ORNL/TM-6283

Large City District Heating Studies for the Minneapolis-St. Paul Area

M. A. Karnitz
A. M. Rubin

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A08 Microfiche A01

ORNL/TM-6283

Contract No. W-7405-eng-26

Engineering Technology Division

LARGE CITY DISTRICT HEATING STUDIES FOR THE MINNEAPOLIS-ST. PAUL AREA

M. A. Karnitz
A. M. Rubin

Manuscript Completed — February 8, 1978

Date Published - May, 1978

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

CONTENTS

LARGE CITY DISTRICT HEATING STUDIES FOR
THE MINNEAPOLIS-ST. PAUL AREA

M. A. Karnitz A. M. Rubin*

ABSTRACT

The Department of Energy, Minnesota Energy Agency, Northern States Power Company, and other local government and private organizations are cooperatively performing an in-depth application study to determine the feasibility of district heating for a large northern U.S. city. Over 90% of the space and water heating requirements are currently supplied by oil and gas. Hence, district heating can potentially replace large quantities of scarce fuels with coal or nuclear resources. In addition, district heating, using a cogeneration power plant, substantially increases the fuel utilization efficiency when compared to an electric only plant.

A Swedish firm, AB Atomenergi, is performing a preliminary economic and technical assessment. The analysis uses current Swedish district heating technology and experience, and adapts it, where necessary, to U.S. conditions. Preliminary Swedish results indicate favorable economics for a large system, which includes residential areas, when technology innovations such as temperature resistant plastic piping are used. For conventional piping technology the economics appear favorable for the commercial areas of the city core.

The peak heat load for the Twin Cities is approximately 4200 MW(t). The scenario presented by AB Atomenergi assumes 2250 MW(t) would be supplied by cogeneration units, and the remaining 2000 MW(t) would be peaking, heat-only units. The dual purpose units would be used as the base load and would supply 90% of the total annual energy load.

The interest generated by the joint U.S.-Swedish effort has guided the participants to more detailed investigations of (1) energy sources, (2) distribution and building systems, (3) environmental acceptability, (4) financial and organizational alternatives. If these evaluations are sufficiently positive, and if the local participants provide sufficient commitments to proceed, the next step would probably include an in-depth design phase that could lead to a demonstration project.

*Department of Energy, Washington, DC.

1. INTRODUCTION

District heating is generally defined as the distribution of thermal energy from a central source for residential and commercial space heating. The central source is usually a boiler-only unit or a dual-purpose facility which produces both electricity and thermal energy. The process used in the dual-purpose plant is known as cogeneration. The most significant advantage of cogeneration power plants compared to conventional steam-electric generating stations is the drastic increase in efficiency of the cogeneration plant. Figure 1 shows graphically the comparative efficiencies of both types of plants. The overall conversion efficiency of an electric-only plant is about 33%. The remaining two thirds of the energy

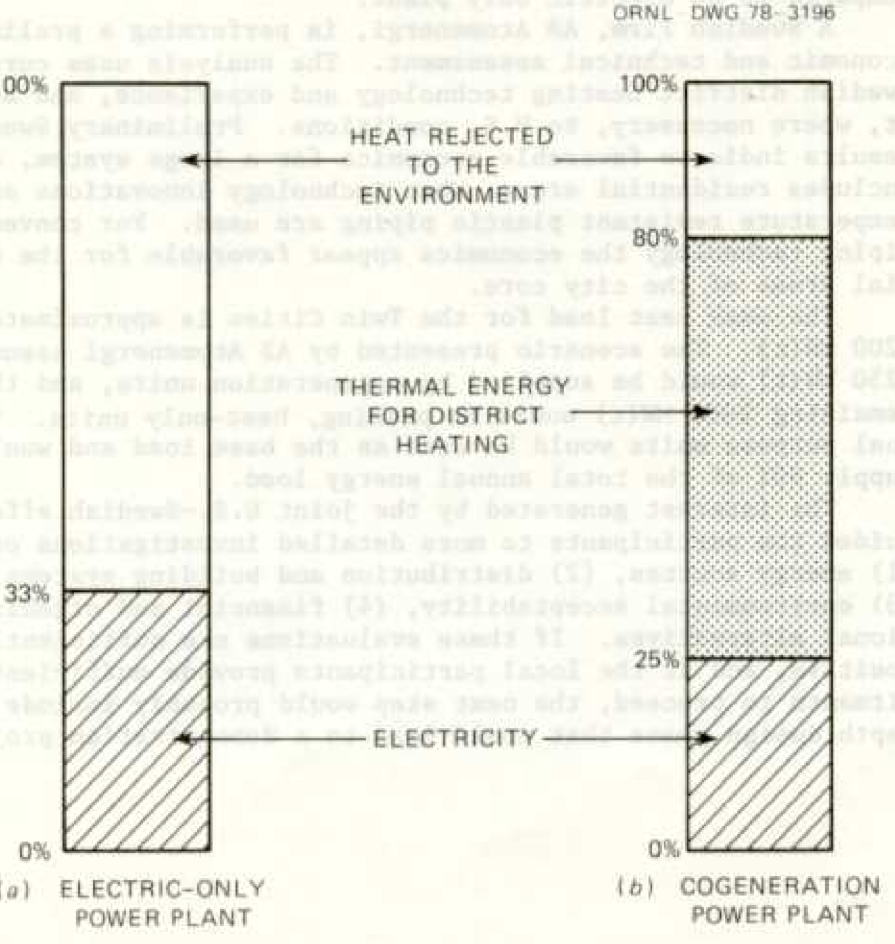

Fig. 1. Comparison of efficiency of electric-only and cogeneration power plant.

is rejected to the environment through once-through cooling systems or cooling towers at a temperature of about 35 to 40°C. A cogeneration power plant, on the other hand, can operate at an overall efficiency as high as 80%, but this requires some sacrifice in electric output. In order to supply thermal energy at a temperature level high enough for district heating (e.g., 100°C), steam must be extracted from the power plant's turbine before it has expanded to its full potential. Therefore, there is some reduction in the power output of the turbine which, in turn, reduces the quantity of electricity generated. However, for each unit of electric energy sacrificed, 5 to 10 units of thermal energy are available for district heating. The higher the temperature supplied for heating, the lower the electric output.

