Nuclear district heating in CMEA countries

A number of approaches have been developed for using nuclear plants as sources of heat

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Historically, nuclear energy sources have been used mainly to produce electricity. The Soviet Union's power generation industry has also followed the path of primarily expanding its nuclear electricity generation capacity. At present, the installed capacity of the 45 nuclear power plant units in the Soviet Union amounts to some 35 gigawatts-electric (GWe). Nuclear power generation is centered, in the main, around the use of water-moderated, water-cooled, pressure-vessel-type reactors (VVERs) (these series-produced power units have an electrical output of 440 and 1000 megawatts), and channel-type, water-cooled, graphite-moderated reactors of the RBMK type (these series-produced power units have an electrical output of 1000 and 1500 megawatts). The VVER-type reactor units developed by Soviet specialists have also served as a basis for the development of power generation in member countries of the Council for Mutual Economic Assistance (CMEA).

Even when the nuclear power generation industry was at an early stage of development in the USSR, it was clear that focusing solely on the production of electricity would not adequately solve the basic problem which beset the industry, namely, supplanting scarce organic fuel in the country's fuel and energy economy. The only way this problem can be solved is by the extension of nuclear energy into the highly fuel-intensive area of heat production for community and domestic heating and for industrial consumers (1.5 times more fuel is used for this purpose than for the production of electricity). In CMEA countries, which are less well-endowed with fossil fuel resources than the USSR, this problem is even more acute.

The plan for developing "nuclear" district heating worked out by Soviet specialists to meet the requirements of the country's fuel and energy sector provides for the combination of four different approaches:

- the use of unregulated steam extraction from the turbines in condensing power plants;
- the construction of mixed, district heating and condensing nuclear power plants with high back pressure (TK) type turbines (district heating and condensing with regulated steam extraction);
- the construction of single-purpose nuclear plants which produce only thermal energy for community and domestic heating purposes (DHAPP);
- the construction of specialized nuclear plants for industrial heating purposes which, thanks to new technical features incorporated in the design, could be located in the immediate vicinity of points of consumption and be used to produce heat and electricity, or heat only.

At this point, the first three of these approaches are the most developed technically. The use of unregulated steam extraction from the turbines of nuclear power plants in operation and those under construction holds a special position among these various approaches. In practice, this is the only form of nuclear heating which has been implemented to date. It was started over 20 years ago when a system was set up to deliver heat from the Beloyarsk plant to supply heat and hot water to the buildings and structures on the plant site itself and to the adjacent living areas. Subsequently, this approach was introduced in other plants as well. The total output of the heating systems in plants already operating is fairly impressive — in excess of 3000 megawatts-thermal (MWth) at the beginning of 1989.

The various turbines in use at present in such nuclear power plants, and those in the process of being manufactured for plants under construction, have varying capacities for the output of heat for district heating purposes. *(See accompanying table.)*

The design features of heat delivery systems from nuclear power plants are based on current radiation safety requirements for thermal energy consumers. Thus, the heating water is circulating in a tertiary (in relation to the reactor core) circuit. Pressure in this circuit is kept higher than the maximum possible pressure of the highest unregulated steam extracted, which prevents radioactive products from getting into the heating water should there be a loss of integrity in the heat exchange surface of the boilers. In plants with RBMK reactors, the heating systems have an intermediate coolant circuit between the

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Characteristics of nuclear district heating units of the steam extraction type

Turbine type	Number of turbines in the unit and the reactor	Guaranteed heating capacity of extraction steam, (MWth)	Temperature range for heated water (°C)
K-220-44	2 × VVER-440	29 × 2	130/70
K-500-65/3000	2 × RBMK-1000	87 × 2	150/70
K-750-65/3000	2 × RBMK-1500	116 × 2	165/70
K-1000-60/1500-2	1 × VVER-1000	232	150/70
K-1070-60/1500-3	1 × VVER-1000	1047 and above	170/70

turbine extraction and the heating water. Pressure in the intermediate circuit is kept higher than the steam pressure but lower than the pressure in the district heating circuit. In plants with VVER reactors, the grid water is heated in grid heaters by the steam extracted from the turbine. The highest pressure extraction steam used is lower in pressure than both the pressure in the reactor circuit and the pressure in the grid circuit. To prevent radioactive contamination of the heating water in an accident situation, the heat exchanger is cut off both for the heating steam and for the heated grid water. There is also constant monitoring of radioactivity levels in the heating water.

