Nuclear power in the Soviet Union

by B.A. Semenov*

Even though the Soviet Union is a large industrial state which bases its economic development on its own mineral fuel resources, it cannot afford to neglect the development of nuclear power, because about 80% of its energy resources are concentrated in eastern regions of the country, while 75% of the population and consumers of power are concentrated in the European part of the USSR. The transport of fuel from the east of the Soviet Union to western regions constitutes about 40% of the turnover of the country's rail freight.

Another important factor which led the Soviet Union to favour nuclear power as a main source of energy was that nuclear power is less damaging to the environment than conventional power.

By the end of 1982, the total installed capacity of nuclear power plants in the USSR exceeded 18 000 MW. In 1981 the Soviet Union's nuclear power plants generated 86 billion kWh electricity – 6.5% of the country's total electricity production. During the next five-year period the generation figure will increase more than threefold and will reach 220 billion kWh in 1985. Since it is planned that the total electric power production in the country will be increased to about 1500 billion kWh, nuclear plants will account for 14% of the total electricity production in the entire country by 1985 and for 24% in the European region.

Although the capital investment costs for nuclear power plants are $1\frac{1}{2}$ to 2 times higher than for plants using organic fuel, the cost figures for electricity production in the European part of the country (including the Urals) show that nuclear power plants are quite competitive. Thus the average cost of nuclear-generated electricity in 1979 was 0.793 copeck/kWh, whereas the average cost of electricity from conventional power plants was 0.753 copeck/kWh.

Of the 18 000 MW installed nuclear capacity, about 12.5 million kW were put into operation over the last seven years from 1976 to 1982. The rate at which nuclear power is being introduced has nearly tripled in the last five-year period compared to the previous one. The rate at which nuclear power plants are being introduced is about 2.5 times higher than the rate of introduction of power plants using organic fuel. During the current five-year period the construction of new fossil-fuelled plants in the European part of the Soviet Union will practically cease, and by 1985 almost all increase of installed capacity will be from nuclear power plants. The Soviet nuclear programme is based on two types of thermal power reactor: the WWER pressurized light-water-moderated and cooled reactor; and the RBMK light-water-cooled, graphite-moderated, channel-type reactor.

The early years of the Soviet programme

The first nuclear power projects were started in the Soviet Union even before the end of the 1940s. In 1950 the decision was taken to construct the country's first nuclear power plant at Obninsk, based on the so-called channel-type, uranium-graphite design of reactor. The world's first nuclear power plant was commissioned on 27 June 1954. I cannot but mention that I had the honour to work in the engineering and physics laboratory, as well as in the operation, of this nuclear power plant during the first five years of its working life. The success of this nuclear power plant demonstrated the great potential which nuclear power held for producing electricity.

The USSR's plans to develop nuclear power could not rely upon only one type of nuclear power plant. This would not have ensured the necessary reliability and stability. But at the same time, to develop any type of nuclear power reactor up to a commercial scale requires time, and huge material and financial resources. To select the types of reactor which would be most appropriate and economic for the Soviet Union, the State Committee for the Utilization of Atomic Energy set up a research and development programme on different types of nuclear power reactors: pressurized-water and boiling-water (vessel type) reactors, channel-type boiling-water reactors, organic-moderated and cooled reactors, etc. In the course of this work some types of power reactors were abandoned before they reached the prototype stage. For instance, it became clear that in practice reactors with organic moderators and coolants are suitable only for small nuclear power plants. Work on this reactor-type resulted in the construction in 1963 of a multi-unit transportable nuclear power plant which had an electrical capacity of 750 kW. The research and development on a number of thermal nuclear power reactor concepts resulted in the construction of prototype units: the first and second

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Table 1. Main nuclear power plants in operation at end of 1982

Name	Unit	Gross electrical power (MW)	Reactor type	Year of reaching nominal power
Novo-Voronezh	I	210	WWER	1964
	II	365	WWER	1970
	III	440	WWER	1972
	IV	440	WWER	1973
	V	1 000	WWER	1981
Beloyarsk	I	100	U-Gr (Channel BWR)	1967
	II	200	U-Gr (Channel BWR)	1969
	III	600	FBR	1981
Kolsk	I	440	WWER	1973
	II	440	WWER	1975
	III	440	WWER	1982
Leningrad	I	1 000	RBMK	1974
	II	1 000	RBMK	1976
	III	1 000	RBMK	1980
	IV	1 000	RBMK	1981
Armenian	I	407.5	WWER	1979
	II	407.5	WWER	1980
Kursk	I	1 000	RBMK	1977
	II	1 000	RBMK	1979
Chernobylsk	I	1 000	RBMK	1981
	II	1 000	RBMK	1981
	III	1 000	RBMK	1982
Rovno	I	440	WWER	1981/82
	II	440	WWER	1981/82
Inzhno-Ukrainskaya (South Ukraine)	I	1 000	WWER	1981/82
Smolenskaya	I	1 000	RBMK	1981/82
Total	26	17 370		

Several small prototype, and district-heating reactors (VK-50, BOR-60, BN-350, Bilibin, etc.) with a total capacity of some 900 MW have not been included in this list.

units of Novo-Voronezh with pressurized-water reactors; the first and second units of Beloyarsk with channel-type reactors; and the Dimitrovograd boiling-water reactor.

The USSR paid special attention to the development of fast breeder reactors because, from the very beginning, it seemed evident that a large-scale long-term nuclear power programme could not be realized without fast breeder reactors. The first experimental reactor, with plutonium fuel, went into operation in 1955. The capacities of experimental reactors which then followed have been successively increased. In 1969, a 12 MWe test prototype fast reactor with sodium coolant, BOR-60, went into operation in Dimitrovograd.

In the process of development, construction, and operation of different prototype units, it became clear which types of nuclear power plants were optimal for the specific conditions of the USSR. In the second half of the 1960s, on the basis of the accumulated experience, it was decided to base further development of nuclear power on two thermal reactor types: the WWER pressurized-water reactor; and the RBMK, channel-type uranium-graphite boiling-water reactor. The main nuclear power plants currently operating in the USSR are listed in Table 1.

The WWER reactor

As already mentioned, the first two units of the Novo-Voronezh nuclear power plant served as prototypes for the standard serial reactor, WWER-440. These prototype units were very reliable and had consistently high load-factors: averaging about 80%, sometimes even higher. In the course of development of the standard reactor, practically all the main components have been upgraded and substantial changes made to the design of the reactor as a result of the operating experience with the first two prototype units. The first two serial WWER-440 reactors were installed at Novo-

Voronezh (units III and IV). Some small changes have been introduced into the design of later units. At the beginning of 1983, 27 WWER-type power reactors were in operation throughout the world, including thirteen units in Bulgaria, Czechoslovakia, Finland, the German Democratic Republic, and Hungary.