District heating has been in existence for approximately 100 years. In 1877, a short underground steam pipe was installed in Lockport, New York, to transport thermal energy from a central source to heat a group of buildings.[1] However, it was not until the early part of the twentieth century that cogeneration/district heating systems came into existence. These systems utilized the exhaust steam from small, noncondensing steam-electric power plants to heat buildings in nearby business districts. The introduction of large, condensing generating stations located remotely from urban areas eliminated the cogeneration energy source for the steam district heating business. At the same time, the petroleum industry was expanding into the space heating market, and competition from inexpensive oil and natural gas curtailed the growth of the U.S. district heating industry.

The history of district heating in Europe is somewhat different than in the U.S.[2] The development of large district heating networks in Europe took place during the rebuilding period after World War II. District heating has found widespread acceptance in Europe, where hot water, rather than steam, is used for heat transport. For large systems, hot water has proven to be more economical than steam because of the high losses associated with steam piped over long distances. The lower cost allowed for more expansive growth of the European systems along with the use of remotely located cogeneration plants. Figure 2 shows a comparison of connected district heating loads on a per capita basis for the United

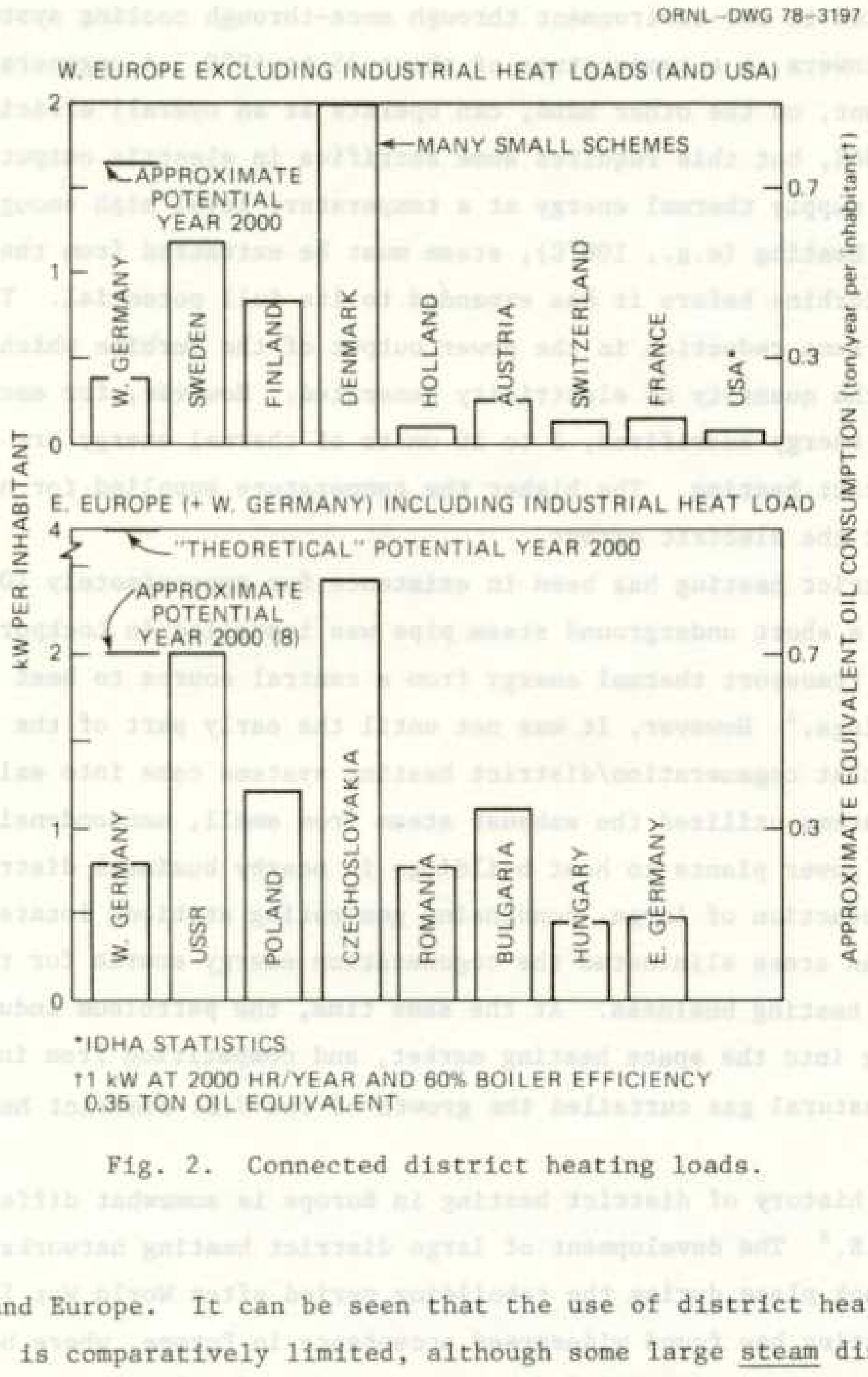

Fig. 2. Connected district heating loads.

States and Europe. It can be seen that the use of district heating in the U.S. is comparatively limited, although some large steam district heating systems are in existence in New York, Philadelphia, Detroit, Boston, and other cities. European systems are continuing to expand. One example is Stockholm's plans to build and connect a cogeneration plant 80 km from the city.

Recent studies indicate that approximately 20% of U.S. energy consumption is for residential and commercial space and water heating.

