

COGENERATION IN THE FORMER SOVIET UNION

William C. Horak
International Projects Division
Brookhaven National Laboratory
Upton, NY 11973
Phone 516-344-2627 Fax 516-344-5344

RECEIVED
JUN 24 1997
OSTI

ABSTRACT

The former Soviet Union made a major commitment to Cogeneration. The scale and nature of this commitment created a system conceptually different from Cogeneration in the west. The differences were both in scale, in political commitment, and in socio economic impact. This paper addresses some of the largest scale Cogeneration programs, the technology, and the residual impact of these programs. The integration of the Cogeneration and nuclear programs is a key focus of the paper.

Soviet designed nuclear power plants were designed to produce both electricity and heat for residential and industrial uses. Energy systems used to implement this design approach are discussed. The significant dependence on these units for heat, created an urgent need for continued operation during the winter. Electricity and heat are also produced in nuclear weapons production facilities, as well as power plants. The Soviets also had designed, and initiated construction of a number of nuclear power plants "ATETs" optimized for production of heat as well as electricity. These were canceled.

INTRODUCTION

Soviet central planning resulted in creation of major projects and applications that integrated planning to achieve perceived efficiencies. Cogeneration was normally used as an integral part of planning to take advantage of power plants, and reduce the need for central heating units. This led to designing and beginning construction of nuclear power plants to produce large amounts of heat and electricity. Design trade-offs were made to avoid unplanned shutdowns due to the need for heating.

Normally multiple nuclear power units were built at the same site. For example, the Zaporozhye Nuclear Power Plant has six 1000 Mwe nuclear power units. Towns with populations of 50,000 people or more were built near the nuclear plants for the people who built and operated the plants and provided the associated infrastructure (schools, stores, entertainment). Large piping systems were run from nuclear units to provide process heat to these towns, taking advantage of nuclear heat generation and avoiding the need for a separate central heating plant.

The Soviets integrated district heat into many different nuclear power plant designs. Each subsequent design generation tended to provide more district heat. An extreme example is Bilibino, where a nuclear plant supplies both electricity and district heat needs of a gold mining town that is isolated during the winter.

RBMKs

RBMKs are graphite moderated, boiling water reactors. These are the reactors that are used at Chernobyl. These were the first nuclear power reactors deployed on a large scale in the Soviet Union. The older units have a very simple steam extraction system from the low pressure turbine, providing steam directly to a heat supply system. Later designs have a more sophisticated, but still quite simple system. The amount of steam extracted is relatively small, e. g. about 60 MW_{th} from a total generation of 3,600 MW_{th}.

VVERs

Water cooled, water moderated energy reactors (VVERs) are pressurized light water reactors. There are three main types: VVER-440 model V230, VVER-440 model V213, and VVER-

*This work performed under the auspices of the U.S. Department of Energy, Contract No. DE-AC02-76CH00016.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

1000s. All VVER-440s have six coolant loops and produce a nominal electrical output of 440 MW_e. The older V230s lack many safety systems, including emergency core cooling systems, containment buildings, and modern instrumentation and control systems. The newer model V213s have emergency core cooling systems and a confinement system that uses bubbler condenser towers to condense steam that would be released in a loss of coolant accident. All VVER-440s have two turbines per reactor. All VVER-1000s (several evolutionary design variations exist), have four primary coolant loops and a nominal design output of 1000 MW_e. All VVER-1000s have upgraded safety systems and a Western-style containment building. With one exception, all VVER-1000s have a single turbine.

Most VVERs have the capability to supply heat for residential and industrial use by extracting steam from the turbine cylinders. This is used for space heating the station and nearby residential areas. [The exceptions are the Finnish plant Loviisa and the two plants under construction in Cuba.] The heating load extracted per turbine ranges are up to 120 MW_{th} in VVER 440s and up to 306 MW_{th} in VVER 1000s. Cogeneration system equipment is located either inside the turbine building, or in a separate building near the turbine building. District heating system pumps provide circulation. A makeup system compensates for leakages and to provides chemically treated makeup water.

Figure 1 shows a VVER-440, two stage, district heating system Slovakia. Three hot water heaters are located outside of the turbine hall. Steam for the first stage is tapped from the fifth extraction point on the turbine high pressure cylinder. Two first stage heaters provide the base thermal load. The third heater (in the second stage), used for peaking operation, is heated by steam from the sixth extraction point on the high pressure cylinder. The water is heated from temperatures of about 70° C to approximately 150° C. VVER 1000s extract steam from the later stages of the low pressure turbine.

