DOE/ET-0076

Report of the Visit of the **United States of America Delegation of the U.S.-U.S.S.R. Coordinating Committee on Scientific & Technical Cooperation in the Field of Thermal Power Plant Heat Rejection Systems to the Union of Soviet Socialist Republics**

November 11-21, 1978

February 1979

Editors:
John W. Neal
William F. Savage

U.S. Department of Energy
Division of Fossil Fuel Utilization

DISCLAIMER

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DRY COOLING TOWERS – RAZDAN POWER PLANT

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CONVERSION FACTORS

Mulitply	By	To Obtain
Atmospheres	14.70	Pounds per square inch
Centimeters	.3937	Inches
Cubic meters	264.2	Gallons
Cubic meters	35.31	Cubic feet
Gigacalories/hr	3.968×10^{6}	British thermal units/hr.
Gigajoule	9.48×10^{5}	British thermal units
Hectares	2.471	Acres
Kilograms/sq. cm.	14.22	Pounds per square inch
Kilometers	.6214	Miles
Meters	3.281	Feet
Meters	39.37	Inches
Millimeters	.03937	Inches
Square kilometers	247.1	Acres
Square kilometers	.3861	Square Miles
Square meters	2.471×10^{-4}	Acres
Square meters	10.76	Square Feet

I. Summary

During the period from November 11-21, 1978, a United States delegation visited the Soviet Union for a meeting of the Joint U.S.-U.S.S.R. Coordinating Committee on Scientific and Technical Cooperation in the Field of Thermal Power Plant Heat Rejection Systems and to participate in a joint symposium on the same subject. Table 1 presents the agenda of the visit.

The U.S. delegation was as follows:

J. Neal, Acting Assistant Director, Division of Fossil Fuel Utilization, U.S. Department of Energy, and U.S. Chairman of the Joint Committee

W. Savage, Acting Chief, Advanced Systems Evaluation Branch, Advanced Systems and Materials Production Division, U.S. Department of Energy

J. Lewin, Union Carbide, Oak Ridge National Laboratory and U.S. Interpreter

J. Maulbetsch, Electric Power Research Institute

G. Englesson, United Engineers and Constructors, Inc.

The Soviet personnel contacted are listed in Table 2. It should be noted, however, that the principal members of the Soviet delegation were as follows:

V. I. Savin, Ministry of Power and Electrification and U.S.S.R. Chairman of the Joint Committee

R. Minasyan, Teploelectroproect

G. Ageev, Teploelectroproect

L. Galperin, Teploelectroproect and Soviet Interpreter

I. Alekseev, Teploelectroproect

During this visit, meetings were held with personnel of the following organizations and at the facilities noted below:

- o Razdan, Armenia dry cooled power plant
- o Teploelectroproect (TEP), Moscow
- o Ministry of Power and Electrification (Moscow and Leningrad)

- B. E. Vedeneev All-Union Institute of Hydraulic Engineering (VNIIG), Leningrad

- Mosenergo Cogenerating Plant 21 (Moscow)

It should be noted that although the Joint Committee title refers only to Heat Rejection Systems, the program of cooperation had been expanded to include cogeneration (concurrent production of electricity and process steam or thermal energy for district heating) and beneficial uses of power plant reject (waste) heat.

The following is a brief summary of data obtained as a result of the meetings, symposium, and facility visits.

1. The Soviet Union has been reducing fuel use per Kwh of power generated with a consumption in 1970 of 348 g (oil) per kwh, 334 g/Kwh in 1977, and 325 g/Kwh in 1978. The Soviets did state, however, that they have not reached the best U.S. performance of 305 g/Kwh. Total electrical energy produced in the U.S.S.R. was 1150 x 10^9 Kwh in 1977.

2. In 1976, about 25% of the electric energy in the U.S.S.R. was produced by plants operating in the cogeneration mode. This represented 60,000 MWe or about 1/4 of the electrical power produced by all central station power plants (240,000 MWe). Approximately 65% of the population get heat from central sources, either cogeneration or boiler plants. The heat utilized from the power plants was about 4 billion gigajoules (4 BGJ) in 1976 or about 40% of the available low level heat. The plan for 1980 is to have 77,000 MWe of cogenerating capacity and to utilize 5 BGJ of thermal energy.

3. Considering the cost of fossil fuels in the Western U.S.S.R., nuclear cogeneration of electricity and heat apears most economic. Both 500 MWe and 1000 MWe Pressurized Water Reactors (PWR's) are being considered for cogeneration with one turbine employed at the lower rating and two at the higher. Both condensing and extraction turbines are being considered and are designated TK-500 and T-500, respectively. Maximum extraction heat values are considered as 450 gigacalories/hr. for the 500 MWe plant and 900 for the 1000 MWe plant. Both two-unit and four-unit power stations are being considered. From 1990 onward, it looks like the 1000 MWe PWR will be "best" for district heating cogeneration use. Two 1000 MWe cogenerating units can meet the demands of 250,000 people.

4. A 500 MWt reactor is being considered for only supplying heat with no concurrent production of electricity.* Hot water would be heated to 150°C at the heat rate of 430 gigacalories per hour. It should be noted that <u>containment will be</u> utilized and that the Soviets are thinking of locating these plants within 2-3 km from large populated areas.

5. In a district heating system, piping costs comprise 70-80% of the heat distribution system and about 40-50% of the amount required for construction of the cogeneration plant. For large pipes carrying hot water for district heating, 2000 tons of steel are required per kilometer. The locating of the 500 MWt reactor near populated areas (see item 4 above) greatly reduces the amount of pipe required and lowers systems capital cost.

6. The Soviet Union is building a wet/dry cooled power plant at Esfahan in Iran. This plant, consisting of four 200 MWe units, will employ dry cooling towers capable of partial operation in a wet/dry mode. These towers are essentially a dry tower within a dry tower. The major outer section operates for base cooling and the inner section operates for peaking. At very high ambient temperatures, water is sprayed in the peaking dry system for air humidification purposes and improved cooling capability.

7. Four dry cooling towers are in operation at the Razdan, Soviet Armenia, power plant. Two are rated at 200 MWe and two at 210 MWe (approximately 350-400 MWt of heat rejected by each tower). A detailed discussion of the Razdan cooling towers is given in Reference 1. It was noted that twice each year the cooling surfaces are cleaned by blowing off by the use of old aircraft jet engines (of which there appears to be a surplus) any material which has collected on them; however, without cleaning over a two-year period, only a 1% loss in power plant efficiency occurred. The turbines are capable of operation up to 12" Hg back pressure. It should be noted that the boilers at Razdan can be fired with natural gas or residual oil. It was also noted that the natural gas supply is "interruptable" since it is obtained from Iran.

8. The Soviets have had a greenhouse in operation for 7 years which also is used for condenser cooling. Condenser cooling water flows over the roof of the greenhouse in a layer 6-8 cm. thick and is taken by downcomers back to the condenser. The water layer provides both insulation and heat for the greenhouse and heat rejection to the atmosphere.

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*See Appendix B, "Cogeneration Nuclear Power Stations and Boiler Stations - Problems and Future Outlook" by V. Tatarnikov, et al.

9. The Soviets have found that domestic fish production can be increased from 100 Kg/ha for a natural lake to 600 Kg/ha for ponds using controlled temperatures and feeding. By the use of fish indigenous to India and the U.S., they believe that this rate can be raised to 1000 Kg/ha. It is planned to grow 2000 tonnes per year of fish at the Kursk nuclear power plant using ponds employing power plant waste heat. This will be the first fish raising system to be employed where there is a continuous control of power plant conditions to meet fish production conditions. Fish farming is also provided for at Unit 2 at the Chernobyl Fish Station.

10. The functions of the B. E. Vedeneev All-Union Institute of Hydraulic Engineering (VNIIG) in Leningrad have been reported in previous documents (e.g., ERDA 77-77). VNIIG is a basic research institution with about 2000 personnel (about one-half being engineers and scientists). There are a number of branches (e.g., Krasnoyarsk in Siberia, Narva in Estonia). There are a total of about 30 laboratories. In Leningrad the total staff is about 1500. One area of investigation at present is turbine runners in that they are attempting to select materials resistance to cavitation since, for pumped storage applications, the runner must act as both a pump and a turbine.

11. A detailed description of the Mosenergo Cogenerating Plant 21 is given in Reference 2. Plant No. 21 provides electric power and space heating for 1.5 million people in the city of Moscow. The plant is oil-fired and consists of six 100 MWe units and two 250 MWe units, all capable of operating in a cogeneration or full condensing mode. Maximum heat capacity is 3,800 gigacalories/hr of which 2200 gigacalories/hr is provided by 14 peak boilers required at temperatures below $0^{o}C$. The average plant heat rate in 1977 was 207 gm/Kwh (reference fuel: 7000 kcal/Kg or 12,600 B/lb) or 168 Kg/gigacalorie. The generating cost was 0.052 R/Kwh ($\sim$7.5 mils/Kwh) or 3.63R/gigacalorie ($\sim$\$1.50/10^6 BTU).*

At the meeting of the Joint Committee, it was agreed that a joint symposium would be held in October 1979 in Washington, D.C. In order to conserve time at the October 1979 symposium, summary papers would be given verbally rather than attempting to present an edited version of the complete paper. These summary papers would be exchanged in August of 1979 and complete papers exchanged at the symposium. This procedure would allow a longer time for technical discussions during the symposium.

*U.S. cost equivalents are based on a commercial exchange rate of $1.56 per ruble (R).

Appendices A and B present the U.S. and U.S.S.R. papers respectively as given at the joint symposium in Razdan. It should be emphasized that due to time limitations, verbal presentations were essentially synopses of the papers but complete papers were exchanged.

Appendix C presents detailed information on the Razdan Power Plant as obtained from a brochure distributed during the plant visit. The original document contains pictures of the plant which are not included in the Appendix.

Appendix D is taken from a Soviet brochure on the Armenian power grid and power plant facilities (nuclear, fossil, hydro). It is included for information purposes.

Note: The conclusions and comments contained in this report are based primarily on the results of plant visits, verbal presentation of papers and comments by Soviet personnel. The reader is referred to the Soviet papers (Appendix B) if there is any misunderstanding with comments given herein concerning verbal presentations of those papers.

II. Results of Technical Meetings and the Symposium

A. Power Plant Heat Dissipation Systems

The major portion of the Razdan Power Station in Armenia, U.S.S.R., is dry cooled. Total design power output for the plant employing natural draft dry cooling is 820 MWe. Four dry towers are employed, two rated at 200 MWe and two at 210 MWe. These towers are of welded steel frames covered with corrugated aluminum sheets. This type of construction was utilized due to earthquake hazards.

It should be noted that the first capacity at Razdan was 320 MWe cooled by small evaporative towers. These are still in operation and the total plant capacity is 1140 MWe with 360 gigacalories of heat available from the cogenerating turbines of the old plant.

The plate/fin type cooling surfaces were utilized (Hungarian Heller-Forgo type) with cooling panels located around the periphery at the base of the dry towers. Control of air flow is maintained by motor operated louvers. The cooling panels are 15m high. The towers are 120m high and have a base diameter of 108m and a top diameter of 60m. A complete description of the Razdan Power Plant and cooling system is given in Appendix C. Details concerning tower design and construction are given in Reference 1.

Since a problem of interest to the U.S. delegation was the effect on cooling performance of particulates collecting on the dry cooling surfaces, data were obtained on the effect of cleaning. It is normal practice to blow off by use of aircraft jet engines any material which has collected on the cooling surfaces twice each year. However, without such cleaning over a two year period (1971-73), only a 1% loss in power plant efficiency occurred. It was believed that surface fouling might be a problem due to the fact that a cement plant is located near the power plant.

Upon entry into the operating cooling towers, flow velocity at the internal faces of the cooling panel was very noticeable. Since it was snowing heavily outside at the time, a fine water mist was also apparent due to melting on the heat transfer surfaces. As would be expected there was no apparent air velocity at the center of the base of the tower. Extra cooling panels are stored inside the base area for replacement as needed. It was indicated, however, that the replacement rate is very low.

Another point concerning the Razdan Plant should be noted. The boilers can be fired with natural gas or residual oil. The natural gas supply is obtained from Iran and it is considered as "interruptable."

The Soviet Union is building a wet/dry cooled power plant at Esfahan in Iran. This plant, consisting of four 200 MWe units, will employ dry cooling towers capable of partial operation in a wet/dry mode. These towers are essentially a dry tower within a dry tower. The major outer section operates for base cooling and the inner section operates for peaking. For example, the major dry section operates up to 30.5°C. From 30.5° to 32.5°C the peaking dry section is brought on line. Above 32.5°C a water spray is started on the peaking section <u>for air humidification</u>. The conventional approach of deluging the dry surfaces with water is not used (such as was planned at Ivanovo) since the design group for the Ivanovo deluge wet/dry cooling towers said that a water film cannot be formed on the Forgo (Hungarian) plate/fin surfaces. The gap between the fins is about 3.5 mm and "there is not sufficient space for air and water." Opening up the fin pitch causes loss of performance when operating in the dry mode. The Ivanovo deluge dry cooling towers are not in operation as yet.

The climatic conditions at Esfahan are as follows:

Average annual temperature	16.1°C
Maximum temperature	40°C +
Minimum temperature	-10.4°C
Relative Humidity @ 40°C	10%

With the humidification system in operation at 40°C, the power plant loses less than 5% in output. Water flow rate in 44 cubic meters per hour.

A detailed discussion of the Esfahan system is given in a paper in Appendix B, "A System of Heat Removal for an Electric Power Station Located in a Dry Subtropical Climate."

The Soviets have had a greenhouse in operation for 7 years which also is used for condenser cooling. Condenser cooling water flows over the roof of the greenhouse in a layer 6-8 cm. thick and is taken by downcomers back to the condenser. The water layer provides both insulation and heat for the greenhouse and heat rejection to the atmosphere. Problems are algae growth and the lack of need for the water layer in the summer. Greenhouse temperatures are in the range of 15°C to 25°C. The present greenhouse system does not have sufficient surface areas to fully meet the condenser required ΔT and a spray system may be incorporated. Further information on this system is given in a Soviet paper in Appendix B.

The Soviets are now building a 6,000 sq. m. greenhouse near Kashira. It is hoped that this installation will answer whether the roof cooling concept should be used in other installations.

B. Fuel Utilization and Cogeneration

The Soviet Union has been reducing fuel use per Kwh. of power generated with a consumption in 1970 of 348g (oil) per Kwh., 334g/Kwh. in 1977 and 325g/Kwh. in 1978. The Soviets did state, however, that they have not reached the best U.S. performance of 305g/Kwh. These fuel rates do not consider any credit for cogeneration. For the Mosenergo Cogenerating Plant 21 in Moscow, the heat rate in 1977 based on credit for heat utilization for district heating was 207g/Kwh. (reference fuel of 7000 Kcal/Kg or 12,600 B/lb) or 168 Kg/gigacalorie.

Planning of a large district heating system for a city takes from 10-15 years with 5-7 years for the major initial construction stage. It was noted by the Soviets that the major areas of research in cogeneration are the following:

1. Improving efficiency of the plant and reliability of the distribution grids.

2. Joint operation of several sources of heat supply on the same grid system.

3. Operation of the cogeneration system.

4. Decreasing the amount of steel piping used in the distribution system. About 2000 tons of steel pipe are required from a large cogenerating district heating plant.

5. Decreasing the use of single pipe (no return) systems.

6. Improving pipe laying without tunnels.

7. Improving piping support structure and equipment for laying and joining pipes.

In 1976, about 25% of total electric energy in the U.S.S.R. was produced by "cogenerating" turbines. This represented 60,000 MWe or about one fourth of the electrical power produced by all central station power plants (240,000 MWe). About 65% of the population get heat from either cogenerating plants or boiler plants. The heat utilized from the power plants was about 4 billion gigajoules (4 BGJ) in 1976 or about 40% of the available low level heat. The plan for 1980 is to have 77,000 MWe of cogenerating turbines and to utilize 5 BGJ of thermal energy. The efficiency of energy use using cogeneration is about 70%. According to the Soviets, the U.S.S.R. and France have the lowest cogeneration heat rates. Total electrical production in the U.S.S.R. in 1977 was 1150 x 10^9 Kwh.

Considering the cost of fossil fuels in the western U.S.S.R., nuclear cogeneration of electricity and heat appears most economic. Both 500 MWe and 1000 MWe PWRs are being considered for cogeneration with one turbine employed at the lower rating and two at the higher. Both condensing and extraction turbines are being considered and are designated TK-500 and T-500 respectively. These turbines would have the following general characteristics:

Inlet steam pressure	60 kg/cm^2
Speed	3000 rpm
Steam rate to turbine	3200 tonnes/h

Maximum extraction heat values are considered as 450 gigacalories/hr. for the 500 MWe plant and 900 for the 1000 MWe plant. Both two-unit and four-unit power stations are being considered. For a city demand of 1500-6000 gigacalories/hr. the nuclear units could provide 60% of the heat and the peak demand (additional 40%) would be picked up by fossil plants. The nuclear plants would be located "at a considerable distance" from populated areas according to the Soviets." For steam extracted for industrial processes, however, the distance to the industrial user cannot exceed 7 km if the delivered steam is to be equal to or better than 13 atmospheres at 235°C.

In the large nuclear plants used for cogeneration, a three-loop system (reactor/main heat exchanger, main heater exchanger/ turbine extraction steam, secondary heat exchanger/grid loop) is utilized to prevent any radioactive contamination. Additionally, the pressure in the grid loop is greater than that in the turbine loop. In the event that radioactivity might possibly be released to the grid loop, automatic shut-off valves, automatic dumping of extraction steam, and automatic grid shut-off valves are provided.

From 1990 onward, it looks like the 1000 MWe PWR will be "best" for district heating cogeneration use. Two 1000 MWe cogenerating units can meet the demands of 250,000 people.

In the construction sequence for a cogeneration plant in a city, the distribution system is constructed first and separate "heat only" boilers are used to quickly meet the district heating demands. These boilers are then phased out or used for peaking or standby after the cogenerating plant is completed. In a district heating system, piping costs comprise 70-80% of the heat distribution system and about 40-50% of the amount required for construction of the cogeneration plant. For the large pipes used in the distribution systems (diameters of 1400 mm to 1000 mm) large tunnels, which also may contain other utility lines, are used in cities. These tunnels are pre-cast reinforced concrete. With pipe diameters between 1000 mm and 500 mm reinforced "foamed" concrete is used for the distribution system tunnels. Up to 500 mm, pipes are not usually laid in tunnels but buried after wrapping with bitumen. Insulated overground pipes are used in some industrial areas and for overpasses.

A 500 MWt reactor is being considered for only supplying heat and no electricity. Hot water would be heated to 150°C at the heat rate of 430 gigacalories per hour. This plant also employs three loops with increasing pressure as one goes to the grid loop. The second loop has provisions for water cleanup. Water flow rates in the third loop are 10,000 tonnes per hour.

The 500 MWt reactor is planned for close-in location to cities. The Soviets claim the following:

1. "Absolute" safety in case of a loss of cooling accident.

2. Complete exclusion of radioactivity going into the grid.

3. Better QA and safety assurance because of low power.

They also noted that the pressure vessels can be built in smaller shops. Containment will be utilized and the Soviets are thinking of locating these plants within 2-3 km from large populated areas. This location will greatly decrease the amount of steel required for distribution system piping and lower capital investment. By use of these units a fuel economy of 800,000 tonnes per year of reference fuel (12,600 B/lb) can be achieved.

All small condensing steam turbine plants have been retrofitted with back pressure turbines. Plants of 25-100 MWe were converted and the Soviets are now considering modification of 150-300 MWe turbines for cogeneration. A special organization does these modifications. These modifications may involve removal of the last LP stages or a false shaft for the LP turbine. The Soviets have also standardized their cogeneration turbines in the range of 50-250 Mwe and have recently introduced a 175 MWe turbine for this purpose. Information on these turbines is given in Table II of Dr. Popov's paper, "Cogeneration Electric Power Stations on Fossil Fuels" (see Appendix B).

The control and balancing of the distribution system appears to be the major problem related to district heating installations in a city. In addition to the primary heat source, stand-by boilers must be provided if the main plant is off-line. These must be brought into operation on schedule to prevent a drop in system flows or temperatures. Stand-by boilers are provided when main plant district heating loads of 300 gigacalories/hr. or more are employed. For control of a district heating system, information on water conditions is transmitted by automatic measuring devices to dispatchers.

During a visit by two members of the U.S. delegation to Mosenergo Cogenerating Plant (Moscow Heating Plant) No. 21, discussions were held with:

N. M. Grigoriev, Director
G. V. Lugovoy, Chief Engineer
Mr. Antonov, Director, Mosenergo Grid System
P. D. Chernaiev, Chief Engineer, Mosenergo

A detailed description of the plant is available in the Committee's previous trip report of February 1977 (see Reference 2). A brief summary is included here for ease of reference.

Plant No. 21 provides electric power and space heating for 1.5 million people in the city of Moscow. The plant is oil-fired and consists of six 100 MWe units and two 250 MWe units all capable of operating in a cogeneration or full condensing mode. One more 80 MWe unit is planned. Maximum heat capacity is 3,800 gigacalories/hr. of which 2200 g-calories/hr. is provided by 14 peak boilers required at temperatures below $0^{o}C$.

The heat distribution system is closed-loop circulating hot water at a rate of 45,000 m^3/hr. Load is controlled by varying supply temperature (T supply = 150°C, p = 14 atm, @ T_{amb} = -25°C). Return temperature is 70°C (p = 1 1/2 atm). The main distribution line is 20 km of 1.2 m diameter pipe. Local distribution is in 0.5 m pipes.

Plant No. 21 supplies 20-25% of the Moscow district heating requirement. The new 80 MWe unit will provide low pressure steam to industry adjacent to the power plant. The unit is planned for start-up in early 1980.

C. Beneficial Uses of Waste Heat

As noted in Section B above, greenhouse heating by means of a water film has been used as a means of decreasing power plant cooling water temperatures. In most cases, however, greenhouse heating has been conducted using condenser discharge water (of the order of $40^{o}C$) in air cooled heat exchangers where the warm air is delivered to the greenhouse growing area. Greenhouse concepts and waste heat utilization for agricultural purposes are presented in both the U.S. and Soviet papers given at the symposium (see Appendices A and B).

Fish raising using power plant waste heat was discussed in some detail. The Soviets have found that domestic fish production can be increased from 100 kg/ha for a lake to 600 kg/ha for ponds using controlled temperatures and feeding. By the use of fish indigenous to India and the U.S., they believe that this rate can be raised to 1000 kg/ha. At the Chernobyl's nuclear power station No. 2, it was estimated that an increase in cooling pond area to take advantage of fish raising using waste heat will result in a savings of 2-1/2 million rubles. Maintaining constant pond temperature (e.g., $23^{o}C$) results in a reduced time for fish to reach maturity by a factor of 2-3. For example, the 12-18 year period for sturgeon to reach maturity is reduced to 4-8 years.

It is planned to grow 2000 tonnes per year of fish at the Kursk nuclear power plant using ponds employing power plant waste heat [Carp (1500 tons), ictalurus (300 tons), trout (150 tons), and sturgeon plus other species]. This will be the first fish raising system to be employed where there is a continuous control of power plant conditions to meet fish production conditions. Also, an essentially closed system will be used. There will be greenhouse yeast raising enterprises, and mushroom farming enterprises. The wastes from fish farming will be used to improve yeast yield, and for mushroom and greenhouse fertilization. The yeast can be used for fish food although additional feed will be required.

D. Other Data of Interest

Although reported in previous documents, a brief summary of the All-Union Institute of Hydraulic Engineering (VNIIG) is included here. VNIIG is essentially the basic research arm for:

- Hydrodynamic investigations of cooling reservoirs and water bodies for cooling.
- Hydrodynamic power storage (pumped storage).

- o High capacity cooling towers.
- o Spray ponds and floating spray modules.
- o Water intakes.
- o Pumps and discharge systems.
- o Fish protection devices at power plant intakes.

In addition to problems related to flow of water and extraction of power from it, this institute is now responsible for solid waste disposal research and conceptual design. Principally this means ash disposal in slurries.

Staffing at present is about 2000 with about one-half being engineers and scientists. There are a number of branches (e.g., Krasnoyarsk in Siberia, Narva in Estonia). There are a total of about 30 laboratories. In Leningrad the total staff is about 1500. A brochure (in English) on the activities of VNIIG was obtained during the visit.

Large models of hydraulic systems (e.g., intakes and outlets) are constructed with areas of 500-1000 sq. meters in order to decrease problems of scale-up. The thermal regime of the area being modeled is investigated. It was indicated that the surface layer temperature distribution can be modeled well.

In a quick walk-through of the hydraulic labs, it was noted that turbine runners for pumped storage systems were being investigated. They are considering both stainless steel and epoxy resins. In the area of polymerics, both solid polymeric and coated metal blades are under study. They wish to have data on materials most resistant to cavitation since cavitation is a problem when the runner has to act both as a pump and a turbine.

One point should be noted concerning nuclear energy centers. The Soviets indicated that they plan to build a center with seven 1000 MWe reactors each employing two natural draft cooling towers. The planned location of this energy center was not defined.

Table 1
AGENDA OF VISIT OF U.S.
DELEGATION TO THE U.S.S.R.

November 10, 1978	20:00	Departure from Washington, D.C., by Pan American Flt. 66 for Frankfurt, by L. H. 342 to Moscow on 11th
Sat., November 11, 1978	18:45	Arrival in Moscow, Hotel
Sun., November 12, 1978	9:00	Departure for airport Domodedovo
	11:50	Flight to Erevan
	14:30	Landing in Erevan - drive directly to Razdan area
		Lunch
	18:30	Hotel
	21:00-22:00	Supper
Mon., November 13, 1978	10:00-13:00	Opening of the Symposium Introductory speech - V. I. Savin Reports
	13:00-15:00	Lunch
	15:00-18:00	Visit to the Razdan Power Plant
	19:00	Hotel
	19:30-21:00	Dinner
Tues., November 14, 1978	10:00-14:00	Trip to Garni and Gegard
	15:00-17:00	Afternoon session
	18:00-19:30	Evening session
	19:30	Hotel
	21:00	Supper

Table 1 (Con't)

Wed., November 15, 1978	10:00-13:00	Morning session
	13:00-15:00	Lunch
	15:00-17:00	Closing session
	17:00-19:00	Free time
	19:00-22:30	Dinner
Thurs., November 16, 1978	10:00-13:00	Meeting of the Coordination Committee
	13:00	Departure for Erevan
	14:00-15:00	Hotel
	15:00-16:00	Lunch
	16:00-19:00	Siteseeing
	20:00-21:00	Dinner
Fri., November 17, 1978	5:30	Departure for airport
	7:15	Flight to Leningrad
	9:55	Landing in Leningrad
	11:00-12:00	Hotel
	12:00	Departure for the Vedeneev Research Institute
	12:30-13:00	Meeting with the Director
	13:00-14:30	Lunch
	14:30-18:00	Technical discussion. Laboratories
	18:00-19:00	Supper
	20:00-23:00	Theatre

Table 1 (Con't)

Sat., November 18, 1978	10:00-11:00	Siteseeing
	11:00-13:30	Hermitage
	13:30-15:00	Lunch
	15:00-17:00	Piskarev Memorial
	17:30-20:00	Free time
	20:00-22:30	Dinner
	23:10	Departure for the railway station
	23:55	Trip to Moscow
Sun., November 19, 1978	8:25	Arrival in Moscow
	9:30	Hotel Ukraine
	10:00-12:00	Rest
	12:00-15:00	Siteseeing
	15:00-17:00	Lunch
	17:00-19:00	Free time
	19:00	Theatre
Mon., November 20, 1978	9:00	Departure for the Ministry of Power and Electrification
	10:00-19:00	Closing session of the Coordination Committee. Signing of mutual documents.
	14:30-17:30	Visit to Power Plant 21 - Englesson and Maulbetsch only
	19:30	Dinner
Tues., November 21, 1978	6:00	Departure for the airport and flight to Washington via Frankfurt and New York, Pan Am 67

Table 2
SOVIET PERSONNEL CONTACTED DURING VISIT

Soviet Participants at the Symposium

Rodionov, N. I., Nikolai Ivanovich - Chief of Fluid Flow Engineering at TEP, Moscow
Savin, V. I. - Minenergo, Moscow
Santuryan, G. R. - Razdan GRES
Minasyan, R. G. - TEP, Moscow
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APPENDIX A

U.S. Papers Presented at November 1978 Symposium

Title of Paper	Authors*
1. "TVA Projects on Agricultural Uses of Waste Heat"	C. Madewell E. Burns D. Mays L. Behrends J. Maddox R. Pile
2. "Technical and Economic Feasibilities of Wet/Dry Tower Systems for Water Conservation"	George Englesson W. Savage Michael Hu
3. "Comparative Cost Study of Various Wet/Dry Cooling Concepts That Use Ammonia as the Intermediate Heat Exchange Fluid"	B. M. Johnson R. T. Allemann D. J. Braun R. D. Tokarz
4. "Waste Heat Utilization from Facilities"	J. Clark I. Boulogiane
5. "Cogeneration Systems for Residential/ Commercial Applications"	R. E. Holtz J. W. Neal
6. Meteorological Effects of Heat and Mositure Releases from Large Power Stations"	A. A. N. Patrinos D. M. Eissenberg
7. "A Status Report on the Ammonia Phase Change Dry Cooling System Research Project"	J. Maulbetsch J. Bartz
8. "Uses of Waste Heat from Electric Generating Plants for Greenhouse Heating"	L. L. Boyd R. V. Stansfield J. Hietala A. M. Flikke G. C. Ashley
9. "Hatchery Culture of Molluscs in Conjunction with Waste Thermal Effluent of a Power Plant"	R. A. Eissenger S. P. Henderson

*The affiliation of each author is given with the papers.

10. "A Computerized System for Estimating Water Availability and Requirements for Power Plant Cooling" — W. Savage, J. Sonnichsen, L. Jacobson

11. "Study of Advanced Technology Cogeneration Systems for Providing Industrial Power and Process Heat" — E. Lister, G. D. Sagerman, R. Manvi, G. J. Barna, R. K. Burns

12. "Characterization of U.S. Industries for Potential Cogeneration Applications" — R. Manvi

Note: Pages in this Appendix are numbered sequentially for <u>each</u> paper. No overall numbering system has been used as in the case of Appendix B. It should also be noted that copies of the slides used in the verbal presentation of some papers were not available in the form for reproduction.

Paper No. 1

TVA'S PROJECTS ON AGRICULTURAL USES OF WASTE HEAT[1]

C. E. Madewell, L. L. Behrends, E. R. Burns,
J. J. Maddox, D. A. Mays, and R. S. Pile[2]
Tennessee Valley Authority
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Introduction

A major concern of the Tennessee Valley Authority (TVA) is to ensure efficient use of resources, especially energy, in the Tennessee Valley region in achieving optimum economic development without degrading the environment. As part of this effort, TVA is exploring many uses for the low-grade heat energy (waste heat) contained in the large quantities of power plant condenser cooling effluent. This paper describes only the agricultural activities of TVA to develop ways to use waste heat, and they have been underway since the early 1970's. The agricultural waste heat pilot-scale research and development projects facilities are located at the National Fertilizer Development Center, Muscle Shoals, Alabama. The primary objectives of the agricultural effort are to: (1) identify potential agricultural uses of waste heat, (2) develop and test technologies and management criteria for more productive uses, (3) demonstrate technologies in commercial-scale production facilities, and

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1. To be presented at a joint U.S.-USSR symposium, November 1978, in the Soviet Union, sponsored by the U.S.-USSR Joint Cooperating Committee on Scientific and Technical Cooperation in the Field of Thermal Power Plant Heat Rejection Systems.

2. C. E. Madewell, Program Manager (Agricultural Economist); L. L. Behrends, Project Aquatic Animal Specialist; Dr. E. R. Burns, Greenhouse Project Coordinator (Horticulturist); Dr. J. J. Maddox, Livestock Waste Recycling Project Coordinator (Plant Physiologist); Dr. D. A. Mays, Soil Heating Project Coordinator (Agronomist); and R. S. Pile, Project Agricultural Engineer.

(4) provide technical assistance for commercial application. Funding for the work has been primarily Federal, appropriated through TVA, but some funding has been provided from the U.S. Environmental Protection Agency and from the U.S. Department of Energy through Oak Ridge National Laboratories (ORNL).

More than 80 percent of the electrical energy produced in the United States is generated by power plants utilizing steam power technology [7]. Only 35 to 40 percent of the heat energy consumed by these power plants eventually ends up as electricity, with the remaining 60 to 65 percent being returned to the environment as "waste heat." Typically, such waste heat is embodied in the large quantities of cooling water necessary to condense the steam in the electricity production cycle. In many instances, this water must be cooled before it is released to rivers to avoid potential thermal pollution. Using this low-level energy from power plant condenser discharge water in food production and other beneficial processes could have a major impact on energy development and conservation, food production, and thermal pollution in the Tennessee Valley, the Nation, and the world. The application of appropriate integrated power plant and waste heat use systems technologies could reduce required cooling capacities and, consequently, reduce capital requirements and operating costs for conventional power plant cooling systems. Overall economic development compatible with the environment would also likely be improved.

The potential benefits of waste heat utilization are great, but there are a number of hurdles to be overcome. These include: (1) temperature, quantity, and quality variations of waste heat with respect to power plant design and site characteristics, (2) selection and modification of existing agricultural production technology and developing new technology where needed, (3) development of power plant interfacing technology for existing power plants and allowance for such systems in new power plant designs, (4) development of appropriate waste treatment systems, (5) development of systems yielding products free from chemical or radioactive contamination, and (6) development of overall systems which are economically efficient.

Agricultural waste heat research and development projects under investigation or being planned for investigation by TVA independently or cooperatively with other institutions include use of waste heat: (1) in greenhouses, (2) in aquatic systems fertilized with livestock waste, (3) for soil heating and irrigation, (4) in environmental control for livestock housing, (5) for crop drying, and (6) in food processing. A multidisciplinary team approach is taken on each agricultural waste heat project.

Other significant waste heat projects which are a part of the overall TVA interdivisional waste heat research and development effort but not covered in this report are: (1) Gallatin catfish project [8], (2) utilization of power plant waste heat for sewage sludge digestion-technical feasibility and economic feasibility [9, 10], (3) technical assessment of industrial and residential use of power plant waste heat [11], (4) TVA Watts Bar waste heat park, and (5) waste heat use workshop.

The remainder of this report is an overview of the TVA waste heat agricultural effort.

Waste Heat Use in Greenhouses

The objectives of this project are to develop and test an environmental control system utilizing waste heat, evaluate and adapt horticultural and floricultural crop production systems compatible with the resulting environment, and make economic evaluations of these systems. A pilot-scale waste heat greenhouse using simulated condenser effluent for heating has been operated at the TVA National Fertilizer Development Center since 1973. Numerous tests of the environmental control capability of a direct-contact heat exchange system using water at Browns Ferry condenser discharge temperatures were conducted. Systems for producing vegetable and ornamental crops in the humid environment were tested. Cost comparisons were made to establish potential economic advantages of waste heat systems. Only a brief summary of the engineering, horticultural, and economic analyses conducted is included in this report. For further information, see waste heat greenhouse progress reports I and II [1, 4, 6].

Engineering tests have shown the direct-contact heat exchanger is capable of maintaining near optimum temperatures for year-round tomato and cucumber production. Night temperatures above 14° C were maintained during the coldest weather experienced with water temperatures of 21° C and flow rates of 0.0936 m^3/sec.·ha. Outside temperatures during these tests dropped to -19° C in January 1976.

The unique characteristic of the waste heat greenhouse environment is the 80- to 100-percent relative humidity. Yields of tomatoes and cucumbers in this humid environment were comparable to those achieved in well-managed commercial greenhouses. Annual yields of more than 314 metric t/ha of tomatoes were produced at conventional planting densities.

Yields of 390 metric t/ha were achieved in other experiments evaluating high-density plantings of selected cultivars. The yield potential for cucumbers was even greater, with annual yields exceeding 448 metric t/ha. Plant diseases associated with the high relative humidity were the most serious production problems identified. Diseases were controlled by maintaining a rigid fungicide spray program and using good sanitation and cultural practices.

The initial investment for the waste heat system was $6,388 higher than a conventional system for a 223 m^2 greenhouse. However, the waste heat system showed an overall cost advantage of $980 per year, which projects to a $44,000/ha advantage annually.

The construction of a waste heat power plant tie-in and a 0.2-ha waste heat greenhouse is almost completed at TVA's Browns Ferry Nuclear Plant to further refine and demonstrate waste heat systems on a commercial scale. The basic greenhouse design was developed for TVA by the Environmental Research Laboratory of the University of Arizona under contract with ORNL. Steps to reduce the higher cost of the waste heat systems, such as eliminating the fiberglass recirculation attic, have been included in the design of the Browns Ferry greenhouse.

The Browns Ferry greenhouse will be subdivided into three operational zones. Two zones will be heated with systems designed to use condenser effluent from the plant. The third zone will be conventionally heated and used as a standard for comparison. One of the waste heat zones will use a system similar to the one tested in the pilot facility. The other waste heat zone will utilize a new heat exchange system designed to use large volumes of condenser effluent.

The three systems will be compared for environmental control capability, crop production, energy use and conservation, capacity to dissipate heat from condenser effluent, and overall economic feasibility. In addition, operation of the greenhouse will enable TVA to identify and resolve problems of interfacing commercial waste heat uses with power production. Environmental, legal, and social questions of producing food near nuclear plants will also be addressed.

Greenhouse production is energy intensive. The amount of heat energy required for greenhouse vegetable and ornamental production varies with the location, type house, energy conservation measures, and the crop being produced. For example, in Knoxville, Tennessee, approximately 14,600 GJ/ha•yr is required to heat a glass-glazed greenhouse for vegetable production. A double-layer polyethylene house, designed to conserve energy, requires about 8,900 GJ/ha•yr. Assuming an average heat requirement of approximately 13,000 GJ/ha•yr, the heat requirement for the 3,776 ha of greenhouses in the U.S. (1974 Census of Agriculture) is about 5.0×10^7 GJ, equivalent to approximately 7.6×10^6 barrels of oil per year.

Growth of the greenhouse industry has been restricted by the increased cost and limited availability of fossil fuels. In some areas, high fuel costs have caused a decrease in vegetable greenhouse acreage. In Ohio, the leading greenhouse vegetable production area in the U.S., acreage dropped from 197 ha in 1974 to 135 ha in 1977 (American Vegetable Grower, November 1977). According to the same survey, greenhouse vegetable acreage in the U.S. dropped from about 526 ha to 443 ha. On the other hand, growth of the bedding plant and ornamental industry has continued. Bedding plant greenhouse acreage increased from 647 to 1,006 ha from 1974 to 1977.

Development of technology to use power plant waste heat is expected to stimulate growth in the greenhouse industry. If waste heat is made available at an economical cost, the acreage could double within five years. Use of waste heat in 50 percent of the expanded acreage would result in conservation of about 3.8×10^6 barrels of oil annually.

Recycling Nutrients From Livestock Manure by Aquatic Agriculture

The major objectives of this project are to:

(1) Develop a method that uses waste heat to enhance nutrient recycling systems using manures from confined livestock production to grow aquatic and/or terrestrial plants.

(2) Develop the cultural conditions required to grow selected aquatic organisms (e.g., fish, clams, and other herbivorous-filter feeding organisms) to consume plants grown from livestock manure and enhance this production with waste heat.

(3) Evaluate the potential of these organisms (plant and animal) as feedstuffs, livestock feed supplements, bait minnows, or other higher value uses.

(4) Make economic evaluations of the waste heat systems where appropriate.

(5) Identify and resolve problems of interfacing livestock waste recycling with waste heat and power production.

(6) Provide technical assistance to commercial users of waste heat.

Various aspects of this project have been tested by TVA at the Muscle Shoals facilities since 1970 [3].

Pollution aspects of livestock manures have become a major concern in agriculture, and manure disposal problems have become more evident due to the increase of confined livestock feeding operations and population growth in the United States. Livestock waste contains plant nutrients that enhance productivity on agricultural land and can be used to provide organic and inorganic requirements for aquacultural production.

The biological recycling work is designed to utilize two waste products--livestock waste and waste heat contained in power plant discharge water--and recover part of the wasted energy associated with these resources. One method of recovering this potential energy is by converting the valuable nutrients (nitrogen, phosphorus, and potassium) contained in livestock waste to single-cell protein (SCP) using aquatic systems. Researchers have found that aquatic plants such as algae have potential in such a system but are costly or difficult to harvest mechanically, and chemical harvesting techniques can limit the usefulness of the product. This project is designed to overcome these hurdles by using aquatic animals such as fish and/or clams as "biological harvesters" of the SCP. The harvesters could be used as a source of high-protein fish meal for livestock feed or other higher value uses. The use of warm water is expected to help optimize, accelerate, and extend production time in the recycling system.

Algae Investigations

Initial efforts were made to identify algae that grow "naturally" as a result of organic waste fertilization and inorganic waste fertilization. Algae grown on both stabilized swine waste and inorganic fertilizer waste (hydroponic nutrient media) from a greenhouse producing tomatoes in sand culture exhibited differences in the ratio of algae species and concentrations achieved. Inoculations of algae were taken from one-year-old cultures growing in a dilute swine lagoon effluent consisting mainly of Oscillatoria (blue-green) and Oocystis (green) species. Oocystis elliptica was the principal green alga species in sediment and suspension of swine waste-grown material, while Micractinium pusillum was the predominant green alga in suspension of the nutrient-grown algae. Green algae were more abundant in the plankton than settled solids of both the nutrient-grown (65 percent) and the swine waste-grown algae (79 percent).

Blue-green algae dominanted in the sediment of both swine waste-grown algae (63 percent) and nutrient-grown algae (57 percent). Oscillatoria was the most prevalent blue-green alga (15.6 percent) except in plankton of swine waste cultures where Lyngbya (4.7 percent) dominated. Cell densities were $\geq 2.0 \times 10^9$ cells/ℓ except in suspension samples of nutrient-grown algae where concentrations were $\approx 5.0 \times 10^7$ cells/ℓ. Diatoms comprise less than 1 percent of the total population. A wide variation in the algal population as a result of cultural fertility practices should be anticipated. Attempts to culture more desirable species of algae with swine manure have not been successful, such as Spirulina and high temperature tolerant Chlorella. The highest rate of growth was achieved in shallow pools (13 cm) with continuous agitation but was subject to wide variation of diurnal temperatures. Under high light intensities, 28° to 30° C water, and continuous agitation, little difference existed between 20-cm- and 40-cm-deep cultures. Cultures were loaded with settled swine manure to NH_3-N concentration of 8 to 10 ppm. Cultures with 5-day growth periods or equivalent water retention times have proved to be the most reliable for producing high-density algal slurries during the summertime. Algal densities during this period were approximately 100 mg/ℓ of ash-free dry weight, and cell counts are generally several hundred million per liter.

Two species of green algae, Kirchneriella lunaris and Kirchneriella contorta, initially dominated (94 percent) the populations in 1976. However, population changes were experienced, and the dominant green algae population evolves to Oocystis elliptica and other Oocystis species with the onset of cool temperatures. During summertime, Scenedesmus sp. have dominated. These 5-day growth periods have produced total dry matter accumulation rates equivalent to 12-30 $g/m^2/day$ with water temperatures of 25° to 30° C, although brief periods of higher growth rates have been experienced. High pH (8 to 10) associated with these algae cultures may present culture management problems for fish production.

Fish Investigations

Silver amur (Hypophthalmichthys molitrix) fish are being investigated as a potential "harvester" for phytoplankton grown from swine manure. This Asiatic carp can reach 18 to 20 kg (40-45 pounds) in pond culture, filters suspended particulate matter, and actively feeds in waters high in algal biomass. Growth of the silver carp was investigated in a 1976 study. Fish weighing 2 g each were stocked into eight 3.66-m-diameter by 76-cm-deep tanks at rates equivalent to 28,600 fish per ha or 3 fish per m^2 of water surface. Fish were fed phytoplankton (dry weight basis) daily at rates of 2, 4, 16, and 32 percent of the fishes' initial live weight. An 80-percent survival rate and 250-percent net gain in 2.5 months of growth were observed at the 32-percent feeding rate. Algal selectivity and digestibility for these fish are poorly understood and may be important for optimizing fish growth. Dissolved oxygen (DO) remained sufficient in the fish tanks through the night, and oxygen saturation was observed well into the early morning hours on some occasions. Ammonia nitrogen remained low in the fish tanks (<1 ppm).

During the summer of 1977, a polyculture of silver carp, bighead carp (*Aristichthys nobilis*), and tilapia (*Sarotherodon nilotica*) was evaluated for the fishes' potential to grow and survive in swine manure fertilized waters. Early results were very promising with silver carp alone, but better results have been achieved with these three species in polyculture. Growth and survival of the tilapia were better than silver carp or bighead carp in swine manure fertilized water; however, stocking densities were different for the three fishes. Bacterial disease, alkaline pH, and gas embolism have been identified as potential problems in culturing these fish but are minimal when appropriate management precautions are taken [2].

Silver carp and tilapia were polycultured at 33° C and compared with no-heat cultures in July and August 1977 with maximum daytime unheated water temperatures of 27° to 30° C. There was little difference in growth between fishes when tested at these temperatures, but fish growth was slightly better in heated water. Experiments will be continued to evaluate the full benefit of using waste heat to elevate water temperatures. Nutritional quality of the algae rather than quantity may limit fish growth during summer months [2].

Evaluating Subsurface Soil Heating and Irrigation

Using waste heat for heating soil to extend growing seasons and improve crop production efficiencies is being investigated by TVA's

Soils and Fertilizer Research Branch at Muscle Shoals, Alabama. Experiments were begun in 1970 in small field plots using buried electric cables as the heat source [5]. Heat conductivity is the most important soil characteristic influencing soil warming because it determines the rate of heat movement away from a heat source. Soil moisture content and bulk density are the primary factors affecting heat conductivity of soils; mineralogical composition is relatively unimportant. Several crops have been grown with combinations of heat or no heat and irrigation or no irrigation. Sweet corn, string beans, and summer squash planted in early April emerged earlier and exhibited more rapid early growth, earlier maturity, and greater yields due to soil heating, either with or without irrigation. With beans or black-eyed peas planted in midsummer, no benefit resulted from heating; and yields were often decreased without irrigation. Little benefit was noted from soil warming on turnips, rye, and ryegrass planted in the fall unless seeding was delayed until the weather was so cold that germination would not occur on unheated plots. In tests run with soybeans, cotton, and corn, only cotton showed a yield increase of possible economic potential.

A new soil heating research facility, including a plastic greenhouse heated only with buried pipes, was constructed at Muscle Shoals in the spring of 1975. Residential water heaters are used to heat water, which is circulated through the soil in closed systems of polyethylene pipe and copper tubing. Simulated water temperature regimes being tested are representative of the TVA Browns Ferry Nuclear Plant, designed for once-through cooling with reservoir water, and the proposed Hartsville Nuclear Plant, being designed for continuous cooling tower operation.

The Hartsville plant is expected to produce condenser discharge water from 38° to 49° C, depending upon the season. Tests using simulated Hartsville water resulted in soil temperatures about 9° C higher at the 7.6- and 15.2-cm depth than the Browns Ferry water. These tests indicate that Hartsville water will heat greenhouse soil to acceptable temperatures for plant growth in the 15.2-cm and deeper layers. However, surface layers may be too cool for good seed germination, and air temperatures were too low for satisfactory winter growth of most warm-season species.

In winter greenhouse tests, broccoli, cauliflower, and Bibb lettuce all produced larger heads and greater yields on soil heated with the simulated Hartsville water; Great Lakes head lettuce produced larger heads on the cooling soil.

Controlling Livestock Housing Environment

Plans are to utilize results from the operation of TVA's waste heat greenhouse environmental control system as a basis for designing an environmental control system for a livestock production facility.

A TVA assessment of current knowledge on the effects of temperature control for livestock housing has been initiated with emphasis directed at potential heating applications that could utilize power plant reject heat. The two production applications offering the greatest potential appear to be broiler production and swine farrowing and brooding [7]. The air temperatures required for these uses appear to be compatible with power plant cooling water temperatures. This assessment will be completed in September 1978, and plans for further involvement in this application of waste heat utilization will then be finalized.

Crop Drying

Agricultural crop drying requires over 3.8 x 10^6 m^3 of liquefied petroleum (LP) gas annually. About 60 percent of this total is used for drying corn and an additional 30 percent for flue-cured tobacco. Either high-temperature, high-speed processes or low-temperature processes using a large volume of air over an extended period of time are used for grain drying. Interest in low-temperature drying, using air temperatures from 1° to 8° C above ambient, has been stimulated by increased fossil energy costs. Considerable research has been directed toward development of solar energy systems for supplying heat in low-temperature driers; much of the technology developed for solar energy systems may also prove economically adaptable to waste heat applicaton.

Grain drying requires about 0.04 to 0.05 MJ/kg per point of moisture removed in conventional drying systems. This can be reduced considerably by using solar energy, and the use of waste heat could offer similar or greater reductions in energy use. Temperatures made available by efficient waste heat systems would be comparable to those used in low-temperature drying. Use would be seasonal, with drying occurring for only a short period each year; and it would lend itself to integration with other uses since maximum drying periods would not normally occur during maximum heat requirements or other uses, and requirements for constant heat are not critical.

Our recent assessment of crop drying with power plant waste heat in the U.S. did not reveal any research projects or studies addressing this potential use [7]. Our plans are to further investigate the potential of waste heat used in crop drying. Efficient heat exchange systems using waste heat need to be developed and evaluated.

Food Processing

The food processing industry accounts for about 5 percent of the Nation's annual energy consumption. Considering the importance of maintaining the U.S. food supply, the increasing world dependence on U.S. food production, and the critical shortages estimated for fossil fuels, it is apparent that other forms and/or sources of energy for the food processing sector should be sought.

The usage of fuels and energy consumption patterns vary considerably among types of food processing plants. A TVA food processing assessment of U.S. waste heat literature showed no pilot-scale or commercial projects using power plant reject heat; however, a study of waste heat feasibility simulation systems showed that an integrated waste heat system (greenhouse, food processing, and ponds) suggested economic promise. Waste heat use in food processing needs to be further researched at the feasibility stage for specific application [7]. Our plans for further work on food processing are uncertain at this time.

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Paper No. 2

TECHNICAL AND ECONOMIC FEASIBILITIES OF WET/DRY TOWER SYSTEMS FOR WATER CONSERVATION

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ABSTRACT

The technical and economic feasibility of wet/dry cooling towers for water conservation was evaluated. Results on economic optimization of wet/dry tower systems for 1000-MWe power plants are presented.

Results are given as the Total Evaluated Cost (TEC) of the cooling system. Separate cost components include initial capital cost, operating expenses, and penalties for the cooling system operation capitalized over the lifetime of the plants.

For the analysis, optimized wet and dry cooling towers are the reference systems. The wet/dry system has separate wet and dry mechanical draft towers. Costs are related to the make-up requirement expressed as a percentage of the water required by a wet system.

The major conclusions are: 1) wet/dry cooling tower systems can be designed to provide a significant economic advantage over dry cooling, yet closely match the dry tower's ability to conserve water, and 2) where water is available, wet cooling will continue to be the economic choice in most circumstances.

INTRODUCTION

The increasing use of evaporative (wet) cooling towers to dissipate power plant waste heat loads has focused on one of the major inherent characteristics of such devices, namely, the consumptive water use. Consumptive water use, because of its cumulative impact, is evolving as a major environmental concern in all parts of the United States. For this reason, federal, state and regional agencies in the U.S. previously have advocated the use of dry cooling for utility plant applications. In response to requests from these agencies, numerous evaluations have been performed which have indicated: 1) the use of dry cooling with high back pressure turbine would considerably increase the costs of construction and operation of steam electric power plants; 2) their use would result in a significant loss of capacity during the same high temperature conditions when most utilities experience their peak electrical demand; and 3) the loss of capacity and peak demand are coincident with the time that the environmental impact of consumptive water use is most severe.

The losses of capacity and energy and the associated economic penalties for a dry tower system can significantly be reduced by the use of an evaporative cooling tower to assist the dry tower. The combined wet and dry towers are termed wet/dry towers. The applications of wet/dry towers also permit the use of conventional low back pressure turbines instead of high back pressure turbines. These high back pressure turbines, which are normally associated with dry cooling applications, are commercially available only for fossil plants in the U.S.

When compared to wet towers the wet/dry towers will significantly reduce the water consumption for cooling purposes. The reduction of water consumption, however, is achieved at the expense of higher capital and economic penalty costs.

Since the water problem in the U.S. was projected to impact on power plant siting and energy growth, the former U.S. Energy Research and Development Administration (ERDA) and the U.S. Environmental Protection Agency (EPA) have sponsored two separate but complementary studies (1,2). The purpose of these studies was to determine the feasibility of using wet/dry tower systems to reduce the power plant water consumption.

The ERDA study dealt with nuclear plants, whereas the EPA study was directed at mine-mouth coal-fired plants in the coal rich Western United States. This paper summarizes the method of economic evaluation, the design approach, and the results obtained in these two studies and a subsequent study for the California Resources Conservation and Development Commission (CRCDC) (3). The ERDA study was previously summarized in Reference 4.

METHOD OF ECONOMIC ANALYSIS

The method used in the economic analyses (1,2,3) is a fixed source-fixed demand method as illustrated in Figure 1. A reference plant is assumed to be of fixed heat source, and there is a fixed demand for its output. It is against this fixed demand that the loss of plant performance for each cooling system is measured. Inability to meet this demand will be charged as a penalty cost which is to be added to the capital cost of the cooling system. Other penalty costs include the cost of supplying make-up water and cooling system maintenance cost. The make-up water penalty is of special significance, since availability of water is a primary concern of this study. The sum of the penalty costs and capital cost of a cooling system is called the total evaluated cost (TEC). The nature of these costs is such that an optimum, i.e. minimum total evaluated cost system can be identified as shown in Figure 2.

The cooling system evaluation involves sizing and costing a cooling system, determining its thermal performance, water consumption, auxiliary power and energy needs and other requirements during a typical annual cycle. The performance information is used to assess the economic penalties which will accrue over the lifetime of the plant. Finally, from a series of designs which meet certain design criteria and a specific water consumption requirement, the minimum cost cooling system is selected. The major components of a cooling system included in the analysis are those shown to the right of Section BB in Figure 3.

DESIGN AND OPERATION OF WET/DRY TOWER SYSTEMS

A number of possible arrangements exist for combining separate wet and dry towers into wet/dry towers which can conserve make-up water while efficiently rejecting the power plant waste heat. Many of these wet/dry towers have been described in the literature (5,6,7). Several of the proposed arrangements have been designed for commercial applications. One which has been offered by a manufacturer and purchased by a major utility for power plant application is the series flow (water) mechanical draft tower system. This system combines separate mechanical draft wet and dry towers into an operational system by means of a cooling water circuit which flows first through the dry tower and then the wet tower. The separate wet and dry towers, however, can be designed to share common structure elements, such as the two wet/dry tower systems purchased by the Public Service Company of New Mexico for its two 450 MWe coal-fired units. These two units are scheduled to be operational in 1979 and 1981. A schematic diagram of the wet/dry tower being constructed at the San Juan Stations is shown in Figure 4.

An alternate design of series flow wet/dry tower system is the one which has been studied extensively in the three studies mentioned earlier (1,2,3). In this alternate design, the wet and dry towers are both functionally and structurally separated; the towers are connected together through pipelines. The schematic diagram is shown in Figure 5.

The approach used in References 1-3 for the design of a wet/dry cooling tower is as follows: The dry tower is sized to reject the entire heat load at a low ambient temperature while maintaining the turbine back pressure within specified limits. The performance of the dry tower is then evaluated at the peak ambient temperature condition to determine the maximum heat rejection capacity of the dry tower without exceeding the specified limiting back pressure. This information is then used to size the wet helper tower needed to reject the remaining heat load at this ambient temperature.

For this cooling system, dry cooling is the basic heat rejection mechanism, and wet cooling is used to provide supplementary heat rejection when necessary. The dry tower is designed to operate continuously during the year; and provisions are included to shut down wet cells if they are not needed at low ambient temperatures. Two different modes of operation analyzed in References 1 and 2 are described below:

1. Mode S1

The first mode is termed the S1 mode (S for series). The main objective of this mode is to operate the wet helper tower as little as practically possible. This mode of operation is illustrated schematically by means of turbine back pressure characteristic of a wet/dry system operated in this mode (Figure 6). During the peak summer ambient temperature, both the wet and dry towers are operating at full capacity as indicated by point 1. As the ambient temperature falls, the wet cells are turned off in succession to maintain the turbine back pressure essentially constant at the wet tower design value. When point 2 is reached, all of the wet cells have been shut down, and the dry tower handles the entire heat load. The back pressure curve between points 1 and 2 is of a saw-tooth nature, which results from the intermittent operations of the wet towers cells as the ambient temperature falls. This operational mode requires continuous feedback controls for the operation of the wet towers. Most new stations are being designed with sufficient computer capacity to provide for this additional measure of station control.

2. Mode S2

The second mode of operation represents a system operating with much less control of the wet tower. The turbine back pressure characteristic resulting from the operation of a wet/dry system in this mode is illustrated in Figure 7. In this mode, all the wet cells are operated continuously until the dry tower design temperature is reached (point 2). As the ambient temperature decreases, the turbine back pressure is allowed to fall. When the ambient temperature drops to the point where the dry tower can reject the entire heat load without exceeding the turbine design back pressure, the wet tower is turned off completely (point 2). As the ambient temperature passes through this point, an apparent instantaneous jump in back pressure occurs. However, in reality, this transition would occur over a long enough time span so as not to create any damaging thermal shock to the turbine and associated equipment. Turbine manufacturers have indicated that changes in back pressures of this magnitude occur daily during the operating life of the turbine.

Wet/dry cooling systems operating in the S1 mode are more water conservative at the expense of greater energy consumption than the same system operating in the S2 mode. Conversely, systems operating in the S2 mode are more energy conservative at the expense of higher water consumption. For the same water usage, the results in References 1 and 2 have shown that the systems designed to operate in S1 mode are, in general, less costly.

WET/DRY TOWER SYSTEM DESIGNS AND COSTS

Typical design and costs of wet/dry tower systems for water conservation from References 1-3 are presented in this section. The wet and dry tower systems are designed to operate with conventional low back pressure turbines with a maximum operating back pressure of 5 in-HgA (127.8 mm-HgA). The dry tower systems are designed for both the conventional low back pressure turbines and the high back pressure turbines; the latter are assumed to have a maximum operating back pressure of 15 in-HgA (381 mm-HgA). The data presented for the wet/dry tower systems are for the S1 operational mode; the make-up water requirements of these systems are expressed as percentages of the annual make-up required by the reference wet tower system.

The design and costs of wet/dry tower systems sized for various make-up water requirements and the reference wet and dry tower systems for a nominal 1000-MWe coal fired plants are shown in Tables 1 and 2. The comparable results for a nominal 1000-MWe nuclear plant at the same site are given in Tables 3 and 4. The ambient temperature variation of the site is shown in Figure 8.

Tables 1 and 3 show the summaries of the major design data for the wet/dry cooling systems of the fossil and nuclear plants. Included in this table are the tower size and operating mode, the maximum operating back pressure, the gross generator output, the condenser or tower heat load at the maximum back pressure, the heat load distribution between the wet and dry towers at the maximum back pressure, and the annual water make-up for the tower systems.

These data indicate that dry cooling tower systems of manageable size can be designed for utility application by peak shaving the heat load with evaporative helper towers. The number of dry cells needed for the wet/dry option are comparable to or less than that required for the dry cooling system using the high back pressure turbine. The data also show that the capacity deficits of 120 MWe and 154 MWe for the fossil and nuclear plants respectively can be reduced by more than 69 MWe and 108 MWe, even with the wet/dry system requiring two percent make-up for the fossil plant and 1 percent make-up for the nuclear plant.

Tables 2 and 4 show that the costs of wet/dry system range between the dry and the wet systems. The costs of the wet/dry systems decrease monotonically as the make-up requirement increases. The total evaluated costs for all of the wet/dry systems are significantly higher than the costs of the wet system, but significantly lower than the costs of the dry system.

The capital and penalty cost components for the heat rejection system are listed in Tables 2 and 4. The direct capital costs are costs for equipment and installation. The indirect cost is 25 percent of the total direct capital cost and covers engineering, construction management, contingency, etc. The penalty costs include six major components: capacity loss, power for tower fans and circulating water pumps, replacement energy, fan energy and circulating water pumping energy, cooling system maintenance, and make-up water.

The capacity loss due to the inefficiency of the heat rejection system and the power required for the fans and pumps are assessed at the peak ambient temperature in evaluating the capacity and auxiliary power penalties. These penalty costs represent the capital cost of electric generation equipment elsewhere in the utility system (assumed to be similar base load unit as the proposed plant in this analysis) to provide the capacity needed to meet the fixed demand.

Penalty costs for replacement energy and for fan and circulating pump energy are the energy costs which will accrue over the lifetime of the plant.

The cooling system maintenance penalty is the cost charged to a cooling system for services which include periodic maintenance and replacement of parts. It is calculated on the basis of percentages of the capital costs of the major equipment and represents the capitalized cost of maintenance over the plant lifetime.

PLANT PERFORMANCE

An example of the plant performance of a wet/dry system for a nominal 1000 MWe nuclear power plant is shown in Figure 9 for a 10 percent make-up wet/dry tower system operating in the S1 mode (1). The performance shown includes the gross and net plant output (gross output - cooling auxiliary power requirement), turbine back pressure, and make-up flow rate over an annual cycle.

When the wet and dry towers are operating together, the turbine back pressure is maintained near its design value of 4.5 in HgA (114.3 mm HgA), and the gross plant output (MWe) is at its lowest value. The wet tower modules are gradually taken out of service as the ambient temperature decreases. The dry tower takes over completely when it is able to carry the plant heat load while maintaining the turbine back pressure at or below the design value. At this point, all the wet towers are out of service, and no water is required as shown by the make-up curve. When the dry tower operates alone and in response to the falling dry bulb temperature, the capacity of the dry tower system increases, resulting in lower back pressure and greater gross and net plant outputs. The gross plant output in Figure 9 reflects the back pressure variation as described above.

WATER USAGE AND COSTS

One of the criteria used in the design of an optimum wet/dry tower is the annual make-up requirement. The annual make-up is the summation of the water usage during each increment of an ambient temperature cycle. Since most streams generally have a low stream flow in summer or fall when the cooling tower make-up requirements are the highest, it is important to determine the water usage requirements on a monthly or a daily basis during the annual cycle.

Figures 10 and 11 show the total amount of make-up required for each month during a typical annual cycle for cooling systems designed to serve a 1000 MWe fossil plant and a 1000 MWe nuclear plant, respectively, at San Juan, New Mexico. Figures 12 and 13 show the maximum make-up flow rate during each month for the two plants. Although the annual percentage make-up is small, the maximum flow rate can be large. For example, even for the one percent make-up system, the maximum make-up flow rate is almost one third of that required by the wet system. This is to be expected since the wet/dry system requires about a third of the wet cells needed for the wet tower. The maximum monthly requirement, however, is less than ten percent of the wet system requirement. The information given in Figures 9-12 can be used to determine whether stream flow conditions match the make-up requirements, or to size the reservoir or impoundment necessary for station operation.

As mentioned earlier, the water penalty is of special significance when making cost comparisons of wet and wet/dry cooling system alternatives. The water penalty cost should include: 1) the water purchase cost, 2) the capital cost of water treatment facilities, such as clarifiers and water treatment chemicals, 3) the capital and operating cost of water supply which includes make-up (intake structure) pumps, pipelines and associated structures, and 4) the cost of blowdown disposal. In Table 2, the water penalty cost for the fossil plant includes the first three items listed above whereas in Table 4, the water penalty cost includes essentially only item 3. As a result, the percent differences in total evaluated cost between the wet/dry systems and the reference wet tower system can be seen to be higher for the fossil plant data in Table 2 than those for the nuclear plant in Table 4.

The effect of water penalty cost on the economic comparison, for the wet/dry and wet tower systems is best illustrated in Table 5. Table 5 presents the cost data of wet and wet/dry tower systems for the proposed 1000 MWe Sundesert nuclear station at Blyth, California. The water penalty costs in this table include all of the aforementioned items. The results show that, with the inclusion of the full cost of water, the economic impact of the use of wet/dry cooling to conserve water may be significantly reduced but remained substantial.

The pertinent tower system design data and evaporation (make-up) rates for the wet and wet/dry tower systems for Sundesert are given in Tables 6 and 7.

ECONOMIC FEASIBILITY OF WET/DRY COOLING SYSTEMS FOR WATER CONSERVATION

Studies sponsored by ERDA (1), EPA (2) and the California State Energy Commission (3), from which the data on wet/dry systems for water conservation have been cited, have concluded:

1. Wet/dry cooling systems can be designed to provide a significant economic advantage over dry cooling yet closely match the dry tower's ability to conserve water. A wet/dry system which saves as much as 99 percent of the make-up required by a wet tower can maintain that economic advantage. Therefore, for power plant sites where water is in short supply, wet/dry cooling is the economic choice over dry cooling. Even when water supply is remote from the plant site, this advantage holds.

2. Where water is available, wet cooling will continue to be the economic choice in most circumstances. Only if resource limitation or environmental criteria make water costs excessive, can wet/dry cooling become economically on par with wet cooling.

3. The economic advantage of wet/dry cooling over dry cooling reduces the need for further development of high back pressure turbines for nuclear power plant applications.

4. The dry surfaces needed for wet/dry options are, in general, less than that required for the dry cooling systems using the high back pressure turbines, but remain large in size. Therefore, the development of improved dry surfaces should be continued for use in wet/dry cooling.

ACKNOWLEDGEMENTS

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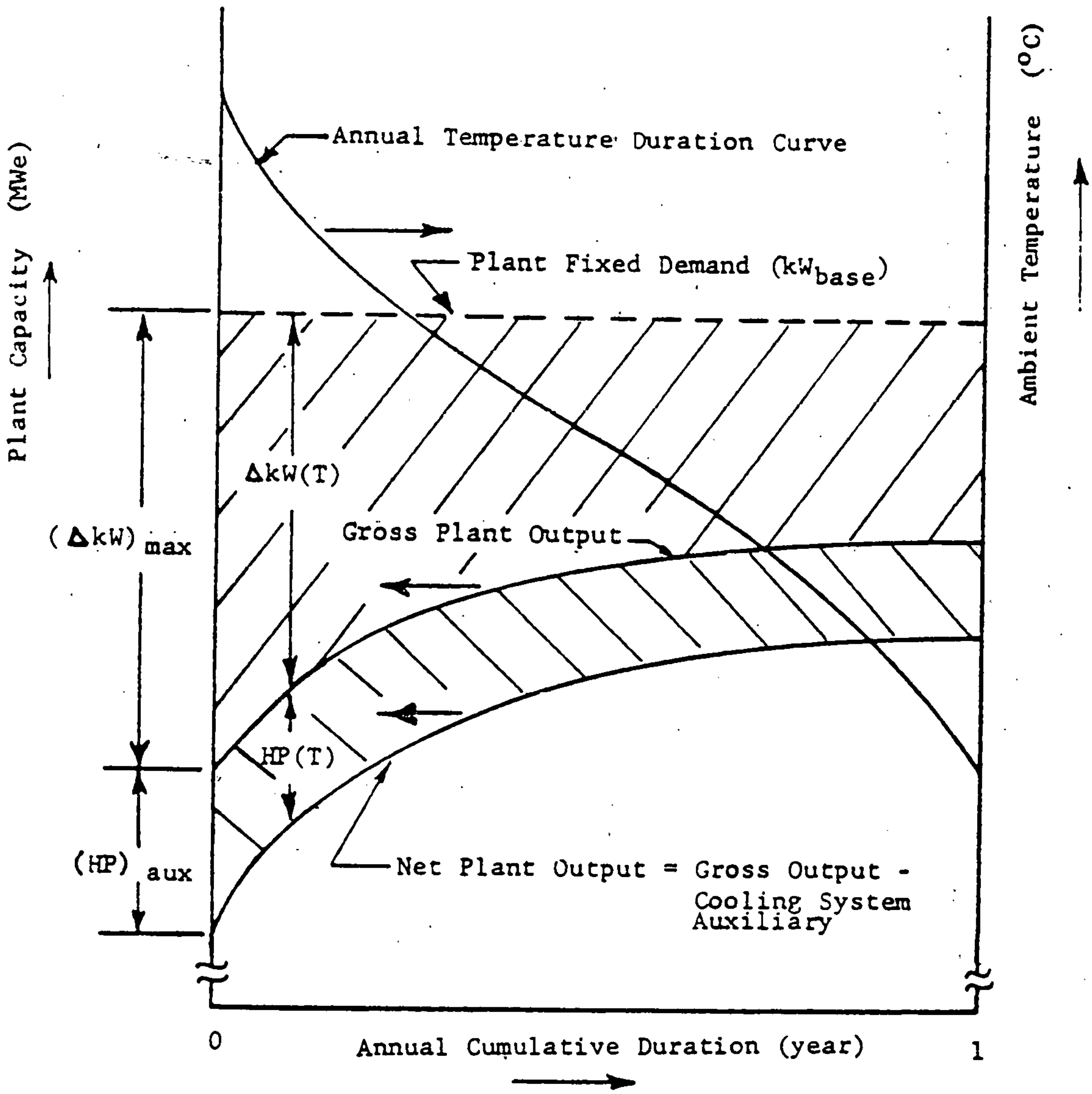

Figure 1 Ambient Temperature Duration and Corresponding Plant Performance

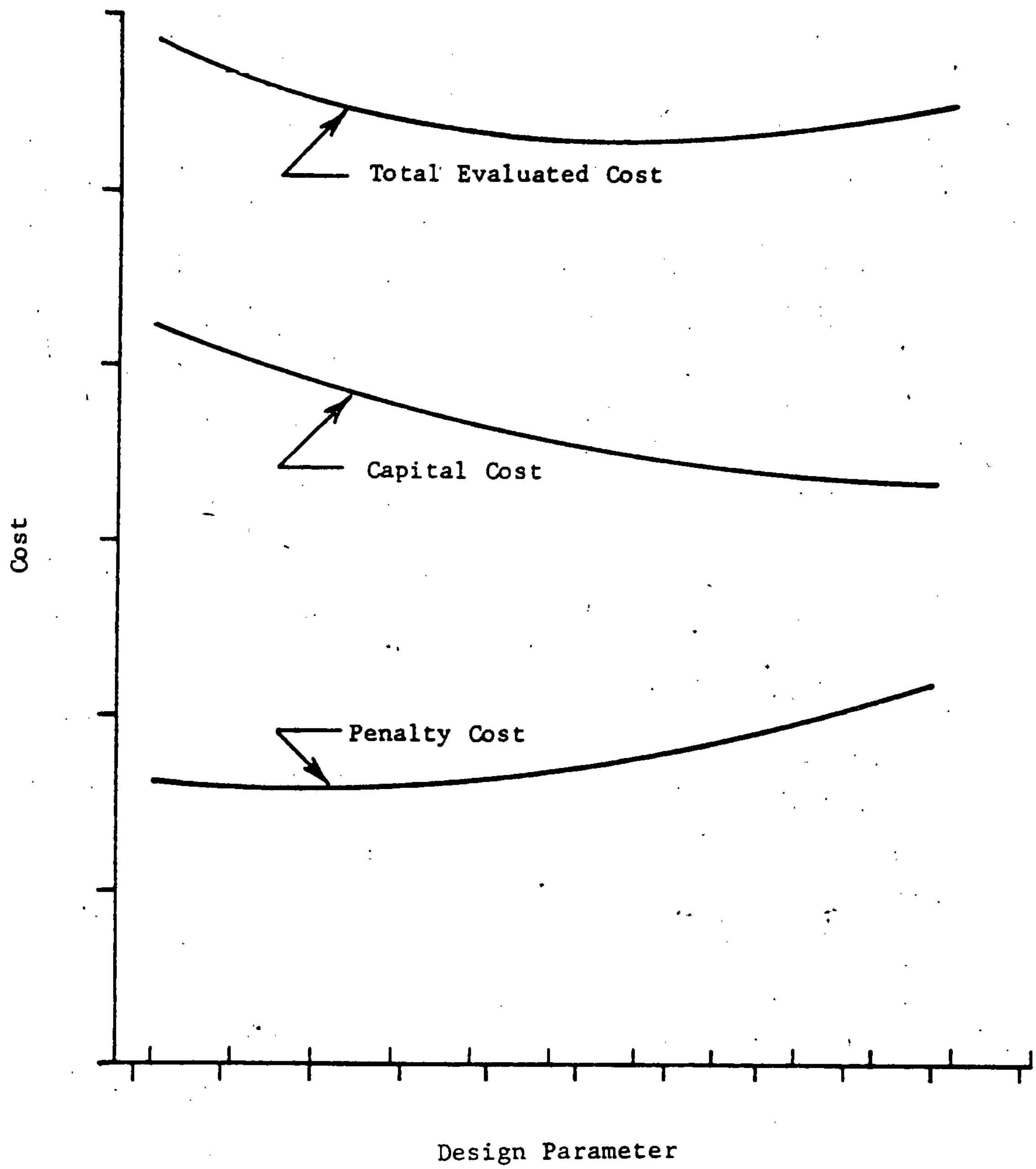

Figure 2 Schematic Diagram of Economic Trade-offs of Capital and Penalty Costs

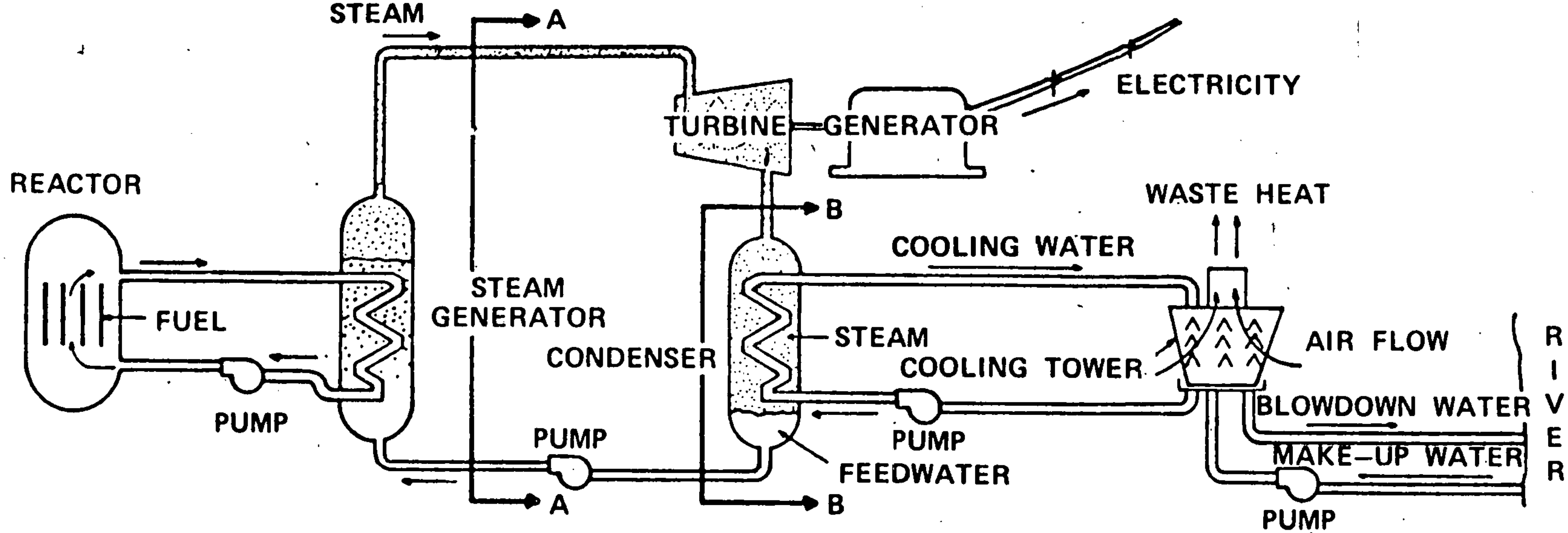

Figure 3 Power Generation and Waste Heat Rejection - Pressurized Water Reactor (PWR) With Evaporative Cooling Tower

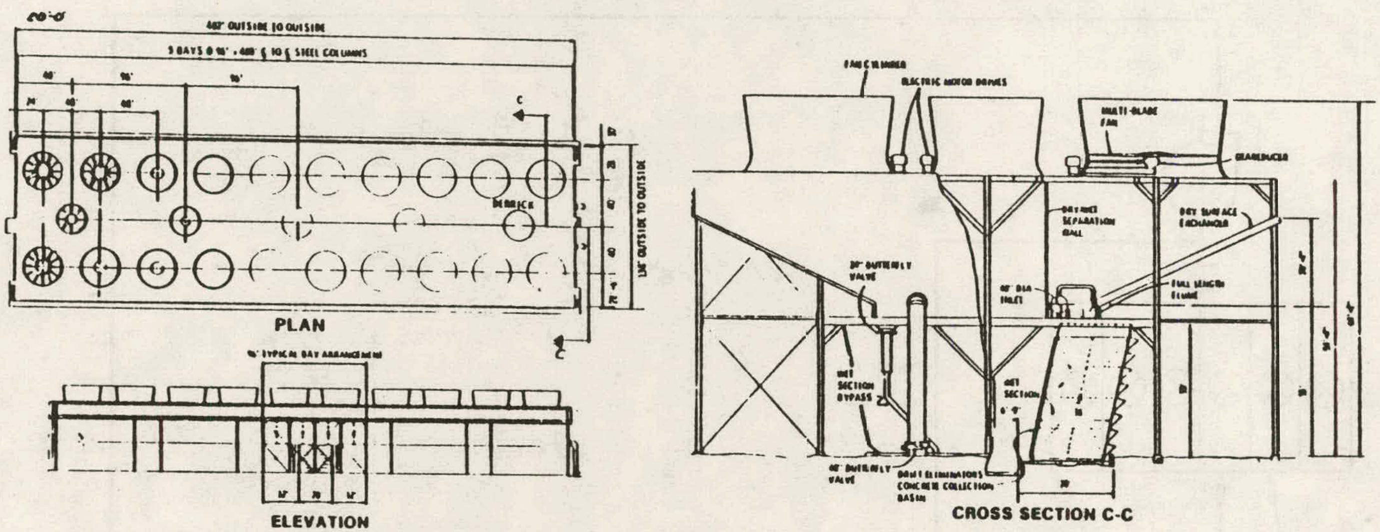

Figure 4 Integrated Wet/Dry Cooling Tower

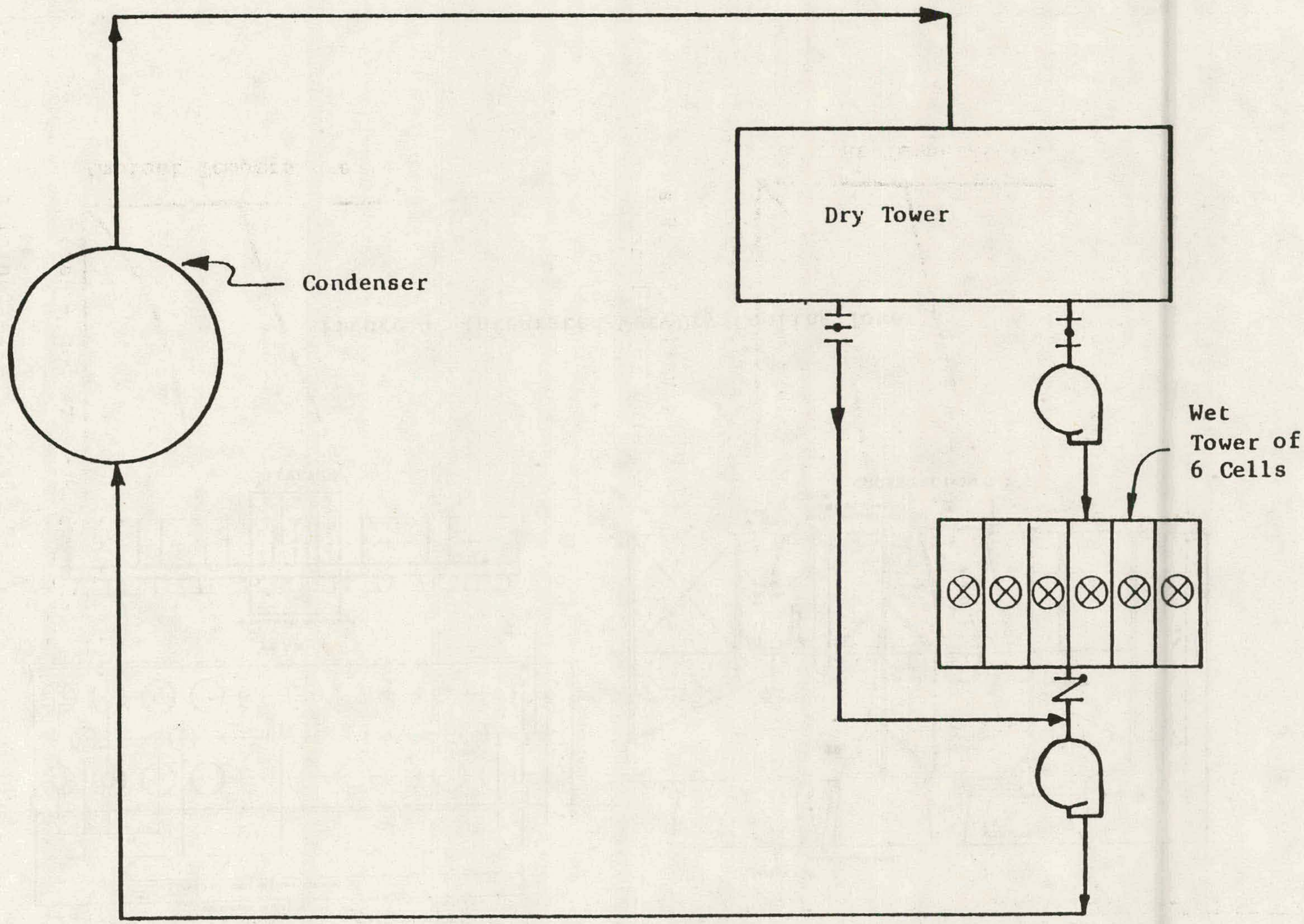

Figure 5 Series-Water Flow Wet/Dry Tower

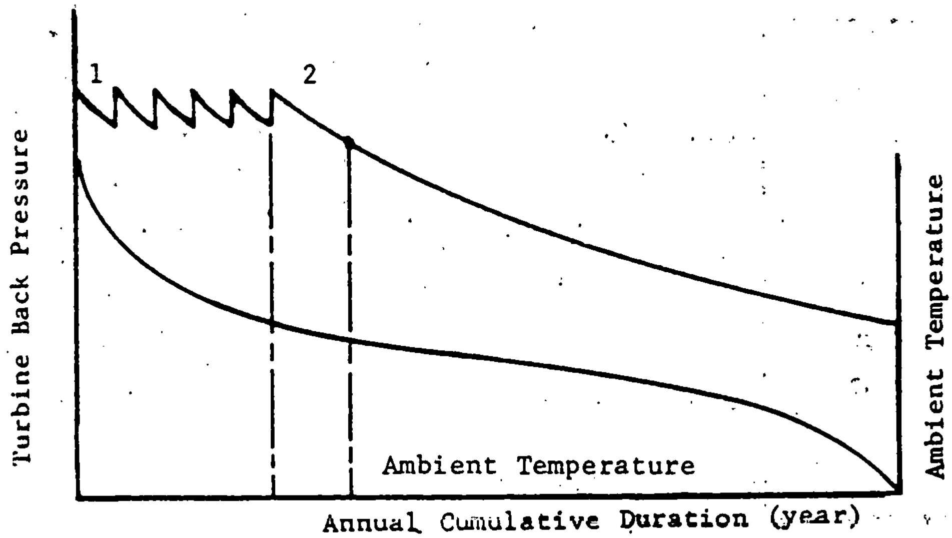

Figure 6 Typical Turbine Back Pressure Variation of a Wet/Dry Tower System Operating in S1 Mode

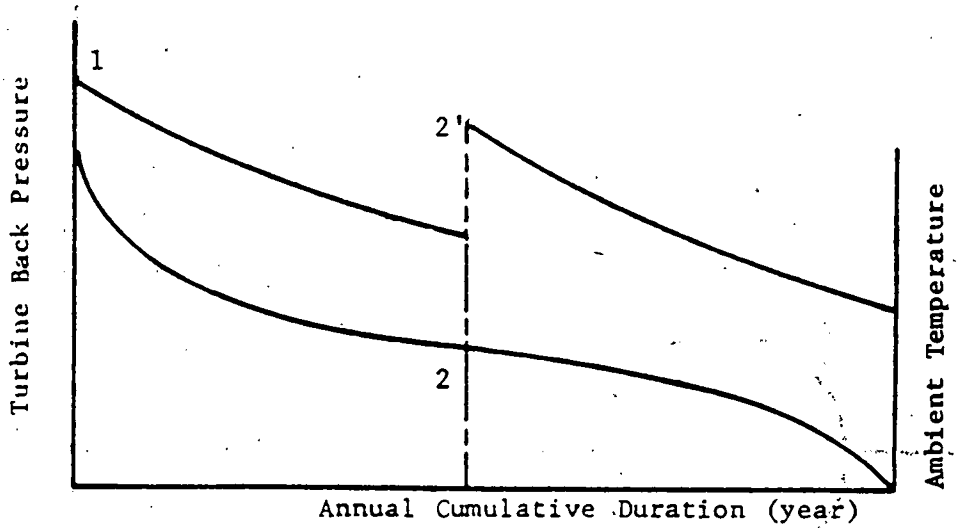

Figure 7 Typical Turbine Back Pressure Variation of a Wet/Dry Tower System Operating in S2 Mode

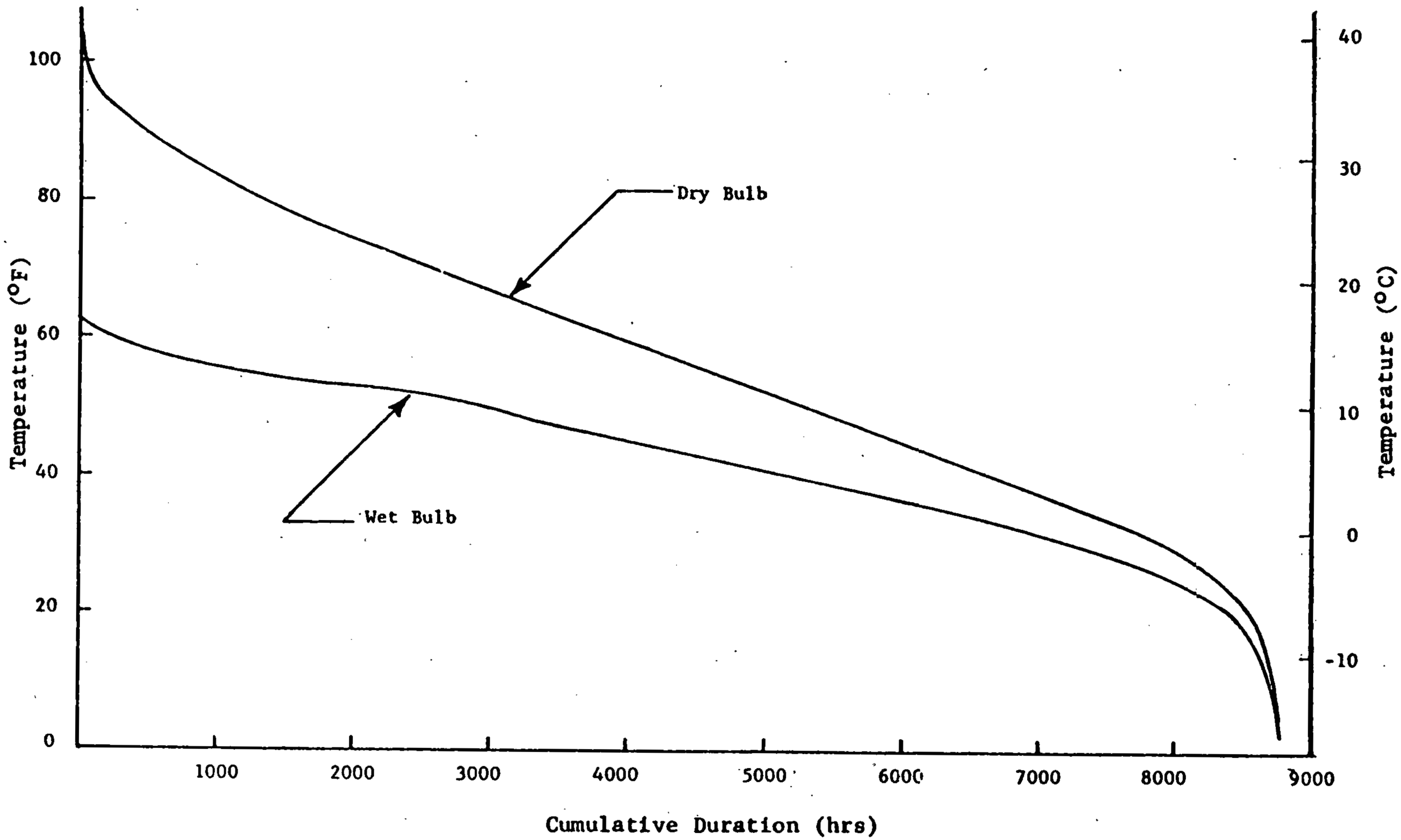

Figure 8 Temperature Duration Curves: San Juan, New Mexico (Farmington, NM)

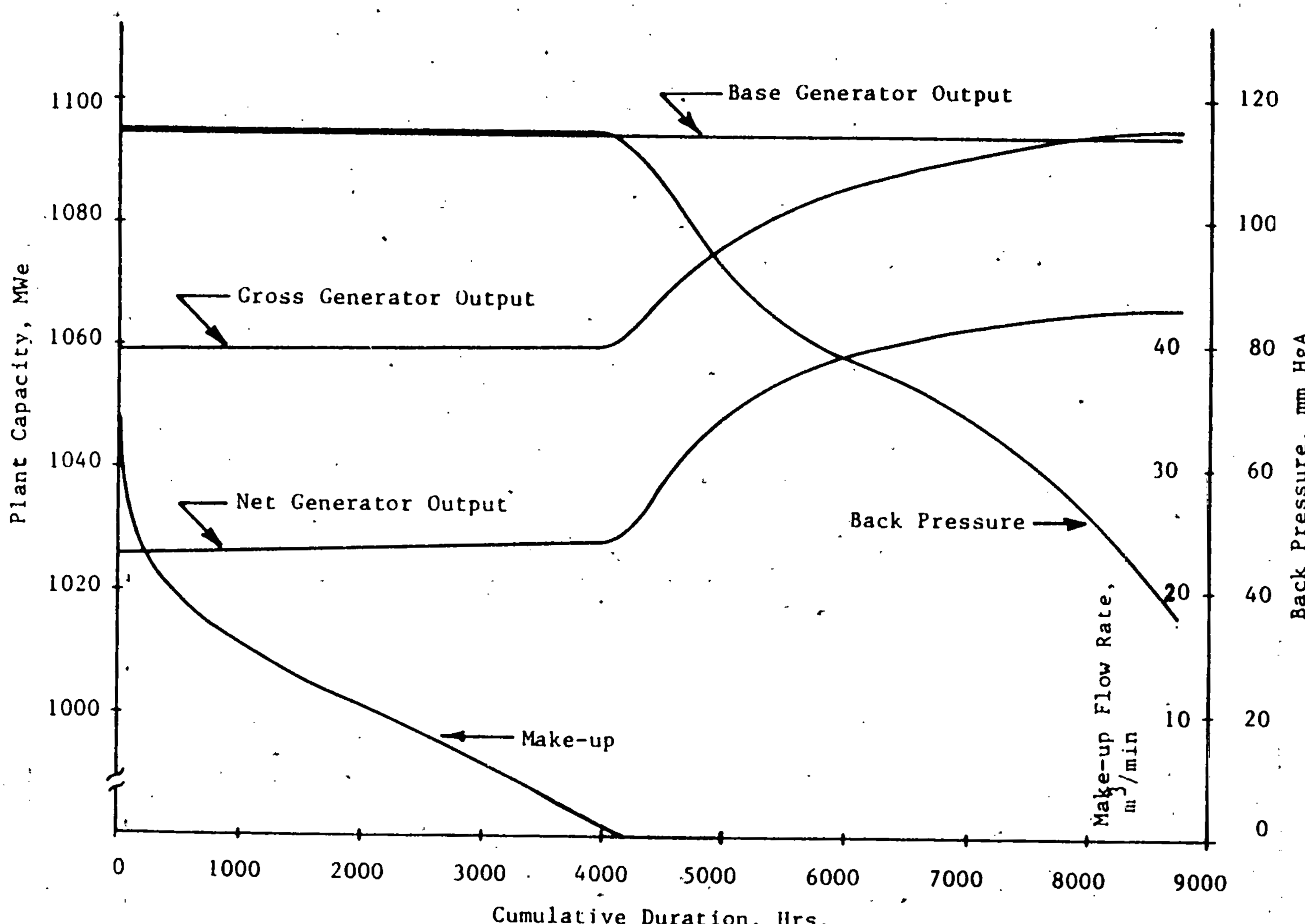

Figure 9 Performance Curves for a 10% Wet/Dry Cooling System for a 1000 MWe Nuclear Plant (Boston, Mass.)

