A promising area for collaboration

Nuclear heat supply systems in CMEA countries

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Nuclear energy is being used widely for electricity generation in the Member States of the Council for Mutual Economic Assistance (CMEA). The installed capacity of the nuclear power plants reached 25 000 megawatts (MW) in 1983, which results in a saving of 50 million tonnes of reference fuel in a year.

If we consider that electricity production accounts for about 20 to 25% of the energy resources, it will be obvious that the possibilities of saving scarce fossil fuel here are limited to a certain extent and that such savings will not exceed 10% even in the very long run.

There is another, much wider, area of consumption of energy resources – heating – which uses up to 40% of fossil fuel. Here, too, extensive possibilities exist for the use of nuclear energy.

For a number of years now the CMEA Member States have been keenly interested in the new area of nuclear utilization – nuclear heating. An analysis of the long-term fuel and energy balance carried out in many countries has clearly demonstrated the need to use nuclear fuel to meet demands for district and industrial heating.

Collaborative effort planned

At its 106th session (1983) the CMEA Executive Committee decided to organize multilateral collaboration between the CMEA Member States in the area of nuclear heating. In pursuance of this decision the CMEA Standing Commissions concerned with collaboration in electric power production and in the peaceful uses of atomic energy, the Inter-Governmental Commission on Collaboration in the Production of Nuclear Power Plant Equipment, and the Inter-Governmental economic body Interatomehnergo are to submit to the Executive Committee in 1985 a draft agreement. The agreement will cover collaboration between the CMEA Member States in the scientific, technical, and design work on nuclear heat and power plants and nuclear heat supply plants intended for the production of industrial steam and for satisfying district-heating demands over the period 1986–2000.

In implementing the above decision, the Commissions at their subsequent meetings (October and November 1983) adopted the procedure and schedules for drafting the collaboration agreement and programme in the field of nuclear heat supply. It should also be pointed out that, at the same time, the Executive Committee decided to work out a programme for the construction of nuclear power plants and nuclear heat sources up to the year 2000, taking into account possibilities for the provision of nuclear fuel and the necessary equipment for the plants.

Various systems under study

We are thus standing on the threshold of multilateral collaboration in the area of nuclear heat supply, which will range from scientific and technical development to the construction programme. In this connection, it might be useful to review the present status of the problem, i.e. to evaluate initial approaches. Our task has been made easier to some extent by the work of a seminar of experts from CMEA Member States on research and development in the field of nuclear heat supply, which was held in October 1983.

Low-temperature heat has an extremely wide range of customers. For example, it is used for district heating, and, in the form of steam of various types, in building and other industries, in the production of paper and pulp, and agricultural fertilizers, and in improving production from oil wells. Development work on nuclear sources of heat is at present concentrated on the heating of residential and industrial buildings and on providing hot water.

In the immediate future nuclear power plants with limited extraction of heat for consumers, nuclear heat and power plants (NHPP), and single-purpose nuclear heat supply plants (NHP) are considered as possible types of nuclear sources of heating. Work also is in progress on single-purpose nuclear plants for supplying industrial heat. All these heat sources have their advantages, and in the future an optimum combination of them will obviously be chosen for each country.

From economic considerations (relatively high capital costs and low fuel component of the cost of heat), the nuclear heat sources are intended for supplying base-heat loads, while peak loads will be covered by fossil-fuel sources. The use of nuclear sources calls for the development of large centralized heat supply systems. The nuclear sources that are being developed will have provision for control of heat supplies over a wide range.

