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ENERGY DIVISION

Annual Progress Report

PERIOD ENDING SEPTEMBER 30, 1976

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ENERGY DIVISION
ANNUAL PROGRESS REPORT
For Period Ending September 30, 1976

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operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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1. Introduction and Executive Summary

W. Fulkerson

As in the past, the format for this annual progress report follows the organizational structure of the Energy Division. Each chapter is a report of the work done by one of the sections or a major program of the division: Environmental Impect Section (Chap. 2), headed by T. H. Row; Regional and Urban Studies Section (Chap. 3), R. M. Davis; Energy Conservation Section (Chap. 4), R. S. Carlsmith; High-Temperature Power Conversicn Systems Section (Chap. 5), A. P. Fraas; and the Low-Temperature Heat Utilization Program (Chap · J. W. Michel. To change the report period from a calendar year to a fiscal year basis, this year's annual report covers activities for only 9 months (January 1, 1976 through September 30, 1976) instead of the usual 12 months.

A major reorganization affecting the Energy Division occurred in September. Art Fraas's High-Temperature Power Conversion Systems Section was moved to the Engineering Technology Division, and a number of people in that division were transferred to the Energy Conservation Section and the Environmental Impact Section of the Energy Division. The purpose of these changes was to consolidate the organization of people working on various projects that had been the joint responsibilities of the two divisions. The organization chart appendixed to the report reflects these changes. However, since the changes were made late in the reporting period, the chapter on the High-Temperature Power Conversion Systems Section is included.

The work of the Energy Division can be characterized by two themes: (1) environmental assessment, including social and economic considerations, and (2) fuel conservation and energy conversion efficiency. The first theme encompasses the preparation of environmental statements and assessments for nuclear power plants and other energy facilities (Chap. 2) as well as regional analyses of social, economic, and environmental effects due to energy system development patterns (Chap. 3). The second theme characterizes a broad scope of conservation-related work, including efforts to understand energy demand patterns and to develop technologies and arrangements for reducing these demands (Chap. 4). This theme also encompasses research directed at improving both high- and low-temperature thermodynamic cycles driven by solar, geothermal, or fossil energy sources (Chaps. 5 and 6).

The work is necessarily interdisciplinary and involves the collaboration of physical, life, and social scientists and engineers. The professional staff of the division includes 22 social scientists, 27 engineers, and 11 physical scientists. Many of the projects involve contributions from the personnel of other divisions, notably life scientists from the Environmental Sciences Division, mathematicians and computer specialists from the Computer Sciences Division, and engineers from the Engineering Technology Division. The division also receives important input from consultants and through research contracts with a variety of firms and universities, particularly the University of Tennessee.

During the year a number of individuals from the Energy Division served on important committees or were honored for their accomplishments. A. P. Fraas was made a Distinguished Development Fellow of the Union Carbide Corporation, the only engineer at ORNL who has been so honored. R. S.

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Carlsmith headed the Buildings and Appliances Resource Group of the Demand Conservation Panel of the Committee on Nuclear and Alternative Energy Sources (CONAES) of the National Academy of Sciences and National Academy of Engineering; E. A. Hirst also served on that group. E. Peelle is a member of the Socio-Political Resource Group for the Risk Impact Panel of the CONAES study and also organized an international symposium, "Socio-Economic Issues for Nuclear Power Plants — A World View," at the American Nuclear Society annual meeting in Washington, D.C., in November 1976.

Major support for the work during the year came from a number of federal agencies: the Energy Research and Development Administration (ERDA), Nuclear Regulatory Commission (NRC), Department of Housing and Urban Development (HUD), and Federal Energy Administration (FEA). Important contributions were also made by the Economic Development Administration of the Department of Commerce, the Electric Power Research Institute (EPRI), the Water Research Council (WRC), the Ohio River Basin Commission, and the U.S. Army.

The major accomplishments and results reported in the various chapters of this report are summarized in the following sections.

1.1 ENVIRONMENTAL IMPACT SECTION

Although the principal activity of the section has again been the preparation of environmental statements for NRC relative to construction of nuclear power plants, the scope of the work for both NRC and ERDA has broadened considerably to include geothermal and coal facilities and other parts of the nuclear fuel cycle. For NRC the expanded effort includes preparing statements for the consideration of operating licenses, in addition to construction permits, for power plants and fuel fabrication facilities. The preparation of statements has also been initiated in connection with two proposed uranium in-situ solution mining operations in eastern Wyoming. Two so-called "early site reviews" were conducted—one for the Blue Hills site near Fairmont, Texas, and the other on the north coast of Puerto Rico. The purpose of the early site reviews is to help utilities identify potentially acceptable power plant sites well before any application for a construction permit is made.

New activities for ERDA include work for the Division of Geothermal Energy (DGE) and for Fossil Energy (FE). For DGE, statements and assessments are being prepared on the hydrothermal, geopressure, and hot dry rock RD&D subprograms and on specific geothermal projects covered by the government loan guaranty program. The work for FE, which is just getting under way, involve technical assistance to ERDA, preparation of environmental statements for coal technology demonstration plants, information services, preparation of an environmental monitoring handbook as a guide for contractors, and an investigation of landfill disposal of coal conversion wastes. The DGE and FE efforts constitute very important diversification and expansion of the environmental impact statement program at ORNL.

The section was also engaged in a variety of other projects, including (1) completion for NRC of an addendum to the final environmental statement on the nuclear fuel reprocessing facility near Barnwell, South Carolina, that covers neighboring ERDA nuclear facilities at Savannah River and the Vogtle and Oconee nuclear plants; (2) an assessment for ERDA of two coal-fired steam plants supplying power to the Portsmouth Gaseous Diffusion Plant at Portsmouth, Ohio; (3) continued assessment for ERDA of the radioactive source terms which might result from the use of a very high temperature gas-cooled reactor to supply process heat for coal hydrogenation; (4) assessments for NRC of the probable impacts of consumer products containing radioisotopes; (5) a study for the U.S. Army Corps of Engineers of the impact of all power plants on the Hudson River relative to the biota in the river (especially striped bass) and sulfur dioxide emissions, and (6) initiation of the preparation of an environmental statement for HUD on the Modular Integrated Utility System (MIUS) for the new community of St. Charles, Maryland.

Although 1976 produced very few nuclear reactor starts, there was activity on 27 cases for NRC, including four new construction permits, three operating licenses, and two early site reviews. Five draft environmental statements and four final environmental statements were completed, and the staff provided testimony and/or participated in eleven Atomic Safety and Licensing Board or Appeal Board hearings.

A general observation is that the process of environmental review for nuclear power plants is becoming more time-consuming and costly. To increase the efficiency of the process, NRC and the Environmental Protection Agency (EPA) have implemented a Memorandum of Understanding (MOU) under which NRC is the lead agency in the preparation of the statement, but the staffs of both agencies collaborate in the statement preparation. This change should reduce some of the costly review which has been necessary in the past. One of the cases initiated under the MOU was the Fort Calhoun Station Unit 2 on the Missouri River near Omaha, Nebraska. The applicant proposes a once-through cooling system, from which the staff concludes that significant impact to the Missouri River fishery can result. Several mitigation measures are under consideration including one proposal by the applicant to reactivate former wetlands along the river, thus providing enhanced habitat for the fishery. The proposal is controversial because its adoption might set a precedent for mitigating rather than minimizing the impacts of plant operation. The issue is being debated by the EPA and NRC staffs.

The case of Indian Point on the Hudson River became active again; a draft and final environmental statement were prepared on the request by the applicant, Consolidated Edison, for an amendment of the Unit 2 operating license to permit once-through cooling for an additional two years. The staff concluded that the two-year extension is not expected to have an unacceptably large impact on the Hudson fishery and that the impact would not be irreversible. The continued involvement with the Indian Point case has resulted in updated models for the river and increasing knowledge of the details of the applicant's extensive research program related to the fishery. This information is being used to help the Army Corps of Engineers assess the impacts of the neighboring Bowline and Roseton fossil-fueled power plants.

In addition to the work on various statements and assessments, four confirmatory research projects were active under NRC support: (1) a study of the multiple uses of cooling reservoirs, (2) an investigation of fish impingement at power plants in the Southeast, (3) a critical analysis of environmental monitoring data from operating power plants, and (4) the development of the unified transport approach to the assessment of aquatic impacts of power plants. The first three projects have been completed or are nearing completion.

The study of multiple uses of cooling reservoirs involved a survey and analysis of the literature concerning reservoir ecosystems. Although stresses due to entrainment and thermal and chemical discharges reduce the populations of phytoplankton, zooplankton, and benthos in the vicinity of intake and discharge structures, far-field effects are less significant and sometimes stimulatory. Since the overall effects on the fish populations seem to be insignificant, cooling reservoirs are often suitable for fish production and associated recreation. This potential for additional use constitutes the most significant advantage of cooling ponds over cooling towers.

The study of fish impingement involved collection of data from 27 fossil-fueled and 5 nuclear plants in the southeastern United States. The majority of fish impinged were shad, especially threadfish shad, and most of the species impinged were small young-of-the-year fish less than 7 cm in length. The parameter most highly correlated with threadfin shad impingement was temperature, the highest vulnerability being associated with the coldest temperatures. Unfortunately, no conclusive results could be drawn concerning specific intake designs. Impingement at river sites was generally lower than at lake or reservoir sites.

Each year millions of dollars are spent on environmental monitoring of operating nuclear power plants, but how useful are the data obtained? To answer this question, an evaluation was made for the NRC Office of Nuclear Regulatory Research of thermal and ecological data collected at eight operating power plants. It was found that the data were inadequate to warrant thorough analysis for all but three of these — Surry, Peach Bottom, and San Onofre. The analysis for Surry and Peach Bottom revealed that the data were sufficient to validate only three of the predictions made in the final environmental statements with respect to ecological effects. Ten of the predictions were shown to be in error, and the data were insufficient to confirm or reject eight other predictions. Due to the limited duration of sampling at San Onofre, ecological predictions could not be validated or disproved. Analysis of the thermal plume monitoring efforts at the three plants resulted in a set of recommendations about how such monitoring should be conducted to best support the ecological monitoring activities. Some of the thermal plume data were found to be useful in validating transport models being developed in the unified transport approach.

The unified transport approach (UTA) is a series of fast-transient, one- and two-dimensional models that can be used to simulate simultaneously the transport of heat, chemicals, radionuclides, sediment, and biota in various water bodies. It is particularly suitable for complicated water bodies such as the ocean or estuaries where there is tidal flow. The models are unified in the sense that, since the mathematical formulations are similar for many of the transport phenomena, the same numerical integration schemes are used, and the models are formulated so that much of the same site-specific input data and the same output display codes can be used. The development of UTA is also being supported by the NRC Office of Nuclear Regulatory Research.

During the year, most of the one- and two-dimensional far-field codes were completed. These include incorporation of formulations to (1) predict the formation of chloramines from chlorine discharges and the dispersion of these chemicals; (2) simulate the interaction of radionuclides with suspended and bottom sediment; and (3) predict the movement of bottom sediment. These far-field models are in the process of being validated against available data. In the cases checked to date, the agreement between field measurements and simulation has been good, but the data are very limited.

In addition, a general perturbation method was developed for zone matching far-field with near-field models. The method was tested for the case of thermal discharge in a cooling pond using a modification of the SMAC (Simplified-Marker-and-Cell) technique for the near field. The critical reentrainment and recirculation effects were clearly quantified.

1.2 REGIONAL AND URBAN STUDIES SECTION

The objective of the Regional and Urban Studies (RUS) Section is to conduct integrated analyses of the social, economic, and environmental effects of alternative energy development and use scenarios at the regional as well as the national level. The approach being developed depends on identifying plausible spatial arrangements of energy facilities corresponding to the various scenarios being studied. These arrangements are derived through a two-step process. First, energy demand is forecast from projections of economic activity for BEA (Bureau of Economic Analysis) regions, and from the demand forecast, supply scenarios can be postulated, giving the type, number, and timetable of energy facilities needed to meet the demand. Second, a computer-assisted methodology is used to match requirements of the energy facilities with the spatial distribution of the resources in the region (e.g., water availability, topography, geology, sensitive or endangered species, air and water quality, geology, seismicity, transportation facilities, fuel supplies, etc.). This matching results in identification of candidate areas where energy facilities could be located. The final allocation depends on meeting the demand subject to the consideration of other objectives and constraints, such as minimum environmental stress, minimum costs, or the collective availability of resources (e.g., how many plants can a given river basin accommodate?).

Once a plausible spatial arrangement has been identified, the range of probable social, economic, and environmental effects can be analyzed. Of course, this analysis may reveal effects that are unacceptable, leading to a redefinition of the spatial arrangement. Thus, the process is an iterative one. The regional analysis efforts are multidivisional: social and economic effects are assessed largely by the Energy Division personnel, environmental effects are analyzed by a group in the Environmental Sciences Division, and the spatial allocation based on resources is done by people in both the Energy and Computer Sciences Divisions.

During 1976, three complementary regional analysis efforts were initiated. The most ambitious of these is the National Coal Utilization Assessment supported by the ERDA Division of Technology Overview. This is a two-year effort involving the collaboration of a number of national laboratories under the leadership of Argonne National Laboratory. Each laboratory will assume responsibility for the analysis in a particular region of the country, the ORNL area being the South. Argonne will be responsible for total integration of results. The assessment will consist of an analysis of the comparative effects to the year 2020 associated with four alternative energy futures: (1) a recent-trend base case, (2) high coal-electric (low nuclear), (3) accelerated synfuels, and (4) high coal-electric together with accelerated synfuels production. The program is designed primarily to provide ERDA with information about possible regional problems and constraints that may confront the development of new coal-based technologies and to identify needed research, but the results should also be useful to other federal agencies as well as to state and regional decision makers. The work is just getting under way, and most of the efforts to date have been to help Argonne define the program and organize the work.

The other two regional analysis efforts involve determination of the likely effects of future energy facilities on water availability. One of these studies, just under way, is being done for the Water Resources Council as part of the 1975 National Water Assessment and will involve projections of future water requirements for nonnuclear energy facilities in the eastern United States. Los Alamos Scientific Laboratory is doing a similar study for the West. The second study is being done in collaboration with Argonne for the Ohio River Basin Commission. This effort, which is focused on the water requirements for electrical power, is nearly complete. Energy demand forecasts have been disaggregated to BEA regions along the Ohio River. A spatial allocation of the required plants, starting from utility plans, has been developed, and water requirements have been determined. Under the assumptions used in the study, the analysis indicates that water supply may be a problem for certain areas.

The study for the Ohio River Basin Commission represents the first large-scale regional analysis done by the section. This is the first time that the necessary methodology *and* geographical data have been available, and the results look very promising. Our capability for doing this sort of analysis for any part of the country, but particularly for the South, should increase rapidly. The required methodology and the geographical data bases have been built up over the last six years, initially under the support of the National Science Foundation, and this year a series of 16 reports was issued documenting this development.

In addition to these integrated regional assessments, a variety of more disciplinary studies and projects are under way in the section. Many of these serve the dual purpose of improving analytical techniques and methods and providing useful results to various sponsors.

The ORNL regional economic model, MULTIREGION, underwent extensive testing and fine tuning during the year. The model was tested against census estimates for 1975 using data between 1960 and 1970 for specifying the model parameters. The MULTIREGION calculations were within an average deviation of 4% for the 173 BEA areas, and a similar comparison with the OBERS projections for 1985 gave an average deviation of 9%. The model is currently being used experimentally to disaggregate national projections of economic activity (employment) and population to the BEA areas in five-year steps to the year 2020 for the National Coal Utilization Assessment. The model will be used to provide regional energy demand forecasts and to assess the secondary economic effects of regional energy development.

Considerable effort was expended in collecting and organizing regional data bases on fuel supply and demand. This work consisted of specializing data available at various geographical scales (e.g., counties, states, electricity reliability areas, and coal production areas) and aggregating or disaggregating the data to the BEA regions on the basis of these statistics. A comprehensive analysis was made of energy conditions in the South based on the 1972 data. This was part of a more general effort for ERDA and the Department of Commerce, Economic Development Administration, to identify regions in the country where disparity between energy demand and resources may seriously affect future economic development. Because of the extensive petroleum and gas fields in Texas and Louisiana, the South accounted for over 73% of all domestic energy production in 1972. It also accounted for 53% of the coal production although the region contains only 13% of the remaining coal reserves, and these are typified by a high sulfur content. Primarily because of these energy-producing activities, southern per-capita energy usage was 12% higher than the national average.

The NRC-supported Maryland Power Plant Siting Study, which has been in progress for several years, was completed in 1976. The work provided the State of Maryland with a computer-assisted siting methodology and typical site selection analyses for eight counties in the northern part of the state. The study resulted in three major conclusions: (1) Siting factors significant to various involved groups (utilities, environmentalists, regulations, etc.) can be identified and their relative importance established through structured group interaction processes such as the "nominal group" process; (2) the computerized site-screening process developed is sensitive to the type of power plant to be sited, the siting factors used, and the relative importance assigned to each factor; (3) the Maryland data base (data collected on a 91-acre grid) is useful for identifying candidate power plant sites, but a methodology that can use more universally available data bases is needed.

One outcome of the Maryland work has been the development of a general candidate-area identification method called ORSAM (Oak Ridge Spatial Analysis Model). The ORSAM consists of a set of siting factor submodels that describes resource availability in terms of the siting requirements of various energy technologies. ORSAM is being applied in the Ohio River Basin Study.

Because of its centricity to energy facility siting, a water availability model (WAS) was developed. The WAS enables the user to select, retrieve, and analyze historical stream flow information from the U.S. Geological Survey daily value water tapes which contain data for all stream-gauging stations in the United States. This model was used in the Maryland Power Plant Siting Project and also in the Ohio River Basin assessment. The WAS has become part of the Oak Ridge Regional Model Information System (ORRMIS), which includes extensive data from satellite observations, census results, topographic maps, aerial photographs, and many other sources. The ORRMIS is a comprehensive system consisting of extensive geographical data sets as well as digitizing and visual display hardware with extensive software systems for manipulating the data to analyze energy facility siting and regional resource problems.

A model is being developed for the Electric Power Research Institute to calculate volumes of coal reserves and mining costs. The methodology is being tested for a 1:24,000 quadrangle in East Tennessee that has been studied and evaluated by TVA geologists. This model, coupled with information needed to indicate environmental constraints, will be used in the National Coal Utilization Assessment to inventory coal reserves by county and cost in the Appalachian region.

The social and economic effects experienced by communities in the vicinity of large energy facilities such as power plants are being identified and characterized through a number of case studies. Investigations at the sites of two operating nuclear power plants — Plymouth, Massachusetts (Pilgrim Plant) and Waterford, Connecticut (Millstone) — and at the site of a nuclear power plant to be built by TVA at Hartsville, Tennessee, were continued and have resulted in some interesting observations and hypotheses. In all three communities, public acceptance of the nuclear plants was high. At Hartsville, the results of two surveys of public opinion indicated support, by about two to one, for the plant; this is about the same level of support that has been found by national surveys and in various recent state referenda. The support at Plymouth and Waterford is even higher, probably because of the large tax support provided by the plants and perhaps because construction effects at these communities were negligible because most workers commuted from neighboring areas.

A plausible categorization of communities according to the likely severity of the socioeconomic impacts which result from the construction and operation of a neighboring power plant, has been made on the basis of the level of tax revenue and the number of people coming into the community during construction. In this categorization, the impacts at Hartsville are expected to be more severe than those at Portsmouth or Waterford since TVA presently pays no local taxes and there will be a large influx of construction workers to the area. In anticipation of this situation, TVA is pledged to mitigate adverse impacts. The TVA mitigation program and similar mitigation plans of other utilities around the country are being evaluated and compared to give insight about the effectiveness of such measures.

In addition to these research activities, socioeconomic impact analyses were conducted for ten environmental statements (nine for NRC and one for ERDA). This work was in support of the Environmental Impact Section, and the issues involved ranged from land use conflicts to public services.

Finally, RUSTIC (Regional and Urban Studies Information Center), which is part of the Data Management and Analysis Group of the section, continued during 1976 to supply socioeconomic data to a variety of federal, state, and academic institutions through a cooperative program with Oak Ridge Associated Universities. New data resources include transportation energy supply, consumption, and conservation files; location files for airports and power plants; human health and vital statistic files; regional economic data files; socioeconomic survey files of the United States; and recent census and related data files. The RUSTIC group also compiled and published a Transportation Energy Conservation Data Book for the Division of Transportation Energy Conservation of ERDA. The data book, which will be periodically updated, is a compilation of data on the major transportation modes and the overall energy use in each mode.

1.3 ENERGY CONSERVATION SECTION

Conservation research in the section emphasizes opportunities for saving fuel in the residential and commercial sectors. Also, electrical energy distribution and use across all sectors of the economy are being examined.

The section continued research on selected topics judged to be important for energy consumption in buildings and appliances. Among these is the ACES system which can reduce heating, air conditioning, and water heating energy use by 50% or more as compared with air-to-air heat pumps and resistance hot water heating. The system combines a high-efficiency heat pump with thermal energy storage and thus can be used for load management (peak shaving) as well as for energy conservation. During the year an initial demonstration facility was built in a single-family house on the campus of the University of Tennessee. Initial heat balance measurements were in good agreement with predicted performance. After correcting startup problems, energy data will be collected over a one-year test period. A second ACES demonstration is being built by the Veterans Administration to supply a 60-bed nursing home in Wilmington, Delaware. This facility is scheduled to begin operation in late 1977. A third demonstration, privately financed, will be in a residence being built by a group of private companies in Richmond, Virginia.

Component development and testing for ACES has been continued in order to establish a basis for cost-effective and reliable designs. Work during the year included tests of ice coils, collector panels to be used for solar augmentation, ice bins, and icemaker heat pumps. The icemaker heat pump offers the possibility of significant reduction in the ACES cost because the ice-bin coils, which are expensive to fabricate, install, and maintain, can be eliminated. The simplicity of a factory-made unit with the ice-making coils included is one attractive alternative being intensively investigated.

It was estimated that, for ice storage to be cost-effective, the price of the ice bin must be reduced to about $18 per cubic meter of storage capacity. A number of bin types were investigated, and of these, wood tanks with vinyl liners, cast concrete septic tanks, and special steel tanks show promise of being economical

Future work on ACES will increasingly consist of information dissemination activities to assist in commercialization of the concept and the development (under subcontract) of two design manuals for large and small buildings. The ORNL staff will assume the responsibility for helping ERDA's Division of Buildings and Community Systems manage the national ERDA program for ACES development.

Substantial improvements in efficiency also appear to be possible for residential air-to-air heat pumps. We are testing a standard-model heat pump in our conservation laboratory to identify sources of inefficiency. Suggested improvements will be evaluated by means of a computer simulation of the heat pump system and then verified experimentally. A standard evaluation procedure is being developed to assess effects of improvements on seasonal performance.

In an extension of the work done last year on the value of night-setback thermostats, the effect of thermostat settings on energy consumption in houses heated by heat pumps was analyzed. Contrary to some expectations, the analysis shows that substantial savings results from nighttime reductions of indoor temperature. For example, in Philadelphia, reducing the nighttime temperature to 15°C from the daytime level of 20°C would reduce seasonal heating requirements by 28%.

As with the ACES program, ORNL will assume responsibility in the coming year for helping ERDA's Division of Buildings and Community Systems manage part of the national program for development of more energy-efficient residential and commercial appliances. This responsibility will include preparing work statements for needed projects; preparing, advertising, and distributing requests for proposals; evaluating proposals; awarding contracts; monitoring the work; and reporting the status of each project to ERDA.

For ERDA and FEA, development of engineering-economic simulation models that can be used to analyze costs and benefits of conservation alternatives was continued. The model of the residential sector, the first to be initiated, was improved in several respects: (1) Explicit use is now made of capital costs in determining equipment choices; (2) the number of end uses was increased from six to eight; and (3) national totals are being disaggregated into regional components for the nine census divisions. During the year, work started on a similar model of the commercial sector.

The residential model was used during the year to provide answers to specific questions from ERDA, FEA, and the National Academy of Sciences. For example, the direct energy and economic impacts of nationwide adoption of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90-75 standards were evaluated. It was found that implementation of the new standards in new housing beginning in 1978 would produce a 3% reduction in total annual residential energy use in the year 2000. When the costs of implementing the standards were taken into account, the benefit–cost ratio was 2.3, indicating overall savings in both energy and money.

For the total residential sector, several scenarios were investigated, and all suggested that the rate of growth of energy use would be considerably less than the 3.6% per year it averaged for the period 1950 to 1975. In fact, it was estimated that the implementation of a strong, cost-effective, but realistic, conservation program (coupled with higher fuel prices) could cut residential energy use growth to 0.4% per year between 1975 and 2000. This estimate also assumes a growth in the formation of households based on the Bureau of the Census Series C population projections and a continuation of the recent historical trend toward multiple-family dwellings. Under these assumptions, residential use in 2000 would be only 10% higher than it is now.

Under NRC support, a different kind of model is being developed to forecast future electricity requirements for each consuming sector and each state. This model uses primarily econometric methods to analyze the effects of variables such as prices of competing fuels, incomes, industrial production levels, population shifts, and weather patterns. The detailed geographical disaggregation will be used to make projections of need for power in individual utility service areas for preparing environmental impact statements. Initial forecasts for the South Atlantic states show continued growth in electricity consumption in all sectors and states. Projected annual growth rates vary considerably among these states—from 4.2% per year in West Virginia to 7.5% in Florida. Growth rates in electricity consumption appear to be quite sensitive to fuel prices and the other components of electricity costs.

Decentralized, relatively small-scale, energy systems continue to be an attractive conservation option. Work in this area includes participation in the MIUS program under the direction of HUD and the Advanced Technology-Mix Energy Systems (ATMES) program for ERDA. Primary focus of the MIUS program is a demonstration project proposed for the new town of St. Charles, Maryland. The ORNL effort consists of analysis of the proposed conceptual designs, preparation of an environmental impact statement, and followup evaluation of actual environmental effects. The initial phases of each of these activities took place during the year, following the start of the St. Charles project in April. In the ATMES program, ORNL has been assigned responsibility for selection and evaluation criteria, technology data collection, and technology evaluation. The ERDA ATMES program is similar in some respects to the HUD-MIUS concept except that the emphasis is on advanced rather than current technology. The program is also concerned with a wider spectrum of communities with respect to both size and complexion. The ORNL staff will develop criteria for (1) evaluating components for potential ATMES applications and (2) collecting the necessary data on these components to facilitate subsequent system design studies. To date, draft evaluation data reports have been prepared for heat pumps, prime movers, absorption chillers, and solid waste pyrolysis.

For the ERDA Office of Conservation, a program of technical assistance to the Division of Electric Energy Systems has been initiated. This division and EPRI are cosponsoring a series of field demonstrations of communication systems for distribution automation. These communication systems will report the electrical distribution system status to a central location and send requisite commands back to action points. Such a communication system can be used for remote meter reading, load control, and collection of information on energy use patterns. In the demonstrations, six manufacturers will supply equipment to six utilities, which will install and operate the equipment. The ORNL role is to provide (1) data coordination to assure comparability among the tests and (2) technical analysis of some of the tests. The initial task, to review program plans of the six teams, is well under way.

1.4 HIGH-TEMPERATURE POWER CONVERSION SYSTEMS SECTION

The principal objective of the section is to promote improved efficiency in high-temperature power conversion systems through innovative engineering design. The emphasis in 1976 continued to be on the alkali-metal steam combined cycle for central power stations and a coal-burning fluidized-bed closed-cycle gas turbine power system which can be used for a variety of small-scale applications (e.g., to power a MIUS). The alkali-metal steam system powered by fluidized-bed coal combustion has the potential to increase the thermodynamic efficiency of central power stations to near 50% (40% is the best currently obtainable with a steam system). The work is being supported by ERDA Fossil Energy. The gas turbine system (air is the working fluid) can supply electricity at about 25% efficiency, but by using the heat discharged from the turbine to supply building heating and cooling and hot water, up to 80% of the heat content of the coal can be used. Fluidized-bed combustion using calcium carbonate in the bed to react with sulfur should permit the use of high-sulfur coal with the gas turbine system in MIUS applications without unacceptable environmental effects. Work on this system is supported by HUD and by ERDA Fossil Energy.

During 1976, work on the gas turbine system included detailed design studies and procurement of critical materials needed for building a proof-of-concept test unit at ORNL. The most difficult design problem was the fluidized-bed furnace containing heat exchanger tubes for the closed-cycle power system. Assembly and subassembly drawings for the ORNL reference design of the furnace were prepared, and proposals were solicited for supplying the furnace for the test unit. Two proposals were received from prospective vendors. After reviewing these proposals, ERDA-FE decided that the commercialization potential for the system would be enhanced if prospective furnace manufacturers were given the opportunity to supply a furnace of their own design. Because of this, no order has been placed.

AiResearch was subcontracted to examine the feasibility of modifying an existing model 831-200 gas turbine generator unit for the ORNL test; the conclusion was that the unit could be modified at reasonable cost. In addition, reference designs were completed for the recuperator, the regenerator, and the waste heat exchanger. In all cases commercially available equipment can be used.

A number of tests were conducted with a ¼-sized (1.3-m-square cross section) lucite model of the fluidized-bed furnace. The results showed that it was possible to operate the bed at one third of the full-power air flow rate and that, at this flow rate, the horizontal mixing of coal from the four coal feed nozzles should be adequate. Heat exchanger tube vibration tests indicated that additional tube support should be provided.

Of three different coal feed systems investigated, one using a simple gravity flow splitter was found to give very good results. The system gave four streams of equal flow within 5% of the mean coal flow rate over the entire operating range of flow rates. This system is now being endurance tested.

Additionally, a study on the reliability of a MIUS system powered by four gas turbine systems for an apartment complex was completed. The study showed that electric energy demand would be met except for about 15 hr per year on the average. In addition, the following studies are in progress: (1) under subcontract to FluiDyne, (*a*) fluidized-bed heat transfer measurements and (*b*) fireside corrosion tests of eight alloys; (2) comparison of the economics of a MIUS system for an apartment complex with (*a*) central station electricity and air-to-air heat pumps for each apartment or (*b*) central station electricity and a central heating boiler for the complex.

Work on the alkali-metal steam combined-cycle system consisted of water tests of the prototype gas-fired potassium boiler module and initiation of studies to determine the relative merits of cesium and potassium as topping-cycle working fluids. The potassium boiler module was installed in the test stand, and water boiling tests using a gas-fired burner were initiated. The water tests revealed that the argon injection system provides adequate nucleation for the boiling potassium applications and that thermal convection flow in the boiler is sufficient to prevent large thermal stresses. In preparation for the tests using potassium, detailed designs were completed for the potassium condenser and the fill and drain system for the boiler.

The comparative study of cesium and potassium has been directed toward parametric cycle analyses for various boiler and condenser temperatures and for three types of furnaces—atmospheric, supercharged (0.3 to 0.5 MPa), and high-pressure (0.6 to 1.0 MPa). Cesium has the advantages of a higher vapor pressure at the maximum steam temperature of 840°C; this higher vapor pressure will tend to reduce creep buckling for pressurized-bed systems. Also, the vapor flow rate for the same power is 60% less with cesium, which leads to reductions in the size of the system including the turbine. The disadvantage of cesium is its cost. After this study is completed, a reference design for a full-scale potassium or cesium fluidized-bed power plant will be initiated.

1.5 LOW-TEMPERATURE HEAT UTILIZATION PROGRAM

The objective of the program is to develop methods and information that will increase the effectiveness of processes for converting heat at moderate temperatures to work or that will otherwise enhance the usefulness of low-temperature heat sources. During 1976, two complementary projects were active—one sponsored by the ERDA Division of Geothermal Energy and the other by the Ocean Thermal Energy Conversion (OTEC) program of the ERDA Division of Solar Energy. The work was a collaborative effort with personnel of the Engineering Division and the Engineering Technology Division. In the cases of both geothermal electric power and OTEC, a large fraction of the capital cost of the planned installations will be for the heat exchangers. The ORNL work is directed at improving the efficiency and reducing the cost of this equipment.

Studies of the enhancement of condensing heat transfer on fluted (Gregorig) surfaces continued during 1976 with measurements on four fluorocarbon candidate thermodynamic working fluids—R21, R22, R11, and R113. Enhancement (relative to smooth surfaces) for vertical tubes varied from a factor of 5.4 for R22 at low heat fluxes to about 2 for R114 at high fluxes. A correlation was developed for the data which appears to be satisfactory for predicting the heat transfer behavior of fluorocarbon working fluids on various fluted surfaces. A rough calculation indicates that the use of condensers with Gregorig surfaces could reduce the direct equipment cost for a 100-MW(e) geothermal plant by $5 million; the reduction will be $10 million if associated indirect cost factors are included in the calculations. This reduction constitutes 18% of the total plant equipment cost excluding the wells. Gregorig surface heat exchangers may be used for the first time in the Raft River Geothermal Demonstration near Idaho Falls; ORNL personnel are providing advice to that project. Future enhancement studies will be conducted using isobutane and other candidate hydrocarbons. In addition, a second experimental loop was designed and constructed for similar experiments with ammonia, which is the primary working fluid being considered for the OTEC system.

To help establish program development goals, an analysis was completed to illustrate the potentials of and limitations to improving OTEC heat exchanger performance. The overall heat transfer coefficient can be improved by (1) increasing either the ammonia- or the seawater-side coefficient or (2) reducing the tube wall and or fouling resistances. The analysis indicated that an improvement in the overall heat transfer coefficient by a factor of 1.3 to 2.6 could probably be achieved, the largest potential payoff coming from improving the seawater-side coefficient. Improvement in the total coefficient will permit a corresponding reduction in the size (and therefore the cost) of the heat exchangers. The following programmatic goals were suggested by the analysis:

1. Improve the seawater-side heat transfer coefficient by about a factor of 2 while maintaining acceptable tube costs and water-side pressure losses.
2. Improve the ammonia-side coefficient by a factor of 3 to 5.
3. Develop a cost-effective biofouling control or cleaning system to maintain the fouling resistance between 2.6 and 5.3 × 10^{-5} m^2·K/W (15 and 30 × 10^{-5} hr·ft^2·°F/Btu).
4. Qualify aluminum as a heat exchanger tube material.

Work is in progress to develop a more general model for simulating the performance and costs of various OTEC plant designs so that systematic comparisons between competing concepts can be made by ERDA. Minimizing cost in the design will require optimization and trade-off decisions between some eight or more variables, including seawater temperature changes, water pumping power, heat transfer geometry, working fluid temperature and pressure drops, and component efficiencies. The interrelationships between these variables will be accounted for in the model.

These analytical studies are part of the effort by ORNL to provide technical assistance to the ERDA-OTEC staff. Other aspects of this assistance include literature surveys and state-of-the-art reviews, reviews of proposals, technical reviews of contractor progress, and the arranging of technical meetings and workshops on various phases of the heat exchanger program.

2. Environmental Impact Section

T. H. Row

2.1 INTRODUCTION

The Environmental Impact Section is primarily concerned with the preparation of environmental statements and assessments and the development of assessment methodologies for energy technologies. During 1976 our activities have involved nuclear, fossil, and geothermal energy; this work has been supported by the U.S. Army, the U.S. Department of Housing and Urban Development (HUD), the Energy Research and Development Administration (ERDA), and the Nuclear Regulatory Commission (NRC).

As in past years, the nuclear energy cycle activities have constituted the major part of our work. The continuing need for environmental statements for siting nuclear power plants composes the largest fraction of our NRC technical support activities. Although the number of new plant applications assigned to ORNL in 1976 was down from previous years, this is not an accurate indicator of the degree of staff involvement. Preparation of a draft and final environmental statement (DES, FES) has in the past accounted for better than 80% of our total work for any one nuclear plant. In the past year, this has changed significantly (even more than indicated in our last annual report[1]). Demands on staff time associated with the Atomic Safety and Licensing Board (ASLB) hearings have become almost equal to that required for statement preparation. We are now also preparing operating license (OL) statements. This shift in emphasis and the "old plants never die" phenomenon have resulted in a continued high work load.

Two special studies—one on the effects of power plant intake structures on fish impingement and another on multiple uses of cooling lakes—were completed this year and should serve as references for future analyses. This type of support activity continues to serve an important function in improving staff capability for impact analysis.

Two research projects—the Unified Transport Approach (UTA) to Power Plant Assessment and the Environmental Monitoring Data Evaluation Study—were continued this year; both are sponsored by the NRC Office of Nuclear Regulatory Research. The purpose of the UTA program is to develop fast-transient, one- and two-dimensional transport models for estimating thermal, radiological, chemical, and biological impacts in complicated water bodies. The monitoring data project reviews biological and hydrothermal data from operating nuclear stations in order to evaluate predicted impacts and synthesize data to provide a better understanding of monitoring requirements.

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1. H. E. Zittel, *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 62–79.

For the NRC Office of Regulatory Standards, we are evaluating the impact of public use of various products that contain radioactive isotopes. The full spectrum of public involvement, from manufacture through consumer use to ultimate disposal, is considered. These evaluations will assist NRC in determining the applicability of existing regulations and the possible need for change.

Our assistance to the NRC Office of Nuclear Material Safety and Safeguards has expanded this year to include assessments of fuel fabrication facilities being considered for relicensing and two uranium in-situ solution mining facility proposals. Since the solution mining technique is relatively new to the uranium industry, assessment of these two facilities promises to be interesting and challenging.

The work for HUD is at a very interesting stage — that is, assessment of the first application of the Modular Integrated Utility System (MIUS) in a new town development. We have prepared a generic environmental statement and are presently designing an environmental monitoring program for the facility.

We continue to provide the ERDA Oak Ridge Operations Office (ERDA-ORO) with environmental evaluations of facilities within this region. The major effort has been directed at the Portsmouth Gaseous Diffusion Plant, for which we are providing environmental impact analyses of the power plants that supply electrical power to the facility. The environmental statement on the Portsmouth plant expansion[2] (see last year's annual report[3]) was issued, comments have been received, and we will assist in preparing the final statement. We are also working with the Paducah Gaseous Diffusion Plant staff to develop the information necessary for an environmental statement on Paducah plant operation.

We consider one of the major accomplishments in 1976 to be our involvement in programs of the ERDA Fossil Energy and Geothermal Energy Divisions. We are providing both divisions with environmental assessments for preparing environmental statements and programmatic investigations. Two programmatic and two site-specific geothermal statements have been completed; three other statements are in progress. The fossil work is being conducted at the level of demonstration plants; we have completed a guide to prospective ERDA demonstration plant contractors which specifies environmental requirements.

2.2 NUCLEAR REGULATORY COMMISSION PROJECTS

2.2.1 Environmental Statements for Power Reactors

H. E. Zittel

The preparation of environmental statements for power reactors continues to constitute a major portion of our NRC technical support work. Shown in Table 2.1 are the plants assigned to ORNL for which licensing action occurred during 1976. Comparison with a similar table in last year's annual report[1] reveals that very few of the plants shown in 1975 have achieved inactive status during the year, whereas six new plants have been assigned to us.

Several of these newly assigned plants (Shoreham, San Onofre, Virgil C. Summer) are applying for operating licenses; until this year, all OL impact statements have been prepared by the NRC staff. For

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2. Energy Research and Development Administration, *Draft Environmental Statement, Portsmouth Gaseous Diffusion Plant Expansion*, ERDA-1549, June 1976.

3. J. R. McWherter, *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, p. 93.

Table 2.1. Nuclear power plants assigned to ORNL having licensing action in CY 1976[a]

Plant	Work initiated	DES	FES	ASLB
Blue Hills ESR	X	X(PDES)		
Cherokee CP				X
Douglas Point CP			X	X
Floating Nuclear Plant Generic		X		
Atlantic Generating Station CP		X		
Greene County CP		X		
Indian Point 2 CP				X(ASLAB)
Indian Point 3 CP				X(ASLAB)
Jamesport CP				X
Montague CP			X(PFES)	
North Coast ESR		X		
Perkins CP				X
Seabrook CP				X
Sterling CP			X	X
Tyrone CP		X		
Wolf Creek CP				X
North Anna 1 & 2 CP			X(addendum)	
Shoreham OL	X	X(PDES)		
Erie 1 & 2 CP	X			
New England CP	X			
Sun Desert CP	X			
Surry 3 & 4 CP			X(addendum)	
Marble Hill CP (Assistance)				X
Diablo Canyon OL (Assistance)				X
Virgil C. Summer OL	X			
San Onofre 2 & 3 OL	X			
Fort Calhoun CP	X	X(PDES)		

[a]PDES preliminary DES; PFES preliminary FES; ASLAB Atomic Safety and Licensing Appeal Board.

the first time, our staff has been able to continue an environmental assessment on a plant for which we prepared the construction permit (CP) impact statement; such assessments will provide us with the opportunity to determine the accuracy of our predictions on construction impacts.

The statements prepared for North Coast and Blue Hills have been designated as early site reviews (ESR). Although the NRC has not yet published official guidelines, the purpose of such reviews is to assess the environmental impact to a given site by a reactor of given capacity; an envelope approach will be used to assess the various parameters (e.g., water usage).

Other duties assigned by the NRC include the preparation of a set of specific staff guidelines (Environmental Standard Review Plans) for assessing the potential environmental impacts of nuclear power plant construction and operation. The ORNL staff has participated with the staffs of Argonne National Laboratory (ANL) and Pacific Northwest Laboratory (PNL) in developing these guidelines.

The ORNL staff has continued to work on a variety of technical projects addressing the various generic problems encountered while carrying out its assessments. Among these projects are studies of (1) the influence of intake structure design on fish impingement, (2) the nuclear fuel cycle cost and sensitivity analyses, and (3) multiple usage of closed-cycle cooling reservoirs.

Because the evaluation of environmental impacts resulting from construction and operation of nuclear power plants requires input from several professions, multidisciplinary task groups have been established. Each group consists of a leader, transport analyst, site and station analyst, terrestrial ecologist, aquatic ecologist, sociologist, and benefit–cost analyst. Each reactor case is assigned to a task group, which, with the NRC staff, prepares the environmental statement and assists in the licensing procedure throughout the case. Task group alignment, as presently constituted, is shown in Table 2.2. For some cases, staff assessment has concluded that changes should be made in the applicant's plans, and for others, the staff has concluded that the applicant's plans are acceptable.

Task group 1 (R. E. Thoma). Activities of task group 1 have included the ongoing development and or production of six environmental statements pertaining to license applications; highlights of three are described below.

Offshore Power Systems—manufacturing license. Task group 1 has been continually engaged in reviews of this application from the outset; the proposed action is opposed by four intervenor groups. During 1976, the NRC announced its intention to expand the statement to three parts. Part I, issued as an FES in October 1975, reviews the effects on the Jacksonville area that would result from operation of the manufacturing facility.[4] Part II, issued as an FES in September 1976, addresses the effects of constructing and operating eight floating nuclear plants (FNP) arranged in two-unit stations along the shore zone of the Atlantic and Gulf coasts.[5] The NRC received 370 comments on the DES of Part II, and responses were prepared for inclusion in the FES by ORNL and NRC staff. Part III, written without the assistance of ORNL, was issued as a DES in October 1976; it addresses the liquid pathway transport of

4. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Floating Nuclear Power Plants, Part I: An Environmental Statement Considering the Operation of the Manufacturing Facility in Jacksonville, Florida*, NUREG-75/091, Docket No. STN 50-437, October 1975.

5. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Floating Nuclear Power Plants, Part II: A Generic Environmental Statement Considering the Siting and Operation of Floating Nuclear Power Plants*, NUREG-0056, Docket No. STN 50-437, September 1976.

Table 2.2. Task groups

Task group 1	Task group 2
R. E. Thoma, leader	R. M. Rush, leader
N. E. Hinkle, benefit–cost analyst	C. Crafton, benefit–cost analyst
R. E. Greene, site and station analyst	A. J. Witten, transport analyst
J. B. Cannon,[a] transport analyst	J. M. Loar,[a,b] ecologist
S. M. Adams,[a,b] ecologist	A. T. Szluha,[a,b] ecologist
R. B. McLean,[b] ecologist	R. L. Kroodsma,[a,b] ecologist
G. W. Suter,[b] ecologist	W. Van Winkle,[b] ecologist
R. W. Brocksen,[a,b] ecologist	R. W. Brocksen,[a,b] ecologist
R. DeVault, socioeconomics	S. M. Adams,[a,b] ecologist
	L. D. Voorhees,[b] ecologist
	T. J. Mattingly, socioeconomics
Task group 3	**Task group 4**
J. M. Loar,[a,b] leader	R. L. Kroodsma,[a] leader
R. L. Spore, benefit–cost analyst	T. J. Clifford, benefit–cost analyst
J. B. Cannon,[a] transport analyst	R. Robertson, transport analyst
A. T. Szluha,[a,b] ecologist	S. M. Adams,[a,b] ecologist
R. K. Schreiber,[b] ecologist	J. M. Mattice,[b] ecologist
T. Cowan,[a] socioeconomics	A. T. Szluha,[a,b] ecologist
	L. D. Voorhees,[b] ecologist
	T. Cowan,[a] socioeconomics

[a]Dual capacity.
[b]Environmental Sciences Division.

radionuclides released under accident conditions from an operating FNP.[6] Evidentiary hearings began on the application in mid-1976; to date, the hearings have been confined primarily to safety issues.

Atlantic Generating Station. As the first site-specific application proposing establishment of an FNP, the Atlantic Generating Station (near Atlantic City) was subjected to environmental review concurrently with the Offshore Power Systems application; the review culminated in issuance of the DES in April 1976 and reissuance in October 1976.[7]

Fort Calhoun Station Unit 2. The proposed Fort Calhoun Station Unit 2 is a pressurized-water reactor (PWR) to be located on the west bank of the Missouri River about 20 miles north of Omaha. The second unit, which will be adjacent and attached to the currently operating Unit 1, will produce 1150 MW(e) (net) of electrical power capacity.

Application was for construction of the station with a once-through cooling system. It is the first application to implement recent Memoranda of Understanding with the Environmental Protection Agency (EPA), State agencies, and the Corps of Engineers. Under these arrangements, the NRC acts as lead agency, obviating separate environmental reviews by the other participating agencies. The staff's conclusion that operation of Unit 2 can possibly produce a significant impact to the Missouri River fishery as a result of fish entrainment has led to the consideration of several mitigative measures. One of these, nominated by the applicant once it was apprised of the staff's preliminary conclusions, is to activate former wetlands along the Missouri River that have become part of the floodplain as a result of river channeling. The proposal is controversial because its adoption might set a precedent for mitigating rather than minimizing the impacts of plant operation. It offers, on the other hand, a potential for fulfilling the spirit of the National Environmental Protection Act (NEPA) in a unique manner by enhancing environmental quality by providing habitat (in the wetland area) presently unmatched in size and quality in the region.

To determine the incremental effects of thermal discharges, we adapted a three-dimensional plume modeling program[8] to simulate the thermal discharge plume. The results (Figs. 2.1 and 2.2) indicate that intensive mixing will occur near the discharge point. Results of the modeling program will be used to determine whether the effluent will be discharged in a manner that will comply with applicable State and federal water quality standards.

Task group 2 (R. M. Rush). Task group 2 has provided a substantial amount of support to licensing actions of the post-FES type, particularly for the Indian Point site. The group has also worked with four other reactors in various stages of the licensing process.

Indian Point Nuclear Generating Plant. This facility consists of three units: Unit 1 [265 MW(e)] began operation in October 1962, Unit 2 [873 MW(e)] began operation in September 1973, and Unit 3 [965 MW(e)] began operation in the fall of 1976. The plant is located on the east bank of the Hudson River about 24 miles north of New York City. The three units together use about 7790 m^3/min (2,058,000 gal/min) of river water for their once-through cooling water systems. A major point of controversy in the licensing of Units 2 and 3 was the expected damage to aquatic biota (especially striped bass) from impingement and entrainment in the cooling water system. For this and other reasons, the license for Unit 2 required the termination of once-through cooling by May 1, 1979, and the license for Unit 3 required termination by September 15, 1980.

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6. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Floating Nuclear Power Plants, Part III, Manufacturing License*, NUREG-0127, Docket No. STN 50-437, October 1976.

7. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Atlantic Generating Station, Units 1 and 2*, NUREG-0058, Docket Nos. STN 50-477 and -478, April 1976; reissued October 1976.

8. W. R. Waldrop and F. B. Tatom, *Analysis of the Thermal Effluent from the Gallatin Steam Plant During Low River Flows*, Rep. No. 33-30, Tennessee Valley Authority, Division of Water Management, Water Systems Development Branch, Norris, Tennessee, June 1976.