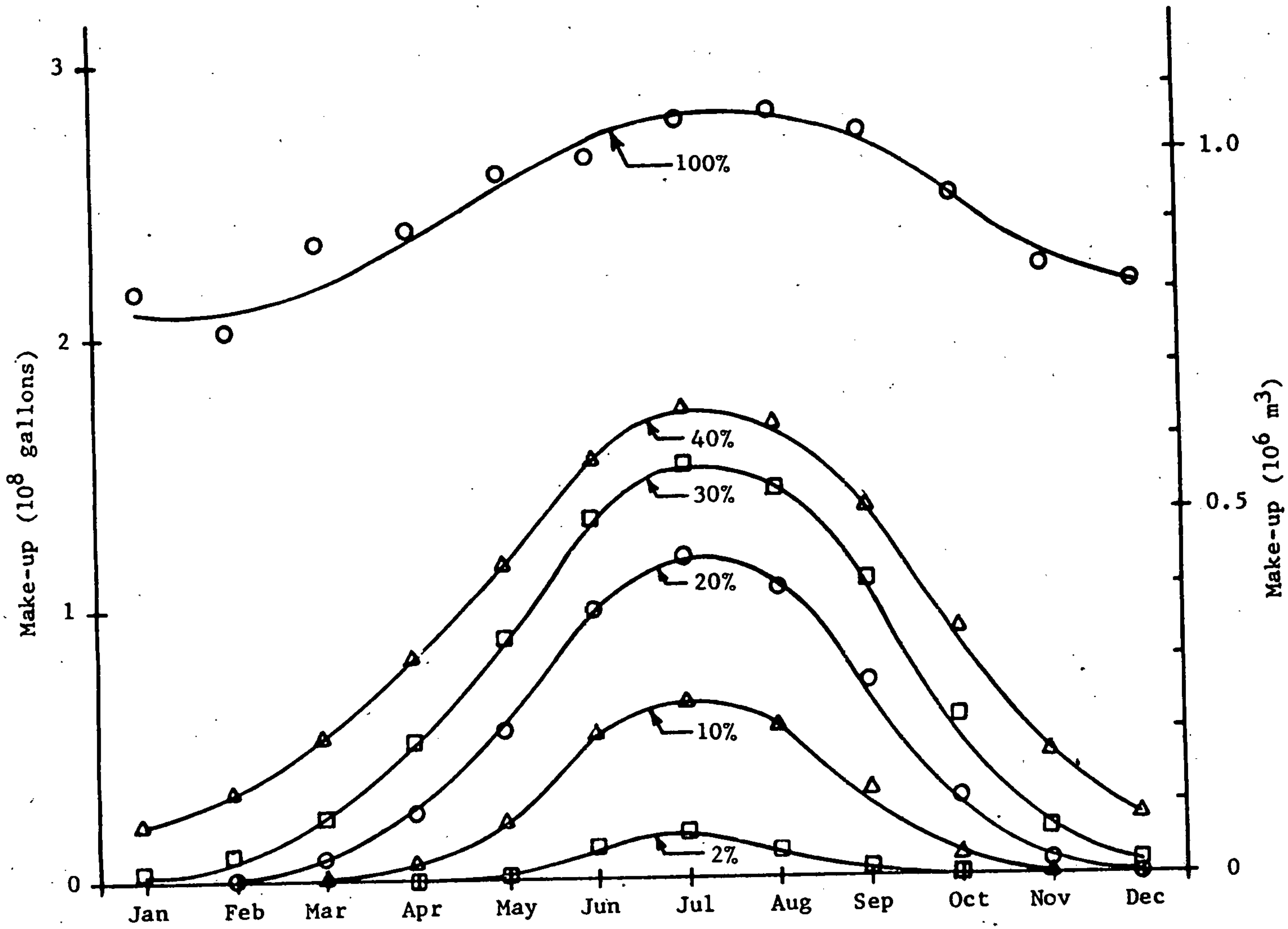

Figure 10 Total Make-up Requirement for Each Monthly Period for a 1000 MWe Fossil Plant at San Juan, New Mexico Mechanical Series Operating in S1 Mode

NOTE: Curves are drawn through the discrete points to facilitate visual observation

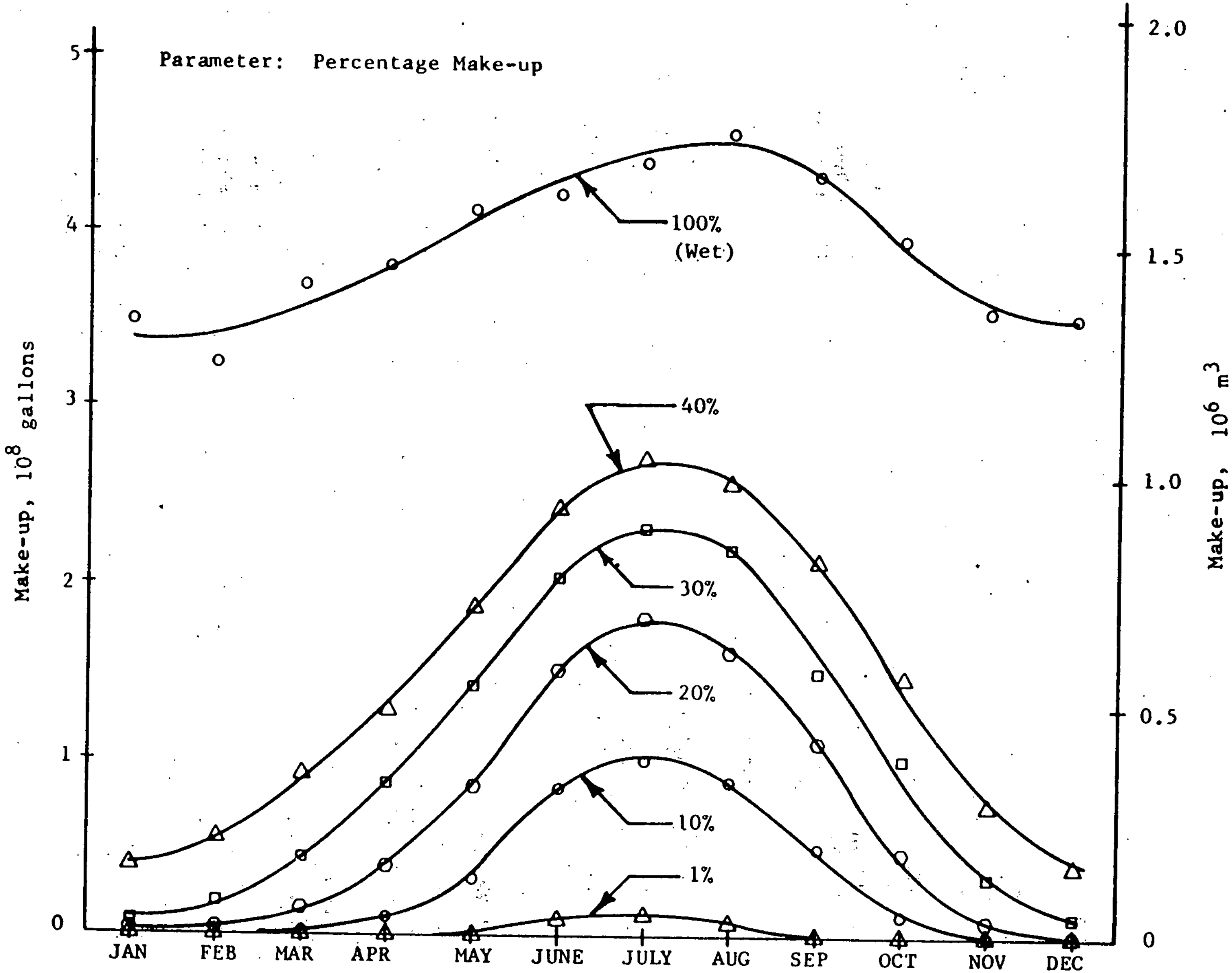

Figure 11 Total Make-up Requirement for Each Monthly Period for a 1000 MWe Nuclear Plant at San Juan, New Mexico Mechanical Series Operating in S1 Mode

NOTE: Curves are drawn through the discrete points to facilitate visual observation

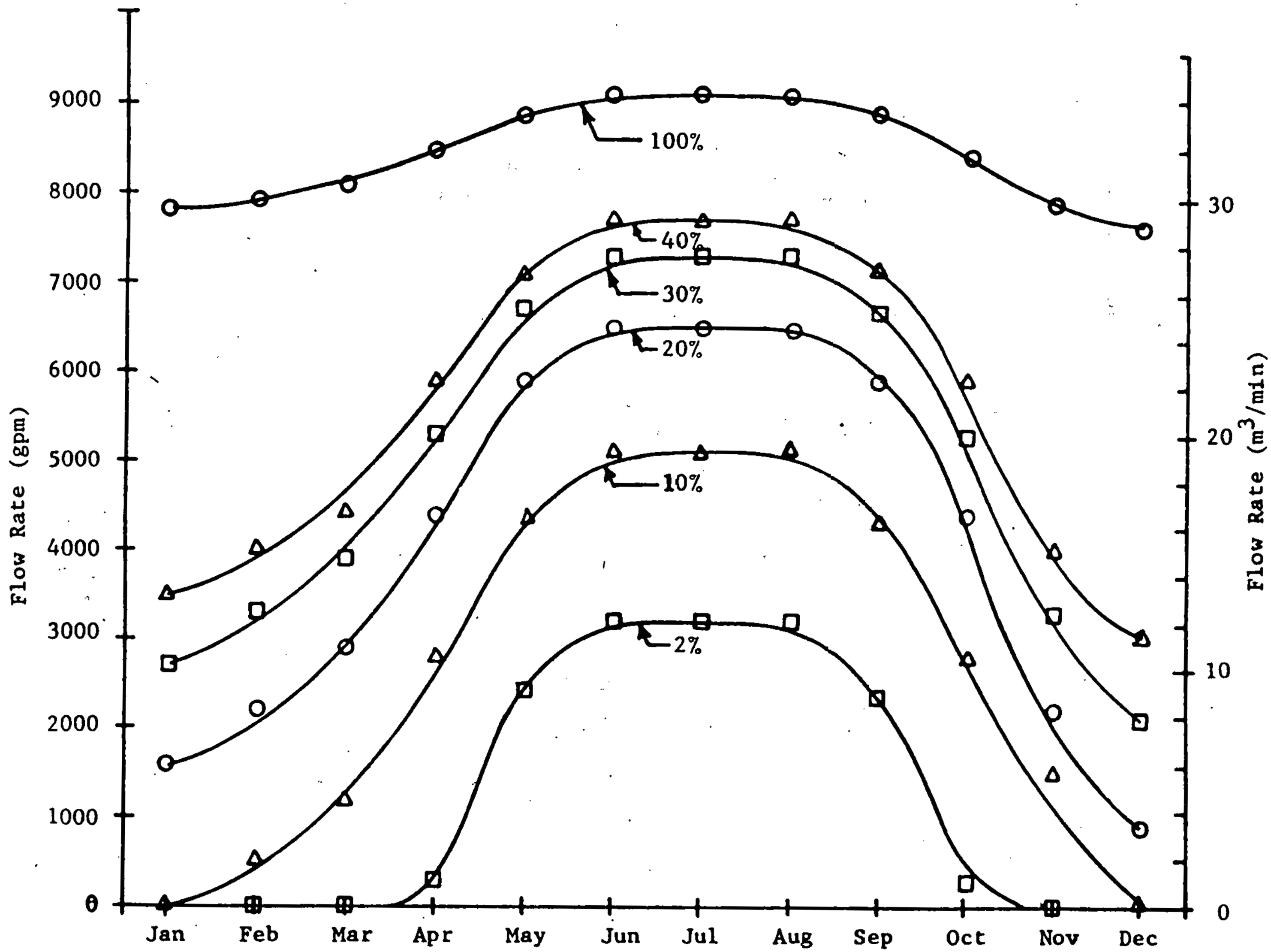

Figure 12 Maximum Make-up Flow Rate for Each Monthly Period for a 1000 MWe Fossil Plant at San Juan, New Mexico Mechanical Series Operating in S1 Mode

NOTE: Curves are drawn through the discrete points to facilitate visual observation

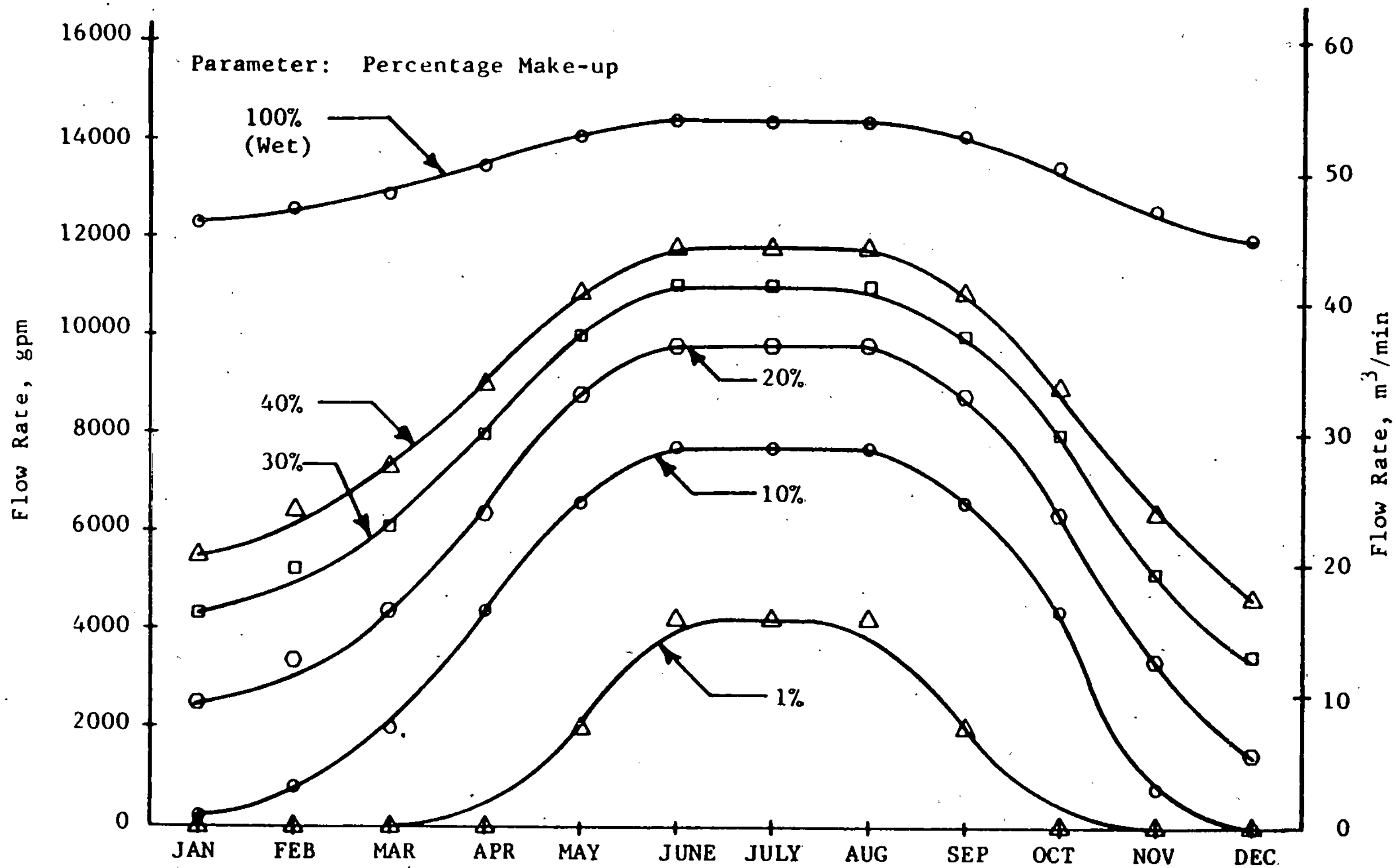

Figure 13 Maximum Make-up Flow Rate for Each Monthly Period for a 1000 MWe Nuclear Plant at San Juan, New Mexico Mechanical Series Operating in S1 Mode

NOTE: Curves are drawn through the discrete points to facilitate visual observation

TABLE 1

MAJOR DESIGN DATA FOR THE OPTIMIZED COOLING TOWER SYSTEMS FOR A 1000 MWe FOSSIL PLANT

SITE: SAN JUAN, NEW MEXICO   BASE OUTPUT: 1039 MWe   WET/DRY TYPE: MECHANICAL SERIES (S1)

Item	Mech. Dry (H)*	Mech. Dry (L)†	Percentage Make-up Requirement# Mechanical Series Wet/Dry					Mech. Wet
			2	10	20	30	40	
Number of Tower Cells, Wet Tower/Dry Tower	0/112	0/274	7/161	11/117	13/98	15/84	17/70	21/0
Maximum Operating Back Pressure P_{max}, in-HgA (mm-HgA)	12.60 (320.0)	5.03 (127.8)	5.0 (127.0)	4.5 (114.3)	4.0 (101.6)	3.5 (88.9)	3.5 (88.9)	3.12 (79.2)
Gross Plant Output at P_{max}, MWe	920.4	989.0	989.5	999.1	1009.5	1019.1	1019.1	1025.6
Heat Load at P_{max}, 10^9 Btu/hr (10^{12} J/hr)	4.86 (5.13)	4.62 (4.87)	4.62 (4.87)	4.59 (4.84)	4.55 (4.80)	4.52 (4.77)	4.52 (4.77)	4.50 (4.75)
Heat Load Distribution at P_{max}, (Wet Tower/Dry Tower), %	0.0/100.0	0.0/100.0	38.7/61.3	60.9/39.1	73.2/26.8	82.2/17.8	85.0/15.0	100.0/0.0
Annual Make-up Water for Wet Towers, 10^8 gal (10^6 m^3)	0.0 (0.0)	0.0 (0.0)	0.625 (0.237)	2.90 (1.10)	5.97 (2.26)	8.85 (3.35)	11.90 (4.50)	29.53 (11.18)

* H-High Back Pressure Turbine

† L-Conventional Low Back Pressure Turbine

\# Percentage of annual make-up required by optimized wet tower

TABLE 2

BASE COOLING SYSTEM COST AND MAKE-UP WATER PENALTY COST COMPONENTS FOR A 1000 MWe FOSSIL PLANT

SITE: SAN JUAN, NEW MEXICO YEAR: 1985 WET/DRY TYPE: MECHANICAL SERIES (S1)

	Mech. Dry (H)*	Mech. Dry (L)†	Percentage Make-up Requirement# Mechanical Series Wet/Dry					Mech. Wet
			2	10	20	30	40	
Capital Cost:								
Cooling Tower	39.07	95.58	60.20	47.27	41.84	38.11	34.43	12.39
Condenser	11.26	14.46	12.07	10.81	10.12	10.14	9.66	10.13
Circulating Water System	7.86	12.51	11.70	10.26	9.16	9.40	8.82	6.50
Electric Equipment	5.36	12.45	9.81	7.60	6.62	6.01	5.29	1.52
Indirect Cost	15.88	33.75	23.45	18.98	16.92	15.91	14.55	7.63
Total Capital Cost of Base Cooling System**	79.43	168.75	117.23	94.92	84.66	79.57	72.75	38.17
Penalty Cost:								
Capacity Loss	57.54	24.27	24.01	19.37	14.30	9.64	9.64	6.48
Power for Tower Fans & Circulating Water Pumps	11.16	23.37	15.18	12.17	11.22	10.99	9.82	5.12
Replacement Energy	29.62	0.49	4.48	8.04	8.54	7.00	7.98	2.23
Fan Energy & Circulating Water Pumping Energy	9.23	17.45	12.19	9.52	8.62	8.51	7.82	4.23
Cooling System Maintenance	3.91	8.15	5.64	4.71	4.19	4.04	3.75	1.81
Total Penalty Cost of Base Cooling System**	111.46	73.73	61.50	53.81	46.88	40.18	39.01	19.87
Make-up Water Penalty Cost:								
Make-up Water Purchase & Treatment Cost	0.00	0.00	0.10	0.48	1.00	1.47	1.98	4.92
Capital Cost for Make-up Water Supply Facilities††	0.00	0.00	5.50	7.00	7.76	8.32	8.59	9.46
Power and Energy Cost for Pumping Make-up Water	0.00	0.00	0.18	0.30	0.38	0.45	0.50	0.74
Total Make-up Water Penalty Cost	0.00	0.00	5.78	7.78	9.14	10.24	11.07	15.12
Total Evaluated Cost of the Complete Cooling System	190.89	242.48	184.51	156.51	140.68	130.00	122.83	73.16

* H - High Back Pressure Turbine

† L - Low Back Pressure Turbine

\# Percentage of annual make-up required by optimized wet tower

** Base Cooling System - Cooling system without make-up and water treatment facilities

†† Including 25% direct capital cost as indirect capital cost

TABLE 3

MAJOR DESIGN DATA FOR THE OPTIMIZED COOLING TOWER SYSTEMS FOR A 1000 MWe NUCLEAR PLANT

SITE: SAN JUAN, NEW MEXICO BASE OUTPUT: 1094 MWe WET/DRY TYPE: MECHANICAL SERIES (S1)

Item	Mech. Dry (H)*	Mech. Dry (L)†	Percentage Make-up Requirement Mechanical Series Wet/Dry					Mech. Wet
			1%	10%	20%	30%	40%	
Number of Tower Cells, Wet Tower/Dry Tower	0/175	0/431	9/263	15/170	18/138	21/119	25/102	32/0
Mode of Wet/Dry Tower Operation	-	-	S1	S1	S1	S1	S1	-
Maximum Operating Back Pressure P_{max}, in-HgA (mm-HgA)	13.09 (332.5)	5.03 (127.8)	5.00 (127.0)	5.00 (127.0)	4.50 (114.3)	4.00 (101.6)	4.00 (101.6)	3.30 (83.8)
Gross Plant Output at P_{max}, MWe	939.8	1047.5	1048.2	1048.4	1059.5	1069.9	1069.9	1082.2
Heat Load at P_{max}, 10^9 Btu/hr (10^{12} J/hr)	7.62 (8.04)	7.26 (7.65)	7.25 (7.65)	7.25 (7.65)	7.22 (7.61)	7.18 (7.57)	7.18 (7.57)	7.14 (7.53)
Heat Load Distribution at P_{max}, (Wet Tower/Dry Tower) , %	0.0/ 100.0	0.0/ 100.0	33.4/ 66.6	57.8/ 42.2	69.6/ 30.4	78.2/ 21.8	81.7/ 18.3	100.0/ 0.0
Annual Make-up Water for Wet Towers, 10^8 gal (10^6 m^3)	0.0 (0.0)	0.0 (0.0)	0.494 (.187)	4.57 (1.73)	9.11 (3.45)	14.19 (5.37)	18.78 (7.11)	47.02 (17.80)

* H-High Back Pressure Turbine

† L-Conventional Low Back Pressure Turbine

TABLE 4

MAJOR CAPITAL AND PENALTY COST COMPONENTS FOR OPTIMIZED COOLING TOWER SYSTEMS FOR A 1000 MWe NUCLEAR PLANT ($\$10^6$)

SITE: SAN JUAN, NEW MEXICO PRICING YEAR: 1985 WET/DRY TYPE: MECHANICAL SERIES (S1)

	Mech. Dry (H)*	Mech. Dry (L)†	Percentage Make-up Requirement Mechanical Series Wet/Dry					Mech. Wet
			1%	10%	20%	30%	40%	
Capital Cost:								
Cooling Tower	61.05	150.35	96.93	68.05	58.71	53.90	50.32	18.88
Condenser	15.22	20.96	19.08	14.63	14.25	13.69	12.29	13.69
Circulating Water System	10.96	19.80	23.18	15.49	14.94	14.21	12.56	7.93
Electrical Equipment	8.22	19.63	16.12	10.97	9.55	8.50	7.67	2.21
Indirect Cost	23.86	52.68	38.83	27.28	24.36	22.58	20.71	10.68
Total Capital Cost	119.31	263.42	194.14	136.42	121.81	112.88	103.55	53.39
Penalty Cost:								
Capacity	92.54	27.90	27.49	27.38	20.72	14.46	14.44	7.05
Auxiliary Power	20.74	45.17	32.17	21.81	20.17	19.32	17.37	9.22
Replacement Energy	58.06	1.28	4.86	14.17	15.06	12.94	14.19	2.70
Auxiliary Energy	20.54	39.50	30.10	20.23	18.54	17.91	16.43	8.88
Make-up Water	0.0	0.0	.07	.68	1.35	2.10	2.79	6.98
Cooling System Maintenance	5.78	12.59	9.30	6.74	6.18	5.76	5.39	2.62
Total Penalty	197.66	126.44	103.99	91.01	82.02	72.49	70.61	37.45
Total Evaluated Cost	316.97	389.86	298.13	227.43	203.83	185.37	174.16	90.87

TABLE 5

MAJOR CAPITAL AND PENALTY COST COMPONENTS PER UNIT
FOR THE WET/DRY AND WET COOLING SYSTEMS ($$10^6$)
SUNDESERT NUCLEAR PLANT

SITE: Blythe, Calif. MAKE-UP INTAKE SITE: OTO YEAR: 1985

Tower System	Wet/Dry					Wet
Annual Make-up Quantity	5%	10%	20%	30%	40%	100%
Capital Cost:						
Cooling Tower	84.611	80.295	73.458	63.820	54.732	21.688
Condenser	20.135	19.094	19.094	17.021	16.227	19.088
Circulating Water System*	23.374	22.070	22.969	15.712	14.437	14.975
Electric Equipment	13.854	13.142	12.160	9.980	8.498	3.004
Indirect Cost	35.493	33.651	31.920	26.633	23.474	14.689
Total Capital Cost of Heat Rejection System	177.467	168.252	159 601	133.166	117.368	73.444
Penalty Cost:						
Capacity Loss	60.290	47.790	34.890	34.890	34.890	13.906
Power for Tower Fans and Circulating Water Pumps	43.657	42.403	41.864	35.217	31.199	19.126
Replacement Energy	21.849	21.741	18.738	25.097	25.754	-3.018
Fan Energy & Circulating Water Pumping Energy	30.225	28.559	27.859	24.081	21.836	13.616
Cooling System Maintenance	12.564	12.240	12.287	10.237	9.479	6.488
Total Penalty Cost of Heat Rejection System	168.585	152.733	135.638	129.522	123.158	50.118
Water Penalty:						
Make-up Water Purchase Cost	0.323	0.655	1.172	1.773	2.447	6.000
Make-up Water Treatment Cost (Capital & Operation)	10.202	13.449	17.986	22.565	27.662	53.873
Make-up Water Supply Cost (Facility, Pumping Power & Energy)	8.061	8.622	9.481	9.675	11.367	12.588
Blowdown Cost (Solar Evaporation Pond)	0.926	1.858	3.340	4.991	8.526	16.487
Total Water Penalty Cost	19.512	24.584	31.979	39.004	50.002	88.948
Total Evaluated Cost of the Complete Cooling System	365.564	345.569	327.219	301.692	290.528	212.510

Note: Heat Rejection System = Circulating Water System in Reference 2.

* Includes pipelines, pumps, motors and associated structures of the heat rejection system.

TABLE 6

SUMMARY OF MAJOR DESIGN DATA PER UNIT FOR THE OPTIMIZED COOLING TOWER SYSTEMS
SUNDESERT NUCLEAR PLANT

SITE: Blythe, Calif. MAKE-UP INTAKE SITE: OTO BASE OUTPUT: 1023.10 at 2.5 HgA

Tower System	Wet/Dry					Wet
Annual Make-up Quantity	5%	10%	20%	30%	40%	100%
Number of Tower Cells, Wet Tower/Dry Tower	13/221	17/203	21/178	25/145	28/115	43
Surface Area of Tower, Acres	9.90	9.43	8.63	7.50	6.44	2.60
Maximum Operating Back Pressure P_{max}, in-HgA	5.00	4.50	4.00	4.00	4.00	3.17
Gross Plant Output at P_{max}, MWe	962.8	975.3	988.2	988.2	988.2	1009.2
Heat Load at P_{max}, 10^9 Btu/hr*	6.65	6.60	6.56	6.56	6.56	6.49
Heat Load Distribution at P_{max}, (Wet Tower/Dry Tower), %	51.3/48.7	63.3/36.7	75.4/24.6	79.4/20.6	82.8/17.2	100.0/0.0
Annual Make-up Water for Wet Towers, 10^3 acre-feet	0.76	1.55	2.77	4.19	5.78	14.18

* A constant auxiliary heat load of 2.16×10^8 Btu/hr must be added to each indicated value.

TABLE 7

EVAPORATION (MAKE-UP) RATES PER UNIT FOR WET/DRY AND WET COOLING SYSTEMS, GPM*
SUNDESERT NUCLEAR PLANT

SITE: Blythe, California

Tower System	Wet/Dry					Wet
Annual Make-Up Quantity	5%	10%	20%	30%	40%	100%
January	0 (0)	0 (0)	0 (0)	0 (0)	1015.0 (1087.5)	9143.1 (9796.3)
February	0 (0)	0 (0)	0 (0)	276.6 (296.4)	1949.5 (2088.8)	9751.0 (10447.6)
March	0 (0)	0 (0)	0 (0)	1144.0 (1225.7)	2575.5 (2759.5)	10049.7 (10767.6)
April	0 (0)	0 (0)	1076.0 (1152.9)	2940.8 (3150.9)	4182.4 (4481.2)	10932.2 (11713.3)
May	0 (0)	766.4 (821.1)	2641.5 (2830.2)	4126.0 (4420.8)	5362.1 (5745.2)	11393.3 (12207.3)
June	865.8 (928.7)	2449.7 (2624.8)	4389.0 (4702.6)	5821.1 (6237.0)	6671.7 (7148.3)	11923.8 (12775.7)
July	2730.3 (2925.3)	4293.7 (4600.4)	5832.0 (6248.7)	7209.3 (7724.4)	7984.0 (8554.4)	12398.4 (13284.1)
August	2320.0 (2485.8)	3947.4 (4229.4)	5552.5 (5949.1)	6626.7 (7100.1)	7838.9 (8398.9)	12409.6 (13296.2)
September	926.8 (993.0)	2631.6 (2819.6)	4291.8 (4598.4)	5890.6 (6311.4)	6801.1 (7287.0)	12238.4 (13112.8)
October	0 (0)	0 (0)	1543.4 (1653.6)	3522.9 (3774.6)	4823.9 (5168.5)	11317.5 (12126.1)
November	0 (0)	0 (0)	0 (0)	914.2 (979.5)	2733.1 (2928.4)	10235.4 (10966.6)
December	0 (0)	0 (0)	0 (0)	0 (0)	1327.9 (1422.7)	9362.6 (10031.5)
Maximum	6379.2 (6835.0)	7862.2 (8423.9)	9273.7 (9936.2)	10042.1 (10759.5)	10579.9 (11335.8)	13209.3 (14153.0)

TABLE 7 (cont'd)

MONTHLY AVERAGE DRY BULB AND WET BULB TEMPERATURES, °F*

Month	Jan.	Feb.	Mar.	Apr.	May	June	July*	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Bulb	51.4	58.4	63.1	73.6	80.2	87.7	94.7	93.0	88.6	76.4	62.6	53.1
Wet Bulb	43.4	46.0	50.0	54.4	59.0	64.0	69.0	65.4	59.7	52.5	45.0	42.5

* The mean maximum dry and wet bulb temperatures for the month of July are: DB = 108.0°F, WB = 80.0°F.

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Paper No. 3

COMPARATIVE COST STUDY OF VARIOUS WET/DRY COOLING CONCEPTS THAT USE AMMONIA AS THE INTERMEDIATE HEAT EXCHANGE FLUID

Prepared for Presentation at the US/USSR

Symposium on Waste Heat Rejection

Systems

By

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Abstract

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COMPARATIVE COST STUDY OF VARIOUS WET/DRY COOLING CONCEPTS THAT USE AMMONIA AS THE INTERMEDIATE HEAT EXCHANGE FLUID

by B. M. Johnson
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R. T. Allemann

A number of advanced concepts for wet-dry cooling systems for power generating plants have been studied for their technical feasibility and economic potential. These studies are part of an ongoing effort, supported by both the U.S. Department of Energy and the Electric Power Research Institute, to increase the flexibility of plant siting and reduce the break-even cost of water at which power companies would choose to conserve water through the use of some dry cooling.

The use of ammonia as a heat transfer medium between the steam condenser of the generator turbine and the air-cooled heat rejection system has been shown to be cost effective in earlier studies which were reported in the previous symposium. This paper summarizes the conceptual design and costs of four different advanced dry/wet concepts, which combine the use of ammonia with evaporative cooling to augment capacity on hot days, and compares them to a state-of-the-art integrated dry/wet circulating water system. All are mechanical draft systems.

The four concepts utilizing ammonia are:

- The HÖTERV plate fin heat exchanger with deluge augmented cooling arranged in vertical stacks on the periphery of circular towers.

- The HÖTERV plate fin heat exchanger with deluge augmented cooling arranged in horizontal A-frames beneath the fans.

- The separate channel augmented tower (SCAT) which embodies the use of chipped-fin aluminum heat exchange surface augmented with water flowing internally through channels isolated from, but adjacent to, the condensing ammonia.

- The augmenting ammonia condenser (AAC) arrangement which uses a similar chipped-fin heat exchanger as above, but is augmented by a separate water-cooled condenser close-coupled to a conventional evaporative cooling tower.

These are compared with the integrated dry/wet tower currently being constructed at the Public Service Company of New Mexico's San Juan Unit 3 station at Farmington, New Mexico, a 550 MWe mine-mouth plant.

The comparable cost of the five concepts, i.e., the sum of the estimated capital cost and the capitalized operating cost (obtained by dividing the annual operating costs by the annual fixed charge rate of 18%) are as follows:

Heat Rejection Concept	Estimated Capital Cost ($ M)	Capitalized Operating Cost Estimate ($ M)	Comparable Capital Cost Estimate ($ M)
Vertical HÖTERV Tower	24.8	3.1	27.9
Horizontal HÖTERV Tower	21.6	3.1	24.7
SCAT Tower	21.5	3.0	24.5
Augmenting NH_3 Condenser	19.8	4.1	23.9
Integrated Dry/Wet	23.4	9.6	33.0

These results indicate that the ammonia dry cooling systems, augmented either by deluging the surface (if the surface configuration facilitates this) or by a separate water-cooled condenser close-coupled to an evaporative tower, have potential cost advantages ranging from 25 to 29% under conditions imposed by the San Juan site.

A program to demonstrate an ammonia dry cooling system, using both types of surface described here, and using both the deluge approach and the augmented condenser, is being undertaken by the Electric Power Research Institute.

Prepared for Presentation at a

US/USSR Symposium on

Waste Heat Rejection and Utilization

Fall 1978

Comparative Cost Study of Various Wet/Dry Cooling Concepts that Use Ammonia as the Intermediate Heat Exchange Fluid

B. M. Johnson, R. D. Tokarz, D. J. Braun, R. T. Allemann

1. PURPOSE OF THIS WORK

Dry cooling of thermal power plants, by which the heat from the power cycle is rejected directly to the air, has been used in a few isolated instances throughout the world for the past 15 years. Very few installations are in operation in the U.S. although it is being given increased consideration for new large power stations. Dry cooling is a more costly option than once-through or evaporative cooling, but there are a few locations now, and there will be far more in the future, at which once-through and all-wet evaporative cooling towers cannot be used because of the increased competition for existing water supplies among growing populations, agriculture and industry. Earlier studies at Battelle, Pacific Northwest Laboratories, have shown that considerable incentives exist for development of an advanced concept which makes use of ammonia as an intermediate heat transfer fluid in a process which provides augmented cooling by evaporation.

This paper summarizes the conceptual design and costs of four different configurations for such a system and compares them to a state-of-the-art integrated dry/wet circulating water system.[1] All are mechanical draft systems.

These studies are part of an ongoing effort, supported by both the U. S. Department of Energy and the Electric Power Research Institute, to increase the flexibility of plant siting and reduce the break-even cost of water at which power companies would choose to conserve water through use of some dry cooling.

1.2 Incentives for Dry/Wet Cooling

Providing some capability for augmented cooling via water evaporation to dry cooled heat rejection systems has been shown to be highly cost-effective. It is probable that in this country most dry-cooled systems for large power plants will have some evaporative cooling capability included in the system to avoid either of the costly alternatives of (1) building excessively large systems to provide adequate heat rejection for peak power projection during the hottest summer days, or (2) buying power from other sources during peak demand periods on the hottest days. With some evaporative cooling capability the dry/wet system can be built so as to use whatever water is available for cooling and thus minimize the required size of the high-priced dry cooling system. How to best provide this evaporative cooling capability with the ammonia system was one of the purposes of this work.

1. R. D. Tokarz, et. al., "Comparative Cost Study of Four Wet/Dry Cooling Concepts that use Ammonia as the Intermediate Heat Exchange Fluid," PNL-2661, Battelle Pacific Northwest Laboratories, May 1978.

1.3 Incentives for Using Ammonia

The use of ammonia as a heat transfer medium between the steam condenser of the turbine-generator and the air-cooled heat rejection system has been shown to be cost effective in earlier studies which were reported in the previous symposium.[1] The use of ammonia offers at least four advantages leading to reduction in system costs. These are:

1. Reduced pumping power in the transport loop;
2. Elimination of the temperature range of the transport loop as a temperature increment between the ambient dry bulb and the condensing steam temperature;
3. The ability to use high performance surfaces on the ammonia side of the steam condenser/ammonia reboiler to reduce the condenser terminal temperature difference, and lastly,
4. No need to prevent freeze up.

2. BASIS OF COMPARISON

The comparisons of the various concepts were performed on the basis of "comparable capital cost" defined as the sum of the estimated capital cost of the installation plus the capitalized operating cost. This latter term is just the operating cost divided by the annual fixed-charge rate of 18 percent. The designs have not been optimized in the sense that they would yield the lowest bus bar cost of electricity. At the time the study was initiated the dry/wet design optimization code was not completed. Instead, each design satisfies a set list of design parameters, particularly with respect to heat rejection capability

[1] Advanced Dry and Dry/Wet Cooling Towers, B.M. Johnson, Battelle-Pacific Northwest Laboratory, Richland, WA. Prepared for Presentation at the US/USSR Symposium on Dry and Wet/Dry Heat Rejection Systems, Washington, D.C., Sept 1977

at a specific ambient temperature, which was established so as to require a predetermined amount of water each year for augmented cooling.

Capital costs included all engineering, construction and material costs associated with the cooling towers, condenser, water treatment equipment and related piping and pumps. Construction costs included the contractor's profit and overhead, but excluded any escalation or contingencies. Operating costs included the cost of auxiliary power for pumps and fans, maintenance, and water treatment.

Credit was taken for improvements in plant heat rate associated with lower back pressures made possible by the advanced designs. However, no credit was taken for increases in load that would be made possible by back pressures lower than the design values of the reference plant.

To assure the validity of the comparisons, every effort was made to use uniformity in the conceptual designs and cost estimation of each concept. All estimates were prepared by an architect-engineer subcontractor [a] from preconceptual design descriptions prepared for each concept. All design descriptions used a common reference plant location, the San Juan Unit 3 of the Public Service Company of New Mexico. This plant was selected as the reference plant for this study because a plant with integrated dry/wet cooling towers is currently under design and construction at this location. As a result, adequate site data were already available on which to base the preconceptual designs of the advanced alternatives, including

- meteorology,
- fuel costs,

(a) S&Q Engineering Corporation

- water availability and quality,
- onsite construction costs,
- transportation costs,
- power costs, and
- site characteristics.

Each of the dry/wet systems was conceptually designed and estimated using the same procedure, including the integrated wet/dry concept used in the reference plant. No cost or detail design information was obtained from the utility about the integrated wet/dry concept, so it, too, was designed and costed on the same basis as the other four. This cost comparison study applies only to the reference plant design conditions. Other sites would have different conditions that could markedly affect the resulting comparison.

2.1 Conceptual Design Bases

The conceptual designs of the three cooling tower concepts were based on performance requirements established by the Public Service Company of New Mexico for the San Juan Unit 3. These requirements are listed below.

1. The heat rejection capability of the cooling system shall be about 2.5 x 10^9 Btu/hr over a yearly cycle.
2. The cooling system shall accommodate the meteorological profile of Farmington, New Mexico (Table 1).
3. The turbine shall be operated at or below a back pressure of 4.5 in. Hg at an ambient temperature of 95^{o}F or below. Above 95^{o}F, the turbine back pressure shall be allowed to increase to a maximum of 5.0 in. Hg.

Table 1. Meteorological Profile at Farmington, NM

Dry Bulb Air Temperature, °F	Wet Bulb Air Temperature, °F	Hours per Year
7	7	55
12	11	98
17	16	198
22	20	336
27	25	553
32	29	698
37	33	688
42	36	708
47	39	678
52	41	648
55	44	388
57	45	259
62	47	704
65	49	411
67	50	274
70	52	351
72	53	234
75	54	295
77	54	197
80	55	245
82	56	164
87	58	331
92	61	179
97	62	34
102	63	1

4. The maximum amount of water available annually for consumptive use is 1900 acre-ft or 5.12×10^9 lb, which is about 20% that consumed by all-wet tower of similar rating.
5. The maximum instantaneous flow rate of consumptive water due to evaporation shall be 2.0×10^6 lb/hr (4000 gpm).

The San Juan River was assumed to be the source of water to the plant. Water treatment requirements for closed-loop recirculating systems associated with dry towers were assumed to include demineralization, vacuum deaeration, corrosion inhibition, and pH control (pH 8.5). Open loop systems used in wet and wet/dry towers were assumed to require lime-soda softening (side stream), scale inhibition and biofouling control. Delugeate treatment to maintain a Langlier saturation index of zero or slightly negative was assumed.

3. ALTERNATIVES CONSIDERED

The four cooling concepts principally studied utilize the ammonia liquid-vapor phase change to transfer heat from the steam turbine outlet to the cooling towers. These concepts are compared with the conceptual design of the integrated dry/wet cooling tower of a configuration similar to that being constructed at Farmington, New Mexico. This design and cost estimate were developed without obtaining design details or costs from either the owner or manufacturer of that system. Consequently all systems were estimated by the same method and from similar data base. However, the ammonia systems' designs had not undergone the extent of engineering optimization studies inherent in a commercial system.

3.1 Ammonia Heat Transport System

The following is a brief description of the salient features of the ammonia heat transport system.

The ammonia heat transport system for power plant heat rejection is functionally similar in many respects to the "direct" system in which the exhaust steam from the last stage of the turbine is ducted directly to an air-cooled condenser. The principal difference is the existence of a steam condenser/ammonia reboiler in which ammonia is "substituted" for steam as the medium for transporting heat from the turbine to the tower (heat sink). In all respects the ammonia system, with vapor moving from the reboiler to the air-cooled condenser and liquid returning to the reboiler, will function and respond to load changes in the same manner as the direct system. Figure 1 is the process flow sketch.

Exhaust steam from the last stage of the turbine is condensed in the condenser/reboiler located directly below the turbine. Instead of water circulating through the tubes, liquid ammonia is boiled as it is pumped through the tubes under pressure, set by the operating temperature in the condenser. The flow rate of ammonia is set to yield a vapor quality emerging from the tubes varying from 50 to 90%. This two-phase mixture is passed through a vapor-liquid separator from which the vapor is sent to the air-cooled condenser, while the liquid is combined with the ammonia condensate from the dry tower and recycled back through the condenser/reboiler.

Table 2. Design Parameters

Tower	Vertical HOTERV	Horizontal HOTERV	SCAT Tower Design	Augmenting NH3 Condenser	Integrated Wet/Dry
Tower size (ft)	259 dia x 56 high	205 x 230 x 57 high	225 dia x 56 high	170 dia x 56 high	482 x 138 x 55 high
Tower Design Temp.	55°F	55°F	55°F	35°F	35°F
Design ITD, degrees	67	67	67 dry, 32 wet	87 dry, 32 wet	90 day, 30 wet
Number of Towers	3	2	2	2	2
Number of Bundles	288	288	122	88	320
Dimensions	47.6 ft x 8 ft x 6 in.	47.6 ft x 8 ft x 6 in.	50 ft x 12 ft x 1 ft	50 ft x 12 ft x 7.2 in.	48 ft x 72 ft x 10 in.
Total Surface Area, ft^2	9.71×10^6	9.71×10^6	8.91×10^6	5.41×10^6	7.206×10^6
Frontal Area, ft^2	1.072×10^5	1.072×10^5	0.732×10^5	0.522×10^5	9.216×10^4
Tube OD, inches	0.78	0.78	0.3	0.3	1.07
Fin Design	Rectangular Plate	Rectangular Plate	Integral	Integral	Single Leg Wrapped
Fin Dimensions	6 in. deep 7.87 ft high	6 in. deep 7.87 ft high	0.707 in. high 12 in. deep	0.707 in. high 12 in. deep	2.25 round
Fins Per Inch	9	9	10.6	10.6	10
Tube Material	Aluminum	Aluminum	Aluminum	Aluminum	Admiralty
Fin Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Tube Geometry	Staggered Rows	Staggered Rows	Rectangular Aligned Channels	Rectangular Aligned Channels	Equilateral
Transfer Tube Pitch, Inches	2.36	2.36	NA	NA	2.35
Heat Transfer Coefficient Btu/hr-ft^2-°F	7.57	7.57	8	9.1	6.41
Frontal Velocity/ Internal Velocity, ft/sec.	8/13.3	8/13.3	12/16.4	14.0/19.1	10.5/15
Air Flow, lb/hr - Dry	1.93×10^8	1.93×10^8	1.97×10^8	1.70×10^8	2.196×10^8
Air Flow, lb/hr - Wet	1.3×10^8	1.3×10^8	0.45×10^8	0.47×10^8	0.24×10^8
Air Mass Flow Rate, lb/hr-ft^2 - Dry / - Wet	1.79×10^3 / 0.9×10^3	1.79×10^3 / 0.9×10^3	2.69×10^3	3.26×10^3	2.38×10^3 / 0.5×10^3
Cooling Water Flow, GPM	7,000 (80 TDH)	21,000 (40 TDH)	170,000 (35 TDH)	200,000 (35 TDH)	219,000 (77 TDH)
Airside Heat Exchange/ΔP/ Total ΔP, Inches H_2O	0.356/0.464	0.356/0.464	0.281/0.384	0.243/0.358	0.345/0.538
Fans - Dry / Wet	57	56	48 / 8	26 / 8	40 / 10
Fan Diameter, ft - Dry / Wet	28	28	28	28	30 / 24
HP Per Fan - Dry / Wet	82.3	82.3	50 / 150	105 / 150	145 / 90
Number of Blades - Dry / Wet	6	6	6	6	8 / 6
Pitch, degrees - Dry / Wet	12	12	10 / 22	16 / 22	14 / 16

The vapor from the vapor-liquid separator flows to the dry tower under the driving force of the pressure difference between these two components created by the temperature difference and the associated vapor pressure of the ammonia.

The steam condenser is composed of horizontal tube bundles, with steam condensation on the shell side, and anhydrous ammonia evaporation on the tube side. Design tube side maximum pressure is 350 psig, 135°F. Tubes are aluminum with the following dimensions:

tube length	50 ft
tube OD	1 in.
tube gauge	12 BWG
tube pitch	1.5 in.
total number of tubes	15,100

The tube is enhanced on the outside for condensation and on the inside for boiling with proprietary Union Carbide Company/Linde enhanced condensation surface. The tubesheets are aluminum and the condenser is equipped with impingement protection where necessary.

The air removal section of the condenser is stainless steel.

The performance and cost of this component are significant uncertainties in this study. The cost algorithms developed for computer optimization studies on the basis of laboratory data indicated its cost would be very nearly similar to that of a conventional turbine condenser. The estimate developed by the architectural engineer and used in this study, reflected the lack of firm data from similar equipment. The architectural engineer estimated the equipment to be 50% more costly than a conventional condenser.

The piping for the system consists of vapor transport piping, vapor distribution piping, condensate collection piping, and condensate return piping. Associated with this system are pumps for condensate return and reboiler circulation, a combination vapor separator/reboiler supply tank, and ammonia storage tanks. The vapor separator/reboiler supply tank is located as close to the steam condenser/ammonia reboiler exit as possible. The upper portion of the tank acts as a cyclone separator to remove liquid ammonia carried over in the vapor leaving the reboiler. The lower portion of the tank acts as a reservoir for supplying the reboiler injection pumps and also provides system surge capacity. The lower portion of this tank has sufficient volume to contain the inventory of two tower quadrants if it becomes necessary to evacuate them for maintenance or in case of leaks. The material for all piping and tanks is carbon steel.

Each of the two condensate return pumps would have a capacity of 10,000 gpm at 27 ft NH_3 TDH. Each of the two condenser recirculation pumps would have a capacity of 20,000 gpm at 30 ft NH_3 TDH. The drain and fill pump would have a capacity of 2500 gpm at 50 ft NH_3 TDH.

Excess storage capacity would be provided by ten 7750-gal pressure tanks. These tanks will store the entire quantity of ammonia if it becomes necessary to evacuate the system for maintenance or in case of emergency.

Provision is made for a nitrogen purge system to flush the air from the system before filling it with ammonia to prevent the possibility of stress corrosion cracking of the steel components. The total volume of the system is approximately 50,000 ft^3. Vents are located at the highest point in each quadrant from which ammonia vapor can be evacuated after the quadrant has been drained and isolated. The vents are piped to a flare station on top of the tower.

3.2 HÖTERV Plate Fin Heat Exchanger with Deluge Augmentation

The initial cooling tower arrangement using the HÖTERV plate fin exchangers was round towers with fans across the top and the heat exchangers around the periphery. Previous studies had shown this to be a cost effective configuration for long fin-tube exchangers. However, as the result of the ensuing cost estimate for the towers, it was concluded that it was not a good arrangement for the HÖTERV bundles arranged horizontally to accommodate deluging. A second configuration was scoped out and estimated in which the heat exchangers were arranged as A frames on a plane below the fins. Figures 2 and 3 show these two arrangements.

With the vertical peripheral arrangement, three towers 260 ft in diameter and 56 ft high (to the fan deck) are needed. The cooling tower is designed to operate as a completely dry system when the ambient temperature is below 55°F. Above this temperature, a portion of the heat exchanger surface is deluged with water on the outside of the plate fins to increase heat rejection capability. In this way sensible heating of the air is augmented by heat transfer to the air through evaporation of the deluge water. The tower design temperature is based upon the maximum use of available water for augmentation (1900-acre ft) with minimum amount of heat exchange surface area.

The airflow through each tower is induced by 19 fans (28-ft diameter) mounted at the top of the tower structure. The heat exchanger bundles (240 tubes/bundle) are arranged around the periphery of the towers. No louvers for air control to prevent freezing of the ammonia are required. However, passive louvers are located beneath each fan to prevent back flow of air when a particular fan is off. For airflow control, one or more fans can be started or stopped. Protection of the heat exchanger surfaces is provided by hail screens mounted directly to the face of each bundle. Table 2 gives specific information on all of the cooling tower systems at design point conditions.

The HÖTERV heat exchangers are 47.6 ft (15 m) long, 7.8 ft (2.3 m) high, and 5.9 in. (15 cm) deep in the direction of airflow. There are 16 bundles/tower quadrant , 96 bundles/tower, and 288 bundles total. The bundles are sloped at a 5 degree angle to promote drainage of the condensed ammonia. They are also canted forward to promote uniform deluging of the plate fins during wet operation.

All of the vapor transport piping lies above grade. The main vapor line transports ammonia vapor from the vapor separator to the general area of the cooling towers through a 48-in. diameter pipe approximately 1000-ft long. The piping then splits into successively small pipes leading to each tower and subsequently to tower quadrants, bundle groups and eventually individual bundles. The condensed ammonia liquid drains to a collection header running around the inside periphery of the tower. The main return line is 18 in. in diameter.

The deluge system is capable of augmenting the entire heat exchanger surface, although the maximum design wet area is probably less than 67%. Augmentation of the plate-fin surfaces is accomplished by allowing an approximate water flow rate of 2 gpm per lineal ft of heat exchanger to run down the plate fins. A small perforated pipe header adds water above each bundle to make up for the deluge water evaporated in the previous bundle. The deluge piping for each tower consists of

- two deluge pumps (vertical sump),
- deluge storage sump,
- distribution piping, and
- deluge distribution headers and splash plates.

The deluge pumps will have a capacity of 1200 gpm at 80 ft of H_2O (two pumps per tower). The suction side of the vertical sump pump will be immersed in a circular concrete channel that catches all the water falling from the tube bundles and serves as a storage sump when the tower is operating dry. Polyethylene or PVC is used throughout. Maximum instantaneous consumptive use rate is approximately 4000 gpm. The maximum recirculation rate to the top of the towers is 7200 gpm, although the maximum anticipated is about 4500 gpm, with additional makeup being added at each of the five layers of heat exchanger in the vertical arrangement. Water treatment will consist of sulfuric acid addition to control pH to 7.6-7.8 and blowdown (800 gpm) to maintain a sufficiently low dissolved solids concentration. The blowdown will undergo lime softener treatment, and the effluent from the treatment plant will be recycled into the deluge system. Sludge from the softener (85 gpm) will be discarded to the effluent pond.

The horizontal arrangement of the HÖTERV heat exchangers differ essentially only in the tower configuration. Each of the two required towers is 205 ft by 230 ft and 57 ft to the fan deck. The horizontally arranged bundles are 35 ft above the ground to provide adequate area for air flow. Twenty eight fans (28 ft diameter) are used.

The A frames of the heat exchanger bundles are tilted at 5° as in the vertical design to promote drainage of the ammonia.

The total recirculation flow of the deluge system is higher, about 20,000 gpm because the bundles are not vertically stacked to provide a means of water flow down the stack.

The savings in this arrangement accrue from the need for only two towers. Table 2 lists the significant design parameters which are very similar to those of the vertical arrangement.

3.3 Separate Channel Augmented Tower

The heat exchanger in this concept is an adaptation of the Curtiss-Wright surface comprising integral fins chipped from an extruded multi-port aluminum tube. Additional cooling is provided by the separate channel augmented tower (SCAT) system, which uses selected channels within each multichannel tube as water channels. (Figure 4) When water is pumped through these channels, increased cooling of the ammonia occurs by heat transfer to the water. The heated water is piped to a wet cooling tower, located either inside the dry tower (this design) or outside. The basic design parameters for the SCAT system are the same as the previous two concepts. The tower can reject the design heat load without the use of any water at a turbine exit temperature of 130^{o}F, an ambient temperature of 55^{o}F, and an 8^{o}F temperature drop across the condenser/reboiler and the ammonia transport lines.

Each of the quadrants of the two towers can be operated all dry or with additional SCAT cooling using the wet tower. The airflow through each tower is induced mechanically with 34 fans (28 ft diameter) mounted at the top of the tower structure. The 50 ft by 12 ft x 1 ft (in the direction of air flow) heat exchanger bundles (80 tubes/bundle) are arranged vertically around the periphery of the towers.

Ammonia vapor enters at the top and saturated liquid ammonia emerges at the bottom. Figure 5 shows the cross-section of the tubes. For the purpose of sizing the tower, the fins over the back portion of the tube where the water channels are located were not included in the calculation of heat transfer to the air during wet operation but were included in the calculation for pressure drop. For enhanced cooling, water is run through five alternating channels in the rear (relative to airflow) of the SCAT tube and then through the wet tower for cooling. The temperature range of this water, the overall heat transfer coefficient, and the effectiveness of this section of the bundle for heat transfer are calculated independently of any interaction with the airflow over the tube. This is justified by the fact that the air and the cooling water would be at approximately the same average temperature in this part of the bundle and the presence of the air would neither add nor subtract from the cooling action of the circulating water. Table 2 lists the significant design parameters of the tower.

The wet tower which provides cooling of the circulating SCAT water is located concentric and within the dry tower structure. A portion of the air drawn through the heat exchanger is taken on through the wet packing and exhausted by the wet tower fans. The rest of the air is exhausted by the dry-only fans arranged in the annular region between the respective peripheries of the wet and dry towers. When the tower is operated at less than fully enhanced cooling capacity, sections of the wet packing are not wetted; none are wetted during all-dry operation (below 55°F). The tower is designed for a 67.5°F wet bulb and 113.6°F dry bulb for air inside the dry tower. A water range of 17.8°F and an approach of 22.5°F is used with inlet water at 107.8 and outlet at 90°F.

Up to 170,000 gpm of circulating water through the SCAT channels is provided by 16 pumps (2 per quadrant in each tower). Very close coupling exists between the heat exchangers and the wet tower. Eight inch polyethylene lines carry water up through heat exchanger and then to the tower. Water treatment is the same as for the integrated wet/dry system although a smaller quantity is needed.

3.4 Augmenting NH_3 Condenser

The concept of using a water-cooled ammonia condenser for augmented cooling, located at the dry tower and close coupled with a wet tower, was selected for the following reasons:

1. Less design uncertainty than with a turbine condenser cooled by both water and ammonia;
2. Close-coupling the ammonia condenser and wet tower was believed to more than offset the increased equipment size and cost resulting from the loss in temperature difference.

The condensers (four for each tower) function in parallel with the dry tower to maintain the pressure in the ammonia. Since the operation of the dry tower is unaffected by the operation of the condenser (unlike the deluge approach), evaporative cooling is not substituted for dry cooling and the dry tower can be somewhat smaller for the same water allotment. Like the integrated tower, described in Section 3.5, it is designed for an ambient temperature of 35°F (ITD=87°F) rather than 55°F (ITD=67°F) for the other three systems.

Placement, spacing, and general configuration is similar to the SCAT towers. However, the higher design ITD and simpler tube configuration result in a smaller tower. The heat exchanger bundles (80 tubes/bundle) are arranged around the periphery of the towers as shown, and the water-cooled condenser (four in each tower) are hung within the annular space between the periphery of the dry and wet towers. The enhancement cooling water is pumped from the center basin to the top header of each of the condensers, passes down and back up through the cooling tubes and out the top header to the wet tower inlet distribution box.

The heat exchangers are bundles of multiport finned channels 50 ft x 12 ft x 7.2 in. (in the direction of airflow) of the integral chipped-fin type manufactured by Curtiss-Wright. Each bundle consists of 80 tubes 50 ft long.

Table 2 summarizes the design parameters for the dry tower.

The eight water-cooled condensers are tube-in-shell pressure vessels designed for 350 psi at 150°F with ammonia on the shell side. Each is 8 ft in diameter and contains 875 U-bend aluminum tubes 1 in. in diameter 50 ft long. Maximum flow through each is 25,000 gpm. The wet tower which provides cooling for the circulating water is integral with the dry tower and is located concentric within this structure essentially the same as with the SCAT concept. The water system is closely similar to SCAT except that slightly more water is used.

3.5 Integrated Dry/Wet Cooling Tower Concept

This heat rejection concept is currently planned for use in the San Juan Unit 3. It was included in this study to provide a basis for comparing these alternative concepts to previous design concepts and to each other. To assure the validity of the comparisons, this system was conceptually designed and estimated using the same bases as the other concepts, i.e., without reference to actual cost figures and design details.

The condenser cooling water is transmitted to the cooling towers via a 96-in diameter concrete piping system and circulated by three 73,000 gpm (77 TDH) vertical well pumps. Two rectangular cooling towers house both the air-cooled heat exchange surface, which is composed of spiral-wrapped finned tubes tilted 25 degrees from horizontal and the wet tower packing. The hot water from the condenser passes first through the dry section and then flows directly into the wet towers. The cooling tower is designed to operate as a completely dry system at temperatures below 35°F by turning off the fans above the wet portion of the tower. A sketch is shown as Figure 6.

There are 10 heat exchanger units per tower, two units in each bay. The spiral-wrapped fin tubes are 1 in. in diameter, of Admiralty metal, with the thin (0.018-in.) aluminum fin wound as a single leg wrap around the tube. They are arranged in a staggered equilateral close-packed spacing three rows deep.

A total of 25 induced draft fans were specified for each tower, 20 in the dry section and 5 in the wet section. Louvers have not been specified although they may be required for airflow control during high winds and for equalizing flow into each bay to avoid local freezing.

The conventional steam condenser contains 28,500 admiralty metal tubes 1 in. in diameter and 35 ft long.

4. BASES FOR COST ESTIMATES

All cost data developed by the architect/engineering firm reflect construction as of mid 1976 and thus include no contingency or escalation.

The preconceptual designs which have been developed and evaluated in this report are not the optimal design for each system, i.e., they are not designs which have been coordinated with the design and sizing of the steam supply to give the lowest cost of busbar electricity. Instead, they are designs which fit a stipulated set of conditions with respect to ambient temperature and heat rejection capability.

Optimization studies of dry (and dry/wet) systems generally compare the "operating costs" of alternative systems in terms of several "penalty costs" which represent the incremental increases in plant operating costs resulting from the use of the dry cooling system in relation to a reference system with a once-through flow of cooling water. Included in the list of penalty costs may be those for (a) an energy penalty because during hot weather the plant cannot export as much energy as the reference plant, (b) a capacity penalty because reserve generating capacity must be available to make up for the deficiencies of the dry cooled plant, (c) a make-up water penalty which reflects the cost of any water treatment unique to the subject plant.

An "optimized" design represents a trade-off between a larger-sized cooling system which has small energy and capacity penalties and a smaller-sized cooling system which has larger penalties.

With the present comparison of five systems there were no such trade-offs involved in the designs. All were sized to meet stipulated parameters

Table 3. Operating Cost Summary
(dollars)

		Vertical Höterv	Horizontal Höterv	SCAT Tower	Augmenting Ammonia Condenser	Integrated Wet/Dry
Hours of Operation	Dry	6 640	6 640	6 640	6 640	6 640
	Wet	4 426	4 426	4 426	5 146	5 146
Circulation Pump Primary Fluid		38 500	38 500	38 500	38 500	694 000
Circulation Pump Augmenting Cooling Water		10 100	19 600	110 900	130 900	--
Water Treatment		79 000	79 000	89 000	105 000	105 000
Fan Power		588 900	571 600	435 400	433 300	798 000
Capacity Penalty (Annualized)		83 300	84 700	95 600	98 000	184 000
Fuel Saving Credit Due to Reduced Back Pressure		-235 000	-235 000	-235 000	-55 000	- 55 600
TOTAL		564 800	558 400	534 400	750 100	1 725 400

of inlet temperature difference, heat rejection capability and annual water rate. Thus, the gross plant output is approximately the same from a plant equipped with each cooling system. However, the total penalties would differ with each design, depending on the characteristics of each with respect to: 1) the power required for fans and water/ammonia recirculating, 2) the capacity penalty for this power, and 3) water treatment and pumping power required for the enhanced (evaporative) cooling system.

In addition, there is a negative energy penalty which arises from increased output in cold weather which differs in each case. All plants have been designed to reject the stipulated heat load at a particular design ambient temperature. At temperatures below this, the plant is capable of operating at rated output with lower fuel consumption because of higher turbine efficiency (lower back pressure). Credit is taken for fuel savings from the higher plant efficiency. The three alternatives using deluge cooling are designed to a higher ambient temperature (55°F vis-a-vis 35°F for the other two) because a large dry tower is required to compensate for the dry capability taken out of service as it is converted to evaporative cooling by deluging. This has the compensating effect that the plant can operate at a lower back pressure in the winter and thus use slightly less fuel.

In summary, in this study the differences in "penalties" among the various alternatives are accounted for by evaluating five "operating" cost terms and a sixth capital cost term. Those six cost terms are:

- power for the main circulating system,
- power for the fans,
- water treatment operating costs,
- power for pumping deluge water,
- fuel savings resulting from the capability to operate at lower than the reference turbine back pressure at temperatures below the design ambient, and
- capital cost of peaking reserve capability to provide auxiliary power to the cooling system.

To combine these "operating" and other penalty costs with the capital costs of the plant, the former are "capitalized" by dividing by an annual fixed-charge rate of 18% and adding them to the capital cost.

Water treatment would include scale inhibition by pH adjustment and biofouling control with chlorine. Blowdown would be treated by lime softening to remove dissolved solids with return of the effluent and drying of the sludge. In addition provision would be made to supply demineralized water from zeolite softeners to flush the deluged surfaces. The main differences in cost are due to the cost of biofouling control.

All operating costs are summarized in Table 3.

5. RESULTS

To facilitate comparison of the total costs of the five dry/wet systems a "comparative capital cost" was used which is defined as the sum of the estimated basic capital cost (i.e., the estimated cost

Table 4. Capital Cost Estimates

(Thousands of Dollars)

	Vertical HOTERV	Horizon. HOTERV	SCAT Tower	Aug. Ammonia Cond.	Integrated Wet/Dry
STEAM CONDENSER	2,653	2,653	2,653	2,653	1,740
COOLING TOWER					
Dry Tower Structures	1,905	998	858	600	2,182
Piping-NH_3	308	102	213	152	--
Heat Exchangers	5,874	5,387	4,982	2,734	
Pumps/Piping-H_2O	305	423	678	703	1,215
Augmented Ammonia Cond.	--	--	--	1,562	
Wet Tower	--	--	263	309	1,078
Fans	1,205	1,186	1,070	880	2,646
Vents & Flair	15	10	10	10	--
Subtotal	9,612	8,105	8,073	6,950	10,307
MAIN COOLING SYSTEM					
Pumps/Piping Vapor	309	344	342	342	--
Pumps/Piping Liq.	422	264	273	273	1,951
Pumps-Reboiler	159	159	159	159	--
Vapor/Liq.Sep.	310	310	310	310	--
Subtotal	1,200	1,077	1,084	1,084	1,951
STORAGE/FILL/DRAIN	780	780	780	780	86
COVER GAS	211	143	143	143	--
WATER TREATMENT	562	628	545	545	451
ELECT/INST	2,263	1,554	1,633	1,633	1,994
BUILDINGS	52	52	52	52	52
COMPLETE SUBTOTAL	17,334	14,994	14,963	13,840	16,584
CONTRACTORS OH & PROFIT	3,329	2,998	2,948	2,631	2,921
ENGRG & COST MGMT	4,132	3,598	3,582	3,394	3,902
TOTAL CAPITAL COST	24,795	21,590	21,493	19,765	23,407

(Without Contingency and Escalation.)

without escalation and contingency) and the capitalized annual operating cost. This latter cost is just the estimated annual operating cost (summarized in Table 3) divided by the annual fixed charge rate of 18 percent.

5.1 Capital Costs of Alternatives

The subsystem capital costs of the four ammonia systems and the integrated wet/dry system are listed in Table 4. The integrated dry/wet concept is considered a baseline for comparison because it represents current practice. The San Juan Plant Unit 3 is currently being constructed with a heat dissipation system of this type. The estimate of the integrated dry/wet concept was performed without the benefit of prior knowledge of actual construction costs of San Junit Unit 3 to put all estimates on the same relative basis and may or may not correspond to actual costs.

5.2 Comparative Costs

The comparable costs of the four concepts plus the state-of-the-art integrated Wet/Dry are listed in Table 5.

Table 5. Summary of Comparative Capital Costs (dollars)

Cooling Tower Concept	Basic Capital Cost	Capitalized Operating Cost	Comparable Capital Cost
Integrated dry/wet	23,407,000	9,586,000	32,993,000
Vertical HÖTERV tower	24,795,000	3,138,000	27,933,000
Horizontal HÖTERV tower	21,590,000	3,102,000	24,692,000
SCAT tower	21,493,000	2,969,000	24,462,000
Augmenting Ammonia Condenser	19,765,000	4,167,000	23,932,000

The costs presented in this paper are approximate in nature. None of the concept designs were fully optimized from the standpoint of all parameters involved. However, all designs and estimates were arrived at utilizing the same bases and uniform procedures. It is not anticipated that exhaustive optimization would change the relative ranking of the concepts with regard to comparative capital costs.

The ammonia systems were found to have potentially lower capital and operating costs than comparable capital cost for the integrated concept considered in this base study. Although the ammonia systems require (1) an ammonia reboiler, which may be somewhat more complex and expensive than a simple condenser, and (2) a complex pressurized ammonia fill and drain system, the ammonia systems have a number of important cost advantages associated with the evaporation-condensation heat transfer system. Among these advantages is the enhanced heat transport from the reboiler to the cooling tower. Only small pumps are required to return the ammonia to the reboiler and to provide forced recirculation. Water treatment costs are also less because of the need for treating smaller quantities of water. Moreover, the cost of the ammonia condenser/reboiler was conservatively estimated to be significantly greater than a conventional turbine condenser but there is reason to question that estimate.

Operating costs for the ammonia systems are substantially less than the integrated concept because 1) less power is required to operate recirculation pumps and fans, and 2) the capacity penalty is lower because less generating capacity must be provided in reserve.

LAYOUT OF STEAM PLANT WITH AMMONIA

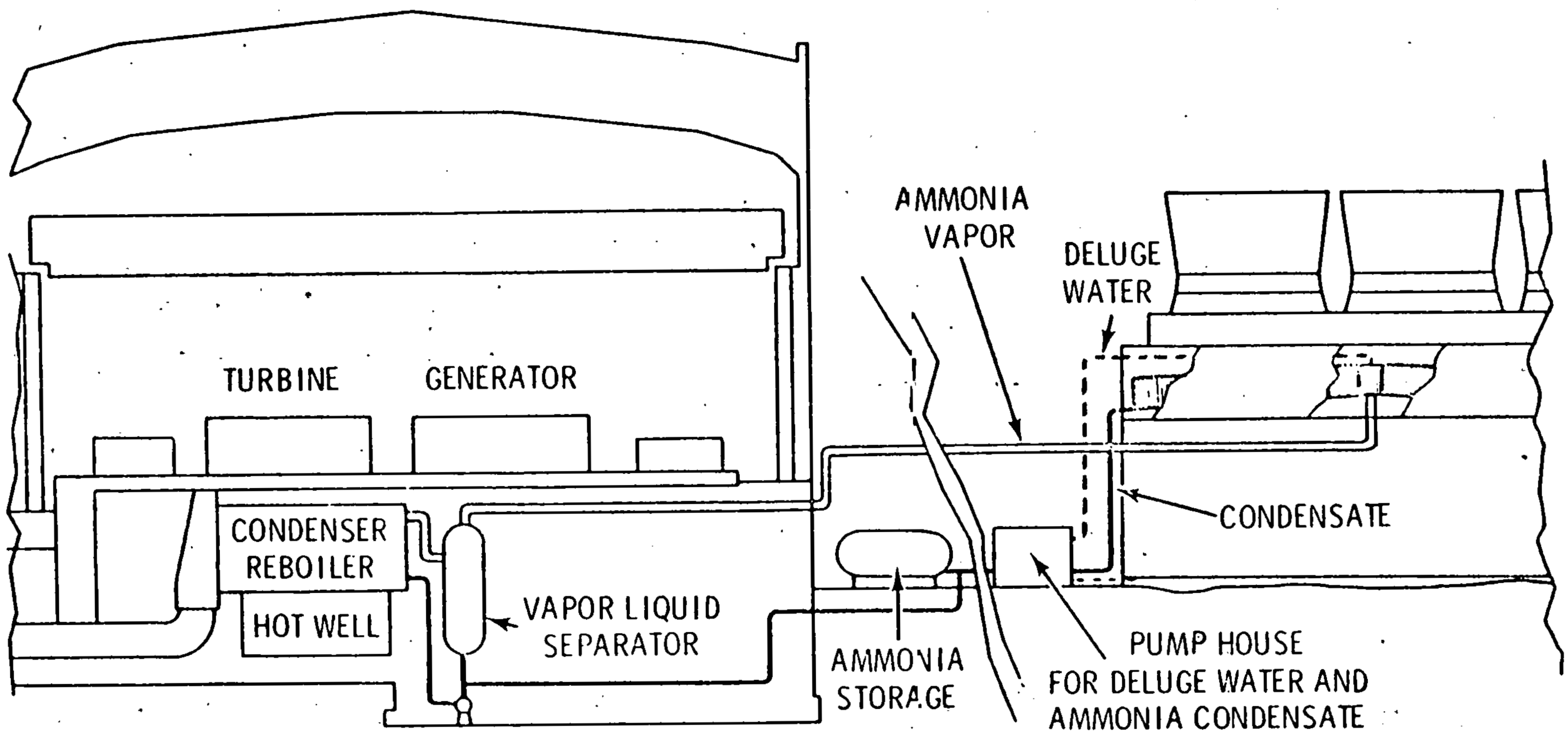

Figure 1 - Sketch of Dry/Wet System Using Ammonia as the Heat Transfer Medium

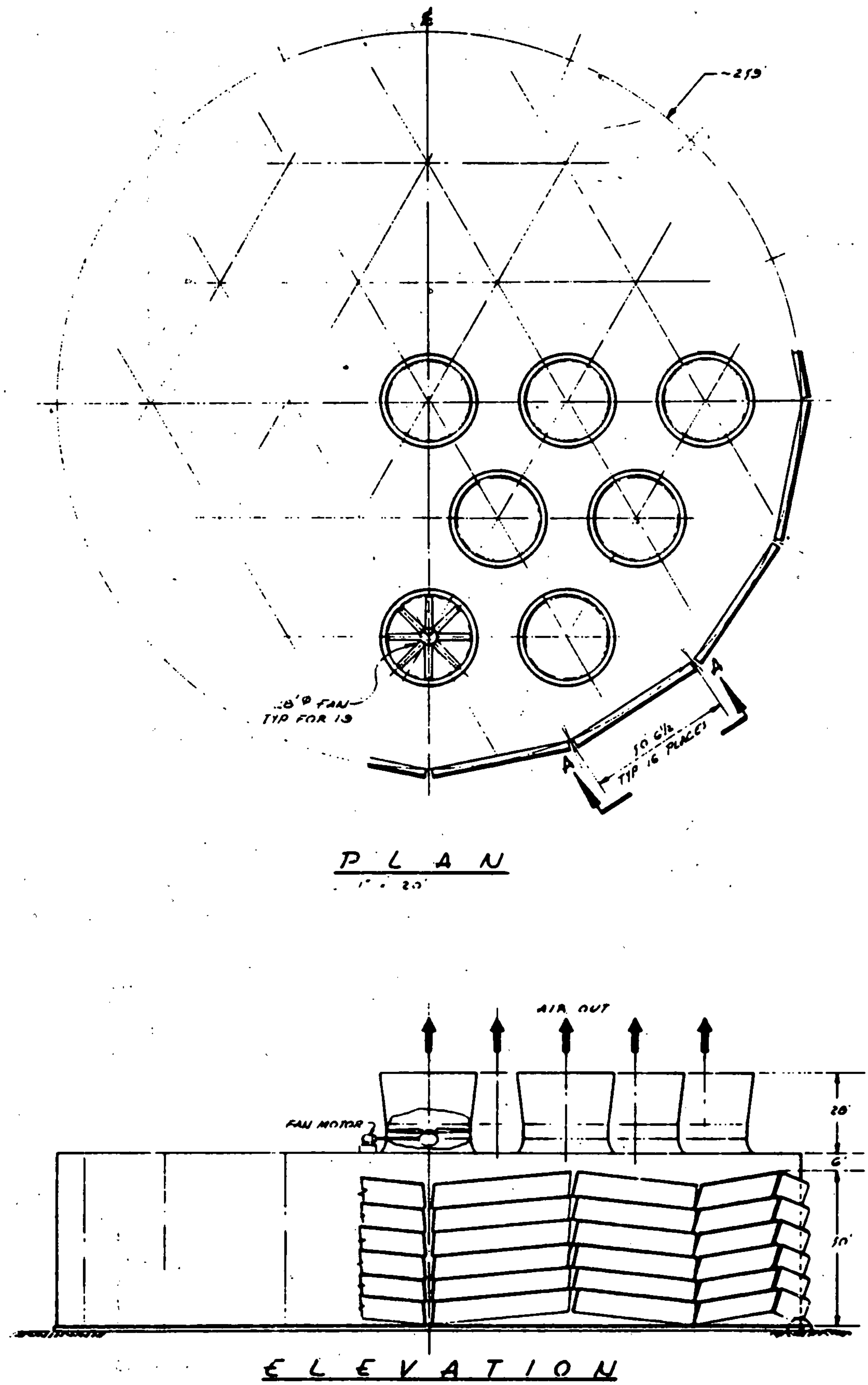

Figure 2 - HÖTERV Heat Exchangers with Deluge Augmentation Vertical Arrangement

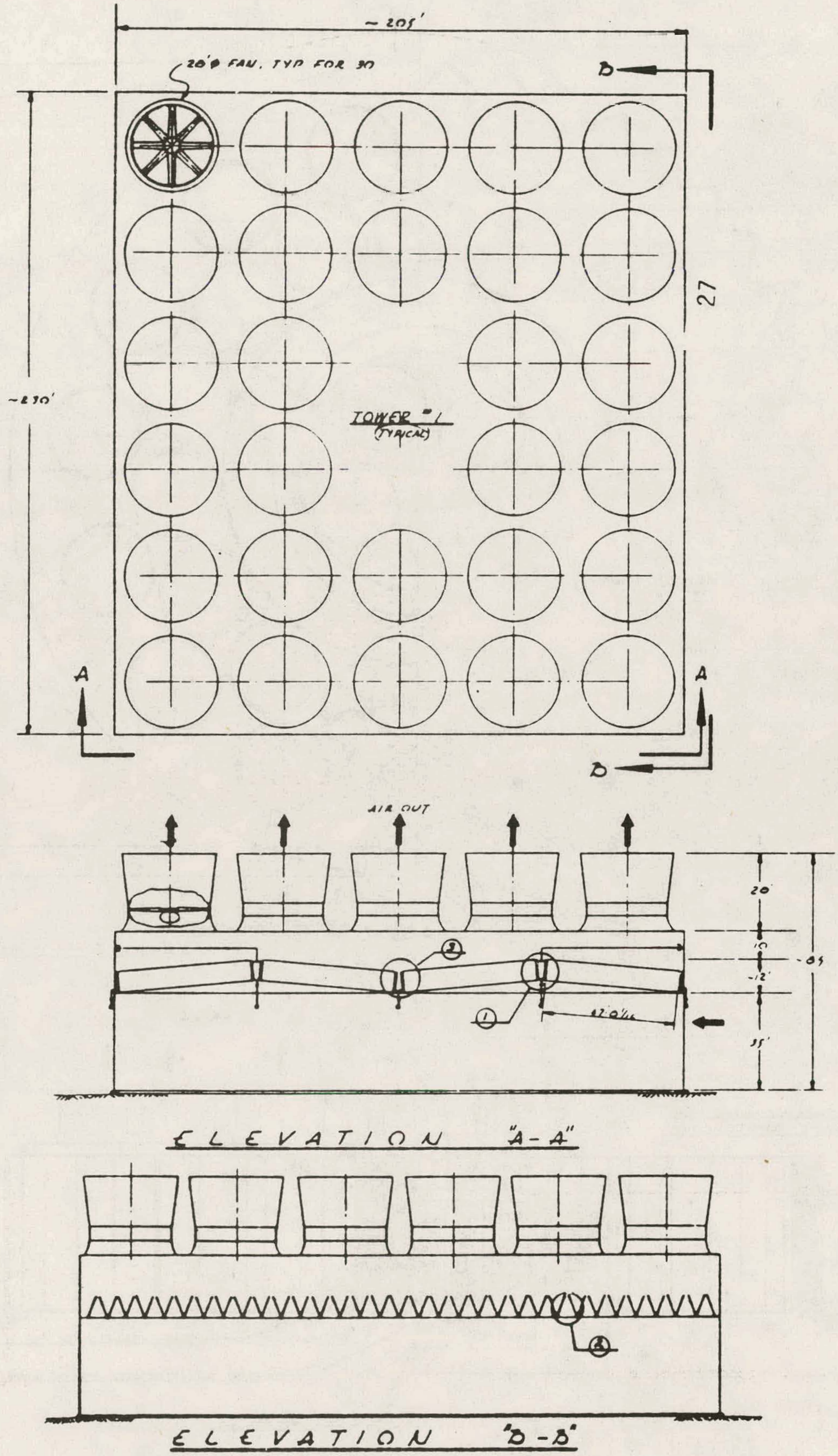

Figure 3 - HÖTERV Heat Exchangers with Deluge Augmentation Horizontal Arrangement

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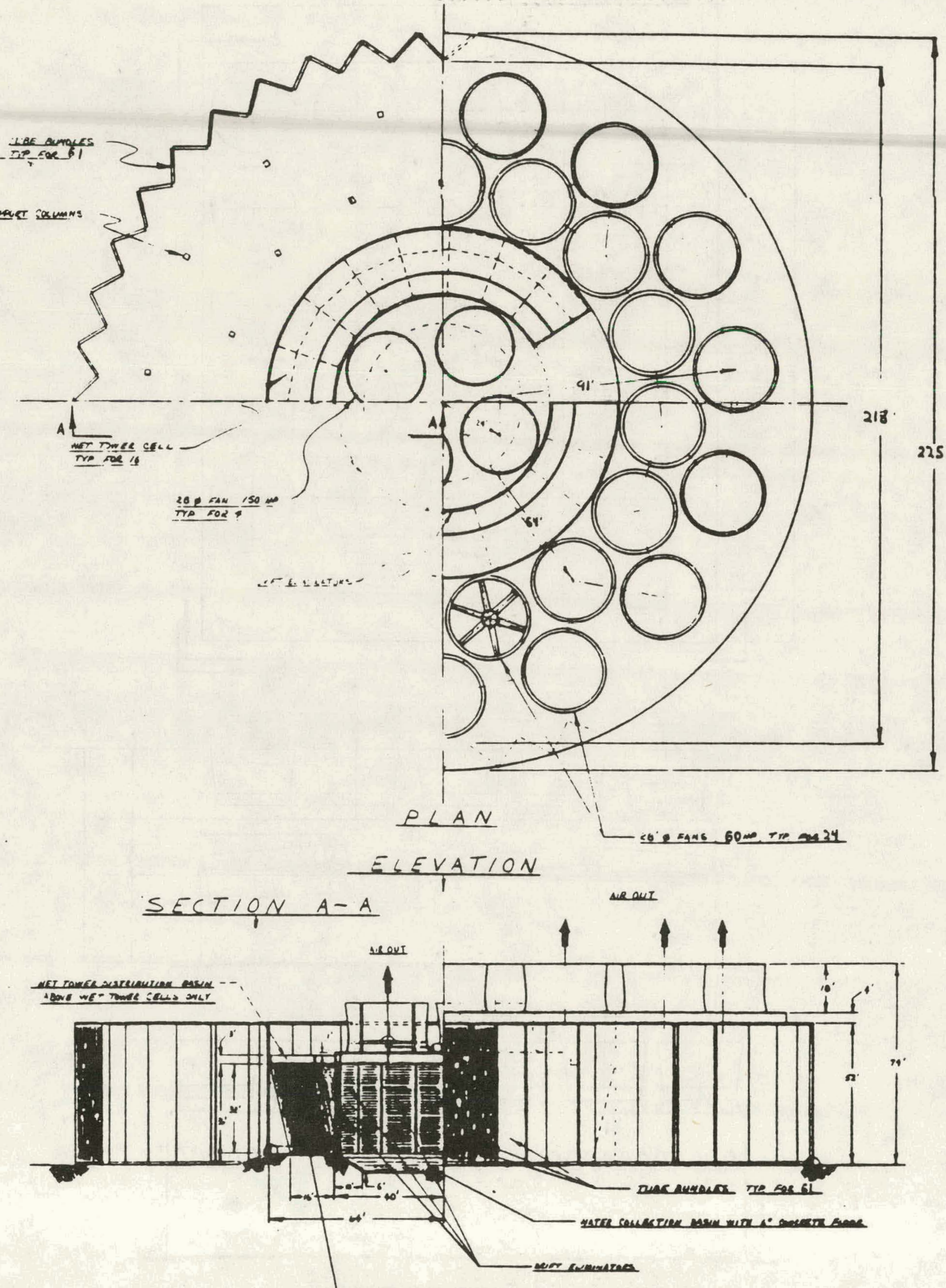


Figure 4 - SCAT Tower Using Curtiss-Wright Heat Exchangers

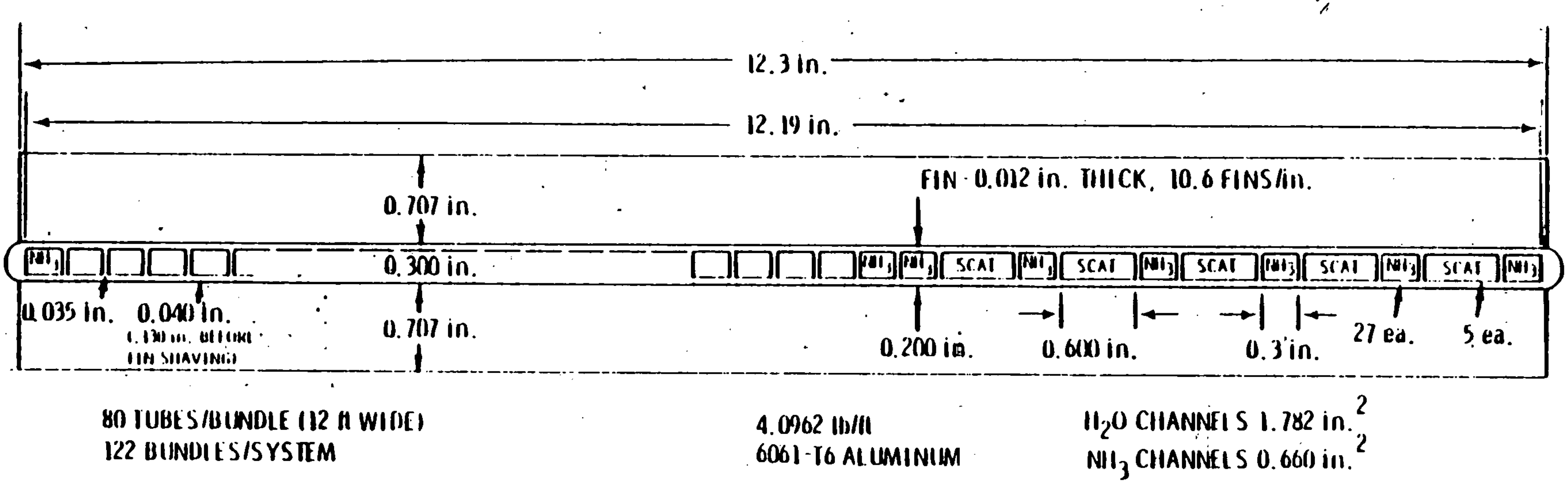
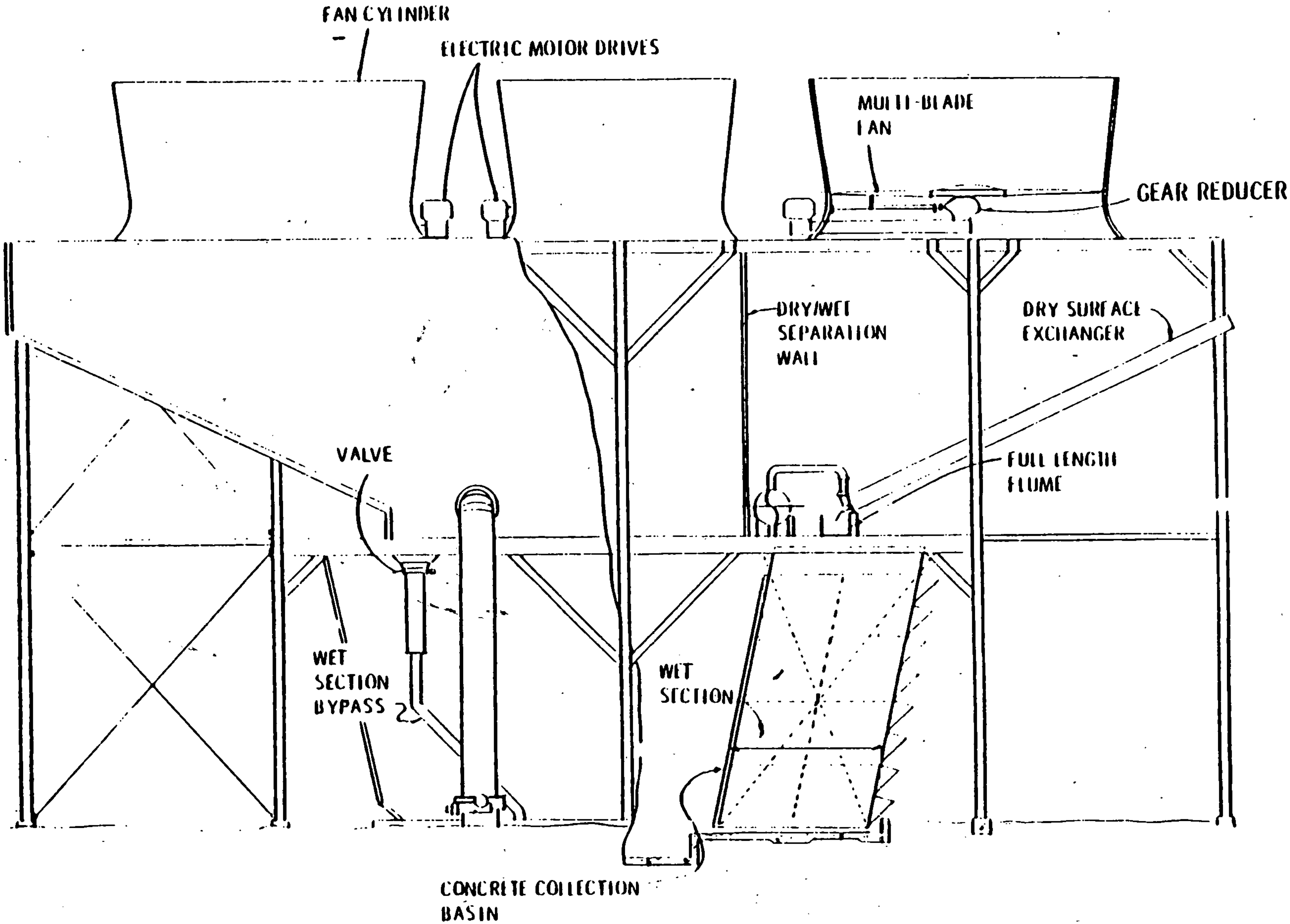


Figure 5 - Cross Section of Curtiss-Wright Exchanger Adapted for the SCAT Tower



CROSS SECTION

Figure 6 - Integrated Dry/Wet Cooling Tower

Paper No. 4

"Waste Heat Utilization from Facilities"

by J. Clark, Jr. and I. A. Boulogiane
Arthur D. Little, Inc.

I. INTRODUCTION

In 1977, the Energy Research and Development Administration, now the United States Department of Energy (DOE), initiated a project to investigate and evaluate the feasibility of economically recovering and utilizing large quantities of energy currently rejected at various federally owned facilities. Funded by DOE, four contractors studied sites in four different states, each surrounded by different social, economic, and institutional environments.

The contractors were asked to review all possible applications (excluding in-plant use) including electrical generation, use in process industries, use for industrial and commercial heating and cooling purposes, and agricultural and aquacultural uses. For each of the possible uses considered the volume of use and conditions of use were described. Technical feasibility was established based on the state-of-the-art technology. The technically feasible solutions of significant size were then evaluated for economic feasibility, taking into account market demand for the goods and services in question, and capital and energy costs at the time the projects could be implemented. Various combinations and orders of use were determined, and a best system of use was proposed by the contractors for each of the sites. They considered level of use, cost effectiveness, financial viability, and socioeconomic considerations to combine the applications proposed by each as the "best" system of uses. Once the requirements of such systems were determined, the contractors evaluated resources needed implement these applications. This included determination of material, labor, site, water and transportation availability, capital requirements and costs, and technology requirements.

The contractors also identified the agencies, institutions, bodies, officials, and organizations or companies that would need to be involved in implementing the system, or who might logically participate in the program for the utilization of waste heat in the future. They described the kind of organizational body that should be established, along with a program to implement such an organization. Each contractor submitted recommendations for programs for implementing the projects recommended for utilizing waste energy now being rejected at a particular site. The systems and criteria used are described in Section II. The benefits accruing to DOE from the studies and the site specific candidate systems are described in Section III of this paper.

II. SYSTEMS AND CRITERIA CONSIDERED

This section discusses the generic classification of the waste heat recovery systems considered, and the technical and economic criteria used to screen applications within these generic uses.

A. Waste Heat Recovery Systems

The three generic classifications of waste heat recovery systems considered for use at federal facilities generating substantial amounts of waste heat were direct use of heat, use of heat pumps to increase temperature, and power conversion for production of electricity.

Type 1: Direct Use of Heat

Evaluations of this type of application included most of the agricultural and aquacultural systems, low temperature industrial uses and district heating.

Type 2: Heat Pump Boosted Heat

The low temperature heat sources can be increased in temperature by means of a heat pump system. If temperatures can be economically increased to the 250°-300° F range, the possible use of waste heat in industrial processes is greatly increased and expanded. Thus, the focus for this kind of application was on use in process industries.

Type 3: Power Conversion

The waste heat sources can be used to drive organic Rankine cycle engine-generators to produce electricity. This application has the advantage of resulting in a readily distributable and usable energy form with a minimum of institutional problems. Generation of electricity in this manner involves high equipment and low and stable energy costs as compared to lower equipment costs but higher, and increasing, energy costs for fossil fueled electric generating systems. As costs of fossil fuel increase further, the economic comparison for the use of waste heat becomes more favorable.

B. Technical Criteria

Several of the criteria considered in the screening process were:

. Total and Percentage Amounts of Waste Heat Used

Applications that are potentially large-scale users, which may or may not permit re-use, or partial use, of waste heat as part of a cascade of uses were ranked.

• Load Factor

All the applications considered for using the waste heat sources require large capital outlays in heat exchangers, piping, and mechanical equipment. Therefore, the economic viability of applications requires using the waste heat source for a high fraction of the time during the year and at close to full capacity of the heat distribution system. An important criteria used in rating potential application was the load factor, defined as:

$$\text{Load Factor} = \frac{\text{heat use during year}}{\text{maximum heat use during year}}$$

where the "maximum heat use during year" is that which could be provided with the equipment installed assuming continuous use for 365 days a year.

• Temperature Level of Heat Use

The lowest cost heat is that which can be delivered to a function and used at a temperature at which it is available without the need for temperature boosting via a heat pump. For that heat which must be boosted in temperature by a heat pump there is still a significant advantage in being able to utilize heat at as close a temperature to the source temperature as possible. Therefore, the applications were rated according to their temperature level requirements.

• Equipment Complexity and Cost

A wide range of system configurations were considered with varying degrees of system complexity and cost. The simplest arrangements are those if which heat is merely transferred from one point to another while the most complex are the power cycles which require sophisticated thermo-mechanical subsystems and, often, large cooling towers.

The relative complexity of the system options were ranked since complexity shows up directly in system cost.

• Operations and Maintenance Cost

The operations and maintenance costs of the system options are usually related to the aforementioned equipment complexity issue. The more complex the equipment, the more maintenance it usually requires; thus, the relative O&M requirements of the system options were considered in the ranking process.

• Technology Status

Two technology status issues were considered in evaluating each application option.

(1) The status of the equipment required to utilize the waste heat source, such as that of the low temperature engines and heat pumps required of the more sophisticated system arrangements, and

(2) The status of the application itself particularly in regard to applications which are not now commercially widespread such as methanol from coal or several of the aquacultural systems being considered.

Applications for which the technology status is well defined had an advantage over those for which there are serious questions regarding performance and cost. The relative technology status of the alternatives considered was, therefore, one of the ranking criteria used to screen applications.

• Energy Value Added

As a practical matter, there is little incentive to locate an operation in close proximity to the waste heat source if energy, in a form providable by that source, is only a small portion of operating costs. The screening process favored those applications where energy is an important factor in production costs.

• Potential Application Size (energy use)

There are two incentives to favor applications which can use relatively large amounts of the waste heat.

(1) There are certain economies of scale associated with the distribution and conversion of heat which result in larger systems being more economical than smaller ones, and

(2) There is psychological merit in proposing applications which either singularly or in combination with others can use a significant percentage of the energy contained in the waste heat stream.

• Use of Natural Resources

Applications calling for major resources which were not available at or near a particular site were rejected. Water is probably the most necessary resource, since it is required in large quantities for many of the aquacultural and industrial operations considered, and for cooling purposes. The extent to which water use constituted a problem at each site was addressed specifically early in the evaluation process.

The technical screening process resulted in a successive reduction of applications carried forward for economic and other evaluation.

C. Economic, Financial and Socio-Political Criteria

After applying the technical criteria to the heat recovery options, including natural resource availability and use, and selecting candidate uses, the contractors conducted a site-specific evaluation of their economic viability. They documented both the projects that met the economic criteria, and those rejected, after they:

1. Identified the products of the enterprises proposed and what is known about the market for these products both within and outside of the regions.
2. Defined the capital costs
   (a) For the enterprise
   (b) For the waste heat delivery components

3. Identified the employment provided by the enterprise, including the waste heat delivery system, and translated this to labor force requirements and availability.
4. Described the raw materials needed and the availability.
5. Described the land requirements, including proximity to source.
6. Analyzed the economic impact of the availability of the waste heat including:
   (1) The costs incurred if the enterprise did not have the waste heat, i.e., obtained energy from the lowest cost alternative source.
   (2) The extent of dependence on the waste heat. What would happen to the enterprise if waste heat was not available? Was there a need for standby alternative sources of energy?

Using the above information, they went to evaluate questions such as:

1. If this enterprise were in place today would it have an economic advantage because of its use of waste heat?
2. If not, what future developments are needed for it to have an advantage? Are there barriers that need to be eliminated?
3. Are the assumptions made regarding costs, life of the project, etc. consistent with normal practice? Have the effects of further escalation in construction, energy and operating costs been fully taken into account?
4. How is the economic feasibility of the application affected by the timing of its implementation? Will it be more feasible in 5 years, 10 years?
5. How sensitive is the use proposed to the temperature and quantity of waste heat available? What alternatives should be explored or considered?
6. How much energy would the facility use that would otherwise be wasted,

or would have to be provided from another source? What would be the estimated savings in BTU's?

Once the economic screening was completed, the contractors documented their "best system" and included in their reports the various requirements to implement it. They then defined the limiting factors and the action needed to deal with them.

D. Regional Economic and Other Factors Considered

In addition to the project-specific economic evaluation described above, each contractor identified the general economic base of the site studied. The uses recommended by them were then reviewed and evaluated by DOE personnel considering site-specific information about the economy, legal socio-political factors, labor force and wages, resource availability, infrastructure, topography, climatic and other conditions. The growth potential for commercial enterprises was evaluated, and constraints were identified. The benefits of implementing the project were also outlined.

The contractors' elaborated on land availability for industrial process, agricultural or aquacultural applications. They described both publicly and privately owned sites in terms of size, price and distance from the federal facility. They also considered restraints, legal, topography, services and zoning.

The contractors reported on current industry, products, and markets. They described what the area can furnish in terms of industry services, and support services, and the linkage required to local governments and special interest groups. The contractors identified what is available in terms of financial assistance, taxes and tax relief or incentives, training and other incentives, and characterized community attitudes toward business.

E. Institutional Definition

The formal review of socio-political environment and the parties that would be closely involved in the implementation of the economically and technically feasible projects involved the consideration of various federal and state laws and regulations, and local/municipal government restrictions. Representatives of government agencies, politicians, other closely involved parties: bankers/ financiers, suppliers/consumers, labor union, business and community leaders, environmentalists and conservationists, media representatives, consumer and minority groups, historical societies, and others were interviewed.

The agencies, institutions, bodies, officials, organizations or companies that will be involved in implementing the system are many, and the interrelationships are complex. The contractors described the kind of organization or body needed to proceed with a program to implement the system, and its role. They indicated what facilitative actions the Department of Energy would need to take to involve the players identified, including legal and/or regulatory changes. The recommendations included descriptions of new interface relationships to be established.

F. Work Program

The final part of the study provided the Department of Energy with recommendations for a program of work that should be undertaken in the next phase, and a timetable for the work recommended.

The benefits accruing to DOE and some site specific results are described in the next section.

III. BENEFITS ACCRUING TO DOE AND SITE SPECIFIC RESULTS

A number of the benefits apply to all four studies, or are the product of the four studies.

Certainly one of the benefits is the development of a better understanding of issues and criteria involved in using the waste heat presently being rejected. Basically, in determining the benefits from developing uses for waste heat, the relevant comparison should be against the cost of developing additional supplies of other sources of energy--not with future average energy costs. Also, as the costs involved in utilizing waste heat are nearly all capital costs (operating costs are minimal), it is of vital importance to proceed quickly with developmental and demonstration projects. Delays will, because of inflation of construction costs, substantially affect the cost of such projects. Once completed, the costs of an electric generation or heat pump installation are for all practical purposes frozen, while the operating cost of alternative installations will continue to increase because of continuing escalation in fuel costs.

Study results indicate that although the generation of electric power using the Rankine cycle approach, and the enhancement of the temperature of water using a heat pump, are technically feasible that the processes need to be demonstrated on a scale adequate to evaluate performance and permit further development and improvement of the technology. Such demonstrations would be of great value in encouraging the utilization of waste heat at many other installations in the United States.

Actually, if use of waste heat results in costs equal to those associated with the use of alternative energy sources, these still would be a benefit to the United States from the conservation of alternative fuel sources. Considering the problem of oil imports and the costs of developing incremental supplies of other fuel resources, there is justification for providing some level of subsidy to waste heat utilization projects (at least initially).

During the course of the four studies, there have been independent assessments of the universe of possible uses of waste heat. The contractors have taken into account the conditions and resources at the specific plant locations and evaluated a wide variety of possible approaches and designs. This needed to be done as the amounts of energy represented by the waste heat rejected at federal facilities is too great not to be thoroughly studied. The studies have provided basic data on analysis and evaluation of potential uses that were not selected for further study, as well as those that were. Uses that were not selected for possible implementation can be further assessed in the future and criteria varied as appropriate. It is important that the analyses are on the record so that future studies can be facilitated without starting at the beginning each time.

The studies generally agree that direct uses of waste heat (at 140°-150° F)for industrial process purposes is not economically feasible. Recommendations for direct use focus on greenhouse applications and aquaculture, where further development is needed. The major uses otherwise are concerned with electric power generation (Rankine Cycle), enhancement of feedwater heat (through a heat pump) for a conventional electric generating station, and upgrading water or steam temperatures by heat pumps to serve a variety of industrial process users. Thus, the studies have focused attention on applications which have the greatest economic potential and for which demonstration of and improvement in technology would be of great value. The results also vary by site.

In particular, one study of use of the waste heat rejected at one federal installation produced an interesting concept in which a self-powered heat pump (which would utilize a substantial amount of waste heat) would be used to heat the feedwater for a 1,000 Mw coal-fired electric generating station. The industries served by the generating station would use no further waste heat from the federal facility, but would be designed to take full advantage of cogeneration to conserve energy. The direct uses recommended include greenhouses and a novel aquacultural project, as well as a number of possible industrial process uses. The waste heat used would be substantial and savings in alternative fuel supplies of significant amount. There also would be substantial economic benefits to be derived by the economy of the region from increased employment and the resulting income.

A second study describes one project, electric power generation based on the Rankine Cycle, which would recapture part of the waste energy from several reactors at a federal project. The power produced would be used to meet the electric power needs of the project. This would permit the savings of substantial amounts of alternative sources of energy (the study estimates an energy equivalent saving for each reactor of 500,000 barrels of oil). A second potential use envisioned the use of a gas-turbine driven heat-pump to produce higher temperature water and steam to serve a combination of appropriate industries. This would use an amount of waste heat with an energy equivalent saving of over one million barrels of oil a year. Substantial benefits to the regional economy would result from increased employment. Direct uses would include greenhouses and aquacultural developments, again with benefits to the economy and to improvements in technology.

A major potential use of the waste heat rejected by a third federal facility is in large scale greenhouse operations. The greenhouse industry is well developed in the region. A sizable greenhouse development would result in substantial savings of energy as well as aid the regional economy and permit expansion of the industry to better serve the regional market for greenhouse products. Other direct uses recommended, a lumber predryer and an alfalfa/grain dryer, also would serve and benefit the local economy and provide a demonstration of the use of waste heat which could be replicated elsewhere.

The study of the opportunities for use of waste heat at the fourth facility came up with a different concept of a heat pump installation. Instead of a gas-turbine driven heat pump, or a self-powered heat pump, the heat pump in question would be driven by purchased electric power. The output of the heat pump could be used, according to this site's contractor report, in a textile finishing operation and for other industrial purposes. This report also considers as possible uses of available waste heat a coal-cleaning operation, a methanol plant, and a pulp and paper installation. The coal cleaning plant may be a valuable way of reducing the sulphur content of regional coal reserves, while a methanol plant, if it proves to be feasible, would substitute coal for natural gas as a feedstock. The use of waste heat in the process, if appropriate, will substitute waste heat for other energy sources. A pulp and paper operation, if feasible, would draw on regional resources and have considerable value for the economy.

The above study also has devoted considerable effort to studying the opportunities to use waste heat for district heating. The data collected in these studies is not only of value for the present study, but will be of considerable use in future studies where such a use of waste heat is being analyzed and evaluated. The study also dealt with modest projects using direct heat for greenhouses and aquacultural development purposes. A Table, Proposed Uses, lists those uses that the contractors recommended for near-term implementation.

Implications for the Future

Finally, perhaps the greatest value of the four studies is that they have shown that there are many advantages and benefits to be gained by taking water at 140°-150°F and raising its temperature only as high as 250° to 350°F. The technology is old from a conceptual standpoint. What is needed is a demonstration of the technology on a scale large enough to confirm the technical success of new designs and related cost projections. Underscoring the long-term importance of such installations is the fact that once completed and in operation, costs are largely frozen. Meanwhile, the outlook for alternative sources of energy over the long-term is one of a continuing escalation in costs. While these trends and conditions work to continually improve the economic feasibility of the use of waste heat, there is also the underlying consideration that much energy is available in waste heat and that use of such heat, wherever available, conserves the U.S. energy supply and is a desirable end in itself, even at a net cost.

TABLE

PROPOSED USES

Direct Use

Agricultural - Greenhouses (including mushroom houses, Alfalfa/ grain drying, lumber pre-drying)

Aquaculture - finfish, clams, crayfish, prawns

District heating

Process Industry Applications

Textile finishing

Coal cleaning

Pulp and paper

Methanol plant

West corn milling

Soybean oil milling

Alkalies and chlorine

Nylon plant

Weaving mills

Textile finishing

Styrene plant

Butadiene plant

Power Conversion

- Open/open steam heat pump to produce 15 and 25 psig steam for delivery to an industrial site, using a pump driven by purchased electric power.
- Self-powered heat pump to delivery 350° feedwater to a coal-fired 1,000 Mw generating station.
- Rankine Cycle process to generate electric power.
- Gas-turbine driven heat pump to utilize waste heat from one reactor to increase water temperature to 250°F, with part of the steam passed by the 850°F exhaust of the gas turbines to produce a higher pressure steam (500°F).

Paper No. 5

COGENERATION SYSTEMS FOR RESIDENTIAL/COMMERCIAL APPLICATIONS

by

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ABSTRACT

The increasing scarceness of oil and natural gas provides the impetus to uncover techniques of conserving these scarce fuels. Methods to conserve these scarce fuels include: 1) development and utilization of technologies that operate at efficiencies that are higher than those which are in current use, 2) using the waste heat from the generation of electricity for space heating and/or cooling, and 3) implementation of technologies that employ non-scarce fuels and/or renewable energy resources. Coal and residual oils are less scarce fuels; and renewable energy resources include solar energy, wind power, urban solid and liquid wastes, and bio-mass.

Reducing the consumption of these scarce resources will involve the implementation of systems which consist of both new and currently available components. The novel integration of these components into systems to match the available resources is necessary to conserve scarce fuels. Many current, emerging, and advanced technologies need to be examined in order to provide energy conserving system designs. Among the components which have potential for implementation in these systems are Diesel engines, advanced gas turbines, incineration techniques, pyrolysis units, solar collectors, thermal storage devices, heat recovery equipment, heat pumps, and electrical storage devices. A discussion of technology options is presented in this paper.

A group of systems which employ these technology options is examined in the paper. From these studies it is evident that there are options to the conventional means of meeting the electrical space heating and cooling, and miscellaneous energy needs of an urban community. Many of these systems are both economic

and energy conserving. It is also clear that the use of community energy systems whether they are district heating and cooling, total energy or selective energy systems, can reduce the amount of scarce fuels needed to supply the energy needs of the community. Compared to an all-electric, conventional system, upwards of 40 and 50 percent of scarce fuel energy can be saved.

The main problem faced by a designer of energy systems in an urban environment is what kind of system to choose and what technologies to incorporate. The use of integrated systems is contingent upon many factors including energy savings, initial costs, fuel costs, refuse disposal costs, system reliability and maintainability, reliability of fuel source and certainty of the estimated energy demand in the community. Further, one must give consideration to the institutional problems of establishing an independent system in an urban environment. It is essential to consider all of these factors when considering an integrated energy system.

TECHNOLOGY OPTIONS FOR ENERGY SYSTEMS

Energy systems are composed of components such as prime movers, electric generators, chillers, boilers and other components. What follows is a very brief review of the types of components which are, or will become, available for use in energy systems, and their characteristics. For simplicity, they will be discussed in order of the time frame of their commercial availability. These are: 1) current technologies which can be obtained from several manufacturers; 2) emerging technologies which would be available commercially by 1985; and 3) advanced technologies which are now under development and could be expected to be available after 1985.

