plant personnel are sent to other stations in the Soviet Union to exchange information regarding operating practices.

Operating experience from nuclear power plants from outside the former Soviet Union is also processed. This information is mainly distributed by VNIIAES and, at present, by the WANO Moscow Center.

6. DESCRIPTION OF PLANT PERFORMANCE USING PRIS DATA AND PLANT INFORMATION

The objective of this chapter is to analyze the operating performance of the WWER-440/230 plants using a variety of indicators drawn from the IAEA's PRIS data base and other internationally accepted performance indicators such as those used by WANO and supplied to the expert group by the relevant national operators.

Operating performance is described at three levels: at the first level, the energy availability factor is used to show how effective these plants have been in supplying power; at the next level, periods that the plants are not supplying power (expressed as energy unavailability factor) are divided into planned and unplanned unavailability; and at the third level unplanned unavailability is analyzed according to the cause, e.g. equipment failure (according to the affected system), operator error and testing. To assess the reliability of the plants, the frequency of forced outage is shown.

6.1. SAMPLE DESCRIPTION

These analyses are divided into three time periods to determine what effect political and other external factors had on operating performance. These include, in particular, the Chernobyl accident, changes in the political and economic situation in eastern Europe and the former Soviet Union and the increase in western access and influence over the plants. For this purpose data have been divided into: the period up to the end of 1986 (Period 1); the period 1987-1989 to show the impact of Chernobyl and increasing economic difficulties in the region (Period 2); and the period 1990-1992 to reflect the opening up of the plants to international scrutiny (Period 3).

To place the performance of the WWER-440/230 plants (Sample 1) in context, comparisons with a number of other groups of plants are given (Table 6.1). These include:

- WWER-440/213 (Sample 2). These represent the next technological step on from the WWER-440/230, being very similar except for the addition of enhanced safety provisions;

- WWER-1000 (Sample 3). These represent a further technological step containing major design changes compared to the earlier plants and also embodying western safety philosophy to a much greater extent;

- all world PWRs, except WWER units (Sample 4). This gives an overall comparison with plants of a similar basic design concept to the Soviet WWERs, but installed in the West;

- all world PWRs with capacity less than 600 MW(e) excluding WWER units (Sample 5). As above, but including only plant of comparable size to the WWER-440/230;

- US Westinghouse PWRs with two coolant loops (Sample 6). These six units (Point Beach 1 and 2, Prairie Island 1 and 2, Kewaunee and R.E. Ginna) represent a more closely analogous group of plants to the WWER-440/230, being of similar size and representing the first 'commercial' design of a particular vendor. They are also located in one economic region (see Box for a fuller description of these plants).

- US Westinghouse PWRs with four coolant loops, net electricity capacity greater than 1000 MW(e) and with more than ten years operating experience by the end of 1992 (Sample 7). These ten units represent another apparently homogeneous set of plants with a substantial record of plant operation.

TABLE 6.1. SAMPLE DESCRIPTION

Sample	Description	No. of Units	Date of Grid Connection (for the first unit)	Cumulative operating experience (reactor-years)	Average Age (years)
1	all WWER-440/230	10	1971-12	159	15.3
2	all WWER-440/213	16	1977-02	136	7.7
3	all WWER-1000	18	1980-05	105	4.8
4	all world PWR, excluding WWER	193	1967-08	2134	10.7
5	all world PWR < 600 MW(e) and excluding WWER	50	1967-08	723	15
6	US Westinghouse PWR - 2 loops < 600 MW(e)	6	1969-12	120	19.8
7	US Westinghouse PWR - 4 loops, > 1000 MW(e)	10	1973-12	146	14.6

6.2. OVERALL PERFORMANCE

Table 6.2 shows the very high level of overall operating performance the WWER440/230 plants (Sample 1) have achieved despite recent lengthy shutdowns for safety backfittings. Performance is significantly higher than for PWRs in general (Sample 4) and somewhat better than all small PWRs worldwide (Sample 5). Nevertheless, a smaller and more homogeneous group of small PWRs (Sample 6) which were close contemporaries of the WWER-440/230 and which also represent a first commercial design has achieved comparable levels of performance. It is worth noting that up to 1991 the cumulative energy availability factor was 80%. The 1992 value is affected by the low availability of Kozloduy 1 and 2 which were closed down for extensive backfittings during this year.

The performance achieved by the WWER-440/230 plants was emulated and even exceeded by the successor design, the WWER-440/213 (Sample 2). However, in the next generation (Sample 3) which was not only scaled up, but also included significant design changes including a much greater degree of western safety philosophy, performance was substantially poorer. This reduction in performance is paralleled in the scaling up of the US Westinghouse design (Sample 7).

TABLE 6.2. CUMULATIVE ENERGY AVAILABILITY AND UNAVAILABILITY FACTORS UP TO 1992 OVERALL RESULTS

Cumulative factors (%)	EAF	PUF	UUF
1 WWER-440/230	78.10	17.60	4.30
2 WWER-440/213	81.50	14.80	3.70
3 WWER-1000 (1987 to 1991)	64.40	23.50	12.10
4 PWR excluding WWER	72.20	17.90	9.90
5 all world PWR < 600 MW(e) and excluding WWER	76.80	17.30	5.90
6 US Westinghouse PWR - 2 loops < 600 MW(e)	83.60	13.50	2.90
7 US Westinghouse PWR - 4 loops, > 1000 MW(e)	64.00	19.40	16.60

Note: EAF is the Energy Availability Factor, PUF is Planned Energy Unavailability Factor and UUF is Unplanned Unavailability Factor.

The US Samples 6 and 7

Sample 6

A useful sample of plants that the WWER-440/230s can be compared with is the 2-loop Westinghouse PWRs that have been installed in the USA. There are six units of this design in the USA, including two units each at Point Beach and Prairie Island and single units at the R E Ginna and Kewaunee sites.

This group of plants has a number of features in common with the WWER-440/230s: they can be seen as part of the first generation of commercial nuclear power plants to be installed in the USA, being completed in the period 1970-74; they are relatively small compared to subsequent units - they lie in the size range 470-511 MW(e) (net); they are considerably more standardized than earlier Westinghouse units, having the same two cooling loop configuration; each site is operated by a different utility, but within a common regulatory structure.

These plants are widely acknowledged as being consistently amongst the highest performers in the USA and, on that basis, the utilities that own them have gained wide respect. However, it is not clear what the main factors behind this performance are. Three main possibilities exist: first, it is due to the skills of the utility; second, it is due to the intrinsic merit of the design, particularly its size; third, it is because the plants were completed relatively early in the commercial history of nuclear power and the designs had not been continually modified to reflect the latest safety requirements.

Sample 7

The Westinghouse 4-loop PWRs over 1000 MW(e) have proved much more variable in their performance but none has performed as well as the 2-loop units. In order to obtain a reliable estimate oflong term energy availability factor, only plants with more than ten years of operating experience are included, i.e. those completed before 1983.

6.3. WWER-440/230 PERFORMANCE VARIABILITY

One of the most striking features of the performance of the WWER-440/230 plants is the low variability in the energy availability factor, both from year to year and from plant to plant. This is illustrated by the low standard deviation of annual EAF of each of the WWER-440/230 and by the low standard deviation of the cumulative EAF of the group as a whole. These values can be compared with the corresponding data for the plant in Sample 7. This sample represents a group of plants with the common basic design installed in only one country and that might be expected on these grounds to achieve a fairly uniform level of performance.

Table 6.3 presents the standard deviation for each plant from year to year for the WWER-440/230 (Sample 1) and the US Westinghouse PWR with 4 loops (Sample 7). The column headed Standard Deviation 2, excludes years where the plant operated for less than 1000 hours. The plants affected are Kozloduy 1 and 2, in 1992 when extensive backfittings were carried out, and Sequoyah 1 in 1986 to 1988, and Sequoyah 2 in 1986 to 1987, when the US NRC closed all plants owned by the TVA.

TABLE 6.3. ENERGY AVAILABILITY FACTORS AND YEARLY STANDARD DEVIATION.

Sample 1 - WWER-440/230		Cumulative EAF (%)	Standard Deviation 1(%)	Standard Deviation 2(%)
Bulgaria	Kozloduy 1	73	21	12 (*)
	Kozloduy 2	78	21	5 (*)
	Kozloduy 3	82	10	10
	Kozloduy 4	85	10	10
Russian Federation	Kola 1	78	8	8
	Kola 2	80	9	9
	Novovoronezh 3	76	15	15
	Novovoronezh 4	81	13	13
Slovak Republic	Bohunice 1	74	9	9
	Bohunice 2	77	5	5
Sample 7 - US Westinghouse PWR, 4 loops, > 1000 MW(e)				
USA	Donald Cook 1	73	15	15
	Donald Cook 2	64	19	19
	McGuire 1	70	13	13
	Salem 1	64	19	19
	Salem 2	63	22	22
	Sequoyah 1	53	35	18 (*)
	Sequoyah 2	59	31	16 (*)
	Trojan	57	18	18
	Zion 1	65	9	9
	Zion 2	68	12	12

Note: Standard Deviation 2 takes into account only plants which operated more than 1000 hours per year.
The asterisks shows the affected standard deviations.

Particularly if extraordinary events such as the backfitting programme at Kozloduy and the NRC shutdown at the TVA's plants are excluded, the standard deviations show that the energy availability of the WWER-440/230 plants varies very little from year to year compared to the US sample. It is perhaps significant that the WWER-440/230 with the highest variability and a relatively poor EAF is Novovoronezh 3, the first plant to be built, where it might have been expected that errors, avoided in later units, might have been made. The variability of the groups as a whole (see also Table 6.4) is also much less, in other words the difference between 'the worst and the best performing WWER-440/230 is much less than for the US sample.

TABLE 6.4. STANDARD DEVIATION OF THE CUMULATIVE ENERGY AVAILABILITY FACTOR

	Cumulative EAF (%)	Standard Deviation (%)
Sample 1 - WWER-440/230	78	4
Sample 7 - US Westinghouse PWR, 4 loops, > 1000 MW(e)	64	6

6.4. IMPACT OF EXTERNAL EVENTS

Table 6.5 shows that the main impact of external events has been in the most recent period, 1990-1992, when planned unavailability has risen sharply. The list of shutdowns longer than three months (Table 6.6) shows that this has been due to long refuelling and maintenance shutdowns when extensive backfitting was being carried out. By contrast, for unplanned unavailability there has been little change in the pattern through time, although there is some evidence of an increase in unplanned unavailability for Russian plants in the period 1990-1992.

TABLE 6.5. ENERGY AVAILABILITY AND UNAVAILABILITY FACTORS FOR WWER-440/230 UNITS

Country	Reactor	<1987			1987-89			1990-92			Lifetime
		EAF (%)	PUF (%)	UUF (%)	EAF (%)	PUF (%)	UUF (%)	EAF (%)	PUF (%)	UUF (%)	
Bulgaria	Kozloduy 1	77	18	5	78	20	2	36	62	2	73
	Kozloduy 2	84	12	5	79	16	5	40	56	4	78
	Kozloduy 3	87	12	1	82	16	2	70	28	2	82
	Kozloduy 4	91	8	1	89	9	2	74	23	3	85
Russian Federation	Kola 1	78	20	2	79	17	4	70	20	10	78
	Kola 2	83	16	2	81	16	3	68	22	10	80
	Novovoronezh 3	77	13	11	78	15	7	65	28	7	76
	Novovoronezh 4	84	11	5	86	11	2	69	21	10	81
Slovak Republic	Bohunice 1	75	21	4	74	23	3	78	19	3	74
	Bohunice 2	78	20	2	80	18	3	72	22	6	77
Average		81	15	4	81	16	3	64	30	6	78

Note: Lifetime means the average energy availability factor since the beginning of commercial operation.

6.5. AGEING EFFECT

It is difficult to disentangle any ageing effects from time-related events, for example the need to carry out back-fitting programmes. Back-fitting has usually been carried out at the oldest plants first. However, this has generally not been because systems have worn out, but because the safety requirements against which they were designed are furthest removed from current standards. This is partly allowed for in Figure 6.1 by excluding the performance of Kozloduy 1 and 2 in 1992, when both units where shut down for backfitting.

Figure 6.1 seems to show that the WWER-440/230s are showing some ageing in contrast to Sample 6, but Table 6.5 shows that a number of the oldest plants have undergone shutdowns of about three months for backfitting. Until this process has been complete, it will not be clear whether this apparent ageing effect is a temporary feature.

TABLE 6.6. WWER-440/230 LIST OF OUTAGES LONGER THAN THREE MONTHS

Reactor	Date (yymmdd)	Duration (hours)	Description (as reported to the IAEA PRIS Data Bank)
Kozloduy 1	750601	3672.0	Annual maintenance of the turbine.
	890724	2728.0	Refuelling, maintenance, repair.
	910904	2853.6	Repair, maintenance and refuelling.
	920101	8784.0	Unit no. 1 was out of operation during the whole year for upgrading and modernization.
Kozloduy 2	920101	8683.0	Repair, maintenance and refuelling. WANO program for backfitting.
Kozloduy 3	890416	2232.0	Refuelling, maintenance, repair
	900610	2597.8	Repair and reconstruction of turbine no. 6
	910628	3152.7	Repair, maintenance and refuelling
	920822	3152.0	Turbine no. 6 was switched off for annual repair and maintenance
Kozloduy 4	910426	2921.0	Repair, maintenance and refuelling
	920701	2802.6	Annual repair, maintenance and modification of turbine no. 8
Novovoronezh 3	890820	2640.0	Major repair of unit
	910104	3958.0	Unit shutdown for major overhaul
Novovoronezh 4	910701	3112.0	Major overhaul of unit
Kola 1	750505	3000.0	Refuelling, maintenance, repair
	790604	2502.0	Refuelling, maintenance, repair
	850624	2759.0	Refuelling, maintenance, repair
	900910	2185.0	Major repair of the unit
Kola 2	920409	2191.0	Major repair of unit
Bohunice 2	880123	2995.0	Refuelling combined with general maintenance and repair

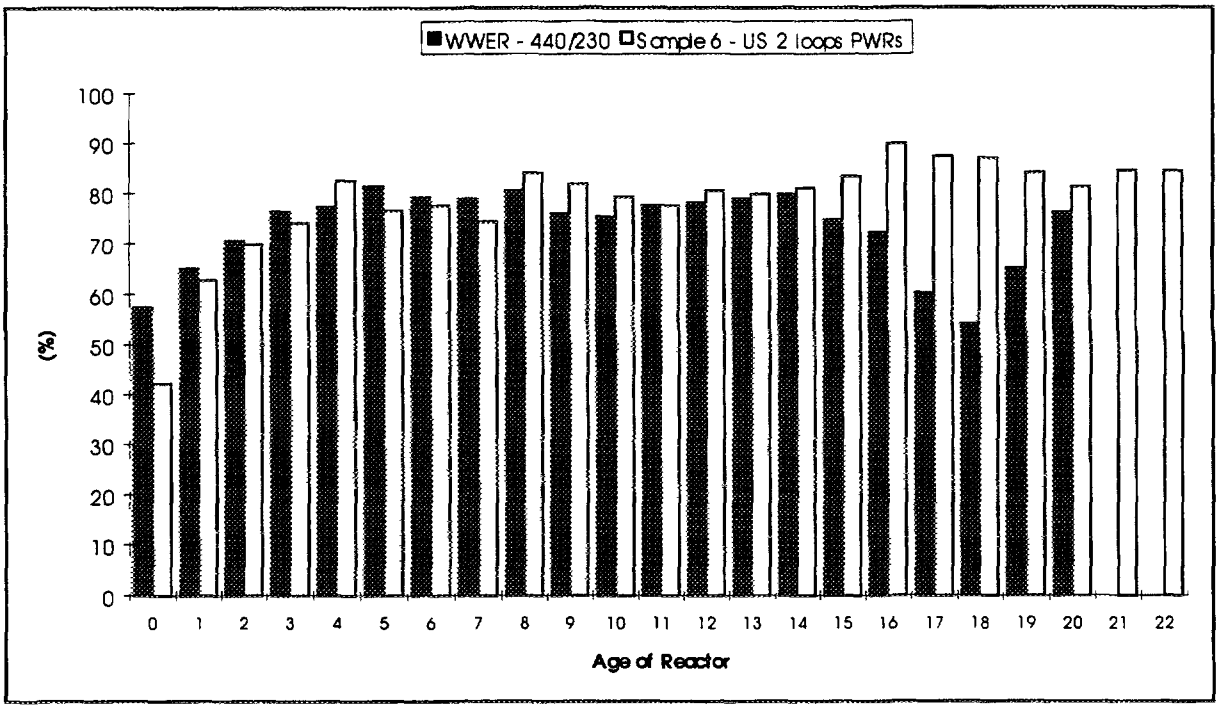

FIG. 6.1. Energy availability by age of reactor.

6.6. CAUSES OF UNAVAILABILITY

By comparison with PWRs in the rest of the World, the WWER-440/230 plants have somewhat shorter planned outage periods, but unavailability through unplanned outages is much shorter (see also Table 6.2). This basic pattern does not seem to have been affected much by events such as Chernobyl and changes in the economic situation and the political structure in eastern Europe and the former Soviet Union (see Table 6.7). The main exception to this is in the most recent period when the implementation of the back-fitting programmes has led to lengthy planned outages particularly at the two earliest Kozloduy units.

TABLE 6.7. ENERGY AVAILABILITY FACTORS BY PERIOD OF TIME

Cumulative factors (%)	EAF			PUF			UUF		
	< 1987	1987 - 1989	1990 - 1992	< 1987	1987 - 1989	1990 - 1990	< 1987	1987 - 1989	1990 - 1992
1 WWER-440/230	81	80	65	15	16	30	4	4	5
2 WWER-440/213	80	84	81	15	14	15	5	2	4
3 WWER-1000	69	65	64	17	21	26	14	13	10
4 PWR excluding WWER (world)	71	71	72	18	18	19	12	11	9
5 PWR <600 MW(e) excluding WWER	76	74	73	16	20	22	8	6	5
6 US Westinghouse PWR - 2 loops	83	84	80	14	15	18	3	1	2

6.7. CAUSES OF UNPLANNED UNAVAILABILITY

Looking in detail at the causes of unplanned unavailability, the similarities between the WWER-440/230 and its immediate successor and the contrast with other groups of PWRs continue (see Table 6.8 and Table 6.9). Again, important external events seem to have had little impact on the pattern of performance (see Table 6.10). The number of hours lost through equipment failures is very low for Sample 1 and Sample 2. Some care must therefore be taken not to give too much significance to particular statistics as one event (e.g., a failure in a particular sub-system), not necessarily typical of the group of plants will have a strong effect on the overall averages. There would appear to be no particular system that is continually troublesome and any generic faults have not yet led to significant numbers of equipment failures.

By contrast, other PWRs, in the rest of the world (Sample 4) and of the latest Soviet design (Sample 3) show much greater losses due to equipment failures and plants in the rest of the world also show a much higher level of unplanned shutdowns for reasons other than equipment failure.

TABLE 6.8. OVERALL RESULTS OF DISTRIBUTION OF EQUIPMENT FAILURES BY SYSTEM AFFECTED CUMULATIVE FACTORS IN PERCENTAGE UP TO 1992

Sample	Nuclear	Primary Generator	Steam Generator	Turbine Systems	Convent. Systems	Electrical Systems
1 WWER-440/230	24	18	35	3	8	2
2 WWER-440/213	17	43	8	6	13	8
3 WWER-1000 (1987 to 1991)	3	5	53	25	5	5
4 PWR excluding WWER (world)	17	17	27	20	6	5
5 PWR <600 MW(e) excluding WWER	17	20	15	23	9	7
6 US Westinghouse PWR - 2 loops	13	9	21	33	12	5

(N.B.: 100% = all equipment failures. Missing here outages classified as 'others')

TABLE 6.9. OUTAGES ANALYSIS BY CAUSE - CUMULATIVE UP TO 1992
(AVERAGE HOURS PER REACTOR YEAR)

	Sample 1 (WWER 230)	**Sample 2 (WWER 213)**	**Sample 3 (WWER 1000)**	**Sample 4 (PWR)**
Nuclear Systems	18.20	20.70	20.20	83.9
Primary	14.20	53.20	38.40	98.3
S.G. Systems	26.80	10.40	390.20	72.4
T.G Systems	2.40	7.00	184.20	111.1
Conventional Systems	6.10	15.50	34.60	45.6
Electrical Systems	1.60	9.30	39.70	36
Others	7.80	7.50	22.90	44.3
Total Equipment Failure	77.10	123.60	730.20	491.60
Total Unplanned	87.50	158.30	738.10	574.50
Total Planned	1382.40	1150.70	1881.20	1568.40
Total External	0.40	0.50	3.70	36.60

TABLE 6.10. OUTAGES ANALYSIS FOR WWER-440/230 UNITS.
(AVERAGE HOURS PER REACTOR YEAR)

	up to 1987	**1987-89**	**1990-92**	**up to 1992**
Nuclear Systems	13.00	19.60	37.30	18.20
Primary	2.40	13.80	52.40	14.20
S.G. Systems	25.70	46.30	25.50	26.80
T.G Systems	3.40	0.00	0.80	2.40
Conventional System	2.30	10.80	13.00	6.10
Electrical System	0.60	1.70	4.50	1.60
Others	6.40	20.90	17.10	7.80
Total Equipment Failure	53.80	113.10	150.60	77.10
Total Unplanned	54.40	118.60	197.70	87.50
Total Planned	1097.00	1312.30	2291.30	1382.40
Total External	0.60	0.10	0.00	0.40

Table 6.11 presents the analysis of forced outage frequency. The forced outage frequency is a measure of how frequently a plant has to be shut down due to problems which cannot be postponed until the next scheduled maintenance period. It excludes events unconnected to the plant, such as grid failures and strikes, but includes events which did not require the plant to be scrammed.

In some respects, this is a more consistent measure of plant reliability than the energy availability factor. Energy availability factor is adversely affected by lengthy planned shut-downs and will also reflect how rapidly a given repair is completed. The latter factor may be affected by how important power from the plant is in ensuring continuous power supplies. For example, in France where there is over-capacity in nuclear generating plant for much of the year, repairs can be undertaken at the pace which minimises costs, whereas in countries where there is a shortage of power, repairs would be completed as quickly as possible. One circumstance when the forced outage frequency may be an unreliable indicator is if the plant is off-line for much of the year. To take an extreme example, if a plant was only on-line for 70 hours in the year and it broke down once in that period, the forced outage frequency would be 100. To take account of this, data is excluded when the plant has operated for less than 1000 hours in the year.

TABLE 6.11. FREQUENCY OF FORCED OUTAGES FOR PWRS - 1987 TO 1992

	1987		1988		1989		1990		1991		1992	
	Rate	**No. of Units**	**Rate**	**No. of Units**	**Rate**	**No. of Units**	**Rate**	**No. of Units**	**Rate**	**No. of Units**	**Rate**	**No. of Units**
1 WWER-440/230	2.17	10	2.08	10	1.12	10	2.47	10	2.48	10	1.59	8
2 WWER-440/213	1.55	11	1.72	114	1.34	14	1.52	14	2.12	14	1.58	14
3 WWER-1000	8.03	7	6.16	10	7.26	13	7.46	16	5.51	16	4.02	18
4 PWR excluding WWER	4.65	153	4.22	167	3.45	179	3.04	187	2.80	189	2.39	192
5 PWR <600 MW(e)	1.42	28	1.39	27	2.15	28	1.77	28	1.76	26	1.45	25
6 Sample of 2 loops US	1.89	6	2.42	6	1.94	6	1.60	6	1.39	6	1.25	6
7 Sample of 4 loops US	4.97	8	6.39	9	4.11	10	6.95	10	3.08	10	5.26	10

Note: The frequency of forced outage is calculated as the number of times the plant suffered unplanned shutdowns in each year, normalised by 7000 hours on-line. The number of units varies from year to year, partly due to plant commissionings and plant retirements and partly because if plant is out of service for the entire year, no frequency of forced outage can be calculated.

The analysis of forced outage frequencies shown in the Table 6.11 provides additional evidence supporting a number of factors identified in other analyses. The observation that large PWRs are less reliable than smaller PWRs is confirmed for the Soviet design, the WWER, for US Westinghouse PWRs and for PWRs in general. The results also seem to reflect the efforts in recent years to reduce unplanned outages and for each of the seven samples, the frequency for 1992 is better than the average for the previous five years. In the western world, there would appear to be a consistent downwards trend in forced outage frequency mirroring the trend in scram rates. However, for subgroups, the trend is not always so clear. There is no clear trend for large US Westinghouse PWRs and for small PWRs world-wide, although there was less scope for improvement in the latter case.

In eastern Europe, the variability from year to year for the WWER-1000 plants may reflect the fact that a large number of plants entered service in the period and generally, plants suffer a higher number of unplanned shut-downs in their first year or two in service than later. The WWER-440/230 plants seem to have operated less reliably in 1990 and 1991 than previously. It is difficult to determine the extent to which this was due to: shortage of resources leading to a poorer standard of maintenance; western scrutiny leading to greater caution in operating the plant; the urgent need for power, leading to more intensive operation of the plants; or simply random variability.

6.8. OTHER PERFORMANCE INDICATORS

The performance analyses that can be drawn from the PRIS data base do not give a complete picture of the operating performance of the WWER-440/230 plants. A much fuller picture could be given using other internationally accepted measures of performance such as those used by WANO and we have tried to assemble as much data of this type as is possible. However, detailed data for each plant and for each year are not available. This is in part because most such indicators have only been precisely defined on an internationally agreed basis since 1989 and it is not always possible to calculate the indicators for earlier periods. It is also because much of this data remains commercially confidential.

Whilst the countries in eastern Europe and the former Soviet Union have attempted to provide full data on many of these indicators, the data set is far from complete. No disaggregated data is available for western plants so it is very difficult to place the data that we have collected in a wider perspective. In the following, we therefore report and comment briefly on the data we have received, but we can draw no strong conclusions from them.

Data collected during this period is presented in Annex E.

Scram rate

The world[10] PWR scram rate (per 7000 critical hours) in 1992 is about 1.0.

It is worth noting that, with the information disseminated by each operator for each site and each unit, the average number of unplanned automatic scrams for WWER-440 units in 1992, is also about 1.0, and so similar to the worldwide results. For the PWR reactors the experience feedback curve for this indicator shows a very strong decline from the early years of operation to reach the worldwide average result as observed in the last years.

Thermal performance

Thermal performance or thermal efficiency is defined as the ratio of the design gross heat rate to the adjusted actual gross heat rate.

The world values published by WANO refer to the gross heat rate. A low gross heat rate reflects high thermal performance. The world gross heat rate has been decreased and reached 10 193 BTU/kW.h in 1992. According to WANO, the 1990 industry gross heat rate was 10 218 BTU/kW.h.

According to the data provided by the plant operators, in 1990, the WWER-440/230 present higher gross heat rate than the US-PWR average. Bohunice units 3 and 4 presented in 1990 an adjusted gross heat rate of 11 353 BTU/kW.h and 11 290 BTU/kW.h, respectively, while the design gross heat rate was 11 353 BTU/kW.h. Kola units 1 and 2 presented the lower adjusted gross heat rate in 1987 (11 191 BTU/kW.h), in 1990 this value was 11 250 BTU/kW.h (this was the industry goal according to WANO). In 1990, the four units at Greifswald presented 11 428 BTU/kW.h, 10 969 BTU/kW.h, 11 002 BTU/kW.h and 11 273 BTU/kW.h, respectively for units 1, 2, 3 and 4.

Fuel reliability

There is no published world value for this indicator. According to WANO, 'the fuel reliability indicator monitors progress in achieving fuel integrity. Maintenance of fuel cladding integrity reduces radiological impact on plant operations and maintenance activities. The long-term industry goal is that units should strive to operate with zero fuel cladding defects.' There are no unavailability related to the fuel integrity in the WWER-440/230.

Collective radiation exposure

Information on collective radiation exposure was provided by Kozloduy, Bohunice, Greifswald and Kola. The collective radiation exposure indicates how effective the radiological protection programmes (including radiation control, radioactive materials) are implemented by plant management. In 1990, the average world value for PWR plants was 218 man-rem per unit (for a total of 176 units). In 1992 this value was 223 man-rem per unit (175 units reporting).

The total collective radiation exposure for all units of Kozloduy nuclear power station was 820.87 man-rem, i.e. 205 man-rem per unit. Higher values were reported from 1978 to 1981, reaching 625 man-rem per unit in 1978, followed by 346 man-rem, 334 man-rem and 306 man-rem in the period from 1979 to 1981. In 1990, Kola 1 reported 153.9 man-rem and Kola 2 presented 284 man-rem. Bohunice 1 and 2 presented 844.62 man-rem for both units, representing an average of 422.3 man-rem per unit.

[10] The world comparison is taken from the WANO Performance Indicators published in 1992.

Volume of low-level solid radioactive waste

This indicator monitors progress toward reducing the volume of low-level waste destined to disposal. Reducing the volume of waste will decrease storage, transportation and burial needs. It also reflects the attention the plant management gives to the activities that generate and process radioactive materials.

The worlwide value for PWR plants has decreased from 500 cubic meters of solid radioactive waste per unit in 1980 to 95 cubic meters of solid radioactive waste per unit, in 1990. The median value for the world PWR is 84 m^3/unit in 1992.

Kozloduy nuclear power plant reported no low level solid radioactive waste. Bohunice 1 and 2 reported together, 250 cubic meters of solid radioactive waste. Kola 1 reported 171.73 cubic meters and Kola 2, 154.38 cubic meters, in 1990. It is worth noting that all reported values are below 100 cubic meters in Kola and Bohunice presented the highest values, 294 and 297.5 cubic meters, in 1985 and 1986, respectively. Greifswald reported low and medium solid radioactive waste for all its units, representing an inventory of 768 cubic meters.

Other information

Although other information, including core average burn up and average burn up of replaced part of fuel were reported by the operators in the scope of this project, they are only presented in the Annex E.

7. THE DETERMINANTS OF OPERATING PERFORMANCE

This report has shown clearly that the central objective of the former Soviet Union's nuclear power programme was to produce plants for itself and for its satellite countries which would generate the maximum possible amount of electricity. This objective was strongly reflected in the design of the plants and the institutional structure that was built up to support the nuclear power programme. Our analysis of operating performance demonstrates that, as a group, the WWER-440/230 plants and the closely related WWER-440/213 plants have met this objective very well. Indeed, the performance achieved compares favourably with that of any other group of nuclear power plants in the world.

Whether the heavy concentration on this central objective was to the detriment of other important criteria, such as the need to operate plant safely and that the power produced should be economic, is not clear and discussion of this is beyond the scope of this report. Nevertheless, it is important to examine the factors that lay behind the consistently good operating performance achieved. There may be features of the system which it will be important not to lose in the restructuring of the electricity sector that is now under way in eastern Europe and the former Soviet Union. And while recreating the Soviet system in the West is neither desirable nor feasible, there may be lessons that could be applied in the West.

7.1. EXPLANATORY FACTORS

This section examines a number of factors, some of which have been identified as significant factors in the relative success and failure of nuclear power programmes in the West, to see whether they were significant in the former Soviet Union. The factors examined are:

1. **Strong centralised state control.** The French nuclear power programme is acknowledged to have been carried through in a highly efficient manner and this success is often attributed to the strong centralised system that underpinned this.

2. **Single design vision.** Some countries had early success, which was not sustained, with their nuclear power programmes using indigenous technologies, such as Canada and the UK. It may be that early in the history of nuclear power development, a unified group of designers had more scope to take full responsibility for conceiving and carrying through to commercial application their designs.

3. **Lack of independent regulatory control.** There may be suspicions that it may be possible to achieve better performance if safety regulation is lax.

4. **Standardisation.** One of the measures frequently suggested to improve the economic performance of nuclear power is standardisation.

5. **A Disciplined and skilled workforce.** The variability in operating performance that is found world-wide may be due to variations in the technical and managerial skills available to the plant owners.

6. **Technological prestige.** In the early period of the commercial development of nuclear power, its successful development was seen by many as important to the future of civilisation and this prestige may have led to it being given priority.

7. **Infant industry status.** While the technology was still seen as immature, but highly promising, the pressures on the designers for the technology to compete rigorously with its economic competitors would be limited allowing high materials specification and generous engineering tolerances.

8. **Size and complexity.** Worldwide smaller older designs of PWR, regardless of vendor, have tended to perform better than their larger newer counterparts.

7.2. TESTING THE HYPOTHESES

No statistical means exist which can prove a causal connection between explanatory factors of the type discussed above and the operating performance of nuclear power plants. Most of the factors are complex, interrelated and qualitative, and therefore difficult to express in numerical form. In addition, the sample size is small and performance cannot be reduced to one simple measure as is required for most formal statistical analyses. Formal statistical analyses can therefore only have limited value in explaining the performance of nuclear power plant and cannot 'prove' or 'disprove' the significance of a given factor. While not providing conclusive proof, the empirical approach adopted in the analysis of operating performance presented in the previous chapter does provide evidence that in some cases supports and in others contradicts the hypotheses presented above. Prior to examining the hypotheses in turn, the main features of performance identified in Chapter 6 are summarised.