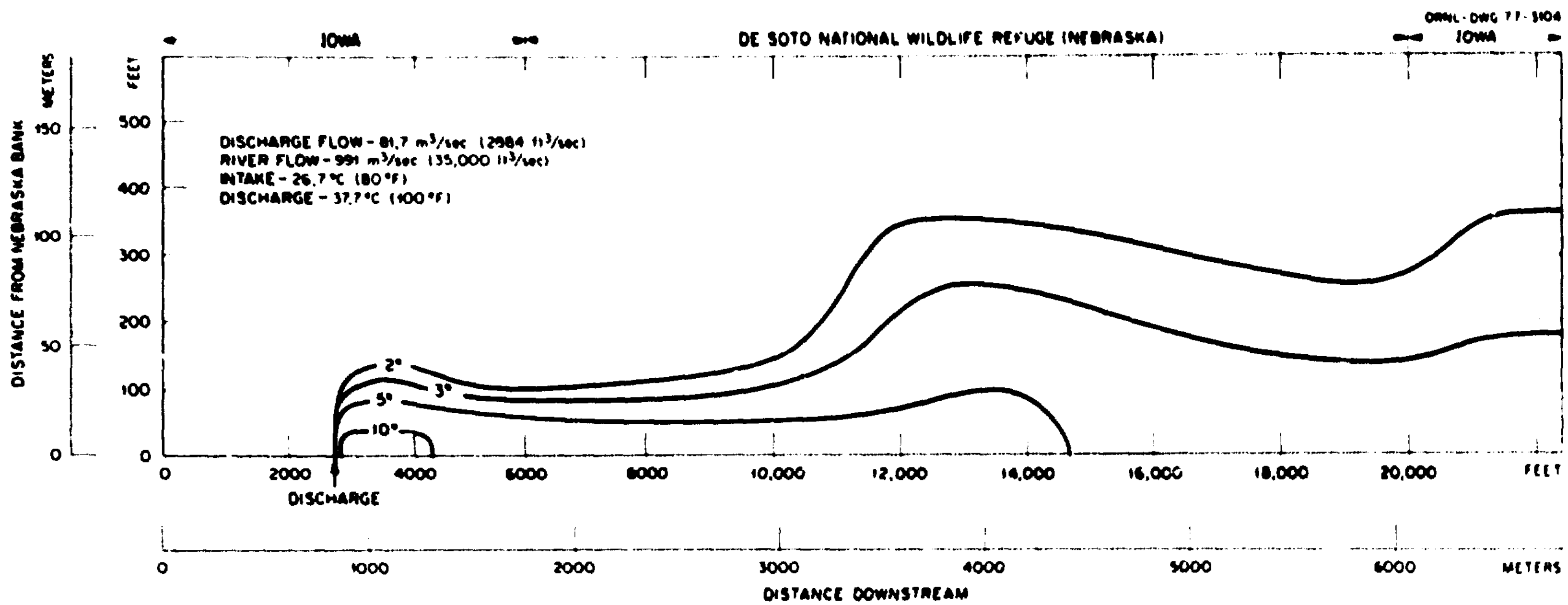

Fig. 2.1. Prediction of the excess temperature (°F) isotherms at 991 m^3/sec (35,000 ft^3/sec) for the Fort Calhoun Station.

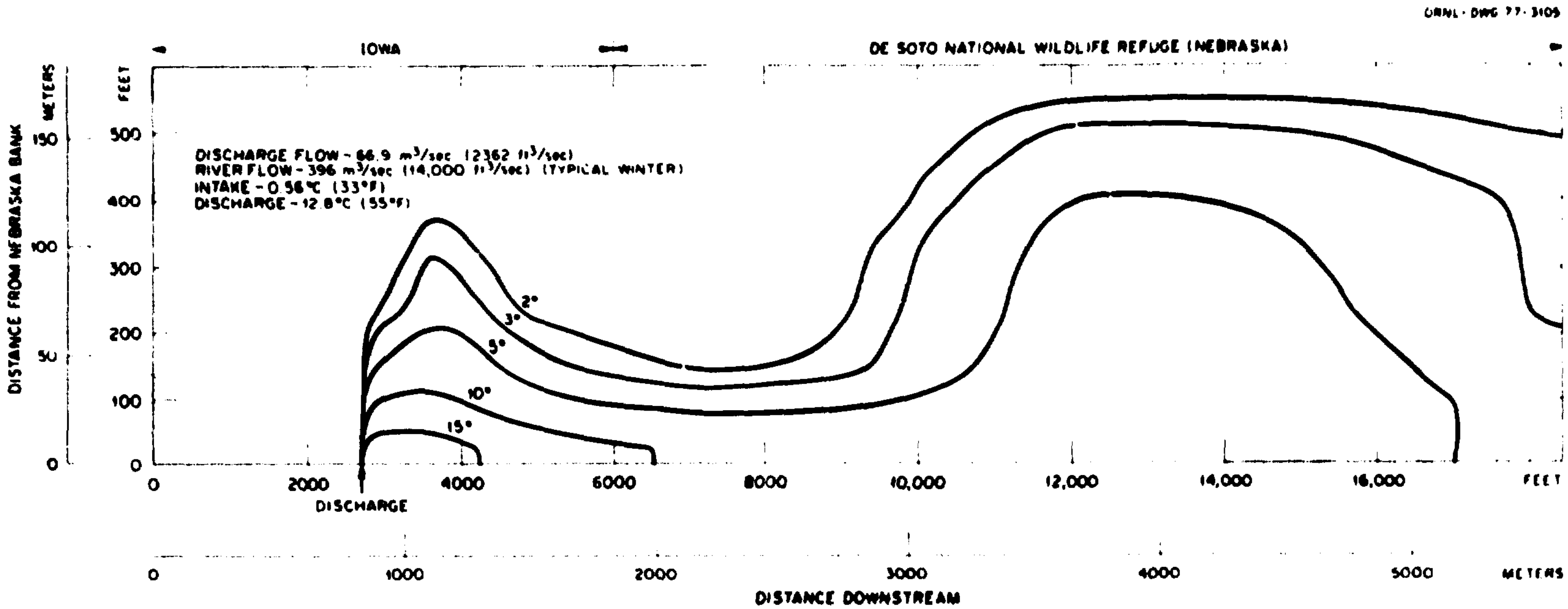

Fig. 2.2. Prediction of the excess temperature (°F) isotherms at 396 m³/sec (14,000 ft³/sec) for the Fort Calhoun Station.

The ORNL staff has expended considerable effort since 1971 in support of the licensing actions for Units 2 and 3. During the course of this work, a striped bass population model[9] and a striped bass young-of-the-year model[10] were developed. In anticipation of future licensing actions for this plant, we are continuing to develop and improve these models and to assess similar models developed by the applicant's consultant. The population model has been modified to a generalized fish life-cycle population model and has been applied to the white perc.. population in the Hudson River. About 100 computer runs have been completed to study the sensitivity of the applicant's one-dimensional transport model for the young-of-the-year striped bass in the Hudson River.

In June 1975 the applicant (Consolidated Edison) requested an amendment of the license for Unit 2 that would extend the period of once-through cooling for two years. The DES and FES relating to this request were prepared by the ORNL staff.[11,12] The staff concluded that the long-term impact on the Hudson River ecosytem of the two-year extension of once-through cooling is not expected to be large and has essentially no risk of being irreversible. The final conclusion was that only a one-year extension is justified to allow time for completion and analysis of the applicant's biological research program.

Jamesport Nuclear Power Station. This proposed facility is to be constructed on Long Island Sound near the town of Riverhead, New York. The station consists of two 1122-MW(e) units and will use a once-through cooling water system. The major environmental problem at the Jamesport Station relates to the design of its intake structure and was discussed in the 1975 annual report.[13]

During 1976 the ORNL staff prepared supplemental testimony relating to specific issues in contention before the ASLB and appeared as expert witnesses before the board. The testimony dealt in some detail with the generating cost comparison of the reference nuclear station and a coal-fired alternative. Interaction of the thermal plume with plumes from other plants, the intake design, and the impacts of dredging were other areas that required staff testimony.

Montague Nuclear Power Station. This proposed facility, to be constructed on the Connecticut River in the town of Montague, Massachusetts, consists of two 1150-MW(e) units and will use a closed-cycle cooling water system with two natural-draft cooling towers. The major environmental impact of this station will be the visual intrusion of the natural-draft cooling towers on the landscape. Because of the closed-cycle cooling system, damage to the aquatic biota is not expected to be severe. However, because of lacking information on the distribution and relative abundance of shad and shortnose sturgeon larvae and young juveniles in the Connecticut River, the applicant (Northwest Nuclear Energy Company) will be required to supply additional data prior to location and construction of the intake structure.

The DES for the Montague Station was issued in November 1975 and the FES will be issued early in 1977.[14,15]

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9. W. Van Winkle et al., *A Striped-Bass Population Model and Computer Program*, ORNL TM-4578 (December 1974).

10. A. H. Eraslan et al., *A Computer Simulation Model for the Striped Bass Young-of-the-Year Population in the Hudson River*, ORNL NUREG-8 (December 1976).

11. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Indian Point Unit 2 (Cooling Tower Delay)*, NUREG-0038, Docket No. STN 50-247, February 1976.

12. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Indian Point Unit 2 (Cooling Tower Delay)*, NUREG-0042, Docket No. STN 50-247, August 1976.

13. R. M. Rush, *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 76–77.

14. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Montague Nuclear Power Station, Units 1 and 2*, NUREG-75 109, Docket Nos. 50-496 and -497, November 1975.

15. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Montague Nuclear Power Station, Units 1 and 2*, to be published.

The visual intrusion of the proposed natural-draft cooling towers is expected to be the major environmental impact of this station. Members of the Resource Analysis and Energy Facilities Siting Group, Regional and Urban Studies Section, Energy Division, have provided valuable input to the assessment of this impact in the form of viewshed analyses and perspective views of the site.

The computer program SEESU was used to determine the extent of intrusion of cooling towers of various heights at the Montague plant site.[16] The area within a 16-km (10-mile) radius of the plant was divided into 8563 cells, each measuring about 306 m (1006 ft) on a side and having an area of about 9.3 ha (23 acres). The coordinates and mean elevation were determined for each cell; this information, along with an indication of whether the cell is predominately land or water, was used as input to the program. The results for a 172-m (565-ft) natural-draft tower at the site are shown in Fig. 2.3; these results indicate in which cells the tower will be visible and whether those cells represent land or water. The program indicated that a tower of this height would be visible from about 40% of the area within a 16-km (10-mile) radius. A similar program indicated that a shorter, 55-m (182-ft) tower would be visible from about 20% of the area.

16. L. C. Tucker, *CATCH: Computer Assisted Topography, Cartography, and Hypsography, Part IV: SEESU — A Subroutine Package for Determining the Visibility of Objects Throughout a Region*, ORNL TM-3790 (June 1976).

ORNL DWG. 77-5382

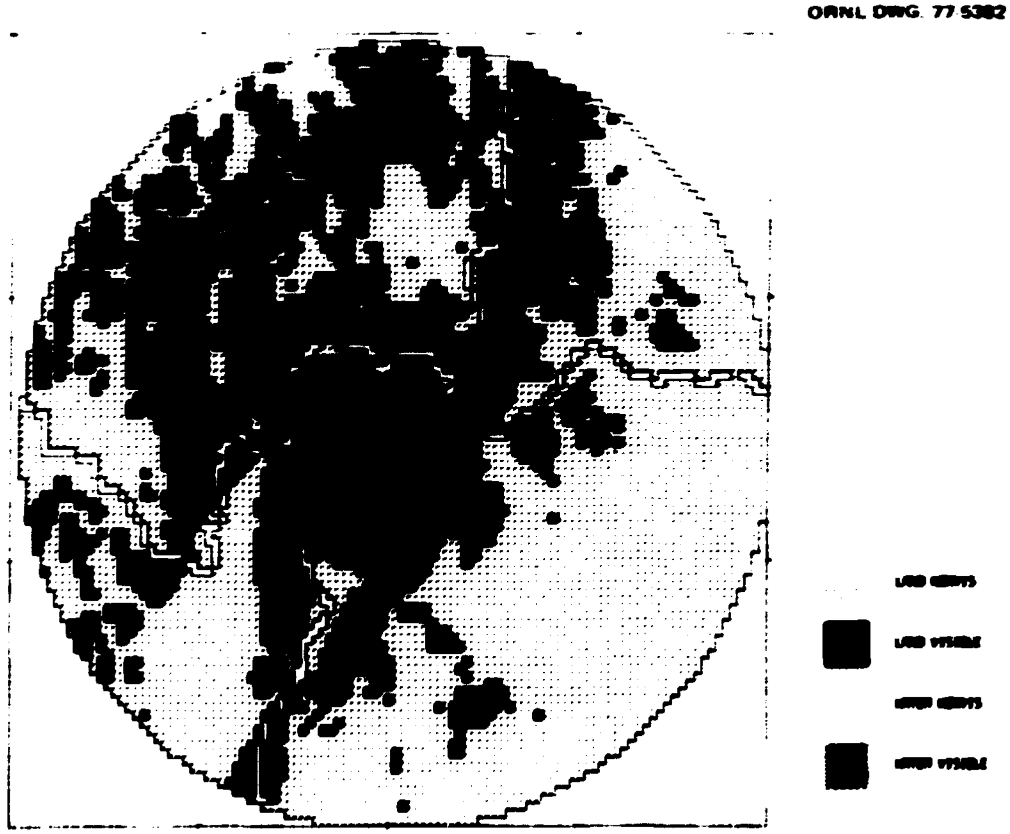

Fig. 2.3. Viewscape for the area within a 16-km (10-mile) radius of the Montague Station, using 172-m (565-ft) natural-draft cooling towers.

Greene County Nuclear Power Plant. This proposed facility, located on the west bank of the Hudson River in the town of Catskill, New York, consists of one 1191-MW(e) unit which will use a closed-cycle cooling water system with two natural-draft cooling towers. Major impact may arise from the fact that the applicant (Power Authority of the State of New York) is exempt from payment of local property taxes; thus, one major benefit of a power plant — local property taxes — is absent. Although the applicant intends to make payments in lieu of taxes, based on the current worth of the property, the staff considers that such revenues will not be sufficient to offset the need for increased services (e.g., schools and transportation). Damage to the aquatic biota of the Hudson River is expected to be small because of the relatively low intake flow for the closed-cycle cooling system.

The DES related to this plant was issued in March 1976 and the FES is expected to be issued in 1977.[17,18]

Task group 3 (J. M. Loar). Task group 3 was completely reorganized during 1976 and is therefore not involved in as many projects as are the other task groups. The members of task group 3, however, carry a large residual of work on reactors assigned to other groups. The group is currently assigned to the Blue Hills ESR and the Virgil C. Summer OL statement.

Blue Hills Station Units 1 and 2. The Blue Hills Station, which will be located near Fairmont, Newton County, Texas, will consist of two 930-MW(e) PWRs. The facility will use a closed-cycle cooling system with three wet mechanical-draft cooling towers for each unit. Makeup water will be pumped from Toledo Bend Reservoir and carried via an 11.9-km (7.4-mile) pipeline to the plant. The cooling tower blowdown, at an anticipated maximum flow rate of 9.3 m^3/sec (10.2 ft^3/sec), will also be carried from the site via a pipeline to the point of discharge over the Sabine River channel about 305 m (1000 ft) offshore. Since the Sabine River serves as the boundary between the states of Texas and Louisiana, both State water quality agencies and the EPA were consulted concerning applicable standards.

The preliminary draft environmental statement (PDES) is being prepared in cooperation with the EPA, as mandated by the Second Memorandum of Understanding between NRC and EPA. Sections of the PDES relating to water quality and intake design are being prepared by the EPA staff, region VI, in Dallas, Texas, and will be reviewed and subsequently modified to include the evaluation conducted by the ORNL staff. Other sections relating to impacts from the heat dissipation system, transmission lines, cooling tower drift, and makeup water withdrawal will be prepared initially by the ORNL staff and forwarded to the EPA for review. By seeking a close cooperation between the NRC and EPA in the initial stages of the environmental assessment, a mutual agreement concerning the ecological impacts from construction and operation of the Blue Hills Station can be reached very early in the decision-making process.

Blue Hills Station Units 1 and 2 will not go into commercial operation until the early 1990s. Gulf States Utilities, which will own and operate the facility, has applied for an ESR, one of the first applications of this kind to be received by the NRC. It should be stated here that the NRC has not yet received legal sanction for an ESR, but is in the process of obtaining that sanction. The purpose of an ESR is to separate the review and approval process for the site from the review and approval for the facility to be constructed on that site. An ESR will have three main objectives: (1) early identification and

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17. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Greene County Nuclear Power Plant*, NUREG-0045, Docket No. STN 50-549, March 1976.

18. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Greene County Nuclear Power Plant*, to be published.

resolution of site-related problems before substantial commitments of resources are made by the applicant; (2) initiation of public participation at an early stage when it can be most effective in the decision-making process; (3) removal of delay caused by siting problems in the review and decision-making process for CP applications. The preparation of an ESR statement for Blue Hills Station Units 1 and 2 represents a new and challenging endeavor for the staff.

Task group 4 (R. L. Kroodsma and H. E. Zittel). Task group 4 is presently involved in the licensing activities for nine reactors. Several of these are in the post-FES stage, whereas others are in the initial review stage.

Perkins Nuclear Station Units 1, 2, and 3. The Perkins Station will be located on a 966-ha (2402-acre) site on the Yadkin River near Mocksville, Davie County, North Carolina. The area is characterized by a predominantly low-quality agricultural activity, inferior soil fertility, disturbed ecology, and low population density. The station will consist of three identical 1280-MW(e) PWRs. The circulating water and exhaust steam will be cooled by a closed-cycle system using cooling water from the Yadkin River; consumptive water use will average about 4% of the river's mean flow. One of the most significant impact assessment problems in this case is the expected consumptive water use, which will involve conversion of land area to water area and will affect downstream water use and water levels at High Rock Lake, a downstream recreational and hydroelectric impoundment.

At the time the FES was issued (October 1975),[19] negotiations between the applicant and the State of North Carolina were under way to determine a definite minimum river flow below which proposed pumping rates would not be allowed. Because a minimum flow had not yet been determined, the ORNL staff based its assessment on a likely minimum flow of 24.9 m^3/sec (880 ft^3/sec), which is exceeded about 98% of the time. Accordingly, the proposed pumping rates would be restricted to river flows exceeding 24.9 m^3/sec (880 ft^3/sec) plus the amount being consumed by the Perkins Station—a total of 28.1 m^3/sec (992 ft^3/sec). During river flows below 28.1 m^3/sec (992 ft^3/sec), the applicant would be required to reduce station output or to supplement Yadkin River flow. The applicant therefore proposed to construct a 557-ha (1401-acre) impoundment on an upstream tributary of the Yadkin River. Water releases from this impoundment during periods of low river flow would maintain flows at about 28.1 m^3/sec (992 ft^3/sec) and would allow full operation of the station during such times.

Construction of the proposed impoundment will convert 557 ha (1401 acres) of relatively productive agricultural and forested bottomland to water acreage. After a site visit to assess the potential impacts to land use and benefits to water use, the ORNL staff concluded that the impact-benefit balance will be acceptable; it was also concluded that the proposed consumptive water use will not have significant adverse impacts on present downstream water users. Results of our assessment were presented at ASLB hearings, which were completed during 1976.

North Coast Nuclear Plant Unit 1, Islote site. The staff has conducted an ESR of the Islote site in Puerto Rico, where the North Coast Nuclear Plant Unit 1 may be constructed. This was our first ESR for a possible nuclear power plant, and we are presently preparing the FES.

The initial application from the Puerto Rico Water Resources Authority was for a one-unit station, consisting of a PWR and using water from the Atlantic Ocean for once-through cooling. On the basis of this application, the staff initiated review procedures typical of the licensing process for nuclear power stations. However, when we completed the PDES, the applicant decided to indefinitely delay construction of the proposed station. We therefore modified the PDES to an ESR statement, which will

19. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Perkins Nuclear Station, Units 1, 2, and 3*, NUREG-75/035, Docket Nos. STN 50-488, -489, and -490, October 1975.

determine the acceptability of the Islote site for a nuclear power plant. In our review we assumed that the applicant will eventually apply for permission to construct a power plant of the same general size and type as described in the applicant's initial application.

We determined that the Islote site would be an acceptable site for construction of such a nuclear station. The site occupies land that was used for sugar cane production several years prior to the application, but has since become relatively useless for growing cane because of the intrusion of salt water into the region. The land is now used primarily for cattle grazing. The relatively large number of endemic endangered animal species of Puerto Rico creates a potential for serious impact from any large construction project. However, the Islote site is very suitable in this respect since all the endangered species occur in other regions of the Island, which will not be affected by the proposed plant or its transmission lines.

Shoreham Nuclear Station Unit 1. The staff is presently conducting the OL review of this nuclear station and preparing the FES. This is the first of many OL reviews in which the ORNL staff will participate (all other OL reviews having been done previously by the NRC). By performing the OL review for Shoreham, the ORNL staff will be able, for the first time, to determine the effects of construction of a plant for which it conducted the CP review. Participation in OL review will allow the staff to become (1) more familiar with the actual construction of a nuclear station and its associated impacts and (2) more proficient in predicting and assessing potential impacts addressed in CP statements. In addition, the staff will be able to provide greater input into the technical specifications for preoperational and operational monitoring programs for nuclear plants.

Technical projects. A variety of technical projects are being carried out concurrently with the work on statements. These projects, generic in nature, normally address those areas that the staff has found to be of concern and for which no definitive work or standards are available. In each case the results of the work are documented and used as reference in the preparation of impact statements.

Multiple use of cooling reservoirs (B. R. Parkhurst[20] and H. A. McLain). The adverse and beneficial environmental impacts of cooling reservoirs have been studied during the past year and compared with those of cooling towers. Generally, the impacts associated with the construction of a cooling reservoir system, particularly from the increased land area required, are greater than those for a comparable cooling tower system. On the other hand, the operational impacts—visual impact, icing, fogging, and noise problems—are generally greater for cooling towers. The principal advantages of cooling reservoirs are their lower operating and maintenance costs, greater reliability, greater cooling efficiency, and potential for multiple use.

A review of the literature on cooling reservoir ecosystems has revealed that entrainment and thermal and chemical effluents generally cause reduced populations of phytoplankton, zooplankton, and benthos in the vicinity of the power plant discharge; adverse far-field effects are generally less significant. The overall effects of a power plant on the fish populations of cooling reservoirs appear to be insignificant: (1) game fish production and growth rates in cooling reservoirs are generally similar to those in other reservoirs; (2) spawning times for certain fish species may be advanced in some cooling reservoirs; (3) thermal tolerances are often higher for fishes in cooling reservoirs than for those in ambient temperature environments; (4) many fish species are attracted to the discharge areas in the winter and avoid it when water temperatures rise above their preferred temperature. These effects are generally consistent with the predicted ecological characteristics, as derived from the thermal characteristics of our model of a 2592-ha (6400-acre) cooling reservoir heated by four 1150-MW(e) reactors.

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20. Environmental Sciences Division.

The possibility that cooling reservoirs may provide multiple uses seems to be their most significant beneficial aspect, as compared with cooling towers, especially in areas having few water bodies for recreational activities. Cooling reservoirs also provide areas in which the cage or raceway culture of food fishes will allow the commercial use of waste heat discharged by power plants. Our conclusion[21] is that, for many areas of the country, cooling reservoirs may provide an environmentally and socially desirable alternative to cooling towers for meeting the water quality objectives of PL 92-500.

Analysis of impingement at power plants in the Southeast (J. M. Loar[20]). An increase in the demand for electricity will cause a corresponding increase in the need for cooling water for future fossil-fired and nuclear generating facilities. A potential adverse impact that could result from this increased water use is the impingement of aquatic species, primarily fish, on plant intake screens. Impingement occurs when aquatic species are pinned against (or impinged on) the 1-cm ($^3/_8$-in.) mesh of the traveling screens by the force of the water as it is pumped into the plant.

A study was conducted to identify factors that influence fish impingement.[22] We contacted 44 utilities that own and operate power plants on inland waters of the southeastern United States and requested impingement data that had been collected in compliance with various federal regulations. We received data for 27 fossil-fired and 5 nuclear plants.

Most of the fish collected at these plants were shad, especially threadfin shad (*Dorosoma petenense*). Most of the impinged species were small young-of-the-year or yearling fish less than 7 cm (2.75 in.) long and weighing less than 8 g (0.28 oz). In general, the parameter that correlated most highly with the impingement of threadfin shad was water temperature. This species, which has been introduced into many reservoirs in which water temperatures fall below 10°C during the winter, is stressed by these cold temperatures and thus becomes susceptible to impingement. Other factors found to influence impingement were low concentrations of dissolved oxygen and high levels of turbidity.

No conclusion could be reached concerning the effects of specific intake designs on impingement because of the variance of results. Among those plants that had intake channels, impingement was found to vary by several orders of magnitude. Impingement was generally lower at river sites than at lake or reservoir sites. The velocity of water near the face of the intake screens could not be conclusively established as a factor having a major influence on impingement since the high velocities observed at several plants did not necessarily result in high levels of impingement.

Several factors related to the time and location of the sampling were noted. Significantly different numbers of fish were impinged (1) during the day vs the night, (2) at different units of a multiunit plant, and (3) at different locations on the screens spanning the intake channel (e.g., at one plant, impingement levels were higher at screens located near the edges of the channel than at those located near the center). These results will be used by various federal agencies (e.g., NRC and EPA) to design and evaluate impingement monitoring programs at both existing and future electrical generating stations. A well-planned and comprehensive sampling program will help ensure that reliable estimates of annual fish losses due to impingement are obtained.

2.2.2 Barnwell Nuclear Fuel Plant

R. B. Craig,[20] Leader

The NRC Office of Nuclear Materials Safety and Safeguards requested that the Environmental Impact Section prepare a supplement to the FES for the Barnwell Nuclear Fuel Plant, Barnwell, South

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21. B. R. Parkhurst and H. A. McLain, *Multiple Use of Cooling Reservoirs*, to be published as ORNL TM report.
22. J. M. Loar, *Analysis of Impingement at Power Plants in the Southeast*, to be published as ORNL TM report.

Carolina. The original FES[23] dealt with the separations facility and the fuel receiving and storage station. Other facilities (i.e., a UF_6 and a waste solidification facility), each requiring a separate license, will also be operated on site. The objective of the supplement is to evaluate (1) the combined effects of construction and operation of all facilities and (2) the relation of these effects to other nuclear facilities in the vicinity (Savannah River Plant, Vogtle Nuclear Plant, and Oconee Nuclear Plant). In addition, new information that has become available since publication of the FES will be included to improve the evaluation of potential impacts.

Since the Barnwell plant, much of which is already constructed and undergoing preoperational testing, is the only reprocessing plant that has the potential to be on line in the near future, it is receiving a great deal of national attention. In many ways the future course of nuclear energy in the United States depends on this plant. The licensing review of the Barnwell plant will consider questions of plutonium and uranium recycling; application of breeder technology; waste generation, transportation, and isolation; and international aspects of nuclear technology.

Construction of the five-facility Barnwell complex will require clearing a total of about 127 ha (315 acres); 115 ha have already been cleared.

The major nonradiological effluents to be released from the Barnwell plant are heat to aquatic systems, sewage treatment liquid to groundwater, and nitrogen oxides, sulfur dioxide, and hydrogen fluoride to the atmosphere. The staff has concluded that (1) holdup times are sufficient for dissipation of excess heat; (2) no measurable addition of nutrients from the sewage spray irrigation project to local surface waters is likely; and (3) both annual average and peak concentrations of nitrogen oxides, sulfur dioxide, and hydrogen fluoride will be within State air quality standards and below the levels that will damage vegetation. No significant interactions between the nonradiological releases from the Barnwell plant and effluents from the other nuclear operations in the vicinity are expected.

Routine operations at the Barnwell plant will release relatively small quantities of radioactive nuclides to the environment. Gaseous radioactive effluents constitute the source of greatest radiation exposure to the general public. The maximum annual dose to an individual at the site boundary from operation of all five facilities at the Barnwell plant will be about 4.5 millirems; the normal background dose is 97 millirems per year. The maximum population dose from Barnwell in 1980 for persons living within 80 km (50 miles) of the site will be about 350 man-rems; including doses received from radioactive releases from the other nuclear facilities in the vicinity of the Barnwell plant (Savannah, Oconee, and Vogtle), the total dose to the 658,000 people living within 80 km in 1980 will be about 530 man-rems. The normal background dose to those people will be about 64,000 man-rems.

Work began in November 1975, and the draft supplement was issued in June 1976;[24] the staff is currently responding to agency and intervenor comments.

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23. U.S. Nuclear Regulatory Commission, *Final Environmental Statement, Barnwell Nuclear Fuel Plant*, Docket No. STN 50-332, January 1974.

24. U.S. Nuclear Regulatory Commission, *Draft Supplement to the Final Environmental Statement, Barnwell Nuclear Fuel Plant*, NUREG-0082, Docket No. STN 50-332, June 1976.

2.2.3 Environmental Appraisals for License Amendments and Renewals for Nuclear Fuel Cycle Facilities

G. W. Keilholtz, Leader

A. J. Kuhaida S. G. Hildebrand[27]
F. Binford[25] K. M. Oakes[27]
S. Reynolds[26] A. M. Solomon[27]
P. A. Cunningham[27] B. J. Dozier[27]

The objective of this project, initiated on August 15, 1976, is to technically assist the NRC in preparing detailed assessments of the environmental impacts associated with existing and or proposed fuel fabrication facilities. Assistance will include (1) preparation of draft assessments and environmental statements and (2) development of testimony or other supportive data as required by the environmental impact review process. Several draft appraisals[28,29] on fuel fabrications have been prepared by the ORNL staff since August.

The CEQ guidelines in 40 CFR 1500.13 state that, in cases for which no previous environmental impact statements have been prepared, agencies have an obligation to reassess ongoing projects to avoid or minimize adverse environmental effects even though they were initiated prior to enactment of NEPA on January 1, 1970. Consequently, when a licensee requests a license amendment or renewal for an activity for which the NRC has not yet prepared a full environmental review, significant environmental aspects of the activity must be evaluated. In addition, amendment and renewal applications that indicate a significant change in process or in kinds and or amounts of licensed nuclear materials should be evaluated for future environmental impact according to the Interim Guidelines.

The Westinghouse Nuclear Fuel Division manufacturing plant, located about 8 miles southeast of Columbia, South Carolina, is of sufficient size to accommodate fabrication of the present annual output of 400 metric tons of uranium (Fig. 2.4). An annual output of 1600 metric tons is planned for the near future. The staff has analyzed the environmental impacts of operating the Westinghouse plan and concluded that no significant impacts will occur from continued operation. The staff has, however, recommended modifications to the existing monitoring programs to enable continual evaluation of the environmental quality.[28]

The Atomics International fuel fabrication activities are centered at its headquarters facility in Canoga Park, California, and at its Nuclear Development Field Laboratory near Chatsworth, California. Activities at the Canoga Park facility include (1) commercial uranium fuel element production using large amounts of enriched uranium and (2) work with laboratory quantities of radioactive material. The work at Chatsworth consists largely of R&D to support the production of advanced types of reactor fuel. The staff's analysis of the environmental impact of operation of the Atomics International facilities indicated that there will be no significant adverse impacts from continued operation.[29]

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25. Operations Division.
26. Analytical Chemistry Division.
27. Environmental Sciences Division.
28. U.S. Nuclear Regulatory Commission, *Draft Environmental Appraisal, Westinghouse Nuclear Fuel Columbia Site (NFCS), Commercial Nuclear Fuel Fabrication Plant*, Docket No. 70-1151, November 1976.
29. U.S. Nuclear Regulatory Commission, *Draft Environmental Appraisal, Atomics International (AI) Commercial Nuclear Fuel Fabrication Facilities*, Docket No. 70-25, December 1976.

ORNL DWG. 77 5383

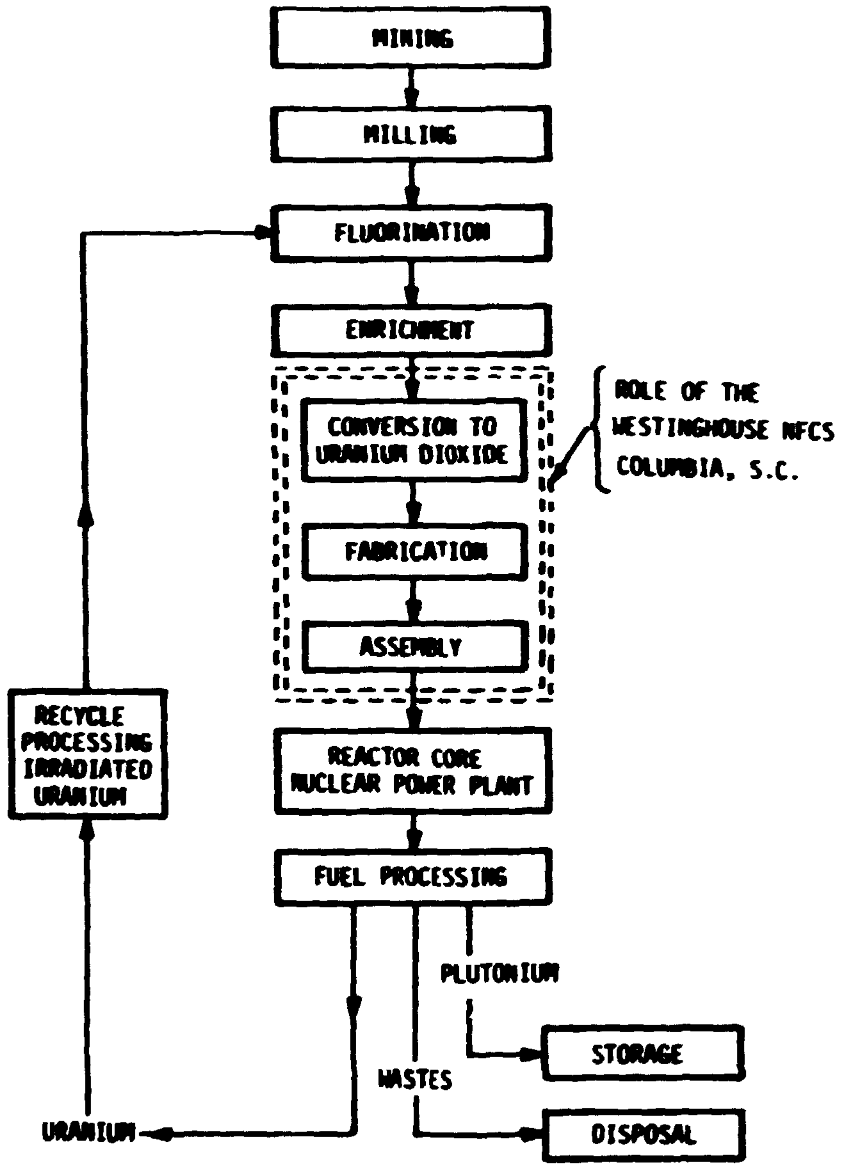

Fig. 2.4. Nuclear fuel cycle.

The staff has also begun to review the application by Exxon and Wyoming Minerals Corporation for a permit for commercial-scale solution mining of uranium. As a result of the preliminary site visit and contact with various concerned agencies, the staff is considering the preparation of a generic statement on solution mining prior to issuance of a site-specific impact statement.

2.2.4 Radioactive Materials in Consumer Products

G. W. Keilholtz G. S. Hill[29]
F. R. O'Donnell[29] R. L. Shoup[30]

Occasionally, consumer products using a chemical, physical, or nuclear property of a radioactive material are developed. Before these products can be made available to the general public, certain regulatory requirements must be satisfied. One requirement is that the potential impacts from distribution, use, and disposal of the products be assessed; ORNL is assigned the task of preparing environmental statements for consumer products that contain radionuclides.

Effort during the year has been directed solely at completing the work begun during 1975. In addition to preparing two statements (on spark-gap irradiators and neutron dosimeters), the staff collaborated with NRC to issue a final version of *Regulatory Guide 6.7: Preparation of an Environmental Report to Support a Rule Making Petition Seeking an Exemption for a Radionuclide-Containing Product*[31] and *Final Generic Environmental Statement on the Routine Use of Plutonium-Powered Cardiac Pacemakers.*[32]

Spark-gap irradiators that contain cobalt-60. Spark-ignited oil burners sometimes experience ignition difficulties because of spark delay, a phenomenon whereby the ignition system either fails to generate a spark within a prescribed, safe time interval or generates a weak, erratic spark. Spark-gap irradiators containing cobalt-60 have been found to alleviate spark delay and thus improve the reliability and performance of spark-ignition systems.

Comments on the DES[33] were received and resolved. The FES is in draft form and is undergoing technical review. Table 2.3 summarizes the impacts that couk' accrue over the 15-year lives of 6000 irradiators installed during the first year.

Personnel neutron dosimeters that con-ain natural thorium. Radiation protection standards require that accurate measurements be made of personnel exposure to radiation. Routine use of dosimeters containing natural thorium can give more sensitive, accurate, and reliable measurements of personnel exposure to fast neutrons than can existing neutron dosimetry systems.

During the year, the DES was completed and issued.[34] Comments were received and answered, and the FES will be issued early in 1977. Table 2.4 summarizes the potential impacts from the distribution, use, and disposal of 300,000 neutron dosimeters containing natural thorium. Monetary impacts are not included in Table 2.4 because the net value of such impacts is expected to be negligible. Thorium-containing dosimeters probably will replace existing dosimeters.

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30. Health Physics Division; now with Office of Waste Isolation, Y-12.

31. U.S. Nuclear Regulatory Commission, *Regulatory Guide 6.7: Preparation of an Environmental Report to Support a Rule Making Petition Seeking an Exemption for a Radionuclide-Containing Product*, June 1976.

32. U.S. Nuclear Regulatory Commission, *Final Generic Environmental Statement on the Routine Use of Plutonium-Powered Cardiac Pacemakers*, NUREG-0060, July 1976.

33. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement, Exemption from Licensing Requirements for Spark-Gap Irradiators that Contain Cobalt-60*, NUREG-75 086, Docket No. PRM 30-54, September 1975.

34. U.S. Nuclear Regulatory Comm ission, *Draft Environmental Statement, Exemption from Licensing Requirements for Personnel Neutron Dosimeters that C ntain Natural Thorium*, NUREG-0074, Docket No. PRM 40-19, October 1976.

Table 2.3. Summary of impacts that could accrue over 15 years from 6000 spark-gap irradiators containing cobalt-60

Impact	Magnitude
Minimal benefits	
Improved oil burner ignition	
Reduced service requirements	
$	102,200+
Man-hours	18,240+
Fewer explosions and fires	
$	33,200+
Death & injuries	Few
Reduced outage of heating unit	
$	Unknown, possibly high
Loss of production	Unknown, possibly high
Personal inconvenience	Unknown, possibly high
Maximal costs	
Price of irradiators, $	30,000
Introduction of Co-60 into the environment	
Number of sources	6,000
μCi	6,000
Disposal of Co-60 in obsolete irradiators (after 15 years of use), μCi	840
Population dose commitment (over 15 years), man-rems	15
Maximum individual dose commitments (over 15 years), millirems	
Distribution workers	2
Installers and servicemen	12
Burner operators	2
General public	0.01

Table 2.4. Summary of potential annual impacts from 300,000 personnel neutron dosimeters containing natural thorium

Impact	Magnitude
Benefits	
Availability of an improved neutron dosimetry system	
Improved measurement of personnel exposure to neutrons	Significant
Improved compliance with radiation protection standards	Important
Costs	
Redistribution of thorium in the environment	
g/year	3,750
Sources/year	75,000
Disposal or recycle of thorium, g/year	3,750
Population dose commitment, man-rems/year	200
Maximum individual radiation dose commitments, millirem/year	
Distribution workers	0.2
Handlers	0.08
Wearers	1.3
Wearers' families	8×10^{-14}
General public	8×10^{-14}

2.2.5 Environmental Monitoring Data Evaluation Study

S. M. Adams[35] D. D. Gray[36]
P. A. Cunningham[35] K. Deva Kumar[37]
A. J. Witten

In licensing nuclear power plants, a certain amount of environmental monitoring is usually required as part of the technical specifications for plant operations. Radiological and nonradiological (ecological) specifications are designed to (1) document potential impacts on the environment and (2) ensure that the power plants are operated without exceeding specifications to avoid environmental damage.

The major objectives of the technical specifications review program are to (1) validate thermal and ecological impact predictions made in the FES by using monitoring data, (2) evaluate the adequacy of preconstruction environmental studies and operational monitoring programs, (3) recommend standardization and other improvements in monitoring, data collection, and data analysis, (4) identify possible environmental impacts common to several power plants having similar hydrological and ecological profiles, and (5) complete analyses useful to the development of simulation models. The thermal and biological measurements were analyzed for the plants reviewed; the radiological aspects were a part of this program.

We have made considerable progress in this work, which is sponsored by the NRC Office of Nuclear Regulatory Research, during the past year; at least parts of objectives 1, 2, 3, and 5 have been accomplished. Completion of objective 4 depends on an evaluation, now in progress, of results from the three national laboratories (ORNL, ANL, and PNL) involved in the program.

In the initial phase of this study, ecological and thermal monitoring programs were reviewed for eight nuclear power plants that had been operational for at least one year: Peach Bottom Units 2 and 3; Surry Units 1 and 2; Oconee Units 1, 2, and 3; San Onofre Unit 1; Palisades; Ginna; Vermont Yankee; and Arkansas Unit 1. Three power plants—Surry, Peach Bottom, and San Onofre—were selected for thorough analysis on the basis of the comprehensiveness, location, and adequacy of their monitoring data.

Predictions of environmental impact made in the respective FESs were compared with results obtained from analysis of biological monitoring data at Surry and Peach Bottom (Tables 2.5 and 2.6); however, the duration of data collection at San Onofre was found to be too short to validate predictions for that station. Examination of Tables 2.5 and 2.6 reveals that the data were sufficient to validate only three of the predictions made in the respective FESs; ten predictions were shown to be in error, and the data were insufficient to confirm or reject eight other predictions.

Review of the hydrothermal monitoring at the three plants has resulted in the following general observations. In planning a hydrothermal monitoring program, two goals must be kept in mind: (1) to ensure that unacceptable environmental impacts do not occur (i.e., by considering possible interactions with the biological monitoring program) and (2) to ensure that specific legal standards are observed.

Biological monitoring alone cannot guarantee that the first goal is met. Without a good picture of the discharge plume, it may not be possible to distinguish natural variations or those caused by other human enterprises from power-plant-induced impacts. Except in catastrophic situations, the

35. Environmental Sciences Division.
36. Now at Purdue University.
37. Computer Sciences Division.

Table 2.5. Surry – comparison of observed impacts with impacts predicted in FES

Predicted impacts	Observations from monitoring data
Phytoplankton	
The phytoplankton community may change toward a heat-tolerant community; dominance of diatoms may decrease, and green and blue-green species may increase in abundance in the plume during summer months	No quantitative data on phytoplankton species changes are available, although diatom genera are generally most predominant at all stations during all months.
During the winter, phytoplankton standing crops may increase in the discharge area.	Phytoplankton densities in the discharge during colder months were higher than those in control areas; however, on an annual basis, thermal additions depressed phytoplankton standing crop.
Zooplankton	
Zooplankton losses will be greatest during the summer months and may have an impact on larval fish growth	Significant reduction of zooplankton densities in the discharge area did not occur during the summer months, although zooplankton standing crops were reduced on an annual basis.
Benthos	
Benthos will probably be eliminated at the discharge groin	Benthos were not sampled in the discharge groin area.
Maximum summer temperatures may eliminate benthic species over a considerable area in contact with the plume.	Benthic standing crops were highest in stations located in the discharge area as compared with controls, particularly in 1975, the year of highest heat rejection.
Attached benthos will be killed at temperatures above 38°C (90°F)	No adequate data were sampled to validate this statement; however, densities of fouling organisms were highest at the discharge station during 1975 [ΔT of 8°C (14°F)].
Blue crab migration out of the discharge area may occur, possibly reducing this industry.	Since no proper sampling gear for collecting blue crabs was employed, no assessment of this prediction can be made.
Larval clams and oysters will be killed by combined salinity and temperature changes.	No data are available for assessing this problem.
Fish	
During the summer, adults of most species may avoid the discharge area; however, during the winter, fish may congregate in the plume.	During summer months the catch per unit effort (CPE) in the discharge is less than in control areas, but during winter months CPE is higher in the plume area.
The overall impact of the Surry plant effluents will be to stress fish populations in the Hog Point area; standing crops and recruitment may be reduced.	Overall, fish densities in the discharge increased from 1973 to 1975. Reduction in recruitment and standing crops cannot be assessed with present data.
Impingement: Impingement of adult fishes on traveling screens during spawning runs is expected.	A strong correlation exists between the number of adult fish impinged and the time of the spawning migration. The highest fish impingement occurs during the fall when young-of-the-year migrate out of the estuarine nursery areas.
Entrainment: Larval and egg stages of marine fishes will be entrained since estuarine areas are used as spawning and nursery grounds	The densities of ichthyoplankton passing through the plant were monitored; however, no assessment of mortality of the entrained individuals was made.

Table 2.6. Peach Bottom – comparison of observed impacts with impacts predicted in FES

Predicted impacts	Observations from monitoring data
Phytoplankton	
A possible reduction in phytoplankton production may occur.	There are no significant differences in concentrations of chlorophyll a between stations or between preoperational and operational years.
An alteration in species composition — a decrease in diatoms and greens and an increase in the more heat-tolerant blue-greens — is expected.	Shifts in species composition cannot be validated since no quantitative cell counts were made.
Zooplankton	
Significant reduction in microcrustaceans during late summer is expected.	No significant differences between zooplankton densities between stations or between years were observed.
Benthos	
Detrimental effects on resident benthos over a small portion of Conowingo Pond exposed to thermal discharges, outfall scouring, and chlorine releases are expected; these effects will not be of sufficient magnitude to be important to pond as a whole.	No significant differences were observed in the biomass of benthos collected at all stations during preoperational and operational periods.
Fish	
Fish will be attracted to discharge plume in winter.	CPE was observed to be higher in the plume in summer than in winter; no differences were observed in CPE during winter between control and discharge areas.
Entrainment	
High entrainment mortality of zooplankton expected, with selection for heat-tolerant forms.	Methods used to estimate entrainment do not give the fraction of living organisms entering the plant that are killed by passage through the condensers.
Standing crops may be lowered partially from entrainment losses.	No significant differences in standing crops of zooplankton were observed between preoperational and operational years.
Impingement	
Standing crops of adult fishes may be partially reduced due to impingement.	No evidence of reduction of standing crops was observed (low numbers impinged); impingement is a function of temperature length (age class) and season of the year.

ecological impact due to a thermal discharge plume is likely to be a long-term effect. To correctly judge long-term effects, the most useful type of thermal information seems to be probabilistic isotherm maps. Such maps would show, for example, the region within the 5°C excess temperature isotherm 50% of the time. The only suitable way to acquire this information is to establish a network of continuously recording thermographs. Such a network should be the backbone of an environmental hydrothermal monitoring program. A thermograph network is also the only way of ensuring continuous surveillance to enforce legal regulations.

We also recommend supplementing the thermograph data with the infrared sensing (from an airplane) of water surface temperatures as a means of studying the configuration of the plume. We have concluded that thermal plume mapping from a boat the technique most frequently used is not a satisfactory technique.

Detailed reports of our work on the Surry, Peach Bottom, and San Onofre monitoring and a separate document containing all our recommendations are being prepared.[38-41]

2.2.6 Development of a Unified Transport Approach for the Assessment of Power Plant Impact

A. H. Eraslan[42,43]

J. E. Akin[43]	D. E. Fields[44,45]	K. K. Kim[43]
J. M. Barton[43]	S. K. Fischer[44]	M. H. Lietzke[46]
J. L. Bledsoe[44]	J. L. Harris[43]	J. E. Park[44]
K. E. Cross[44]	D. M. Hetrick[44]	M. R. Patterson[44,47]
H. Diament[43]	J. T. Holdeman[44]	R. D. Sharp[44]

During the past eighteen months, NRC has sponsored the implementation of a unified transport approach (UTA) for developing mathematical models for the assessment of power plant impact on aquatic environments.[48] The objective of the program is to develop fast-transient, one- and two-dimensional transport models and their associated general-usage computer codes which can be employed in estimating the thermal, radiological, chemical, and biological (entrainment and impingement) impact of power plant operations on rivers, estuaries, lakes, and coastal regions.