Current Technologies

A partial listing of the various energy system components available for use in an urban energy system is shown in Table 1. It is easy to see that one can have a wide list of choices in meeting the energy demands of a community no matter what the distribution is between electrical and thermal load.

Among the prime movers one can choose either Diesel engines, gas turbines (simple and regenerative cycle), steam-turbines or combined-cycle plants. The net electrical efficiency of a combined-cycle plant, which has a gas turbine with a steam-turbine bottoming cycle, can range from 35-45 percent and could be quite attractive in urban systems. Diesel engine-generator efficiencies, which vary according to engine size and speed, vary from about 23-40 percent. Gas turbines efficiencies can vary from 15-35, depending on size and cycle chosen. Although gas turbines have relatively low efficiencies, the possibility exists of using the recovered heat from the exhaust gas stream as was done in the combined-cycle plant. Steam turbine-generator efficiencies vary from 18 to 35 percent. The choice of prime mover is dependent upon the needs of the system. Many larger systems which have large thermal to electrical load ratios have a tendency to use steam turbines while smaller systems use Diesels for reliability and better efficiency in the smaller size ranges.

Other components which can appear in the central plant of an urban energy system include compressive and absorptive chillers, boilers and thermal storage. Compressive chillers, which can have coefficients of performance (COP) over 4.0, can be driven by an electric motor or directly by one of the above prime movers. The waste heat from the prime movers can be used in absorptive chillers. The single effect absorption chiller has a COP of about 0.6, while the double effect machine which requires higher quality steam has a COP of about 1.0. Boilers usually can be operated between 50-85 percent efficiency depending on the operation of the boiler. Thermal storage offers an attractive alternative especially in systems which have a low thermal to electrical demand during one part of the day while the reverse is true at another time of day.

Solid waste incineration with heat recovery offers an excellent way of reducing the scarce fuel requirement while, at the same time, meeting the thermal needs of the community. Upwards of 10 percent of the energy needs of a community can be provided by this method. However, the amount of waste needed to economically use this system usually restricts its use to rather large communities which not only use a lot of energy but produce enough solid waste as well.

Thus, there are a significant number of components available today to put together economical and energy conserving community energy systems. But what is potentially available in the future which may make these systems more attractive?

Emerging Technologies

There are many technologies which are currently under development and demonstration which are expected to be available in the period between now and 1985. A partial listing of these technologies is given in Table 2. These seem to have potential for being included in urban energy systems.

The first three technologies; Fuel Cells, Closed Cycle Gas Turbines, and Organic Rankine Cycle Engines offer significant promise for urban energy systems. Fuel cells, for example, can be designed to vary the electrical efficiency up to as much as 70 percent. The current models have maximum efficiencies of about 38 percent and, like internal combustion engines, the rejected heat can be recovered to help meet the thermal needs. The fuel cell is quiet and non-polluting but in its present version uses natural gas as a fuel. Given the appropriate pretreatment of the gases from pyrolysis or coal gasification plants, there should be greater flexibility in fuel source.

Closed cycle gas turbines are attractive because they may allow the use of fuels which are not scarce. The closed cycle gas turbine may be considered to be an external combustion engine. Thus, it should be possible to use coal, or its products, as heat sources and relieve the engine of its dependence on high quality, more scarce, fuels.

The organic Rankine cycle turbine offers a method of producing shaft power from relatively low temperature exhaust gases from internal combustion engines and incineration units. Further, and they may be its most attractive application, it can be used to obtain shaft power from solar thermal collectors. Thus, the engine offers a significant flexibility for using relatively low grade temperature sources.

The Annual Cycle Energy System (ACES) currently under development and test in Tennessee offers a unique method of energy conservation for the individual building by storing "cold" during the winter and "heat" during the summer while using a heat pump. The system is currently being tested in a single family residence but, in principle, the concept could be extended to larger buildings and perhaps communities if enough space for storage were available. During the winter the heat pump extracts heat from the water and it freezes; in the summer water is passed through the coils in the ice storage bin and circulated through the house for cooling. It is estimated that this system could save up to 50 percent of the energy needed to meet heating, cooling and hot water needs.

Solid waste pyrolysis offers a technique for meeting the fuel requirements of the community while also solving the land fill problem. Pyrolysis units can potentially be built in relatively small sizes and their product gas, which is usually of low-Btu content gas, can be used as fuel in Diesel engines, gas turbines, fuel cells and be mixed with more high quality gas and piped around the community for other uses. As with incineration, upwards of 10 percent of the total energy needs can be met in this manner. Similarly, methane production from solid or liquid waste can offer some significant advantages especially if the product gas has a high Btu value.

The application of solar thermal energy to urban systems can be attractive for water heating and in conjunction with the organic Rankine cycle engine can supply useful shaft power. Development of lower cost collectors and more efficient systems could help solar play a bigger role in urban systems.

Coal conversion processes, along with coal combustion in boilers, points the way to using a less scarce fuel in an urban energy system. Of course, one must consider the amount of pollutants which may be released if these units are located close to, or in, the community they serve. The atmospheric, fluidized bed coal combustion system offers a method for using coal and eliminating the emission of sulfur products.

Advanced Technologies

In the post 1985 period a host of technologies are expected to become commercially available. Most of these technologies, of which a partial list is given in Table 3, are currently in the early investigative phase of their development. For this reason, these will not be discussed in detail here. Suffice it to say that these new technologies will boost the efficiency of energy conversion and, in some, will allow a broader application of non-scarce fuels, such as coal, urban wastes, and solar energy.

ANALYSIS OF INTEGRATED ENERGY SYSTEMS

This paper provides the analysis of several designs of integrated energy systems. Included in these systems are a fuel cell based system, a heat pump centered system, and a Diesel engine based system. The addition of a pyrolysis unit which employs the refuse from the site, with the Diesel engine based system, is also examined. Thermal storage is used in all these systems. These systems are compared with a conventional system and with each other in terms of scarce fuel consumption.

These studies involved the conceptualization of each system, an assessment of annual system performance, and an initial assessment of the life cycle costing for each system. This effort is not intended to be a complete engineering feasibility analysis. The scope is limited as follows: 1) the concepts employed herein were generated by using engineering judgements (no system optimization has been employed), 2) three concepts were selected for each of the two commuities considered (an exhaustive study of all possible technologies was not conducted), and 3) no grid connection was employed, unless the grid was the primary source of energy for the system.

The two types of communities which were focused on are:

1. a 115-acre regional shopping center, and
2. a planned 725-acre new community (commercial/residential), including the shopping center.

Several concepts of integrated energy systems which meet the energy demands for both the shopping center and commercial/residential areas were examined. These systems, which employ current, emerging and advanced technologies have been evaluated with regard to potential energy savings and life-cycle costs.

For the shopping center, the annual electrical consumption for the lighting of the mall and tenant buildings is 52%, and the energy consumption for heating and cooling represents 48 percent of the total. For department stores in the shopping center, the annual energy demand for lighting and HVAC appears to be nearly equal. The annual energy consumed at the shopping center is as follows:

non-HVAC	5.2×10^7 kWh/year
HVAC	4.8×10^7 kWh/year

For the entire commercial/residential area, less the shopping center, 36 percent of the energy demand is for non-HVAC use while 64 percent is for the HVAC system. The annual energy consumed in the commercial/residential area (less the shopping center) is:

non-HVAC	5.0×10^7 kWh/year
HVAC	8.8×10^7 kWh/year

Hence, the total annual energy used at the entire complex is around 2.38×10^8 kWh. Of this 1.02×10^8 kWh are used for non-HVAC while 1.36×10^8 kWh are required to satisfy the HVAC demands.

Energy Systems for the Shopping Center

Due to the current energy picture in the United States, concepts which will provide both energy and life-cycle cost savings while meeting the energy requirements of communities have excellent potential for development and implementation. Three such concepts have been examined for both the shopping center and the entire complex. These three concepts are:

1. A system which employs a bank of Diesel engine-generators to meet the electrical demand of the shopping center. The waste heat from the

engines is used for space heating and cooling at the shopping center, and the excess waste heat has potential to augment the space conditioning requirements in the surrounding commercial/residential areas.

2. A heat pump centered system which utilizes electrically, or prime mover, driven heat pumps to meet the HVAC load of the shopping center. This can be an all-electric system in the strict sense, but it has potential for energy savings because a heat pump operates with a COP greater than unity.

3. A system which employs first generation, phosphoric acid, fuel cells as the prime movers to meet the electrical demands of the shopping center. The waste heat from the fuel cells is used for space heating and cooling at the shopping center in a manner similar to the Diesel engines.

Each integrated energy system has been designed to meet the peak electrical, heating and cooling power requirements in the course of a year.

An application of current technology is represented by the Diesel engine centered power system. The emerging technology application involves the use of heat pumps, while the emerging to advanced technology system employs fuel cells as he prime mover to supply electrical power as well as thermal energy to meet heating and cooling demands.

Each of these three basic systems can be employed in a host of ways. Technologies such as energy generation from solid wastes, solar energy use, cold from snow removal for summer cooling, and diurnal thermal storage can be employed to reduce fuel costs and improve energy savings. The options of using solid wastes and storage have been examined and are briefly discussed.

The study of these three integrated energy systems for both the shopping center and the entire complex will demonstrate that considerable energy and cost savings can be achieved. The energy conservation potential of solid waste utilization and thermal storage was also considered in each case.

These three systems are assumed to use different sources of energy. The systems and their primary fuel sources are listed in Table 4.

The Diesel and fuel cell based systems have the electricity and heat generated at a central location, and require distribution systems. The heat pump centered systems employ grid electricity and can have individual heat pumps for each building or be located in a central location with a distribution system. Decisions favoring one system over the others are contingent upon many factors -- such as energy savings, costs, system reliability, availability of the fuel source, and environmental considerations.

In order to conduct the studies, some design and component characteristics and cost numbers had to be assumed. Table 5 summarizes these design and cost parameters. During the winter, the electricity used for lighting supplies most of the heating requirements while the shopping center is in operation. The excess heat resulting from lighting is removed with the circulation of outside air; however, during the summer this results in an added cooling load.

Estimates of annual energy requirements are made in the following manner: Over a year at the shopping center, the amount of heating required is equal to 50 design days while the amount of cooling is equal to 75 design days. For the commercial/residential areas the annual heating requirement is equivalent to that of 66 design days, and the annual cooling is equivalent to about 15 design days.

The results of the performance and cost studies for the shopping center are contained in Table 6. For the shopping center, the fuel cell and Diesel based systems result in larger fuel savings and a larger annual return than does the heat pump centered system; although all three systems show energy and cost savings when compared to the conventional all-electric system.

As an example, Fig. 1 illustrates the energy generation and consumption profiles for a winter design day using the fuel cell based system. The internal heat generation at the shopping center is more than adequate to meet the space heating, except in the early business hours and off hours. Hence, most of the heat recovered from the prime mover during the business hours can be placed in storage and extracted when the demand exceeds generation, as illustrated.

An additional option available for heat and possibly usable fuel is solid waste (i.e., refuse). A technique to extract the energy from solid waste and use it in either Diesel engines or fuel cells is pyrolysis. The waste generated at the shopping center results in about 7.8 tons/day of essentially Type 0 trash with a heating value of 8500 Btu/lb. A pyrolysis unit could provide about 3×10^{10} Btu/year of fuel which could be used in the Diesel engines. Including this pyrolysis fuel in the Diesel based system reduces the outside fuel consumption and increases the overall thermal efficiency of the system as shown in Table 7.

Energy Systems for the Shopping Center/Commercial/Residential Areas

The total annual load for the shopping center/commercial/residential complex is 2.38×10^8 kWh; 1.02×10^8 for non-HVAC (electric) and 1.36×10^8 for HVAC. Fuel cell, Diesel engine, and heat pump based systems have been examined to meet the total energy demands of the complex.

As in the shopping center, energy systems have been designed to meet the peak electrical, heating, and cooling requirements. The Diesel engine and fuel cell prime mover systems have been conceptualized to operate independent of the grid, although these two systems could be augmented by a grid connection. The heat pump centered system is fed by the grid since its incoming energy is electricity, although an attractive alternative is to drive the heat pumps with a Diesel engine. The results of the performance and cost studies for the entire development are shown in Table 8. It is seen that all three candidate systems show both energy and cost savings when compared to the conventional system. As was the case for the shopping center only, the fuel cell and Diesel engine based systems result in greater annual fuel savings than does the heat pump centered system.

Overall system economics included the determination of the added capital and operating and maintenance costs compared to a conventional, all-electric system. The effect of taxes, depreciation and interest costs were not factored into the study since these could be strongly affected by the financial strategy employed.

It should be noted that both the fuel cell and Diesel engine based systems described employed heat pumps in individual buildings. Use of heat pumps in both these systems showed tremendous gains in energy savings when compared to systems which did not employ heat pumps.

CONCLUSIONS AND SUMMARY

From the discussions on technology options and the study of the Diesel, heat pump, and fuel cell based systems, it is evident that there are options to the conventional means of meeting the electrical space heating and cooling, and miscellaneous energy needs of an urban community. Many of these systems are both economic and energy conserving. It is also clear that the use of community energy systems, whether they are district heating and cooling, total energy or selective energy systems can reduce the amount of scarce fuels needed to supply the energy needs of the community. Compared to an all electric, conventional system upwards of 40 and 50 percent of scarce fuel energy can be saved mainly because of the waste heat usage from electrical generation.

The main problem faced by a designer of energy systems in an urban environment is what kind of system to choose and what technologies to incorporate. The use of integrated systems is contingent upon many factors including energy savings, capital costs, fuel costs, refuse disposal costs, system reliability and maintainability, reliability of fuel source and certainty of the estimated energy demand in the community. Further, one must give consideration to the institutional problems of establishing an independent system in an urban environment. It is essential to consider all of these factors when considering an integrated energy system.

TABLE 1. PARTIAL LISTING OF CURRENT TECHNOLOGIES

● DIESEL ENGINES	● CENTRAL CHILLERS
● GAS TURBINES	● BOILERS
● STEAM TURBINES	● HEAT PUMPS
● COMBINED CYCLE PLANTS	● THERMAL STORAGE
● ELECTRICAL GENERATION	● SOLID WASTE INCINERATION

TABLE 2. PARTIAL LISTING OF EMERGING TECHNOLOGIES

- FUEL CELLS
- CLOSED CYCLE GAS TURBINES
- ORGANIC RANKINE CYCLE ENGINES
- ACES
- ELECTRIC COMPRESSED AIR STORAGE
- SOLID WASTE PYROLYSIS
- METHANE PRODUCTION
- SOLAR THERMAL
- COAL GASIFICATION AND LIQUEFACTION

TABLE 3. PARTIAL LISTING OF ADVANCED TECHNOLOGIES

- ADVANCED RANKINE CYCLE
- MINTO WHEEL
- STIRLING ENGINES
- ELECTROCHEMICAL STORAGE
- ADVANCED FUEL CELLS
- SOLAR PHOTOVOLTAICS

TABLE 4. THREE BASIC INTEGRATED ENERGY SYSTEMS AND THEIR FUEL SOURCE

SYSTEM	FUEL
● DIESEL ENGINE SYSTEM	DIESEL FUEL OIL
● HEAT PUMP CENTERED SYSTEM	ELECTRICITY FROM GRID
● FUEL CELL SYSTEM	NATURAL GAS

TABLE 5. ASSUMPTIONS AND DESIGN CHARACTERISTICS

1. Costs

   A. Shopping Center — 2.1c/kWh
   B. Balance of Complex — 3.0¢/kWh
   *C. #6 Fuel Oil — $1.94/million Btu
   D. Natural Gas — $1.42/million Btu

2. Design Characteristics

   A. Peak non-HVAC (MW)

      Shopping Center - 12.5 MW
      Balance of Complex - 14.9 MW
      Entire Complex - 23.0 MW

   B. Maximum Design HVAC Loads ($Btu/ft.^2$) (i.e., Design Day)

	Cooling	Heating
Shopping Center Mall and Tenant Building	57.0	22.0
Shopping Center Department Stores	55.0	20.0
Commercial	50.0	40.0
Residential	20.0	50.0

3. Component Characteristics

   A. Diesel Engines

      Electrical Efficiency - 34%
      Recoverable Heat - 36%
      Waste Heat - 30%

   B. Fuel Cell

      Electrical Efficiency - 38%
      Recoverable Heat - 46%
      Waste Heat - 16%

   C. Heat Pump - COP = 2.0 (Avg.)

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* #6 Oil = 155,000 Btu/gal = 6.45 gal/million Btu, 25 $.30 gal = $1.94/million Btu.

TABLE 6. PERFORMANCE AND COSTS FOR FUEL CELL, DIESEL, AND HEAT PUMP BASED SYSTEMS VS. THE CONVENTIONAL SYSTEM FOR THE SHOPPING CENTER

	FUEL CELL	DIESEL	HEAT PUMP
Annual Electricity Consumed (kWh)	3.75×10^{7}	3.72×10^{7}	5.32×10^{7}
Annual Fuel Consumed (Btu)	3.49×10^{11}	4.34×10^{11}	6.05×10^{11}
Annual Energy Cost ($)	4.56×10^{5}	8.22×10^{5}	1.12×10^{6}
Annual Fuel Savings (Btu)	43.5×10^{11}	3.60×10^{11}	1.79×10^{11}
Annual Fuel Savings (%)	55	46	22.4
Energy Cost Savings ($)	9.52×10^{5}	6.26×10^{5}	3.31×10^{5}
Incremental Capital Cost ($)	3.79×10^{6}	2.47×10^{6}	2.35×10^{6}
Incremental O/M Cost ($)	8.17×10^{4}	3.65×10^{4}	---
Annual Savings ($)	8.70×10^{5}	5.90×10^{5}	3.31×10^{5}
Annual Return (%)	23.0	23.9	14.1
Payback (Year)	4.36	4.18	7.1

TABLE 7. INCREASES IN OVERALL THERMAL EFFICIENCY BY INCLUDING PYROLYSIS FUEL IN DIESEL BASED SYSTEM

SYSTEM	Btu/YEAR	FUEL SAVINGS (%)
DIESEL GENERATOR	4.34×10^{11}	46
DIESEL GENERATOR AND PYROLYSIS	3.94×10^{11}	49.7

TABLE 8. PERFORMANCE AND COSTS FOR FUEL CELL, DIESEL, AND HEAT PUMP CENTERED SYSTEMS VS. THE CONVENTIONAL SYSTEM FOR THE SHOPPING CENTER, COMMERCIAL, AND RESIDENTIAL DEVELOPMENT

	FUEL CELL	DIESEL	HEAT PUMP
Annual Electricity Consumed (kWh)	1.39×10^8	1.39×10^8	1.97×10^8
Annual Fuel Consumed (Btu)	1.45×10^{12}	1.58×10^{12}	2.24×10^{12}
Annual Energy Cost ($)	2.06×10^6	3.07×10^6	5.91×10^6
Annual Fuel Savings (Btu)	1.27×10^{12}	1.14×10^{12}	0.68×10^{12}
Annual Fuel Savings (%)	54	51.6	18.9
Energy Cost Savings ($)	5.11×10^6	4.63×10^6	1.26×10^6
Incremental Capital Cost ($)	14.77×10^6	13.58×10^6	6.36×10^6
Incremental O/M Cost ($)	5.00×10^5	1.39×10^6	0.35×10^5
Annual Savings ($)	4.61×10^6	3.24×10^6	1.22×10^6
Annual Return (%)	31.2	23.8	19.3
Payback (Year)	3.2	4.2	5.2

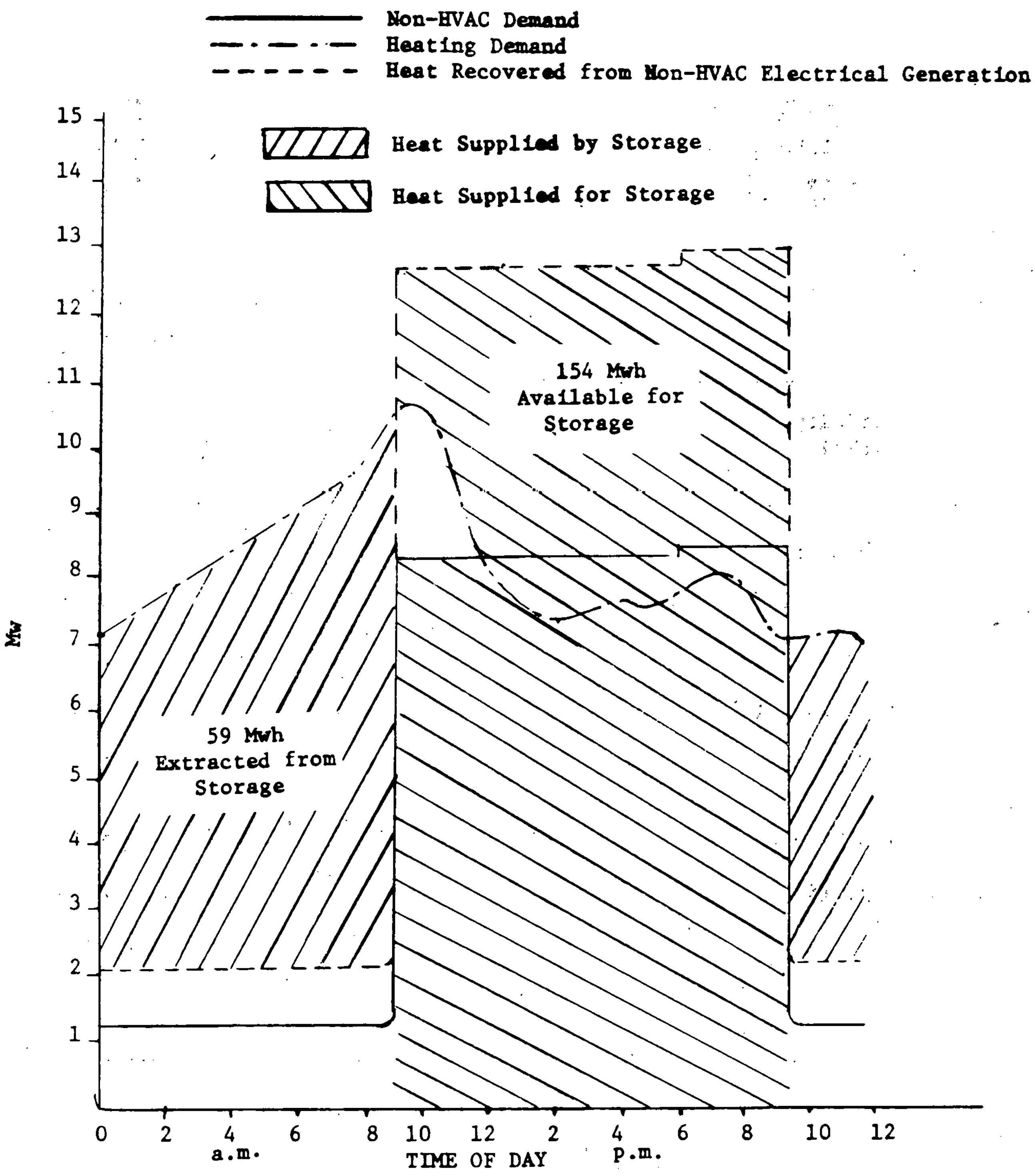

Fig. 1. POWER GENERATION AND CONSUMPTION PROFILES FOR A PEAK WINTER DAY WITH THE FUEL CELL BASED SYSTEM

Paper No. 6

METEOROLOGICAL EFFECTS OF HEAT AND MOISTURE RELEASES FROM LARGE POWER STATIONS (PRECIPITATION MODIFICATION)*

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1. INTRODUCTION

Among the various atmospheric effects attributed to the operation of the cooling towers and ponds of large power stations is that of precipitation modification.[1] The important characteristics of such cooling systems vis-a-vis the conventional once-through cooling system is that the waste heat is discharged directly into the atmosphere in both sensible and latent forms. This discharge represents a persistent perturbation in the lower atmosphere, which under certain conditions could upset latent instabilities and trigger rainfall storms or enhance the intensity of naturally occurring precipitation events. It should be emphasized that we feel that it is the persistent nature of the perturbation, rather than its magnitude, that is the possible origin of precipitation enhancement.[1] For a modern, four-unit power plant with an electrical capacity of about 3,000 MWe, the estimated atmospheric discharge is about 5,000 MWt and 50,000 gals per min of water; these amounts are small compared with the energy and moisture associated with even a moderately sized thunderstorm. The magnitude of the perturbation could potentially become important, however, if the concept of "energy centers" with electrical capacities exceeding 10,000 MWe, becomes a reality in the future.[2] Such a concept is currently being considered, especially for future nuclear plants to insure nuclear nonproliferation.

The U.S. Department of Energy (DOE) has established a program called METER (Meteorological Effects of Thermal Energy Releases) to investigate the atmospheric effects of cooling towers and ponds.[2,3] Effects being investigated include drift deposition, fog and icing, shadowing, and precipitation modification.[4] As part of this nationwide program, the Oak Ridge National Laboratory (ORNL) is studying precipitation modification from large cooling towers.[5,6,7] For that purpose, the Bowen Electric Generating Plant (Plant Bowen) in Northwest Georgia has been chosen as a test site. This 3,200-MWe coal-fired power plant of the Georgia Power Company uses four natural-draft cooling towers and is the largest of U.S. power plants having cooling towers as the sole cooling method. Completed in the early 1970's, it is situated about 40 mi NW of the city of Atlanta in a broad valley amidst gently rolling hills.

The ORNL activities presently include both climatological and field studies. Extensive use has been made of the U.S. National Weather Service (NWS) data accumulated over several decades in Northwest Georgia. Apart from providing preliminary indications of precipitation modification effects, these data have aided in the general understanding of the climatology in the vicinity of Plant Bowen and have paved the way for the field studies currently underway. These field studies, employing a dense network of rain gauges and windsets, are expected to provide the statistical data base necessary to estimate the plant's effect (if any) on precipitation.

2. CLIMATOLOGICAL STUDIES WITH NWS DATA

The National Weather Service (NWS) collects meteorological data at a number of key stations across the country. Most of these stations are located on major airports. This network of NWS stations is augmented by the Cooperative Network which is operated by volunteer observers who record one or more meteorological variables and report them to the NWS. The meteorological variables, monitored at the above NWS stations, include temperature and humidity, wind speed and direction, precipitation amount, etc. Those of the Cooperative Network generally record precipitation. Figure 1 displays the NWS and Cooperative Networks in Northwest Georgia. Fifty-nine of these stations within a 60-mi radius from Plant Bowen were selected for climatological studies. These stations, operating continuously or intermittently, have provided daily rainfall amounts since 1949. Surface wind data from the two NWS stations (Atlanta and Rome Airports) have also been included in the analysis as well as upper-air wind data from the Athens Airport about 90 mi E of Plant Bowen.

2.1 Data Quality Evaluations

In dealing with precipitation data from the Volunteer Network, it is important to recognize that these data are collected by a great number of individuals over a long period of time and with different instruments. Because of the wide variety of possible errors associated with such data acquisition, we carried out a careful preliminary evaluation of the quality of the obtained data. This consisted of two parts: field visits and analytical tests. The field visits were undertaken primarily to assess the exposure and quality of the instruments themselves. As a result of these field visits, several of the original 59 stations were dropped because of poor exposure.

The analytical method known as "double mass"[8,9] was then used to determine whether extraneous occurrences (e.g., a change of rain gauge location exposure) caused a consistent departure of the recorded data from the long-term mean. Data from another nearby station with dependable records were used as a basis for comparison. Thus, we designate the recorded rainfall

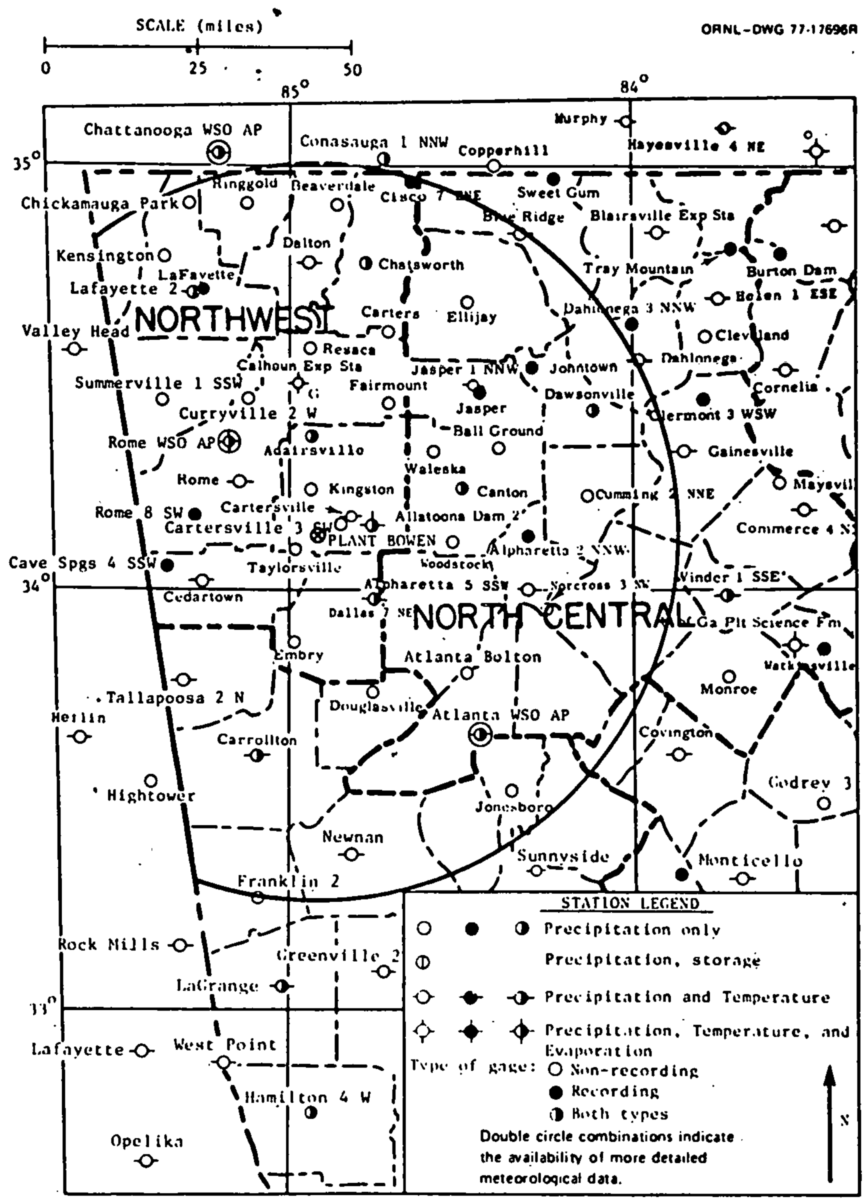


Fig. 1. Map of Northwest Georgia depicting the National Weather Service (NWS) and Cooperative Network stations. The stations within the circle are used for the climatological study.

amount from a given rain gauge station X as X_i where i = 1,2,...,N and i is the constant time interval over which the data are recorded (e.g., daily, monthly, etc.). From a collection of the above data, we created the following cumulative record

$$X_{j+1} = \sum_{i=1}^{j} X_i$$

where j = 1,2,...,N ($X_1 = 0$).

Similarly, for a station Y we have

$$Y_{j+1} = \sum_{i=1}^{j} Y_i \quad (Y_1 = 0)$$

Now assume that station X is the dependable one and Y is the questionable one. By eliminating j from X_j and Y_j, we plot the relationship Y = f(X) on a cartesian coordinate frame. The result will be a series of data points in the first quadrant. If the straight line segments that best approximate consecutive groups of points (i.e., the least squares fits) have approximately equal slopes, then we can conclude that station Y has acceptable data. If an obvious change in the slope is evident after some point, we can conclude that after the time corresponding to that point the continuity of the record was severed. In that case, we either consider the record as being composed of two different records from two different stations prior and subsequent to that point (e.g., in the case of an instrument relocation); or in the case of multiple significant slope changes with no apparent reason, we disqualify the station. Figure 2 displays the double-mass graph of winter precipitation totals (December through February) for the "Atlanta Bolton" station vs the "Atlanta Airport" station. This graph, as well as initial contour maps containing the "Atlanta Bolton" station, led to the discarding of this station's data from further analyses. Figure 3 presents the double-mass graphs for the "Dallas" station's winter record vs the respective ones for the "Embry" and "Douglasville" stations. Despite the fact that the "Dallas" station was relocated six times during the period 1948 to present, the double-mass graphs show no appreciable changes in the slope. As a result, the records from all

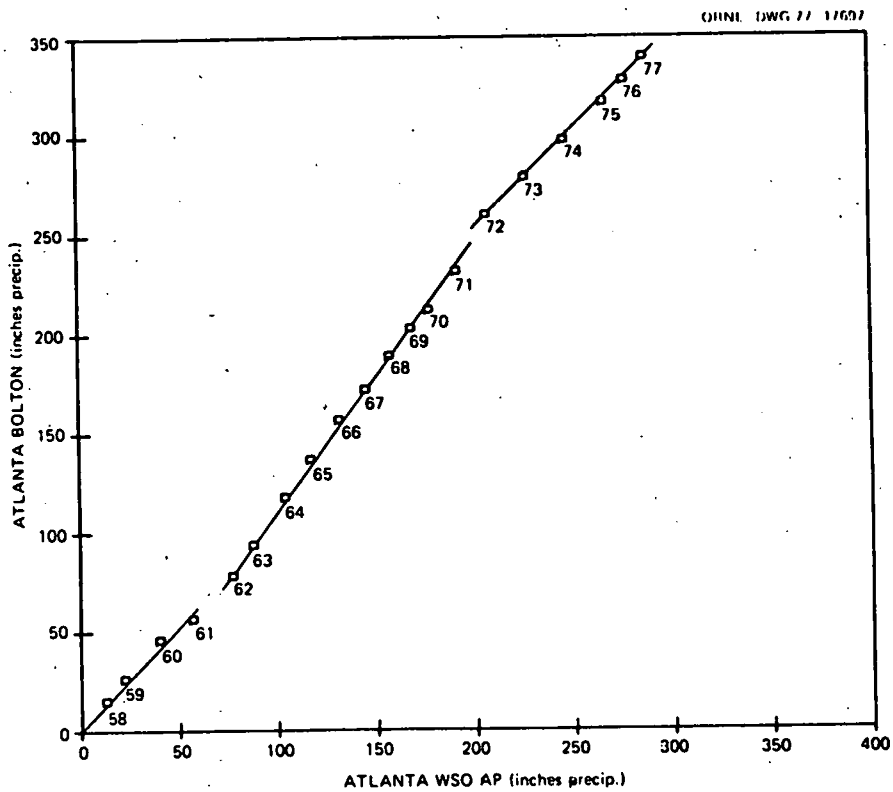


Fig. 2. The "double-mass" graph of winter precipitation totals for the Atlanta Bolton station vs the Atlanta Airport station.

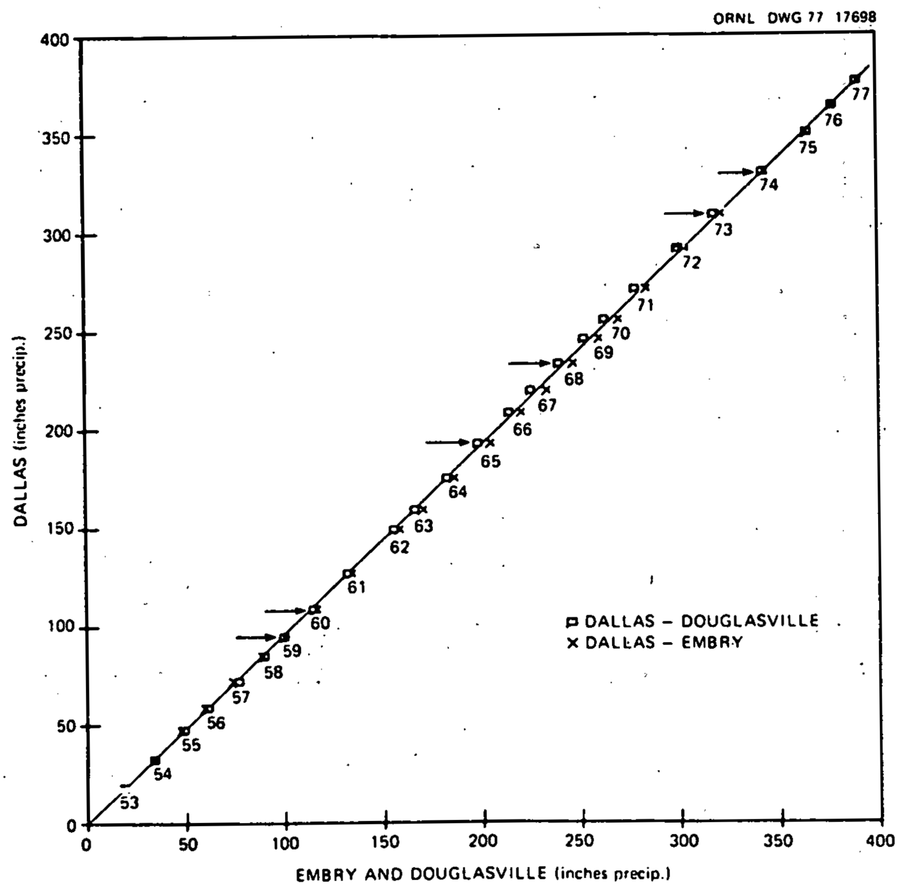


Fig. 3. The "double-mass" graphs of winter precipitation totals for the Dallas station vs the Embry and Douglasville stations. Arrows indicate the years during which the Dallas station was relocated.

"Dallas" stations were joined together into one continuous record representing the general area over which the "Dallas" station has been located.

2.2 Data Stratification and Inference

As mentioned in the Introduction, Plant Bowen's effect on rainfall could manifest itself in several ways. The most obvious one is a general increase of rainfall in the downwind area. This additional rainfall can be detected as either an increase with respect to the upwind area or with respect to the areal long-term mean. The natural spatial and temporal rainfall variability complicates the investigations in the choice of the time period for study (storm duration, day, month, etc.); and the determination of the magnitude of the effect since, depending on the time stratification, the potential effect could be buried in the natural "random noise."[10] Another manifestation of the effect could be an increase in storm frequency in the vicinity of the plant with or without a substantial increase in rainfall amounts. In all cases, the monitoring of the power plant's thermal output is important since the effect would be expected to increase with increasing output.

It was apparent at the start that the NWS data would be insufficient by themselves to study the power plant's effect in all the aspects described above, because of limitations of data density and quality.[11] Nevertheless, analyses were carried out utilizing the NWS data. To our surprise, they yield several significant results. It is important to note at this point that in all the analyses using NWS rainfall data the smallest data increment (in the time sense) was one month. Most analyses dealt with seasonal rainfall totals. The seasons were chosen as follows: December through February (winter), March through May (spring), June through August (summer), and September through November (fall). Some work was also done with wet and dry season stratifications, primarily to distinguish between the two main types of rainfall situations (frontal and convective). The wet season included the months of December through April, and the dry season the remaining ones.

The framework for these analysis of rainfall modification based on the NWS data was a combination of target-control and preoperational-postoperational techniques.[10] Some sample results are presented: Figure 4 depicts the surface wind-rose constructed from the recorded surface winds at Atlanta

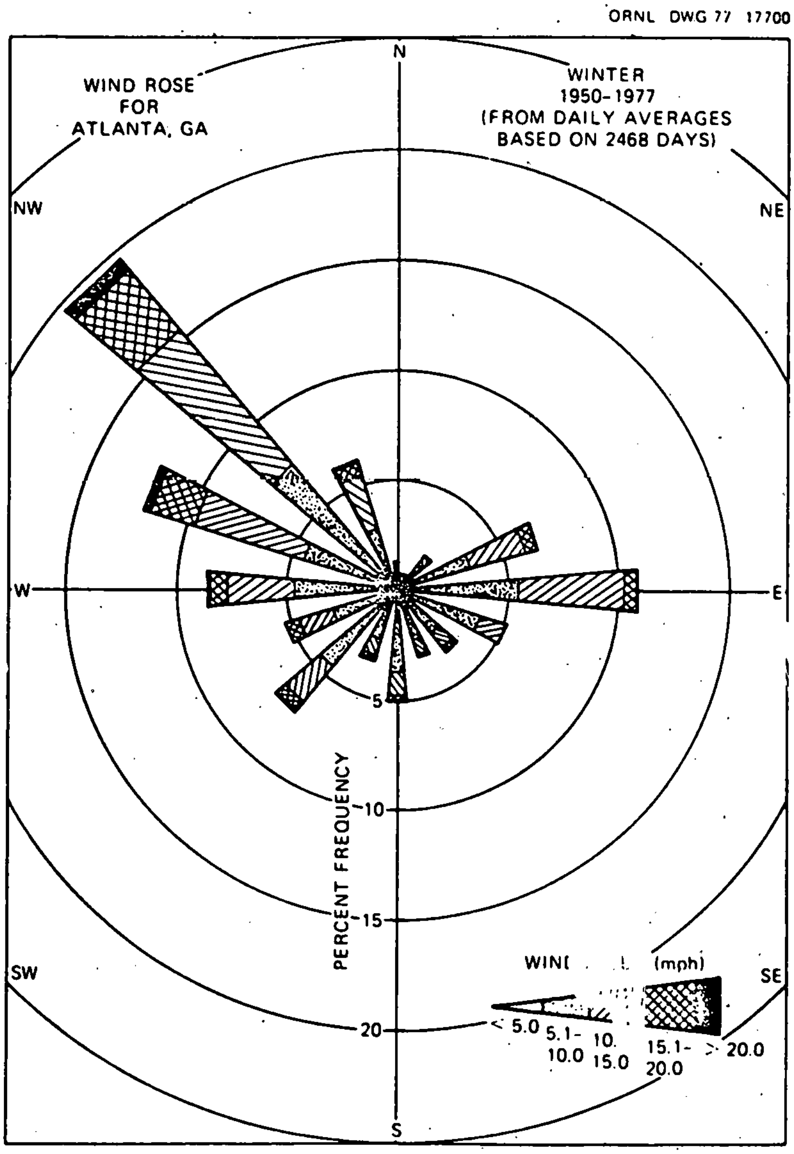


Fig. 4. Surface wind-rose for the Atlanta Airport station for the winters of 1950 through 1977.

Airport for the winters of 1950 through 1977. The resulting distribution displays predominant northwesterly winds. This is a very encouraging fact for the climatological study, since it shows that the city of Atlanta with its potential urban effect lies downwind of the plant. An examination of surface wind data at Rome Airport also indicated a predominant northwesterly direction for the winter months. Figure 5 depicts the wind roses for the upper-air winds at the Athens Airport, about 90 mi east of Plant Bowen, for the period 1956-1976. Wind roses were developed for two pressure levels, 850 and 500 mb, from the data obtained at 12-hr intervals. The prevailing wind direction is clearly from the west at both levels. Based on the prevailing surface and upper-air winds, we postulate the general southeastern area from Plant Bowen as the target area. Figure 6 displays the contour map for the ratios of postoperational (PO) to preoperational (PREOP) normalized winter precipitation means for the 30 stations within a 40-mi radius of Plant Bowen. The normalized precipitation means were generated as follows. The total precipitation amounts for each winter season at each station was divided by the arithmetic areal mean for each winter season. This guarantees that the areal variations of precipitation for each winter season will contribute equally to the subsequent averaging (wet and dry seasons have equal weights). The preoperational means are the arithmetic means of the normalized precipitation values for the period 1950-1971; and the postoperational ones, for the period 1972-1976 (Plant Bowen's first unit became operational in October 1971). The ratios of the latter (PO) to the former (PREOP) are displayed in Fig. 6. It is noted that precipitation high appears in the general downwind area of the plant. As discussed earlier, it is premature to attribute this result to a plant-induced effect. In fact, following the application of a rank (Wilcoxon T) test,[12] it was found that the statistical significance of the result was rather small. Nevertheless, this result serves as a starting hypothesis to be confirmed or discredited by the results of the field study. Figures 7-10 display the contour plots for the ratios of the five-year postoperational normalized means to four different five-year preoperational means (51-55, 56-60, 61-65, 66-70). Taking into account natural variations, we observe that the precipitation high persistently appears to the south and east of the plant (the downwind region). Similar five-year running mean ratio plots were generated with other preoperational five-year

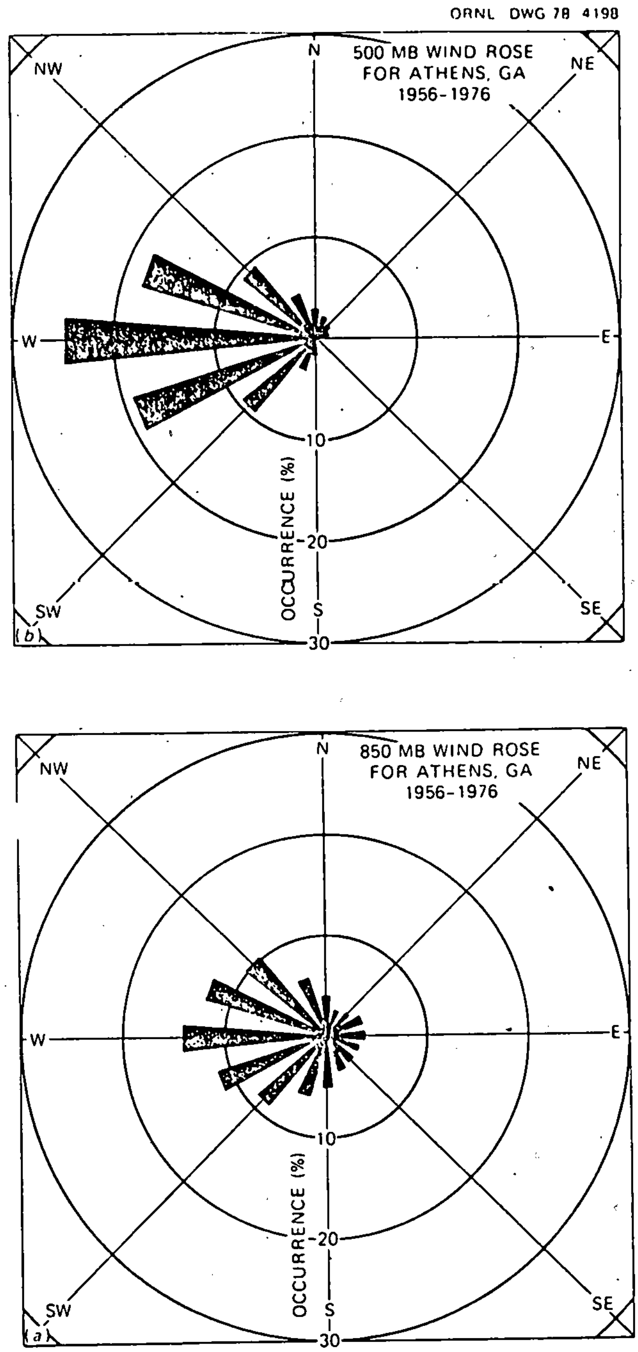
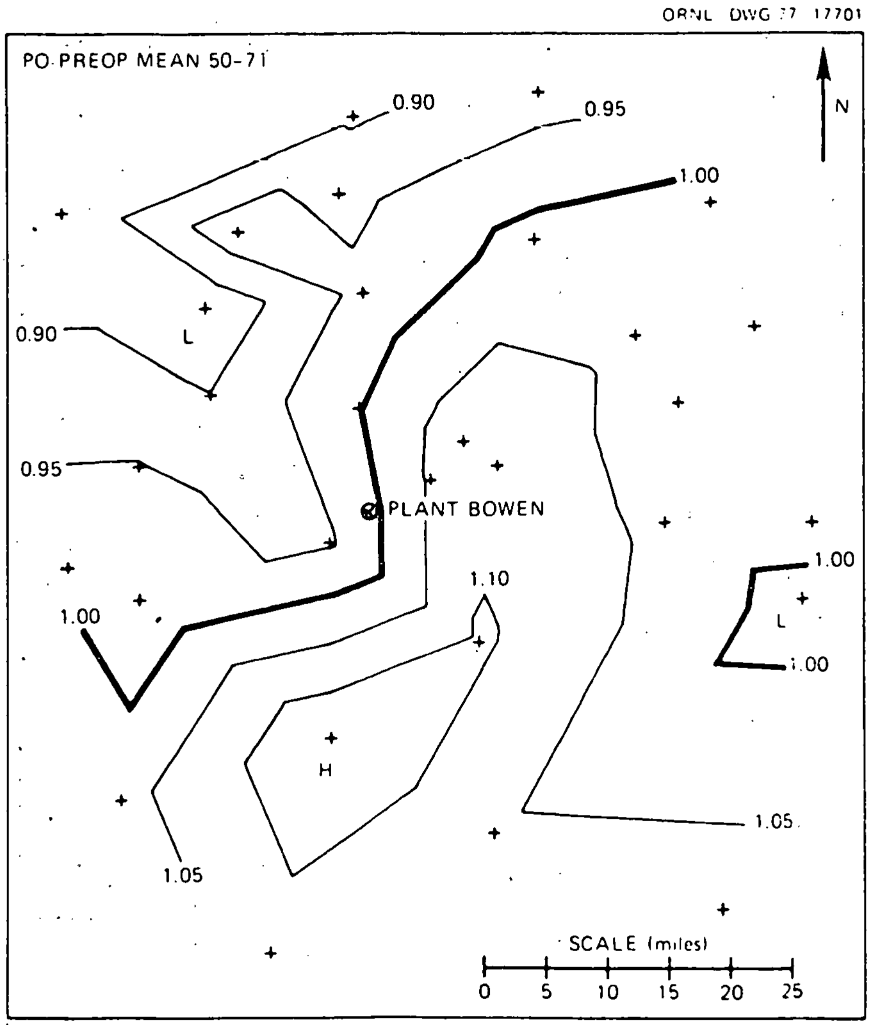


Fig. 5. Wind direction distributions of winds at the 850- and 500-mb pressure levels at the Athens Airport for the period 1956-1976.



. 6. Contour map of ratios of postoperational (PO: 1972-1976) to preop tional (PREOP: 1950-1971) normalized precipitation means (winter).

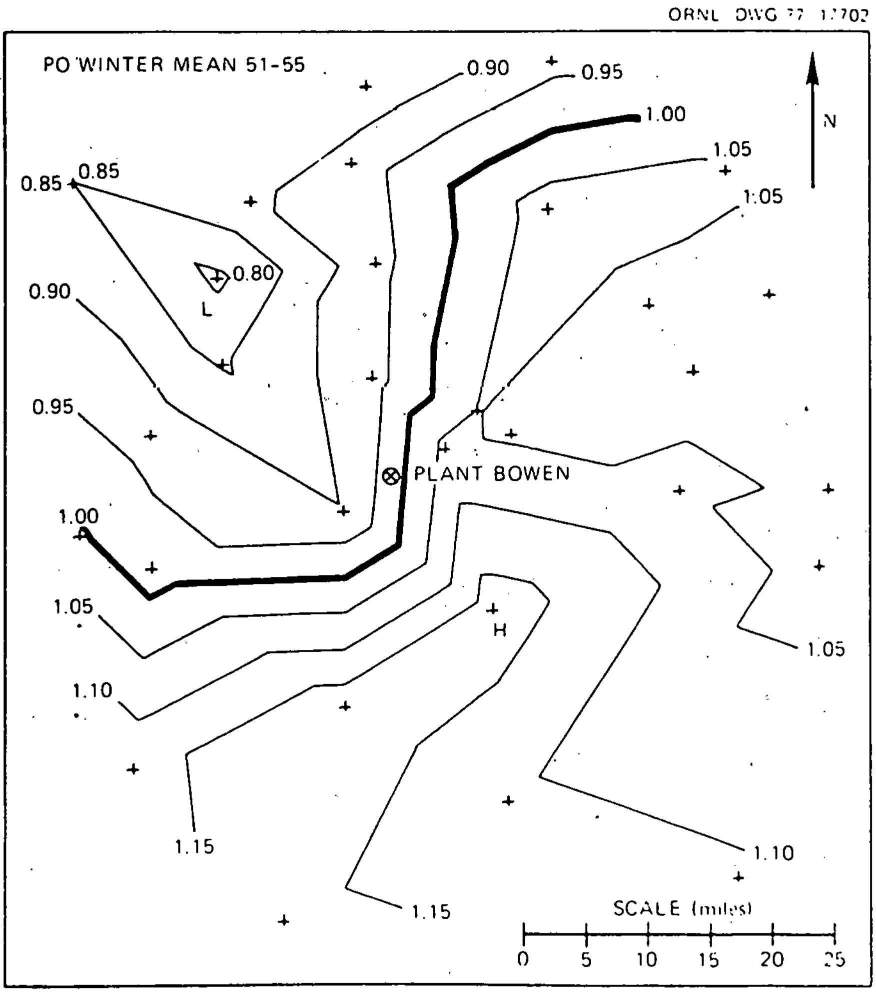


Fig. 7. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1951-1955) normalized precipitation means (winter).

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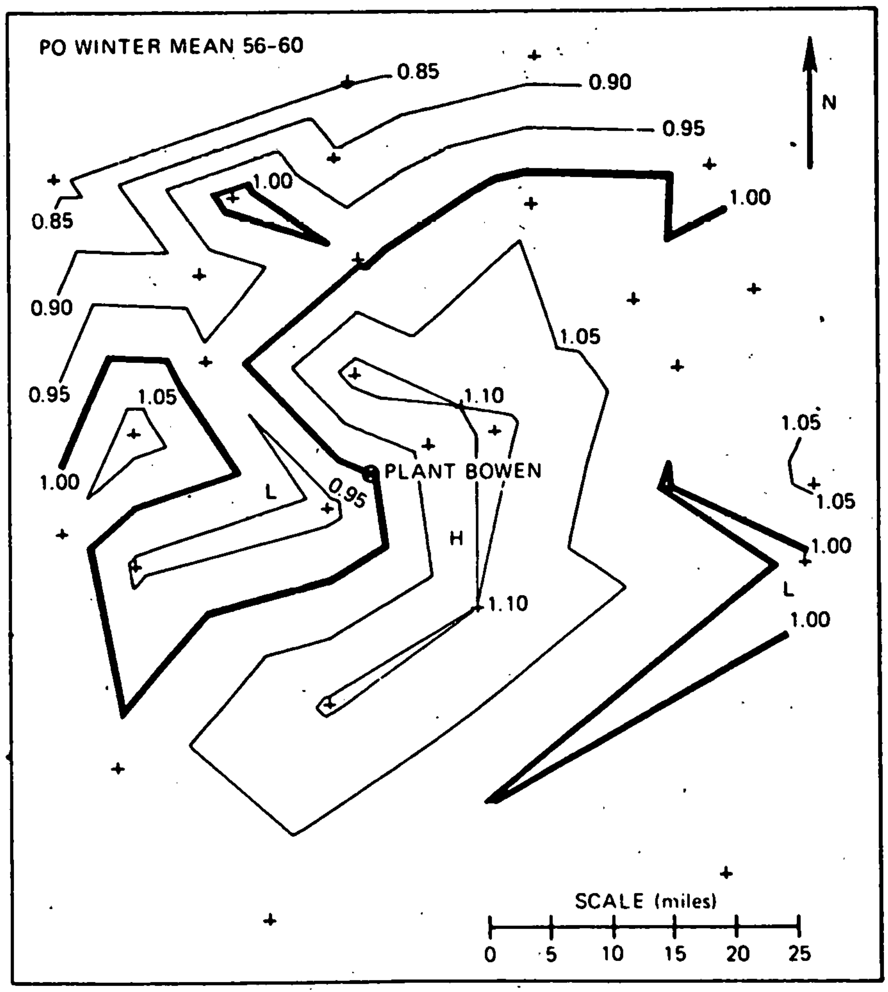

Fig. 8. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1956-1960) normalized precipitation means (winter).

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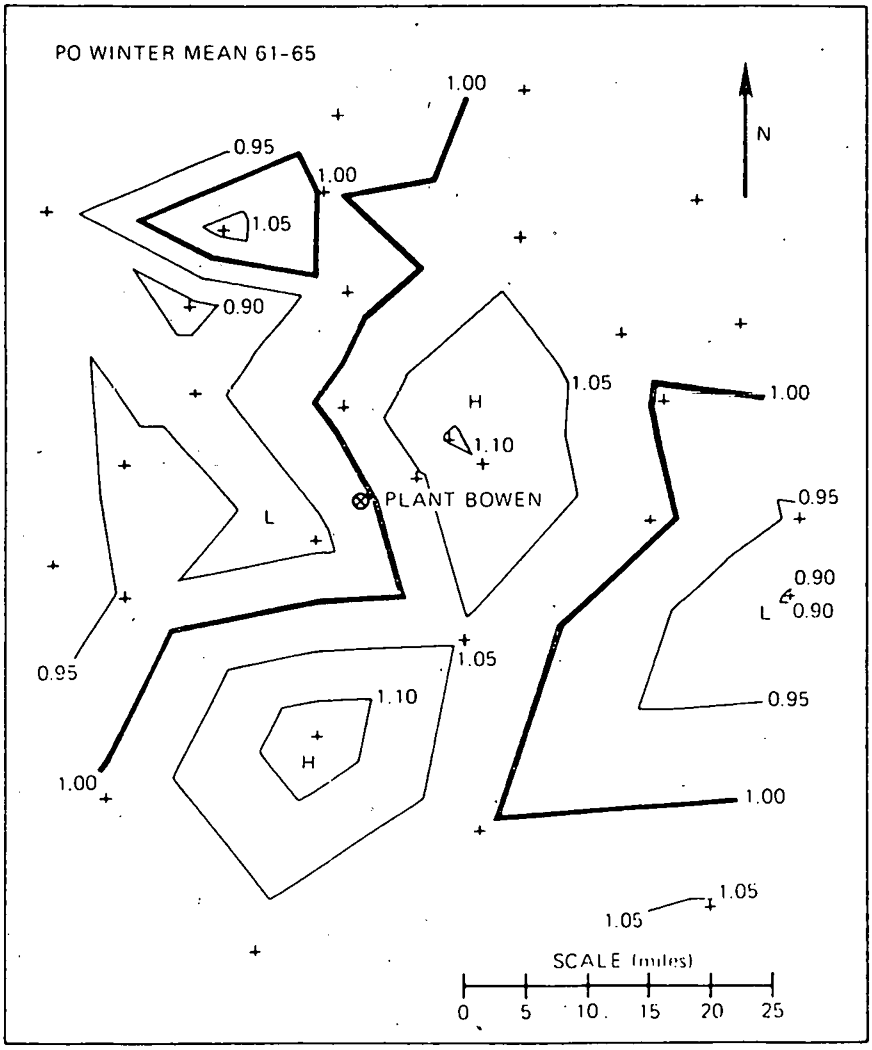

Fig. 9. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1961-1965) normalized precipitation means (winter).

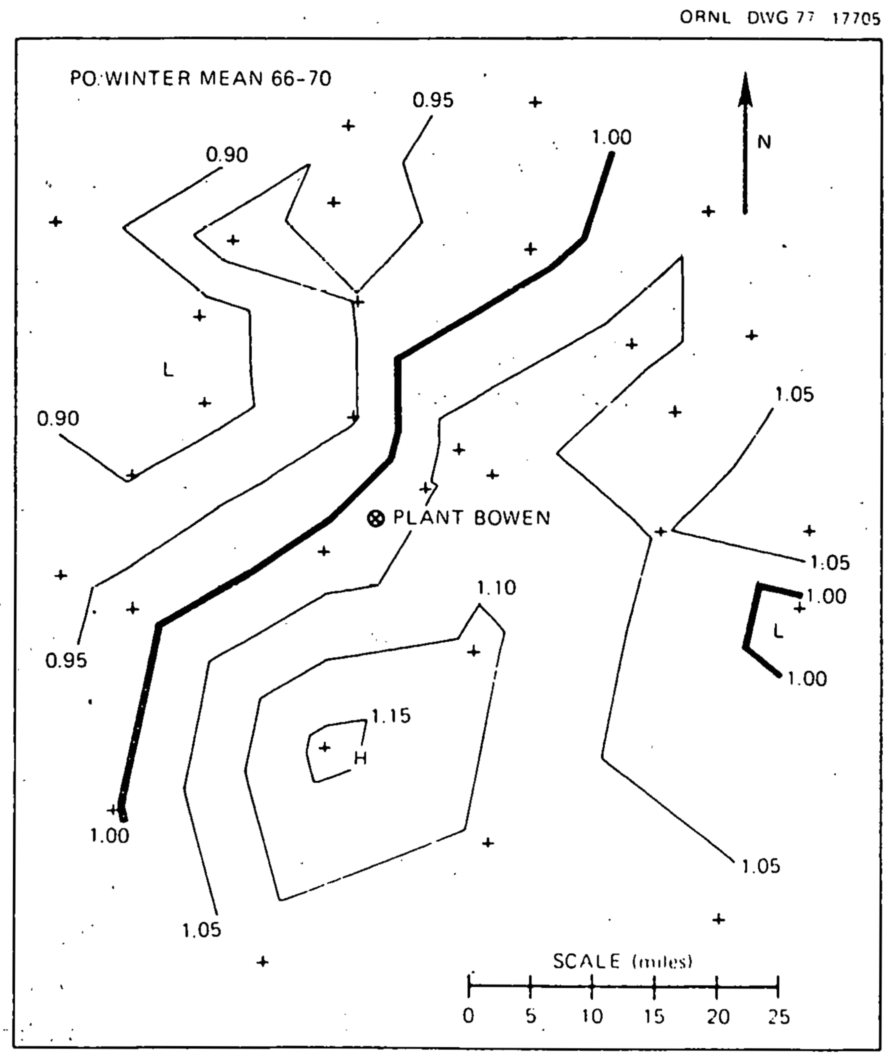

Fig. 10. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1966-1970) normalized precipitation means (winter).

periods in the numerator for comparison. The plots displayed considerable random behavior with no persistent patterns in the precipitation highs and lows. Figure 11 displays the equivalent of Fig. 6 for an enlarged network (the stations within a 60-mi radius of Plant Bowen) and for the postoperational period 1972-1978. The basic patterns of the contour plots is the same in both figures. A series of statistical tests were then applied to the data to test the significance of the result. Apart from the rank (Wilcoxon T) test mentioned above, parametric tests such as the Student's t-test were attempted with limited success. The roots of the difficulty lie in the use of monthly rainfall totals which exhibit unwieldy frequency distributions and resist treatment by standard parametric statistical techniques. Current research includes attempts to characterize these frequency distributions by more complex techniques.

2.3 Spatial Correlations

The use of the spatial correlation as a tool to investigate rainfall modification effects is quite controversial.[13] One proposed method (not described in this paper) attempts to utilize the spatial correlation for that purpose by establishing the background natural variability of the spatial correlation function. Spatial correlations have also been used to characterize the local climatology and to produce quantitative measures of rainfall relationships between stations.[14,15,16] Figures 12-14 display the correlation coefficient contour plots we obtained for three stations ("Beaverdale 1E," Ball Ground," and "Atlanta Airport") computed on the basis of 300 consecutive common months. It is noteworthy that the correlation coefficient isopleths have a predominant direction along the WSW-ENE. This direction coincides with the direction of the predominant storm tracks;[17,18,19] a plausible explanation of the phenomenon is that storm systems moving along a given direction produce precipitation amounts along that direction with consistent relationships (these relationships are probably a function of topography, storm type, etc.). Moreover, the possibility exists that a storm moving along a given direction would produce rain along a relatively narrow strip in that direction with no rain elsewhere. This is translated into high correlations along that direction with low correlations in the perpendicular direction. Since the correlation coefficients presented here are computed on the

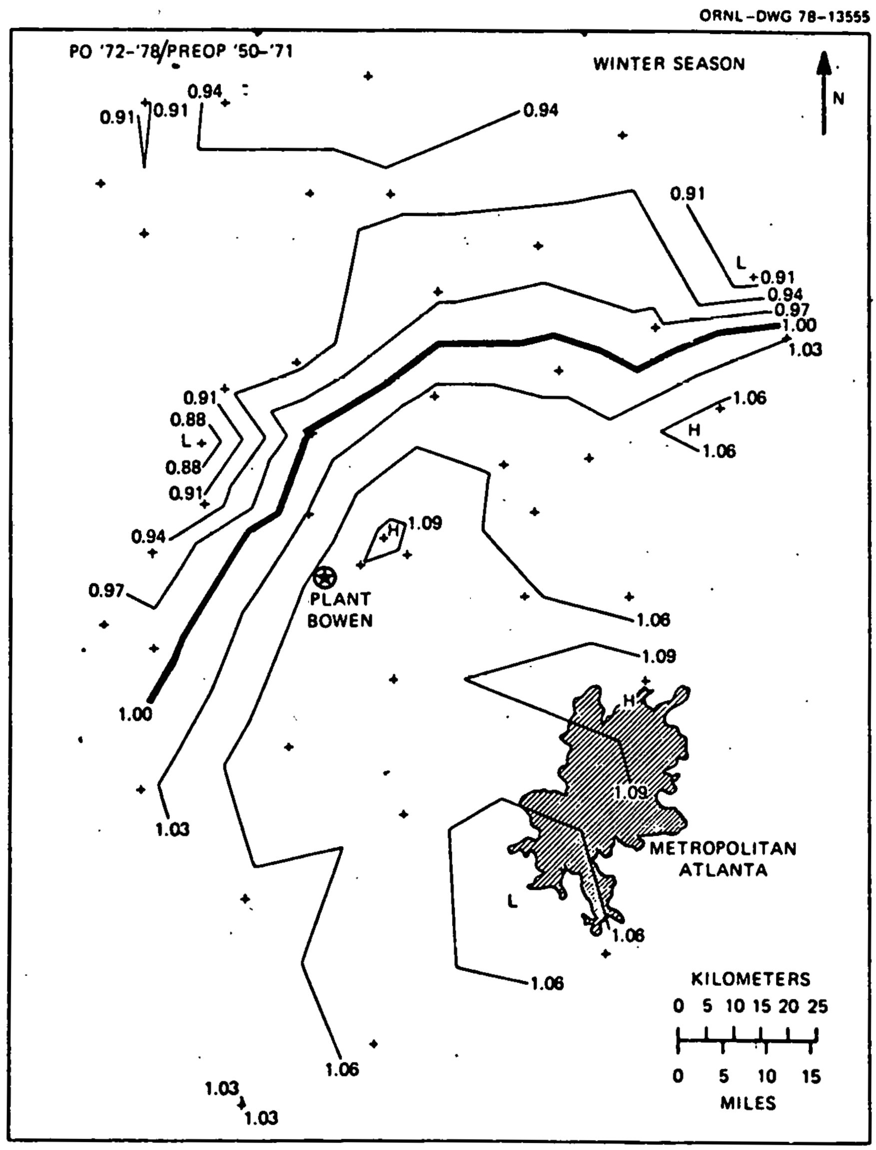

Fig. 11. Contour map of ratios of postoperational (PO: 1972-1978) to preoperational (PREOP: 1950-1971) normalized precipitation means (winter).

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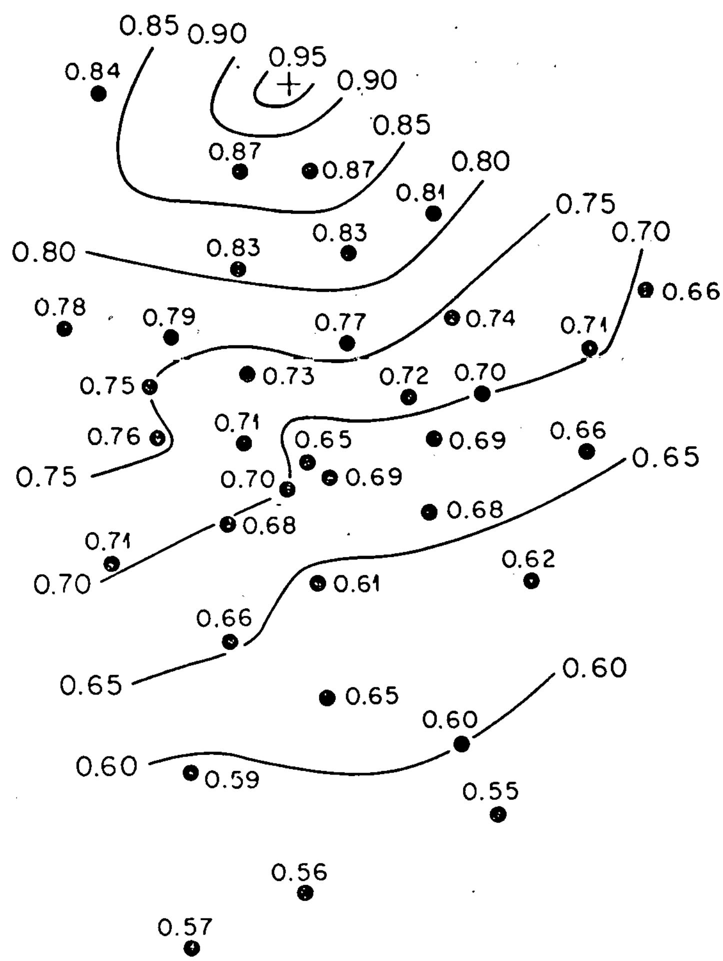

Fig. 12. Contour map of the spatial correlation coefficients for the Beaverdale 1E station (based on 300 monthly totals).

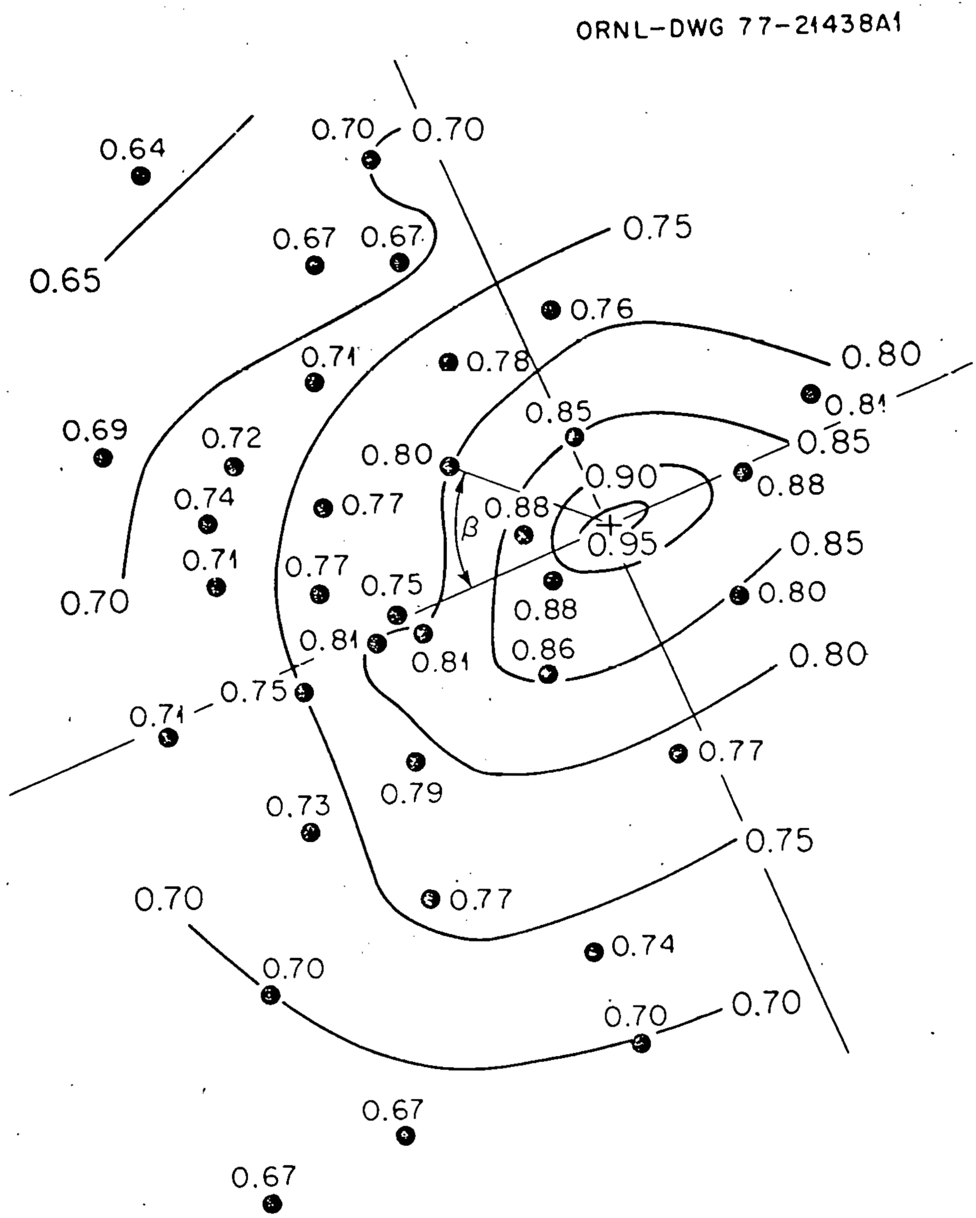

Fig. 13. Contour map of the spatial correlation coefficients for the Ball Ground station (based on 300 monthly totals).

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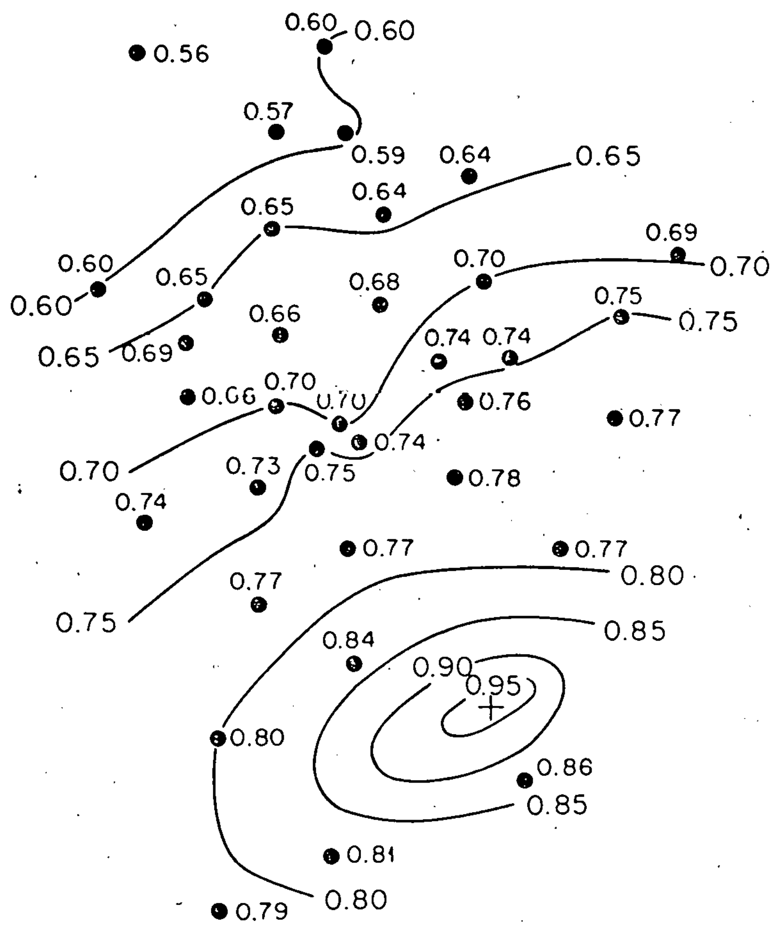

Fig. 14. Contour map of the spatial correlation coefficients for the Atlanta Airport station (based on 300 monthly totals).

basis of monthly totals, the above-mentioned sharp differences are to some extent smoothed out over the various storms. Nevertheless, the observed patterns support this theory to a satisfactory degree.

The relationship between the correlation coefficient and distance was investigated by displaying all computed correlation coefficient values vs the normalized distances between stations (the distances were normalized by the distance between the "Beaverdale 1E" and "Franklin 2" stations). A coordinate system was established in which the x-axis was aligned with the direction of the prevailing storm tracks (Fig. 13), and the origin was located at the respective station; β is defined as the angle ($0° \leq \beta \leq 90°$) which the position vector for every other station forms with the x-axis. Figure 15 contains the results, where stations with $0° \leq \beta < 20°$ are depicted by a $\cdot$, with $20 \leq \beta \leq 70°$ by a o, and with $70° < \beta \leq 90°$ by a +. As expected from the patterns of the correlation plots, stations with small β have larger correlation coefficients when compared with equidistant stations with large β. Despite the considerable scatter of points, there is evidence of a quasilinear relationship between the two quantities beyond a certain distance. It remains to be seen whether that relationship is intrinsic to the network area, is dependent on the type of predominant storms, or obeys some universal law.

2.4 The Plant Bowen Field Study

The Plant Bowen field study was felt to be necessary for several reasons. The current state-of-the-art in precipitation studies recommends a rain gauge density of about 1 gauge per 16 sq mi; the NWS network falls short of that number of an order of magnitude. This density requirement becomes particularly important for rainfall events of the convective type (summer rainfall), and our speculation is that precipitation modification would maximize during such events. The second reason for carrying out the field study was that the potential effect was believed to be sufficiently small so that higher resolution instrumentation (recording rain gauges) would be necessary to investigate rainfall on a storm event basis. An additional dimension of the problem was the need for a concise knowledge of the prevailing winds in the vicinity of the plant during the rainfall events for the implementation of the control-target area technique.[10]

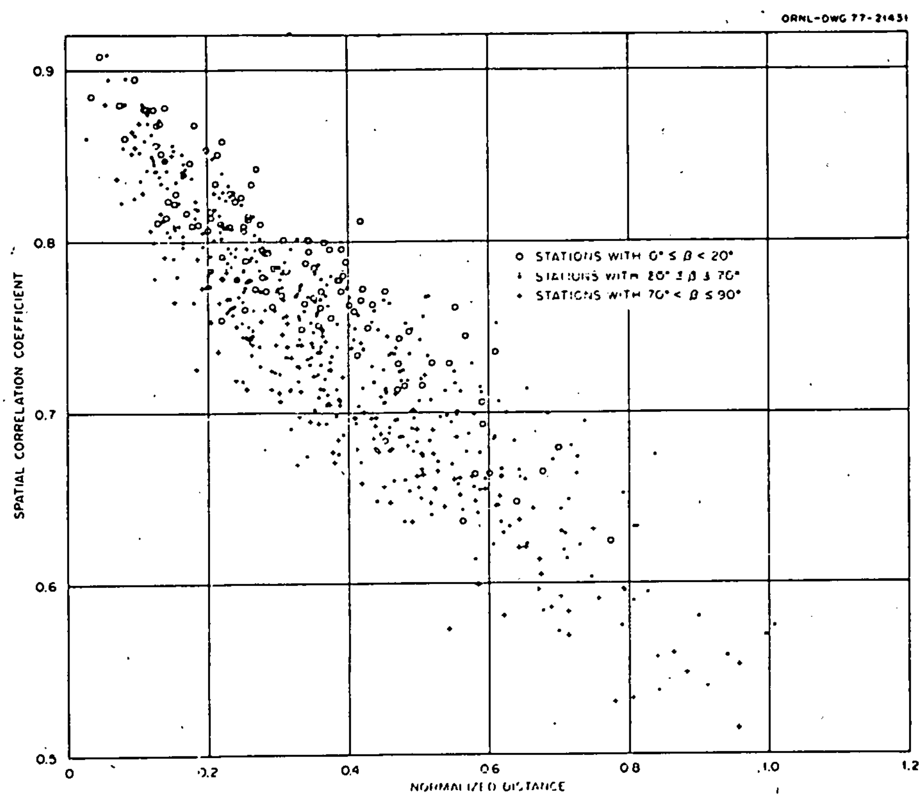

Fig. 15. Spatial correlation coefficients vs normalized distances for all stations satisfying the 300 common-month requirement.

The METER-ORNL precipitation network was installed in February 1978. Figure 16 depicts the present network against the topographical map of the area. It is composed of 49 recording rain gauges and 4 recording windsets. The rain gauges are of the weighing-bucket type continuously recording on a weekly chart. The windsets include a cup-anemometer, a wind-vane, and a strip-chart recorder operating on a monthly basis. Three-hr weather maps obtained from the NWS provide information regarding the prevailing synoptic conditions (storm type, storm movement, etc.). In addition, the power plant's thermal output (on an hourly basis) during the rainfall events is obtained from the Georgia Power Company. Additional wind data are recorded at the power plant's meteorological station located a few miles from the cooling towers. The above information is being accumulated on a storm-by-storm basis. Precipitation events are considered distinct storm events when they are separated by at least two hrs with no rain over the entire network. The complete data base, thus, is composed of "storm profiles," such as those presented in Figs. 17 and 18 for two storms in March 1978.

The Bowen Plant field study is currently underway and is expected to continue for five years with a data base of approximately 600 storms.[20] It is believed that this data base will be sufficient to detect any plant-induced effect and provide its qualitative description as well as a quantitative measure of its magnitude.

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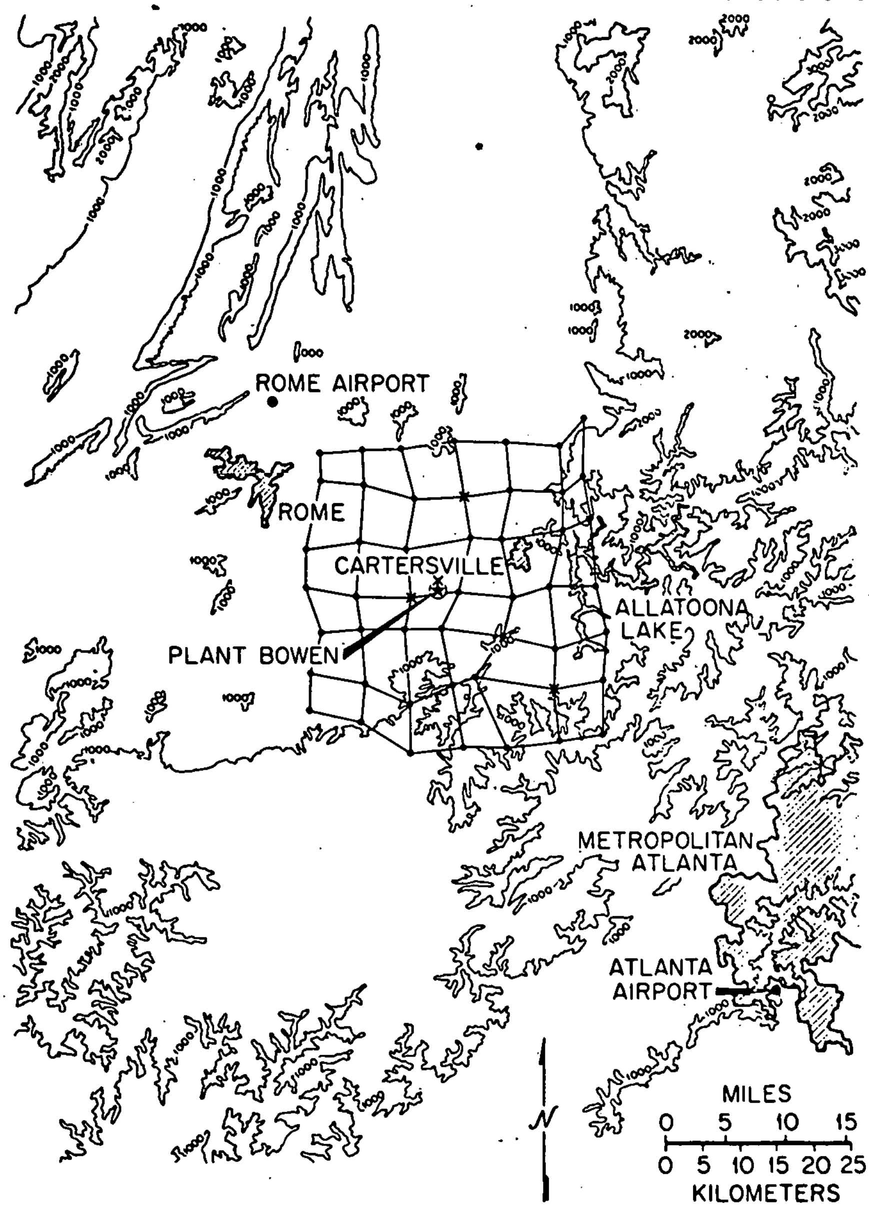

Fig. 16. The METER-ORNL network superimposed on the topographical map of NW Georgia. The minimum elevation in the valley is about 600 ft above mean sea level. Dots denote the rain gauge stations and crosses depict the wind-set locations.

METER - ORNL NETWORK PRECIPITATION CONTOURS

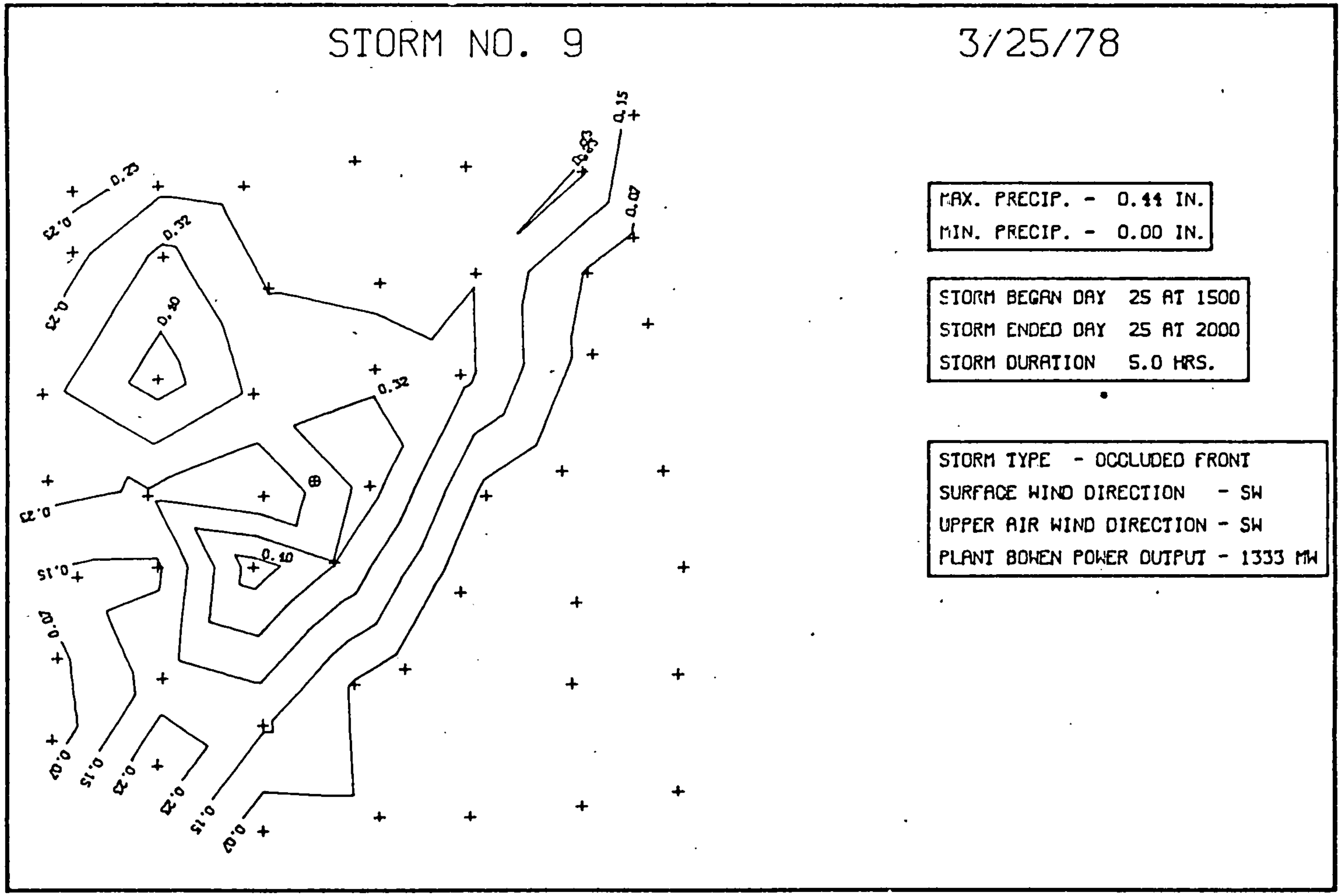

Fig. 17. Storm Profile No. 9.

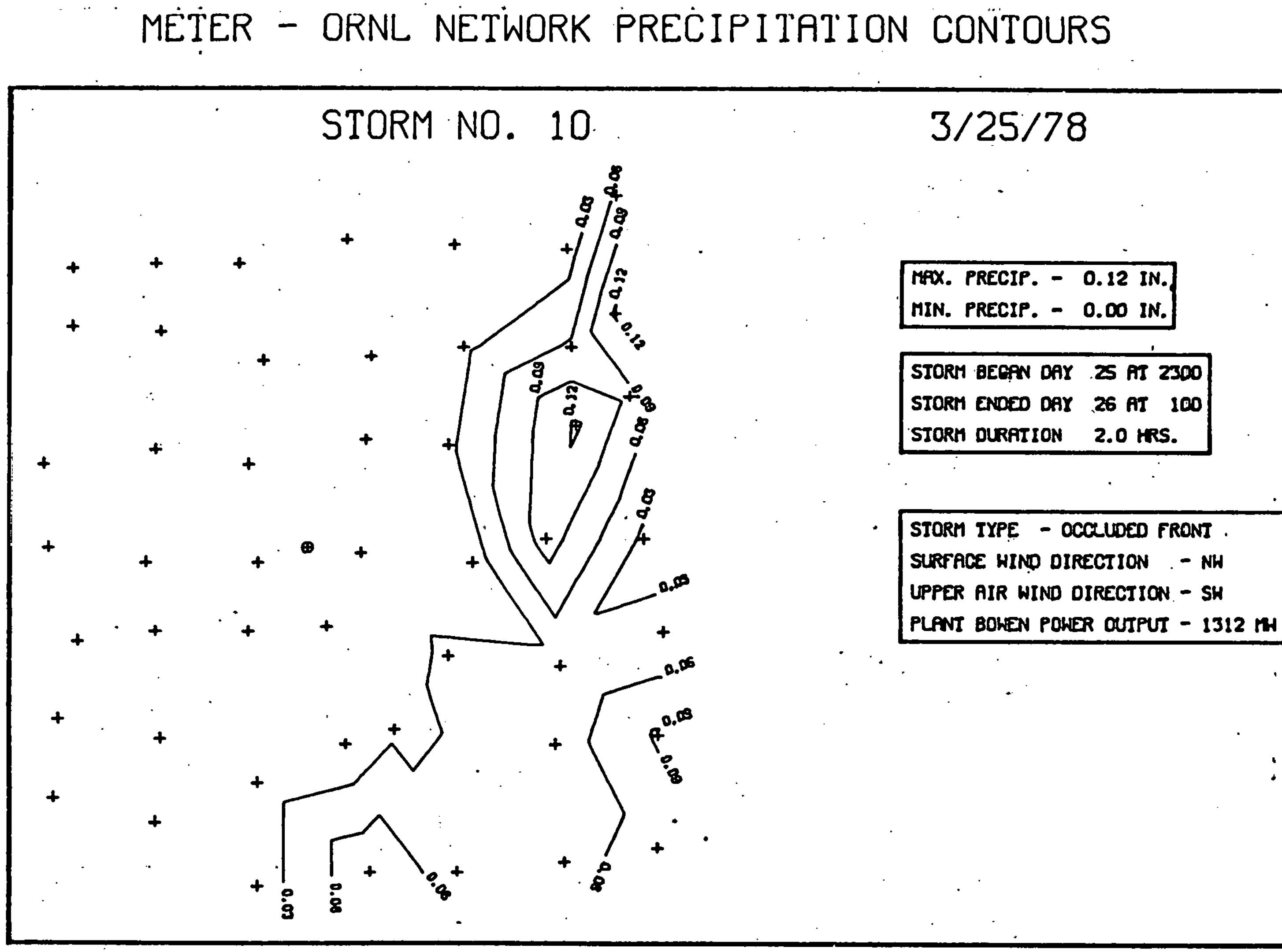

Fig. 18. Storm Profile No. 10.

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FIGURE CAPTIONS

Fig. 1. Map of Northwest Georgia depicting the National Weather Service (NWS) and Cooperative Network stations. The stations within the circle are used for the climatological study.

Fig. 2. The "double-mass" graph of winter precipitation totals for the Atlanta Bolton station vs the Atlanta Airport station.

Fig. 3. The "double-mass" graphs of winter precipitation totals for the Dallas station vs the Embry and Douglasville stations. Arrows indicate the years during which the Dallas station was relocated.

Fig. 4. Surface wind-rose for the Atlanta Airport station for the winters of 1950 through 1977.

Fig. 5. Wind direction distributions of winds at the 850- and 500-mb pressure levels at the Athens Airport for the period 1956-1976.

Fig. 6. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1950-1971) normalized precipitation means (winter).

Fig. 7. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1951-1955) normalized precipitation means (winter).

Fig. 8. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1956-1960) normalized precipitation means (winter).

Fig. 9. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1961-1965) normalized precipitation means (winter).

Fig. 10. Contour map of ratios of postoperational (PO: 1972-1976) to preoperational (PREOP: 1966-1970) normalized precipitation means (winter).

Fig. 11. Contour map of ratios of postoperational (PO: 1972-1978) to preoperational (PREOP: 1950-1971) normalized precipitation means (winter).

Fig. 12. Contour map of the spatial correlation coefficients for the Beaverdale 1E station (based on 300 monthly totals).

Fig. 13. Contour map of the spatial correlation coefficients for the Ball Ground station (based on 300 monthly totals).

Fig. 14. Contour map of the spatial correlation coefficients for the Atlanta Airport station (based on 300 monthly totals).

Fig. 15. Spatial correlation coefficients vs normalized distances for all stations satisfying the 300 common-month requirement.

Fig. 16. The METER-ORNL network superimposed on the topographical map of NW Georgia. The minimum elevation in the valley is about 600 ft above mean sea level.

Fig. 17. Storm Profile No. 9.

Fig. 18. Storm Profile No. 10.

Paper No. 7

A STATUS REPORT ON THE AMMONIA, PHASE-CHANGE DRY COOLING SYSTEM RESEARCH PROJECT

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ABSTRACT

A STATUS REPORT ON THE AMMONIA, PHASE-CHANGE DRY COOLING SYSTEM RESEARCH PROJECT

Previous research,supported by the U.S. Department of Energy (DOE) and the Electric Power Research Institute, has identified the ammonia-based dry cooling system as the most promising approach to water conservation in power plant cooling for utilities. The system configuration which has been selected as optimum in these studies will now be demonstrated on a 6 Mwe test facility at a Pacific Gas and Electric power plant in Bakersfield, California.

The demonstration will include the use of ammonia in the transport loop, the use of enhanced heat transfer surfaces in the steam condenser/ammonia reboiler, and the use of deluge water augmentation on the air-cooled condenser in addition to all-dry operation. The facility will be designed and constructed during 1979 and 1980. Testing is scheduled after 1981 through 1984. In addition to component performance data, the test program will emphasize (1) the effect of the power plant environment on the component performance and reliability; (2) reliability of proposed fabrication techniques for the aluminum components; (3) dynamic responses of the system to power plant operating transients and to emergency conditions.

Introduction: The Need for Dry Cooling

Recent energy projections call for the addition of more than 1000 new steam-electric generating plants in the next 25 years. These plants must reject heat to the environment in the ratio of approximately 2 watts of rejected heat for each watt of electricity generated.

The future increase in rejected heat load must be accommodated in a publicly acceptable manner with minimal depletion of water (where it is scarce), conservation of fuel resources, and a minimum of adverse impact on jobs and lifestyle, environmental damage, and excessive economic penalties.

Absolute water scarcity is not likely to become a problem in the U.S. in the foreseeable future.[1] The mean annual runoff in the continental U.S. is 1200 billion gallons per day (bgd). Current storage capacity provides about 280 bgd in dependable surface supply. An additional 70 bgd are withdrawn from underground water sources and 55 bgd from saline water supplies.[2] In spite of this water abundance, however, shortages do occur and will continue to occur because the water is not uniformly spread throughout the country. Interbasin water transfers are often prohibitively expensive, especially if they involve long distances.[3]

The greatest competition for fresh water is likely to occur in the 11 Westernmost states of the continental U.S. These are the states where rainfall is the lowest and irrigation is most intensive. A recent study estimated that 2.5 million acre-ft of fresh and waste water potentially would be consumed annually to meet cooling requirements in the 11 states by the year 2000. This is almost 5% of the estimated water consumption (including ground water) of 59.6 million acre-ft for irrigation in 1970 in these 11 states.[4]

Power plant cooling is the major consumptive requirement for water at both fossil and nuclear plants. Dry cooling would be a major benefit in increasing siting flexibility, particularly for siting in arid Western coal fields. In addition, dry cooling would reduce the impact on local water supplies for municipal or argicultural use.

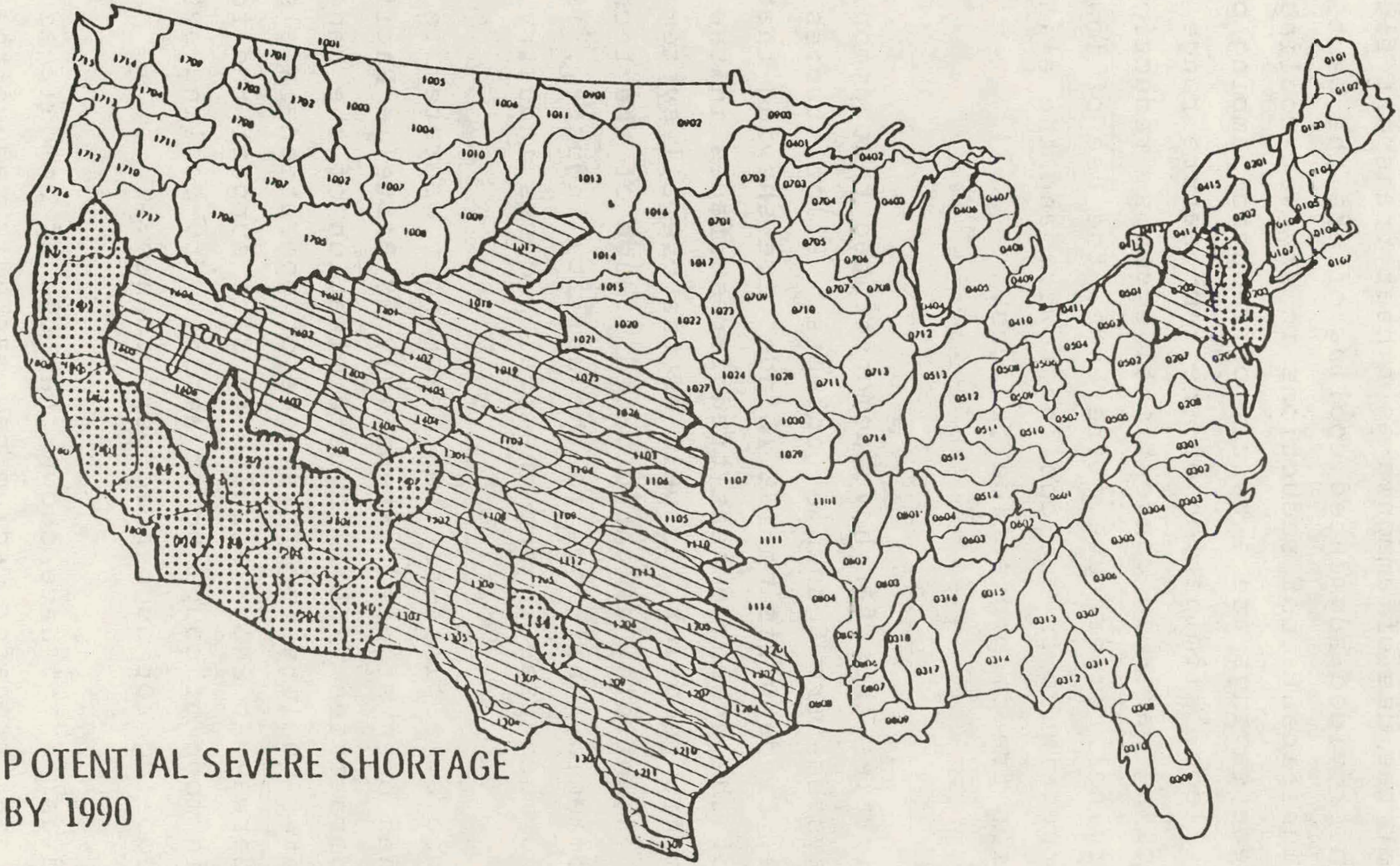
The use of dry cooling in place of wet (evaporative) cooling will save over 7000 gpm (approximately 8000 acre-ft/year) for a 1000 MWe plant.