Summary of performance

Chapter 6 showed that one of the most striking features of the performance data for the WWER-440/230s and the closely related WWER-440/213s is the low variability of energy availability across all plants and through time. The low variability through time has three features: first, the mean performance level does not fluctuate markedly from year to year; second, performance varies little between plants; and third, there is no strong time trend.

The lack of variability from year to year can be partly attributed to the fact that the plants have not yet encountered any generic faults, such as steam generator corrosion, which require lengthy shut-downs to remedy them. The lack of time-trend is also significant. Particularly from the mid-1980s onwards it might have been expected that increasing national and international scrutiny would lead to more lengthy maintenance and repair periods and more rigorous enforcement of safety rules would lead to more frequent enforced shut-downs. From 1990 onwards, there has been some lengthening of the average planned maintenance time as a specific back-fitting programmes is implemented at each plant. However, apart from this, there has been no apparent trend of longer maintenance periods and more frequent forced shutdowns.

1. Strong centralised state control

One of the most striking features of the Soviet nuclear power programme was the high degree of centralisation and the strong powers that were available to these central authorities. Chapter 2 showed the high priority that the Soviet authorities attached to the development of nuclear power and the dominant role that they foresaw nuclear power playing in electricity generation. How the priority given to nuclear power compared to that given in the West is difficult to determine, but it appears to be at least comparable to that given to nuclear power in France.

In Chapter 4, it was shown that all major decisions on all aspects of plant construction and operation were channelled through the central Soviet authorities in Moscow at the Minenergo. This Ministry had the authority to draw on whatever resources were required and to implement decisions throughout the CMEA countries. The Soviet system did not encourage opposition or local initiatives which might have weakened this line of command. Chapter 5 suggests that it was also an efficient mechanism for gathering experience from the construction and operation of plants and ensuring that this experience was utilised effectively.

Centralisation tends to lead to uniform standards, it does not ensure high standards - if the central authorities make poor decisions, these will be uniformly implemented. However, centralisation may allow valuable resources to be concentrated and may simplify overall management of the programme. Therefore centralisation does not, by itself, explain the high level of performance, although the remarkable uniformity of performance from plant to plant does seem to confirm the significance of central control. Centralisation also led to a number of other features, such as standardisation and the single design vision which are discussed below.

2. Single design vision

The industrial complex (described in Chapter 4) that developed, designed and manufactured the early WWERs was a remarkably concentrated one. The designers maintained the responsibility to see through their vision to commercial fruition. Governmental decision-making was located in only one ministry, not spread across a number as is the case now in most western countries. Safety regulation was not made fully independent until the mid 1980s, well after the WWER-440/230s and WWER-440/213s had been designed and built. The Soviet system gave no effective scope for public concerns to be aired and acted upon. The designers were therefore essentially free to produce designs which reflected only their priorities and beliefs. As these technologies were further developed, new generations of designers were brought in, other influences, such as western practice, safety-related modifications had an impact and the purity of vision of the original designs may have been lost.

As with centralisation, this lack of plurality does not guarantee high standards. If poor decisions are taken, the lack of checks and balances means that these failings may not be detected and will be embodied in the finished item. This need not matter if the product being designed does not have significant safety concerns: failings can be quickly detected and remedied. In addition, if there are other competing designs being developed these can fill any gap left if a particular design fails. Indeed, in these circumstances, the potential benefits of a 'pure' design over one compromised by the imposition of several layers of influence may be felt to more than outweigh the risks of failure.

However, these conditions clearly do not apply to nuclear power plants: inadequate safety provisions cannot be tolerated and development costs are too high for a large number of competing designs to be developed. The lack of plurality in the Soviet system must therefore be seen as risky and the risks are clearly illustrated by the Soviet nuclear power programme. The WWER-440/230s and WWER-440/213s have been shown to be highly effective as reliable generators of power and the basic design must be regarded as highly successful. By current standards, the back-up safety systems (but not the basic design) are clearly inadequate, especially for the WWER-440/230s, although it should be noted that most designs from the west of that era fall well short of the standards now required. A more pluralistic system might have led to a continuing programme of upgrading safety which would not have the left the oldest plants so far out of line with current thinking.

The weaknesses of such a monolithic system are better illustrated by the RBMKs. Like the WWER-440s, the RBMKs have proved to be highly effective as reliable generators of electricity, but the lack of checks and balances meant that a serious and fundamental design flaw was not acted upon until it was too late - after the Chernobyl disaster.

3. Lack of independent regulatory control

It was only in the mid-1980s that regulatory authorities, rigorously separated from those concerned with maximising production, were established in the former Soviet Union. And even later before distinctive national capabilities were established in the satellite CMEA countries, independent of the central Soviet authorities (see Chapter 4). Particularly in the poorer, less sophisticated economies of the region, these new agencies have faced problems due to lack of experience and their previous political dependency on the former Soviet Union, and this has made it difficult to assert distinctive national control. The national regulatory bodies were mostly involved in regulation of the operation of plants rather than in the design and construction phase. In addition, with the exception of the IAEA Incident Reporting System in which some countries participated from the mid-1980s, the plants were not completely open to international scrutiny for safety until 1989.

Given that all the plants are situated in regions that are heavily dependent on these plants for their power supplies, a decision to shut down a plant could have significant consequences for human welfare and the performance of the national economy. This heavy responsibility may have meant that there have been times when these plants were maintained on-line when an independent regulatory authority, without responsibility for maintaining power supplies, would have required that the plant be shut down and repaired. This priority on electricity production would have been reinforced by the safety systems of the plant which, for example, allowed operators to override scram signals if they believed that they were spurious. If this occurred to any significant extent, this may have allowed better operating performance than would have possible with a more conservative safety-led operating and regulatory regime.

Despite the apparent dramatic tightening of the safety regime that seems to have taken place, Chapter 6 shows that there is little indication that this has effected routine performance. The major factor affecting performance in recent years has been the programme of extensive backfitting which has been undertaken for the WWER-440/230 plants. This has led to shut-downs of a year or more for the plants affected.

4. Standardisation

Standardisation is expected to bring a range of benefits including lower component costs, simplification of licensing procedures and quicker plant construction. For operating performance, standardisation should allow experience gained at one plant to be applied at all others of the same type and that, when problems are encountered, one solution can be applied across all plants. In fact, standardisation is not a precise term and the American concept of standardisation is markedly different from that of the French and that of the former Soviet Union. Discussion of this factor therefore requires careful definition of the form standardisation has taken (see Box for a more detailed discussion of the various forms of standardisation).

As was shown in Chapter 3, the WWER-440/230 plants cannot be regarded as rigorously standardised, but they do represent a reasonably uniform group in terms of their design features and components. They are the first generation of Soviet PWRs and build on experience from two smaller earlier units installed at Novovoronezh (now retired). In that respect, the approach differs markedly from that adopted for the early gas-cooled plants in the UK where each of the nine commercial Magnox stations used a separate and distinctive design.

Standardisation alone does not inevitably lead to good performance - a poor design cannot become a good one simply by replication - but it does allow the learning process to be more effective. The greater the degree of standardisation, the more likely it is that experience at one plant can be applied directly at other plants. It is important to note that this can only be an effective process if good channels exist to collect and disseminate this information and resources are available to act on it.

Chapter 5 shows the importance of the Novovoronezh site as a centre for the promotion of the learning process with the first two units of the WWER-440/230 design being built there as well as their immediate predecessors. In addition, the presence of supervisory Russian teams at plants in the satellite countries meant that even outside the former Soviet Union, helped the process of feedback of operating experience to the designers.

Standardisation

Standardisation can have three main dimensions and it is important to be clear in what sense the term is being used if confusion is to be avoided. First, standardisation can be applied to the dimensions and materials of the design. At its most rigorous, a common set of drawings would be used for all plants of the standard design and all plants would have an essentially identical design. In practice, this level of standardisation is seldom achievable, except for units, built simultaneously or closely sequentially at the same site. The design for units on different sites will have to be modified to reflect local geological conditions and other site specific factors. In addition, as experience with early units of a series and perhaps other similar plants is gained, it is likely that minor changes to the design will be made to take account of this learning.

The French nuclear power programme was fully standardised apart from site specific features for 'tranches' of about 10 plants ordered within a period of 1-2 years, at which time experience accumulated during that period was embodied in an updated standard design. By contrast, whilst changes in the nuclear island were relatively infrequent for plants ordered in the US, the fact that orders were spread between a number of architect engineers and between a large number of utilities, who were often anxious to 'customise' the design to their own specifications meant that differences in the balance of plant were large. The 16 WWER-440/230s were ordered over a period of six years and installed on six different sites and it is unlikely that strict design standardisation would have been a feasible option. In addition, some discretion in the balance of plant was allowed, notably at Bohunice, although these changes had to be agreed by central Soviet authorities. However, there was no scope for the large degree of customisation that existed in the USA. It appears that the nuclear island was largely standard in all cases and, further, the differences between the WWER-440/230 and its successor, the WWER-440/213, were largely confined to the balance of plant and the safety features. In that respect, it may be justifiable to regard both designs as variants of an essentially standard design.

A second dimension of standardisation relates to the manufacturing of components. At its most rigorous, standardisation in this respect would require that components would be manufactured by the same supplier, from the same production line and using raw materials of the same specification and the resulting plants would be essentially identical. The French nuclear power programme was almost entirely standardised in this respect, as was the US SNUPPS programme in which the components for six plants of identical design were ordered as a batch. The WWER-440/230s were probably ordered in too small numbers to justify production line facilities for the main components which were probably fabricated on a single or batch basis. In addition, some components were supplied by more than one manufacturer, further reducing the degree of standardisation.

A third concept of standardisation refers to the functional performance of the component systems. In this sense, a plant can be said to be standardised if it meets a set of performance standards. In this form of standardisation, no design features are specified and two plants of 'standard' design could be physically entirely different. With respect to nuclear power plant, this concept of standardisation forms the basis of the current EPRI standard plant development programme. Performance criteria are specified in such a way that, in principle, any design of nuclear power plant, from PWR to gas-cooled plant could meet them. This concept of standardisation has not yet been applied to nuclear power plants that have been ordered, although clearly if plants are of standardised design and manufacture, they will inevitably meet the criteria for functional standardisation.

Overall, using the design and manufacture aspects of standardisation, the WWER-440/230s must be regarded as less standardised than the French 'tranches' of PWR, but rather more standardised than US plants of a given size and supplier. Compared to practice with early designs in other countries, such as in Britain, where each Magnox was a separate and new design, the WWER-440/230 was highly standardised.

5. A Disciplined and skilled workforce

The economic importance of the nuclear power plants, the prestige attaching to the nuclear programmes and strong central management from Moscow were powerful factors encouraging good performance from the workforce.

As noted above, the regions in which the plants were sited are reliant on these plants for their power supplies and poor performance was likely to lead to immediate local hardship. The high labour intensity of these plants meant that their construction led to the creation of a new local community heavily dependent on the continuing operation of the plant.

Relations with the central Soviet authorities were not always ideal. Whilst the central Soviet authorities were assiduous in gathering in all relevant information from the plants, the communications out from the centre were less satisfactory. Instructions frequently contained little explanation and justification. Requirements for spares had to be submitted to the central Soviet authorities and there were often delays in meeting these orders.

This meant that if the plants were to remain on-line, staff had to develop a high degree of self-sufficiency, for example, having to improvise repairs to components on site. In addition, the fact that the plants were much less automated and had much less comprehensive and rigorous procedures than is the case in the west, meant that the staff had to operate the plant using their skills rather than simply following procedures. Indeed, according to the work ethos that prevailed, consulting an operating manual would have been seen as an admission of ignorance rather than as a conscientious act. This meant that the performance of the plant was much more a reflection of the skills of the staff and this may have encouraged them to take more of a pride in their work than might otherwise have been the case.

Operating staff have good formal qualifications, usually with university degrees. The prestige of the nuclear power programmes gave operators high status and good rewards and this gave them a strong incentive to perform well enough for them to retain their position. Particularly in the early period of development of nuclear power, this may have been reinforced by a strong belief in the technology and a desire to contribute to the successful development of nuclear power.

One of the features of the operation of the WWER-440/230 group of plants was the strong links between staff responsible for the operation and maintenance of the plants and also the central (Russian) decision-making for key factors. All the operators from the first operating crews were trained at the same centre, also at Novovoronezh, and it seems that they retained personal links after this period. These informal links may differ from the western concept of operating experience feedback but they have been useful in ensuring that relevant operating experience was disseminated effectively to other sites. The uniformity of training may also have counteracted the wide range of skill bases of the countries, which ranged from Bulgaria with its relatively unsophisticated industrial base to the former CSSR which has a tradition dating back to the last century of skills in heavy electrical engineering.

The importance of strong motivation and a high level of operator skills is hard to test directly. In recent years, staff turnover at some of the plants has grown and the increased scrutiny of national and international regulatory authorities would have reduced the scope for the staff to act on personal initiative. This suggests that whilst it is highly unlikely that good staff skills and motivation were anything other than beneficial, this factor may not have been of overwhelming importance. In addition, the very high performance of the Loviisa plant which was much more fully automated has also performed very well. This plant would not be expected to benefit from any team spirit amongst WWER staff, nor is it likely that central Soviet control over the plant would have been strong. The high levels of performance may be more related to the intrinsic features of the design.

6. Technological prestige

This effect relates to the status of these plants as commercial pioneers of a new prestigious technology. The WWER-440/230s were amongst the first commercial plants to be built in eastern Europe and this may have affected their design in a number of ways. First, nuclear power technology was still new and, as noted in Chapter 2, was regarded by the Soviet authorities as a technology whose successful development would enhance the prestige of the former Soviet Union. It would therefore have been able to draw on the best engineers, designers and manufacturing skills available. Financial resources to support their work may also have been more forthcoming. It was also seen as one of the most challenging technologies being undertaken. At a national level, government funds were available to fund technology development. At a personal level, the technology was able to attract and reward the highest quality personnel who would be keen to be associated with such a high-profile and challenging technology.

7. Infant industry status

This potential factor was partly covered above in relation to the skills and motivation of the workforce. Infant industry status could also have had an impact in another way. The pressure on the technology to be economically competitive may have been less than for a more mature technology. This was especially so given the very high long-term expectations that were held for nuclear power and its role as a show-case for Soviet technology. In addition, because experience with materials was limited, it would not have been clear what materials to specify to ensure that the plant was durable over its expected life. In this situation, there may have been a tendency to allow wider operating margins and over-specify materials so that designers would be more certain of meeting their performance criteria. By contrast, cost-cutting measures aimed at matching the cost of competitor technologies may have contributed to poorer than expected performance in the USA, for example, in the corrosion that has affected steam generators. And the WWER-440's successor, the WWER-1000, which was designed with a much heavier emphasis on achieving cost targets, has also performed markedly worse than either of the WWER-440 designs.

The incidence of generic faults has been low and there has not had to be any major repair programmes to replace systems which were not durable enough. This does suggest that materials selection was indeed conservative. Material selection was not however faultless. For example, in specifying the material for the reactor pressure vessel, inadequate attention was paid to the potential embrittlement of the steel by neutron irradiation.

8. Size and complexity

The lack of new small designs with any operating experience makes it difficult to determine whether the superior performance of smaller older plants over their larger, newer counterparts can be attributed to their small size or their position in the development of nuclear power. Large plants, chosen in order to improve the economic performance by winning scale-economies, may be more complex than small plants simply because of their size and therefore more difficult to manage and maintain effectively and this may tend to result in poorer operating performance. However, large modern plants may be more complex than small old plants because of the addition of safety systems. Maintenance of these systems will tend to lengthen annual maintenance and, if they develop faults, this may lead to an unplanned shut-down which would not otherwise have been necessary. A particular problem may arise if additional safety systems are specified after the basic dimensions of the plant are determined. These could restrict working space and further complicate maintenance procedures.

It may be that the low variability in performance across plants can be attributed to the factors such as centralisation and standardisation which would tend to equalise performance (for example through learning). Even with the WWER-440/213s in Finland, which would appear least likely to benefit from interchange of information, there are good informal links with eastern Europe, particularly with the Paks plant in Hungary. But it may be that, perhaps because of its small generating capacity, the WWER-440/230 is simply a relatively undemanding design which would tend to produce good performance whatever the context.

The WWER-440/213 design differed little in many important respects from the WWER-440/230 and was able to replicate its excellent performance. The additional safety systems added do not appear to have had any detrimental effect on performance. However, the performance of the substantially different WWER-1000 design has been much poorer. Ironically, this design followed western design and safety features much more closely than its predecessors. The extent to which this inferior performance has been due to poorer design staff, cost pressures on materials and lower political visibility and therefore priority to the work is not clear. The WWER-1000 was designed with more up to date safety requirements in mind and the explanation that poor performance can be attributed to the distortion of the design by subsequently imposed safety requirements does not appear to be supported.

For example, if the deterioration in performance is due to the addition of safety systems which make plant maintenance procedures more lengthy and result in more potential causes of equipment failures, small modern designs embodying current safety standards may be no more reliable than large modern designs. Equally, if as argued above, the steady flow of new safety requirements has damaged the design logic of the existing large plants, a design of large plants, conceived with current safety and performance criteria in mind might be no less reliable than a similar small plant. However, if smaller plants are intrinsically less complex and thus easier to operate and maintain than large ones, this could account for the superior performance of the WWER-440/230s (and WWER-440/213s) compared to the WWER-1000s.

7.3. SUMMARY

While the above analysis has considered eight apparently separate factors, in reality these are largely only different facets of two major factors, centralisation and the priority status of the technology. The highly centralised, authoritarian Soviet structure inevitably led to some degree of standardisation of designs and uniformity of standards. It also allowed the designers to bring their vision to fruition with a minimum of 'interference' from regulators and the public in general which may have meant that the designs could retain a simplicity that would not otherwise have been possible.

The high priority attaching to the successful development of the technology meant that the best physical and human resources were available. It also reduced economic pressures which might have led to lower specification materials and perhaps attempts to gain economies of scale by building larger plants.

Centralisation is likely to lead to uniformity of performance, while high priority attached to the technology is likely to increase pressure to ensure that the goals set for it are met. There exist no statistical means of allocating credit amongst the possible contributory factors any more precisely for the success of the WWER-440/230s in meeting their main objective, that of reliable electricity generation.

APPENDIX
ENERGY CO-OPERATION DEVELOPMENT IN CMEA COUNTRIES

A. 1. PIONEERING PERIOD (1955-1970)

A. 1.1. Foundation laying (1955-early 1960s)

General features of the period

This was the period of post-war reconstruction effort. Some quantitative goals of industrialization, along with improvement of general standards of living of the population, were pursued. The creation of a regional energy infrastructure, including pipelines and electric transmission lines, became a priority.

After some years of lethargy, the Council for Mutual Economic Assistance (CMEA) was revitalized in 1956 by the establishment of eight Standing Commissions but disagreements among CMEA members and failures to deliver promised assistance and equipment hindered the effectiveness of co-operation. The supply of energy remained within the ministerial system even after members' administrative and managerial reforms. The "division of labour" resulted in a regional/national responsibility; each partner in an agreement was considered responsible for completing the portion of infrastructure, e.g. pipeline, passing through its own territory.

"The CMEA policy on decision-making was that all member States with an interest in a particular question must concur with a decision" (Reisinger, p. 23). The energy agreements, generally, were bi- or trilateral with the former Soviet Union in the role of major partner.

Energy sector

In December 1958, the construction of the so-called Druzhba (Friendship) oil-pipeline was agreed. This had branches reaching from Byelorussia to Poland and the former GDR in the North, and the former Czechoslovakia and Hungary in the central area.

In 1959 during the XI CMEA Session, the first step was agreed towards linking the countries' electric grids into a regional power system called MIR (peace). At this stage, the regional system would have connected, by means of 110 and 220 kV lines, the European region to the European Power System of the former USSR (in that period still a work in progress).

Nuclear sector

During the 50s, after the experience of the AM-1 prototype at Obninsk (1954), of the Siberian Nuclear Power Station (1958) and of three small pressurized reactors for the propulsion of the "Lenin" ice-breaker (1956-1959), the Soviets were able to offer technical and economic assistance to their partners regarding: laboratories, reactor prototypes and personnel training. Two types of agreements were made in this period: for nuclear research in civil field and for development of nuclear reactor prototypes. Within the limits of the former, the nuclear research centres of Rez in former CSFR, Rossendorf in the former GDR, Swierk in Poland, besides those in Budapest, Sofia and Bucharest, were built. The Institute of Dubna, founded in 1956, became the most important training centre for scientists and technicians of CMEA member States.

In 1955, the former Soviet Union and the former CSFR agreed to build in Bohunice an experimental gas-cooled, natural uranium, heavy-water moderated reactor prototype (about 150 MW(e)). It seems this project was proposed by the Soviet Union to its partner as a co-operative project, but it remained mostly under the control of the Soviet side. In fact the reactor, along with all necessary technical assistance, should have been supplied by the former Soviet Union. The prototype should have been finished by 1960 but it only went critical in December 1972, achieving full power in 1974[11]. This reactor remains the only attempt in the CMEA region to carry out the development of a new design region outside the Soviet Union.

In 1956, the former Soviet Union and the former GDR agreed to build a pressurized water reactor prototype (70 MW(e)) at Rheinsberg. Construction started only in 1960 and was finished in 1966. The Soviet Union specified the general layout and supplied the vessel, pumps and turbine-generator, while the GDR was responsible for steam-generators and other smaller components. A third agreement regarding a 100 MW(e) reactor was signed with Hungary, also in 1956, but it was quickly abandoned.

A. 1.2. The first steps (early 1960s- 1971)

General features of the period

Due to the failure of Khrushchev's 1962 call for a supranational CMEA planning, "bilateralism" remained the general rule for the 60s, but considerable effort was devoted to accelerating the integration process. Late in the 60s the CMEA partners "began agreeing to help develop Soviet resources' exploitation in return for Soviet exports of resulting energy" (Reisinger, p. 50).

Very long term energy planning began in 1962 with aggregation and iteration to formal consistency of a CMEA energy balance to 1980. Producing a projection of an energy balance became the prime duty of the Bureau for Integrated Planning Problems set up within CMEA's Executive Committee when it was established in 1962.

Gas trade between the Soviet Union and its east European partners began to be significant.

Energy sector

In December 1964, the former Soviet Union and the former GDR agreed to build a new pipeline, Bratstvo (Brotherhood) to increase gas import/export. In 1970 the same partners agreed to construct another gas pipeline, Transgaz, that had to serve several countries and was to be extended to the Austrian border.

In 1962 as a consequence of several previous agreements, the Central Dispatch Administration was established in Prague, to operate the MIR grid. The first steps towards the great electric interconnection were made:

- by 1962 six transmission lines (220 kV), connecting the power systems of Hungary, the former GDR, Poland, the former Soviet Union and the former CSFR were completed;

- by 1967 Romania was connected with the former USSR, the former CSFR and Bulgaria so completing the interconnection "ring".

Nuclear sector

The former Soviet Union with the experience gained from Novovoronezh 1 and 2 (completed in 1964 and 1969, respectively) and Rheinsberg increased its mastery of pressurized water reactor

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[11]The reactor was shut down in 1979 as a result of investigations following an accident which happened on February 1977.

technology. In 1967, construction of the first two units of the unified model WWER-440/230 (Novovoronezh 3 and 4) was started.

In 1965, the former Soviet Union and the former GDR agreed on the construction of two WWER-440/230 plants in Greifswald (also known as Nord or Bruno Leuschner). One year later, an agreement with Bulgaria was signed for the construction of two more WWER-440 units at Kozloduy. In 1970, the 1966 agreement to build Paks (in Hungary) was reviewed and an agreement with Romania for the construction of one WWER-440 plant (Olt river) was also concluded. In the same year, the former Czechoslovakia took the decision to build two WWER-440 units (V-1) in Bohunice and, later on, two more units (V-2) in Dukovany[12].

"Typically, these agreements for constructing NPPs specified that the Soviet Union would provide the general layout, give equipment and materials, provide the fuel and receive and send specialists" (Reisinger, p. 51).

In 1970, construction works started at the Kozloduy and Greifswald sites, given that work at Bohunice was initiated only in 1974, these two units were the last of the first WWER generation to be built. The Soviet-Finnish agreement (1970) to supply two WWER-440 gave rise, subsequently, to the formulation for the first time, in the former USSR of a complete set of requirements for the safety of nuclear power plants.

A. 2. THE COMMERCIAL PERIOD (1971-1991)

A. 2.1. The first decade (1971-1981)

General features of the period

The first oil crisis, with the subsequent rise in the price of fossil fuels sharpened interest in nuclear power generation; while the ambitious agreements signed in previous decade, which obliged the former Soviet Union to deliver six complete reactors to its partners, in addition to reactors it had planned for itself had already provided a strong incentive to Council's member States to pool their economic and technological resources.

In response, a series of bilateral agreements signed in the middle 1970s called for joint work in producing equipment for nuclear stations and specified that the former Soviet Union was to provide information and documentation, which the other parties would use to build and ship to the former Soviet Union a certain amount of equipment (Reisinger, pp. 54, 55). In 1974, former Czechoslovakia took over production of the WWER-440 nuclear reactors and among the other goals of the Xth Soviet Five Year Plan (FYP) the enormous Atommash works, for serial production of reactor vessels, had a decisive place.

In 1975 a *Co-ordinated Plan of Multilateral Integration Measures* was decided for the 1976-1980 period, and from 1976 five broad production sectors were selected for *Long Term Target Programmes of Co-operation* (LTTP). The Long Term Programme was a technique for planning supplies across traditional ministerial boundaries introduced within the former Soviet Union by Gosplan in the 50s, similarly the LTTPs cut across conventional procedures by requiring that its formulation in a co-ordinated Plan is a distinct constituent of each members' Five Year Plan (Kaser).

For the Council FYP (1976-1980) it was agreed that nuclear components would still have to be supplied according to bilateral agreements drafted between the Soviet v/o Atomenergoexport

[12]At least other two Soviet-Czech agreements are mentioned in the literature, but they were either abandoned or metamorphosed in the definitive, 1970, agreement regarding the two units for Bohunice.

(previously Technopromexport) and each counterpart separately. Afterwards Interatomenergo had to become responsible for supplying equipment - or if it was the case the whole plant[13].

The strategy to develop the great electrical interconnection become part of the nuclear development strategy.

In January 1975, CMEA announced a change in the method of determining CMEA trade prices for raw materials and energy. The new method applied a moving average to the previous five years' prices. This meant that the former Soviet Union would pass on the western price hikes for oil and gas to the east Europeans more quickly than under the existing formula[14] (Reisinger, p. 55).

Since the late 1970s, the energy intensity and the energy use per capita in the CMEA area have been higher than, for example in the European Community. On the other hand, the CMEA member States economies experienced simultaneously and persistently " shortage and waste"; to describe this intrinsic contradiction, a Hungarian scholar coined the phrase " shortage economy ".

Energy sector

Several agreements regarding the construction of pipelines to transport gas were signed during the 70s; generally they included some recompense for Soviet capital investment, to be repaid by following gas deliveries (Soviet-Hungarian Agreement in 1971 for the second branch of the Bratstvo, Soviet-Polish Agreement in 1973). The General Agreement on Collaboration in the Opening of the Oremborg Gas Deposit and The Construction of a Gas Pipeline, Soyuz, from Oremborg to Uzhgorod and from there to the Central Europe (Romania, Bulgaria and the former Czechoslovakia) was signed in 1974.

Oil also received considerable attention in the 70s (Soviet-Polish Agreement in 1975, Soviet-Hungarian Agreement in 1977). Two energy-related associations were established to deal with oil exploitation, Petrobaltic in 1975 (the former Soviet Union, the former GDR and Poland), Internefteproduct in 1978.

Nuclear sector

In 1970, with the first two WWER-440/230 units under construction at Novovoronezh, and with the almost contemporary construction of the first two RBMK 1000 units at the Leningrad and Kursk sites, the Soviet nuclear choice was already made. The IXth FYP (1971-1975) projected the installation of 7400 nuclear Megawatts and the following Xth FYP (1976-1980) decided on a massive resort to nuclear power west of the Urals (13000-15000 MW(e) should have entered into operation).

In 1974 the "Nuclear Safety Regulations for NPPs" (PBYa-04-74)and in 1976 the "Radiation Safety Standards" (NRB-76) were issued in the former Soviet Union.

Early in the 70s, the Standing Commission for Peaceful Use of Atomic Energy formed seven Councils for Scientific and Technological co-operation acting in the following areas: Research Reactors (Romania), Fast Neutron Reactors, Material Testing and Waste Treatment (former Soviet Union), Depleted Fuel Reprocessing (former CSFR), Water Problems and Radiation protection in NPPs (former GDR).

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[13]According to DOE document (see Bibliography), it seems that the passage of orders between Atomenergoexport and Interatomenergo took place, effectively, only in 1985.

[14]During the previous period, Soviet terms of trade with the six European members of the Council deteriorated by 20 %. The new formula of lagged world market prices remedied this from the Soviet standpoint (Lavigne).

In 1971-1972, the construction of the two Loviisa reactors started in Finland. Representatives of a unique mixture of Soviet design, American (Westinghouse) containment and German (Siemens) instrumentation and control systems, they can be considered as the precursors of the second (and may be also of the third) WWER generation. Second generation (WWER-440/213) reactors were built later on at Kola (3 and 4) and Rovno (1 and 2) in the former USSR, Bohunice (3 and 4) and Dukovany (1, 2, 3 and 4) in the former Czechoslovakia, Paks (1, 2, 3 and 4) in Hungary.

In 1974, Poland was the last partner to sign an agreement with the former USSR for the construction of two nuclear reactors; the former GDR (1973) and Bulgaria also signed agreements to enlarge Nord and Kozloduy respectively with other units.

In 1975, the former Czechoslovak government decided to build the two units (V2), previously planned for Dukovany at Bohunice and using the 213 design rather than the 230 (Soviet-Czech agreement in 1976). Other Soviet-Czech agreements were reunited in the "Program of Collaboration in Atomic Energy in Czechoslovakia through 1990 ".

In April 1976, the Soviet Union agreed to supply two WWER-440 reactors to Cuba. Like the Finnish reactors, these two units had to incorporate a containment structure as well as a number of additional safety improvements, for this reason these reactors are sometimes referred to as Model 318.

At the end of the decade, following the former GDR example[15] (Stendal), Bulgaria signed an agreement to add two 1000 MW(e) units at Kozloduy.

The installation of several 400 kV lines - mainly connecting Hungary, Romania and the former USSR along with the availability of more powerful turbine-generator sets (500 MW) paved the way towards the upgrading of the interconnection strategy: greater capacity installed per site, high voltage transmission lines (750 kV) which were generally to be originated at Soviet NPPs. The first step was the multilateral Agreement of February 1974, which foresaw a 750 KV line connecting Vinnitsa (former USSR) and Albertirsa (Hungary). In 1976, the XIII CMEA Session approved the so-called General Scheme of Unified Power Systems. In 1977, the previous agreement was replaced by the *General Agreement on Collaboration in the Long Term Development of the Unified Electric Power System through 1990.* The agreement, which incorporated the previous Albertirsa-Vinnitsa line, foresaw two more great transmission lines, one was to go from Khmelnitski NPP (former USSR) to the Polish city of Rzeszow and further to Czechoslovakia; the other would go from South Ukraine NPP, through Isacca in Romania, to Dobrudja in Bulgaria. All the States except Romania signed that agreement to build the former on March 1979 (Reisinger, p. 49), while the former Soviet Union, Bulgaria, Romania formalized the latter project in 1982. In both cases, the east Europeans agreed to help construct the NPP that would supply the electricity.

Atomic power seemed the only economical long term source of electricity, and the 1977 General Agreement listed atomic energy and energy conservation as the main means to satisfy the forecast needs of the economies for electricity.

Long-term nuclear planning began late in 1970, in the context of negotiating the LTTP. In 1978, the *Energy, Fuel and Raw Material Programme* placed a high priority on the development of nuclear power to the year 1990 and the *Machine Construction Programme* called for a great east European role in providing nuclear equipment. The 1979 agreement for *Multilateral Specialization and Co-operation in the Production and Mutual Delivery of Equipment for Atomic Power Station through 1990* formalized this understanding. Under the terms of this agreement, former Czechoslovakia would

[15] In the literature are mentioned at least two previous agreements, the first of which foresaw eight nuclear reactors and the second only four for the Magdeburg station, but both were not implemented.

continue to be a major CMEA supplier of nuclear equipment,[16] eventually including the WWER-1000 (Reisinger, p. 58); in that period, the first unit of this kind was still under construction at Novovoronezh.

As the states were working out an effective division of labour in the nuclear power industry, agreements on east European aid for Soviet facilities began to appear. The biggest project was the building of a plant at Khmelnitski. The former Soviet Union, Poland, the former Czechoslovakia and Hungary signed the agreement in March 1979 (Reisinger, p. 59). The east Europeans were to receive electrical power from 1984 through 2003 in proportion to their investment, and the plant was to send one-half of the electricity produced into the MIR system. Other agreements of this type include that Polish-Soviet, in 1980, regarding assistance in the building of Kursk and Smolensk NPPs; the Romanian Agreement, in 1981, regarding assistance in the building of South Ukraine NPP.