Total operating experience with the WWER-440 reactors amounts to 115 reactor-years; maximum calendar duration of operation is 13 years. These reactors have a load-factor in the region of 0.75 to 0.90, and their base-load operation is highly reliable. The average annual load-factor of the WWER reactors is higher than that of conventional power plants.

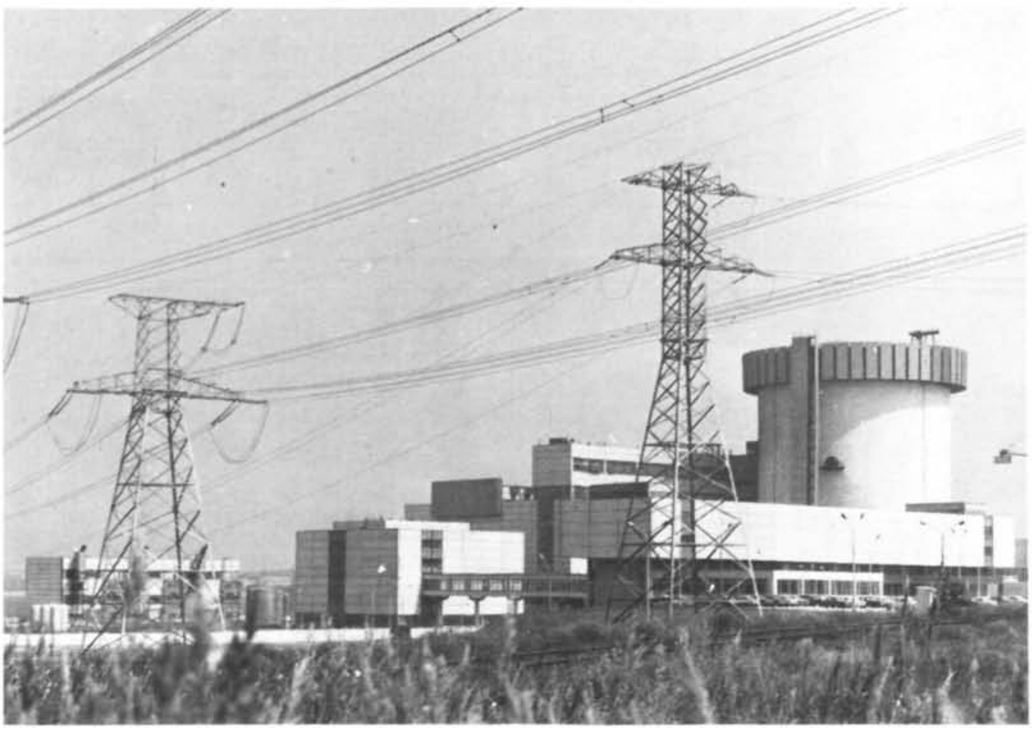
Research and development work on the existing WWER-440 reactors has resulted in the design of a much more powerful 1000 MW WWER, the first unit of which was put into operation at Novo-Voronezh in 1980. Based on the experience of construction and operating the first WWER-1000 unit, some improvements have been introduced into the design of the standard serial 1000 MW reactor.

The WWER reactors currently in operation, under construction, or planned up to the year 1990, are listed in Table 2. Together with the increase in unit power of the reactor, its range of utilization is also being extended: design and construction of WWER-1000 reactors in seismic regions have been started. It is planned to use the WWER reactors not only to regulate the frequency and power regimes in electrical grids but also for the combined production of heat and electricity.

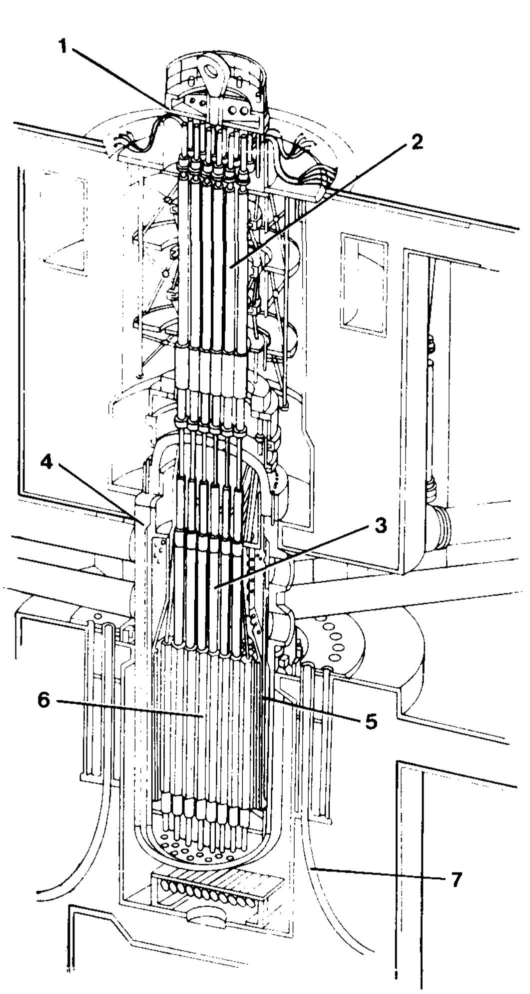
Table 2. WWER reactors built, under construction, and planned up to 1990

Name	Units	Power (MW)	Remarks
Novo-Voronezh	1	210	prototype
	2	365	prototype
	3	440	serial
	4	440	serial
	5	1 000	serial
Kolsk	x4	440	polar conditions
Armenian	x2	407.5	altitude 1100 m seismic region
Rovno	x2	440	
	x3	1 000	
South Ukrainian	x4	1 000	
Kalinin	x4	1 000	
Zaporozhskaya	x4	1 000	
Khmelnitskaya	x4	1 000	
Rostov	x4	1 000	
Balakov	x4	1 000	
Krimea	x2	1 000	
Kuibishev	x3	1 000	
Baskir	x3	1 000	
Total	48	40 905	

Since the electrical output of the combined heat and power WWER-1000 currently under construction near Odessa will depend on how much of the reactor's thermal output is used for heating, this plant is not included in the table.



Part of the WWER nuclear power station at Novo-Voronezh.



A sectional view of the WWER-1000 reactor showing (1) upper block; (2) control rod drive gear; (3) control rod guide and protection tubes; (4) reactor pressure vessel; (5) reactor shaft; (6) reactor core; (7) ducts for ionization chambers and their cabling.

On the basis of its many reactor-years of operating experience, the WWER is clearly capable of providing reliable and economical electrical power (Table 3). As can be seen from the table, the capital cost of WWER-type reactors has been decreasing during the first period of their introduction and, for the third and fourth unit of Novo-Voronezh, reached the value of 200 roubles per kW installed. The increase in capital cost of nuclear power plants constructed later can be explained by factors of local character, as well as by general trends following upon the increase in the cost of production of conventional fuel. Some of these units were constructed in the far North (Kolsk), and the Armenian nuclear power plant has been designed for seismic conditions and is, therefore, more expensive. Still it is worth noting that the evolution in capital cost of Soviet WWERs has no comparison with the increase of pressurized-water reactor costs in the West during the same period. This latter, of course, was the result of a complex of other, sometimes not directly comparable factors.