Dry cooling, however, will never be economically preferable to wet cooling if water is available. At present, utilities have concluded that, in most instances, if water can be obtained by any means (such as buying agricultural land, thereby obtaining the accompanying water rights which could then be diverted to power plant cooling), evaporative cooling should be used in preference to dry cooling. For example, although all cost and performance for cooling systems are site-specific, the general overall situation is that power from plants using evaporative towers and cooling ponds costs about 3 to 6% more than from plants using once-through cooling. Power from completely dry-cooled plants using available technology would cost 10 to 15% more than when wet towers of current design are used, and 15 to 20% more than once-through cooled units.[5]

However, it is likely that utilities will be restricted by societal pressure and legislative action from using fresh water for evaporative cooling in water-short regions. Even in Eastern and Midwestern regions where water is relatively plentiful, the availability of an economical dry or dry/wet cooling technology can markedly increase siting flexibility by removing proximity to a major water source as a primary constraint.

Projections of water availability and demand[6] have been coupled with projections of requirements for new electric generation capacity on a regional basis as shown in Fig. 1. Note that a relatively large portion of the Northeast faces serious water shortages in the next decade. This projection indicates that 30-50 GWe of new capacity will require dry or dry/wet cooling by the year 2000.

DEVELOPING LIMITS OF WATER AVAILABILITY AND USE
AREAS OF POTENTIAL WATER SHORTAGE



POTENTIAL SEVERE SHORTAGE BY 1990

POTENTIAL SERIOUS SHORTAGE BY 1990

NEED FOR DRY COOLING

BASIS: 4.6% ELECTRICAL POWER GROWTH IN WATER SHORT AREA

PROJECTION: 14 - 26 GW_e (TOTAL) BY 2000

FIGURE 1

Basis for Ammonia, Dry-Cooling System Research:

From the evaluations of earlier work, reported at the last US/USSR Symposium in the U.S. in September 1977, it was concluded that the use of ammonia as a heat transport fluid in a process which provided augmented cooling offers the best possibility for significant cost reductions in dry/wet cooling systems. These savings are a result of reduced pumping power in the transport loop, elimination of the temperature range on the condenser cooling water in conventional systems, reduction in the condenser terminal temperature difference, the use of low cost fabrication techniques in the cooling tower, and the elimination of the need for freeze protection devices.

Research activities thus far have demonstrated that ammonia dry and dry/wet systems are feasible concepts. Pilot studies at Union Carbide, Linde Division (UCC/Linde) are showing that the performance of the enhanced heat transfer surfaces in the steam condenser/ammonia reboiler, as well as the overall system behavior, is essentially as anticipated. Much of the technology of handling ammonia, while new to the utility industry, is well understood and much used in the chemical process industry.

The performance of a plate-fin heat exchanger operated in the deluge mode has been studied extensively at Battelle Pacific Northwest Laboratories (PNL). A determination of the range of acceptable water quality for this mode of operation is also currently underway at PNL. Results to date support the feasibility of this mode of coupling an ammonia dry-cooling system to evaporative cooling for augmented performance.

Economic studies[5,10,11] have shown that use of ammonia as an intermediate heat transfer medium may markedly reduce the cost of dry cooling in power plants. Other cost evaluations[1] have indicated that wet augmentation of a dry system is the most likely initial application of dry cooling for power plant cooling.

If a small amount of water (approximately 1 to 10% of the annual consumption of a wet cooling system) is available for the augmentation of dry tower performance on the hottest days, cost reductions of the order of 10-20% on the cost of all-dry systems can be achieved.

The process flow is outlined in Figure 2. Exhaust steam from the last stage of the turbine is condensed in the condenser/reboiler. Liquid ammonia is boiled as it is pumped through the tubes at a flow rate set to yield an exit vapor quality less than 100%. This two-phase mixture is passed through a vapor-liquid separator from which the vapor is sent to the air-cooled heat exchanger where is is condensed, while the liquid is combined with the ammonia condensate from the dry tower and recycled back through the condenser/reboiler.

On the basis of the extensive work that has been done to select the ammonia phase-change process, the projected cost-effectiveness of the system, and the results of the laboratory studies to date, the system selected for demonstration is the 6 MWe size.

At conservatively estimated total evaluated cost savings of $100/kWe relative to presently available dry cooling technology, total potential savings to the industry range from $2 to $5 billion by the year 2000. The reasons for these cost savings are reduced temperature difference, reduced pumping power, and elimination of freeze-up protection requirements. Furthermore, the siting flexibility may produce cost savings which more than offset the greater cost of dry or dry/wet cooling.

AMMONIA SYSTEM PROCESS FLOW SKETCH

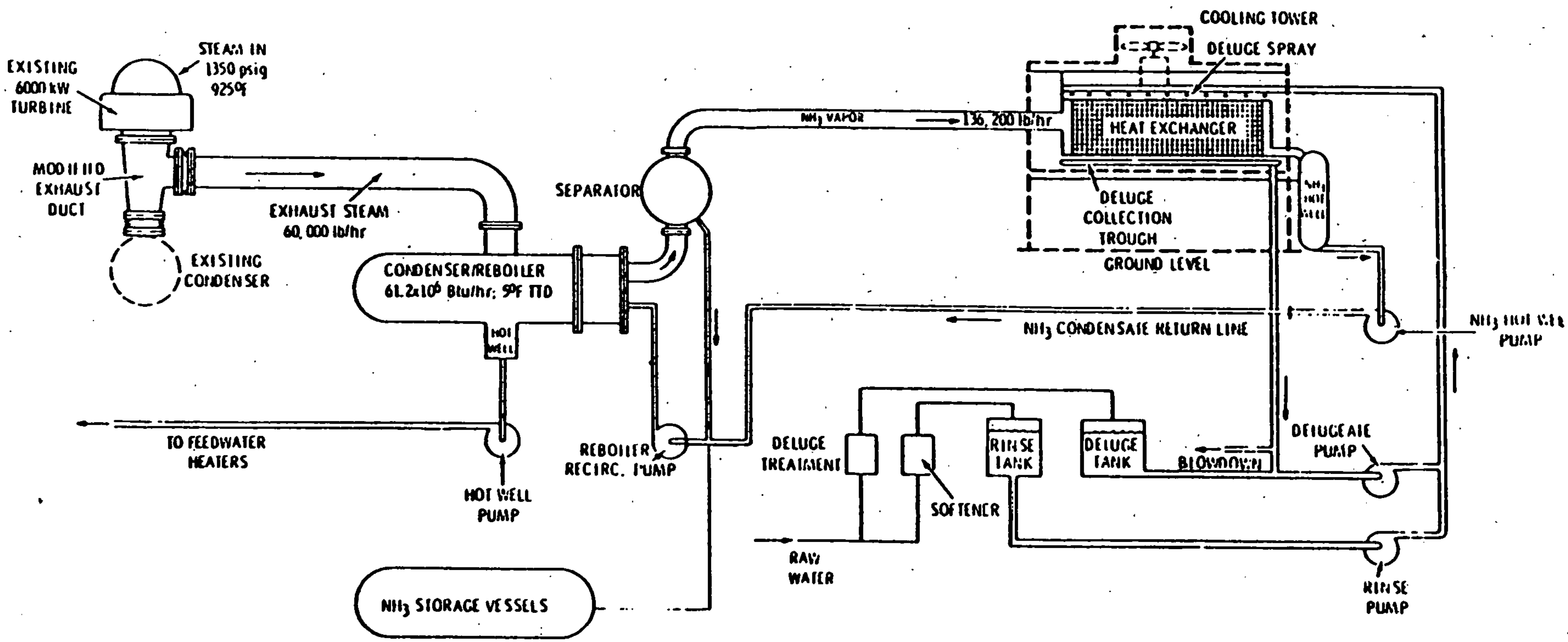


Figure 2

Project History:

The project began in the autumn of 1974 when the EPRI staff held discussions with UCC/Linde on the applicability of an ammonia transport loop to dry cooling systems. Interest was heightened in dry cooling in January 1975 at the EPRI Advanced Systems Task Force. The Heat Rejection Program Committee identified water conservation as the highest priority topic in the heat rejection area. The program was formally begun in February 1975 by the Advanced Systems Task Force. Approval was granted for the first dry cooling project for initial feasibility studies and an economic analysis.

In the autumn of 1975, coordination meetings were held with DOE (ERDA) and the EPRI staff. Agreements were made to exchange data, coordinate projects, and work toward a joint demonstration. Subsequently, a meeting of an ad-hoc committee of Western utilities was held at EPRI to review results of the EPRI and ERDA program. This meeting resulted in a confirmation of utility industry interest in the ammonia system and established the need for demonstration at the 5-10 MWe scale. In addition, the Kern plant of Pacific Gas and Electric Company was identified as a potential demonstration site.

Current Status:

The project to date has consisted of four phases:

Phase I	Technical Evaluation - Evaluation of existing operating experience with dry cooling and critical appraisal of new technology
Phase II	Pilot-Plant-Scale Development - Heat transfer and process studies
Phase III	Design Optimization - Development of computer codes to optimize the design of state-of-the-art and advanced systems

Phase IV Conceptual Design Studies - An A/E conceptual design cost estimate is the basis of the present budget projections

An expansion of the Advanced Dry Cooling Tower Project is currently in progress. This expansion will include the design, construction, and operation of a facility to demonstrate the use of ammonia as a heat-transport fluid in dry and dry/wet cooling systems.

The demonstration is a logical continuation of a state-of-the-art survey; a technical and economic feasibility study of an ammonia, phase-change dry-cooling system; pilot tests of ammonia phase-change cooling system components; economic optimization of wet, dry, and dry/wet cooling systems; field test and modeling of a dry/wet cooling tower; and analysis of dry/wet tower design, optimization and operation.

Parallel efforts at DOE/ERDA have complemented and confirmed the results of EPRI work and led to the same conclusions regarding the need for a scaleable-size demonstration and the type of demonstration required. While both groups have selected the ammonia concept as most promising, EPRI's experimental work has emphasized an all-dry system and DOE has emphasized dry/wet options. Both approaches will be included in the demonstration.

In order to bring this technology to a stage where it can be specified with confidence as a commercially available option, a demonstration of adequate size to permit scaling to prototype design was considered essential. The demonstration provides (1) validation of performance predictions from pilot-scale tests, (2) assurance of safe, reliable operation over a period of a few years, and (3) evidence of operability and maintainability by utility operating personnel. A three-year operational test at the 6 MWe size range was considered necessary to meet these requirements.

The project will be a joint effort by EPRI and DOE. EPRI will be the major funder and have lead management responsibility for the design, procurement, and construction phases. DOE will be the major funder and have lead management responsibilities for the testing and operations phase.

The objectives of the Advanced Dry Cooling Tower project are to demonstrate the design, fabrication, construction, and maintenance of an advanced dry cooling system incorporating: (1) the use of evaporating and condensing ammonia in the condenser/tower transport loop, (2) high performance heat transfer surfaces in the steam condenser/ammonia reboiler, (3) low cost cooling tower heat transfer surfaces and fabrication methods suitable for both all-dry and dry/wet operation.

The project objectives will be achieved by the design, construction, operation, and testing of an ammonia, phase-change cooling system at the Kern Plant. The system will demonstrate the best available technologies for both dry and dry/wet operation on a 6 MWe house turbine used for on-site power generation. The system, Fig. 3, will condense up to 60,000 lb/hr of steam from a small "house turbine" which is an integral part of the power plant.

The major technical uncertainties to be resolved by the large-scale test are the effect of the environment on component reliability and performance, system dynamic response to normal and emergency utility operating transients, and the ability of the design and fabrication methods to sucessfully address problems of safety and public health over several years operation. These technical uncertainties have been reduced to a minimum through extensive analysis, laboratory testing, and economic optimization during technical evaluation efforts to date.

ADVANCED CONCEPTS TEST FACILITY P.G. & E. — KERN PLANT

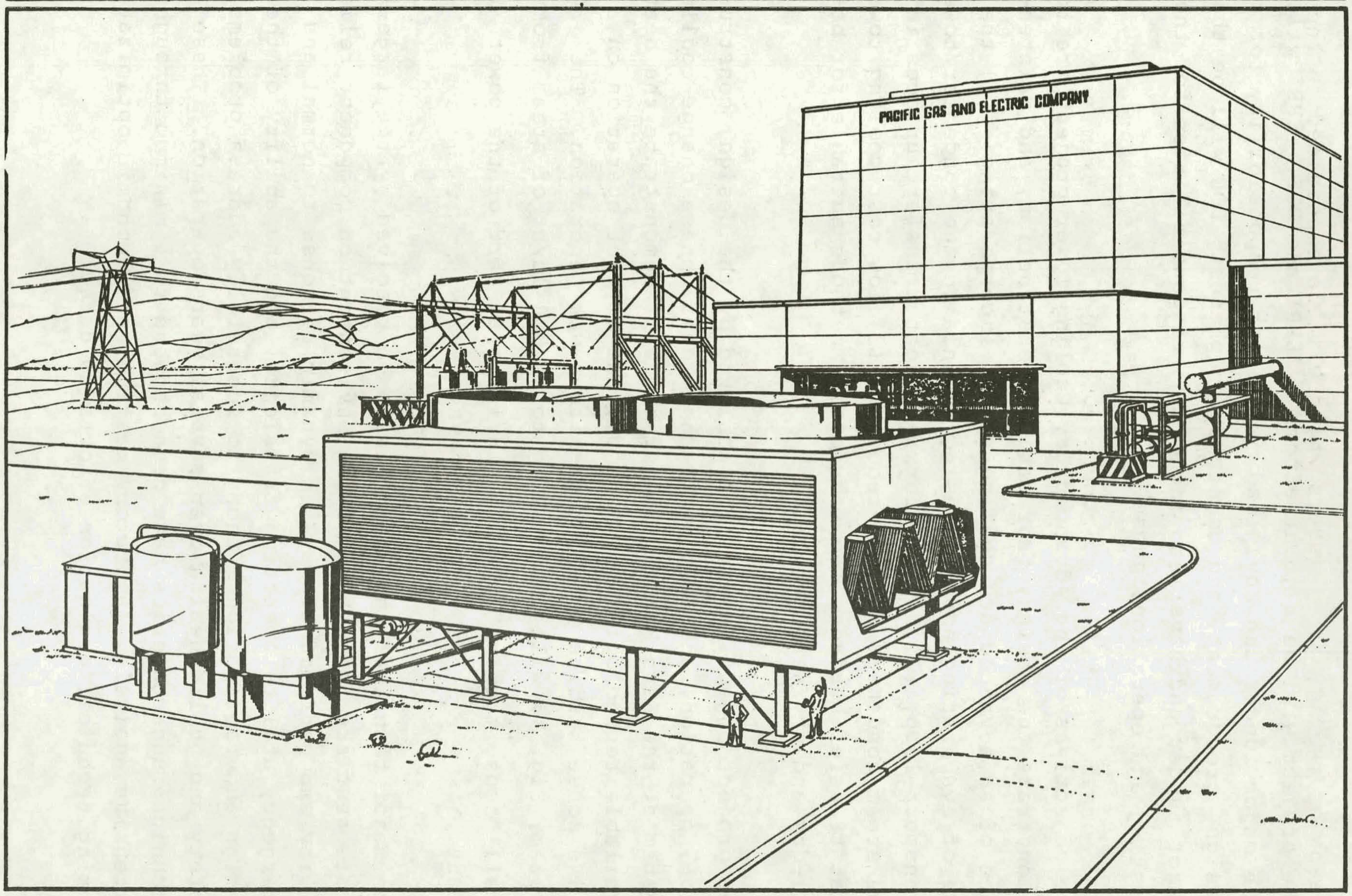


FIGURE 3

The major technological issues which will be emphasized in the large-scale test are:

1. Effect of environment on components: The economics of the system are closely tied to the performance of the condenser/reboiler and the dry tower. Extensive fouling of surfaces in either component would be very detrimental. Operating experience is the only way that the extent of fouling which must be allowed for in the design can be determined. With respect to deluge cooling, the extrapolation from accelerated laboratory studies of water chemistry to long-term performance with actual site conditions is uncertain.

2. Component reliability: Aluminum tubing in the condenser/reboiler is believed to be the material of choice so long as no leaks occur. Since aluminum cannot withstand ammonia in the presence of water, the integrity of tube-to-header joints will be critical. Similarly, the dry tower surface must be fabricated with a higher degree of reliability than is the case of a conventional water cooler.

3. Process integration: The dynamic response of the system has not been studied in great detail. While it is not expected to differ significantly from a conventional dry cooling system, this must be substantiated by the testing on an actual turbine system.

Personnel and public health and safety and other environmental aspects are also areas of concern. This project will address these concerns in detail, which will help simplify licensing of future commercial installations.

The extensive design studies and pilot facility work have given confidence that these problems have been addressed successfully on a pilot scale and hence are technically in-hand. It remains to be shown that a system based on full-size component modules and run under standard utility operating and maintenance procedures will be acceptable for scale-up to a commercial-size unit. Design alternatives are available if process changes are deemed necessary.

This project has three major goals:

- Design and construction of an ammonia-based cooling system test facility with the capability of both dry and dry/wet operation
- Operation of the facility and collection of performance data for at least three years
- Performance of a parallel program of supporting research and development

1.	Approve design criteria/authorize detailed design activity	November 1978
2.	Approve procurement for design of major components	February 1979
3.	Approve fabrication of major components	October 1979
4.	Approve detailed facility design/ authorize construction	January 1980
5.	Accept facility/authorize testing	April 1981
6.	Review first year test results	April 1982

The project consists of five phases:

Phase I	Feasibility Analysis and Laboratory Studies
Phase II	Conceptual Design Studies
Phase III	Demonstration Facility Design
Phase IV	Demonstration Facility Construction
Phase V	Facility Operation and Testing

At present, Phases I and II are nearly completed.

The detailed schedules for Phases II, III, IV and V are as follows:

Design	Date
Complete preliminary design dry tower	10/15/78
Issue RFQ for heat exchangers	11/15/78
Receive quotations for heat exchangers	02/01/79
Complete and approve preliminary design of test facility	07/01/79
Select manufacturers for heat exchangers	07/01/79
Start detailed design of test facility	07/15/79
Complete and approve detailed design of test facility	01/01/80
Construction	
Award construction contract	01/21/80
Start construction on site	07/01/80
Receive heat exchangers on site	09/01/80
Complete construction of facility	02/01/81
Operation	
Shakedown of experimental facility	02/01/81
Start initial testing	04/01/81
Complete testing program	02/01/84

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Paper No. 8

USE OF WASTE HEAT FROM ELECTRIC GENERATING PLANTS FOR GREENHOUSE HEATING

by

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Moscow - USSR
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ABSTRACT

Northern States Power, the University of Minnesota, and the United States Environmental Protection Agency have jointly conducted a demonstration project using waste heat from the condenser discharge of an electric generating plant to heat a 0.2 hectare (1/2 acre) doubly polyethylene greenhouse. The project was started in 1975 and has been tested for three heating seasons.

The first year electric boilers were used to simulate the warm water temperatures (29.5°C - 85°F), since the power plant was still under construction. The second year the greenhouse heating system was connected to a warm water supply pipeline directly from the first unit of the power plant. The third year, the second unit of the power plant was completed giving the greenhouse 2-unit reliability for its heating system.

The demonstration of waste heat has been successful, even in the harsh Minnesota (north central United States) climate. In 1977, two commercial greenhouse operators have built their own facilities at the site of the power plant and are taking warm water service from the utility. The first is a 0.47 hectare (1 acre) rose growing greenhouse. The second is a .096 hectare (0.2 acre) greenhouse used for growing vegetables.

The greenhouse heating system consists of centrifugal fan air handlers with fin tube heat exchangers. The warm air is distributed by flexible polyethylene ducts. In addition, plant root zones are warmed by a system of 2.54 centimeter (1 inch) rigid polyethylene pipes spaced 0.61 meters (24 inch) on centers and buried .305 meters (12 inch) below the soil surface.

Crops grown in the greenhouse are roses, snapdragons, potted geraniums, potted cinerarias, tomatoes, lettuce, green peppers and containerized evergreen seedlings. All crops have responded favorably to the warm water heating system.

INTRODUCTION

Northern States Power Company of Minneapolis first began to investigate the possible use of the heat energy in cooling water from their electric generating plants in 1970. Following a meeting in December, 1970, convened by NSP to explore with several state agencies and several University of Minnesota units, NSP and the Agricultural Experiment Station began a partnership to investigate more completely the possible uses of warm water. At that time NSP plants were of the "through cooling" type usually with a "cooling pond" and some with "helper" cooling towers. However, some new plants had been or were being planned for closed cycle operating and one, Prairie Island at Red Wing, was actually under construction.

The University formed two three-man teams comprised of an agricultural engineer, a horticulturist and a soil scientist to study along with others at the University, at NSP and elsewhere, the best ways to use the then unused heat energy in the cooling water. NSP provided financial support for the study. It soon was evident that little use could be made of the warm water from the "through cooling" generating plants. Discharge water temperatures in winter when it could be used for heating were approximately 10°C (50°F), or about the permitted 10°C (18°F) above the ambient temperature of the intake water at 0°C (32°F). Most heating applications for enclosed plant production or residence required temperatures of 15.5°-21.1°C (60° - 70°F). Even use for soil heating showed little promise because few crops grow well at temperatures of 10°C (50°F) or lower. Frost protection was considered but soon rejected because water droplets cool to ambient air temperature if they travel 4.6-6.1 meters (15-20 feet) through the air. The main consideration in frost protection is the release of heat, 334,934 joules per kilogram (144 BTU's/lb.), by the water as it changes state from liquid to solid, i.e. to ice.

The review of heating requirements for various applications and the projection that all, or nearly all, future steam cycle generating plants would operate on a "closed cycle" basis eventually led to the project about which we report now. Closed cycle designs called for condenser discharge temperatures of no less than 29.5°C (85°F). If water temperature reductions during delivery from condensers to the use point could be limited to 0.5-1.7°C (1°-3°F), then an operating differential between the source water and the use environment of 5.5°C-11.1°C (10°-20°F) could be expected. It appeared that adequate heat transfer could take place for heating structures, if equipment were properly sized and operated. With this encouragement the two study teams began traveling to learn more about possible applications.

One of the early visits was to the Environmental Research Laboratory at the University of Arizona and to their "total energy" pilot study at Puerto Penasco Mexico. Another team visited the Oak Ridge National Laboratories. Our teams also visited the commercial greenhouse area around Cleveland, Environmental Structures of Cleveland, Wright Roses of Cranbury, New Jersey, Hydroponics of Houston, Eugene Water and Electric Board of Eugene, Oregon, Oregon State University, the Federal Water Quality Laboratory at Corvallis, and TVA at Muscle Shoals, Alabama, as well as several other places. Following the early visits the various opportunities were discussed among University personnel and then presented to NSP and interested state agencies.

After many discussions and deliberations NSP and the University decided to approach EPA about funding a demonstration project for greenhouse heating. A proposal for a four-year project for a 0.4 hectare (one acre) greenhouse was submitted to the Corvallis Laboratory for review and suggestions in January, 1973. EPA informed us that they would be unable to fund it at that time at the size and for the length of time we proposed. It is important to recognize that at this time, early 1973, the energy situation was beginning to surface and that there was some shift in emphasis underway in EPA from thermal pollution (the prime emphasis when we started) to energy utilization and conservation. It is our judgment that our project probably would never have been funded under the "thermal pollution" reduction theme. You simply cannot profitably construct enough greenhouses near a generating plant, or at least any significant number of plants, to reduce "thermal pollution" significantly, especially in the summer when condenser discharge temperatures are highest and no greenhouse heating is required.

Recognizing that energy utilization and conservation were to become increasingly important and with additional "closed cycle" generating plants scheduled to begin operation in 1976 and 1977, NSP decided with the University's commitment of technical assistance to finance and operate a small pilot project, a 6.7 meter (22 feet) by 30.5 meter (100 feet) "hoop" type house covered with two layers of polyethylene. The greenhouse was made available by the Hans Rosacker Floral Company at their Circle Pines greenhouse range. A 7.3 meter (24 feet) by 9.1 meter (30 feet) building was placed at one end of the greenhouse to house the heating equipment, the electric water heaters to provide the warm water, the control panels and the needed instrumentation. A major reason for moving forward with the pilot project was to assess the adequacy of and the problems in a cold northern climate of the "flooded pad" method of heating developed at the Oak Ridge National Laboratory. We were concerned particularly about the high humidity environment and the possibility of associated pathological diseases. We also were concerned about the long-term efficiency of such a system and possible carry-over of potential toxicants from the water to the plants. Water used in "closed cycle" cooling systems must have additives to control rust, microbial growth and algae. In addition some potential harmful naturally occurring constituents in the water are concentrated because of the continuous evaporative process for cooling. We decided that there were so many potential problems that we also should simultaneously evaluate a conventional air handler designed for use with hot water from 54.5°C to 76.7°C (130°F to 170°F). The air handler was not rated for 29.50°C (85°F) so we had to estimate the performance with the lower temperature water. This unit while massive, especially compared to gas fired air handlers or unit heaters used in greenhouses, performed so well we decided to abandon the use of the "flooded pad" system. The Corvallis office of EPA urged us to consider some soil heating based upon favorable information from observations by the Eugene Water and Electric Board group. As a result soil heating was also evaluated at the Rosacker range.

Following the successful pilot effort at the Rosacker range, NSP and the University prepared and submitted a revised proposal to EPA in January, 1975. This was funded in May, 1975. Construction began in August, 1975; heating began in November, 1975 and the first crops were planted in January, 1976.

This proposal was for an approximate 0.2 hectare (1/2 acre) area for a period of two years. That two-year period was completed in May, 1977. Because of the success and interest in adoption EPA extended the project an additional year through June 30, 1978, but without additional funding. We were able to finance the extension with carry-over funds and funds generated by the project.

DESCRIPTION OF THE PROJECT

Power Plant

The Sherburne County (Sherco) Power Plant, located 45 miles northwest of Minneapolis, is a two unit coal-fired operation with a total rated output of 1,360 megawatts (MW). It has closed-cycle mechanical draft wet cooling towers for thermal pollution control and a limestone scrubber system for air pollution control. The first unit which began in commercial operation in May, 1976 has a condenser cooling water flow rate of 15.77 cubic meters per second (250,000 gpm) with a design cooling water temperature differential, ΔT, of 16.1°C (29°F). The winter design minimum temperature of the water at the condenser outlet is 29.5°C (85°F). This then is the design temperature for the warm water for the greenhouse heating systems.

Greenhouse and Headhouse

The greenhouse selected is an arch roof gutter connected type covered with double layer polyethylene. Two side walls and one end wall also are double layer with a fiberglass outside wall and polyethylene inside. It is comprised of 14 bays, each being 5.2 meters (17 feet) wide and 29.3 meters (96 feet) long. This provides a gross enclosed ground area of 2,123 square meters (22,848 square feet), or slightly over 0.2 hectare (1/2 acre). The height from the ground to the gutters is 2.44 meters (8 feet).

The double layer plastic covered greenhouse was selected over glass because of greater resistance to heat transfer and a lower initial capital cost. The 5.2 meter (17 foot) span was selected over lesser spans to provide greater clear area for mechanical equipment. A clear span inflated house was considered at one time. However, the cost of the PVC covering for it was escalating. Also, considerable equipment and energy were needed just to keep it operable.

The headhouse is a 12.2 meter (40 feet) by 18.3 meter (60 feet) prefabricated steel building with a concrete floor. It is divided into a 12.2 meter (40 feet) by 10.1 meter (33 feet) production area, a 6.1 meter (20 feet) by 8.2 meter (27 feet) boiler room, a 3.7 meter (12 feet) by 8.2 meter (27 feet) data acquisition and control room, and a 2.4 meter (8 feet) by 8.2 meter (27 feet) area containing two offices and a restroom. The production room includes a small 1.8 meter (6 feet) by 3.1 meter (10 feet) walkin cooler and an outside vented chemical storage cabinet. The boiler room houses two 390 kilowatt boilers, a 10 kilowatt propane fueled standby generator and the nutrient injection equipment as well as the necessary piping and valves for operating the heating systems.

Heating Systems

The design criteria were established based upon the minimum winter condenser water temperature of 29.5°C (85°F) and the ambient winter conditions for St. Cloud, Minnesota, which is about 32 kilometers (20 miles) northwest from the greenhouse location. The minimum outside air design temperature is -34.5°C (-30°F). We chose 10°C (50°F) as a tolerable, though not fully desirable, inside air temperature. Based upon these temperature extremes, the calculated design heat loss is 644,756 watts (2,200,000 BTU/hour) or approximately 46,000 watts (157,000 BTU/hour) per bay. Obviously, the two end bays have a greater heat loss because they each have a cold side wall surface area of 71.4 square meters (768 square feet) that the other bays do not have.

We decided to use a two component heating system comprised of a forced-air system to supply most of the needed heat and a soil heating system to provide some heat, but primarily to provide some crop root zone temperature control. Twelve of the 14 bays were equipped with centrifugal fan air handlers powered by 2,237 watts (3 hp) electric motors designed to deliver 3.3 cubic meters per second (7,000 cfm) at 74.7 pascals (0.3 inches) static (water pressure.) The air handlers have fin tube heat exchangers estimated to transfer 42,495 watts (145,000 BTU/hour) from 29.5°C (85°F) entering water to 10°C (50°F) entering air. The design water flow rate is 0.0018 cubic meters per second (29gpm). The warm air is distributed the length of the bay through 0.76 meter (30-inch diameter) flexible polyethylene ducts with holes punched to provide uniform delivery. Two bays were equipped with a unit hot water heat exchanger in each end directed to discharge air toward each other. These units have 0.64 meter (27 inch) propeller fans powered by 746 watts (1 hp) electric motors. The unit heat exchangers were designed for a free air delivery of 3.26 cubic meters per second (6900 cfm). The heat exchange rate was estimated to be 17,584 watts (60,000 BTU/hour) from 29.5°C (85°F) entering water to 10°C (50°F) entering air. These units use no air distribution ducts.

The soil heating system is comprised of 2.54 centimeters (1 inch) diameter rigid polyethylene pipe spaced 0.61 meters (24 inch) on centers and placed 30.5 centimeters (12 inch) below the soil surface. The polyethylene pipes have a warm water supply pipe at one end and a cooler water return pipe for set of eight pipes in each bay. The design water flow rate is approximately 0.000063 cubic meters per second (1 gpm) per inch. We estimated a design ΔT of 5.6°C (10°F) from 29.5°C (85°F) water in the pipe to the surrounding soil in contact with the pipe. The ΔT estimate of 5.6°C (10°F) was based upon a 10°C (50°F) soil surface temperature and a desired root zone temperature of 15.6°C (60°F).

The warm water for heating the greenhouse is taken from two cooling tower riser pipes each about 1,070 meters (3,500 feet) distant (one way) from the greenhouse. It leaves one of the risers above ground in an insulated 30.5 centimeter (12 inch) diameter steel pipe which then goes underground and connects to a 3.5 centimeter (12 inch) diameter lo-head PVC plactic pipe at a nominal depth of 1.52 meters (5 feet) below the soil surface. The water leaves the second cooling tower through an 18 inch insulated steel pipe then underground into an 18 inch cast iron pipe that also connects to the 30.5 centimeter (12 inch) PVC pipe. The insulated steel pipe leaving the risers of each of the cooling towers also is heat traced (provided with heating cable) for added protection against freezing. The PVC pipe and cast iron pipe are both uninsulated. Because the soil is very sandy and quite coarse at the 1.52 meter (5 foot) depth, we did not deem insulation necessary. Water flows through this pipe continuously during the heating season at a rate of approximately 0.10 cubic meters per second (1,600 gpm). This is estimated to be enough to heat at least 0.6 hectare (1 1/2 acres) of similar greenhouse at the design conditions. Warm water is supplied to the greenhouse heating systems from the main supply line by four 3.728 kilowatt (5hp) pumps, each capable of delivering 0.0095 cubic meters per second (150 gpm). These pumps operate in parallel with the numbers of pumps operating at one time determined by the number of greenhouse bays that require heat at any given time. The design water flow rate is 0.0256 cubic meters per second (406 gpm) for the air heating system and 0.0071 cubic meters per second (112gpm) for the soil heating system or a total of 0.0327 cubic meters per second (518 gpm). As a result, the fourth pump operates only if more than 12 bays require both air and soil heating at the same time. The cooler water from the greenhouse return lines is pumped back into the main water supply return line where it returns to the cooling towers and is discharged into the sump. A schematic drawing of the heating systems and water supply is shown in figure 2.

Cooling System

The greenhouse cooling system is completely independent of the heating systems. It is a standard evaporative cooling system comprised of 0.91 meter (36 inch) high evaporative pads of "Cel Dek" across the entire end wall of each bay. Water from a nearby well is recirculated so it can run by gravity over and through the pads at a rate of 0.0076 cubic meters per second (120 gpm) or 0.00003 cubic meters per second per foot of length. Air is drawn through the wetted pads by fourteen 0.9 meter (36 inch) propeller type louvered exhaust fans, one located in each bay. The design total cooling airflow rate is 84.5 cubic meters per second (179,000 cfm) or 6.04 cubic meters per second (12,800 cfm) per bay. A schematic drawing of the heating and cooling systems is shown in figure 3.

Control Systems for Heating and Cooling

The control systems are relatively simple, some being manual, yet, at this time. Temperature is the only variable under automatic control. As originally designed, each bay had two thermostats, one for heating and the other for cooling. Earlier this year, each of five bays in which roses are being grown were equipped with a second thermostat for heating control. With time clock switching, this permits different day and night settings. The greenhouse is divided into two separate control zones, each consisting of seven bays. A central control panel permits manual selection of modes of operation, i.e., heating or cooling, and further, heating with outside air or with return air. The manual operation permits some control of relative humidity as well as temperature. This permits different environments in each half of the greenhouse. This is quite important for optimum production of roses. Further, manual control eliminated the need for automatically controlled outside dampers and associated potential problems of freeze-up in the open position that could cause damage to heat exchanger coils and even loss of crops.

The air heating thermostat(s) in any bay indicates the starting of the primary water circulation pump(s) and the associated fan(s) in that bay. They also initiate the appropriate opening and closing of the return and outside air dampers on the centrifugal air handlers. Both dampers must be closed when the fans start to prevent rapid inflation damage to the polyethylene air distribution duct. The soil heating thermostats control the starting of secondary booster pumps necessary for the soil heating system. The cooling system in each bay is independently controlled by separate thermostats starting and stopping the gravity lowered exhaust fans.

Emergency Systems

The greenhouse is equipped with an advanced warning alarm system which monitors three parameters critical to the successful operation of the heating system. Project personnel are alerted by the following conditions: 1) greenhouse air temperature below 10°C (50°F) (possibly caused by mechanical failure of equipment); 2) by water supply temperature below 23.8°C (75°F) caused by the power plant going out of operation; and/or 3) by loss of electrical power. The greenhouse is supplied electricity from another source, so two 390 kilowatt electric hot water boilers serve as a standby source of heat. These boilers provided the warm water for heating for the 1975-76 heating system before the first unit of the power plant was commercially operative. If there is an electric power outage during the heating season, six 102,575 watts (350,000 BTU/hour) propane-fired forced air heaters will be put into operation. Electricity for their operation and for lights will be provided by a 10 kilowatt propane-fueled standby electric generator.

Crop Production Systems

Water and fertilizer for crop production is provided by irrigation systems. Water for irrigation comes from a drilled well on the property that was formerly used for field irrigation. Plant nutrients in solution are injected in the appropriate amounts into the irrigation systems. Roses are irrigated using a perimeter system of rigid polyethylene pipe. Emitters covering 180° spray fine droplets of water containing nutrients uniformly over the soil of the bed. Tomatoes, lettuce, peppers, snapdragons and freesia are watered with porous paper base tubing which under about 4 psi pressure provides a trickle system. The porous tubing is placed on or just below the soil surface in the row or between closely spaced rows. Geraniums and cineraria are watered by a capillary mat which is wetted with the porous tubing. Forest tree seedlings and woody ornamentals are watered with small spray nozzles. Power plant cooling water cannot be used for irrigation because of additives.

Crop supports are important for most of the crops being grown. Roses are supported by three levels of 20.3 centimeters by 20.3 centimeters (8 inch by 8 inch) welded wire anchored to support posts at each end of the beds and supported intermediately at 3 points. Snapdragons were supported in a similar way, but using only one level of plastic netting. Tomatoes are supported by strings attached to the base of each plant and supported by steel pipe overhead. Two rows of tomatoes, which are planted in rows 30.5 centimeters (12 inches) apart and alternated within the two rows, are supported by one pipe. The slight slope away from the working aisle which results has proved useful. The peppers were not supported, but should be if grown again because some heavily laden stems broke.

Insecticides and fungicides, if needed, are applied with a pressure sprayer and long extension hose. Tomatoes are pollinated daily with an electric vibrator. This is essential because air velocities of the heating and cooling systems are not adequate for pollination.

A 1.83 meter (6 foot) by 3.05 meter (10 foot) by 2.29 meter (7 foot, 6 inch) high 3.517 watt (12,000 BTU/hour) walkin cooler was purchased to assist in maintaining rose quality, particularly during warm weather. The cooler which is held at 1.7°C (35°F) permits us to make alternate day deliveries of the roses. Tomatoes and other crops are delivered on the other days. Tomatoes cannot be held in the same cooler with roses because the tomatoes produce ethylene gas as a by-product of respiration during ripening. This would greatly reduce the useful life of the roses.

A van with an add-on air conditioner that discharges cooled air into the cargo area is used for delivering the produce to wholesalers with whom we work in the Twin Cities area.

Data Collection

We believed it was absolutely essential to have an automatic data system to provide a rather complete environmental history, both inside the greenhouse and outside. An automatic system recording on either magnetic tape or printing on paper tape or both simultaneously scans and records 227 data transducers at predetermined intervals, usually one-half hour. The system is microprocessor controlled. Data from the magnetic tape is computer processed in the form of tables and plots to provide time function relationships of environmental and water supply conditions. The data also are used to analyze the overall energy balance of the greenhouse system.

Temperatures are recorded at ten individual locations in each bay of the greenhouse. Three points are monitored at each of three locations. Two air temperatures and one soil temperature are recorded. The six air temperatures within a bay cover the range from top to bottom of the plant canopy. The soil temperatures are measured at 10.2 centimeters (4 inches), 20.3 centimeters (8 inches) and 30.5 centimeters (12 inches) below the surface. Dew point and the associated ambient temperature are measured at one location in each bay. Total incident solar radiation is recorded at one location inside the greenhouse and at one location outside the greenhouse at rooftop elevation. Star pyranometers with one hour integrators are used. Air and soil temperatures are measured with 24-page copper constantan thermocouples. Dew point temperatures are measured with heated lithium chloride electrical hygrometers. Water supply and return temperatures are measured with immersion type copper-constantan thermocouples.

Manual readings are made daily of total greenhouse water flow, soil heating water flow and electrical power consumption of each type of equipment, i.e., circulating water pumps, heating fans, and exhaust fans.

OPERATION EXPERIENCE

Greenhouse and Environmental Systems

The greenhouse and the heating systems performed wholly satisfactory during the 1975-76 heating season. During this season, the warm water was provided by the electric boilers. The greenhouse and the heating systems also performed wholly satisfactory during the 1976-77 heating season, which was the coldest on record during the last 100 years, and the second coldest ever on record. The performance of the greenhouse and heating systems is shown in figure 10 for January 9, 1977, the coldest day during the 1976-77 heating season. The inside air temperature is the average of three measurements at about the 1.52 meter (60 inch) level above the ground. The intake air temperature was 14.4°C (58°F) when the outside air temperature reached its lowest level of -41.4°C (-42.6°F) at 8 a.m. The supply water temperature from the condenser at the same time was 32.7°C (90.9°F) and the water ΔT between heat exchanger supply and return was 2.8°C (5.1°F).

Surprisingly, we found that water from the condensers was a higher temperature 32.2°-37.8°C (90°-100°F), than had been expected during the most severe weather. The reasons were: 1) when it is severely cold, NSP electric system demands are high requiring high output from the generator, and 2) when ambient outside temperatures drop to -28.9°C (-20°F) to -34.4°C (-30°F), plant operators increase condenser discharge water temperature to minimize the possibility of ice formation in the cooling towers. Operational data for the plant shows a positive correlation between condenser water temperature and generator output. Table 1 provides information relating to generator output, condenser discharge water temperature, greenhouse water supply temperature, greenhouse air temperature and outside air temperature for November 12, 1976.

The greenhouse cooling system was not installed in time to be operative in 1976, but performed well as expected in 1977. We encountered no problems with it.

Crop Production

Crops were first planted in January, 1976. Five bays were planted to roses, three varieties of hybrid teas and two of sweethearts. The roses first came into production in late April, 1976 and with the exception of one variety produced well. That variety has reached sufficient maturity after about one year, so it is now producing exceptionally well. Tomatoes are planted in eight bays and peppers in one bay. Both came into production in April and were removed in July.

Both were disappointing in terms of yield and also because of local wholesale price levels in terms of economic return. These were replaced with lettuce and snapdragons from August through January. Lettuce shows little promise because of high labor input compared to returns. Snapdragons appear fairly promising in terms of economic return with limited labor input.

The 1977 season started in February with seven bays of tomatoes. In most bays, they are spaced 71.1 centimeters (28 inches) apart compared to about 55.9 centimeters (22 inches) in 1976. However, we also planted some at 61 centimeters (24 inches) and some at 81.2 centimeters (32 inches), so we could make comparisons. They are planted in rows 30.5 centimeters (21 inches) apart and alternated so they are offset half the spacing distance along the row. A 61 centimeter (24 inch) work alley is left between each pair of rows. One bay has potted geraniums placed on a capillary mat for watering. Between last season and this, about 1/4 of a bay has been devoted to containerized forest tree seedlings and to woody ornamentals for nursery liners.

We expected and achieved better tomato production results during 1977 for several reasons. We had all of our operating equipment on hand and should have benefited from the 1976 experience. In addition, we installed carbon dioxide generators for use when the greenhouse is closed. High levels of CO_2 are necessary for maximum photosynthesis and crop production. It is well known that CO_2 is rapidly depleted in tightly enclosed structures. We also had the evaporative cooling system operative to moderate short high temperature extremes during the peak of the tomato production season.

Unsolved Problems and Desirable Modifications

The most severe problem to date was deposits in the water supply lines and the heat exchangers during the 1976-77 season. Performance of the heat exchangers was estimated to have reduced to the 50 percent level. Following cleaning with acid and chlorination, the performance was returned to 80-90 percent of the design level.

Flow in the 30.5 centimeter (12-inch) water supply line from the cooling towers dropped from 1600 gpm at initial start up to 0.0631 cubic meters per second (1000 gpm). The lines were cleaned during 1976-77 and the performance restored. They were thoroughly flushed during the summer and chlorination devices placed in the line at each tower. This appears to have solved the problem completely.

Some problems were encountered in providing adequate plant nutrients. There appears to be some leaching in the sandy soil. There also is an indication that fertilizer recommendations were too low considering the very rapid growth that takes place. The soil should be carefully selected or modified for future installations or hydroponic systems considered.

The structure probably should have a 3 meter (10 foot) sidewall for roses. A 3 meter (10 foot) height could be a problem for tomatoes, if the tomatoes were allowed to grow that high because the upper clusters of fruit would have to be picked from a ladder. A possible solution is to lower the plants after lower clusters are completely picked. Ideally, cross supports for the pipes supporting the tomatoes should be incorporated into the greenhouse design. The soil heating system probably should be lowered to at least 45.7 centimeters (18 inches) below the surface to minimize potential damage by tillage equipment. Also the main supply and return lines should be increased in size.

Large acreages of greenhouses may require some redesign of the warm water return line to the cooling towers, because the greenhouse use does not cool the water sufficiently. Also, it would be desirable to have underground electrical service directly from the distribution center to further reduce the possibility of electrical service interruption.

ECONOMICS OF WARM WATER HEATING

Obviously, the extent of the advantages of using warm water for greenhouse heating depends upon the cost of other fuels. However, natural gas can be ruled out because it can be obtained for new installations only on an interruptible basis. Warm water heating requires larger size equipment than for hot water or steam. The larger equipment also usually costs more to operate. The estimated cost of heat for the demonstration project is $1.35 per 1.055×10^9 watt-seconds (million BTU's). Comparable costs for fuel oil and electricity are $3.20 and $5.55, respectively. Warm water thus represents a saving of $1.85 per 1.055×10^9 watt-seconds (million BTU's) over fuel oil. Based on an estimated 19.20×10^{12} watt-seconds per hectare-year (7,400,000,000 BTU's per acre-year), the savings would be $33,850 per hectare ($13,700 per acre) annually based upon present costs. We estimate that the warm water system would use about $13,590 per hectare ($5,500 per acre) additional electricity annually leaving a net annual savings of $20,260 per hectare ($8,200 per acre). This saving would have to pay for the added investment in a warm water heating system.

ADOPTION

Commercial groups expressed interest from the beginning. A local floral company constructed a 0.4 hectare (1 acre) double plastic house with 3 meter (10 feet) sidewalls during the summer of 1977. They plan on increasing the area under cover to 1.2 hectares (3 acres) in the next few years. This structure is devoted entirely to floral crops grown in the soil. Another local company has built two 7.9 meter (26 feet) by 39.6 meter (130 feet) hoop type houses. They are growing vegetable crops using a "nutrient film" (hydroponics) system. Other commercial greenhouse operators are seriously discussing locating at the generating plant site. NSP is moving forward to provide warm water within the next 1-2 years to an area suitable for approximately 5.67 hectares (14 acres) of greenhouses.

CONCLUSIONS

Greenhouses can be heated satsifactorily and economically with warm water. The technology is available for immediate use, although improvements in design and methods of operation should evolve. If the demand develops, NSP could provide land and warm water for as much as 40.5 hectares (100 or more acres) of greenhouses at the Becker location.

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The authors wish to express their appreciation to the following University of Minnesota faculty members for their assistance with the project: 1) Agricultural Engineering - Kenneth A. Jordan, Evan R. Allred and Frank Lang; 2) Horticultural Science and Landscape Architecture - Richard E. Widmer, Paul E. Read, David W. Davis and Harold F. Wilkins; 3) Soil Science - James B. Swan, Donald Baker, George R. Blake, William Fenster, Curtis Klint, Janis Grava and Charles Simpkins; Plant Pathology - James Groth, Francis Pfleger, Elwin Stewart and Sager Krupa; and Forest Resources - Alvin Alm.

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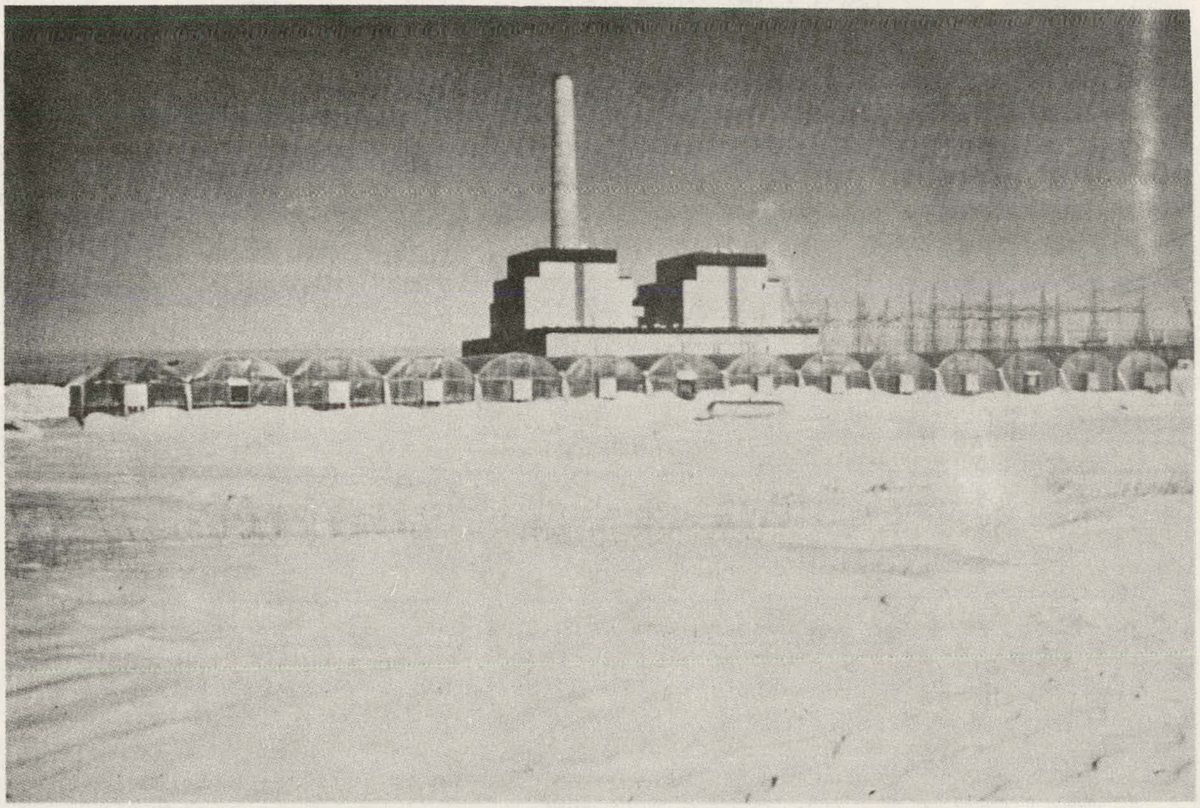

Figure 1. Northern States Power Co. 1380 Megawatt Coal Fired Generating Plant at Becker, Minnesota with Warm Water Heated Greenhouse in the Foreground.

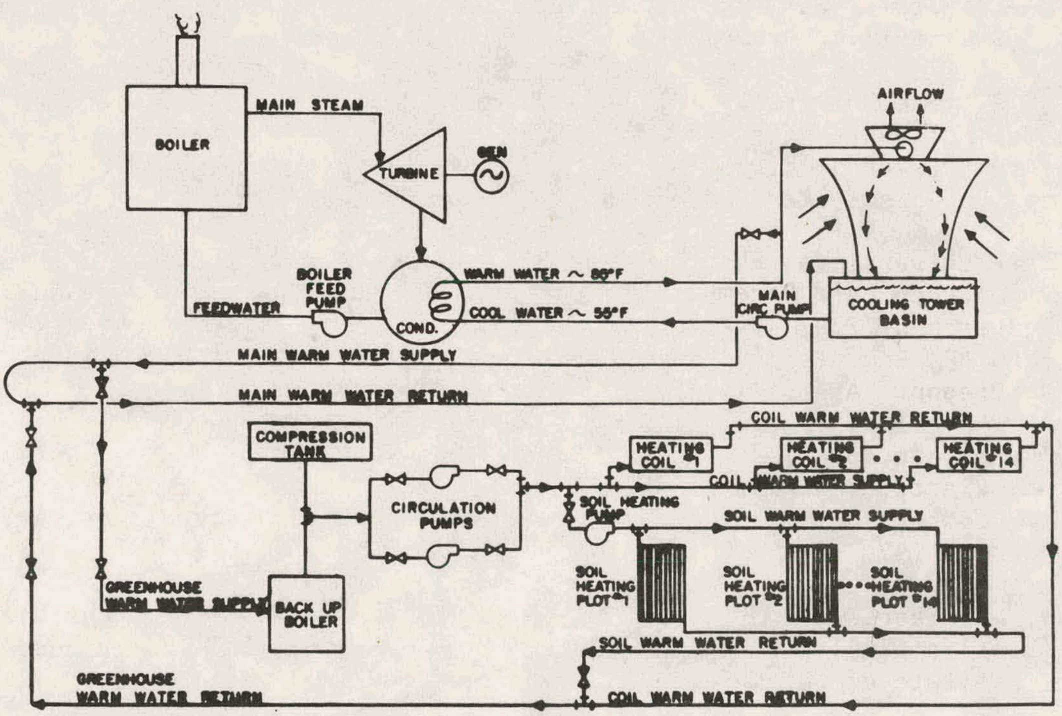

Figure 2. Schematic Diagram of the Flow of Water in the Generating Plant and to, through and from Warm Water Greenhouse Heating Systems

HEATING AND COOLING SYSTEM SCHEMATIC

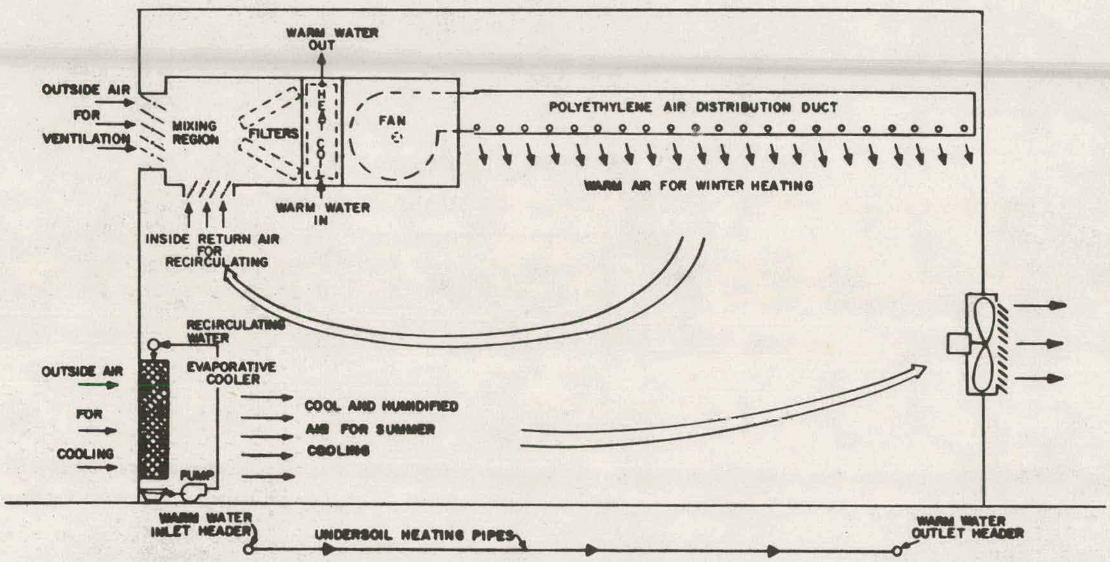

Figure 3. Schematic Diagram of Heating and Cooling Systems in the Warm Water Greenhouse.

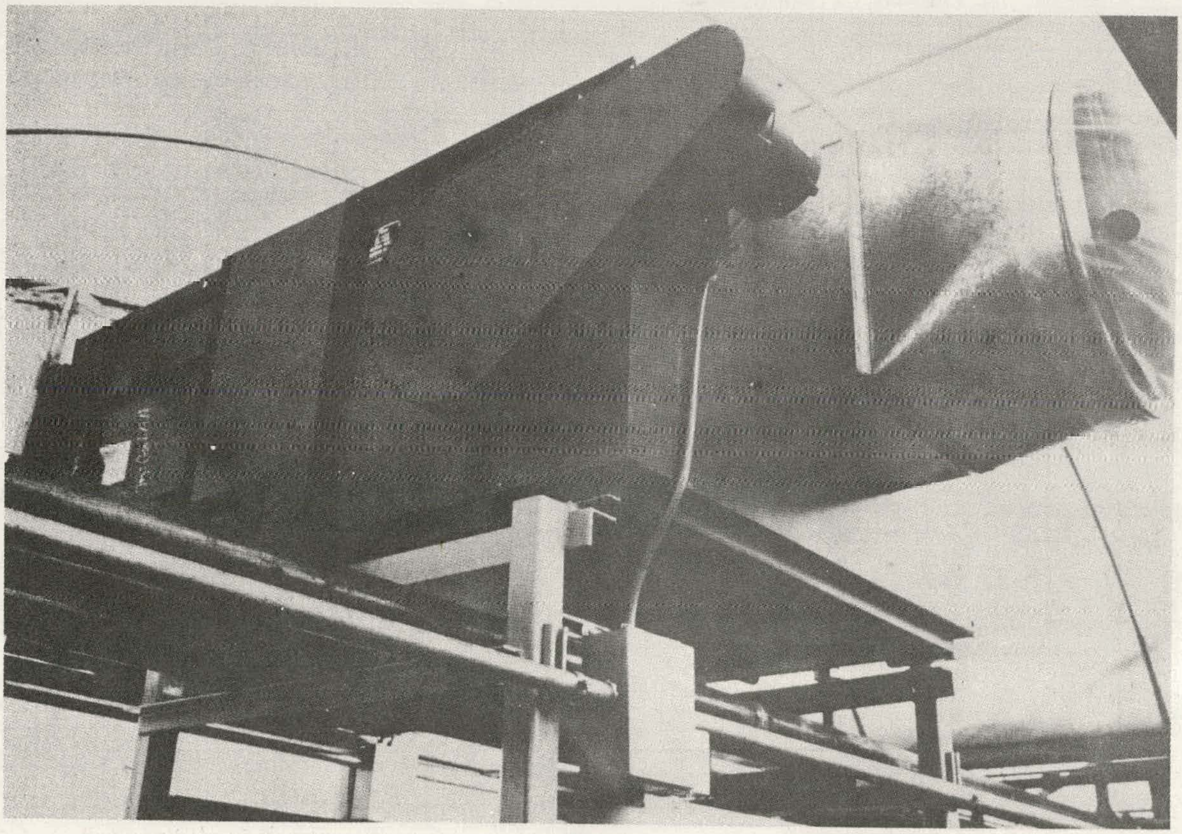

Figure 4. Ceiling Located Air Handler - Warm Water Heat Exchanger Used for the Primary Source of Heat in 12 of 14 Bays

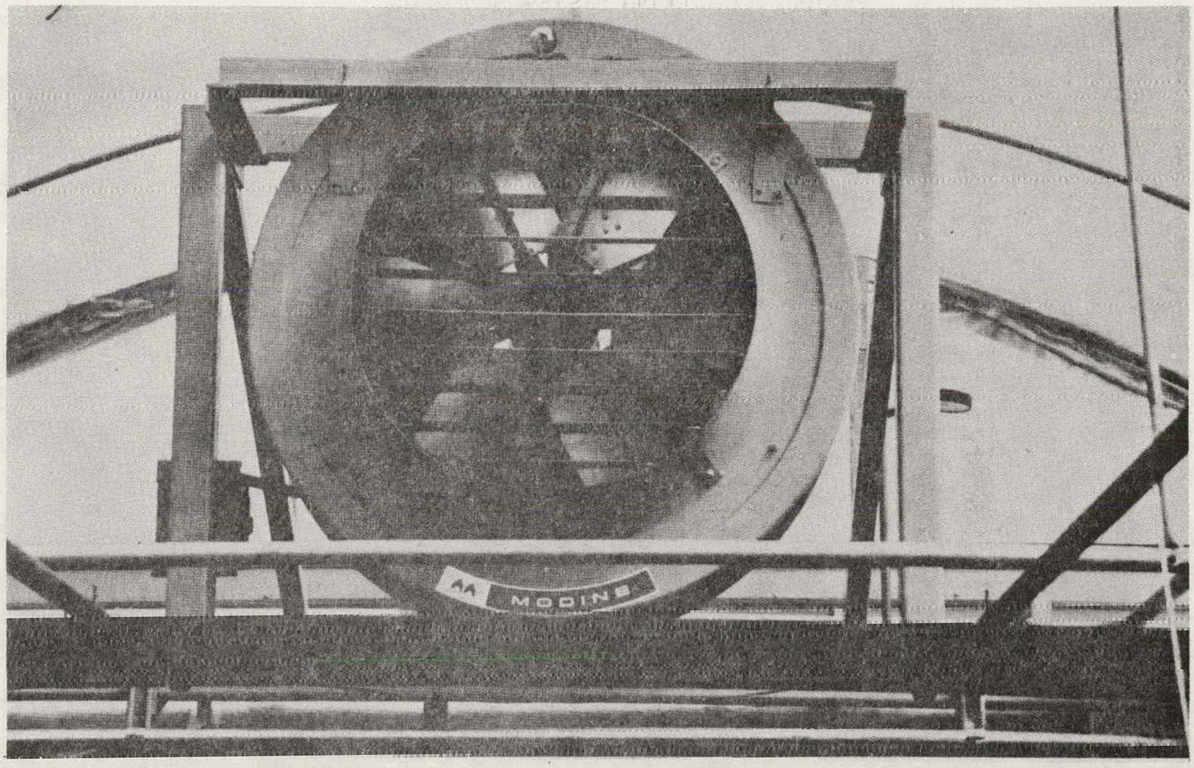

Figure 5. Modine Warm Water Heat Exchanger Located in the Ceiling of Each End of Two Bays to Serve as the Primary Source of Heat.

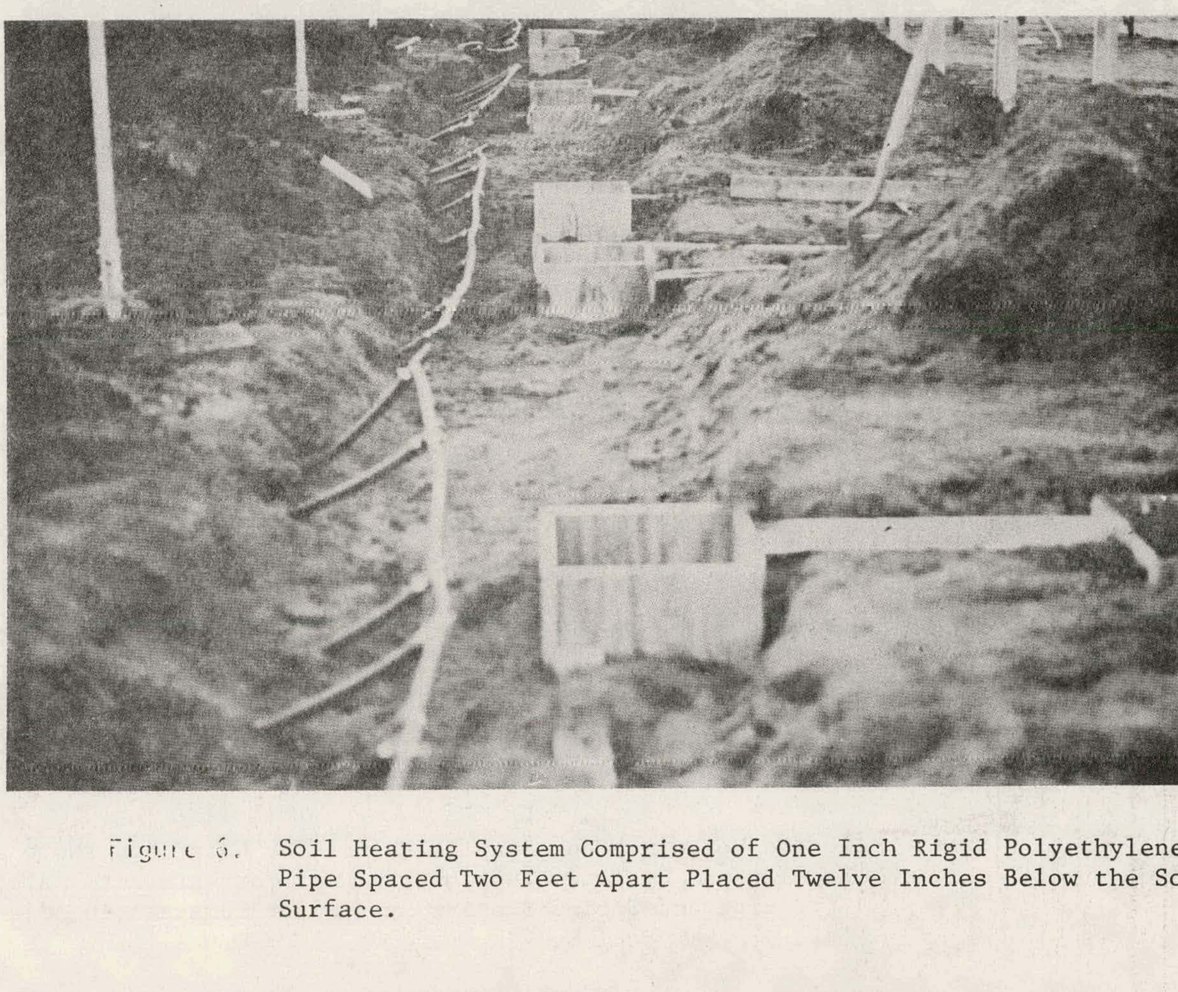

Figure 6. Soil Heating System Comprised of One Inch Rigid Polyethylene Pipe Spaced Two Feet Apart Placed Twelve Inches Below the Soil Surface.

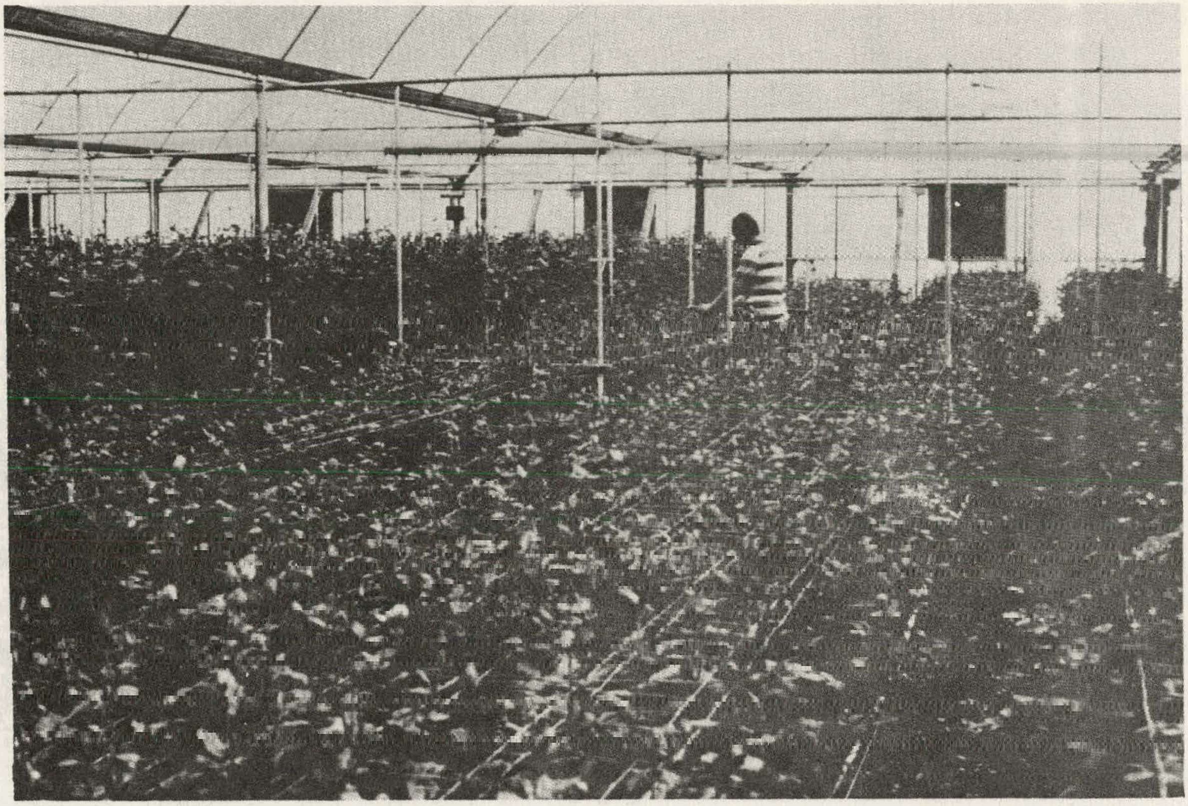

Figure 7. Roses in Early Stages of Growth. Note Welded Wire Support System. Also Note Exhaust Fans in Ends of Bays That Draw Air Through the Evaporative Pads for Cooling. Also Visible (Barely) in the Foreground Aisle is the Rigid Polyethylene Pipe Forming the Perimeter Irrigation System.

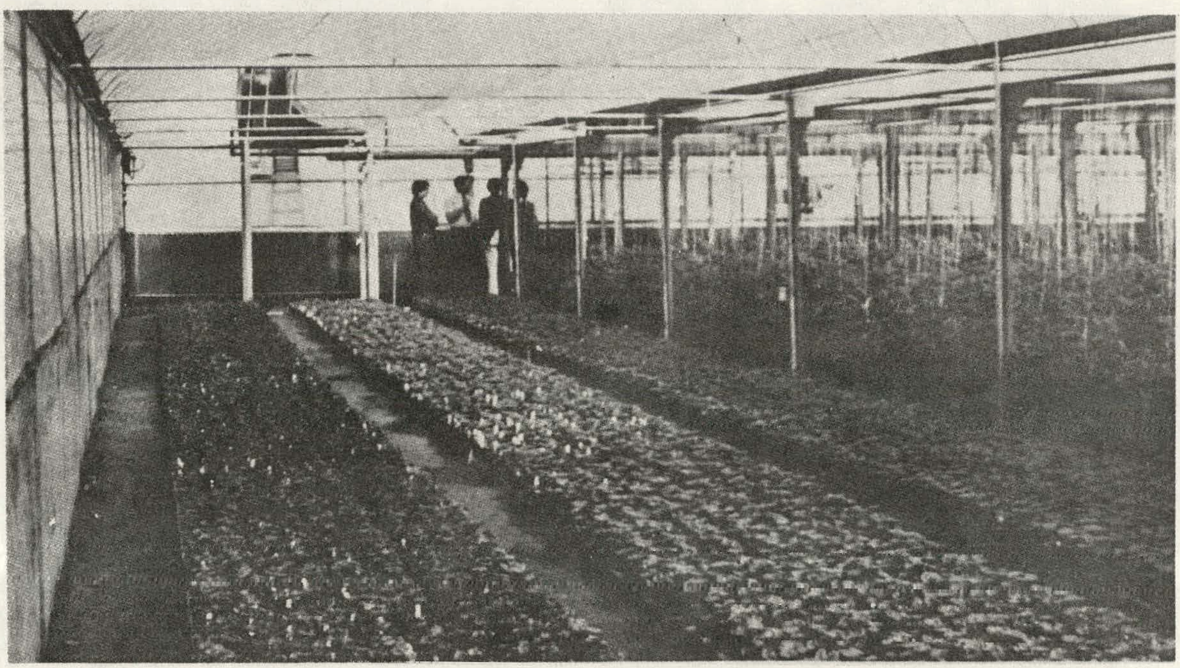

Figure 8. Potted Geraniums on a Capillary Mat for Watering. Note Air Handler and Plastic Distribution Duct for Warm Air. Also Note Pipe and String Support System for Tomatoes in Adjacent Bay.

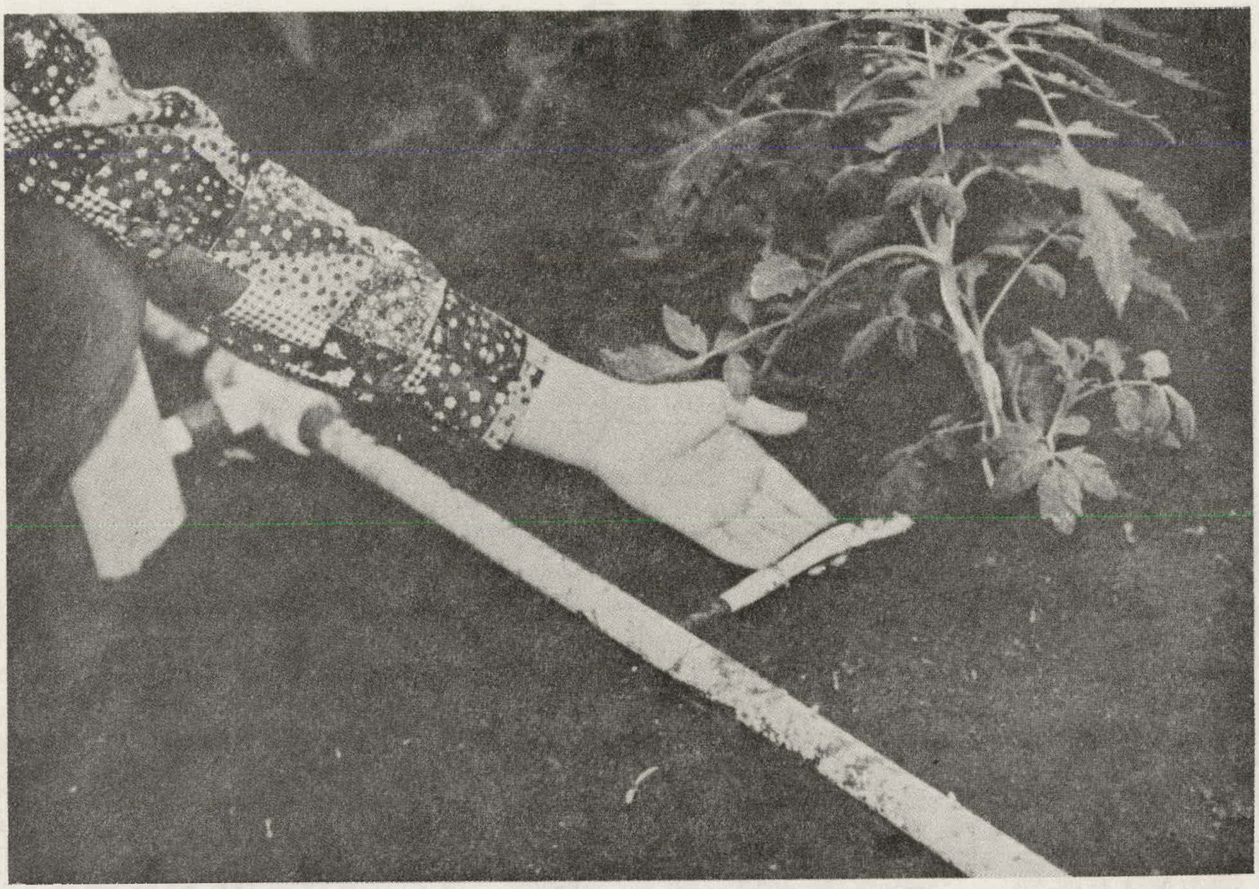

Figure 9. Irrigation System Used for Tomatoes Comprised of Rigid Polyethylene Distribution Pipe and Flexible Porous "Via Flow" Delivery Tube Placed Just Below the Soil Surface.

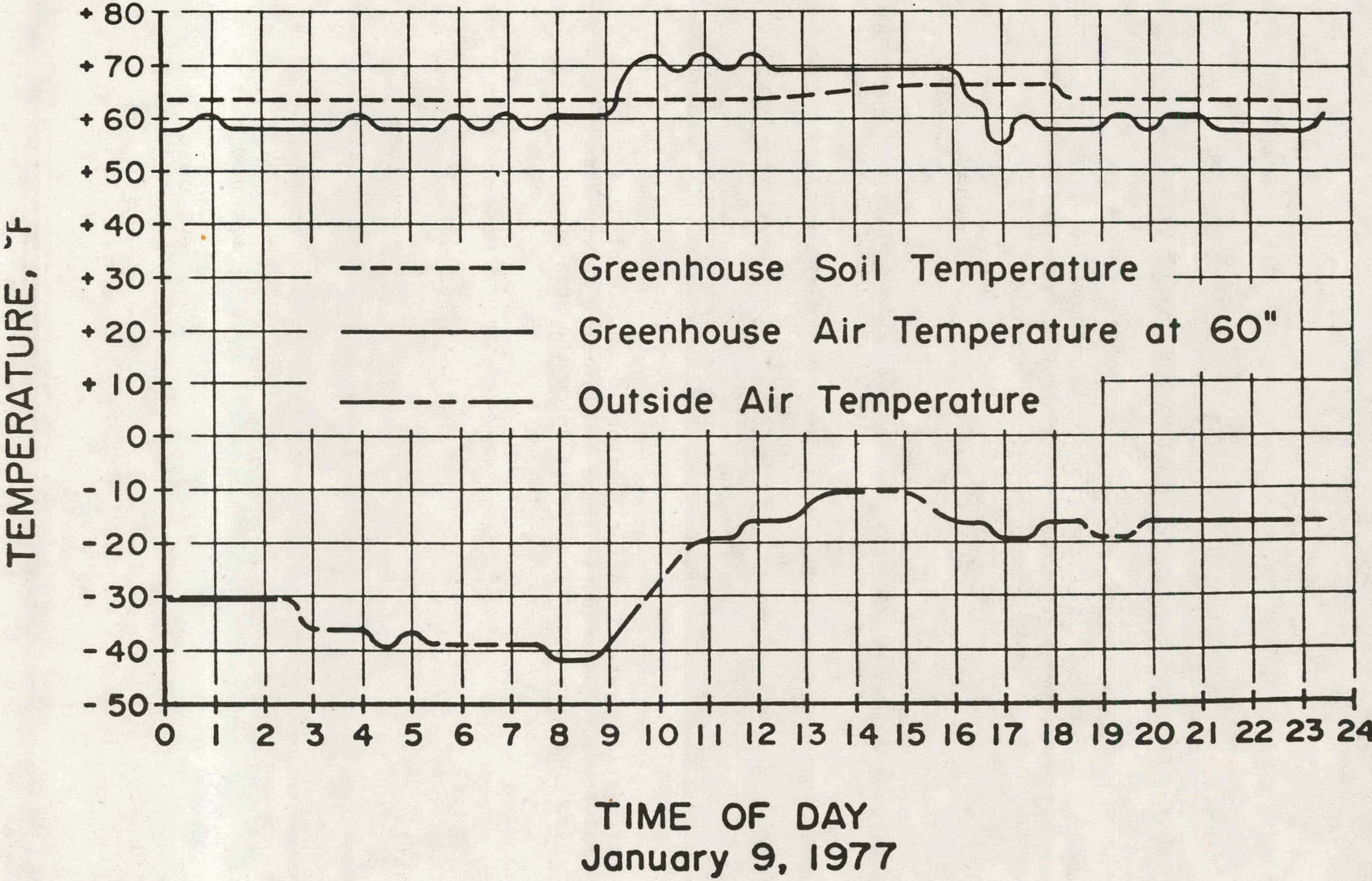

Figure 10. Performance of the Warm Water Heating Systems During the Coldest 24-Hour Period of the 1976-77 Heating Season.

Paper No. 9

Hatchery Culture of Molluscs in Conjunction with the Waste Thermal Effluent of a Power Plant

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Abstract

Although a good deal of popular attention has been given to the application of power plant thermal aquaculture, few attempts have in fact been made, and fewer commercial applications have been attempted. International Shellfish Enterprises evaluated the use of power plant thermal effluent for the culture of bivalve shellfish from 1970 to 1976 at a fossil fueled power plant at Moss Landing, along the California coast. The power plant draws sea water for steam condensation from a harbor, heats the sea water an average of 14 degrees centigrade, and discharges the water 800 feet offshore through two point discharges into the waters of Monterey Bay in the Pacific Ocean.

Initial attempts to utilize this water were evaluations of growth response by a number of oysters, clams, scallop, and abalone ranging in size from 2 mm to 30 mm. Growth response was encouraging enough to explore further use in hatchery work. The power plant effluent water was used

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for brood stock conditioning, larval culture, and seed culture with variable results. Problems encountered with use of this water related to large populations of bacteria which were pathogenic to the shellfish cultures, chemical contaminants in the form of high ammonia fractions in the power plant source waters and bromine residuals resulting from the power plant biocide applications. Attempts to de-toxify this water with biological filtration and sterilization were useful but not deemed economically feasible. In early 1976, attempts to utilize this power plant effluent were curtailed.

Presently, an attempt to use this effluent water in a plastic heat exchanger shows promise to extract useful heat for culture operations.

Introduction

With the prospects for U.S. electrical power demands doubling in the next decade, increasing concern about the ecological effects of thermal effluent has resulted in increased regulatory legislation to control thermal effluents, and proposals to accomodate or alleviate the problems of thermal effluent through engineering modifications and proposed multiple use of the effluent. Proposals to utilize thermal effluents from power plants have included urban residential heating, agriculture, and aquaculture. The use of power plant thermal effluent for aquaculture has probably received the major public attention in the last decade, with proponents claiming that the culture of aquatic plants and animals in this warm water could reduce production costs and the time required to rear the products to marketable size. In addition, even though it may be unfeasible to claim that aquaculture use of thermal effluent may reduce the final discharge temperatures to comply with present regulations, the possibility does exist to slightly reduce the discharge waters through aquaculture use, and aquaculture may be considered a positive means of compensation for the adverse effects of the power plant effluent water.

In marine water based power plant effluent utilization, only a few attempts have been made to utilize this water. Most of these efforts have been industrial and university sponsored experimental efforts. Commercial applications have been limited, with the most successful attempt by the Long Island Oyster Company which raises hatchery grown oysters and clams in a power plant effluent lagoon in New York.

International Shellfish Enterprises evaluated the use of thermal effluent for aquaculture from 1970 through 1976 as part of its efforts in establishing a shellfish hatchery and growing operation in California. It is not the intention of this paper to present the years of data collected during these evaluations, but to describe the principal problems encountered in applying thermal power plant discharge waters to a commercial aquaculture operation.

These problems have been grouped in two general areas: those concerned with the effects of the power plant operation itself, and those problems associated with the source waters used by the power plant for its cooling operations.

Background

International Shellfish Enterprises was established in early 1970 as a commercial mariculture venture with the intention of establishing a fully integrated shellfish operation, controlling hatching, larval, and early juvenile growth stages, and finally the growth of several species of shellfish to marketable size. The company has progressed from a start-up phase of testing from 1970 through 1973, through a commercial facilities construction phase from 1973 through 1975, to a fully functional commercial operation which has operated since 1975. The company today operates a 6,000 square foot shellfish hatchery producing several million 2-3 mm oyster and clam seed per month, an extensive shellfish nursery operation in a nearby estuary where several million shellfish seed per month are reared from the hatchery size to 25-40 mm, and a developing shellfish growing operation in the same estuary where the nursery products will be grown to marketable size. The company presently sells its nursery shellfish seed to shellfish farmers throughout the world.

Application of thermal effluent has been restricted to trials at the I.S.E. hatchery facility, shown in Figures 1 and 2, at its present location adjacent to the Moss Landing

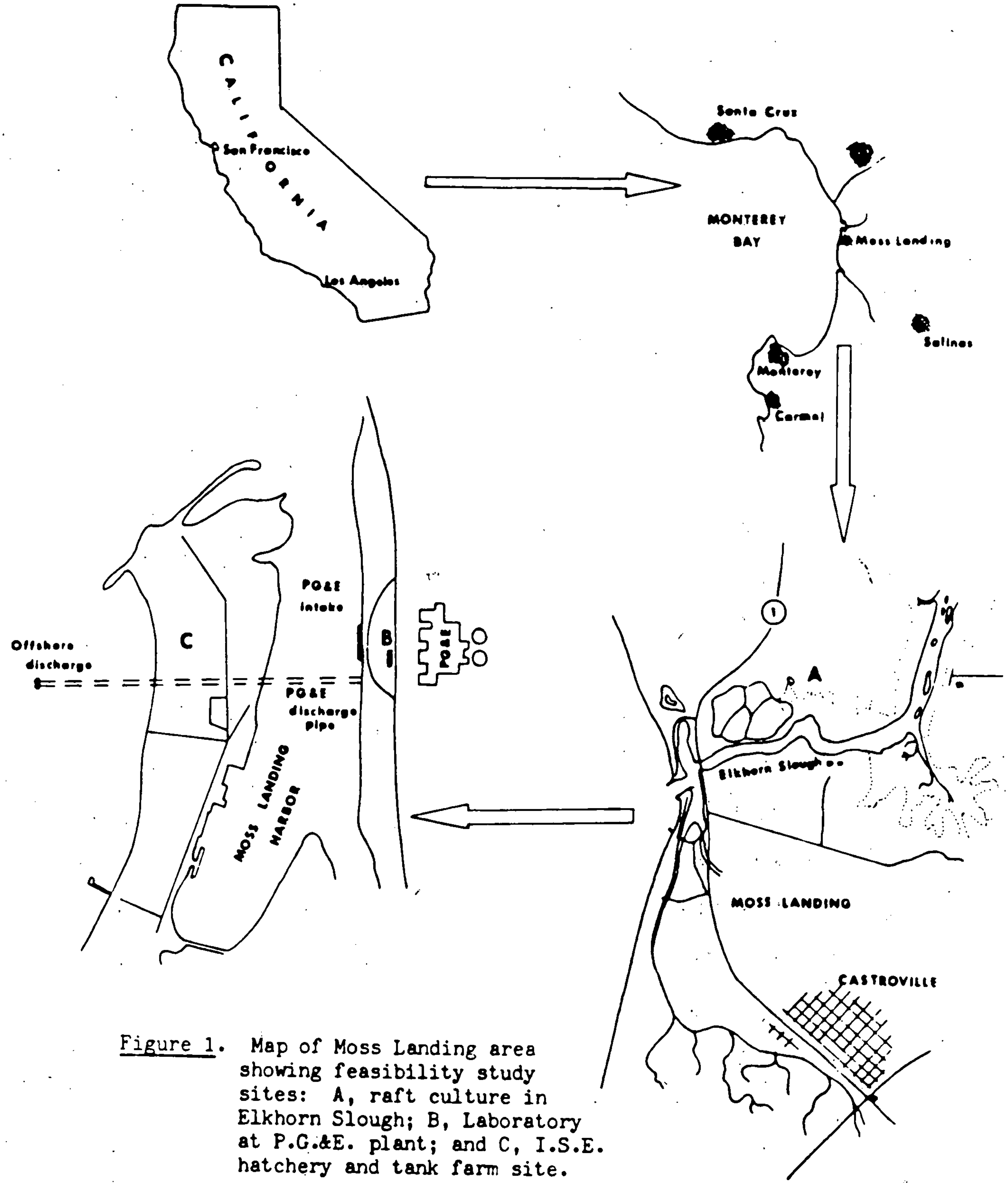

Figure 1. Map of Moss Landing area showing feasibility study sites: A, raft culture in Elkhorn Slough; B, Laboratory at P.G.&E. plant; and C, I.S.E. hatchery and tank farm site.

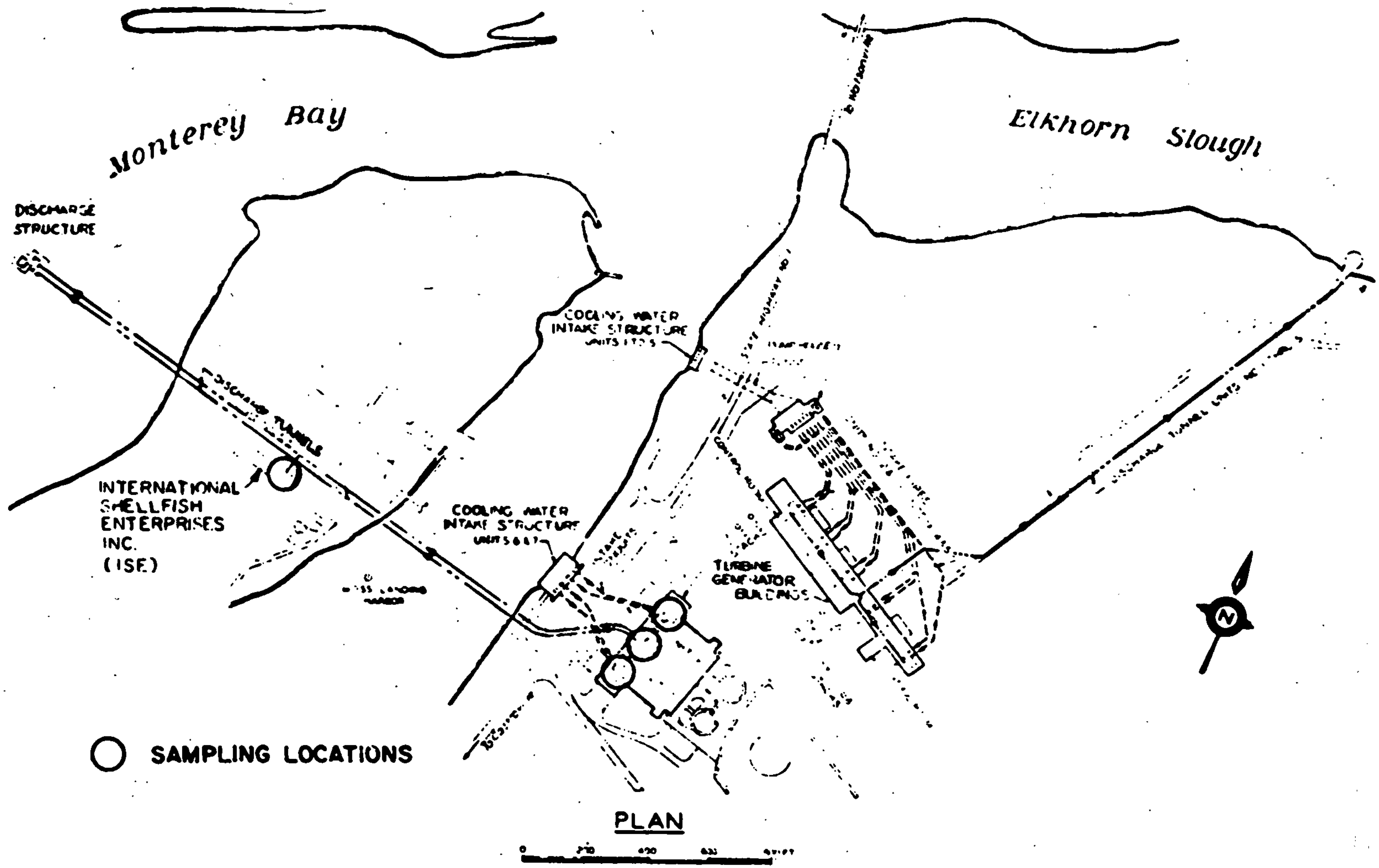

Figure 2. Moss Landing Power Plant

Harbor.

Pacific Gas and Electric Company operates a fossil fueled electric generating facility at Moss Landing with a gross generating capacity of 2110 megawatts, making it one of the largest such plants in the world. The power plant circulates 1,000,000 gallons per minute (63.1 m^3/sec) of sea water drawn from a harbor, passes this water through titanium steam condenser tubes, and discharges the effluent 800 feet offshore into the Pacific Ocean. Plastic pipes from the I.S.E. hatchery connect into this discharge pipeline and can draw up to 250 gallons per minute of the thermal effluent for hatchery use.

Evaluation trials in utilizing this thermal effluent for shellfish culture included rearing oyster and clam larvae from fertilization to metamorphosis in 1000 liter culture containers, rearing recently metamorphosed oyster seed to sizes of 1-2 mm, and rearing 25-60mm oysters to adult sizes of 70-100 mm. Water for these trials was passed through high rate sand filters, and in the larval culture trials further filtered with polyethylene 1 micron tube filters, and finally exposed to ultraviolet light sterilization. Without presenting a detailed account of these culture trials, the principal problems in dealing with the power plant effluent will be presented below.

Power Plant Operational Problems

The principle problems in applying thermal effluent to aquaculture practices related to the operational characteristics of the power plant itself. These problems were power plant effluent temperature cycling, screening system wastes, and biocidal activities.

Temperature cycling. When the power plant effluent was utilized in culture trials, especially with juvenile and adult shellfish, using continually flowing water to the shellfish, temperature cycling of the power plant generating units became a major problem.

Although sea water intake temperatures for the cooling system were relatively stable throughout the year, seasonal and even diurnal discharge temperature changes were at times extreme. Sea water intake temperatures averaged 12°C during the winter, with temperatures averaging 15°C during the summer months, with average temperature increase of 10°C after the water passed through the condensers. However, with daily variations in consumer demand for electricity in California, generating units would be started or stopped in short periods of time, and with little advance warning, the discharge temperatures would vary as much as 8°C.

In addition, six times during the period from 1970 to 1976 periodic shutdown of all the generating units for several week periods would leave only ambient temperature water circulating through the discharge pipelines.

Although these temperature variations had little effect on static cultures of shellfish, since the water could be monitored and tempered if necessary, flowing water cultures of shellfish at times exhibited large mortalities from gas bubble disease. This syndrome occurs when abrupt water temperature changes causes gas emolism in the cultured shellfish, a result of varying dissolution rates of oxygen and nitrogen with temperature change.

Although abrupt changes of temperature can be monitored and mixing valves can be used to temper the water temperature, this hardware does not generally exist built of materials compatable with sea water of shellfish culture needs. Plastic modulating valves must be custom manufactured for this purpose, and for high flow rate use, the cost of this hardware becomes extremely high.

Screening system wastes. The Pacific Gas and Electric Co. power plant at Moss Landing utilizes a series of travelling screens to exclude large marine organisms from plugging the condenser tubes. These travelling screens operate on a time schedule, but occassionally turn on unexpectantly when pressure differential sensors before and after the screen activate the system. When these organisms are washed from the travelling screens, they are washed into the discharge pipelines. A typical screen washing will include upwards of 400 kilograms of fish, jellyfish, and crustaceans. On those occassions when I.S.E. was pumping thermal discharge water into the hatchery and the screening operations were in process, large amounts of these organisms were pumped into the hatchery. In addition, these organisms contributed extremely high levels of organics to the discharge waters.

The net result of these screening activities was the availability of organics in the sea water which provided nutrients for bacterial growth in the shellfish cultures.

Biocidal activities. Chlorine is injected intermittently into the cooling water flow of the Moss Landing power plant to control slime-causing bacteria and algae. Chlorination is conducted once per day, with 1.0 mg Cl_2/l injected for 15 minutes at the entry to the condenser tubes. Chlorine residuals at the I.S.E. hatchery access to the discharge lines have been measured at .22 mg Cl_2/l, the oxidant remaining largely bromine residual. Studies at I.S.E. on chlorine and bromine residuals indicate that chronic toxicity to oyster larvae occurs ablve .1 mg Cl_2/l.

As a result of these studies, discharge pipeline pumping activities into the I.S.E. hatchery were curtailed during power plant biocidal application.

Circulating Water Source Related Problems

Several problems in dealing with the power plant discharge water were found to be related to the quality of the water at the circulating water intake location. These problems were high levels of pathogenic bacteria and toxic levels of ammonia.

Bacterial problems. During the numerous attempts to utilize the power plant effluent water for shellfish larval culture, consistent mortalities in the larvae prevailed. Culture comparisons of this water with an alternate source drawn form the open ocean indicated that very high levels of pathogenic bacteria were present in the power plant effluent water. These bacteria were characterized as Vibrio sp., especially V. parahemaelyticus, V. alginolyticus, and V. anguillarium, and Aeromonas sp. These bacteria are well known as pathogenic to oyster larvae.

Toxic ammonia levels. Chemical analysis of the power plant effluent showed it to be at times extremely high in ammonia, and coupled with a normal high pH in the surrounding waters of 8.3-8.6, high levels of toxic ammonia gas were found. Levels of ammonia of 10-40 ug-at/l were usually found, with occasional levels of 100 ug-at/l found at low tide periods. At the high pH levels for the surrounding waters, this results in un-ionized ammonia fractions ranging from 3 to 14 ug-at/l. Bioassay at the I.S.E. hatchery of the toxcity of un-ionized ammonia to oyster larvae have shown that levels of over 1.5 ug-at/l of ammonia are lethal to the larvae if exposure exceeds 24 hours.

In an attempt to eliminate ammonia levels from the power plant discharge water, a flow-through biological filter was utilized. The filter utilized dolomite granules as the biological substrate. Although combinations of biological filtration and intense aeration reduced ammonia levels by a factor of ten, and lowered pH levels to 7.8-8.0, these methods were too costly for the high flow rates required for shellfish culture.

These brief descriptions of bacterial and ammonia contamination are presented as problems related to the power plant wource water, as these contaminants were present in the harbor water and not as a result of any power plant activity.

In mid-1976 I.S.E. curtailed further use of the power plant discharge water for hatchery operations, resorting to use of open ocean water sources. The problems in dealing with frequent temperature changes, biocidal treatment schedules, bacterial, and ammonia contamination presented greater problems than the benefits of using the power plant effluent could offer.

Recently, I.S.E. has renewed efforts at using the power plant effluent in the hatchery operation. An effort is presently underway to extract heat from the effluent to supplement the present heating of open ocean seawater. Before sea water is pumped through a carbon heat exchanger for use in the hatchery, it passes through several plastic tube solar heating modules situated in tanks of circulating power plant effluent water. It is anticipated that by using this supplemental heat source, savings will be realized in operating the boiler-fired sea water heat exchanger, and at the same will avoid the inconsistencies experienced in use of the effluent water.

It has been the purpose of this paper to present some of the engineerihg and biological observations from several years of attempting to utilize a power plant effluent for aquaculture. Many of the problems encountered in trying to harness this energy source stem from the nature of power plant siting. Most power plants, and certainly most of those under construction now are necessarily sited in coastal areas which are already heavily industrialized, in an effort by current legislative direction to reduce impact on ecologically stable areas of our coastlines. This factor will tend to preclude the direct use of power plant for very critical aquaculture use because of severe water quality limitations in such geographic areas. Although oyster larvae are extremely sensitive to water quality vagaries, many of the varying operating parameters described in attempting to use the Moss Landing power plant effluent are extreme enough to preclude culture of less sensitive aquaculture candidates, such as salmon or lobster.

While it is safe to assume that most aquaculture candidate species will reach market size faster in warmer water temperatures, their direct culture in power plant effluent is very limiting for commercial success, due to the necessity in any commercial venture to have predictability in stock production. In a power plant effluent having these vagaries, it would be necessary for the mariculturist to design facilities with adequate back up water heating capacities, a very costly enterprise. It would seem a more economic and a sounder management approach to take indirect advantage of the heat energy from a power plant effluent to suppliement existing heating facilities.

Paper No. 10

A COMPUTERIZED SYSTEM FOR ESTIMATING WATER AVAILABILITY AND REQUIREMENTS FOR POWER PLANT COOLING

by

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INTRODUCTION

The potential water problems associated with cooling thermal power plants in the United States were outlined in a paper "Water Requirements in the United States and Need for Dry and Dry/Wet Cooling" by W. F. Savage and G. Englesson which was presented at the meeting of the Joint US-USSR Coordinating Committee on Scientific and Technical Coordination in the Field of Thermal Power Plant Heat Rejection Systems in the Soviet Union in February 1977. As noted in the paper, based upon the assumption that limitations of surface water could be used as a basis for predicting the need for dry cooling, it was projected that a significant number of new power plants by the year 2000 would require dry or dry/wet cooling. The majority of these facilities will be required in the arid Southwestern part of the United States where competition over water has existed for many years. Severe-to-major problems are projected for the Lower Colorado and California regions, with major to moderate problems projected for the Great Basin, Upper Colorado, Rio Grande, Texas Gulf, Missouri and Middle Atlantic Regions. These areas are shown in Figure 1.

To better understand the water problems that exist in the United States, it must be recognized that considerable competition exists over the available water resource. Furthermore water laws in the United States are very complex particularly in the West where the appropriate rights doctrine allows water to be bought and sold. As a means of assimilating the immense data base which exists on water resources characteristics and availability, a computerized system has been developed. The system was designed primarily to assist the individual engaged in siting thermal power plants, however, the utility of the system is much more general. Characteristic type data on both surface water and ground water sources are included in the system. The data are organized around the use of an eight digit water resource cataloging unit. Similar to states and counties, a water resource cataloging unit represents a specific surface area within the United States. However, in the case of the water resource cataloging unit the area represents a natural hydrologic drainage basin. By using the water resources cataloging unit, the surface of the United States is sub-divided into more than 2000 areas. The water resource cataloging unit is used to index all water resources and power plant data contained in the information retrieval system. Furthermore, the water resource cataloging unit is used as an indexing scheme for correlating water demand.

To model the demand for water within the thermal power plant sector of the U. S. economy, a simple input/output technique using normalized data on forecasted electrical energy growth is employed. The demand coefficients are multiplied by consumptive use or evaporative loss coefficients to obtain an effective consumptive use factor for each subregion, i.e., $(\text{MWe})\left(\frac{\text{MWt}}{\text{MWe}}\right)\left(\frac{\text{cfs}}{\text{MWt}}\right)$

where MWe = electrical megawatts, MWt = thermal megawatts, and

cfs = cubic feet per second.

DATA BANK

The water resources element of the information system contains basically four types of data: data on the water resource cataloging unit, surface water data, ground water data, and data on oceans and bays. Table 1 provides a summary of the water data incorporated into the system. For each of the more than 2000 Water Resource Cataloging Units data on; surface area, the dominant state and county within which the cataloging unit is found, the current population, runoff characteristics, and comments on water rights are included. Data on annual runoff is provided since it is sometimes assumed to be a theoretical upper limit of surface water supply. Comments on water rights are not presently included in the system but will be added over the next couple of years. The intent of this feature is to provide a description of the overall status or allocation, if appropriate, for water in each water resource cataloging unit.

In each of the water resource cataloging units, as many as four surface water resources can be defined. Surface water sources consist of rivers, lakes, and reservoirs. Types of data stored on rivers are; mean monthly flow, mean monthly low flow data (i.e., 1 in 10 and 1 in 20 year occurrences), and water quality parameters consisting of temperature and total dissolved solids. The primary source for the flow data is the U. S. Geological Survey. This agency has collected flow data from virtually tens of thousands of gaging stations throughout the United States for numerous years. The 1 in 10 and 1 in 20 mean monthly low flow condition are derived from mean monthly flow data using statistical models. Statistical models which assume Gamma, Beta, and Log Normal distribution were used for the purpose of establishing the 1 in 10 and 1 in 20 low probability conditions.

For lakes and reservoirs, data on surface area, volume, temperature, and total dissolved solids is provided. The sources of the data are reports published by various state and federal agencies in the United States. Data on oceans and bays is limited to one source per water resource cataloging unit. Only data on salinity and temperature are provided.

An extensive effort has been placed upon collecting and organizing ground water data. Ground water is used extensively in some parts of the United States. At the present time ground water is withdrawn at a rate of 80 billion gallons/day. Twenty-five percent of the total withdrawal is in the state of California.