Since 1978, the Interatomenergo had issued more than two hundred documents, based upon Soviet standards and rules, covering the following items:

- Nuclear safety
- Reliability and quality in NPP
- Design of NPP (organizational structure of design, procedures of design)
- Components and pipes in NPP (standards and codes for calculation, materials, welding, etc.)
- Building of NPP
- Start-up of NPP
- Operation of NPP.

A. 2.2. The second decade (1981-1991)

General features of the period

The lack of a clear political leadership - following Brezhnev's death in 1982 and the two subsequent interregna of Andropov (1982-1984) and Chernenko (1984-1985) - along with the consequences of a persistent economic crisis led to general stagnation. Bilateralism again became the predominant form of co-operation. Even bilateral economic co-operation was in decline, however (Reisinger, p. 51).

Some efforts were made to reorientate general energy policy (also due to environmental concerns) towards promotion of increasing energy efficiency and savings; but the governmental conservation policies remained no more strictly enforced than in the West.

The previous tendency to substitute natural gas for oil was strengthened. In the long term energy strategy, natural gas was considered a sort of "transition fuel" which would have bridged a future coal and nuclear powered electricity production.

The Soviet Union, implementing the new pricing formula, tried to reduce the heavy subsidization of CMEA partners' economic development. Another aim of this policy was the establishment of higher quality standards for commodities imported as payment for fuel expenditures.

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[16]The Czechoslovak industry (SKODA Plzen - reactor vessel -, VZKG Ostrava - steam generator and pressurizers -, SIGMA Lutin and Modrany - feedwater pumps, pipes -, SES Tlmace - steam separators, etc.) succeeded in its effort providing, e.g., 21 reactor vessels.

Energy sector

The ambitious objectives of the 1985 Comprehensive Agreement were quickly scaled down, being clearly unfeasible. During the XLIV CMEA Session the so called "Collective conception of the Socialist International Division of Labour from 1991-2005" was defined, in which a "common market" was outlined.

The level of Soviet fuel exports to east Europe began to decline, with the only exception being gas, whose exploitation and export grew steadily during 80s. In this regard, a new pipeline, Progress was agreed and constructed to join Yamberg to Uzhgorod. East European again had responsibility for a section of the line in return for deliveries of gas over a twenty-years period.

Nuclear sector

Several agreements were signed in this period, some of them dealing with the new, unified, 1000 MW(e) units - WWER-1000/320 -, but they rather represented a follow-up of the strategy established during the 70s than new impulses to CMEA nuclear policy.

Romania, the maverick of the group, which already in 1978 had signed an agreement with Atomic Energy of Canada Limited (AECL) for one CANDU reactor, in July 1981 placed an order for a second unit and started negotiations - with also the participation of Ansaldo (Italy)/GE (USA) - for three more units, thereby introducing a deep crack in the homogeneity of the nuclear area.

A new key document, "General Safety Regulations of Nuclear Power Plants during Design, Construction and Operation" (OPB-82) was issued in former USSR in 1982. Later on, in 1988, this document was further updated (OPB-88).

In 1985, a special organization called ISKO was established, within the Interatomenergo framework, to collect information relevant to equipment failures and defects (by means of ad-hoc questionnaires distributed to NPPs), to store these data in an international data bank, to spread every three months the information collected to countries in which NPPs were in operation and/or in which the components and systems were produced. The Information System for Incidents (ISI) was organized by several council members Regulatory Authorities always within the Interatomenergo framework.

The halt to nuclear development arrived in April 1986 with the Chernobyl accident. Despite the new "Comprehensive Program on Scientific-Technical Collaboration" signed in 1985 - and in which the nuclear sector was one of the five areas of emphasis - and despite the following new protocol signed during the XLIII CMEA Session "supplementing, specifying and extending over 1991-2000" the 1979 Agreement on co-operation in nuclear equipment, the CMEA, the policy of nuclear development came to an end.

The earthquake in Armenia (1988) led the Government of Armenia to shut down permanently Armenia 1 and 2 reactors in 1989. In 1990, as a result of governmental decisions, the operating units of the Greifswald NPP were shut down and construction of the remaining units abandoned.

In 1989, a meeting of the members of the Council of National Regulatory Bodies in the Field of Nuclear Energy (the former GDR, Bulgaria, the former CSFR and former Soviet Union) was held in Berlin. The participants agreed on the "Position Paper of the National Regulatory Bodies in the field of nuclear energy with regard to the backfitting and safe operation of NPP units of the first generation with reactors type WWER-440". The 16 requirements of the protocol were based on the statement that the safety level of the WWER-230 model was insufficient as compared to the modern safety level and that measures had to be taken to raise it.

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ANNEX A
GENERAL PLANT DESCRIPTION
OF THE REFERENCE UNIT WWER-440/230

1. CORE CHARACTERISTICS, REACTIVITY CONTROL, PRIMARY CIRCUIT

1.1. Core Characteristics

1.	Fuel material:	UO_2
2.	Discharge burn up (MWd/t):	32000
3.	No. of fuel assemblies:	312 + 37
4.	No. of fuel rods:	126
5.	Average core power density (kW/dm³):	84.4
6.	Linear average power density (W/cm):	125
7.	Cladding material:	ZrNb 1.0
8.	Linear average power density (W/cm):	0.65
9.	Active core length (m):	2.42
10.	Average reload enrichment (%U234):	2.4
11.	Average reload enrichment (%U235):	3.6
12.	Method of refuelling (off or on-power):	off-power
13.	Design frequency of refuelling:	yearly
14.	Part of core withdrawal (%):	33.3

1.2. Reactivity Control

1.	Means of reactivity control	
	No. of control rods:	37
	Liquid poison (Yes or No):	Yes

1.3. Primary Circuit

1.	Number of primary loops:	6
	Material:	X8CrNi18.12Ti (08X18H12T)
2.	Number of primary recirculation pumps:	6 Type: GZEN-310
	Power (kW):	~2200
3.	Number of primary isolation valves:	12 Type: wedge-type sluice valve
4.	Coolant inlet/outlet temperature (°C):	
	Water inlet temperature (°C):	265
	Water outlet temperature (°C):	293
5.	Core coolant pressure (Kg/cm²):	125
6.	Steam generator:	
	Number of steam generators:	6 Type: PGV-4E
	Thermal power (kW):	229,200
	Primary side mass flow (t/h):	≥6500
	Steam output mass flow (t/h):	452
	Steam pressure (Kg/cm²):	46.0
	Feedwater inlet temperature (°C):	225/158 (with/without HP preheaters)
	Shell material:	
	Tubes material:	22 K (carbon steel)
7.	Reactor vessel main characteristics	X8CrNi18.10Ti (08X18H10T)
	Design pressure (Kg/cm²):	125
	Design temperature (°C):	283.5

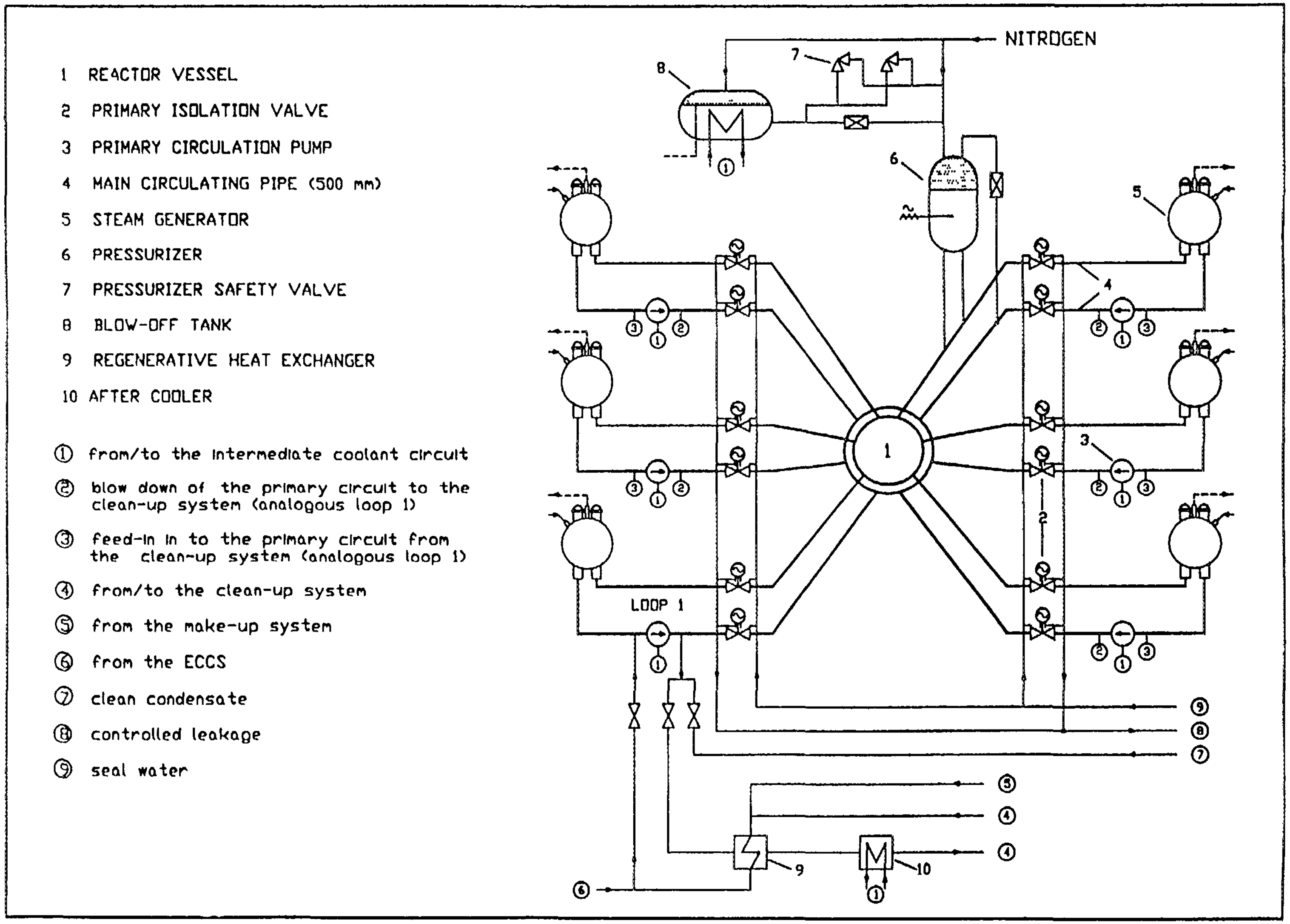

Fig. 1. Primary Circuit, Performance Analysis of Old Pressurized Water Reactors

2. PRIMARYCIRCUIT SUPPORT SYSTEMS

The main support systems of the primary circuit are the Clean-up System, the Make-up and Sealing WWater System, the Intermediate Cooling System for the Main Circulating Pumps and the Intermediate Cooling System for the Rod Driving Mechanism Cooling. General description of these systems (without Sealing Water System), characteristics of their main equipment and flow diagrams are given below.

The design of all these systems based on the main design principle of the WWER-440/230 reactor type project: Due to lack of possibilities to cover large LOCA, all connection lines to the primary circuit (with exception of surge lines to the pressurizer) are pipes with flow restrictors, which lead to leakages lover than diameter 32 mm (Design Basis Accident - LOCA) in case of leak or break. For that reason also all connections of these support systems are performed with low diameter and these systems are low capacity systems.

2.1. Clean up System

General Description

High-Pressure, Low-Temperature Ionite unit, with regenerative heat exchanger and post-cooler, using preSsure difference by primary circulating pumps

Main Components

Number of pumps:	-	Type: - Power (kW): -
Rated mass flow (t/h):	20	
Rated head (m of H_2O):	45 to 50 (from PCP)	
Number of heat exchangers:	2	Type: RHX; Post-cooler
Number of filters:	3	Type: CF,AF,MBF
Number of demineralizers:	-	Type: -

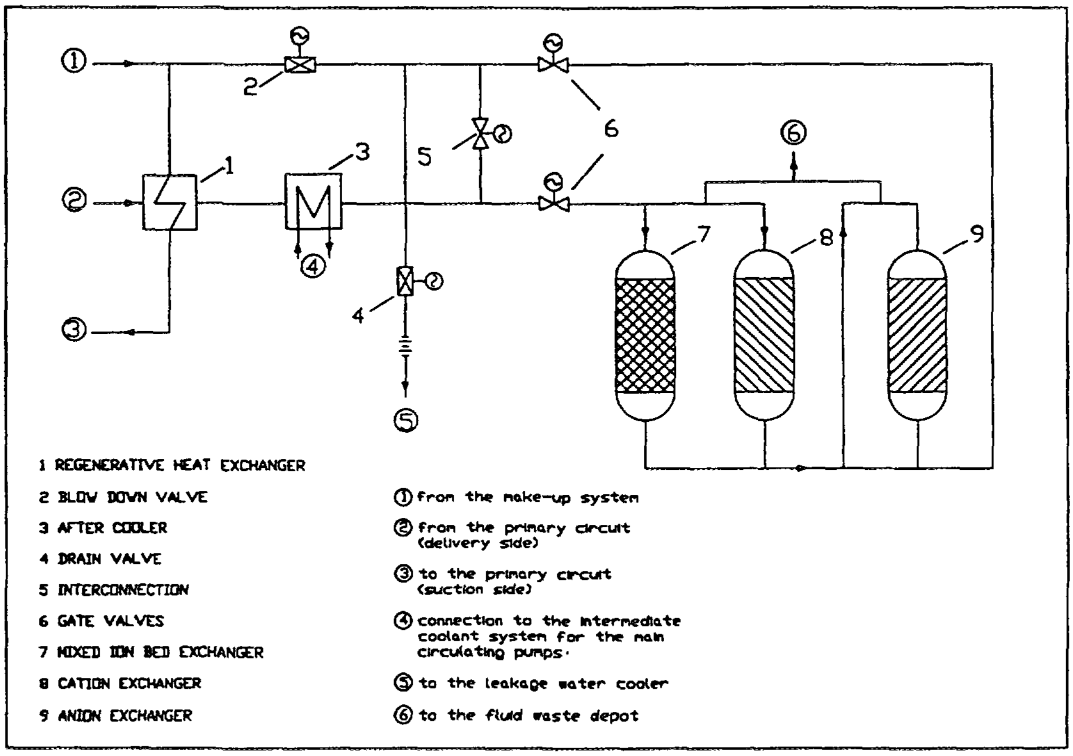

Fig. 2. Clean-up System

2.2. Make up System

General Description

Low power feed-in system in primary circuit with preheater and deaerator and dosing lines for H_3BO_3; NH_4OH; N_2H_4; KOH

Main Components

Number of pumps:	3	Type: TP 6.3/160 (Plunger pump)	Power (kW): 40
Rated mass flow (t/h):	0.6 to 6.0		
Rated head (m of H_2O):	1600		
Number of tanks:	-		
Volume (m^3):	18 (deaerator)		
Number of deaerators:	1	Type: -	

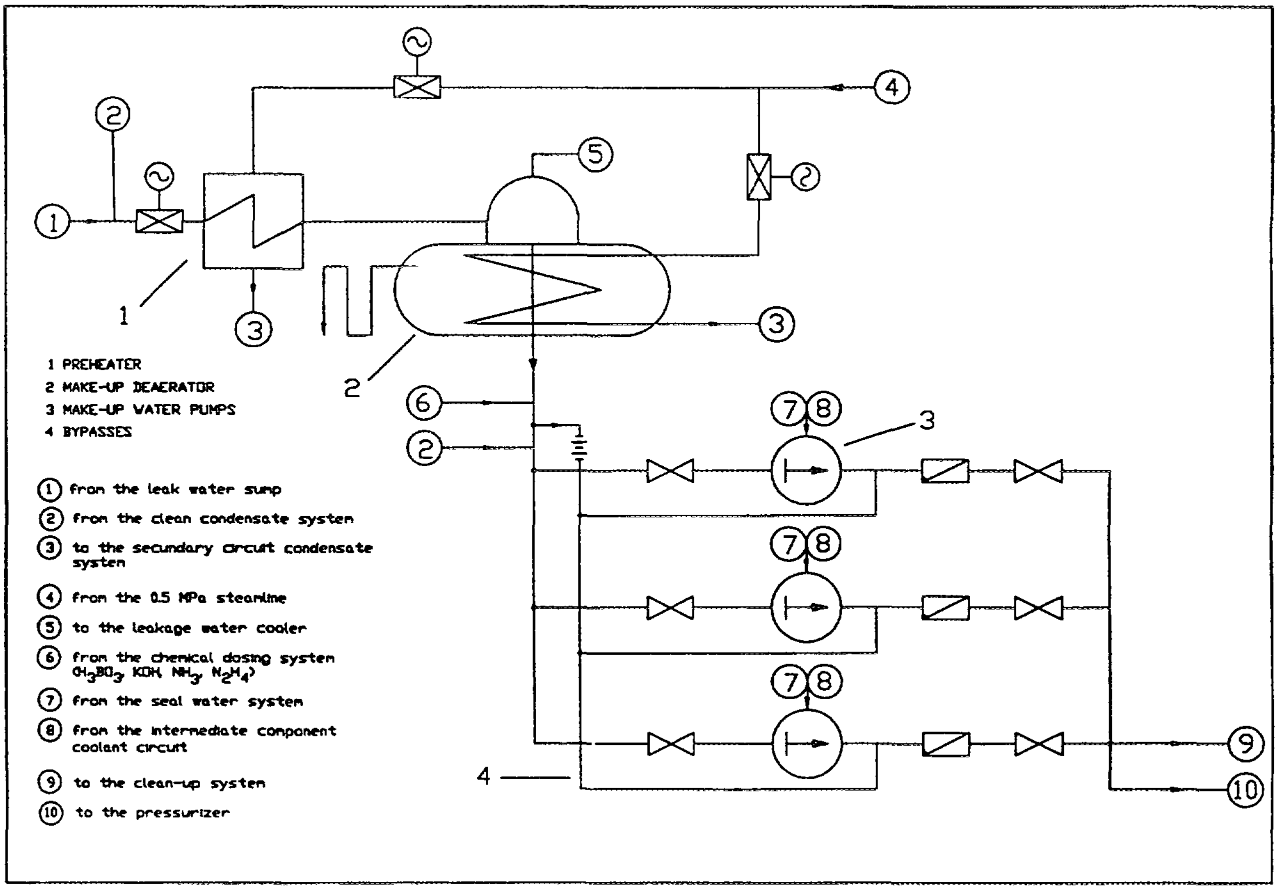

Fig. 3. Make Up System

2.3. Intermediate Cooling System for Main Circulating Pumps

General Description

Cooling system for several cooling functions in the area of the main circulating pumps (MCP) (coolers of the autonomous cooling circuit, fan cooling, stator and bearing cooling), for blow-off tank cooling and after cooler of the Clean-up System with heat sink, cooled by the Service Water System.

Main Components

Number of pumps:	3	Type: 6H B-60	Power (kW): 27
Rated mass flow (t/h):	360		
Rated head (m of H_2O):	33		
Number of heat sink heat exchangers:	2	Type: Water cooled/straight-tube	
Number of tanks:	2		
Volume (m^3):	40 (buffer tank), 25 (emergency tank)		

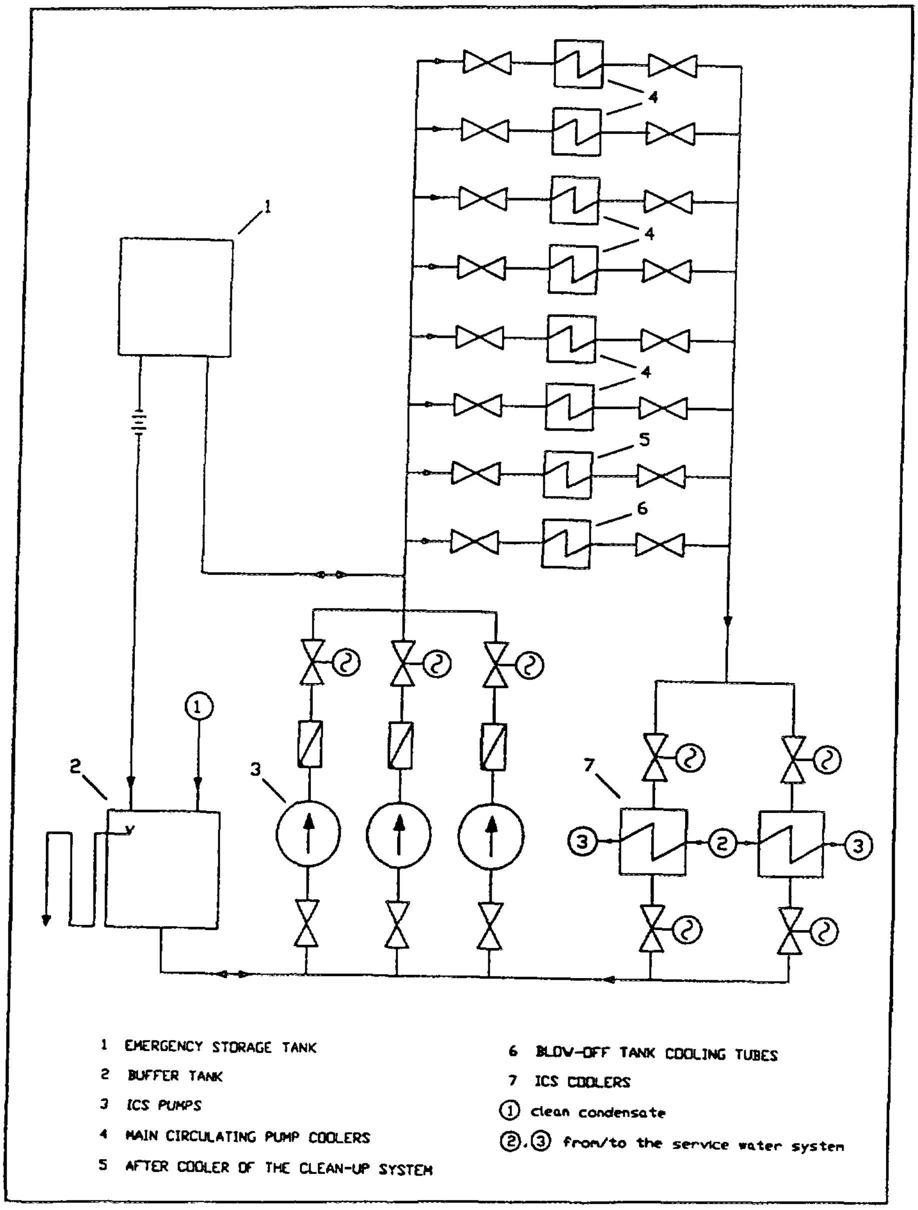

Fig. 4. Intermediate Cooling System for Circulating Pumps

2.4. Intermediate Cooling System for Rod Driving Mechanism Cooling

General Description

Closed cooling system for rod driving mechanism cooling, consisting of pumps, filters, heat exchangers and buffer tank, cooled by intermediate cooling system for component colling (ICCS).

Main Components

Number of pumps:	3	Type:	ZNS-38-88
Rated mass flow (t/h):	38	Power (kW):	17
Rated head (m of H_2O):	88		
Number of heat sink heat exchanger:	2		
Number of tanks	1	Type:	Water cooled straight tube heat exchanger
Volume (m^3):	0.84		
Number of filters:	2		
Size: Diameter (mm):	220		
Length (mm):	500	Type:	Mechanical, with perforated mesh element

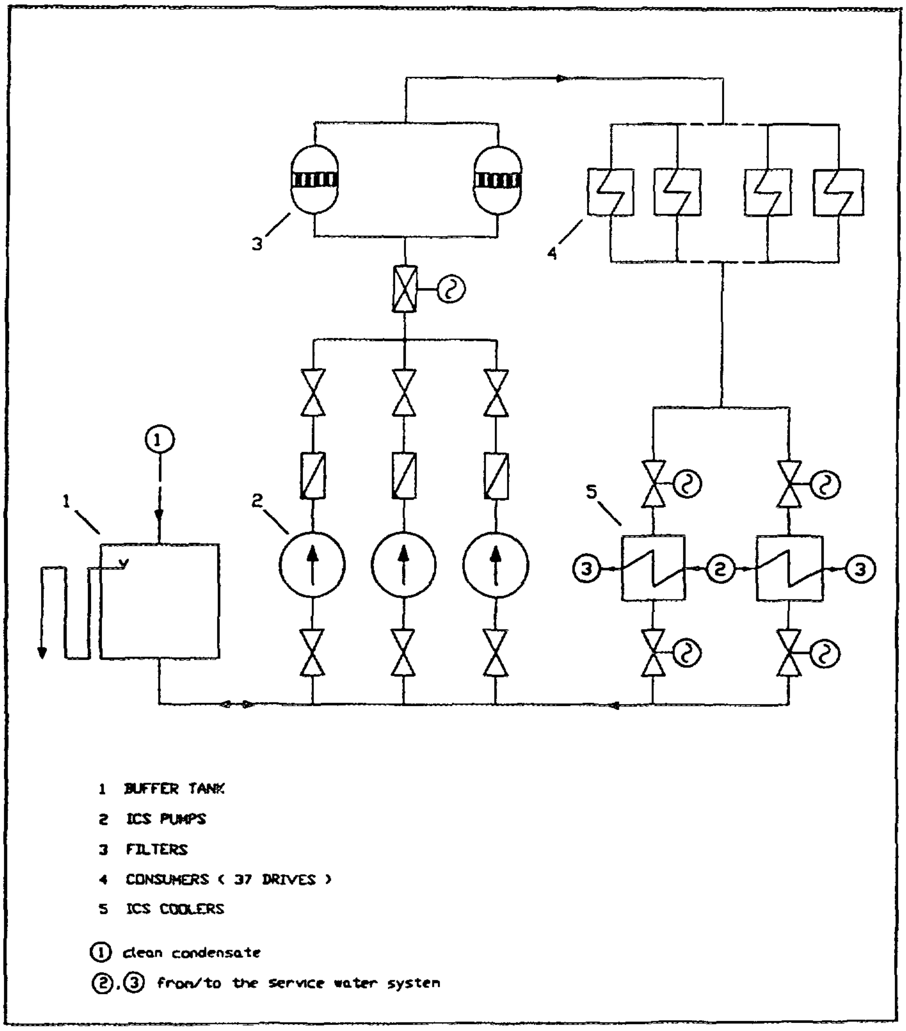

Fig. 5. Intermediate Cooling System for Rod Driving Mechanism Cooling

3. EMERGENCY CORE COOLING, PRESSURE CONFINEMENT AND SPRAY SYSTEM

As previously mentioned the design based accident (DBA) of WWER-440/230 plants is a LOCA, following rupture of pipe diameter 100 mm in the primary circuit with flow restrictor diameter 32 mm.

For that reason these units have only low power Emergency Injection Systems, which can be actuated by high and low pressure in the primary circuit.

In case of LOCA the radioactivity released in the environment is limited by means of the so-called Pressure Confinement System. That means, that the whole equipment of the primary circuit is located in special compartment rooms, which are able to cover about 1 bar over pressure.

Limitation of the overpressure in the confinement in case of LOCAs below DBA and in case of DBA will be performed by means of the Confinement Spray System.

3.1. Emergency Injection System

General Description

The Emergency Injection System is able to feed in the primary circuit on high and low pressure conditions. It consists of pumps, emergency boron water tank and it is connected with the sump in the steam generator compartment room. In case of loss of offsite power only two pumps (one per train) can be actuated.

Main Components:

Number of loops:	2
Number of principal pumps:	6
Type: EP-50	(Greifswald -1, 2; Kozloduy-1; Novovoronesh-3, 4; Kola-1, 2; before backfitting)
Power (kW):	400
Shutoff or rated head (m of H_2O):	1350 - 1160
Rated volume flow (m^3/h):	48
Type: ZN-65/130	(Greifswald-3, 4; Kozloduy-2, 3, 4; Bohunice V-1)
Power (kW):	380 - 520
Shutoff or rated head (m of H_2O):	1350 - 450
Rated volume flow (m^3/h):	65 - 150
Emergency boron water tank volume (m^3):	800 - 850

3.2. Pressure Confinement Spray System

General Description

The Low Pressure Confinement Spray System is able to feed-in the confinement atmosphere in case of LOCA and to cool the boron water and coolant reflux mixing, if temperature in the emergency boron water tank is higher than 60^0 C by means of the recirculation line, consisting of pumps and heat exchangers, cooled by service water system.

This limited capacity of this double-function system is one of the reasons for the limited scope of DBA.

Main components

Number of loops:	3 (due to only two trains of emergency power supply:2)
Number of pumps:	3
Type: 7KX-13	(Greifswald 1, 2; Novovorones 3, 4; Kola 1, 2; Kozloduy 1)
Power (kW): 75	
Shutoff or rated head (m of H_2O):	60 ... 30
Rated volume flow (m^3/h):	400
Type: 8HDB-X	
Power (kW): 110	
Shutoff or rated head (m of H_2O):	60 - 35
Rated volume flow (m^3/h):	400 - 600
Number of heat exchangers:	2 Type: straight-tube heat exchager
Thermal power exchanged (Kcal/h):	1.5 * 10^7

3.3. Pressure Confinement System

General Description

Building structure of the reactor plant, covering main high presure components of the nuclar steam supply system, consisting of pressure compartment rooms and venting flaps, able to tackle internal overpressure of 1 bar. It is cooled by means of the Pressure Compartment Cooling System, a closed air cooling system with water cooled heat exchangers.

Main Parameters

Volume (m^3): 20,000	Net volume (m^3): 14,000
Design overpressure (kg/cm^2):	1.0
Design leakage rate (%/day):	600
Number of flaps:	9
Total flaps:	8.25
Opening pressure (kg/cm^2):	0.6 ... 0.75 (small flap); 0.8 (big flaps)

Main Components

Number of fans:	5
Type:	radial-flow fan 29 - 55.12 with prolonged shaft
Rated volume flow (m^3/h):	80,000
Number of heat exchangers:	10
Type:	water-cooled straight-tube heat exchanger
Thermal power exchanged (Kcal/h):	3.7 * 10^5

4. RESIDUAL HEAT REMOVAL

General Description

Residual heat removal for WWER-440/230 plants will be carried out by help of the main equipment of the secondary circuit in addition with special pressure reducing stations and several heat exchangers (process condenser, after cooler, long-term cooler).

Main Components

Number of pressure reducing stations:	2 (one for each unit)
Capacity (t/h):	60
Inlet steam pressure range (kg/cm^2):	≤47
Process (technological) condenser	
Type: straight-tube heat exchanger	Capacity (t/h): 53.0
After-cooler	
Type: straight-tube heat exchanger	Capacity (t/h): 53.0
Long-term cooler	
Type: straight-tube heat exchanger	Capacity (t/h): 600
Cooling pumps	
Number:	2
Type: KRZ-200/50012	Power (kW): 132.0
Rated volume flow (m^3/h):	460
Shutoff or rated head (m of H_2O):	66

5. ELECTRICAL SUPPLIES

General Description

Electrical Supplies of the reference unit WWER-440/230 include off-site supplies, on-site supplies for normal operation and emergency interruptible and non-interruptible power supplies. Only the on-site electrical supplies are similar in all the reactor plants.

Off-site supplies:

Stand-by-transformer; unit transformers by means of generator power circuit breaker

Number of off-site power supplies:	3	
Voltage of off-site power supplies:	*/6 kV	(Stand-by-transformer)
	*/15.75 kV	(unit transformer)

On-site supplies:

Number of buses for on-site power supplies:	8	
Number of Diesel Generators:	3	
Output power (kW of KVA):	1600	
Redundancy:	1.5	
Number of battery system:	1.5 (one for unit, one for twin units)	
Total battery capacity per system:	1152 Ah	
Estimated time reserve of battery systems:	0.5 h(4)	
Uninterruptible AC supplies		
Number and supply type:	2 x 380V	connected with DG-busses by Thyristors and with DC-busses by reversible motor generators

*: transmission line voltage (110, 220, 330, 380, 400 or 500 kV)

6. INSTRUMENTATION AND CONTROL

General Description

The Instrumentation and Control (I&C) consists of three plains: the sensor plain, logic plain and control plain. The sensor plain is wired up in one train and three channels. The construction of I&C alters from one-train to two-train-system with crossing from the sensor plain to the logic plain. These two trains are separated almost completely in two rooms.

Very important disadvantages inside of the I&C are the non-execution of fail-safe principle and non-existing of self-monitoring.

6.1. Reactor-Protection System

The Reactor Protection System (RPS) is constructed as the I&C in three plains (sensor plain, logic plain, control plain). Inside the sensor plain exists a difference between the technological part of RPS and the nuclear technology part of RPS. The technological part is wired in one train with three channels and the nuclear-technical part consists of two trains with three channels. In corresponding to the I&C, the technological part changes from one-train-state to the two-train-state with crossing from sensor plain to the logic plain. The complete system is developed in two channels and three trains apart from the above menteioned exception.