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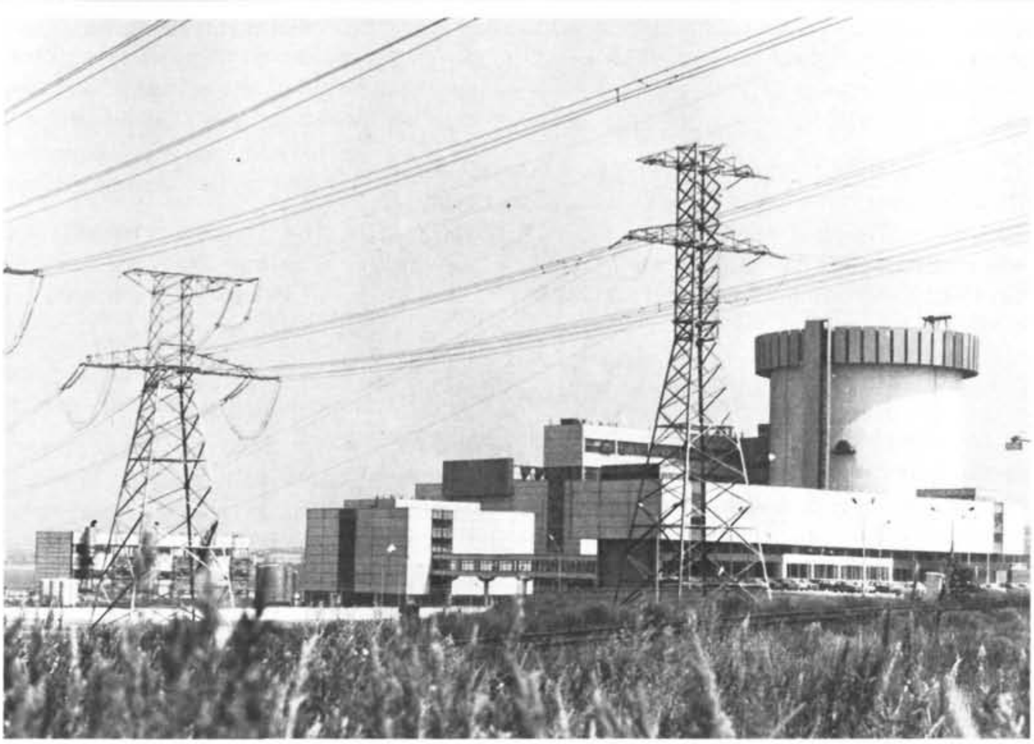


Heat is extracted from the 1000-MW WWER nuclear power plant at Novo-Voronezh in the USSR to supply nearby industrial consumers with hot water and steam.

Developments in USSR

In terms of world practice, the Soviet Union is now in the forefront of development work on nuclear heating. It will therefore be worthwhile, first of all, to dwell on activities in progress in the USSR.

About 55% of the Soviet Union's heat requirements are met from large centralized heat supply plants (66% in the case of towns). The remainder is met from numerous small uneconomical boilers (more than 250 000 in the country) and individual, mainly domestic, plants.

The existence of a large number of small plants results in a substantial over-consumption of fuel, and in inefficient loading of the industry that manufactures costly and uneconomical boilers, which require a great deal of metal. Therefore, improvement in the country's heat economy lies mainly in the direction of large-scale planned centralization of the heat supply based on heat-and-power plants (HPP), large boilers and, in the long term, on nuclear heating sources.

For this purpose, non-controlled extractions of steam from nuclear power plants were resorted to for the first time in the world in the USSR, when 21 gigacalories per hour (Gcal/h) district-heating plants were put into operation at the Beloyarsk nuclear power station. Many years of experience in operating them has confirmed that heat supplied by nuclear power plants can be reliable, economical, and safe.

At present, heat is extracted from the Beloyarsk, Chernobyl', Kursk, Novo-Voronezh, Kola and many other nuclear power stations. The connected load is between 30 and 200 Gcal/h. The heat is supplied to consumers in the immediate vicinity of the stations for heating purposes and applying hot water to production buildings, industrial sites, construction sites, the residential settlement belonging to the plant, for purposes of special water purification, and so on. The supply mainly takes the form of hot water. Steam is provided in small quantities.

The heat diagram and design of the condensation turbines now used in nuclear power plants offer the following possibilities for obtaining heat from non-controlled extractions: the K-220-44 turbine (for WWER-440) 25 Gcal/h, and K-1000-60/1500 (for WWER-1000) 200 Gcal/h. The rated extraction capacity can be increased further by introducing additional pre-heating stages.