The major problems associated with defining the ground water potential are due to: 1) the heterogeneous nature of ground water supplies, and 2) identifying the existence and/or boundaries for each aquifer. Similar to surface water sources, a maximum of four ground water sources can be entered for each water resource cataloging unit. To date the primary emphasis has been directed towards first defining, and second obtaining data on high yield aquifers. High yield aquifers are defined as those aquifers capable of yielding in excess of 500 gallons/minute (1.89 cubic meters/minute). As presently planned in addition to yield, data on depth, thickness, total dissolved solids, temperature, specific capacity and comments on water rights will be included in the information system. The primary source for ground water data is the U. S. Geological Survey WATSTORE ground water site Inventory File. In the ground water site Inventory File are data for more than 600,000 wells located in the United States.

In addition to minimum yield, other criteria which have been used for purposes of screening candidate aquifers are; a maximum aquifer depth of 1000 feet, a minimum specific capacity of 25 gallons per foot (.3 cubic meters per meter) of draw down, and a water quality constraint which limits the total dissolved solids to 5000 parts per million.

Data on hydroelectric and thermal power plants with a capacity rating of 100 MWe or more are included in the information system. Table 2 summarized the data included in the system. Three basic types of power plant data are included; general plant information, power plant cooling information, and operational data. For purposes of comparison it is worthwhile to note that in 1975 water withdrawals for steam-electric power plants were 90 billion gallons per day (3.79 million cubic meters per day) representing ninety-four percent of all withdrawals for energy production in the United States and twenty-six percent of the total fresh water withdrawals. With the trend towards off-stream cooling (e.g, use of cooling towers), the total withdrawal of surface waters for purposes of cooling thermal power plants are forecasted to decrease in the years ahead. However, consumptive use through blowdown and evaporation are forecasted to increase.

General plant data included in the system consists of plant name, utility name, plant location, plant type and overall rated capacity. The location of the plant is referenced with respect to; city, county, state, water resources cataloging unit, and latitude and longitude. Additional information on the specific Federal Energy Regulatory Commission power supply area and region served as well as the year of commercial start up are included.

Of particular importance is the inclusion of data on the type of condenser cooling system. In the United States thermal power plants are cooled through the use of once through cooling, cooling ponds, and cooling towers. Cooling system characteristics such as withdrawal rate, consumption blowdown, and discharge rate are contained. The source of the cooling water is also included in the information system.

Yearly power plant operational data such as total generation, heat rate, and capacity factor are also included. The source for nearly all data on power plant design and operation are obtained through publication provided by Federal Energy Regulatory Commission, and the Edison Electric Institute. Trade journals such as "Power Engineering", and "Electrical World" are also used periodically.

The data on power plants and water resources are organized into a hierarchical structure for purposes of retrieval using a generalized commercially available system. The hierarchical structure for the data base is shown in Figure 2. The information system can be operated on a batch or on-line interactive mode. The information system is presently operational on a Univac 1110 computer.

DEMAND FORECASTING

Recognizing that a continuing need exists for updating projections on power growth, a predictive model has been developed for use in conjunction with the information system. As indicated in the introduction, supply and demand modules were developed using basic input-output techniques.

To begin with, information on existing and projected power growth and transmission facilities were synthesized into a number of power generation areas. Figure 3 shows the 230 power generation areas which were developed using this procedure. Normalized power growth coefficients, i.e.,

$$MWe_i \Big/ \sum_{i=1}^{230} MWe_i$$

were developed for each of the power generation areas based upon forecasted economic and agricultural growth characteristics prepared by research economists in the United States. The 230 power generation areas were next correlated with the Water Resources Cataloging Unit indexing scheme by overlaying the power generation areas on a map of the United States showing the Water Resource Subbasins (WRSB). The 204 Water Resources Subbasins in the contiguous United States are shown in Figure 4. For purposes of forecasting electrical energy demand and growth patterns it was assumed that disaggregation or sub-division to the level of water resources sub-basins gave a sufficient level of detail. For purposes of comparison, each water resources sub-basin contains on the average 10 cataloging units.

Using this approach, the total demand for electricity is inputted to the predictive model and the model is used to estimate the specific water demand in each water resource subbasin. Comparison can then be made regarding the water supply and demand for water or a subbasin, which can be extrapolated into water resource cataloging units.

FUTURE WORK

The information system is operational and numerous inquiries for data have been received. Additional work is required in reviewing and acquiring data on ground water and water rights. To date the potentially high yield aquifers have been defined and preliminary data on existing test wells for each candidate aquifer has been obtained. Pump test data for the various wells will be collected and entered into the information system.

Additional development of the predictive capability are planned. A future model will relate supply and demand through the use of specific end use coefficients for each primary use of electrical energy: industrial, residential, and commercial. Models for each of the end uses will be developed using standard economic activity factors and population as the primary independent variables. A demand model will be formulated for each Water Resource Subbasin. The demand for electrical energy in each Water Resource Subbasin can then be evaluated as a function of time using economic activity factors and population as the primary independent variables. The electrical demand can then be compared with the proposed supply and water availability thus defining where advanced power plant cooling methds need to be used.

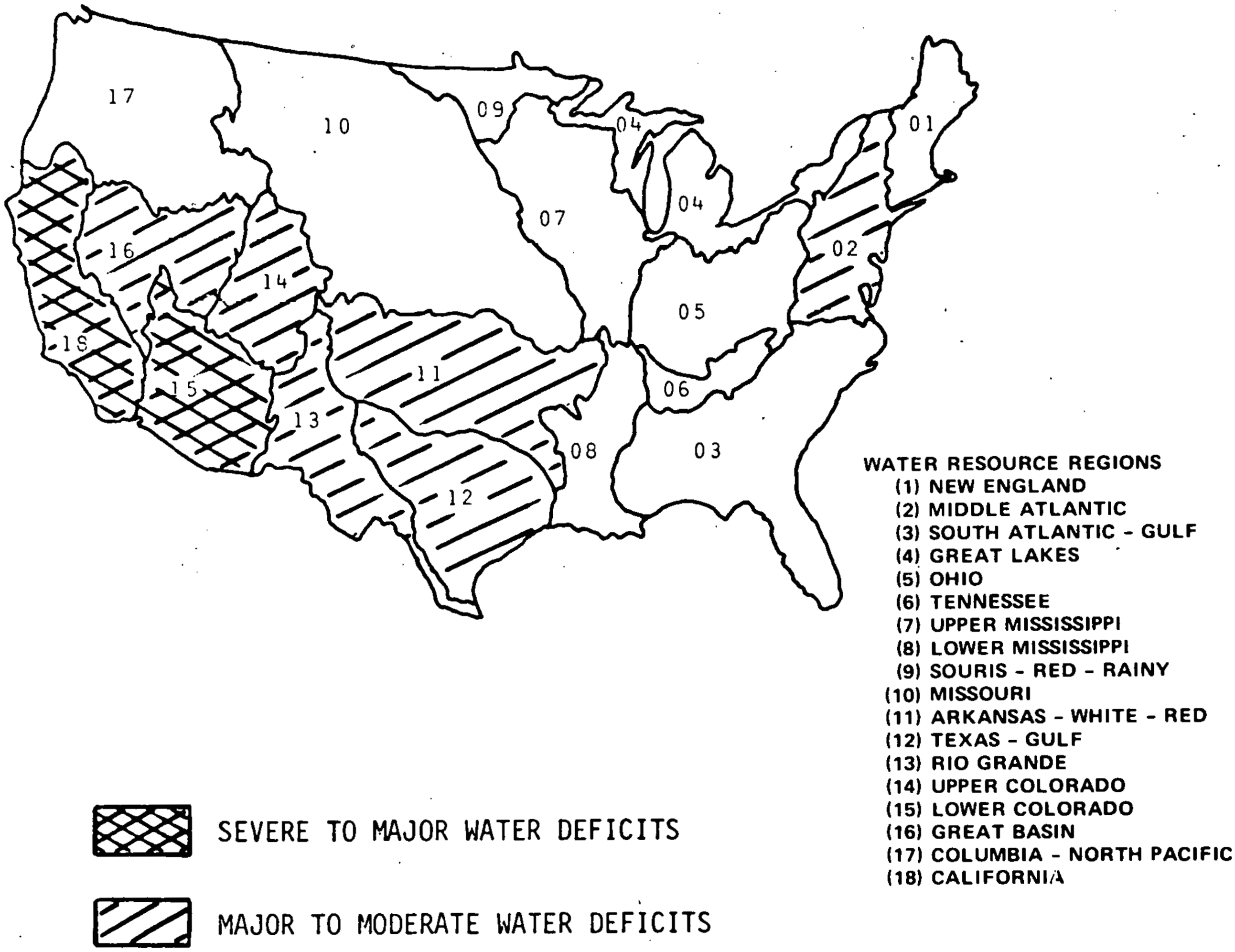

FIGURE 1: POTENTIAL FOR WATER SHORTAGES IN WATER RESOURCE REGIONS OF THE UNITED STATES. (YEAR 2000 FORECAST)

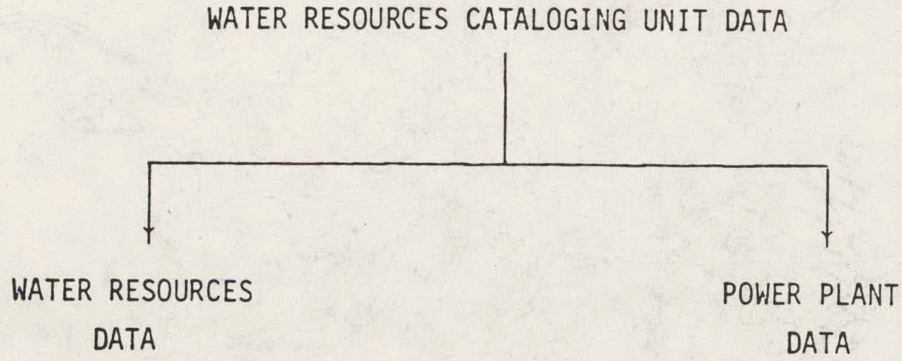

FIGURE 2: HIERARCHICAL STRUCTURE FOR THE THERMAL POWER PLANT WATER USE INFORMATION SYSTEM

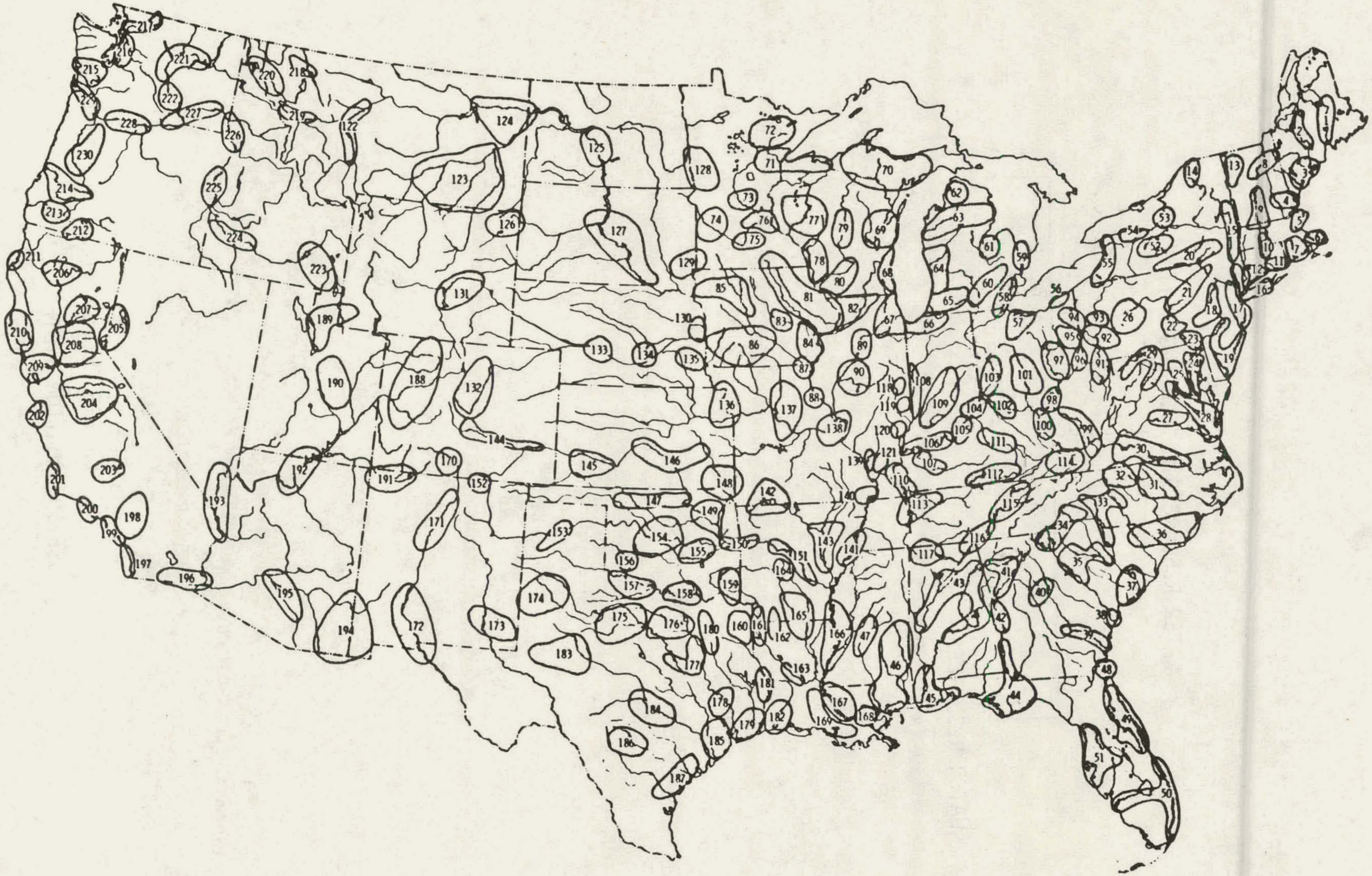

FIGURE 3: POWER GENERATION AREAS IN THE UNITED STATES

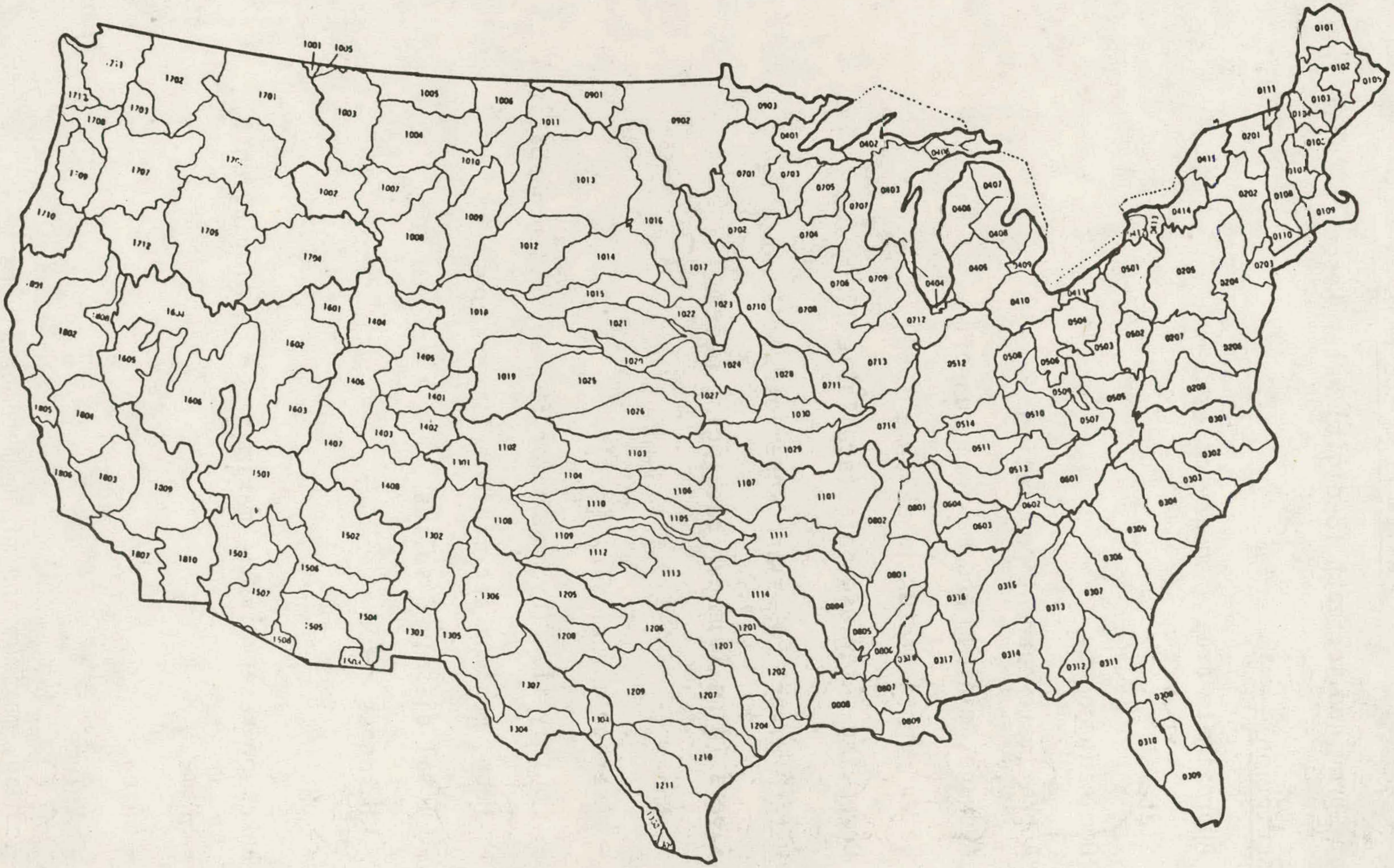

FIGURE 4: WATER RESOURCES SUBBASINS IN THE CONTIGUOUS UNITED STATES

TABLE I

WATER RESOURCE DATA

Data provided for each (8-digit) Water Resource Cataloging Unit

Area Description

- Approximate area - square miles
- State
- Dominant county
- Approximate current population
- Average, minimum and maximum run-off
- Water rights status (available 1980)
- Competing water use data (available 1980)

Surface Water (River, Lakes and Reservoirs)

- Rivers (4 maximum per cataloging unit)
  - Name
  - Average annual flow (cfs)
  - Monthly flow (by month for 50, 90, 95% probability)
  - Mean, maximum and minimum temperature
  - Total dissolved solids
  - Hardness
  - pH
- Lakes or reservoirs (4 maximum per cataloging unit)
  - Name
  - Area
  - Volume
  - Mean, maximum and minimum temperatures

TABLE 1 (cont'd)

WATER RESOURCE DATA

- Total dissolved solids
- Hardness
- pH

Ground Water (maximum of 4 aquifers per cataloging unit)

- Name
- Depth (below ground level)
- Thickness
- Total dissolved solids
- Hardness
- pH
- Temperature
- Specific capacity
- Yield of large diameter well
- Committed water rights (available 1980)

Ocean/Bays (1 only per cataloging unit)

- Name
- Salinity
- Mean, maximum and minimum temperature

TABLE II

GENERATING PLANT DATA

Data provided for each thermal generating plant with rating of 100 MWe or greater. Applicable data for hydroelectric units are included for convenience.

General Plant Information

- Plant name
- Utility name
- Plant location
  - City, county, state
  - Water resource cataloging unit
  - Latitude and longitude
  - Federal Energy Regulatory Commission power supply area and region
- Plant type
- Plant capacity (MWe)
- First year of commercial operation

Plant Cooling Information

- Type (once through, tower, etc.)
- Cooling water source
- Flow rate of receiving water body
- Withdrawal, consumption, blowdown, discharge rates

Plant Operational Data (yearly)

- Generation
- Heat rate
- Capacity factor

Paper No. 11

STUDY OF ADVANCED TECHNOLOGY COGENERATION SYSTEMS FOR PROVIDING INDUSTRIAL POWER AND PROCESS HEAT

by

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ABSTRACT

Cogeneration is broadly defined as the simultaneous production of electricity or shaft power and useful thermal energy. The Department of Energy (DOE) is responsible for the advancement of cogeneration technology using energy conversion systems (ecs) with both today's commercially available technology and advanced energy conversion system technology. In line with the latter responsibility, a study is being performed by the National Aeronautics and Space Administration (NASA) for DOE called the Cogeneration Technology Alternatives Study (CTAS)". The objectives of the study are to evaluate and compare various advanced ecs in industrial cogeneration and to assess the energy savings, life-cycle energy cost, and environmental impact benefits of using advanced technology. The following systems are included in the study: steam systems, open-cycle gas turbines, combined gas turbine/steam turbine systems, diesel engines, closed-cycle gas turbines, Stirling engines, high and low temperature fuel cells and thermionics. Fuels include distillate and residual quality petroluem fuels, coal-derived gaseous and liquid fuels, and coal.

STUDY OF ADVANCED TECHNOLOGY COGENERATION SYSTEMS FOR PROVIDING INDUSTRIAL POWER AND PROCESS HEAT

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Introduction

Cogeneration is defined broadly as the simultaneous generation of electricity or shaft power and useful thermal energy. This definition applies to a wide variety of industrial and commercial/residential applications. The cogeneration concept offers the potential for increases in overall energy utilization efficiency. Up to this time, cogeneration has seen relatively limited use in the United States. However, in light of diminishing domestic oil and natural gas reserves and rising fuel prices, the application of cogeneration concepts exhibits the potential for significant benefits in the future.

The United States Department of Energy (DOE) is responsible for the advancement of cogeneration technology using energy conversion systems with both today's commercially available technology and advanced energy conversion system technology. In line with the latter responsibility, the DOE Division of Fossil Fuels Utilization has initiated the Cogeneration Technology Alternatives Study (CTAS) which will address the merits of advanced cogeneration systems for providing industrial power and process heat.

Objectives and Scope

The objectives of the CTAS effort are as follows:

1. Identify and evaluate the most attractive advanced energy conversion systems for implementation in optimized industrial cogeneration applications for the 1985-2000 time period.
2. Quantify and assess the advantages of advanced energy system technology compared to the use of today's commercially available technology.

Table 1 lists the advanced energy conversion systems which are included in the CTAS effort. The systems are being examined at technology levels which might be commercialized in the 1985-2000 time period. Steam systems, gas turbine systems and diesel engines are also being examined at conditions representing today's commercially available technology. Results for the cases using these commercially available technology systems are being used as a baseline for assessing the advantages of advanced technology. The potential benefits from the use of organic Rankine bottoming cycles, advanced technology heat pumps, and thermal energy storage are also included in the study.

The advanced energy conversion systems are being examined for application in industrial plants belonging to the Manufacturing Division of the Standard Industrial Classification system, a product-oriented classification system developed by the United States government. The effort is focused on cogeneration systems for the six major industry groups listed in Table 2. These six major industry groups accounted for approximately 80 percent of all energy consumed in U.S. manufacturing industries in 1974.

The study is predicated on the need to accommodate a transition from the use of natural gas and light oils to heavy oils and coal and coal-derived fuels. Therefore, the use of coal or minimally processed petroleum or coal-derived liquid fuels is emphasized. Characteristics of the coal and liquid fuels being employed in the study are given in Table 3. In addition LBTU gas produced from various types of on-site gasifiers which are integrated with selected conversion systems is being utilized. Natural gas or HBTU gas from coal are also being considered for industrial processes which might require that type of fuel and cannot substitute another fuel.

The coal characteristics in Table 3 are typical of a high sulfur bituminous coal predominantly found in the eastern U.S. The petroleum distillate and residual fuel characteristics represent a No. ? Diesel and No. 5 grade oil which might be indicative of these fuels as used in the 1985-2000 time period. The coal-derived liquid fuels characteristics are intended to be representative of minimally processed distillate and residual quality fuels produced by coal processing plants appropriate to the 1985-2000 time period.

Study Organization

The organizational approach to the study is a major feature of the overall CTAS concept. The CTAS organizational structure is shown in Figure 1. CTAS is one element of a larger project called the Advanced Cogeneration Technology (ACT) Project which is being sponsored by the DOE and managed by the National Aeronautics and Space Administration (NASA). The ACT Project will identify and provide for the development of advanced energy conversion system technologies which will permit the commercialization of optimized industrial cogeneration powerplants for the 1985-2000 time period. CTAS is being carried out by the NASA for DOE utilizing two NASA laboratories, the Lewis Research Center (LeRC) in Cleveland, Ohio, and the Jet Propulsion Laboratory (JPL) in Pasadena, California. The dominant effort in CTAS is being performed by companies from private industry under contract to the government. The intent is to use the expertise, capabilities, and judgment which resides within industrial concerns to insure that the most realistic results are obtained. A similar government/industrial team approach was used successfully in the Energy Conversion Alternatives Study (ECAS), a study of advanced technology systems for base-load electric utility applications. ECAS was performed by NASA for the Energy Research and Development Administration (the predecessor to DOE), and the National Science Foundation.

Project Management of CTAS is being provided by NASA/Lewis Research Center. The Project Management responsibilities of LeRC include both the management of the industrial contracts and the coordination of the contractor, JPL and LeRC in-house efforts. NASA/LeRC was selected by DOE for project management because of its capabilities in and understanding of the various advanced energy conversion systems being studied and its experience in managing large, complex studies.

In addition to the management functions, LeRC is performing a technical support function which includes selected in-house analyses to complement and/or supplement the contractor results. This support is important to the management of the contracted studies and provides a basis for the evaluation and reconciliation of contractor results. The primary emphasis of the in-house support activity at LeRC is in the area of advanced energy conversion system analysis.

The Industry/Process Support effort shown in Figure 1 is being performed at the Jet Propulsion Laboratory. The purpose of this effort is to provide support in the industry process area. This support is being utilized by LeRC in managing the CTAS contracted studies and also provides for studies by JPL of important areas complementing the contracted efforts. One example of this latter function is the identification and study of regional factors which might have a significant influence on advanced technology cogeneration system selection.

The final component of the CTAS organizational approach is the contracted effort with private industry. These contracted analyses will be performed by two teams from the industrial sector which will perform essentially parallel studies directed toward the CTAS objectives. The teams are each made up of a prime contractor and a number of subcontractors which provide expertise to the team in specific areas.

The two prime contractors are the General Electric Company (G.E.) in Schenectady, New York, and the United Technologies Corporation (UTC) in South Windsor, Connecticut. The subcontractors consist of both additional groups within the prime contractor's organization and separate companies, each of which offer a particular background and/or expertise essential to some aspect of CTAS. Some of the major participants on the two industrial teams and the general areas of responsibility of the participants are shown in Table 4. The large number of organizations involved and the diversity of disciplines represented is a direct consequence of the breadth and complexity of the CTAS effort.

As mentioned earlier, the two teams are performing essentially parallel studies. The reason for two parallel efforts is to obtain results using different design approaches, philosophies and views of the potential advances in the technologies possible for commercialization by

1985-2000. NASA will then have the responsibility for analyzing and evaluating the contractors' results, reconciling differences between the results of the two teams, and drawing insights not only from areas of agreement but also from the differences in results that occur.

Key Features of the Technical Approach

For the purposes of this study, industrial cogeneration is specifically defined as either:

1. Generation of electric power at an industrial plant with the rejected heat used for process heating (Front End/Topping).
2. Use of heat from a process for generation of electric power at an industrial plant (Back End/Bottoming).

Figure 2 depicts these two basic cogeneration configurations pictorially. In the Front End/Topping system, fuel is consumed in the energy conversion system to generate electricity for use in the plant. The rejected heat from the system is used to raise steam (or provide heat in other forms) which is then used in the industrial process plant. Electricity may be imported to the site if the conversion system cannot provide enough electric power to satisfy the site requirements. Electricity is exported to the utility grid if the energy conversion system produces more than is needed by the industrial plant. An auxiliary boiler may also be needed to supplement the steam produced by the heat rejected from the system. In the Back End/Bottoming configuration, fuel is used to generate heat for the process plant and the exhaust products from the industrial processes are used as thermal input to an energy conversion system which then produces electric power. Emphasis in the study is being placed on the Front End/Topping configuration.

The study considers cogeneration on the basis of individual industrial plant sites. Although additional benefits may accrue from consideration of a centralized cogeneration concept where a large energy conversion system provides the electric power and process heat requirements for a number of plants clustered around it, this is not being included as part of CTAS. Likewise, the use of rejected powerplant thermal energy for district heating is not included in the study. It is DOE's intent to address these latter concepts in separate studies which would consider central station-type cogeneration plants.

Two key features of the technical approach being employed are screening and characterization. Screening is used to reduce the number of cases to what is tractable and to focus the effort on those cases which have a hign likelihood of being attractive in terms of such criteria as overall energy efficiency, oil and natural gas savings, and energy costs. Focusing on the six major industry groups identified in Table 2 is a simple example of screening.

Characterization is used here to mean the utilization of simplified, representative relationships or "models" rather than consideration of the detailed, complex situation which actually exists. For example, industrial process plant requirements can be characterized in terms of the ratio of electrical to thermal energy required, representative temperatures at which process heat is needed and the overall quantity of electrical or thermal energy required rather than detailed consideration of each of the multiplicity of process streams and electrical and mechanical power requirements.

Another key feature of the technical approach is the use of common ground rules throughout the study. This is to insure that differences found among systems and between the two contractors' results represent real differences among systems or differences resulting from differences in design approaches or technical assumptions for the technologies. A number of the areas where common ground rules have been established are listed in Table 5.

The basic methodology used in the study is depicted in Figure 3. The cross-hatched areas represent possible points in the study where the number of cases considered can be reduced by screening. The initial step in the study is to screen and characterize the many possible industrial process plants and energy conversion systems. Then the energy conversion system characteristics are "matched" to the process/plant requirements to synthesize cogeneration systems. Those system-process combinations which do not appear to be a good match may be eliminated from further consideration. For those combinations that pass through this "matching" screen, fuel savings and capital costs are estimated on the basis of the characterizations or "models" used to represent the energy conversion systems and process plants.

For the more attractive of these, industry specific economic calculations such as estimates of the return on investment and annualized life-cycle energy costs are made. Factors both internal and external to the specific industries being examined affect the relative economics of the various advanced systems. An example of an internal factor is the minimum acceptable rate of return on an investment which is used by an individual company in its investment decision-making. This can vary from industry to industry, from company to company within an industry, and even from time to time for a single company as it re-examines how to invest its funds. Examples of external factors are tax rates and cost of purchased electricity and fuel which affect all the industries. Results for those cogeneration systems which have appeared to be attractive in previous steps are then used to estimate potential national benefits.

The data generated in these steps are then used for comparison and evaluation of the advanced energy conversion systems. By retaining cases representing the use of commercially available technology throughout each step in the process, an assessment of the advantages of employing advanced technology can also be made.

Industrial Process/Plant Framework

The advanced energy conversion systems of interest are being examined in the context of characterizations of the manufacturing plants of the United States. Approximately one-third of all energy consumed in the U.S. is used for providing electricity and process heat to industry. The potential exists, therefore, for significant energy savings on a national basis through the application of advanced energy conversion systems in cogeneration.

In 1974, however, there were about 450 types of manufacturing industries listed as part of the Standard Industrial Classification system. To gather data for all these industries individually would require a significantly greater effort than justified for this study. Instead, the approach being used is to select a smaller number of industries and industrial process/plants which constitutes a representative cross section of the energy intensive industrial plant requirements. Results using this representative cross section of industry can then be used to assess the potential impact of cogeneration on U.S. energy consumption, particularly energy from oil and natural gas. Because the energy conversion systems being examined are based on advanced technology which might be made available for the 1985-2000 time period, the industrial plant requirements are also being projected to that period.

Approximately 70 different types of process/plants are being considered in one or both of the contracted studies. The process/plants selected represent a variety of fuels used, thermal and electrical requirements, process temperature requirements, plant sizes and load profiles for the electrical and thermal demands. Plants appropriate for both Front End/Topping and Back End/Bottoming cogeneration configurations are included, though emphasis is on the topping application. Figure 4 shows the major industry groups of the manufacturing sector of industry represented in the selections, along with the total relative energy consumption for all plants within each of the various major industry groups. While the focus is on the six major industry groups identified previously (namely, chemicals and allied products; primary metals; petroleum refining and coal products; paper and allied products; stone, clay and glass; and food and kindred products), a small number of process/plants have also been selected from four additional major industry groups to broaden the coverage of industries considered.

The 70 process/plants selected account for approximately 60 percent of the total energy consumed by manufacturing industries in the U.S. Table 6 delineates some of the detailed information being collected on the approximately 70 process/plants selected. From this detailed information, characterizations of the various industrial plants are being made which will form the framework for the study of the advanced energy conversion systems.[1]

Energy Conversion Systems

Each system identified in Table 1 is being investigated with a variety of fuels. The energy conversion system/fuel combinations which are being included in CTAS are summarized in Figure 5. Emphasis is being placed on the use of heavier, minimally processed fuels and coal -- especially in the advanced technology versions of the systems. The fuel selections being made are intended to permit an assessment of the capability of each system to make the transition from the use of natural gas or light oils to heavier oils and coal and coal-derived fuels in the 1985-2000 time period. Each system is being configured to operate in an environmentally acceptable manner with the fuels indicated.

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[1] A companion paper at this Symposium entitled "Characterization of U.S. Industries for Potential Cogeneration Applications" by R. Manvi presents characterizations of a large number of industries and an example of a methodology which can be used for selecting of industries for the study of potential cogeneration applications.

Both atmospheric and pressurized fluidized bed furnaces with in-bed desulfurization are selectively considered for the coal-fired cases. In those cases where coal is utilized without in-bed desulfurization, flue gas desulfurization is used. For three of the systems, the open cycle gas turbines, combined cycles, and high temperature fuel cells, an air-blown coal gasifier is integrated with the energy conversion system. Steam cycles and organic Rankine cycles are being investigated as bottoming cycles using heat rejected from the industrial processes. Approximately 30 fuel/system combinations are being investigated by each contractor.

Each type of energy conversion system is also being analyzed for a range of configurations, system technologies, design approaches, and operating parameters such as temperature and pressure levels. Off-design characteristics of the various systems are being examined as well as the effects of size on system performance and costs. The sets of conditions being investigated are selected to be consistent with the technology levels which could be made commercially available in the 1985-2000 time period and the type of fuel used. As mentioned previously, for the steam systems, open cycle gas turbines and diesel engines, the range of conditions studied also includes conditions consistent with today's commercially available equipment to serve as a baseline for assessing the advantages of advancements in energy conversion system technology.

Examples of some of the types of system variations being studied are as follows: back pressure and extraction steam turbines; air and water cooled gas turbines in simple cycle, recuperated, and combined cycle configurations; steam injected gas turbines; low and medium speed diesel engines; closed cycle gas turbines using air or helium as the working fluid; Stirling engines in different size regimes; low temperature phosphoric acid and high temperature molten carbonate fuel cells; and thermionic systems employing air-cooled or steam-cooled collectors.

After initial trials of matching the various energy conversion systems to the process/plant needs, approximately 120 cogeneration systems are being selected for detailed study. These cogeneration systems include a variety of matching options or strategies such as matching the electrical requirements of the plant or matching the thermal energy requirements of the plant. Also included is the use of heat pumps to raise the temperature of the rejected heat from the energy conversion system or from waste streams from the industrial process to a more useful level. Finally, a strategy of using thermal energy storage to better manage time variations in the process plant requirements is being explored.

As the synthesized cogeneration systems progress through the various screening steps, a large body of data is being developed from which comparisons of the advanced energy conversion systems can be made. Both quantitative and qualitative information is being used in the comparisons and evaluations of the systems. Some of the factors which are being used in the evaluation of the systems are listed in Table 7. The results for each system are also being examined for sensitivity to changes in the values for the various ground rules used in the study such as fuel costs and price of electricity.

Concluding Remarks

Cogeneration of electricity and heat at an industrial site offers the potential for energy and fuel savings through increases in overall energy utilization efficiency. This study of advanced energy conversion systems for providing industrial power and process heat is providing data on the relative merit of advanced systems in industrial cogeneration. The results of the study will be used by DOE in ranking the competing advanced technologies, establishing research and development funding priorities and providing direction to the development program for advanced energy conversion systems in cogeneration applications. Published results from the study will be available in the fall of 1979.

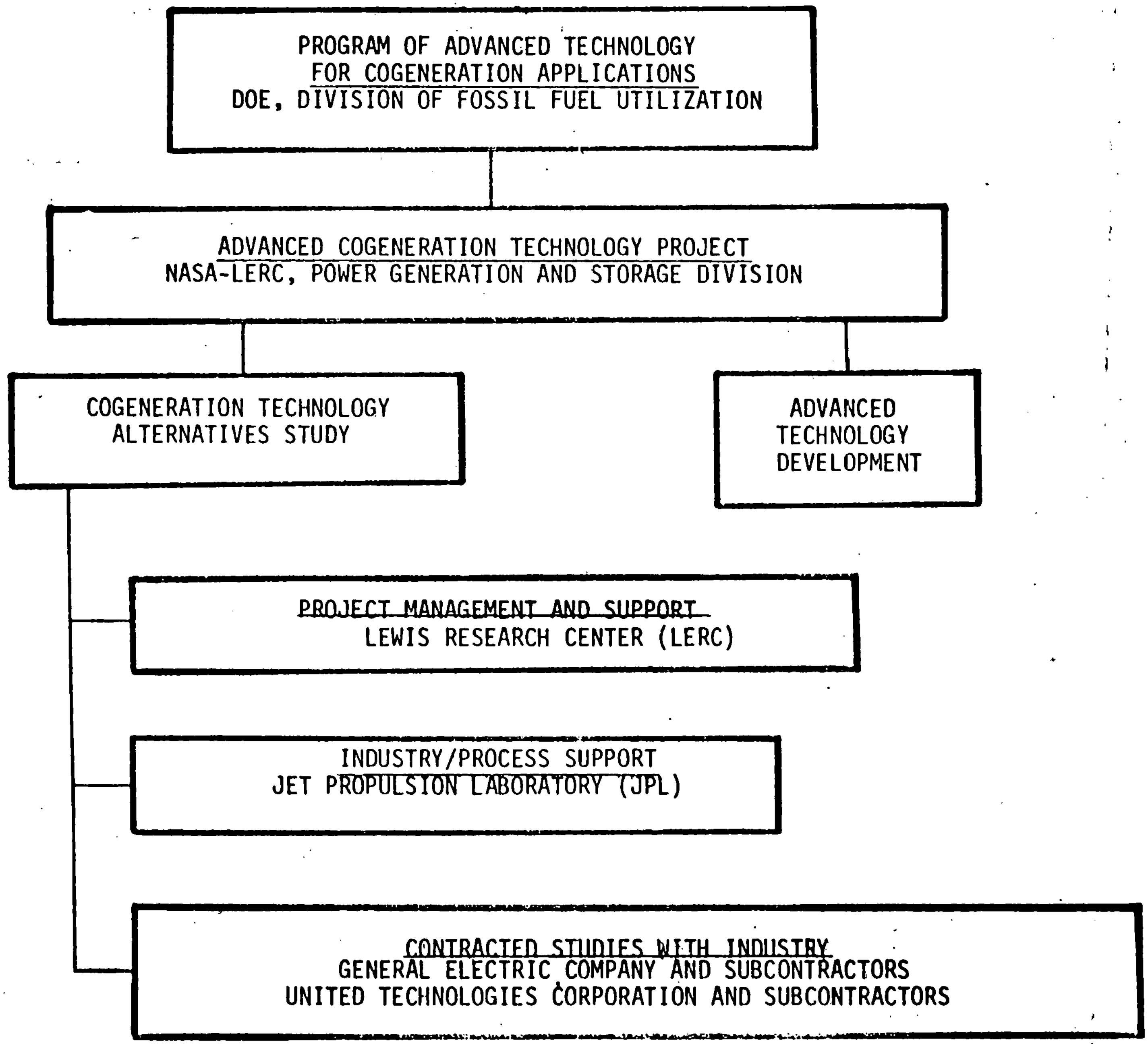
PROGRAM OF ADVANCED TECHNOLOGY FOR COGENERATION APPLICATIONS
DOE, DIVISION OF FOSSIL FUEL UTILIZATION
ADVANCED COGENERATION TECHNOLOGY PROJECT
NASA-LERC, POWER GENERATION AND STORAGE DIVISION
COGENERATION TECHNOLOGY ALTERNATIVES STUDY
ADVANCED TECHNOLOGY DEVELOPMENT
PROJECT MANAGEMENT AND SUPPORT
LEWIS RESEARCH CENTER (LERC)
INDUSTRY/PROCESS SUPPORT
JET PROPULSION LABORATORY (JPL)
CONTRACTED STUDIES WITH INDUSTRY
GENERAL ELECTRIC COMPANY AND SUBCONTRACTORS
UNITED TECHNOLOGIES CORPORATION AND SUBCONTRACTORS

FIGURE 2

COGENERATION CONFIGURATIONS

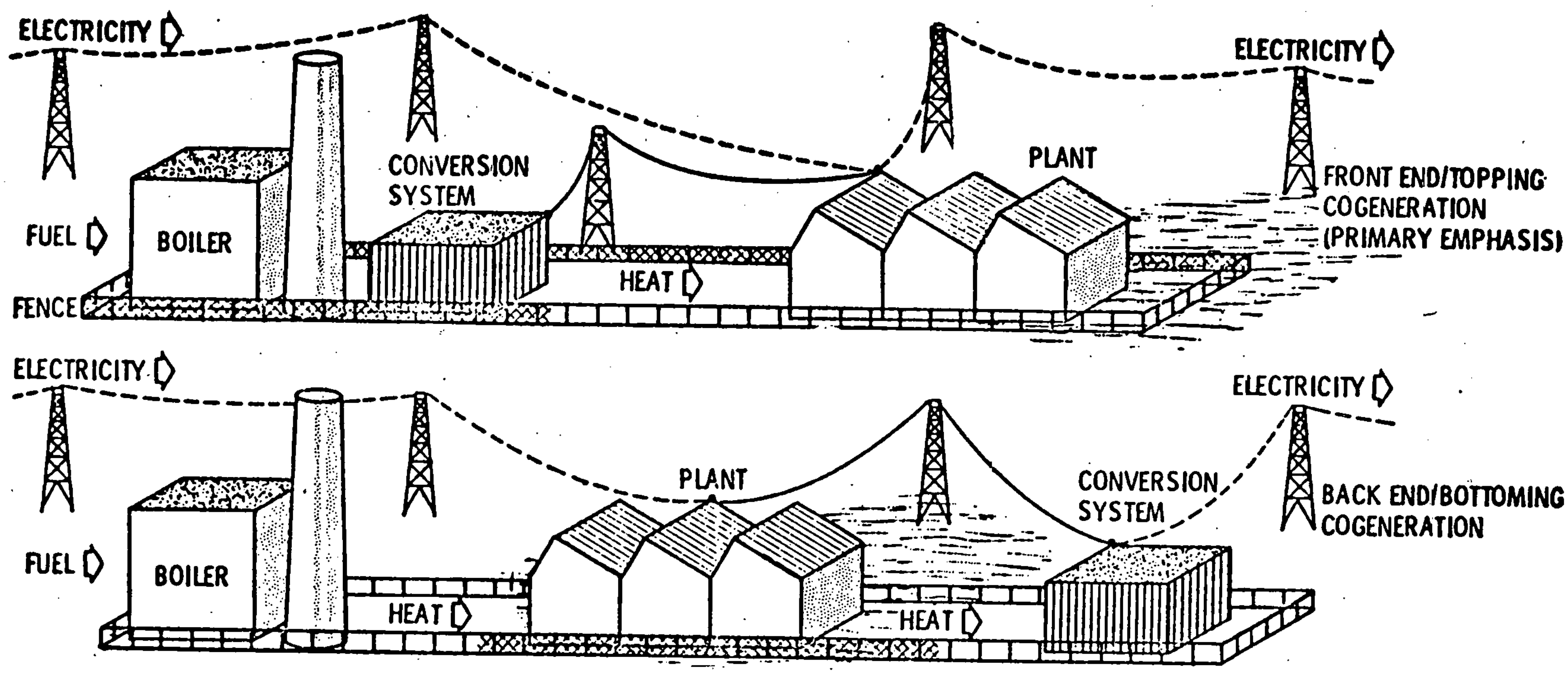

FIGURE 3

CTAS METHODOLOGY

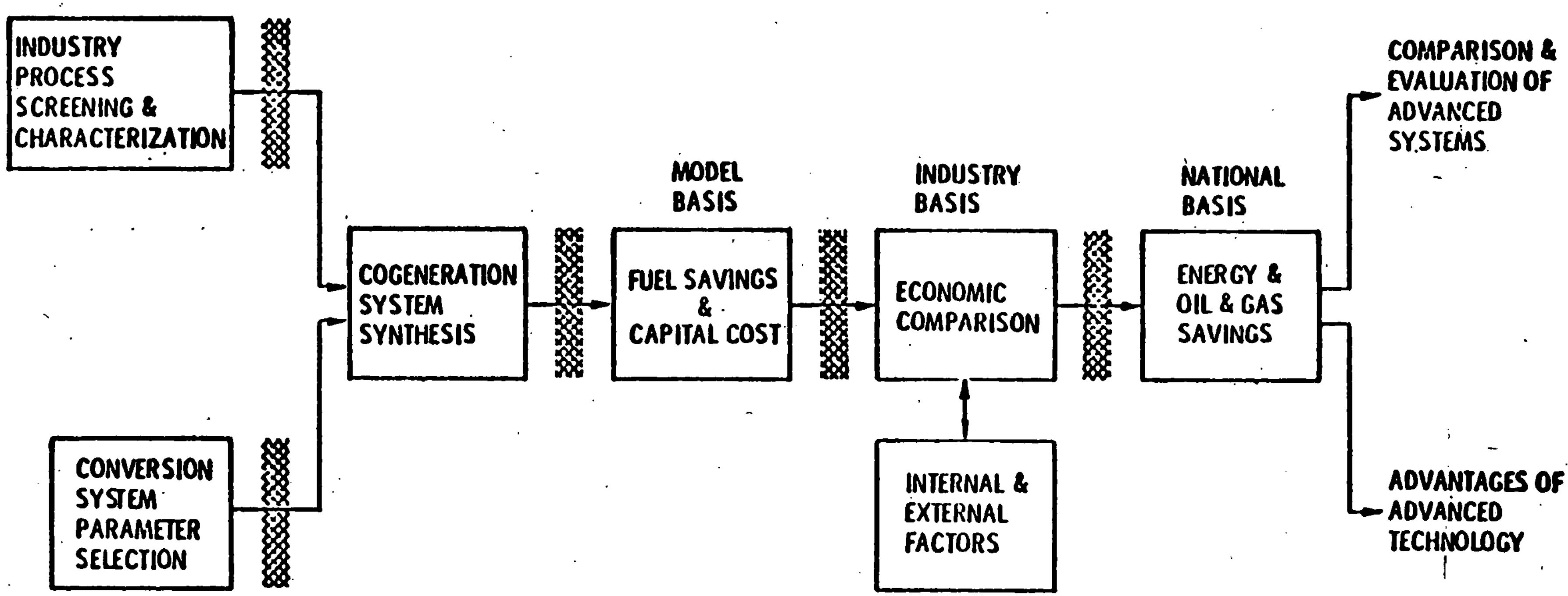

FIGURE 4 - PROCESS/PLANT SELECTIONS

MAJOR INDUSTRY GROUPS	GROUPS REPRESENTED
CHEMICALS AND ALLIED PRODUCTS	X
PRIMARY METALS	X
PETROLEUM AND COAL PRODUCTS	X
PAPER AND ALLIED PRODUCTS	X
STONE, CLAY, AND GLASS PRODUCTS	X
FOOD AND KINDRED PRODUCTS	X
MACHINERY, EXCEPT ELECTRICAL	
TEXTILE MILL PRODUCTS	X
FABRICATED METAL PRODUCTS	
ELECTRICAL EQUIPMENT AND SUPPLIES	
RUBBER AND PLASTIC PRODUCTS	X
LUMBER AND WOOD PRODUCTS	X
PRINTING AND PUBLISHING	
TRANSPORTATION EQUIPMENT	X
APPAREL AND OTHER TEXTILE PRODUCTS	
FURNITURE AND FIXTURES	
LEATHER AND LEATHER PRODUCTS	
TOBACCO MANUFACTURING	

RELATIVE ENERGY CONSUMPTION

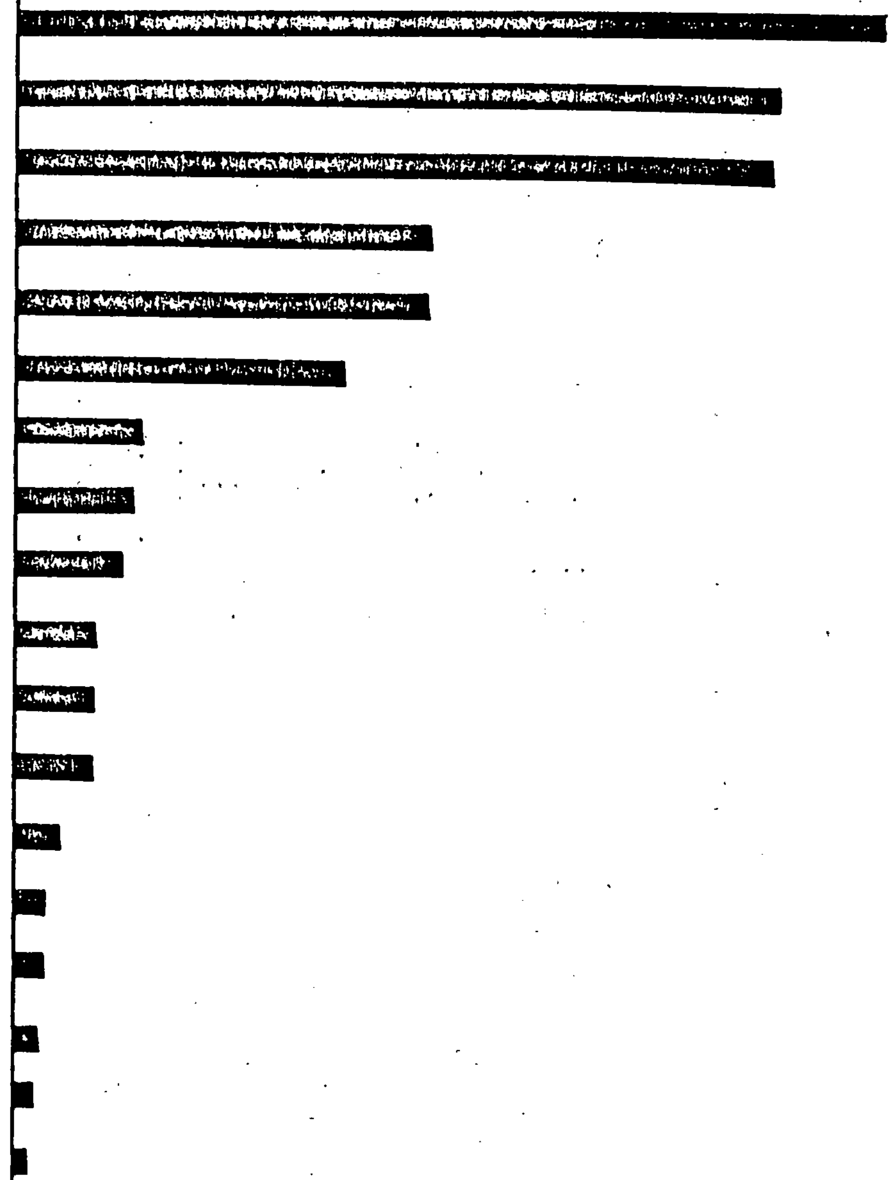

FIGURE 5 ENERGY CONVERSION SYSTEM/FUEL COMBINATIONS CONSIDERED IN CTAS

ENERGY CONVERSION SYSTEM / FUEL	DISTILLATE GRADE	RESIDUAL GRADE	COAL	COAL GASIFICATION	INDUSTRIAL BY-PRODUCT HEAT
STEAM TURBINE	X	X	X		X
OPEN CYCLE GAS TURBINE	X	X	X	X	
DIESEL	X	X	X		
COMBINED GAS TURBINE/STEAM TURBINE	X	X	X	X	
CLOSED CYCLE GAS TURBINE		X	X		
STIRLING		X	X		
FUEL CELLS	X			X	
THERMIONICS		X	X		
ORGANIC RANKINE					X

TABLE I

ADVANCED TECHNOLOGY CONVERSION SYSTEM CANDIDATES

- STEAM TURBINE
- OPEN CYCLE GAS TURBINE
- COMBINED GAS TURBINE/STEAM TURBINE CYCLES
- CLOSED CYCLE GAS TURBINE
- DIESEL
- STIRLING
- FUEL CELL (HIGH- AND LOW-TEMPERATURE)
- THERMIONICS
- OTHER ADVANCED CYCLES AS APPROPRIATE TO THE 1985-2000 TIME PERIOD

TABLE 2

MAJOR INDUSTRY GROUPS

- CHEMICALS AND ALLIED PRODUCTS
- PRIMARY METALS INDUSTRIES
- PETROLEUM REFINING
- PAPER AND ALLIED PRODUCTS
- STONE, CLAY AND GLASS PRODUCTS
- FOOD AND KINDRED PRODUCTS

TABLE 3

FUELS CHARACTERISTICS

	PETROLEUM-DERIVED		COAL-DERIVED		
	DISTILLATE	RESIDUAL	DISTILLATE	RESIDUAL	COAL
Sulfur, % wt.	.5	.7	.5	.7	3.9
Nitrogen, % wt.	.06	.25	.8 nominal	1.0 nominal	1.0
Hydrogen, % wt.	12.7	10.8	9.5 nominal	8.5 nominal	5.9
Ash, % wt.	--	.03	.06	.26	9.6
Trace Elements[1]	low	high	moderate	high	high

[1]Vanadium, Sodium, Potassium, Calcium, Lead

TABLE 4 CTAS CONTRACTOR TEAMS

	General Electric Company (GE)	United Technologies Corporation (UTC)
Program Management	GE-Energy Technology Operation	UTC-Power Systems Division
Energy Conversion Systems	GE Internal Divisions Delaval, Incorporated North American Phillips Corporation Institute of Gas Technology	UTC Internal Divisions Bechtel, Incorporated Sulzer Brothers, Incorporated Rasor Associates Aerojet Energy Conversion Company Mechanical Technology, Incorporated Dr. Phillip Myers, Consultant Cummins Engine Co., Inc.
Industrial Processes	GE Internal Divisions Dow Chemical Company Kaiser Engineers, Incorporated J.E. Sirrine Company General Energy Associates (Drexel University)	Gordian Associates

TABLE 5 AREAS WHERE COMMON STUDY GROUND RULES WILL BE APPLIED IN CTAS

- FUEL SPECIFICATIONS AND COSTS
- ENVIRONMENTAL STANDARDS
- UTILITY SYSTEM FUELS AND EFFICIENCIES
- COAL-TO-COAL DERIVED FUEL CONVERSION EFFICIENCIES
- PRICE OF ELECTRICITY
- GOVERNMENT INCENTIVES
- ECONOMIC METHODOLOGY
- CAPITAL COST ESTIMATING BASIS

TABLE 7 FACTORS FOR COMPARISON OF ENERGY CONVERSION SYSTEMS

- POTENTIAL FOR INCREASED OVERALL ENERGY EFFICIENCY
- POTENTIAL FOR OIL AND GAS SAVINGS
- FUEL FLEXIBILITY
- ABILITY TO ACCOMMODATE A TRANSITION FROM PRESENT FUELS TO HEAVY OILS, COAL, AND COAL-DERIVED FUELS
- ECONOMIC ATTRACTIVENESS TO INDUSTRIAL USERS
- TOTAL ANNUAL ENERGY COSTS
- ENVIRONMENTAL CHARACTERISTICS
- NATURAL RESOURCE REQUIREMENTS
- WASTE DISPOSAL REQUIREMENTS
- RETROFIT POTENTIAL
- APPLICABILITY TO A WIDE RANGE OF PROCESSES AND INDUSTRIES
- POTENTIAL RELIABILITY

TABLE 6 TYPE OF INDUSTRY/PROCESS DATA COLLECTED

- THERMAL, ELECTRICAL, AND MECHANICAL ENERGY REQUIREMENTS.
- LOAD PROFILES FOR THERMAL, ELECTRICAL,AND MECHANICAL ENERGY UTILIZATION.
- TEMPERATURE AND PRESSURE OF HOT WATER, STEAM, OR AIR REQUIRED.
- TYPES OF FUELS COMMONLY USED BY THE PROCESS.
- NUMBER OF PLANTS IN THE COUNTRY; THEIR SIZE AND LOCATION.
- BY PRODUCT FUELS AND HIGH TEMPERATURE EFFLUENTS.
- TRENDS IN PROCESS EVOLUTION AND ENERGY CONSUMPTION.
- PERCENT OF INDUSTRIAL ENERGY USED BY THE PROCESS IN 1985-2000.
- PERCENT OF NATIONAL ENERGY USED BY THE PROCESS IN 1985-2000.

Paper No. 12

CHARACTERIZATION OF U.S. INDUSTRIES FOR POTENTIAL COGENERATION APPLICATIONS

by
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ABSTRACT

Cogeneration of electricity and heat at an industrial site offers the potential for energy conservation through improved overall energy efficiency. In support of a study of advanced energy conversion systems in industrial cogeneration applications,[1] the Jet Propulsion Laboratory (JPL) performed a survey aimed at identifying and characterizing the requirements of the most energy-intensive U.S. industries. Focus of the effort was on the characterization of industries in the following six major industry groups: chemicals; petroleum refining; primary metals; paper and pulp; stone, clay and glass; and food processing. In 1974. these six major industry groups accounted for 80.3% of all energy consumed in U.S. industries. This paper characterizes the industries on the basis of plant electrical and thermal requirements, fuels used, the ratio of energy cost to the overall product cost, and other parameters of importance to cogeneration application. Also presented is an example of methodology which can be used in selecting industries for the study of potential cogeneration applications.

[1] See paper entitled "Study of Advanced Technology Cogeneration Systems for Providing Industrial Power and Process Heat"

INTRODUCTION

The need for energy resource conservation makes the high fuel utilization resulting from the cogeneration of electric and thermal energy attractive in many industrial applications. The concept of on-site electric generation is not new; earlier in this century industrial plants commonly generated electricity. The evolution of low cost electricity by utilities through "economy of scale" led the trend away from industrial power generation. As late as 1950, 15% of the U.S. electrical power was generated in industrial plants mostly with back pressure or extraction steam turbines producing both electricity and steam. By 1973 this percentage had decreased to about 5%. Not only has the percentage of total generated power dropped, but from 1965 to 1973, the absolute magnitude of power produced on-site also decreased by about 20%. However, with the rapid increase in the price of fossil fuels and the ever rising capital cost of new generating facilities, cogeneration is receiving renewed attention. In addition to the advantages of fuel conservation and reduced capital and operating cost there is the probability of reducing greatly the lead times now required for large utility plants. Based on these advantageous features of cogeneration, a meaningful thrust in the Department of Energy's (DOE) overall program has been directed toward a serious study of the energy concepts with high fuel utilization, prime movers with high electrical efficiency, size flexibility, and suitable environmental characteristics for industrial cogeneration. The Cogeneration Technology Alternatives Study (CTAS) is designed to provide a data base to assist DOE in establishing priorities for the research and development of advanced energy conversion system technology for optimized industrial cogeneration applications in and beyond 1985-2000 time period. In order to provide a valid frame work for selection of the industrial cogeneration systems and their evaluation, representative industrial processes are to be selected. The Jet Propulsion Laboratory (JPL) performed a survey aimed at identifying and characterizing the requirements of the most energy intensive U.S. industries. This paper characterizes the industries on the basis of plant electrical and thermal requirements, fuels used, the ratio of energy cost to the overall product cost, and other parameters of importance to cogeneration application.

DEVELOPMENT OF QUANTITATIVE DATA

Our first objective was to identify the major energy consuming industries. The magnitude of an industry's total energy use was believed to be an important criterion in judging where the most significant opportunities for high fuel utilization might be realized from cogeneration, since even a modest level of cogeneration in a major energy consuming industry could have dramatic national consequences. The Census of Manufactures' data [1] were considered to be the best source of quantitative energy-use information since these are clearly the most comprehensive available. One drawback of the Census data [1] is that they are based only on purchased energy; data on energy generated internally from raw material utilization (as with hydrocarbon feedstocks), or heat recovery from exothermic chemical reactions, or from wastes cannot be determined from these sources. Hence, other recently available sources of industrial energy use were reviewed to gather the following data:

- Block diagrams of industrial plants/processes showing major unit operations [6].

- Process heat requirements [2,3].
- The temperatures at which the process heat is required [2,3].
- Process electrical energy requirements [1,2].
- Load profiles for electrical, thermal, and mechanical energy needs.
- Number of plants in the country [3,4].
- Typical outputs and total energy needs [6].
- Dollar value added by the manufacturing process [2].
- Lost work (Loss of thermodynamic availability) [5].
- Type, quantities, and prices of fuel used [1].
- Evolutionary trends in process utilization [1].

U.S. MANUFACTURING INDUSTRIES SUMMARY DATA

The U.S. federal government classifies the entire field of economic endeavors in accordance with the Standard Industrial Classification Codes (SIC). The Cogeneration Technology Study (CTAS) is interested only in the activities under Division D, Manufacturing which includes the 20 groups in the two-digit classifications from SIC 20 through 39. The system classifies manufacturing and industrial plants and establishments in accordance with their products rather than the processes employed or the fuels consumed. Not surprisingly, there is a wide variation in energy consumption from category to category because of the nature of products and because of the structure of the classification system. Table 1 shows the energy ranking by major 2-digit industry groups. Note that, in 1974, the first six groups -- chemicals and allied products; primary metals; petroleum and coal products; stone, clay and glass products; paper and allied products; and food and kindred products accounted for 80.3% of the total energy consumed.

TABLE 1: ENERGY RANKING BY MAJOR INDUSTRY GROUP (2-DIGIT SIC) [1]
(2 DIGIT SIC CODE CATEGORIES RANKED BY 1974 CONSUMPTION)

Rank	Consumption, 10^{12} kJ/Year	2-Digit SIC Code	Description	Cumulative Percentage
1	3090	28	Chemicals and allied products	
2	2787	33	Primary metals	
3	1654	29	Petroleum and coal products	80%
4	1410	32	Stone, clay and glass products	
5	1404	26	Paper and allied products	
6	1009	20	Food and kindred products	
7	435	34	Fabricated metal products	
8	396	37	Transportation equipment	
9	388	35	Machinery, except electrical	
10	341	22	Textile mill products	
11	287	24	Lumber and wood products	
12	269	30	Rubber and misc. plastic products	
13	265	36	Electrical and electronic equip. and supplies	20%
14	95	27	Printing and publishing	
15	75	38	Instruments and related products	
16	69	23	Apparel and other textile products	
17	62	25	Furniture and fixtures	
18	54	39	Miscellaneous manufacturing	
19	24	31	Leather and leather products	
20	21	21	Tobacco manufacturing	
Total	14137			

The classification system extends to the 4-digit level, but the product oriented system does not provide a simple energy arrangement. There are 451 SIC 4-digit industries included in the manufacturing Division, D. In CTAS, we have emphasized the study of industrial processes in the top six SIC 2-digit groups, but also included some processes outside this group based on judgement of the knowledgeable professionals. The top six SIC 2-digit industry groups are briefly described below.

SIC 28: Chemicals and Allied Products

The chemicals and allied products industries manufacture thousands of products, many of which are manufactured with totally different technologies. Approximately 71% of the energy consumption within the SIC 28 category occurs in the manufacturing processes of industrial chemicals (SIC 281). Within SIC 281, 84% of the energy is consumed by only a handful of chemicals such as chlorine, ethylene, ammonia, industrial gases, phosphoric acid, styrene, methanol, alumina digestion, and phenol.

SIC 33: Primary Metals

SIC 33 includes manufacturing establishments engaged in the smelting and refining of ferrous and nonferrous metals from ore, pig or scrap; in the rolling, drawing, and alloying of ferrous and nonferrous metals; in the manufacture of castings and other basic products of ferrous and nonferrous metals; and in the manufacture of nails, spikes, and insulated wire and cable. It also includes the production of coke. Approximately 85% of the energy consumption within the primary metals category occurs in the manufacturing processes for steel, aluminum, and copper. Except that all components deal with the smelting, refining, casting, or some other treatment of metals, the technologies in the various components differ significantly. For example, the steel-making technology is much different than that of aluminum. The former is coal-intensive whereas the latter is electricity-intensive.

<u>SIC 29</u>: Petroleum Refining

The petroleum industry converts crude oil and natural gas liquids to a variety of fuels and other products such as chemical feedstocks and lubricants. Refineries may be classified as simple, complex, or fully integrated, depending upon the processes performed. There is a wide range of energy use in the petroleum refining industry depending upon the type and relative complexity of the refinery.

<u>SIC 32</u>: Cement and Glass

There are two basic processes for producing cement, wet and dry. The only difference between these processes is that the wet process utilizes a slurry to feed the raw materials into the kiln or preheater, whereas the dry process feeds the materials dry. Dry processes are increasingly being utilized because of greater energy efficiency.

Four major glass industrial categories - SIC 3211 (flat glass), SIC 3221 (glass containers), SIC 3229 (pressed and blown glass), and SIC 3296 (fiberglass wool insulation) - are large energy consumers because each category includes glass melting as part of the process. The dramatic fact is that the four glass melting segments use 60 to 85 percent of their energy in just melting, firing, and conditioning. Temperatures for these processes are in excess of 2000°F.

SIC 26: Pulp and Paper Industry

Energy consumption within the paper industry is concentrated in wood digestion (cooking), evaporation, furnace combustion, drying and kiln operations. The paper and allied products industry includes pulp making, paper making, paper-board making, conversion of paper and paper-board into final products, and making of building paper and board. The data show that pulp making (SIC 261), paper making (SIC 262), and paper-board making (SIC 263) utilized about 86% of energy consumed by SIC 26.

Four principal processes - ground wood and other mechanical, kraft, semi-chemical, and sulfite - are used to produce most of the industry's pulp. Use of sulfite process has declined recently.

SIC 20: Food and Kindred Products

SIC 20 accounts for a large, diverse food processing industry which is subclassified into nine three-digit designations. There are 46 four-digit subclassifications and 187 subclassifications at the five-digit level. It is difficult to analyze each of these segments in detail. Because of time constraints, only meat packing (SIC 2011), prepared meats (SIC 2013), dehydrated fruits and vegetables (SIC 2034), wet corn milling (SIC 2046), beet sugar (SIC 2063), and malt beverage (SIC 2082) have been analysed in detail to characterize their energy requirements.

In the industrial sector, energy is used for a number of purposes; including the non-energy use as a feedstock for chemical manufacture. Excluding feedstock, the breakdown of the total industrial use of energy is as follows:

Process steam	44.5%
Electric drive	21.1%
Electrolytic-processes	3.1%
Direct process heat	30.5%
Other	0.8%

Process steam and direct process heat together accounts for 75% of the total industrial use of energy. It is clear that the greater portion of the energy used in the industrial sector is used in the form of thermal energy rather than in the form of power, and this is an important fact to consider in estimating the potential for cogeneration in industry.

Detailed information on the amounts of process heat, forms of heat, the temperature ranges, and amounts of heat in specific applications in specific processes, electric energy needs are needed because all these variables strongly influence the potential for industrial cogeneration. Table 2 shows the thermal and electric energy needs of 25 SIC 4-digit industries ranked according to thermal energy use. Altogether, data was collected on 74 SIC 4-digit industries which are estimated to have the most process heat needs. The required application temperatures are also shown. Figure 1 shows the percentage of industrial process heat required at temperatures less than or equal to a particular temperature. 70% of the industrial process heat is required at less than or equal to 550°C.

TABLE 2: LIST OF INDUSTRIAL PROCESS THERMAL & ELECTRIC ENERGY REQUIREMENTS [4,1]
(RANKED ACCORDING TO THERMAL ENERGY USE)

Rank	SIC	Industry/Process	Thermal Energy 10^{12} kJ/Year(Q)	E(10^9 KWH)	Application Temperature °C	Ratio E(3.6)/Q	Cogeneration Potential Topping	Bottoming
1	3312	Blast Furnace & Steel Mills	3467	49.6	100-1500	0.051	✓	✓
2	2911	Petroleum Refining	2666	25.9	100-650	0.034	✓	✓
3	2611	Pulp Mills		2.6	100-1100	0.103	✓	
4	2621	Paper Mills	1125	18.5	100-1100	0.103	✓	
5	2631	Paper Board Mills		9.9	100-1100	0.103	✓	
6	2661	Building Paper		1.5	100-1100	0.103	✓	
7	3241	Hydraulic Cement	500	9.9	125-1500	0.071	✓	✓
8	3321	Gray Iron Foundrries		6.5	100-1500	0.086	✓	✓
9	3322	Malleable Foundries	453	1.5	100-1500	0.086	✓	✓
10	3323	Steel Foundries		2.7	100-1500	0.086	✓	✓
11	3221	Glass Containers	163	1.1	650-1600	0.085		✓
12	2819	Alumina	156	2.1	125-1200	0.048	✓	✓
13	3274	Lime Calcining	137	0.7	1000	0.019		✓
14	2823	Cellulolosic Fibers	124	0.6	100-300	0.017	✓	
15	2951	Paving Mixtures	98	0.6	125-170	0.021	✓	
16	2812	Alkalies & Chlorine	93	12.5	170	0.519	✓	
17	2824	Non-Cellulosic Fibers	79	6.9	100	0.309	✓	
18	2262	Finishing Plants, Synthetic	78	1.1	90-140	0.048	✓	
19	3251	Brick & Tile	74	0.8	1375	0.037		✓
20	2011	Meat Packing	70	4.0	60-260	0.206	✓	
21	2063	Beet Sugar	68	0.2	60-150	0.010	✓	
22	2421	Saw Mills & Planing Mills	67	6.8	150	0.336	✓	
23	3211	Flat Glass	62	1.1	500-1500	0.064		✓
24	2436	Veneer	61	1.8	100	0.108	✓	
25	2435	Plywood	53	0.5	125	0.035	✓	

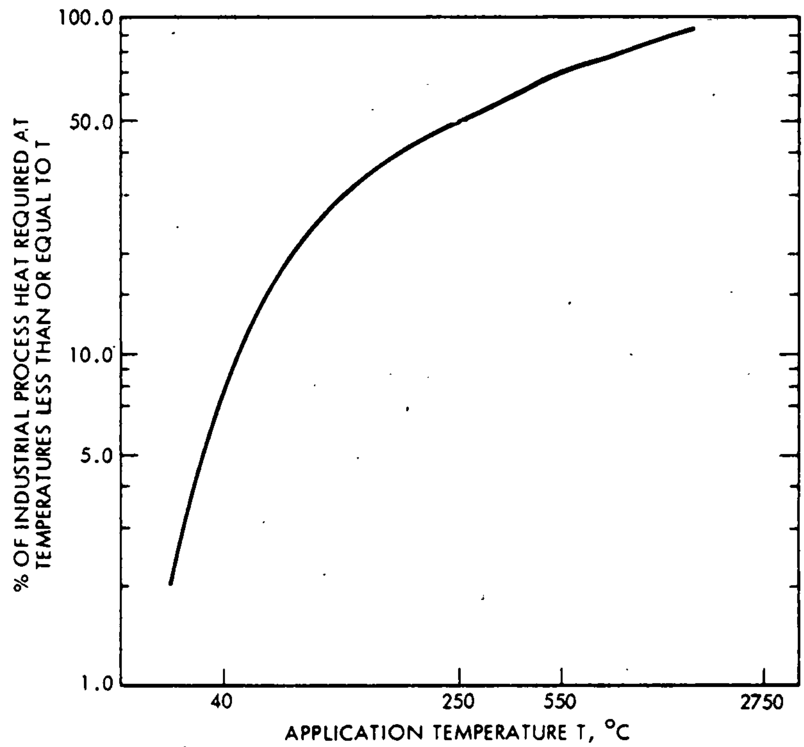

Figure 1: Cumulative Distribution of Process Heat Requirements

Figure 2 shows the purchased fuel unit costs versus total energy cost per dollar value added for the most energy intensive industries. This data by itself, though interesting, is not sufficient to establish the need for cogeneration in any particular industry. In the next section, we describe a simple methodology to utilize this important information along with other calculated factors by which we can judge attractive cogeneration candidates.

INDUSTRY SELECTION FOR COGENERATION

The assembled industry energy data can be analyzed for identification of attractive cogeneration candidates based on the following considerations.

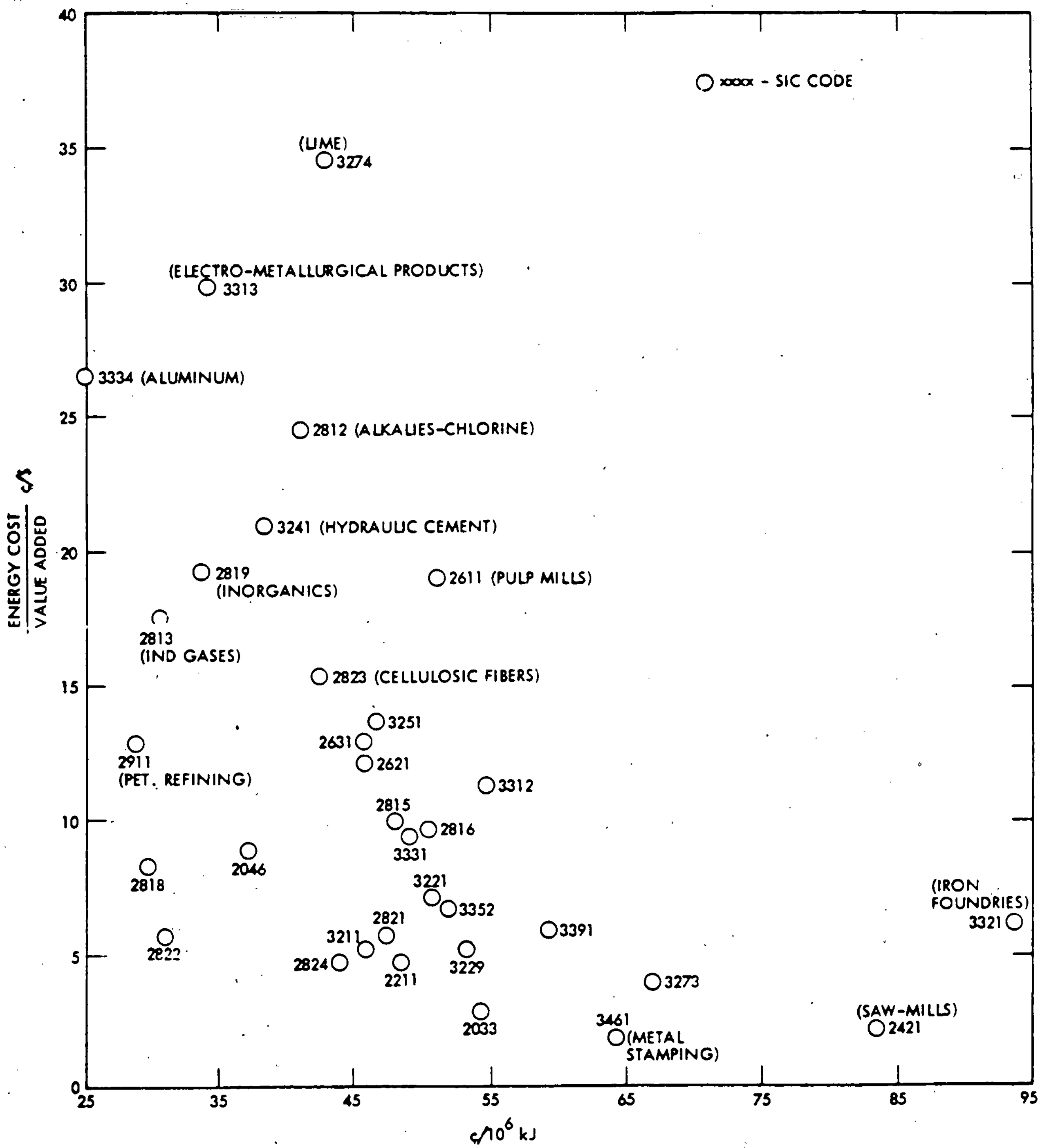

Figure 2: Purchased Fuel Unit Costs Versus Total Energy Cost Per Dollar Value Added [2]

Criterion	Rationale
A. Total energy used (process thermal energy used)	To make a national impact, the candidate industry/process should be a major energy consumer.
B. Energy per dollar value added	If the industry consumes significant amounts of energy/unit, then its output product is very sensitive to the energy cost. Hence, this industry is an attractive candidate for energy cost reduction measures.
C. Lost work	Recently, the concept of "availability" has been increasingly used to evaluate second law efficiency of industrial processes. This leads to the concept of "lost work" which is the difference between the available work flowing into a process and that flowing from the process. It represents a burden on the energy resources, and therefore represents a good basis for the establishment of energy conservation priorities.
D. Electric power/heat ratio (E/Q)	In order for an industry to be a good cogeneration candidate, there should be

a proper match between its electric power and process heat needs. If the process needs only electrical energy with no process heat needs, then cogeneration does not make any sense. On the other hand, if the process needs only heat, cogeneration could be attractive to export electricity.

E. Duty and Coincidence factors

Duty factor is the ratio of average to maximum loads and is generally an indication of how uniform the electric & thermal requirements are throughout a year. Coincidence factor in cogeneration analysis is the time duration for which electric and thermal requirements are in phase. For economic reasons, both these factors should have a high value.

The industry recommendations for cogeneration can be based on:

1. Ranking Factor

$$\text{Duty Factor} \times (\text{Total Energy Used}) \times \left(\frac{\text{Energy}}{\$\ \text{Value added}}\right) \times \left(\frac{\text{Lost Work}}{\text{Energy Used}}\right) \times$$

$$\text{Coincidence Factor} = (\text{Duty Factor}) \times \left(\text{Coincidence Factor}\right) \times \frac{(\text{Energy Used})(\text{Lost Work})}{\$\ \text{Value Added}} \qquad (1)$$

Industries that are high energy consumers combined with significant lost work are good candidates for energy conservation measures, especially, if the dollar values added in manufacturing processes are small and they have high duty and coincidence factors.

2. <u>Comparison of $(E/Q)_{Required}$ to $(E/Q)_{Available}$ from On-Site Energy Conversion System</u>

It is obvious that to export electrical energy to recover cogeneration investment, the on-site energy conversion system should produce more electricity than what is required by the process. Hence

$$(E/Q)_{Available} \geq (E/Q)_{Required} \tag{2}$$

This inequality holds whether we are designing a cogeneration system to meet process total electric or heat demands. $(E/Q)_{Available}$ from an energy conversion system depends on the temperature at which heat is required, because the thermal efficiency of the energy conversion system is a function of the temperature. $(E/Q)_{Available}$ from an on-site energy conversion system can be expressed as

$$(E/Q)_{Available} = \frac{\eta}{C(1-\eta)} \tag{3}$$

Where C = heat recovery fraction, and η is the thermal efficiency. If C is assumed to be 0.6, then for many of the energy conversion systems under consideration in CTAS, $(E/Q)_{Available}$ can be estimated to be in the range of 0.2 → 1.7. Therefore the recommended topping cycle cogeneration candidates, as shown in table 2, are based on this consideration.

3. <u>Fuels used</u>:

Industrial processes which are heavily dependent on natural gas and oil at the present time for meeting their thermal needs will definitely be more interested in advanced technology cogeneration with coal or coal derived fuels. These candidates will offer the best opportunities for high fuel utilization leading to considerable savings in the use of natural gas and oil.

Table 3 shows sample results of exercising this example selection methodology.

CONCLUSIONS

Manufacturing industries in the United States will experience difficulties in acquiring adequate supplies of energy necessary to sustain economic growth throughout this decade and into the next. This uncomfortable situation stems from several sources. First, the national supply of acceptable (i.e., non polluting and inexpensive) fossil fuels is being consumed at a rate faster than comparable sources are being found. Second, a major portion of such resources are under control of other countries. Finally, alternative sources -- such as nuclear energy and coal -- are not meeting optimistic expectations as additional sources of energy as a result of the complicated interaction of many factors. Increasing concern for the environmental quality has delayed the exploitation of nuclear energy and restricted the utilization of coal. Utilization of solar energy is increasingly receiving attention, but its economics is not well understood. Therefore, the immediate desire is to conserve finite and depletable domestic reserves of gas, oil, uranium, and low sulfur coal. The successful solution to the energy problem will depend, to a great degree, on the optimized

TABLE 3: SAMPLE RESULTS OF THE SELECTION METHODOLOGY

SIC	Industry	A	B	C	D	E	F	G			
		Purchased Total Energy 10^{15}kJ	Energy/ Value Added 10^6kJ/$	Lost Work/ Energy Used	Duty Factor	Coincidence Factor	Ranking Factor Product (AxBxCxDxE)	Purchased Fuel%			
								Coal	Oil	Gas	Others
3312	Blast Furnace & Steel Mills	1.614	0.163	0.257	0.9	1.0	0.06(5)*	70	9	20	1
2911	Petroleum Refining	1.567	0.365	0.996	0.9	1.0	0.51(1)	–	23	73	4
2869	Organic Chemicals, NEC	1.039	0.225	0.197	0.9	1.0	0.04(6)	13	8	67	22
2621	Paper Mills	0.605	0.242	0.192	0.9	1.0	0.03(7)	20	38	42	–
2631	Paperboard Mills	0.539	0.255	0.196	0.9	1.0	0.03(8)	19	31	50	–
3241	Hydraulic Cement	0.521	0.449	0.769	0.9	1.0	0.16(2)	39	10	51	–
2819	Inorganic Chemicals	0.405	0.395	0.202	0.9	0.8	0.02(9)	–	9	91	–
3334	Primary Aluminum	0.400	0.725	0.811	0.9	0.6	0.13(3)	34	12	54	–
2821	Plastic Materials	0.193	0.093	0.198	0.9	1.0	0.003(12)	–	25	75	–
2812	Alkalies & Chlorine	0.191	0.517	0.768	0.90	1.0	0.07(4)	–	–	100	–
2824	Organic Fibers	0.162	0.090	0.063	0.9	1.0	0.001(13)	37	36	27	–
3221	Glass Containers	0.149	0.119	0.725	0.9	1.0	0.011(10)	37	15	48	–
2865	Cyclic Intermediates	0.149	0.174	0.240	0.9	1.0	0.005(11)	23	9	53	–

*( ) Rank

use of converted energy forms and on the maximum utilization of byproduct or waste energy and materials. One approach to achieving a more efficient use of energy by manufacturing industries is through the use of cogeneration systems. Advantages of the cogeneration systems when compared to present practices, include: (1) decreased overall energy cost, (2) increased energy efficiency, (3) better management of scarce fuels, (4) assured supply of electric power to the cogenerating industry, and (5) decreased overall pollutant emissions. These advantages, however, must be weighed against (1) possible increased local emissions (2) increased capital investments, and (3) complex institutional, legal/regulatory considerations. The Department of Energy has sponsored several recent studies addressing these issues.

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APPENDIX B

U.S.S.R. Papers Presented at the November 1978 Symposium

PAPER NO. 1

Industrial Power Supply Institute

DEVELOPMENT OF COGENERATION IN THE USSR

Yefim Sokolov, Doctor of Technical Science
Vasilii Korytnikov

JOINT SOVIET-AMERICAN SYMPOSIUM ON REMOVAL OF HEAT FROM FOSSIL FUEL AND NUCLEAR POWER STATIONS

(Subject 08.0203)

September 1978
Razdan

Joint Soviet-American Symposium on Removal of Heat from Fossil Fuel and Nuclear Power Stations (Subject 08.0203)
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Yefim Sokolov
Vasilii Korytnikov

DEVELOPMENT OF COGENERATION IN THE USSR

I. ENERGY BASE AND THE EFFICIENCY OF THE COMBINED METHOD OF PRODUCTION OF HEAT AND ELECTRICAL ENERGY

Of all forms of energy produced the forms most widely used at the present time are thermal and electrical, the production of which in the USSR consumes about half of all fuel-energy resources procured.

Of great importance in electrical energy, which in the modern world has the leading role in the development of the productive forces of society.

The significance of electrification for the progress of the USSR is expressed by the famous formula of V. I. Lenin: "Communism is Soviet power plus electrification of the entire country".

In the scale of development of electrification the Soviet Union has made great strides. From near the last place in the development of energy in Europe, occupied by Russia, the USSR has moved to first place in Europe and second (after the USA) place in the world.

In 1913, on the eve of the First World War, the production of electrical energy in Tsarist Russia was 1.95 billion kWh.

In 1920, i.e., by the time of adoption of the State Plan for Electrification of Russia (the GOELRO plan), the production of electrical energy in the country had decreased to 0.5 billion kWh.

In 1977 the USSR produced 1150 billion kWh of electrical energy, i.e., 590 times more than in 1913. In 1977 the production of electrical energy consumed over 20% of all the fuel-energy resources procured in the country.

In yearly production of electrical energy per capita of population the USSR is now at the level of the highly developed European countries and Japan. In 1977 this factor was about 4400 kWh/person-year in the USSR.

Soviet electrification is based on fossil fuel power stations, at which about 87% of all the electrical energy is produced.

The second widely used form of energy in the national economy and in everyday life is medium and low potential heat*.

In 1976 over 10 billion GJ** (2.4 billion Gcal) of heat was produced for heating, ventilation and hot water supply of residential, public and industrial buildings, which required about 25% of all the fuel-energy resources procured in the country.

The electrical energy demand in the USSR doubles about every 12-13 years, and the heat demand doubles about every 15-18 years.

In 1980 the production of electrical energy in the USSR will reach 1340-1380 billion kWh. According to preliminary data the low and medium potential heat demand will be about 12 billion GJ (2.9 billion Gcal). About 80% of this quantity of heat will be produced at centralized sources (heat-and-power plants [HPP's] and large boiler stations).

At the present time fossil fuel is the main primary resource for production of electrical energy and heat. In the near future (10-15 years) nuclear fuel will be used significantly in addition to fossil fuel.

Particularly important in organizing a practical energy supply for the country is cogeneration, the most modern method of centralized heat supply and one of the main ways of improving the thermal economy of electrical energy production.

By the term cogeneration we mean centralized heat supply based on combined production, i.e., joint production of heat and electrical energy.

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*Low potential heat is considered to be heat with a temperature level up to 150°C; medium potential, with a temperature level from 150 to 350°C.

**1 GJ = 0.239 Gcal.

Combined production is the main difference of cogeneration from the so-called separate method of thermal energy supply, when electrical energy is produced at condensation thermal power stations (CPS's) and heat is produced at boiler stations.

The main energy effect of cogeneration is in replacement of the heat produced in separate energy supply in boiler stations by the used heat taken from the thermal power cycle of the power plant, thanks to which the useless expulsion of heat into the environment from the power plant is eliminated during conversion of combusted fuel to electrical energy. The source of electrical energy and heat production in cogeneration is the HPP.*

The heat from the operating medium (steam or gases) having a raised potential (high temperature and pressure) at first is used for producing electrical (mechanical) energy in turbines. Later the heat from the cooler operating medium is used for district heating. When such a combined usage is in effect, the specific amount of heat used for producing electrical energy is considerably lower than when electrical energy and heat are produced separately and when heat beyond the turbines is expelled into the environment and lost.

Fig. 1 shows the ideal Carnot cycles of steam power plants - both condensation (Fig. 1a) and cogeneration (Fig. 1b) in the T-S diagram.

Tb	is the average heat supply temperature to the cycle
TH	is the average heat output temperature from the cogeneration cycle
To.c	is the ambient temperature.

The amount of heat supplied is the same in both cycles and is equal to:

$$Qn = T_b \Delta S \qquad (1)$$

The amount of work derived in the condensation cycle is:

$$lK = (T_b - T_{o.c}) \Delta S \qquad (2)$$

and in the cogeneration cycle is:

$$lT = (T_b - T_H) \Delta S \qquad (3)$$

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*The translator has chosen this acronym to refer to Heat Power Plant. The original Russian acronym is TETs which refers to cogeneration plant which produces both electrical power and steam/heat for process and domestic heat.

The amount of waste heat effectively used in cogeneration:

in the condensation cycle $Q_k =)$ (4)

in the cogeneration cycle $Q_t = T_H \wedge S$ (5)

Specific heat outlay:

in the condensation cycle $$Q_k^p = \frac{Qn}{lk} = \frac{\frac{Tb}{Toe}}{\frac{Te}{To.c} - 1} \quad ; \qquad (6)$$

in the cogeneration cycle

$$Q_t^p = \frac{qn-qT}{lT} = 1 \quad ; \qquad (7)$$

The specific combined production, i.e., amount of work units obtained in the cogeneration cycle per unit of waste heat

$$\ni_T = \frac{lT}{qT} = \frac{T_b}{T_H} - 1 \quad ; \qquad (8)$$

The specific heat economy per unit of heat removed from the cogeneration cycle is

$$\Delta q = \ni_T (q_k^p - q_T^p) = \frac{T_B}{T_b - T_{o.c}} \cdot \frac{T_{o.c}}{T_H} \qquad (9)$$

Equation (9) makes it clear that the specific heat economy due to combined production grows with an increase in heat supply temperature T_b to the cycle and with a decrease in heat removal temperature T_H from the cycle.

The specific combined production in actual steam cogeneration installations with irreversible losses in mind is shown in Fig. 2.

The combined production of electrical energy in the HPPs is one of the basic ways of continually lowering from year to year the unit outlay of fuel for producing electrical energy in the USSR. In 1976 it averaged 65% of the total production of electrical energy at general purpose HPPs, i.e., HPPs in the USSR Minenergo (USSR Ministry of Power) system.

At the present time general purpose HPP's comprise 83% of the total installed capacity of the HPP's of the country and 73% in yearly heat output.

The specific saving of standard fuel* at HPP's due to combined production of electrical energy at the present time is Δq = 12 kg/GJ or about 30% of the fuel consumption on heat production in modern high-economy boiler stations.

In 1976 the saving of standard fuel due to combined production of electrical energy at general purpose HPP's was about 30 million tons or about 11% of the total fuel consumption on production of electrical energy at all general purpose thermal power stations, i.e., at all thermal power stations of USSR Minenergo.

Figure 3 shows the dynamics of the change in the specific consumption of standard fuel (net) at USSR general purpose power stations in the last 15 years from 1961 to 1976, and also the specific fuel consumption in 1980 according to the expert evaluation of the author.

In the last 15 years the mean specific consumption of standard fuel (net) at HPP's decreased by 190 g/kWh from 462 to 272 g/kWh. In spite of significant progress also in the area of thermal economy of condensation power stations (CPS's) the difference in the mean specific consumption of fuel of CPS's and HPP's in this period increased continuously and reached 91 g/kWh in 1976. It may be assumed that in 1980 this difference will be about 100 g/kWh.

The mean specific consumption of standard fuel (net) for all general purpose thermal power stations decreased by 122 g/kWh in 15 years, from 459 to 337 g/kWh. In this decrease of the mean consumption of fuel 84 g/kWh was obtained due to HPP's, i.e., 69% of the decrease obtained. Table I gives certain energy characteristics showing the development of cogeneration from general purpose HPP's in the period 1960-1976.

In this period the production of electrical energy at general purpose HPP's rose by a factor of 4.1 from 66 to 271 billion kWh. The specific combination production of electrical energy per unit of used heat increased by a factor of 1.7 from 174 to 293 kWh/Gcal. The combination production of electrical

*The heat of combustion of standard fuel is 7000 kcal/kg = 29,300kJ/kg.

energy at HPP's increased by a factor of 8.3 from 21 to 174 billion kWh. The proportion of combination production in the total production of electrical energy at HPP's rose from 32 to 65%, i.e., doubled.

Due to the widespread development of cogeneration and to general technical progress in condensation power stations, the USSR together with France presently occupies first place in the world in thermal economy of electrical energy production, ahead of England, the USA, the Federal Republic of Germany and other developed countries.

The specific fuel consumption on electrical energy production in the USSR decreases systematically from year to year.

The mean fuel consumption (net) at USSR general purpose stations in 1975 was 340 g/kWh, in 1976 337 g/kWh, and in 1977 334 g/kWh.

In 1975 the specific fuel consumption (net) was: in France 333 g/kWh, in the FRG 341 g/kWh, in the USA 370 g/kWh, and in England 374 g/kWh.

In cogeneration there are two main principles of practical energy supply:

a) Combination production of heat and electrical energy, accomplished at heat-and-power plants;

b) Centralization of heat supply, i.e., supply of heat from a single source to numerous thermal users.

The basis of the first principle -- combined production of electrical energy and heat -- being a specific feature of cogeneration, was examined above.

The second principle -- centralization of heat supply -- is not a feature of cogeneration alone. Centralization of heat supply can be accomplished not only with supply of heat from HPP's, but also with heat supply from other sources, for example large boiler stations or industrial heat utilization stations.

Centralization of heat supply in itself also usually provides a fuel saving due to higher efficiency of large boiler stations, and the still greater efficiency of the large boilers in modern HPP's in comparison with local boiler stations, in spite of the additional heat losses in the networks with centralized heat supply.

Centralized heat supply favors the public welfare of the heat supply regions, improves the comfort of the buildings supplied, and decreases the labor costs on service of the heat management of cities and industrial regions.

Cogeneration is a higher form of centralization of heat supply and the most practical method of utilizing the fuel resources of the country for thermal energy supply. Due to the significant social, economic and ecological advantages, cogeneration was determined to be one of the main trends in energy development of the USSR from the first years of organization of the Soviet society.

2. THE MODERN LEVEL OF COGENERATION IN THE USSR

The history of Soviet cogeneration is inseparably connected with the general development of Soviet power engineering.

The orientation of the Soviet power industry toward combined production of electrical energy and heat was provided in the state plan for electrification of Russia - the famous GOELRO plan - developed on the initiative of V. I. Lenin by a group of scientists and engineers under the supervision of G. M. Krzhizhanovskii and approved by the VIIth All-Union Congress of Soviets in December 1920. This idea, completely justified by the experience of Soviet cogeneration development experience, is widely realized in the cities and industrial regions of our country.

Successful development of cogeneration requires development and practical realization of time- and scale-coordinated plans for construction and operational introduction of heat sources, heating networks and the heat-demand installations of users. In principle, the planned economy of our country favors solution of this problem.

The birthday of Soviet cogeneration is assumed to be 25 November 1924. On this day Leningrad put into operation the first general purpose heat line, installed in accord with a project by and under the supervision of Soviet cogeneration pioneers L. L. Ginter and V. V. Dmitriev.

After Leningrad cogeneration began in Moscow. The All-Union Thermal Engineering Institute (VTI) was the initiator of Moscow cogeneration. In 1928 the first general purpose heat line was laid in Moscow from the experimental VTI HPP to a number of industrial enterprises. Start-up of the first cogeneration installations in Leningrad and Moscow was the stimulus for development of cogeneration in many other cities of the USSR.

Figure 4 gives data characterizing the development of cogeneration from the moment of its origin (1924) to the present time (1976) and future prospects to the end of the tenth five-year plan (1980).

In 1976 the electrical capacity of cogeneration turbines installed at USSR power stations was 63 million kW, i.e., about 1/3 of the capacity of all the thermal power stations of the country. The combined production of electrical energy at HPP's was about 200 billion kWh, i.e., over 20% of the total production of all thermal power stations of the country. The yearly heat output from HPP's was 4 billion GJ (950 million Gcal), which met about 40% of the total national demand for low and medium potential heat. In addition to cogeneration, there was a significant development of heat supply from industrial and regional boiler stations in the USSR, as well as from heat utilization stations. The heat output from all these sources was about 3.6 billion GJ in 1976 (850 million Gcal), which met 35% of the total heat demand of the country. In 1976 from centralized sources alone 7.6 billion GJ (1800 million Gcal) of heat was produced in 1976, which met 75% of the thermal demand of the country.

The expected level of development of cogeneration and centralized heat supply by the end of the tenth five-year plan (1980) was determined to be as follows according to the expert evaluation of the author: electrical capacity of cogeneration turbines 77 million kW; yearly production of electrical energy by cogeneration turbines 400 billion kWh, including 270 billion kWh by the combined method. Heat output from HPP's 4.8 billion GJ (1.15 billion Gcal), heat output from other centralized heat source installations 4.5 billion GJ (1.07 billion Gcal).

The total heat output from all centralized heat supply installations will be 9.3 billion GJ (2.2 billion Gcal), which will satisfy about 80% of the needs of the country's users with low and medium potential heat.

Both in the scale of development of cogeneration and in the scale of development of centralized heat supply the USSR easily occupies first place in the world.

3. IMPROVING THE COGENERATION ENERGY BASE

Soviet cogeneration is based on regional heat-and-power plants, from which heat is provided both to industrial enterprises and to nearby cities.

For heat supply to heating-ventilation installations and for hot water supply to residential and public buildings and industrial enterprises the heat carrier used is mainly water. At the present time the proportion of water as heat carrier comprises 48% of the total yearly heat output from HPP's. The Soviet Union has the largest water networks in the world. The use of water as a heat carrier permits use of low pressure used steam from the bleeds of cogeneration turbines for heat supply, resulting in an increase in the specific combined production of electrical energy per unit of heat produced.

For example, at initial steam parameters at HPP's of 13 MPa, 555°C and with use of water as the heat carrier the mean temperature of heat takeoff from the turbine bleeds in meeting the residential heating load is 80°C and the specific combined production of electrical energy is 155 kWh/GJ (640 kWh/Gcal). Using steam as the heat carrier for these purposes, with a pressure at the station collector of, for example, 0.8 MPa, the specific combined production is 80 kWh/GJ (325 kWh/Gcal), i.e., about half the amount as with water.

The thermal economy of HPP's improves on increase of the initial steam parameters, decrease of the steam pressure in the turbine bleeds, with use of multi-stage preheating of the network water, with increase of the number of hours of utilization of the thermal capacity of the bleeds, and on limitation of the proportion of electrical energy production by the condensation method.

Improvement of the economic characteristics of cogeneration results from increase in the size of HPP's and increase of the unit capacity of boiler stations and turbine units, block layout of equipment, and also from use of cheap water-heat boilers and low pressure steam boilers to handle brief seasonal, and technological peaks of the heating load and for heating supply reserve.

In a number of cases the use of water-heat boilers of large capacity gives, in addition, a gain in the scheduling of capital investment, permitting minimum initial cost of centralization of heat supply in regions where the operational introduction of HPP's lags behind the introduction of heat users in time. After the operational introduction of the HPP's these water-heat boilers are used to cover the peak part of the heating load and for heat supply reserve.

In order to decrease the time required for construction of HPP's and to significantly reduce their initial cost and the labor costs on construction it is important to use mass production techniques in heat-and-power plant installation. The USSR has developed projects for series production HPP's of high factory readiness for various types of fuel, providing for construction by assembly of unitized technological construction sections with various types of turbines and boilers of the same type. The construction of these HPP's basically amounts to installation of standard unitized large-unit members at the construction site.

At the present time in the USSR we are manufacturing series-production high-economy cogeneration turbines of high capacity for high (13 MPa) and supercritical (24 MPa) steam parameters: type T with heating bleed; unit capacity from 50 to 250 MW (T-50/60-130, T-105/120-130, T-250/300-240); type PT with heating-industrial bleeds, with unit capacity from 60 to 130 MW (PT-60/75-130/13, PT-50/60-130/7, PT-80/100-130/13, PT-135/165-130/1), type R with back pressure with unit capacity from 40 to 100 MW (R-40-130/31, R-50-130/13, R-100-130/15).

In the near future we will begin production of new turbines at initial parameters of 13 MPa with high unit capacity heating bleed at 175 and 180 MW, T-175/210-130 and T-180/215-130.

The USSR has significant reserves of natural energy resources, including fossil fuel. But due to the geographic dispersal of the regions of location of the main energy resources (the eastern regions of the country) and the main regions of utilization of electrical and thermal energy (the European part of the USSR), there is a deficit of fossil fuel in the Eastern part of the USSR.

In order to improve the fuel-energy balance of the country we are planning in the European part of the USSR, as well as in other regions in the country most removed from the fossil fuel base, to use nuclear fuel as the primary energy resource.

Naturally, use of nuclear fuel at HPP's for combined production of electrical energy and heat is more efficienct from the energy point of view than when using the separate method of production of electrical energy at condensation power stations and heat at boiler stations.

The main advantages of nuclear HPP's (NHPP's) are:

a) The relative independence of the location of the NHPP site from the location of the fuel base due to the insignificant weight of nuclear fuel consumption and the resulting low costs for transport and storage of the fuel.

b) The possibility of a freer method of selection of sites for construction of NHPP's in accord with ecological conditions due to the absence of discharge of pollutants with the exhaust gases, contaminating the environment.

Experience in the operation of existing nuclear power stations (NPS) shows that at these stations there is no discharge of waste waters contaminated by radioactive substances. Radioactive gases and aerosols are removed before discharge through the ventilation pipes. Many years of observations of the concentration of radioactive substances in the air, soil and reservoirs near operating nuclear power stations shows no harmful effect of the NPS's on the environment.

The first NHPP in the USSR was put into operation in the settlement of Bilibino (Siberia) in 1973. This HPP was projected electrical capacity of 48 MW consists of 4 power units with electrical capacity of 12 MW each. The power units consist of single-circuit channel water-graphite reactors and T-12-60 cogeneration turbines with heating bleeds.