The output signal from RPS to the rods is made twice by means of two from three selective circuits.

The diversity and room separation is not carried out completely in RPS.

Number of channels system:	2
Logic (2 of 2 x 3 or other):	2 of 2 x 3

6.2. Description of Emergency Protection Levels (AZ-1; AZ-2; AZ-3; AZ-4):

AZ-1: reactor trip
AZ-2: trip of one group of control rods at a time
AZ-3: stepping in of one group of control rods at a time
AZ-4: stop rod withdrawal

TABLE 1 - EMERGENCY PROTECTION SIGNALS

AZ-1 TRIP ACTUATION PARAMETER	SET POINT	LOGIC
1. Low period in source range	10s	2x (2*3)
2. Low period in intermediate (and power) range	10s	2x (2*3)
3. High neutron flux in power range	112%	2x (2*3)
4. Low water level in pressurizer and low pressure in primary circuit (signal "Big LOCA")	L_p = 2400mm p = 11.8 MPa	2*3
5. High differential pressure over the core	0.38 MPa	2*3
6. Unit power loss (closing two or more than 2 stop valves of both turbines by switce off of both generators) (signal generation in both sets of primary coolant pumps automatics) By operation of one turbine-generator AZ-1 Trip Actuation Parameter-closing two or more than 2 stop valves by switch off of that generator	-	2x (2*4)
7. Closing of 2 or more than 2 stop valves of the last operating turbine	-	2*4
8. Trip or more than 2 primary coolant pumps - by signals of low pressure difference - by signals of low electrical power	 0.2 MPa -	3*6
9. Loss of 380V-AC power supply to the control room of the reactor control and protection system (buses No. 1, 2 or NMo. 3, 4)	-	
10. Loss of 220V-DC power supply to the control room of the reactor control and protection system (buses No. 1, 2 or No. 3, 4)	-	
11. Loss of power supply to the logic system AZ	-	2*3
12. Manual	-	-

TABLE 1 - EMERGENCY PROTECTION SIGNALS (cont.)

AZ-2 TRIP ACTUATION PARAMETER	SET POINT	LOGIC
1. High neutron flux in intermediate range	-	2x (2*3)
2. High neutron flux in source range	-	2x (2*3)
3. Low pressure in primary circuit	11.3 MPa	2*3
4. High pressure in the confinement	30 kPa	2*3
5. High temperature in the accessible part of the confinement (room of primary coolant pumps drives and main isolating valves-drives)	100° C	2*3
6. Persistence of AZ-3 signal for more than - by neutron signals (high neutron flux or low period) - by technological signals	10 sec 20 sec	
7. Manual		

AZ-3 TRIP ACTUATION PARAMETER	SET POINT	LOGIC
1. Low period in intermediate and power range*	20 sec	2x (2*3)
2. High neutron flux in power range*	107%	2x (2*3)
3. High temperature primary coolant at core exit**	310° C	3*6
4. High pressure in primary circuit**	13.7 MPa	2*3
5. High temperature in the autonomous circuit of** primary coolant pumps	80° C (inlet) 120° C (outlet)	3*6
6. Loss of power in the circuits of primary** coolant pumps automatics	-	
7. Trip of 1 or 2 primary coolant pumps or closing of the stop valves of 1 turbine if the reactor power controller failed or switched off	-	-

* AZ-2 Trip actuation parameter by AZ-3 signal persistence for more than 10 sec.
** AZ-2 Trip actuation parameter by ZA-3 signal persistence for more than 20 sec.

7. CONVERSION SYSTEM

General features of the conversion system design are the following:

(1) two turbines for one reactor
(2) use of saturated steam turbine K-220-44 with extensive preheater system and moisture separator-reheaters
(3) common feedwater supply for two turbines consisteing of feedwater and emergency feedwater system with large water cources in the feedwater tanks

More detailed information for the main steam system, turbine system, condenser, condenser system and feedwater supply are given below for NPP Greifswals unit 1.

7.1 Conversion System

Main steam lines

Number of main steam isolation valves:	6
Type: motor operated valves	
Steam flow (t/h):	450
Isolation time (s):	140
Number of main steam lines:	6
Material carbon steel 15Mo3	
Rated steam flow (t/h):	450
Stop, control and bypass valves	
Number of stop valves:	4
Steam flow (t/h):	750
Isolation time:	0.5 s
Number of control valves:	8
Steam flow t/h):	400
Number of bypass valves:	4
Total bypass capacity:	4 x 400 t/h

Turbine system	K-220-44
H.P. turbine stage	
Inlet steam flow (t/h):	1440
Inlet steam temperature (°C):	254°C
Inlet steam pressure (kg/cm^2)	44
Inlet steam enthalpy (kcal/kg):	668.5
Outlet steam flow (t/h):	1000
Outlet steam temperature (°C):	133
Outlet steam pressure (kg/cm^2):	3.1
Outlet steam enthalpy (kcal/kg):	584.6
Number of moisture separator-reheaters:	2
Number of combined valves (stop & control):	2
Number of L.P. turbine stages:	2
Stage inlet steam flow (t/h):	829
Stage inlet steam temperature (°C):	241

Stage inlet steam pressure (kg/cm^2):	2.79
Stage inlet steam enthalpy (kcal/kg):	704.3
Outlet pressure (kg/cm^2):	0.052 - 0.03
Outlet pressure enthalpy (kcal/kg):	577.2

Number of condensers:	2
Type:	K-10120
Materials tubes:	Cu Ni Fe 10
shell:	carbon steel
Automatic cleaning system:	Taprogge-system
Material:	temper-rubber

Number of condensate pumps:	3
Type:	KSW-500-220
Power (kW):	500
Rated volume flow (m^3/h):	500

Pre-heaters

Number of pre-heaters strings (HP, LP):	2 HP
Number of pre-heaters per strings (HP, LP):	3 HP; 5 LP
Thermal power exchanged (kcal/h):	$9.45 \cdot 10^7$(HP); $1.02 \cdot 10^8$(LP)

Number of deaerators:	2
Type:	DC-800
Capacity (t/h):	800

Main generator description:			
Rated power (MVA):	250	Frequency (Hz):	50
Output voltage (KV):	15.75	r.p.m.:	

7.2. Feedwater System

General Description

Two-train system (one for 3 SG) with one collector on the suction site and two colectors before and after high pressure preheaters on the delivery site of the feedwater pumps.

Pumps Characteristics

Number of pumps	5
Type:	PE-850-65
Power (kW):	2000
Rated volume flow (m^3/h):	760 ... 960
Rated head (m of H_2O):	650 ... 720

7.3. Emergency Feedwater System

General Description

Connected by collectors on the suction site and on the delivery site two-train system (3 SG for each train).

Pumps Characteristics

Number of pumps:	2
Type:	SPE 65-56
Power (kW):	200
Rated volume flow (m^3h):	56
Rated head (m of H_2O):	650

8. AUXILIARY SYSTEMS

The most important auxiliary systems are the Circulating Water System (condenser cooling), the Service Water System and the Intermediate Cooling System for Component Cooling (ICCS)

Also here the main design principles are the same or very similar, but due to site specifics technical solutions have also differences, especially the circulating water and the service water system.

8.1 Circulating Water System (condenser cooling)

Number of pumps:	2
Type:	KDE 2000/25
Power (kW):	3500
Rated volume flow (m^3h):	36000 - 55000
Rated head (m of H_2O):	24
Average temperature of the cooling water:	12°C

8.2. Station Service Water System

General Description

Common system for two units, for each unit one train, with safety-related and non-safety-related consumers, open system by sea-water

Pumps Characteristics

Number of pumps:	5
Type:	KDE VD-500/50
Power (kW):	320
Rated volume flow (m^3h):	1700
Rated head (m of H_2O):	45

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ANNEX B
FORMER USSR

1. HISTORICAL REVIEW, POLICY AND ENERGY CONTEXT

The Soviet Union has had a long and intriguing nuclear history; this annex is intended to highlight the most important milestones and to identify the main makers of this history. In the attempt to complete the scenery and hence to make clear trends and decisions taken, some notes regarding energy policy and resources availability will be given.

1.1 The key institutions

The former Soviet Union was divided, from the political standpoint, into 15 Federal Republics. From an administrative, economic point of view the former USSR (later on referred to simply as the USSR) was divided into 19 Economic Regions.

The Russian Federation comprised 10 Economic Regions:

North-West	North Caucasus
Center	Urals
Volga-Vyatka	West Siberia
Black land	East Siberia
(Central) Volga	Far East

The Ukraine Rep. comprised three Economic Regions:

Donets Dnepr
South West
South

The other Federal Republics were grouped into three Economic Regions:

Baltic (Estonia, Latvia, Lithuania and Kaliningradskaya region-oblast-)
Trans Caucasus (Armenia, Georgia and Azerbaidzhan)
Central Asia (Kirgizia, Uzbekistan, Tadzhikistan and Turkmenistan).

The Byelorussia and Kazakhstan Republics coincided with homonymous Economic Regions, while Moldavia was not included in any Economical Regions.

Due to the USSR's rigidly centrally planned economy several institutional structures (State Committees, Ministries) have had a direct role or some influence in nuclear power development and management (see Fig. 1).

Their role, the degree and extension of their influence, has changed from time to time, but nevertheless the key actors can be identified and their operative areas summarized.

The **State Planning Committee (Gosudarstvenny Planovy Komitet, Gosplan)** acted at the level of staff of the Council of Ministers:

- general co-ordination of five-year-plans as for all economic sectors, included the energy sector;
- preparation and supervision of plans of Ministries involved in the energy sector;
- consultant for energy policy.

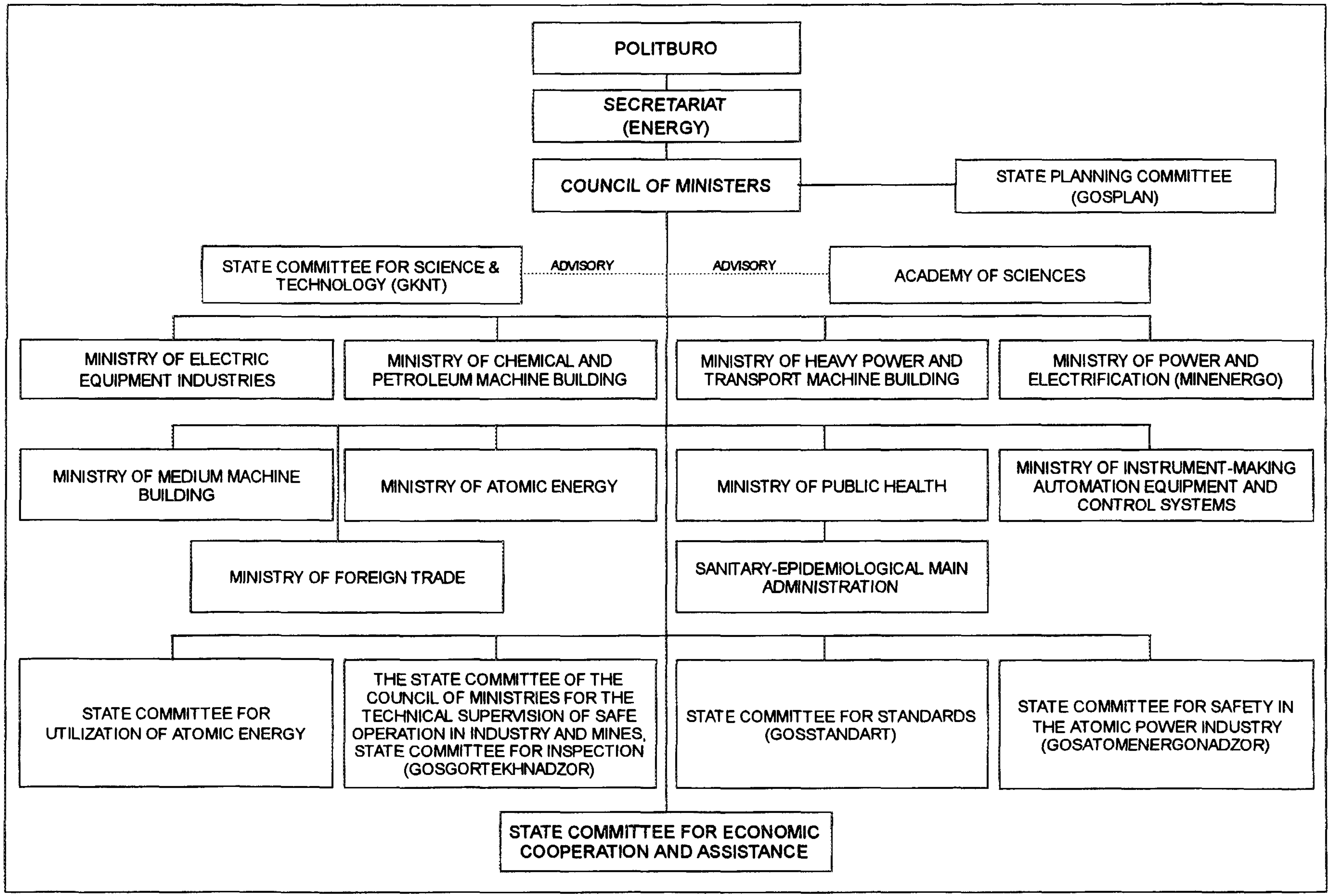

Fig. 1. Top Level Organizations with WWER Related Responsibilities

Acting as advisory committees to the Council of Ministers there have been :

a. The State Committee for Science and Technology (Goskomitet po Nauki i Tekhniki, GKNT):

- definition of R & D priorities in energy area;
- evaluation of R & D proposals coming from Sciences Academies, and Ministries;
- support in obtaining foreign technologies;
- management of technical and scientific exchanges with foreign Countries.

b. The USSR Academy of Science:

- supervision of energy research as for new sources, renewable energy sources, technology development.

At a lower level there have been:

a. The State Committee for Utilization of Atomic Energy (Goskomitet po Atomnoi Energii, GKAE):

- management of peaceful employment programmes of atomic energy;
- supervision of research programmes, especially those involving foreign Countries.

b. The State Committee for the Supervision of Nuclear Power Safety (Gosatomenergonadzor or GAEN) established in 1984:

- regulatory body responsible for design, construction and operation of NPPs (including research and ship propulsion reactors);
- definition and enforcement of safety rules.

c. The Ministry of Public Health (Minzdrav SSSR) has been responsible for radiation protection of workers and civil population.

d. The USSR State Committee for Hydrometeorology (Goskomgidromet SSSR) has been responsible for environmental protection, especially as regards radioactive pollution of air, ground and water.

Energy Related Ministries

Several ministries have been active in this sector: the Ministry of Geology, the Ministry of Oil Industry, the Ministry of Gas, the Ministry of Chemical and Petroleum Machine Building, the Ministry of Instrument Making Automation Equipment and Control systems, the Ministry of Coal, etc. But the Ministries most involved in the nuclear area have been:

a. The USSR Ministry of Power and Electrification (Minenergo SSSR):

- responsible for construction and operation of almost all the NPPs;
- responsible for the whole energy sector management.

b. The USSR Ministry of Atomic Energy (Minatomenergo SSSR) established in July 1986:

- responsible for NPPs operation and design.

c. The USSR Ministry of Heavy Power and Transport Machine Building:

- responsible for designing and manufacturing large nuclear equipment.

d. The USSR Ministry for Atomic Power Industry (MAPI) established in July 1989 re-uniting the previously mentioned Minatomenergo and the Ministry of Medium Machine Building:

- responsible for specialized manufactures of large components;
- includes research institutes, designers, building constructors;
- research and military manufacture.

1.2. Country energy policy

Three main periods can be singled out in the Soviet energy policy.

The origins (1917-1950) After the October Revolution the USSR energy policy was drafted by V.I. Lenin himself in the so-called GOELRO plan (State plan for the electrification of the Russia, 1920).

In this plan the paramount importance ascribed by the socialist leadership to electric power development was stressed for the first time. The main goals of this plan are worth summarizing because they outlined the fundamental options of the whole Soviet energy policy:

- within the plan time limits (10-15 years), the USSR economy had to become independent of foreign fuels and energy import;

- development of fuel and energy resources in strict accordance with country development plans, and centralized management of the production and processing of fuel and generation of electricity and heat power;

- development of the electric power sector was to receive the highest priority.

The expansion (1950 - 1980). After the great effort devoted to post war reconstruction, this period was characterized by impetuous growth of the industry and of energy consumption. Increasing importance was attached to the so-called **Fuel and Energy Complex (FEC)**, recognized as the economy fly-wheel [1].

During this phase the USSR became the world's largest producer of fossil fuels and the second largest consumer. The whole energy transport system was improved and developed, construction of the Unified Power System began (see point 1.4), and the so-called "Friendship" oil pipeline and the gas-pipeline Urengoi-Uzhgorod to supply the CMEA partners were built.

The abundance of fossil fuel (see point 1.3) made nuclear power less attractive and there is some evidence (G. Medvedev, *Chernobyl Notebook*), that at the end of 50s there was strong opposition, at State level, to implement comprehensive nuclear plans. The most important reason for that was the

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[1]The Fuel and Energy Complex can be defined as the whole of all activities relevant to primary energy resources (mining, transformation, stock, transport) and all the activities relevant to secondary ones (production, transmission, distribution) Several ministries have been involved in this interconnected system, according to the 12th Five Year Plan they were the Ministry of Power and Electrification (Minenergo SSSR), the Ministry of Atomic Energy (Minatomenergo SSSR), the Ministry of Petroleum Industry (Minnefteprom SSSR), the Ministry of Gas Industry (Mingazprom SSSR), the Ministry of Coal Industry (Minugleprom SSSR), the Ministry of Industrial Construction for Petroleum and Gas (Minneftegazstroi SSSR)

poor economic convenience of such a choice. To outrun that reason, since the early stages an intensive effort was made to reduce nuclear power costs (e.g. using the by-product heat, design replication, etc.). Continuous cost analysis proved that only the European part of the country could give hospitality to competitive nuclear power plants.

On the other hand the objective of warming homes and greenhouses drove the plants closer to cities thereby counterbalancing safety requirements.

At the end of the 8th Five Year Plan (1966-1970), following the experience gained from operation of the first two units, with the second couple of WWER already in construction at Novovoronezh, and with the almost contemporary construction of the first two couples of RBMK at Leningrad and Kursk sites, the nuclear commercial era started (in Table 1 some data regarding the nuclear pioneering period are summarized).

TABLE 1 - ELECTRIC INSTALLED CAPACITY [2]

YEAR	TOTAL CAPACITY (MW)	NUCLEAR CAPACITY (MW)
1950	19 600	-
1955	37 200	5
1960	66 700	105
1965	115 000	910
1970	167 000	1613

The subsequent 9th Five Year Plan (1971-1975) projected the installation of 7400 nuclear Megawatts and foresaw the installed nuclear capacity by 1980 as 30.000 MW(e). Neither the first nor the second goal was achieved. In fact the nuclear capacity in 1975 reached about 5500 MW(e), 1760 of which came from Novovoronezh 3 and 4 and Kola 1 and 2.

In this five years period some negative trends in the energy sector became apparent: plant and equipment obsolescence, gradual worsening of energy production and resources exploitation in comparison with planned targets, the consumption of a tremendously energy voracious industry.

On these grounds, and as a consequence of the first oil-crisis and of the positive results of the first RBMKs operation, the Soviet decision makers decided on massive resort to nuclear power west of the Urals - about 13,000 - 15,000 MW(e) should have entered in operation, more than 65% of which should have been of RBMK - and a more realistic target of 19,400 MW(e) was set for the 10th Five Year Plan. Other high priorities of the plan were:

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[2]With regard to nuclear capacity and power generation, the comparison of data derived from different sources sometimes presents difficulties and controversy might arise. To square the information some factors have to be kept in mind:

- several Soviet sources are themselves controversial;
- some sources present simply the total amount, not specifying whether special station (e.g. the "Troistsk" station), dual purpose reactors (e.g. Schevchenko, Bilibino), are included or not;
- for a long period official data covered only the NPPs under the control of Ministry of Power and Electrification and not all the NPPs.

All prototypes or research reactors (namely AM-1, TES-3, VK-50, BOR-60, Beloyarsk and Siberian stations) depended on GKAE.

- uranium prospection,
- to bring the enormous Atommash Works, for serial production of reactor vessels and other components under pressure, to an end.

The delay in completing this manufacturing complex was, later on, pointed out as one of the reasons for RBMK prevalence in that period.

In fact in 1980 there were only Novovoronezh 3 and 4, Kola 1 and 2, and Armenia 1 and 2 in operation, while the 1000 MW Novovoronezh 5 was just connected to the grid and entered in operation one year later.

The third period (1983-1991) is characterized by the *Long Term Energy Program*. This plan, which according to an early version, should have covered the period 1983-2000, envisaged inter alia the following items:

- increasing the role of gas and of low-price coal (opencast mining in the Kansk-Achinsk basin) to feed the great thermal power plants located in Siberia and, generally, in the Far-East:
- increasing resort to nuclear power plants in the Western part of the country;
- to carry out the Unified Power System;
- energy savings and to increase efficiency in energy use and production.

The RBMK type, up to the Chernobyl disaster, had a more rapid growth and the installed capacity well exceeded that of WWER.

Several reasons for explaining the different pace (and the competition) between the two types can be mentioned. Nevertheless maintenance of this trend during the early 80s, when the leading world position was attained by PWR and completion of the fifth unit of Novovoronezh had proved that WWER construction costs were cheaper than RBMK-1000, could hardly be explained on the grounds of economic results and safety aspects.

A possible explanation could be pointed out only in the advantages offered by RBMK as converters - to produce and stockpile plutonium - in view of the planned fast-breeders operation during the last decade of the century.

Nevertheless, completion of the Atommash works along with completion of the unified WWER-1000/320 general layout - by Atomenergoprojekt -, and with the more modern construction and organization techniques experienced in Zaporozhe and Balakovo, permitted the Soviet leadership after Chernobyl to switch over to the WWER type to cope with the new situation.

As a whole the Energy Program was flawed right from inception due to rapid failure of the key elements:

- energy prices were too low to encourage energy conservation;
- lack of direct incentives at the level of energy production enterprises as well as at the consumer level restricted the economy's responsiveness to innovative needs;
- plant managers did not have sufficient personal responsibility for energy saving;
- assignment of fixed energy quotas to be met by plant managers had a perverse "negative" feed back;
- lack of capital to renew obsolete plant and equipment.

A second version of the plan, still under preparation in 1990, strengthened the goals of the previous one, stressing again the importance of all conservation measures along with a stronger call for increasing efficiency in energy use.

1.3. Energy resource

The USSR had at its disposal probably almost all the resources needed to assure the country's economic development.

Coal

The Donbass and the Urals coal fields are situated in the European part of the country while, just to mention the most important: the great basins of Ekibastuz and Karaganda (both in Kazakhstan), the Kansk-Aschinsk and Kuznetsk coal fields (opencast mining of low calorific coal), and the Tungunska and Lena deposits are located in the Eastern part.

The whole of the USSR's coal reserves is enormous. According to Soviet estimates geological reserves of hard and brown coal constitute 6790 billion (10exp9) tons, which account for about 55% of total world reserves.

Petroleum

The old, famous oil fields of Baku, Grozny, Kuban and of the Black Sea are situated in the Caucasian region. A great deal of Soviet production, during the 60s, came from the area between the Urals and the Don river.

Actually, the major oil bearing areas: Tyumen, Tomsk and Omsk are in the Siberian region. The great Siberian oil fields assured the USSR's complete independence from oil imports and covered almost all the CMEA partners' needs.

Gas

For a long period gas exploitation remained concentrated in the Western regions (Northern Caucasus, Azerbaijan, Western Ukraine, Orenburg region); but from the 70s an increasing contribution has come from Siberia. The Tyumen and Tomsk areas, the Urengoi deposits, and the Yamal peninsula let gas-exploitation multiply.

Table 2 presents some data regarding fossil fuel exploitation during the 80s, at the beginning of the 12th Five Year Plan.

TABLE 2 - FOSSIL FUEL EXPLOITATION IN THE 1980s

YEAR	COAL/LIGNITE 10^6 tons	PETROLEUM 10^6 tons	GAS 10^9 m^3
1980	652.8	603.2	405.6
1985	647.8	595	599.2
1990	795	635	850

A great effort has been devoted to establishing an effective gas and oil transport system between the great Siberian fields and the western industrialized regions. Nevertheless the dimensions of the country, the delays in implementation of the plans and technological problems in building large diameter pipes have always hampered satisfactory exploitation of resources. It is certain that the worsening of "energy production and transport" was one of the reasons for massive resort to the nuclear source.

Uranium

There is not complete, reliable, information regarding USSR uranium resources and exploitation.

From available data it seems that the USSR did not have large reserves, at least not enough to cover both civil and military needs. On the other hand, it is known that the joint production of the former USSR, former GDR and former Czechoslovakia would have covered all CMEA needs. According to this situation, a general agreement was signed by all CMEA countries - with the only exception of Romania - to deliver (sell) all exploited minerals to the USSR.

The Soviets, on their own, would have established the whole fuel cycle infrastructure and, in accordance with the general arrangements, would have provided fuel assemblies and, at the back-end, would have received the spent fuel.

As for the quality of Soviet uranium resources "many of the deposits found in the USSR have no analogous abroad. They include uranium-molybdenum associations of stock works type, ... and associations of uranium with albitite, with titanium or with iron ore ... Another distinctive type of deposit is a uranium-phosphate association in clays ... The co-products of uranium deposits are often recovered together with uranium yielding molybdenum, iron, rare earths and phosphatic fertilizers. The recovery of these co-products usually improves the economics of mineral operations and makes it economical to work ores with a low uranium content " (Dienes L. and Shabad T. ,1979).

Among the most important exploitation centres there were: Zheltye Vody in the Krivoy Rog basin (Ukraine), Lermotov in the Caucasus, Vishnevogorsk in the Urals, Fergana Valley in central Asia, Vikhorevka and Krasnokamensk in Siberia.

1.4. Power production and transmission

Grid - Unified Power System

The USSR power system development can be split-according to the division previously proposed for energy policy - in three phases.

The first stage (1917-1950) "saw the formation of single-area interconnected power systems: the Moscow, Leningrad, Donbass, Dnieper power systems and of republican power systems, such as the Azerbaijan, Georgia and Armenia power systems. This stage of the power system development was distinct in that the building of electric power stations was effected in parallel with the construction of power lines to interconnect these power stations" (Zhimerin D.).

The second phase (1950 - 1980). During the post war reconstruction "the process of linking single area power systems into yet larger territorial power systems continued. The completion in 1956 of the 2.3 GW Volzhskaya Hydro project and the 400 (500) kV power line to Moscow created the prerequisites for the formation of a power grid for the **European Power System (EPS)** ... A 330 kV power line was built in 1966 between the Kalinin power system and Leningrad to link to the EPS the interconnected North-West PS which itself embraced seven subsystems"(Zhimerin D.). During the 8th

FYP (1966-1970) about 51.000 MW(e) were installed, so that a total capacity of 166.150 MW(e) was attained.

"Since 1973 running in parallel with the EPS are the power systems of all the European socialist countries, being linked through the 500 and 750 kV interstate power lines" (Zhimerin D.).

At the end of 9th Five Year Plan (1971-1975) the total installed capacity achieved was 218,000 MW(e), and at the same time the European, the Siberian, the Central Asia and the Far East Power Systems constituted the foundations for the **Unified Power System (UPS)**.

The Long Term Energy Program. A strong effort was devoted, within the limits of the Energy Program, to develop the 750 and 1150 kV intersystem power lines.

In 1987 the UPS consisted of about 106 regional power systems (Energas), connected with 110 *kV and 220 kV lines, supplying power to single administrative or industrial region; these systems were* interconnected, by means of 220 kV, 500 KV and 1150 KV lines, in eleven consolidated Power Systems nine of which belonged to UPS.

The UPS as a whole covered a geographical area of about 10 million Km^2, inhabited by about 220 million people, with 700 power stations working in parallel, and linked more than 4/5 of the whole USSR power production (European, Siberian and Kazakhstan power supply)

The European Power System, in which there were almost all the NPPs, comprised the following subsystems: North East, Center, Mid-Volga, Caucasus, North Caucasus, Transcaucasus and Urals. These subsystems were interconnected by means of 500 kV, 750 kV, 800 kV power transmission lines.

Thermal power stations (mainly fed with local coal, peat and oil), nuclear and hydro power stations (the latter to cover peak load, the former to cover the country base load) worked jointly in the European Power System. In the Siberian Power System the role of great thermal power stations (located in the great basins of Kansk-Achinsk Irkutsk, Kuznetsk) and of the hydro ones (Einser and Angara Falls) was almost equal; while in the Kazhakhstan Power System, the thermal power stations (stoked with coal coming from Ekibastuz and Karaganda) were prevalent.

Due to the enormous dimension of the country, a particularly burdensome problem has been the electric line losses. In 1985 a loss-on average of 9.33% (Minenergo grid) was recorded which was about twice the world average loss in that period (4.5 - 5.5%).

Moreover the unsatisfactory results achieved as regards construction and set working of power stations, in implementing the Five Year Plans, often led - in some areas - to problems in supplying power to industry and population and to a continuous lack in necessary power reserves-e.g. in the period 1970-1985 the country energy production increased about 2.1 times, while installed capacity grew only 1.9 times, with the contemporary flattening of the country load-diagram.

Another problem linked to the country's dimensions is that of power system control. To manage this problem the Soviets created a four level hierarchic supervisory system. "Presently the USSR supervisory control service consists of the following:

- the Central Supervisory Control of the USSR Power System,
- the Joint Supervisory Control of the European Power System,
- the Joint Supervisory Control of Territorial Interconnected Power Systems,
- *the Central Supervisory Control of Single Area Power Systems.*

TABLE 3 - TRANSMISSION LINES EXTENSION (1000 km)

KV YEAR	1500 (cc)	1150 (ca)	750 800	500	300	220
1980	--	--	3.4	25.5	24.3	92.8
1985	--	0.9	5.6	34.7	28.4	115.0
1990 (*)	2,4	3.6	10.1	52.4	31.8	135.8

(*) initial estimate

The Central Supervisory Control system of the electric power industry has to ensure not only an uninterrupted supply of electric and heat power but also control and analyze the economic indicators of power plants, electric networks and power systems as a whole.

A factor of supervisory control optimization is fuller use of the installed capacity of the most efficient stations" (Zhimerin D.).

Power production in the 1980s.

At the beginning of 12th Five Year Plan (1986-1990) the total installed capacity was 315,000 MW; 70% of which in the form of thermal stations, 18% in the form of hydro-plants and only 9.5% in the form of NPPs (see Tables 4, 5 and 6).

TABLE 4 - ELECTRIC POWER CAPACITY IN THE 1980s (GW(e))

	Total	Thermal (Cogeneration)		Hydro	Nuclear
1980	266.8	201.1	(75)	52.3	13.4
1985	315.1	224.8	(90)	61.7	28.5
1990 (*)	341	239		64.1	37.2

(*) initial estimate

TABLE 5 - ELECTRIC POWER PRODUCTION IN THE 1980s (TW.h)

	Total	Thermal	Hydro	Nuclear
1980	1293.9	1037.1	183.9	72.9
1985	1544.2	1162.3	214.5	167.4
1990(*)	1719	1241	250	329

(*) initial estimate

TABLE 6 - ELECTRIC POWER PRODUCTION BY SOURCE (%)

	Coal	Oil	Gas	Hydro	Nuclear	Others
1980	35	27	16.5	14.2	5.6	1.7
1985	24.8	19.6	30.3	15	9	1.3
1990(*)	24.4	11.7	28.7	14.2	19.5	1.5

(*) initial estimate

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ANNEX C
FORMER CZECH AND SLOVAK FEDERAL REPUBLIC[1]

1. HISTORICAL DEVELOPMENT OF THE CZECH AND SLOVAK FEDERAL REPUBLIC (CSFR) NUCLEAR TECHNOLOGY

The former Czechoslovak nuclear programme was based upon an agreement on assistance and cooperation with the Soviet Union which was signed in 1955. The first heavy water gas cooled reactor (HWGCR), Bohunice A-1, for experimental power production was commissioned in 1972 and shutdown after the accident in 1977. In 1970 the government decided to base the nuclear programme on the WWER reactors. The first two units at Bohunice with WWER-440/230 were the last units of this type built in the CMEA countries.

1.1. Key Institutions

The key institution was the Czechoslovak Atomic Commission which was alone responsible for the nuclear programme development at the very first stage of CSFR nuclear programme. The other central ministries were involved later and they were responsible for different aspects of the programme. The Ministry of Heavy Industry was responsible for heavy industry involvement, the same responsibilities in areas of electrical equipment, I&C and other parts were under the Ministry of Fuel and Energy, as electricity production supervisory body was responsible for engineering and future operation. Names and responsibilities of different ministries changed but the responsibilities for nuclear programme were assigned to the new ones.

1.2. Energy Policy

The extensive development of the Czechoslovak economy during the 1970s and 1980s required the permanent increase of the power inlets.

Actually, establishing an energy policy is complicated by the political social and economic implications of the change from a centrally-planned to a market economy, and by differences between the republics. One of the most difficult task is to make the economy less polluting and less energy consuming.