The UTA uses all the fundamentally common features of transport of thermal energy, radionuclides, chemical constituents, and aquatic biota in (1) the theoretical development of the

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38. U.S. Nuclear Regulatory Commission, *A Critical Evaluation of the Nonradiological Environmental Technical Specifications, Vol. 1, Program Description, Summary, and Recommendations*, ORNL NUREG TM-69 (to be published).
39. U.S. Nuclear Regulatory Commission, *A Critical Evaluation of the Nonradiological Environmental Technical Specifications, Vol. 2, Surry Power Plant Units 1 and 2*, ORNL NUREG TM-70 (to be published).
40. U.S. Nuclear Regulatory Commission, *A Critical Evaluation of the Nonradiological Environmental Technical Specifications, Vol. 3, Peach Bottom Atomic Power Station Units 2 and 3*, ORNL NUREG TM-71 (to be published).
41. U.S. Nuclear Regulatory Commission, *A Critical Evaluation of the Nonradiological Environmental Technical Specifications, Vol. 4, San Onofre Nuclear Generating Station Unit 1*, ORNL NUREG TM-72 (to be published).
42. Project director.
43. University of Tennessee staff.
44. Computer Sciences Division.
45. Currently on leave at Murray State University, Kentucky.
46. Chemistry Division.
47. Task group leader.
48. A. H. Eraslan et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 79 83.

models and (2) the application of the models to actual site-specific problems. A schematic representation of the organizational structure of the UTA research program is presented in Fig. 2.5.

The basic discrete-element development of the governing mathematical systems, from the integral forms of the physical conservation (and biological population balance) principles, is the same for both convective and turbulent transport in all one-, two-, and three-dimensional thermal, chemical, radiological, and biological transport models.

An important part of assessing power plant impact on the aquatic environment is estimating the reentrainment and recirculation of the discharge effluent. The systematic methodology developed for the zone matching of near- and far-field analyses, based on identical formulations for determining the reentrainment and recirculation effects in all two-dimensional transport models, is also applicable. Different parts of the overall theoretical transport modeling program are indicated on the left-hand side of Fig. 2.5 with horizontal, parallel arrows to emphasize that the mathematical models are being developed simultaneously.

From theoretical considerations, the UTA models are identical except for various intrinsic characteristics associated with specifically different phenomena (e.g., surface heat transfer in thermal models, chemical reaction kinetics in chemical models, decay rates and sediment transport and exchange in radiological models, and population dynamics and behavioral characteristics of the aquatic biota in biological models). The necessary modeling subprograms for these different intrinsic phenomena are illustrated in Fig. 2.5 by the vertical listings separated with dashed lines to emphasize the fact that they can be developed without affecting the integrity of the basic unified transport formulation of the models.

The numerical techniques employed in solving the semidiscretized systems of coupled, nonlinear, ordinary differential equations are identical in all the transport models, and they are based on well-established consistent and stable (convergent) mathematical algorithms.

The general-usage computer code structures are also based on the fundamental concept of the UTA program to use all the common transport characteristics to formulate mathematical models. All computer codes are being developed in a unified, parallel form so that all one-, two-, and three-dimensional models for thermal, chemical, radionuclide, and biological transport will have basic subroutines with identical structures, statement numbers, and FORTRAN variables.

The computational algorithms associated with the numerical solution techniques are also identical in all models. The auxiliary programs for the input data and output results are also similar, with identical structures and averaging procedures, but they have different variables for the different intrinsic properties (e.g., temperature for the thermal codes, concentrations for the chemical and radiological codes, and population density for the biological codes). Different parts of the overall effort to develop numerical solution methods and computer codes are shown on the right-hand side of Fig. 2.5 by horizontal, parallel arrows to indicate that these programs are being developed simultaneously and incorporated with minimum duplicative effort.

The project is a joint program between ORNL and the University of Tennessee. The combined research team includes the staff members of the Energy, Chemistry, and Computer Sciences Divisions and a group of professors and graduate students of the Department of Engineering Science and Mechanics of the University of Tennessee.

During 1976 we completed (1) one-dimensional hydrodynamic, thermal, salinity, chemical, radiological (radionuclides in water), sediment, and biological transport models; (2) two-dimensional thermal, chemical, radiological, and biological transport models; and (3) the associated optimized general-usage computer code for each. We also developed a general methodology for the zone matching of near- and far-field analyses and modified the simplified-marker-and-cell (SMAC)

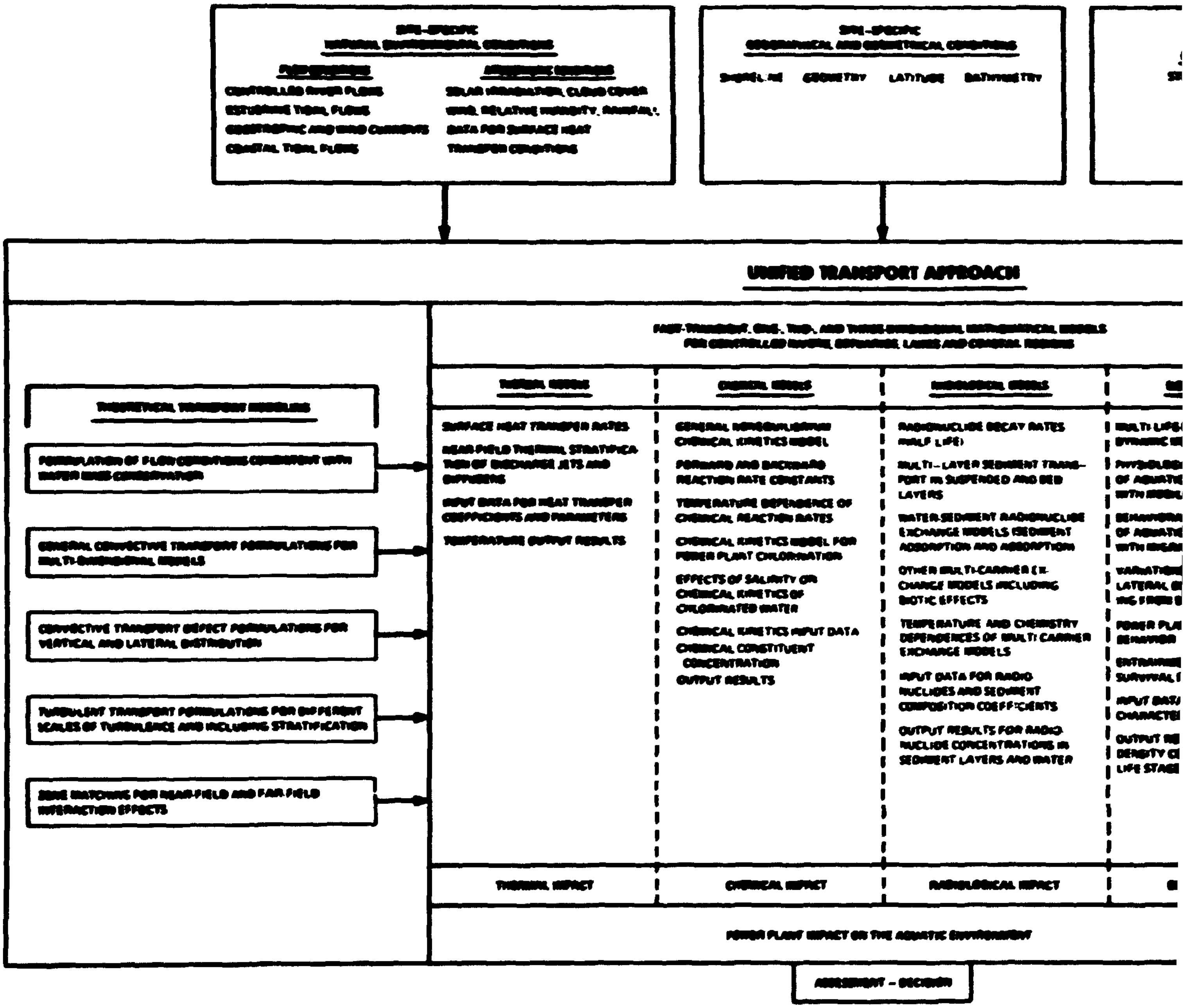

Fig. 2.5. Organizational structure of the unified transport approach.

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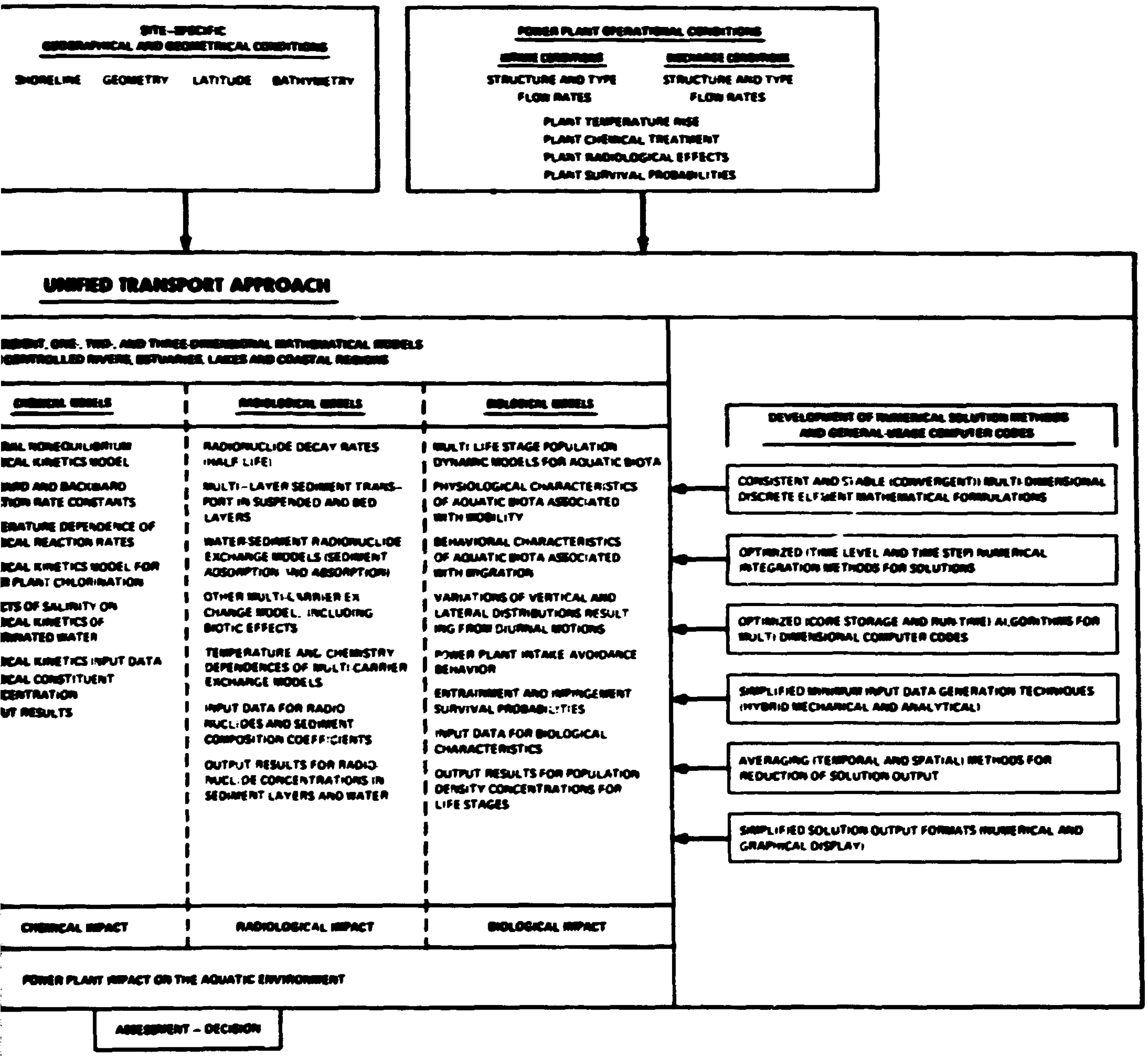

2.5. Organizational structure of the unified transport approach.

2

technique to a general-usage computer code (ORSMAC) for accurately estimating critical reentrainment and recirculation effects.

An extensive validation program for the UTA models was initiated. In applications of the models to site-specific cases for which reasonably accurate data were available, the computer simulations were in excellent agreement with field-measured conditions for both one- and two-dimensional models.

Results of the UTA project during its first 18-month period clearly established that (1) UTA seems to be an efficient mode of research for developing mathematical transport models and applying those models to site-specific analyses of power plant impact and (2) the UTA transport models can save substantial time, effort, and computer cost because thermal, chemical, radiological, and biological simulations of the impact are done simultaneously rather than individually.

Optimization of mathematical models and general-usage computer codes. The UTA mathematical models and associated computer codes will be used by NRC and other federal and state agencies (and possibly utility companies and consulting firms) to analyze site-specific problems related to power plant impact. Once the limits of accuracy of the desired analysis are determined for a particular site-specific case, two practical points of consideration become extremely important in the choice of the mathematical models: (1) the cost of computer time and (2) the time and effort required for preparing the input data and analyzing the computer output. During the past year, a major task has been to improve the numerical solution techniques, computer storage, and run-time requirements and to develop efficient, automated data preparation and graphical output display programs.

Optimization of numerical solution techniques and computational algorithms. An extensive study was completed to determine the feasibility of more efficient and advanced predictor–corrector-type numerical integration methods for improving the computer storage and run-time requirements of the original UTA computer codes, which employ a modified fourth-order Runge-Kutta-Gill method with truncation error correction. The proposed alternative methods were implemented in the existing one- and two-dimensional ESTONE and FAROUT thermal codes. We concluded that the presently employed Runge-Kutta-Gill method is the most reliable and efficient numerical method for solving the systems of ordinary differential equations associated with the discrete-element formulations of the UTA mathematical transport models.

The code was optimized in other ways. The computer run times and storage requirements of all one- and two-dimensional UTA codes were improved significantly by eliminating duplicative computational steps and branch statements in the main computational algorithms. Core storage requirements in all two-dimensional UTA models were significantly reduced by eliminating unnecessary storage for external elements.

Direct computational comparisons were made between the original and the optimized versions of the one-dimensional hydrodynamic, thermal, and salinity code ESTONE for rivers and estuaries and the two-dimensional thermal code FAROUT for coastal regions. In applications of ESTONE, the optimized version required 18% less storage and 48% less run time than did the original version. Improvement of the storage requirement for the FAROUT code was different in different applications, depending on the complexity of the shoreline boundaries of the regions. Reduction in storage requirements for the optimized version varied between 38% (San Onofre coastal region) and 64% (Roseton–Danskammer region in the Hudson River). The computer run times in the optimized version of the FAROUT code were reduced by about 64% in all applications. In applications of the advanced and optimized version of the one-dimensional code ESTONE to the 245 km (152 miles) of the Hudson River using 3.2-km (2-mile) discrete elements, the computer run-time requirement is 2.0

CPU seconds for 1 hr of real time simulation (or about 30 sec of CPU time for one tidal cycle simulation) on the interactive DEC system PDP-10 computer.

Hence, the UTA mathematical models and associated general-usage computer codes can be applied to real, site-specific problems in power plant impact assessments with reasonable computer storage and run-time requirements on presently available computer systems.

Automated input data preparation and graphical output display programs. Application of the two-dimensional UTA computer codes (e.g., thermal code FAROUT) requires considerable amounts of geometry data for constructing the discrete-element system and depth conditions in a region. Rather than generating the complex input data internally, the UTA computer codes intentionally require independent external preparation of this data to avoid costly computer runs caused by errors in the input geometry data. To aid the users of the two-dimensional UTA computer codes, stand-alone, computer-assisted data preparation programs were developed for generating the geometry input data.

The geometric data preprocessor program (PREPR2) requires input data that can be obtained directly from regional maps of the power plant sites; the data specify the rectangular grid system and the shoreline geometry of the region. The program contains all the necessary logic for calculating the areas, centroids, and enclosure surface widths of all the irregularly shaped boundary discrete-elements.

An efficient method for generating geometrical data from maps is to employ electromechanical digitizers. To consider the feasibility of this method for generating data necessary for the FAROUT code, a preliminary study, using a Texas Instruments Model 980A minicomputer and a Science Accessories GRAF PEN model GP-3 sonic digitizer, was undertaken. This electromechanical equipment was used to generate the necessary shoreline geometry data for the PREPR2 directly from maps of the regions (e.g., Conowingo Reservoir and Indian Point). Use of the electromechanical digitizer system enables the user to generate the shoreline geometries in less than 10 min.

The two-dimensional UTA code FAROUT also requires input data for the mean water level depth in all the discrete elements. A stand-alone program, DEPTHR, was developed to aid the users in generating this high-resolution and detailed depth data from reasonably accurate but coarse-grid depth data in the region.

The final form of the geometrical input data for the two-dimensional FAROUT code, generated either manually or by the two stand-alone preprocessor programs (PREPR2 and DEPTHR), can be reconstructed and displayed by the computer program GRAFAR. The program was developed for use with the DEC system PDP-10 computer with both Tektronix graphical display terminal and also with Calcomp pen-and-ink plot equipment. The graphical display program GRAFAR uses the input data to draw the grid system and shoreline and identifies each discrete element as internal, boundary, or external, as shown in Fig. 2.6 for the region in the vicinity of Indian Point on the Hudson River.

The two-dimensional graphical display program, GRAFAR, has the capability to plot streak-lines for the flow field, constant depth contours, isotherms for temperature, isoconcentration contours for chemical constituents, radionuclides, and biological populations. The program was developed for CRT or Calcomp plots, and it can be readily used in an interactive system similar to DEC system PDP-10 with Tektronix CRT terminals.

A subprogram package was developed and incorporated in all one-dimensional UTA codes (e.g., ESTONE) for averaging and graphical display of the output results. Considering that tidal-averaged and daily averaged conditions in an estuary could be important, a generalized output

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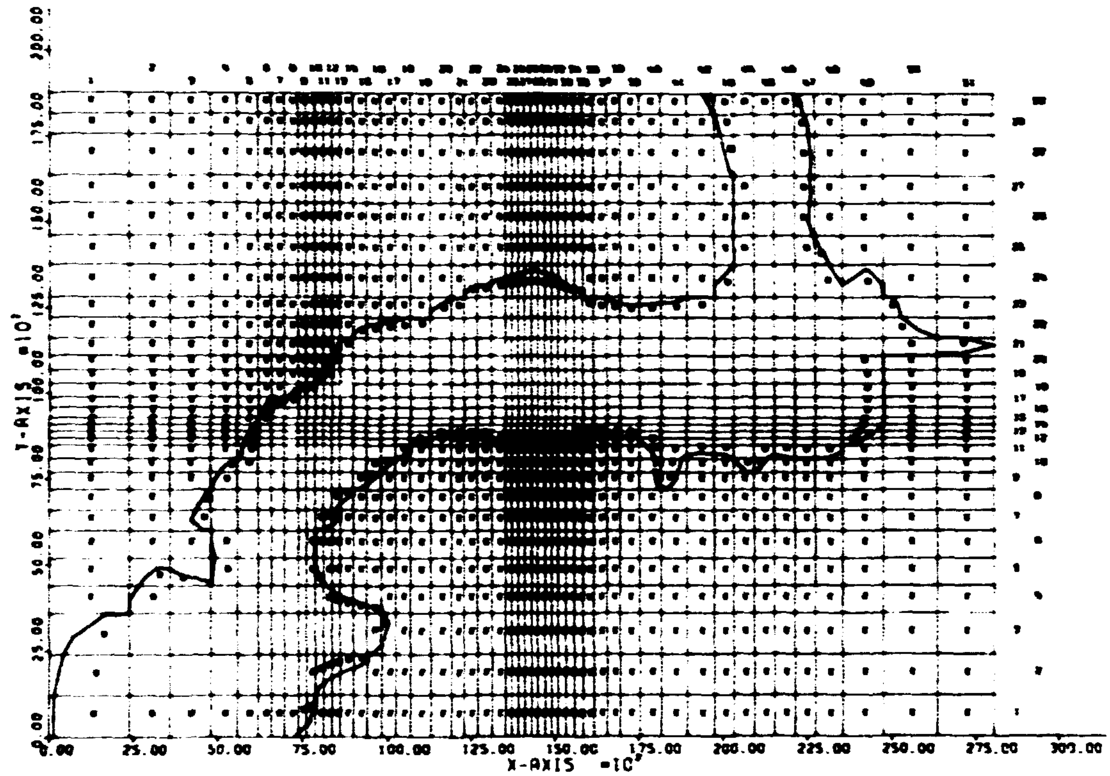

Fig. 2.6. Discrete-element representation of the Indian Point site on the Hudson River showing internal, boundary (B), and external (E) elements.

analysis program, STORER, was developed. The code performs search operations, within a specified period, for the minimum or maximum values of any variable in the model. It also can perform temporal averaging over a specified period of time (e.g., tidal period or day) for any specified variable at any longitudinal location along a river or an estuary. The one-dimensional output display program, PLOTER, also has four options for output type: (1) longitudinal distribution at a specified time, (2) temporal variation at a specified location (i.e., discrete-element), (3) longitudinal distributions of minimum or maximum values, and (4) tidal-averaged longitudinal distributions. A typical line-printer plot output from PLOTER for distributing minimum, average, and maximum surface elevation conditions in the Hudson River is shown in Fig. 2.7.

A two-dimensional line-printer plot program, PLOTWO, was also developed for all two-dimensional thermal, chemical, radiological, and biological output results of the UTA general-usage computer codes. In applications of the two-dimensional models (e.g., FAROUT), PLOTWO can be implemented inline with the transport computer code, and the numerical output can be completely eliminated in favor of graphical display. A typical line-printer plot output is presented in Fig. 2.8 as dimensionless isoconcentration contours for simulating a hypothetical release condition of typical radionuclides in the coastal region of the San Onofre Nuclear Generating Station.

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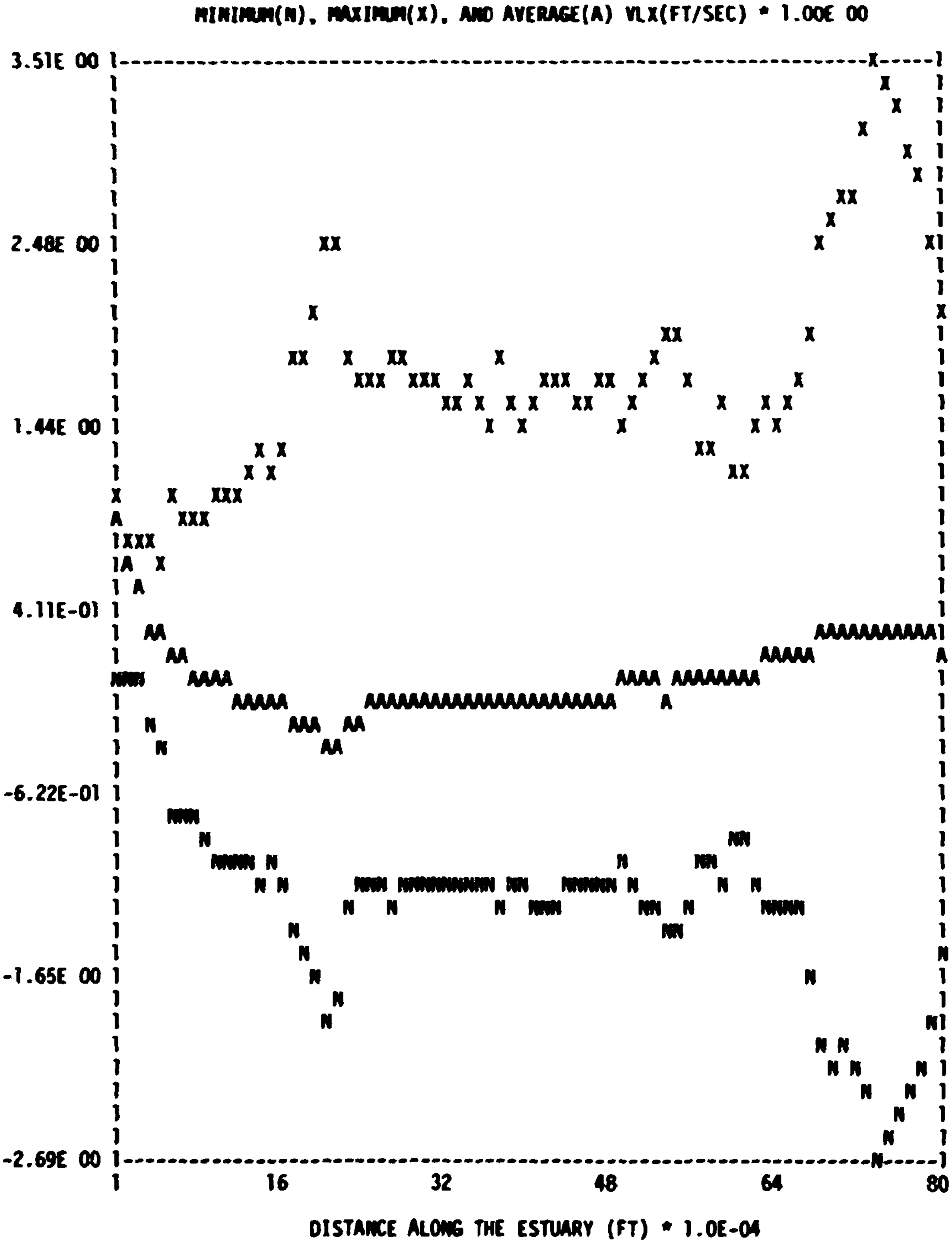
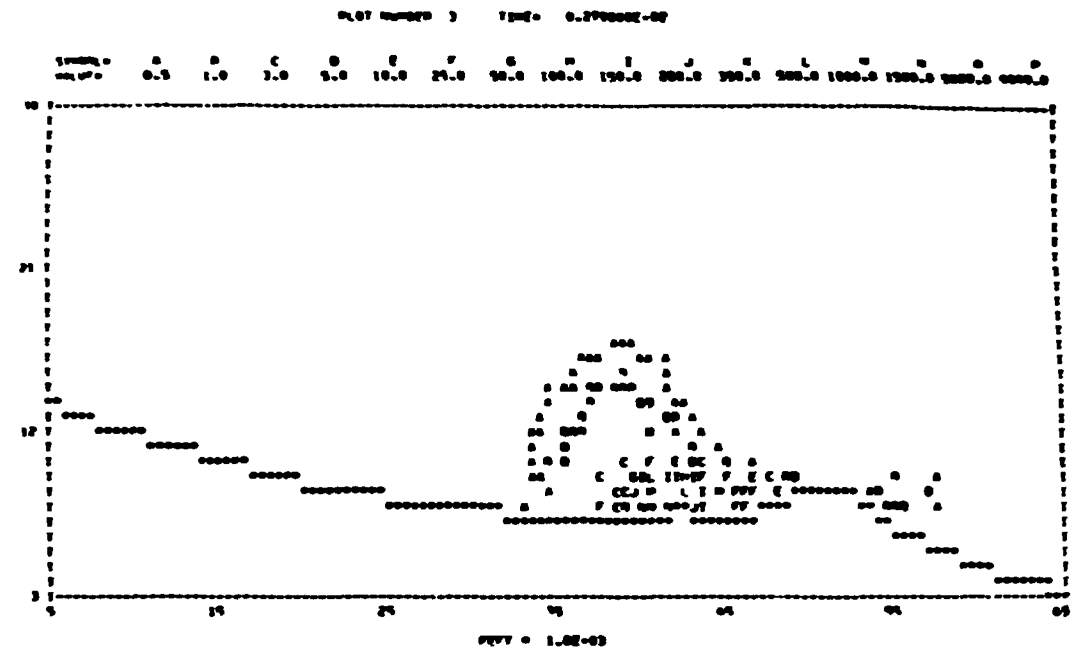
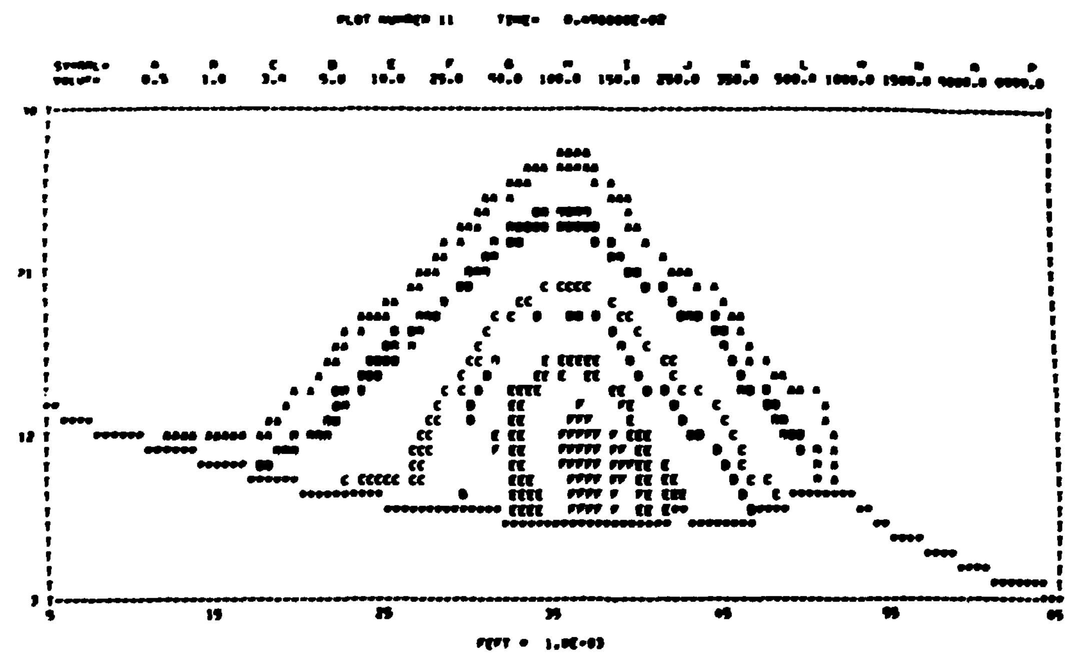


Fig. 2.7. Line-printer plot of mean flow velocity in the Hudson River showing minimum (N), maximum (X), and average (A) values as a function of distance downstream from the Troy Locks.

ORNL-DWG 77-3110



(a) 1.55 hr AFTER PLANT SHUT-DOWN



(b) 24.8 hr (2 TIDAL CYCLES) AFTER PLANT SHUT-DOWN

Fig. 2.8. Simulation of ^{137}Cs concentrations in a hypothetical release at the San Onofre Nuclear Generating Station. (*a*) Concentrations at the end of the release and (*b*) concentrations after two tidal cycles.

The detailed development of the computer programs PREPR2 and GRAFAR is presented in technical reports.[49,50]

In summary, all the presently existing one- and two-dimensional general-usage computer codes associated with UTA thermal, chemical, radiological, and biological transport models were optimized to require (1) minimum computer core storage and run times, (2) minimum effort and expertise on the part of the users to prepare the input data, and (3) minimum effort to interpret the computer output results, which can be displayed graphically as CRT, Calcomp, or line-printer plots.

Thermal program. During the past year the overall thermal program has consisted of two major tasks. The first task was to improve the mathematical formulations and optimize the computational algorithms of the existing one-dimensional model ESTONE for controlled rivers and estuaries and the two-dimensional model FAROUT for lakes and coastal regions. All the new methods and computational schemes for optimizing the mathematical models and associated general-usage computer codes were first developed for the thermal codes ESTONE and FAROUT; then, consistent with the fundamental concept of the UTA, these schemes were directly incorporated into the chemical, radiological, and biological transport models of the UTA program.

The second major task of the thermal program was to validate ESTONE and FAROUT by comparing computer simulation results with the available field-measured data from actual operational power plants. Preliminary comparisons indicated that the accuracy of simulations was extremely sensitive to input data about the historic regional flow conditions, atmospheric conditions, and detailed power plant operational conditions. Therefore, the auxiliary modeling and subroutines of the computer codes were greatly revised to accurately represent the detailed historic input data.

Modeling of the end conditions for dams was generalized to consider input data for any combination of specified durations (i.e., hourly, daily, or weekly) to accurately determine flow conditions. Formulation of the ocean conditions was also generalized to include multiharmonic variations to accurately simulate tidal flow conditions in estuaries and coastal regions. The surface heat transfer model was generalized to incorporate detailed input data for specified durations of all important atmospheric variables. Modeling of the operating conditions of power plants and pump storage facilities was completely generalized to include detailed input data for any combination of specified durations during different operational periods.

Hence, the final UTA one- and two-dimensional thermal models and their associated general-usage computer codes (ESTONE and FAROUT) are predictive thermal models that can be used to simulate the thermal impact of an operating power plant on the aquatic environment in an actual site-specific application. Optimization of the codes and improvement of their applicability to actual thermal impact problems were completed during 1976.

Tidal-transient, one-dimensional model (ESTONE) for controlled rivers and estuaries. A fast-transient, one-dimensional model that can be applied, without special modifications, to estuaries having reversing periodic tidal flow conditions and rivers having extreme flow rate variations due to controlled dams or pump storage facilities was developed. In applications using the commonly employed one-dimensional models, the simulations of the hydrodynamic conditions are difficult for fast-transient flow conditions. The computer solutions usually require an excessive number of grid

49. J. T. Holdeman, *PREPR2: A Program to Aid in the Preparation of Input Data for the FAROUT Two-Dimensional Code*, ORNL CSD TM-19, to be published.

50. B. Thomas, J. L. Bledsoe, and J. T. Holdeman, *GRAFAR: A Computer Code for Graphic Display of Input Data to the FAR2D/FAROUT Code*, ORNL CSD TM-22, to be published.

points and extremely small time step sizes. Therefore, assessment of the thermal impact of multi-power-plant regions or long estuaries (e.g., Hudson River) and for long periods of time (e.g., six months) become very expensive. Our new model, ESTONE, avoids these problems.

A completely new mathematical algorithm was developed in the UTA program for the discrete-element formulation of the momentum principle in modeling hydrodynamic conditions; this new method evaluates the flow rates in each discrete element at two points, located halfway between the upstream and downstream enclosure surfaces and the center of the discrete element. The second important novel feature of the tidal-transient, one-dimensional thermal model ESTONE is that the transport fluxes for all the physical properties are rigorously formulated by considering both the vertical and lateral variations of velocity, temperature, and salinity conditions over the cross-sectional areas in a river or estuary. Furthermore, the model does not require any additional data to specify longitudinally varying dispersion coefficients which may differ among estuaries (e.g., salinity intrusion modification), as do all other existing one-dimensional thermal models.

The mathematical development of the UTA tidal-transient, one-dimensional thermal model ESTONE for controlled rivers and estuaries and its various applications to actual site-specific problems (e.g., the Hudson River and Conowingo Reservoir) are described in a technical report[51] and a user's manual.[52]

Tidal-transient, two-dimensional model (FARTMP) for lakes, estuaries, and coastal regions. The original version of the tidal-transient, two-dimensional far-field thermal model FAROUT was completely reformulated and optimized to develop a computationally efficient thermal model, FARTMP; FARTMP accurately predicts the temperature distributions in lakes and coastal regions under specified natural and plant-induced flow conditions. The preliminary formulation of the FAROUT model required the simultaneous specification of both the local depth and the two components of velocity as time-dependent variations in a region. The necessary input data, based on sparse flow measurements, sometimes resulted in an over-specification of the flow fields that could not satisfy the mass conservation principle in each discrete element of the model. The final version of FARTMP requires the specification of only the two velocity components of the flow field, and using two conservation principles for water mass and thermal energy, it simultaneously predicts both the depth variations and the temperature distributions in a region.

During the past year, the tidal-transient, two-dimensional thermal model FARTMP has been applied to numerous site-specific problems for validation of the model on the basis of actual field-measured temperature data from operational power plants in lakes, estuaries, and coastal regions. The computer simulations in the validation study included Peach Bottom Atomic Power Station on the Conowingo Reservoir; Indian Point, Lovett, Bowline, Danskammer, and Roseton power plants on the Hudson River; and San Onofre Nuclear Generating Station on the California coastline.

A typical comparison of the computer simulations by the FARTMP thermal code with the actual field-measured data for the temperature distributions in the Conowingo Reservoir in the vicinity of the Peach Bottom Atomic Power Station is presented in Fig. 2.9. The computer

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51. A. H. Eraslan et al., *A Tidal-Transient, One-Dimensional, Discrete-Element Model for Simulating Hydrodynamic, Thermal, and Salinity Conditions in Controlled Rivers and Estuaries for Predicting the Impact of Power Plant Operations*, to be published as an ORNL report.

52. A. H. Eraslan et al., *ESTONE: A Computer Code for Simulating Tidal-Transient, One-Dimensional Hydrodynamic, Thermal, and Salinity Conditions in Controlled Rivers and Estuaries for Predicting the Impact of Power Plant Operations*, to be published as an ORNL TM report.

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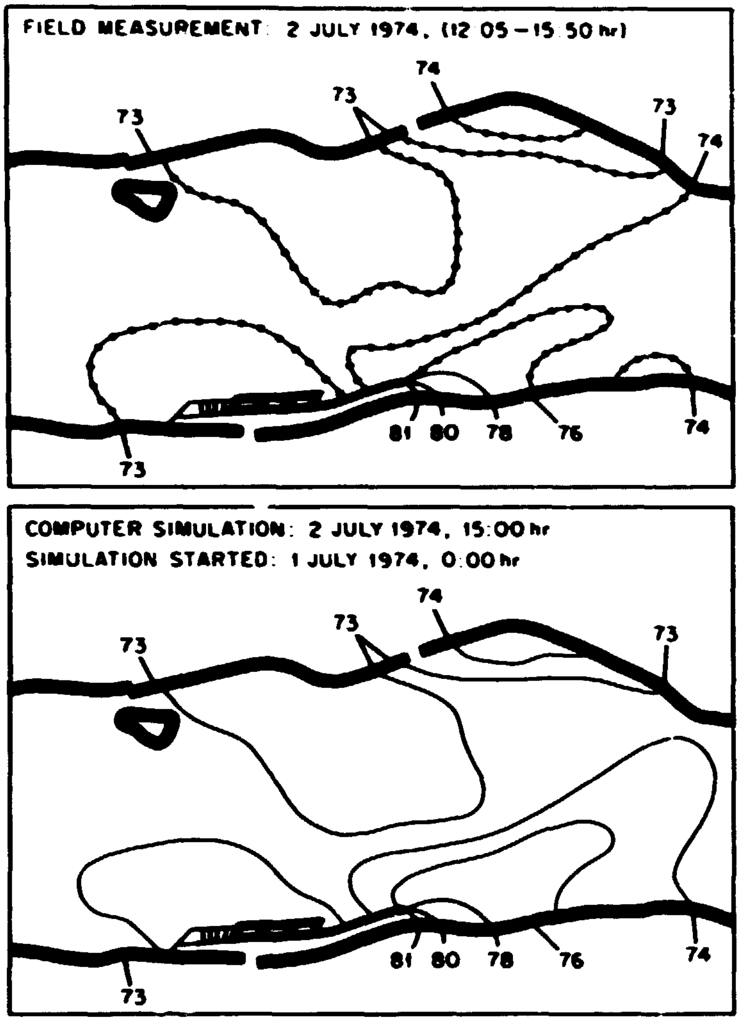

Fig. 2.9. Temperature distributions in the Conowingo Reservoir in the vicinity of the Peach Bottom Atomic Power Station.

simulations were obtained without any modification of the parameter values in the thermal model. In all cases for which reasonably accurate data were available for the flow and power plant operational conditions, excellent agreement was obtained between the model simulations and the field-measured data for the regional temperature distributions.

The development of the tidal-transient, two-dimensional thermal model FARTMP is described in a technical report[53] and a user's manual document.[54] Detailed studies of the model applications to

53. A. H. Eraslan et al., *A Tidal-Transient, Two-Dimensional, Discrete-Element Model for Simulating Depth and Temperature Distributions under Specified Flow Conditions in Lakes, Estuaries, and Coastal Regions for Predicting Thermal Impact of Power Plant Operations*, to be published as an ORNL report.

54. A. H. Eraslan et al., *FARTMP: A Computer Code for Simulating Tidal-Transient, Two-Dimensional Depth and Temperature Distributions under Specified Flow Conditions in Lakes, Estuaries, and Coastal Regions for Predicting Thermal Impact of Power Plant Operations*, to be published as an ORNL TM report.

site-specific problems for validation of both the one-dimensional model ESTONE and the two-dimensional model FARTMP are presented in other reports.[55-57]

In summary, the thermal program accomplished its objectives during 1976, that is, to develop and optimize the one- and two-dimensional transport models and to apply those models to site-specific problems for model validation. We are currently completing technical documents that contain the results of the research effort.

Chemical program. The objective of the first phase of the UTA chemical program was to develop the necessary mathematical models for predicting the chemical impact of chlorinated water discharged from the power plant cooling systems. The overall effort was divided into two parts: (1) detailed study of the chemical kinetics of the chlorination process in the power plants and (2) development of fast-transient, one- and two-dimensional chemical transport models for simulating the chemical constituent concentrations in the aquatic environment.

Development of the chemical kinetics model for the chlorination process. To determine the chemical composition of chlorinated discharge water, we developed a realistic chemical kinetics model to simulate the chlorination process in the power plants for fresh water (reactions in saline water will be incorporated when the rates are available). Primary emphasis was focused on the production of inorganic and organic chloramines, which can be toxic to fish and other aquatic biota at low (parts per million) concentrations.[58]

The model was formulated on the basis of three nonequilibrium chemical reactions, with forward and reverse reaction rates, that involve the production of inorganic chloramines (NH_2Cl and $NHCl_2$) and a composite representation of the organic amines as RNH_2. The basic chemical reactions included inorganic nitrogen concentrations in the water as ammonia and considered the reactions of inorganic and organic amines with hypochlorous acid. In addition to the three basic reactions, the model also considered the rate of irreversible uptake of chlorine to satisfy the chlorine demand of the intake water. The forward and reverse reaction rate constants were modeled to include the effects of water temperature and pH in a general form common to the reactions of most organic amines with hypochlorous acid. The values of the parameters used in the reaction rate constants were determined on the basis of theoretical considerations and experimental data for reactions that occur in nonsaline water.

A modular computer program, CHLORN, was developed to simulate the chemical concentrations in the discharge water of the power plant cooling systems based on the chemical kinetics model for the chlorination process in fresh water. Input to the model includes the operational conditions of the power plant; the temperature, pH, and chemical composition of the intake water; and the schedule of system chlorination cycles. Using this input, the computer code predicts the detailed variations with time of the different chemical constituents in the discharge water. A typical computer simulation of the varying chloramine concentrations in the discharge water from cooling tower blowdown is presented in Fig. 2.10

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55. H. A. Diament et al., *A Comprehensive Mathematical Modeling and Computer Simulation Study of the Thermal Conditions in the Vicinity of the San Onofre Nuclear Generating Station with Comparison to Field-Measured Data*, to be published as an ORNL/TM report.

56. K. K. Kim et al., *A Comprehensive Mathematical Modeling and Computer Simulation Study of the Hydrodynamic and Thermal Conditions in the Vicinity of Peach Bottom Atomic Power Station in the Conowingo Reservoir with Comparison to Field-Measured Data*, to be published as an ORNL/TM report.

57. J. L. Harris et al., *A Comprehensive Mathematical Modeling and Computer Simulation Study of the Hydrodynamic and Thermal Conditions in the Vicinity of Indian Point Nuclear Generating Station in the Hudson River with Comparison to Field-Measured Data*, to be published as an ORNL/TM report.

58. M. H. Lietzke, *A Kinetic Model for Predicting the Composition of Chlorinated Water Discharged from Plant Cooling Systems*, ORNL-5205 (January 1977).

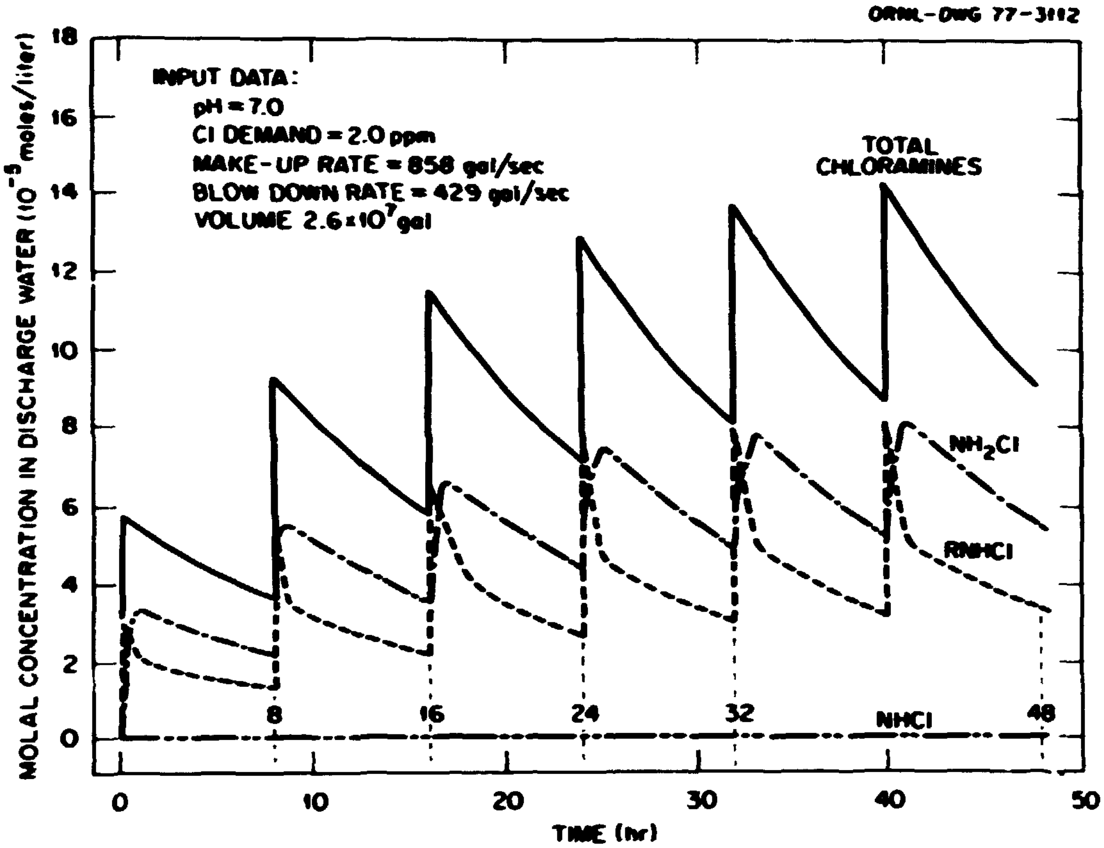

Fig. 2.10. Variation of chloramine concentrations in discharge water from a cooling tower for six 8-hr chlorination cycles.

for six 8-hr chlorination cycles, starting from nonchlorinated initial conditions in the system. Results indicate that the concentrations in the discharge water attain quasi-steady-state conditions after about 40 hr of plant operation, and they vary between constant upper and lower bounds during the periodic chlorination cycles.

The mathematical development of the chemical kinetics model for the power plant chlorination process and its associated computer code CHLORN are presented in the technical report.[58] A separate, more general routine, CHMKIN, was developed to handle hydrolysis reactions.

Tidal-transient, one-dimensional chemical transport model (CHMONE) for controlled rivers and estuaries. The tidal-transient, one-dimensional chemical transport model for rivers and estuaries was completed. Consistent with the general concept of the UTA, the basic transport phenomena were formulated identically to the already complete one-dimensional thermal model ESTONE, which included the simulations of hydrodynamic, thermal, and salinity conditions in rivers and estuaries. Since the hydrodynamic and thermal conditions were necessary and common to both one-dimensional models, the mathematical formulation of the salinity concentration was replaced by the array of constituent concentrations to obtain the chemical model CHMONE directly from the thermal model ESTONE for controlled rivers and estuaries.

The chemical kinetics model for the power plant chlorination CHLORN was directly incorporated in the formulation of the general model for power plant operations. An additional chemical kinetics model and its associated subprogram, CHMKIN, was developed and incorporated in the chemical transport model for the hydrolysis of the chloramines in the receiving water body.

The computer code CHMONE of the tidal-transient, one-dimensional model was structured exactly as the thermal code ESTONE, which includes the solutions for salinity. The necessary data for the two models were formatted identically except for the additional data for (1) the chemical kinetics of the chlorinated water used in the modular subroutines for the plant operations CHLORN and (2) the hydrolysis of the chloramines CHMKIN. Hence, in applications to a site-specific problem, the two models can be employed individually or as a combined model without necessitating any change in the site-specific data input to either.

Applications of the one-dimensional chemical transport model for validation have not been completed because accurate and detailed field-measured data for chloramine concentrations in rivers and estuaries resulting from power plant chlorination are not readily available.

A typical application of the one-dimensional chemical transport model is shown in Fig. 2.11 for the simulation of hypothetical chlorination conditions in the Hudson River; the freshwater flow is assumed to be sufficiently high to limit the salinity infusion zone downstream of the power plant. The results of this application demonstrate the capability of the model to simulate the periodic upstream and downstream movement of the high chloramine concentration peaks with the tidal flow conditions during the specified 8-hr chlorination cycle of the power plant. The preliminary results also suggest the possibility that proper selection of the chlorination times relative to the tidal cycles could reduce the level and extent of the chloramine concentrations in an estuary.