The average cost of electricity produced by WWER nuclear power plants in 1981 is significantly lower than that produced by conventional power plants. For WWER nuclear power units with operating time of more than one year, the average load-factor is generally higher than its design value of 0.8.

RBMK reactors

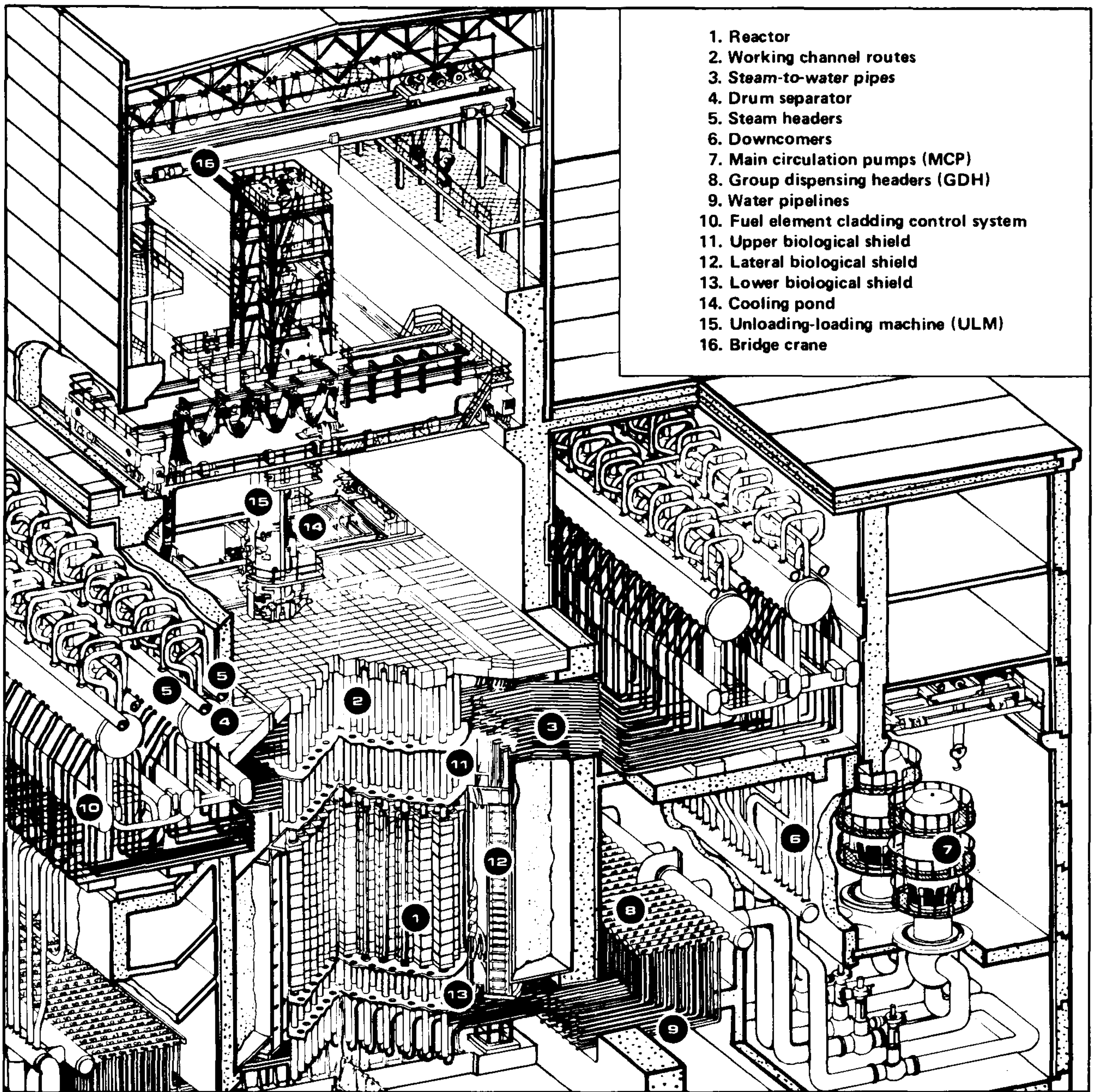
The development of channel-type light-water-cooled, graphite-moderated reactors began with the commissioning of the first nuclear power plant in Obninsk in 1954. Thereafter the Siberian 600 MW nuclear power plant was put into operation, then, the first and second units of Beloyarsk with capacities of 100 and 200 MW.

The next stage in the development of channel-type reactors in the USSR was the boiling-water high-power reactor RBMK-1000. The design of the RBMK channel

Table 3. Performance of WWERs

Power plant	Unit	Installed capacity (MW)	Capital cost (rouble/kW)*	Electricity production 1977–81 (10^8 kWh)	Average load-factor 1977–81
Novo-Voronezh	I	210	326	7.4	0.80
	II	365	256	13.9	0.87
	III–IV	880	200	30.1	0.81
	V	1 000	308	6.0 (1980–81)	–
Kolsk	I–II	880	263	31.0	0.80
Armenian	I–II	815	327	15.4	0.62
Total	9	4 150	280 (average)	103.8	0.78 (average)

* Exchange rate of approximately US $1.3 to the rouble.



A sectional view of the RBMK-1000 reactor. With an electrical power of 1000 MW, the reactor's thermal power is 3140 MW; the coolant flow is 37.5×10^3 t/h and steam capacity 5.4×10^3 t/h. The reactor inlet water temperature is 270°C and the saturated steam temperature 284°C with a pressure in the separator of 70 kg/cm². The initial fuel enrichment is 1.8%.

reactor provides the possibility of obtaining high power. On-load refuelling ensures flexibility of the fuel cycle and increases the availability of the plant.

Many factors favouring the channel-type graphite-uranium boiling-water reactors were taken into consideration in the development and design work. They were fully confirmed during construction and operation:

- The fabrication of major RBMK-1000 components can be done at existing manufacturing plants, and does not require the construction of new industrial enterprises with purpose-built fabricating equipment.
- There are essentially no upper power limits for channel-type reactors resulting from fabrication, transportation and mounting of the components.
- The design feature of having more than 1000 individual primary circuits increases the safety of the reactor system – a serious loss-of-coolant accident is practically impossible.
- Because of the good physical characteristics of the reactor and the on-load refuelling system, low-enriched fuel can be used with high efficiency; the discharged fuel has a low fissionable material content; the burn-up is high; and the plutonium produced in the fuel is utilized.