Heavy industry has been relied on for growth, but the central planners concentrated on expanding electricity supply rather than improving the efficiency of industry. Industrial facilities are 40 to 50 years old and a huge investment will be needed to modernize them. A first step by the government is to move from cheap to expensive energy, despite the unpopularity of such a move.

The necessity of the structural changes

It is necessary to reach the desirable fall of the power resources by the structural reconstruction of the national economy and the corresponding change of the structure of the final power consumption by the bigger part of the noble forms. The most important changes should be:

- the reduction of the steel production by 4-5 million ton,
- the changes in the metallurgy of non-ferrous metals,
- the more accomplished treatment of the row oil the enlargement of the part of the qualified chemistry in the whole production,

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[1]All data and information are related to the situation before the CSFR separation into two independent States: Czech Republic and Slovak Republic in 1992. The former Czechoslovakia is referred here as CSFR.

- in the agriculture, it is necessary to consider the needs of the industrial fertilizers not only as the whole quantity but also as to the assortment and quality.

The main reasons given for the nuclear continuing programme are that nuclear energy is environmentally clean, safe, economic and provides security of supply.

The plans for the reduction of coal production and its intensive use have been stimulated by doubts over the extent of reserves as well as by the heavy environmental damage being caused. Pollution from coal-fired power stations is among the highest in Europe and is particularly severe in the lignite mining region in North Bohemia.

1.3. Energy Resources

Figure 1 presents the development of the primary energy supply for the period 1970-1990 and planned energy supply for the period 1990-2010. The decreasing role of the solid fuels and increasing contribution of nuclear energy are the most characteristic features of the 50 years period. The nuclear energy is much more important for the electricity supply. The share of nuclear energy was about 25% in 1990 and after 2000 it will cover more than 50% of electricity production (see Fig. 2).

The CSFR is not rich in natural resources. Energy production is dominated by the use of coal and lignite, most of which is of poor quality. Coal reserves are estimated at 2000 mtoe and coal provides 55% of primary energy supply. Domestic gas and oil production is minimal and the country relies overwhelmingly on imports from the Soviet Union for supplies of these fuels. Over the past decade there has been a marked decline in the use of oil while gas consumption has almost doubled.

The hydroelectric potential has been put at 16 TWh/y, about 25% of which is used at present. The capacity of hydroelectric stations has grown from 1588 MW(e) in 1975 to 3000 MW(e) in 1992.

Uranium resources are among the largest in the world but some mines are now reaching the ends of their economic lives and the government policy is to reduce production.

The exploration, mining and processing of uranium and the supporting engineering and R & D are managed by the Uranium Industry Company (CSUP). There are eight mines (in South Moravia, North, Central and West Bohemia) and three processing mills in operation.

Production is currently around 2000 t U/year, but with the ending of exports to the Soviet Union and the withdrawal of government subsidies there will be a gradual reduction in output. Production of around 1000 t U/year would then be concentrated at the Hamr mine (North Bohemia), which is responsible for over 60% of present output, and its associated processing mill at Straz.

The previous arrangement under which the uranium mines were under joint Soviet/Czechoslovak control and the Soviet Union bought all the output was ended in 1990. In future, the Soviet Union will buy only enough uranium to meet the CSFR's needs for nuclear fuel.

All the fuel for Czechoslovak reactors has been supplied by the Soviet Union (using the Czechoslovakian uranium) through Skodaexport, and the Soviet Union has also provided conversion and enrichment services at world prices (Nukem and US DOE rates).

There is now renewed interest in the local production of nuclear fuel because of the likely move to western-type reactors and the steep increase in costs resulting from the decision by the Soviet Union to charge for fuel cycle services in hard currency.

The Institute of Nuclear Fuels is studying the prospects for cooperating with a western partner in the production of fuel for both WWERs and other reactor types.

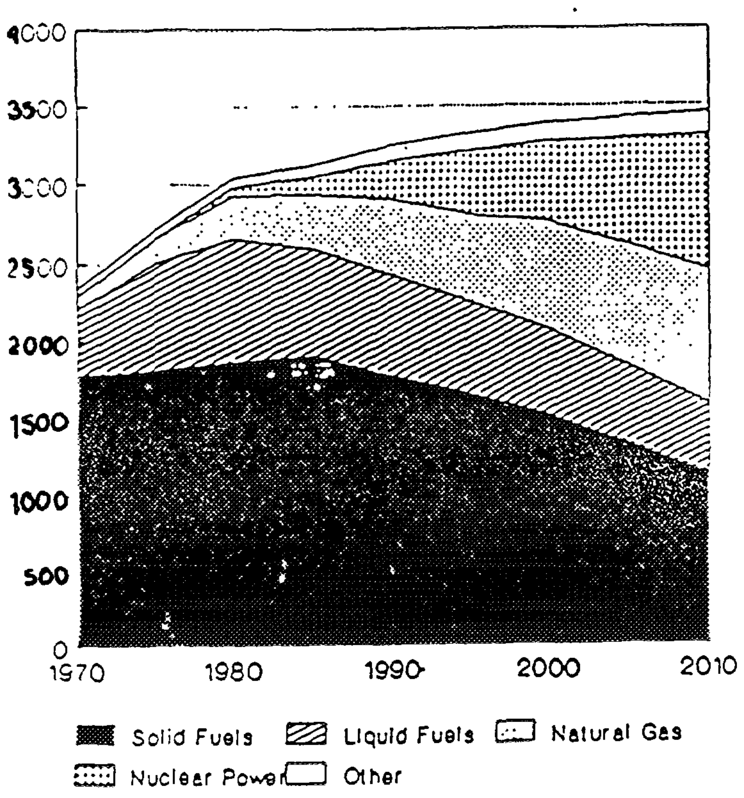


Fig. 1. Primary Energy Supply by Source (PJ)

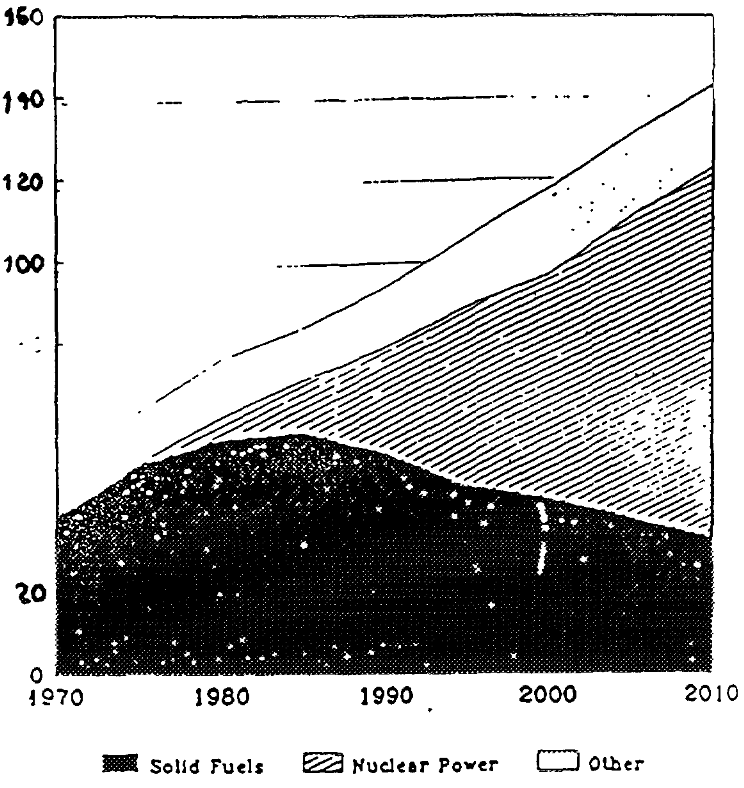


Fig. 2. Electricity Supply by Source (TW.h)

The back end of the fuel cycle has also been secured by agreements with the Soviet Union which inter alia cover the return of spent fuel to the Soviet Union. Originally it was intended that fuel would be transported to the Soviet Union after three years storage at the power station. However shortly after the first WWER was commissioned, the former USSR sought to increase the delay to ten years, and then after negotiations a period of five years was agreed.

To meet this need for additional storage time, an intermediate ground-level wet storage has been built at Jaslovské Bohunice to serve all three WWER stations. It can hold 600 t of spent fuel and 200 t of reserve fuel.

Studies have been conducted into the closing of the fuel cycle but the once-through cycle is still preferred. However this approach received a major shock at the end of 1988 when the former Soviet Union decided that it would start charging for the acceptance at spent fuel in hard currency. Since then no spent fuel has been transported to the former Soviet Union. The Soviets have said they are still willing to accept spent fuel from the former CSFR either for permanent storage or for reprocessing. But under the new pricing policy, the first option would increase generating costs by 25%. The cost of the second option is still being assessed.

In the light of the problems of returning spent fuel to the Soviet Union, studies have been done on alternative storage for 40 to 50 years in the CSFR or to use the West companies services.

About one third of fuel assemblies are changed each year during reloading shut down period. The designed refueling scheme was modified for NPP V-1. Original scheme of refueling "OUT-IN-IN" was changed to low-leakage scheme to decrease the fast neutron flux on the reactor pressure vessel. Dummy assemblies are used at outer row of V-1 unit to reduce further the neutron flux on reactor pressure vesset (RPV). The thermal capacity of reactor was not changed as the linear power was allowed increase due to sufficient design margins. The fuel enrichment is two values 2.4 and 3.6 % U-235. The average fuel burn up is higher than that was designed.

1.4. Power Production and Transmission

Public electricity generation is in the hands of two state-owned utilities, Czech Power Plants (Ceské Energetické Závody-CEZ) and Slovak Power Plants (Slovenské energetické podniky - SEP). There are eleven distribution companies (eight in the Czech Republic and three in the Slovak Republic). The central grid system is operated by Czechoslovak Power Dispatch (CSED) on behalf of both CEZ and SEP.

The Bohunice NPP is one of the plants belonging to Slovak electrical utility organizations (SEP), which is the State enterprise.

SEP includes the following plants and organizations:

- Nuclear power plants (NPP) Bohunice
- Nuclear power plants Mochovce
- Thermal power plants Vojany and Nováky
- District heating plants Košice
- Hydro-power plants Trenčín and Dobšiná
- Elektrovod Bratislava (design and construction of electrical transmission lines).

Figure 3 presents the organization chart of the SEP which is responsible to the Slovak for Economy. At the period of analyses the interconnections among different organization are shown in Figure 4.

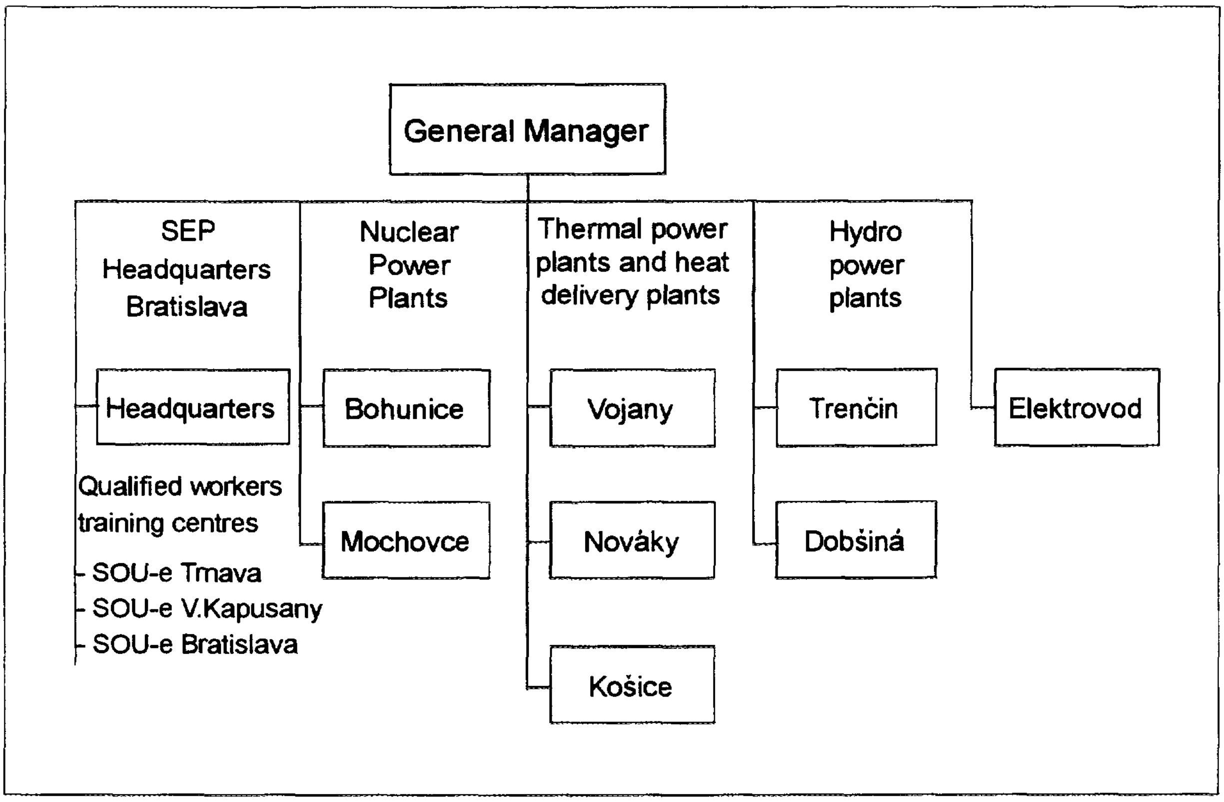


Fig. 3. Organizational Chart of SEP State Enterprise

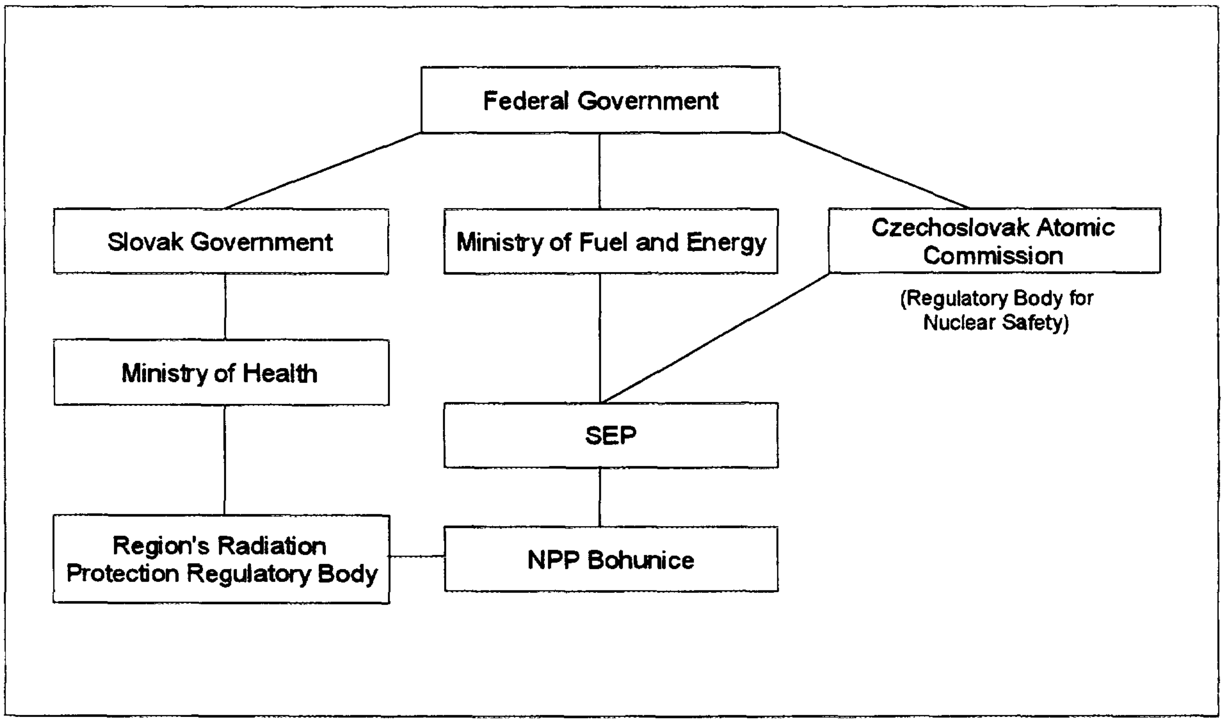


Fig. 4. Former CSFR Organizational Structure

The whole CSFR grid system is operated by the Czechoslovak Power Dispatch in Prague. The NPP V-1 is controlled by the Slovak grid Dispatch in Zlima. All NPPs prefer to be operated in the basis regime. During weekends and holidays NPPs are sometimes requested to decrease their output to 75-50% of capacity. Due to the specific regime of NPP V-1 which is in force since 1 April 1989 the plant operates only in basis regime. The partly load following regime is requested from the other units.

2. DESCRIPTION OF NUCLEAR SYSTEM STRUCTURE

2.1. R & D and Architect - Engineer

The main designer of the NPP V-1 Bohunice was Teploenergoprojekt - Power plant project engineering enterprise (USSR). The Energoprojekt (CSFR) was the designer of the secondary side. All primary circuit equipment was supplied by the former USSR, the secondary circuit equipment and turbine-generator were supplied by CSFR's heavy machinery. The leading organization was the Skoda works. The main civil constructor was the Hydrostav, Slovak enterprise. The primary circuit equipment was extra tested by Czechoslovak organizations before assembling - as the special pre-in-service inspection. The manufacturing inspection at the former USSR factories to make by Czechoslovak organization was impossible due to the restriction from the former USSR side.

The manufacturers and operators are supported by their own R & D capacities and by the independent organizations.

The Nuclear Research Institute (ÚJV) at Rez near Prague, which - comes under CzEAC, is concerned with reactor physics, nuclear safety (on behalf of the Nuclear Safety Inspectorate), materials and chemistry, and operates several research reactors. The Research Institute for Power Plants (VUJE), at Trnava in the Slovak Republic, is the main contractor for work in support of the operation and maintenance of nuclear power plants, operational safety analyses, start-up control radwaste treatment technology and on life extension.

Research on nuclear fuel services is performed by the Institute of Nuclear Fuels which is part of the Uranium Industry Company (CSUP).

The contribution of different organizations in CSFR to the plant operators is shown in Table 1.

TABLE 1 - CONTRIBUTION OF CSFR ORGANIZATIONS TO PLANT OPERATORS

Activity	Organizations involved
Safety analyses	VÚJE, ÚJV, VÚPEK, Škoda,
In-service inspection	Škoda, VÚJE, Vítkovice, VÚZ
Maintenance and outage activities	Škoda, Vítkovice, Sigma, Kralovopolská, VÚEZ, VÚJE,
Core calculations	VÚJE,
Backfitting	VÚJE, Škoda, Energoprojekt
Radwastes conditioning	VÚJE, ÚJV
Water chemistry improvement	VÚJE, EǴU

Organizations not mentioned in the text before:

VUZ - Welding Research Institute, Bratislava, Slovakia
VUEZ - Power Equipment Research Institute, Tlmace, Slovakia

2.2. Manufactures and Industrial Support

Industrial support system

The nuclear programme development was strongly encouraged by the Federal Government. The nuclear industry capacities were built and the share of Czechoslovak organizations in the NPP construction and servicing continuously drawn up.

By 1989 Czechoslovakian companies have been responsible for some 85% by value of the nuclear stations in operation and under construction. The architect-engineer for nuclear power stations is Energoprojekt. The main contractor has been Skoda, which has been involved in design work as well as the supply of pressure vessels, mechanical and electrical equipment and turbines. Other companies are Vitkovice (pressurizers and steam generators), Elektromont (I and C), Sigma (pipework), Vzduchotechnické závody (ventilation and air-conditioning), Kralovopolska (reactor auxiliary equipment, and radwaste treatment and disposal), and CKD (diesel generators and water treatment).

2.3. Plant Construction and Ownership

See sections 1.5 and 2.1

2.4. National Authorities

The regulatory regime has been influenced by the fact that the nuclear programme has been based on Soviet-type PWRs with a high degree of standardization in construction and operation, a large local share in the supply of components, close cooperation with other CMEA countries and particularly the Soviet Union, and an open fuel cycle.

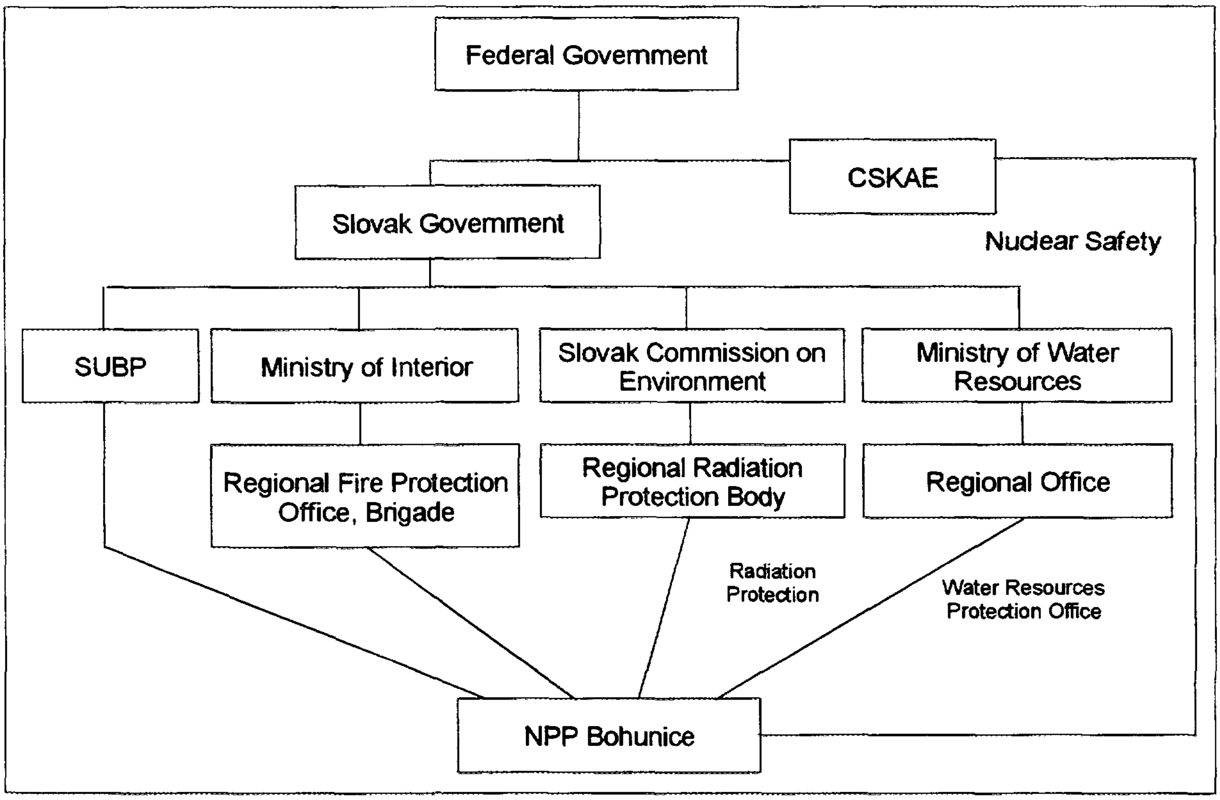
The Czechoslovak Atomic Energy Commission, which is responsible for nuclear safety, is a federal agency and it is supported by other independent agencies covering radiation protection, technical safety, and fire protection, which operate at the republics level. The Ministry of Interior Affairs is responsible for physical safety.

The Nuclear Safety Inspectorate (NSI) within the CzAEC is divided into three divisions: Nuclear Safety Assessment, Components and System Assessment and Nuclear Materials. There is a total staff of 54, of which 14 are resident inspectors at NPP sites. In the four main statutory steps in the licensing process for nuclear power plants - site approval including exclusion zone, construction permit, operating license and decommissioning - the republic in which the plant is sited has to approve the decisions of the CzAEC.

Approvals for fuel loading, physical start-up, power start-up, and trial operation (six months) are given by the CzAEC alone. Operating licenses are granted first for two years, and are linked with schedules for work on in-service inspection.

The CzAEC through the NSI now has sole responsibility for issuing safety regulations (these were previously issued in cooperation with the former Federal Ministry of Fuel and Energy). The Commission is represented in the government by the minister-chairman of the Federal Committee for the Environment. It present annual reports on its activities (mostly the work of the NSI). In fulfilling its statutory obligations, the NSI can in certain circumstances have direct access to the government.

Fire protection is based on the Slovak National Committee Act 126/1985. It is governed by the Slovak Republic Ministry of Interior. The Regulatory Body in Slovakia is the Headquarters Fire Department in the Ministry of Interior which has in every region the Region Fire Department. At the plant the special fire protection and industrial safety division exists, which serves for all four units at the site. Fire brigade consists of about 70 men. Fire prevention section consists of 5 persons. The scheme of different governmental bodies involved into NPP regulation is on the Figure 5.



Note: SUBP - Slovak Office for Industrial Safety (includes offices for pressure vessel and lifting devices inspection)

Fig. 5. Governmental Bodies Involved in NPP Regulation

2.5. Public acceptance

With the change in political control nuclear power issues are being discussed openly. There has been opinion poll to determine the public's attitude to nuclear power and this showed that 46% were in favour and 41% against. There are marked differences between regions, with support for nuclear power highest in those parts of the country suffering most from pollution.

Whereas the Federal Government and the Slovak government are broadly in favour of nuclear power, the position of the Czech government is equivocal. Its Ministry of the Environment opposes Temelin 3 and 4 and the continued use of Soviet technology, but accepts that nuclear power is the only long-term solution to the country's environmental problems. The Green party is also divided, being in favour in some areas and opposed in others.

A major factor is the stand taken against the Czechoslovakian reactors by the Austrian government and other organizations in Austria, which have formed an Austrian-Czechoslovak Anti-Nuclear Committee. They are particularly opposed to Bohunice V-I and the extension of Temelin.

The utilities are making strong efforts to improve the flow of information about nuclear power.

3. DESCRIPTION OF NPP ORGANIZATION, MANAGEMENT AND POLICY

3.1. Plant Operation Structure

Original plant organization structure (see Figure 6) was created according to the CSFR practices and as it was used for the first NPP with the HWGCR reactor. For WWER 440/230 it had to be changed before the first unit commissioning according to the Soviet expert requirements and it was similar to the NPP organization in USSR. There was not clear definition of the maintenance responsibility, as it was shared between operation and centralized maintenance. The structure was influenced by the fact that next NPP was under construction at the same site. The organization chart of NPP Bohunice (as valid in November 1991) is in the paragraph 2.1.1 as well as utility (SEP) organization, to which NPP Bohunice belongs. The plant manager was responsible for all activities at the site. The group of USSR experts was directly involved into the operation of NPP. The operational shift personnel was supported by the USSR experts at the shift. Their number was gradually decreasing. The number of shifts increased from five to six now. The organization structure was reviewed by the OSART mission in 1991 and the organization structure amendment was recommended.

3.2. Management Policy

Goals for each year were established by the State plan which contains main indicators such as: electricity production, availability, outages, limits of expenses (salaries and wages, services, investment etc.). The operational and other internal indicators for different organizational units were derived from the State plan indicators to fulfill the State plan goals. The system of plant manager orders and other administrative acts were used to control the electricity production and all necessary activities including nuclear safety and radiation protection.

The day to day activities were controlled by the regular meetings of the top management (plant manager, deputy plant managers, some department heads). Regular meetings were organized on the lower level of management too.

The quality assurance (QA) function was not established through the overall programme. The strong quality control (QC) system was created during construction to inspect all the primary circuit pressure boundary components supplied from the USSR. The verification of quality control in most of departments is done by the line organization control. Different type of commissions, which were composed of plant staff members and of members of outside organization, are used for internal reviews. The results were reviewed usually by the regulatory body organizations, or independent technical supporting organization.

The nuclear safety and radiation protection were the main concern of special organizational units from the start of operation. The special committee ("failure committee") review all failures at the plant and prepared the proposal for corrective actions, which were approved by the management after consultation with USSR designer in case of modifications. The failure trends were reviewed as the system for failure data collection was established with the depth sufficient for such analyses. Main concern was to the instrumentation and control (I & C) systems failure analyses.

3.3. Training of Personnel

Most of operational personnel moved from the operation of A-1 NPP (HWGCR), which was shut down approximately two year before WWER 440/230 start-up. The personnel was trained in training centres in Slovakia and in USSR. The full scope simulator training and on job training was originally organized in USSR (Novovoronezh NPP). Lately all training was organized in central training center (operators, management and top engineering staff) and in utility training center

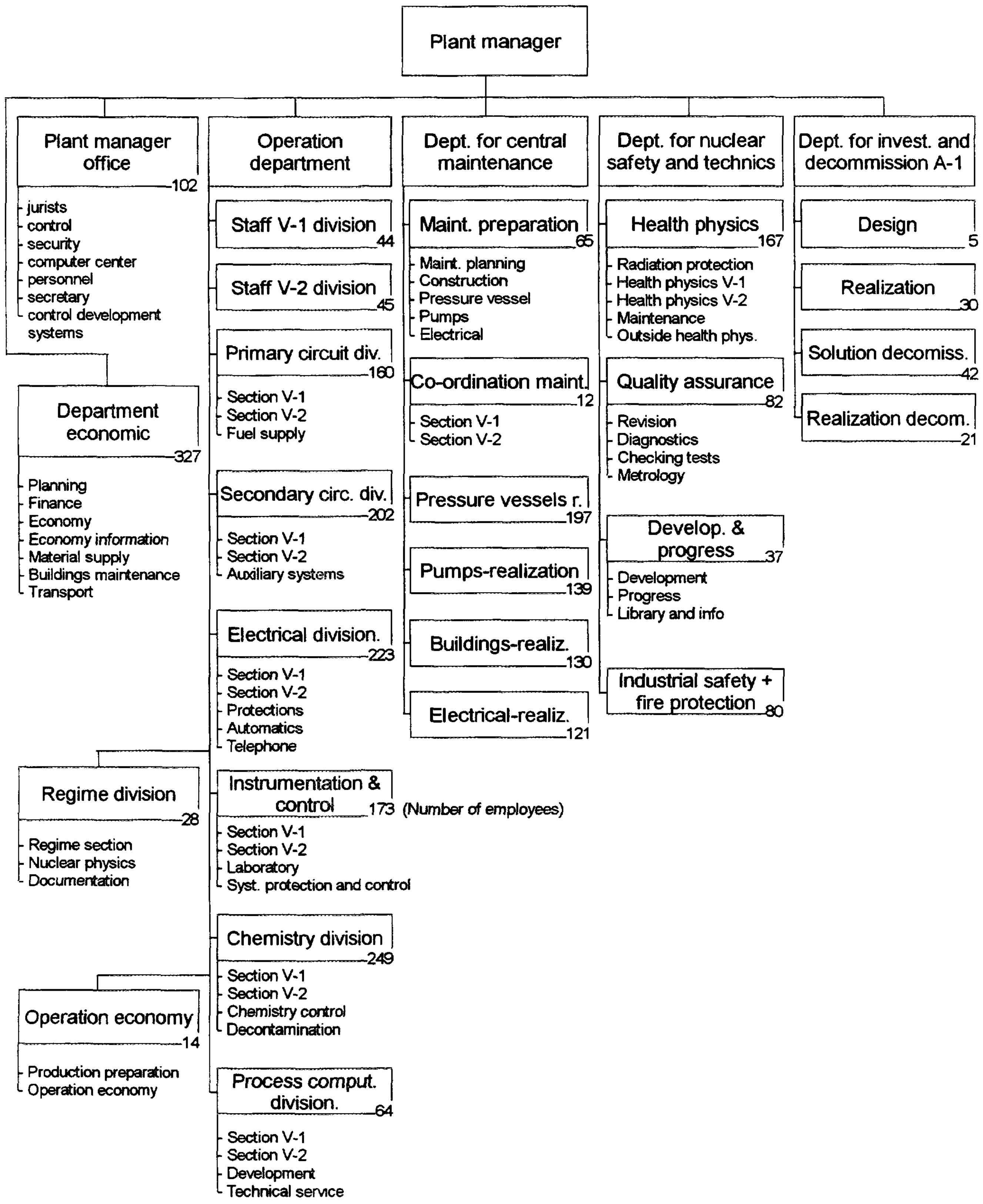


Fig. 6. Organizational Chart of Bohunice Nuclear Power Plant (February 1991)

(foremen, technicians). Training was organized from the very beginning as structured, long term process, taking into account original education and industrial experience of personnel.

The training process was terminated by the state exam for control room personnel and by exams at the training centre for other categories. The license for control room operators is valid two years, after that the operator has to pass new exam. Due to this personnel preparation the operating personnel is knowledgeable and professional. They were trained to operate the units with out consulting the procedures.

For control room shift personnel only the graduated candidates were required. Most of all NPP personnel were dedicated to the nuclear programme as at that time it was the top technology implemented in the country.

Due to the high quality of personnel and the experience in the nuclear industry many improvements were implemented during construction and many modifications were done during operation to increase safety and availability of the plant.