Table 1 shows representative values for VVER cogeneration systems in the Czech Republic and Slovakia. As can be seen there is an increased district heat load for the newer plants at Mochovce and Temelin. This has been achieved by modifying the extraction points in the turbines. The Temelin plant was originally designed to supply 300 MW_{th} of district heat. Temelin is now being modified and completed by Western organization.

ATETs

Versions of the VVER-1000 design called "ATETs" (a Russian acronym) were large-scale cogeneration Soviet designed units optimized to produce process heat. The earliest version to have been constructed in Odessa used two turbines and provided up to 1040 MW_{th} process heat and 900 MW_e in a combined power production and heat generation mode, during the winter. In the summer, the electric output could be increased to 1000 MW_e.

The second version used a single turbine and could produced up to 1400 MW_{th}. Electric output of 1080 MW_e could be produced during the summer. The Soviets had planned to construct these units in Minsk, Karkov, and Volgograd.

Both types of plants were canceled after the Chernobyl accident because of their location near major population centers. There has been some recent discussion of completing the unit in Minsk,

Belarus. The Odessa plant staff remains and is now working on safety analyses for the United States program to improve nuclear safety in the former Soviet Union.

BILIBINO NUCLEAR POWER PLANT

The Bilibino NPP is located about 100 miles north of the Arctic Circle in Siberia. The plant is located in a major gold mining region where the cost of shipping in fossil fuels is prohibitive. There are four graphite moderated, boiling water cooled, EGP-6 reactors. Construction began in 1965. The first unit began operation in 1974 and last unit in 1976. These plants are rated at 62 MW_{th} (12 MW_e). Each unit has six primary cooling loops with natural circulation, and jet pumps for feedwater from the turbine generators. The total plant produces up to 48 MW_e and 78 MW_{th} of district heat. The plant is capable of operating in a load following mode. Figure 2 shows a schematic of Bilibino.

The plant availability has been quite good, with plant capacity factors of over 80%. There have been a very small number of unplanned shutdowns and no reports of fuel element failures. Changes and improvements were made in 1985. The changes include modifications to allow the plant to provide heat to the entire town of Bilibino, including heat to a large greenhouse.

The design contains certain passive safety features, including the use of natural circulation coolant, negative reactivity coefficients and high thermal conductivity fuel. However, the plant lacks a containment building. Instead, the four reactor units are built on steel reinforced concrete slabs. All four reactor units are contained in a single room in individual concrete vaults. The reactor building is a frame building with aluminum panel walls. The reactor vessels are steel cylinders 20 feet in diameter and 17 feet high, containing graphite logs. Within the graphite core, there are 273 bayonet tube fuel channels and 60 control/safety rod channels. The fuel element is tubular, with 3% enriched uranium in magnesium matrix with stainless steel cladding. A nitrogen system is used to provide cover gas and a cooling system for the graphite blocks.

The Bilibino steam turbines were manufactured in Czechoslovakia. The design contains features common to Soviet designed turbines. There is a moisture separator reheater between the high pressure and low pressure stages. Steam for district heating is extracted high pressure stage exit. This steam heats water in the intermediate circuit. This intermediate circuit is at a higher pressure than the primary system in order to prevent radioactive contamination. Intermediate water is heated to 150° C and transported by a pipeline 3.5 km to the town district heat plant. A tertiary system is heated by the intermediate system to 95° C, for heating and hot water supply (at 65° C). The secondary and tertiary systems are monitored for radioactivity and pressure. If the secondary system pressure drops below the primary or if radioactivity exceeds the value of the feedwater system, the system is shut down.

The Bilibino design uses dry cooling towers for the ultimate heat sink, because the local water supply is not reliable during the winter months. Because of this system, electricity output is sometimes restricted during the short summer.

BN-350

The BN-350 is a sodium cooled, loop type, fast flux reactor located in Aktau, Kazakhstan. The unit started operation in 1972. Unique among Soviet designed reactors, the unit was designed to provide electricity, residential heat, and process heat for a 12,000 metric tons of fresh water a day desalination plant.

The reactor is rated at 1,000 MW_{th} and normally produces 125 MW_e. There are six loops, five of which are normally used. There are three levels of heat removal systems, i.e., a primary sodium coolant system, an intermediate system with sodium to water heat exchangers, and a steam/water system.