It is important, and an economically attractive idea, that the fullest possible use be made of the existing capacity of district heating systems in nuclear power plants. Even allowing for some reduction in electricity output due to the extraction of steam for district heating purposes, the dual-purpose (generation of electrical and thermal energy) use of nuclear power plants with VVER-440 power units decreases the volume of inorganic fuel used by 30 000 tonnes coal equivalent per year for each nuclear unit. Even greater savings are possible when plants with VVER-1000 power units take part in centralized district heating. The volume of organic fuel saved by each power unit of this type amounts to 130 000–750 000 tonnes of coal equivalent per year, depending on the type of turbine installed.

Despite this important incentive, in the majority of nuclear power plants maximum use is not being made of this capacity to provide heat. The reason for this is that the location of the plant is not always ideal in relation to potential heat consumers. The "guaranteed" consumers (within the plant and plant living quarters) usually use only a small part of the total potential heat output from a district heating unit. The calculated total heat consumption of users on site amounts, as a rule, to approximately 30 MWth for one power unit with an electrical output of 1000 or 1500 MWe. Likewise, the total calculated heat consumption of users in the associated plant living quarters does not exceed 260 MWth. In community and domestic heating schemes (heating, hot water, ventilation), nuclear sources are base-loaded and operate jointly with peak sources using organic fuel. As a result, for a 4-unit plant with series-produced VVER-1000 plus K-1000-60/1500-2 turbine, the optimal "load" of the nuclear part of the district heating plant due to on-site requirements (within the compound and in living quarters) is not greater than about 230 MW, whereas the total capability is about four times greater. Thus, in modern plants working at design power level, there is a fairly large capacity for heat production which could be harnessed.

The most sensible course would be to use this available capacity to provide centralized heating for consumers in the adjacent region; i.e., industrial and residential complexes. But there are a number of limitations to such schemes. Technical and economic considerations dictate a specific area of coverage for centralized heating systems for each nuclear power plant.* Beyond that area, the total cost of compensating for underproduction of electricity (owing to the fact that the plant is working in a heat-producing regime) and of transporting the heat to the point of consumption, exceeds the economies to be made from supplanting organic fuel. The size of this coverage area is determined by climatic conditions in the region (which influence the heat output regime), the cost in relation to the organic fuel supplanted, the amount of heat being delivered by the nuclear power plant, the real conditions involved in the laying of the heat transport line from the plant to the industrial and residential complexes where the heat is to be used, the type of generating equipment installed in the plant, and a few other factors. Another significant consideration is the question of which alternative modes of district heating can actually be used in the area to provide a realistic comparison with heating delivered by nuclear power plants. It is not very easy to take all these factors into account when nuclear power plants are to be built since the closeness of a potential heat consumer is not the only, and frequently not the most important, criterion in the authorization process for

* "Use of nuclear power plants as centralized heating sources for industrial and residential complexes, and agricultural energy complexes", by Losev, V.L. Sigal, M.V., et al., *Teploehnergetika 8* (1988) (in Russian).

a construction site. Current radiation safety requirements in the USSR regulate the minimum permissible distance from a nuclear power plant site to major populated areas. Thus, for example, in the case of a plant with an electrical output of 4000 MWe, this distance varies from around 25 km (if the population density in the area is 100 000–500 000) to 100 km (if the population density is over 2 million). For a large number of reasons, however, nuclear power plant construction sites have to be located far beyond the standard distances mentioned above. Hence, for the majority of nuclear power plants currently operating, there are significant heat output reserves which have not been utilized.