At the present time a wide range of design and research developments on creation of large regional NHPP's are underway in the USSR.

Studies at a high design heating load on the order of 1750 MW (1500 Gcal/hr) and over show that NHPP's are economically competetitive with HPP's on fossil fuel (FHPP's).

Further progress on HPP's on fossil fuel will be made mainly in the direction of improving the operational reliability and improving the structure of the equipment.

Introduction of all the new capacity of these HPP's at high and supercritical initial parameters, in addition to improving the loading of the turbine bleeds, will lead to further increase of the specific combination production of electrical energy per unit of heat produced from the turbine bleeds, and also to increase of the proportion of combined production of electrical energy at HPP's.

At the heat output from general purpose stations of 3.8 billion GJ (0.9 billion Gcal) expected in 1980, the combined production of electrical energy at these HPP's will be about 250 billion kWh, and the fuel saving due to the electrical production of the HPP's will exceed 35 million tons.

4. IMPROVEMENT OF HEAT SUPPLY SYSTEMS

An important component part of cogeneration is the centralized heat supply system, the task of which is transport of the heat carrier from the heat supply source to the demand regions and distribution of the carrier to the heat users.

In connection with the development of industry and the intense residential construction in certain regions of the country large territorial developments arise with a high heating load concentration, connected by intraterritorial engineering structures, including heating networks.

In these regions this necessitates conversion in the near future from local heat supply of individual enterprises or individual municipal regions to complex heat supply of large territorial developments of so-called agglomerations.

This conversion should be accomplished under dynamic conditions, i.e., under the conditions of development of the system, using the previously installed and operating heat supply installations as elements of the general agglomeration system of centralized heat supply.

In connection with the increase in requirements for quality of planning and requirements for the purity of the air basins of cities, and also due to changes in the fuel structure of power generation in the direction of increase of the proportion of solid fuel and nuclear fuel, many large HPP's, especially those for energy supply for large cities and industrial-municipal agglomerations, will be located at a significant distance from heating demand regions, often far outside the city limits, requiring installation of heat transport lines of significant length and corresponding increase of the initial costs for the heating networks.

One of the main methods of decreasing the initial costs for construction of heating networks and operational costs for transport of heat is increase of the design water temperature in the feeder line from the presently adopted and widely used level of 150°C to 170-190°C. This solution is economically justified in the USSR not only for the regions of Siberia, the Urals and Kazakhstan, with comparatively low closing costs for fuel, but also for the European regions of the USSR with high closing costs for fuel.

The reliability of heat supply is of extremely great importance.

In order to improve the reliability of heat supply long main water networks should be divided into sections 2-3 km long. This will decrease the water losses from the heating network during emergencies, since the damaged segment of the network is localized on both ends using sectionalizing valves. This will simplify correction of the damage and will accelerate the connection of the network to operation after the emergency.

In modern heat supply systems of large cities the heat carrier - network water - is usually supplied from each large HPP to the heat supply regions through several mains. These mains should be connected together by unitizing connections (interconnections).

Significant reserves in operating cogeneration systems may be utilized with correct regulation of them and adjustment of the operating conditions.

The actual specific combined production of electrical energy, the operational costs on transport of heat and the quality of heat supply as a whole depend significantly on the completeness of use of the heat carrier in the users installations. Increase of the quality of heat service and improvement of the utilization of the heat carrier in users' installations involves improvement of the automation of local regulation.

In order to level out the yearly heating load schedule it is interesting to utilize the used heat of HPP's for heating of greenhouses and hotbeds, and also for production of cold in the air conditioning equipment of industrial enterprises and public buildings. In the near future there will be a significant increase in the cooling load of air conditioning units, especially in regions with a hot climate (Central Asia and the Transcaucasus Republics).

An important problem is reduction of the initial costs for construction of heating networks, acceleration of their construction and improvement of the reliability and service life of heat lines. Both in the USSR and abroad progress is being made in this area in the direction of mass production of structures by manufacture of heat line units at the factories and mechanization of their construction.

In the USSR there have been significant scientific research and construction operations in the area of improving underground heat lines.

In Leningrad, Moscow and other cities there has been wide use of heat line designs of practically all pipe diameters in monolithic sheaths of reinforced concrete, put on the pipes under factory conditions.

An industrial heat line design has been developed in monolithic sheaths of cellular phenolic Poroplast FL.

Designs have been developed for channelless heat lines with monolithic sheaths based on asphalt binder (asphalt-perlite, asphalt-ceramic, etc.) for pipelines of up to 400 mm diameter.

There are a number of pipeline segments in pilot operation using asphalt-Izol both as bulk insulation and for filling of pipes with hot melted compound.

A method of protecting underground pipe systems against outside corrosion by induction enameling of their outside surface has been developed and tested under laboratory conditions and on test segments.

5. THE ECOLOGICAL EFFECT OF COGENERATION

Centralization of heat supply, and especially cogeneration, have a significant effect on improvement of the sanitary state of the environment. Due to the fuel saving obtained in 1976 as a result of combined production at the HPP's of the country in the amount of 36 million tons the amount of yearly discharge of gaseous combustion products has decreased by 130 million tons.

A significant additional effect in decreasing the pollution of the environment of populated areas is obtained with cogeneration as a result of the construction of large heat-and-power plants outside the city area.

The creation of large sources of combined production of thermal and electrical energy made it possible to organize effective capture of the fuel combustion products and waste-free systems for treatment of the make-up water, which in small, and even large boiler stations operating only for heat supply is practically impossible both due to the amount of work required and the capital investment required.

The development of cogeneration in existing old cities permits closing of over a thousand boiler stations each year, which significantly improves the sanitary condition of these cities.

In small boiler stations water treatment is usually performed using the sodium cation exchange method, in which highly mineralized water enters the wastewater. In cogeneration, with production of heat at large HPP's large installations may be provided for waste-free treatment of the make-up water, for example multistage evaporator units.

The ecological danger of decentralized heat supply is aggravated due to low stack height, leading to low dispersal of the wastes and high waste concentration in the layer near the ground. Modern large HPP's have significantly more effective ash catching equipment than boiler stations and are equipped with high stacks. All this significantly improves the purity of the air basin.

The construction of HPP's on nuclear fuel, planned in the near future, will simplify solution of the ecological problem due to the absence of discharge of gaseous pollutants into the atmosphere.

6. REDUCTION OF LABOR COSTS IN THE ENERGY FIELD

With cogeneration there is a significant decrease in labor costs for operation of thermal power systems and of the installations of industrial regions and cities in comparison with separate heat supply, which under the conditions of the USSR with 100% employment of the labor force and inavailability of free labor reserves is very important. Cogeneration permits a decrease in the number of personnel servicing the municipal energy system by a factor of 5 to 7 in comparison with heat supply from local heat sources and by 30 to 35% in comparison with heat supply from large regional boilers.

7. DEVELOPMENT OF COGENERATION SCIENCE

Successful Soviet cogeneration at all stages of its development will be favored by scientific studies closely correlated by practice. Engineering and technical personnel, designing, constructing, operating and adjusting cogeneration systems and installations participate actively in these studies in addition to the scientific workers. Soviet energy workers have created a science providing correct solution of all the main technical and technical-economic problems of cogeneration and development of the main methods for further development of this science.

Soviet scientists have compiled textbooks and instruction manuals which in the universities and technical schools of the country will provide the basis for systematic preparation of engineering and technical cadres for cogeneration and retraining of the working cadres.

CONCLUSIONS

One of the main energy trends in the USSR is cogeneration, i.e., centralized heat supply on the basis of combined production of electrical and thermal energy.

Cogeneration gives a great fuel saving, significantly improves the sanitary state of the environment due to decrease of the quantity of combustion products discharged and reduces labor costs for operation of thermal energy systems and installations of cities and industrial regions.

Soviet cogeneration is based on large HPP's, from which heat is sent to industrial enterprises and nearby cities and populated areas.

Soviet cogeneration makes wide use of water as the heat carrier, which provides high specific combined production of electrical energy and a high specific fuel saving per unit of heat taken from the turbine bleeds.

Improvement of HPP economic characteristics results in an increase in the initial steam parameters, a decrease of the steam pressure in the turbine bleeds, an increase in the unit capacity of boiler and turbine units, unit layout of the equipment, use of cheap water-heat and steam boilers to cover brief peaks of the seasonal and technological heating load, and mass production in the construction of heating networks.

In 1976 on the basis of combined production of electrical and thermal energy at general purpose HPP's a standard fuel saving of 30 million tons was obtained, which is about 11% of the total fuel consumption on production of electrical energy in the country.

Due to the development of cogeneration and to general progress in the energy field, in recent years the USSR has become one of the leaders among the industrially developed countries of the world in the level of thermal economy of electrical energy production.

In 1977 the mean specific consumption of standard fuel (net) on production of electrical energy was 334 g/kWh, which corresponds to a (net) efficiency of 0.37.

The development of cogeneration in the USSR is favored by improvement of heat supply systems and mass production in heat line construction.

In the USSR we have developed mass production designs for heat lines in monolithic sheaths of reinforced concrete, phenolic Poroplast, asphalt-perlite and other materials, permitting a significant decrease in material and labor costs for construction of heating networks.

Table I. Development of cogeneration from general purpose stations in 1960-1976.

Installed electric and thermal capacity	Units	I960	I965	I970	I975	I976
Established electrical capacity of cogeneration turbines	million kW	II,9	23,7	36,9	49,I	52,I
	arbitrary units	I,0	I,99	3,I	4,I4	4,4
Production of electrical energy by cogeneration turbines	billion kWh/yr	66	I35	I95	256	27I
	arbitrary units	I,0	2,05	2,96	3,88	4,I
Production of electrical energy in the cogeneration mode	billion kWh/yr	2I	55	I05	I58	I74
	arbitrary units	I,0	2,62	5,0	7,5	8,3
Proportion of combined production of electrical energy at HPP's	%	32	40,8	54	6I,7	64,4
Heat output from HPP's	billion GJ/yr	0,6I	I,29	2,I4	2,65	2,9
	arbitrary units	I,0	2,I2	3,5	4,35	4,75
Including exhaust heat	billion GJ/yr	0,5	I,05	I,76	2,3	2,5
	arbitrary units	I,0	2,I	3,52	4,6	5,0
Specific combined production of electrical energy per unit of used heat		0,I5	0,I88	0,2I5	0,247	0,252
	kWh/GJ	4I,6	52,I	59,6	68,5	70
	kWh/Gcal	I74	2I8	250	288	293
	arbitrary units	I,0	I,25	I,43	I,64	I,68

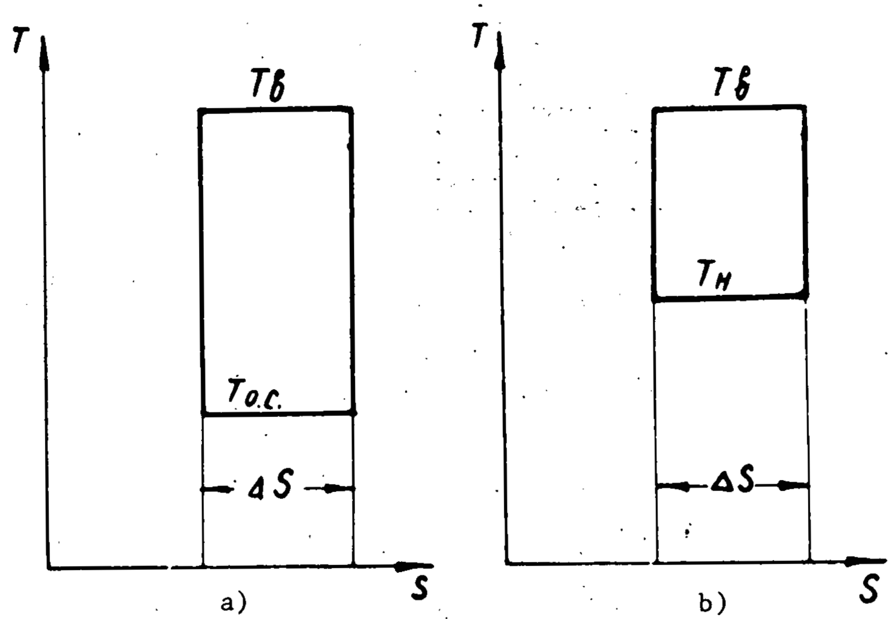

Figure 1. Ideal cycles of thermal power stations in a T-S-diagram:

a--condensation,
b--cogeneration.

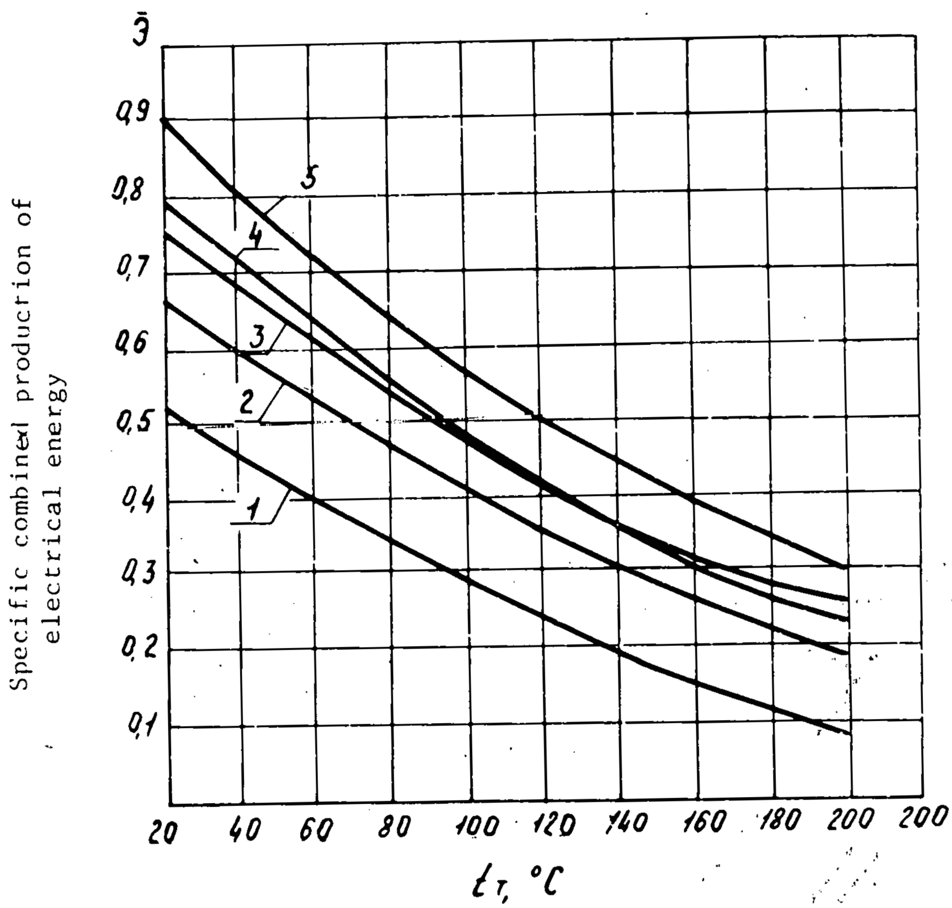

Figure 2. Specific combined production of electrical energy on the basis of heating demand. Initial steam parameters ahead of turbine: 1--P = 3.5 MPa, t = 435°C; 2--P = 9 MPa, t = 535°C; 3--P = 13 MPa, t = 555°C; 4--P = 13 MPa, t = 540°C, t_{rs} = 540°C; 5--P = 24 MPa, t = 540°C, t_{rs} = 540°C (rs = reheated steam).

Specific fuel consumption (net) at USSR Minenergo Power Stations

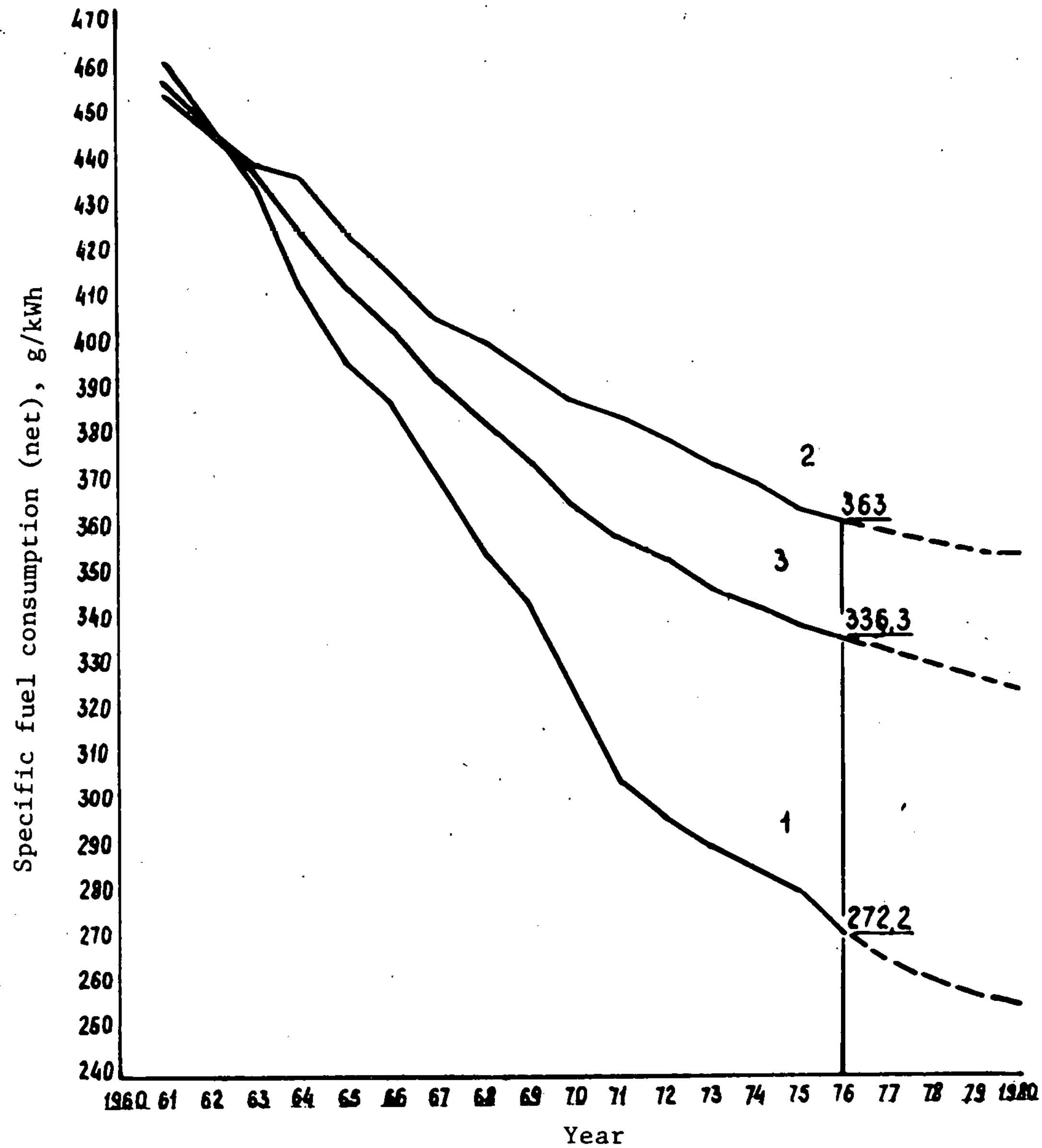

Figure 3. Specific fuel consumption (net) at general purpose thermal power stations. Broken lines--estimated. 1--mean for all HPP's; 2--mean for all condensation power stations; 3--mean for all thermal power stations.

Development of cogeneration in the USSR

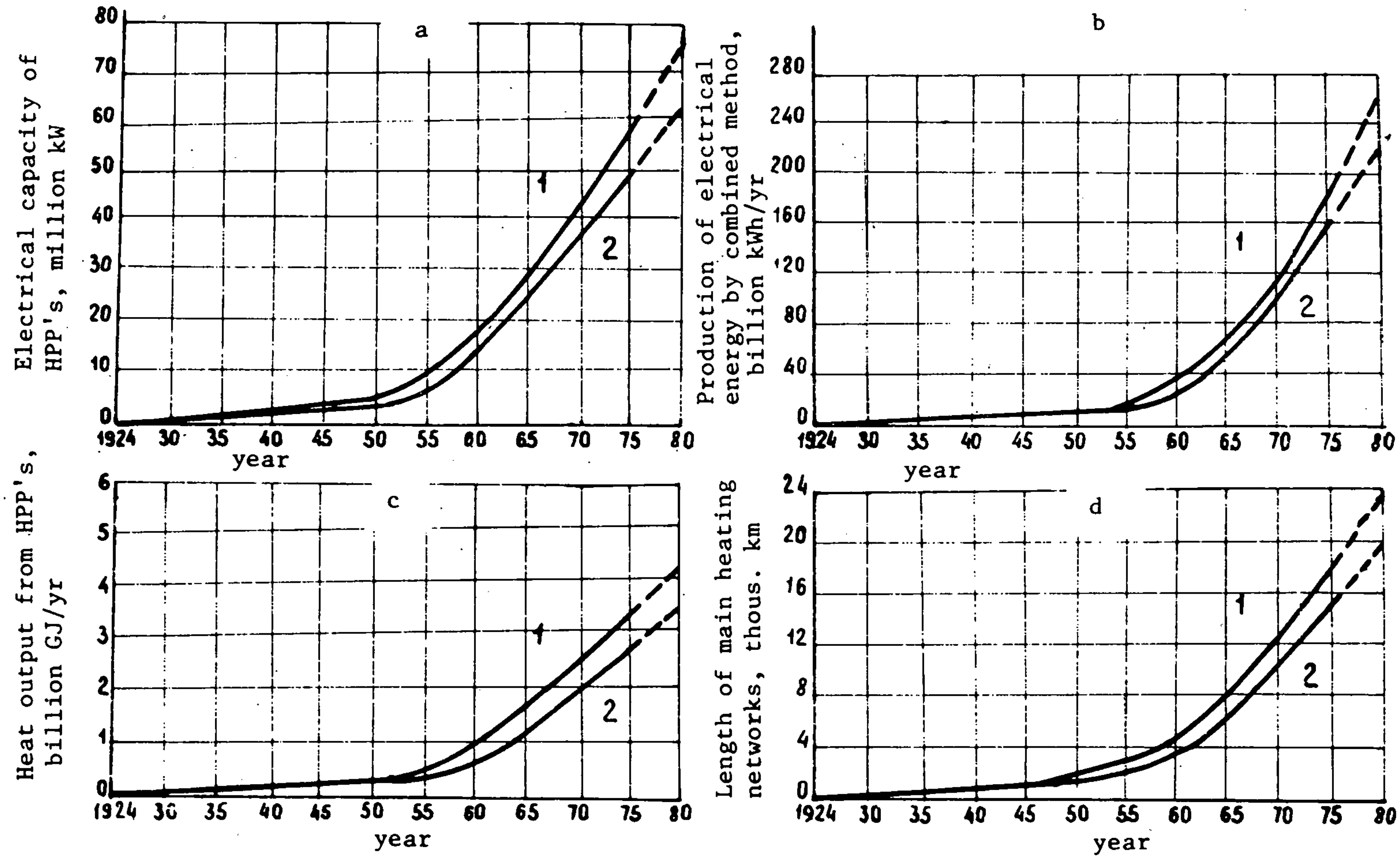

Figure 4. Development of cogeneration in the USSR.
1--total; 2--general purpose stations. Broken lines--estimated. a--electrical capacity of HPP's; b--production of electrical energy by the combined method; c--heat output; d--length of heating network mains.

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PAPER NO. 2

All-Union State Order of Lenin and Order of the
October Revolution Design Institute
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COGENERATION POWER STATIONS ON FOSSIL FUEL

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A cogeneration power station (heat-and-power plant [HPP]) is a complex technical installation for conversion of the potential energy reserves of various organic fuels to thermal and electrical energy.

The present report will examine only HPP's based on the steam-power cycle, which are widely used in the Soviet Union, and will not mention steam-gas, gas turbine and other HPP's.

HPP-power stations with useful removal of heat

As is well known, for a steam turbine condensation power station the most significant loss of fuel energy in the continuous process of conversion of heat to work, due to the second law of thermodynamics, is the loss of the "cold source". For modern energy installations operating on the Rankine cycle with regeneration the thermal efficiency is 40 to 50%. Figure 1 shows the Rankine cycle in a TS-diagram. The area lying under the curve 3-3'-4-5-1 measures the quantity of heat supplied to the working body. The area lying under line 3-2 measures the quantity of heat given off to the "cold source". The usefully utilized heat of the condensation cycle is shown by the area of the figure 1-2'-2-3-3'-4-5-1. The heat loss "in the cold source", unavoidable in the production of electrical energy on the condensation cycle, may easily be used for heat supply purposes. The process of combined production of electrical energy and heat is termed the cogeneration cycle. In this case the heat of the spent steam is practically utilized.

However, the users can utilize this heat only if the heat carrier is at a sufficiently high temperature, necessitating an increase of the pressure of the spent steam.

The cogeneration cycle is shown on Figure 1 by the outline 1-2'-2-7-6-3-4-5-1.

Here the heat going for production of electrical energy is shown by the area of the figure 1-2'-3'-4-5-1. The heat utilized by external users is shown by the area 3-6-7-2-3.

The decrease in the production of electrical energy during operation on the cogeneration cycle is measured by the area 2-2'-3'-3-2.

The cogeneration cycle uses special types of steam turbines, which are termed cogeneration turbines: these are turbines with regulated cogeneration cycle is measured by the area 2-2'-3'-3-2.

The cogeneration cycle uses special types of steam turbines, which are termed cogeneration turbines: these are turbines with regulated cogeneration and production steam bleeds (type T and PT) and turbines with back pressure (type R).

Technical-economic calculations show that the degree of useful utilization of fuel at HPP's is more than 2 times greater than at condensation power stations due to the significant decrease of losses in the "cold source".

Cogeneration turbines

HPP's are divided into two groups by purpose and turbine equipment installed - pure heating and industrial-heating HPP's, which provide industrial process steam in addition to cogeneration. Turbines with a production steam extraction are installed at HPP's with consideration of prolonged use of this extraction during the year. Turbines with back pressure are selected to cover the base load demands for industrial steam and residential heat.

HPP's use hot water and steam as the heat carrier. The pressure of steam utilized by external users should be minimized in order to provide the greatest combined production of electrical energy.

The pressure in the regulated bleeds and the back pressure of cogeneration turbines is chosen in accord with the state standards and is shown in Table I.

The efficiency of cogeneration is determined by the quantity of electrical energy production based on heat consumption, depending only on the initial turbine steam parameters and the steam pressure in the bleeds.

Table II shows the main types and characteristics of the largest cogeneration turbines produced by factories in the USSR.

The type of cogeneration turbines for HPP's is determined by the nature of the heating loads. The proportion of heating load handled from the turbine bleeds is characterized by the cogeneration coefficient. For heating HPP's the calculated cogeneration coefficient is the ratio of the calculated heat consumption from the turbine bleeds to the assigned calculated total HPP load for heating, ventilation and hot water supply.

The optimum value for the calculated cogeneration coefficient depends on the nature and conditions of heat demand, fuel costs, requirements of the power system for HPP operating conditions, the initial steam parameters and other factors.

The calculated cogeneration coefficient is a very important parameter, determining the choice of the equipment and the operating conditions of the heating HPP (the electrical capacity of the HPP, the yearly number of hours of utilization of the thermal capacity of the bleeds, and consequently the proportion of production of electrical energy on the cogeneration cycle).

Technological plans and equipment of HPP's

Modern cogeneration turbines with heating bleeds are characterized by staged heating of the network water successively in two network preheater stages, supplied with steam from two heating bleeds with an expanded bleed steam pressure regulation range, and also by the possibility of using the heat of the steam going to the condenser for preheating of the return network (first heating stage) or make-up (raw) water in the so-called "fixed bundle" of the condenser, with the main cooling surface of the condenser disconnected.

The use of "fixed bundles" permits operation of these units in the most economical mode for a significant part of the heating season without loss of heat in the turbine condenser. Fixed cogeneration bundles are used most effectively at HPP's operating in heat supply systems with direct water collection, having a greater quantity of make-up water.

HPP's use various types of boiler units with steam output of 220 t/hr, 400-500 t/hr, and 1000 t/hr, depending on the type of turbines installed, the type of fuel burned and the heating plan used.

The heating plans of modern HPP's may have cross connections for live steam and feed water or be of the strict block type. HPP's with intermediate superheating of steam use single-block plans (boiler-turbine), (for example a number of large HPP's in Moscow, Kiev, Leningrad and Khar'kov). HPP's without steam superheating with a predominantly heating load generally use these single-block plans (for example HPP-2 in the city of Rostov and Severnaya HPP-2). HPP's without superheating with a predominantly steam load use plans with cross connections and block plans. The use of block plans permits a decrease in cost and simplification of the operation of the technological part, a decrease in the amount of construction due to simpler layout designs, and a decrease in the number of service personnel.

Often a characteristic feature of heating HPP's is the fact that they have water-heat boilers with heat output of 50, 100, and 180 Gcal/hr to cover peak heating loads. Energy construction experience shows that in many cases it is favorable to install and put into operation water-heat boilers before readiness of the energy boiler and turbine equipment. This "advance introduction" plan permits timely handling of rapidly growing heating loads of new residential developments and avoidance of unproductive expenses for construction of small boiler stations. After start-up of the HPP turbines these boilers are transferred to operation in their design mode as peak units.

The HPP electrical schedule is dependent on the heating load conditions, but due to connection with the power system this operational feature of the power station is not reflected on the main electrical circuit.

Industrial HPP's are characterized by distribution of a significant part of the electrical energy at the generator voltage of 6-10 kV, since there are many electrical energy users in the vicinity of the power station.

For transmission of excess capacity or generator voltage users' reserve distribution devices of 35, 110 and 220 kV (less often 330 kV) are used.

In the increase of the efficiency of cogeneration power stations a significant role is played by the capital investment for their construction, especially when the HPP's are located within cities, which imposes strict requirements for environmental protection, culture of production and industrial esthetics. The attempt to increase HPP efficiency necessitates a search for new optimal designs: improvement of the layouts of HPP general plans, main buildings and equipment of the auxiliary shops, simplification and reduced cost of structural members, improvement of external heat supply equipment and modernization of heating plans.

Up to the present time several types of gas-mazut-fired HPP's have been built, differing both in the inventory of equipment on the general plan and in the layouts of the general plans and main buildings.

Of these the most modern are:

HPP-2 in the city of Rostov - a Teploelektroproekt VGPI project. The auxiliary shops and services are not unified, and are located in separate buildings. The main building is single-span. The heating plan is of the block type. The Rostov HPP-2 is equipped with a compact gas-tight boiler with cyclone furnace with steam output of 500 t of steam per hour. The total span of the main building is 51 meters. The electrical accommodations are located between the boiler and turbine, and partially between the turbines on individual supports. The unit control panel is built on from outside.

HPP-ZIGM - a project of the VNIPIEnergoprom Institute. A large part of the auxiliary shops and services are unified in a combination auxiliary building. A two-span main building with standard boilers has a deaerator level built into the boiler division. The deaerator level is not connected to the operation of the HPP main building frame, and this plan led to increase of the boiler division span and to heavier columns. The thermal plan has cross connections.

The VNIIPIEnergoprom institute successfully solved the problem of unifying the design and equipment of cogeneration power stations with PT-60-130 and T-110/120-130 turbines with boiler units with steam output of 420 t/hr.

The Severnyi HPP-2 - a project of the Riga division of the Teploelektroproekt Institute. The project has now been used for five HPP's of which the Severnyi HPP-2, with PT-80/100-130 and T-110/120-130 turbines and boiler units with steam output of 500 t/hr has been built and is operating successfully. At these HPP's the project provides for installation of type T, PT and R turbines with capacity from 50 to 210 thous. kW at turbine steam parameters of 130 kg/cm^2 (13 MPa).

The general plan of the Severnyi HPP-2 is based on maximum unitization of all the buildings and equipment of the site with separate autonomous technical processes. In the combined main building of this HPP is the main energy equipment - the turbines and boilers (the energy part of the combined main building) and various auxiliary shops and services - water heat boilers, pump stations, chemical water treatment, central repair shops, flotation unit, etc. (the auxiliary part of the combined main building). The cross section of the combined main building is in the form of a three-span frame with the dimensions:

machine hall	39 meters;
deaerator level	7.5 meters;
boiler station	30 meters
column spacing	12 meters

and on the boiler side adjacent to the combined main building is the "open area", with the regenerative air preheaters, ventilators and exhausts (when necessary).

The machine hall and deaerator station are made without a basement, service height 12.0 meters with respect to the height of the condensation station of 0.00 meters.

The energy part of the combined main building is built up of unified technological construction sections, the boundaries of which are the structural axis of the building.

In the auxiliary part in the boiler division at the 8.00 meter level are the water-heat boilers, under which are the first and second lift network pumps; the neutralizer and sedimentation tanks with pump equipment under them are in 2 levels.

At the temporary end of the auxiliary part of the boiler division is a complex of equipment for treatment of grease-containing water from the collector of the heating networks.

In the auxiliary part of the machine division are the water treatment filters in three levels and the maintenance and repair shops. Along the front wall of the machine hall are the chemical water treatment clarifiers, under which is the pump equipment.

The auxiliary part is built up of standardized technological units.

The equipment for receiving of lime, coagulant and other reagents, the compressor station, electrolyzer unit, forging-thermal equipment division of the maintenance service, scales and garage, which cannot be located in the main building for reasons of explosion safety and for sanitary-health reasons are in a separate building - the auxiliary services unit (ASU) located near the combined main building in the stack area.

The main building uses a ventilation system combined with the preheating of the blower air entering the boiler division. The heat elimination from the equipment and pipe systems is assimilated by the ventilation air and is fully used on outside-the-boiler preheating of the blower air. The use of this design permits a 5-7% increase in the efficiency of the most advanced HPP's built in accord with the designs briefly outlined above.

Many problems remain to be solved

In the direction of decreasing capital investment in heat elimination systems and heating networks work is being done on channelless laying of pipe systems, mass production techniques in heat network construction and use of nonmetallic piping.

Further improvement of the efficiency of cogeneration power stations is being made:

- Development of a series production power station design using solid fuel with consideration of various physicochemical properties of a wide range of domestic coals;

- Widespread development of compact boilers with cyclone furnaces, tested at the Rostov HPP-2 during burning of mazut fuel oil. In addition to decreasing the amount of construction work and the capital investment, the use of these boilers eliminates the necessity for heavy assembly.

- Improvement of structural designs and equipment, technological systems and layouts to decrease the area, volume and consumption of materials, as well as labor costs during construction and installation;

- Standardization of the elements of technological and electrotechnical equipment and pipe systems to provide large-scale manufacture of fully completed installation units.

Design institutes and other organizations of the energy field are carrying out operations in many directions to search for new designs providing high HPP efficiency and meet the growing demands for the welfare and culture of the population of our country.

TABLE I

Rated pressure, kg/cm^2 (MPa)		Pressure regulation limits, kg/cm^2 (MPa)	
of regulated bleed	after turbine (back pressure)	of regulated bleed	after turbine (back pressure)
I,2(0,II8)	I,2 (0,II8)	0,6-2,5(0,059-0,246)	0,6-2,5 (0,059-0,246)
IO (0,98)	IO (0,98)	8-I3(0,785-I,28)	8-I3(0,785-I,28)
I3 (I,28)	I3 (I,28)	IO-I6(0.98I-I,573)	IO-I6(0,98I-I,573)
-	I5 (I,47)	-	I3-I7(I,28-I,67)

Table II.

Turbine	Rated capacity, MW	Live steam pressure, kg/cm² (MPa)	Live steam temp., °C	Rated consumption of live steam, t/hr	Pressure in regulated bleeds, kg/cm² (MPa): Cogeneration bleed, Preheat stage I	Pressure in regulated bleeds: Cogeneration bleed, Preheat stage II	Pressure in regulated bleeds: Production bleed	Rated load of cogeneration bleed, Gcal/hr (GJ/hr)	Rated load of production bleed, t/hr	Number of regenerative preheaters: high pressure	Number of regenerative preheaters: low pressure	No. of cylinders	Feed water temperature, °C	Number of stages	Heating surface area of preheaters, m²	Cooling surface area of condenser, m²
I	2	3	4	5	6	7	8	9	I0	II	I2	I3	I4	I5	I6	I7
T-100/120-130	II0	I30 (I2,75)	565	480	0,5–2,0 (0,049–0,245)	0,6–2,5 (0,059–0,245)	–	I75 (75I,8)	–	3	4	3	232	23+2x x 2	2x2300	2x3I00
T-P5/210-130	I75	I30 (I2,75)	555	745	0,5–2,0 (0,049–0,I96)	0,6–3 (0,059–0,294)	–	270 (II60)	– –	3	4	3	232	22+2x x 3	2x5000	2x6000
T-250/300-240	250	240 (23,54)	560/565	955	0,5–I,5	0,6–2	–	330 (I382,7)	–	3	5	4	263	22+2x9	2x5000	I4000
PT-60/75-130/13	60	I30 (I2,75)	565	350	0,7–2,5 (0,069–0,245)		I0–I6 (0,98–I,57)	52 (2I7,9)	I40	3	4	2	232	30	–	3000
PT-80/100-130/13	80	I30 (I2,75)	555		0,3–I,0 (0,029–0,098)	0,5–2,5 (0,049–0,245)	I0–I6 (0,98–I,57)	68 (284)	I85	3	4	2	232	30	2xI300	3000
PT-135/165-130/13	I35	I30 (I2,75)	555	750	0,4–I,2 (0,039–0,II7)	0,9–2,5 (0,088–0,245)	I2–2I (I,I8–2,06)	II0 I460,9	320	3	4	2	232	26	2xI300	6000
R-100-130/15	I00	I30 (I2,75)	555	760	–	–	I2–I5 (I,I8–I,47)	–	650	3	–	I	234	I3	–	–

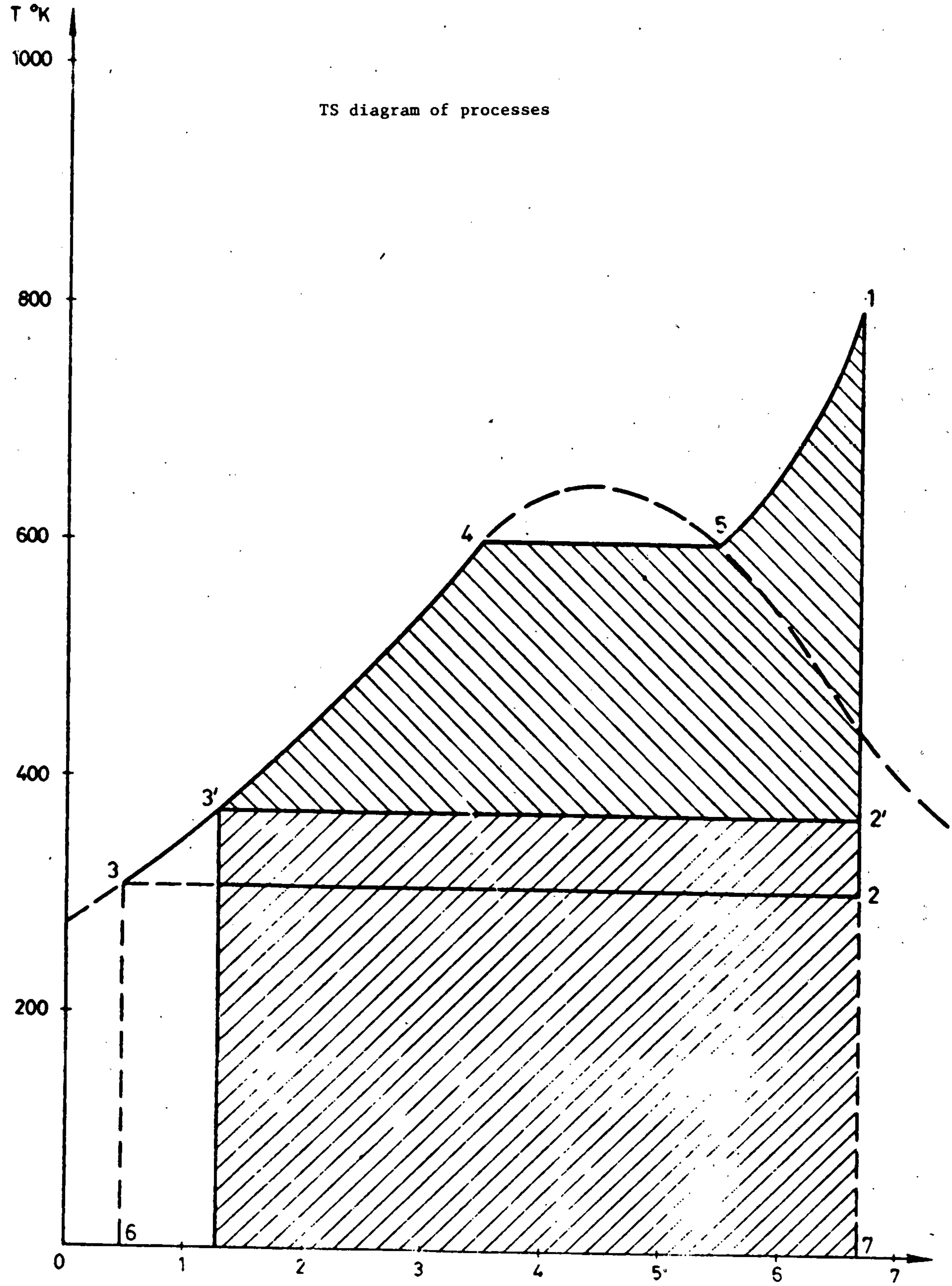
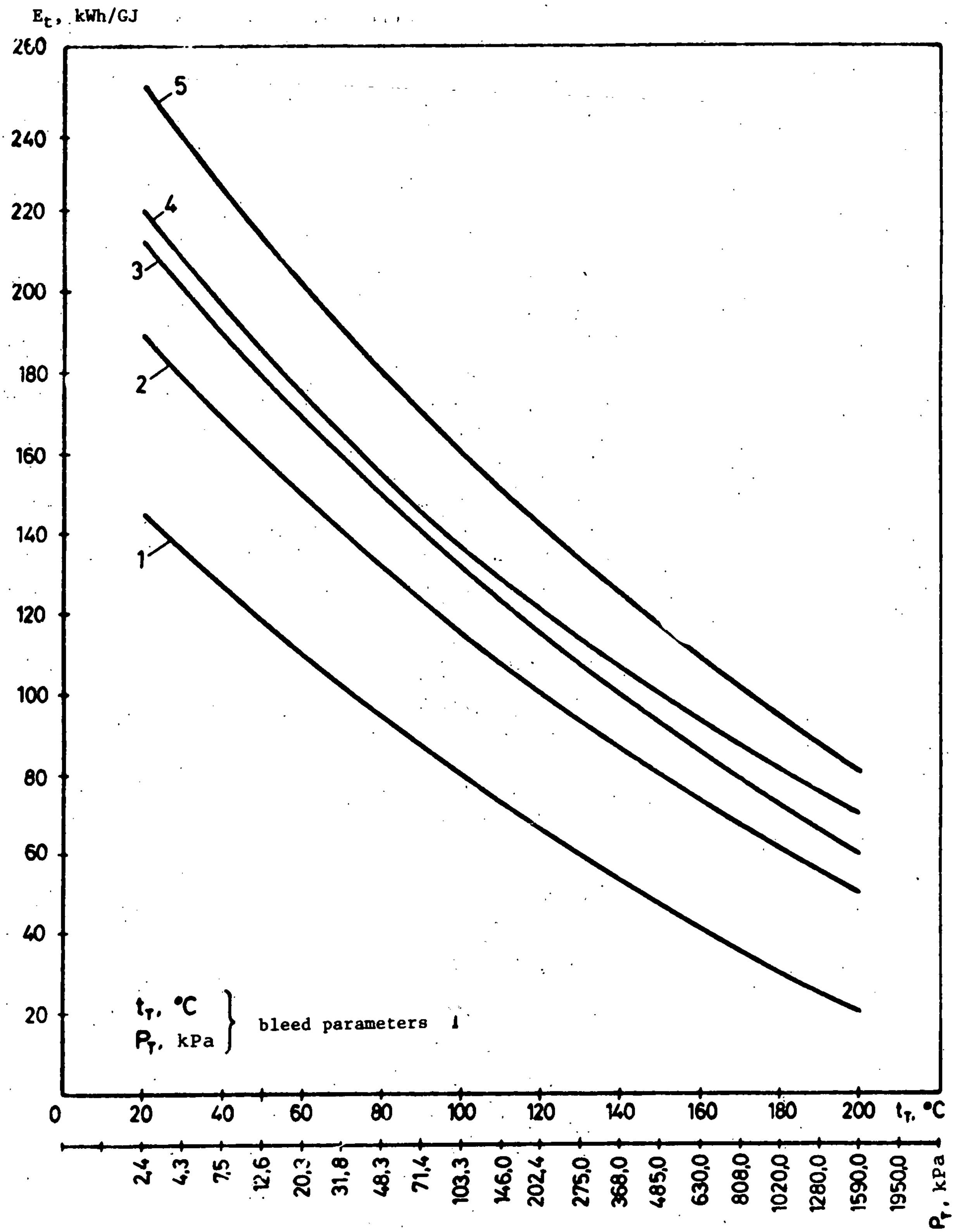

T °K
1000
TS diagram of processes
800
600
400
200
0
1
2
3
4
5
6
7
1
4
5
3'
2'
3
2
6
7
S, kJ/kg·deg

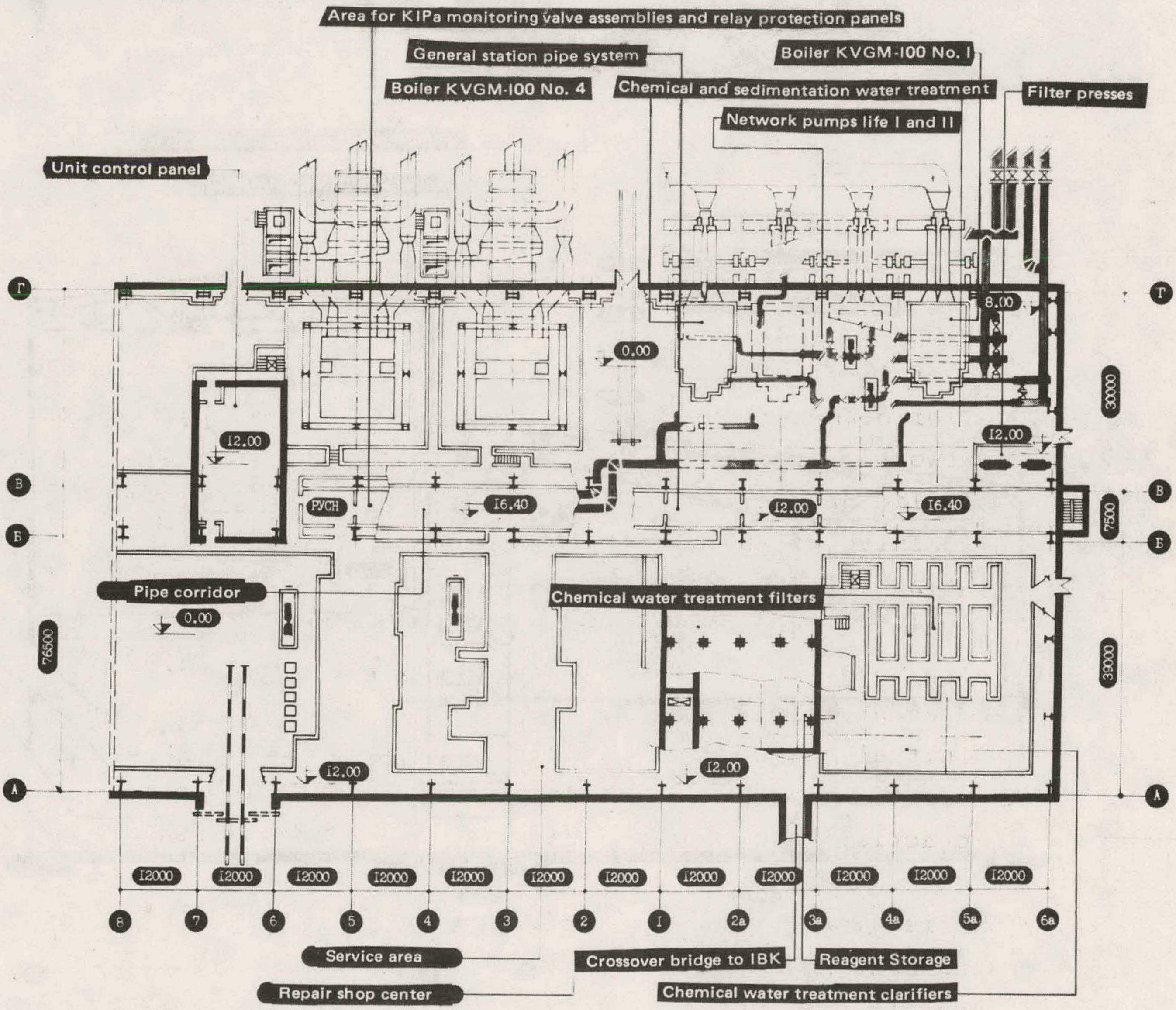
Figure 1.



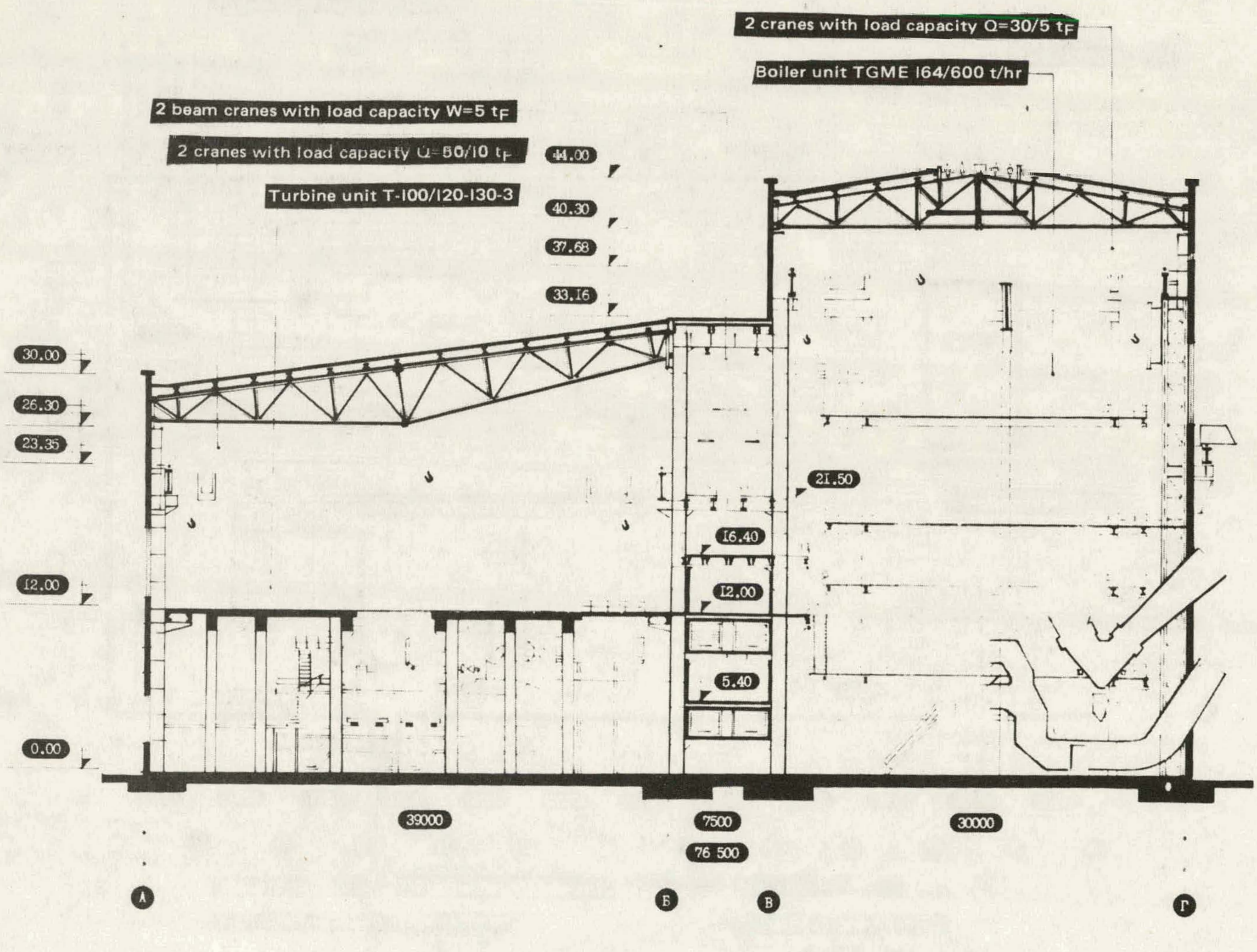
E_t, kWh/GJ
260
240
220
200
180
160
140
120
100
80
60
40
20
0
5
4
3
2
1
t_T, °C
P_T, kPa
bleed parameters 1
20
40
60
80
100
120
140
160
180
200
t_T, °C
2,4
4,3
7,5
12,6
20,3
31,8
48,3
71,4
103,3
146,0
202,4
275,0
368,0
485,0
630,0
808,0
1020,0
1280,0
1590,0
1950,0
P_T, kPa

Figure 2.

Plan of main building of Severnaya HPP-2

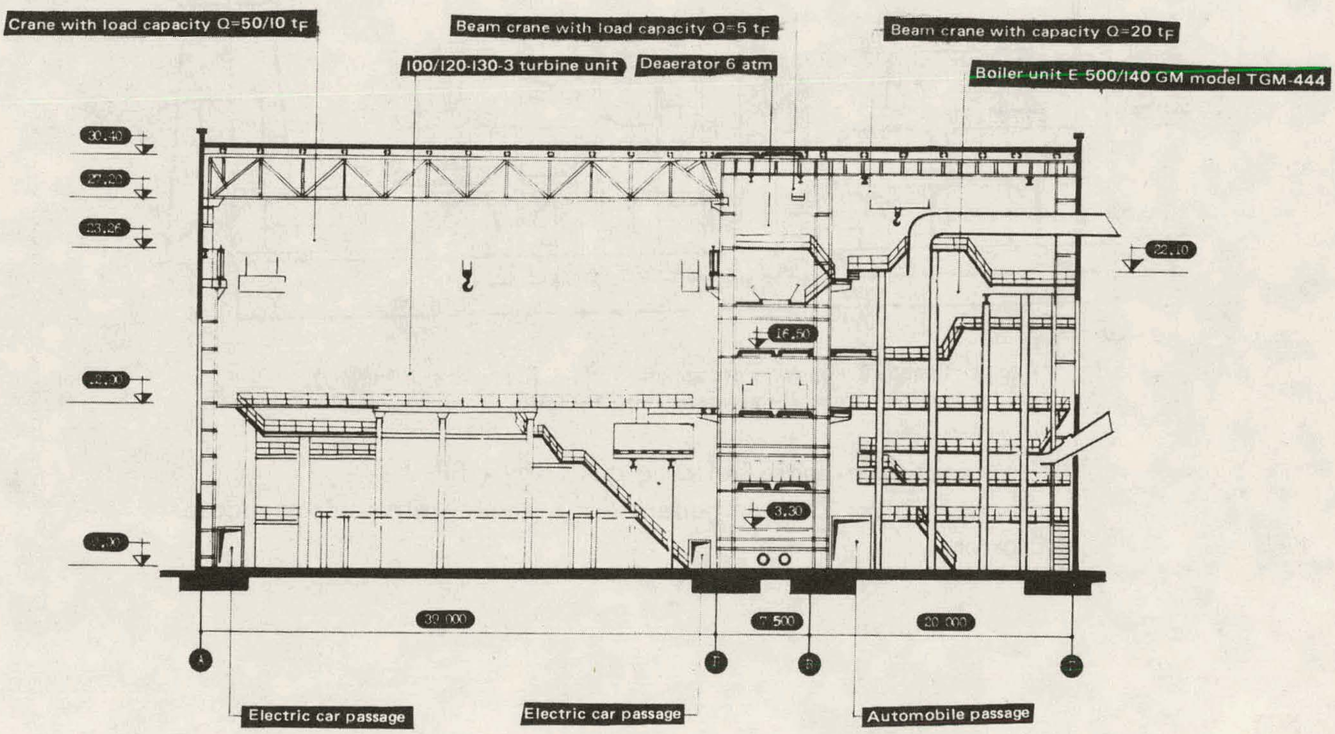


Cross section of main building of Severnaya HPP-2



Cross section of main
building with compact boilers

*This appears to be a planned compact boiler station
as a follow-on to the HPP-2 of Rostov.



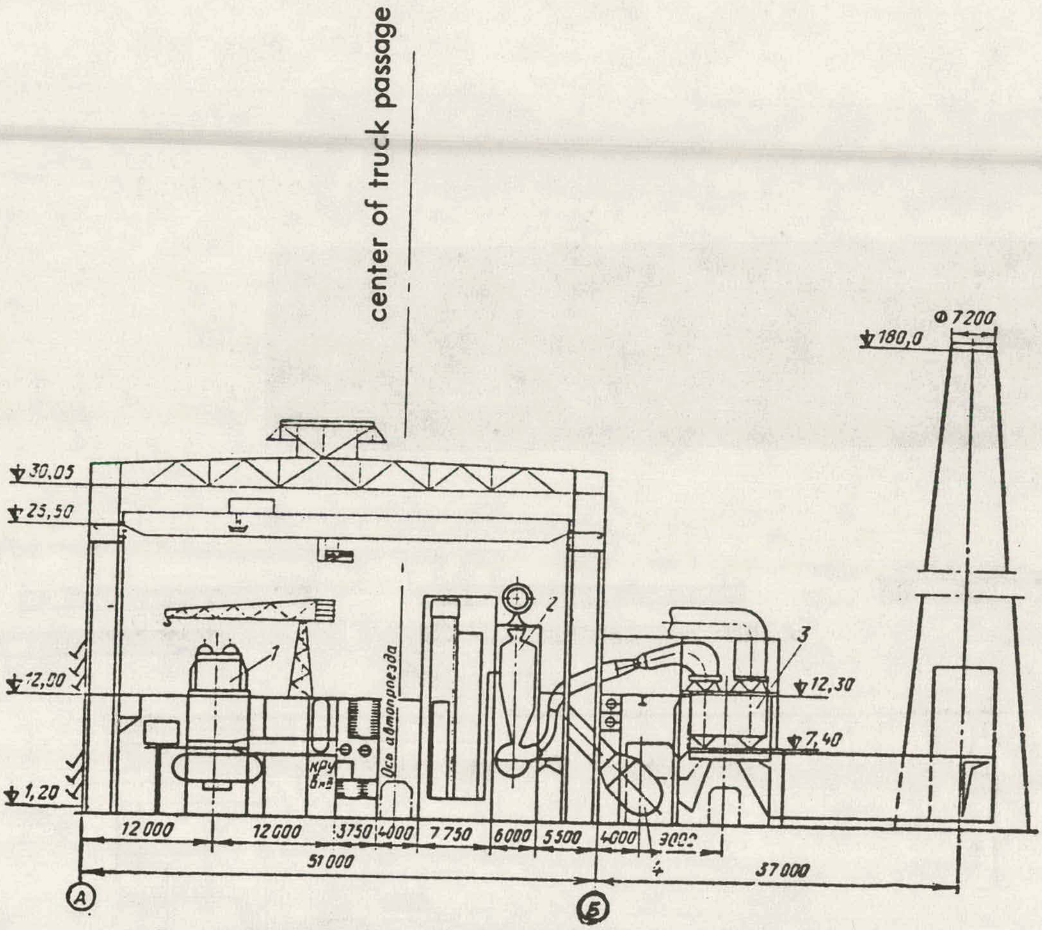


Рис. 1. Главный корпус Ростовской ТЭЦ-2 (поперечный разрез).
1 — турбогенератор; *2* — парогенератор; *3* — РВП; *4* — воздуходувка.

Cross section of main building of Rostov HPP-2
1. turbogenerator; 2. steam generator; 3. regenerative air preheater
4. blower

from "Teploenergetika" Nov. 1977
"The design of heat power stations
in the USSR and future tasks" by
Okhotin, V. N. and Gusev, V. N.

J. Lewin

PAPER NO. 3

All-Union State Scientific Research and Structural
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"VNIIenergoprom"

DESIGN, CONSTRUCTION AND OPERATION OF CENTRALIZED HEAT SUPPLY SYSTEMS

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Joint Soviet-American Symposium on Removal of heat from
Fossil Fuel and Nuclear Power Stations

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Razdan

Notes

The report covers aspects of planning, construction and operation of centralized heat supply systems.

In the planning, construction and operation of centralized heat supply systems in the USSR work is now being performed on a number of problems:

- Combined operation of several sources on common heating networks;
- Optimization of hydraulic conditions;
- Single-pipe transport of heat;
- Protection of underground heating pipes against external corrosion;
- Adoption of channelless laying of heating networks;
- Improvement of structural elements and equipment of heating networks;
- Improving economy and reliability of heat supply systems.

DESIGN, CONSTRUCTION AND OPERATION OF CENTRALIZED HEAT SUPPLY NETWORDS

The centralized heat supply used in the USSR, especially cogeneration, based on large heat-and-power plants (HPP's), requires acceleration of operations connected with development of heating networks and increase of the capital investment on their construction.

The increase in the size of heat sources leads to increasing distance between the source and the connected users and to increase of the radius of operation of the heating networks. This is also a result of stricter requirements for environmental protection and the difficulty of acquiring the necessary sites for construction of large HPP's in municipal areas. All this necessitates the location of HPP's outside the area of municipal development.

The capital costs on construction of heating networks reach 70-80% of the total costs for construction of centralized heat sources and 40 to 50% of the costs for construction of heat-and-power plants.

Under these conditions further improvement of centralized heat supply systems requires significant improvement of the circuits, structures and operating conditions of heating networks in order to reduce their cost and consumption of materials, improve the construction methods and the operating reliability.

At the present time in the USSR a number of HPP's are in operation with unit electrical capacity to 1300 MW and with design heat output of 4000 Gcal/hr. The electrical capacity of newly designed and constructed HPP's reaches 1500-2000 MW with a calculated heat output of up to 5000 Gcal/hr.

The trend toward increase in size of heat sources and the forced increase in distance between the sources and the heating loads put forward the problem of using existing condensation power stations (CPS) and nuclear plants for municipal heat supply by modification of their equipment, and also creation of heat sources for heat supply of several populated areas. The development of new heat supply systems with nuclear heat sources - nuclear HPP's (NHPP's) and nuclear boiler stations (NBS's) is one of the important problems at present.

Increase of the distance of transmission of thermal energy puts forward the problem of improving the operational reliability of heating networks and heat supply systems as a whole, since failure of a main of large diameter will lead to disconnection of a large number of connected users, and the great length and capacity of the heating pipes increases the duration of operation to correct failures. The diameters of the heating mains being constructed at the present time reach 1400 mm.

The radii of operation of certain heating networks exceed 30 km.

As a rule, heating network systems are assumed to be two-pipe dead-end systems or radial systems.

Water heat networks are usually designed to be common for all types of loads (heating, ventilation, air conditioning, and hot water supply).

Heating pipes with design heat consumption of 3000 Gcal/hr and over are provided with a reserve.

Most widely used in the USSR is underground laying of heating networks in impervious channels, the proportion of which is about 80%.

In large cities through channels are used in laying of heating networks, in which other engineering communications are also located (water lines, electrical cables, communication lines, etc.). The majority of channels for heating networks consist of industrially manufactured prefabricated reinforced concrete elements.

The volume of channelless laying is about 6%. The most widely used channelless laying designs are laying in asphalt-perlite (pipes with diameter to 500 mm) and reinforced foam concrete (pipes with diameter to 1000 mm).

Underground laying is used mainly on transit segments through undeveloped territory, and also in passing through the territory of industrial enterprises and at complex intersections with natural or artificial obstacles.

In connection with the increase in size of heat supply sources and the movement of large HPP's outside of cities the extent of underground laying is increasing.

In centralized heat supply systems for heating, ventilation, conditioning, hot water supply and low-potential industrial loads the heat carrier used is water.

In the USSR two different heat supply systems are used and are equally developed: the open system with direct introduction of public network water for hot water supply, and the closed system, with installation of hot water preheaters at central or individual heating points of users.

The open system is used when it is possible to provide the heat source with water of potable quality to the full extent necessary for user hot water supply.

With open systems there is significant simplification of the equipment of the heating points, since there is no necessity for hot water heaters, organization of central heating points or for four-pipe laying of branching heating networks. The open system permits solution of the problem of single-pipe transport of heat. With the open system there is no internal corrosion in the hot water supply systems, since the make-up water is subjected to deaeration and the necessary treatment.

The operation of open systems requires increased attention to the quality of the water entering the heating network and maintenance of the hydraulic conditions.

Regulation of the heat output in water-type heating networks is usually accomplished by the qualitative method, providing change of the temperature of the network water depending on the outside temperature.

The most widely used temperature schedule is 150-70°C. The optimum operation schedule is determined by technical-economic calculation for each given object.

At a design heat consumption in the heating networks of 600 Gcal/hr and over telemechanization of the heat supply system is provided (remote signaling, control and measurement and dispatcher communication).

Centralized heat supply networks are designed on the basis of an approved heat supply plan of the city or industrial center (TEO). The heat supply plan is developed for a design service life of 10-15 years separation of the first line of construction for a period of 5-7 years. The plan resolves the main questions concerning heat sources, fuel, and layout of heating networks on the basis of technical-economic calculations, and determines the total capital investment in the heat supply system.

Heating networks are usually designed in a single stage - the technical work project. Design in two stages - technical project and working plans - is allowed for large and complex objects.

Centralized heat supply network projects make wide use of standard, widely used economic individual projects, and standard structural members of high factory readiness.

In the USSR heating network designs have been created allowing full mass production of their equipment.

At the present time in the practice of design, construction and operation of centralized heat supply networks work is being done on a number of problems, among which are: improvement of the economy and reliability of large heat supply systems; combined operation of several sources on common heating networks; optimization of the operating conditions of the heating networks; finding ways to decrease the consumption of metal on heat transport systems; single-pipe transport of heat from HPP's, CPS's and nuclear sources outside of cities; improvement of channelless laying of heating networks; improvement of structural elements and equipment of heating networks.

Combined operation of HPP's and regional boiler stations on common heating networks

The development of the majority of heat supply systems begins with the construction of boiler stations, and only subsequently, with increase of the heating loads to levels justifying the construction of an HPP, is the system transferred to cogeneration.

In industrial centers, boiler stations are usually located directly on sites set aside for construction of HPP's and are built as peak sources of heat for these HPP's.

In cities, where for territorial, architectural, health and other reasons it is difficult to construct HPP's and they are moved outside of the cities, advance construction of regional boiler stations is performed directly in the heat demand regions, since location of them on the territory of the future HPP's requires advance construction of long heating networks.

Staged development of heat supply for cities using existing and newly constructed large boiler stations in the heat demand regions in the beginning as the main sources of heat followed by conversion of them to peak sources and conversion to cogeneration provides:

- The best correlation of the schedules for introduction of heating capacity of the heating sources and of the users of heat energy without idling of capital investment and unproductive costs for construction of temporary boiler stations;

- Decrease of the capital investment for construction of heat transmission networks between the HPP's and regional boiler stations and the consumption of electrical energy on transport of the heat carrier due to the possibility of using high temperature schedules for regulation of the heat output without actually increasing the design temperature of the heat carrier in the transit heating pipes;

- A high degree of reliability of the heat supply system due to the location of not less than 50% of the heating capacity of the heat sources directly in the heat demand regions, especially in open heat supply systems, where in an emergency situation it remains possible to supply the design mean hourly water flow for hot water supply from the HPP;

- Rapid reaching of the design technical-economic characteristics by the energy equipment due to timely preparation of the heating loads and construction of heating networks.

Regional and large industrial-heating boiler stations built in a city should be designed with consideration of their subsequent use in the cogeneration systems and should be located on the track of possible directions of heat transport from the HPP's.

Improving the reliability of heating networks

The increase in the reliability of large centralized heat supply systems and improvement of their operating conditions result in a sharp division of the heating networks into main line and distributive parts. This division may be accomplished on connection of distribution networks to main lines through regional heating points (RHP's).

The heating load of regions connected using RHP's is chosen to be 40-60 Gcal/hr. The RHP's are equipped with metering and monitoring instruments, automatic regulation and remote control equipment, and circulation and make-up pumps for creation of autonomous circulation in the distribution network and make up for the distribution network on emergency disconnection. When necessary the RHP's are also equipped with mixing and booster pumps, making it possible to maintain hydraulic and temperature conditions different from the operating conditions of the main heating pipes in the distribution networks.

Distribution networks from RHP's should usually be of the two-pipe dead-end type. It is recommended that each user be connected to the distribution network through individual heating points (IHP's), and a dependent or independent plan be used depending on the height of the building and the layout of the distribution network.

Increase of the size of connection nodes and creation of RHP's simplifies organization of the monitoring and control of the heat supply system, since one main with heating load of about 1000 Gcal/hr will have a total of 20-25 connection nodes.

When a region has two or more mains it is recommended that they be joined by reserve connectors, providing heat service for the majority of users during an emergency situation in the heating network mains.

A distribution network reserve is usually not provided, since the pipe systems do not exceed 300 mm in diameter and any failure can be corrected in a few hours. Users who do not permit even brief disconnection of the heat supply (hospitals, child care, etc.) should have their own reserve heat sources.

Optimization of the heat output regulation temperature schedules

One method of decreasing capital investment on the construction of heating networks and operational costs on transport of thermal energy is increase of the heat output regulation temperature schedules.

The optimum temperature schedules are calculated on a computer.

Increase of the design temperatures in the feeder pipes from 150°C to 180-200°C leads to decrease of the capital investment in the heating networks from 2 to 30% depending on a number of factors:

- The length of the transit heat pipes;
- The design heating load and its density;
- The heat supply system (open or closed), etc.

Increase of the temperature schedules necessitates an increase in the cogeneration bleeds of the turbines, and in a number of cases to use of the steam of industrial bleeds with a corresponding decrease in the production of electrical energy on the heating demand. Depending on the type of turbines, the heat supply system and the proportion of the hot water supply load the yearly fuel loss for each 10°C of increase of the design temperature of the network water is from 2 to 6 tons for each Gcal/hr of connected heating load.

Increase of the heat output temperature schedules also causes a decrease in the available capacity of the HPP and of the yearly output of electrical energy, which requires corresponding compensation in the power system. The optimum water temperatures should be chosen in each individual case on the basis of technical-economic calculations with consideration of all local conditions.

Increase of the design temperatures in the feeder pipes to 170-190°C proves to be economical in many regions of the country with a length of the transmission heat pipes of over 6-8 km.

Single-pipe transport of heat

The widespread adoption of open heat supply systems in the USSR with direct selection of network water for hot water supply, as well as increase of the proportion of hot water supply load in the total heating load create favorable conditions for organization of single-pipe transport of heat. Conversion to single-pipe transport of heat, eliminating return of the heat carrier, will permit a sharp reduction of the consumption of materials for heating networks and the capital investment on their construction, decrease the consumption of electrical energy and increase the total efficiency of the cogeneration systems.

An invariable condition of use of single-pipe transport of heat is provision of a balanced flow of network water for heating-ventilation needs and hot water supply for users, excluding loss of water and heat with wastes.

Waste-free operation may be achieved by finding possibilities for transfer of excess network water to other heat sources; increase of the temperature of the network water at the HPP outlet; and decrease of the proportion of heat produced by the base heat supply source, i.e., reducing the cogeneration coefficient.

A balanced flow of network water in the region itself (with a single heat source) may be achieved only in the southern regions of the USSR, where the proportion of the hot water supply load in the total heating load reaches 0.33. Here the temperature of the network water in a single-pipe main under the design conditions should be 200°C.

Single-pipe centralized heat supply systems with balanced flow of network water may be used in practically any region with use of cogeneration, when the main heat source (HPP or CPS) is located at a significant distance from the users and the peak sources are located directly in the heat demand regions. Here only the connecting (transit) mains between the main and peak heat sources are single-pipe, and the heating networks from the peak heat sources to the users are two-pipe. In this case balancing of the water flow is achieved by increasing the heat output regulation temperature schedule.

In practicality of using single-pipe heat transport systems in given objective situations should be based on the necessary technical-economic calculations, performed with consideration of all local factors and construction conditions.

Improvement of channelless laying of heating networks

The use of channelless laying permits approximately a 50% reduction in costs on construction operations and a 25 to 40% decrease in costs for construction of underground pipes with a simultaneous reduction of construction labor costs by not less than a factor of 2 or 3.

The greatest economy is provided by conversion to nonchannel laying of branch heating networks with a standard diameter of less than 300 mm. Conversion to channelless laying also permits an acceleration of the installation of heating networks due to simplification of construction-installation operations under the cramped conditions of municipal development.

In the USSR we have over 40 years of experience in channelless laying. In 1930-1950 a significant part of the heating networks were laid channelless. However, due to a number of deficiencies in construction the extent of channelless laying decreased in recent years.

At the present time the main channelless laying designs of heating networks are designs in asphalt-perlite and reinforced foam concrete.

Channelless laying designs with thermal insulation based on asphalt-perlite provide a decrease of the initial costs for construction of heating networks of up to 35-40%. This design was widely used in many cities and rural areas. In the ninth and tenth five-year plans the national economic efficiency of conversion to channelless laying of heating networks served as the basis for construction of about 70 technical lines. A deficiency of this design, based on the use of high-melting asphalts with thermal insulation filler, is the high sulfur content in the asphalts used, having the property of aging and forming cracks, which permits corrosion of the outside surface of the pipes and does not provide the design service life of the heating network. This design can be improved by improving the temperature stability of the asphalt-perlite, preliminary anti-corrosion protection of the pipes, and providing good sealing and strength of the covering water resistant layer, applied in the form of a continuous polymer sheath 3 to 4 mm thick.

Since 1949 Leningrad has been using a design for channelless laying of heating networks of autoclave-type reinforced foam concrete.

Due to the possibility of mass production and due to its economy this design has practicallv replaced all other methods of underground laying of heating networks in Leningrad, providing a decrease in the capital investment of up to 20-25%, especially on heat pipes of large diameter from 300 to 1000 mm. On heat pipes of smaller diameters the decrease in costs on construction of heating networks was 5 to 7%. A deficiency of this design is the hydrophilic nature of the foam concrete and the structure as a whole, in spite of the presence of a three-layer water resistant coating (of Izol or Brizol) and the asbestos-cement plastering. This is explained by the corrosion of the pipes, especially at sites of passage of the heat pipes through walls and on the adjacent segments. Another deficiency of this design is the high initial costs for construction of the production base, which with poor transportability of the insulated pipes limits the zone of practical use of the design to large cities with a large amount of construction of heating network mains.

The USSR is also developing and using other types of non-channel laying designs: asphalt-Izol, asphalt-porous clay filler-concrete, phenolic porous plastic, etc., however, these designs have not yet been widely used.

Improvement of heating network designs

Work to improve heating network designs is underway in the USSR in a number of directions.

The main material used for transport of thermal energy is metal, the economy of which is of particular national economic importance. The use of pipes of low-alloy steels with reduced wall thickness on main lines alone will permit a decrease in the consumption of metal by 15-20% without increasing capital investment for construction.

A decrease of the metal consumption of heat pipes results from the adoption of nonmetallic pipes (asbestos cement, plastic, etc.) in distribution heating networks of diameter up to 200 mm at heat carrier temperatures up to 100°C, and also in hot water supply systems.

The use of enameled pipes for heating networks significantly increases the service life of the heating networks and the reliability of the heat supply systems, permitting elimination of a number of measures directed toward increase of the reliability of heat transport systems.

At the present time work is underway toward widespread use of lens expansion pieces in place of П-shaped and packing expansion devices in heating networks. The replacement of П-shaped expansion devices with those of the lens type, in addition to decreasing the consumption of materials and the capital investment in the heating networks by up to 10%, will provide a decrease in the consumption of electrical energy on pumping of the heat carrier by up to 25-30% and will simplify the laying of heating networks under the close conditions of cities.

An improvement in the existing designs of channel laying of heating networks is made in the direction of increase in the mass production of the individual elements with conversion to large-unit installation of factory ready units.

Underground laying makes wide use of designs on a pile foundation, low laying at a height of up to 1.2 meters above the ground, and roller and ball supports for the pipe systems.

Operation of heat supply systems

The organization structure of heating network operation in the USSR varies and is largely dependent on local conditions - the size of the heat supply system, its ownership, the nature of the heat users and other factors. From the operational point of view heat supply systems may be divided into 3 groups:

The first group includes heat supply systems from city block boiler stations with water-heat or steam boilers. These systems are usually fully serviced by residential organizations.

The second group includes associations of city block and regional boiler stations and the heating networks from them, controlled by the same management.

The third group includes heat supply systems from general purpose HPP's or industrial HPP's. In this case the HPP's and the heating networks from them are serviced by various USSR Minenergo power system enterprises. The heating network operation enterprise, receiving thermal energy from the HPP, provides transportation of the energy through external networks, distribution to the heating points of the users and monitoring of its use. The release of the heat is performed in accord with agreements which stipulate the mutual obligations of the parties.

Normal heat supply is possible only with strict observation of the hydraulic conditions of each of the users.

In large heat supply systems there is usually a two-stage dispatcher control plan - a central dispatcher point and a regional dispatcher point. Monitoring of the operation and condition of the equipment in the users' installations is provided through combined dispatcher points (CDP's), subordinate to the residential organizations. In this case from one point (CDP) monitoring of the operation of several tens of subscriber heating points is organized.

Within a large municipal operational organization there are usually several operational regions. The main problems of the operational region are: organization of observations of the technical condition of the networks, prophylactic maintenance on them, distribution of circulating water to subscribers and monitoring of its use.

In accord with these problems the operational region should have an on-duty service and maintenance and operational personnel. The performance of large-scale maintenance operations involving laying of underground pipe systems is usually accomplished either by specialized construction-installation organizations or by the maintenance shop of the operational service.

PAPER NO. 4

"TEPLOELEKTROPROEKT"

COGENERATION NUCLEAR POWER STATIONS AND BOILER STATIONS - PROBLEMS AND FUTURE OUTLOOK

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JOINT-SOVIET AMERICAN SYMPOTIUM ON REMOVAL OF HEAT FROM FOSSIL FUEL AND NUCLEAR POWER STATIONS

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INTRODUCTION

The modern stage of development of energetics in the USSR and throughout the world is characterized by expansion of its fuel base by utilization of nuclear fuel for production of electrical energy.

Considering that at the present time about 40% of fossil fuel is being consumed for the production of thermal energy, in addition to the widespread adoption of nuclear fuel for production of electrical energy, it becomes very important to use it for purposes of centralized heat supply.

The development of cogeneration and heat supply on the basis of nuclear sources is of great interest first of all from the point of view of replacement of scarce fossil fuel (gas, mazut, coal) with nuclear fuel.

By 1990 we expect a significant increase in the heat demand. In structure of heating loads the main type of centralized heat supply sources continues to be industrial-heating heat-and-power plants (HPP's) and boiler stations with a load range from 500 to 5000 Gcal/hr; here the majority of these plants will have a predominant heating load in hot water.

At the present levels of fossil fuel and electrical energy costs in the USSR it is economically favorable in the European part of the USSR to use nuclear HPP's (NHPP's), beginning with a heating load in hot water of 1500 Gcal/hr and over and nuclear heat supply stations (NHS's) in the 600-1500 Gcal/hr load range.

The recent tendency for increase in the cost of fossil fuel, especially gas and mazut, leads to a decrease in the minimum heating loads covered from nuclear heat supply sources.

In addition, with significant unit capacities of the heat supply sources, in addition to the problem of providing them with fossil fuel, we have the problem of protection of the purity of the air basin, providing railway transport for fuel supply, construction of tall stacks, etc. The use of nuclear sources for heat supply significantly simplifies solution of these problems.

In 1973 the Bilibino Nuclear HPP with capacity of 48 MW, the first in the USSR, was put into operation with maximum heat output of 100 Gcal/hr.

At the present time preparatory operations are underway for widespread use of nuclear energy to cover heating loads from nuclear HPP's, condensation-cogeneration nuclear power stations and nuclear heat supply stations.

Below we examine the main design proposals, selection of equipment, safety problems and other problems of creating nuclear heat supply sources.

NUCLEAR HPP's

Proceeding from present operating experience concerning the reliability and radiation safety of various types of reactors and their technical-economic characteristics, for nuclear HPP's at the level of up to 1990 the installation of VVER-1000 and VVER-500 reactors is planned.

It is proposed that the composition of the turbine equipment for NHPP's be chosen in accord with the capacity of the reactors with the possibility of creating reactor-turbine blocks, for the VVER-500 and reactor-two turbine blocks for the VVER-1000. These turbines, having large cogeneration bleeds, are not presently produced by the industry of the USSR.

The special cogeneration-condensation and cogeneration turbines, type TK-500-60 and T-500-60 are being developed. The turbines are characterized by the level of the maximum heating bleed and the minimum steam passage to the condenser.

They have the following characteristics:

Live steam pressure	60 kg/cm^2
Rated electrical capacity	500 thous. kW
Rotation rate	3000 rpm
Steam consumption to turbine	3200 t/hr
Maximum heating load	
-for the TK-500 turbine	450 Gcal/hr
-for the T-500 turbine	900 Gcal/hr

Two-block and four-block NHPP's are examined with VVER-1000 and VVER-500 reactors, designed to cover a total heating load from 1500 to 6000 Gcal/hr at a cogeneration coefficient of 0.6 (the ratio of the thermal power of the NHPP turbines to the total heat demand).

For peak-reserve stations it is planned to use existing and new boiler stations operating on fossil fuel, the yearly consumption of which here will be about 10-15% of the total consumption if there were no nuclear sources.

The variants with VVER-1000 reactors provide for installation of two T-500 or TK-500 turbines per block, with VVER-500 reactors for each turbine of the same type in each block.

The first circuit includes the reactor and a number of systems, the most important being the following:

- The main circulation circuit,
- The first circuit blowout-makeup system,
- The emergency systems for cooling of the active zone and suppression of the pressure in the sealed compartments of the first circuit, etc.

The second circuit includes two turbine units and the corresponding block systems.

The network heating installation system forms the third circuit and includes the block system for heating and transport of the network water and the general station heating network make-up system.

The heating of the network water is accomplished successively in two stages by 0.4-2.0 atm and 0.6-3.0 atm bleed steam. For each TK-500 turbine there are four network preheaters, two connected in parallel for each heating stage.

Stage I and II network pumps are provided. The pressure of the network water after the first network pump stage is greater than the maximum possible pressure of the upper heating bleed, which excludes entry of radioactivity into the network water on loss of seal of the network water heater surface.

The reactor portion of each block consists of a sealed protective shell designed for full pressure on emergency outflow of the first circuit heat carrier and a peripheral volume, adjacent to the shell, all on a rigid platform base.

The layout of the machine hall is examined with transverse and longitudinal placement of the turbines.

The equipment layout of a main building with VVER-500 reactors may have the same basic designs as with VVER-1000 reactors with longitudinal placement of the turbines.

An NHPP with two VVER-1000 reactors and four TK-500 turbines may put out to the user a maximum of 1800 Gcal/hr respectively without consideration of peak sources.

Depending on the users' heating load levels, for this type of point the installation of the corresponding equipment at NHPP's may be recommended. Here the selection of the main equipment may largely depend on the space conditions of the region where construction of the NHPP is planned. For example, with unfavorable heat removal (cooling) conditions and a small increase in the electrical loads in the given region it may prove economically practical to install VVER-500 reactors with T-500 turbines, which at the same heat output require half the cooling water of NHPP's with TK-500 turbines.

At the present time nuclear HPP's are planned at a significant distance from the prospective city limits. Meeting this condition requires procurement of a large quantity of pipe to lay the heating network mains. For example, transport of 1800 Gcal/hr of heat in hot water at a temperature of 120-130°C from an NHPP with capacity of 2.0 million kW requires up to two thousand tons of large diameter pipe to lay each km of heating system main. This great consumption of metal and large diameter pipes for transport of heat from NHPP's should be taken into consideration in solving questions concerning planning of the direction of development of NHPP's and NHS's. Variants of increasing the temperature of the network water from the HPP's are being examined in order to decrease the consumption of metal on heating networks, as well as systems with open hot water collection with a single-pipe network.

Many years of operating experience with nuclear power stations, both in the USSR and abroad, shows that stations with water-water reactors during normal operation have comparatively low radioactivity of the heat carrier in the first circuit, as well as low discharges of radioactivity through the ventilation stack, which provides good station safety with practically no unfavorable effect on the environment and population.

Even when making all unfavorable assumptions in the projects, the calculations show that the operating discharges, as iodine, from the two power units of an NHPP with VVER-1000, are less by a factor of 3, and as aerosols are less by a factor of 10 than stipulated by the "Sanitary rules".

Thus we may assume that the total discharge of radioactivity from NHPP's will be insignificant, at the level of several percent of the allowable.

NHPP developments also consider various emergency conditions which may arise during operation.

The maximum emergency is considered to be instantaneous transverse bursting of a main circulation pipe with diameter of 850 mm.

In order to provide safety in this emergency situation there are various protective devices, to limit the damage of the active zone of the reactor, and localizing devices, to limit the spread of radioactive substances.

All the systems responsible for station safety are designed with high safety factors, are completely independent of each other and from external energy supply sources.

The doses of internal and external irradiation of the population at the limit of the sanitary protective zone during the maximum emergency considered will be significantly less than that stipulated by the normative documents.

In order to bring nuclear HPP's closer to the heat users in the future problems of further improvement of the safety of NHPP's are being studied.

The network water heating systems at NHPP's exclude the possibility of radioactive contamination of the network water both during normal operation and during emergencies, for which the NHPP's have:

- A three-circuit heat output system;
- Heating of the network water by turbine bleed steam is performed only through the heat transmitting surface of the network preheaters;
- Pressure of the heating medium (bleed steam) below the pressure of the network water;
- Disconnection devices (valves) are provided, automatically disconnecting the bleed steam to the heat exchangers during operation of the emergency protection of the reactor and on decrease of the network water pressure below the pressure of the heating

medium. Duplicated valves are installed on the network water pipe systems, disconnecting the cogeneration equipment on appearance of radioactivity in the network water and on decrease of the network water pressure below the heating medium pressure, there is continuous monitoring of the radioactivity of the network water and the heating medium of the second circuit and the corresponding warning and emergency signals are transmitted.

Calculations show that NHPP's with VVER-1000 reactors have better characteristics and that this type of reactor will apparently be the basis for solution of the problem of centralized heat supply from nuclear HPP's up to 1990.

PROBLEMS OF INDUSTRIAL STEAM SUPPLY FROM NHPP's

Steam takeoff directly from the turbine bleeds for industrial process needs is unallowable due to possibility of radioactivity on leakage of steam generator tubes. Thus in order to obtain and send out industrial steam, the NHPP system should include a third circuit with steam converters.

Using this system the pressure of the industrial steam (third circuit) is less than the pressure of the heating steam. In an emergency situation on bursting of pipelines or steam converter collectors, the third circuit may receive steam from the second circuit for the time necessary for localization of the problem. Here, evaluations show that the integrated discharge of radioactivity will not exceed the annual intake (AI) stipulated by the norms.

The pressure of the industrial steam which can be obtained using this system is determined by the pressure of the bleed steam entering the evaporator and by the level of heating necessary to provide transport of the steam, since on increase of the pressure of the secondary steam there is a decrease in its possible heating by the live steam.

Assuming that the temperature of the live steam ahead of the turbine is 274°C, the maximum temperature of heating of the output steam may not be over 260-265°C.

Analysis of the industrial loads of the users shows that the greatest steam demand is for steam with a pressure of 10 to 13 kg/cm^2 at the user. In order to prevent condensation of moisture during transport of steam through the users' networks, leading to hydraulic shocks in the networks, the steam should enter the users' heating points in a superheated state, superheated by 30-50°C with respect to the saturation temperature at the final pressure.

Hydraulic analyses of the steam systems show that steam at 18 kg/cm^2 and 260°C may be transmitted from the NHPP to the users' heating point for a distance of up to 7 km with final parameters of 13 kg/cm^2 and 235°C.

Decrease of the final parameters of the steam at the industrial heating points to 10 kg/cm^2 and 215°C makes it possible to increase the distance of transport of the steam to 11 km at an initial pressure of 18 kg/cm^2 and 12 km at 22 kg/cm^2.

Taking the above into consideration, it appears possible for an NHPP with water-water reactors to produce industrial steam at high flow rates for large-scale industry outside the city and at a distance of not over 10 km from the NHPP. Here the industry should use steam of relatively low parameters, and regularly throughout the day and year.

CONDENSATION-COGENERATION NUCLEAR POWER STATIONS

The problem of using large condensation turbines installed at standard nuclear power stations for transport of heat to users from unregulated bleeds is considered.

Soviet industry is presently producing the K-500-60/1500 condensation turbine for nuclear power stations with VVER-1000 reactors; the K-1000-60/1500 turbine is in the preparation stage.

These turbines are provided with a small heat output up to 60 Gcal/hr, which is used for heating of the buildings of the nuclear power station and residential site.

The heat output from the unregulated bleed of the K-1000-60/1500 turbine may be increased to 200 Gcal/hr without modification of the turbine; here it is necessary to install a three-stage boiler system, which necessitates changing of the layout and certain structural changes. It is also possible in principle to increase the heat output from this turbine to 400-500 Gcal/hr. This, however, requires significant modification of the design and thermal system of the equipment.

Proceeding from the above, the use of condensation nuclear power stations appears favorable for heat supply to nearby populated areas with moderate heating loads. For example, a nuclear power station with capacity of 2000 MW (2xK-1000-60/1500) may without significant modification handle, together with peak sources, the residential and industrial heating loads in hot water of a city with population of 200 to 250 thousand.

Calculations show the economic feasibility of using unregulated bleeds of nuclear power station condensation turbines to provide an increased heat output.

NUCLEAR HEAT SUPPLY STATIONS

One of the main tasks in solving problems of centralized heat supply from nuclear sources is meeting the conditions of their maximum proximity to users of thermal energy.

This condition may be most fully met by the nuclear heat supply station (NHS) variant presently being developed in the USSR, which is designed to produce only thermal energy with transmission of hot water with a maximum temperature to 150°C to users. The purpose of the NHS permits us to consider the use of a low-potential reactor of relatively low capacity.

The thermal capacity of one of the reactor variants is 500 MW (430 Gcal/hr).

An NHS with two such units is being considered, which together with peak heat sources may cover a total regional heating load of about 1500 Gcal/hr.

The reactor is a heterogeneous integral water-water device.

The pressure in the reactor is provided and maintained by a steam system, built into the reactor, for pressure compensation by partial boiling of the heat carrier in the upper part of the active zone.

The NHS operates on a three-circuit system (main, intermediate and network circuits); the pressure in the intermediate circuit is lower than in the network circuit, which excludes leakage into the network water sent to the user. The use of natural circulation of the heat carrier in the first circuit permitted layout of all the main circulation circuit inside a single shell with outlet from it of only small make-up and blowout pipe systems of the first circuit and the pipes of the intermediate circuit.

The intermediate circuit is nonradioactive, consisting of three heat bleed loops from the reactor and transmission of it to the network water.

The consumption of network water in the heat mains from the NHS will be about 10,000 t/hr and will depend on the connection system to the heating networks of the NHS and the peak sources.

In project developments of NHS's additional measures are considered to assure safety in bringing nuclear installations near large citites.

The main building of an NHS with output of 860 Gcal/hr consists of the reactor divisions of two blocks, a special built-in water treatment plant, shops with a fresh fuel unit and a water treatment unit.

A total demand for make-up water at an NHS with consideration of the consumption for chemical water treatment, SVO [sedimentation water treatment?], and potable water needs is only 500 to 600 m^3/hr with location of 50% of the heat network make-up installation at the NHS and a closed hot water supply system.

The proximity of NHS's to large cities and connection of the users with the station through the network water very acutely poses the problem of assuring radiation safety.

The main requirements are:

- Exclusion of dangerous gaseous discharges of radioactivity;
- Assuring safety in emergency situations;
- Reliability of the cooling of the active zone under all operating conditions;
- Full exclusion of the possibility of entry of radioactivity into the network water.

The low parameters of the heat carrier of the first circuit and the low reactor capacity permit significant simplification of the design of the reactor itself and the system of the installation which, on the whole, makes it possible to solve the problem of ensuring safety at a qualitatively higher level.

The operation of the active zone of an NHS reactor is characterized by significantly less heat stress than at nuclear power stations, which creates fewer possibilities of damage to the fuel elements, and as a result of which it appears allowable to operate the NHS's with a smaller number of unsealed fuel elements (heat-emitting elements). Here the calculated specific activity of the heat carrier of the main circuit is 1 or 2 orders of magnitude below the specific activity assumed for a nuclear power station, and the calculated discharge of radioactivity to the atmosphere during normal operation of the MHS is less than 1 curie-day.

The calculated dosage of radiation of the population at the boundary of the sanitary-protective zone during normal operation of the NHS due to discharge of radioactive products through the ventilation stack does not exceed 1% of the dosage created by the natural background at the site.

Due to the fact that the entire main circulation circuit is located inside the reactor housing the maximum pipeline which may leak and lead to discharge of the radioactive heat carrier of the first circuit in the NHS building is determined by the auxiliary make-up systems - the blowout of the first circuit and its diameter is evaluated at 80-100 mm with a narrowing device about 32 mm.

In evaluating the doses of irradiation of the population with a safety factor it is assumed that as a result of a maximum emergency there will be leakage of 10% of the fuel element shells.

Here the calculated total dosage of irradiation of the population at a distance of 1000 meters from the site of discharge is less than the natural background of the site.

Among the measures providing protection of the network water against the entry of radioactivity are:

- The three-circuit network water heat transmission system;
- Continual blowout of the intermediate circuit with continual monitoring of the radioactivity in it and disconnection of the loop on appearance of radioactivity;
- A higher pressure in the network circuit than in the intermediate circuit, excluding the entry of radioactive water into the heating network even during an emergency leak of the network heat exchangers;
- Disconnection of heat users from the NHS automatically by operation of valves on a pressure drop in the heating network with one-time leakage of a network heating surface.

From technical-economic comparisons of variants of heat supply sources on fossil and nuclear fuel with a total heating load of 1500 Gcal/hr it follows that:

- A nuclear heat supply station with output of 860 Gcal/hr has lower relative costs than a nuclear HPP with 500 MW power units;
- With consideration of the tendency for increased cost of fossil fuel a nuclear heat supply station becomes more effective than HPP's or boiler stations on fossil fuel.

In comparison with other possible centralized heat supply sources a nuclear heat supply station has its advantages. Low heat carrier parameters and relatively low capacity of the reactor unit permit:

- Significant simplification of the reactor design with manufacture of the housing at plants not having special equipment;
- Assurance of a high level of safety by accessible means;
- The use of measures to protect the main equipment against external mechanical effects;
- Reduction of the distance of the NHS from large heat users to a distance of 2-3 km.

The location of nuclear heat supply stations in direct proximity to large populated areas, in turn, permits:

- Significant reduction (in comparison with an NHPP) of the capital investment and metal demand of large diameter pipes for construction of heating mains;
- Significant decrease of the appropriation of valuable urban land for construction of heat mains;
- Displacement from the fuel-energy balance of the region of fossil fuel with an unburdening of the fuel transport load into the city in the amount of 0.8 million tons of reference fuel per year;
- Improvement of the sanitary condition of the municipal air basin;
- Significant reduction of the demand for industrial process water, which is scarce in many cities.

Guarantees of radiation safety of nuclear heat supply stations, their economic efficiency and the advantages listed above permit us to consider nuclear heat supply stations, in addition to nuclear HPP's, to be a promising source of centralized heat supply to residential-public and industrial users.

YEARLY GRAPH OF HANDLING OF HEATING LOAD

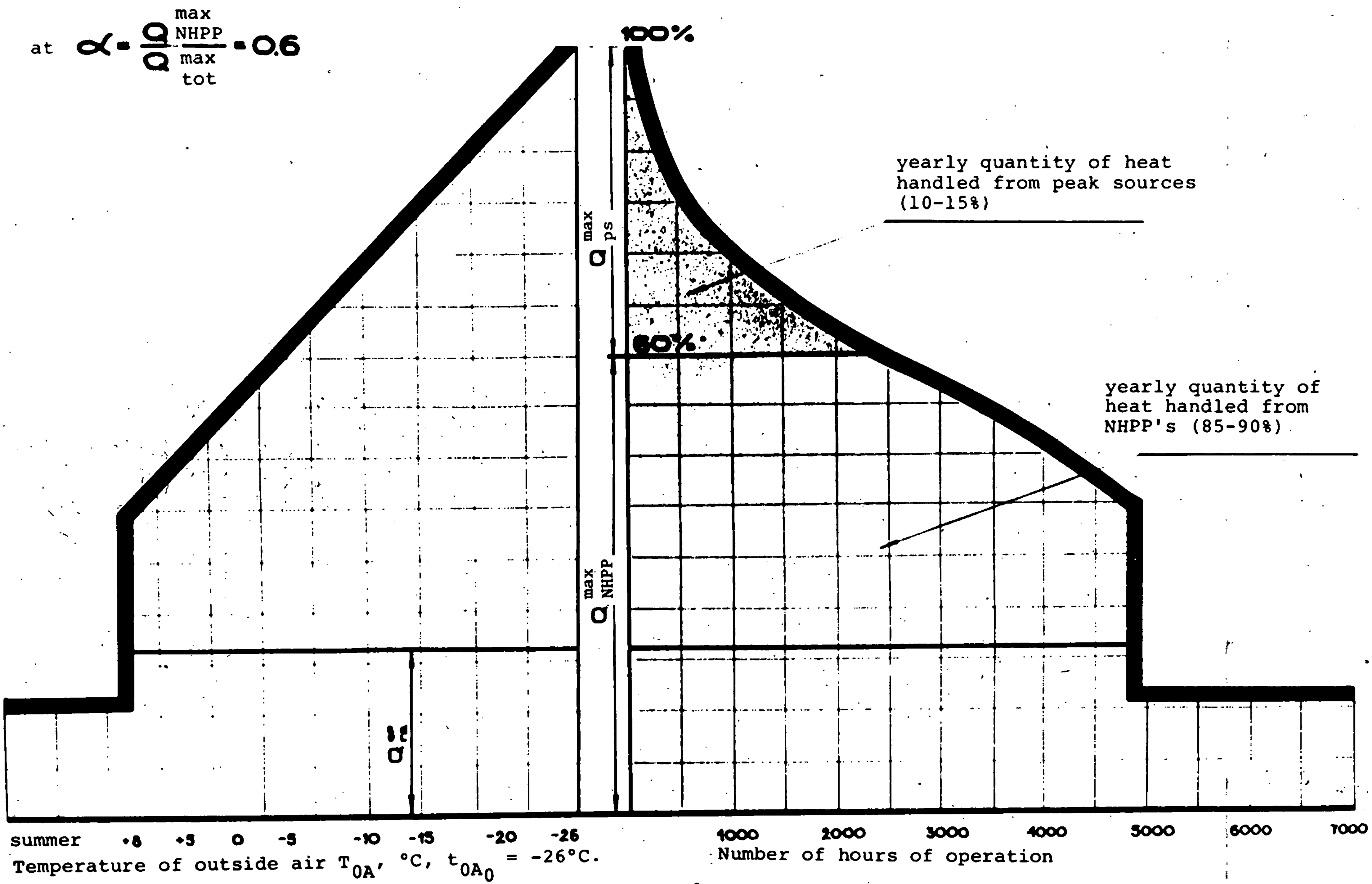
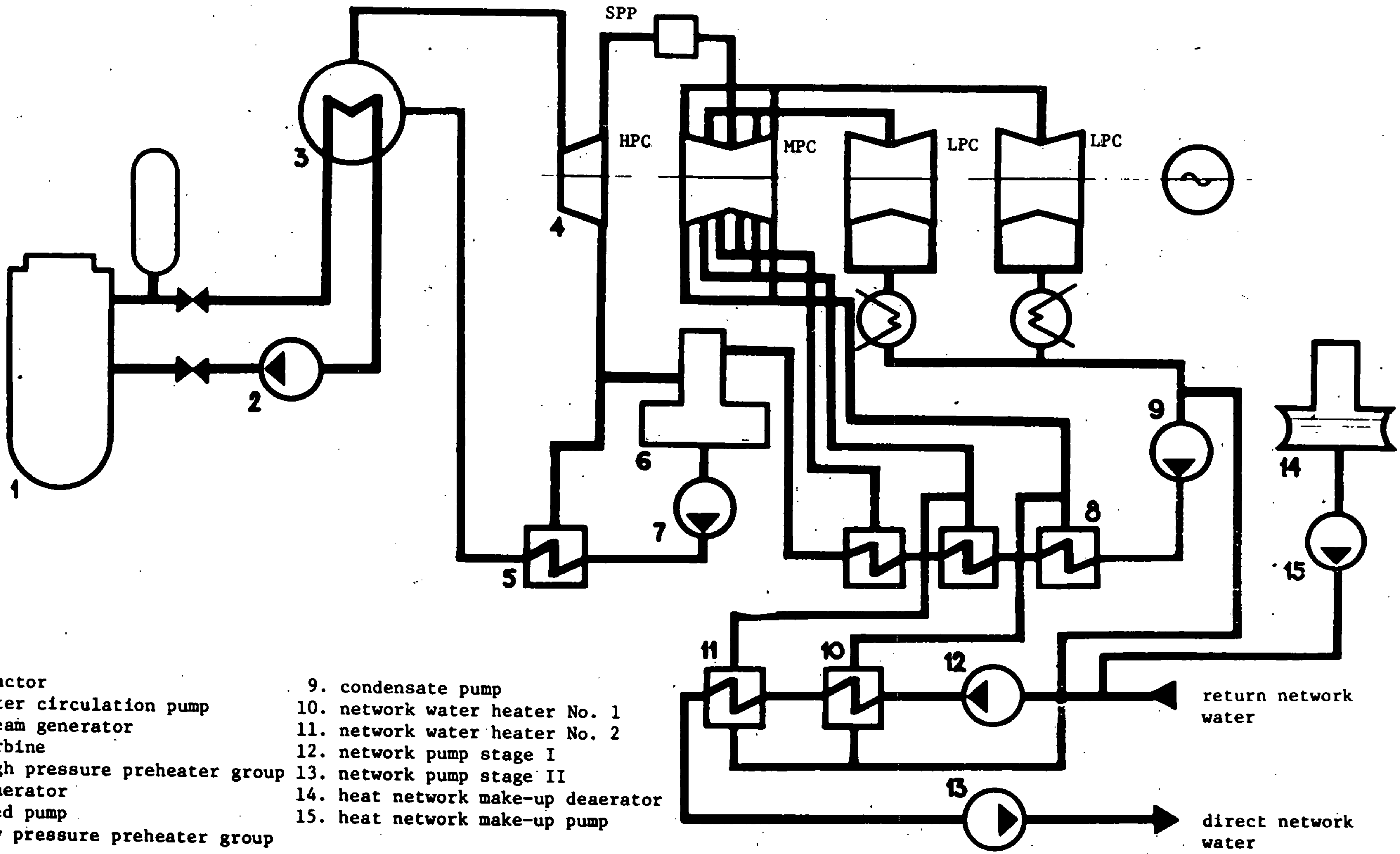


Figure 1.