Development work is in progress on the use of condensation turbines with large extractions for district heating (on the order of 500 Gcal/h and higher for the WWER-1000 nuclear power stations under construction, for example, for the second phase of the Rostov power station). This will afford extensive possibilities for using the condenser-type nuclear power plants for supplying large heat-consuming regions.

Economical heat for cities

While nuclear power plants are designed mainly to generate electricity, the condenser-type district-heating plants (NHPP with TK-type turbines) are intended not only for generating electricity but also for supplying much higher heat loads. The use of the TK-type turbines in these NHPPs steps up the heat extraction to 900 Gcal/h from one 1000-MWe unit.

The first NHPP of this type is being built in the Soviet Union for district heating in Odessa. It has a capacity of 2000 MWe. The plant will have two units, each of which will consist of a WWER-1000 reactor and two TK-450-500/60 turbines. The total heat load to be covered in the city by this plant, together with peak boilers based on fossil fuel in the calculated maximum (winter) load operation, will be about 3000 Gcal/h.

The commissioning of the Odessa NHPP will ensure annual fossil fuel savings of about four million tonnes of reference fuel. Also, several hundred small boilers in the city will be closed down with all the ecological benefits which this involves. In the future it is planned to build NHPP of this type to supply heat to Kharkov, Minsk, Volgograd and other cities.

It is important to note that the capacity of a power unit with heat extraction of 900 Gcal/h will be about 900 MWe, i.e. only 100 MWe lower than in the pure condensing mode. Production of heat by this method (district heating) is highly economical.

In NHPPs, WWER-1000 reactors are used as in nuclear power stations. So the safety-related restrictions on siting near large industrial and residential agglomerations apply in this case, too.

For example, the Odessa NHPP is situated 25 kilometres from the city. This requires the laying of costly heat networks with a considerable quantity of piping (about 60 000 tonnes for a diameter of one metre) and reservation of land for conveying the heat in pipelines. In some cases, the construction of NHPP may be limited by siting considerations, scarcity of industrial water needed in large quantities for cooling the condensers, lack of demand for electricity generating capacities, and other reasons.

Extra safety features

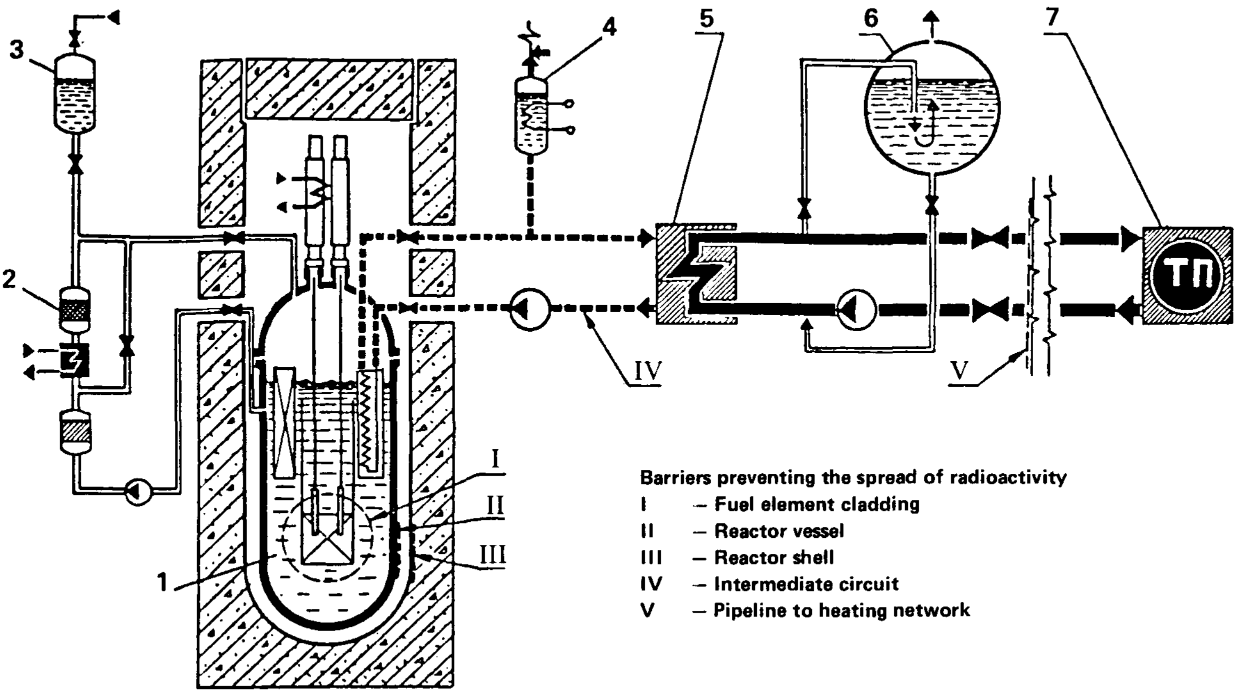
In view of the above, a single-purpose heat source has been developed in the USSR, namely the nuclear heating plant with a 500-MW unit heat capacity (AST-500). For use in CMEA Member States, Soviet specialists also have developed a nuclear heat supply plant of lower capacity (AST-300 with 300 MW), since most countries have limited possibilities for using a 500-MW reactor (considering the number of sufficiently large heat-consumption centres). The AST-300 is similar to the AST-500 in its basic design features.