Plants operating and planned

There are several examples of effective utilization of nuclear heat. The Balakovo nuclear power plant, for instance, provides the town of Balakovo with heating (the town is 12 km from the plant, the heat requirement is over 1000 MWth), the Rostov plant provides heating for the town of Volgodonsk (13 km from the plant, heat requirement of over 1000 MWth), the Tatarsk plant supplies heat to the town of Nizhnekamsk (40 km from the plant, heat requirement up to 2000 MWth), and the Bashkir plant to the town of Neftekamsk.

Supplying heat to consumers at some distance from nuclear power plants is also now carried out or is being planned in CMEA countries. In the German Democratic Republic, the Bruno Leuschner nuclear power plant has been providing district heating for the town of Greifswald since 1984 (22 km from the plant, heat output — 260 MWth). A heating system for the town of Magdeburg, based on the Stendhal plant now under construction, is in the planning stage (distance from the plant — 95 km).

In Czechoslovakia, it is planned to equip all plants with VVER-440 reactors (12 power units in all) for district heating: the Bohunice plant will supply the town of Trnava with heat, the Dukovany plant the town of Brno, the Mochovice plant the town of Levice. There is a plan to organize heating for the town of Ceské Budejovice from the Temelín plant. The heat transport grids from these plants are very extensive and heat output is fairly high (for example, the heat pipeline from the Dukovany plant to Brno is 40 km long and the calculated heat output is 500 MWth).

In Poland, the idea of using the Zarnowec nuclear power plant to provide heating for the Gdansk-Gdynia area is being considered (the plant is 75 km from Gdynia). There is also a plan to provide the town of Poznan with heating from the Warta plant which is scheduled to be built.

In Bulgaria, a project for a district heating system centered on the Belene nuclear power plant to serve the towns of Pleven (58 km), Svishtov, and Belene, is in the development stage. The total calculated heat output for these towns would be around 700 MWth. It is also planned to use the Kozloduj plant to supply heat for the town of Kozloduj.

The technical features intended for inclusion in the heat output systems of these plants are similar in many respects to those already mentioned as being used in the USSR for the delivery of heat from plants with VVER reactors. It should be noted that CMEA countries co-operate closely on the solution of nuclear district heating problems. This co-operation is co-ordinated under a comprehensive programme for scientific and technical progress for the period up to the year 2000, which has been adopted by those countries.

Along with the use of plants now in operation and those under construction for district heating purposes, as indicated above, technical decisions have been reached to set up specialized nuclear heating sources — both dual-purpose combined heat-and-power plants (CHP) and single-purpose nuclear district heating plants (DHAPP). The USSR power generation development programme, which has already been adopted, includes plans to construct a number of such plants between now and the year 2000.

A CHP design was developed for the European part of the USSR, based on VVER-1000 reactor facilities and new turbine units (TK-450/500-60/3000 turbines) with regulated steam extraction and a high thermal output.* A two-unit CHP plant of this type can ensure a heat output of up to 2100 MW. The plan was to bring at least three plants of this type into service by the year 2000, in Odessa, Minsk, and Khar'kov. It should be pointed out that these plants are not simply district heating plants, but mixed heating and condensation units (owing to the fact that the turbines used in them have a large "added" condensing capacity). However, this is inevitable where reactors with a large unit output are involved.

The review of technical policy with respect to nuclear power generation following the Chernobyl accident brought about a change in attitude to the CHP station designs which had already been developed. As the construction sites for the plants had been chosen in the late 1970s and early 1980s (i.e. when less rigorous requirements were in force than at present), the Odessa and Minsk CHP plants did not satisfy the new approach to safety and their construction was stopped. Design work on the Khar'kov plant was also halted.

The design of a single-purpose district heating atomic power plant (DHAPP) was developed in the USSR simultaneously with the CHP project.