Development of the UTA tidal-transient, one-dimensional chemical transport model is described in a technical report,[59] and its associated computer code CHMONE is documented in a user's manual.[60]

Tidal-transient, two-dimensional chemical transport model (CHMTWO) for lakes, estuaries, and coastal regions. The two-dimensional chemical transport model is being developed directly from the two-dimensional thermal model FARTMP by including (1) the discrete-element formulations of the chemical constituents conservation equations and (2) the chemical kinetics models for the power plant chlorination and the hydrolysis of chloramines in the receiving water body, which were already completed for the one-dimensional chemical transport model CHMONE. The general-usage computer code, CHMTWO, of the two-dimensional chemical model will have a structure identical to that of the thermal code FARTMP since the temperature and chemical constituent concentrations are simultaneously calculated in the chemical code. Again, consistent with the practical aspects of the UTA, the site-specific data for the two codes CHMTWO and FARTMP are identical.

In summary, the model development phase of the chemical program was completed during 1976. We are presently developing the chemical kinetics model for chlorinated saline water and applying both the one-dimensional CHMONE and the two-dimensional CHMTWO to actual site-specific problems for model verification based on available data.

Radiological program. The first phase of the radiological program was concerned with the development of fast-transient (within tidal cycle), one- and two-dimensional mathematical models

59. A. H. Eraslan et al., *A Tidal-Transient, One-Dimensional, Discrete-Element Model for Simulating Hydrodynamic, Thermal, and Chemical Constituent Concentrations in Controlled Rivers and Estuaries for Predicting the Effect of Chlorination of Power Plant Discharges*, to be published as an ORNL report.

60. S. K. Fischer et al., *CHMONE: A Computer Code for Simulating Tidal-Transient, One-Dimensional Hydrodynamic, Thermal and Chemical Concentrations in Controlled Rivers and Estuaries for Predicting the Effect of Chlorination of Power Plant Discharges*, to be published as an ORNL TM report.

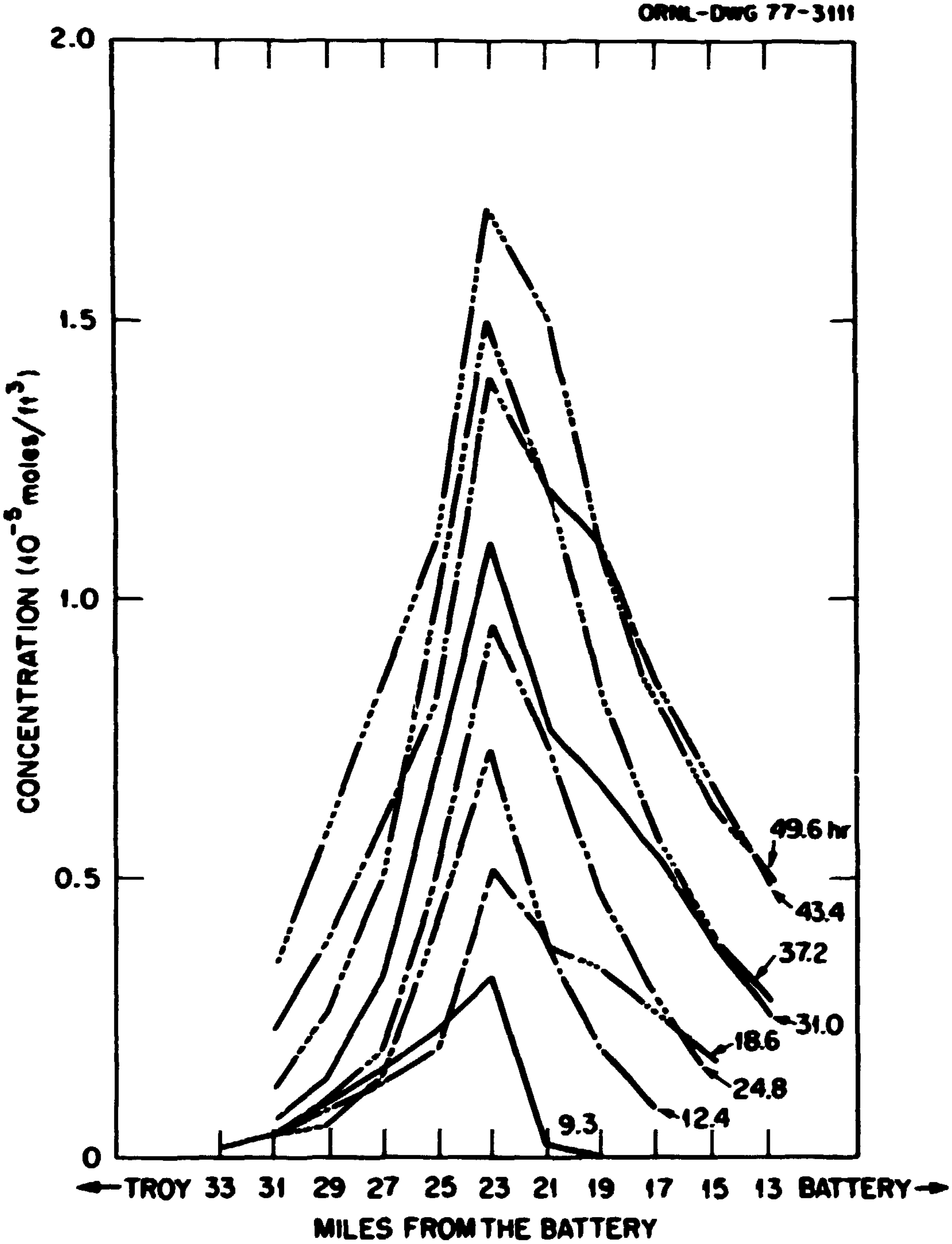

Fig. 2.11. Hypothetical NH_2Cl chlorination concentrations at MP 23 from the Battery in the Hudson River with freshwater flow.

for the transport of dissolved radionuclides in the receiving water body. Because of the significant radionuclide uptake by sediments, the second phase of the program concentrated on developing advanced multisize and multilayer sediment transport models and exchange rate models for describing the transfer between the dissolved and adsorbed states.

Fast-transient, one-dimensional dissolved-radionuclide transport model (RADONE) for controlled rivers and estuaries. The fast-transient, one-dimensional transport model for dissolved radionuclides was derived directly from the already completed and validated thermal model ESTONE by eliminating the temperature part and by converting salinity into radionuclide concentrations. Consistent with the general concept of UTA, the radiological model and its associated computer code, RADONE, were developed according to the general formulation and computer structure of all the existing UTA one-dimensional transport models. The appropriate formulation of the decay rates for the radionuclides was also incorporated in the RADONE model.

The fast-transient, one-dimensional dissolved-radionuclide transport model was applied to various hypothetical problems to study the cumulative radionuclide concentrations released by normal multiplant operation in rivers and estuaries. Model verification has not been completed since detailed field-measured data for dissolved radionuclide concentrations are very limited. A model verification study for the Clinch River in Tennessee was initiated to simulate the hydrodynamic conditions and the longitudinal distributions of the various radionuclides used in the 1967 controlled-release experiments.[61]

The one-dimensional model was also applied to the simulation of hypothetical conditions representative of accidental release scenarios. The radionuclide concentrations in the plant cooling systems were specified as dimensionless unit doses for specified durations. Computer simulation experiments were completed for instantaneous increases in discharge doses more than 10^6 times as great as the normal operational discharge doses for short durations under typical estuarine flow conditions (e.g., Hudson River). In all cases the computer code RADONE was able to predict realistic radionuclide concentration distribution, thus verifying its applicability to site-specific problems.

The mathematical development of the tidal-transient, one-dimensional dissolved radionuclide transport model is presented in a technical document,[62] and its associated computer code RADONE is documented in a user's manual.[63]

Fast-transient, two-dimensional dissolved-radionuclide transport model (RADTWO) for lakes, estuaries, and coastal regions. The two-dimensional model for the transport of dissolved radionuclides was developed directly from the already completed two-dimensional thermal code FARTMP by converting temperature formulations into radionuclide concentrations in water. Consistent with the general concept of the UTA, the mathematical formulation of the dissolved radionuclide model was developed identically to that of the thermal and chemical transport models, and the structure of its associated computer code RADTWO was constructed identically to that of the corresponding thermal code FARTMP and chemical code CHMTWO. The final version of the

61. E. G. Struxness et al., *Comprehensive Report of the Clinch River Study*, ORNL-4035 (April 1967).

62. A. H. Eraslan et al., *A Fast-Transient, One-Dimensional, Discrete-Element Model for Simulating Hydrodynamic Conditions and Transport of Radionuclides in the Water in Controlled Rivers and Estuaries*, to be published as an ORNL report.

63. A. H. Eraslan et al., *RADONE: A Computer Code for Simulating Fast-Transient, One-Dimensional Hydrodynamic Conditions and the Transport of Radionuclides in the Water in Controlled Rivers and Estuaries*, to be published as an ORNL TM report.

dissolved radionuclide transport code RADTWO was computationally optimized; it included the conservation equations for both water mass and radionuclide mass (except for decay) in every discrete element of the flow region.

The two-dimensional RADTWO was applied to various site-specific problems which were also being considered for the application of the two-dimensional thermal code FARTMP for model validation. Since field-measured data for tidal-transient dissolved radionuclide concentrations were not available for any coastal region, the application of the RADTWO was limited to the simulations of various hypothetical operational scenarios under normal and accidental release conditions.

A typical site-specific application of the model to simulate hypothetical accidental release conditions was considered for the San Onofre Nuclear Generating Station. It was assumed that, for two tidal cycles (after start of operation), the plant, operating under normal conditions, released 100 dimensionless units of ^{132}Cs (158.4-hr half-life) in the cooling water system. It was assumed that, at the beginning of the third tidal cycle, an accidental release of 100,000 dimensionless units was continuously added to the cooling water system for a duration of 1.55 hr before the plant was shut down. Direct line-printer plot simulations by the computer code RADTWO for the two-dimensional distribution of ^{132}Cs concentrations in the coastal region are shown in Fig. 2.8 at (*a*) 1.55 hr and (*b*) 24.8 hr (two tidal cycles) after shutdown (see p. 41).

The simulations indicate that, shortly after shutdown (Fig. 2.8*a*), high concentration levels (1500 and 1000 dimensionless units) of dissolved ^{132}Cs could exist in the immediate vicinity of the plant between the discharge location and the shore. These concentrations approximately correspond to a dilution ratio of 80 based on the release concentration of 100,000 dimensionless units. However, 24.8 hr after shutdown, the region containing dissolved ^{132}Cs extends to about a 2.5-mile radius (Fig. 2.8*b*), but the maximum concentration level in the region drops to 25 dimensionless units, which is 25% of the release (100 dimensionless units) occurring under normal operational conditions. As demonstrated by the particular site-specific application, RADTWO can be used to simulate the temporal variation and distribution of dissolved radionuclides as they disperse and decay in a coastal region under tidal flow conditions.

The development of the UTA fast-transient, two-dimensional dissolved-radionuclide transport model is described in a technical report,[64] and its associated computer code RADTWO is documented in a user's manual.[65]

Preliminary transient, one-dimensional adsorbed-radionuclide transport model (HOTSED) for rivers and estuaries. After completion of the fast-transient, one- and two-dimensional dissolved-radionuclide transport models, the research effort in the radiological program was concentrated on modeling the transport of radionuclides adsorbed on the sediment. To study the transport of radionuclides with the sediment, a preliminary computer code HOTSED[66,67] was constructed by combining the hydrodynamic part of the tidal-transient, one-dimensional code

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64. A. H. Eraslan, H. Diament, and R. D. Sharp, *A Fast-Transient, Two-Dimensional, Discrete-Element Model for Simulating Depth and the Transport of Radionuclides in the Water under Specified Flow Conditions in Lakes, Estuaries, and Coastal Regions*, to be published as an ORNL report.

65. A. H. Eraslan et al., *RADTWO: A Computer Code for Simulating Fast-Transient, Two-Dimensional Depth Distribution and the Transport of Radionuclides in Water under Specified Flow Conditions in Lakes, Estuaries, and Coastal Regions*, to be published as an ORNL TM report.

66. D. E. Fields, *LINSED: A One-Dimensional Multireach Sediment Transport Model*, ORNL CSD-15 (October 1976).

67. D. E. Fields, *HOTSED: A One-Dimensional, Tidal-Transient, Discrete-Element Model for Simulating Hydrodynamic Conditions and Adsorbed and Dissolved Radioisotope Concentrations in Controlled Rivers and Estuaries*, ORNL CSD-16 (January 1977).

ESTONE for controlled rivers and estuaries with the existing sediment transport code CHNSED[68] for uniformly flowing rivers. Preliminary results from this model indicated that the transport of adsorbed radionuclides can be modeled on the basis of transport of suspended and bed sediment.

However, since the original sediment transport model CHNSED was applicable only to uniformly flowing rivers, with mathematical formulation and computer code structure totally different from the UTA model for dissolved-radionuclide transport (RADONE), it was impossible to develop an optimized adsorbed-radionuclide transport model consistent with the general concept of the UTA. Therefore, we developed an advanced sediment transport model having capabilities compatible with the other existing one-dimensional models of the UTA program.

Tidal-transient, one-dimensional sediment transport model (SEDONE) for controlled rivers and estuaries. The mathematical development of the new tidal-transient, one-dimensional sediment transport model uses the discrete-element formulation that is completely compatible with the other existing one-dimensional UTA transport models. The hydrodynamic part of the sediment transport model is identical to the common hydrodynamic submodel in thermal ESTONE, chemical CHMONE, and dissolved-radionuclide RADONE transport models. The discrete-element formulation of the sediment mass conservation principles considers multilayers, consisting of a suspended sediment layer, a creeping-bed sediment layer, and the stationary resident-bed sediment layer; each layer contains different particle sizes. The mathematical model simultaneously solves for the concentrations of all the different particle sizes in all three layers for each discrete element by considering both longitudinal transport (according to the general UTA formulation) and vertical transport between sediment layers.

The new one-dimensional sediment transport model, SEDONE, was first applied to the simulation of sediment concentrations along the Hudson River. The limited amount of field-measured data[69] for the sediment discharge in the lower 16-km (10-mile) section of the river was used to adjust the parameter values in the model and to verify the computer simulations. The variation of the sediment discharge rate during a tidal cycle in a cross section about 3.2 km (2 miles) from the Battery was used to select the appropriate values for the model parameters.

With values of all model parameters fixed, on the basis of comparisons of simulations with the field-measured data from the cross section 3.2 km (2 miles) upstream from the Battery, the sediment transport model SEDONE was used to simulate the hydrodynamic conditions and sediment concentrations along the total length of the Hudson River. Comparison of the computer simulations with another set of available field-measured data for the axial velocity and volumetric sediment discharge rate at a cross section 16 km (10 miles) upstream from the Battery is shown in Fig. 2.12. The computer simulations were found to be in excellent agreement with the field-measured data.

The development of the tidal-transient, one-dimensional sediment transport model is presented in a technical report,[70] and its associated computer code SEDONE is documented in a user's manual.[71]

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68. D. E. Fields, *CHNSED, Simulations of Sediment and Trace Contaminant Transport with Sediment/Contaminant Interaction*, ORNL/NSF/EATC-19 (March 1976).

69. F. L. Panuzio, "Lower Hudson River Siltation," pp. 512–50 in *Proceedings of the Federal Inter-Agency Sedimentation Conference 1963*, U.S. Department of Agriculture, Miscellaneous Publication No. 970, June 1965.

70. A. H. Eraslan, D. M. Hetrick, and M. R. Patterson, *A Tidal-Transient, One-Dimensional, Discrete-Element Transport Model for Simulating Hydrodynamic Conditions and Three-Layer, Variable-Size Sediment Concentrations in Controlled Rivers and Estuaries*, to be published as an ORNL report.

71. D. M. Hetrick et al., *SEDONE: A Computer Code for Simulating Tidal-Transient, One-Dimensional Hydrodynamic Conditions and Three-Layer, Variable-Size Sediment Concentrations in Controlled Rivers and Estuaries*, to be published as an ORNL/TM report.

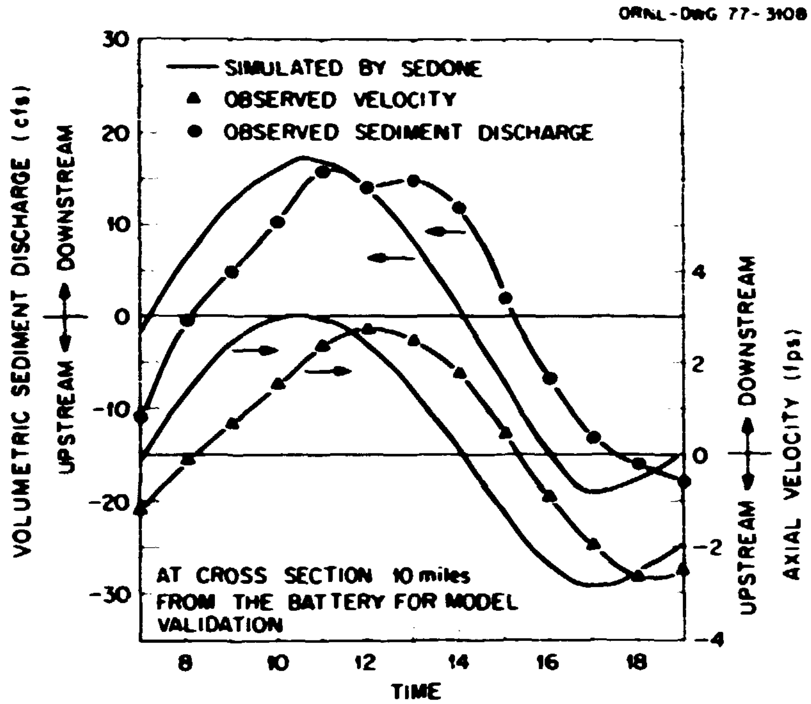

Fig. 2.12. Measured and simulated values of axial velocity and volumetric sediment discharge rates in the Hudson River at a cross section 16 km (10 miles) upstream from the Battery. The time is in hours.

Preliminary model for sediment uptake. The development of a mathematical model that can be used to consider the transport of both dissolved and adsorbed radionuclides requires the formulation of a realistic model for the sediment uptake and release of radionuclides. A preliminary sediment exchange model was developed from nonequilibrium rate constants. The formulation of the exchange rate terms considers both linear and second-order forms for the concentrations of the dissolved and adsorbed states. The values of the exchange rate constants depend on the particular radionuclide and the distribution of particle sizes in water.

A review of the literature clearly indicated that the necessary information about the sediment uptake and release of radionuclides in natural water bodies was not available. Limited data from laboratory experiments run during the Clinch River Study[61] was the most usable information available for the development of the radionuclide exchange model. Results of the applications of the preliminary exchange model to the sediment uptake of ^{90}Sr and ^{137}Cs are shown in Fig. 2.13.

The purpose of this study was to determine the values for the exchange rate constants to be employed in the model for the two radionuclides. Although the calibration aspect of the study was more important than verification of the model, the results of the applications to both ^{90}Sr and ^{137}Cs showed that the agreement between the simulations and the experimental data was acceptable for long durations.

The development of fast-transient, one- and two-dimensional transport models for dissolved radionuclides was completed. A completely new sediment transport model that can be applied to both uniformly flowing rivers and tidal-transient estuaries was developed and validated by field-measured data. We are now developing a fast-transient, one-dimensional radionuclide transport model that will include the important effect of the sediment uptake based on realistic sediment transport and radionuclide exchange models.

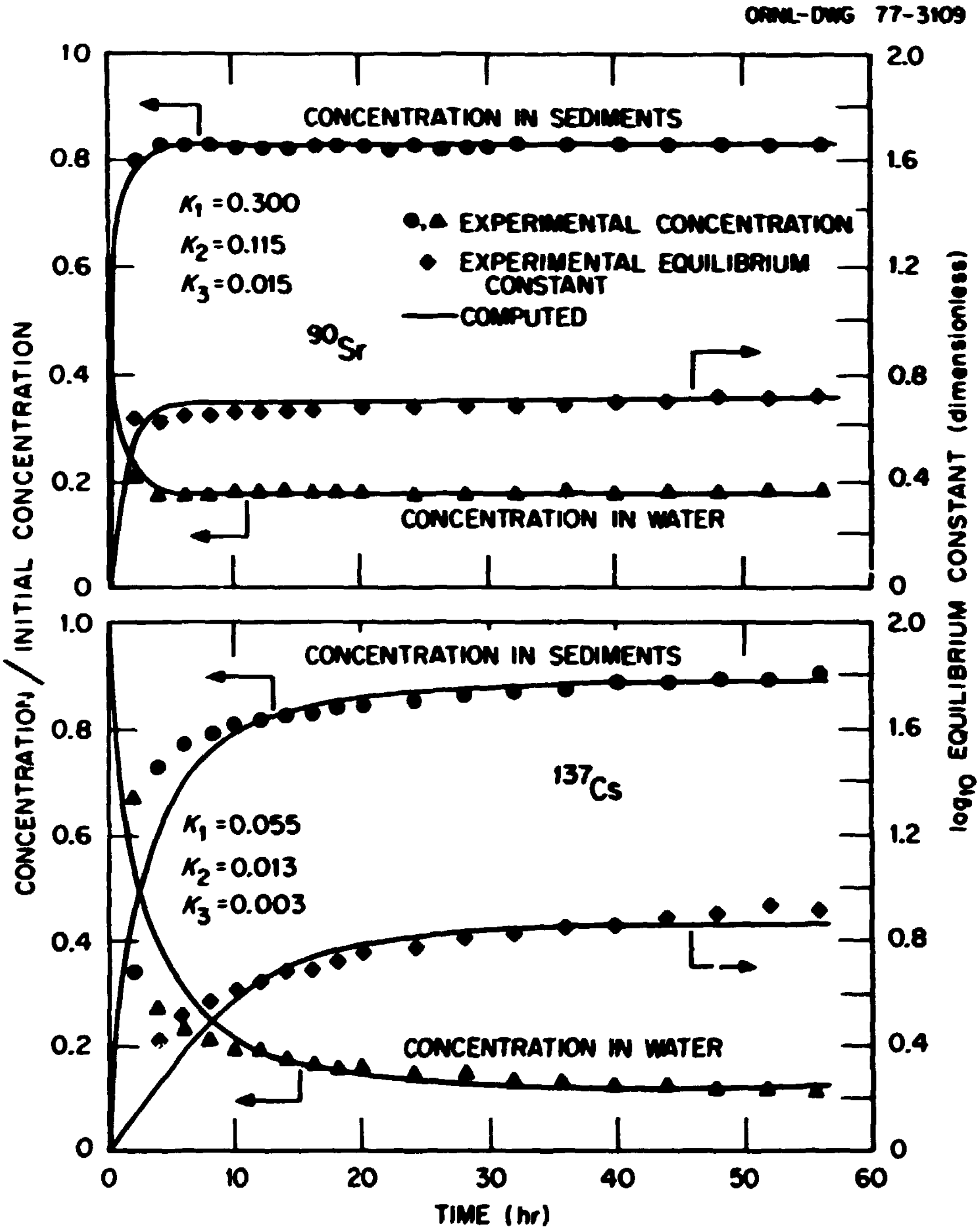

Fig. 2.13. Measured and simulated radionuclide concentrations in water and sediment for the Clinch River.

Zone-matching program. The impact of any effluent discharged into an aquatic environment depends on two fundamental physical phenomena that control its ultimate dissipation: (1) dilution in the near-field zone, which reduces the concentrations of the effluent due to entrainment caused by the momentum of discharge, and (2) the overall diffusion, dispersion, and decay of the effluent in the far-field zone of the receiving water body under the controlling influence of the ambient flow conditions. Associated with these two physical phenomena are two problems that are critical to the assessment of the impact of power plant operations: (1) reentrainment, which could drastically reduce the near-field dilution, and (2) recirculation into the intake structures, which could gradually, but appreciably, increase the discharge concentrations of the effluent. Although their importance is realized,[*] most mathematical models overlook these two problems because of the unavailability of the necessary mathematical methodology that can rigorously and realistically incorporate them in the complete analyses for environmental impact assessments.

A concentrated effort has been directed toward the study of the reentrainment and recirculation problems. During 1976, major accomplishments were achieved in the development of computer simulation models and rigorous mathematical methodologies that can realistically incorporate the effects of reentrainment and recirculation in the complete analyses for the assessment of the power plant impact on aquatic environments.

ORSMAC—a computer simulation model for submerged discharges. The SMAC computer simulation model[72] developed at the Los Alamos Scientific Laboratory was extensively modified to incorporate the required capabilities for simulating reentrainment and recirculation flow fields for submerged discharges under ambient crossflow conditions. Since the basic formulation of the SMAC model considers the conservation of mass and both components of the momentum equations exactly, without simplifying assumptions, the model is not limited by the restrictions of the classical near-field jet models that are used extensively in environmental impact analyses.

Modifications to the SMAC model included mathematical aspects of formulation[73] and changes in the computer code structure to optimize computer run times and storage.

The results of typical printer-plot streak lines are shown in Fig. 2.14 for a submerged turbulent jet discharge into crossflow. The simulations are for a 2.7-m(9-ft)-deep receiving water body having a crossflow velocity of 0.6 m/sec (2 ft/sec). The jet discharge is 1.5 m (5 ft) wide, and the discharge velocity components are 1.5 m/sec (5 ft/sec) vertically and 1.5 m/sec (5 ft/sec) horizontally to represent a 45° discharge. The assumed conditions are representative of the strong crossflows found at submerged discharges that cannot be solved by the simplified jet discharge models commonly used in environmental impact studies. The computer simulations realistically predict all the pertinent hydrodynamic characteristics of the submerged discharge in strong crossflows, including the formation of the surface wave downstream of the discharge location.

Preliminary simulations of the submerged discharges by the ORSMAC code clearly demonstrated the capability of the model to predict the hydrodynamic conditions in shallow receiving water bodies. Our continuing effort is directed toward applications of the model for validation based on field-measured data and laboratory experiments.

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72. A. A. Amsden and F. H. Harlow, *The SMAC Method: A Numerical Technique for Calculating Incompressible Fluid Flows*, Los Alamos Scientific Laboratory Report LA-4370 (May 1970).

73. C. W. Hirt, B. D. Nichols, and N. C. Romero, *SOLA—A Numerical Algorithm for Transient Fluid Flows*, Los Alamos Scientific Laboratory Report LA-5852 (April 1975).

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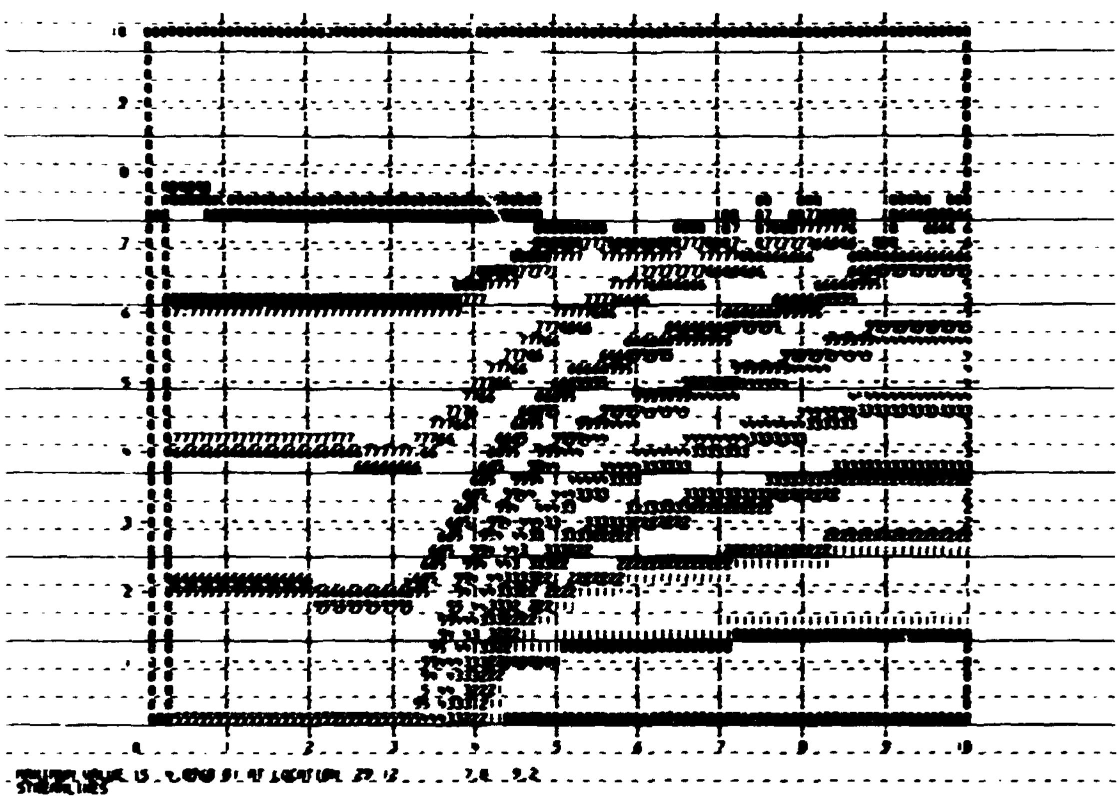

Fig. 2.14. Submerged turbulent jet discharge into crossflow calculated with ORSMAC. Discharge velocity is 1.5 m/sec (5 ft/sec) vertically and 1.5 m/sec (5 ft/sec) horizontally into 2.7 m (9 ft) of water at a crossflow velocity of 0.6 m/sec (2 ft/sec). Each stream line is marked by a string of identical digits; the fluid flow is tangent to the stream lines. The numbers indicate the local relative magnitude of the stream function. The liquid surface is marked by the irregular horizontal string of 0's.

The mathematical aspects of the ORSMAC model and its associated computer code are presented in a technical report.[74]

Systematic methodology for matching near- and far-field analyses based on uniformly valid singular perturbation theory. The preliminary studies in this part of the program were concentrated on developing the fundamentals of zone-matching methodology. The purpose was not to extend available methods but to attempt to solve some of the most critical problems encountered in the assessment of power plant impact.

The fundamentals of the zone-matching methodology were based on the "uniformly valid singular perturbation theory."[75] Study of other singular perturbation methods based on asymptotic expansions with limit-matching principles clearly indicated the superiority of the selected method.

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74. J. F. Park, K. E. Cross, and A. H. Eraslan, *ORSMAC – An Algorithm to Calculate Fluid Circulation Patterns in the Vicinity of a Submerged Jet*, K/CSD-4 (January 1977).

75. A. H. Eraslan and J. A. Benek, paper presented at the 5th SECTAM Conference, Raleigh, North Carolina, April 1970; published in *Developments in Theoretical and Applied Mechanics*, G. L. Rogers (ed.), vol. 5, p. 819, 1971.

The preliminary mathematical development was limited to two-dimensional formulations in relatively simple geometrical regions for the sake of brevity in the presentation of general theory.

The significant feature of the new singular perturbation methodology is that its near- and far-field perturbational systems can use precisely the same mathematical techniques for the jet discharges and the potential flow feeds that are commonly used in power plant impact analyses.

The general zone-matching methodology was first applied to the simulation of hydrodynamic conditions from a vertical submerged discharge under different crossflow conditions. This problem is significant because the submerged diffuser design is considered to be one of the best heat dissipation systems for coastal regions. A typical computer simulation with moderate crossflow conditions is presented in Fig. 2.15. The results clearly indicate the existence of two vortices that cause reentrainment and, hence, reduced dilution in the near field. The existence of the two vortices quantitatively verifies the qualitative argument presented in ref. 76. The results from the zone-matching methodology are qualitatively similar to those from the direct computer simulations by the ORSMAC code.

The methodology was also applied to the simulation of flow conditions in a cooling pond. This problem is distinctly different from the vertical submerged diffuser conditions since the discharge is horizontal, the pond is completely bounded, and the intake is included in the flow region. Results of a typical application are shown in Fig. 2.16.

The simulations clearly illustrate (1) the reentrainment effect as two vortices appearing both above and below the discharge relative to the location of the intake and (2) the reduction in direct recirculation due to the jet entrainment from the intake side of the discharge. Hence, the application of the zone-matching methodology clearly predicts the correct behavior of flow conditions in the cooling pond.

The mathematical development of the singular perturbation theory and the results of the preliminary applications of the zone-matching methodology are presented in a technical report.[77]

In summary, the zone-matching program accomplished the initial development of the urgently needed mathematical models for analyzing the reentrainment and recirculation problems that are critically important in the assessment of power plant impact on aquatic environments. Our current work is directed toward the applications of both the computer simulation code ORSMAC and the zone-matching methodology to site-specific problems for model validation based on available, field-measured hydrodynamic and temperature data from actual operational power plants.

Biological program. The biological program is supported by the National Power Plant Team, Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, and by the Office of Nuclear Reactor Regulation, NRC.

The overall research task includes the development of tidal-transient, one-, two-, and three-dimensional biological transport models consistent with the general concept of the UTA. These models are being developed simultaneously with the UTA thermal, chemical, and radiological transport models. Some of the complex biological models also include the thermal and chemical transport models in their general formulations to determine the dependence of the physiological and behavioral characteristics of various biota on the physical conditions in aquatic environments.

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76. G. H. Jirka, G. Abraham, and D. R. F. Harleman, *An Assessment of Techniques for Hydrothermal Prediction*, Department of Civil Engineering, Massachusetts Institute of Technology Rep. No. 203 (1975).

77. A. H. Eraslan, J. E. Akin, and A. K. Atakan, *A Uniformly Valid, Singular Perturbation Theory for Zone-Matching of the Near-Field and Far-Field Analyses Employed in the Assessment of Power Plant Impact*, to be published as an ORNL report.

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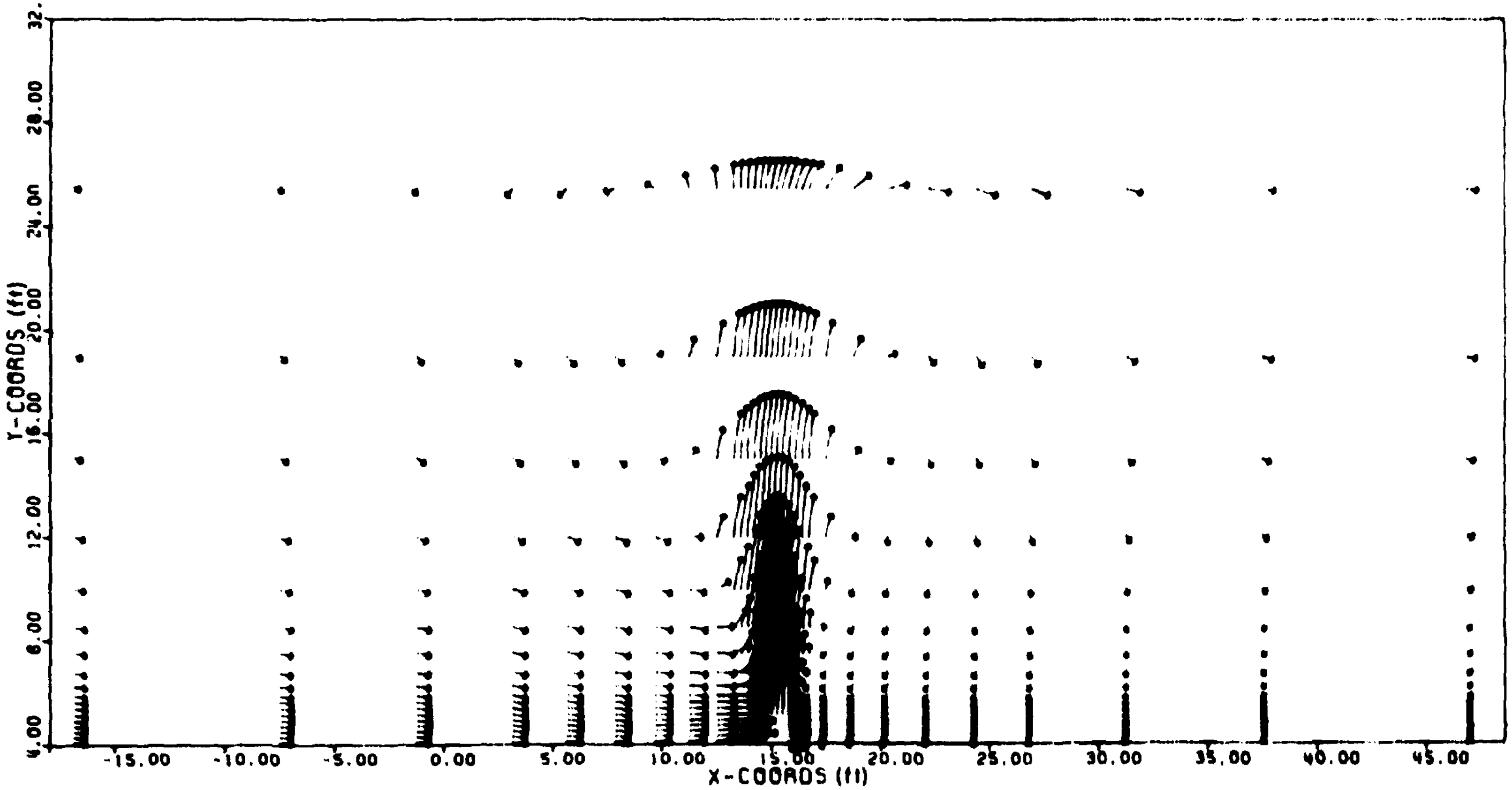

Fig. 2.15. Perturbational zone-matching simulation of vertical discharge under moderate crossflow.

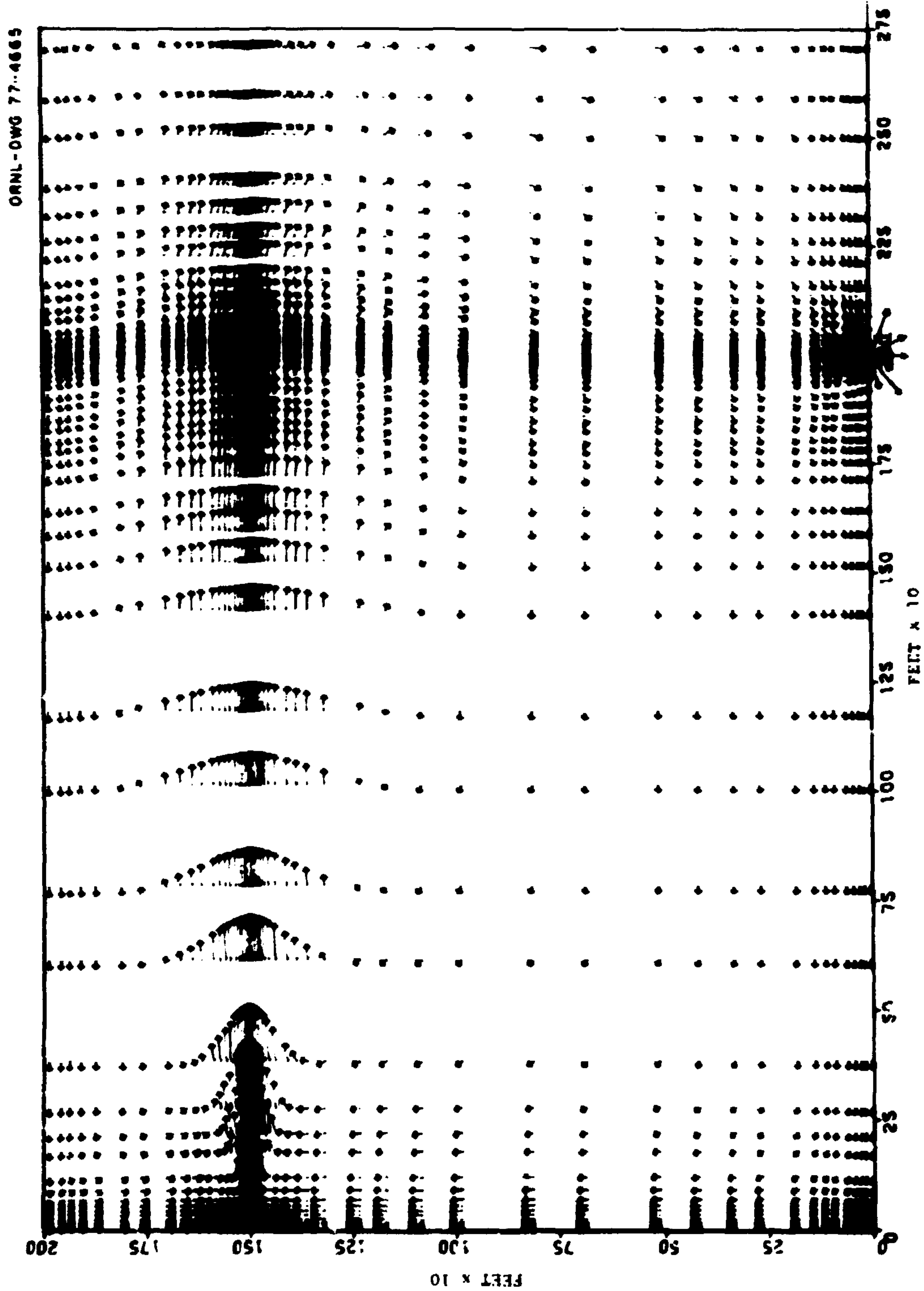

Fig. 2.16. Perturbational zone-matching simulation of horizontal discharge in a rectangular cooling pond.

The preliminary applications of the biological transport models are mainly concerned with the striped bass young-of-the-year populations in the Hudson River. The results of these studies are presently being prepared for presentation as scientific reports and publications.

2.3 ENVIRONMENTAL STATEMENTS AND ASSESSMENTS FOR OAK RIDGE OPERATIONS OFFICE OF ERDA

J. W. Boyle

2.3.1 Environmental Analysis for ERDA-ORO Facilities

The Environmental Impact Section manages and coordinates environmental impact assessments and statements on request by ERDA-ORO. One of these is the preliminary draft environmental analysis of Oak Ridge Operations, which was released for internal review in 1975. The analysis, which was described in the 1975 annual report,[78] includes detailed descriptions of ORNL, the Oak Ridge Gaseous Diffusion Plant (ORGDP), Y-12, and other smaller ERDA facilities in Oak Ridge. During 1976, the activity on this document was confined to editorial modification because of the high priority assigned to other activities. Similar analyses also are to be prepared for the Paducah Gaseous Diffusion Plant in Kentucky and the National Lead Company of Ohio plant in Fernald, Ohio. The ORNL staff has made site visits to Paducah to assist in planning the monitoring programs, which will be started early in 1977.

2.3.2 Portsmouth Gaseous Diffusion Plant Expansion

H. F. Bauman[79]	R. C. DeVault[82]	R. J. Raridon[81]
L. Berry	H. Diament[82]	J. L. Rich[84]
J. W. Boyle[80]	C. Kleinstreuer	W. Staub[82]
L. J. Costomiris	L. Martin[82]	J. S. Suffern[81]
C. C. Coutant[81]	H. A. McLain	F. G. Taylor[81]
R. B. Craig[81]	B. D. Murphy[83]	D. C. West[81]

In July 1975 the ORNL staff (with personnel from ORGDP and Goodyear Atomic in Portsmouth) began to evaluate the potential environmental impacts of construction and operation of a large [8.75 million separative work units (SWU)] expansion of the existing Portsmouth Gaseous Diffusion Plant site. The resulting environmental statement considered in detail the potential impacts on land and water use, ecology, and local socioeconomics. Consideration of this added uranium enrichment capacity is the so-called ERDA hedge plan to get needed enrichment capacity on line if, as appears probable, private

78. J. R. McWherter, *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 91–94.
79. Engineering Technology Division.
80. Task group leader.
81. Environmental Sciences Division.
82. Consultant.
83. Computer Sciences Division.
84. Information Division.

enrichment is not authorized by Congress. The PDES was issued in December 1975. The DES was issued in June 1976[85] and is currently being reviewed by other federal agencies; the FES will be issued in April 1977.

In October ERDA requested the assistance of ORNL in preparing an assessment of the environmental impact associated with continuing operations at the Portsmouth plant; the assessment assumed a time frame of 1981, which is the expected date of major additions to the Portsmouth plant. Goodyear Atomic Corporation, relying heavily on the Portsmouth DES, was to prepare the Portsmouth Gaseous Diffusion Plant sections.

The major task for ORNL was to prepare sections on the power-generating facilities that supply electric power to the Portsmouth Gaseous Diffusion Plant. The Portsmouth plant, which has been operating since 1955, uses electricity primarily from two dedicated coal-fired electrical generating stations—Clifty Creek Power Plant (1304 MW) near Madison, Indiana, operated by Indiana-Kentucky Electric Corporation and Kyger Creek Power Plant (1086 MW) near Gallipolis, Ohio, operated by Ohio Valley Electric Corporation. The 350-MW additional energy required to put the Cascade Improvement and Upgrading Programs (CIP-CUP) on stream in 1981 will be obtained from an eighteen-company grid and is treated in a generic sense. A team was assembled, and the site visit, data collection, and writing were completed in less than three months.

In our contribution, we described the existing environment (geology, hydrology, meteorology, and terrestrial and aquatic ecology) for Clifty and Kyger Creek plants; sections on the social profile, land and water use, and registered landmarks were included. The potential environmental impacts from continued operation of these power plants and the additional 350 MW from the regional power grid were assessed with respect to water and air quality, heat dissipation to the Ohio River, terrestrial and aquatic ecology, social effects, transmission lines, and accidents.

In addition to examining the impacts of continuing the present Portsmouth plant and Clifty-Kyger relationship, we also studied the impacts of (1) shutting down the Portsmouth plant and allowing the utility to sell Clifty and Kyger power, (2) continuing Portsmouth operation with the Clifty and Kyger operation integrated into the utility system (rather than being 100% dedicated); (3) continuing Portsmouth operation with power coming from other utilities; and (4) continuing Portsmouth operation with power coming from a newly built plant. All four alternatives for electricity supply were determined to be more costly, less desirable, or not significantly different from the proposed plan. Alternative subsystems to the two existing plants were also considered.

2.4 VERY HIGH TEMPERATURE GAS REACTOR ENVIRONMENTAL IMPACTS ASSESSMENT

C. D. Bauman   E. L. Compere[86]
C. J. Barton[81]   S. B. Gough[81]

The industrial use of nuclear reactors as a source of process heat has been considered for some time.[87] The work is sponsored by the Environmental Effects Branch of the ERDA Division of Reactor Research and Development.

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85. Energy Research and Development Administration, *Draft Environmental Statement, Portsmouth Gaseous Diffusion Plant Expansion*, ERDA-1549, June 1976.

86. Chemistry Division.

87. I. Spiewak et al., *Assessment of Very High-Temperature Reactors in Process Applications*, ORNL TM-5242 (November 1976).

The study of the environmental effects of using a modified General Atomic–type high-temperature gas-cooled reactor as a process heat source has been completed; a final report will be issued in early 1977. The reactor studied has a 1600° F primary coolant (helium), which is used as a source of process heat for the 1400° F steam–methanation reformer step in a hydrogen-producing plant (via hydrogasification of coal liquids).

A detailed examination of the fuel and operating characteristics of the reactor was made, and the fission product activity in the primary coolant was calculated as a function of helium purification system flow. Numerous purification system turnover times (3.75 to 15 hr) were considered; the turnover time was defined as the active primary helium inventory/helium purification system flow rate. Noble gas activities in the primary coolant were predicted to be about 1 × 10^4 Ci for a 5-hr turnover time. Iodine and tritium concentrations in the primary coolant were also calculated.

The primary consideration in the study was the utility of an intermediate heat exchanger (IHX) between the reactor and the process. If no IHX is used, it is possible for the plant product to become contaminated if fission products leak from the primary system or if tritium diffuses through the walls of the reformer into the product stream. Conservative assumptions were applied in determining the product contamination (no IHX) and the doses to the general public resulting from product use.

Of the many possible uses of the product, the one that may give the highest dose rate to people would be using the product gas with natural gas (a 50:50 mixture is proposed) in unvented kitchen ranges in the home. Such use will expose occupants of the home to an estimated 0.0002 millirem of fission products per year. Since this exposure is only about 0.0002% of the average dose to citizens of the United States from background radiation, the hazard from this use appears negligible. Tritium dose in a similar situation is slightly higher (0.006 millirem per year), but is still very small in comparison with natural hazards.

The results of the study indicate that the IHX is not cost-effective in reducing radiation exposures resulting from product contamination by fission products, activation products, or tritium.

2.5 ENVIRONMENTAL STATEMENT FOR MODULAR INTEGRATED UTILITY SYSTEMS PROJECT

W. J. Boegly, Jr.[81] B. J. Dozier[81]
J. W. Boyle[80] R. E. Gant[82]
W. D. Mixon

The MIUS is a small onsite utility concept for providing electricity, heat, water, sewage treatment, and solid waste disposal to a small community (see Sect. 4.4). A MIUS demonstration plant, now in the conceptual and preliminary design stage, is to be constructed in St. Charles, Maryland; startup of the finished plant is scheduled for June 1979. The ORNL staff is responsible for (1) writing an environmental impact statement for the demonstration plant and (2) evaluating the environmental effects of construction and operation phases of the MIUS.