Figure 3 shows the flow diagram for the desalting system. The primary sodium transfers heat to the intermediate system through an intermediate heat exchanger. As in most liquid metal cooled reactors, the intermediate (non-radioactive) sodium is kept at a higher pressure than the primary (radioactive sodium). Twelve steam generators and six superheaters heated by the intermediate sodium provide steam. The desalination plant is fed by steam extracted from the low pressure turbine exit.

SUMMARY

Central planning and government control of the entire infrastructure made it possible to deploy large scale cogeneration systems. Nuclear units provided the steam supply in many of these applications. These units appeared to be economical because they used low quality steam that was of little value to produce electricity. Safety concerns lead to the cancellation of a design optimized for cogeneration. The conceptual frame work for these units was based upon supplying heat at no cost. Most end use was not metered or even controlled. The result was cogeneration systems in which production efficiencies were overtaken by an extremely inefficient distribution system because of the lack of any incentive to conserve energy.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Table 1
Cogeneration Characteristics of VVER 440 model V213 and 1000 Plants

Plant	Bohunice (440 MWe)	Dukovany (440 MWe)	Mochovce (440 MWe)	Temelin (1000 MWe)
Number of Turbines	2	2	2	1
Heat Load per Turbine	60	85	120	306
T_{inlet}	70	60	70	65
T_{outlet}	150	144	150	150
Town	Tmava	Brno	Levice	Ceske Budejovice
Distance, km	18	48	20	30

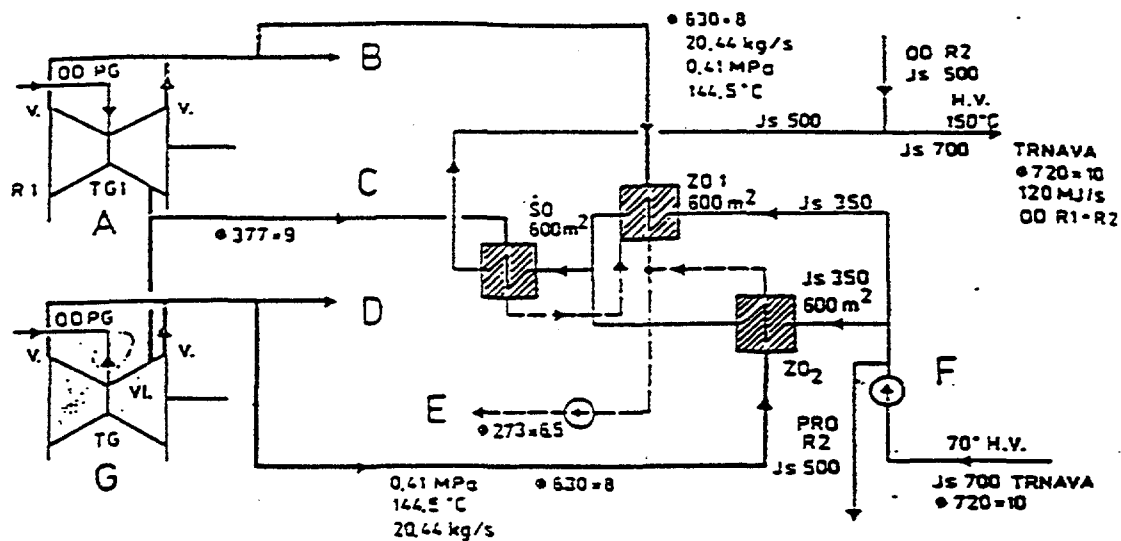


Figure 1 Flow Diagram of the District Heating System at the Bohunice Nuclear Power Plant (VVER 440 model V213)

A, G steam extraction from turbine high pressure system;

B, D Steam extraction from outside the turbine high pressure cylinder.

C total steam flow rate is 18.8 kilograms per second at 0.88 Megapascals and 188°C.

E heating steam condensate; F District heating water pump.