Table 4. Operating results of RBMK-1000 reactors

Name	Year	Installed capacity (MW)	Electricity production (TWh)	Load-factor (%)
	1979	2000	13.1	74.4
Leningrad	1980	3000	18.82	71.4
	1981	4000	24.1	73.8
	1979	2000	10.35	64.1
Kursk	1980	2000	13.89	79.1
	1981	2000	13.54	77.3
	1979	2000	12.23	69.8
Chernobylsk	1980	2000	14.21	80.9
	1981	2000	13.44	75.2

After the first two RBMK-1000 units of the Leningrad nuclear power station had been commissioned (unit I in 1973, and unit II in 1975), the construction of a series of these 1000 MWe reactors was started. During the nine-year period from December 1973 to December 1982 ten RBMK-1000 units, representing a total capacity of 10 000 MWe, were put into operation in the USSR. (This includes a further two 1000 MW units at Leningrad.)

The nuclear power plants are designed to have twin reactors; the two independent reactor systems having a number of interchangeable auxiliary systems. Such a design has advantages in construction, operation, and maintenance. It makes it possible to start the construction and mounting of the components for both units almost simultaneously. The average construction time per two 1000 MW units was 7.68 years, thus bringing the average construction time of one unit to 3.84 years.

In 1980 the RBMK-1000 reactors produced 47 billion kWh or 64.5% of all electrical power (73 billion kWh) produced by all nuclear power plants of the country. The results of operation of RBMK reactors during the last three years are presented in Table 4. As can be seen, the average load-factor of these eight nuclear power plants is about 75%. This is of course an outstanding result, not often quoted or recognized.

The successful operation of RBMK-1000 reactors at nominal power and the reserves found in their design (without changing the size and number of fuel assemblies) have made it possible to increase the power of each process channel or fuel assembly by a factor of 1.5. Using only special heat transfer intensifiers, the total power of the reactor has been increased to 1500 MW. At present the construction of the first stage of Ignalino nuclear power plant with two RBMK-1500 reactors is under way. The commissioning of the first unit will be the first step in the construction of a new generation of channel-type reactors which, since they will be more economical, should succeed the RBMK-1000 reactors. The capital cost of RBMK-1500 reactors will be 20 to 30% less than for RBMK-1000 reactors and thus will reduce the cost of each kWh produced.

Fast breeder reactors

In spite of the successful operation of two thermal reactor types, the Soviet Union clearly recognizes that the solution to long-term nuclear fuel problems for large-scale nuclear power programmes requires wide use of breeder reactors. This is why the development of breeder reactors has a special priority in the Soviet Union. And this is why, parallel with the development and introduction of thermal reactors, the fast reactors, BN-350 and BN-600, have been designed and commissioned.

Almost ten years have passed since the beginning of power operation at the BN-350 reactor. The reactor produces 700 MWth which provides for generation of electricity equivalent to 121 MWe and for daily production of 85 000 tonnes of distilled water. The BN-600 reactor, unlike the BN-350, has an integral design and module-type steam generators. The BN-600 started power operation in April 1980 and in December 1981 the reactor was brought up to nominal power of 1470 MWth. By 1 January 1982, the unit had produced 3.7 TWh of electricity after about 10 000 hours of operation. Maximum burn-up of fuel reached 7%.

The next generation of fast breeder reactors, BN-800 and BN-1600, are being designed for serial commercial introduction. The designs of both reactors are based on the experience and achievements of their predecessors, and have now been completed. The main design parameters of the BN-800 and BN-1600 reactors are analogous except for the power rating. The increased electrical capacity of the BN-800 compared to the BN-600 has been achieved with approximately the same capital cost, which represents the main factor in the improved economics of the BN-800 reactor. Significant economy is also achieved because components practically identical to those already developed for the BN-600 facility are being used in the BN-800 reactor as well. The main design features of the BN-1600 reactor are similar to those of BN-600 and BN-800 reactors.

Nuclear safety in the USSR

The safety of nuclear power plants in the Soviet Union is assured by a very wide spectrum of measures, the most important of which are:

Securing high quality manufacture and installation of components;
Checking of components at all stages;
Development and realization of effective technical safety measures to prevent accidents, to compensate for possible malfunctions, and to decrease the consequences of possible accidents;

The control-room of the 1000 MW RBMK Smolenskaya nuclear power plant, one of the most modern power reactors in the Soviet Union.

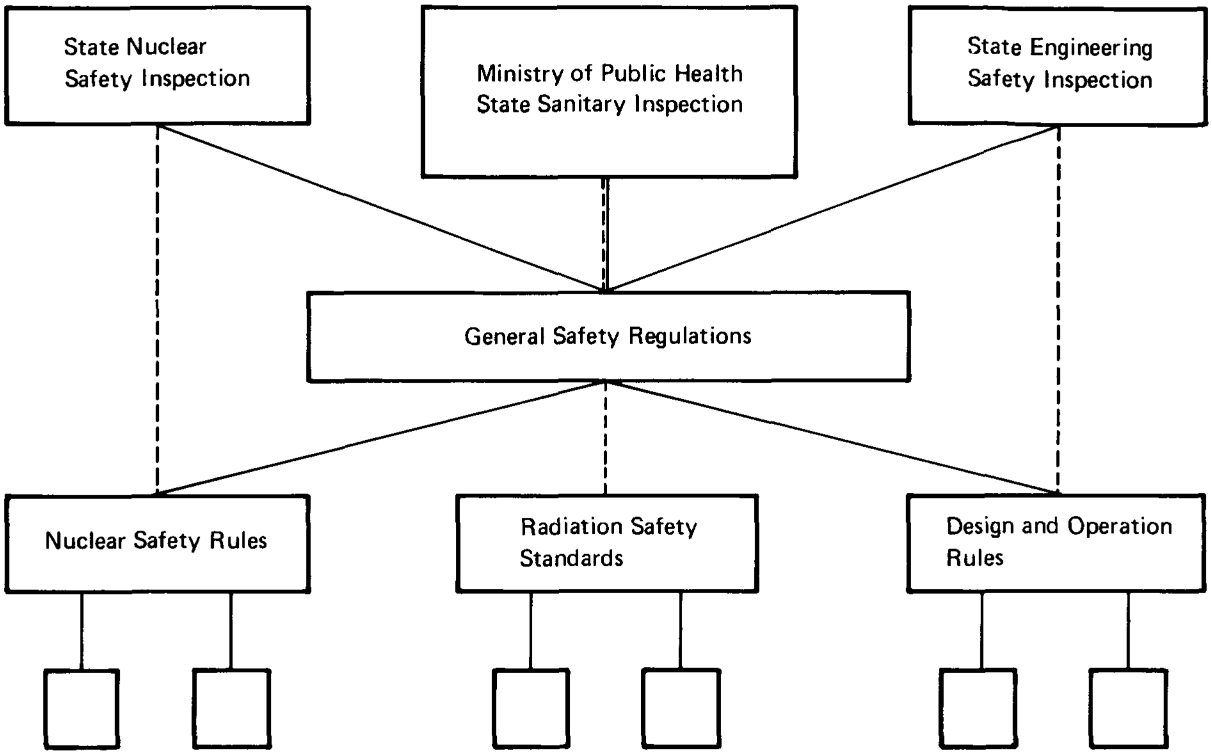
Development and realization of ways of localizing radioactivity released in case of an accident;
Realization of technical and organizational measures to ensure safety at all stages of construction and operation of nuclear power plants;
Regulation of technical and organizational aspects in securing safety; and
Introduction of a system of state safety control and regulation.