St. Charles is a new planned community for 72,000 people in Charles County located about 25 miles southeast of Washington, D.C. The city of St. Charles encompasses 3240 ha (8000 acres) and, when fully developed, will consist of five villages containing about fifteen neighborhoods; each neighborhood will have its own recreational center including tennis courts and swimming pool. Each neighborhood will have its own primary school, and each village will have a junior and senior high school. An 18-hole golf course has been constructed and is managed by the county recreation department. Land use is balanced among residential, commercial, industrial, community, and recreational areas.

The MIUS service area will encompass about 130 acres and will include the commercial area in the Smallwood Village portion of St. Charles and more than 700 nearby dwelling units accommodating about 2000 people.

Goals of the MIUS are to reduce energy consumption, conserve natural resources, and minimize environmental impact—all at a reduced total cost to the nation for utility services. It is estimated that the thermal efficiency will vary between 50 and 65% during the year, thereby reducing total energy consumption and conserving fossil fuel as compared with conventional systems.

Water is a critical natural resource in southern Maryland, and reuse of the treated wastewater is consistent with one of the objectives of MIUS (i.e., conserving Maryland's resources). It is anticipated that the wastewater will be used to irrigate the nearby golf course, which has a great need for water at the present time. A sensitive natural area, the Zekiah Swamp, lies to the east of the golf course; the State of Maryland will not permit any surface runoff of this wastewater into the Zekiah Swamp. One task of the ORNL team is to evaluate the impact on Zekiah Swamp.

Monitoring necessary to evaluate impacts of the MIUS is outlined in a plan that has been presented to HUD-NBS (National Bureau of Standards). This monitoring plan describes the effects expected from the MIUS operation, lists the data needed to evaluate these effects, suggests the instrumentation and analytical techniques to be used, and states how the data will be used to evaluate the impact. The environmental statement will be prepared in the coming year when the initial design work on the MIUS plant is completed.

2.6 GEOTHERMAL ENERGY ENVIRONMENTAL PROJECT

H. G. Arnold[88]

Rob Nicholas	L. H. Stinton[91]	R. M. Cushman[89]
J. P. Baker[89,90]	W. R. Williams[91]	G. W. Suter[89]
R. B. Craig[89]	W. P. Staub[92]	E. G. St. Clair[91]
B. J. Dozier[89]	R. W. Brocksen[89]	

The ERDA Division of Geothermal Energy (DGE) accepted ORNL's proposal to prepare environmental assessments and statements for their geothermal activities at the programmatic level and for specific projects. The DGE currently is funding geothermal projects covering (1) resource development and utilization, (2) equipment development, and (3) regional planning and coordination for energy development. At the time that work started in March 1976, environmental assessments covering these three programmatic areas were to be prepared under one of three subprograms based on resource type—hydrothermal, geopressure, or hot dry rock.

2.6.1 Environmental Impact Assessments for ERDA Geothermal Programs

The DGE must initially prepare programmatic environmental assessments in accordance with 10 CFR 711 for the Geothermal Research, Development, and Demonstration Program; programmatic environmental impact statements will be required as each subprogram progresses. Thus, we will prepare

88. Project manager.
89. Environmental Sciences Division.
90. Now at Cornell University.
91. Engineering Division.
92. Consultant, University of Tennessee.

a hydrothermal, a geopressure, and a hot dry rock programmatic assessment, each due at different times to correspond with the level of activity in each subprogram, followed by an environmental impact statement of each, also at staged intervals.

Hydrothermal programmatic assessment. The DGE Hydrothermal Subprogram has been funded at a higher level than the other two subprograms because of the more advanced state of the technology associated with that resource type. The draft hydrothermal environmental assessment was prepared for DGE review in November 1976.[93]

The hydrothermal assessment included the western United States, Alaska, and Hawaii. Hydrothermal resource regions were defined on the basis of similarities of geology, ecology, and climatology associated with the geothermal resources; definition of the eleven regions simplified the assessment of environmental effects by (1) restricting the study to areas in which geothermal hydrothermal systems may occur and (2) grouping such areas into ecologically similar groups.

Geopressure programmatic assessment. Geopressured resources consist of geothermal water at higher-than-normal pressure. Presently known resources occur along the Texas–Louisiana Gulf Coast. The goal of the DGE Geopressure Subprogram is to develop technological, environmental, and societal activities to encourage the use of geopressured resources. Because the degree of resource development is considerably less for geopressure than for hydrothermal sources, this subprogram will receive a lower rate of funding until certain technological goals are achieved. A first draft of the programmatic assessment was prepared and transmitted to DGE in October 1976.[94]

Hot dry rock programmatic assessment. The Hot Dry Rock Subprogram of DGE will also be funded at a lower level than the Hydrothermal Subprogram until technological developments to justify more rapid growth are completed. The environmental assessment for this subprogram was started in 1976, but a draft has not yet been completed. Because the hot dry rock geothermal resource almost covers the western United States, the region to be assessed is quite extensive; however, the state of development of hot dry rock utilization is such that only sketchy environmental analyses will be possible. Therefore, at this time, the assessment will require less effort than will the hydrothermal assessment. As with the hydrothermal resource, hot dry rock resource regions have been defined; these are basically enlargements of the hydrothermal resource regions since there is a close correlation between hot dry rocks and hydrothermal occurrences.

2.6.2 Environmental Impact Assessments for ERDA Geothermal Projects

The DGE has requested ORNL to prepare environmental assessments for two specific projects: (1) the well flow test for the Hawaii Geothermal Project and (2) the Coso Geothermal Project at the Naval Weapons Center in California. The Hawaii Geothermal Project is a completed well that requires an environmental assessment prior to the flow testing phase necessary to analyze the reservoir characteristics. The Coso Geothermal Project is an evaluation of slim-hole (less than 13-cm-

93. Energy Research and Development Administration, *Draft Environmental Assessment of the Hydrothermal Subprogram of the Division of Geothermal Energy*, November 1976.

94. Energy Research and Development Administration, *Draft Environmental Assessment of the Geopressure Subprogram of the Division of Geothermal Energy*, October 1976.

diam) drilling as an exploratory tool for hot dry rocks; several slim holes are to be drilled on Naval Weapons Center land near Coso Hot Springs, California. A final assessment of each project has been submitted to the DGE for comment.[95,96]

2.6.3 Geothermal Loan Guaranty Program Assessment

In addition to the DGE activities, ERDA supports geothermal research and development through the Geothermal Loan Guaranty Program (10 CFR 790), in which qualified applicants receive ERDA guaranties for commercial loans. The ORNL staff is preparing the environmental assessments and statements required by 10 CFR 711 and 10 CFR 790 under a cooperative agreement between DGE and the San Francisco Operations Office of ERDA, which is managing the Geothermal Loan Guaranty Program. We have participated in meetings with prospective applicants, made site visits, and started writing one environmental assessment (Honey Lake, California) for a loan guaranty project.

2.7 FOSSIL ENERGY ENVIRONMENTAL PROJECT

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J. N. Baird[97]	D. Kumaraswamy[98]	R. D. Roop[98]
L. W. Barnthouse[98]	D. W. Lee	M. S. Salk[98]
H. M. Braunstein	B. D. Murphy[98]	F. S. Sanders[98]
R. J. Haynes[98]	R. G. S. Rao	D. J. Wilkes[99]
D. L. Kaserman	L. W. Rickert[99]	

The newly funded Fossil Energy Environmental Project represents a significant change in the scope and direction of the Environmental Impact Section. One year ago the section was engaged almost entirely in nuclear assessments and received virtually 100% of its funding from the NRC and ERDA-ORO. Although the work with nuclear plants still remains dominant, about 25% of FY 1977 funding will be earmarked for nonnuclear assessments; funding for fossil energy assessments will account for about 80% of this amount.

The ORNL staff will provide ERDA, Fossil Energy (FE) Division, Major Facilities Project Management (MFPM), with an environmental support program consisting of seven major tasks:

1. To prepare environmental assessments and programmatic statements for the technologies to be demonstrated.
2. To prepare site-specific environmental impact statements for demonstration plants.
3. To prepare an environmental monitoring handbook which will be revised periodically and will guide contractors in establishing environmental and socioeconomic monitoring programs.
4. To investigate landfill disposal of solid wastes from coal conversion plants and other environmental problems associated with demonstration plants.

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95. Energy Research and Development Administration, *Environmental Assessment of the Hawaii Geothermal Project Well Flow Test Program*, November 1976.

96. Energy Research and Development Administration, *Environmental Impact Assessment of the Coso Geothermal Project*, January 1977.

97. Consultant.

98. Computer Sciences Division.

99. Information Division.

5. To provide technical assistance to ERDA-FE-MFPM.
6. To develop a three-part document to be included in requests for proposals (RFP) that will describe for the potential contractor the environmental factors to be addressed in initial responses, requirements for environmental reports, and the continuing environmental responsibilities of the contractor.
7. To perform various information functions within the Fossil Energy Environmental Project and for ERDA-FE-MFPM.

To date, task 6 has been completed, and several short-term technical assistance projects (task 5) have been completed.

Part 1 of the document described in task 6 discusses the factors that should be addressed by the contractor to show that he has considered environmental matters in the initial project plans and that he has used, or will use, environmentally sound criteria for site selection. Part 1 also tells the contractor how to demonstrate that environmental protection will be considered during the planning process, plant construction, and plant operation.

Part 2 describes the contractor's initial responsibilities if awarded a contract from ERDA. The contractor will be required to plan and implement a monitoring program to collect baseline data for predicting the beneficial and adverse impacts of constructing and operating the proposed facility. The contractor will submit to ERDA an environmental report of sufficient detail that ERDA can fulfill its requirements under NEPA to prepare an environmental impact statement. Preparation of the environmental report will require a complete analysis by the contractor of the interaction between the proposed demonstration facility and the prevailing natural and socioeconomic environment.

Finally, part 3 describes ongoing environmental monitoring and impact assessment for which the contractor will be responsible during construction and operation. The purpose of this requirement is to determine which, if any, adverse or beneficial environmental impacts have occurred; those that are postulated prior to the project and those which are unsuspected are to be included. This consideration includes a possible need for mitigating adverse impacts as they are encountered during the construction and operational phases of the demonstration plant activity. The contractor must operate the plant in compliance with all federal, state, and local laws and regulations, and he should be aware of ongoing research which may affect the project.

2.8 U.S. ARMY, NEW YORK ENGINEER DISTRICT STUDY OF THE EFFECTS OF POWER PLANT OPERATION ON THE HUDSON RIVER

T. H. Row   H. A. McLain
S. W. Christensen[100]   B. D. Murphy[102]
A. H. Eraslan[101]   W. Van Winkle[100]

The ORNL staff is analyzing power plant operation on the Hudson River, giving special emphasis to the Bowline Point Generating Station. The study, to be published in early 1977 as an ORNL report,[103] will serve as a major reference source to the New York Engineer District and Mitre Corporation, who

100. Environmental Sciences Division.
101. Consultant, University of Tennessee.
102. Computer Sciences Division.
103. S. W. Christensen et al., *A Selective Analysis of Power Plant Operation on the Hudson River with Emphasis on the Bowline Point Generating Station*, to be published as an ORNL report.

will be preparing an environmental impact statement on this subject. The ORNL study will consider all operating and planned power plants on the Hudson River between the 59th Street and Albany power plants. Particular emphasis will be accorded the Bowline and Roseton fossil-fired power plants because of their larger size (2440 MWe) as compared with other operating fossil-fired units (1632 MWe). The nuclear units at Indian Point are included in the analysis.

Three major considerations will be examined in detail: (1) assessment of the thermal impact; (2) assessment of the entrainment and impingement losses to the striped bass young-of-the-year in the Hudson River; and (3) assessment of the air quality impact.

The thermal impact assessment will include near- and far-field analysis of the thermal discharge from the power plants. Actual geometry data, design details, estuary flow data, and atmospheric conditions will be used in the analysis. Detailed consideration of the near-field effects will be made for the Bowline and Roseton Plants, whereas the far-field analysis will incorporate all plants on the Hudson River.

Existing computer simulation models will be used to assess the entrainment and impingement losses to the striped bass population; the models will analyze (1) distribution of striped bass eggs, larvae, and juveniles in the Hudson River; (2) compensation in the Hudson River striped bass population; (3) forecasts of percentage reduction in the number of young-of-the-year striped bass due to power plant operation; (4) forecasts of the subsequent impact on the Hudson River striped bass population; and (5) zone and degree of influence of the Hudson River striped bass populations.

Air quality investigations will include effects of the cooling towers currently planned as well as the sulfur dioxide and particulate releases.

3. Regional and Urban Studies Section

R. M. Davis

3.1 INTRODUCTION

During FY 1976 the Regional and Urban Studies (RUS) Section focused its attention on the analysis of national and regional effects of energy development and use. The section's work has evolved in recent years from a heavy emphasis on basic studies and methodology development to its current emphasis on the analysis and assessment of the social, economic, and environmental effects of energy-related developments. Much of this current work is funded by the Regional Studies Program (RSP), Division of Technology Overview (DTO), Energy Research and Development Administration (ERDA). Other portions of the section's work are funded by the Nuclear Regulatory Commission (NRC), Department of Commerce, Water Resources Council (WRC), and other federal and regional agencies. A major accomplishment in 1976 was the publication of several reports documenting the extensive work performed in earlier years under the Regional Environmental Systems Analysis (RESA) Program of the National Science Foundation.

A key objective of the section is to design and conduct regional integrated assessments that can be used to help balance social, economic, and environmental goals with energy development goals. An example is our participation with other national laboratories in the National Coal Utilization Assessment sponsored by the ERDA-DTO-RSP. The overriding objective of this program is to identify on a regional and national basis the range of environmental, social, and economic effects that are likely to result from various strategies for coal development and use. Particular emphasis in the assessment is given to new technologies and to the identification of any significant problems that will need to be solved before widespread development and use of these new technologies will be acceptable.

The National Coal Utilization Assessment is an example of the type of regional integrated assessment performed by the RUS section; our general approach is shown in Fig. 3.1. We begin by selecting existing accepted national energy scenarios for deriving future energy needs for large regions (several states) as well as smaller regions [generally Bureau of Economic Analysis (BEA) areas]. From a characterization of available and future energy technologies, a plausible technology mix that would meet future regional energy requirements is selected. The social, economic, environmental, and energy technology characteristics of the region are used to develop criteria for siting future energy resource developments and energy facility locations. These criteria are applied to the regional resource base to develop candidate areas for facility location and patterns for future resource development. These patterns are used to conduct the social, economic, and environmental assessments which are integrated into comprehensive regional assessments. Where significant regional impacts are identified, the siting criteria, technology mixes, or both may be modified to minimize the effects on these regional systems. A more detailed discussion of the ORNL approach to regional integrated assessments is provided later in this chapter.

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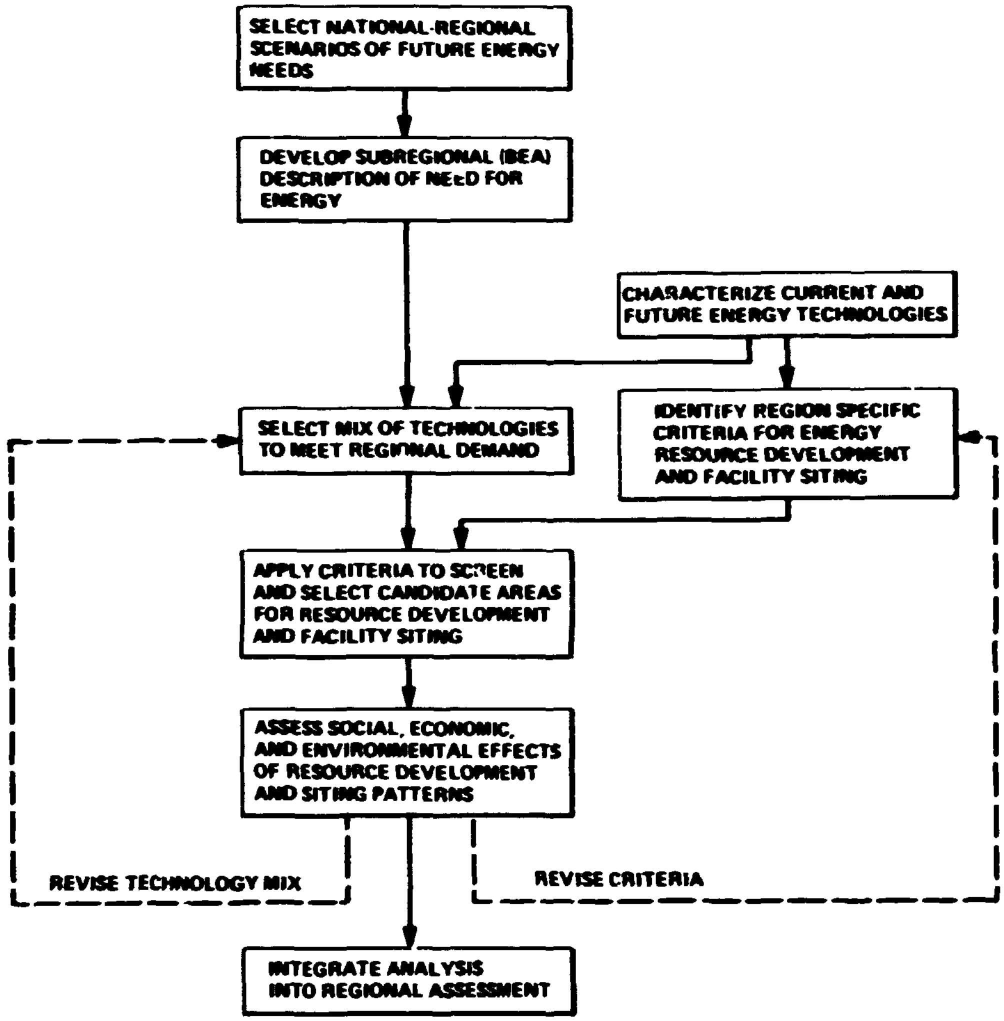

Fig. 3.1. ORNL approach to regional integrated assessments.

The ORNL portion of the current coal assessment focuses on the South; other national laboratories are focusing on their respective regions of the country. Argonne National Laboratory (ANL) is serving as program manager for the assessment. The coal assessment is designed to provide key information to ERDA administrators on the potential side effects of coal development and technologies on a regional basis. The assessment will also provide useful information to state and regional decision makers and industries. Although our current assessment focuses only on coal, we expect future national and regional assessments to focus on nuclear, solar, geothermal, and other fuel types.

Within this assessment, we are proceeding along two paths: (1) to develop new components of assessment methodology where existing procedures are inadequate or absent and (2) to make assessments with the methodologies presently available. Because each area enriches the other, we deliberately attempt to maintain a balance between our efforts of research and application.

Several additional projects have been active in the RUS section during FY 1976. The Regional Economic Analysis Group, under sponsorship of the ERDA-DTO-RSP, has developed an energy profile of the South for 1972 that provides a description of typical energy production, consumption, and transportation patterns for each state in the region. An ongoing effort sponsored by the Economic Development Administration has been directed at determining the availability and consumption of various energy types and developing related energy data bases at the BEA level.

The Resource Analysis Group, under a project sponsored by NRC, has developed and applied a land use screening procedure that was used to identify candidate areas for future nuclear power plant development in northern Maryland. A program sponsored by ERDA-DTO assessed the availability of Appalachian coal resources in terms of the reserves and potential environmental impact of coal resource development. In a project sponsored by the Electric Power Research Institute (EPRI), a model was developed to calculate volumes of coal reserves and specific mining costs. The WRC has sponsored an ongoing program to assess the impacts of future nonnuclear energy development on water throughout selected water resource regions in the eastern United States. In a related program, sponsored by ERDA-DTO and the Ohio River Basin Commission (ORBC), we are assessing the effect of future energy development on water availability and water quality in the Ohio River Basin.

The Social Impact Analysis Group, under an ongoing ERDA-DTO sponsorship, has been analyzing the social effects of alternative energy-generating technologies. In related work sponsored by NRC, the effects of construction and operation of nuclear facilities on communities and surrounding regions have been analyzed. Members of this group have also prepared and reviewed parts of environmental impact statements and participated in several hearings as part of the NRC licensing process for nuclear power plants.

The Data Management and Analysis Group, under continuing sponsorship from ERDA's Division of Transportation Energy Conservation, prepares an annual summary of statistical information on energy use in various transportation sectors. Through a program sponsored by the ERDA Office of Environmental Information Systems, this group maintains the Regional and Urban Studies Information Center (RUSTIC), which provides socioeconomic data to public and private agencies.

3.2 REGIONAL ECONOMIC ANALYSIS GROUP

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H. W. Herzog[4,5] P. L. Rice[2]
C. R. Kerley[2] D. P. Vogt[7]
R. A. Nakosteen[4,6] G. W. Westley[7]

3.2.1 Introduction

The Regional Economic Analysis Group conducts research into the spatial distribution of economic activity and population and relates these distributions to energy production and consumption

1. Group leader.
2. Economist.
3. Research assistant.
4. Part-time.
5. Consultant.
6. University of Tennessee, graduate student.
7. Computer Sciences Division, applications analyst.

and to other natural resource and economic requirements for energy. Because of the importance of early planning in the development and assessment of energy technologies, much of our work follows a projection framework. Thus, the Regional Economics Analysis Group uses national projections of employment and population for target years such as 1985, 2000, and 2020 to estimate consistent projections for small functional economic regions (BEA areas). These economic estimates are then used to estimate current and future energy requirements and energy conditions for these regions.

Past work has centered on methodological development of an employment–population forecasting system for functional economic areas, a system we call MULTIREGION. When final testing and validation is complete, we anticipate that MULTIREGION will serve as a major tool of analysis.

Work conducted during the past year has centered on MULTIREGION and on constructing regional energy data bases on a spatial grid comparable to that used for MULTIREGION. We plan to use the MULTIREGION system to regionalize national energy demand aggregates and to investigate the interaction of energy and economic development by focusing on five issues.

1. How will alternative future patterns of economic activity influence the regional distribution of energy consumption?
2. How will alternative strategies in energy policy influence future patterns of regional economic activity?
3. Which national energy alternatives are most sensitive to changes in existing regional trends of economic growth and change?
4. Will regional distributions of energy production facilities and distribution networks constrain regional economic growth?
5. Will regional distributions of water, manpower, or natural resources constrain national energy alternatives?

Clearly, these issues are wide-ranging and will not be quickly nor easily answered. Nonetheless, we have attempted to incorporate sufficient flexibility into our analyses that each may be addressed in a systematic manner.

In the sections that follow, a brief description of MULTIREGION and information concerning initial validity tests will be given, followed by a discussion of our data base and work accomplished this past year for estimating regional distributions of energy commodities.[8]

3.2.2 Socioeconomic Projections

Over the past several years, the Regional Economic Analysis Group has undertaken a continuing series of studies into patterns of regional demography, manufacturing and other employment, and labor force participation. Empirical relationships have now been estimated for each of these components, and the emerging quantitative representations have been united into a computerized projection system that estimates future patterns of socioeconomic activity for a spatial grid of 173 BEA areas.[9]

Overview.[10,11] MULTIREGION generates projections of population and employment across a grid of 173 BEA areas in five-year steps. In combining demographic and economic behavior,

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8. The reader is also directed to Sect. 3.3, which discusses water availability for energy production and reports a portion of our past year's work.

9. BEA areas are mutually exclusive functional economic areas that include the total land area of the United States. They were defined by the Office of Business Economics (now the Bureau of Economic Analysis of the Department of Commerce) in 1969.

10. R. J. Olsen et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 99–104.

11. R. J. Olsen et al., *MULTIREGION: A Simulation Forecasting Model of Population and Employment*, to be published as an ORNL TM report.

MULTIREGION interprets each BEA region as a labor market. A cohort-component approach is used to combine the effects of births, deaths, aging, and migration into a potential labor supply. An employment analysis separates economic activity into three general categories manufacturing, local service, and natural resources (and subsequently into components of these categories) and is used to provide estimates of labor demand. Among the required inputs are national control totals for employment by type and for population by age group. MULTIREGION then calculates regional shares, which are converted to regional employment and population projections that in the aggregate add up to the national total. The major output parameters derived from MULTIREGION for each BEA are population (male, female, and total) for 16 age groups and labor demand (number of employees and national share) for 37 industry groups.

Computational sequence. Figure 3.2 identifies the major elements of a region's economy, when viewed as a labor market, and the computational steps used by MULTIREGION to prepare regional forecasts of population and employment. Because MULTIREGION operates in five-year steps (1970, 1975, 1980, etc.), some labor supply and demand components are assumed to adjust to regional socioeconomic conditions immediately. Thus, a two-stage computation is followed: (1) Trial values of some explanatory variables are used to produce first-stage estimates of regional labor supply and demand; (2) the first-stage labor market conditions are then used to recompute final regional estimates. At both stages, regional aggregates of employment, population, and labor supply are balanced to predetermined national totals, interregional migration balances are met, and regional labor market boundaries are imposed. Computations for a BEA economic area proceed as follows: (1) Trial population values are computed (population of this period is assumed to equal that of last period plus births minus deaths plus in-migrants minus out-migrants); (2) trial labor supply values are computed by multiplying the estimated population by labor participation rates; (3) trial labor demand values are computed as the sum of (*a*) forecasted agricultural and mining employment, (*b*) region's share of forecasted national manufacturing employment, and (*c*) local service employment; (4) trial labor market conditions are computed by bringing together trial labor supply and demand values; and (5) final labor market conditions are computed by repeating steps (1) through (4) in view of the trial labor market conditions of step (4).

Uses of MULTIREGION. MULTIREGION may be used to provide baseline forecasts of regional employment and population patterns consistent with the national forecast model chosen as the control. When the national forecasts are updated to reflect recent changes in the economic environment, MULTIREGION can be easily updated as well to provide regional forecasts that will reflect these national changes.

In addition, three characteristics of MULTIREGION make it ideally suited for examining the differing regional impacts of alternative national economic (energy) policies: (1) the detailed structure of the population model which relates migration to both the age structure and regional economic conditions, (2) the interaction of the economic activity of neighboring regions, and (3) the use of a national input–output model for determining the level of national activity. MULTIREGION can estimate, for a particular scenario, the direct and indirect employment effects on industrial activity, the consequent direct and indirect changes in the spatial pattern of that employment, and the potential changes in regional migration and population growth as employment patterns respond to the national level of economic activity.

We intend to use MULTIREGION to assess the regional impact of alternative national energy scenarios to better understand potential employment and growth constraints to differing regional demands on energy resource extraction and supply patterns. For example, for the National Coal Utilization Assessment, we will trace the implications of increased total and regional employment for

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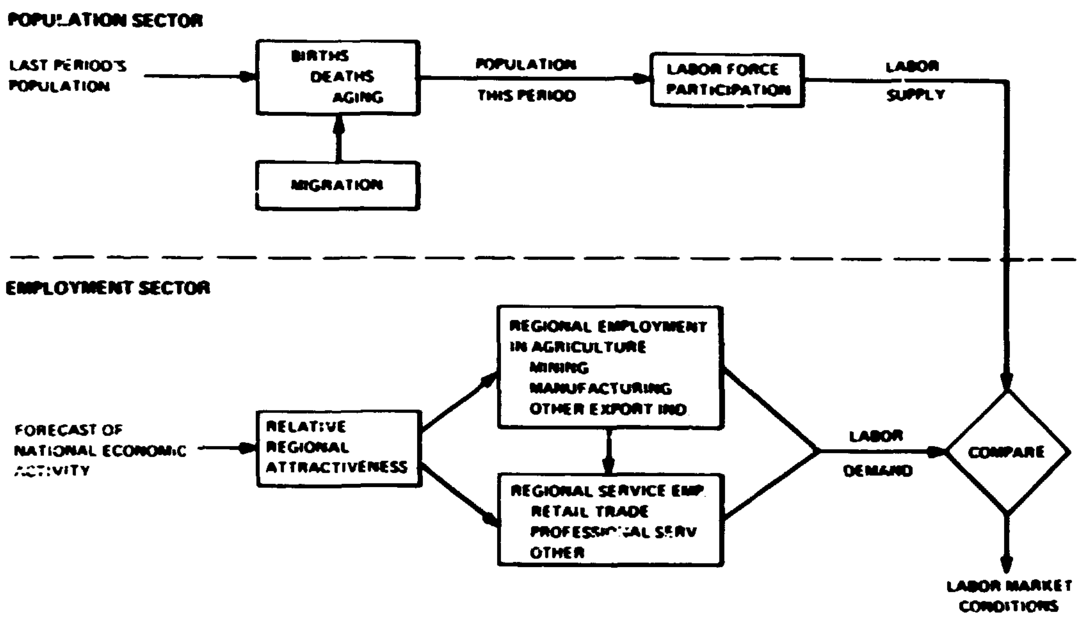

Fig. 3.2. ORNL–MULTIREGION approach to regional analysis.

expanding coal extraction and consider the indirect employment and population implications of alternative extraction sites.

Model validation and tuning. MULTIREGION is currently being subjected to a rigorous validation and tuning process prior to full-scale use of the model's outputs. This process is an important and necessary step in the development of any regional model for several reasons. First, there is currently only an imperfect theory of how and why regions develop. MULTIREGION is designed around a structural framework and computational sequence that approximate actual regional relationships. Testing is therefore necessary to ascertain how individual components of the model, which appear individually appropriate, perform when combined through the simulation framework. Second, only limited data are available on how regional relationships change over time. Thus, the dynamic validity of the model should be verified. Third, certain regions will always appear as exceptions. In tuning the model for projection purposes, these exceptions must be taken into account and the model adjusted to account for these unusual regional differences.

A two-step validation procedure has been adopted to validate and tune the MULTIREGION model. These steps include operating the model over two time frames, 1960–1970 and 1970–1985. Model estimates of population, employment, and other regional economic and demographic indicators are compared with the 1970 actual data (census), 1975 estimated data (census), and 1985 projected data (OBERS). It should be stressed that the MULTIREGION projections presented are unconditioned by judgment and are intended to compare different scenarios rather than to accurately predict the behavior of any single region. Thus, the exercise is an experiment in the purest sense, and one that will only partially reflect the final accuracy of MULTIREGION projection series when model adjustments take into account the difficulties discussed above. Although we conducted similar exercises for all model outputs, BEA population totals will be discussed since our comparisons have progressed the furthest in this area.

Differences between MULTIREGION projected population totals and the three benchmark data points discussed above are compared using the average percentage deviation. This statistic is calculated by computing the absolute value of percent differences for all BEAs between MULTIREGION total population values and the total population values of each test series and taking the arithmetic mean of the resultant differences. As shown in Table 3.1, there was an average deviation of roughly 7% between 1970 actual population and the population projected by MULTIREGION. Similarly, the average deviation was 4.42% for 1975 and 8.02% for 1985.[12]

Evaluating these statistics is somewhat difficult; nonetheless, two simple comparisons should prove useful. In an earlier study, ORNL calculated similar statistics comparing three recognized projection series[13] the National Planning Association, OBERS, and Bureau of the Census. The average absolute deviation between these projections ranged between 3.1 and 5.1% when 1980 state level projections were compared. A similar analysis was performed by the Bureau of the Census to test the accuracy of their county population estimates program.[14] In this case, the bureau-calculated population estimates were controlled by an estimated state total. Estimated projection deviations were then calculated from actual county census numbers on a county-by-county basis. When this procedure was carried out using several estimating techniques, average deviations ranged from 4.6 to 7.4%.

In general, we expect projection at the BEA level to be more difficult than at the state level and somewhat easier than at the county level. Similarly, we expect projecting a finer breakdown of population and employment to be more difficult than projecting aggregated totals. Given the above results, it appears that MULTIREGION is capable of making reasonably accurate population projections. However, a more severe test will come when components of population and employment are similarly analyzed.

Further testing and validation of MULTIREGION are currently under way; Figs. 3.3 3.5 illustrate the results of the model's validation tests to date. Figure 3.3 indicates that Florida, portions of the

12. U.S. Water Resources Council, *1972 OBERS Projections: Regional Economic Activity in the U.S.*, vol. 1, Series E Population, U.S. Government Printing Office, Washington, D.C., April 1974.

13. D. J. Bjornstad et al., *State Population Projections: A Comparative Review of National Series and Their Practical Usefulness*, ORNL UR-120 (February 1975).

14. U.S. Bureau of the Census, *Federal-State Cooperative Program for Local Population Estimates: Test Results April 1, 1970*, Series P-26, No. 21, U.S. Government Printing Office, Washington, D.C. (April 1973).

Table 3.1. Comparison of MULTIREGION projected BEA population with 1970 census population, 1975 estimated population,[a] and 1985 OBERS population[b]

	MULTIREGION 1970 vs census 1970	MULTIREGION 1975 vs Coop Program 1975	MULTIREGION 1985 vs OBERS 1985
Mean absolute percent deviation[c]	6.95	4.42	8.02
Standard deviation	6.76	3.88	6.38
Smallest error	0	0	0
Largest overestimate, %	33	[illegible]9	30
Largest underestimate, %	31	21	29

[a] Data obtained from the Federal State Cooperative Program for Local Population Estimates.

[b] U.S. Water Resources Council, *1972 OBERS Projections, Vol. 2, BEA Economic Areas*, April 1974.

[c] Mean absolute percent deviation $= \frac{1}{173} \sum \left(\frac{\text{MULTIREGION} - \text{benchmark}}{\text{benchmark}} \right) \times 100$.

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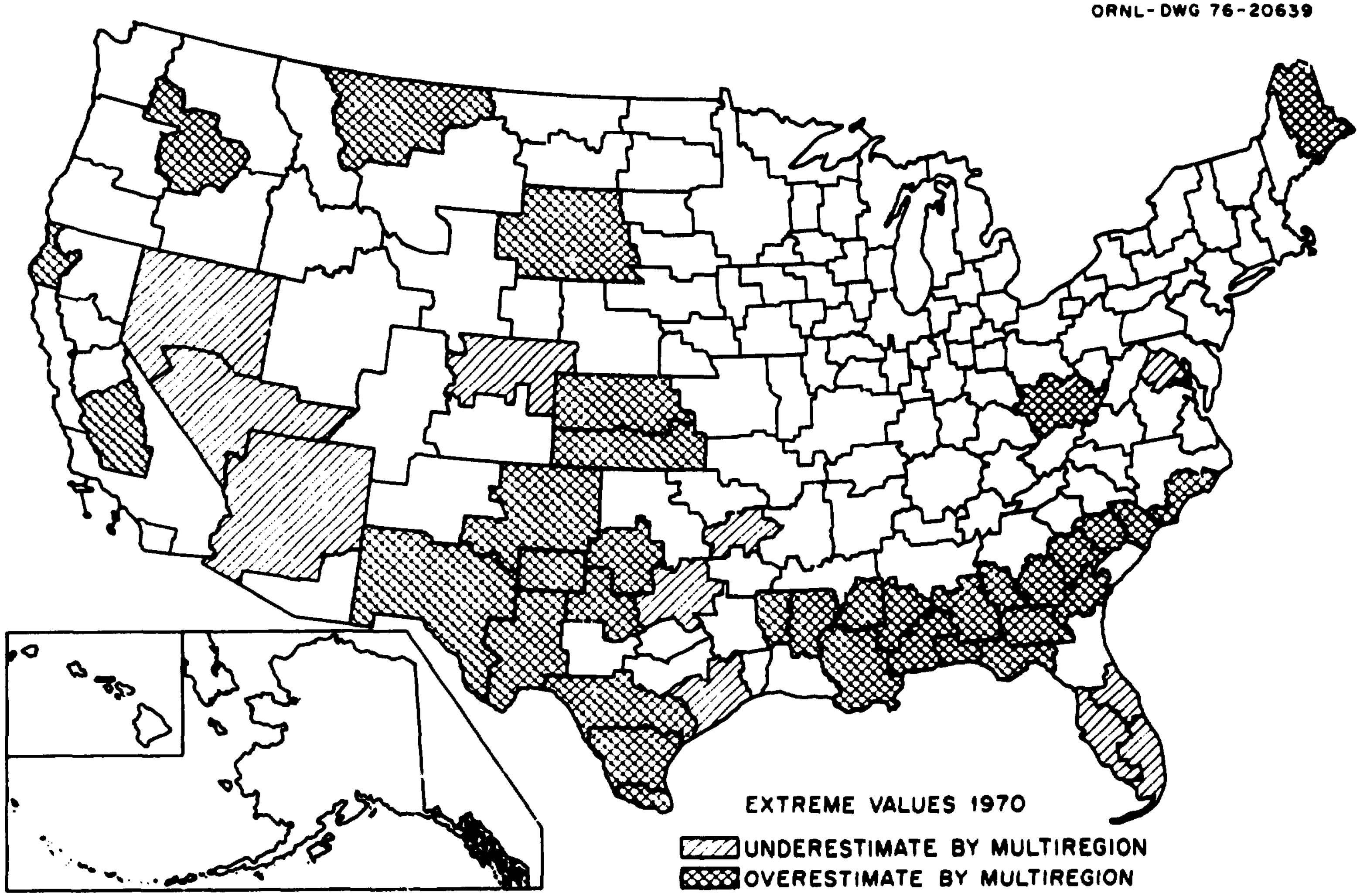

Fig. 3.3. Comparison of 1970 MULTIREGION population projections and 1970 census population.

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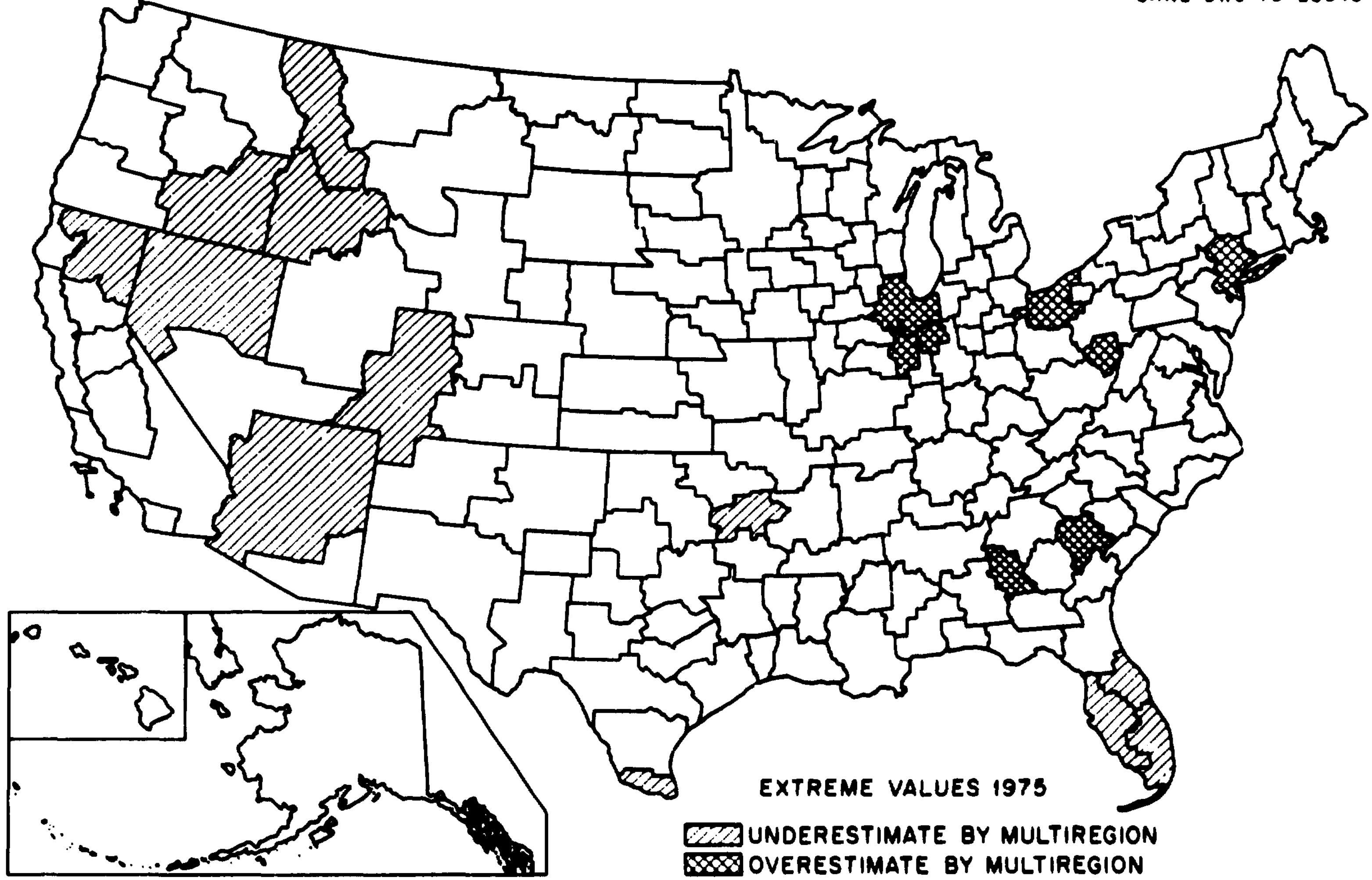

Fig. 3.4. Comparison of 1975 MULTIREGION population projections and census population estimates.

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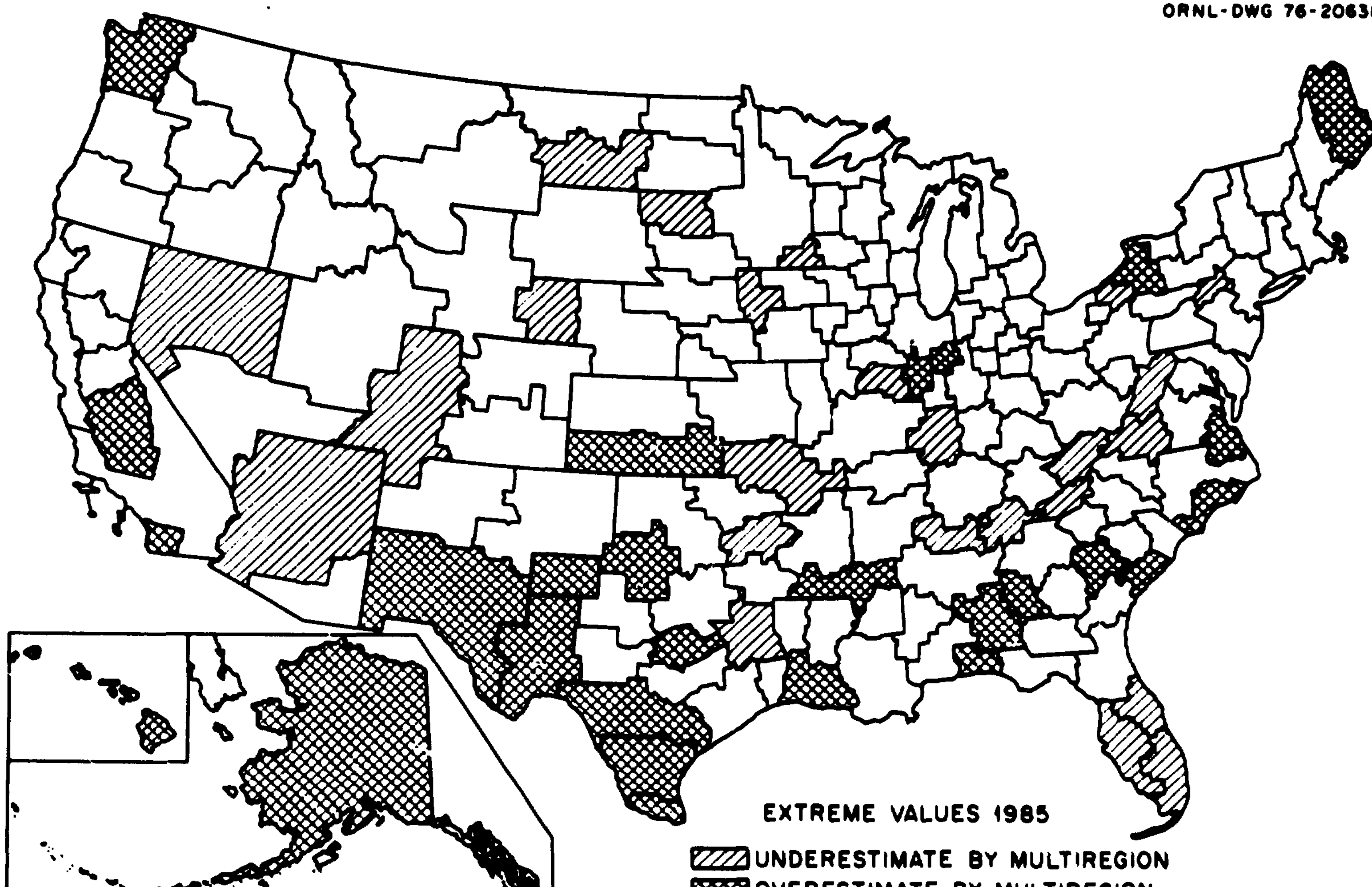

Fig. 3.5. Comparison of 1985 MULTIREGION and OBERS population projections.

Southwest, the Denver area, the Dallas Fort Worth area, and the Houston area grew at a faster rate during the estimating period than was projected by MULTIREGION. Figure 3.4 illustrates that this growth continued into 1975 in Florida and in portions of the Southwest, but that surprisingly few groups of deviations are present. In fact, it appears that increasing the projected growth rate in a small number of BEAs would have led to an extremely close approximation of actual population trends since error in underestimating population was minimal and probably exacerbated by the fact that total population was controlled.

A mixed pattern is present in Fig. 3.5, in which OBERS and MULTIREGION population figures are compared. OBERS anticipates more growth in Florida and the Southwest than did MULTIREGION, but few other patterns are evident. With minor adjustments, it appears that MULTIREGION and OBERS population numbers are largely interchangeable. We are in the final stages of evaluating MULTIREGION and are planning to use the model in a number of energy planning and analysis assessments currently under way in the RUS section. MULTIREGION will continue to be improved as we gain more experience with the model during these assessments.

3.2.3. Energy and Socioeconomic Patterns

The first step toward analyzing energy use and production, as they relate to regional employment and demographic distributions, is to compile regional energy data bases. Historically, energy data have been collected by a diverse set of spatial grids (e.g., petroleum administration districts, electric reliability areas, and coal production areas) that are frequently incompatible. Fortunately, the Bureau of Mines has collected most of this data at the state level. Below the state level, statistics on energy production are available by extracting information from numerous state agencies when gaps in federally collected data exist. As for energy use, virtually no substate data exist. We have thus chosen to synthesize substate energy use statistics through an allocation procedure based on the levels and composition of economic activity and population.

Energy conditions in the South.[15] The ERDA-DTO-RSP has encouraged the national laboratories to examine their respective regions carefully and to ascertain special conditions that affect energy. As a preliminary step, an energy profile of the South[16] was compiled to provide a description of typical energy production, consumption, and transportation patterns relative to those of other regions. The year 1972 was deemed most suitable for a baseline analysis because of the relatively stable energy prices characterizing the economy prior to the Arab oil embargo and subsequent energy shortage. A later update should indicate in what areas the patterns have changed.

The fourteen states making up the region of study represented less than 29% of the U.S. population, but accounted for over 73% of all domestic energy production in 1972. Primarily as a consequence of this energy-producing activity, particularly in Louisiana and Texas, southern per-capita energy usage was 12% higher than the national average. As is true throughout the United States, the industrial sector used the largest share of total energy. The residential sector accounted for the smallest share, partly, perhaps, because per-capita income was 20% lower in the region than elsewhere. All consuming sectors exhibited greater than average dependence upon natural gas, which is relatively cheap within the region.

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15. P. L. Rice, *Energy Conditions in the South*, ORNL TM-5568 (December 1976).

16. The South is here defined to include Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia. The exact boundaries of the southern region may vary slightly for other research programs, depending on the geographic divisions of the particular problem under study.

The South is a net exporter of crude oil, natural gas, natural gas liquids, refined petroleum products, and coal. Table 3.2 indicates the production, consumption, receipts, and shipments of crude oil and natural gas in the South in 1972. The region has played a pivotal role in determining historical energy patterns and will probably continue to do so since it holds 72% of the remaining proven reserves of natural gas and 49% of the remaining proven reserves of oil. However, the southern role in coal production should decline in the future: Although the South accounted for 53% of 1972 coal production, it contains only 13% of the remaining coal reserves, the majority of which contain high amounts of sulfur.