Furthermore, over 90% of these requirements are supplied by oil and gas. This constitutes an enormous target of opportunity for substituting coal and nuclear resources for fossil fuels, which are more limited in supply. It is for this reason, as well as the success of European district heating systems, that the Advanced Systems and Materials Production Division (ASMP) of the Department of Energy (DOE) has undertaken a program to determine the technical and economic feasibility of supplying thermal energy from nuclear power plants. A brief summary of the overall program, of which one portion involves district heating, is presented in Ref. 3. The program is expected to contribute significantly to DOE's overall objective of reducing dependence on imported oil by providing economic and environmentally sound energy options and promoting conservation of energy. Other Federal and State agencies and private industry are participating in this effort, which is being coordinated by Oak Ridge National Laboratory (ORNL).

To determine the feasibility of district heating under U.S. conditions, DOE-ASMP initiated a site specific study to evaluate cogeneration/district heating for a large city. The study, which is summarized below, focuses on technical, economic, environmental, and institutional issues relating to a large hot water district heating system for the Twin Cities of Minneapolis-St. Paul.

2. DESCRIPTION OF ONGOING STUDIES

There are several reasons why the Minneapolis-St. Paul area was chosen as the site for a district heating study. First of all, it meets the technical criteria such as high number of degree days, large potential load, and the feasibility to consider both coal and nuclear as potential fuels. However, the main reason for selecting the Twin Cities is the serious interest of a number of local companies and agencies. The local participants include Northern States Power Company (NSP), the Minnesota Energy Agency (MEA), Minnegasco (Minneapolis Gas Utility), the University of Minnesota, the Minnesota Pollution Control Agency (MPCA), and the Metropolitan Council. The two mayors and a number of city council members of both cities have also indicated interest and enthusiastic support for the program. Once the city had been selected, the next step was to decide on who could perform the site specific application study. Since the Europeans have considerable experience with hot water systems and have also done a great deal of research, DOE/ORNL subcontracted AB Atomenergi of Sweden to perform a preliminary economic and technical assessment. AB Atomenergi has performed similar studies in other countries. Therefore, it was concluded that this experience would be beneficial to a U.S. study and would permit the completion of work within a reasonable time period. The work of AB Atomenergi is jointly funded by DOE-ASMP and DOE-Building and Community Systems (BCS), a division in DOE Energy Conservation. The following paragraph is a brief description of the work scope.

> "The objective of the U.S.-Swedish district heating study is to analyze the prospects of a major district heating scheme for a large city in the United States. The basic source of heat is reject heat from a large power station. The analysis considers various alternatives and different fuel price growth projections. The study will illustrate the methodology of analyzing such schemes in the United States. The analysis will be based on current Swedish district heating technology and experience, adapted where necessary to U.S. conditions. There will be an additional analysis based on technology now under development which promises better economics. A computer program will be used to optimize the various alternatives.* Comparisons will be made with nondistrict heating options. Cost and fuel requirements over long periods will be compared. Environmental consequences and institutional problems will be identified. General conclusions for other U.S. cities will be acknowledged."

The joint U.S.-Swedish study officially began on April 15, 1977, with a series of meetings in the Twin Cities. Dr. Peter Margen, AB Atomenergi, outlined the approach of the study, and the local participants responded enthusiastically. The Minnesota Energy Agency committed a man-year of

---

*Hot water under pressure at temperatures up to approximately 150°C will be considered. This relatively high distribution temperature would permit thermal energy to be used for absorption air conditioning which would provide a significant load for the district heating system during the summertime.

technical assistance to provide leadership and to coordinate the data gathering on population, heat loads, etc., which is required input for the AB Atomenergi analysis. Northern States Power offered information on their existing power plants and made a commitment to supply heat load data for St. Paul (NSP owns and operates a steam district heating system and the natural gas system in St. Paul). Minnegasco offered to supply the heat load data for Minneapolis. The physical plant staff of the University of Minnesota, which is located between the Twin Cities, offered information on their heat load data, tunneling costs, and building retrofit costs. The joint U.S.-Swedish study is expected to be completed by July 1978.

Preliminary Swedish results to date indicate favorable economics for a large system, including residential areas, for the newer technology of temperature resistant plastic piping. For conventional piping technology, the economics appear favorable for the commercial city core areas. The peak heat load for the larger system is approximately 4200 MW(t). The city core area has a heat load density of 56 MW(t)/km^2, while the surrounding regions with a population density greater than 1600/km^2 have a heat load density of 7.6 MW(t)/km^2. The Conventional steel piping is not economical for such low heat load densities as those in the surrounding residential areas.

AB Atomenergi's preliminary scenario assumes 2250 MW of thermal energy would be supplied by cogeneration units. This is about half of the total capacity [4200 MW(t)], however, the thermal energy from cogeneration units would supply 90% of the total annual energy load. The remaining 2000 MW(t) would be inexpensive heat-only units that would supply about 10% of the yearly load (Fig. 3). The 2250-MW(t) cogeneration capacity would be made up of 750 MW(t) from three converted units and 1500 MW(t) from new units. The assumed growth of the entire system is given in Fig. 4. There are three stages of development over the 15-year buildup of the system. The initial stage consists of converting turbines in existing in-town power plants to extract steam for district heating. Existing district heating boilers and new cogeneration plants would then be utilized to supply heat as high heat load density areas in the center city districts are connected to the network. Existing, as well as peak load boilers, would provide

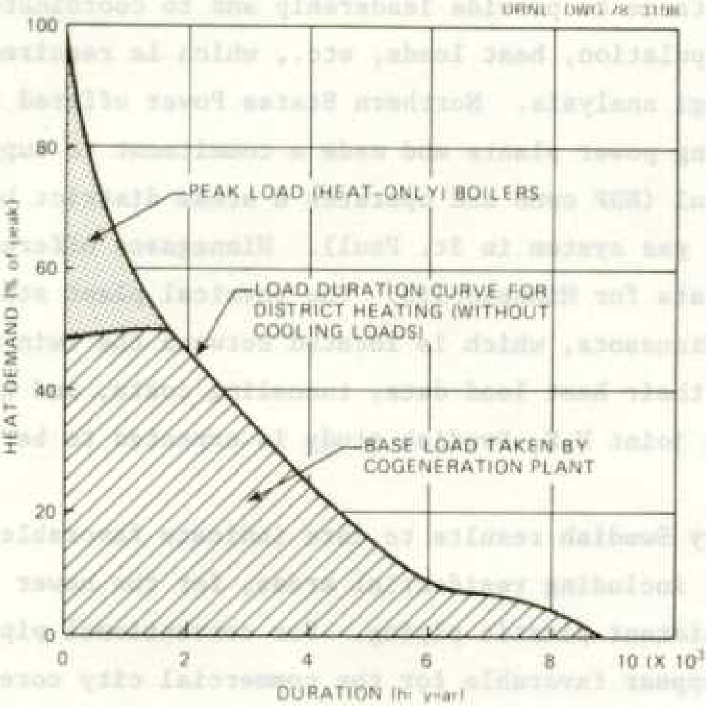

Fig. 3. Load allocation diagram used.