3.4. Maintenance

The maintenance structure was adequately staffed and capable of performing necessary functions to support safe operation of plant. The different maintenance departments have a large number of engineers who in many cases have been working in the plant since its construction. The number of staff was in 1991 about 650 employees, what is much higher than in West countries. Except some special works, the NPP maintenance staff is able to cope with most of maintenance and repair work and minor modifications. During outages for refuelling only a few outside organizations are involved (SKODA - turbogenerator, RPV test etc.) which covered only about 20% of the work. The preventive maintenance programmes applied to all components and the predictive maintenance programmes applied to the cable testing, large transformers and generators are main methods to keep equipment in good condition.

3.5. Technical Support

The technical support capabilities, both internal and external, were broadly used during all time of operation. Plant technical support units are involved into surveillance test programme establishment. The operational experience feedback from in-house and external failure information are well defined and established. Plant modifications are carefully planned, monitoring of various core parameters was amended using results of R&D.

Plant management and also lower level managers supported R&D organizations, partly funding the state or utility R&D programmes, completely funding their own R&D activities. Implemented results of these R&D activities contributed to the plant availability increasing. As the example: the precise outlet and inlet reactor coolant temperature measurement implementation increased the output of reactor; the installation of the new computer system to the design information system increased the reliability of the plant.

3.6. Principles of Fuelling and Refuelling

One third of fuel assemblies in the core is changed each year during refuelling. The classical design scheme of refuelling OUT-IN-IN was used from the very beginning of operation. Only a few leaking fuel assemblies were found during the whole operation time.

Due to the high quality of fuel and using the operational experience the new fuel load pattern was used which is different from the designed one. Higher fuel burn-up than designed was reached without any negative influence on plant availability.

The load pattern had to be changed to reduce the neutron flux of RPV due to the higher rate of RPV embrittlement than it was expected. The dummy elements were used at the peripheral row of fuel assemblies and low-leakage pattern was implemented.

3.7. Back-fitting Implemented and Analyses Performed within the Framework of 81 + 14 Measures Agreed with Regulatory Body

Broad programme of back-fitting according to the recommendation of CSFR Regulatory Body was implemented during 1990-93. The Regulatory Body requirements consists of 81 originally required measures and 14 additionally formulated. They were oriented to the upgrading of different NPP systems and to the additional safety analyses. The following actions were performed.

Reactor coolant system (RCS) and reactor auxiliary systems:

- samples of the welding material have been extracted from the weld No. 0.1.4 of the reactor pressure vessels of units No. 1 and 2 for the purpose of chemical analysis (especially with respect to the content of CU and P);
- annealing of reactor pressure vessels of both units;
- replacement of the outer fuel assemblies by the dummies in the reactor core at Unit No. 1;
- RCS pressure monitoring system at temperatures below the brittle fracture for pressure thermal transients;
- RCS pressure limitation system at temperatures below the brittle fracture temperature for normal operation conditions;
- gas venting (removal) from reactor pressure vessel and from SG manifolds.

Steam generators, pressurizer and RCS loops:

- upgrading of the pressurizer safety valve system strength, replacement of old safety valves, installation of one pressurizer relief valve.

Upgrading of in-service diagnostics of RCS components by implementation of:

- acoustic emission monitoring system ALUS;
- RCS system leak detection system based on humidity monitoring in the confinement area;
- monitoring of vibrations of reactor coolant pumps;
- monitoring of loose particles in RCS.

Reactor protection system:

- added scram HO-I signals:

  a. 2-out-of-6 steam generators (SG) level drop
  b. RCS pressure drop
  c. pressurizer level increase
  d. loss of neutron flux indication within source range

- improvement of the reliability of HO-II slow scram signal on confinement pressure increase;
- high pressure (HP) ECCS[2] injection pump start on RCS pressure drop.

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[2]ECCS: emergency core cooling system.

Confinement systems:

- improvement of confinement tightness;
- obtaining a subatomospheric pressure in the confinement within the required time period after beginning of small LOCA;
- protection of confinement sumps against blockage.

Spray system:

- doubling the redundancy of the spray pump discharge lines;
- shortening of the time delay of spray system;
- monitoring of water presence in the room of ECCS pumps.

Emergency feedwater system:

- interconnection of the discharges of emergency feedwater pumps with SG blow-down lines.

Electric power distribution system:

- minimizing of the total number of electric protections tripping diesel-generators (DG);
- increase of power in the essential power systems of the second category;
- optimizing of the load sequencer scheme (APS), of automatic fast transfer of drives to back-up ones and of automatic starting circuits of DGs;
- improvement of the house load scheme.

Instrumentation and control system:

- upgrading of inadequate sensors by qualified ones for reactor protection and safety systems;
- realization of a safety panel with safety related measurements and of a remote control shutdown panel.

Seismic upgrading:

- seismic upgrading of buildings and structures;
- seismic upgrading of the RCS equipment;
- all new design improvements comply with the requirement of seizin resistance requirements.

Fire protection:

- replacement of the existing fire alarm system by Cerberus system;
- installation of a stable halon fire extinguishing system in selected power distribution cabinets;
- removal of all cable joints in 5 kV cables in reactor and turbine building.

Analyses concerning design improvements implemented during the back-fitting process:

Reactor pressure vessel:

- analysis of consequences of non-symmetrical water level recovery in reactor pressure vessel and of the pressure-thermal shock.

Steam generators, pressurizer and RCS pipeline:

- calculation of strength and fatigue of the most exposed parts of the SGs and pressurizer;
- calculations of the development of cracks in the bolts of SG flanges;
- calculations of seismic fatigue for 5th and 7th grades of MSK-64.

Reactor protections:

- analysis of the possibility of cancelling reactor trip signals HO-II;
- the confirmation of the acceptability of the LBB concept in the frame Safety Analysis Reports of V-1 units.

ANNEX D
BULGARIA

1. GENERAL DESCRIPTION OF THE NATIONAL POWER SYSTEM (1970-1990)

1.1. National Energy Policy and Economy

Bulgaria's energy policy has always been formulated based on the limited indigenous energy resources. The basic factors of the development of the Bulgarian power system during the period 1970-1990 were of various character. As dominating ones could be considered:

- limited primary energy resources;
- planned administrative economic system;
- much energy consuming industry;
- scientific, technical and technological backwardness;
- tight economical dependence on the former USSR and the East European countries;
- limited contacts with the new technological achievements of the developed industrial countries, etc.

The commercially utilizable resources of high grade energy carriers - crude oil, natural gas and bituminous coal - are small and they meet less than 1% of the nation's primary energy carriers demand. Bulgaria has large deposits of low quality brown coal, but not much bituminous coal, and also some anthracite.

The local output of primary resources meets about 30% of the total demand. The recent schedule of electricity consumption in Bulgaria is as follows:

Industry	73%
Public accommodating	17%
Transport and communications	13%
Agriculture	7%

Coal is imported for metallurgical purposes and for power generation. Oil and gas import dependence is over 90%. Electricity is also imported, primarily from the former USSR, but is also exported predominantly to other ex-CMEA countries, connected via MIR energy grid.

Bulgarian hydro resources are also limited, barely 1,650 kWh per capita annually. The commercially utilizable hydroelectric potential is estimated to about 14 billion kWh annually, including the river Danube's share. Thus for only 1/3 of it has been utilized, the respective figure for the inland rivers barely 40%.

The new energy sources do not participate significantly in the covering of the national balance. The reserves of geothermal water found thus far, have an annual energy potential equipment to 350,000 tce.

The uncorrected operation of the most of the hydro power plants and the utilization of the dams' water for irrigation purposes, has limited their pick power availability to the network. Beside this, utilization of the thermal power in a regime of often shut-down and restart, which strongly deteriorated their reliability. The main problems of the thermal power utilities are the ecological ones and the equipment warning out.

Nuclear fuel covers over 9% of current primary energy resources demand. Its reserves were considered sufficient to support further growth of nuclear energy. In the country was developed as well uranium ore mining, which recently was under consideration, evaluated as not beneficial and is gradually shut down.

The primary resources limits, the growth of the electricity demand, and the world's scale of the nuclear power plant development, were the background of the nuclear power strategy during the period 1970-90. Bulgaria now rates third in the world in per head generation of electricity from nuclear power station. It supplied about 40% of the country's electricity in 1990. The development of the nuclear power at present is in stagnation in Bulgaria. At these conditions the power system strategy had formed three main development directions:

1. Maximal utilization of the local energy resources;
2. Nuclear power generation growth;
3. Saving of fuel energy.

Bulgarian government has cooperated with Western organizations seeking to provide help in upgrading the Kozloduy Plant. The country continues to rely on the Kozloduy units and its aging thermal power plants to meet demands.

1.2. Primary resource (general share, import & export)

The share of indigenous energy resources in the energy balance was constantly increasing and was 32.2% in 1989. Some information on the recent status according to Economist Intelligence Unit's (EIU) country profile 1991-92, is provided in Tables 1 and 2.

TABLE 1 - LATEST AVAILABLE ESTIMATED ENERGY RESOURCE
exajoule (10 E 18 joule)

	SOLID	LIQUID	GAS	HYDRO	TOTAL
Total amount in place	42.68	0.07	0.17	2.56	45.45

TABLE 2 - PRODUCTION AND TRADE IN ENERGY SOURCES

	1983	1984	1985	1986	1987	1988	1989
PRODUCTION							
Natural Gas (bn. cub. m)	0.10	-	-	-	-	-	0.09
Lower rank (brown/lignite) Coal (mm tons)	32.2	32.1	30.6	34.0	36.0	-	35.8
Coal ('000 tons)	1,270	1,186	1,087	1,156	1,314	-	1,561
IMPORTS							
Oil (mm tons)	15.6(a)	20.2(a)					
Natural gas (bn cub.m)	4.50	4.54	5.45	5.68	6.07		
Hard coal (mm tons)	7.09	7.20	8.06	7.29	7.25		
Coke(mm tons)	0.50	0.54	0.66	0.47	0.31		
EXPORTS							
Oil products							
Hard coal (mm tons)	0.22	0.29					

or 533.5 million tce of sub-bituminous coal - 261.9 million tons of natural fuel or 106.2 million tons tce. of bituminous coal - 13.5 million tons of natural fuel or 2.85 million tce. In fact these figures refer to the utilizable reserves only of the pits currently in exploitation and of those to be commissioned before 2000. Table 3 shows the coal output in the 1980's.

TABLE 3 - COAL OUTPUT (thousand tons)

	1980	1984	1985	1986	1987	1988	1989
Lignites	24129	26602	25252	29,878	31375	29168	29503
Sub-bituminous	6819	6931	6726	6,440	6616	6119	5850
Bituminous	445	372	380	368	372	380	380
Anthracites	104	91	91	85	82	71	70
TOTAL OUTPUT	31497	33896	32449	36771	38445	35738	35803

1.3. Electricity production (general share, import & export)

The gross electricity demand in Bulgaria for 1989 was 48,675 million kWh, or 1% less than in 1988, a decrease primary due to the lower electricity demand by the industries (20,253 million kWh as against 21,208 million kWh in 1988.

In 1989 the utilities power plants in Bulgaria produced 39978 million kWh, while total electricity production was 44,259 million kWh thus meeting 89.4% of total demand.

The nuclear power plant generated 14,456 million kWh, or 32.9% of total generation. This is by 1,400 million kWh less than 1988. The reasons are mainly longer warranted maintenance of unit 5 and the measures taken to improve safety of the other units.

In order to maintain the energy balance, the deficit of Kozloduy was compensated by the greater loading of the thermal power plants as well as by bigger electricity imports.

Some recent data on the electricity balance, capacity and generation are on Tables 4, 5, 6 and 7.

TABLE 4 - ENERGY BALANCE, 1990 (mn tons oil equivalent)

	Oil	Gas	Coal	Electricity	Other	Total
Production	0.3		11.2	4.5(a)	0.4	16.4
Imports	12.5	5.5	3.5	1.5(a)		23.0
Exports			0.2	0.2(a)		0.3
Primary Supply	12.8	5.5	14.6	5.8(a)	0.4	39.1
Net transformation	1.3	0.5	5.2	2.9		9.9
Final Consumption	11.5	5.0	9.4	2.9(b)	0.4	29.2

(a) Primary electricity production, imports and exports are expressed as input equivalents on an assumed generating efficiency of 33%

(b) Output bases

TABLE 5 - ELECTRICITY IMPORTS/EXPORTS (bn kWh)

	IMPORTS	EXPORTS
1983	5.31	2.81
1984	5.87	3.33
1985	7.45	2.94
1986	5.43	1.47
1987	5.33	0.96

TABLE 6 - ELECTRICITY PRODUCTION (GW(e).h)

	Nuclear	Thermal	Hydro	Total	Nuclear Share (%)
1970		17.4	2.2	17.5	
1974	.9	19.8	2.1	20.2	4.59
1975	2.5			22.7	11.47
1976	5.0			24.7	20.24
1977	5.9			26.5	22.17
1978	5.9			28.3	20.92
1979	6.2			29.0	21.34
1980	6.2			31.2	19.76
1981	9.1			33.2	27.50
1982	10.8			35.3	29.63
1983	12.3	27.8	3.5	38.2	32.23
1984	12.8	28.7	3.3	40.0	31.83
1985	13.1	26.3	2.2	41.6	31.54
1986	11.2	27.4	2.3	41.8	29.99
1987	11.5	28.5	2.5	40.2	28.60
1988	16.0	26.5	2.6	45.0	35.63
1989	14.6	27.1	2.7	44.3	32.91
1990	13.5			37.8	35.73

Source: IAEA EEDB and PRIS Databanks

TABLE 7 - ELECTRICITY CAPACITY

	Nuclear Capacity (MW(e))	Total Capacity (MW(e))	Share of Inst. Cap. (%)
1974	408	6,169	6.61
1975	816	7,060	11.56
1976	816	7,210	11.32
1977	816	7,082	11.52
1978	816	7,518	10.85
1979	816	7,993	10.21
1980	1,224	8,197	14.93
1981	1,224	9,059	13.51
1982	1,633	9,499	17.18
1983	1,632	9,633	16.94
1984	1,632	9,798	16.66
1985	1,632	10,243	15.93
1986	1,632	10,243	15.93
1987	2,585	10,743	24.06
1988	2,585	11,309	22.85
1989	2,585	11,113	23.26

Source: IAEA PRIS Databank

2. FACTORS AFFECTING PLANT PERFORMANCE BEYOND PLANT MANAGEMENT CONTROL

2.1. Nuclear Electricity Production Organization

Electricity generation in Bulgaria is managed by the National Electric Company (NEC). It was created in November 1991 as a joint venture between 53 individual power plants included in 14 independent utilities. All of them are state property. NEC is directly subordinated to the Council of Ministers in Bulgaria and its total activity is supervised by a National Supervisory Council for Energetics. Kozloduy NPP is a branch of NEC.

Fire protection is organized by a specialized division, the National Fire Protection Service. The personnel medical care and supervision is performed by the Plant Medical Service, subordinated to the Ministry of Health.

Supplier/design (Architect Engineering)

Concerning the States agreement between Bulgaria and the former USSR, Kozloduy Units 1 to 4 units are designed, supplied and operated according to the Soviet normative documents. The main designers were "Atomenergoproekt" - Moscow, and "Energoproekt" - Sofia. "Energoproekt" designs as well required modifications, changes, back-fitting measures for safety and reliability increase and feedback measures. Contracts with outer organizations and research institutes are signed on some problems, which can not be solved by the NPP management.

Industrial Support System

The import of spare parts and materials is done mainly from the former USSR, as well as from Czechoslovakia, Poland, Germany, Sweden, Finland, United Kingdom, Japan and USA. The process is slow and bureaucratic. In fact, there is no spare parts production for automatic industry in Bulgaria. Some spare parts are produced in the NPP workshops.

The secondary circuit and electrical equipment (e.g. turbines, feed water pumps, heat exchangers, piping, generators, transformers, etc.) maintenance is performed mainly by the company "Atomenergoremont". The installations and reconstructions are performed by the AESP. Instrumentation maintenance is performed by IAEA and Kozloduy subsidiary company "Interpriborservice".

All maintenance activities are regulated by signed contracts between NPP and the outer enterprises and organizations.

Load Diagram (Operation Mode)

Kozloduy NPP units 1 to 4 operate in a basic regime. The units operate at a lower than 100% power during reactors shutdowns and restarts.

2.2. Regulatory System

The State Regulatory Body for nuclear and radiation safety is the Committee for the Use of Atomic Energy for Peaceful Purposes (CUAEPP). The interaction between the NPP and CUAEPP is regulated by the Law on the Use of atomic Energy for Peaceful Purposes and by 2-6 documents of CUAEPP. The control is performed by the CUAEPP's Safety Inspection including as well several on-site inspectors.

The state regulatory body for the personnel radiation exposure is the Ministry of Health. The interaction is performed by the 117 Decree of the Council of Ministers from 02.04.1964 and the Rules for the radiation and safety control organization of the Ministry of Health.

The Ministry of Environment controls the operation of NPP as well.

The NPP emergency readiness for severe accidents in controlled by the staff of the Bulgarian Civil Defense.

2.3 Regulatory Policy (Licensing, Operation, Technical Specification, Environmental Conditions, etc.)

The licensing procedures concerning the operation of NPP and the activities carried out on NPP site by outer organizations are carried out by CUAEPP. Up to now at NPP were applied Soviet Operating Technical Specifications. At present these specifications are reviewed and updated by working groups from NPP and "Energoproekt" specialists. The control on the technical specifications implementation is performed by NPP management and the CUAEPP. The quality assurance is provided by NPP specialists, working at the administrative section and at Electricity Production sections I and II. Their quality assurance (QA) programmes for every unit are to be approved and controlled by CUAEPP.

2.4. Public Acceptance

During the last years, the public concern about the nuclear power plant's operation is studied, discussed and paid greater attention by the media and the government. In the country exist some individual and group anti-nuclear spirits, influenced mainly by the previous lack of information on the safety and reliability of NPP Kozloduy's performance. At present the NPP operates its own groups for Public Relations, in tight coordination with the international and national media and information centers. According to the official data and concepts, the economy of the country will collapse without the nuclear power generation, which is quite well understood by the population. The public interest towards the NPP performance is understandably increased during the winter. The general public is regularly informed on the NPP output and status, through the Press Center of the Council of Ministers and the national media. In light of public protests of the new plant - Belene construction, as well as concerns about seismic risk, the Bulgarian government decided in mid 1991 to halt construction.

3. FACTOR AFFECTING THE PLANT PERFORMANCE UNDER PLANT MANAGEMENT CONTROL

3.1. Plant Operation Structure

The operating NPP Management is performed by a temporary unit structure. Operating management is the new way of decision making and performance of actions. concerning the main and supplementary equipment, supporting systems and devices, performed only by employ charge off it. The NPP staff is working on six shifts. The shift schedule is based on the principle "3 working days, followed by 2 days off". Follow some data on the Temporary Plant Operation Structure: Top NPP management via the General Plant Manager and the Deputy Plant Manager through the other departments (Table 8).

TABLE 8 - TEMPORARY PLANT OPERATING STRUCTURE

Administrative Plant Management	Departments/Units
1. Administrative Management	Office Finances Plant Operation Research and Development Maintenance Safety Security
2. Electricity Production I	Nuclear Reactor Unit-1 Nuclear Reactor Unit-2 Nuclear Reactor Unit-3 Nuclear Reactor Unit-4
3. Electricity Production II	Nuclear Reactor Unit-5 Nuclear Reactor Unit-6
4. Radioactive Waste Treatment	

3.2. Management Politics (Planning, Staff Organization, Training, Leading and Controlling, Research and Development)

Planning:

The year planning must proved the performance of feedback measures, plan and preventive repair, according to the special regime. Non-planned outages and power decreases, connected with safety assurance, must not be regarded as an accident or spoilage in terms of the "Accidents investigation procedure:. A system for additional qualification to the personnel should be instituted to ensure the safety operation.

Personnel Training:

The last probabilistic assessments show that probability for human errors are of order 10E-3 - 10E-2, which is few orders higher than the probability fear main equipment failures. To reduce the importance of human factor, it has to:

- improve the operator-machine interactions
- increase the professional level of the operators

Until the commissioning of NPP "Kozloduy" simulators, the operators are and will be trained at other countries simulators, using a schedule, confirmed by the CUAEPP.

The personnel training and qualification activities at NPP, are organized by the on site training center and concern: new personnel involvement, special training stages, operational personnel emergency training, theoretical education, working places ergonomics' yearly prophylactic medical checking, periodical psychophysiological and sociological assessments, practical examination for particular job, training and methodology boards work, contacts with pupils and students, post graduate qualification, work permission system checking.

A state examination of units personnel, according to the items of the normative document No. 6 of CUAEPP is performed.

Scientific - Technical Assistance:

- and expert estimation of the technical state and resources of the system and components of the power units, taking into account the terms of work, physical state, cycle of loading and operational regimes;
- a list of accidents;
- a quantitative analysis with a technological severe accident scenario, according to the adjusted list and in the framework of IAEA Regional Programme on Computer Aided Safety Analysis RER/9/002;
- technological operation recommendations;
- technological and updating of operational and emergency procedures, based on the technological recommendations;
- a quantitative reliability analysis of NPP equipment and preparation of conducting of PSA analysis, Level 1 for all units, according to IAEA Regional Programme RER/9/005, on PSA of WWER-440 type reactors.

3.3. Management Policy Implementation (Maintenance, Operation, Refuelling, Waste, In-service Inspection, Fuel Cycle)

The main organization section for repair and maintenance in Kozloduy NPP at the moment is of department type. The planning of the repairs is performed by using of a plant-preventive maintenance schedule (PPM). It includes prophylactic, current and main repair of all main and supplementary equipment and safety systems. Basic for the annual PPM schedule carrying out is the criterion for equipment run time, recommended by the procedures organizations.

The maintenance is performed into two was as follows:

- on a self-support basis, by the NPP repair personnel. In this way the refuelling, reactors vessel revision and all primary circuit equipment revision and repairs are performed. The repairs of the electrical devices for internal needs and of the supplementary turbine systems repairs are performed in the same way.

- by assigning a task. The main performer of this way of repairs is the maintenance enterprise "Energoremont". It includes the main repairs of the turbines, transformers and supplementary equipment. The "Energoremont" enterprise performs also all reconstruction and modernization of the secondary circuit equipment.

Repairs of high and low voltage motors, pumps, pipings are performed out site.

The main activities, supporting the safe and reliable operation of the NPP are performed by the plant personnel. These activities are separated as follows:

1. equipment testing programme
2. reactor technic and core control
3. fresh and spent fuel handling
4. operational experience feedback
5. power units backfitting and modernization

The concept and design for the safety level up to the contemporary standards, are developed with the participation of external organizations "Energoproekt"-Sofia, CPUAE-Sofia, as well as by design, construction and regulatory organizations from the former USSR. The reconstruction concept is approved also by WANO. As it is known, the out-of-budget IAEA project considers this problem too.

The equipment tests are performed before commissioning of the unit, after refuelling or before restart of a reactor, that has been scrammed for longer than three days. All devices included in the safety related systems are tested by the National standards. Monthly tests are also performed according to a plan, approved by the Shift Supervisor. Another set of tests follows the repair of every device.

Principles of Fuelling and Refuelling

During the period 1974-1983, the WWER-440/230 reactors at NPP used assemblies without perforation. The route of assembly moving during refuelling was OUT-IN-IN, which corresponds to the zonal principles of nuclear fuel location. The maximum enriched assemblies were loaded at the core periphery, while lower enriched assemblies were loaded in the central part. The coordinates of fuel movement within the core were determined on the bases of calculations. For each reactor refuelling, a set of calculations of individual versions were made for the purpose of selecting the optimum.

The optimum refuelling schedule should provide for:

- the set operation time after each refuelling;
- reactor operation and rated parameters with reasonable values of the assembly output factor Kq and core output factors;

- the required core subcriticality with shut down reactor in cold condition.

Calculations have been carried out by means of computing programmes, developed at the Institute of Nuclear Power "I.V. Kurchatov"-Moscow. Upon first fuelling with 1.6%, 2.4%, 3.6% U-235 enrichment the assemblies remain in the core for one, two or three fuel campaigns, respectively.

3.4. Others

Operational Feedback

In order to avoid repeating of failure due to faults in design, repair, operating procedures, operating practices, etc., every unit commission is a Plant Manager. Members are experts from the departments relevant to the failure. The commission investigates the case and issues a protocol, in which the causes for the failure and the necessary measures are described. All the operational and (if necessary) the maintenance staff is acquainted with the final protocols. Special analysis are performed every three months, in order to compare the results of the previous periods.

A system for implementation of NPPs operational experience is under development. Intensive data exchange is already developed by the Equipment Quality Information Systems (EQIS), by the Accident Information System (AIS), by NUCNET network, etc.

ANNEX E
OTHER PERFORMANCE INDICATORS

1. KOZLODUY NUCLEAR POWER PLANTS (UNITS 1, 2, 3 AND 4)

1.1. Number of Automatic Annual Scrams (Scrams per year, after commercial operation).

Table 1 - Number of Automatic Scrams per Year After Commercial Operation

	Unit 1	Unit 2	Unit 3	Unit 4
1974	8			
1975	7	5		
1976	5	3		
1977	8	1		
1978	3	0		
1979	4	4		
1980	0	0		
1981	2	0	11	
1982	2	2	5	1
1983	0	2	2	0
1984	0	2	2	2
1985	1	2	2	0
1986	1	0	2	1
1987	0	3	2	1
1988	1	1	0	1
1989	1	0	1	1
1990	1	2	4	1

1.2. Cycle Duration (time between refuelling, < 12, 18 or 24 months)

< 12 months.

1.3. Time of Reactor Critical (i.e. annual hours that the reactor was critical)

Not provided.

1.4. Thermal Performance and Self Consumption

Table 2 - Adjusted Actual Gross Heat Rate (kJ/kW.h)

	Unit 1	Unit 2	Unit 3	Unit 4
1975	11 897.60	12 294.20		
1976	12 058.30	11 960.50		
1977	11 711.00	11 921.20		
1978	11 734.40	11 726.90		
1979	11 642.30	11 801.70		
1980	11 719.10	11 749.90	12 431.70	
1981	11 872.30	11 721.10	11 721.50	
1982	12 206.40	12 565.60	11 958.50	12 074.10
1983	12 256.70	12 044.50	11 666.00	11 889.80
1984	12 282.70	12 079.60	11 746.10	11 578.90
1985	12 177.20	12 278.70	11 795.90	11 666.50
1986	11 921.10	12 211.40	11 685.80	11 734.40
1987	11 808.30	12 239.60	11 688.30	11 904.20
1988	12 007.80	12 333.00	11 394.40	11 833.10
1989	11 956.70	12 255.30	11 487.30	11 886.40
1990	12 322.40	12 522.30	11 626.30	12 104.20

Design gross heat rate (kJ/kW.h)= 11187

Table 3 - Thermal Performance

	Unit 1	Unit 2	Unit 3	Unit 4
1975	1.06	1.10		
1976	1.08	1.07		
1977	1.05	1.07		
1978	1.05	1.05		
1979	1.04	1.05		
1980	1.05	1.05	1.11	
1981	1.06	1.05	1.05	
1982	1.09	1.12	1.07	1.08
1983	1.10	1.08	1.04	1.06
1984	1.10	1.08	1.05	1.04
1985	1.09	1.10	1.05	1.04
1986	1.07	1.09	1.04	1.05
1987	1.06	1.09	1.04	1.06
1988	1.07	1.10	1.02	1.06
1989	1.07	1.10	1.03	1.06
1990	1.10	1.12	1.04	1.08

Note: Thermal performance is the ratio between the adjusted actual gross heat rate by the designed gross heat rate.

Table 4 - Thermal Production (MW.h(th)) and Self Consumption (MW(e))

	Thermal Production (MW.h(th))	Self Consumption. MW(e))
Unit 1	33 000	32.2
Unit 2	33 000	32.2
Unit 3	33 000	32.2
Unit 4	33 000	32.2

1.5. Collective Radiation Exposure (unit exposure based on TLD or film badge)

Table 5 - Collective Radiation Exposure (man-rem) for all Units.

year	(man-rem)
1974	36.25
1975	366.94
1976	457.50
1977	342.70
1978	1 250.55
1979	692.13
1980	668.46
1981	612.29
1982	984.65
1983	1 001.41
1984	1 025.65
1985	810.55
1986	1 234.49
1987	951.14
1988	888.79
1989	868.56
1990	820.87

1.6. Volume of Low and Medium Level of Solid Radioactive Waste

Table 6 - Volume of Low and Medium Level of Solid Radioactive Waste

Low level solid radioactive waste	Medium level solid radioactive waste
< 30 mrem/h = zero	30 - 1000 mrem/h = zero

1.7. Core Average Burnup and Replaced Part of Fuel Average Burnup

Table 7 - Core Average Burnup (MW.d/kg U)

	Unit 1	Unit 2	Unit 3	Unit 4
1975	10.04			
1976		10.15		
1977	18.69	17.54		
1978	21.64	20.71		
1979	21.79	21.23		
1980	21.60	20.82		
1981	21.64	21.90		
1982	20.26	22.40	13.97	
1983	20.39	21.60	18.93	13.59
1984	20.02	21.35	20.42	16.90
1985	20.63	21.81	22.23	21.63
1986	21.89	22.07	22.46	21.62
1987	22.02	23.37	22.01	23.00
1988	21.50	23.30	19.31	22.32
1989	22.72	22.89	23.10	20.99
1990	22.84	22.83	23.65	24.05

Average burnup of replaced part of fuel (discharged portion) (MW.d/kg U): not provided

1.8. Volume of Radioactive Effluent Expressed in Bc/kW.h for Different Effluent.

No information was provided.

1.9. Fuel Reliability

Table 8 - Iodine 131 and Iodine 134 Activity (in microcurie per gram)

	Unit 1		Unit 2		Unit 3		Unit 4	
	I-131	I-134	I-131	I-134	I-131	I-134	I-131	I-134
1974	9.8E-1	5.2E-2						
1975	2.4E00	1.0E00	4.3E-3	2.5E-3				
1976	4.3E-2	9.8E-1	3.5E-3	2.6E-2				
1977	5.6E-2	1.1E-1	4.0E-3	6.8E-2				
1978	3.7E-2	8.8E-1	2.9E-3	6.2E-2				
1979	2.3E-2	4.6E-1	1.6E-3	3.1E-2				
1980	1.8E-2	3.4E-1	7.4E-4	1.9E-2	3.8E-6	2.1E-4		
1981	2.3E-2	3.5E-1	5.6E-4	1.1E-2	4.5E-3	1.2E-2		
1982	1.5E-2	2.0E-1	5.3E-4	8.5E-3	7.1E-3	1.7E-2	4.4E-5	4.4E-4
1983	1.2E-2	2.6E-1	2.1E-3	8.5E-3	2.7E-2	1.4E-1	2.0E-4	1.3E-3
1984	1.2E-2	3.3E-1	2.3E-3	1.1E-2	9.6E-3	2.2E-1	4.6E-4	5.1E-3
1985	9.7E-3	2.4E-1	4.1E-2	5.0E-2	2.0E-2	1.4E-1	3.8E-4	8.3E-3
1986	6.4E-3	1.4E-1	1.2E-1	1.7E-1	1.0E-3	6.1E-2	4.6E-4	7.7E-3
1987	1.0E-2	1.7E-1	7.5E-2	2.5E-1	1.2E-3	2.9E-2	9.8E-4	5.4E-3
1988	9.5E-3	1.3E-1	4.3E-2	3.8E-1	2.7E-3	3.1E-2	2.4E-3	9.4E-3
1989	4.4E-3	1.1E-1	1.0E-2	3.0E-1	3.2E-3	5.9E-2	2.5E-3	1.4E-2
1990	3.8E-3	9.5E-2	2.0E-2	2.3E-1	3.9E-3	7.7E-2	1.8E-3	1.8E-2

Enter the monthly average steady-state reactor coolant activities for iodine 131 and iodine 134. Steady-state is defined as continous operation for at least three days at a power level that does not vary more than ± 5 percent.

Rem. There is no gueranty for steady-state reactor coolant activity determinations before 1987.

1.10. Purification Rate Constant

Table 9 - Purification Rate Constant (2.4E-5 /s)

	An average power level at which the coolant activity was determined			
	Unit 1	Unit 2	Unit 3	Unit 4
1974	90			
1975	82	83		
1976	80	95		
1977	100	100		
1978	97	100		
1979	98	95		
1980	100	100	20	
1981	100	95	100	
1982	100	95	96	90
1983	100	90	100	97
1984	95	88	96	100
1985	100	100	95	95
1986	98	100	90	100
1987	100	100	100	100
1988	100	82	100	95
1989	98	95	100	96
1990	90	97	100	95

2. BOHUNICE NUCLEAR POWER PLANTS (UNITS 1, 2, 3 AND 4)

2.1. Number of Automatic Annual Scrams (Scrams per year, after commercial operation).

Table 10 - Number of Scrams per Year

	Unit 1	Unit 2	Unit 3	Unit 4
1981	4	5		
1982	4	6		
1983	2	4		
1984	2	3	16	
1985	3	3	9	
1986	2	2	6	6
1987	3	3	4	3
1988	1	3	3	7
1989	2	1	2	1
1990	2	1	3	4

2.2. Cycle Duration (time between refuelling, < 12, 18 or 24 months)

< 12 months.