Hydroelectric activity is currently centered in Tennessee and Alabama. Although less than 45% of the total potential hydroelectric capacity in the South has been developed, the balance is not likely to be developed in the foreseeable future.[17] Only 1% of the electricity in the region was generated at nuclear facilities in 1972, but most observers expect this figure to grow rapidly over the next ten years. In 1972 utilities relied primarily on coal and natural gas, but it appears that coal will be extensively substituted for natural gas in the near future. Thus, the importance of coal and nuclear energy will likely increase in the future as the South follows the national trend away from the use of petroleum products in electricity generation.

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17. Science and Public Policy Program, *Energy Alternatives: A Comparative Analysis*, University of Oklahoma, Norman, Oklahoma (May 1975), p. 9-5.

Table 3.2. Natural gas and crude oil patterns in the South, 1972

	Natural gas		Crude oil	
	Amount (10^9 ft^3)	Source and distribution (%)	Amount (10^6 bbl)	Source and distribution (%)
Production	19,008		2,520	
Receipts	297	99.9, from Ohio 0.1, from New Mexico	132	45.6, from New Mexico 36.6, from foreign sources 7.8, from Indiana, Illinois, and Michigan 2.6, from Kansas 2.4, from Pennsylvania and New York 2.1, from Utah 2.1, from Ohio 0.6, from Colorado and Utah
Shipments	8,552	25.4, to Kansas 15.6, to Ohio 13.0, to Indiana 10.2, to New Mexico 10.1, to Maryland 9.2, to Pennsylvania 9.2, to Missouri 5.9, to Illinois 1.2, to Colorado 0.2, to D.C. 0.1, to Mexico	641	34.3, to Illinois 19.7, to Ohio 16.3, to Indiana 11.4, to Pennsylvania 5.7, to New Jersey 5.6, to Kansas 3.6, to Missouri 2.9, to Michigan 0.6, to Delaware and Maryland 0.1, to California
Miscellaneous losses	228		10	
Usage	10,525		2,001	

With its 605 processing plants and 100 refineries, the South accounted for 81% of all natural gas processed and 47% of all crude oil refined in 1972. As previously noted, the South was a net exporter of refined petroleum products, including gasoline, distillates, jet fuel, and liquified petroleum gas (LPG). Although this processing activity provides the bulk of the nation's requirement for petroleum products, it also requires the use of substantial quantities of energy. The amount of natural gas per employee used by the industrial sector of the South is twice as great as that used by the industrial sector in other regions.

The employment mix within the industrial sector is important to the determination of fuel mix as well as to the regional share of energy usage by the sector. Both petroleum and chemical manufacturing, for example, require substantial amounts of energy per employee, but the apparel and leather goods industries require relatively little energy. An index of energy use by the manufacturing sector (which accounts for 25% of the region's employment) was created for the South and each of its states, as well as for the other regions, to reflect the impact of variations in employment mix upon total energy demand. Relative energy usage for each three-digit standard industrial classification (SIC) in the nation as a whole was determined and used as a measure of energy intensiveness. The employment mix of each state was then weighted by this measure of energy intensiveness. As shown in Table 3.3, the South had the highest index of any region in 1972, and West Virginia was the most energy-intensive state. West Virginia is the fifth largest per-capita energy user in the nation.

Table 3.3. Industrial energy indices in the South, 1972

State or region	Index[a]
Alabama	1.476
Arkansas	0.872
Florida	0.776
Georgia	0.684
Kentucky	1.254
Louisiana	2.759
Mississippi	0.658
North Carolina	0.549
Oklahoma	1.041
South Carolina	0.908
Tennessee	1.310
Texas	1.858
Virginia	0.826
West Virginia	4.116
South	1.197
Northeast	1.070
Rocky Mountain	1.122
West Coast	0.840
Midwest	1.133
United States	1.101

[a]
$$\text{Index}_j = \sum_i \left(\frac{E_i}{\sum_i E_i}\right)\left(\frac{L_{ij}}{L_j}\right) .$$

where

j = state or region,
E = total energy consumed yearly in equivalent kilowatt-hours,
i = 3-digit SIC industry,
L = employment.

An underlying assumption of these indices is that similar industries use similar input mixes despite regional location; for example, all chemical manufacturers use the same amount of energy per worker. Such an assumption overlooks possible variations in energy use which arise from differing availabilities of energy, labor, capital, and other raw materials. Subsequent analysis of each individual state indicated that not only do states differ in terms of industrial mix, but industries also differ in terms of overall input mix. Where energy is abundant, energy usage tends to be higher relative to labor and capital usage.

An assessment of socioeconomic impacts of alternative energy futures involves minor as well as major consuming sectors. For the South, a disproportionate number of households were found to rely upon electricity for space and water heating, and the housing stock was found to be atypically characterized by a large percentage of mobile homes, which are notably inefficient in energy use. Thus, the residential sector of the South is more greatly dependent upon both electricity and LPG than are other regions. Electricity prices are lower than those prevailing in the rest of the United States, but LPG prices are slightly higher. With 47% fewer mean heating degree-days, this sector uses less energy for space heating, but twice as much energy for air conditioning, as do other regions of the country. The commercial sector, which accounts for about 60% of the employment, relies less on oil and gas and more on electricity than do commerical sectors in other regions, but pays less for all three energy forms than do other parts of the nation. With the exception of its heavy reliance on natural gas for pipeline transportation of fuels, the transportation sector of the region exhibits no unusual patterns.

We intend to conduct subsequent analyses of the South that will update these findings and provide a method for evaluating the impact of future changes in supply conditions, given the changing patterns of production, consumption, and transportation that occurred in 1974 following the first interruption of foreign oil supply. Such detailed analyses by sector and fuel should provide a portion of the information necessary to federal and state policy makers dealing with subnational energy issues.

Development of regional energy data bases. The Regional Economic Analysis Group has maintained an ongoing effort sponsored by the Economic Development Administration to develop a detailed energy data base at the BEA level for 1972 and subsequent years. A BEA-level data base is somewhat unique; only the county energy data developed by Brookhaven National Laboratory (BNL) is comparable.[18] The BNL data do not reflect the energy production and consumption patterns of any given year, but are an annual compilation of statistics for 1970, 1971, 1972, and 1973. While the BNL data base is sufficient for the analysis of certain pollution effects, it is not satisfactory for socioeconomic analysis because it does not include important time and space characteristics. Thus, a data series was specifically designed to support our social and economic research programs.

Production data. The Bureau of Mines published annual coal production by county in the *Minerals Yearbook* from the detailed reports on production and mine operation prepared by coal producers. We aggregated these county data by BEAs for consistency of the data base. The BEA production of uranium was determined by disaggregating state production figures on the basis of employment and number of uranium mines. In most cases production was concentrated in a single BEA so that errors were minimal.

State publications of oil production by county (or field) are available for the major oil-producing states. We identified fields and located them within counties in order to construct BEA data bases from county groups. Where oil fields overlapped county, BEA, or state lines, the dominant BEA was credited with the total production of the field. Specific information was available, therefore, for 98% of total

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18. E. R. Drysdale and C. E. Calef, *Energetics of the United States: An Atlas*, Brookhaven National Laboratory, 1975 (computer tape).

crude production in 1972. The remaining 2% of production was allocated on the basis of known locations of oil wells within the other producing states.

State publications of gas production by county or field are also available for the major gas-producing states. These reports, along with the Bureau of Mines data, provided information for 96% of U.S. gas production. The remaining 4% was estimated on the basis of footage drilled, the number of exploratory and proven oil and gas wells, the percentage of oil produced from associated and nonassociated wells, and the success ratio associated with each type of drilling.

The Bureau of Mines also publishes statistics on refinery location and capacity by township. We aggregated these township statistics by BEAs for use in allocating state production totals of refined petroleum products, such as gasoline and distillates, to those BEAs. Similarly, the *Oil and Gas Journal* publishes statistics on processing plant location and capacity by county. The 1974 output of LPG, butane, ethane, etc., by county was used to allocate the 1972 state totals because an extensive survey was not published in that year.

Hydroelectric and nuclear capacity and associated electricity generation by BEA were determined on the basis of the 1967 and 1975 data files of the Federal Power Commission and annual issues of *Steam Electric Plant Factors*. Production and capacity estimates were included in the data set in terms of the source of generation rather than place of ownership. The 1975 information on new plants was used to augment the 1967 data after adjustment for plant retirements between 1967 and 1972.

Consumption data. Since detailed statistics on energy use are generally not kept below the state level, it was necessary to develop an approach for allocating control statistics for states to substate areas. The creation of this regional data base not only provided useful information on the production and consumption of fuels by type and sector, but more importantly, it provided a methodology for determining energy patterns at the BEA level in subsequent years. Moreover, knowledge acquired in the process of developing the data was critical to the establishment of methodologically sound bases for forecasting regional energy production and consumption in the future.

Although our approach for allocating energy control totals to substrate areas is relatively simple, it possesses three characteristics that make it particularly useful for our work: (1) It is general, permitting disaggregation from several high levels of aggregation to several smaller ones; (2) it makes use of available data without detailed statistical manipulations (in most cases, detailed regional energy information is simply deficient and must undergo significant manipulation); (3) it permits ease of update. We have been impressed that new data sources, many of which were previously unused, are rapidly becoming available. We have thus chosen a simple but general approach that we intend to improve, primarily by acquiring better data. Perhaps most important, however, the approach is operational.

The basic form of this allocation procedure can be represented by

$$D_{fir} = US_{fi} \cdot Index^{s}_{fi} \cdot SPEC_{fir} \cdot ACT_{ir} . \qquad (1)$$

where

D_{fir} = estimated demand for fuel f, sector i, and region r.

US_{fi} = average United States use of fuel f in sector i per unit of activity (e.g., fuel used per primary metal worker).

$Index^{s}_{fi}$ = relative use of fuel f in the sector i and state s compared with the U.S. average for that fuel and sector.

$SPEC_{fir}$ = special adjustment for fuel f in sector i and subregion r (e.g., SPEC = 0 if fuel f is not available).

ACT_{ir} = activity levels in sector i and subregion r corresponding to definition of US_{i} (e.g., number of primary metal workers).

Each of the projects in which we have used this scheme has considered different fuels (f), sectors (i), and regions (r). Consequently, the computed values of the indices have been collected from a variety of sources. As we gain experience, we will create a data base of activity variables and indices at a level as detailed as possible given the existing data. This data base will allow the use of the same data for a variety of different applications and permit more resources to be devoted to refining and analyzing the historic indices.

The indices are computed from historical data for 1971 or 1972 for the residential, commercial, industrial, and transportation sectors. The industrial sector has additional detail corresponding to the level of disaggregation in MULTIREGION and OBERS projections. The year used and limitations on the ability to define all indices for all sectors are determined by the data. The use of such historical indices for forecasting can involve restrictive assumptions, which vary according to the particular application. In general, using historical indices implies that the state patterns and sectoral differences in energy use forecasts are proportional to those in the base year from which the data are drawn.

As additional data become available, we intend to test this proportionality assumption, as well as to analyze how the state patterns and national-level indices are related to the underlying regional determinants of energy choice (e.g., regional fuel price differentials and availabilities) and other regional characteristics (e.g., regional income and heating and cooling demands).

3.3 RESOURCE ANALYSIS GROUP

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3.3.1 Introduction

The central research focus of the Resource Analysis Group is to delineate and analyze human and natural resources and to specify the interactions of these resources in meeting future national and regional energy needs. Our present emphasis in resource allocation is on energy development. To pursue this task, we have melded the objectives of six separate research projects into a central theme of resource analysis and energy development while still fulfilling the specific requirements of each project; the cumulative benefits to each project are greater than if each project were pursued independently

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20. Computer Sciences Division.
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In connection with ERDA's National Coal Utilization Assessment, we are engaged in a study to identify future plausible energy facility siting patterns for the southern United States and to determine the attendant resource developments that will be required. Presentation of our research accomplishments during 1976 is organized according to the necessary steps for performing resource analyses and delineating suitable energy facility siting patterns to meet future energy needs.

The six research projects presently funded in our group are

1. ERDA-DTO-Sponsored Energy Facilities Siting: A National-Regional Assessment Project. The objective is to develop possible energy facility siting distributions for the southern United States by using several different energy demand and development assumptions and to specify associated impacts. This project is part of the National Coal Utilization Assessment.
2. NRC-Sponsored Maryland Regional Siting Factors Study. The objective is to develop and implement a land use screening procedure capable of identifying candidate areas for power plants in northern Maryland. This project is drawing to a conclusion.
3. ERDA-DTO-Sponsored Coal Mining Impacts: An Environmental Assessment in Appalachia Study. The objective is to assess the availability of Appalachian coal resources in terms of the reserves and the environmental impacts that might be associated with development. This study is also part of the National Coal Utilization Assessment.
4. EPRI-Sponsored Computer System for Assessment of Coal Reserves Study. The objective is to develop a model to calculate volumes of coal reserves and specific mining cost variables suitable for use by mine operators.
5. WRC-Sponsored Water for Energy Assessment Project. The objective is to assess the impacts of future nonnuclear energy development on water throughout selected water resource regions in the eastern United States.
6. ORBC-Sponsored Ohio River Basin Energy Facility Siting Study. The objective is to assess the effect of future energy development on water availability and water quality in the Ohio River Basin.

3.3.2 General Approach to Resource Analysis and Energy Facility Siting

To prepare for future siting applications, members of our group have completed a thorough review and analysis of various siting methodologies currently in use throughout the United States. This effort culminated in a report drawing conclusions from both literature and experience and recommending optimal combinations of techniques that should be employed in regional and site-specific energy facility siting studies.[25]

As a result of past experience in regional modeling at ORNL[26] and extensive review, we concluded that a two-phase site selection procedure capable of multiple analyses under different constraints is best suited to determine feasible energy facility siting patterns and to perform the necessary resource analyses. The two-phase procedure involves (1) eliminating areas unsuited for

25. B. F. Hobbs and A. H. Voelker, *Analytical Power Plant Siting Methodologies: A Theoretical Discussion and Survey of Current Practice*, to be published as an ORNL TM report.

26. For documentation of the ORNL-NSF regional modeling work, see C. W. Craven, Jr., et al., *Reflections on Regional Environmental Systems Analysis*, ORNL RUS-26 (to be published), which provides a history of the ORNL experience and a guide to additional documentation.

energy facilities because of lack of resources (i.e., water or transportation facilities) or economic, environmental, or institutional constraints and (2) evaluating or ranking remaining areas in terms of siting potential based on the combination of characteristics sought in an ideal site.

Because some components of the site selection process are not amenable to computer procedures, parts of the site allocation process must be handled subjectively and manually. Also, we note that the procedure should accommodate a hierarchical scaling of analyses, stepping down spatially from large regional scales (e.g., census regions) to subregional scales (multiples of counties) and ultimately to site-specific levels, when environmental impact statements are required. We do not intend to recommend particular sites since this function is more properly the responsibility of utilities or state planning agencies, but our procedures should be useful for this purpose.

Figure 3.6 is a flowchart summarizing how we perform the analysis to identify energy development patterns. National energy demand scenarios are exogenously provided (by FEA or ERDA) as a beginning point for our analysis. The Regional Economic Analysis Group disaggregate these energy demand forecasts for the southern United States to subregional units (BEAs) that we consider to be load centers. Energy demands by BEAs are then mapped to determine the spatial distribution of demand and future differential growth patterns that may be expected.

For each BEA, technology mixes to meet future demands are developed from our knowledge of (1) energy technology characteristics, (2) time horizons for new technologies, and (3) the technology mixes projected for each census region (provided exogenously by the national scenarios). Also, information covering utility plans for future plant types (when available) and the general availability of suitable sites within each BEA will be used in determining the technology mixes needed to satisfy demand.

Parallel to these analyses, technology characterizations in terms of resource needs and unit facility siting requirements (water consumption, land requirements, transportation needs, and pollutants) are generated. Siting criteria for various technologies in terms of resource needs, potential environmental effects, and social and legal limitations are determined, and the relative importance of each siting criterion is then developed. Knowledge of siting criteria and resource requirements also permits the determination of resource data and siting information that must be compiled in our spatial-temporal information system.

In the energy facility screening and siting process, the above information is used to test the resource requirements of new energy development against the resources available. This task, however, requires the development of site factor models which describe resource availability in terms of the siting requirements of various energy technologies. These site factor models are collectively called the Oak Ridge Spatial Analysis Model (ORSAM). Each site factor model is designed to spatially describe a specific siting criterion for the type of energy facility (e.g., nuclear, fossil, or other power plants or coal conversion plant) to be sited. For example, simple knowledge of stream flow volume is not sufficient to determine whether adequate cooling water is available without first determining potential low flows and maximum water consumption situations. In essence, the siting factor models replicate the siting criteria considerations.

Ultimately, candidate energy facility siting and resource utilization patterns emerge from the site-screening process. These distributions provide input to the social, economic, and environmental impact analyses described in Sects. 3.2 and 3.4. The following subsections describe in more detail the components of the resource allocation and siting process and the application of these ideas to our six research projects.

Need for energy. The disaggregation and allocation of national energy projections to BEA regions is performed by the Regional Economic Analysis Group. The projections used in our

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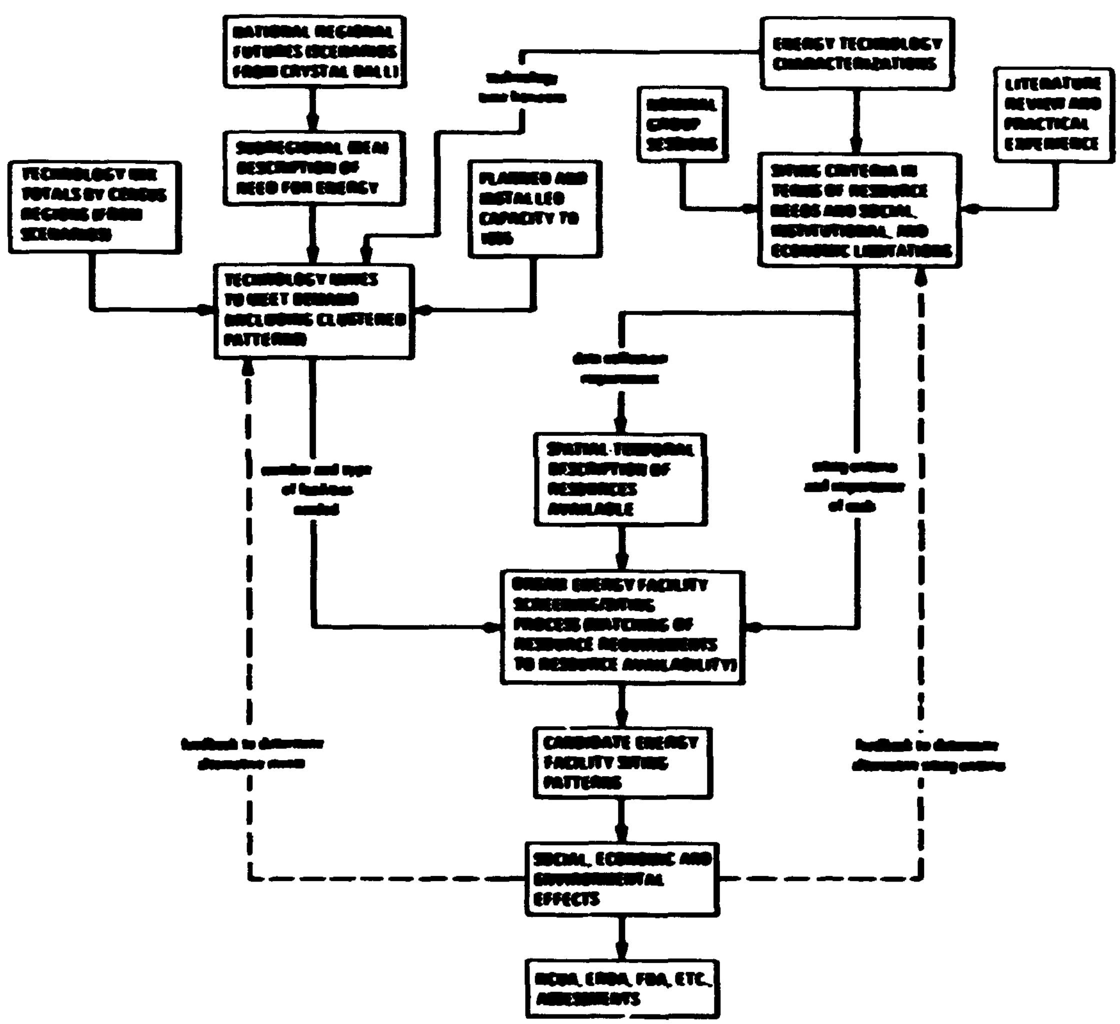

Fig. 3.6. Siting analysis approach used at ORNL.

analysis were derived by BNL and are essentially the same projections used by ERDA; near-term projections are identical to those used by FEA. In the Ohio River Basin study, the projections are provided at the state level by ANL and are then disaggregated further to BEA and state BEA portions by the Regional Economic Analysis Group.

Projections of increased electrical energy demand by the years 1985 and 2000 have been mapped for the entire United States (Figs. 3.7 and 3.8). These maps illustrate the proportionate increase in electrical demand beyond 1972 by year, the amount to be provided to meet future needs, and the areas in which additional conservation might be emphasized.

Planned and installed electrical capacity. Projection of 1985 energy facility siting patterns is based on data provided by the Federal Power Commission (FPC).[27] The FPC data provide

[27] These data are provided by the Federal Power Commission, Office of Public Information; the data set is called the "Generating Unit Reference File."

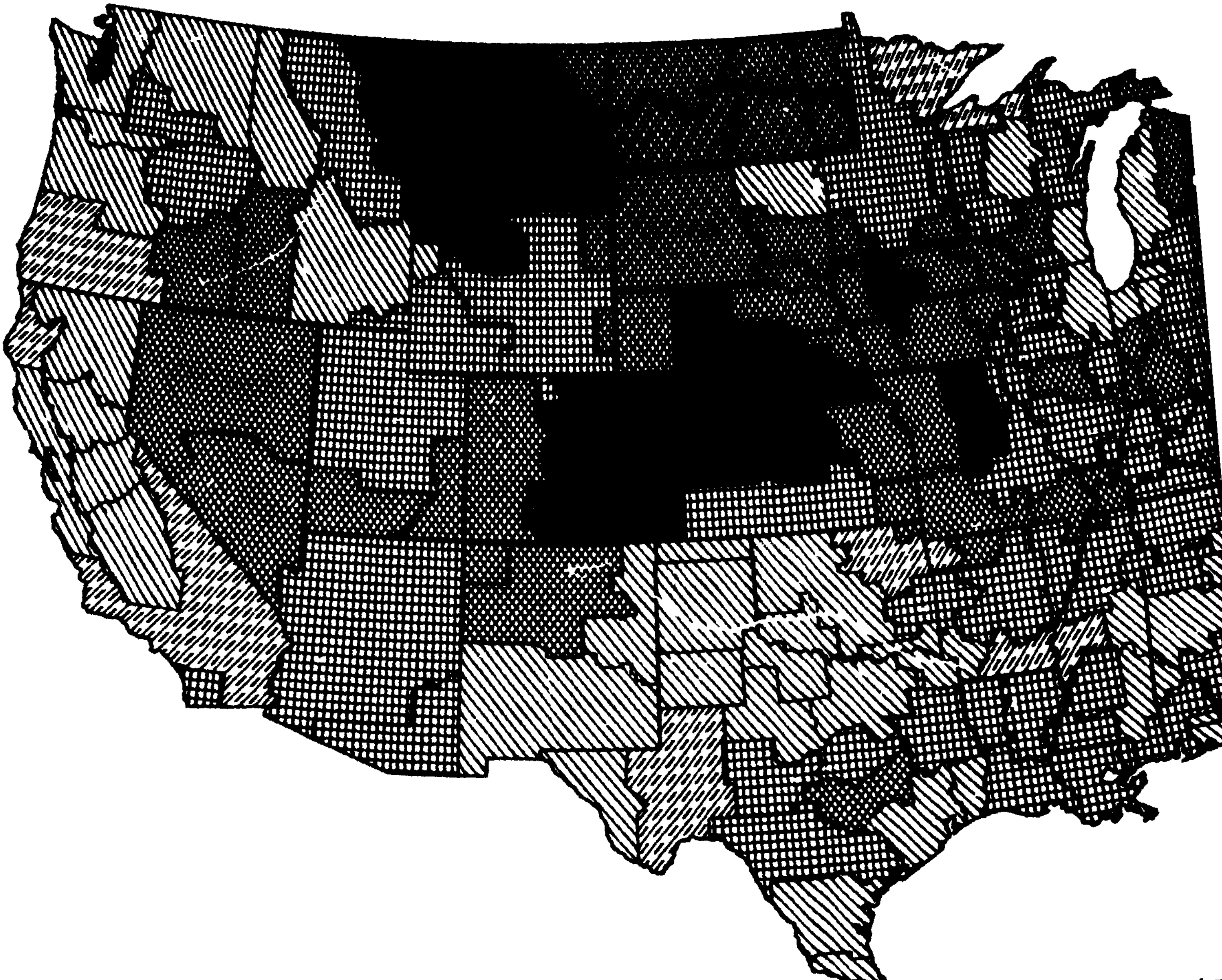

Fig. 3.7. Average annual percentage increase in electrical energy dem

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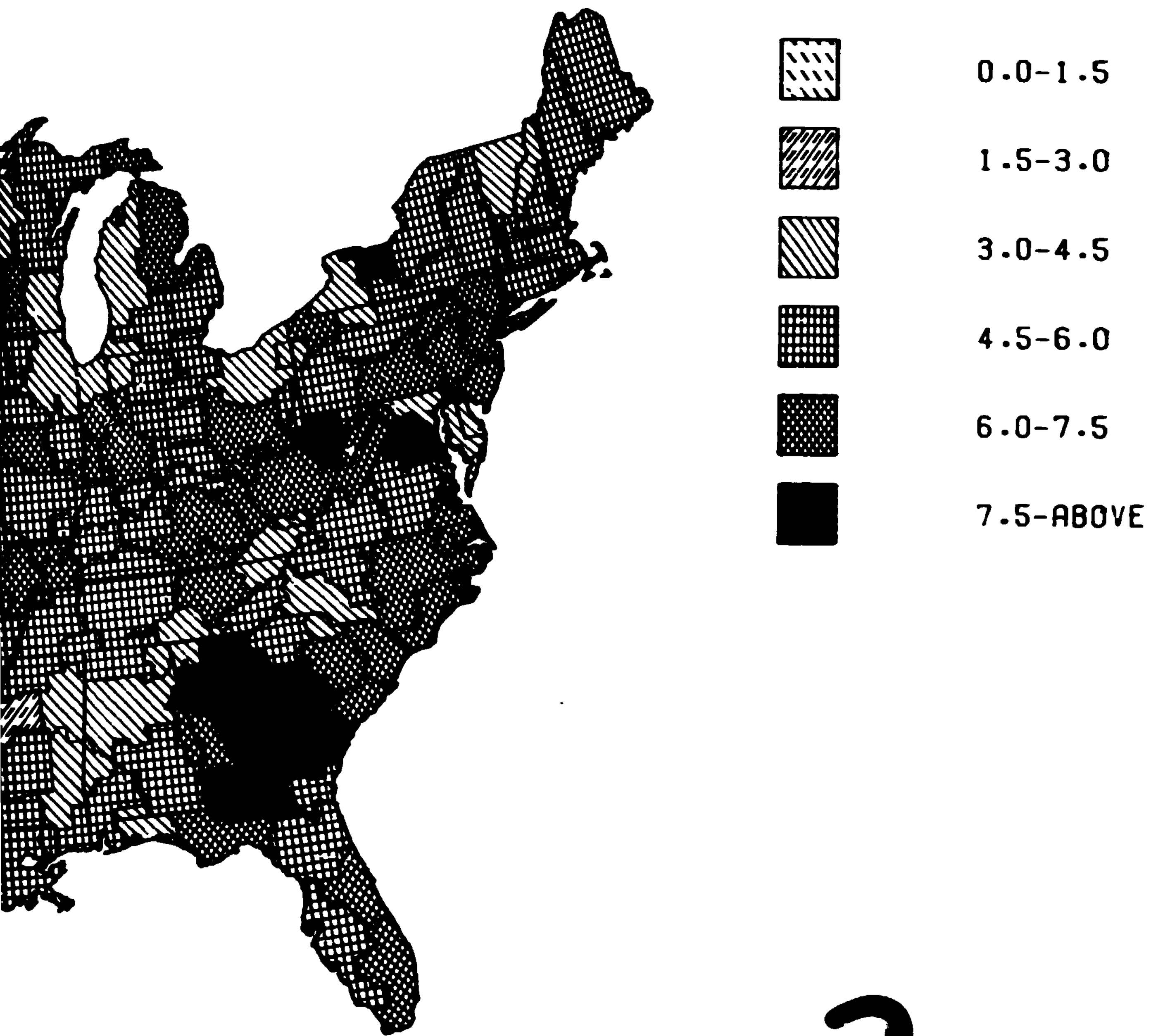

trical energy demand by BEA region between 1972 and 1985.

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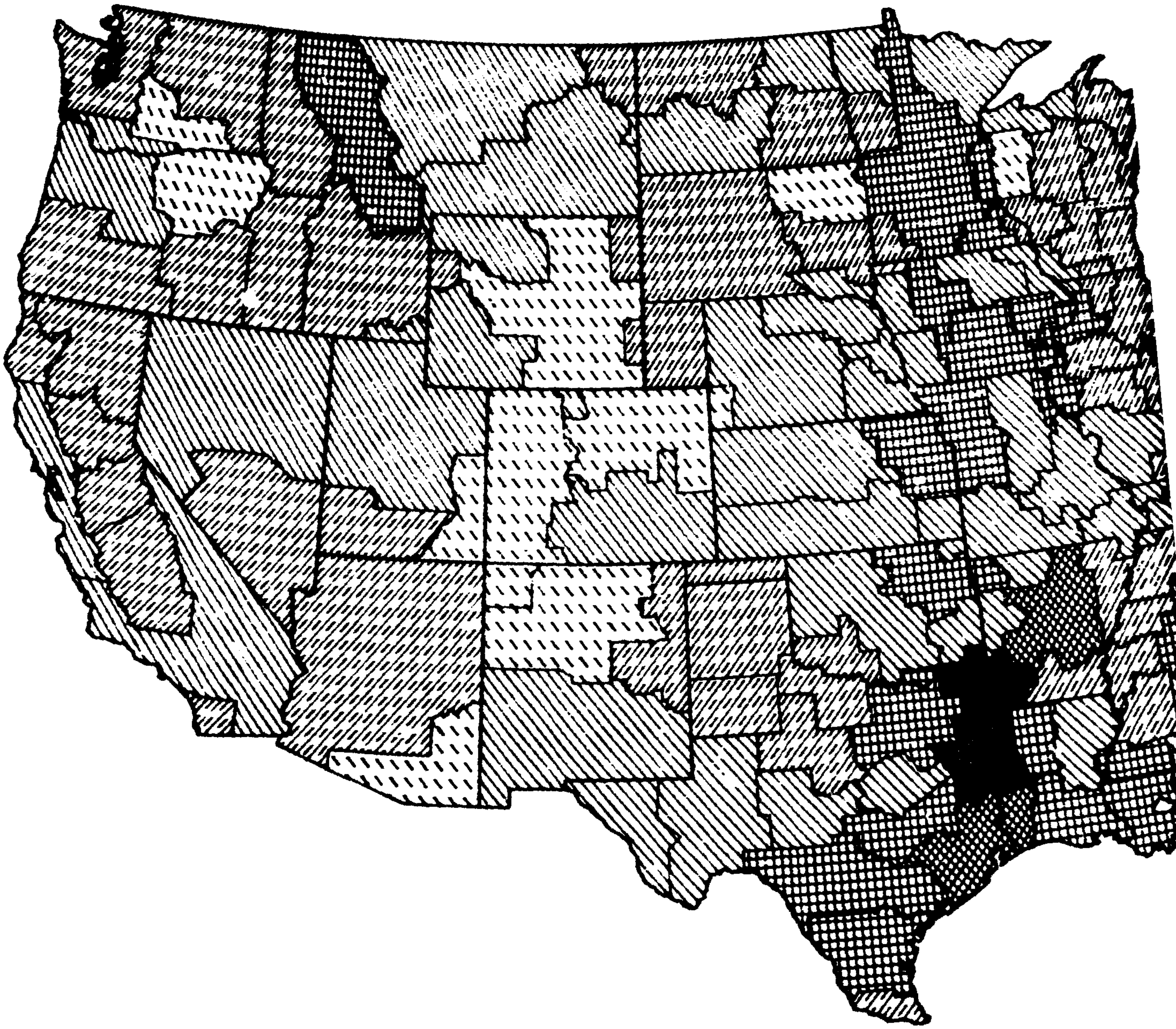

Fig. 3.8. Average annual percentage increase in elec

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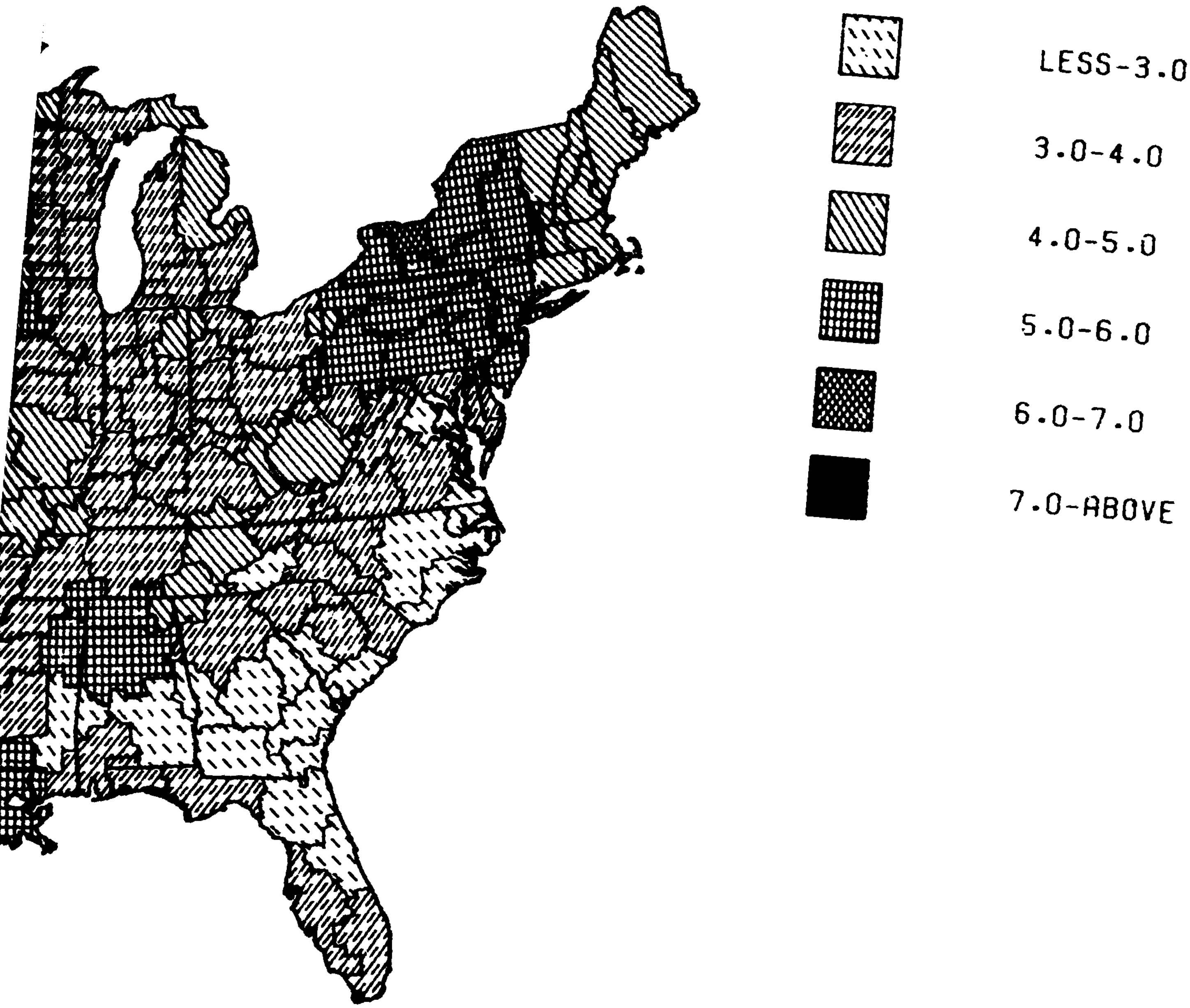

...ical energy demand by BEA region between 1985 and 2000.

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information on the location of proposed power plants and the generating capabilities of each plant. The 1985 planned and existing generating capacity (in megawatts) is illustrated in Fig. 3.9; capacity to be added or retired (negative numbers indicate retired units) between 1975 and 1985 is shown in Fig. 3.10. Finally, the differential between the planned and existing capacity and the needed electrical capacity in 1985, as projected by the Regional Economic Analysis Group, is presented in Fig. 3.11.

Siting criteria. One of the first steps in developing a siting methodology is the careful identification of those factors that must be considered by the utilities and state agencies in locating acceptable energy facility sites. To accomplish this important step in a systematic manner, we have adapted group processing techniques to the problem of factor identification. This year we conducted two sessions of a particular technique called the nominal group process technique (NGT) with experts familiar with nuclear power plant siting.

The nominal group process technique is a highly structured, interactive approach that has gained wide acceptance in health, social service, education, industry, and government.[28] The process consists of four basic steps: (1) nominal (silent and independent) generation of ideas in writing by a panel of participants; (2) round-robin listing of ideas generated by participants on a flip chart in a serial discussion; (3) discussion of each recorded idea by the group for clarification and evaluation; and (4) independent voting on priority ideas with group decision determined by mathematical rank ordering. The strengths of the technique lie in enhanced participation of group members, the step-by-step movement toward the goal, and cross-education of participants.

The output of our sessions consisted of lists of weighted factors which have since become the basis for the factor models used in our siting methodology. The factors identified by one of our NGT panels for site level are shown in Table 3.4.

Our experience with NGT is described in detail in a report now in press.[29] We plan to conduct more group processing sessions in the future to identify factors pertinent to coal-fired power plants and other types of energy facilities. In addition, we plan to experiment with various types of group process techniques in accomplishing this goal.

Site factor models. The ERDA National Coal Utilization Assessment will use a candidate site-screening procedure to locate potential areas suitable for energy facilities across the southern United States on the county level. Siting patterns derived from this analysis include sites for nuclear and fossil-fired power plants and coal conversion plants. Distributions will be developed for each of the four National Coal Utilization Assessment scenarios by year (1985, 2000, and 2020).

Calculation of suitability will depend upon the ORSAM factor models, which are constructed to replicate as well as possible the considerations given by agencies making siting decisions using various criteria such as water availability, seismic risk, air quality, coal availability, and others.

Proximity to load centers. A simple gravity-potential model[30] is being used to map the proximity of any given county relative to the economic costs of transmitting power to surrounding

28. A. L. Delbecq et al., *Group Technique for Program Planning. A Guide to Nominal Group and Delphi Process*, Scott Foresman, Glenview, Ill., 1975.

29. A. H. Voelker, *Power Plant Siting: An Application of the Nominal Group Technique*, ORNL NUREG TM-82 (to be published).

30. The potential of each county for satisfying projected demand is computed with a gravity model in the form

$$P = (\text{BEA demand})\; d$$.

applied between the centroid of each county and all BEA centers. P is the calculated accessibility potential for county i, and d is the distance in miles between the county centroid and each BEA center. The distance exponent, 1.5, was empirically derived to reflect the increased cost of delivering power over increased distance and to reflect a maximum 241-km (150-mile) transmission limit to a load center.

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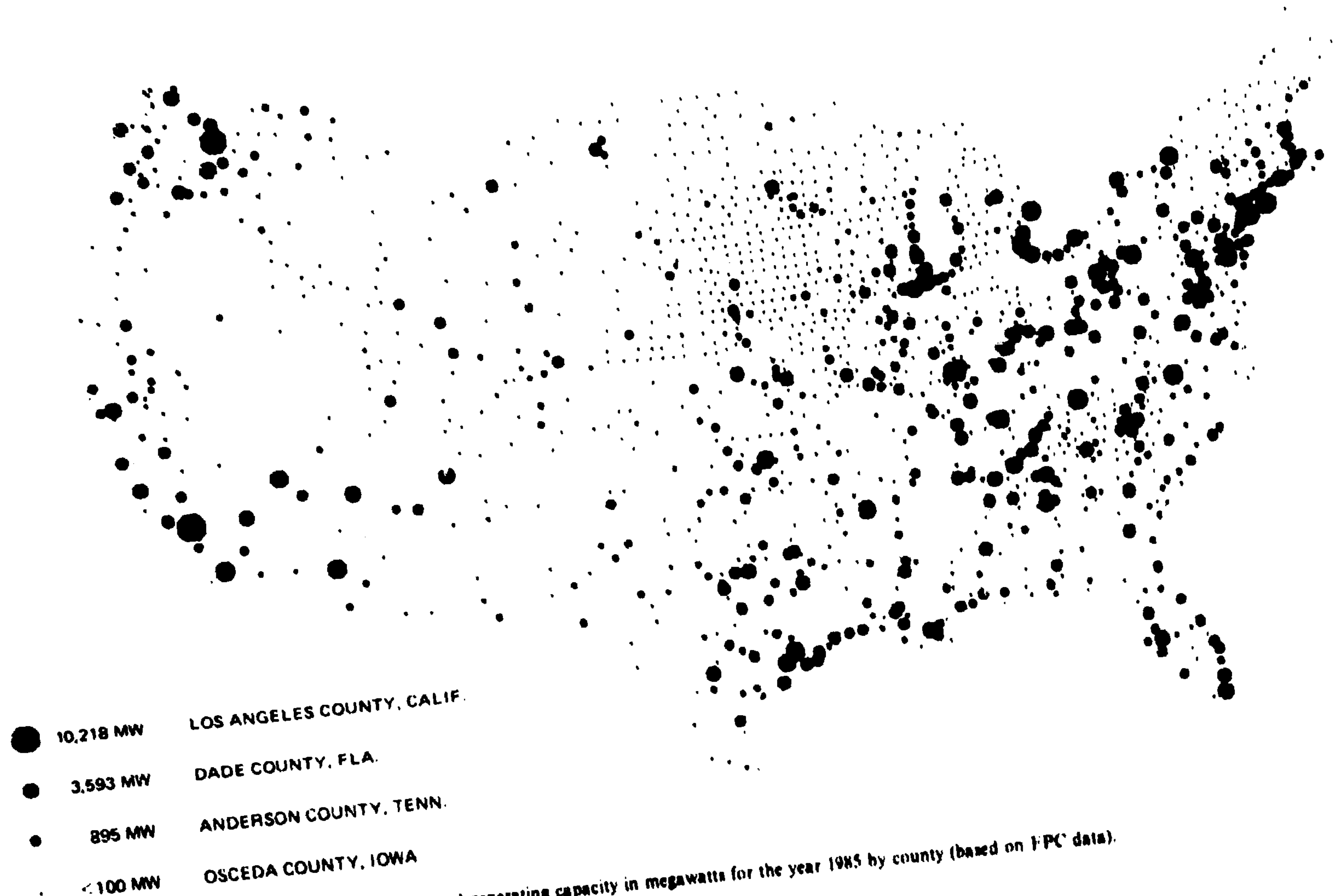

Fig. 3.9. Planned generating capacity in megawatts for the year 1985 by county (based on FPC data).

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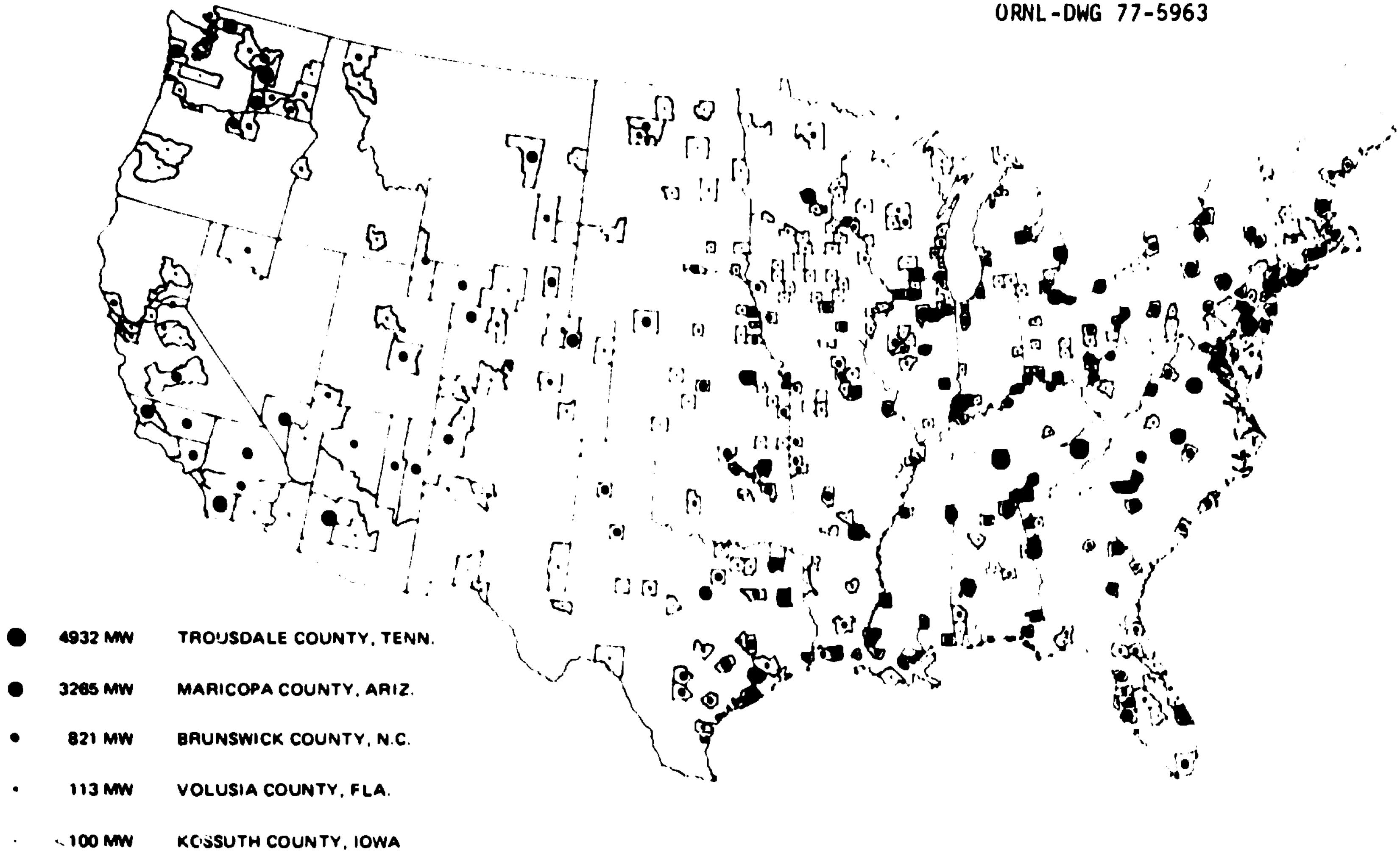


Fig. 3.10. Generating capacity in megawatts to be added between 1975 and 1985 by county (based on FPC data).