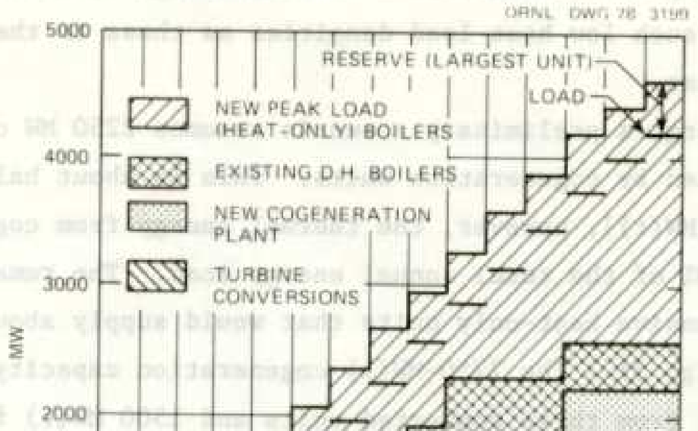

Fig. 4. Assumed load build-up rate and plant extension program.

emergency backup for the cogeneration units. Finally, the outlying residential areas would be connected to the main network starting with the denser areas close to the city.

It was realized early that in order to make the study realistic there were several areas that needed further investigation. There was an immediate need for additional technical and economic assessment. The Building Owners and Managers Association for the Twin Cities made the point that it was necessary to assess the cost of converting existing buildings to a hot water heating system. Northern States Power acknowledged a need for a detailed assessment on problems related to extracting thermal energy from existing turbines. Also, considerable effort was needed to study environmental issues. Questions such as how district heating could contribute toward improved air quality and where new plants could be sited needed answers.

2.1 Ancillary Technical and Economic Assessments

The Minnesota Energy Agency addressed the question of estimating building conversion costs by proposing a detailed study on the economics of retrofitting existing buildings in the downtown area of the Twin Cities. The scope of work for this study is outlined below.

> "Determine the type of heating system for the buildings in the study area. Classify the types of systems according to technical characteristics and determine the most economic method of converting each type. Select specific representative buildings for detailed conversion evaluations. Determine the applicability of the general conversion methods to each building in the city core and representative buildings outside the core area. Develop recommendations for future buildings to minimize costs of conversion to district heating system."

The work will be carried out in conjunction with about ten architectural firms who originally designed a total of 400 to 500 buildings in the Twin Cities area. One firm is responsible for writing guidelines to specify the procedure for determining techniques to evaluate converting different types of buildings. This is being done with the assistance of a Swedish consultant applying building conversion technology that has been widely utilized in Sweden. The guidelines will be valuable in insuring that each building conversion is assessed in a consistent manner. This study, which is sponsored cooperatively by DOE-ASMP and Minnesota Energy Agency, began on July 15, 1977, and will take about ten months to complete. Initial indications are that conversion of modern buildings having internal hot water distribution systems would be relatively simple. About 60% of the existing downtown buildings have hot water distribution systems, whereas less than 1% of the buildings in the downtown area are electrically heated.

2.2 Studies by Northern States Power Company

Northern States Power Company owns and operates coal-fired electric generating plants in both Minneapolis and St. Paul. The location of existing plants in and around the Twin Cities area is shown in Fig. 5. The highbridge plant in St. Paul has four active units with a total generating capacity of slightly less than 400 MW(e). The Riverside plant in Minneapolis is approximately the same size. The unit size varies from 35 to 220 MW(e), with the age ranging from 12 to 45 years. NSP has hired Ekono, a Finnish consulting engineering firm, to perform a preliminary study to determine the amount of thermal energy that can be extracted from the Riverside and Highbridge plants. The study, which should be completed sometime in December 1977,will answer a number of questions concerning the potential for cogeneration in relationship to existing condensing power plants.

Another effort that involves the cooperation of NSP is a DOE-ASMP study with United Engineers and Constructors.[4] NSP is a typical U.S. utility that is building large facilities [800–1200 MW(e)], whereas European district heating systems are based on smaller plants of about 200 MW(e). There are no existing large cogeneration/district heating facilities over 250 MW(e), and the intent of this study is to analyze the technical feasibility for the larger plants. This preliminary effort of about two man-months of work included two major areas: (1) a conceptual design of an 800 MW(e) cogeneration power conversion system, and