* In the far north of the USSR, the country's first CHP has been functioning successfully since 1974. It includes four power units with electrohydraulic converter-type reactors and heat-delivery turbines with regulated steam extraction (Bilibino CHP).

See "Nuclear heat- and -power plants for the heat supply of towns and conurbations", by Kuznetsov, Yu.A., Sakharov, A.G., Abrosimov, A.F., in: *V International Conference on Centralized District Heating*, 7-10 September 1982, Kiev, Collection of Reports, Section II, Issue 1, reports 11-29 (in Russian).

This was done because the construction of heating-condensing plants is in some cases limited by a lack of process water, large quantities of which are required to cool the condensers of turbines with large "added" condensing capacity, and because there is no demand in some regions for extra electrical capacity, among other reasons. A water-cooled, water-moderated reactor with a unit output of 500 MWth was specially designed for the DHAPP. This single-purpose type plant, the AST-500 can be located in the immediate vicinity of population centres; i.e. up to 5 km from the city limits.* The AST-500 project is being implemented at present in the towns of Gorky and Voronezh. There had been plans to build a number of DHAPPs in the European part of the Soviet Union; however, the negative attitude of the public towards nuclear power after the Chernobyl accident has delayed (and in certain cases cast doubt upon) the implementation of some nuclear power projects which had previously been scheduled for construction.

There is definite interest in single-purpose nuclear heating plants in CMEA countries. It should be noted, however, that owing to the specific nature of urban construction in these countries, they require facilities with a significantly smaller capacity than those commonly used in the USSR power generation system. In the light of this, the USSR has developed a design for a reactor facility with a unit output of 300 MWth, having technical features similar to those used in the AST-500. In addition, work is being carried out in co-operation with specialized organizations in CMEA countries for building facilities with an even smaller output.

In addition to the work on improving the designs for specialized nuclear heating plants, and the development of new types of reactors for them, the search for ways of utilizing more fully the heat output potential of existing nuclear power plants is of great practical significance. Analysis shows that this type of source will dominate the nuclear power infrastructure of the USSR and CMEA countries for a long time into the future.

* The plant is described in detail in "Nuclear electric plants", by Kats, V.L., Kuznetsov, Yu.A., Pleskov, G.I., Tatarnikov, V.P. *At. Ehlektr. Stn. 4* (1981) (in Russian).

Two approaches, in particular, seem highly promising:

- using the available capacity of the heating facilities of nuclear power plants for long-distance industrial heat supply;
- conversion of nuclear power plants which have outlived their standard service life to a DHAPP system (with the reactor facility operating at reduced power and in a less intensive regime).

The implementation of the first of these approaches will allow the pool of potential customers for thermal energy from nuclear power sources to be extended significantly, and it will introduce nuclear energy into the extremely fuel-intensive area of industrial heat supply. Developmental work done in the USSR and Czechoslovakia has shown that, in the matter of long-distance heat supply to industrial consumers, it makes economic sense to employ a system in which heat is transported in the form of pressurized hot water from the nuclear power plant to the point of consumption. The hot water would then be used to produce steam with the required parameters in the customers' equipment (preferably thermocompressors).* At present this work is approaching the technical implementation stage.

The second approach is, at present, at an earlier stage of development, but it is extremely important that an answer be found since it would help solve two problems at once: first, prolonging the operational life of the main equipment in a nuclear energy source, and second, establishing large-scale centralized heat supply sources over a short period of time and at comparatively low cost.

In conclusion, we can confidently assert that the use of nuclear energy sources for centralized district heating purposes is an area which has been adequately explored technically, has been extensively deployed, and which holds great promise.

* "Long-distance transport of heating water from nuclear power plants for steam supply to consumers," by Sigal, M.V, Gusakov, V.I., Dlugosel'skij, S.V., *Teploehnergetika 12* (1987) (in Russian), and "The problems and use of thermocompression of water vapour", by Petrovski, I. in: *Symposium on exchange of experience of CMEA member countries*, Vol. 2, Prague (November 1986) (in Russian).