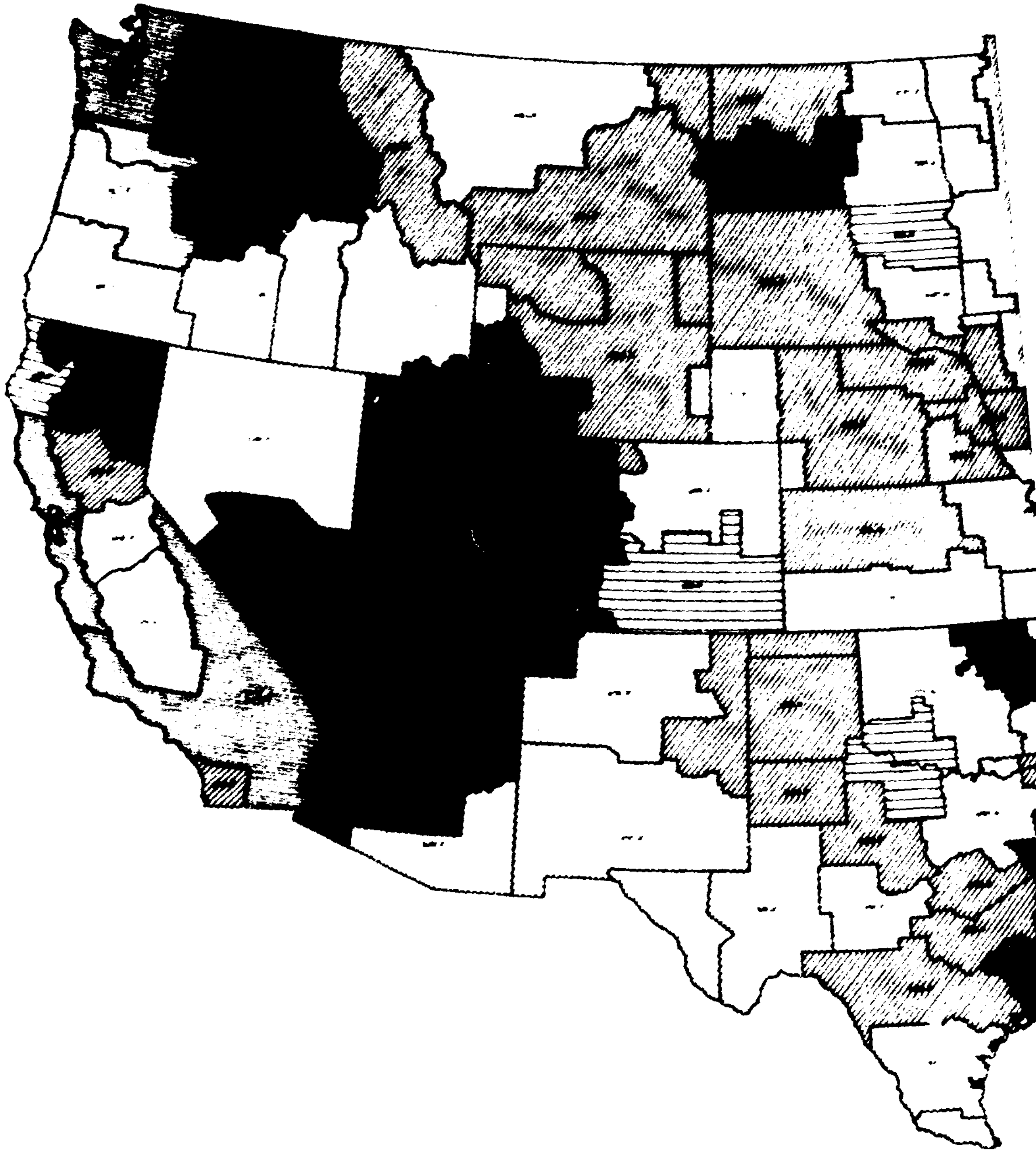
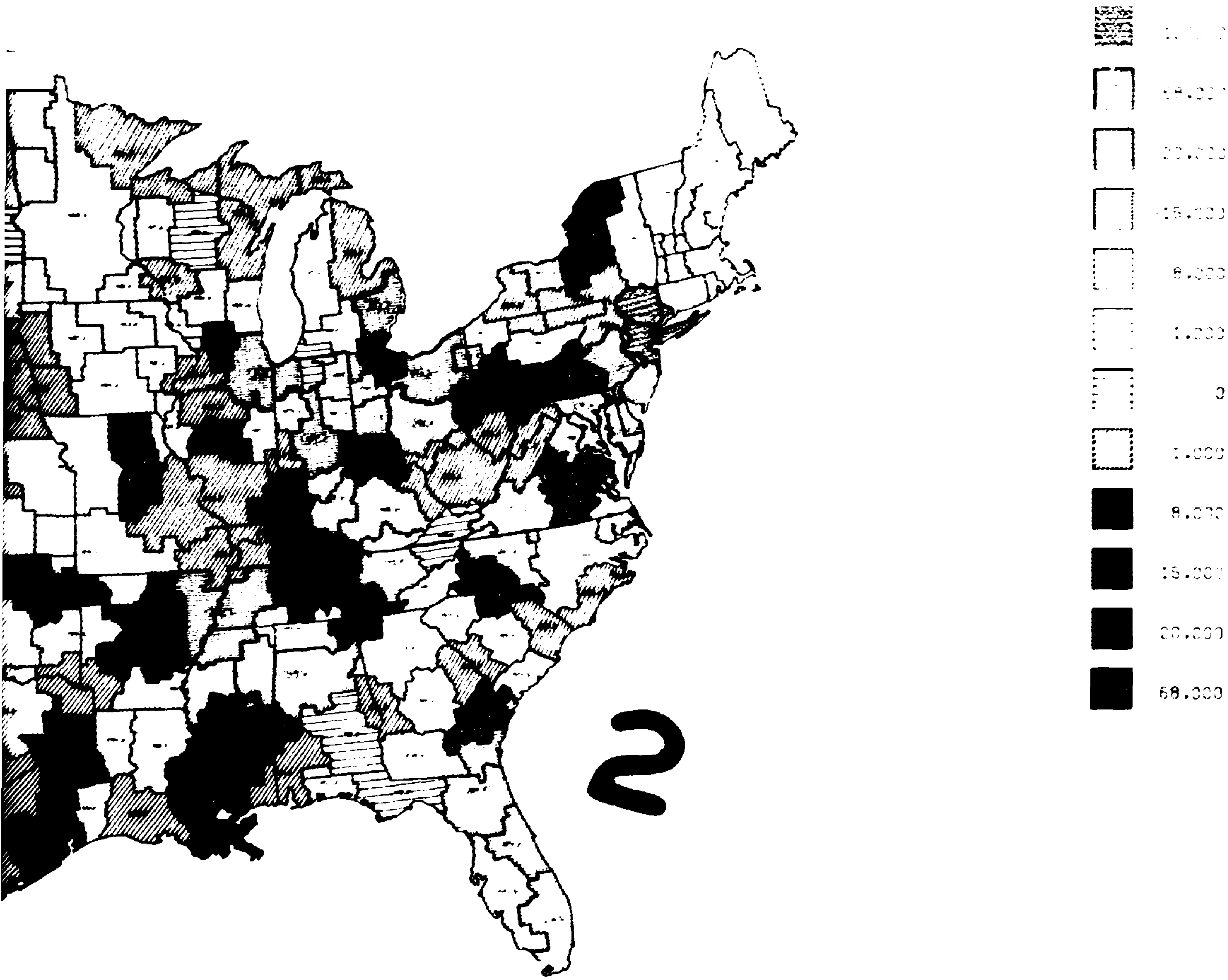


Fig. 3.11. Net surpl
disaggregation of ERDA



plus or deficit in capacity in megawatts needed by BEA region for 1985 (based on FF data and ORNL
MA projections).

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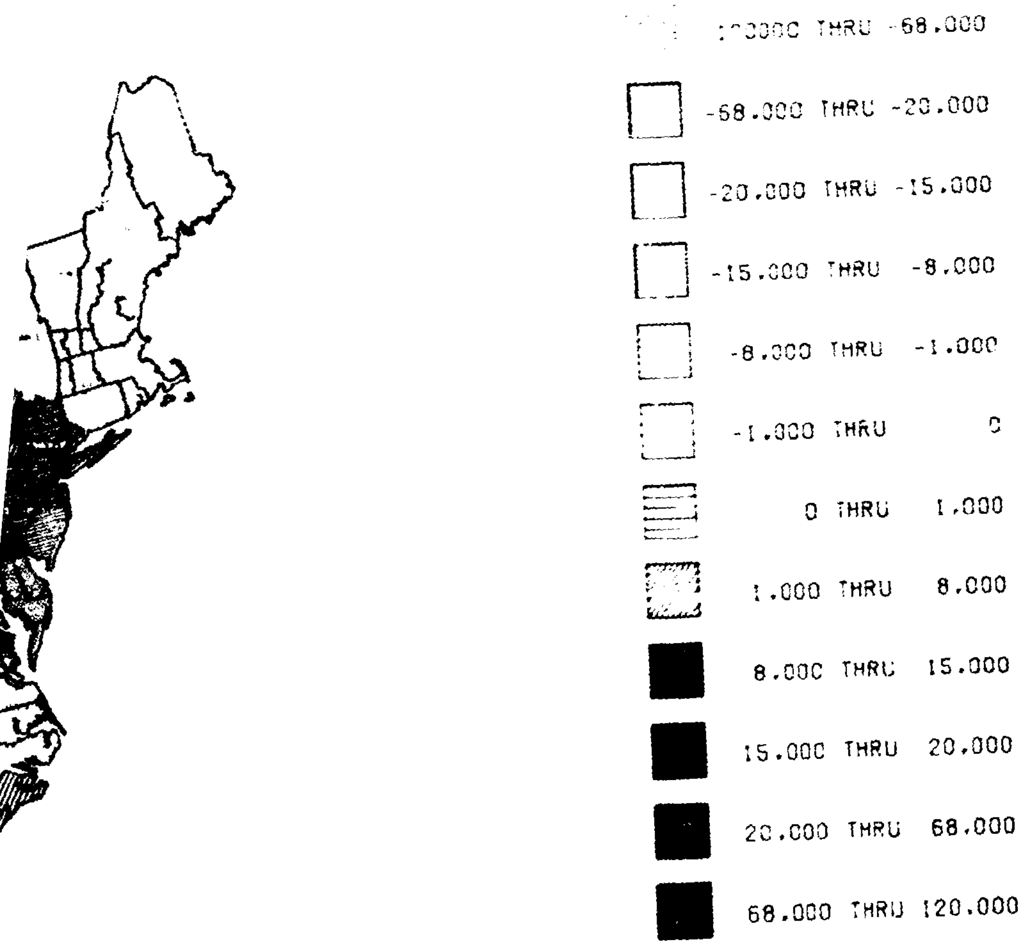

ts and ORNL

Table 3.4. (continued)

Importance weight	Factor	Defining term or statement
48	Maximum beneficial multiuse	Recreation, education, developmental
43	Unfavorable attitude of regional population	Potential for organized regional opposition
42	Minimum distance to transmission grid	Line construction costs and environmental impact
41	Maximum reliability of offsite power	Power to run plant, a safety concern

load centers. Transmission is limited to about 240 km (150 miles) and is based upon present technology in transmitting power along ac lines.

Calculation of 1985 proximity to demand for the United States is presented in Fig. 3.12; proximity to surrounding load centers is shown for each county. Note that proximity is highest at the central county of each BEA and decreases to the point at which counties located more than 240 km (150 miles) from any major load center are rated lowest. The demand figures for each BEA used in the calculations have been transformed to reflect the added electrical generating capacity beyond 1972 that must be sited to meet demand in the year 1985. The planned or installed capacity, as projected by the FPC data, has been subtracted from forecasted required capacity for each BEA, thus indicating where projected electricity demand and actual planned capacity diverge.

Water availability. We expect water availability to be the prime locational determinant in energy facility siting even in the water-abundant eastern United States. Water requirements for a given facility may be calculated readily, but evaluating the availability of a dependable water supply to meet those requirements is much more difficult. Furthermore, we must account for all existing and planned facilities for a given river system. Water supplies are unevenly distributed among and within the several regions of the nation having substantial annual and seasonal variation. We saw the need, therefore, to develop computerized tools to assess water availability from a regional perspective down to specific site evaluation. The water availability system (WAS) analysis procedure for the Maryland Power Plant Siting Project is based on historical stream flow data and aids such availability analyses.[31]

The WAS enables the user to select, retrieve, and analyze the historical stream flow information from the U.S. Geological Survey (USGS) daily-value water tapes, which contain data for all USGS stream gauging stations in the United States. The WAS package is divided into four distinct subsystems, operating in sequential fashion, that enable the user to (1) delimit any region of the United States by state, county, size of drainage area, or latitude-longitude frame; (2) recall daily flow values from the USGS water types for all gauging stations within the study region; (3) compute low flow recurrence frequencies and apply theoretical probability distributions; and (4) predict the reservoir drawdown capacity that would be necessary to maintain any given rate of stream flow at any specified rate of consumption. Separating the parts of the model allows the first and third phases to be conducted on an interactive mode computer which facilitates frequent user decisions. The intermediate phase of data

31. J. S. Jalbert and A. D. Shepherd, *A System for Regional Analysis of Water Availability*, ORNL/NUREG/TM-82 (December 1976).

Table 3.4. Site factors identified in NGT session

Importance weight	Factor	Defining term or statement
97	Adequate foundation	Licensibility, concern with liquefaction and solution channels
94	Minimum proximity to geologic faults	Capable faults avoided, cost to investigate ancient faults
90	Maximum availability of suitable surface water supply	Both quantity and quality of intake water; cost of taking and cleaning water — only considered in sufficient low flow
90	Acceptable air diffusion characteristics	Radiological diffusion; high cost to overcome poor characteristics
90	Minimum conflict with existing and potential land use	Present use of site; loss of opportunity costs
89	Minimum impact on aquatic biota	Sensitive life stages of important species
89	Minimum adverse impact on endangered species or habitat	
87	Minimum total economic costs	Differential costs of plant, transmission system, water, and relocation of people
87	Minimum susceptibility to maximum hydrological meteorological events	
86	Minimum proximity to undesirable population distribution	NRC guidelines are maximum limit for this factor
86	Minimum impact on water quality	Impact on water quality from radiological, thermal, and chemical output
83	Minimum impact on unique cultural, historical, or archaeological sites	
79	Minimum adverse impact on local institutions	Includes hospital, school, and other social impact
79	Maximum availability of ground water	Availability without affecting offsite users
78	Minimum construction problems	Stem from roughness of terrain and presence of ground water
76	Minimum impact on terrestrial biota	Habitat destruction
75	Minimum adverse impact on local economy	
75	Minimum proximity to industrial hazards	Danger to plant from hazardous industrial processes in surrounding area
70	Availability of land parcels of sufficient size	Ability to aggregate site from individual parcels with minimum cost and delay
69	Maximum compatibility with local government attitudes	Attitude of local government toward development
68	Maximum G value for DBE	Calculation of potential acceleration caused by seismic activity
66	Minimum aesthetic impact	Includes both visual compatibility and noise
65	Minimum distance to acceptable transportation systems	Construction costs to get to rail, barge, and highway
64	Minimum adverse impact on recreation	Proximity to incompatible recreation use such as national wildlife refuge
63	Minimum adverse impact on regional economy	
56	Unfavorable attitude of local population	Potential for local opposition
51	Maximum proximity to load	Affects system reliability, costs, and stability

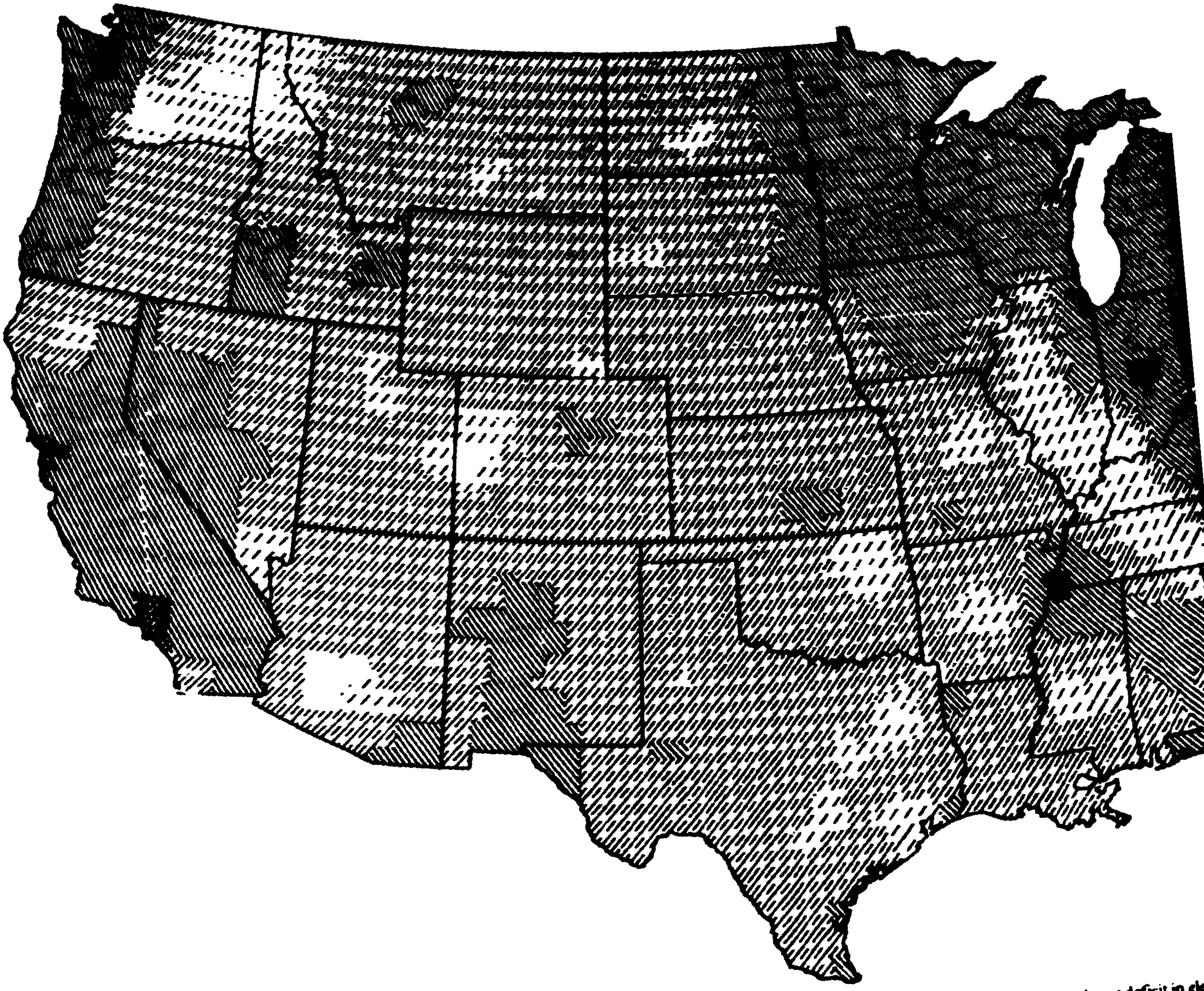

Fig. 3.12. Proximity to estimated 1985 surplus or deficit in el[...] for each county *i* as[...] on a gravity model that defines proximity *P* for each county *i* as

$$P_i = \sum D_j d_{ij}^{\cdot}$$

where *D* is the surplus or deficit capacity in 1985 for each BEA *j*. [...]
and BEA *j*.

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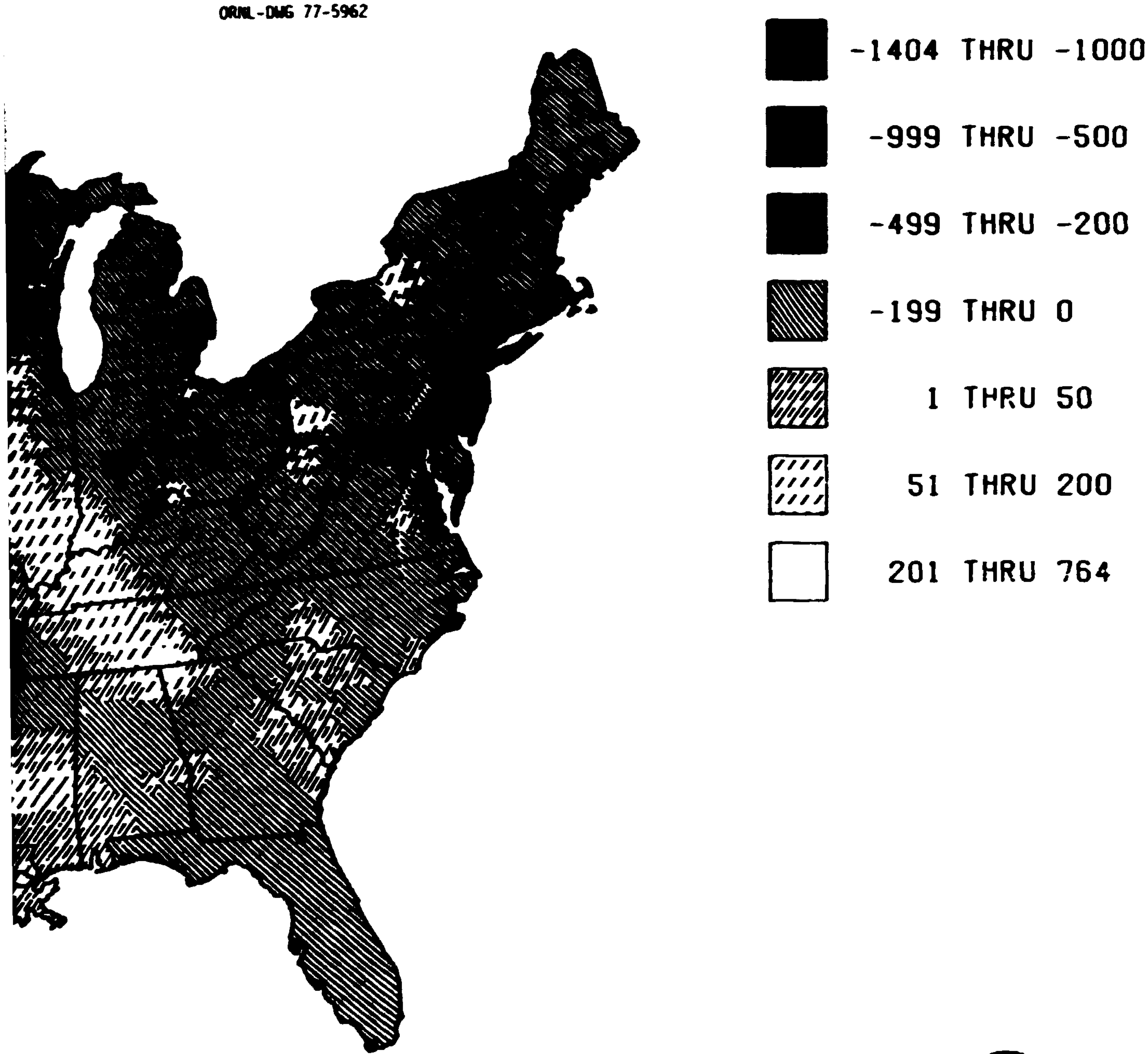

s or deficit in electrical generating capacity calculated on a county basis. Based
ach county *i* as

r each BEA *j*, and *d*ᵢ is the distance in miles between the centroids of county *i*

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retrieval, however, uses a batch mode computing system and usually does not require user interaction.

The study area for the definition and selection process may be delineated by latitude-longitude frame, state(s), county(ies), or drainage area size specifications. Data retrieved for each station include (1) USGS code number and name of the station; (2) latitude and longitude; (3) size of the drainage area served; (4) state and county Federal Information Processing System (FIPS) code; (5) monthly average flows by water-year (only for months yielding complete sets of daily flow records); (6) number of days of record for each year; (7) yearly average flow; (8) yearly maximum and minimum flows; (9) overall average, maximum, and minimum flows for the entire period of station record; (10) the 1-day, 7-day, and 14-day low flows calculated for each season of record in the data; (11) the recurrence fractions for the volume flows equaled or exceeded at that station 99, 95, 92, 90, 85, 80, 75, 70, and 50% of the time; (12) the number of output tape records used; and (13) a continuous record of data representing the actual daily measurements of the historical flows of each station. Current capabilities of the analysis subsystem are (*a*) determination of stations' historical low flows; (*b*) computation of low flow recurrence frequencies and application of theoretical probability distributions; and (*c*) modeling of reservoir capacity requirements to support a given consumptive level while maintaining specified minimum stream flow standards. Addition of other models or analyses is permitted with relative ease by modular design of the subsystems and the computer-compatible format of the data generated by the programs.

The WAS package is also well suited to investigating a broader range of water resource questions, including evaluations of water availability to meet projected energy demands. The application of the WAS program to the Maryland Power Plant Siting Project is described in ref. 32.

In performing our energy facility siting analysis for the southern United States, we entered low flow information generated by WAS for gauging stations into our geographic data information system. Figure 3.13 presents 7-day, 10-year low flows for selected streams in the Ohio River Basin region that were used in our energy facility siting analyses for the ORBC. Low flow values are shown for each county bordering on the main stem of the Ohio River or on tributary streams having sufficient flow to support at least one energy facility. Values for counties having gauging stations were calculated and allocated to intervening counties through visual interpolation. Note that values used for the main stem represent modified low flow calculations reflecting the effect of reservoir regulation. These calculations were provided by the U.S. Army Corps of Engineers.[33]

Coal availability. Under contract with EPRI, our research group is developing a model incorporating geologic and mine engineering factors to calculate volumes of coal reserves and specific mining cost variables. Drill core data and coal outcrop measurements for such variables as geographic location of drill hole, coal seam thickness, overburden type and thickness, and coal quality collected by TVA field geologists (using the 1:24,000 block quad in East Tennessee as a test case) are being digitized and stored in a computer. Contour lines indicating the coal seam thickness and the thickness of overburden are drawn by a computer routine by interpolating between the drill core locations (Figs. 3.14 and 3.15). In addition, calculation of measured and inferred reserves can be made on the basis of standard criteria used by TVA and USGS (Fig. 3.16).

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32. J. E. Dobson, *The Maryland Power Plant Siting Project: An Application of the ORNL Land Use Screening Procedure*, ORNL NUREG TM-79 (October 1976).

33. Water flow numbers for the main stem of the Ohio River were generated by the U.S. Army Engineer Division; see U.S. Army Engineer Division, Ohio River, Cincinnati, Ohio, 1970 (1968 system, less Rowlesburg, 7-day duration, 10-year frequency low flows, main stem Ohio River).

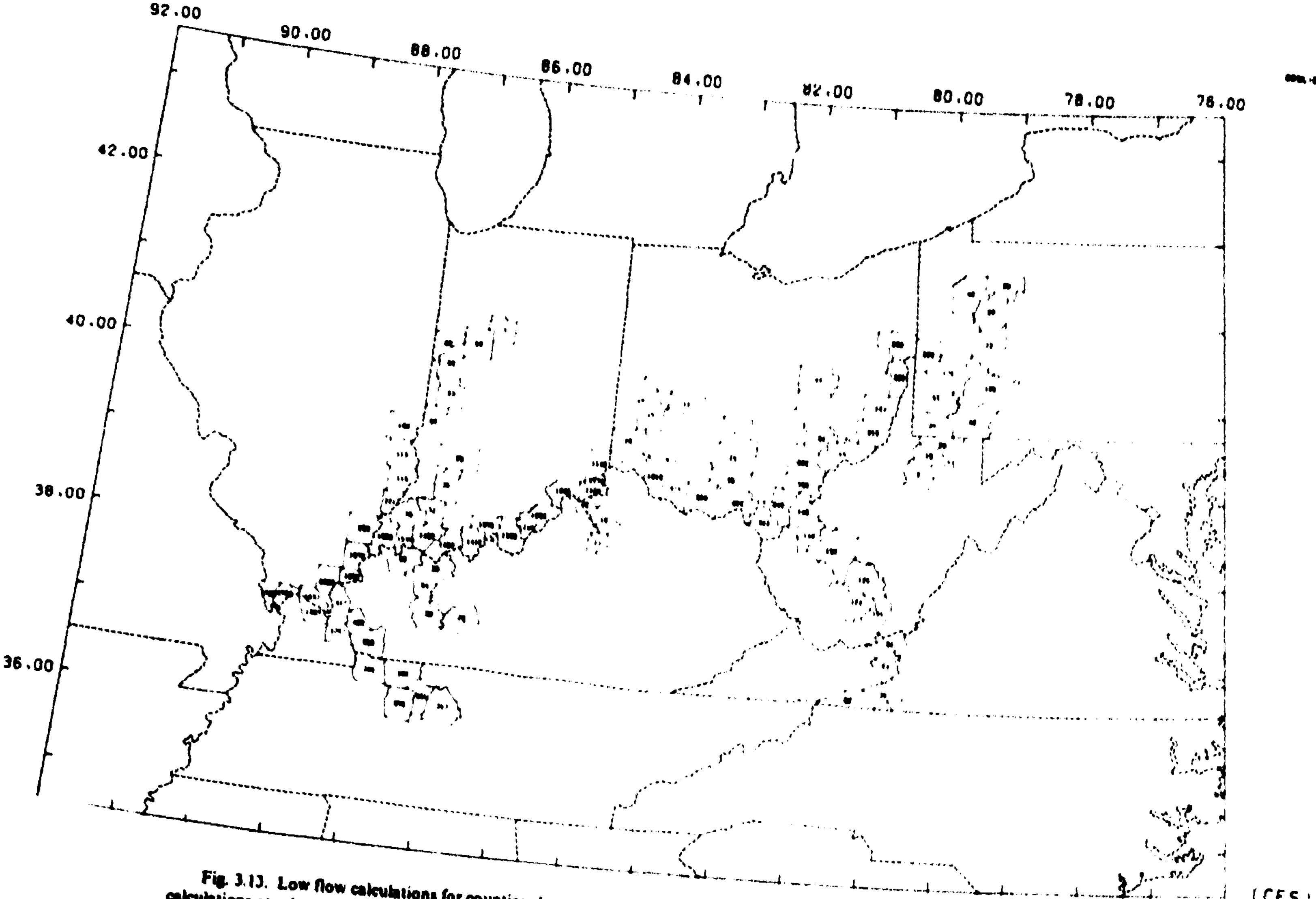

Fig. 3.13. Low flow calculations for counties along the Ohio River and major tributaries (based on 7-day, 10-year low flow calculations at selected gauging stations). Numbers are for flow in cubic feet per second.

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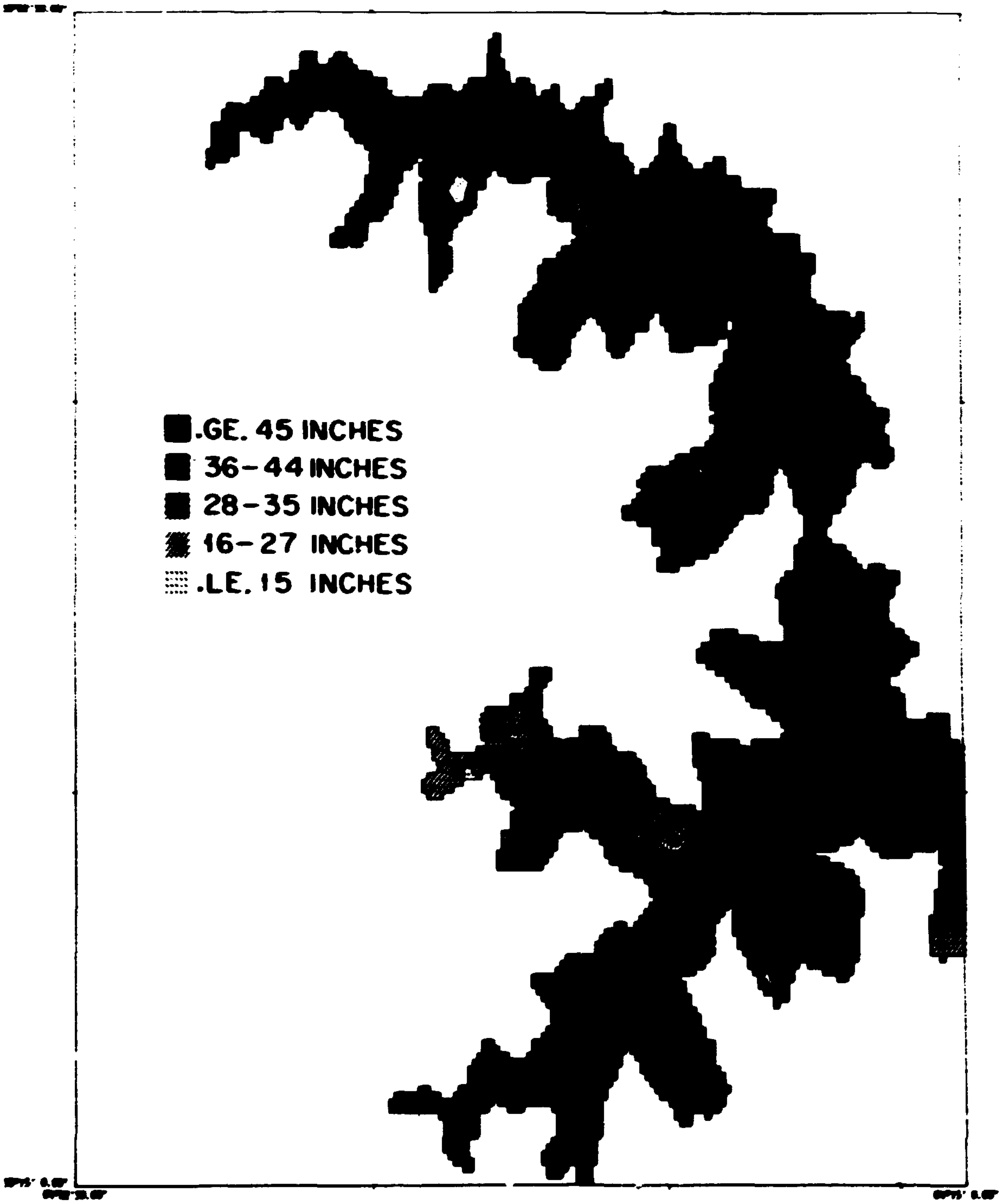

Fig. 3.14. Coal seam thicknesses for red ash seam in the 1:24,000 block quadrangle of East Tennessee (based on data provided by TVA, Fossil Energy Branch).

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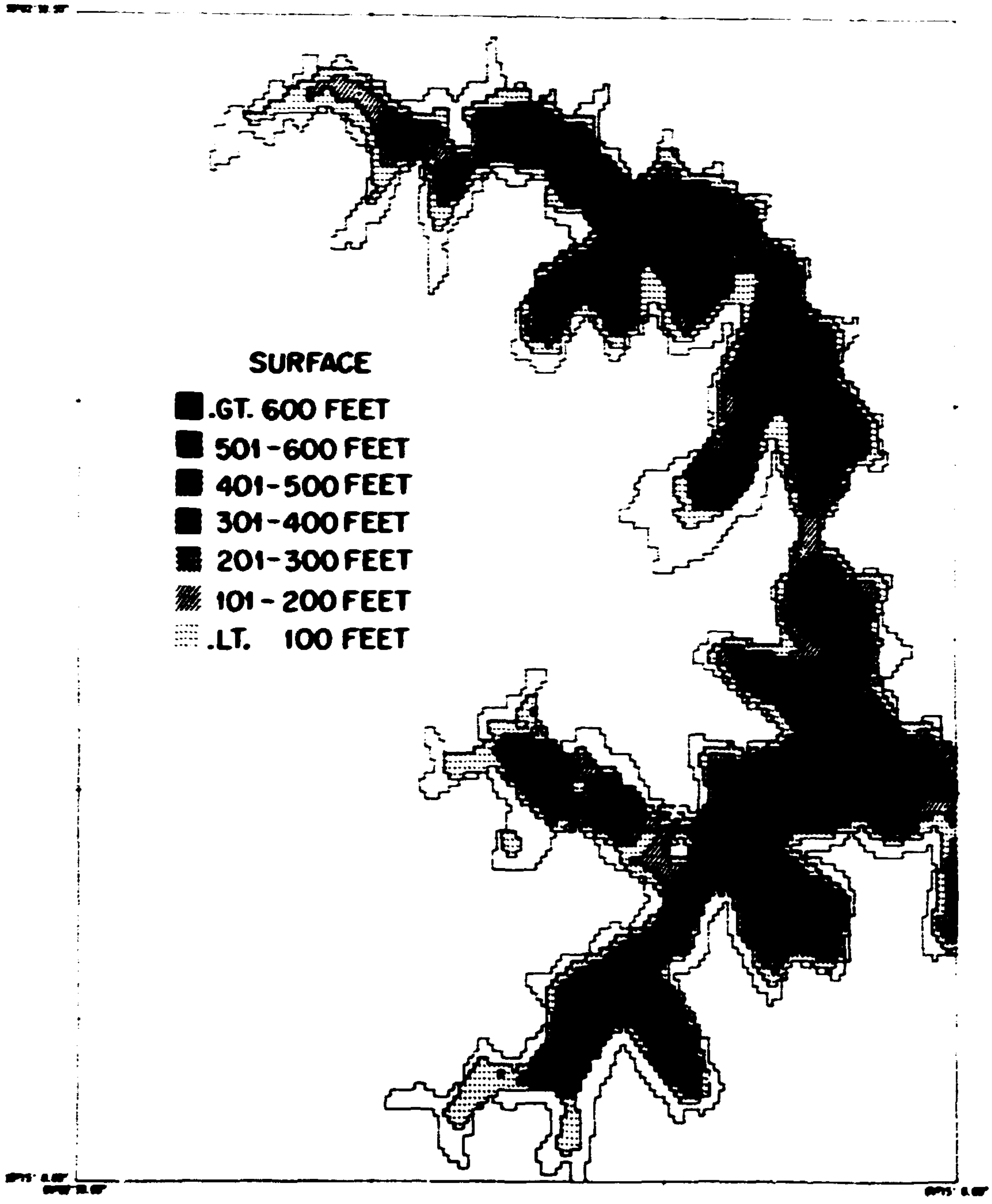

Fig. 3.15. Thicknesses of coal seam overburden for red ash seam in the block quadrangle of East Tennessee (based on TVA Fossil Energy Branch data and ORNL digital elevation data).

ORNL-DWG 77-4195

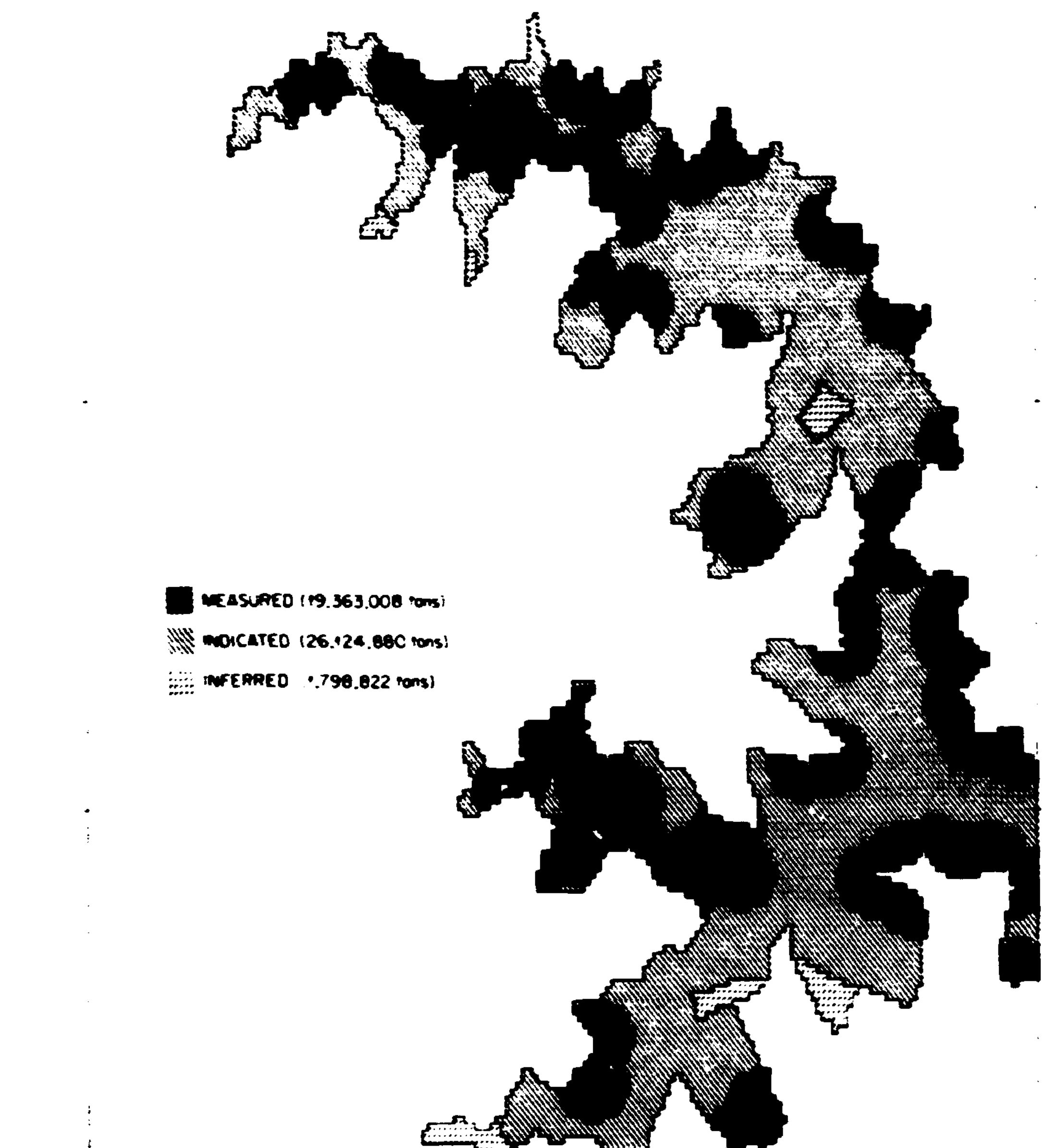

Fig. 3.16. Interpretation of measured, indicated, and inferred coal reserves for the red ash coal seam (based on TVA Fossil Energy Branch data).

A variety of more sophisticated and comprehensive coal reserve models similar to our effort are being developed around the country, and we expect to incorporate characteristics of these models into our work. We have established a working arrangement with the USGS to use their National Coal Data Base System called PACER. What makes the ORNL-EPRI model unique, however, is that the program is geared toward immediate use by coal mine operators because it incorporates existing field data collected by traditional methods.

As part of the National Coal Utilization Assessment, we are inventorying coal reserves by county in the Appalachian region in terms of the f.o.b. price. Coal reserves are assessed from an economic perspective which accounts for variables such as coal seam thickness, coal quality, mining and reclamation costs, and overburden thickness. The feasibility of coal-fired generating plants in a given demand area can be determined when f.o.b. coal price at the mines is combined with a transportation cost model. The ultimate result is a systematic ordering of the areas in which coal is likely to be mined. By coupling this result with a transport model, one can determine the delivered cost for coal at various points throughout our southeastern region.

In addition to calculating the distribution and availability of coal reserves, we will determine certain environmental limitations for the use of coal from the Appalachian region. For example, significant coal reserves may lie in areas of high recreation potential, areas of critical wildlife habitat, and/or areas of low or sensitive water quality; any one of these factors might be seriously diminished or destroyed by mining of coal resources. An accurate assessment of coal reserves should flag these environmentally sensitive areas, and any decisions regarding potential mining sites should necessarily recognize and respect these caveats.

Recreation limitations. The outdoor recreation potential of the coal-bearing counties in the Appalachian region is being determined with respect to how well a hypothetical park built in a given county ranks in (1) its ability to satisfy the predicted recreation demand within a region bounded by a 2-hr driving time from the given county and (2) the absolute number of people within this bounded region who could be expected to visit such a park (a state-park-size facility is assumed).

A gravity model is used to predict the number of recreation participants within the given region who could be expected to travel to the hypothetical park. Gravity models are based on the concept that approximate bodies are drawn toward each other as functions of spatial distance and individual attractiveness. The recreation participation values represent both an absolute number and a percentage of the total potential recreating population. Essentially, these numbers are a function of (1) certain characteristics of the given region's population size, income and age distribution, and related socioeconomic factors; (2) certain characteristics of the hypothetical park such as the total available acreage, water acreage, and shoreline miles; and (3) spatial separation between originating populations and the park, as measured by travel time. Simply, then, the number of potential visitors is a function of the recreation character of the given region's population base and a function of the accessibility and attractiveness of the park relative to other competing options.

Because the model can generate a county recreation potential ranking based on the ability to satisfy predicted regional demand for recreation, all coal counties in Appalachia can be viewed in terms of their criticality to their respective regions. If only absolute numbers of potential recreators were calculated, as is the case with most recreational models, the resulting rankings would be skewed toward those counties nearest the large urban centers. To date, the coal-bearing counties in East Tennessee have been identified and a 2-hr driving time boundary around each county has been manually calculated. The system is in the process of being automated, and when complete, its utility and feasibility will be greatly extended.

Wildlife limitations.[34] Limitations due to critical wildlife habitat areas have been shown to be identifiable in a process which employs a combination of topographic, social, and environmental variables. The method provides a reasonably accurate assessment of habitat quality in a specific geographic area prior to surface mining activity and should be able to project changes in quality both during mining and after reclamation. Figure 3.17 consists of two maps comparing the habitat before mining with that after mining and showing reclamation habitat with respect to white-tailed deer in the 1:24,000 Duncan Flats quad of East Tennessee. Further research on wildlife impacts is continuing in the Environmental Sciences Division.

Water quality limitations.[35] The first step in assessing water quality limitations to coal mining activity involves the establishment of baseline estimates of natural water quality conditions. A model can then be run to simulate the cumulative water quality impacts expected from mining the calculated reserves. Areas are thus identified where these cumulative impacts are likely to approach or exceed established standards for water quality. In the past year seven parameters of water quality have been checked in selected drainage basins in Appalachia against USGS water quality data; results have been clouded by anomalies believed to derive from groundwater seepage from underground mines. As a result, baseline estimates, to be useful, must be drawn from simulations based on natural watershed characteristics such as forest cover, geologic data, and topography.

Air resources limitations. Since air quality is an important consideration in siting coal-consuming energy facilities, we have investigated the applicability of various air quality models for measuring the spatial distribution of air pollutants. The usefulness of current models for very large regions such as the Southeast has not yet been demonstrated, although we are continuing our efforts in this regard. We are currently using Air Quality Maintenance Areas (AQMAs) designated by the Environmental Protection Agency as a surrogate measure for air quality standards. The AQMAs are regions defined by combinations of counties in which future air quality degradation will be carefully monitored by regulatory agencies; therefore, AQMAs represent areas somewhat less suitable for siting coal-using facilities. To date, the AQMAs for the southern United States have been identified and entered into our county-level information system.

Transportation limitations. Tentative agreement has been reached with the Federal Rail Administration to use its National Rail Network Model to calculate rail transport accessibility at the county level for the United States. Rail accessibility information will then be merged with existing data concerning water transportation to produce transportation accessibility measures at the county level in terms of energy facility siting constraints.

Population distribution limitations. Population density in terms of constraints to the siting of energy facilities (particularly in the case of nuclear facilities) has been mapped for the United States (Fig. 3.18). Several options in calculating site restrictions based on NRC siting regulations have been developed. Eventually, these options will be available in map form, depending on the technology being considered and the site constraint option desired.

Social-institutional limitations. The NGT panels which guided our selection of siting factors listed a number of factors relating to impact on social systems; we have pursued the quantification of these factors during the year. To date, we have adapted a generalized social impact assessment methodology for siting and have begun the task of quantifying four major areas of impact—cultural, institutional, local service, and local economic impact. This has proven to be our most difficult

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34. This work was conducted by H. E. Keegan of ORNL's Environmental Sciences Division and reported in an unpublished manuscript, "Contour Strip Mining, Its Environmental Effects, and a Technique for Wildlife Habitat Assessment."

35. This work was conducted by J. R. Hyndman of ORNL's Environmental Sciences Division.

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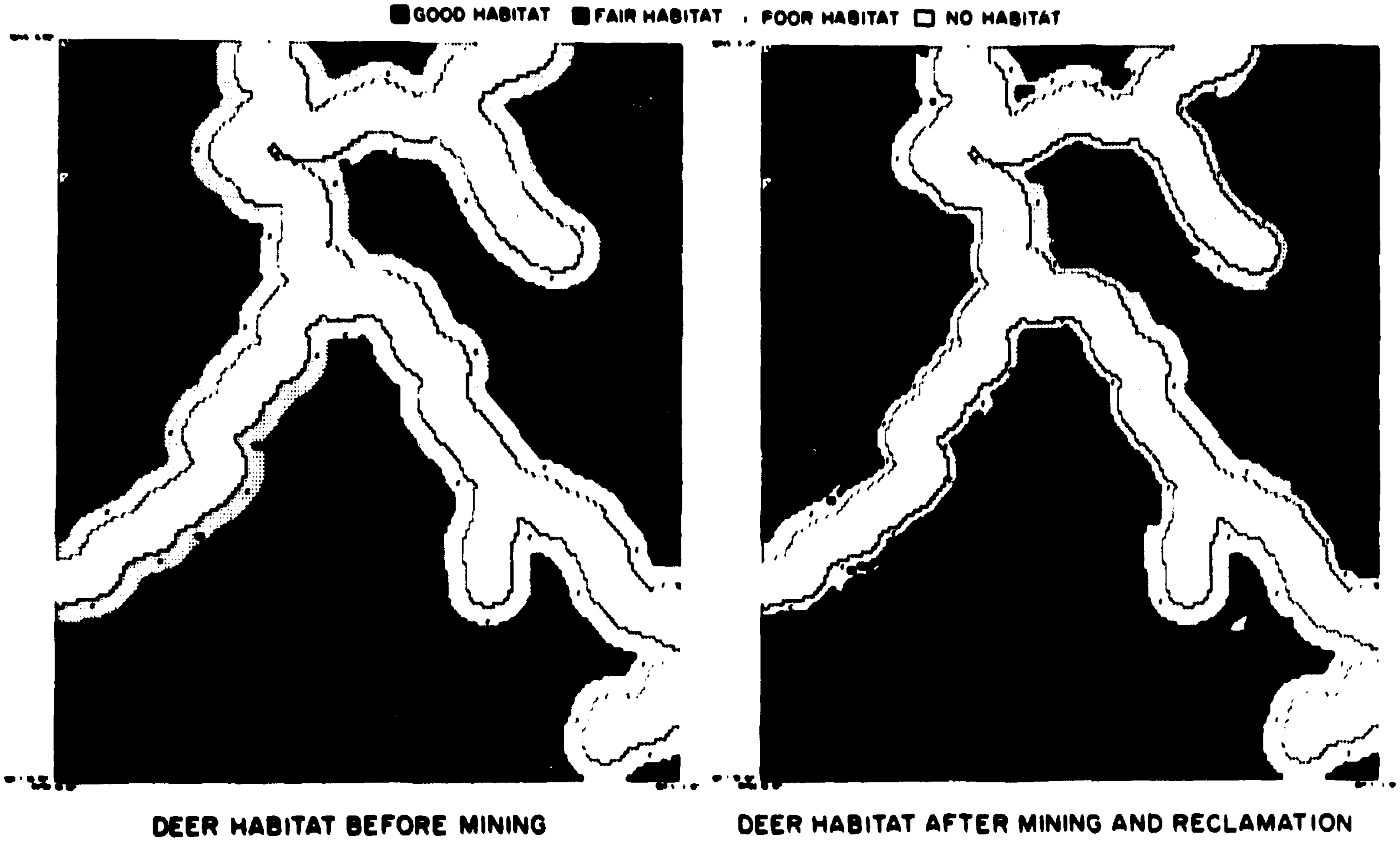

Fig. 3.17. Comparison of white-tailed deer habitat before strip mining with that after mining and reclamation for the 1:24,000 Duncan Flat quadrangle of East Tennessee. Habitat after mining is based on full reclamation.