Since nuclear heat supply plants (NHP) are a new concept in nuclear energy, it is worthwhile discussing them in greater detail. To be economically efficient and competitive with other types of heat sources, these plants should be located as close as possible to heat-consumption centres. This gives rise to additional safety requirements to offset their proximity to cities. Study of the choice of reactor type suggests that safety requirements are most fully satisfied by a vessel-type, water-moderated, water-cooled reactor, the design of which is based on the following main principles:

- The low pressure in the primary circuit and moderate power density in the core reduce the potential impact of accidents and enhance the reliability of core cooling.
- Natural circulation of the primary-circuit coolant ensures high reliability in core heat removal.
- The integral layout of primary-circuit equipment minimizes branching of the circuit and renders it unnecessary to use large-diameter pipes that are potentially dangerous because of the possibility of major breaks in the circuit.
- The two-vessel design, in which the pressure vessel is built with a minimum gap inside a containment vessel, ensures that the core remains under water in the event of failure of the main vessel and also that radioactive products are localized.

Basic specifications of the AST-500 and AST-300 reactors

	Unit of measure	AST-500	AST-300
Thermal capacity	MW	500	300
Primary-circuit coolant:			
pressure	MPa	2.0	2.0
temperature at core entry/exit	°K	399/477	393/473
Surface area of built-in heat-exchangers/number of sections	m^2/number	5000/18	2000/15
Intermediate-circuit pressure	MPa	1.2	1.2
Heat network:			
pressure in network heat-exchanger	MPa	2.0	2.0
temperature in inlet/outlet headers	°K	413/333	393/323
Core:			
specific power density	MW/m^3	27.1	23
fuel element diameter/nuclear fuel type	mm	13.6/UO_2	13.6/UO_2
number of fuel assemblies	number	121	85



Multiple radiation barriers are integral to the design of the AST-500 nuclear district-heating plant currently being built near the USSR cities of Gorky and Voronezh. The layout shows (1) the reactor; (2) primary-circuit bypass purification system; (3) boron solution injection system; (4) intermediate-circuit pressurizer; (5) heat-exchanger to heating network; (6) emergency cooling system tank; and (7) heat consumers. Similar in basic design features, a 300-MW plant has been developed for use in CMEA countries.

- A three-circuit design for heat removal from the reactor with an intermediate separating circuit, inside which pressure is lower than in the heat network, precludes escape of radioactive products from the reactor to the customer through leaks in the heat-exchange surfaces.

The design features adopted for the NHP ensure radiation safety for the population during both normal operation and in the event of accidents.