The regulation of safety by official documents is one of the main tools for ensuring the safety of nuclear power plants in the USSR. The state supervision of nuclear power plant safety is accomplished by:

- The State Committee on Supervision of Safe Operations in Industry and Mining under supervision of the Council of Ministers of the USSR (Gosgortekhnadzor of the USSR), which supervises compliance with regulations and standards of *engineering safety* in design, construction, and operation of nuclear power plants;

- The State Nuclear Safety Inspection (Gosatomnadzor of the USSR) which supervises compliance with rules and standards of *nuclear safety* in design, construction, and operation of nuclear power plants;

- The State Sanitary Inspection of the USSR under the Ministry of Public Health which supervises



Nuclear safety regulatory bodies and documents in the USSR

compliance with rules and standards of *radiation safety* in design, construction, and operation of nuclear power plants.

The established system of three supervisory bodies has largely determined the structure of the whole complex of regulatory documents on nuclear power plant safety.

The main regulatory document on nuclear power plant safety in the USSR, *General regulations to ensure the safety of nuclear power plants in design, construction, and operation,* was enforced in 1973. This document covers all types of commercial reactors used and to be used in the USSR in the nearest future (WWER, RBMK, BN, and district-heating reactors). In this approach, requirements are presented in a general way, without concrete details. In most cases the *General regulations* only prescribe tasks which have to be solved to ensure safety (*what* must be done); they do not determine the solutions (*how* it should be done).

Other normative documents (codes, guides, rules, procedures) develop further and specify more concretely the *General regulations,* establishing thus the basis for activities of designers and corresponding supervisory bodies. One of the main documents in the field of engineering safety is *Regulations for design and safe operation of components for nuclear power plants, test and research reactors, and installations.*

The basic document in Gosatomnadzor's activity, *Nuclear safety regulations for nuclear power plants,* was introduced in 1975. It regulates nuclear safety, governing not only criticality problems in reactor operation, but also refuelling, transportation and storage of fuel assemblies. It contains the main technical and organizational requirements to ensure nuclear safety in the design, construction, and operation of nuclear power plants, and the training requirements for personnel associated with reactor operation.

In the field of radiation safety, the basic document by which the health and inspection protection bodies are guided is *Radiation safety standards (RSS-76).* These standards were worked out on the basis of recommendations of the International Commission on Radiological Protection (ICRP) and establish the system of dose-limits and principles of their application. *The health regulations for design and operation of nuclear power plants,* issued in 1978, further develop and specify the basic RSS-76 document to include siting, monitoring, and inspection problems.

The system of regulatory documents on nuclear power plant safety is complemented by the system of state standards developed and established by the State Committee on Standards (Gosstandart of the USSR). The system of standards extends the system of regulatory documents by ensuring nuclear plant safety through establishing requirements for many components, materials, processes, etc.

The above documents play a significant role in nuclear power plant quality assurance.

Uranium exploration and mining

Large-scale development of nuclear power in the USSR is impossible without creation of a nuclear industry using the most modern technology in all stages of its fuel cycle. The development of nuclear power and the nuclear industry in the USSR would be impossible without securing the raw material resources. In a rather short period of time, uranium deposits have been discovered in the country and a reliable resource-base established. There are quite favourable prospects for its further extension and increase.

Uranium-ore deposits in the Soviet Union are located in very different climatic and geographical zones, many of them have complicated geological, hydrological, and climatic conditions. They are found at different depths from a few metres, to 2000 m and even deeper. The ore bodies are of very different shapes in different locations and of varying mineralogical content. Commercial deposits of uranium in the Soviet Union are characterized by a wide variety of conditions of localization and of various generic types. At the present time uranium mining represents a separate and important branch of the mining industry. Depending on individual geological conditions of deposits and the content of uranium in the ore, the treatment of uranium deposits is carried out by: underground mining; open pit mining; or *in situ* leaching.

Ion-exchange technology has been very rapidly developed for the uranium industry and is at present the basic industrial method of extracting uranium and other elements from the ores and concentrates, from natural and mine-water, to obtain end-products of high purity. A method of uranium extraction from phosphoric acid solutions, which form in the process of acid-leaching of uranium-bearing phosphoride rocks, has been successfully used in industrial-scale operation in the Soviet Union for about 15 years.

Enrichment and fuel fabrication

In the second half of the 1940s, industrial facilities for the production of uranium hexafluoride and its subsequent enrichment were developed and built in the Soviet Union within a very short period of time. The technology of hexafluoride production developed in parallel with that of nuclear power and has reached now a high degree of sophistication. Developing methods and setting up industrial plants for isotope separation of uranium by gas diffusion presented extremely complicated scientific and engineering problems. All these problems have been successfully solved by the USSR.

Fuel-fabrication technology in the USSR at the present time has been developed to such a level that it can meet all the contemporary requirements for both the production scope and the required operational parameters of the fuel.