2.3. Time of Reactor Critical (i.e. annual hours that the reactor was critical)

Table 11 - Average Time of Reactor Critical

	Unit 1	Unit 2	Unit 3	Unit 4
Average	7 187	7 295	7 135	7 515

2.4. Thermal Performance and Self Consumption

Table 12 - Thermal Production (MW.h(th))

	Unit 1	Unit 2	Unit 3	Unit 4
Average	9 168 454	9 554 090	9 189 132	9 955 327

Table 13 - Self Consumption (MW(e))

	Unit 1	Unit 2	Unit 3	Unit 4
Average	30.50	29.75	28.62	28.00

2.5 Collective Radiation Exposure (unit exposure based on TLD or film badge)

Table 14 - Collective Radiation Exposure (expressed in man-Sievert)

	Unit 1 + Unit 2	Unit 3 + Unit 4
1981	1 652.37	
1982	3 152.32	
1983	2 196.13	3.11
1984	1 081.40	10.98
1985	5 284.42	685.75
1986	1 556.95	410.85
1987	1 601.83	963.39
1988	2 820.08	621.88
1989	1 511.28	433.33
1990	844.62	393.07

2.6. Volume of Low and Medium Level of Solid Radioactive Waste

Table 15 - Volume of Low Level Solid Radioactive Waste

	Unit 1 + Unit 2				Unit 3 + Unit 4			
Year	W	D	W	D	W	D	W	D
1981		150						
1982		199						
1983		179						
1984		126						
1985		294						
1986		297.5				45		
1987		135				69.5		
1988		250				82.5		
1989		250				48		
1990		250				36		

Where,

W = processed waste shipped for disposal from both on-site and off-site facilities, expressed in cubic meters;

D = processed waste in storage awaiting shipment for disposal, e.g. the processed waste that is ready for shipment for disposal and that is stored either on-site or off-site at the end of the year.

Table 16 - Volume of medium level solid radioactive waste

	Unit 1 + Unit 2				Unit 3 + Unit 4			
Year	W	D	W	D	W	D	W	D
1981	Not evaluated (values are covered in preceding table).							
1982								
1983								
1984								
1985								
1986								
1987								
1988								
1989								
1990								

Where,

W = processed waste shipped for disposal from both on-site and off-site facilities, expressed in cubic meters;

D = processed waste in storage awaiting shipment for disposal, e.g. the processed waste that is ready for shipment for disposal and that is stored either in-site or off-site at the end of the year.

2.7 . Core Average Burnup and Replaced Part of Fuel Average Burnup

Table 17 - Core Average Burnup (MW.d/kg U)

	Unit 1	Unit 2	Unit 3	Unit 4
1981	10 318	11 454		
1982	10 607	10 275		
1983	10 677	10 335		
1984	11627	10 417	8 692	
1985	10 727	11 625	7 748	11 355
1986	8 711	10 432	9 432	8 528
1987	8 235	10 784	8 499	7 951
1988	8 314	10 824	9 570	9 769
1989	9 600	10 900	9 885	10 028
1990	10 088	10 717	9 632	9 614

Table 18 - Average Burnup of Replaced Part of Fuel (Discharged Portion) (MW.d/kg U)

	Unit 1	Unit 2	Unit 3	Unit 4
1981	22 639	11 356		
1982	32 858	22 528		
1983	32 312	32 650		
1984	32 860	31 568	8 747	
1985	31 382	30 342	15 417	11 429
1986	31 472	29 124	22 017	19 783
1987	29 263	31 558	23 565	27 220
1988	26 467	29 033	23 662	25 714
1989	27 445	31 196	27 532	25 987
1990	28 237	29 788		28 644

2.8. Volume of Radioactive Effluent Expressed in Bc/kW.h for Different Effluent

Table 19 - Volume of Radioactive effluents - Liquid effluents (summary beta-activity per year/ 10^6 Bq)

	Unit 1 + Unit 2	Unit 3 + Unit 4
1981	107,8	
1982	735,2	
1983	157,8	
1984	201,6	141,1
1985	490,2	148,6
1986	136,4	196,5
1987	324,8	94,3
1988	132,4	48,6
1989	83,0	28,7
1990	97,97	39,78
H^3 - activity /10^9 Bq/ - Liquid effluents		
1981	2386,4	
1982	5914,3	
1983	6475,9	
1984	4727,0	829,6
1985	7104,0	5463,8
1986	657o,4	8015,1
1987	6728,1	6926,5
1988	3247,0	5033,0
1989	5034,1	5406,9
1990	7107,2	5894,8

		Unit 1 + Unit 2	Unit 3 + Unit 4
Aerosols /10^6 Bq/	1981	1588,3	
	1982	807,8	
	1983	842,1	
	1984	2690,4	73,3
	1985	1175,8	550,5
	1986	4274,4	2277,9
	1987	749,1	157,9
	1988	1073,6	152,4
	1989	1115,1	93,6
	1990	344,9	85,97
H^3 /10^9 Bq/	1981	1887,7	
	1982	1573,1	
	1983	2704,0	
	1984	3273,1	114,0
	1985	229,8	37,5
	1986	2784,0	624,0
	1987	1846,9	337,6
	1988	1175,2	407,1
	1989	1016,3	461,8
	1990	708,1	255,1
Gases /10^{12} Bq/	1981	93,7	
	1982	131,2	
	1983	96,0	
	1984	36,2	5,6
	1985	31,1	36,4
	1986	34,3	11,7
	1987	26,5	10,9
	1988	26,4	11,00
	1989	28,2	10,8
	1990	9,3	10,7

		Unit 1 + Unit 2	Unit 3 + Unit 4
J^{131} /10^6 Bq/	1981	483,3	
	1982	2191,0	
	1983	391,7	
	1984	409,7	161,6
	1985	419,6	1809,9
	1986	416,1	2047,3
	1987	147,4	1632,4
	1988	499,7	908,8
	1989	512,8	1274,4
	1990	633,3	1084,4

2.9. Fuel Reliability

Not provided.

2.10. Purification Rate Constant

Not provided.

3. KOLA NUCLEAR POWER PLANT (UNITS 1 AND 2)

3.1. Number of Automatic Annual Scrams (Scrams per year, after commercial operation)

Table 20- Number of Scrams per Year

	Unit 1	Unit 2
1973	5	
1974	3	
1975	3	8
1976	1	6
1977	2	4
1978	2	2
1979		1
1980		
1981		
1982		
1983		
1984		1
1985		
1986		2
1987	2	1
1988		1
1989		
1990	1	

3.2. Cycle Duration (time between refuelling, < 12, 18 or 24 months)

Table 21 - Cycle Duration or Time Between Refuelling (months)

	Unit 1	Unit 2
1	22	8
2	19	8
3	12	11
4	11	13
5	11	7
6	11.5	10
7	12	11
8	12	10
9	11	11
10	12	9
11	11	11
12	7	11
13	11	11
14	11	10
15	10	
16	10	
17		

3.3. Time of Reactor Critical (i.e. annual hours that the reactor was critical)

Not provided.

3.4. Thermal Performance and Self Consumption

Thermal Performance

Table 22 - Adjusted actual gross heat rate (kJ/kW.h)

	Unit 1		Unit 2	
	Designed	Actual	Designed	Actual
1973				
1974	11 305	11 363		
1975	11 305	11 221	11 305	11 480
1976	11 305	11 396	11 305	11 505
1977	11 305	11 664	11 305	11 329
1978	11 305	11 292	11 305	11 308
1979	11 305	11 283	11 305	11 300
1980	11 305	11 316	11 305	11 283
1981	11 305	11 451	11 305	11 442
1982	11 305	11 530	11 305	11 514
1983	11 305	11 350	11 305	11 388
1984	11 305	11 354	11 305	11 451
1985	11 305	11 459	11 305	11 388
1986	11 305	11 186	11 305	11 241
1987	11 305	11 191	11 305	11 216
1988	11 305	11 178	11 305	11 233
1989	11 305	11 308	11 305	11 195
1990	11 305	11 250	11 305	11 342

Table 23 - Thermal Production (MW.h(th))

	Unit 1	Unit 2
1973	1021.20	
1974	2176.30	42.50
1975	1122.60	1520.00
1976	2624.40	2100.70
1977	2887.60	2823.30
1978	3204.80	3198.90
1979	2615.80	3284.60
1980	3716.90	3507.40
1981	3091.30	3296.80
1982	3080.10	2648.00
1983	3470.50	3305.70
1984	3353.40	3269.60
1985	2575.10	3287.30
1986	3108.80	3065.30
1987	3268.20	3345.40
1988	3150.90	3085.00
1989	2876.50	2909.50
1990	2942.40	2811.60

Table 24 - Self Consumption (MW(e))

	Unit 1	Unit 2
1973	103	
1974	195.3	9.10
1975	106.80	136.90
1976	202.70	157.50
1977	186.60	196.10
1978	226.00	216.50
1979	180.20	227
1980	250.60	240.60
1981	220.40	241.90
1982	232.00	185.00
1983	253.10	233.00
1984	241.40	235.10
1985	186.40	231.70
1986	242.90	222.70
1987	232.90	230.70
1988	225.90	213.30
1989	204.40	202.30
1990	208.80	203.60

3.5. Collective Radiation Exposure

Table 25 - Collective Radiation Exposure

	Unit 1	Unit 2
1973	8.33	-
1974	33.87	-
1975	80.39	62.11
1976	275.36	144.7
1977	389.32	254.88
1978	160.63	327.83
1979	226.09	166.87
1980	99.91	129.91
1981	324.2	116.69
1982	151.5	248.69
1983	69.93	77.83
1984	71.3	65.06
1985	172.69	81.82
1986	93.87	174.75
1987	80.94	127.57
1988	120.79	182.65
1989	249.16	413.88
1990	153.9	284.00

3.6. Volume of Low and medium Level of Solid Radioactive Waste

Table 26 - Volume of Low and Medium Level of Solid Radioactive Waste (8 mCu/sec.)

	Unit 1		Unit 2	
	W	D	W	D
1973	missing	–	missing	–
1974	"	–	"	–
1975	"	35	"	5
1976	"	84	"	28
1977	"	30	"	4
1978	"	151,4	"	76,7
1979	"	62,4	"	51,8
1980	"	39,2	"	87,96
1981	"	56,1	"	60,1
1982	"	87,1	"	44,7
1983	"	74,8	"	120,1
1984	"	71,5	"	73,28
1985	"	124,6	"	75,66
1986	"	73,25	"	61,95
1987	"	84,1	"	121,1
1988	"	64,2	"	58,88
1989	"	185,5	"	87,8
1990	"	171,73	"	154,38

Table 27 - Medium Level Solid Radioactive Waste (8-260 mCu/sec)

	Unit 1		Unit 2	
	W	D	W	D
1973	missing	–	missing	–
1974	"	–	"	–
1975	"	6	"	–
1976	"	16	"	4
1977	"	9	"	7
1978	"	18,4	"	6,85
1979	"	16,5	"	14,5
1980	"	29,43	"	72,4
1981	"	16,25	"	19,45
1982	"	42,43	"	17,31
1983	"	13,86	"	44,47
1984	"	46,3	"	47,88
1985	"	21,4	"	9,06
1986	"	10,2	"	10,48
1987	"	10,4	"	15,1
1988	"	11,45	"	12,98
1989	"	27,8	"	10,33
1990	"	20,2	"	17,95

Where,

W = processed waste shipped for disposal from both on-site and off-site facilities, expressed in cubic meters;

D = processed waste in storage awaiting shipment for disposal, e.g. the processed waste that is ready for shipment for disposal and that is stored either on-site or off-site at the end of the year.

Table 28 - Volume of High Level Solid Radioactive Waste (>260mCu/sec)

	Unit 1		Unit 2	
	W	D	W	D
1973	missing	–	missing	–
1974	"	–	"	–
1975	"	–	"	–
1976	"	4,6	"	–
1977	"	4,8	"	2
1978	"	5,84	"	2.39
1979	"	0,8	"	1,15
1980	"	0,75	"	0,6
1981	"	0,82	"	1,1
1982	"	1.8	"	0,65
1983	"	0.5	"	0,83
1984	"	1,08	"	1,98
1985	"	5,42	"	2.88
1986	"	4,84	"	4.68
1987	"	4.85	"	6,66
1988	"	3.18	"	4,09
1989	"	6.86	"	3.98
1990	"	4,61	"	4,96

Table 29 - Volume of Radioactive effluents (gaseous, etc)

	First Part (Units 1 + 2)
1973	380,30
1974	1047,00
1975	1720,00
1976	1811,00
1977	1638,00
1978	1925,00
1979	2027,40
1980	1972,00
1981	2224.50
1982	1746,50
1983	2055,30
1984	1644,40
1985	4676,23
1986	5867.65
1987	7771,40
1988	5637,20
1989	3838,00
1990	4614,00

Where,

W = processed waste shipped for disposal from both on-site and off-site facilities, expressed in cubic meters,

D = processed waste in storage awaiting shipment for disposal, e g the processed waste that is ready for shipment for disposal and that is stored either on-site or off-site at the end of the year

3.7. Core Average Burnup and Replaced Part of Fuel Average Burnup

Table 30 - Core Average Burnup (MW.d/kg U)

Unit 1			Unit 2		
Cycle	Year	Burn-up	Cycle	Year	Burn-up
1	1973-75	12.60	1	1974-76	9.40
2	1975-77	12.10	2	1976-77	8.30
3	1977-78	9.60	3	1977-78	9.80
4	1978-79	10.50	4	1978-79	11.70
5	1979-80	10.70	5	1979-80	6.60
6	1980-81	10.60	6	1980-81	10.40
7	1981-82	9.90	7	1981-82	9.70
8	1982-83	11.10	8	1982-83	10.10
9	1983-84	10.40	9	1983-84	9.90
10	1984-85	9.70	10	1984-85	8.60
11	1985-86	10.90	11	1985-86	11.20
12	1986-87	7.00	12	1986-87	11.20
13	1987-88	12.40	13	1987-88	11.90
14	1988-89	11.30	14	1988-89	10.20
15	1989-90	11.20	15	1989-90	11.40
16	1990-91	10.10	16	1990-90	3.50
			17	1990-91	5.50

Table 31 - Average Burnup of Replaced Part of Fuel (discharged portion) (MW.d/kg U)

Unit 1			Unit 2		
Cycle	Year	Burn-up	Cycle	Year	Burn-up
1	1973-75	11.80	1	1974-76	9.20
2	1975-77	22.60	2	1976-77	14.90
3	1977-78	31.20	3	1977-78	24.90
4	1978-79	32.00	4	1978-79	
5	1979-80	30.30	5	1979-80	31.30
6	1980-81	30.20	6	1980-81	29.50
7	1981-82	29.40	7	1981-82	27.70
8	1982-83	31.20	8	1982-83	29.40
9	1983-84	30.70	9	1983-84	30.10
10	1984-85	28.70	10	1984-85	27.10
11	1985-86	30.10	11	1985-86	29.90
12	1986-87	26.00	12	1986-87	27.30
13	1987-88	27.50	13	1987-88	27.70
14	1988-89	27.70	14	1988-89	27.70
15	1989-90	31.80	15	1989-90	32.20
16	1990-91	31.80	16	1990-90	24.60
			17	1990-91	30.80

3.9. Fuel Reliability

Table 32 - Parameters of Reliability of Fuel (Rated Activity x 10-5, Cu/l)

Year	Month	Unit 1		Unit 2	
		Y-131	Y-134	Y-131	Y-134
Before 1979 there is no data available.					
1979	01	3,2	0,9	1,3	4,6
	02	1,5	0,6	1,3	5,0
	03	1,6	0,8	1,4	5,3
	04	1,0	1,1	1,1	5,7
	05	0,86	2,3	1,3	5,8
	06	–	–	1,5	4,7
	07	–	–	1,2	5,0
	08	–	–	1,3	5,0
	09	–	–	1,3	5,0
	10	0,24	0,51	–	–
	11	0,43	0,5	4,7	2,4
	12	0,45	0,48	1,4	3,9
1980	01	3,2	0,9	1,1	3,2
	02	1,5	0,6	1,8	3,7
	03	1,6	0,8	2,1	4,2
	04	1,0	1,1	3,2	4,0
	05	0,86	2,3	1,2	4,2
	06	1,02	2,9	–	–
	07	2,4	3,0	1,6	6,4
	08	–	–	1,2	8,3
	09	0,5	1,3	0,86	6,3
	10	0,63	1,4	0,53	6,6
	11	0,39	1,6	0,74	6,3
	12	0,38	1,8	0,75	10
1981	01	0,25	2,3	0,65	8,9
	02	0,43	2,5	0,87	9,3
	03	0,50	2,9	4,3	13
	04	0,9	3,3	5,2	13
	05	1,8	4,3	–	–
	06	9,8	6,4	1,0	5,6
	07	–	–	0,78	6,5
	08	–	–	0,43	7,4
	09	0,45	2,3	0,48	5,7
	10	0,66	1,6	0,47	7,6
	11	0,76	3,2	0,44	6,7
	12	0,38	3,3	0,49	8,7
1982	01	0,5	4,4	0,74	13
	02	0,47	3,7	0,72	12
	03	0,55	3,7	1,6	8,8
	04	0,30	0,11	0,44	7,2
	05	0,10	0,9	-	–

	06	0,41	3,6	–	–
	07	0,33	2,8	–	–
	08	–	–	0,43	6,4
	09	–	–	0,56	6,3
	10	1,0	1,7	0,56	6,3
	11	0,85	2,5	0,66	6,5
	12	0,57	2,6	0,76	7,4
1983	01	0,5	6,2	0,79	7,8
	02	0,5	3,2	0,77	7,6
	03	0,38	3,1	3,2	7,4
	04	0,48	3,2	4,7	7,6
	05	0,49	3,3	5,4	6,7
	06	0,48	3,1	–	–
	07	–	–	–	–
	08	–	–	4,7	6,5
	09	–	–	3,7	4,3
	10	0,44	2,5	2,8	5,6
	11	0,47	2,7	2,4	5,7
	12	0,23	2,8	0,74	6,3
1984	01	0,30	2,9	0,63	6,5
	02	0,32	4,1	0,65	4,6
	03	0,38	3,0	1,1	5,7
	04	0,48	1,5	1,3	5,6
	05	0,50	1,5	0,58	3,7
	06	0,53	2,7	–	–
	07	–	–	–	–
	08	–	–	1,4	3,5
	09	0,24	1,4	1,1	2,3
	10	0,33	1,5	1,3	2,2
	11	0,32	1,5	1,3	2,5
	12	0,26	1,3	1,2	3,2
1985	01	0,23	1,4	0,45	2,8
	02	0,23	1,4	0,33	2,1
	03	0,18	1,4	0,80	2,2
	04	0,22	2,1	–	–
	05	0,31	1,5	0,53	1,0
	06	0,31	2,3	0,42	1,9
	07	–	–	0,33	1,8
	08	–	–	0,35	1,9
	09	–	–	0,52	2,0
	10	1,9	0,8	0,51	2,3
	11	2,2	0,9	0,51	2,4
	12	0,50	1,2	0,62	2,3
1986	01	0,56	1,6	6,2	2,1
	02	0,55	1,1	4,3	2,2
	03	0,57	1,9	–	–
	04	0,54	2,7	–	–
	05	0,54	2,5	0,61	1,6
	06	0,31	1,7	0,52	1,7
	07	0,29	2,0	0,45	2,0
	08	0,19	1,7	0,86	1,7
	09	–	–	3,4	1,9
	10	0,8	1,4	3,4	1,9
	11	0,75	1,2	0,15	2,1
	12	0,30	1,3	0,61	2,4

1987	01	0,36	2,1	0,55	2,5
	02	0,36	2,4	0,53	3,4
	03	0,31	2,0	–	–
	04	0,27	2,5	–	–
	05	–	–	0,35	1,5
	06	0,36	7,3	0,44	2,4
	07	0,52	1,5	0,35	2,4
	08	0,55	1,6	0,35	1,4
	09	0,61	1,5	2,5	1,4
	10	5,7	0,9	2,3	1,3
	11	5,4	2,0	7,0	2,2
	12	8,0	1,5	4,4	1,6
1988	01	7,0	2,0	4,7	1,5
	02	6,3	2,6	5,8	2,2
	03	6,5	2,3	5,8	2,5
	04	7,0	2,3	–	–
	05	1,5	2,2	–	–
	06	–	–	3,7	2,0
	07	1,5	1,5	9,0	1,6
	08	1,3	0,84	9,1	2,0
	09	1,5	1,2	11	1,3
	10	1,8	1,4	9,3	2,0
	11	3,5	1,5	14,0	2,2
	12	3,5	1,5	18,0	2.2
1989	01	3.5	1,3	20,0	2,5
	02	5,0	1,7	21,0	2,4
	03	4,5	1,6	–	–
	04	5,0	1,9	–	–
	05	13	1,6	–	–
	06	–	–	12,0	1,5
	07	–	–	10,0	1,5
	08	7,5	1,0	8,9	1,9
	09	18,0	1,2	11,0	2,1
	10	16,0	1,3	16,0	3,2
	11	3,6	1,7	5,6	3,6
	12	1,6	2,8	5,0	3,2
1990	01	1,4	1,2	1,9	3,0
	02	1,3	1,3	2,8	2,9
	03	7,8	1,5	3,2	3,0
	04	5,0	1,7	–	–
	05	5,0	1,9	–	–
	06	–	–	5,0	2,8
	07	–	–	4,6	3,5
	08	–	–	4,7	2,7
	09	0,37	0,21	–	–
	10	0,30	0,30	4,3	2,3
	11	0,32	0,36	2,0	1,0
	12	0.26	0.41	2,1	1,0

Rated activity at the moment of taking the sample.

3.10. Purification Rate Constant

Table 33 - Parameters of purification of Coolant of 1^{xx} circuit

Year	Month	Unit 1		Unit 2	
		A - Speed of purification l/h	P - Power	A - Speed of purification l/h	P - Power
1979	01	0,1	107	0,1	106
	02	0,1	107	0,1	107
	03	0,1	107	0,1	107
	04	0,1	107	0,1	107
	05	0,1	52	0,1	107
	06	–	–	0,1	107
	07	–	–	0,1	107
	08	–	–	0,1	107
	09	–	–	0,1	88
	10	0,1	105	–	–
	11	0,1	106	0,1	47
	12	0,1	106	0,1	106
1980	01	0,1	107	0,1	106
	02	0,1	107	0,1	106
	03	0,1	107	0,1	106
	04	0,1	107	0,1	106
	05	0,1	107	0,14	52
	06	0,1	106	–	–
	07	0,1	107	0,1	107
	08	–	–	0,1	107
	09	0,1	106	0,1	107
	10	0,1	106	0,1	107
	11	0,1	106	0,1	106
	12	0,1	106	0,1	106
1981	01	0,1	107	0,90	107
	02	0,1	105	0,10	102
	03	0,1	107	0,10	107
	04	0,1	103	0,10	107
	05	0,1	106	–	–
	06	0,1	90	–	75
	07	–	–	–	107
	08	–	–	–	107
	09	0,1	90	0,10	107
	10	0,1	105	0,10	70
	11	0,1	102	0,11	50
	12	0,1	102	0,11	102
1982	01	0,1	102	0,1	100
	01	0,1	91	0,1	100
	03	0,1	89	0,1	85
	04	0,1	96	0,1	50
	05	0,1	68	–	–
	06	0,1	77	–	–
	07	0,1	50	–	–
	08	-		0,09	90

	09	–	–	0,09	77
	10	0,1	105	0,10	107
	11	0,1	106	0,10	107
	12	0,1	107	0,10	107
1983	01	0,1	106	0,1	107
	02	0,1	105	0,1	107
	03	0,1	106	0,1	107
	04	0,1	107	0,1	85
	05	0,1	107	0,1	107
	06	0,1	95	–	–
	07	–	–	–	–
	08	–	–	0,1	105
	09	–	–	0,1	107
	10	0,1	107	0,1	107
	11	0,1	107	0,1	105
	12	0,1	107	0,1	107
1984	01	0,1	106	0,1	107
	02	0,1	105	0,1	107
	03	0,1	106	0,1	107
	04	0,1	107	0,1	85
	05	0,1	107	0,1	107
	06	0,1	95	–	–
	07	–	–	–	–
	08	–	–	0,1	105
	09	0,1	107	0,1	107
	10	0,1	107	0,1	107
	11	0,1	107	0,1	105
	12	0,1	107	0,1	107
1985	01	0,1	100	0,1	100
	02	0,1	100	0,1	105
	03	0,1	105	0,1	107
	04	0,1	107	–	–
	05	0,1	107	0,1	89
	06	0,1	107	0,1	100
	07	–	–	0,1	100
	08	–	–	0,1	100
	09	–	–	0,1	100
	10	0,1	107	0,09	100
	11	0,1	107	0,09	100
	12	0,1	107	0,09	100
1986	01	0,1	100	0,09	98
	02	0.1	100	0,09	100
	03	0,1	100	–	–
	04	0,09	100	–	–
	05	0,10	100	0,10	100
	06	+	100	0,50+	100
	07	0,1+	72	0,50+	100
	08	0,09+	52	0,50+	100
	09	–	–	0,50+	100
	10	0,08	97	0,06	90
	11	0,05	100	0,10	100
	12	0,09	100	0,10	100
1987	01	0,09	100	0,10	100
	02	0,10	100	0,10	100
	03	[illegible]	100		

	04	0,10	100	–	–	
	05	–	–	0,10+	100	
	06	0,10	100	0,10+	96	
	07	0,09+	100	0,10	100	
	08	0,09	100	0,10	100	
	09	0,09	100	0,10	100	
	10	0,10	100	0,10	100	
	11	0,09+	100	0,05	100	
	12	0,09	100	0,05	100	
1988	01	0,1	100	0,10	100	
	02	0,1+	100	0,09+	100	
	03	0,1	100	0,09	100	
	04	0,1	100	–	–	
	05	0,1	97	–	100	
	06	–	–	0,10	100	
	07	0,1+	100	0.10+	100	
	08	0,1	100	0,10	100	
	09	0,09	100	0,10	100	
	10	0,10	100	0,10	100	
	11	0,09	100	0,10	100	
	12	0,1	100	0,1	100	
1989	01	0,1	100	+	100	
	02	0,1	100	+	100	
	03	0,1	100	–	–	
	04	0,1	100	–	–	
	05	0,1	96	–	–	
	06	–	–	0,1+	82	unstable
	07	–	–	0,1+	96,82	unstable
	08	0,1	100	0,06+	100	
	09	0,1+	100	0,06+	100	
	10	0,1+	100	0,09+	100	
	11	0,07	100	0,10	100	
	12	0,1	100	0,10	100	
1990	01	0,1	100	0,1	100	
	02	0,1	100	0,1	100	
	03	0,1	100	0,10	100	
	04	0,1	100	–	–	
	05	0,1	100	–	–	
	06	–	–	–	100	unstable
	07	–	–	0,1	100	
	08	–	–	0,1	97	
	09	0,1	95	–	–	
	10	0,1	95	0,1	90	
	11	0,1	97	0,1	90	
	12	0,1	95	0,10	90	

Note: - Planned maintenance
+ AF-1 Switched off
• Usage of SVO-1 was not monitored
Where A - average per year of coefficient of purification which is determined as expenditure for SVO/sec divided by volume of coolant of the primary circuit under the operating temperature with exception of KO.
P - average level of power when the radioactivity measurements were made.

4. NOVOVORONEZH NUCLEAR POWER PLANTS (UNITS 3 AND 4)

4.1. Number of Automatic Annual Scrams (Scrams per year, after commercial operation)

Table 34 - Number of Scrams per Year

	Unit 3	Unit 4
1972	19	
1973	7	8
1974	2	1
1975	1	5
1976	1	8
1977	1	6
1978	1	3
1979	0	1
1980	2	3
1981	3	3
1982	2	1
1983	3	2
1984	0	1
1985	3	2
1986	1	1
1987	0	1
1988	1	0
1989	0	1
1990	1	0

4.2. Cycle Duration (time between refuelling, <12, 18 or 24 months)

Table 35 - Cycle Duration of Time Between Refuelling (months)

	Unit 3	Unit 4
1971		
1972		
1973	15.10	
1974	13.90	10.80
1975	7.40	13.30
1976	15.20	12.30
1977	10.70	9.90
1978	12.00	12.30
1979	11.80	10.80
1980	12.10	11.30
1981	7.80	10.90
1982	12.00	13.30
1983	8.00	8.30
1984	10.60	11.50
1985	11.30	11.10
1986	14.30	11.30
1987	?	13.20
1988	12.30	10.30
1989	13.20	11.00
1990	13.00	13.50

4.3. Time of Reactor Critical (i.e. annual hours that the reactor was critical)

Table 36 - Time of Reactor Critical (hours/year)

	Unit 3	Unit 4
1971	87	
1972	7 120	82
1973	7 123	8 072
1974	7 990	7 759
1975	6 695	7 949
1976	7 534	7 943
1977	7 811	7 638
1978	7 962	7 235
1979	7 457	6 698
1980	8 245	7 619
1981	7 934	8 278
1982	8 030	8 279
1983	7 158	8 216
1984	8 185	7 580
1985	8 197	8 245
1986	8 043	7 688
1987	6 011	8 892
1988	8 110	7 152
1989	6 040	8 358
1990	8 611	6 622

4.4. Thermal Performance and Self Consumption

Table 37 - Thermal Production

	Unit 3	Unit 4
1971		
1972	1 891	
1973	2 813	2 786
1974	2 885	3 202
1975	2 174	2 857
1976	2 438	3 112
1977	2 303	3 056
1978	3 150	2 881
1979	2 850	2 656
1980	3 087	3 018
1981	3 060	3 280
1982	3 015	3 057
1983	2 683	3 218
1984	3 306	3 246
1985	3 275	3 385
1986	2 943	3 040
1987	2 322	3 203
1988	3 166	2 770
1989	2 242	2 991
1990	3 057	2 488

Table 38 - Thermal Performance

	Unit 3	Unit 4
1971		
1972	3 414	
1973	3 134	3 209
1974	3 277	3 158
1975	3 267	3 108
1976	3 267	3 113
1977	3 118	3 083
1978	3 117	3 085
1979	3 296	3 135
1980	3 241	3 167
1981	3 272	3 220
1982	3 312	3 282
1983	3 298	3 275
1984	3 136	3 174
1985	3 172	3 131
1986	3 178	3 166
1987	3 136	3 124
1988	3 162	3 161
1989	3 256	3 324
1990	3 182	3 156

Table 39 - Self Consumption (%)

	Unit 3	Unit 4
1971	50.00	
1972	10.20	20.00
1973	9.89	7.74
1974	8.85	7.86
1975	9.50	7.42
1976	9.70	7.87
1977	7.90	8.04
1978	7.89	8.22
1979	7.87	8.55
1980	8.02	8.61
1981	8.08	8.05
1982	8.08	8.49
1983	8.49	8.23
1984	8.56	8.37
1985	8.29	8.59
1986	8.24	8.15
1987	8.19	8.15
1988	8.20	8.76
1989	9.59	8.38
1990	8.46	8.87

4.5. Collective Radiation Exposure (unit exposure based on TLD or film badge)

Not provided.

4.6. Volume of Low and Medium Level of Solid Radioactive Waste

Not provided.

4.7. Core Average Burnup and Replaced Part of Fuel Average Burnup

Not Provided.

4.8. Volume of Radioactive Effluent Expressed in BC/kW.h for Different Effluent

Not provided.

4.9. Fuel Reliability

Not provided.

4.10. Purification Rate Constant

Not provided.

5. GREIFSWALD NUCLEAR POWER PLANT (UNITS 1, 2, 3, 4)

5.1 Number of Automatic Scrams per year After Commercial Operation

Table 40 - Reactor Scrams due to Accidents During Power Operation (starting from the connection of the 1st Turbogenerator Set to the Network)

year	unit 1	unit 2	unit 3	unit 4
1974	5	-	-	-
1975	4	18*	-	-
1976	6	5	-	-
1977	1	4	2	-
1978	1	3	7	-
1979	1	1	4	6
1980	1	6	5	4
1981	2	5	2	1
1982	-	-	3	1
1983	2	3	2	3
1984	5	2	4	4
1985	2	-	2	3
1986	7	2	2	2
1987	-	3	1	2
1988	4	3	4	1
1989	-	-	3	2
1990	-	-	-	1
Sum	41	54	41	30

* 9 of which in trial run.

5.2 Cycle Duration (time between refuelling, <12, 18 or 24 months)

Not provided.

5.3. Time of Reactor Critical (i.e. annual hours that the reactor was critical)

Not provided.