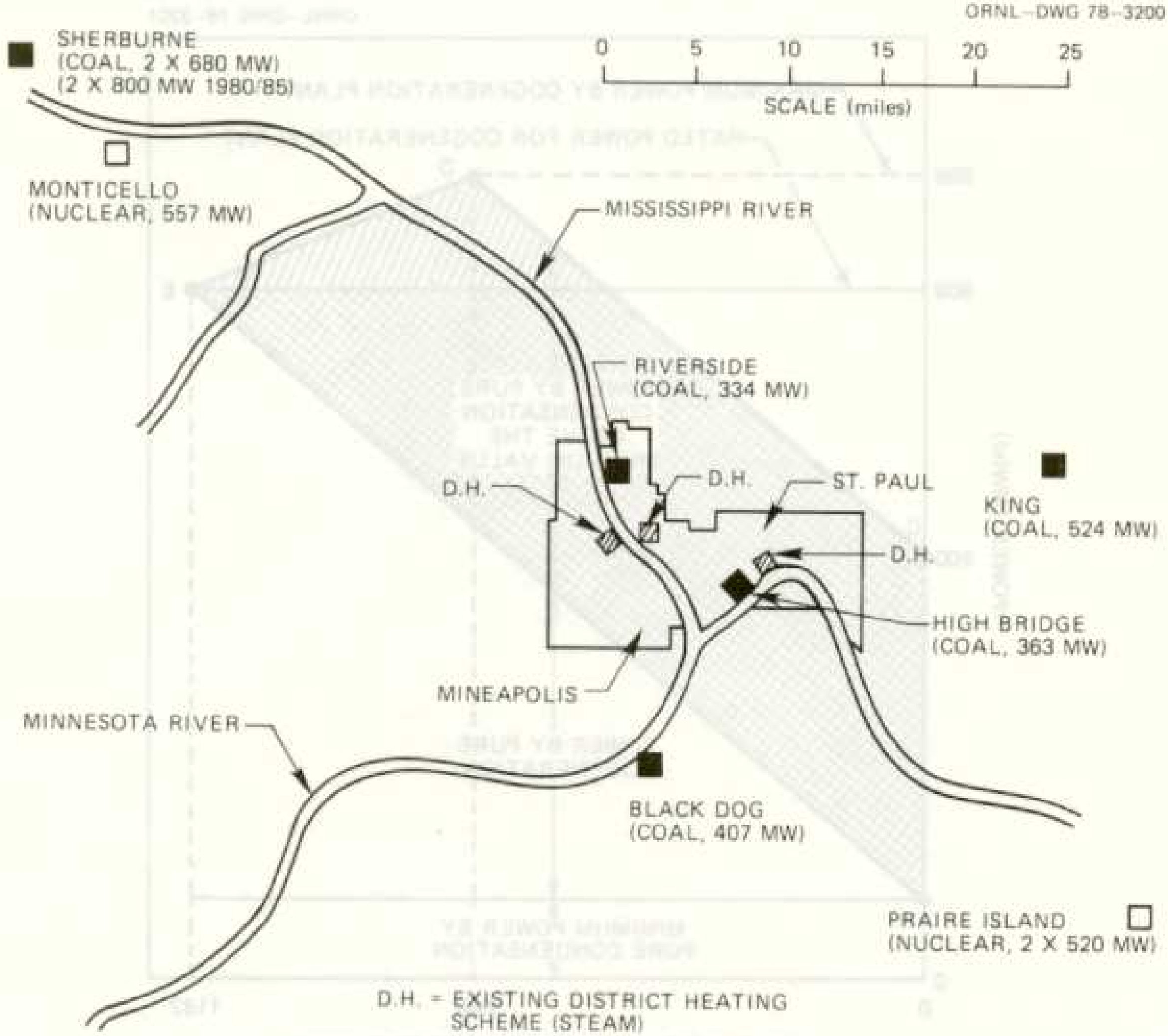

Fig. 5. Twin Cities metropolitan area location of thermal power plants.

(2) the comparison of cogeneration and conventional power plants of equal rated capacity in terms of heat rates and fuel savings.

The results of the conceptual design study provide some insight into the operational characteristics of a typical cogeneration plant with controllable steam extraction. Figure 6 shows the relationship between the production of heat and electricity. The shaded area in the figure represents the allowable range of operation of the power plant. It can be seen that the cogeneration plant has a certain degree of flexibility, which allows some independence between the thermal and electric output of

ORNL-DWG 78-3201

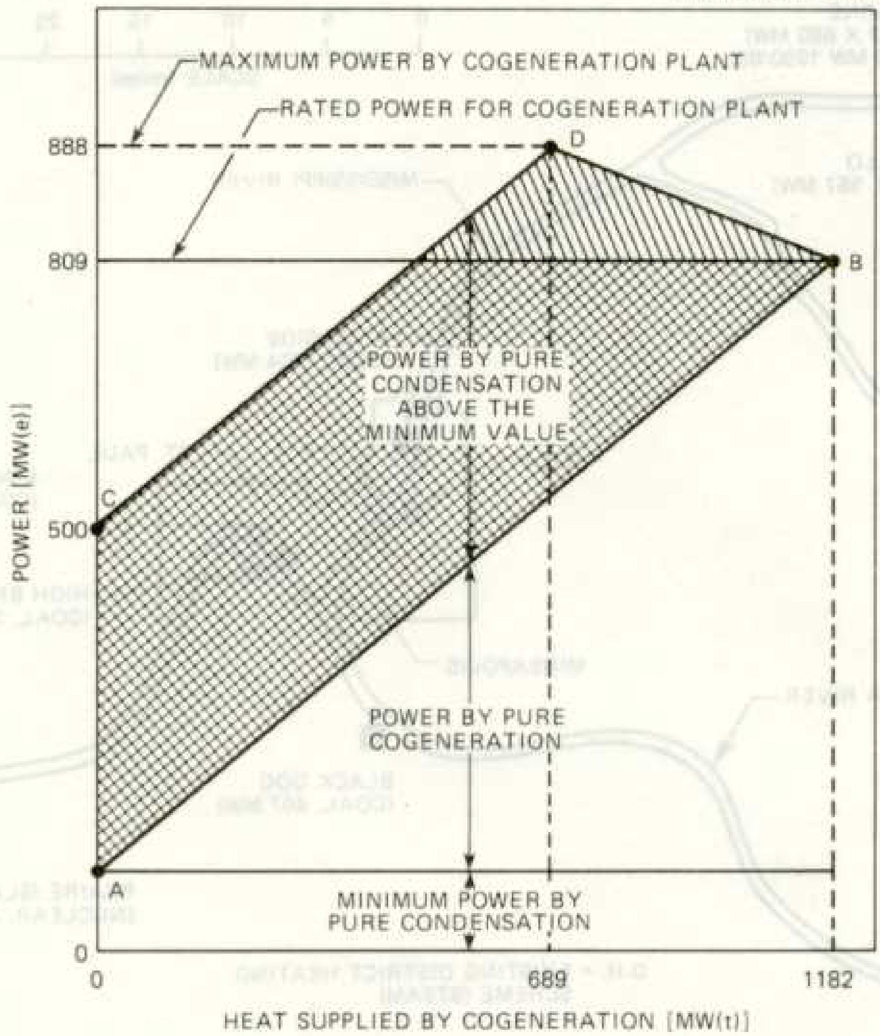

Fig. 6. Electric power — heat load diagram of a condensing cogeneration turbine with one controllable steam extraction.