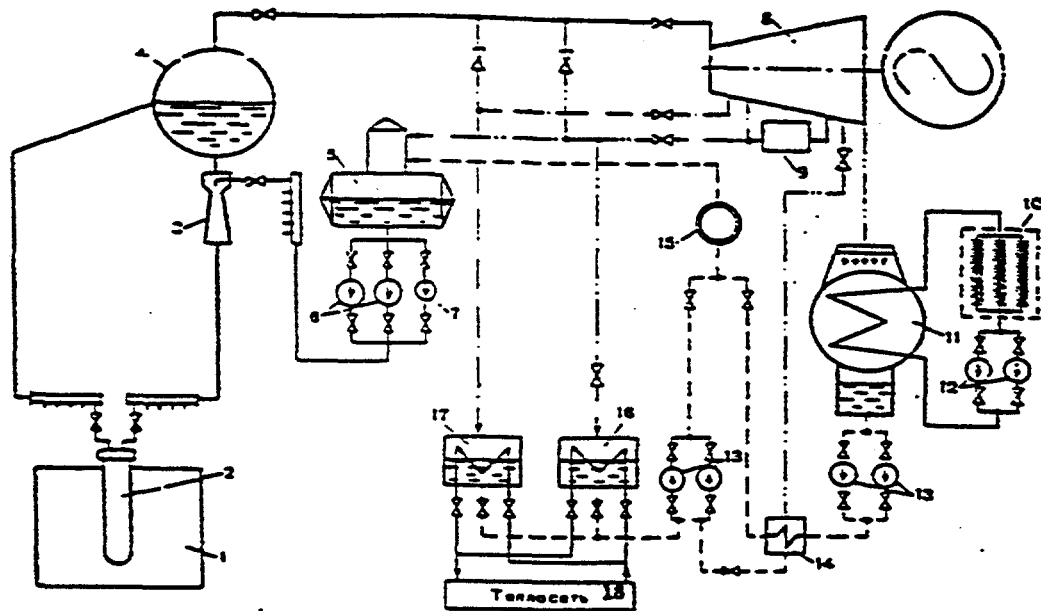


Figure 2 Flow Diagram of the Bilibino System

1 reactor; 2 fuel channel; 3 mixer with effective head; 4 drum separator; 5 deaerator; 6 feed water pumps; 8 turbine generator; 9 intermediate separator; 10 radiator coolers; 11 condenser for turbine; radiator cooler pumps; 13 condensate pumps; 14 low pressure heater; 15 iron trapping filter; 16 main network heater; 17 peak network heater; 18 heat network

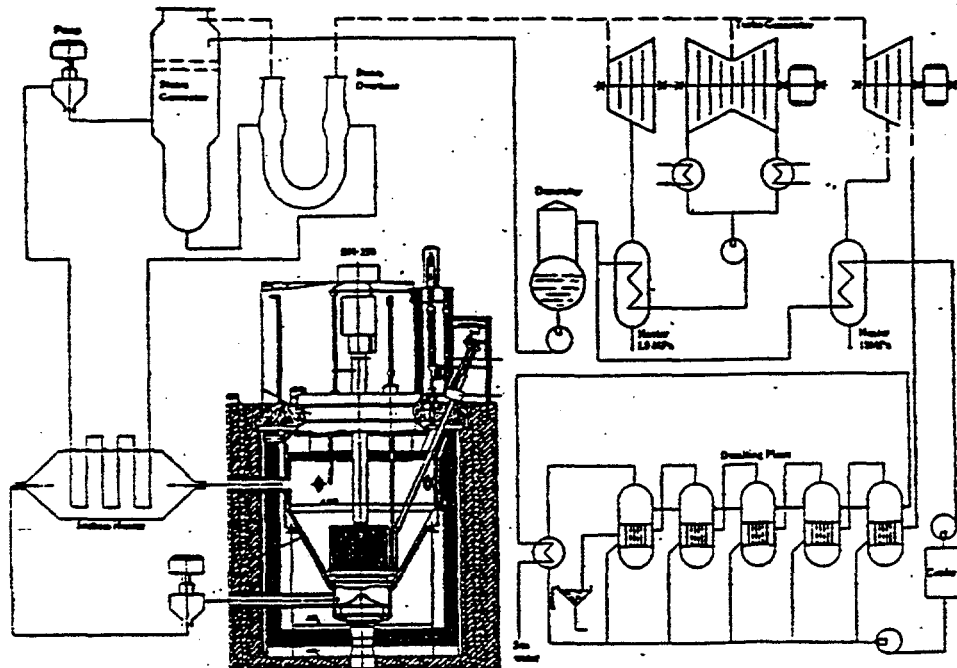


Figure 3 Flow Diagram of the BN 350 Nuclear Desalting System