Calculations for the NHP with two AST-500 reactors show that radioactive product discharges and radiation doses in the locality are much lower than permissible levels. Even in the case of accidents with the worst radiation consequences involving failure of the intermediate-circuit piping with a diameter of 500 millimetres, the individual exposure doses are lower (by a factor of 10^4) than the dose-limits for the maximum design-basis accidents.

The circuit layouts ensure safety of the population using water from the supply network by preventing leakage of the intermediate-circuit water into the heat network both in normal operation and in accident situations. For all these reasons, the NHP can be located safely in the immediate vicinity of heat-consumption centres – as close as two kilometres from the limits planned for future expansion of cities, as laid down under the standards in force in the USSR.

The NHP makes wide use of design features which have become traditional in USSR nuclear power engineering and have been well proven in the practice of operating the WWER and high-power channel-type reactors (RBMK). They relate to the choice of fuel elements, fuel-assembly cladding, control mechanism of the safety system, cluster-type regulators, and other structural components. Extensive research and development activities were also necessary to prove that the features adopted were sound.

Pilot plants being built

In 1983 the Politburo of the Central Committee of the Communist Party of the Soviet Union approved proposals prepared by the USSR Council of Ministers concerning the construction and commissioning of NHP for the period up to 1990.

Pilot NHP with two 500-MW units already are under construction in Gorky and Voronezh. Their construction and commissioning are especially important since they will provide the first practical experience in industrial utilization of large nuclear heat-supply sources.

The Gorky NHP is being built at a distance of two kilometres from the planned city limits, the average distance from consumption centres being 10 kilometres. Its thermal capacity is 1000 MW (two 500-MW units), which is about 50% of the capacity of the centralized heat-supply system under construction. The latter's annual output of heat energy will be more than six million Gcal, including five million Gcal from the NHP, i.e. more than 80%. The total length of the heat network exceeds 60 kilometres, including 40 kilometres of transit networks. With the commissioning of the NHP, 270 small inefficient boiler plants using fossil fuel will be shut down.

The centralized heat-supply system incorporates, for the first time in the case of closed systems, the concept of heat storage to balance the uneven daily operation of hot water supply systems. Open tanks with a total volume of 20 000 cubic metres are used for storage purposes. At specific times, the latter will save fossil fuel, through the use of nuclear fuel, of up to 360 tonnes of reference fuel per day.

An important offshoot of designing the Gorky NHP system is the formulation of the basic design requirements for similar systems. These systems should be built with a two-stage design. The first stage consists of the heat sources (base and peak) combined into a single energy system through transit heat networks. The second stage comprises the main and distribution networks and the customers' systems with heat-extraction control. The transmission of heat from the first to the second stage should take place in converter units with the help of mixer pumps or through heat-exchangers. These units should be located in the consumption regions and at the peak heat sources. The latter sources have to be connected in parallel to the transit heat networks.

Technico-economic calculations show that the centralized heat-supply system design used for the Gorky NHP is the most economical of all the possible options.

Czechoslovakian programme: regional systems

Research and development work on nuclear heat supply also is in progress in other CMEA Member States.

In Czechoslovakia the problem of satisfying the country's heat energy needs will be resolved by building centralized heat-supply systems, by cogeneration of electricity and heat using domestic types of coal and, in the very near future, by the use of nuclear heat-supply sources. Studies indicate that, in the long run, the use of nuclear sources is inevitable and that it is almost the only possible solution for supplying heat to major centres of economic activity in the country.

The proposed programme for utilization of nuclear sources is expected to ensure, by the year 2000, the extraction of 41 000 terajoules annually (TJ/a) of heat energy and savings in fossil fuel amounting to 1.6 million tonnes of reference fuel, the latter figure rising to 4.7 million tonnes by the year 2010.

The decision taken by the Czechoslovak Government Praesidium in 1981 concerning the conversion of condenser-type power stations into the district-heating mode also envisages heat supply from all nuclear power stations under construction. This concept requires the establishment of large regional systems of centralized heat supply. The construction of boilers and small HPP will be restricted, with a substantial reduction in adverse environmental effects of local heat sources.