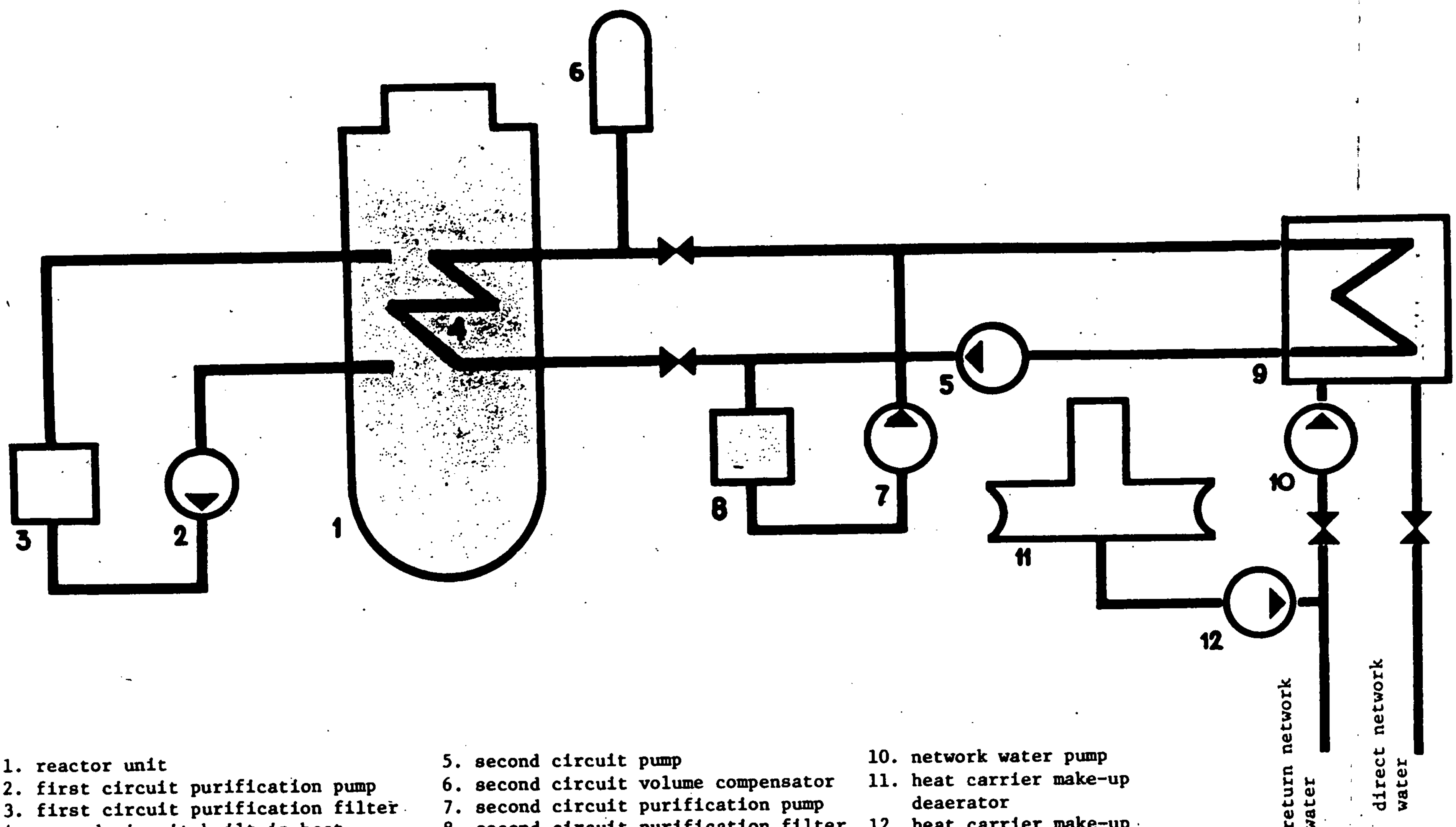
DIAGRAM OF HEAT OUTPUT FROM NHPP



1. reactor
2. water circulation pump
3. steam generator
4. turbine
5. high pressure preheater group
6. deaerator
7. feed pump
8. low pressure preheater group
9. condensate pump
10. network water heater No. 1
11. network water heater No. 2
12. network pump stage I
13. network pump stage II
14. heat network make-up deaerator
15. heat network make-up pump

Figure 2.

DIAGRAM OF HEAT OUTPUT FROM NHS



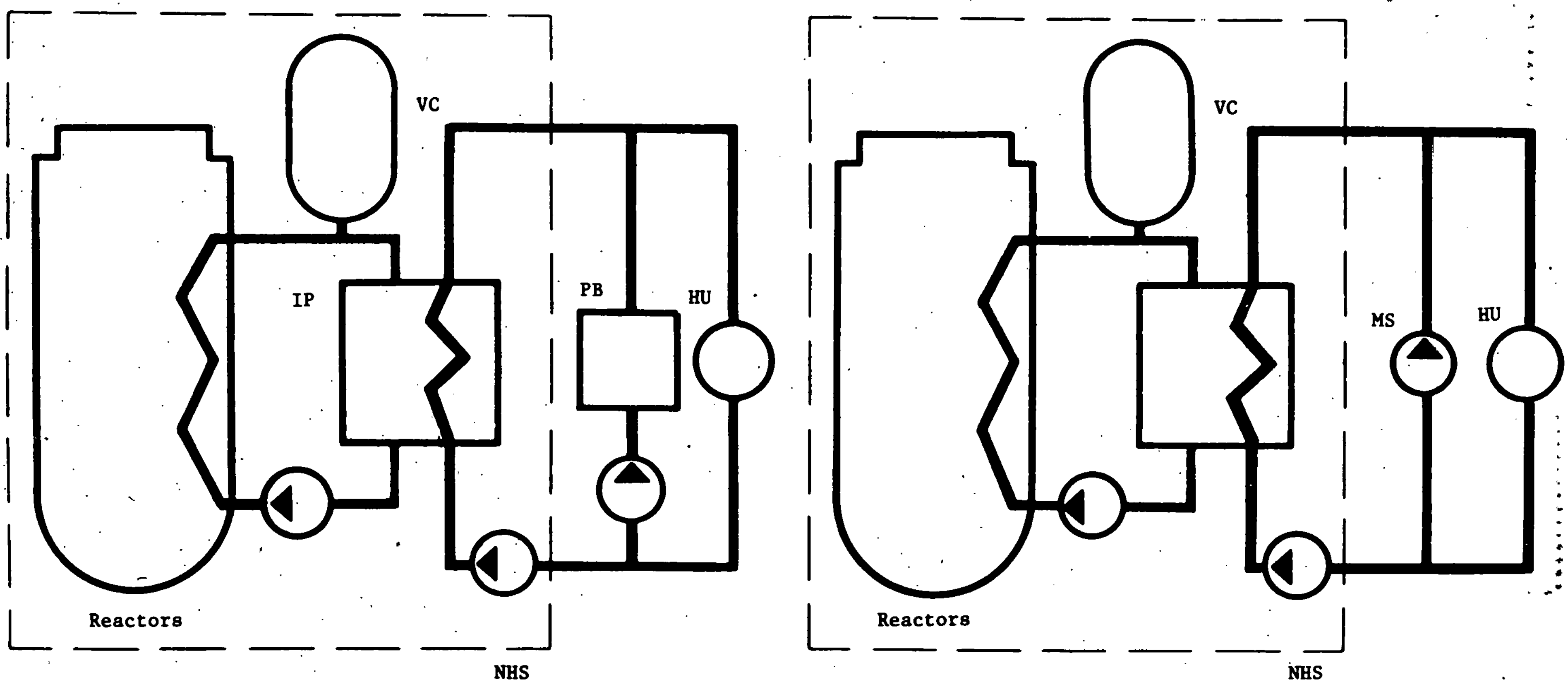
1. reactor unit
2. first circuit purification pump
3. first circuit purification filter
4. second circuit built-in heat exchanger
5. second circuit pump
6. second circuit volume compensator
7. second circuit purification pump
8. second circuit purification filter
9. network water heater
10. network water pump
11. heat carrier make-up deaerator
12. heat carrier make-up pump

Figure 3.

DIAGRAM OF HEAT SUPPLY FROM NHS

Diagram of NHS with peak boiler

Diagram of NHS without peak boiler



IP--NHS intermediate circuit preheater;
PB--peak boiler;
HU--heat user;
VC--volume compensator;
MS--mixing substation.

Figure 4.

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PAPER NO. 5

HEAT-POWER INSTITUTE

A SYSTEM OF HEAT REMOVAL FOR AN ELECTRIC POWER STATION LOCATED IN A DRY SUBTROPICAL CLIMATE

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JOINT SOVIET-AMERICAN SYMPOSIUM ON REMOVAL OF HEAT FROM FOSSIL FUEL AND NUCLEAR POWER PLANTS

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Razdan

INTRODUCTION

One of the main problems which must be resolved in designing a new electric power plant is the matter of removing heat from main and auxiliary equipment.

Traditionally, withdrawal of heat of electric power plants is accomplished with the use of water. However, this method is not suitable if the power plant is to be located in a water-poor region for reasons of proximity to fuel sources or power consumers.

One must attack this problem in earnest in the construction of a power station in the arid and desert regions of the earth, specifically in the dry tropics.

The dry tropics are characterized by high air temperature, low humidity, low rainfall and few fresh water sources. Fresh water is primarily used for drinking and agricultural purposes.

The way out of this situation may be the use of a closed air-condensation system to cool both the basic circuit of the power station as well as the auxiliary equipment.

The merits and the shortcomings of the air-condensation system are well known. In these closed systems there are practically no losses of water. In winter a sufficiently deep vacuum in the turbine condensers can be secured. In addition, problems connected with the intake of mineralized cooling water into the feed water of boilers are eliminated.

The chief shortcoming is the fact that, even if the air cooling elements have extended surfaces, the nominal capacity of the energy block can not be ensured at air temperatures above 30°.

In systems with air cooling, heat transfer to the air takes place through the walls of the cooling elements due to surface contact, i.e., due to convective heat transfer. In doing so the air is only heated; its moisture content is not increased, as it takes place in evaporative cooling.

As a result approximately 3 times more air is required for air cooling than for cooling in conventional cooling towers. This is the reason for the increase in the size of draft towers or the number of fans in systems with air cooling while the low coefficient of heat transfer makes it necessary to have highly extended surfaces in the heat exchangers.

With the goal of ensuring the nominal capacity of power blocks during periods with high outside air temperatures a number of proposals have recently appeared regarding the creation of "wet-dry" towers, where evaporative cooling is used along with air-condensation cooling.

The various schemes for combining the wet and dry sections are being discussed: parallel connection for air and water, series connection for air and parallel for water, and other schemes.

However, all these proposals have significant faults and the chief of these is the complexity of the design.

Already the appearance of numerous patents and design developments speaks of the urgency of the matter.

The Teploelektroproekt [Heat-Power] Institute, together with the Institute of Power Engineering of the Bulgarian People's Republic, developed for the Isfahan electric power station in Iran a plan for a combined air-condensation installation, in which wetting of the cooling surface of the peak heat exchangers is specified with the goal of intensifying the cooling process.

The use of irrigation allowed the nominal capacity of the power block to be maintained at air temperatures to 34.5°C, and the drop in power output capacity is less than 5% at the maximal observed temperature, 40°C.

The consumption of water for irrigation of the peak heat exchanger is determined by the number of hours the air temperature has been above 30°C and by the electric load curve.

II. COOLING SYSTEM OF THE ISFAHAN THERMOELECTRIC POWER STATION IN IRAN

The Isfahan thermoelectric power station, capacity 600 MW, has 4 blocks 200 MW each, for series-manufactured turbines type K-200-130.

The power station is located at 1590 m above sea level.

Mazut, which is obtained from a nearby oil refinery, is used as fuel.

The water source is a river which is 22 km from the power station. Meteorological factors of the region in which the power station is located are given in Table I.

The following temperatures and air humidities were assumed as calculation figures:

- mean annual outside air temperature 16.1°C
- absolute maximum outside air temperature +40 °C
- absolute minimum air temperature -10.4°C
- relative humidity (at air temperature of +40.0°C) 10%

In correspondence with the electric load curve, which in summer has a peak at the hot time of the day, the system for combined cooling of the block must ensure the needed temperature for vapor condensation and dispersion of heat with minimum consumption of make-up water. The basic operating parameters of the block cooling system are given in Table II.

The allowable drop of block capacity, at the absolute maximum outside air temperature of +40°C, must not exceed 5% of nominal.

Figure 1 gives curves of the change of block output, temperatures of vapor saturation in condenser and flow of make-up water to irrigate peak coolers in dependence on the operating regime of the block for outside air temperatures from +28°C to +40°C.

The low water supply of the power station, the relatively hot and dry climate of its region, as well as the rigid requirements with regard to the supply of electric power to the consumer, predetermined the selection of the combined system for cooling the blocks of the thermoelectric power station -- a system with an air condensation unit (VKU) and peak-irrigated peak coolers.

The cooling system can operate in three modes depending on the outside air temperature.

In winter and at air temperatures to +30.5°C, the cooling system operates in a "dry tower" mode.

At air temperatures from +30.5°C to 32.5°C the cooling system operates in a transitional mode: part of the thermal load is assumed by blocks of "peak" coolers, which are connected in parallel to the "dry tower". In the transitional mode the "peak" coolers operate without irrigation.

In summer, when the outside air temperature reaches the extreme values at which the peak electric load occurs, the cooling systems operate in a "peak mode": the blocks of "peak" coolers are irrigated, resulting in a sharp increase of heat removal.

Blocks of oil-water coolers are made by analogy with the "peak" coolers.

The cooling of the oil of the turbine and electric feed pumps is performed according to an independent scheme. In the winter the water coolers operate in the main cooling circuit, while in summer they operate according to an independent scheme.

The "peak" regime also calls for irrigation of oil coolers and water coolers. The main advantage of the combined cooling system is the low consumption of make-up water (220 m^3/hr for all the needs of the power station).

Figure 2 shows the technological scheme for the combined cooling of the block of the Isfahan thermoelectric power station.

Spent steam from the turbine exhausts (TsND) goes to a jet condenser (K1, K2), where it is condensed by a flow of cooling water of the same quality as the condensate.

The cooling water heated in the condenser is transferred by circulation pumps to a cooling tower with natural air draft. Fifteen-meter cooling heat exchangers made up of ribbed aluminum panels within which water flows through pipes in two courses are installed in the low part of the tower along its outside parimeter. The panel ribbing ensures efficient heat transfer. Blocks of "peak" coolers made up of 5-meter ribbed aluminum panels are installed within the tower. The blocks are equipped with an irrigating device to wet the surfaces in "peak" mode.

Air ventilation of the cooling circuit of the "dry tower" is provided by the natural draft of a 120 m tower, while that of the "peak" coolers is provided by fans.

Water cooled in the "dry tower" is returned to the turbine condensers.

A quantity of water corresponding to the amount of condensed steam is picked up by the condensate pumps from the condenser or from the return circulation water line and is then transferred through the condensate purification system to the feed water heat up system.

Some of the design and operating features of the equipment of the combined cooling system should be mentioned.

1. Jet condenser.

The condenser is a two-flow condenser with parallel connection to the exhausts of turbines.

Both condenser housings (K1, K2) are made from welded steel sheets.

The cooling water is sprayed by means of spray jets. These jets create a thin film of water which provides excellent heat transfer and deaeration. The hydraulic resistance of the jets is 1-1.5 m H_2O.

A system of perforated troughs in the lower part of the water chambers is provided for cooling of the steam-air mixture being removed by the vacuum pumps.

The jets and perforated troughs are made from stainless steel in order to avoid corrosion.

The lower part of the condenser is fashioned as a condensate receiver, in which an amount of water sufficient for filling of an entire sector of the cooling tower (70-100 m^3) can be collected. Since the cooling water circuit is completely closed and the pressure in the cooling system is above atmospheric pressure, any leakage is unacceptable. The maximum quantity of air taken from the condensate must not exceed 20 kg/hr.

If there are no losses of water in the boiler and in the cooling system, the water level in the condenser should not change. Make-up of water is provided if there are accidental leakages.

Make-up water is supplied by pump from make-up water tanks (MT) in the chemical treatment plant [demineralizer]. A regulating valve (A16) is installed on the make-up line; this valve operates in correspondence with the water level in the condenser.

The valve regulates the flow of make-up water to the condenser so that the water level in it is constant. The first filling of the cooling system is accomplished from the same make-up tanks via a valve (A17). The water level in the condenser is monitored by level gages, from which pulses are fed to the executive mechanisms of the corresponding cut-off and regulation armature valves.

Thus, for example, if there is a sharp rise of water level in the condenser (mark 5), level gage 5 sends a pulse to an electrically actuated gate valve (A104), which opens and excess condensate drains off to storage tanks (T).

If there is a sharp drop in the water level in the condenser (mark 3), gage 3 sends a pulse to switch off the circulation pumps (CP1, CP2) and to close valves (A3, A4). When the cooling sectors of the tower are being filled the water level in the condenser falls for a short period by 1-1.2 m (level 2), since the filling water comes from the condenser.

In this case the water in the condenser is made up from the storage tanks (T) with the aid of transfer pumps (TP), which are switched on by a pulse from level gage 2. When the designed water level 1 is achieved in the condenser the gage for this level sends a pulse to switch off the transfer pumps.

2. Circulation pumps.

Circulation of the cooling water in the amount of 25,100 m^3/hr is provided by two vertical circulation pumps.

The power required for cooling water circulation is 2240 kW.

The basic features of the circulation pumps are:

- static head: 25 m H_2O,
- output: 3.5 m^3/s,
- rating of drive motor: 1120 kW,
- voltage: 3 x 6000 V, 50 Hz,
- weight of pump: 18 t,
- weight of electric drive motor: 12 t,
- total weight of two groups of circulation pumps with drive motors: 60 t.

When one pump is in operation, the flow of water goes directly to the return circulation line to ensure sufficient pressure in the upper part of the coolers. In this case one of the valves A7 or A8 must be closed.

3. "Dry tower"

For outside air temperatures to +30.5°C the dry tower provides the necessary cooling of the condensate and operation of block at nominal capacity. Traditional dry tower execution is provided.

The draft tower is made with a metal skeleton and facing made of corrugated sheet aluminum.

Technical data of the draft tower are:

- height: 120 m
- upper diameter: 62 m

- diameter of base: 109.2 m
- weight of steel construction: 1334 t
- weight of aluminum sheathing: 165 t
- volume of concrete foundation: 2800 m^3.

Air-water aluminum cooling deltas 15 m high (119 in all) are installed in the lower part of the tower along the external circular loop.

The outside of the deltas have a system of electrically actuated louvers which regulate the air flow.

The opening of the louvers is in functional dependence on the cooling water temperature on output from the dry tower. The cooling water temperature gage on the return circulation line sends a pulse to close the louvers when its temperature reaches +15°C.

Earthquake activity on the order of 7 points was taken into consideration when designing the tower.

The cooling deltas along the circumference of the tower are installed on elastic metal pedestals; cooler outlets are connected to the ring manifolds by rubber sleeves.

With regard to cooling water the dry tower is divided into 6 independent sectors. All the sectors can be connected to or disconnected from the water cooling circuit independently of one another.

This division of sectors makes possible easy filling and emptying of the cooling system, as well as prophylactic and maintenance operations without shutting down the water circulation process.

Water heated in the condensers is fed to the "dry towers" via a circulation line ø 1800 mm. Water circulates within the "dry tower" through the main ring manifold. The ring manifolds for the cooling sectors are connected to the latter by means of gear-actuated butterfly valves A111 (first sector). Cooling water is withdrawn via manifolds of the same kind and the circulation line for return water. In an emergency situation (failure of a cooling delta) evacuation of the cooling sector is provided by the block for emergency drainage of the system. Thus, the block for emergency drainage of the far sector includes electrically actuated valves A111, A112, A113 and A114.

The emergency overflow block for the entire cooling system of the block includes hydraulically actuated valves A105 and A106.

"Peak" coolers are, when necessary, connected to the main ring manifold of the "dry tower" in parallel to the cooling sector by means of valves A115 and A116 (first sector).

The external surfaces of the cooling deltas are cleaned by water under pressure.

The cleaning device consists of a vertical distributor 15 m in height, which moves around the tower on rails in the upper part of the coolers. Wash jets are mounted on the distributor along its entire height.

The wash device can move to any delta and can rotate around its vertical axis.

The wash jets extend into the gaps of the open louvers and feed wash water to the ribber coolers.

The vertical distributor is connected to the cooling water ring main line of the tower by a flexible rubber hose.

Consumption of water for one cleaning is not over 200-300 m^3.

4. The "peak" cooler.

The "peak" cooler consists of two 5-meter straight-through cooling panels which are series-connected with respect to the flow of water. The panels are located in parallel planes and mounted on a single rigid frame. Cooling of warm water flowing over the tubes within the panels is accomplished by air, which, being circulated by a fan, passes through the ribbed intertube space of the panels. The fans are placed over the panels and are mounted on a common support frame. The air flow is regulated by means of louvers. Irrigation of the cooling panels by water from the main cooling circuit is provided in "peak" regime.

The combined cooling system of the block of the Isfahan thermoelectric power station calls for the installation of 30 "peak" coolers (5 for each cooling sector). Besides their basic task -- cooling of water heated in the condenser in the transitional and "peak" regimes -- the "peak" coolers act as heaters for the main cooling elements (the deltas) during startup of the cooling system at low outside air temperatures.

The "peak" coolers are installed directly beyond the cooling deltas within the tower and along the perimeter of the cooling sector. Air is supplied to the "peak" coolers through channels under the cooling deltas.

When the cooling deltas are being heated the louvers are completely closed. A back air flow (from the tower -- outward -- in front of the cooling deltas), which heats the cooling circuit of the "dry tower", is set-up by reversing the fans.

Figure 3 shows the technological scheme for cooling the auxiliary equipment.

Oil and water are cooled by oil coolers and water coolers, which are identical to "peak" coolers in their design execution.

Heated oil from the machine hall is supplied through a distribution manifold to the oil coolers. The cooled oil is returned through a return manifold to the machine hall.

Two independent systems are provided: one for cooling the oil of the feed pump motors; the second for cooling the bearings of the turbine and generator.

The oil coolers are located in an open site.

The degree of oil cooling depends on the air flow through the oil cooler. The air flow is regulated by means of louver devices which are installed on the oil coolers or by switching off certain fans.

In order to provide a large number of steps for regulating the shut-off of the fans, two oil coolers are connected sequentially and this pair is connected in parallel to the forward and back mainlines. Three pairs of coolers are working coolers. A reserve pair of coolers is provided. During hot weather the surface of the oil cooler is wetted, so that the temperature of the cooled oil is stabilized.

A thermotechnical description of the oil coolers is given in Figure 4.

Water of the same quality as the condensate is used to cool the generator and other auxiliary equipment. Heated water passes through a distribution manifold to water coolers. The layout, design and connection of the water coolers for the auxiliary equipment are analogous to the corresponding oil coolers.

In summer the required water temperature is provided by wetting the surface of the water coolers. In winter, and at low outside air temperatures, the generator and other auxiliary equipment are cooled by water, which is cooled in the main cooling system -- the "dry tower". The water coolers do not operate at this time -- they are switched off and evacuated. In summer the generator and other auxiliary equipment are cooled by an independent system, by means of the water coolers, since the temperature of the water cooled in the main cooling system rises above the acceptable maximum for the auxiliary equipment. Transfer to the independent system is performed by closing valves V5 and V6 and opening V1, V2 and V3.

A thermotechnical description of the water cooler is given in Figure 5.

III. CONCLUSION

The search for ways to raise the efficiency of "dry towers" has brought about the design of combined systems for air condensation of steam.

One such system -- a system with "dry towers" and "peak" coolers -- was proposed by the Teploelektroproekt Institute for the Isfahan TES in Iran.

Thermotechnial calculations made for the Isfahan thermoelectric power station, which in summer has an electric load peak in the hot time of the day, showed that the system with "dry towers" and "peak" coolers provides the necessary temperature for steam condensation and dispersion of heat at nominal turbine output.

The combined cooling system proposed by the institute is distinguished by extremely low water use -- 220 m^3/hr.

And finally, this cooling system allowed series-manufactured turbine equipment to be used for the power station without structural modification and adaptation for operation under the conditions of the hot and dry climate of the region of the Isfahan thermoelectric power station.

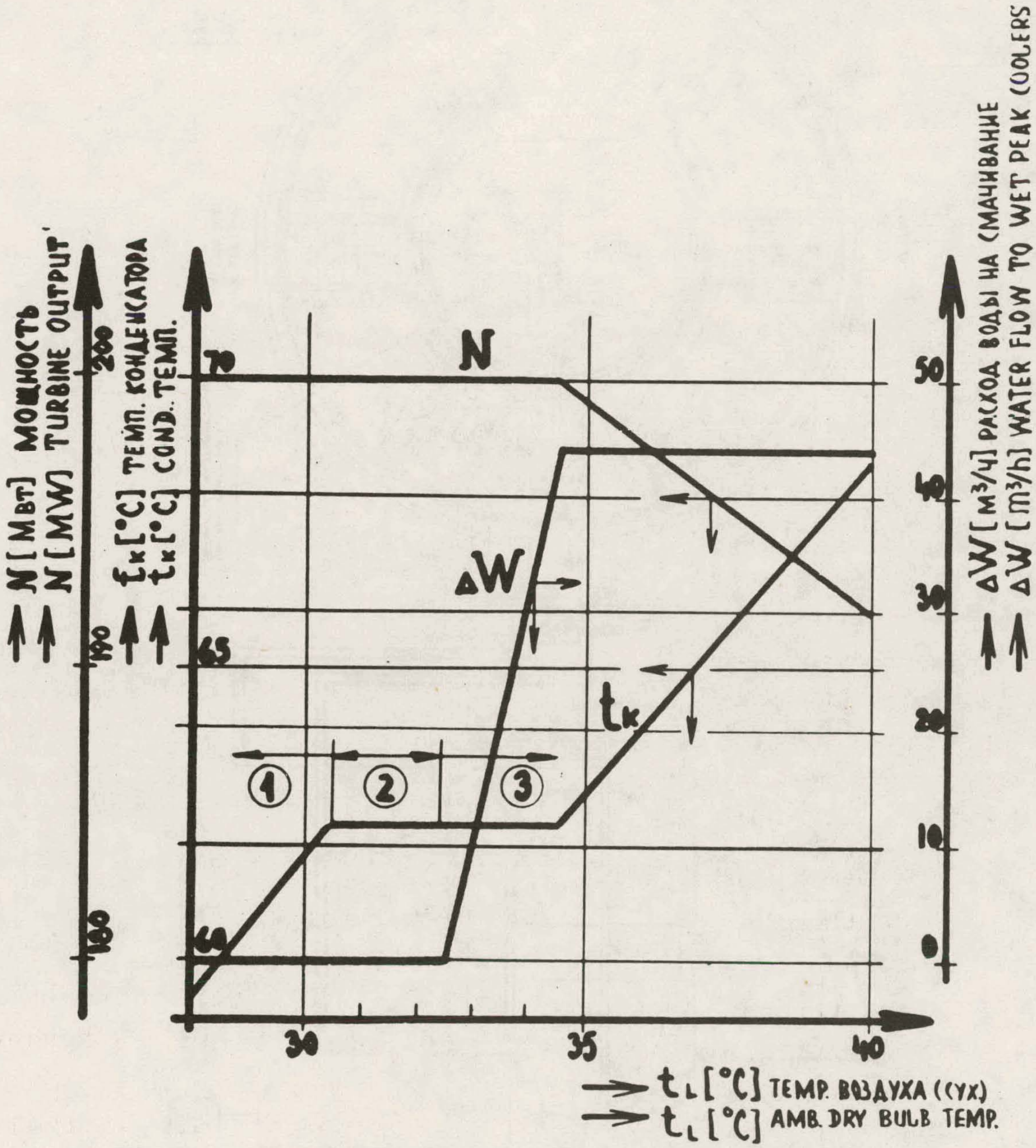
Table 1

Item	Unit	Month of year											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1. Mean monthly air temperature	°C	2,8	5,I	9,8	I4,8	I9,9	25,3	28,0	26,4	22,7	I6,7	I0,0	4,3
2. Mean monthly air humidity	%	64	54	45	40	38	30	28	28	32	38	50	52

Table 2

Outside air temperature, °C	I6,I	+30,0	+40,0
Temperature of saturation of vapor in condenser, °C	46	6I,7	70,I
Pressure in condenser, atm (abs)	0,I02	0,225	0,32
Heat dispersion, Kcal/hr	$237 \times I0^{6}$	$257 \times I0^{6}$	$263 \times I0^{6}$
Regime of cooling system operation	"Dry tower"	Transitional, "dry" plus peak coolers	peak, "dry tower" + peak coolers + irrigation
Flow rate of make-up water to irrigate peak coolers, kg/hr	-	-	44000

Рис. 1
Drw. N 1



1. ГРАДИРНЯ
   COOLING TOWER WITHOUT PEAK COOLERS
2. ГРАДИРНЯ С ПИКОВЫМИ ОХЛАДИТЕЛЯМИ
   COOLING TOWER WITH PEAK COOLER FANS IN OPERATION
3. ГРАДИРНЯ С МОКРЫМИ ПИКОВЫМИ ОХЛАДИТЕЛЯМИ
   COOLING TOWER WITH PEAK COOLER FANS AND SPRAYS IN OPERATION

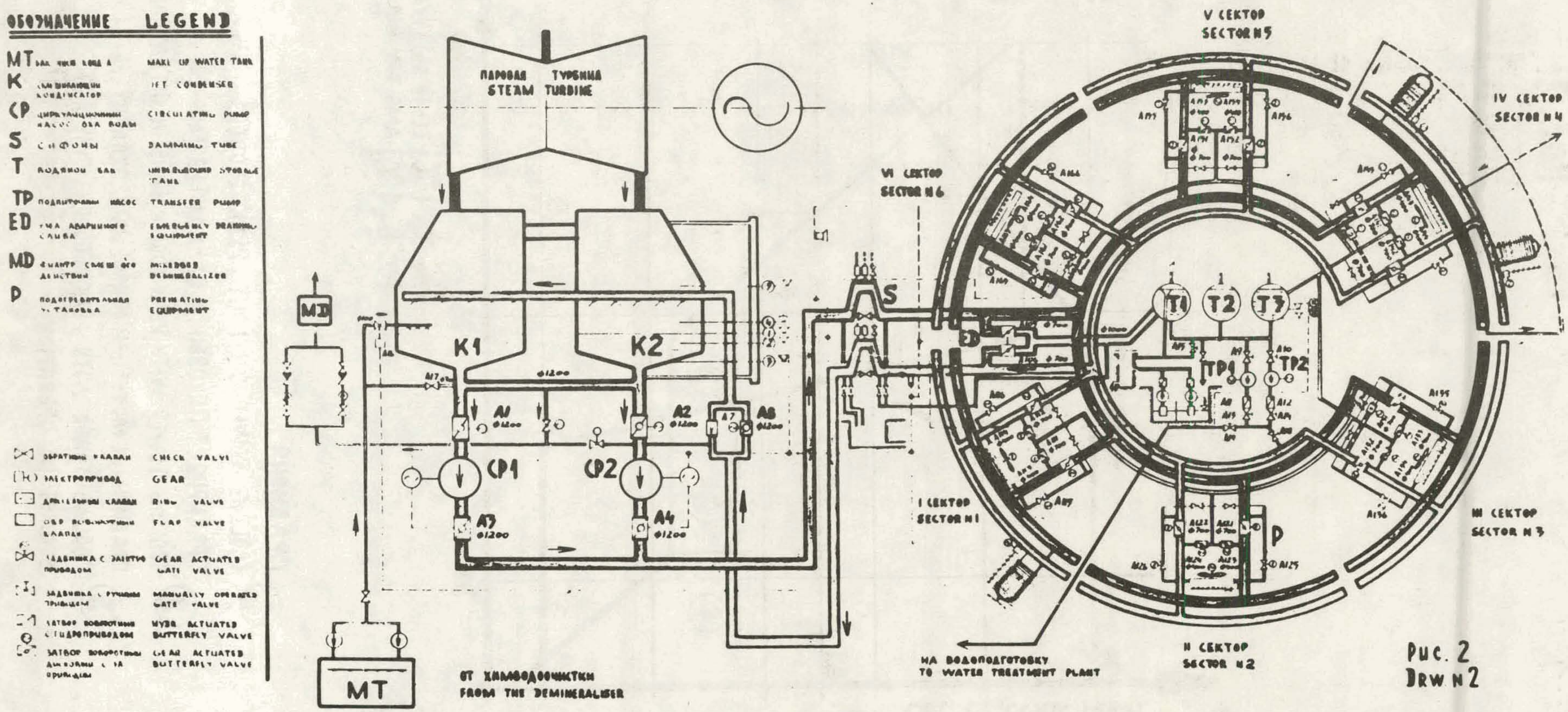

LEGEND
MT MAKE UP WATER TANK
K JET CONDENSER
CP CIRCULATING PUMP
S DAMMING TUBE
T UNDERGROUND STORAGE TANK
TP TRANSFER PUMP
ED EMERGENCY DRAINING EQUIPMENT
MD MIXED BED DEMINERALIZER
P PREHEATING EQUIPMENT
CHECK VALVE
GEAR
RING VALVE
FLAP VALVE
GEAR ACTUATED GATE VALVE
MANUALLY OPERATED GATE VALVE
HYDR ACTUATED BUTTERFLY VALVE
GEAR ACTUATED BUTTERFLY VALVE
ПАРОВАЯ ТУРБИНА
STEAM TURBINE
K1
K2
CP1
CP2
MD
MT
A1
A2
A3
A4
A7
A8
S
ED
T1
T2
T3
TP1
TP2
P
VI СЕКТОР
SECTOR N 6
V СЕКТОР
SECTOR N 5
IV СЕКТОР
SECTOR N 4
III СЕКТОР
SECTOR N 3
II СЕКТОР
SECTOR N 2
I СЕКТОР
SECTOR N 1
TO WATER TREATMENT PLANT
FROM THE DEMINERALISER

Рис. 2
Drw N2

Рис. 3
Drw. N 3

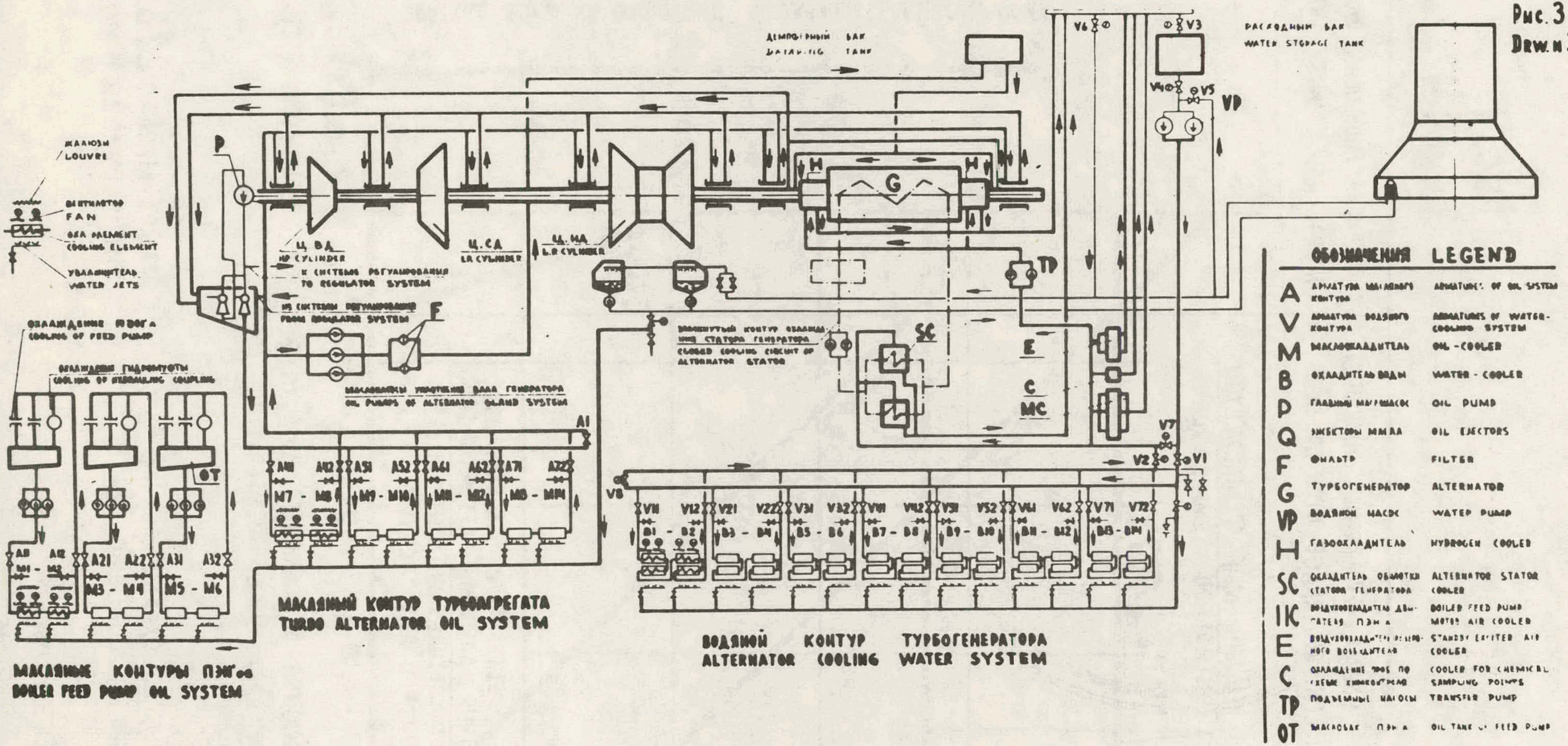
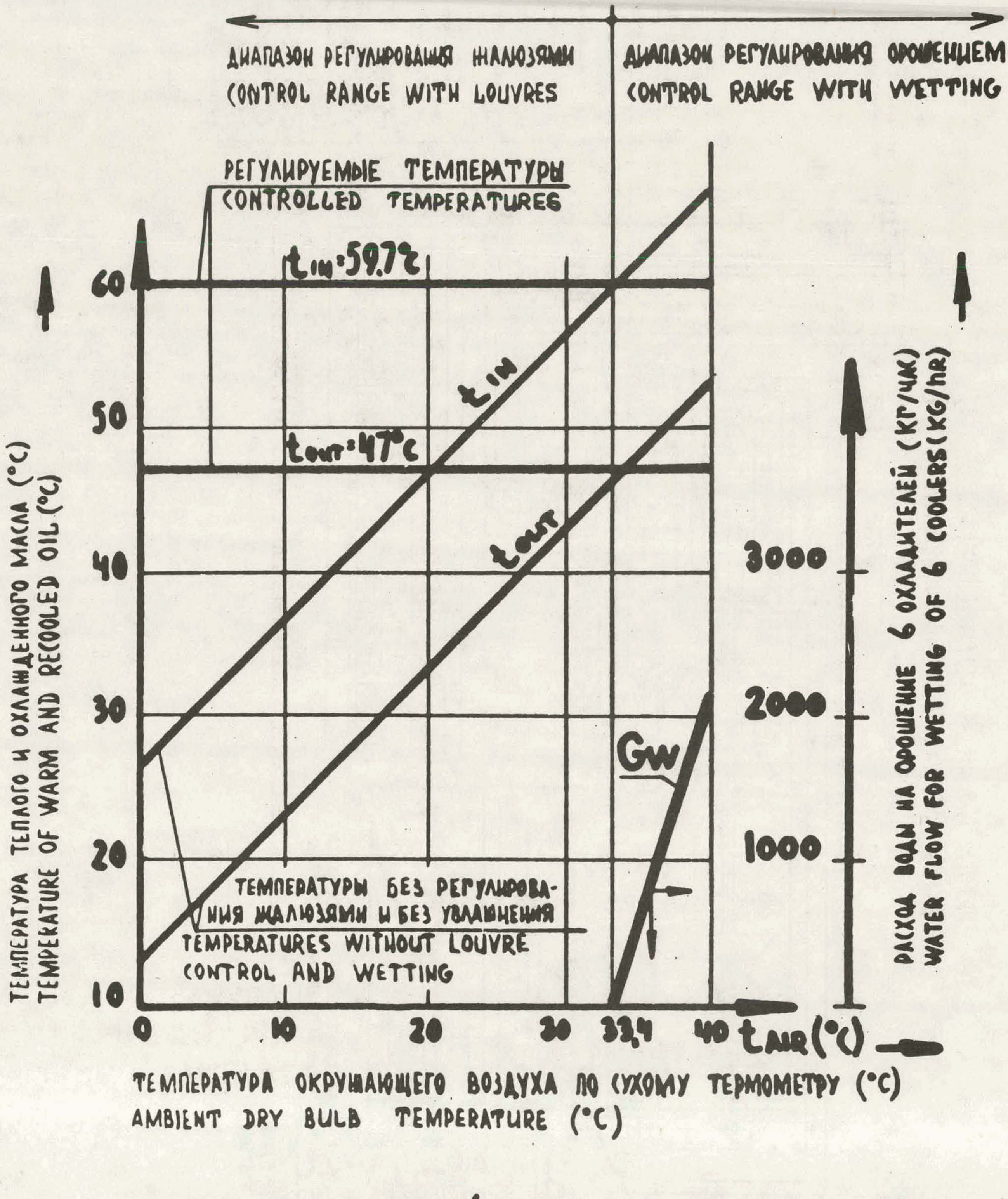

ЖАЛЮЗИ
LOUVRE
ВЕНТИЛЯТОР
FAN
COOLING ELEMENT
WATER JETS
ОХЛАЖДЕНИЕ ПЭНа
COOLING OF FEED PUMP
COOLING OF HYDRAULIC COUPLING
OT
P
Ц.ВД
HP CYLINDER
Ц.СД
I.P. CYLINDER
Ц.НД
L.P. CYLINDER
К СИСТЕМЕ РЕГУЛИРОВАНИЯ
TO REGULATOR SYSTEM
ИЗ СИСТЕМЫ РЕГУЛИРОВАНИЯ
FROM REGULATOR SYSTEM
F
МАСЛОНАСОСЫ УПЛОТНЕНИЯ ВАЛА ГЕНЕРАТОРА
OIL PUMPS OF ALTERNATOR GLAND SYSTEM
ДЕМПФЕРНЫЙ БАК
DAMPING TANK
H
G
TP
SC
E
C
MC
ЗАМКНУТЫЙ КОНТУР ОХЛАЖДЕНИЯ СТАТОРА ГЕНЕРАТОРА
CLOSED COOLING CIRCUIT OF ALTERNATOR STATOR
РАСХОДНЫЙ БАК
WATER STORAGE TANK
V6
V3
V4
V5
VP
V7
V2
V1
V8
A1
A11
A12
A51
A52
A61
A62
A71
A72
M7 - M8
M9 - M10
M11 - M12
M13 - M14
A21
A22
A31
A32
M1 - M2
M3 - M4
M5 - M6
V11
V12
V21
V22
V31
V32
V41
V42
V51
V52
V61
V62
V71
V72
B1
B2
B3 - B4
B5 - B6
B7 - B8
B9 - B10
B11 - B12
B13 - B14
МАСЛЯНЫЙ КОНТУР ТУРБОАГРЕГАТА
TURBO ALTERNATOR OIL SYSTEM
МАСЛЯНЫЕ КОНТУРЫ ПЭНов
BOILER FEED PUMP OIL SYSTEM
ВОДЯНОЙ КОНТУР ТУРБОГЕНЕРАТОРА
ALTERNATOR COOLING WATER SYSTEM
ОБОЗНАЧЕНИЯ LEGEND
A АРМАТУРА МАСЛЯНОГО КОНТУРА ARMATURES OF OIL SYSTEM
V АРМАТУРА ВОДЯНОГО КОНТУРА ARMATURES OF WATER-COOLING SYSTEM
M МАСЛООХЛАДИТЕЛЬ OIL-COOLER
B ОХЛАДИТЕЛЬ ВОДЫ WATER-COOLER
P ГЛАВНЫЙ МАСЛОНАСОС OIL PUMP
Q ЭЖЕКТОРЫ МАСЛА OIL EJECTORS
F ФИЛЬТР FILTER
G ТУРБОГЕНЕРАТОР ALTERNATOR
VP ВОДЯНОЙ НАСОС WATER PUMP
H ГАЗООХЛАДИТЕЛЬ HYDROGEN COOLER
SC ОХЛАДИТЕЛЬ ОБМОТКИ СТАТОРА ГЕНЕРАТОРА ALTERNATOR STATOR COOLER
IK ВОЗДУХООХЛАДИТЕЛЬ ДВИГАТЕЛЯ ПЭНа BOILER FEED PUMP MOTOR AIR COOLER
E STANDBY EXCITER AIR COOLER
C ОХЛАЖДЕНИЕ ПРОБ ПО СХЕМЕ ХИМКОНТРОЛЯ COOLER FOR CHEMICAL SAMPLING POINTS
TP ПОДЪЕМНЫЕ НАСОСЫ TRANSFER PUMP
OT МАСЛОБАК ПЭНа OIL TANK OF FEED PUMP

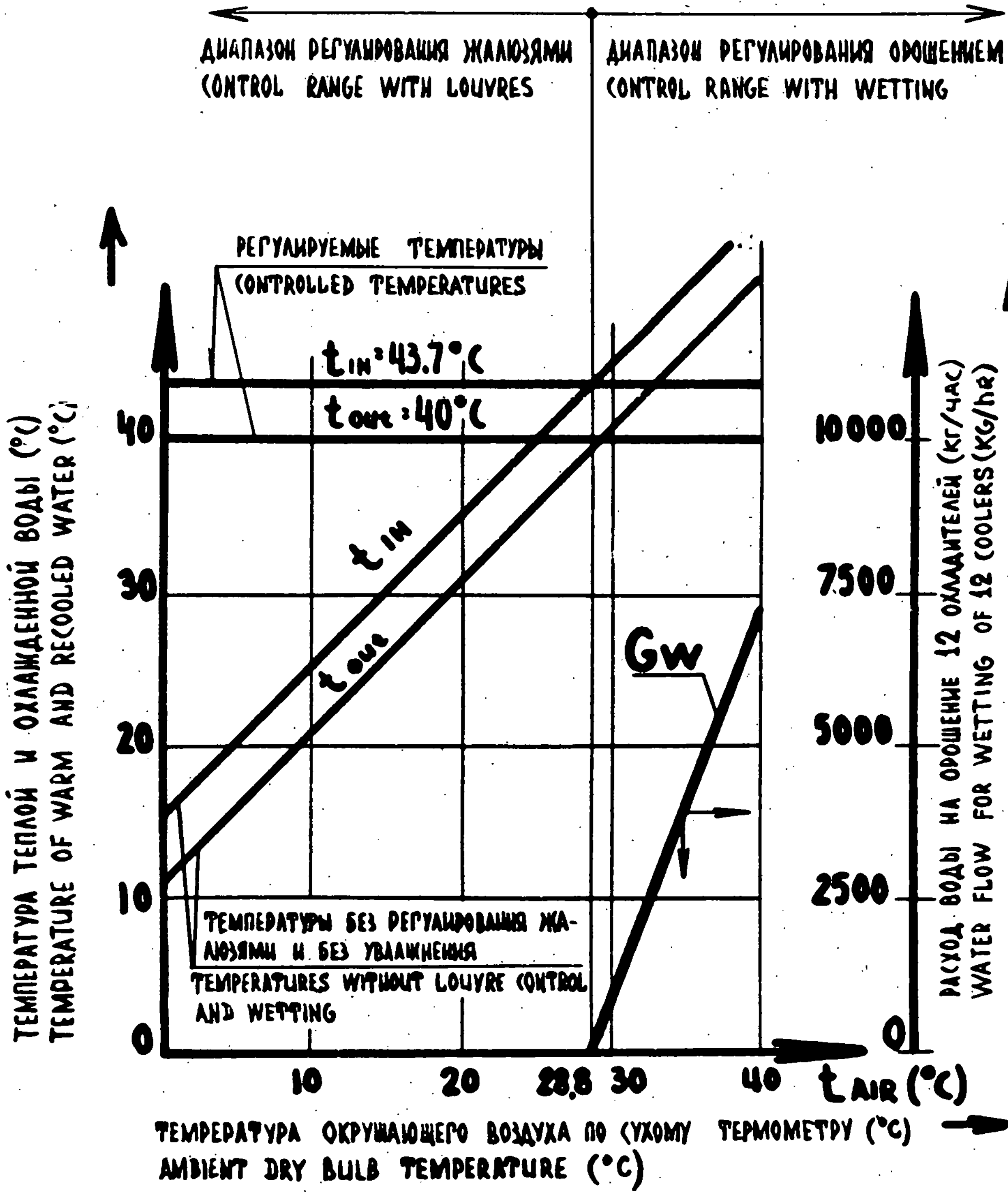
Рис. 4
Drw. N 4



КОЛИЧЕСТВО ОХЛАДИТЕЛЕЙ: 6
NUMBER OF COOLERS: 6

РАСХОД МАСЛА: 228 м³/час
OIL FLOW: 228 m³/hr

Рис. 5
Drw. N 5



КОЛИЧЕСТВО ОХЛАДИТЕЛЕЙ: 12
NUMBER OF COOLERS: 12

РАСХОД ВОДЫ: 920 $м^3$/час
WATER FLOW: 920 m^3/hr

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PAPER NO. 6

"HEAT POWER DESIGN INSTITUTE"

USE OF WASTE HEAT TO HEAT HOTHOUSES. BASIC DIRECTIONS AND ENGINEERING DECISIONS.

Authors: R. Minasyan
I. Korolev
T. Razmikova

JOINT SOVIET-AMERICAN SYMPOSIUM ON REMOVAL OF HEAT FROM FOSSIL FUEL AND NUCLEAR ELECTRIC POWER PLANTS
(Subject 08.0203)

September 1978
Razdan

All-Union State Order of Lenin and Order of the October Revolution Design Institute. Teploelektroproekt.

USE OF WASTE HEAT TO HEAT HOTHOUSES. BASIC DIRECTIONS AND ENGINEERING DECISIONS.

Of the problems connected with the rational utilization of natural resources and particularly fuel, an important place is occupied by the problem of using waste heat.

It is well known that about 50-55% of heat is discharged with spent steam into turbine condensers and is withdrawn by cooling water.

The total discharge of heat is 22.5 x 10^6 Gcal for an electric power station 2.4 million kW in output with 8-10 type K-300-240 turbines at an output of 14-15 x 10^9 kWh/yr, of which 17.5 x 10^6 H cal per year goes to losses in the turbine condensers.

The chief obstacle to the use of waste heat to heat closed spaces is its low temperature potential. The temperature of the water passing through turbine condensers depends on the cooling system, the type of coolant, the temperature and humidity of the outside air.

Waste water has the highest temperatures in the summer, when the need for such heat is negligible.

Existing experience and theoretical consideration indicate that low-potential heat can be utilized with the greatest benefit biologically: in agriculture, in hothouse gardening, in animal husbandry, in fish farming (to heat up soil, hothouses, animal dwellings, for irrigation and sprinkling, for growing algae and feed protein and for intensive fish farming).

To heat soil, hothouses, and animal dwellings it is expedient to use heat with an elevated potential, such as is possessed by the waste water from power stations with synthetic coolants. It is expedient to use the waste heat of direct flow and direct flow-return systems, which has a lower potential, for intensive fish farming in warm waters, irrigation and sprinkling, and, in a number of instances, to heat soil.

The most favorable conditions for the use of waste heat exists as condensation power stations, where the discharge of a large quantity of heat in winter is constant. For example, the waste heat of a condensation thermoelectric station 1200 MW in capacity can heat 100-150 ha of hothouses with a high degree of reliability.

In this report we discuss aspects of the use of waste heat to heat hothouses and present a description of various heating systems.

1. Basic economic and engineering prerequisites

Of the many good products of man fresh vegetables, fruits, greens, which are unreplacable sources of vitamins, trace elements and salts, have special importance for normal development and health. According to data of the Academy of Sciences USSR the minimum physiological norm for the use of vegetables is 140 kg per year per person.

Of this quantity, if there is well-organized extended storage of vegetables grown in open soil, about 10 kg/man-year (approximately 7%) must be produced in hothouses.

To meet the needs of the population for vegetables during the winter it is necessary to have an average of about 0.17-1.0 m^2 protected soil per person.

An extensive program adopted in the USSR for improving the supply of vegetables and fruits for the population calls for an increase in the production of out-of-season vegetables by more than twofold during the current five-year plan. In doing so one-fourth of that produced will be grown in hothouses and other enclosed-soil structures. 22-23 thousand ha of hothouses will be built in the USSR before 1990.

The most favorable temperatures for growing hothouse cucumbers and tomatoes are: air from 15°C to 30°C, soil from 18°C to 27°C. These temperatures are maintained by pipe and air heating elements in the tent of the hothouse (heat transfer agent -- water at 95-130°C) and under-soil pipe heating with a heat transfer agent at 40-45°C.

Heat is lost from hothouses primarily through the enclosing structure (about 90% of all losses) and through the soil (about 10%).

The total heat requirements for a hothouse plant, at an outside air temperature of -30°C, is about 5 Gcal for 1 ha of hothouse of the block type.

The very high seasonal and daily variation in the use of heat of hothouses should be pointed out. For example, during the warm season of the year, when the coolings systems of power stations operate under high stress and waste water has the highest temperature potential, hothouses do not need heating. The need for heat falls abruptly in the daytime because of intensive solar radiation in spring and autumn and even on clear winter days with negative outside air temperatures. At the same time, hothouses must be heated at night even in the summer in regions with an abrupt continental climate.

This variation, as a rule, does not correspond with smooth operation of power stations with a relatively constant discharge of heat. To a significant degree this factor complicates systems for heating hothouses with waste heat, as well as the regulation and automation of these systems.

The cost structure of hothouses making up a 6 hectare block (not counting the additional costs of tying into the project) in the central regions of the country (at a theoretical outside air temperature of -30°C) appears thus:

1. Building structures - 32%
2. Heating system for hothouses - 32%
3. Other installations - 26%

The use of metal per 1 m^2 area of modern hothouses is about 28 kg, including 7 kg (28.5%) for the support structures and 21 kg (71.5%) for the pipes of the heating system. The costs for installing the heating system depend on the climatic zone of construction.

According to the data of a hothouse state farm -- the Moskovskii combine -- the proportion of boiler installations in the total capital investiments for hothouses is 7%, while costs for heating are more than 26% of annual operating costs.

An increase in the production of hothouse vegetables inevitably involves a corresponding increase in the use of high grade fuel. It is sufficient to point out that no less than 30 million t nominal fuel per year will be required to heat 22-23 thousand ha of hothouses at the 1990 level.

In connection with this it seems economically advantageous to use the low potential waste heat of industrial enterprises and thermal power stations to heat hothouses.

As is well known, only 33-40% of the available thermal capacity is used to produce electric power at fossil fuel and nuclear electric power stations. The remainder is irretrievably dispersed to the environment. Depending on the cooling system, the season and climatic conditions of the region which the thermal power station is located, the temperature of waste water can vary over a broad range. Table I gives mean annual and seasonal changes of the cooling water temperature after turbine condensers for various systems of technical water supply.

It follows from the table that the water in circulating systems of water supply with synthetic coolants has the highest temperatures: i.e., those with evaporation towers, with air-condensation installations (VKU) and combined wet-dry towers.

A certain quantity of heat having a relatively higher potential is discharged after the oil coolers of the turbines and feed pumps.

II. Heating systems for hothouses

In the Soviet Union the development of hothouse vegetable production proceeds primarily by means of the construction of large hothouse plants having enclosed-soil areas of 20-50 and 100 ha. These plants are normally built according to standard designs which have been developed by special institutes.

One of the more industrial standard projects was developed for a 6-hectare block for climatic conditions with theoretical winter air temperatures of -20 and -30°C.

The block of hothouses consists of five 1-hectare soil hothouses, one 1-hectare vegetable hothouses with a nursery section, buildings for general and service purposes, a boiler installation and a connective corridor.

The plan of such a block is shown in Figure 1.

Tent and underground heating is provided in the hothouses. The heat transfer agent for the tent heating is water at 95-70°C. Heat transfer agent for under-soil heating is water at 40°C. Steam and water supplies for the block of hothouses is provided by its own boilers.

In the design regard the hothouses are open span structures with a span of 6.4 m. The skeleton is steel, of special profiles. The enclosures are glass. The foundations are reinforced concrete.

Heat consumption or heating for regions with a theoretical outside air temperature of -20°C is 4 Gcal/hr, and 5.2 Gcal/hr for the -30°C region. A theoretical minimum temperature of no less than +15°C is provided in the hothouses.

From the standpoint of energy the main shortcoming of these hothouses is the need for use high-grade gaseous or liquid fuel for heating. In addition, the pipe system for heating requires a very high consumption of metal per square meter of hothouse (= 20 kg/m^2).

The desire to use fuel rationally and to reduce the high metal consumption of the heating system led to the development of various hothouse designs heated with low potential waste heat from electric power stations or other industrial enterprises in the USSR, the USA and in other countries.

A description of these systems is given below.

I. Hothouse with water-filled roof

The solutions which have been tested in experimental installations include hothouse types whose enclosing transparent structures are separated from the outside environment by a continuous sheet of warm water. In experiments performed in 1945-1950 the thickness of the water layer on a sloped glass roof of a hothouse was taken to be 10-14 mm. In experiments of Professor E. D. Korol'kov (Agricultural Academy named for K. A. Timiryazev) the thickness of the water layer on a flat roof reached 60-70 mm. In all cases the water surface was open.

Figure 2 shows a schematic diagram of such a hothouse.

In experiments carried out on February 8, 1969, when the outside air temperature was -27°C and the temperature of the water being supplied to the roof was +45°C, the water flowing from the roof had a temperature of +26°C, while air temperatures in the hothouse were: +20°C at 20 cm from the roof, +19°C at 90 cm from the roof and +15°C above the soil (there was no soil heating). Here the water flow rate to the roof was 80-100 ℓ/hr per 1 m^2 roof.

Figure 3 gives an orientational graph of the seasonal change of the temperature of waste water. Three zones can be seen on the graph. Two of them correspond to a shortage of heat in the hothouse, while one corresponds to an excess of heat.

Basic principles for the thermal calculation of this type of hothouse are given below.

The temperature of the water on the roof can be determined from the equation of thermal balance of a water-filled roof:

$$\Sigma Q_W = G_W \cdot c_W \cdot \Delta t_W \qquad [1].$$

It follows from Equation 1:

$$\Delta t_W = \frac{\Sigma Q_W}{G_W \cdot C_W} \qquad [2],$$

where: Δt_w - depth of cooling of water on roof, °C;
G_w - flow rate of water to roof, kg/hr;
ΣQ_w - total heat transfer of water on roof, kcal/hr;
C_w - specific enthalpy of water, kcal/kg·°C.

On the other hand:

$$\Sigma Q_W = Q_{W_1} + Q_{W_2} \pm Q_{W_3} + \Delta J_W \qquad [3],$$

where: Q_{w1} - heat transfer by evaporation, kcal/hr;
Q_{w2} - heat transfer by convection, kcal/hr;
Q_{w3} - radiation balance, kcal/hr;
ΔI_w - additional radiation by surface of water heated above normal-natural termperature, kcal/hr.

$$Q_{W_2} = Q'_{W_2} \pm Q''_{W_2} \qquad [4],$$

where: Q'_{w2} - heat transfer by convection to atmosphere, kcal/hr;
Q''_{w2} - heat transfer by convection through roof into hothouse, kcal/hr;

The value of Q_{w3} is determined from the expression:

$$Q_{W_3} = (Q+q)_n \cdot (1-a) - \text{[illegible]} - Q_4 \qquad [5],$$

where: $(Q+q)_n$ - total solar radiation at observed overall cloud cover, kcal/hr;
a - albedo of water surface;

I_n - effective radiation by water surface at normal-natural temperature of water, kcal/hr;

Q_4 - heat transmitted to hothouse through roof by penetrating solar radiation, kcal/hr.

Here it is considered that part of the solar radiation penetrates into the hothouse through the layer of water in the glass roof.

The magnitudes of Q_{w1}, Q_{w2} and ΔI_w are determined from conventional dependences of theory of heat and mass exchange of a water surface with atmosphere.

In winter operation a temperature drop equal to the heat-up in the condenser is achieved by reducing the quantity of water supplied to the roof, or by cooling it in other coolers of the power station.

The heat losses of a hothouse with the water-filled roof and with a dry roof are determined from equation:

$$Q_2 = \pm Q_5 \pm Q_6 \pm Q_7 \pm Q_8 + Q_9 + Q_{10} - Q_4 \qquad [6],$$

where: Q_2 - total losses of heat of the hothouse, kcal/hr;

Q_5 - losses of heat through the water-filled or dry roof, kcal/hr;

Q_6 - losses of heat through side glass, kcal/hr;

Q_7 - losses of heat through soil, kcal/hr;

Q_8 - losses of heat through the concrete base pedestal, kcal/hr;

Q_9 - losses of heat to transpiration of plants, kcal/hr;

Q_{10} - losses of heat in ventilation of hothouse, kcal/hr.

Calculations for dry and water-filled roofs for mean monthly meteorological conditions and for mean air temperatures of the cold days show that the total mean annual losses of heat for a 1-hectare hothouse are:

a. for a water-filled roof:

137 Gcal - with consideration of solar radiation;

16380 Gcal - without consideration of solar radiation;

b. for a dry roof:

9000 Gcal - with consideration of solar radiation;

12000 Gcal - without consideration of solar radiation.

The heat losses at a mean air temperature for the coldest days of -32°C was:

a. for a water-filled roof:

0.25 Gcal/hr - with consideration of solar radiation;

0.30 Gcal/hr - without consideration of solar radiation.

b. for a dry roof:

2.86 Gcal/hr - with consideration of solar radiation;

2.92 Gcal/hr - without consideration of solar radiation.

The results of the calculations are given in Figures 4 and 5.

The presence of warm water on the roof of the hothouse allows the thermal losses of the hothouse to be reduced significantly and thereby reduces costs for heating it.

The experience of operation has shown that a layer of water on the roof, while admitting the visible portion of the sunlight, substantially retards the infrared portion of the spectrum, protecting the hothouse from overheating during periods with intensive solar radiation.

Operation of a hothouse with a water-filled roof also revealed a number of important shortcomings. This primarily includes its high metal consumption and the need to build a watertight roof.

There are also great difficulties due to the need to maintain transparency of the roof, which becomes dirty with dust and algae.

Matters of ventilation, cleaning of the roof, heating of the soil bed and other elements await solution and experimental testing.

2. Hothouse with air heating

Figures 6, 7 and 8 showed the design of a hothouse heated by waste heat by means of the heat exchangers of the power station cooling system.

The heat exchangers are placed in annexes to the conventional standard hothouse as heating points.

The heat transfer agent -- condensate at a temperature of 35-45°C -- flows in the pipes of the heat exchangers, and air blown by fans through the intertube space of the heat exchanger is heated and supplied to the hothouse.

Here the heat exchangers fulfill two functions:

1. As part of the cooling system of the thermoelectric or nuclear power station the heat exchangers are coolers of the condensate from the turbine condensers, thus ensuring its cooling;

2. They are the chief source of heat for the hothouse, maintaining the necessary temperature and humidity conditions in it.

Proceeding from this, three main operating regimes for the hothouse can be discussed:

1. Winter regime:

In the theoretical winter regime, at outside air temperatures of -25°C to -30°C a constant volume of air circulates in the hothouse and through the intertube space of the heat exchangers; the maximum quantity of this air (for a selected heat output of the heat exchanger and given area of the hothouse) is limited by the maximum allowable air velocity in the hothouse (on the order of 1.5 m/s).

Supply of outside air during these periods is eliminated. Air intake is accomplished from the hothouse. Air blown by fans is pumped through the heat exchanger, heated and supplied to the hothouse. The temperature of the heated air is used to cover the thermal losses of the hothouse (Q_2). The air cooled in the hothouse is returned to the heat exchangers.

2. Summer regime

With outside air temperatures above the temperature of the air in the hothouse and with intensive solar radiation it is possible that the hothouse will overheat. In this case air is brought in from outside. The air heated in the heat exchangers can be completely discharged to atmosphere, bypassing the hothouse, through open windows in the ceiling. Irrigation of the heat exchangers can be used for purposes of cooling the condensate. The effect of evaporative cooling is simultaneously used to regulate the humidity of the air in the hothouse. If there is significant excess heat in the hothouse it is possible to ventilate it. In this case air intake is accomplished from outside and from the hothouse through open windows in its roof.

3. Autumn-spring regime.

With moderate outside air temperatures and elevated solar radiation the amount of air going to the hothouse will be a variable figure according to the outside air temperature. In addition, the necessary degree of cooling of the condensate depends on the temperature and humidity of the air going to the heat exchanger. Air pickup is from outside and from the heat exchanger. The mixed air is pumped by fan through the heat exchanger and heated. Part of the heated air, equal to the amount taken from outside is discharged from atmosphere through windows open in the ceiling of the heating point. The other part is supplied to the hothouse, compensating the thermal losses of the hothouse and maintaining the necessary temperature and humidity regime in it.

The thermophysical properties of the mixed air (i_Σ, t_Σ, L_Σ, etc.) depend on the degree of its mixing n. In dependence on the amount of air coming from outside $0 < 1$, since n characterizes the proportion of outside air in the total amount of air.

In the winter regime n = 0, while in the summer regime n = 1. The intake of outside air is regulated by means of louvers, the opening of which is in dependence on n. In the general case $0 \leq n \leq 1$ for the hothouse. Thus, establishing the optimum value of n for each concrete case unambiguously determines the necessary depth of cooling of the condensate and the required temperature and humidity conditions in the hothouse.

The thermotechnical calculation of a hothouse heated by waste heat is based on the following assumptions:

1. The number of heat exchangers installed in the heating point of the hothouse is determined based on the following conditions:

- the consumption of heat per hectare of hothouse at an outside air temperature t_1 = -30°C is 5 Gcal/hr;

- the difference of the air temperature in the hothouse is no more than 5°C;

- the maximum allowable air velocity in the hothouse is 1.5 m/s;

- the depth of cooling of the heat transfer agent is within 8-10°C, while maintaining the required temperature and humidity conditions in the hothouse;

- the air in the hothouse moves in a closed cycle (n = 0).

2. The needed fan output or L_{Σ}^{max} is determined from the condition that the needed depth of condensate cooling be secured in summer.

Here n = 1.

3. The optimum value of n is determined from the condition that the needed depth of condensate cooling and required temperature and humidity conditions be ensured in the hothouse in the autumn-spring period.

In doing so 0 < n < 1.

The thermotechnical calculation of the hothouse is performed on the basis of a combined resolution of the following equations:

$$n = \frac{L_1}{L_{\Sigma}} \qquad [1],$$

where: n - degree of air mixing
L_1 - flow rate of outside air, t/hr
L_{Σ} - total flow rate of mixed air, t/hr

$$L_1 \cdot i_1 + L_2 \cdot i_2 = L_{\Sigma} \cdot i_{\Sigma} \qquad [2].$$

where: i_1 - heat content of outside air, kcal/kg
i_2 - heat content of hothouse air, kcal/kg
i_{Σ} - heat content of mixed air, kcal/kg
L_2 - flow rate of hothouse air, t/hr.

$$i_{\Sigma} = n \cdot i_1 + (1-n) \cdot i_2 \qquad [3],$$

$$L_{\Sigma} \cdot i_{\Sigma} + Q_0 = L_{\Sigma} \cdot i_3 \qquad [4],$$

where: Q_0 - heat output of heat exchanger, kcal/hr
i_3 - heat content of heated air, kcal/kg

$$\mathcal{L}_2 \cdot i_3 = Q_2 + \mathcal{L}_2 \cdot i_2 \qquad [5]$$

where: Q_2 - heat losses of heat of hothouse, kcal/hr.

$$\eta = 1 - \frac{Q_2}{\mathcal{L}_I \cdot (i_3 - i_2)} \qquad [6].$$

The advantage of a hothouse with air heating is the fact that its heating system is designwise not connected with the hothouse and therefore industrial designs for modern hothouses can be used.

Another merit is the possibility of creating better ventilation and regulation of a more favorable microclimate in the hothouses.

The need to use forced air draft (fan) should be counted among its shortcomings.

3. Systems with convective-evaporative and convective heating

Interesting studies were carried out in the USA on the design of hothouse heating systems allowing waste heat to be used. In 1970 a hothouse 6 x 14 m in size with convective-evaporative heat exchangers was built at the Oak Ridge National Laboratory. The basic portion of the heat was taken off in an evaporative heat exchanger, which was a panel 5 cm thick filled with pine shavings. Water at 40°C in the amount of 37 ℓ/min was supplied to the upper part of the panel and passed vertically downwards, wetting the surface of the shavings. Air forced by fans penetrated the panel and was heated or cooled according to the humidity and temperature of the air and the temperature of the water being supplied to the panel. After the evaporative panel the air passed through a heat exchanger made of ribbed pipes, where it was further heated and dried. These operations led to the construction of an experimental hothouse in Muscle Shoals, Alabama. The principle of the operation of this hothouse is the same as at the Oak Ridge Laboratory.

It permitted the beginning of the development of a draft plan for a larger hothouse, 2000 square meters in area, at the Browns Ferry nuclear power plant.

4. Hothouse with convective heating

This type of hothouse, 2000 square meters in area, was built in 1975 along side the Sherburn Country (Minnesota) power station. The block-type hothouse consists of 14 sections 5.18 x 29.26 m in size. The side enclosure was made from corrugated glass plastic covered on the inside by polyethylene film. The roof was made from two-ply polyethylene. Theoretical heat losses of the hothouse at t = -34°C and inside temperature of 10°C are 553000 kcal/hr (644 kW). Each section has its own heat exchanger rated at 36,500 kcal/hr (42.5 kW). The theroetical temperature of the water being supplied is 29.44°C, its flow rate is 110 ℓ/min, the air flow rate is 200 m^3/min. Warm air is supplied to each section through a perforated film air line 762 mm in diameter. The soil is heated by polyethylene pipes 25 mm in diameter, which are along the sections of the hothouse at 61 cm intervals at a depth of 30.5 cm. The flow rate of water to the pipes is 3,785 ℓ/min, the temperature drop along the length of the pipe is 5.5°C for an air temperature in the hothouse of 10°C and soil temperature of 15.6°C.

An evaporative cooling panel and an axial-flow exhaust fan for air cooling in summer are also installed in each section.

In case the warm water supply is turned off there is an emergency heating system, which consists of a 380 kW electric boiler, a portable 10 kW generator and 6 propane heaters having a total output of 88,000 kcal/hr (102.5 kW).

Experimental operation of the hothouse showed that the system for heating with waste heat provides the required temperature regime even under the most several conditions. Thus, for example, at an outside air temperature of -41°C, which was reported at 8:00 on January 9, 1977, and with water at 32.6°C being supplied, the temperature in the hothouse was maintained at 14.4°C. Here there was a temperature drop of 2.6°C.

Conclusions

The experience gained in the operation of experimental hothouses heated by low potential heat confirms the possibility and principle and economic feasibility of using this kind of heating system. This same experience has shown that the necessary temperature and humidity conditions for out-of-season raising of vegetables and other crops are ensured by the use of systems with air heating. Hothouses with convective-evaporative heating are in this regard inferior to hothouses with air heating because of the relatively high humidity of the air circulating in the hothouse. Hothouses with water-filled roofs, while possessing a number of merits, also have serious faults, the chief of which is the difficulty of maintaining transparency of the roof. In regard to design, hothouses with air heating are preferable, since they allow standard design solutions to be used. Maintaining a water tight roof presents serious difficulties under the conditions of the water-filled roof.

More extensive industrial use of waste heat to heat hothouse plants in the near future is practicable. However, significant work is required both of a research nature as well as with regard to design developments in the design of hothouses of this type which are not inferior to conventional hothouses in all factors.

[Note: Figures were not included with Russian text.]

Table 1

Technical water-supply systems	Temperature of cooling water after turbine condensers, °C			
	Average	Winter	Summer	Autumn-Spring
1. Direct-flow systems	20-22	I2-I4	25-32	I8-22
2. Recycle systems with cooling ponds	23-25	I5-I6	35-37	20-22
3. Recycle systems with evaporation towers	3I-32	23-26	38-42	28-32
4. Recycle systems with air-condensation installation (VKU's)	35-40	25-30	45-55	32-35
5. Combination convective-evaporative coolers	28-30	25-35	38-42	28-32

Fig. 1. Block of Hothouses

(consists of five 1-hectare soil hothouses, one 1-hectare vegetable hothouse with a nursery section, buildings for general and service purposes, a boiler installation and a connective corridor.)

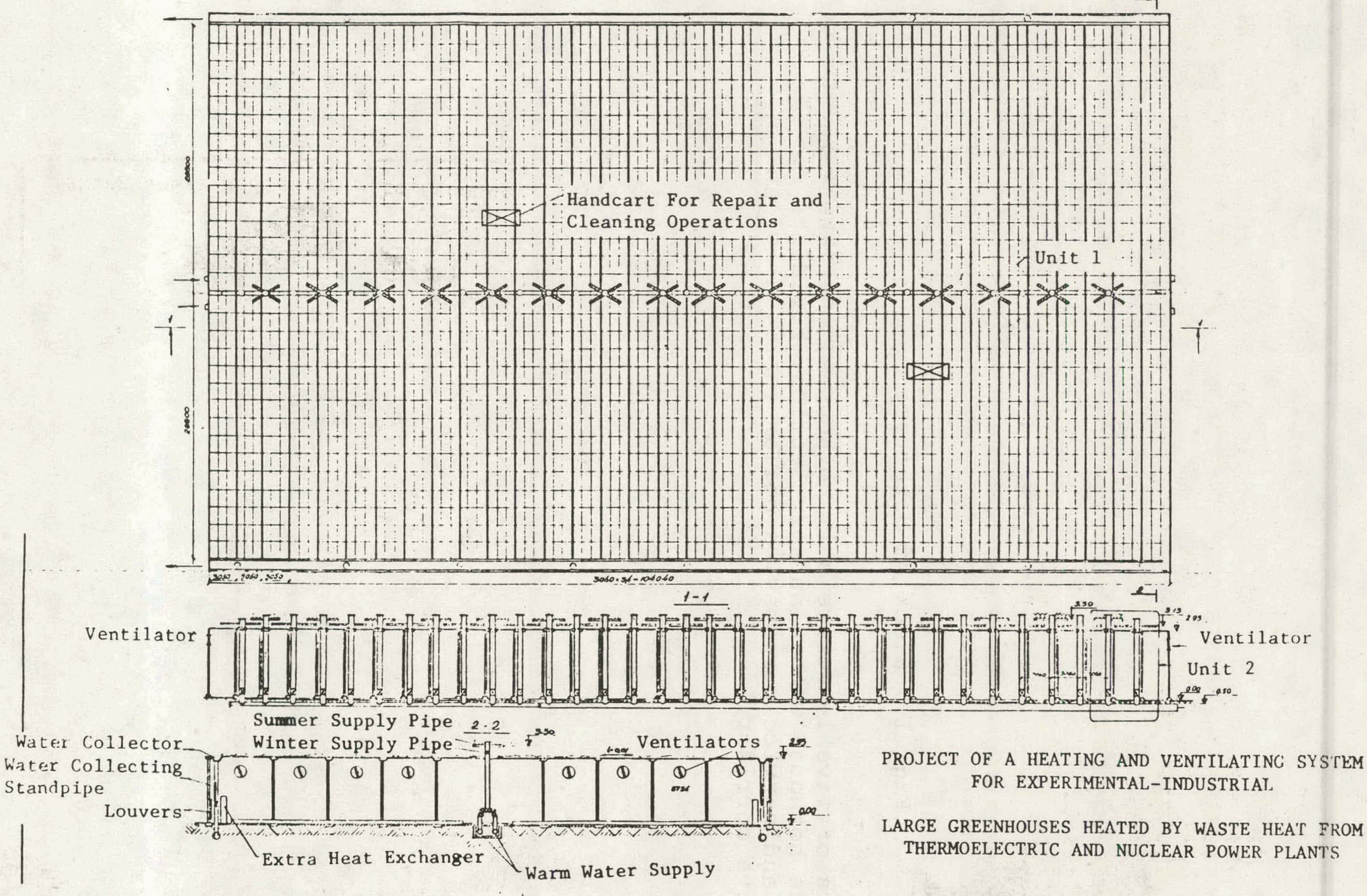


Fig. 2. Plan of Greenhouse with Water-Filled Roof. This figure was taken from last year's translation (ORNL-tr-4485) entitled A Project of a Heating and Ventilating System for Experimental-Industrial Large Greenhouses Heated with Thermoelectric Power Plant and Nuclear Power Plant Waste Heat which is applicable.

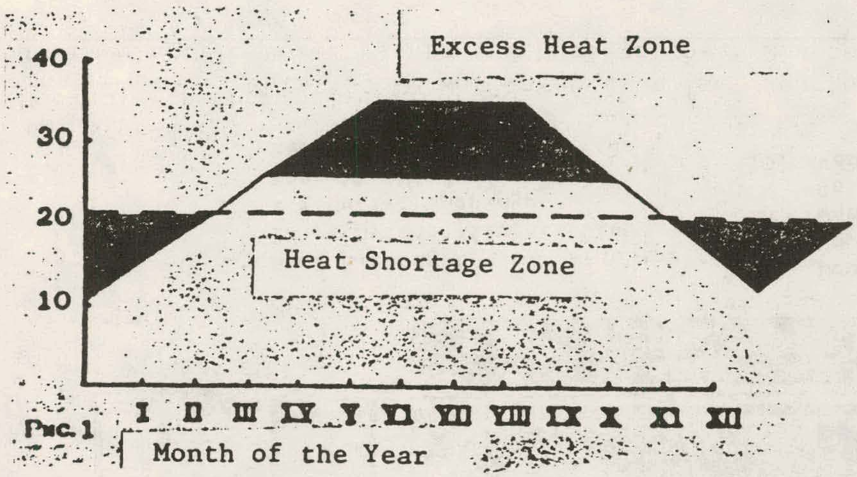


Fig. 3. Seasonal Change of Waste Water Temperature.*

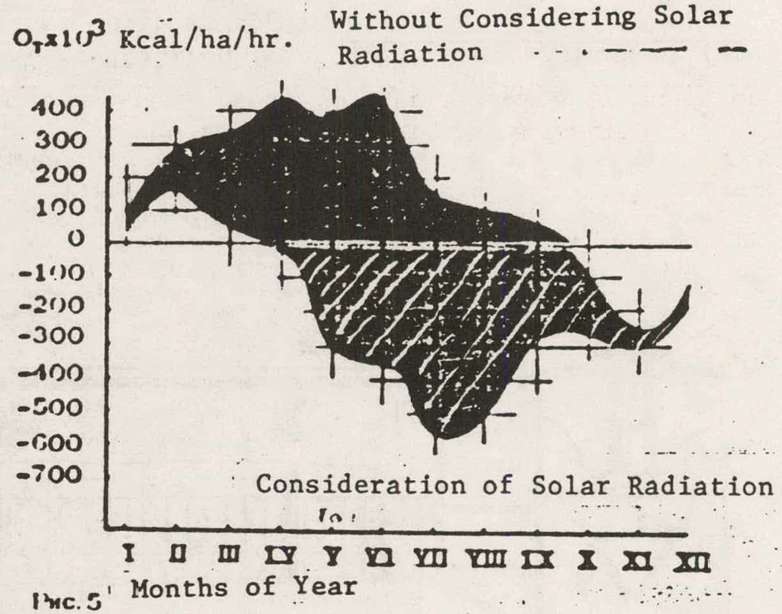


Fig. 4. Total Heat Losses of Greenhouse with Water-Filled Roof.*

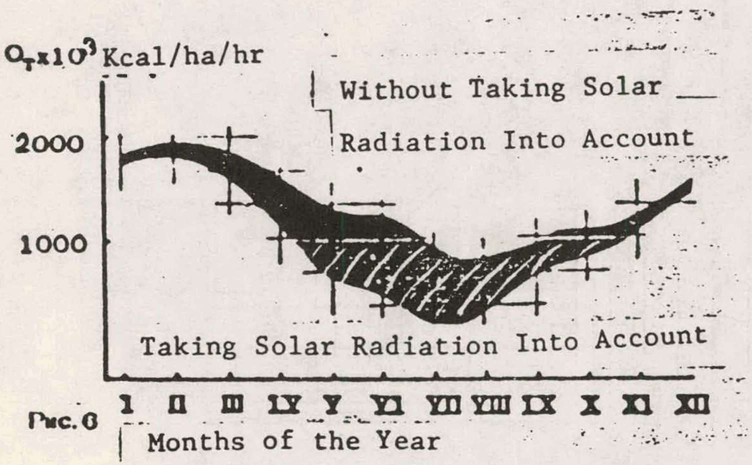
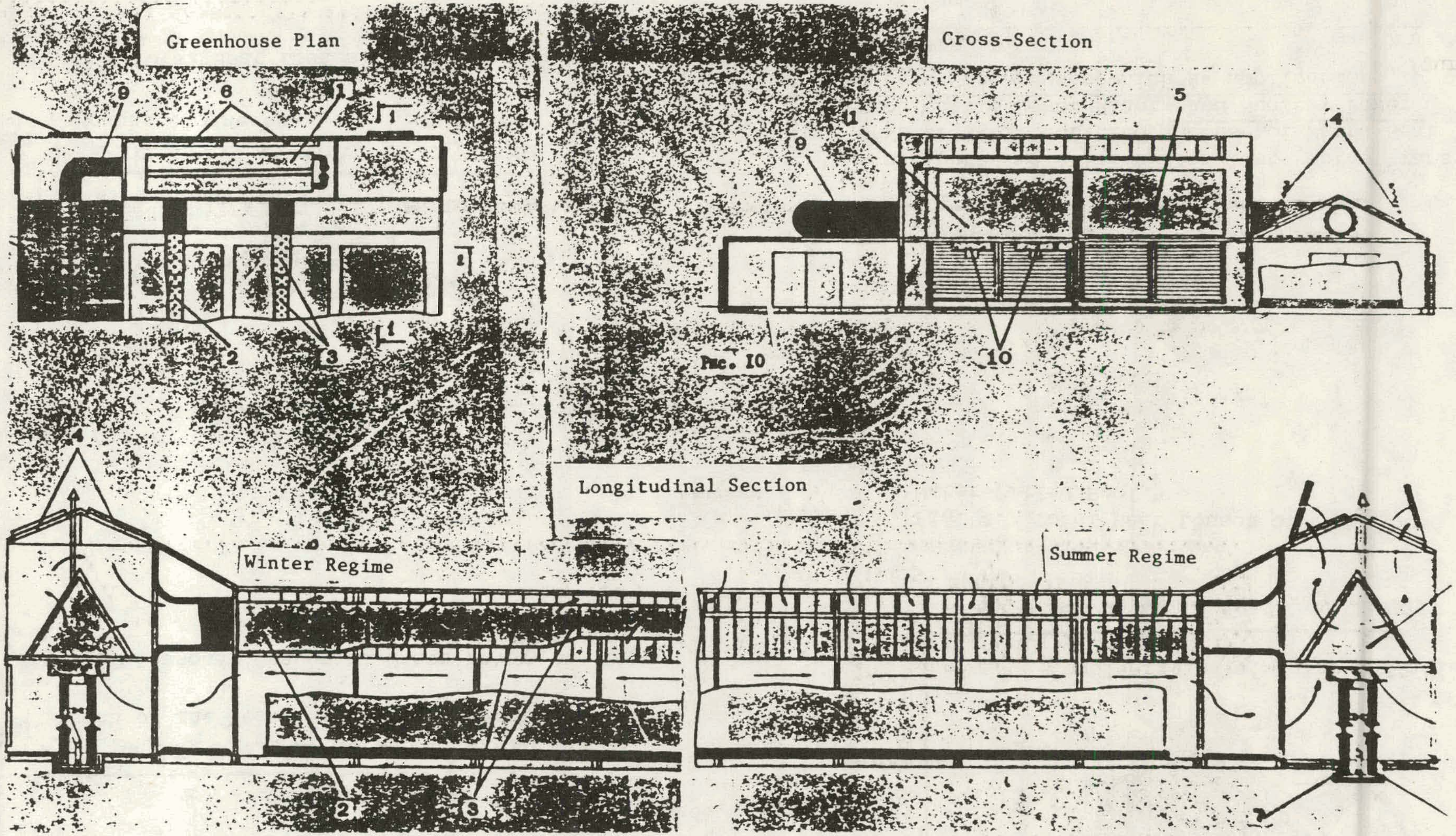


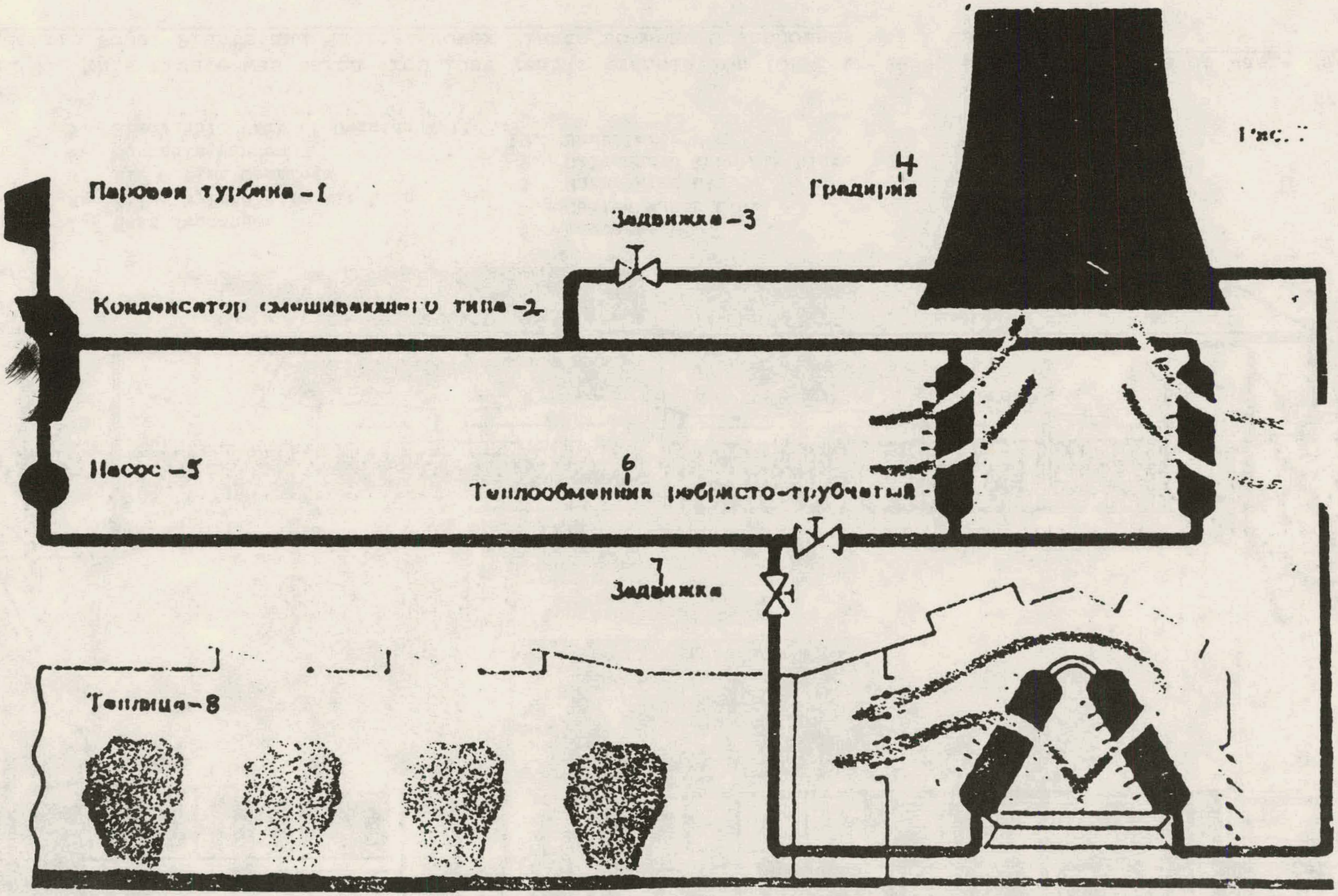
Fig. 5. Total Heat Losses of Greenhouse with Dry Roof.*

*These figures were taken from last year's translation (ORNL-tr-4483) entitled The Use of Waste Heat from Thermoelectric Power Plants and Nuclear Power Plants to Heat Greenhouses which is applicable.



1. Heat Exchanger
2. Polyethylene Film Air Line
3. Air Outlet Openings
4. Moveable Windows
5. Removeable Part of Outside Wall
6. Louvers
7. Cooled Water Line
8. Warm Water Line
9. Galvanized Iron Air Line
10. Ventilator

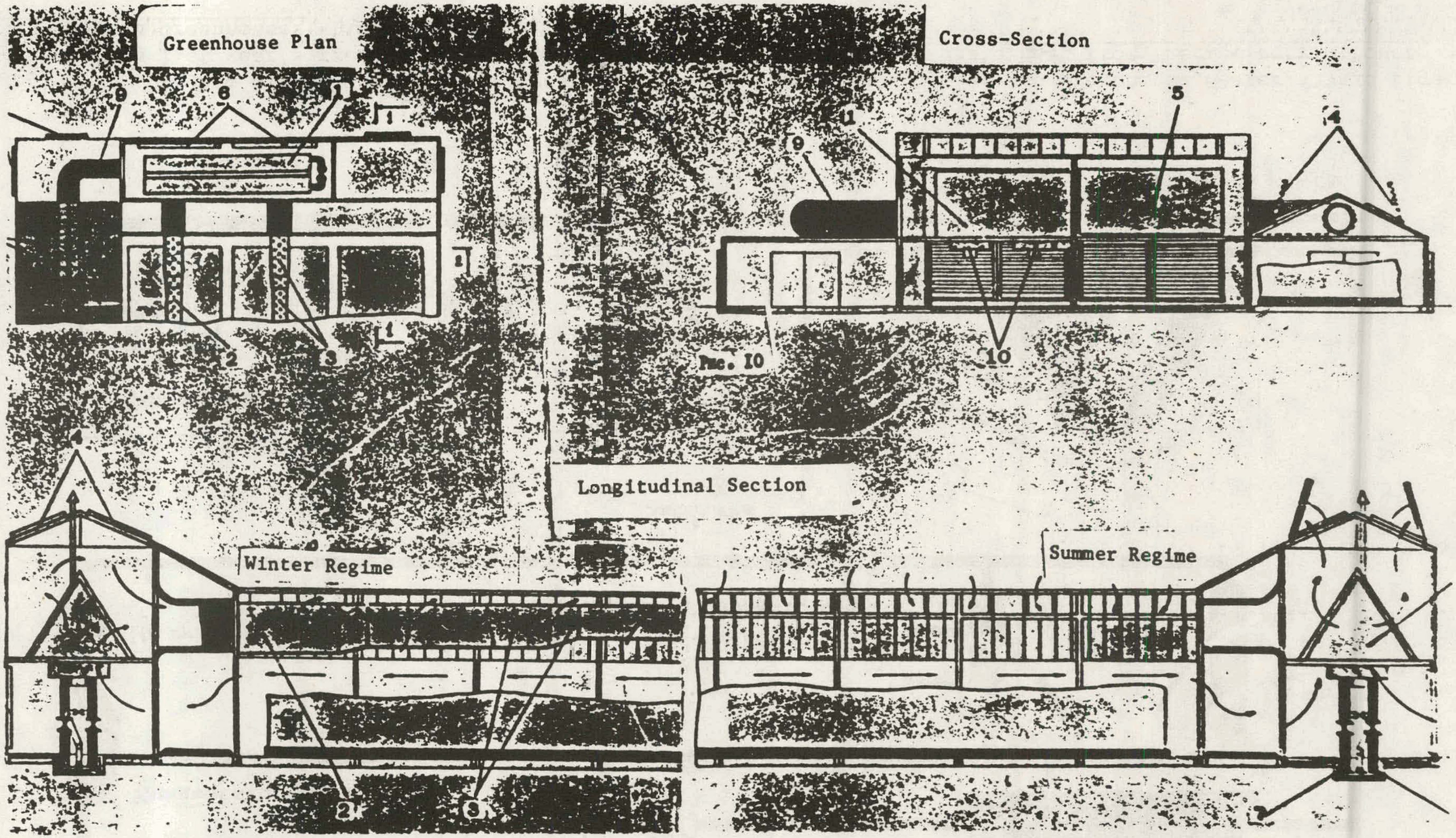
Fig. 6. This figure was taken from last year's translation (ORNL-tr-4483) entitled The Use of Waste Heat from Thermoelectric Power Plants and Nuclear Power Plants to Heat Greenhouses which is applicable.



1. Steam Turbine
2. Mixing Type Condenser
3. Valve
4. Cooling Tower
5. Pump
6. Ribbed-Tube Heat-Condenser
7. Valve
8. Greenhouse

ORNL-tr-4483

Fig. 7. Diagram of Combined Air-Condensation Electric Power Plant Cooler and Greenhouse Heater. This figure was taken from last year's translation (ORNL-tr-4483) entitled The Use of Waste Heat from Thermoelectric Power Plants to Heat Greenhouses which is applicable.



1. Heat Exchanger
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8. Warm Water Line
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10. Ventilator

Fig. 8. This figure was taken from last year's translation (ORNL-tr-4483) entitled <u>The Use of Waste Heat from Thermoelectric Power Plants and Nuclear Power Plants to Heat Greenhouses</u> which is applicable.

PAPER NO. 7

Ministry of Power Engineering and Electrification USSR

All-Union Order of Lenin Design-Research
Institute Gidroproekt
named for S. Ya. Zhuk

THE USE OF WASTE HEAT OF AN ELECTRIC POWER STATION FOR WARM WATER FISH FARMING

PROBLEMS AND FUTURE OUTLOOK

G. G. Cangardt, V. G. Farberov, L. A. Korneeva, and
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JOINT SOVIET-AMERICAN SYMPOSIUM ON REMOVAL
OF HEAT FROM FOSSIL FUEL AND ATOMIC ELECTRIC POWER PLANTS

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Razdan

The vigorous growth of industrialization throughout the world is founded on an energy base, which calls for predominate development of thermal power engineering, including nuclear power engineering, which is causing thermal pollution of the environment, mainly the aqueous environment, on an evergrowing scale. In addition, the use of irreplaceable natural resources: fuel, earth and water, in power production is rising significantly.

An important alternative to this undesirable process is the development of a system of measures aimed at comprehensive utilization of waste heat, which will likely help to reduce appreciably the significance of the negative factor of thermal pollution and can produce an additional national economic benefit in the form of valuable food products, primarily, protein products of animal origin.

At the present time a number of directions for the utilization of the waste heat of power sources have been noted. The best developed of these is the use of warm waters for fish farming.

Research in the field of the fish farming use of warm water was begun in the USSR in 1960. The initial task was to use herbivorous fish of the Far East complex (*Ctenopharyngodon idellus, Hypophthalmicthys molitrix*) for biological reclamation of cooling ponds. This work was successfully completed, thus ensuring effective elimination of aqueous plant life with simultaneous production of fish to 600 kg/ha.

In the same years studies were begun on intensive breeding of fish in fish ponds. It was shown that it is possible to produce up to 200 kg commercial carp per 1 m^2 pond area. In order to raise the economic efficiency of industrial farms in warm waters biological technology for the maintenance of the more valuable delicacy fish: trout, sturgeon, etc., has been developed. Today, the basic elements of the biological technology of these subjects have been developed and is being used by industry.

Successful biological and physiological fish farming research ensured the possibility of producing not only commercial fish, but also full-fledged breeders as well as viable fry in the warm waters of electric power stations. In the opinion of Soviet specialists the use of warm waters is most effective specifically for the reproduction of fish. Here costs for capital construction and feed for the fish are substantially less than for commercial farms, as a result of which the raising of fry turns out to be economically very effective. It is proposed to use this fry to stock lakes, water reservoirs and pond fish farms. Because of the enormous water resources of the USSR, the demand for stocking material is practically unlimited, which ensures an excellent outlook for the development of this trend. Reproduction of herbivorous fish of the Far East complex in warm waters at the same time provides complete satisfaction of the need for fish stocking material for biological reclamation of cooling ponds.

Use of warm waters for the breeding of valuable commercial fish has significantly reduced the period required for the maturation of the breeders -- 2- to 3-fold compared to the onset of sexual maturity under natural conditions. This factor is especially valuable in raising fish with a long period for sexual maturation such as sturgeon, which mature at 12-18 years. The technique developed in the USSR for raising sturgeon breeders and producing commercial black caviar envisions maturation of fish at 4-8 years. In this case the biological technology is based on complete optimization of the temperature, gas and other regimes and on the use of high efficiency physiologically complete food mixtures.

The changeover to fish breeding under regulated temperature and other conditions created the prerequisites for spawning at predetermined and economically expedient times. This was seen especially clearly in the breeding of carp -- the main object of industrial fish farming in the USSR. At the present time Soviet specialists have a procedure with which carp fry can be produced in any calendar period over the year. Maintenance conditions for breeders have also been developed in which one and the same female can produce progeny at 3 month intervals. All this has allowed Soviet specialists to change over to a year-round "assembly line" system of carp breeding with all the management and economic advantages which issue from this.

Under the severe climatic conditions of the USSR the use of the warm waters of electric power stations is exceptionally promising for the creation of industrial fishing complexes, which will include fish farming enterprises with the traditional breeding technology (pond, lake, in water reservoirs, etc.) and fish farms in warm waters, where breeding and winter maintenance of fish will be carried out.

Technology developed by Soviet specialists is allowing fish fry to be produced significantly earlier than the conventional schedules for fish spawning under natural conditions. Stocking of ponds even with a relatively small shortening of the natural spawning period (10-15 days) raises the efficiency of fish breeding by 50% (with respect to fish productivity and final weight of fish).

The wintering of fish in warm waters turned out to be exceptionally effective under the conditions of the USSR. With traditional technology fish are at low temperatures for half a year. During this period they not only do not grow, but become thinner, weaker, are subject to mass diseases and frequently they perish. The use of warm water has allowed the growing period to be extended, and disease to be reduced and even under winter conditions a weight gain to be obtained.

The main object of cultivation in the Soviet Union is carp. The biological properties of this species make it irreplaceable for breeding in warm-water industrial fisheries. The most valuable property of this species is its broad food spectrum and ability to assimilate plant protein. As is well known, the rations (kombikorm ["combi-feed"]) for other species of fish which are cultivated in farms must contain no less than 30% animal protein, which is necessary for normal growth and development. Here the fish being raised are not producers but rather consumers of animal protein, and their production volumes will be determined by economic and social factors.

Investigations by Soviet specialists have shown the possibility of raising carp on feeds with low concentrations of animal protein and even on feeds which consists only of vegetable components. Studies made by us have shown the possibility of feeding carp on basically new rations, which are based primarily on products obtained by means of microbiological synthesis -- protein-vitamin preparations and yeast. The promise of these products is well known, but proteins obtained in reactors cannot be used in large doses not only for man, but also for agricultural animals. In our experiments carp in warm water grew well on products containing up to 80% microbiological synthesis products.