the plant. This is highly desirable, especially for district heating applications where the heat load varies considerably throughout the year. The maximum electric power output as a function of the thermal load is represented by the line C-D-B; the minimum electric output is given by the line A-B. With no steam extraction, the maximum electric output is 500 MW(e). At a thermal load of 690 MW(t), a maximum power output of 888 MW(e) can be produced. Any additional increase in thermal energy extraction above 690 MW(t) up to the maximum of 1180 MW(t) then decreases the power output. This maximum, represented by point B, is at the turbine rated power level of 809 MW(e).

The efficiency of the power plant under various operating conditions is shown in Fig. 7. It can be seen that the net turbine heat rates for cogeneration are significantly better than those for conventional condensing turbine generators. The most efficient operation is at 100% steam extraction which is at the rated power of 809 MW(e). On an annual basis, the fuel savings obtainable by such a cogeneration plant is equivalent to about 2 1/2 million barrels of oil. At $12 per barrel, this results in a savings of about $30 million per year.

There are plans to do a detailed coal cogeneration/district heating plant assessment supported jointly by NSP and DOE. The assessment would be site specific with a detailed examination of (1) new and existing cogeneration units located at existing in-town facilities, and (2) a new facility located outside the Twin Cities. The in-town option would have the benefits of using a developed site and a relatively short thermal energy transport distance. However, most existing in-town facilities have physical limits on the size of units that could be installed; also, environmental constraints may limit the acceptability of additional in-town units. The out-of-town option would examine a conventional size unit that has the advantage of economy of scale but the disadvantage of having to transport thermal energy over relatively long distances. The results should establish the economic and environmental feasibility over a significant size range of units.

NSP is also sponsoring a detailed district heating marketing assessment for their St. Paul service area. In the past, the economics of expanding the St. Paul system has been unfavorable; but recent changes in the supply and cost of energy and capital, along with the recognition of the need to conserve scarce fuels, have brought about the need to re-evaluate the central heating concept. This in-depth effort will examine expanding the existing steam distribution system and also the possibility of conversion to hot water. This is a rather large study approximately equivalent to five man-years of effort and will take ten months to complete.

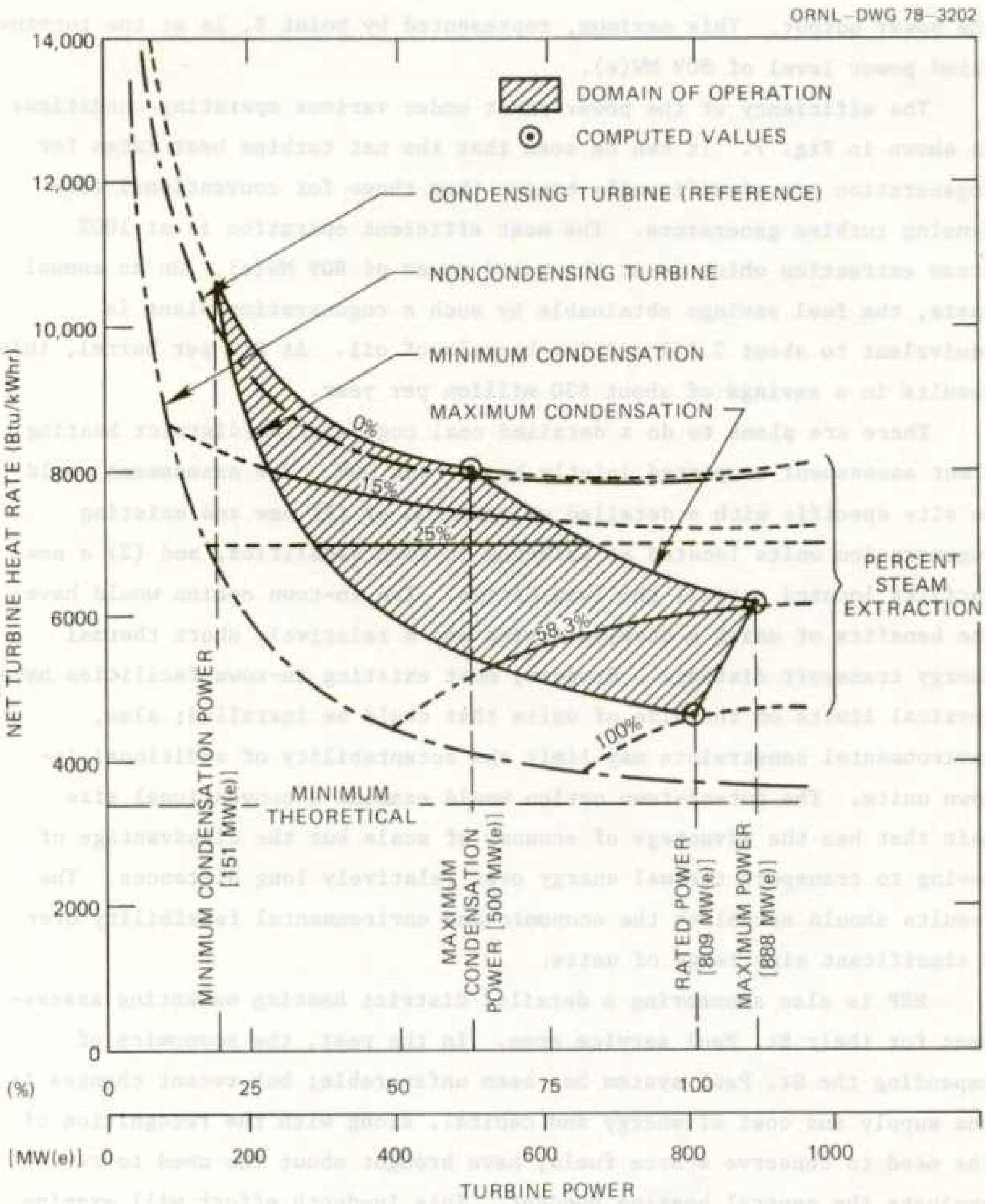

Fig. 7. Comparison of net turbine heat rates for power production by condensation and by cogeneration.