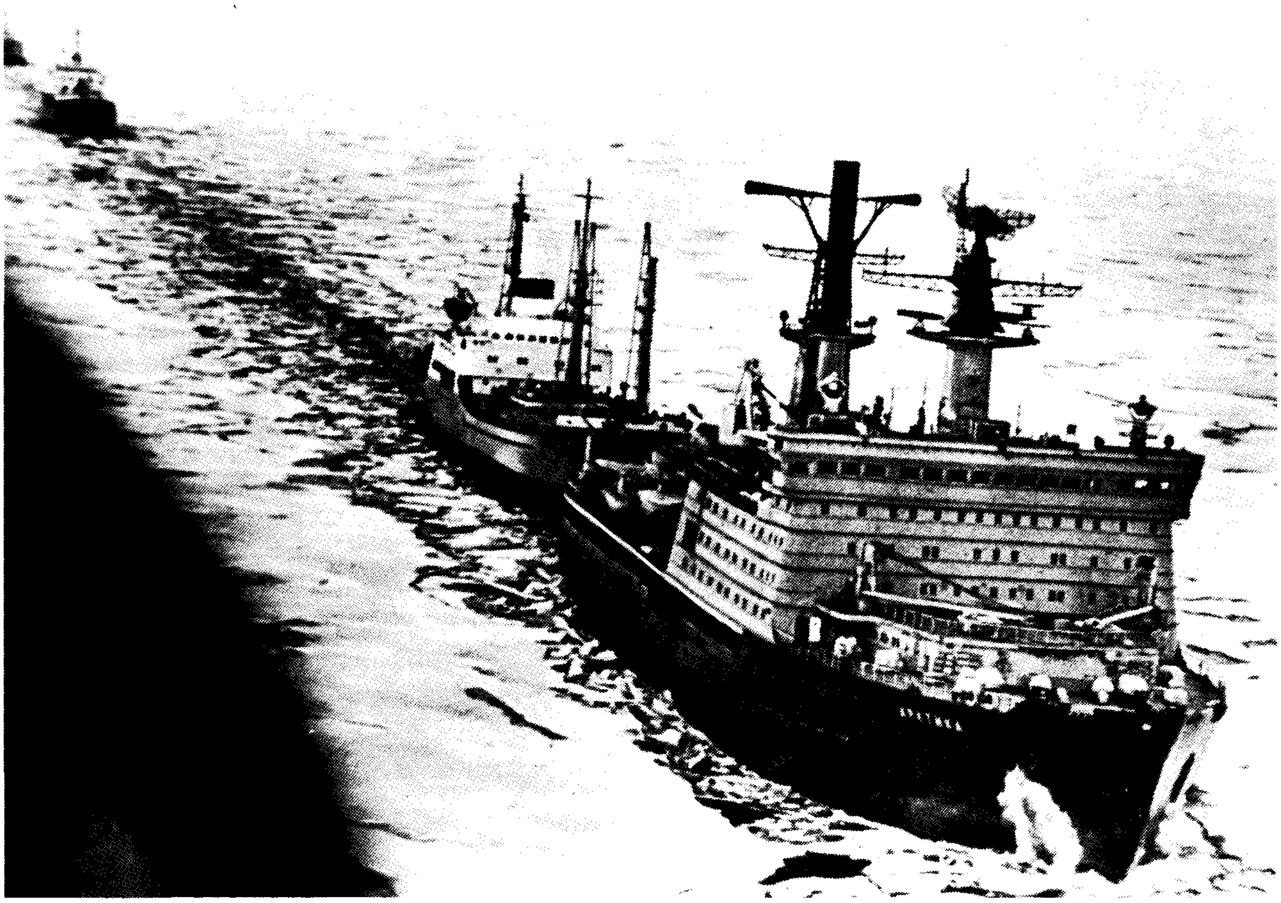
Stable, well-proven technologies of fuel-element manufacture together with correctly selected design solutions have ensured the very high reliability of the cores of the nuclear power reactors now in operation. Fuel-pin failure resulting in the release of fission products into the coolant has become a very rare phenomenon and the number of failed fuel rods is now less than 0.2%. To meet the increased scale of nuclear fuel fabrication, effective, automated production and control equipment have had to be developed. In Soviet fuel fabrication plants, welding and filling of the fuel tubes with pellets is fully automated. Ultrasonic checks on weld quality, monitoring of fuel-rod integrity and of the rods' geometrical parameters, density, etc. are all highly mechanized. The level of technology reached practically excludes fuel-element failures in the initial period of operation, when fabrication defects are particularly revealed.

On the basis of the technological achievements in fuel fabrication, the fuel's operating parameters have been further upgraded. Thus the fuel for WWER-1000 reactors was originally designed for a two-year regime with a maximum burn-up of 40 GW day/tonne of uranium. The positive operating experience accumulated with the reactor and investigations in research reactors have allowed the Soviet Union to start fabricating fuel elements designed for a three-year cycle of operation, with a burn-up of 55 GW day/tonne of uranium. Starting in 1983 the WWER-1000 reactors will operate on a three-year cycle. The burn-up for RBMK-type reactors is planned to reach 25 to 30 GW day/tonne of uranium.

Spent fuel management

From the very beginning, the Soviet Union planned to close the nuclear fuel cycle, that is, to reprocess spent fuel and use the plutonium in fast reactors. Spent fuel from nuclear power plants built in other countries with the Soviet Union's assistance will be reprocessed in the USSR, so in a sense the Soviet Union can be considered as a regional centre for nuclear fuel reprocessing.

Standard nuclear power plant designs for the WWER reactors envisage storing spent fuel for a three-year cooling period. However, because of delays in the serial construction of fast reactors, construction of additional, separately located spent-fuel stores designed for about ten years of nuclear power plant operation is being considered. This solution, however, does not remove the need to transport and reprocess spent fuel, but just slows down its implementation. Spent fuel from WWER-440 reactors is transported by train using four to eight special container vans and two accompanying cars. For fuel shipment from RBMK and WWER-1000 reactors other types of railway containers are being developed.



The nuclear-powered ice-breaker *Arktika*, which went into operation in 1974, leading a convoy of ships through northern waters.

When the problem of creating a Soviet nuclear industry arose in the 1940s, scientists at the Radium Institute in Leningrad developed the technology of plutonium extraction from irradiated fuel. By 1950 the USSR already possessed the industrial technology to extract Pu-239 from irradiated natural uranium. In 1952 work started to perfect a method of reprocessing the irradiated fuel which would be discharged from the first nuclear power plant in Obninsk. After many years of work, scientists, technologists, and designers have developed reprocessing technology for WWER and RBMK fuel elements which separates and extracts uranium and plutonium from fission products with a high degree of efficiency.

Waste management

Proper management of radioactive wastes produced by nuclear power plants and fuel reprocessing facilities is an important subject of the USSR programme of nuclear research and development.

Low-level wastes: A universally applicable way of purifying low-level liquid wastes has been developed using a two-stage ion-exchange process. The ion-exchange resins are regenerated and repeatedly used, and the solutions are evaporated. After hardening, the residues are sent for storage, while the water can be used for technical purposes. The final volume of wastes to be stored is only 0.2% of the initial one.

Medium level wastes are currently kept in stainless steel tanks (without cooling systems). For more reliable and more economic storage, bituminization has been developed and it is planned to introduce rotary bituminization devices with an output of 100, 200, and 500 L/h at nuclear power stations. Bitumen blocks with an activity of 10^6 to 10^7 Bq/L are being stored experimentally in clay soils. The possibility of vitrifying intermediate-activity waste is also being studied.

High-level waste: Vitrification is considered to be the most promising method of conditioning high-level wastes. The process has been comprehensively studied and resulted in the technological development of one-stage and two-stage versions of a highly productive process of vitrification.

The vitrified products are put into 200 L containers and placed in vertical concrete pipes, cooled by air. The repository design envisages the possibility of withdrawing the solidified wastes and loading them into transport casks. The time of residence of solidified wastes in a repository depends on their initial heat release. Wastes with a specific heat release of 5×10^{13} W/m^3 require a six-year retention.

The Ministry of Geology has carried out a complex study of geological and hydrological conditions in many regions for existing and planned nuclear facilities. However, the results of all scientific and field studies do not yet provide a final answer on the most suitable type of rocks for waste disposal. Rock-salt, clays, granite, gneiss, diabase, porphyrite, and similar rocks are under consideration.