5.4. Thermal Performance and Self Consumption

Table 41 - Thermal Output of the Reactor in GW.h

Year	Block 1	Block 2	Block 3	Block 4
1974	4 315,2	-	-	-
1975	3 494,8	3 651,9	-	-
1976	8 221,0	8 090,2	-	-
1977	7 269,3	7 760,1	-	-
1978	7 705,2	8 321,8	7 547,2	-
1979	8 311,1	9 653,4	8 999,1	1 989,3
1980	9 480,0	9 194,0	9 195,7	9 612,4
1981	8 928,3	9 781,1	10 304,6	9 117,2
1982	6 239,4	8 496,5	9 856,9	10 051,5
1983	9 165,4	9 616,7	9 905,5	9 759,8
1984	9 301,8	9 277,4	9 211,8	10 047,8
1985	10 043,5	10 236,2	10 431,6	9 972,6
1986	9 325,8	7 336,1	9 980,1	9 711,8
1987	7 329,4	9 686,9	10 302,2	10 058,9
1988	8 254,7	10 229,2	9 242,7	10 571,9
1989	10 142,9	10 118,6	10 013,4	9 172,9
1990	10 003,5	1 447,9	1 859,2	4 248,5
Sum	137 531,3	132 928,0	116 850,0	104 314,6

Table 42 - Specific Internal Consumption in kJ/kW.h (Design Value 11,121.6 kJ/kW.h)

year	unit 1	unit 2	unit 3	unit 4
1974	11 392	-	-	-
1975	11 279	11 656	-	-
1976	11 924	12 158	-	-
1977	11 748	11 652	-	-
1978	11 769	11 773	11 630	-
1979	11 874	11 631	11 677	11 706
1980	11 669	11 777	11 819	11 715
1981	11 678	11 665	11 712	11 713
1982	11 812	11 853	11 635	11 693
1983	11 726	12 044	11 692	11 546
1984	11 759	11 930	11 651	11 550
1985	11 814	11 974	11 689	11 750
1986	12 127	11 740	11 727	11 952
1987	12 016	11 954	11 714	11 720
1988	11 990	12 051	11 666	12 109
1989	11 797	12 053	11 893	12 053
1990	12 057	11 573	11 607	11 893
cumu-lative	11 831	11 860	11 710	11 780

5.5. Collective Radiation Exposure (unit exposure based on TLD or film badge)

Table 43 - Collective Radiation Exposure (man Sv) for all Units

year	collective dose (man Sv)
1974	0,2
1975	3,5
1976	2,3
1977	1,8
1978	3,7
1979	7,5
1980	8,1
1981	6,5
1982	7,6
1983	5,8
1984	5,7
1985	4,5
1986	3,7
1987	9,9
1988	12,2
1989	8,7
1990	6,7

5.6. Volume of Low and Medium Level of Solid Radioactive Waste

Table 44 - Solid Radioactive Wastes (Low and Medium Level[1]) in m^3

year	waste	transportation	inventory at the end of the year
1974		-	
1975		-	
1976	576	-	576
1977		-	
1978		-	
1979	120	96	600
1980	150	49	701
1981	210	175	736
1982	165	133	768
1983[2]	81	78	771
1984	72	92	751
1985	117	133	735
1986	135	122	748
1987	150	120	778
1988	140	141	777
1989	230	237	770
1990	214	216	768

1) in accordance with TGL 190-921 (TGL - standard of the GDR for quality specification and terms of delivery) - Types of waste and classification criteria for radioactive wastes

2) since 1983 a 20t-waste press has been in operation

5.7. Core Average Burnup and Replaced Part of Fuel Average Burnup

Table 45 - Fuel Burn-up at the End of the Campaign (MW.d/kg uranium)

5.7. Core Average Burnup and Replaced Part of Fuel Average Burnup

Table 45 - Fuel Burn-up at the End of the Campaign (MW.d/kg uranium)

year	unit 1	unit 2	unit 3	unit 4
1974	-	-	-	-
1975	8,025	-	-	-
1976	-	10,291	-	-
1977	15.979	-	-	-
1978	20,563	18,979	-	-
1979	19,474	19,565	12,389	-
1980	16,517	19,091	18,077	11,988
1981	17,040	17,777	19,149	18,176
1982	18,308	21,136	20,490	19,514
1983	16,568	19,968	20,581	20,354
1984	20,447	20,434	20,825	20,732
1985	20,581	20,850	20,773	20,959
1986	22,479	22,507	22,029	22,769
1987	21,424	22,766	23,212	19,695
1988	20,549	22,956	22,617	19,868
1989	20,759	23,059	22,702	22,658
1990	22,537	20,645	16,552	25,034

Source: Burn-up computer programme for the core "KIRKE"

Table 46 - Fuel Burn-up of the Unloaded Fuel (MW.d/kg uranium)

year	unit 1	unit 2	unit 3	unit 4
1974	-	-	-	-
1975	7,926	-	-	-
1976	-	9,954	-	-
1977	18,339	-	-	-
1978	30,345	32.917	-	-
1979	29,617	31,327	10,338	-
1980	27,736	29,140	22,807	11,578
1981	24,616	27,440	30,010	23,247
1982	28,871	30,040	30,056	30,513
1983	25,321	31,732	31,499	29,164
1984	30,345	30,391	30,905	32,075
1985	32,221	32,591	32,374	31,959
1986	31,399	32,697	32,757	31,987
1987	31,867	33,949	32,849	31,782
1988	30,478	33,841	33,416	28,954
1989	32,016	33,994	30,909	33,679
1990	22,537	20,645	16,552	25,034

source: Burn-up computer programme for the core "KIRKE"

5.8. Volume of Radioactive Effluent Expressed in BC/kW.h for Different Effluent

Not provided.

5.9. Fuel Reliability

Table 47 - Reliability of the Nuclear Fuel - Unit 1

5.9. Fuel Reliability

Table 47 - Reliability of the Nuclear Fuel - Unit 1

refuelling cycle	I-131 (Bq/l)[1)]	I-134 (Bq/l)[1)]
10/75 - 7/76	8,1 E+6	2,7 E+7
9/76 - 5/77	5,6 E+5	8,1 E+6
7/77 - 7/78	1,2 E+6	1,8 E+7
10/78 - 3/79	6,7 E+5	1,1 E+7
11/79 - 7/80	4,1 E+5	5,9 E+6
9/80 - 6/81	4,2 E+5	3,6 E+6
9/81 - 7/82	1,3 E+5	1,3 E+6
12/82 - 5/83	8,6 E+4	7,5 E+5
9/83 - 6/84	2,5 E+5	7,8 E+5
9/84 - 7/85	1,2 E+5	5,3 E+5
9/85 - 7/86	1,5 E+5	3,7 E+5
9/86 - 8/87	1,7 E+5	3,4 E+5
1/88 - 9/88	2,2 E+5	3,9 E+5
12/88 - 9/89	1,4 E+5	3,5 E+5
11/89 - 12/90	1,3 E+5	3,0 E+5

1) the maximum of the daily tests (in the beginning three tests per week) during power-operation in the campaign

Table 48 - Reliability of the Nuclear Fuel - Unit 2

refuelling cycle	I-131 (Bq/l)[1)]	I-134 (Bq/l)[1)]
8/76 - 1/77	8,1 E+6	1,3 E+7
5/77 - 3/78	2,1 E+7	3,2 E+7
6/78 - 3/79	8,8 E+6	1,3 E+7
5/79 - 3/80	4,4 E+6	1,4 E+7
5/80 - 3/81	2,0 E+6	7,0 E+6
5/81 - 3/82	4,0 E+6	3,2 E+6
6/82 - 2/83	2,1 E+6	3,4 E+6
4/83 - 3/84	4,5 E+5	1,9 E+6
5/84 - 3/85	6,1 E+5	1,5 E+6
5/85 - 3/86	8,0 E+5	1,4 E+6
3/86 - 3/87	3,2 E+5	1,5 E+6
6/87 - 3/88	1,0 E+6	1,2 E+6
5/88 - 4/89	2,8 E+5	9,7 E+5
6/89 - 2/90	1,9 E+5	7,1 E+5

1) the maximum of the daily tests (in the beginning three tests per week) during power-operation in the campaign

Table 49 - Reliability of the Nuclear Fuel - Unit 3

refueiling cycle	I-131 (Bq/l)[1)]	I-134 (Bq/l)[1)]
4/78 - 5/79	3,1 E+6	4,1 E+5
5/79 - 5/80	2,8 E+6	8,1 E+5
5/80 - 5/81	9,6 E+5	1,1 E+6
6/81 - 5/82	9,3 E+5	8,5 E+5
8/82 - 4/83	1,7 E+6	1.4 E+6
6/83 - 4/84	3,0 E+5	8,9 E+5
7/84 - 5/85	3,9 E+5	6,3 E+5
7/85 - 5/86	4,4 E+5	2,1 E+5
7/86 - 5/87	6,4 E+4	1,0 E+5
7/87 - 6/88	1,1 E+5	2,0 E+5
9/88 - 7/89	4,2 E+6	2,6 E+5
9/89 - 2/90	9,3 E+5	8,9 E+4

1) the maximum of the daily tests (in the beginning three tests per week) during power-operation in the campaign

Table 50 - Reliability of the Nuclear Fuel - Unit 4

refuelling cycle	I-131 (Bq/l) 1)	I-134 (Bq/l) 1)
10/79 - 9/80	2,5 E+6	1,2 E+6
12/80 - 9/81	6,5 E+5	1,1 E+6
1/82 - 8/82	7,3 E+5	1,4 E+6
11/82 - 3/83	1,3 E+6	7,4 E+5
11/83 - 8/84	6,7 E+4	6,9 E+5
10/84 - 8/85	2,4 E+6	[illegible],0 E+5
10/85 - 9/86	3,0 E+5	3,7 E+5
11/86 - 7/87	4,0 E+5	1,5 E+5
9/87 - 1/88	1,4 E+4	4,9 E+5
3/88 - 2/89	8,4 E+5	2,9 E+5
5/89 - 6/90	1,7 E+4	1,1 E+5

1) the maximum of the daily tests (in the beginning three tests per week) during power-operation in the campaign

Table 51 - Stack Exhaust for Twin Unit I (Units 1 and 2, one vent stack for both)

year	aerosoles [1] (MBq)	noble gases (TBq)	iodine (MBq)
1974	888	245	6 983
1975	888	1 185	24 394
1976	888	410	11 322
1977	888	407	9 572
1978	888	407	13 616
1979	888	405	9 213
1980	888	405	4 699
1981	517	112	16 698
1982	1 104	126	4 353
1983	222	89	7 615
1984	231	148	3 301
1985	283	132	1 909
1986	378	114	3 439
1987	348	184	4 765
1988	476	200	5 359
1989	308	106	2 355
1990	352	81	1 759

1) half-life period ≥1 day.

Table 52 - Stack Exhaust for Twin Unit I (Units 3 and 4, one vent stack for both)

year	aerosoles 1) (MBq)	noble gases (TBq)	iodine (MBq)
1974	-	-	-
1975	-	-	-
1976	-	-	-
1977	-	34	777
1978	666	203	5 233
1979	888	315	2 971
1980	888	405	1 369
1981	469	63	3 709
1982	114	70	3 890
1983	139	41	2 612
1984	144	43	1 043
1985	177	56	1 975
1986	116	51	2 224
1987	159	46	3 851
1988	119	77	4 976
1989	156	96	3 093
1990	94	41	1 478

1) half-life period ≥ 1 day.

5.10. Purification Rate Constant

Not provided.

ANNEX F
THE IAEA POWER REACTOR INFORMATION SYSTEM (PRIS)

Virtually every publication, paper or presentation on the subject of nuclear power policy, refers to the number and capacity of nuclear power plants in operation and under construction in the world, accumulated experience, number of countries with nuclear power, annual construction starts, and connections to the grid, availability or load factors achieved. This type of information is essential to illustrate the current status of nuclear power development, and establish a basis for the analysis that follows.

Such information has long been collected by the IAEA. Starting in 1970, operating experience data in addition to basic information and design data was assembled and published in annual reports. In order to facilitate the analysis of power plant performance as well as to produce relevant publications, all previously collected data were computerized in 1980, when the Power Reactor Information System (PRIS) was born. Since then, PRIS has been continuously updated and improved reinforcing its position as the most complete and widely used data bank on nuclear power reactors in the world.

PRIS covers two kinds of data for nuclear power plants: general and design information and data on operating experience. Both types of data are held on all reactors that are in operation, under construction, or shutdown in the IAEA Member States and in Taiwan, China.

PRIS is useful in identifying individual units with their main characteristics and in individual countries. Since 1990, the IAEA has consolidated into PRIS, available but fragmented information on additional technical characteristics, for example, covering items related to the mode of plant operation, safety characteristics and features, existence of safety analysis reports and of emergency plans and plant environment. This additional information on plant characteristics provides a better overview of the plant design and mode of operation and will be implemented by the end of 1994.

In order to help assess plant performance, a number of indicators are usually used principally: plant availability and unavailability; planned and unplanned outages; nuclear safety related events; unavailability of safety systems and support functions; worker safety related events; radiation exposure; fuel reliability; and volume of radioactive waste. Of these, PRIS provides information on availability and unavailability factors, load factor, planned unavailability factor and unplanned unavailability factors split between causes within and external to the plant.

Outage analysis provides indications on causes of unavailability. Statistical analysis using PRIS, as well as studies performed on the level of individual units or utilities, provides indication about which are the usual problem areas and what remedial actions and measures can be applied to achieve performance improvements.

Originally PRIS data was stored using a generalized database management system. Now, PRIS has been redesigned and down-loaded to a LAN-based environment using client-server architecture for database systems. The database is now installed on Microsoft SQL server under the OS/2 operating system. The primary objectives of the new design were to improve flexibility of data entry, reduce the complexity of relational operations and provide user-friendly interfaces for database maintenance and end-users. The graphical user interface was developed using front-end (client) tool Object View under Microsoft Windows.

The new system contains two different interfaces, one for database maintenance and a second for data retrieval (the Reporting System). Through the Reporting System users can access detailed information about a country, its reactor sites and nuclear power plants. It presents the general and design information for a nuclear power plant, its yearly and monthly production, including performance factors and outages. It also presents country electricity and nuclear production. The system enables the user to make flexible queries using a set of selection criteria, it presents tables or charts and enables data to be down-loaded to any Windows application. The new system has been used in the IAEA since the beginning of 1994 and is scheduled to be released to the IAEA Member States through dial-up or through the Internet by the end of 1994.

PRIS Services

As well as providing material for all IAEA publications, PRIS is used to produce two annual IAEA publication: Operating Experience with Nuclear Power Stations in Member States, published since 1971, and Nuclear Power Reactors in the World, Reference Data Series No. 2, published since 1981. Statistical analyses are also carried out either for use within the IAEA or on request from Member States and outside organizations.

In 1989 the PRIS database was made available for direct access via the international public data networks or public switched telephone system. This service, call PRIS On-line, operates free of charge. Currently, about 70 users in 28 Member States and four international organizations have on-line access. This service will be improved with the release of the new system, which enables a direct connection to the PRIS database under Windows through the Internet or through direct dial-up connection to the IAEA.

In parallel with the on-line access system, the Agency has offered MicroPRIS to the Member States, free of charge, since January 1991. This is a personal computer (PC) version of data available on diskette in a form readily accessible by standard commercially available PC packages. Currently, there are about 200 subscribers in 54 Member States and 8 international organizations using MicroPRIS.

ANNEX G
ENERGY CO-OPERATION IN THE EASTERN EUROPEAN COUNTRIES (1955-1991)

1. BACKGROUND

After the Second World War the sharp political/cultural division of the industrialized world between East and West led to open, harsh competition between these two geopolitical areas.

Some other distinguishing features characterizing the so-called Soviet bloc are worth stressing briefly:

- its geographic unity;
- the pre-eminent role of the communist/socialist party which led to a centrally planned economy and a high degree of centralization;
- the indisputable leadership of the former Soviet Union.

This latter feature, by providing continuity in the basic features of Soviet-east European relations, gave rise to great and long lasting stability in the area that, notwithstanding contingent crises, allowed a high degree of implementation of medium and long term strategies. The former Soviet Union recognized at an early stage the constraints set by competition with the West and of the consequent need to counter the Western challenge, using all possible resources and allies. As a result, it attempted to tie the states of Eastern Europe into a complex web of political, economic and social ties that would result in mutual interdependence in the region.

The anchoring frame of the web was institutionalized by means of two organizations: the Warsaw Treaty of Friendship, Co-operation and Mutual Assistance, briefly referred to as Warsaw Treaty Organization (WTO) and the Council for Mutual Economic Assistance (CMEA), sometimes referred to as COMECON.

2. THE COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE (CMEA)

CMEA was effectively founded in January 1949, in Moscow, by the representatives of Bulgaria, Hungary, Poland, Romania, the former Soviet Union and the former Czechoslovakia. Albania joined the Council in February 1949, while the former German Democratic Republic was admitted in September 1950. The establishing Treaty was formally recognized by the United Nations Organization (UN) only 10 years later, in December 1959. The core group[1] was flanked, in the Council, by some other countries, such as Cuba (July 1972) , Mongolia (June 1962) and Viet Nam (in 1978), while some others, e.g. former Yugoslavia, had first the status of observer and later on, in 1964, the status of associated member (see Figure 1). In 1973, a co-operation agreement between CMEA and Finland was signed.

The principal aim of CMEA was to promote "the international socialist division of labour" and the effective use of national resources within the limits of a comprehensive effort of co-ordination and integration of member States economic policies.

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[1]Albania left de facto the CMEA and WTO in 1961.

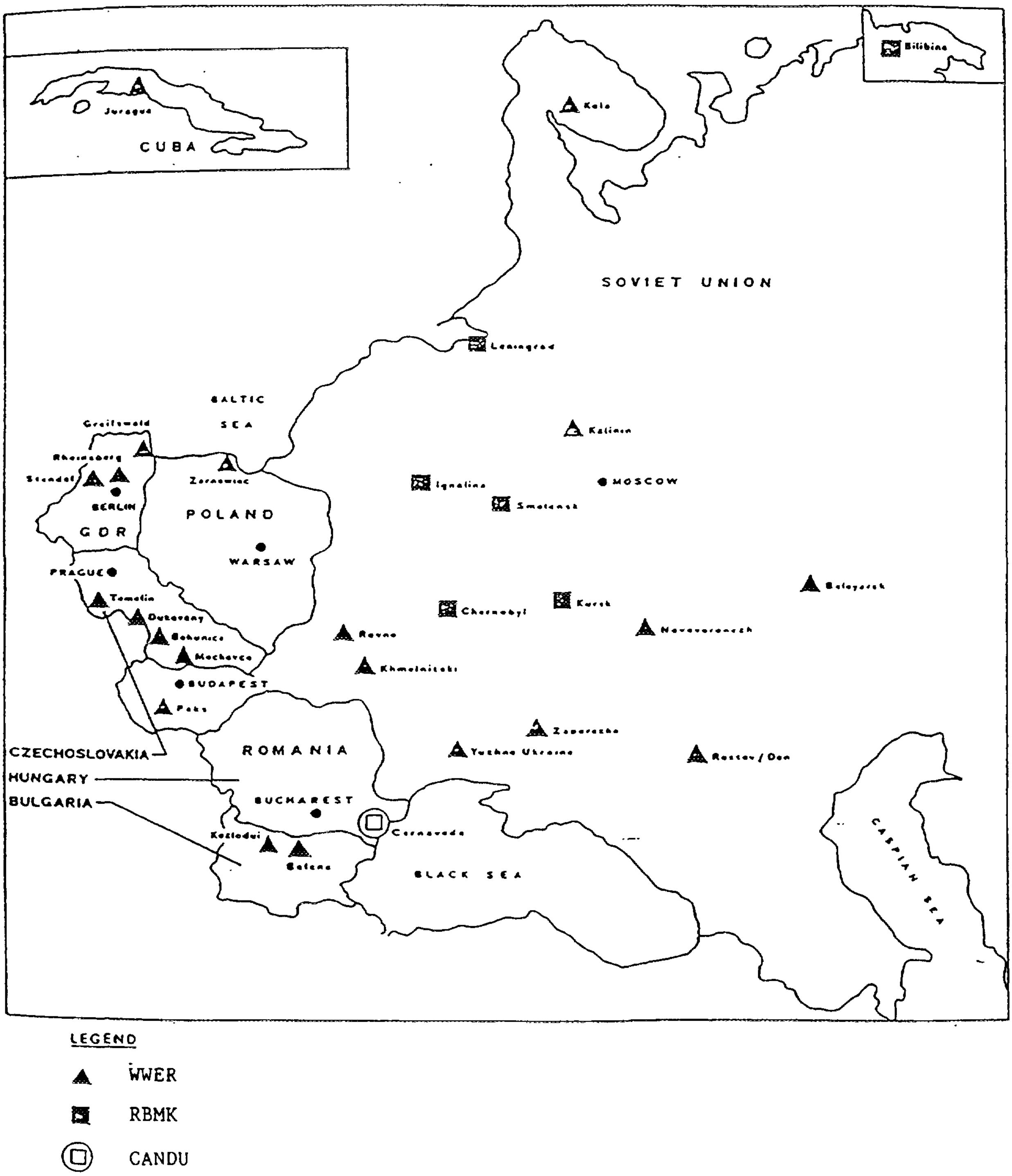

Fig. 1. Former CMEA Member Countries, 1993

The organizational structure of the CMEA comprised

- the Session (yearly or twice yearly meetings of Prime Ministers),

- the Executive Committee, established in 1962 (several yearly meetings of Deputy Prime Ministers),

- the Standing Commissions, which were established in 1956 (eight at the very beginning but, in 1987, they were 23),

- the Secretariat, which was the official Council representative for international relations

Later on, in 1971, the Executive Committee was flanked by other Committees the important Committee on Co-operation in Planning[2] (in which the countries' representatives were the heads of national planning organizations) and the Committee for Scientific and Technical Co-operation In 1974, a third committee was established the Committee for Co-operation in Material and Technical Supply[3] A fourth one, the Committee on Engineering was created in 1985 (see Figure 2) Collateral organizations within the CMEA were the International Bank for Economic Co-operation and the International Investment Bank

According to Article IV of the CMEA statute, the acts of the Council (recommendations and decisions) could bind the member countries only if the parties agreed, that is the Council could simply confirm agreements already in existence The working language was Russian while the languages of all other members were recognized as official CMEA languages

Three Standing Commissions[4] were established to deal with scientific and technological energy related issues

- The Standing Commission for Coal (with its head office in Warsaw),
- The Standing Commission for Oil and Gas (with its head office in Bucharest),
- The Standing Commission for Electric Power, (with head office in Moscow),

This latter Commission was in charge of evaluating energy production data coming from member States, estimating the countries' future needs, elaborating strategies and proposals in order to solve problems relevant to electric power development The Commission particularly had to analyse information and to elaborate proposals in order to reduce production costs, to shorten power station construction time, and to support the construction of transmission lines and interconnection grids In 1967, within the framework of the Commission, the Nuclear Power Section was established This Section was required to attend to problems regarding the design, construction and operation of nuclear power plants

[2]Among its first tasks was to elaborate a fuel and energy balance for 1990-2000 and a programme for nuclear power generation It also established a Permanent Working Group for Fuel and Energy Balance

[3]In 1988, the Committee on Material and Technical Supply was dropped and four new committees were created (Reisinger)

[4]The Standing Commission for Machine Building was in charge of co-ordinating the nuclear components sector, on during the 1970s the responsibility passed to Interatomenergo

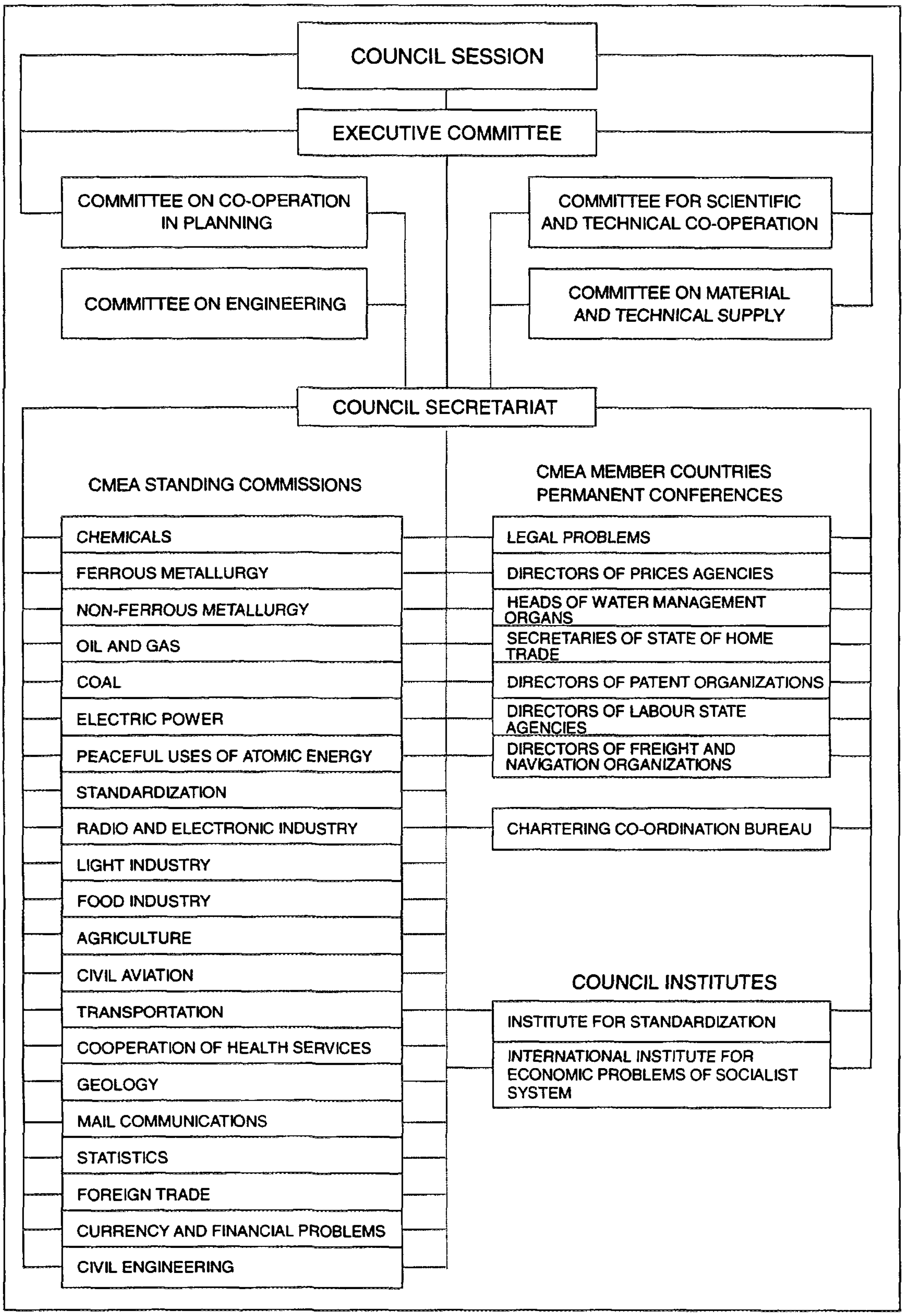

Fig. 2. Organizational Structure of CMEA in 1986

In 1960, at the XIII CMEA Session, a fourth Commission, the Standing Commission for Peaceful Use of Atomic Energy was established. This was based in Moscow and was in charge of organising scientific and technical, bi- or multilateral co-operation between member States.

During the XXV CMEA Session (held in Bucharest in 1971) the Comprehensive Program for the Development of Socialist Economic Integration was approved which introduced several changes in CMEA organisation and, inter alia, promoted multilateralism and also called for long-term planning. As a consequence of the Comprehensive Program, several multilateral organisations were created or reorganised (see Figure 3):

- the so called interstate economic organisations, established on the basis of state-to-state agreements, mainly dealing with specific fields of the economy, science and technology (e.g. the Central Dispatch Administration, and Interelektro - established in 1974, which was responsible for the supply of equipment for electric generation and transmission);

- the international economic organisations established on the basis of agreements concluded by governmental agencies or by economic organisation of interested countries. Members of such organisations were economic entities (e.g. enterprises, foreign trade organisations).

In February 1972, all member States - except Romania - signed the agreement establishing the International Economic Organisation for Nuclear Instrument Manufacture, Interatominstrument, based in Warsaw. In December 1973 the second and most important union was established, the International Economic Organisation for Co-ordination of Plant Production for Nuclear Power Stations, Interatomenergo, based in Moscow. All member states, plus former Yugoslavia, had their representatives actively participating in the association, which was requested to organise co-operation in the production and supply of nuclear components; technical assistance to Member States during design, construction and operation of NPPs; and to promote standardization and unification[5].

3. CMEA NUCLEAR RELATIONS WITH WEST

The origins and the resulting military connections led to almost all nuclear technology world-wide being considered "restricted" and hence subject to severe controls as regards any information or technology exchange. On the one side, the NATO countries, plus Japan, established in 1952 the Co-ordinating Committee on Multilateral Export Controls (COCOM) which was required to examine every technological exchange with possible military implications. On the other, similar restrictions were enforced by Soviet leadership among the WTO partners. Against this background, another factor that hindered technological co-operation between East and West was, from the early 1960s, an increasing divergence in technological direction; whether there would have been any real economic returns for co-operation is not clear.

Despite this, some attempts at collaboration were made, especially between European counterparts, but they either remained limited to peripheral or theoretical aspects or, as in the case of Kaliningrad Nuclear Power Plant project launched in the mid-1970s by the former USSR and Germany, were abandoned due to COCOM concerns. The only exception to this situation were the Soviet-Finnish agreements for the supply of two reactors.

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[5]Members of Interatomenergo were Ministry for Building Machines and Electronics (BG), Chemimash - supplier of components for chemical industry - (HU), Kraftwerksanlagenbau - supplier of components for power stations - (GDR), MEGAT - supplier of components for power stations - (PL), IMGB - Heavy machinery industry - (RO), Soyuzglavzagranatomenergo (USSR), Skoda (CSSR), YUMEL -Electrical and mechanical machinery industry (YU).

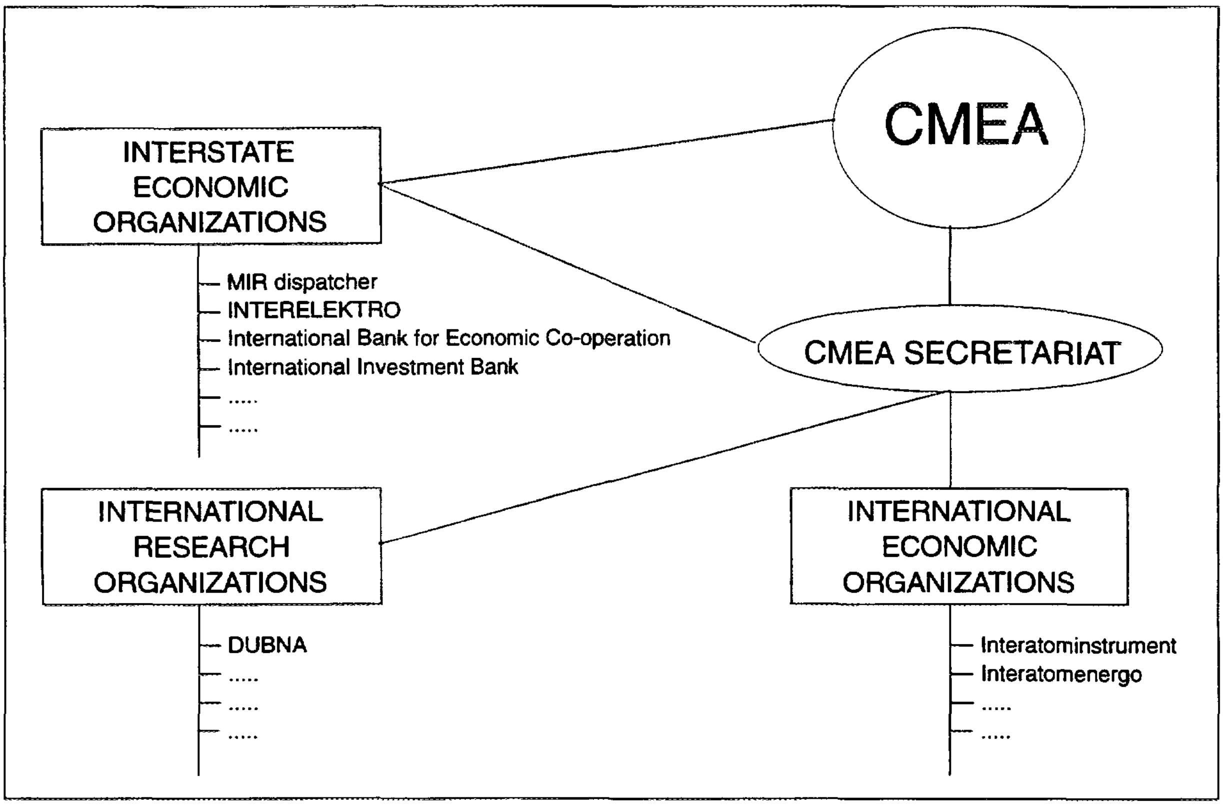

Fig. 3. CMEA Organizations

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5-8 July 1993 (3)
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