2.3 Environmental Assessments

Air quality considerations are obviously critical to the implementation of district heating. One stack used in the production of electricity and thermal energy would replace emissions from many low level space heating stacks. A number of Swedish cities that have a large fraction (60 to 95%) of heat supplied by district heating also have greatly reduced levels of SO_2 concentration compared to towns which utilize many small oil-fired boilers.[5] The effect district heating can have on the air quality depends to a large extent on the type of fuel being replaced.

Approximately 90% of the heating requirements in the Twin Cities area is currently supplied by natural gas. Projections for the future indicate a change in fuel availability. Replacing natural gas with oil would increase local emission levels; replacing natural gas with electricity for space heating would be very inefficient and would increase average emission levels for the entire state. Presently, the Twin Cities have been designated a nonattainment area by the Environmental Protection Agency (EPA) in particulate and sulfur dioxide emissions. EPA is requiring states to submit a plan for attainment and maintenance of environmental standards which will involve compliance agreements, stipulation agreements, and the use of best available technology for control of emissions. Existing technology usually involves mechanical stack gas control devices which are energy intensive. Using oil for space heating might dictate emission controls on small stacks, whereas the district heating alternative would alleviate the implementing of controls on small stacks. District heating might be considered as an ingredient in environmental attainment and maintenance plans.

Based on the control strategy concept, the DOE Division of Environmental Control Technology is sponsoring an air quality modeling study. The assessment is being performed by ORNL Environmental Impact Section in coordination with the Minnesota Energy Agency and the Minnesota Pollution Control Agency for the Twin Cities. The analysis will compare three scenarios: (1) current environmental conditions, (2) environmental conditions projected for the mid 1990's without district heating, and

(3) environmental conditions with a district heating/cogeneration system. Results of the study should be available by the end of 1978.

District heating would also reduce thermal pollution to rivers and lakes. There are a large number of existing electric generating units that use once-through cooling; and, if some of these units were modified in order to supply thermal energy to the district heating grid, there would be a reduction in the amount of thermal energy rejected to the environment. The most significant reduction would occur in the winter when the space heating load is the highest.

2.4 Study of Nuclear Cogeneration Plants

Another assessment is the examination of nuclear/cogeneration for district heating. The improvement in air quality using a nuclear plant, in comparison to coal, is a major reason to include this option. Nuclear energy is a complex and often emotional issue, but the U.S. energy situation will not allow foreclosing such an option without rigorous studies.

Nuclear reactors have been used for district heating in Sweden and the USSR. Beginning in 1964, the Swedish Agesta reactor provided 70 MW of thermal energy to a suburb of Stockholm.[6] The plant also supplied electricity to the grid, but it was shut down in 1974 because the economics of such a small plant were unfavorable. A dual-purpose nuclear plant located in the north of the Soviet Union at Bilibino has been operational since 1973.[7] The first nuclear cogeneration plant in the U.S. is under construction in Midland, Michigan, and is scheduled to go on-line in 1982. Four million pounds of steam per hour will be piped from the Consumers Power Company's plant to Dow Chemical Company for process heat applications. In addition to the applications of nuclear power mentioned above, numerous studies on dual-purpose and small power reactors for district heating have been undertaken. A summary of some of these efforts is presented in Ref. 8.

The present study will focus on an intermediate size [1200 MW(t)] Babcock and Wilcox pressurized water reactor (PWR) known as the Consolidated Nuclear Steam System (CNSS). The CNSS concept, which stems from nuclear merchant ship propulsion steam systems, but is designed to operate at a higher power level, is described in Ref. 9. Compared to conventional loop-type PWR's, the CNSS has additional inherent safety features. This aspect, along with other characteristics of the reactor, such as size and compact design, may provide the basis for the possibility of obtaining regulatory approval for plant siting nearer to centers of population.

2.5 Study on Institutional Issues

An assessment currently in the planning stages deals with the need to address institutional issues relating to cogeneration/district heating. These barriers include financing, rates, tax policy, organization structure, hook-up policy, franchizing, environmental regulation, and construction impacts. The proposed study would analyze the institutional issues of implementing district heating in the Twin Cities on an ownership case study basis and make appropriate recommendations to remove or circumvent such barriers, if possible. Alternative ownership structure would be assumed; and for each structure there would be (1) a list of barriers, (2) feasible solutions, and (3) recommendations.

3. SUMMARY

The introduction of large-scale hot water district heating in the U.S. presents complex economic and institutional issues. It is the goal of this program to resolve some of the problems by means of in-depth application studies. Most of the district heating studies described in this paper will be completed by the end of 1978. If these evaluations are sufficiently positive, the next step would probably be an in-depth design phase that could lead to a demonstration project. Hopefully, the Minneapolis-St. Paul studies will also provide a basis for the evaluation of district heating/cogeneration in other U.S. cities.

REFERENCES

1. *District Heating Handbook*, Third Edition, National District Heating Association, Pittsburgh, Pennsylvania, 1951.

2. V. Scholten, "Survey about the Existing District Heating Systems," presented at Topical Meeting on Low Temperature Nuclear Heat, Otaniemi, Finland, Aug. 21–24, 1977.

3. T. Beresovski and A. M. Rubin, "Studies Relating to Thermal Energy Supply from Central Nuclear Power Stations," *District Heating* 63(2), 22–27 (December 1977).

4. G. F. Pavlenco and G. A. Englesson, *Preliminary Study of Large Co-generation/District Heating Power Plants*, to be published by NTIS (1978).