As nuclear sources of heat, Czechoslovakia proposes primarily to use nuclear power plants with heat extraction (NHPP and also NHP).

All nuclear power stations with WWER-440 (altogether 12 units) in operation or under construction in Czechoslovakia make provision for heat extraction to supply heat to neighbouring towns. The Bohunice nuclear power station will supply heat to Trnava, the Dukovany station to Brno, and the Mohovce station to Levice.

When supplying heat (hot water at 150/170°C) from one nuclear power plant unit with the Skoda condenser turbine units (2 × 220 MW), which are not specially equipped for heat extraction (nuclear power plants V-1 and V-2), a maximum of 170 MW(th) can be extracted. The next modification of the Skoda 220-MW turbines (for the Mohovce station) is designed for district-heating extractions of up to 230 MW from one unit.

Case studies show potential

Let us take as an example the feasibility study for supplying heat to Brno from the Dukovany nuclear power station, which has been carried out by Czechoslovakian specialists. It is planned to provide 500 MW of heat and the length of the network will be 40 kilometres. The heat supply will take the form of a closed system, consisting of two pipelines with a diameter of one metre (24 000 tonnes of pipes). The equipment (pipes, pumping stations, etc.) can be provided by the national industry.

The new network of the centralized heat-supply system is already under construction in the city. The investment will pay off in 10 years. Analysis shows that the production of heat from the nuclear power station provides the only possible and economically viable solution to the problem of a centralized system for Brno.

A characteristic feature of Czechoslovakia is the predominance in some regions of thermal loads utilizing steam not only for industrial but also for heating purposes. The Czechoslovakian specialists are studying the possibility of providing steam from the Temelin nuclear power station (with a WWER-1000) to the centralized heat-supply system for České Budějovice.

It is propôsed to use NHP for heat-consumption centres situated beyond the radius of economically feasible heat transport from nuclear power plants or fossil-fuel HPP. At the first stage, the AST-300 plant is envisaged for the Ostrava-Karvina complex by 1995 and for Bratislava by the year 2000. The siting studies and activities for these specific cases already have started.

The 500- and 300-MW NHP have a limited scope in Czechoslovakia, where smaller plants would be of greater use. It is therefore intended to develop NHP with a capacity of 100 to 200 MW, for which, in the opinion of the Czechoslovakian specialists, new concepts need to be considered.

The Czechoslovakian industry has an extensive potential for participation in the manufacture of NHP equipment.

In Poland, options being assessed

No specific programmes on the use of nuclear heat sources have yet been adopted in Poland although calculations and design assessments are in progress for NHPP and NHP.

The construction of an NHPP with WWER-1000 is relevant only to the largest urban and industrial centres: the Warsaw urban agglomeration (before the year 2000) and the region of Silesia and Cracow (after the year 2000). During the years 1990–2000 the country may need up to eight NHP with a capacity of 300 or 500 MW.

Because of their high unit capacity, the use of these plants will be limited to a few large heat-consumption areas: Silesia, Cracow, Gdansk, Stettin, Poznan, and Lodz. Moreover, Poland has many relatively small towns where the problems of heat supply and environmental protection are especially acute. NHP would be advisable for these regions; however, it is necessary to develop 100- to 200-MW plants for this purpose. At present, development work is in progress on a reactor for 200-MW NHP.

Nuclear heat supply to the Gdansk urban agglomeration is under consideration. The main heat-consumption centre is the region comprising three cities: Gdynia, Gdansk, and Sopot (total demand of 3140 MW). The planned socio-economic development here envisions an average annual growth of 116 MW in thermal capacity. Up to 1990 it will be covered by the coal-fired HPP; thereafter new energy sources will be required.

In this connection, the options under discussion are one NHP with 500-MW reactors, or two NHP with 300-MW reactors, or heat extractions from the Zarnowiec nuclear power station under construction. In the latter case, the fairly long distances of transport (50 to 80 kilometres) will be the limiting factor.