Nuclear ice-breakers

When speaking of progress in the nuclear power field in the USSR, one should certainly mention the creation of the nuclear-powered ice-breaker fleet. The exploration of northern seas is of great significance for the country and the availability of nuclear-powered ice-breakers has marked a new era in the exploration of the Arctic Sea routes.

The first nuclear-powered ice-breaker in the world *Lenin* was constructed in 1959 and celebrated its twentieth anniversary of operation in the Arctic ice in December 1979. The next ship in the series of nuclear-powered ice-breakers, the *Arktika,* went into operation in 1974, and in 1977 the ice-breaker *Sibir* started work. The latter two ships are equipped with a standard 75 000 horsepower nuclear power installation and their technical specifications are better than those of the ice-breaker *Lenin.* The operating experience with nuclear-powered ice-breakers in periods of prolonged navigation, the unprecendented journeys of *Arktika* to the North Pole and of *Sibir* to transarctic high latitudes, have demonstrated conclusively that nuclear-powered ice-breakers can solve tasks which are beyond the possibilities of conventional ice-breakers. The Soviet Union is also considering the use of nuclear-powered lighter carrier-ships in Arctic regions.

The first nuclear-powered ice-breaker in the Soviet fleet, and the first in the world, the *Lenin.* It was built in 1959.

Further perspectives

As already mentioned, the Soviet Union considers nuclear power one of the most important energy sources and a part of the long-term solution to the problems of fuel and power supply. In 1981 the 26th Party Congress decided that almost all growth of electricity production in the European part of the country should be achieved by the construction of nuclear power and hydroelectrical plants. The decision will significantly alleviate the problems of fuel and power supply. But at the same time, since less than 25% of the organic fuel resources consumed in the USSR are used for electricity production and, since during the forthcoming five-year period nuclear power plants can provide base-load consumers with electrical power only in the European part of the country, the contribution of nuclear power to the fuel supply cannot exceed 10 to 15%. This means that nuclear power, while substantially alleviating the fuel and power supply problems, is not yet able to solve them radically. The solution of these problems is possible only through substantial broadening of the sphere of utilization of nuclear power.

About 20% of organic fuel consumed in the USSR is burned for central heating. The main consumers of centralized heat are again located in the European part of the country. Thus the extension of nuclear power to centralized heating is considered as one of the most important tasks in the solution of fuel and power problems.

First steps to solve these problems have already been made. Since 1973 a nuclear heat and electricity production plant has been operating in the far north-east of the USSR, in Chukotka region, supplying the town of the diamond miners Bilibin with heat and electricity. Also since 1973 the BN-350 fast reactor has been successfully supplying the 100 000 inhabitants of the town of Schevchenko with electricity and fresh water. Currently, waste-heat from the Beloyarsk, Leningrad, Kursk, and Chernobylsk plants is being utilized.

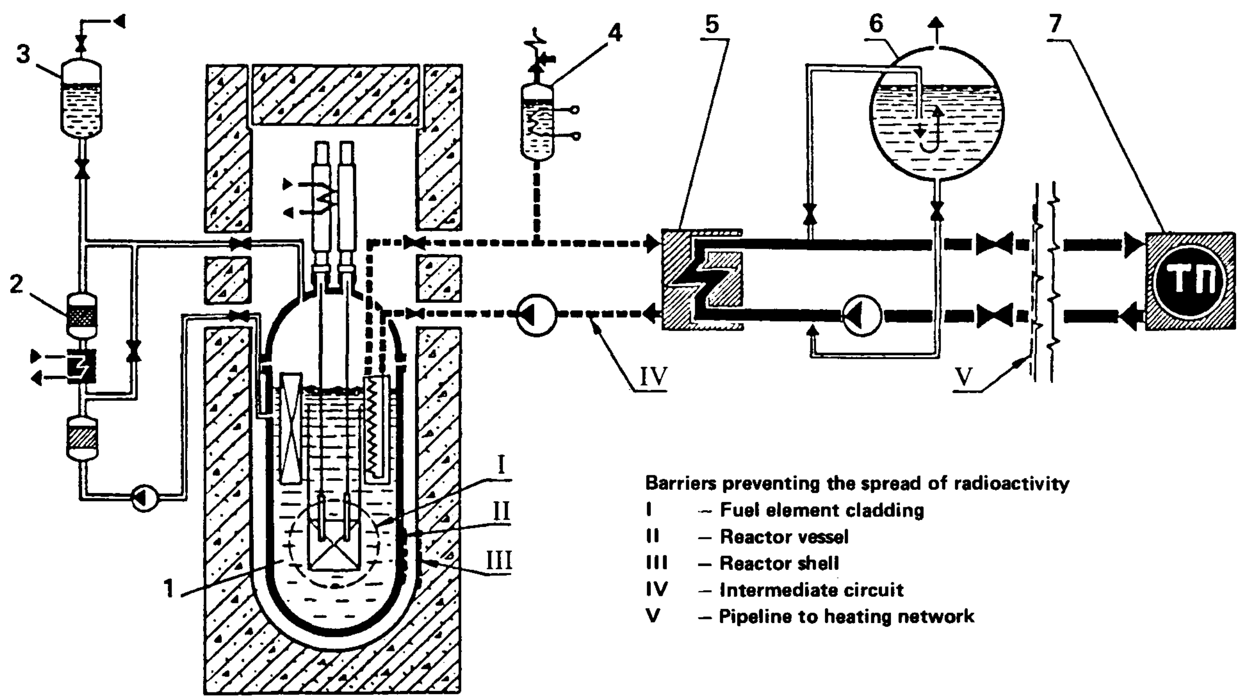
Studies show that heat can be supplied from nuclear energy sources either by dual-purpose nuclear heat and electricity plants, or by using nuclear power plants only for heat supply – nuclear boilers. Thermodynamically, dual-purpose plants are more efficient, but more complicated to build and operate. Extensive research and development, and design studies have shown that nuclear boilers are both sufficiently powerful (300 to 500 Gcal/h) and safe sources of heat supply to be located near densely populated areas, thus eliminating expensive long-distance district-heating pipelines. The first 500 MWth nuclear boiler plants (AST-500) are being constructed in Gorky and Voronezh and it is expected that many more such plants will be widely used in the future. Nuclear power plants supplying heat cost more to build than boiler plants operating with organic fuel but, owing to the cheapness of nuclear fuel, the cost of the heat produced should be approximately half that from organic fuel. The construction of the first big dual-purpose nuclear power plant for both electricity and heat production has started near Odessa. A WWER-1000 nuclear power reactor has been chosen as energy source.

Since more than 15% of organic fuel in the USSR is consumed directly in industry – including chemistry, metallurgy, etc. – the introduction of high-temperature reactors for industrial heat production as well as to make synthetic fuel is being considered as another possibility of widening the field of applicability of nuclear power and thus economizing conventional fuel resources. Research and development in this field is also under way.