5. *Combined Power and Heat 1975*, Swedish District Heating Association, Stockholm, Sweden, 1975.

6. K. Hannerz, Y. Larsson, and P. Margen, "Reactor Waste Heat Utilization and District Heating Reactors," IAEA paper CN-36/275, presented at International Conference on Nuclear Power and Its Fuel Cycle, Salzburg, Austria, May 2–13, 1977.

7. B. B. Baturov et al., "The Use of Nuclear Reactors for Central Heat Supply and District Heating," IAEA CN-36/338, presented at International Conference on Nuclear Power and Its Fuel Cycle, Salzburg, Austria, May 2–13, 1977.

8. *Nuclear Engineering International* 22(261), 41–57 (August 1977).

9. *400 MWe Consolidated Nuclear Steam System (CNSS) — 1200 MWt/ Conceptual Design*, prepared by Babcock & Wilcox, BAW-1445, ORNL/Sub-4390/4, June 1977, available from NTIS, Springfield, Virginia.

Internal Distribution

1. T. D. Anderson
2. S. Baron
3. S. E. Beall
4. J. E. Christian
5. J. G. Delene
6. H. L. Falkenberry
7. E. C. Fox
8. W. K. Fulkerson
9. J. F. Harvey
10. R. F. Hibbs
11–35. M. A. Karnitz
36. O. H. Klepper
37. J. O. Kolb
38. M. Levenson
39. W. R. Mixon
40. M. Olszewski
41. G. D. Pine
42. H. Postma
43. M. W. Rosenthal
44. T. H. Row
45. M. R. Sheldon
46. M. J. Skinner
47. I. Spiewak
48. H. E. Trammell
49. D. B. Trauger
50–51. Central Research Library
52. Document Reference Section
53–54. Laboratory Records Department
55. Laboratory Records, RC

External Distribution

56. Director, Advanced Systems and Materials Production Division, Nuclear Energy Program, DOE, Washington, DC 20545
57. G. A. Bornstein, Economic Regulatory Administration, DOE, Washington, DC 20545
58. S. N. Cavros, Building and Community Systems, DOE, 20 Massachusetts Avenue, Washington, DC 20545
59. R. L. Cowles, Conservation and Solar Applications, DOE, 12th and Pennsylvania Avenue, NW, Washington, DC 20461
60. D. R. Israel, Office of Energy Research, DOE, Washington, DC 20545
61. R. L. Johnson, Policy and Evaluation, DOE, Washington, DC 20545
62. Robert McFarren, Resource Applications, Federal Building, DOE, 12th and Pennsylvania Avenue, Washington, DC 20461
63. R. G. Oehl, Advanced Systems and Materials Production Division, Nuclear Energy Program, DOE, Washington, DC 20545
64. W. F. Savage, Advanced Systems and Materials Production Division, Nuclear Energy Program, DOE, Washington, DC 20545
65. I. Sewell, Building and Community Systems, DOE, 20 Massachusetts Avenue, Washington, DC 20545
66. A. J. Streb, Industrial Energy Conservation Division, DOE, 20 Massachusetts Avenue, Washington, DC 20545
67. I. Ylvasaker, Office of Program Integration, DOE, Washington, DC 20545
68. Director, Research and Technical Support Division, DOE, ORO
69. Director, Reactor Division, DOE, ORO
70. H. W. Behrman, DOE, ORO

71. M. A. Barnes, KVB, Inc., 600 South County Road #18, Minneapolis, MN 55426
72. D. Cabrilla, Environmental Protection Agency, Office of Radiation Programs, Mail Code AW 459, Washington, DC 20460
73. E. A. Clymer, Philadelphia Electric Company, 2301 Market Street, Philadelphia, PA 19101
74. P. F. Donnely, Argonne National Laboratory, 9800 S. Cass Avenue, Argonne, IL 60439
75. D. A. Dougherty, EPRI, Palo Alto, CA 94303
76. C. W. Easton, Seattle Steam Corporation, 1205 Peoples National Bank Building, Seattle, WA 98171
77. H. Jaehne, Northern States Power Company, 411 Nicollet Mall, Minneapolis, MN 55401
78. J. P. Karkheck, Building 129, Brookhaven National Laboratory, Upton, NY 11973
79. C. C. Lee, Environmental Protection Agency, 5555 Ridge Avenue, Cincinnati, OH 45268
80. K. Linwick, IDS Properties, 2500 IDS Center, Minneapolis, MN 55402
81. C. Maday, Environmental Protection Agency, Energy Strategies Branch, Research Triangle Park, NC 27711
82. P. H. Margen, AB Atomenergi, Flack, 611 01 Nykoping 1, Sweden
83. H. E. Nurmi, Detroit Edison Company, 2000 Second Avenue, Detroit, MI 48226
84. J. C. Pearce, Northern States Power Co., 411 Nicollet Mall, Minneapolis, MN 55401
85. V. Rabl, Argonne National Laboratory, 9800 S. Cass Avenue, Argonne, IL 60439
86. W. Soderberg, Director of Physical Plant, 200 Shope Building, University of Minnesota, Minneapolis, MN 55455
87. F. Strnisa, New York State Energy Agency, Swan Street Building, Empire State Place, Albany, NY 12223
88. R. W. Thron, 300 Metro Square Building, 7th and Robert, St. Paul, MN 55101
89. R. H. Tourin, New York State ERDA, 230 Park Avenue, New York, NY 10117
90. M. Treitman, Environmental Protection Agency, 230 South Dearborn, Chicago, IL 60604
91. Mike Valentine, Minnesota Pollution Control Agency, 1935 West County Rd., B2, Roseville, MN 55113
92. R. Visness, State of Minnesota Energy Agency, 740 American Center Building, 150 E. Kellogg Blvd., St. Paul, MN 55101
93. W. L. Waleen, Minnesota Gas Company, 9525 Wayzata Boulevard, Minneapolis, MN 55426

94–120. Technical Information Center, DOE, ORO