It must be specially emphasized that the food value of carp produced by industrial methods using kombikorms is significantly higher than for natural water reservoirs. This phenomenon, which was first investigated by Soviet specialists, was completely confirmed in the GDR and FRG.

Therefore, there is every reason to believe that carp is the fish of the future because of its striking ability to convert products of microbiological synthesis and vegetable feeds into valuable protein. Because it does not expend energy in maintaining constant body temperature and overcoming forces of gravity, the carp, along with other herviborous fish, should be viewed as an important source of animal protein, advantageously distinguished from warm-blooded agricultural animals by its economy.

Carp is also distinguished from other species of crop fish by its fecundity in combination with batch [illegible], which makes possible multiple production of numerous progeny from a limited number of breeders, which is especially important for industrial methods of farming, where maintenance of a large number of breeders is economically inexpedient.

Carp has a high growth potential, which is manifested under optimum conditions, where it reaches a weight of 3 kg in 3 months.

However, carp cultivation under the conditions of industrial farms has an important problem, which lies in the biological nature of the larva (incomplete development of enzyme systems), which leads to the need to include live feeds in their rations, in contrast to other types of crop fish (salmon, sturgeon, sheatfish).

Satisfaction of this requirement of the larva leads to the need for a live feed plant within the warm water fishery, cultivating feed organisms which are accessible to the larva in early stages. The foreign experience in solving this problem is based on the use of brine shrimp as a feed object. However, this method has a number of shortcomings, primarily, the direct dependence on the condition of the raw material base.

The industrial method for year round cultivation of small feed forms (Infusoria, Rotifera, moina), which we have developed to outproduce previous methods by several orders of magnitude, yields 20 g crude matter per 1 ℓ culture per day. This method allows the need of carp larva for live feed to be met completely.

In addition to carp sturgeon (bester), eels, warm water fish of the American and Indian complexes, herviborous fish, etc. can also be successfully grown in warm waters.

In the USSR comprehensive utilization of the warm waters from power sources for fish farming is being planned, calling for the creation of the following types of fish farms in dependence on specific conditions:

1. Farms with grid ponds are used at practically all types of power stations discharging warm water. The basic advantage of these farms is their simplicity, low construction costs and low operating costs.

2. Basin farms are economically expedient when using the warm waters from nuclear power stations and high-power thermoelectric power stations.

Basins can be of reinforced concrete construction or earth construction with polyethylene sheeting. The cost of earth basins is 1/3 of the cost of reinforced concrete ones, but the latter have a longer life span, and the use of prefabricated constructions and industrial methods for installing them is possible.

Basin farms are the most progressive form for carrying out warm-water fish raising. Here optimization of all the parameters of the environment, mechanism and automation of production processes are possible.

3. Fish farming use of cooling ponds is expedient at every water reservoir receiving heated waters.

In addition to carp, cooling ponds are stocked with herbivorous fish, which allows the natural feed base of the water reservoir to be utilized more fully and prevents overgrowth of the reservoir. Thus, biological reclamation of the pond contributes to favorable conditions for the operation of cooling ponds.

4. Fish nurseries using warm water produced early fry of carp and herbivorous fish for stocking ponds in commercial farming lakes, water reservoirs and cooling ponds.

5. Pond farms are built when, for reasons of optimum temperatures, the use of warm waters for the more efficient basin

and breeding farms is inexpedient (t° above 23° less than 4 months per year).

A combination of several of the above-mentioned forms of warm water fisheries is possible.

Until recently fish farms of the USSR used the waste warm waters of electric power stations at temperatures dictated by the interests of power engineering alone. In doing so the water temperature in the winter was significantly below the temperatures needed for effective fish growth, while they rose to dangerous limits in the summer.

Advances in the fish farming use of warm waters and the increase of the production of fish in warm waters allowed the question to be raised about converting to mutually coordinated technology for the production of electric power and food products. In this case the power station would supply to the fish farm throughout the year the water at a temperature more favorable for fish growth without the use of additional heating and cooling systems. The technology of modern electric power stations allowed water to be produced at various temperatures and to be transferred to the fish farm in isolated streams.

A large scale fish farming complex having a capacity of 2000 t fish per year has been created at the Kursk nuclear power station on the basis of this principle for the production of electric power and fish in the USSR.

The objects of breeding at this enterprise will be:

Carp (*Cyprinus carpio*)	- 1500 t
Ictalurus (*Ictalurus puncatatus*)	- 300 t
Trout (*Salmo irrideus*)	- 160 t
Sturgeon	
Herbivorous	

The design of the fish farming complex was developed by the Gidroproekt Institute on the basis of its experimental projects in the cultivation of fish under governed conditions.

The basis for this technology is optimization of the temperature regime at all stages of the growth and reproduction of fish.

This allowed the accomplishment of a continuous year-round method for breeding carp, which calls for monthly spawning and daily recovery of commercial production.

The use of continuous technology has a number of advantages over the traditional form for raising fish in a single cycle. These basically are:

1. The possibility of a year-round supply of fresh fish for the population.

2. A significant reduction in the output of the pump station (8 m^3/s versus 40 m^3/s for the accepted unit consumption of water).

3. Reduction of production areas.

4. The smooth flow of work of the enterprise without peaks and valleys allows the number of servicing personnel to be reduced.

A detailed study which we made on the influence of temperature on the physiological processes showed that there is no single narrow temperature optimum which is specific for this species of fish. In addition to significant differences in the optimum temperatures for fry and adults, it was established that there is a difference in the temperature optimum for the demand and use of food, for the use of feeds of various composition, for the direction of the processes of protein and fat synthesis. In specific temperature intervals a change of water temperature by 3 degrees can double the growth rate of the fish and correspondingly the use of feed by them.

The difficulties encountered in designing and operating the first generation of warm water fish farms were considered in designing the fish farming complex at the Kursk nuclear power station. In addition to investigating the temperature regime much attention was given to the rapid and most complete removal of the products of the life activity of the fish, which requires the creation of a fundamentally new design for the fish farming basins.

In connection with the lack of natural food in industrial methods of fish farming in warm water it became necessary to work out economical and physiologically complete feed mixtures for fish of various ages (primarily for carp and sturgeon) with a relatively low concentration of feeds of animal origins and consisting of available components. Technology for feeding carp and sturgeon of various ages and at various temperatures, optimum daily norms, frequency of feeding, technology for manufacture and distribution of feed had been developed previously under experimental conditions.

A fundamentally new element of technology, which was first used at the Kursk fish factory, is purification of the waste effluent of this enterprise. A large quantity of biogenic elements in the form of fish excrement and unused residues of feed are discharged into the cooling pond along with the water passing through the fish farming basins in industrial fish feeding. This is quite irrational both from the standpoint of the eutrofication of the cooling pond as well as from the standpoint of nonproductive losses of food matter which has not been assimilated by the fish.

At the present time we are working out various schemes for utilizing the biogenic effluent of industrial fish enterprises which calls for trapping the solid effluent with the use of a hydrocyclone unit with subsequent utilization of it in agriculture, for cultivation of live feeds, for repeated use by fish, for the production of protein-vitamin preparations by means of microbiological synthesis. Utilization of the biogenic wastes of industrial fish farming enterprises allows a conversion to the use of the nutrients of the feed and biogenic elements in a closed cycle, which appreciably raises the economic efficiency of the enterprise and presents environmental pollution. The problem is simplified by the fact that in contrast to industrial and domestic effluents fish enterprises do not discharge substances which are toxic or pathogenic for man.

Biological research and engineering developments has allowed industrial technology to be developed for raising carp in the warm waters of nuclear power stations.

The realization of this technology in the design of the Kursk fish factory will provide:

- a 2.5-fold acceleration of the maturation of carp breeders compared to pond farms;
- technology for the monthly year-round production of fish larva;
- technology for raising carp fry providing for a growth of carp larva at a stocking density of 70 thousand/m^3;

- production of this year's brood of carp having an average weight of 30 g at an output of 8000 fish/m^2 and productivity of 24 kg/m^2;

- production of commercial carp having an average weight of 500 g at an overall productivity of 150 kg/m^2 or 250 kg/m^3;

- reduction of the schedule for the production of commercial carp to 8 months.

At the present time a whole host of warm water farms have been built both here and abroad. The Cherepetsk, Mironovskoe and Kiev farms are operating successfully in the USSR. However, all these operate on a single-cycle scheme and only at the Kursk project has this fundamentally new approach to the fish farming use of waste warm water been realized.

It should also be noted that the fish farm being built is the first step in the creation of an energy-biological complex at the Kursk nuclear power station.

At the present time new types of hothouses intended for low potential heat are being developed.

The use of waste heat for the needs of the microbiological industry is quite promising. At the same time, the waste products of the fish farming complex can serve as starting materials for the production of feed yeasts and certain enzymes in microbiological production.

A new direction is the use of waste heat to heat mushroom farms, in which the wastes of the fish farming enterprise are used as fertilizers.

The first experiments in placing a floating substrate for growing certain vegetable and berry crops on the water area of fish breeding ponds in cooling ponds presents much interest. Here a double benefit is achieved: additional production and purification of the water of biogenic elements.

All these studies are aimed at creating a unified energy-biological complex operating in a zero-waste technology. Only in this case is it possible to produce maximum benefits.

In the future it is planned to step up the work in the comprehensive utilization of waste heat, moreover the interests of power engineering and the branches using warm waters must be correlated by a common technology calling for optimization of the operation of all segments of this complex. In various instances it is possible that one or another branch will predominate.

Future development of warm water fish farms will proceed in close correlation with all participants of the energy-biological complex. Farms operating on a continuous technology will be developed preferentially.

It is believed that these studies will result in the development of scientific bases and concrete proposals for the creation of these farms at all large scale power objects.

Figure 1. Block diagram of energy-biological complex.

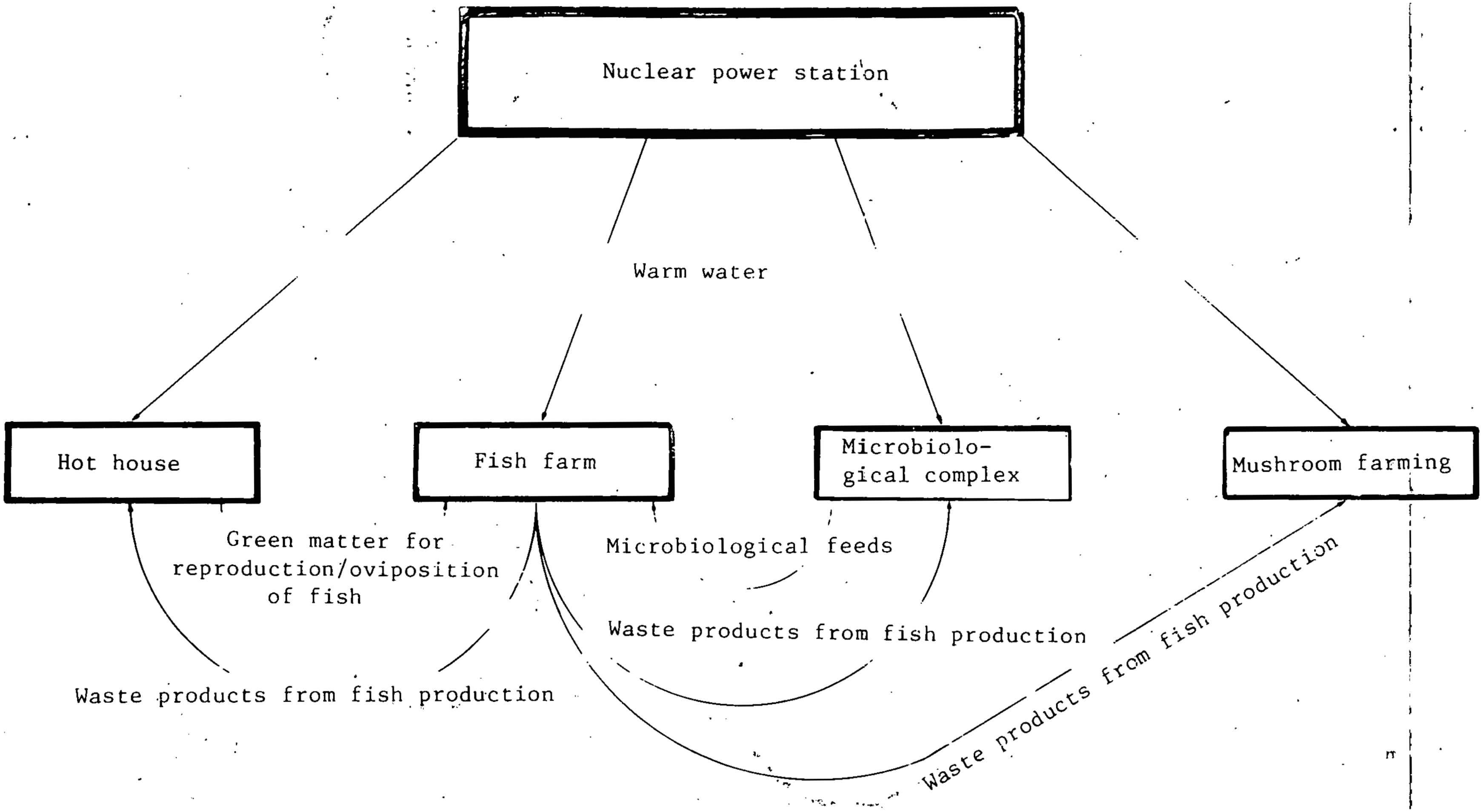
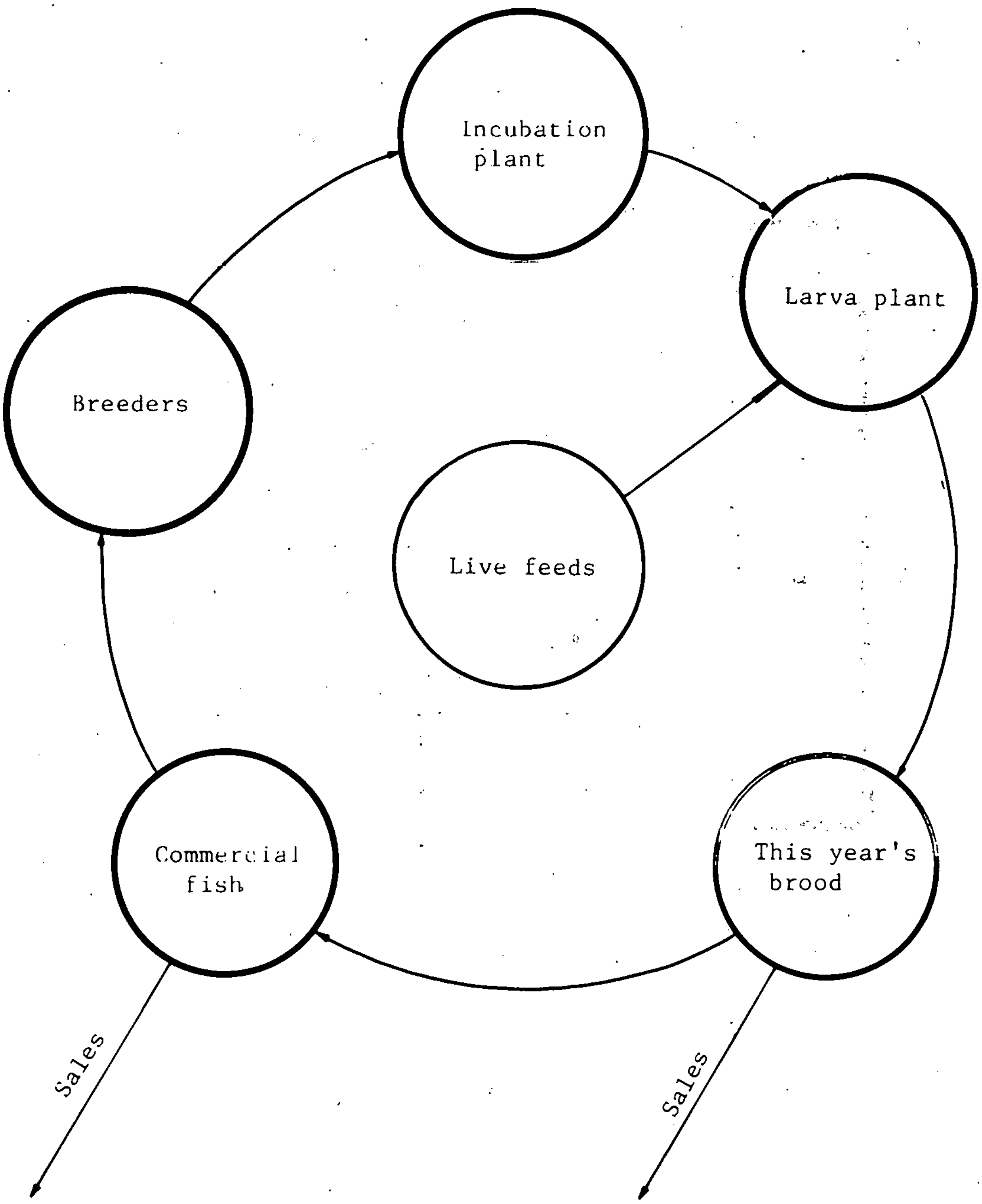


Figure 2. Block diagram of fish farm at Kursk nuclear power station.



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PAPER NO. 8

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(Teploelectroproyekt)

BASIC PRINCIPLES OF THE SPECIFICATION AND DESIGN OF HEAT REMOVAL SYSTEMS FOR FOSSIL FUEL AND NUCLEAR POWER PLANTS IN THE USSR

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INTRODUCTION

The variety of natural conditions of the USSR, the increasing shortage of water in a number of the industrial regions of the country, the demands of environmental protection, the increase in the capacity of power stations and in the amount of heat given off by them, as well as the need for a comprehensive resolution of problems of the various branches of the national economy in designing heat systems of fossil fuel and nuclear power plants predetermines the great variety of the cooling systems used.

In selecting a power plant cooling system the acceptability of many possible system variants is usually reviewed, after which the more expedient and workable variants are, in correspondence with the laws of the USSR, presented for analysis and approval to health inspection agencies, fish resource protection agencies and agencies regulating the distribution of water resources.

The optimum variant of the heat removal system is adopted according to the totality of economic factors and approval conditions.

1. DIRECT-FLOW SYSTEMS

In those cases where heat is removed into rivers and general-use bodies of water (including seas, oceans, water reservoirs, canals, etc.), the specifications of the "Rules for the protection of surface water..." are observed; according to these rules the average monthly water temperature in a body of water 500 m from the point of warm water discharge must not rise by more than 3°C compared to the natural average monthly water temperature at the surface for a hot year with a certainty within 10%. For bodies of water used for fish farming the average monthly water temperature of the hottest month must not exceed 28°C more than once in 10 years, while for bodies of water where salmon and whitefish dwell, this temperature must not exceed 20°C.

An obligatory condition for the use of open direct flow cooling systems with water intake from bodies of water used for fish farming is the prevention of fish and especially fry from falling into the water supply of the power plant. In some cases construction of fish farms is allowed as compensation for the loss of fish in water supply systems.

For observation of the norms of temperature regime for bodies of water receiving warm water, the following technical solutions are provided in dependence on the hydrology and morphology of the body of water:

- discharge of warm water into bays or bodies of water cut off from the main body of water for preliminary cooling;

- spray installations above warm-water discharge canals, for preliminary cooling and aeration of waste water during hot periods of the year;

- ejection water-discharge systems, which ensure threefold dilution and mixing of warm water at its discharge point. In addition to reducing the water temperature ejection water discharge reduces the appearance of algae, garbage and young fish to the water intake and by stepping up flows improves the quality of water in the body of water;

- deep water intakes from stratified bodies of water with depths of more than 10-12 m ensures the intake of the colder water from bottom layers.

- In those cases where the difference between the temperatures of the surface and bottom layers is 8°C or more, and the volume of the body of water is sufficiently large, even after the water is heated in the turbine condensers by 9-10°C the temperature of the discharge water in the warm periods of the year may be lower than the temperature of the surface layers of the body of water.

Besides reducing the temperature of cooling water these water intakes eliminate the appearance of floating trash, algae and slush ice in the water supply system, and also serves as a fish protection device due to its low intake velocities (0.05-0.2 m/s) and the shadow created by the hood, baffle plate.

In addition to deep water intakes the following have been used as fish barrier devices:

- electric fish barriers with electrodes lowered into a conducting channel and connected to a constant current source. However, such fish barriers have not turned out to be effective;

- net fish barriers with a fish outlet and with jet washing of the fabric of the net having mesh from 2 x 2 mm to 4 x 4 mm.

Net fish barriers have also not found extensive application at power plant water intakes because of their size, difficulty of operation (cleaning of trash), the need to remove them during the freezeover period, high costs and so forth.

Net drums of various designs are used for relatively low water flow rates to 2-5 m^3/s. Conical screens with fish outlets and rotating wash device are also used.

For low water flow rates to 5-10 m^3/s filtering fish barriers in the form of cassettes made of various filtering materials are used with various methods for cleaning them and stone rubble dams are also used.

Fish barriers in the form of floating booms and baffle hoods provide 65% efficiency of fish protection.

The design and construction of experimental air bubble fish barrier curtains is being carried out at the water intakes of two power stations.

It should be noted that at the present time extensive research is being carried out in the USSR and abroad on effective designs for fish protection devices, but sufficiently good decisions have not yet been worked out for their extensive use.

2. RETURN SYSTEMS WITH COOLING PONDS

The high required cooling water consumption, which reaches 300 m^3/s and more for a nuclear power plant, the rigid requirements for the protection of bodies of water from a thermal effect of power plant waste water (in our opinion not yet sufficiently substantiated and not taking into full account the variety of climatic conditions of the country) and the low efficiency of existing methods of fish protection restrict the use of direct-flow systems for removing heat into bodies of water, even though at the contemporary level about 30% of the power stations operate with this kind of cooling system.

About 50% (with regard to output) of the thermal and nuclear power plants of the country were designed with return cooling systems with cooling ponds, which are set aside for the separate use of power plants.

Cooling ponds are normally designed for low-value (swampy, salty) lands -- in ravines, valleys of small rivers, in cut-off shallow water areas, in water sheds with filling and make-up water from external sources.

The area of cooling ponds is selected in accordance with the output and type of power station, topographic, geologic, hydrologic, etc., conditions and ranges from 2-3 to several dozens of square meters. On the average the optimum unit area of the pond is 4-5 m^2/kW for a fossil fuel power plant, and 7-9 m^2/kW for a nuclear power plant.

The principles for organizing the flow of cooled water in cooling ponds depend on the depth of the pond, its plan configuration and wind direction.

For shallow ponds with an average depth of 3.5-5.0 m the flow of cool water is distributed over the surface of the cooling pond with the aid of open discharge canals, jet-directing dams, floating collecting walls so that the highest water temperatures and correspondingly the maximum heat transfer is on the maximum part of the water area in the regions of the water discharges.

For deep ponds with a depth of more than 10 m volume circulation schemes are used with artificial temperature stratification.

Cooled water is collected by deep water intakes, and warm water is discharged in a dispersed fashion into the surface layers of the cooling pond. In doing so long canals and jet-directing dams are not built, and the water intakes and water discharges are placed in direct proximity from each other (even up to combining them) and from the area of the power plant.

In cooling ponds for the private use of fossil fuel and nuclear power plants and which are isolated from general purpose bodies of water and streams, the water temperature level is not restricted by the specifications of the "Rules for the protection of bodies of water...". A specific thermal regime (the temperature level is significantly higher than in natural bodies of water), specific hydrobiological conditions which are often favorable for raising thermophilic plants and fish, are created in them.

Combating overgrowth of ponds with higher aqueous plant life is performed mechanically (mowing machines), biologically by raising plant-eating fish (silver carp, grass carp, telyapiya, etc.). Overgrowth of the water supp y track by mussels and algae, is as a rule dealt with by periodic prophylactic heating of the track to a temperature of 35-45°C by feeding hot water to the intake of the circulation pumps or by reverse flow of water through the condensers and pumps. At this temperature level the larva of mussels, *Balanus*, zebra mussels and algae perish in 30-50 minutes. Hot water washing is carried out without turning off the turbines during a period of a load drop (at night, during weekends) at a frequency of 1-2 times per month during the growing period.

Filled cooling ponds located at high points are often used as hydrostatic basins for water storage power stations, allowing a significant peak output to be obtained due to the available capacity of water from the pond through the hydraulic power station and allowing the load curve of a nuclear power station to be smoothed out by pumping water to fill the pond during periods of low electric loads.

In such energy complexes a low-lying general-purpose body of water is also used for cooling, while the higher filled pond -- the hydrostatic basin for daily regulation -- is used for precooling of waste water to normative temperatures.

In addition, the hydrostatic basin can be used to supply water for irrigation with warm water and to hothouses with water-filled roofs, since because of its height it towers above farming land in the vicinity of the power complex. Such solutions involving comprehensive utilization of water resources and the waste heat of nuclear power plants allows the thermal efficiency of the power plant and the efficiency of water use to be increased while observing environmental protection laws.

3. RETURN SYSTEMS WITH COOLING TOWERS

In cases where the power station is located near the points of consumption of thermal and electric power (thermoelectric power plants in cities and at industrial enterprises) or at fuel sources (at coal mines), where it is impossible or economically inexpedient to create cooling ponds systems for removing heat with the aid of cooling towers are used. Until recently evaporative towers with irrigation areas from 1200 m^2 to 9400 m^2 with tower height from 40 to 150 m were most commonly found (up to 15% of power plants). In regions with moderate climates the towers were built from monolithic reinforced concrete. There are towers 60 m in height built from prefabricated reinforced concrete elements. For northern regions with air temperatures below -28°C and also for regions with seismic activity greater than 7 points the cooling towers are made with a steel framework and are faced with corrugated aluminum sheet material.

The water distribution of towers is hydrostatic tube-type with plastic spray nozzles, the irrigators are counterflow film irrigators made of asbestos cement sheets or wood battens, and the skeleton of the irrigator is made from prefabricated reinforced concrete elements. Large towers are outfitted with louver-type water traps. The optimum irrigation density is 8-10 $m^3/m^2 \cdot hr$.

Fan towers are used in Soviet power engineering little and only in regions having a hot and humid subtropical climate, since they are less economical to operate.

In the USSR there is favorable experience in the use of "dry" towers for 200 MW plants in a region of high water scarcity.

4. COMBINATION COOLING SYSTEMS

In recent years combination cooling systems have become common. These have relatively small cooling ponds 5-8 km^2 in area in combination with additional artificial cooling towers, spray devices, which are turned on in the hot periods of the year. The advantage of these systems is the sufficiently high thermal inertia of the system, which allows peaks in the temperatures of the cooling water to be smoothed out; the possibility of lengthy operation of the system without adding make-up water due to the operation of the water reservoirs; maintenance of optimum temperature regime in the winter; greater maneuverability in changing loads of the power plant.

In these systems the coolers operate in parallel and the flow rates of cooling water are distributed among the coolers in dependence on the changing meteorological factors and loads. In addition, the great freedom in the design of the general plant allows combination schemes to be used when expanding existing power plants.

In a number of regions of the country having continental climate and mountain-feed river networks, i.e., with high flow in the summer and very low flow in winter, it has turned out to be expedient to use combination cooling schemes with "dry" towers, which are intended for operation in the winter when there is a temperature drop between the cooled water and the outside air of 60-70°C.

In summer, when the water temperature in the rivers is low and flow rates of water are rather high, direct flow water cooling is provided. Such schemes are economically justified for northern regions, where the water streams freeze to the bottom in winter (permafrost regions) and it is very difficult to obtain make-up water. For the regions of Central Asia with intensive land irrigation the heating of the water used for irrigation in the condensers of the power stations increases the harvest.

5. SUMMARY

Specification of a cooling system for thermal and nuclear electric power plants represents a difficult and complex task and is resolved for each power plant on the basis of optimization calculations which take into account not only the specific conditions of the regions and site of the thermal or nuclear power plant, capital investments and operating costs for power engineering, but also the economic effect obtained in other branches of the national economy in the utilization of waste heat in agriculture and fish farming, the extension of navigation periods, and the improvement of the sanitary condition of bodies of water and the air of basins.

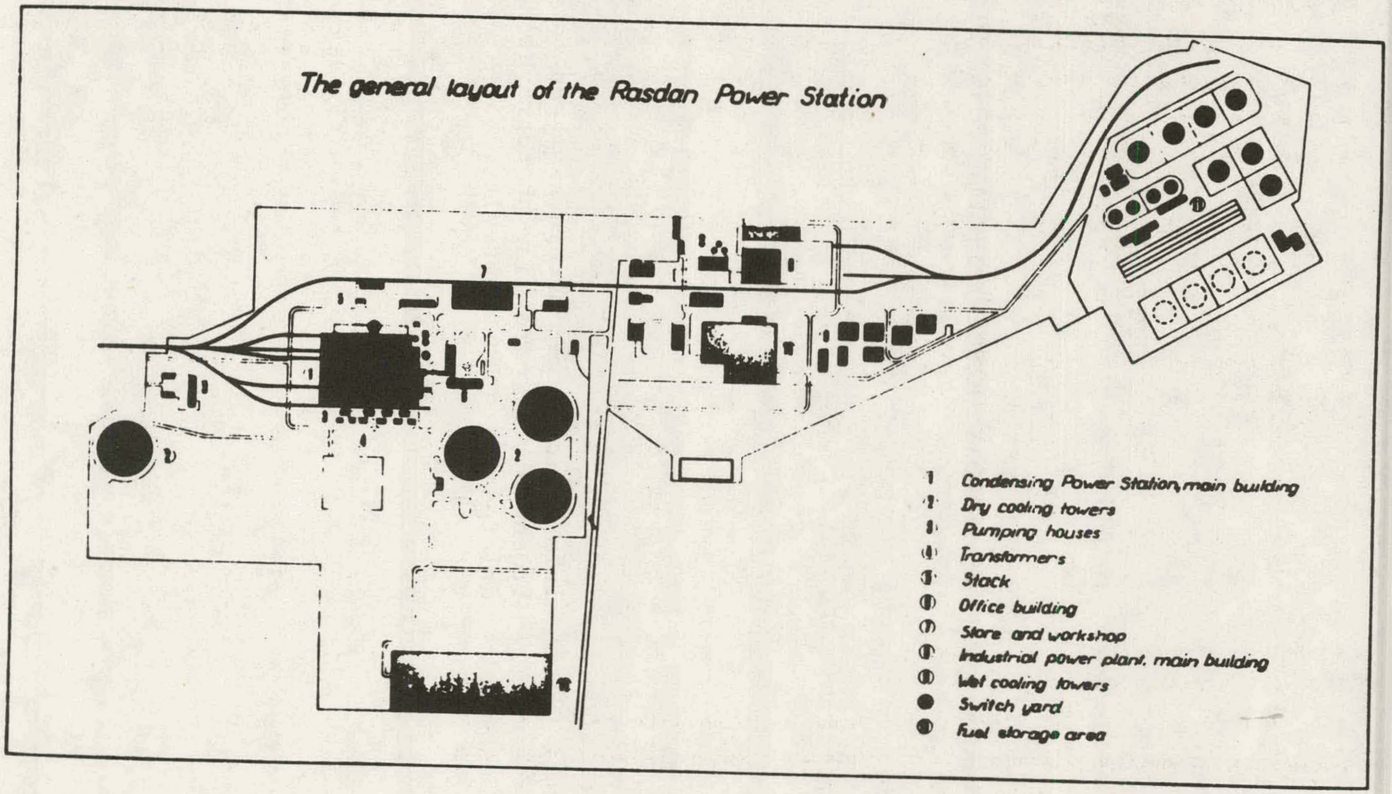
The difference in the conditions for the construction of power plants have predetermined the broad range of unit cost factors for various systems for removing heat with respect to capital investments from 3 to 30 rubles per kW installed power.

APPENDIX C

RAZDAN (RASDAN) THERMAL POWER STATION

Note: Information given herein has been taken from a brochure. Accompanying photographs have been deleted for sake of brevity.

Rasdan Thermal Power Station



HISTORICAL REVIEW

The Rasdan Thermal Power Station belongs to the Power System of the Armenian SSR, through which it is linked up with the integrated Trans-Caucasian grid.

The development of the Armenian Power System has been started with the construction of hydraulic power stations in the years before and during World War II.

During the 1960's, the growth rate of power production was increased by the rapid industrial development. In order to meet the demands, construction of thermal power stations of larger unit capacities was started. This trend was promoted by the fact that, due to the technical development of industry, long distance transportation of electric power and fuel became possible.

In the period between 1959 and 1965 the construction of three larger gas and oil fired district heating power stations has been started in Yerevan, Kirovokan and Rasdan.

In the above mentioned period the capacity of thermal power plants in the Armenian SSR increased by 274 MW.

In the following years the capacity of the existing power stations has been increased.

The capacity of the Yerevan district heating power station has been increased to 550 MW, and installed capacity of the Rasdan P. S. in its present state reaches 1 120 MW.

Today the Rasdan Power Station produces more then 50% of the total output of the Armenian Power System.

Continuous and unlimited electric power and heat supply to the consumers is assured by the systematic extension of the capacity of the Armenian power system.

The Rasdan Power Station consists of two main parts: an industrial power plant and a condensing power plant. Construction of the industrial plant was started in 1963 and the last unit was put into operation in 1970.

The industrial plant consists of two PT-50 type 50 MW and two T-100 type 100 MW extraction condensing turbines.

In the industrial plant turbosets are cross-connected.

Construction of the condensing plant was started in 1969. In its present state, it consists of two K-200-130 type 200 MW and two K-210-130 type 210 MW turbines.

Extension of the Rasdan power station up to a capacity of 1120 MW raised problems of cooling water supply. The shortage of local water supply and rapid development of irrigation in agriculture necessitates the saving of the existing water reserves, therefore all the four turbines of the power plant have been provided with dry cooling towers system Heller which has been developed in Hungary and it has been imported from there.

A residential quarter provided with all comforts has been built for the staff of the power station and of other industrial works situated in the neighbourhood.

The residential quarter is provided with the necessary shopping centre, schools, infants nurseries, kindergartens and other social establishments.

INDUSTRIAL PLANT

The boilers and the turbines of the industrial plant, having a total capacity of 300 MW, are cross-connected.

BOILERS

The steam supply is assured by 5 mixed natural gas and residual fuel oil fired boilers made by the Barnaul Boiler Factory. The boilers are of the single drum natural circulation type. On both the front and rear side 5 burners are installed which are suitable for gas and residual fuel oil firing. The boiler consists of a radiated vertical combustion chamber, a horizontal and a convection down-coming flue gas pass. A rotary regenerative air heater is used for air heating.

Technical data:

No. of boilers	1 to 5
Manufacturing works	BKZ Barnaul
Type	BKZ-320-140 GM
Capacity	320 t/h
Steam pressure	140 atg
Steam temperature	560° C
Feedwater temperature	230° C
Boiler efficiency	
– with residual fuel oil firing	91.9%
– with natural gas firing	92.4%
Temperature of outlet flue gas	
– with residual fuel oil firing	154° C
– with natural gas firing	137° C
Auxiliary equipment	
induced draught fans per boiler	2
forced draught fans per boiler	2
Rotary regenerative air preheaters per boiler	2

Fuel:

Natural gas 47% of the total fuel cunsumption

Calorific value	9020 kcal/Nm³
Transportation	by pipeline

Residual oil 53% of the total fuel consumption

Calorific value	9950 kcal/kg
Ash content	0.5%
Moisture content	0.1–0.2%
Sulfur content	0.3–0.4%
Specific weight	925 kp/m³
Transportation	in railway tanks

TURBINES

The industrial plant is provided with two PT-50-130/7 type and two T-100-130 type extraction condensing turbines.

Technical data:

PT-50-130/7 turbines

No. of turbines	1 and 2
Electrical output	50 MW
Speed	3000/min
Initial steam pressure	130 atg
Initial steam temperature	555° C
Condenser pressure	0.053 ata
Steam extraction	
with regulated pressure of 7 ata	118 t/h
with non-regulated heating extraction at pressures of 0.6 to 2.5 ata, and with non-regulated heating extraction at a pressures of 0.5 to 2.0 ata total	76 t/h
equivalent to	40 × 10⁶ kcal/h

T-100-130 turbines

No. of turbines	3 and 4
Electrical output	100 MW
Speed	3000/min
Initial steam pressure	130 atg
Initial steam temperature	555° C
Condenser pressure	0.053 ata

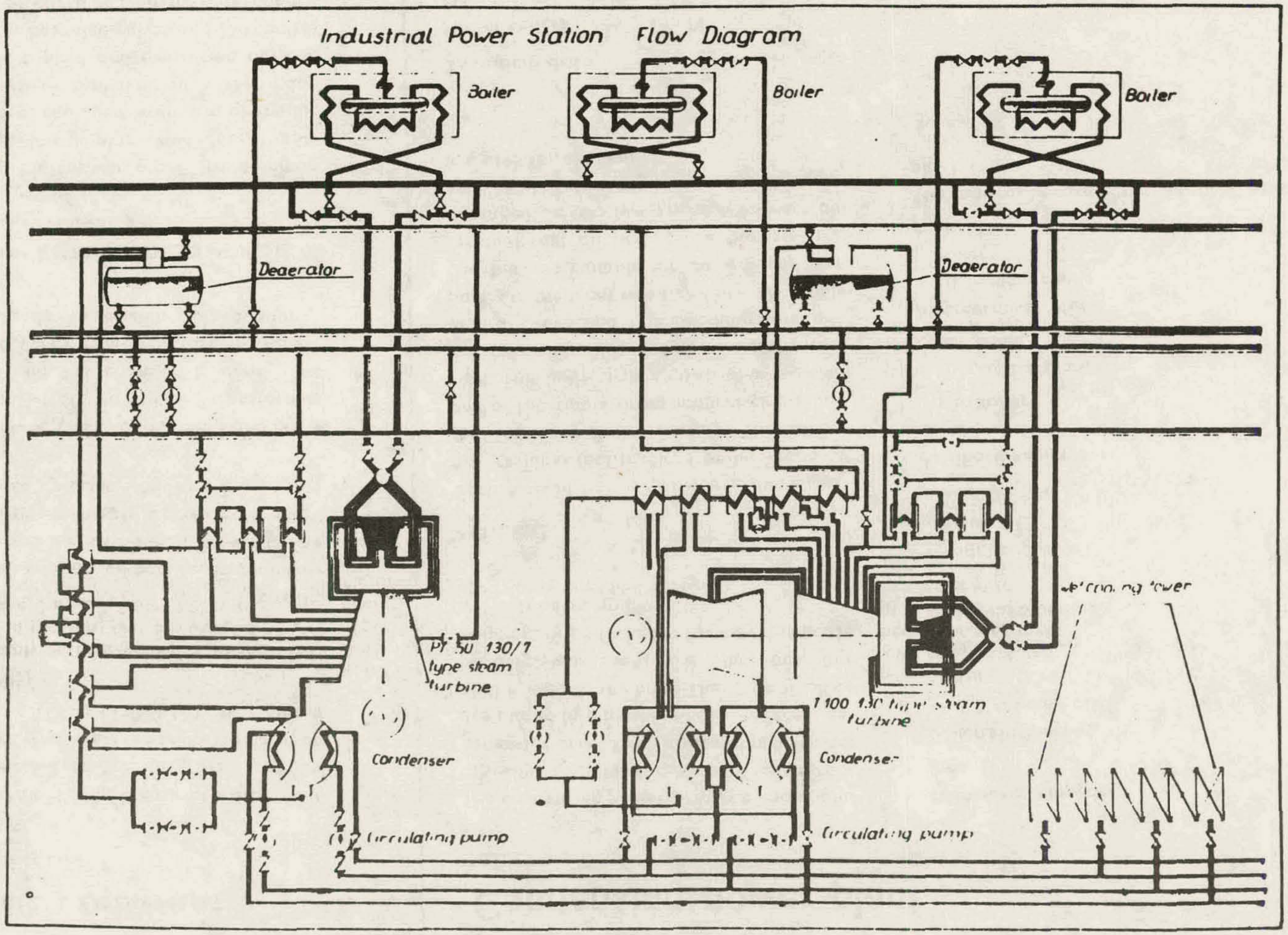
Steam extraction:

with non-regulated heating extraction at pressures of 0.6 to 2.5 ata with non-regulated heating extraction at pressures of 0.5 to 2.0 ata total	310 t/h
equivalent to	160 × 10⁶ kcal/h

Condenser: with built-in tube bundle for preheating make-up water.
Cross-connection between turbosets permits all turbines to be connected with all boilers.
The industrial power plant is provided with 6 boiler feedpumps which are working on a common system as well as 2 circulating water pumps per each turbo set.
Natural draught wet cooling towers are used to cool the condensers.
Water consumption of the industrial power plant is: 1450 to 1500 t/h.
Water is supplied by a pumping station located on the nearby river Marmarik.

GENERATORS

No. of generators	1 and 2	3 and 4
Type	TVF-60-2	TVF-100-2
Power factor	0.8	0.85
Rotor current	1635 amp	1650 amp
Stator voltage	6.3 kV	10.5 kV
Exciter voltage	210 V	280 V
Exciter current	1635 amp	1680 amp
Stator cooling	hydrogen	
Rotor cooling	hydrogen	



ELECTRICAL EQUIPMENT

The generators of the industrial power plant are connected to the integrated grid by means of two TDTN-63 000/110/35 type and two TDCG-125000/220 type main transformers.

The outdoor switchgear is operated on two different rated voltages: 110 kV and 35 kV. MKP-110 and MKP-35 type oil circuit-breakers are installed between main transformers and the distribution network. The auxiliary power supply is provided through two service and one standby 6.3 kV cable circuits.

For the power supply of sets No. 3 and No. 4 one TDNS-16000/10.5 type transformer with off-load tap changer is used. One TDN-16000/110 type transformer is built in as a standby for auxiliary power supply.

INSTRUMENTS AND CONTROL

The industrial power plant, the common water treatment plant and fuel supply system are equipped with an automatic control system consisting of Soviet made automatic control and measuring devices. 500 remote operated valves and 250 control units can be operated from the plant control room. 2000 measuring units are used for controlling the thermotechnical processes. Turbosets of the industrial power plant have been commissioned as follows

No. 1 PT-50-130/7	Dec. 1966
No. 2 PT-50-130/7	Oct. 1967
No. 3 T-100-130	Oct. 1969
No. 4 T-100-130	Dec. 1969

Condensing power plant

The condensing power plant, having a total capacity of 820 MW, consists of four turbogenerator units. The 4 condensing turbosets are placed in a machine-house independent of the industrial plant. The central office building, workshops and other auxiliary buildings are attached to the machine house of the condensing plant.

BOILERS

Each turbine unit is provided with a gas- and residual fuel oil fired boiler made by the Taganrog Boiler Factory. The boilers are of the single drum natural circulation type. This boiler type consists of a radiated vertical combustion chamber, a horizontal and a convection down-coming flue gas pass. On the front side there are 12 combined burners suitable for natural gas and residual fuel oil firing. The burners are arranged on two levels with 6 burners on each level. Rotary regenerative air heaters are used for air heating.

Technical data:

No. of boilers	I to IV
Manufacturing works	TKZ Taganrog
Type	TGM-104
Capacity	640 t/h
Superheated steam pressure	140 atg
Superheated steam temperature	545° C
Reheated steam pressure	22 atg
Reheated steam temperature	545° C
Feedwater temperature	230° C
Boiler efficiency	
—with residual oil firing	93.85%
—with gas firing	94.24%
Exit flue gas temperature	
—with residual oil firing	135° C
—with gas firing	121° C
Auxiliary equipment	
Induced draft fans per boiler	2
Forced draft fans per boiler	2
Regenerative rotary air heaters per boiler	3

Fuel:
The same as in case of the industrial power plant.

TURBINES

The condensing power plant consists of two K-200-130 and two K-210-130 type turbines.

Technical data:

No. of turbines	I to II	III to IV
Electrical output	200 MW	210 MW
Initial steam pressure	130 atg	
Initial steam temperature	540° C	
Reheated steam pressure	20 atg	
Reheated steam temperature	540° C	
Condenser pressure	0.06 ata	
Specific heat consumption of unit	2040 kcal/kWh	
Type of the condenser	jet condenser	
Cooling system	Natural-draught dry cooling towers System Heller	
Auxiliary cooling	Mechanical-draught wet cooling tower	

Condensing system

For the cooling of condensers of the four turbogenerator sets natural-draught dry cooling towers System Heller were installed. This type of cooling system was developed in Hungary.

With the dry cooling system, no water is required for condenser cooling. Therefore, taking into consideration the limited water resources in the Armenian SSR, the adoption of this cooling system was fully justified.

At the same time the construction of the air condensation system also offers the possibility of investigating the application and service conditions of such equipment with turbines of larger unit capacities and under climatic conditions prevailing in the Soviet Union. The air condensation equipment in Rasdan can be regarded as a special solution as the site is 1750 m above the sea level.

As a consequence of the low specific weight of the cooling air, the natural draught cooling towers are about 1.7 times higher than the cooling towers of the same capacity when built at sea level. Thus, instead of a 70 m high cooling tower built under normal conditions, 120 m high cooling towers were selected for Rasdan. These cooling towers have further special features. Considering the earthquake hazards, extremely light cooling towers had to be built using steel structures covered with corrugated aluminium sheets.

The dry cooling system has been designed in Hungary jointly with the Teploelektroprojekt in Rostov. All the main equipment, including the complete cooling towers and air-cooled heat exchangers, the cooling water pumps, and recuperative water turbines, as well as the jet condensers have been manufactured in Hungary.

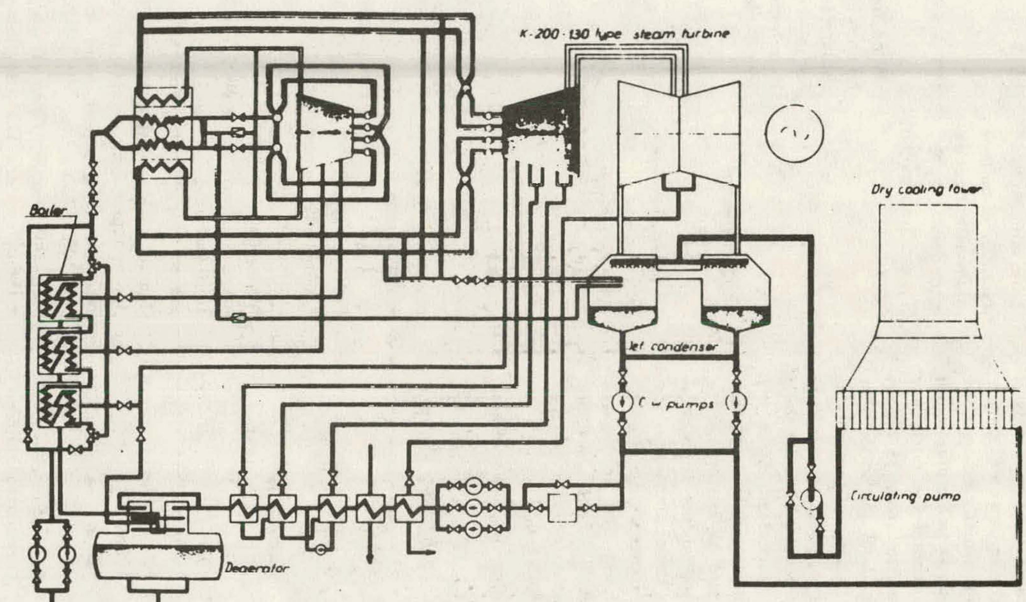
The air condensation equipment consists of a totally closed cocling water circuit. Warmed-up cooling water leaving the condenser is cooled down in the aluminium elements arranged around the periphery of the cooling tower. In order to obtain better condenser vacuum, jet condensers have been provided. Using jet condensers, a temperature differerce less than 0.5° C between condensing steam and outlet cooling water can be guaranteed. Since the cooling water circuit is completely closed, feed water quality can be maintained in the c.w. system, permitting the application of jet condensers. By the application of the air condensation equipment, scale deposits in the condenser tubes and consequent deterioration of specific heat consumption—which is associated with surface type condensers—can be avoided.

Technical data of the air condensation equipment:

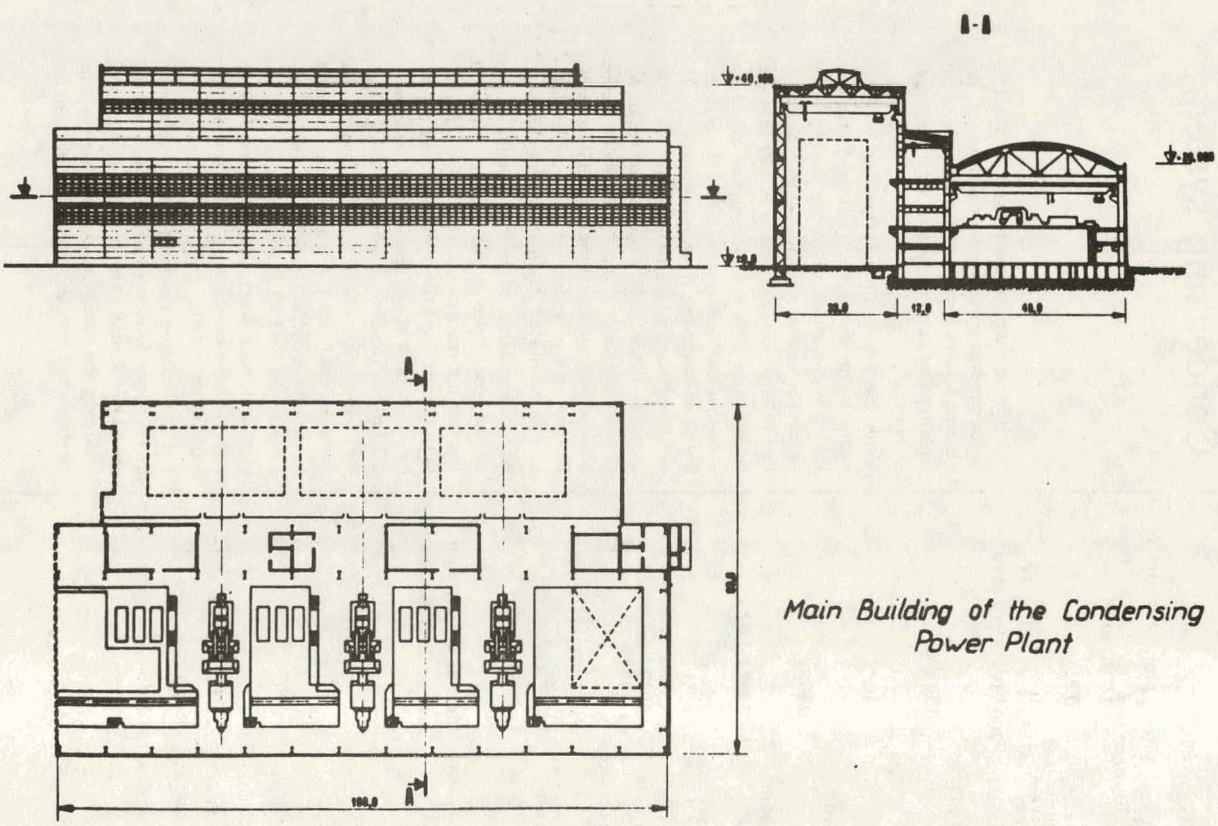
Condenser heat duty per unit	240.8×10^6 kcal/h
Steam quantity entering the condenser	450 t/h
Design air temperature	5.2° C dry bulb.
Cooling water quantity	22.000 m³/h
Cooling water temperature rise in the condenser	10.9° C
Number of cooling towers per unit	1
Base diameter	108 m
Height	120 m
Top diameter	60 m
Material	Steel structure with corrugated aluminium covering
Weight of steel structure	1300 t
Weight of aluminium covering	130 t
Number of built-in aluminium heat exchangers	119
Type of heat exchangers	slotted fin type aluminium heat exchangers-System Forgó—consisting of 15 m high and 9 ton weight elements
Control of heat dissipation	with motor operated louvres
Number of condensers per unit	2
Condenser system	
—Type	jet condenser
—Weight	2×60 t
—Type of spray nozzles	Flat water-film spray nozzles 1872 per condenser
Number of cooling water pumps	Two 50% capacity pumps per unit
Driving motor	6000 V, 1100 kW
Recuperative water turbine per unit	1
Recuperative generator	6000 V, 620 kW
Total pumping power	1580 kW

Due to the application of the dry cooling system water consumption of the units of the condensing power plant is not more than 100 to 150 m³/h.

From this quantity 70 to 80 t/h is used as make-up water. The remaining quantity is required for auxiliary cooling.



Condensing Turbine Unit - Flow Diagram



Main Building of the Condensing Power Plant

GENERATORS

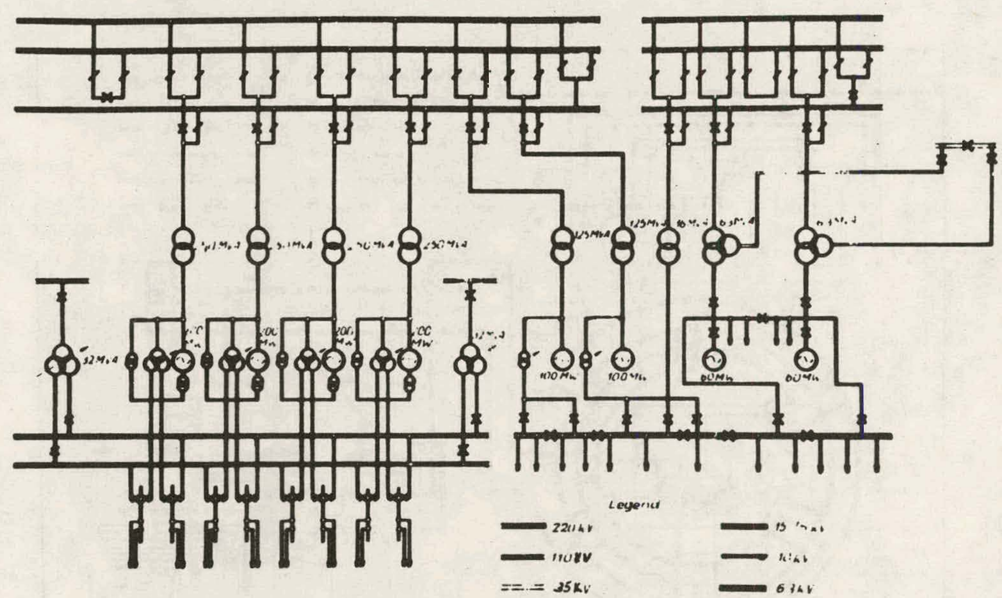
No. of generators	I to IV
Type	TGV-200 M
Power factor	0.85
Rotor current	1890 amp
Stator voltage	15.75 kV
Stator current	8625 amp
Exciter voltage	475 V
Exciter current	2000 amp
Stator cooling	water
Rotor cooling	hydrogen

ELECTRICAL EQUIPMENT

Each of the four generators having an output of 200 and 210 MW is connected to the 220 kV network by means of a generator transformer of. 250.000 kVA. The type of the transofrmers is TDC-250.000/220. On the 220 kV voltage level a double bus-bar system and a bypass bus system are available to ensure overhand of circuitbreakers and transformers. The transformers are connected to the 220 kV network through BZN-220/10 type air-blast circuitbreakers. Bearing in mind the high mountain conditions, lightning arresters are installed in the 220 kV circuits.

One TRDN-32.000/110 type transformer and a TRDN-35.000/35 A type standby transformer is used for auxiliary power supply of the condensing power plant. In case of outages of the auxiliary plant. the standby transformer is switched-on automatically.

Schematic diagram of electrical equipment



INSTRUMENTS AND CONTROL

With the four units of the condensing power plant the technological processes are automated. 250 remote operated valves per unit equipped with electric motor drives can be operated from the control panel.

From the unit control room the 200 regulating organs of each unit can be operated by a selective control. All blocks are provided ferrodynamic instruments with PF type integrated output converters, the output signals of these are suitable for connection to an EVM type electronic computer. For each turbogenerator unit 1400 such measuring units are installed. The units are also provided with signal integrating devices, and the mean values are printed out in every 8, 16 and 24 hours. It was the first time in the Soviet Union that for 200 MW units such automatic systems have been provided, which greatly facilitate the starting process, improve the safety of operation and diminish fuel consumption during start-up. Such equipment comprise the turbine speed regulator, the fuel supply regulator, the superheated steam temperature regulator.

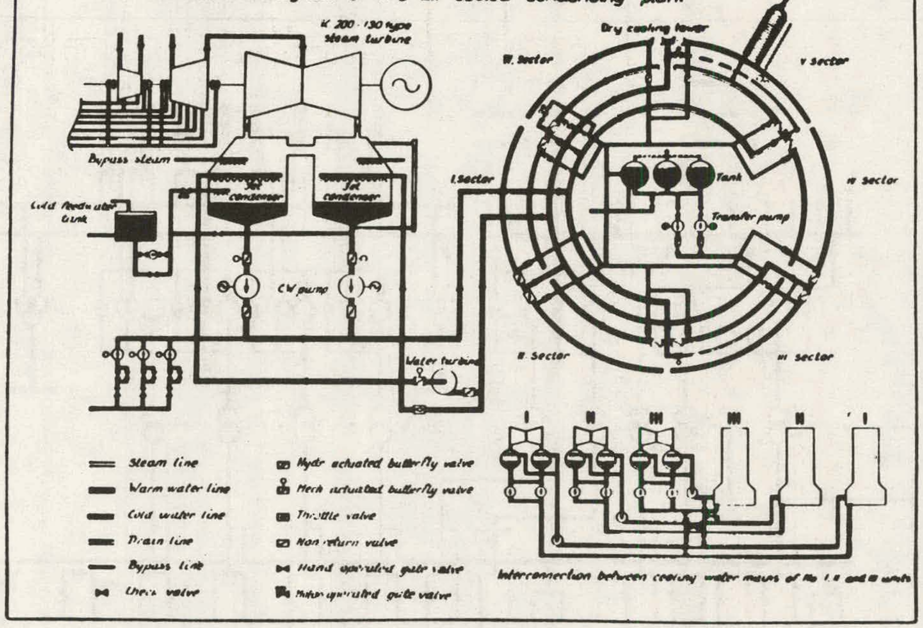
The operation of the air condensation equipment is also fully automated.

Fully automatic sequence control systems are provided for filling-up and draining of cooling towers, the starting and stopping of circulating water pumps and for operating the frost-protective equipment, so outages due to maloperations can be avoided.

Units of the condensing power station have been commissioned as follows:

No. I	K-200-130	Jan.	1971
No. II	K-200-130	Dec.	1971
No. III	K-210-130	Oct.	1972
No. IV	K-210-130	July	1974

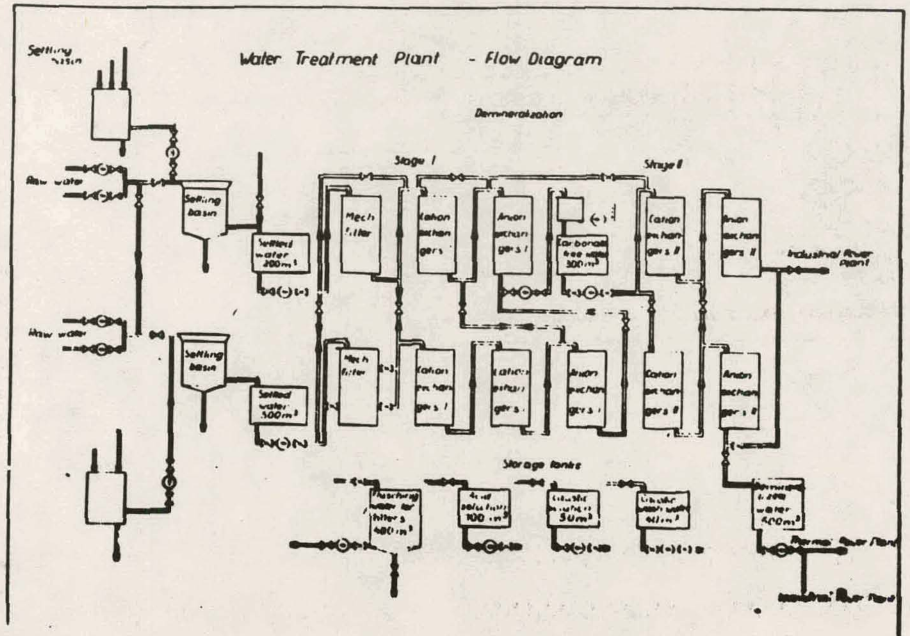
Connection diagram of the air cooled condensing plant



WATER TREATMENT PLANT

The raw make-up water, preheated in the turbine plant is led by a double piping system into the settling basin of the water treatment plant. In the settling basin suspended matters are removed by adding coagulant chemicals. From the settling basin water enters the reservoir and from there it is pumped through mechanical filters. The mechanical filters are provided with antracite filling.

The settled, filtered raw water gets into the two-stage cation-anion ion exchangers. After the first stage a CO_2 gas separator is built-in. The demineralized water leaving the water treatment plant is stored in a tank and from here it is delivered to the industrial and condensing power plants. The two power plants have a common water treatment plant having a capacity of 600 m^3/h.



APPENDIX D

ELECTRIC POWER SYSTEM OF ARMENIAN SSR

Note: Information given herein has been taken from a brochure. Accompanying photographs have been deleted for sake of brevity.

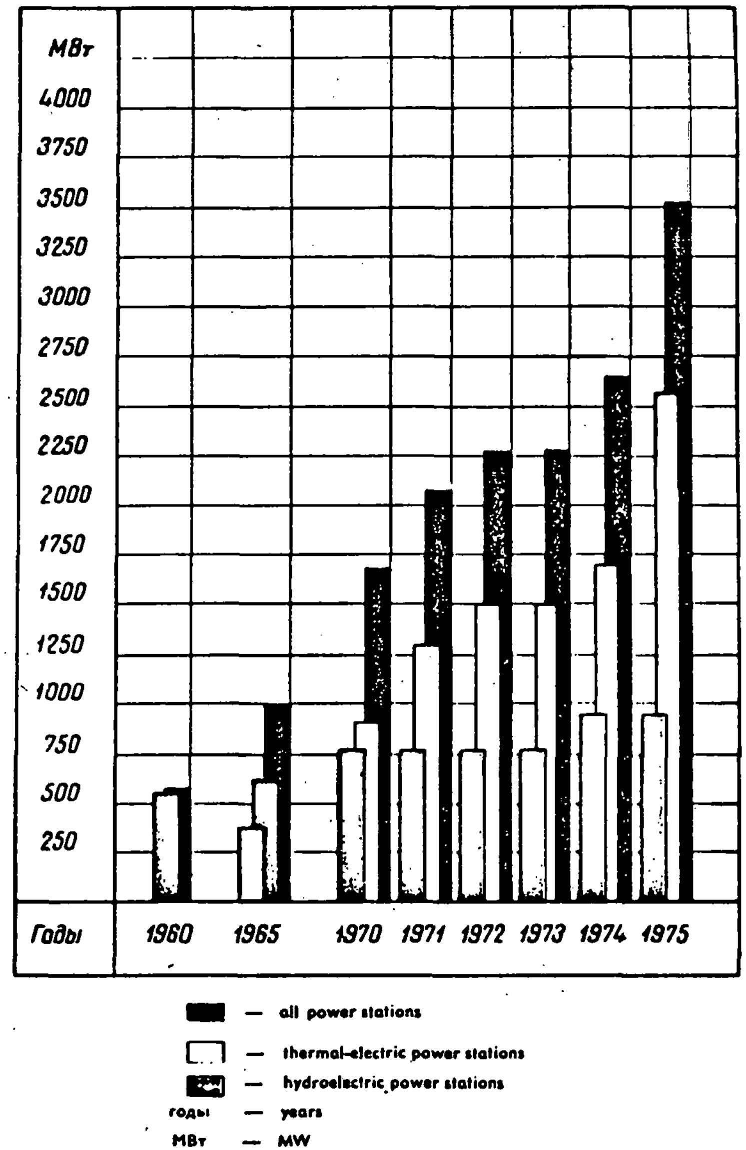
The electric power system of Armenian SSR covers the entire territory of the Republic. It is part of the Transcaucasian united power system which also includes the power systems of Georgia and Azerbaijan. The territory serviced by the power system amounts to 29.8 thousand sq. km with a 2.6million population.

The Armenian power system incorporates power plants and stations of all kinds, such as condensing plants, heat-electric generating stations and hydroelectric power stations. An atomic power station is now being constructed. The installed capacity of all the power stations of the system made up 2.48 million kilowatts on the 1st, January, 1975 with the power output in 1974 of 8.5 milliard kWh.

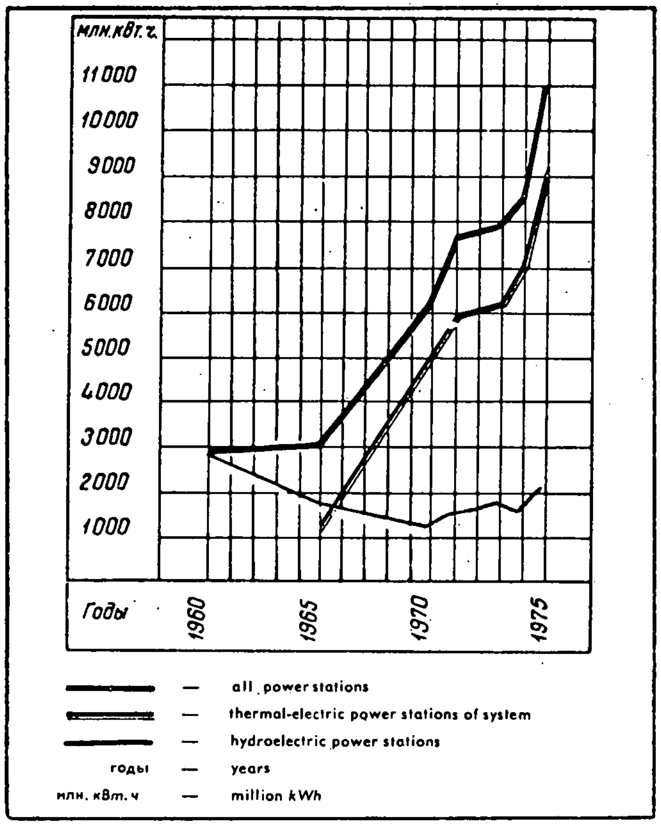
The power system management of Armenian SSR has developed from small individual power plants incorporating low-power equipment to a large power system which meets the power requirements of highly developed socialist industry and highly productive and mechanized agriculture.

The total capacity of power stations of pre-revolutionary Armenia made up only 3165 kW at an annual power output of 5.1 million kWh. The largest power plants built near copper ore deposits belonged to foreign concessions. In 1909 an Alaverdy hydroelectric power station was constructed on the Debed river. It incorporated three 360-kW water-wheel generators and was second in power output in tzarist Russia.

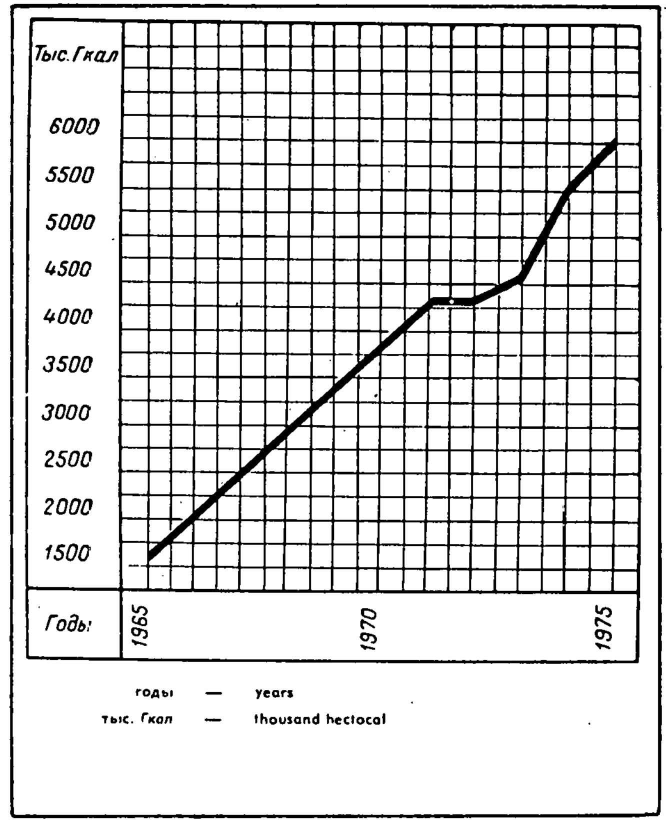
In 1920 the Soviet power was established in Armenia as a result of the victory of a national uprising supported by the Red Army. The people took the wealth of the country in their own hands.



Installed Capacity of Armenian Power System Stations



Power Output in Armenian SSR



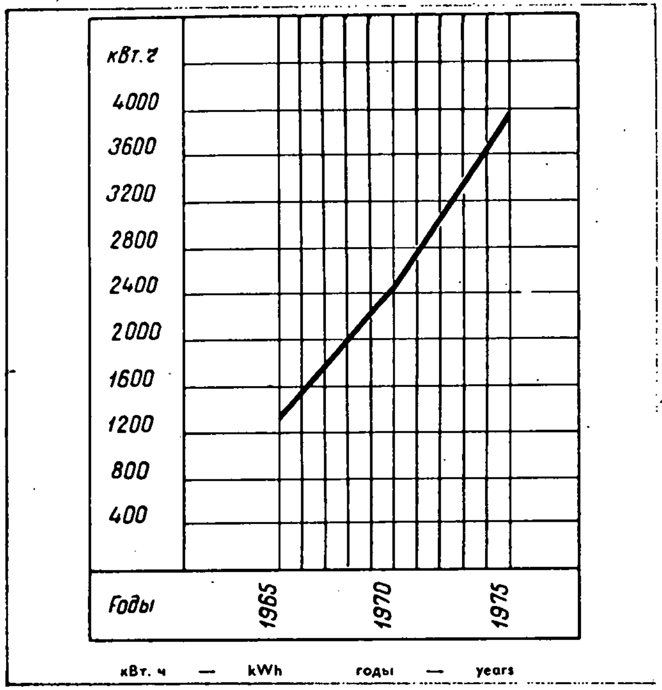
Thermal Power Delivered by Power Stations of Armenian Power System

The development of the Republic's national economy was determined by the Lenin's GOELRO plan (Plan of electrification of Russia) which envisaged in particular, the construction of a hydroelectric power plant of about 85-thousand kW capacity on the Goktcha (Sevan) lake. During the early step of development of power generation, emphasis was laid on local power resourses, i. e. on hydraulic power.

In early twenties, it was decided to build a hydroelectric power station on an irrigation canal near Yerevan. In May, 1926, the first stage of the Yerevan hydroelectric power station comprising two 880-kW water-wheel generators was put in operation and in 1929 its capacity was as high as 4560 kW. At the same time, power transmission lines of 22 kV connected the hydroelectric power station with the Aygerlitch pump plant (the first mechanical irrigation installation) and then, with the Arzni health resort.

The best equipped hydroelectric power stations built during the first Five-Year Plans were the Dzoraget station of 22.2-thousand kW capacity on the Dzoraget river (1932) and the Yerevan-2 hydroelectric power station of 2.4-thousand kW capacity (1932), the latter being the first automated station in the USSR. The Dzoraget station was connected with the Kirovakan city via the first in Armenia power transmission line of 110 kV.

In spite of apparent success achieved in the construction of



Power Output per Capita in Armenian SSR

hydroelectric power stations it was obvious, however, that dependable power supply for the needs of national economy cannot be ensured through the utilization of the run-off of mountain rivers which have no water reservoirs for hold-over storage. A necessity arose to build power stations having a stable power output all year round, such as thermal-electric stations or hydroelectric stations with seasonal storage reservoirs. Since Armenia has no fuel deposits and the cost of imported fuel was rather high at that time, the development of hydroelectric power engineering was quite natural.

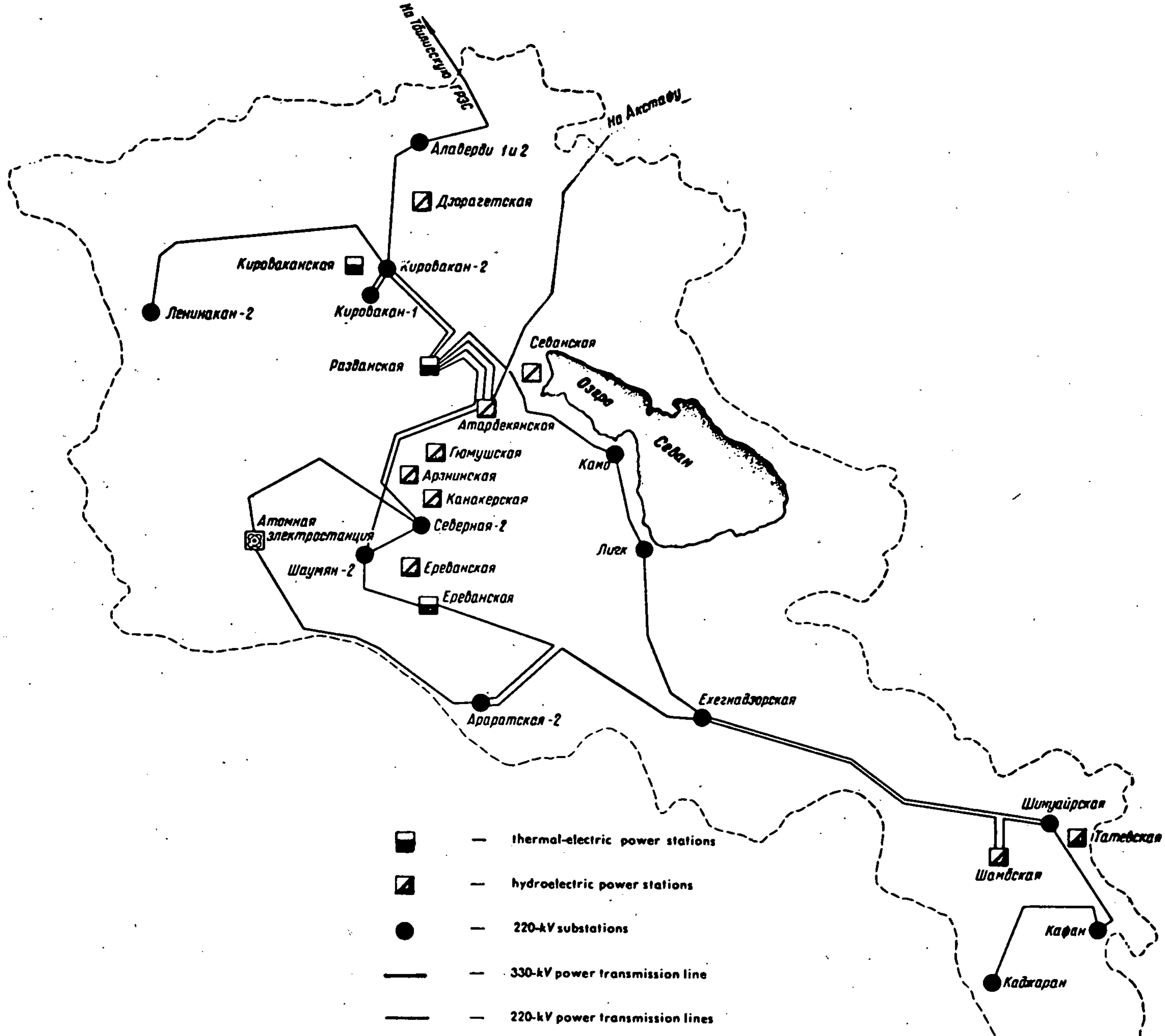
The problem of reliable power supply for the needs of the Republic's industry and agriculture and of the development of the irrigation system was solved due to the utilization of the Sevan lake and Razdan river waters.

In 1931 a plan was drawn up envisaging the utilization of the waters of the Sevan lake and the Razdan river for irrigation and power generation. It was planned to construct a cascade of six hydroelectric power stations and 17 irrigation canals to supply water to a cultivcted area of 120 thousand hectares in the Ararat plain.

The Kanaker station was the first of the cascade. The first water-wheel generator of this station (10.6 thousand kW) started in 1936 made it possible to afford highly dependable power supply to the consumers of the Yerevan power centre and to join the hydroelectric stations of the Republic for parallel operation. By that time the Armenian regional power system management (Armenergo) was organized.

Since early 1938, as the construction of the Kirovakan-Spitak-Yerevan, and then Spitak-Leninakan 110-kV power transmission line was brought to the end, Armenergo began joining the hydroelectric stations for parallel operation. Hence the Kanaker station was combined with the Dzoraget station and its capacity reached 42 thousand kW. Somewhat later, the Kanaker station was placed in joint operation with No. 1 and No. 2 Yerevan stations, and by the end of that year, with the Leninakan station.

Thus, by the end of 1938 all the power stations of the Republic were united into the Armenian power system, the leading one being the Kanaker power station which has considerably increased the reliability of power supply for the needs of national economy due to its storage ability.



Layout of Power System of Armenian SSR

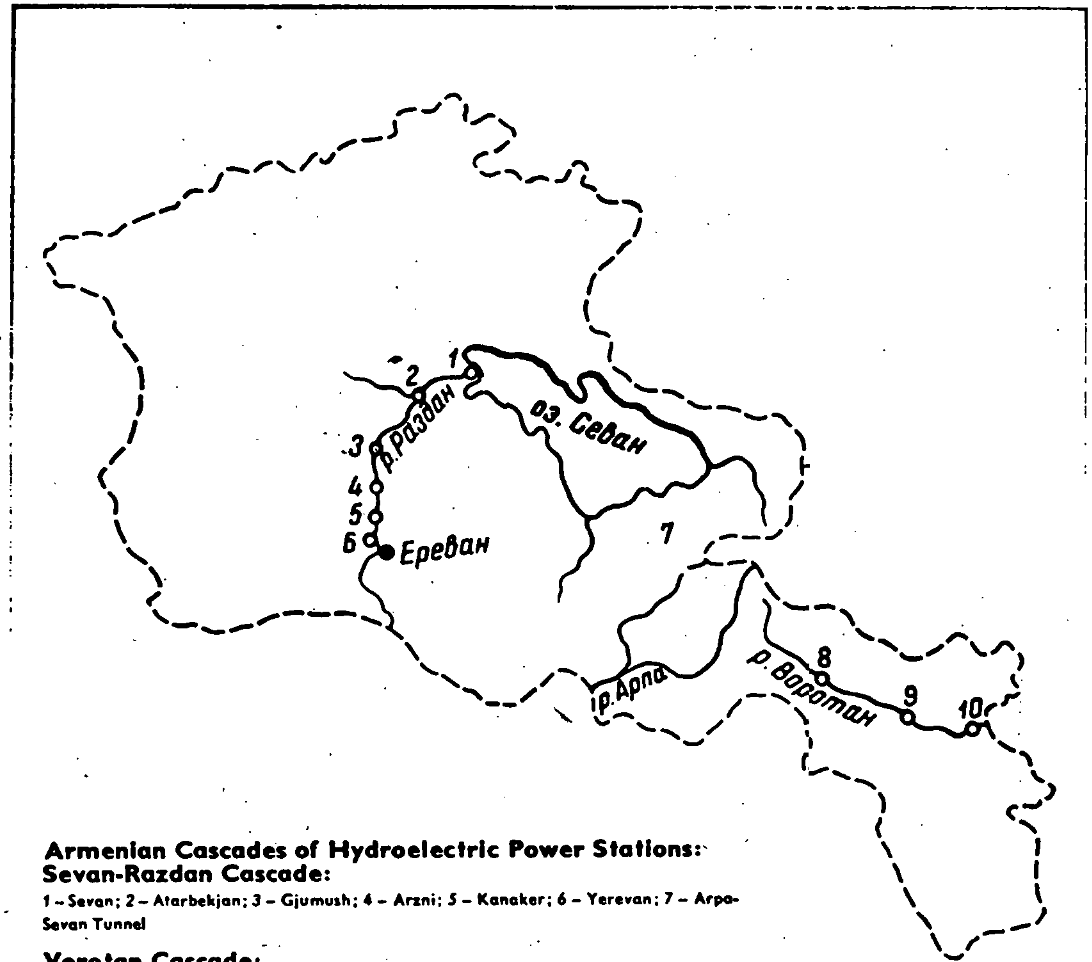
All the power stations built and placed in service after 1938, with the exception of a few ones, were included into the power system. Only farming power plants of Selenergo and collective farms, as well as small hydroelectric power stations and the power generating train belonging to the enterprises of the Ministry of Non-ferrous metallurgy in the south of Armenia were not joined to the Republic's power system. These power stations were included in the system in 1958 after the Atarbekyan-Shinuajr-Kadzharan 220-kV power transmission line was completed.

The construction of the first stage of the Sevan-Razdan cascade, the Sevan hydroelectric power station, was started in 1940. This station was meant, in addition, to function as a water intake; preparatory work was carried out for the construction of the Gjumush hydroelectric power station. When the Great Patriotic War broke out, the construction of power generating and supply installations was ceased for the time being. The war was not yet over, however, when the construction of the Sevan-Razdan cascade was recommenced. In 1953 the largest Gjumush hydroelectric power station of 224-thousand kW capacity was placed in operation. The power output of the Armenian system grew twice as high. The characteristic feature of the power system of that time was that it included, for the most part, high-manoeuvrability hydroelectric power stations.

In the second half of the fifties the initial plan of utilization of the Sevan lake waters was revised. Backed up by a great experience in the hydropower construction in the USSR, the Armenian specialists were able to build high-dam hydroelectric power stations on the Vorotan river. Meanwhile, an immense progress in Soviet thermal power engineering gave rise to the construction of thermal power stations in Armenia. The plan was revised and a decision was adopted by the USSR government to maintain the water level of the Sevan lake as close as possible to its natural level, to reduce the water pass from 1200 to 500 million cu. m (380 million cu. m for irrigation and 120 million cu. m for power generation). To restore water storage in the Sevan, it was envisaged to build a tunnel of more than 48 km to transfer part of the Arpa river flow to the Sevan lake.

In 1960 the output of the Armenian power system reached 577 thousand kW. However, it was insufficient to compensate for the reduction in power output of the Sevan-Razdan cascade while the power demand of industry and agriculture was growing. In 1960 the power systems of the three Transcaucasian Republics Azerbaijan, Georgia, and Armenia — were joined to operate in parallel. Power transmission lines were brought to the Akstafa switchgear centre from the Mingetchaur hydroelectric power station of Azglavenergo, from the Tbilisi supercentral power station of Gruzglavenergo, and from the Atarbekjan hydroelectric power station of Armglavenergo. The power deficiency in the Armenian power system was compensated for by power transmitted from Azerbaijan. The 220-kV power transmission lines connecting the Akstafa and Tbilisi stations as well as the Akstafa and Mingetchaur stations were changed in 1964 to 330 kV, which made it possible to transmit more power to the Armenian power system.

The first large thermal-electric station of the open type was put in operation in Yerevan in 1963. The Kirovakan heat-electric



Armenian Cascades of Hydroelectric Power Stations:
Sevan-Razdan Cascade:

1 – Sevan; 2 – Atarbekjan; 3 – Gjumush; 4 – Arzni; 5 – Kanaker; 6 – Yerevan; 7 – Arpa-Sevan Tunnel

Vorotan Cascade:

8 – Spandarjan; 9 – Shamb; 10 – Tatev

generating plant was started in 1964. The thermal-electric engineering was further developing cumulatively. During the eight Five-Year Plan (1966–1970) the investment in power engineering grew twice as large as during the preceding five years. 682-thousand kW capacity was newly assimilated, including that of the Razdan heat-electric generating plant (300 thousand kW), the Yerevan heat-electric generating plant (200 thousand kW), Kirovakan heat-electric generating plant (25 thousand kW). The construction of the Razdan supercentral power station was developed. The design capacity of this station is 1200 thousand kW.

In 1970 the Tatev hydroelectric station of 157.2-thousand kW capacity was built on the Vorotan river. The construction of the first Armenian atomic power station was started.

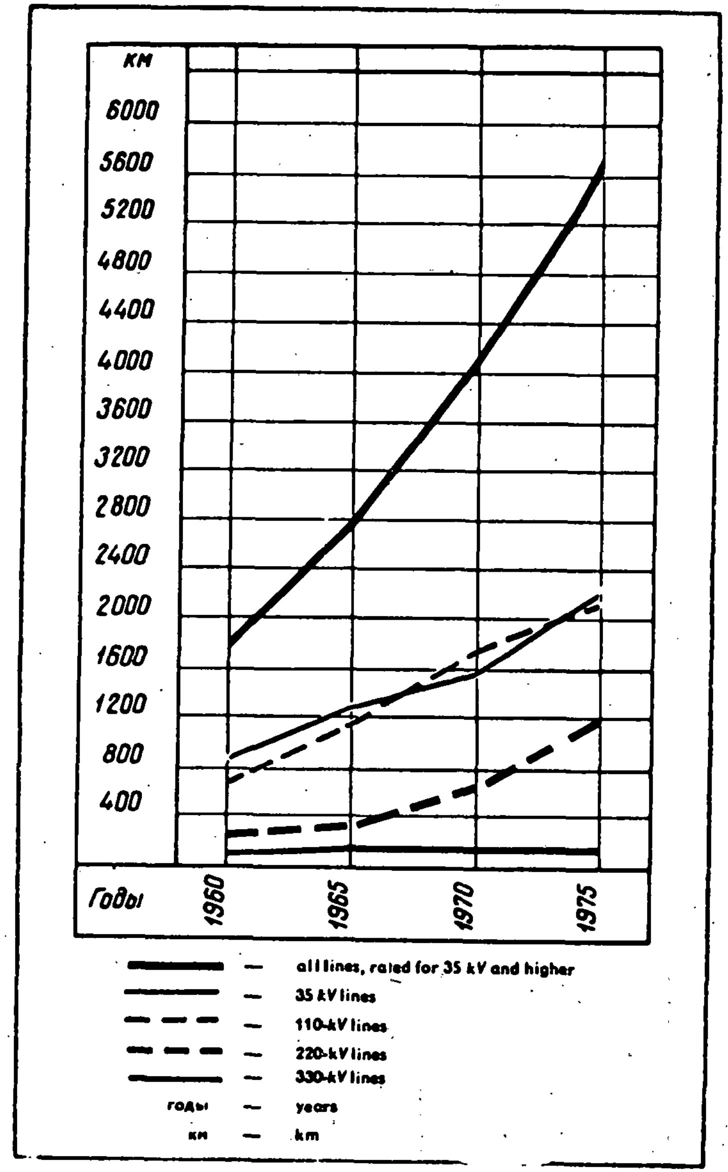
In 1970 the capacity of the power system reached 1677 thousand kW and its power output considerably increased.

Along with the construction of power stations, power transmission lines and substations were erected, particularly after 1960. In 1970 the length of power transmission lines, rated for 35 kV, increased almost twice, that of lines, rated for 110 kV, 2.5 times, and that of 220-kV lines, almost 3 times. Within ten years the transformer power capacity grew six as high and reached 4300 thousand kVA. While in 1960 the power system did not comprise 220-kV substations, in 1970 the installed capacity of 220-kV substation transformers made up 1030 thousand kVA.

A new technology has been widely introduced in the Armenian power system since 1950. Technological processes on the hydroelectric power stations have been automated.

By 1965 the water-wheel generators of all the main hydroelectric power stations of the system were fully automated. The Sevan, Dzoraget, No. 1 and No. 2 Yerevan hydroelectric power stations were shifted to automatic control without constant attending personnel. Measures were taken on the main hydroelectric power stations to make their water-wheel generators suitable for running as synchronous condensers, sixteen of them being changed over to synchronous condenser operation automatically. Automatic water-coarse regulators were installed in the Dzoraget, Atarbekjan and some other hydroelectric stations. To ensure trouble-free operation of the automated hydroelectric power stations, the latter were reconstructed, the equipment was renewed, closed-circuit electrical control, telemechanics and high-frequency coupling over the high-voltage lines were introduced.

In 1965 the centralized power and frequency control system was fully introduced and made it possible to automatically control power transmission over the intersystem 330-kV line



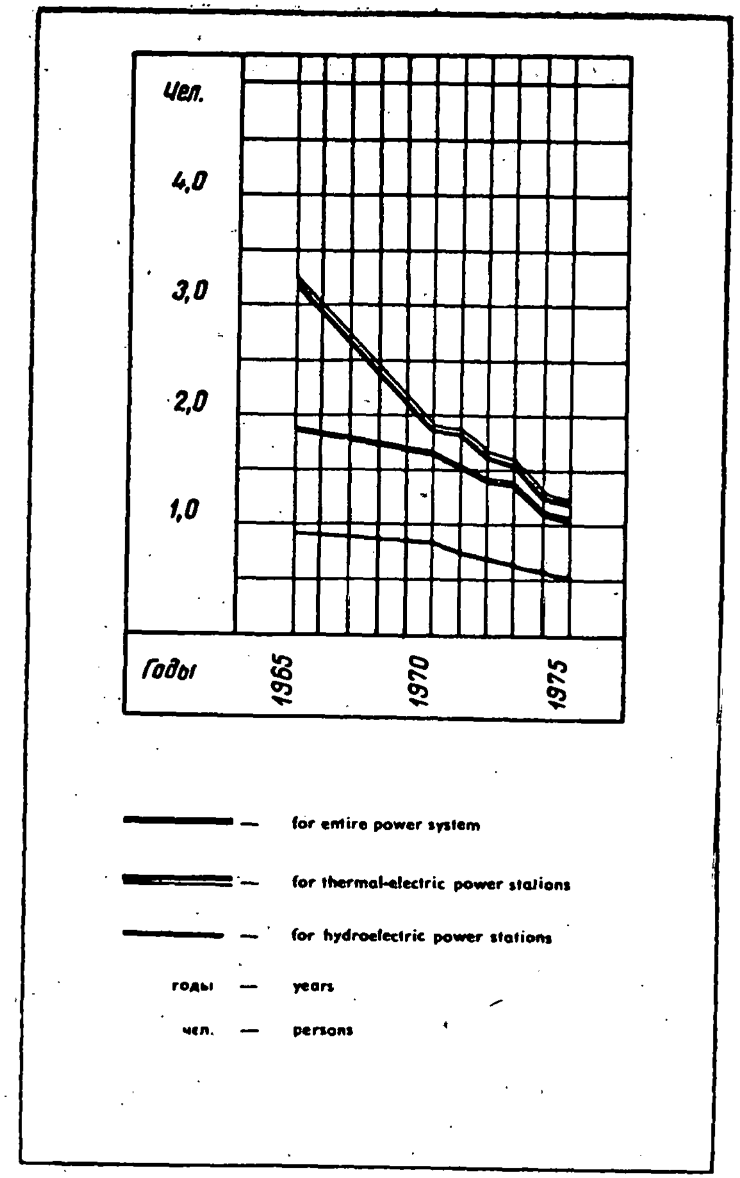
Grow of Length of High-Voltage Power Transmission Lines in Armenian Power System

connecting the Atarbekjan hydroelectric power station with Akstafa. The power system is controlled from the Yerevan main control centre.

Great attention was given to the automatic controllers of thermal processes. Hence, in 1965 six boiler units of the Yerevan and Kirovakan heat-electric generating plants were equipped with automatic feed controllers, two boiler units were furnished with combustion controllers and three units received superheated steam controllers. Deaerating plants of the Yerevan and Kirovakan heat-electric generating plants are fully automated. Process protective gears were introduced in the boilers and turbines of these stations.

The 200-MW power generating units of the Razdan supercentral power station incorporate feed controllers, superheated steam temperature controllers, condenser vacuum controllers, thermal load controllers, furnace pressure controllers, emergency spray controllers, etc. The power units are equipped with an automatic control system built around computers and logic circuits. The cooling towers of the Razdan supercentral power station are furnished with automatic differential pressure regulators which control the pressure of inlet and outlet (cooled) water.

The Republic's industrial production will rise during the ninth Five-Year Plan (1971–1975) by more than 60 per cent. As a result, the growing demand of electric and thermal power will cause an increase in the generation of electric power to 9.1 milliard kWh and in the thermal power supply to consumers of up to 6 million hectocalories.

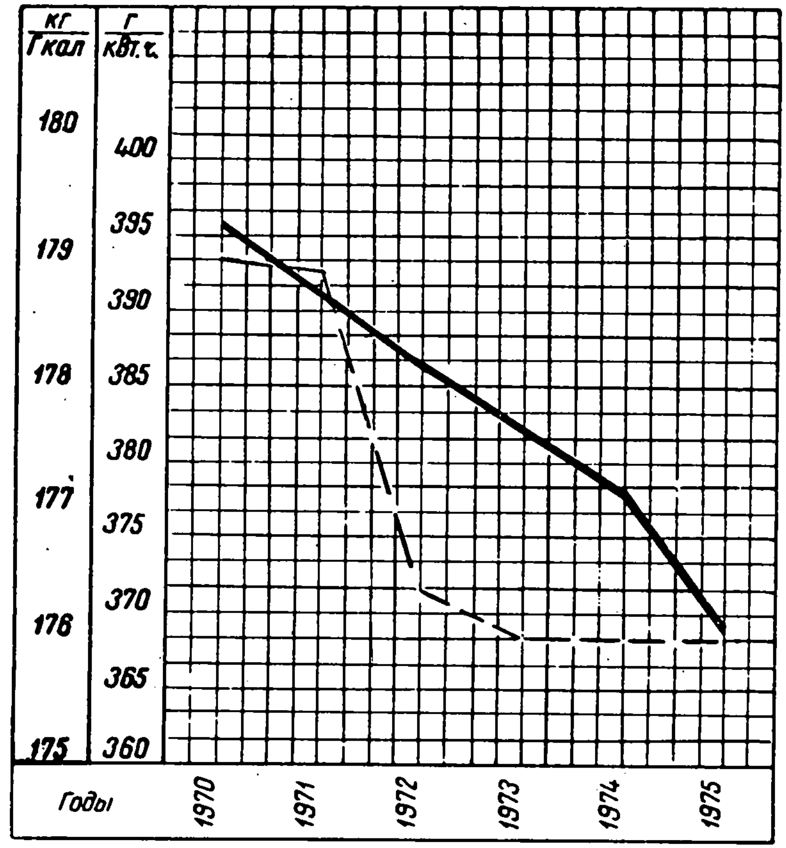


Number of Industrial Production Personnel per 1000 kW of Installed Capacity

Four 200-thousand kW power units are being placed in operation on the Razdan supercentral power station. The Kirovakan heat-electric generating plant is expanding. The construction of the Armenian atomic power station of 815-thousand kW capacity is now underway. The middle and upper stages of the cascade of hydroelectric stations on the Vorotan river – the Shamb station and the Spandaryan hydroelectric power station – are still under construction. The Arpa-Sevan tunnel will be soon completed. The water level in the Sevan will be maintained constant while water passage from the lake for power generation will be increased mainly in winter time. As a result, the Sevan-Razdan cascade of hydroelectric power stations will contribute more to the control of the power system loads.

1600 km of power transmission lines, rated for 35 kV and higher, will be put in operation within the ninth Five-Year Plan. New power transmission lines (2000 km) and substations of 0.4 to 10 kV are being further erected to satisfy the needs of farming and domestic power consumers.

The organization and development of the electric power system in Armenian SSR accomplished with the brotherly assistance of all the peoples of the Soviet Union was closely connected with the creation and advance of national specialist in the job. Many of those, who started from Armglavenergo, are now working in many electrical enterprises of the all-Union importance.



— per 1 Hectocal of heat

— per 1 kWh of electric power

годы — years

кг/Гкал — kg/Hectocal

г/кВт.ч — G/kWh

Specific Consumption of Arbitrary Fuel for Power Stations of Armenian Power System

MAIN POWER STATIONS OF POWER SYSTEM OF THE ARMENIAN SSR

Razdan Thermal-Electric Power Station

The Razdan Supercentral Power Station is a power-generating enterprise comprising a condensing power plant and a heat-electric generating plant both having a common management.

Design power of the condensing power plant is 1200 thousand kW. The plant comprises power units each consisting of a 200-thousand kW turbine unit and a 640-t/h boiler unit. The irst power unit was placed in operation in 1971.

The heat-electric generating plant capacity is 300 thousand kW. It comprises two 50-thousand kW turbine units, two 100-thousand kW turbine units, and five 320-t/h boilers. The first turbine unit was put in operation in 1966 and the last one, in 1969.

Fuel is furnace oil and gas.

Yerevan Heat-Electric Generating Plant

The plant capacity is 550 thousand kW. It comprises five 50-thousand kW heat-generating turbine units with five 420-t/h boiler units, and two power generating units, each comprising a 150-thousand kW turbine unit and a 500-t/h boiler unit. The first turbine unit was started in 1963, the last (seventh) one, in 1966.

Fuel is furnace oil and gas.

Armenian Atomic Station

Design capacity of the station is 815 thousand kW. It comprises two power-generating units. Each unit consists of water-moderated water-cooled power reactor BB3P-440 and two 220-thousand kW turbine units.

Sevan-Razdan Cascade of Hydroelectric Power Stations

The cascade includes six stages. The total installed capacity is 556 thousand kW; average annual power output within the period of 1963 to 1972 has made up 1.21 milliard kWh.

Hydroelectric power stations	Capacity, thousand kW	Mean annual output, million kWh	Number and power of units, MW per unit	Rated flow rate, cu. m/s	Maximum head, m	Volume of water basin, million cu. m		Year, placed in operation
						full	useful	
Sevan	34.24	57.4	2×16.96 1×0.32	65.0	50.0	—	—	1948
Atarbekjan	81.6	161.3	2×40.8	70.0	138.0	—	—	1959
Gjumush	224.0	453.5	4×56.0	70.0	297.0	5.6	4.1	1953
Arzni	70.56	199.0	3×23.52	70.0	118.0	1.0	0.3	1956
Kanaker	102.0	225.5	4×12.5 2×26	60.0	173.0	—	—	1936
Yerevan	44.0	114.0	2×22.0	62.0	90.8	0.3	0.1	1961

Vorotan Cascade of Hydroelectric Power Stations

This cascade of three hydroelectric power stations is being built on the Vorotan river. The total installed capacity of the cascade stations is 404.2 thousand kW. Mean annual output is 1.1 milliard kWh.

Hydroelectric power stations	Capacity, thousand kW	Mean annual output, million kWh	Number and power of units, MW per unit	Rated flow rate, cu. m/s	Maximum head, m	Volume of water basin, million cu. m		Year, placed in operation
						full	useful	
Spandarjan	76	157	2×38.0	30	394	277	237	1977
Shamb	171	330	2×85.5	75	314	96	80	1976
Tatev	157.2	670	3×52.4	33	576	13.6	1.8	1970

ELECTRIFICATION OF NATIONAL ECONOMY IN ARMENIAN SSR

The dependable electric power system of the Republic has made it possible to develop industry, farming, agriculture, to improve the living conditions of the population, to raise their standard of culture.

Power Consumed in Armenian SSR, million kWh/per cent

Description	Years			
	1960	1965	1970	1975 (planned)
Power output	2746.8	2855.2	6107.5	9110
Power supply to consumers	2716.4 100	3858.7* 100	5755.2 100	7557 100
including:				
Industry and construction	2320.4 85.4	3109.5 80.6	4388.9 76.1	5362 71
Transport	44.1 1.6	112.9 2.9	187.0 3.3	265 3.5
Agriculture	110.6 4.1	287.8 7.5	511.3 8.9	870 11.5
Domestic needs of urban population	224 8.3	290.4 7.5	525.0 9.2	850 11.2

* Power supply to consumers exceeds the power output which is compensated for at the expense of the neighbouring power systems included in the Transcaucasian united power system.

The most developed branches of industry in Armenia are non-ferrous metallurgy, machine building (electrical engineering, radio engineering, machine-tool and apparatus building), textile, manufacture of natural structural materials, as well as vine-growing and fruit-growing and associated wine and canning industries.

A 48-fold increase in the production output of Armenia was achieved in 1972 as compared with the prewar year of 1940. Power requirement for industry has increased 17-fold within the same period of time. While in old times Armenia displayed at international fairs and exhibitions only agricultural raw materials and their produce, the range of goods exported by Soviet Armenia has considerably extended. Nowdays, Armenia exports abroad manufactured goods, such as electrical machines, machine-tools, electronic devices, etc. The Republic delivers its goods to all the regions of the Soviet Union and to 70 foreign countries.

Armenia is now growing into one of the USSR centres of manufacture of electronic computers. The "Razdan" and "Nairi" series of transistorized computers, which were designed and manufactured exclusively by Armenian specialists, have gained a fine reputation.

The development of economics of the Republic has brought about a considerable increase in freight turnover. Electrification of the Tbilisi-Leninakan-Yerevan-Sevan mainline railway has made it possible to greatly increase its capacity. The total length of electrified railways in Armenia is about 500 km.

Power consumption in agriculture has increased 62 times in 1972 as compared to 1940. Full electrification of agriculture was completed as early as in 1960 through the use of local power plants. By the close of 1964 the Armenian power engineers were first in the USSR to transfer all the farming power consumers to centralized power supply from the power system lines. Old power transmission lines were modified and new lines of 0.4–6–10 and 35 kV with substations were erected.

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