German Democratic Republic: urban prospects

The directives of the Tenth Congress of the German Socialist Unity Party on the five-year economic development plan for the German Democratic Republic (GDR) have outlined an energy production policy based on the use of domestic resources, namely brown coal. Because of the greater use being made of brown coal, its shortage cannot be expected to decrease, even with the increase in production to 300 to 310 million tonnes by 1990. The prospects for nuclear heat in the GDR can be judged from the fact that even now 80 million tonnes of brown coal are needed every year for centralized heat supply alone.

Since nuclear power plants and NHPP have to be sited for safety reasons far away from large population centres and, consequently, need high-cost networks to convey the heat, GDR specialists consider the NHP to be advantageous for urban heat supply.

The GDR is examining the possibility of using the AST-500, in regard to the characteristic features of its construction in the country. It is noted, for example, that the designed entry and exit temperatures basically correspond to the conditions prevailing in the large district-heating systems in the GDR, including those of the Berlin system (the largest in the country).

In spite of their economic advantages, the scope of the high-capacity NHP is limited – there are five district-heating systems with capacities from 500 to 1000 MW and one with a capacity of more than 1000 MW. One- and two-unit variants of NHP are under consideration.

The GDR is carrying out theoretical and experimental studies on thermohydraulic processes, together with the dynamics of reactors for NHP, heat storage, and so on. For these purposes, experimental facilities have been set up at the Technische Universität Dresden and at Ingenieurhochschule Zittau. Work is in progress on heat extractions from the operating Bruno Leuschner nuclear power station, and preparations are under way for the manufacture of non-nuclear equipment for nuclear heat sources by domestic industry.

Bulgaria: a nuclear imperative

In Bulgaria inadequate domestic energy resources make it imperative to use nuclear sources of heat. Industrial loads play a decisive role in the development of centralized heat supply in that country. All its HPP have been built primarily to cater to industrial areas and secondarily to district heating and hot water supply. As a result, during 1980–82 centralized heat supply to industry accounted for 55 to 60% of the country's fuel consumption, while that to the population accounted for only 10%.

Bulgaria has 27 centralized heat supply systems. Both industrial zones and population centres are characterized by small- and medium-scale heat loads. Thus, by 1990 a load above 1000 MW is expected only in two cities – Sofia and Plovdiv. Only in three other cities will the load lie between 500 and 1000 MW.

In the future, therefore, Bulgaria will need nuclear heat sources with capacities from 100 to 500 MW for industrial as well as domestic needs. Plants with a capacity of 500 MW may be used only in isolated cases by the year 2000. The Bulgarian specialists intend to consider nuclear heat sources with capacities of 100 to 200 MW to meet the country's specific demands.

Outside CMEA, interest aroused

Nuclear heat supply sources are arousing interest not only in CMEA Member States, but also in many developed capitalist countries, especially those with temperate and cold climates. The 200-MW Secure project developed jointly by Swedish and Finnish firms for district heating in towns with a population of 50 000 to 100 000 is well known. The French have developed a low-temperature 100-MW nuclear heat source Thermos, which has an immersion-type reactor and integral equipment layout. The Canadians are looking into the use of low-capacity nuclear heat sources (from 2 to 20 MW) in the northern regions of their country. A number of other countries have gained practical experience in heat extraction from nuclear power plants for the supply of heat.

Technico-economic studies have shown that nuclear heating sources are fully competitive with fossil-fuel plants. The higher investment costs are offset by lower production costs. One 1000-MW NHP can cater to urban areas with a population of 300 000 to 400 000, resulting in annual fuel savings amounting to 700 000 tonnes of reference fuel. Another point in favour of nuclear sources is their indisputable advantages in terms of environmental cleanliness.

Nuclear heat as a new branch of nuclear power engineering is in its infancy. Much effort and time will be needed to establish industrial-scale nuclear heat supply sources in CMEA Member States. Multilateral co-operation between Member States of CMEA will play an important part in accelerating this process.