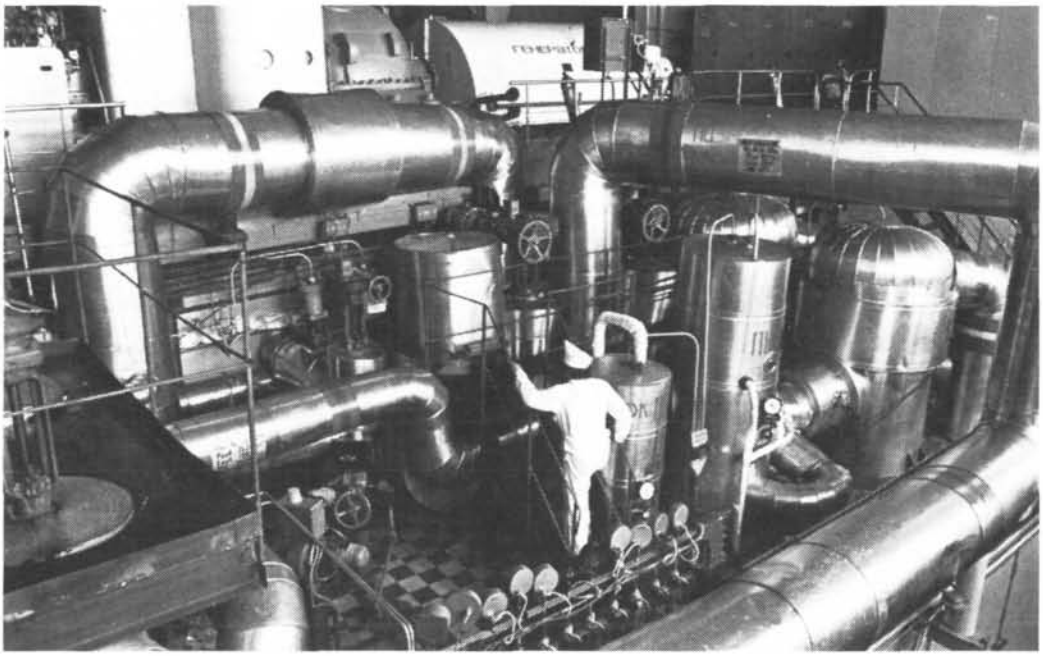
It is realized, of course, that the broad introduction of nuclear power into most power-intensive branches of the country's economy requires a reliable and assured supply of nuclear fuel. This is why the development and introduction of fast breeder reactors is considered a paramount task. One of the important tasks for the nuclear industry is, therefore, considered to be serial production of breeders.

Co-operation within the CMEA

In the field of nuclear power, the Soviet Union is co-operating closely with the countries of the Committee of Mutual Economical Assistance (CMEA). The long-term programme of co-operation in the fields of energy, fuel, and raw materials envisages technical co-operation in the construction and introduction of nuclear power plants in the CMEA countries. As the basic reactor-type for nuclear power development in the CMEA countries, the WWER-440 standard reactor has been selected for the first stage, the WWER-1000 for the second. By 1990 the CMEA member countries (excluding the USSR) plan to build nuclear power plants with a total installed capacity of approximately 37 000 MW. An international commercial organization, Interatomenergo, has been founded for the co-operative manufacture and supply of equipment for nuclear power plants by the member countries of the CMEA. Yugoslavia is also taking part



Layout of the AST-500 nuclear district-heating plant, showing (1) the reactor; (2) primary-circuit by-pass purification system; (3) boron solution injection system; (4) intermediate circuit pressurizer; (5) heat exchanger to heating network; (6) emergency cooling system tank; (7) heat consumers.

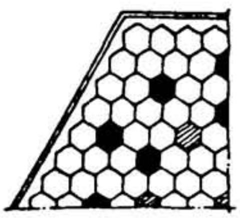


The turbine hall of the Bilibin nuclear power plant which supplies a diamond-mining town in Chukotka region in the far north-east of the USSR.

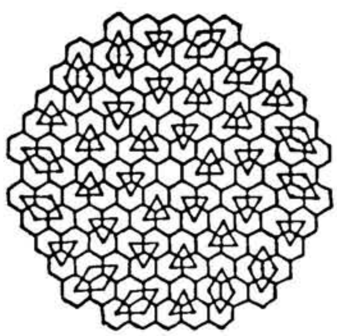
in these activities. Up to now four WWER-440 power reactors are operating in the German Democratic Republic, four in Bulgaria, two in Czechoslovakia. Hungary has recently commissioned its first unit, Poland and Cuba have started construction. The total installed nuclear power capacity in the CMEA countries, including USSR, will reach approximately 100 000 to 120 000 MW by 1990.

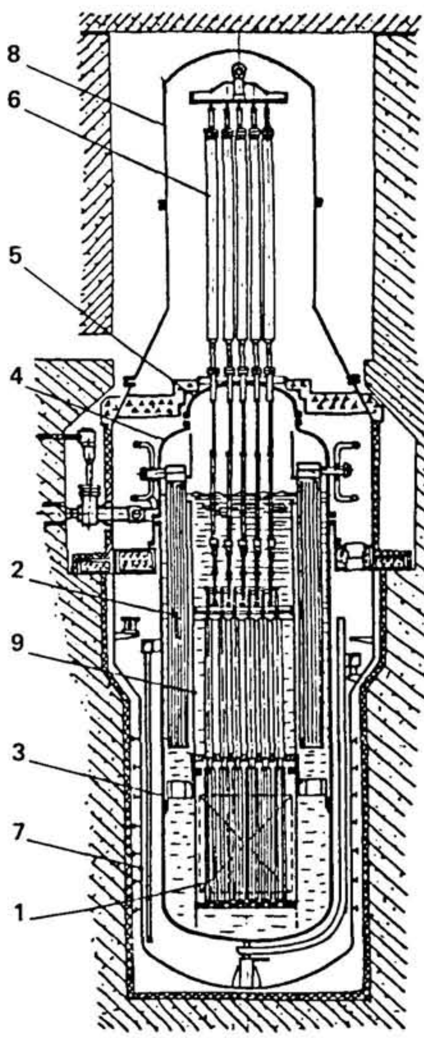
I believe that both the results achieved and the plans for further nuclear power development in the USSR and other CMEA countries are impressive, particularly in the light of the well-known difficulties and problems that many other countries have had. I believe also that the successful realization of the USSR's and other CMEA countries' plans for expansion of the nuclear power sector will contribute substantially to the development of nuclear power throughout the world.

Fuel assembly composition



Core diagram





A sectional view of the AST-500 district-heating reactor, showing (1) core; (2) heat exchanger; (3), (4) lower and upper part of the reactor vessel; (5) reactor roof; (6) control rod drives; (7), (8) lower and upper parts of reactor shell; (9) shaft of draft sector of natural circulation circuit.