ORNL-DWG 77-5791

Fig. 3.18. Population density as a function of limiting nuclear power plant siting for the United States (based on an unofficial 500 persons sq mile density constraint).

factor model built to date, and in developing it, we are using input from the Social Impact Assessment Group. Of necessity, much of our quantification will consist of verbal descriptions created by interpreting diverse sources of information such as survey input. The local service impact measure is being developed in close cooperation with TVA, and we intend to use TVA experience as input to the construction of the model.

3.3.3 Development of the Oak Ridge Regional Model Information System

The geographical data system being used in the resource analysis and energy facility siting work of the Resource Analysis Group and the data input and analysis components currently being interfaced with the Oak Ridge Regional Model Information System (ORRMIS) are being developed in the Computer Sciences Division through support from the Energy Division. This work is discussed in more detail in ref. 36.

Input data, both raw (e.g., maps and aerial photography) and machine-readable (e.g., satellite and census tapes), are stored in one of several different types of data bases. Data are organized according to the most efficient method of information representation (e.g., cell and polygon data), as determined by the users, and may be retrieved for a number of different purposes. Figure 3.19 illustrates how data are stored, retrieved, and analyzed and how results are displayed in a variety of forms. The data base may be accessed for editing, updating, transformation (e.g., interpolating from random points to a grid system), and simple display.

Each step (input, storage retrieval, analysis, and display) represents complex processes ranging from interactive digitization systems for input to three-dimensional surface contour plots for display (Fig. 3.20). The software for performing these functions has been developed as individual generalized modules or packages because many of the routines used in one step are also used in other steps (e.g., the map projection routines are used for input data rectification as well as output map display). Due to the complexity of the data structures and the analyses or models being built, no single giant software command system has been developed to house and supervise all the individual modules. Instead, each user problem is solved by picking available modules "off the shelf" (or by developing new ones as required) and linking them in the most efficient manner to solve the user problem.

The software for the data system has been developed on a user-need basis. This approach tends to point out quickly the shortcomings and needed improvements, as well as the computer science expertise needed in each area.

Many different types of information must be manipulated by the data system. Figure 3.21 presents the major types of data and corresponding software systems that are being developed. All of these components (e.g., water availability models, site-population constraint models, and land availability models) feed into ORSAM, which in turn provides output that may be used to determine candidate areas for the siting of energy facilities.

In each step (input, storage, analysis, and display), there are about twelve major developmental efforts currently under way; the following subsections describe one example from each step.

Data input requirements: An interactive semiautomated digitization system. The purpose of an interactive semiautomated digitization system is to allow information from maps, photographs, etc.,

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36. R. C. Durfee and R. G. Edwards, *Geographical Data Systems: Overview and Concepts*, ORNL-RUS-27 (to be published).

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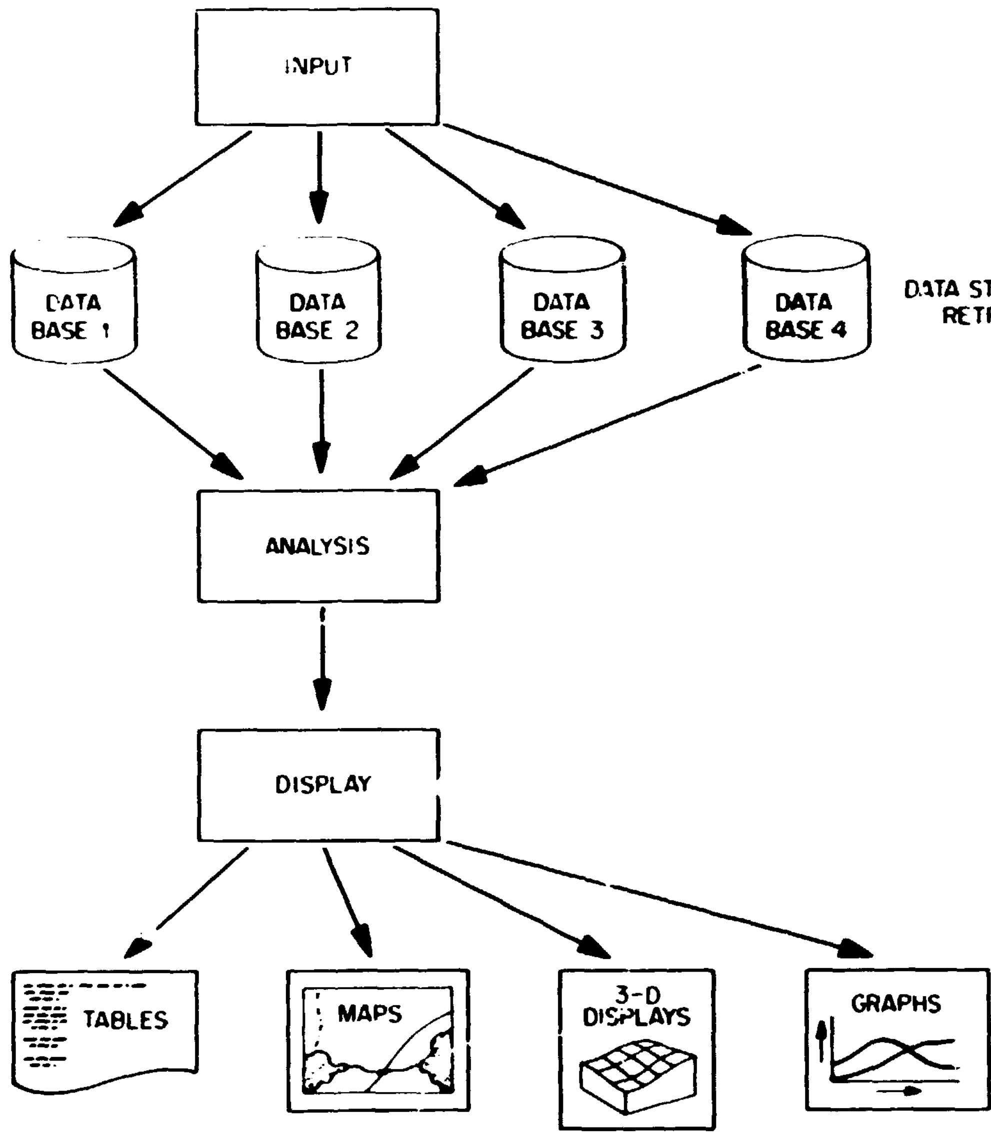

Fig. 3.19. Simplified diagram of the ORRMIS data system.

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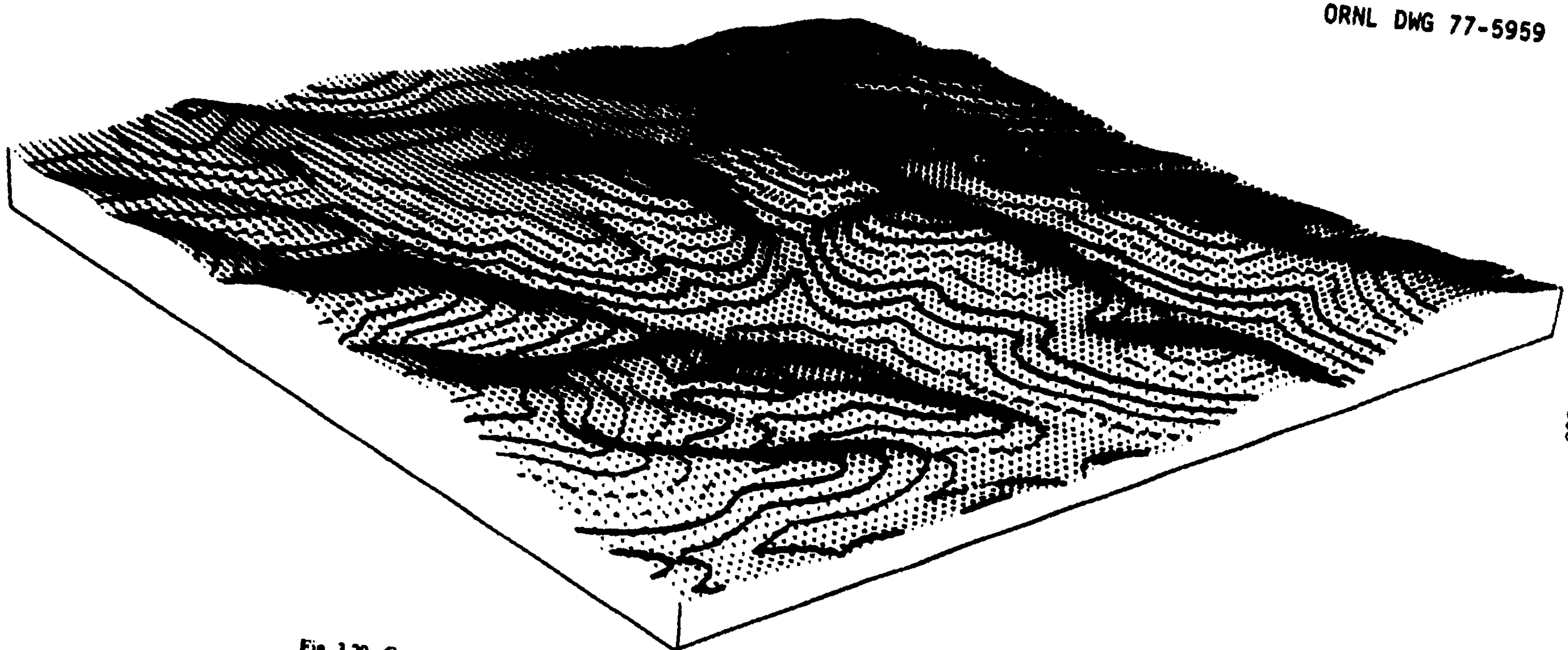

Fig. 3.20. Contour lines superimposed on topography for allocation dam area [10-m grid, 6.1-m (20-ft) contours].

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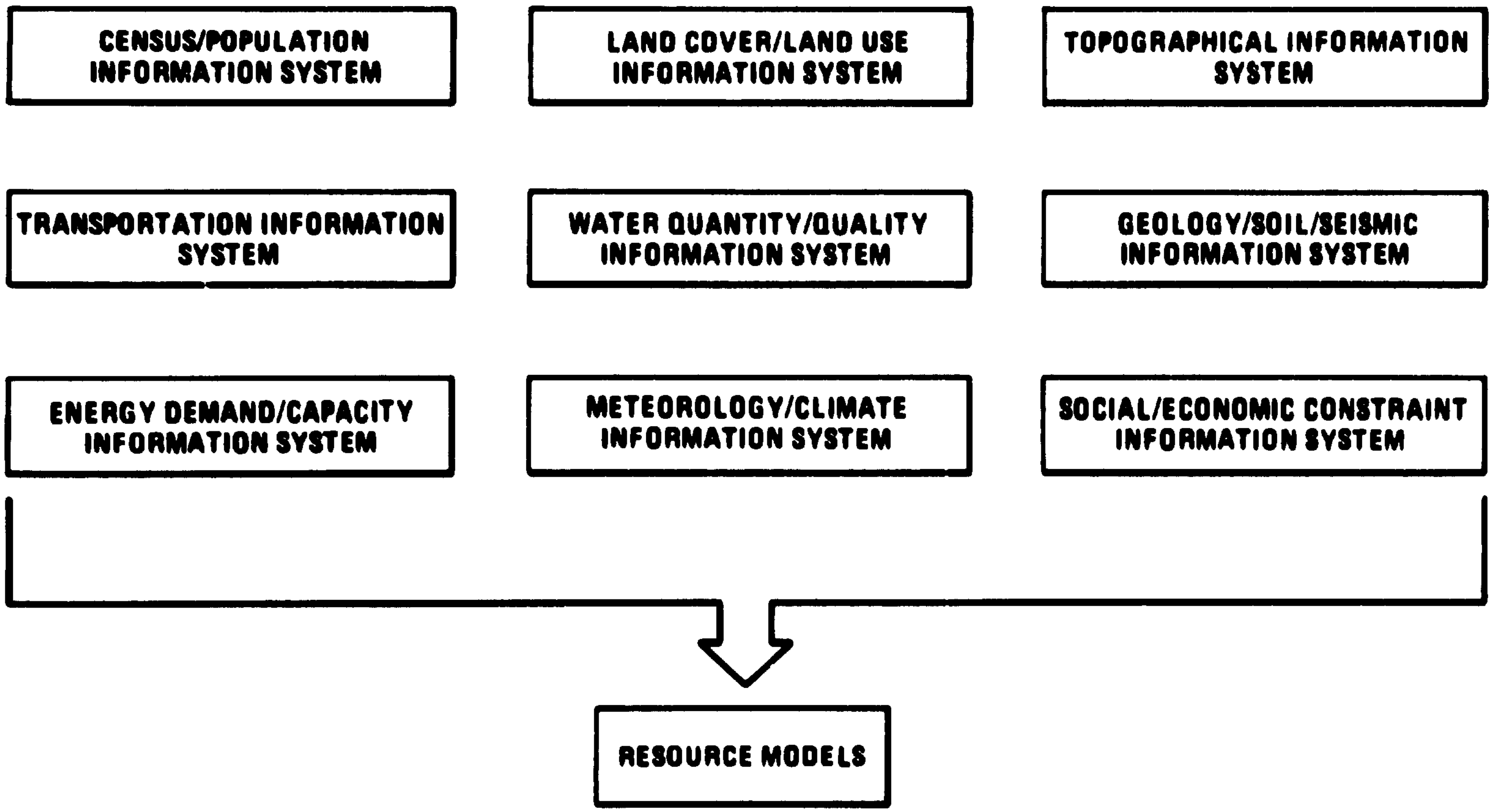

Fig. 3.21. Major types of data information.

to be digitized by an operator aided by an on-line computer system (Fig. 3.22). A tremendous amount of information (e.g., on transportation systems, river systems, power transmission networks, and seismicity) is available on base maps which, when digitized in machine-readable form, may be used for sophisticated resource analyses such as determining transportation accessibility, water availability, and population distribution. The current system shown includes (1) a digitizing station for operator map input, (2) a CRT graphics terminal with a hard copy unit for local map display, (3) a "floppy" disk for local storage of digitized data, and (4) a phone line interface into the host time-sharing computer for data processing (ORNL uses a PDP-10 time-sharing system).

The basic digitization process requires an operator to move the cursor over the map features to be digitized. A continuous stream of integer x-y coordinates is sent from the tablet to the CRT terminal for display. The data may then be stored on the floppy disk or sent on to ORNL's PDP-10 computer for processing. Processing involves converting integer coordinates into latitude-longitude, checking and editing simple errors, and displaying maps onto the CRT terminal for interactive editing.

The present system is a significant improvement over previous manual data acquisition techniques, especially considering the low cost of the equipment (about $25,000). However, because of the heavy time-sharing load on the PDP-10, the slow phone-line speed, and the inability to quickly overlay digitized data on the source map for comparison, this system is not well suited for high-volume production work. Additional equipment, including an on-line minicomputer and a video projection system, is needed to significantly improve (by a factor of 10 or more) the process, from initial data input to final corrected hard copy output. Most of the equipment is presently being purchased although a few pieces are still needed.

Much of the software developed for the system is also used in other areas of the geographical information system. For example, an algorithm to filter out x-y coordinates not needed to properly represent the curvature of a line (e.g., a highway) can be used in both data input (to reduce the number of unnecessary points) and map output as a function of map scale (to reduce plotter time).

Data base storage–retrieval: County level data base system. As mentioned previously, a number of different types of data bases are being developed and stored in data structures according to user need. For example, the U.S. Bureau of Census population data is stored as point data (population counts by enumeration district centroids), referenced by latitude-longitude; the Department of Defense topographic elevation data base (TOPOCOM) is stored in 0.4047-ha (1-acre) grid cells (elevation at centroid of each cell), referenced first by a latitude-longitude rectangle of an area and then by row and column number of each cell; and the coal seam data base is created and stored as polygonal data (boundary around coal seam outcrops), referenced by coal seam number or a latitude-longitude rectangle of the area. Although these data are stored and retrieved in various forms for general accessibility, often several data base types must be transformed into one so that variables may be simultaneously analyzed in the same coordinate system and the same data structure. For example, the population data stored by enumeration centroids must be interpolated to a grid system of cells to compute population density before it can be combined with other gridded data. When gridded population density is compared with polygonal data (e.g., polygonal county outlines), contours must be constructed from the gridded data and stored in polygonal form. Figure 3.23 shows examples of different types of data structure transformations for which software has been developed. (Some software packages are still not generalized.)

The primary purpose of this section is to briefly describe one of the data bases that is being developed for the regional power plant siting analysis. The basic storage unit for this data base is the county. A number of different variables are being collected for each county across the southern

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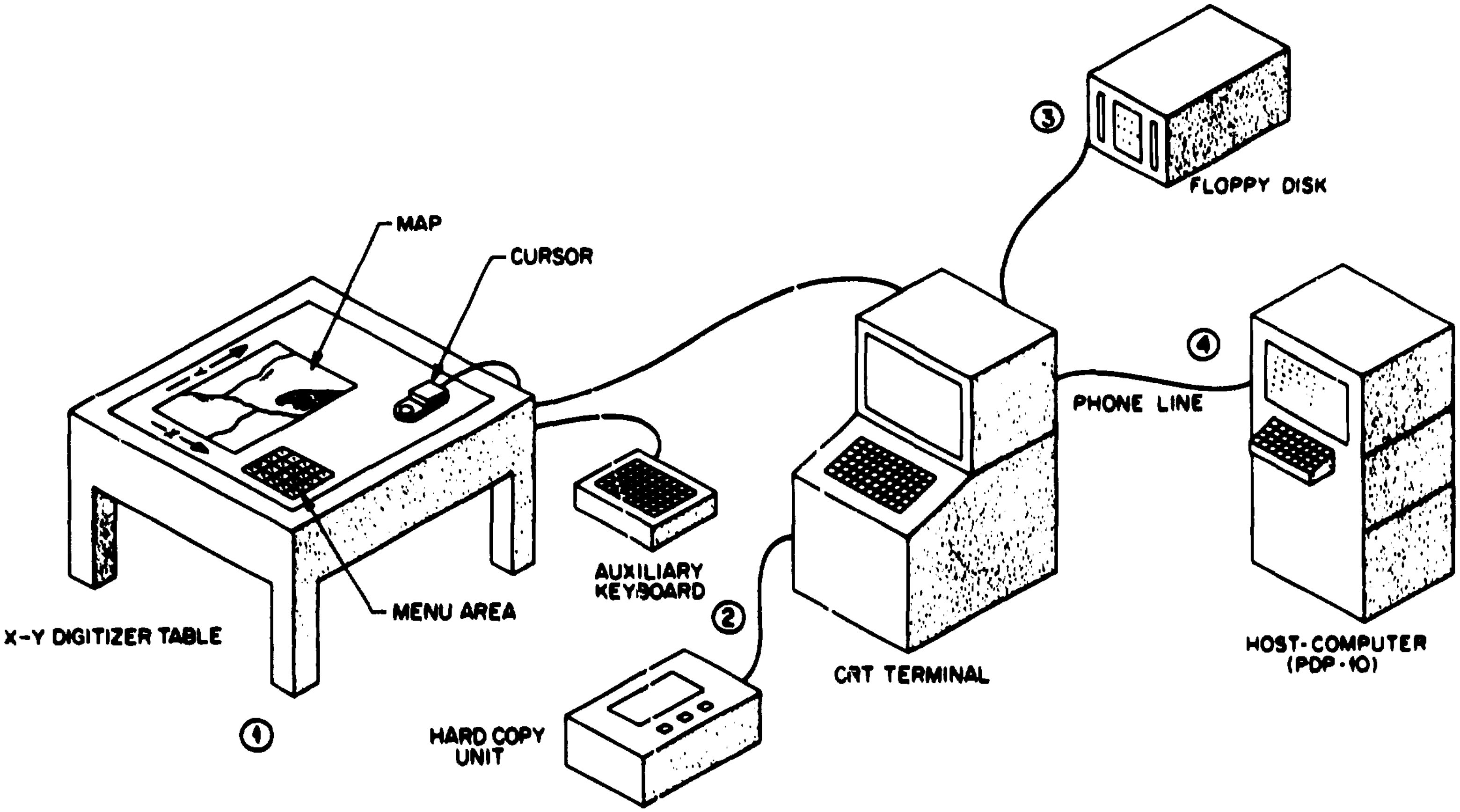


Fig. 3.22. Interactive semiautomated digitization system.

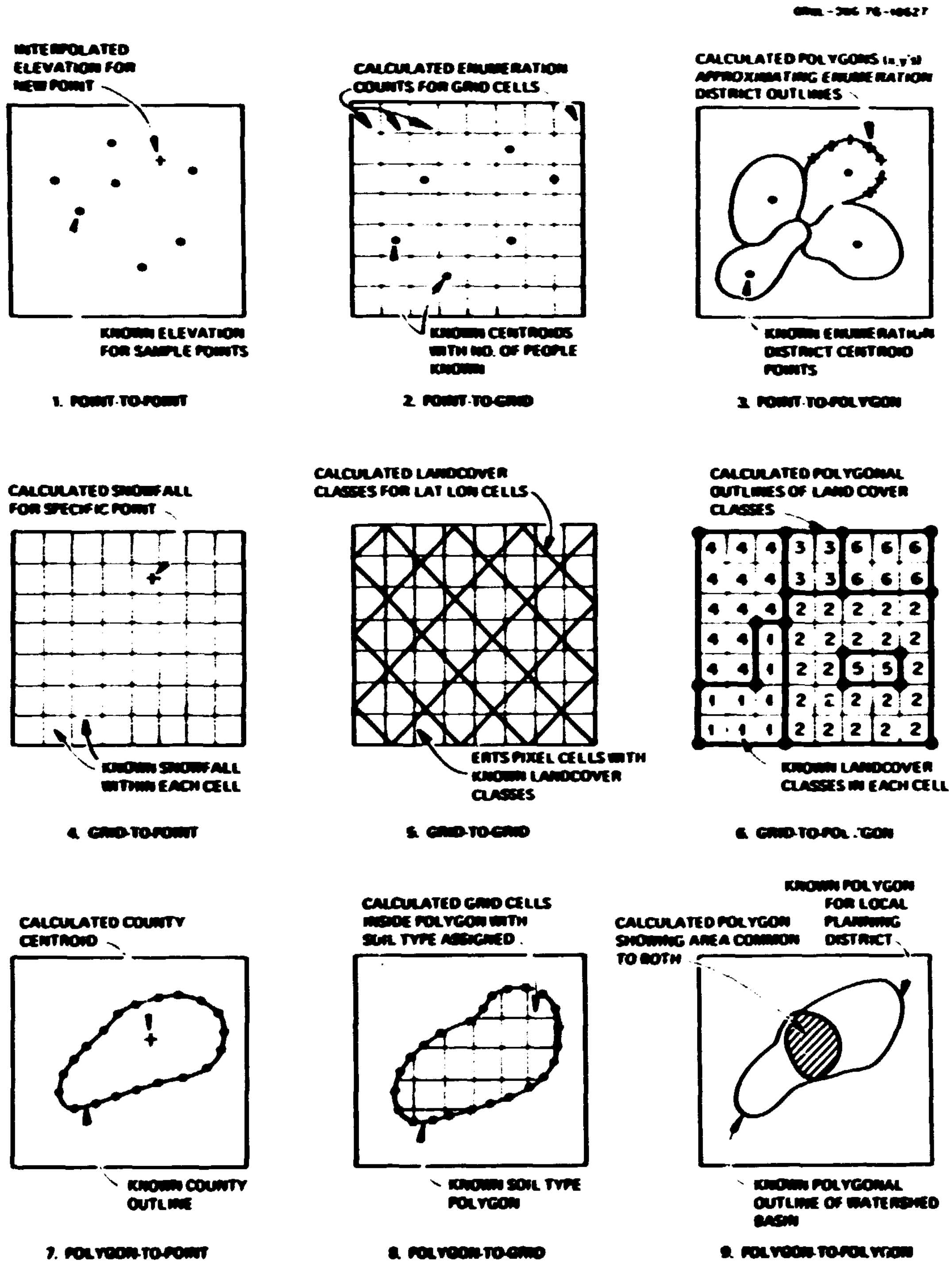


Fig. 3.23. Geographical data structure transformations.

United States. Using a direct access file for storage and retrieval, the data area is referenced either by county FIPS code, latitude-longitude of a point within the county (e.g., county centroid), state and county name, or a latitude-longitude window (rectangle) including multiple counties. Examples of the variables include seismicity class, presence of rail lines, water flow, energy demand, barge channel depths, presence of endangered species, population accessibility, public lands, wildlife monitoring stations, and geology.

The data base actually consists of two types of files: (1) the cartographic file containing the polygonal outlines in latitude-longitude defining the county boundaries and (2) the thematic file containing the data values associated with each county. To analyze or map the data, both files will normally be accessed. For example, part of the siting process is to determine the proximity of each area in the South to future energy demand. This information allows a determination of the accessibility potential of each county in relation to the economic costs of transmitting energy to surrounding high-demand areas. In this case the cartographic file would be accessed to determine adjacency, and the thematic file would be accessed to obtain the actual energy demand values for each county.

Since the data base is being stored as a direct access file, it is possible to retrieve the county information in any order desired. Thus, the user is allowed to cross state boundaries at will during an analysis, rather than being required to process sequentially all the counties within a given state.

As new data are collected, they are converted, when possible, into a form that may be stored in the county data base. Some data, such as LANDSAT or TOPOCOM data available on a 0.4047-ha (1-acre) cell grid, are being studied to determine the feasibility of aggregating such detailed data up to the county level. At this point, there is a possibility that topographic data can be aggregated by slope classes and terrain roughness up to a county level (or at least to a 7.5-min quad level).

Analysis: TOPOCOM topographical analysis system. There are many different types of analyses that are performed in solving any one of the tasks assigned to the Resource Analysis Group. Some analyses, such as the calculation of transportation accessibility or the calculation of background air pollution over a large region, are preparatory to the actual modeling itself. Other analyses are actually part of the synergistic modeling effort in which previous analysis results are combined simultaneously with other data variables to determine the optimal location of a power plant facility. These modeling and forecasting efforts usually require software that allows user interaction so that researchers may iteratively search for a solution subject to changing criteria. For example, economists and environmentalists would use different criteria to site a power plant.

Since several modeling analyses have already been discussed, this section will describe one of the preparatory analyses that are required to provide topographic information (e.g., slope aspect, ridge line), watershed information, and drainage pattern data. This information is useful not only in the energy facility siting and the coal reserve studies but also in assessing the environmental impact of strip mining upon water systems, an assessment which is part of the Appalachian coal study.[37]

The basic source of information in this system is the TOPOCOM data base of elevations, digitized by the Defense Mapping Agency (DMA) from the 1:250,000 quad sheets. The DMA data base for the continental United States has been purchased by the Computer Sciences Division at ORNL. By extracting the crude contour data from the TOPOCOM tapes, rectifying it to latitude-longitude, and applying a sophisticated least-squares interpolation (using 16 neighboring data points from the

37. R. B. Honea et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 125–31.

nearest two contour levels), a gridded set of elevation data can be calculated for any area in the county. From these elevations new refined contours may be mapped as shown in Fig. 3.24. The accuracy of the interpolated elevations depends on the accuracy and contour spacing of the original data, but is generally within 40 ft of true elevation.

Once gridded elevations are calculated, it is possible to calculate several important parameters useful in the resource analysis tasks: (1) slope by degrees or percent, (2) aspect in degrees from north, (3) ridge lines, (4) watershed boundaries, (5) drainage patterns, and (6) possible floodplain areas. Figure 3.25 shows the watersheds and their boundaries (green) for a complete 7.5-min quad in East Tennessee. Shown in blue are those potential streams that would drain each watershed. The red cells represent the point at which all the water leaves a particular watershed. The large blue areas that are several cells wide show areas where flooding might occur due to very flat topography.

The techniques used to compute this information are quite complex because of (1) the large number of 0.4047-ha (1-acre) cells that make up a 1:24,000 quad and (2) the desire to achieve high efficiency and low machine costs. Because of their complexity, the computer algorithms will not be described.

This type of topographical information is valuable, especially on a regional level, where digitizing costs and time prevent the collection of detailed data. The DMA digitizing and processing effort, which required a number of years to develop, represents an excellent data resource.

It is possible to combine variables such as slope, strip-mined areas, soil conditions, watershed basins, rainfall, and runoff to evaluate the effect of open strip mines on surface water.[38] Topography and slope are also valuable for selecting sites for power facilities and determining visibility of the cooling towers and stacks to the surrounding population.

Display: Polygon mapping system. A wide variety of software tools are being developed or are currently available to graphically display spatial data. Rather than describing each of the different plotting programs, this section describes typical output from the polygon mapping system. Figure 3.26 is a typical polygon map of the United States showing the 1975 generating capacity (in thousands of megawatts) at existing power plants by county. Each county is shaded according to generation capacity, and within each shading pattern an integer has been plotted (legible only at original scale of 1:5,000,000) showing the actual numerical capacity. Note also that the county and state polygons have been drawn and that a legend is attached. A variety of map projections (e.g., Alber's equal area) are available, and the map scale is specified by the user.

Although the map looks relatively simple, the software to create it is quite complicated. For example, each line making up a shading pattern must be intersected with the county boundary to determine starting and stopping points. The computer automatically plots the optimal location for the integers, rather than requiring the user to input the location of each integer. The state and county polygons are structured so that common boundaries, whether state or county, are plotted once. State lines can be dashes rather than solid. Aggregations of counties (such as BEA regions) could be plotted if desired. Symbols could be used instead of integers, and alphanumeric labels attached.

In summary, a wide variety of user options are available for presenting data effectively in geographical map form. The ability to perform the techniques efficiently is due to the underlying polygonal data structure used. The importance of graphical display is two-fold: (1) to present data

38. R. B. Honea et al., "Regional Scaled Methodologies for Environmental Assessment: A Case Study of Appalachian Coal Extraction," accepted for publication in *Journal of Environmental Systems*.

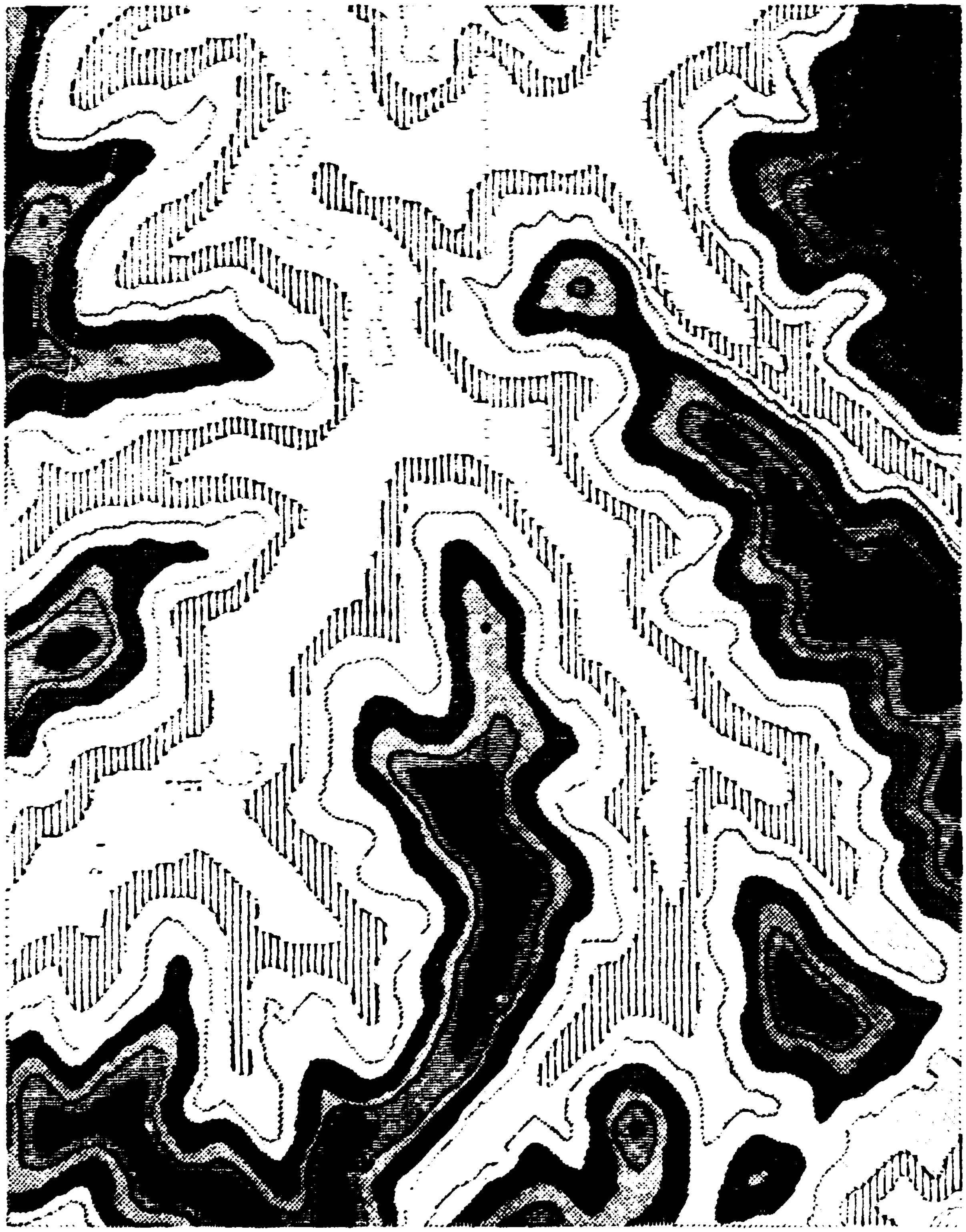
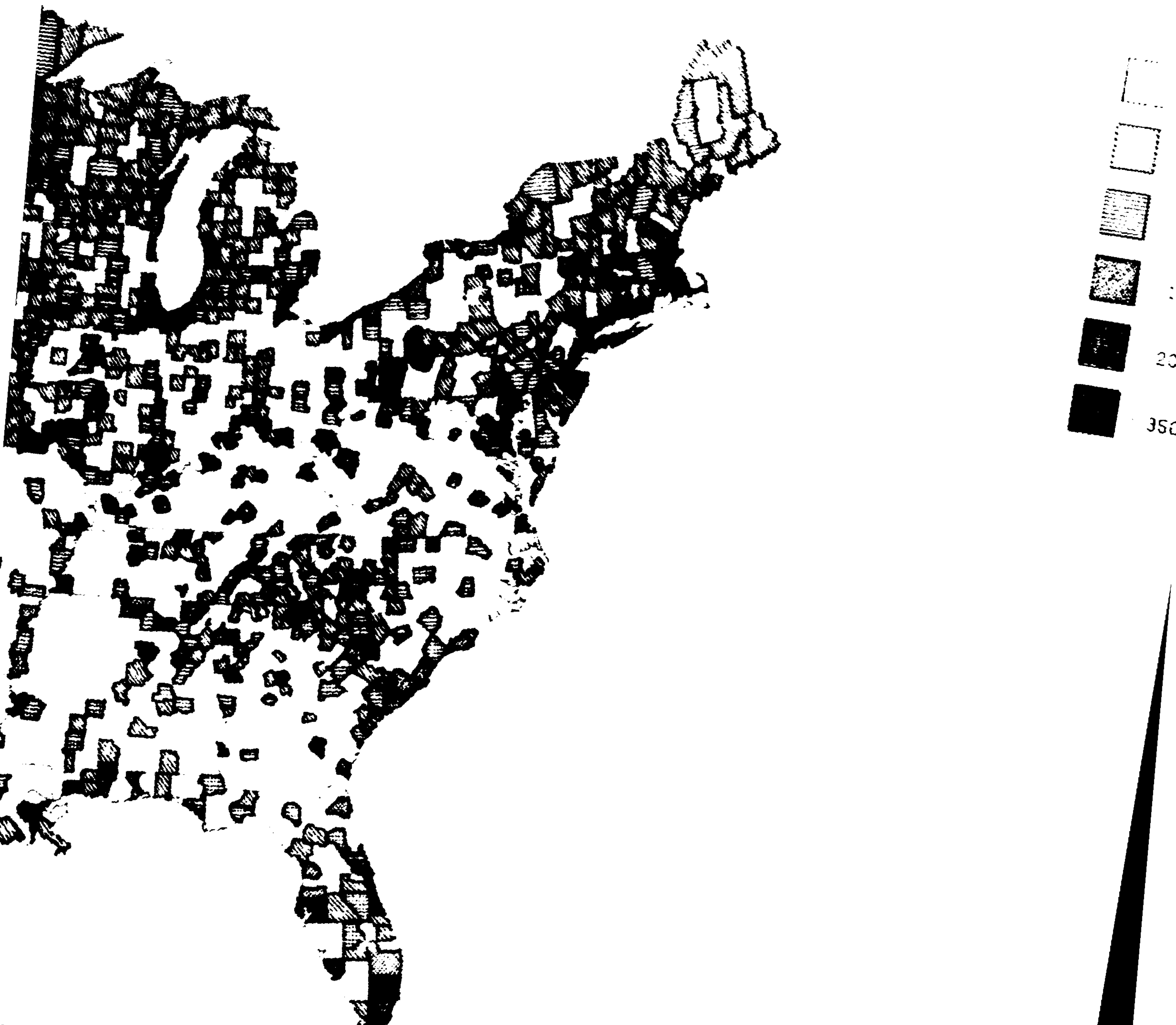


Fig. 3.24. Shaded contours form interpolated TOPOCOM elevation data for 7.5-min quadrangle.

Fig. 3.25. Watersheds and drainage patterns for 7.5-min quadrangle.

Fig. 3.26. Electri



tts for 1975 by county (based on FPC data).

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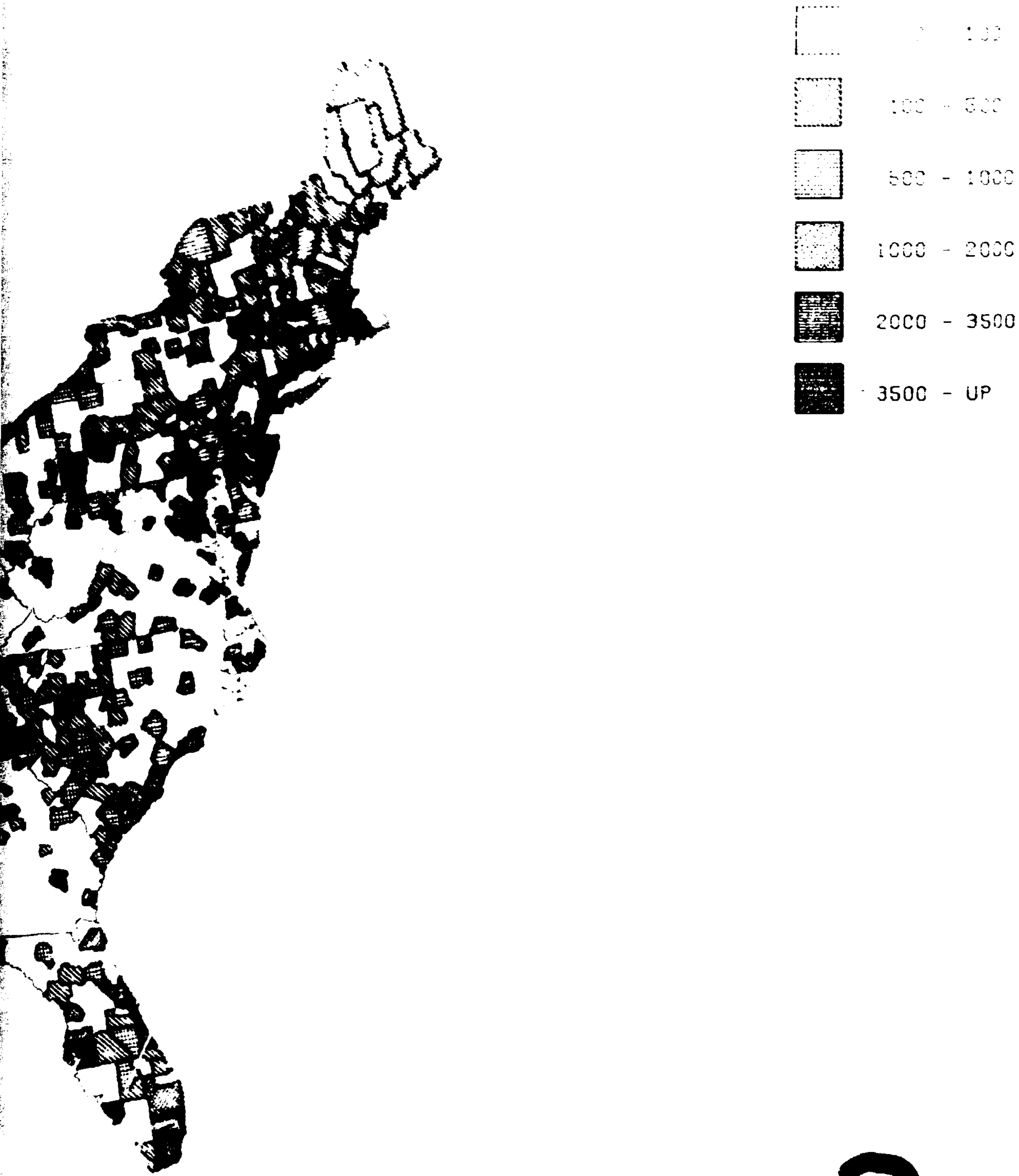

FPC data).

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to a viewing audience and (2) to serve as a valuable tool to researchers by revealing previously hidden relationships and suggesting new ideas and strategies to be attempted in future models and analyses.

3.3.4 Siting Analyses

Two applications of our resource analysis capabilities are described in the following subsections. The first involves the calculation and mapping of power plant suitability for the State of Maryland using varying technologies and constraints; the second involves an analysis of water availability to meet future energy production needs in the ORBC region.

Maryland Power Plant Siting Project. Since 1974 the Resource Analysis Group has been engaged in developing a procedure for regional and local siting analyses known as the ORNL Land Use Screening Procedure (LUSP).[39-42] The Maryland Power Plant Siting Project (MPPSP), in which the ORNL-LUSP was used to identify candidate areas for power plant sites in northern Maryland, was completed in October 1976. The objectives of the study were (1) to test the usefulness of the ORNL-LUSP in candidate area selection, (2) to test the applicability of the Maryland automated geographic information (MAGI) system to siting issues, (3) to examine the effects of alternative siting policies, and (4) to determine the sensitivity of the ORNL-LUSP to variations in siting criteria for different types of facilities characterized by fuel and cooling system options.

The project employs a geographic information system containing 52 variables, 27 of which were obtained from MAGI, for each 37.15-ha (91.8-acre) cell in the northern eight counties of Maryland. Each variable is characterized by discrete categories or absolute values on a continuous scale; for example, "scrub oak" is a discrete category of the variable "forest type," and "30 to 40 people per square mile" is a range of values of the continuous variable "population density."

The siting priorities and opinions of four different groups of siting specialists have been expressed as criteria matrices consisting of an importance weight[43] for each variable and a compatibility index[44] for each category or range of values. Twenty-two separate matrices have been applied to the data base in a cell-by-cell calculation of the form

$$S_i = \sum_{V=1}^{N} C_{Vi} I_V \Big/ \sum_{V=1}^{N} I_V \quad . \tag{2}$$

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39. J. E. Dobson, *The Maryland Power Plant Siting Project: An Application of the ORNL Land Use Screening Procedure*, ORNL/NUREG/TM-79 (to be published).

40. J. S. Jalbert and A. D. Shepherd, *A System for Regional Analysis of Water Availability*, ORNL/NUREG/TM-82 (to be published).

41. J. S. Jalbert and J. E. Dobson, *A Cell-Based Land Use Screening Procedure for Regional Siting Analysis*, ORNL/NUREG/TM-80 (to be published).

42. A. H. Voelker, *Power Plant Siting: An Application of the Nominal Group Technique*, ORNL/NUREG/TM-81 (to be published).

43. This is a value from zero through ten indicating the relative importance of a given variable in the siting decision; highly important variables are assigned a value of ten.

44. This is a value from minus one through ten indicating the positive or negative contribution a specified characteristic would make to the ability of a cell to host the specified facility. Highly compatible classes of a variable may be assigned a value of ten; a minus one indicates that the cell is excluded from consideration regardless of how attractive other characteristics may appear.

where

S_i = suitability score for cell i.
V = variable (e.g., land use or proximity to stream flow).
N = total number of variables.
C_{ik} = compatibility index for value of variable V occurring in cell i.
I_k = importance weight of variable V.

Clusters of cells scoring one or more standard deviations above the mean are defined as candidate areas. Figures 3.27–3.30 illustrate the spatial distribution of candidate areas in northern Maryland obtained from various criteria matrices for fossil-fired and nuclear plants. The figures indicate that it is possible to distinguish among different siting objectives and among different facilities characterized by fuel type and cooling option.

We found that considerable differences sometimes exist between the criteria matrices and the resultant distributions defined by different respondent groups. Because of the low-cost repeatability of the software, the ORNL-LUSP has been proven a useful tool for simulating the effects of various siting alternatives in candidate area selection and for identifying potential conflicts.

A major component in the success of our study was the availability of a digital geographical data base, MAGI. Without such data, development of the siting analysis capability would be impractical because of the initial costs of acquiring the geographical data base. Besides being useful in the analysis, the MAGI data base was necessary to add supplemental variables and perform additional modeling to obtain factors identified by siting specialists. One conclusion was that additional research was needed to develop procedures to rapidly construct a digital geographical data base, perhaps using ERTS, TOPOCOM, and EPA or USGS data.

The results of the MPPSP suggest that

1. The ORNL-LUSP is a useful tool for regional screening of geographic information systems even when the systems are not designed for the specific problem of power plant siting. The State of Maryland is presently implementing the ORNL-LUSP software for future use.
2. The ORNL-LUSP can serve as a means of simulating alternative siting policies to anticipate potential conflicts before they become matters of public concern.
3. Since the construction of a geographic information system is the greatest potential constraint to the development of an automated screening procedure, the data base should be designed to serve diverse uses. The shared cost can be minimized by considering the needs of potential users during system development and by including only those variables which receive high importance weights on numerous criteria matrices.
4. Siting factors must be viewed in the context of a spatial hierarchy of physical, economic, and social phenomena. Each factor should be examined at the appropriate level of spatial resolution and stored in a multiscale data base.
5. The greatest limitation to the interpretation of the candidate area maps in this study is that most siting factors are represented by raw variables rather than by indices derived from factor models.

Ohio River Basin Study. In January 1976, ANL and ORNL were requested by ERDA to assist the ORBC in determining the impacts of future energy development on water availability and quality in its region. Representatives from ANL and ORNL attended several ORBC meetings to formulate a research plan. Figure 3.31 presents the procedure to be used in our analysis.

Electricity demand figures (developed by ANL) for each state in the ORBC were provided to ORNL's Regional Economic Analysis Group for spatial disaggregation to BEAs and state portions

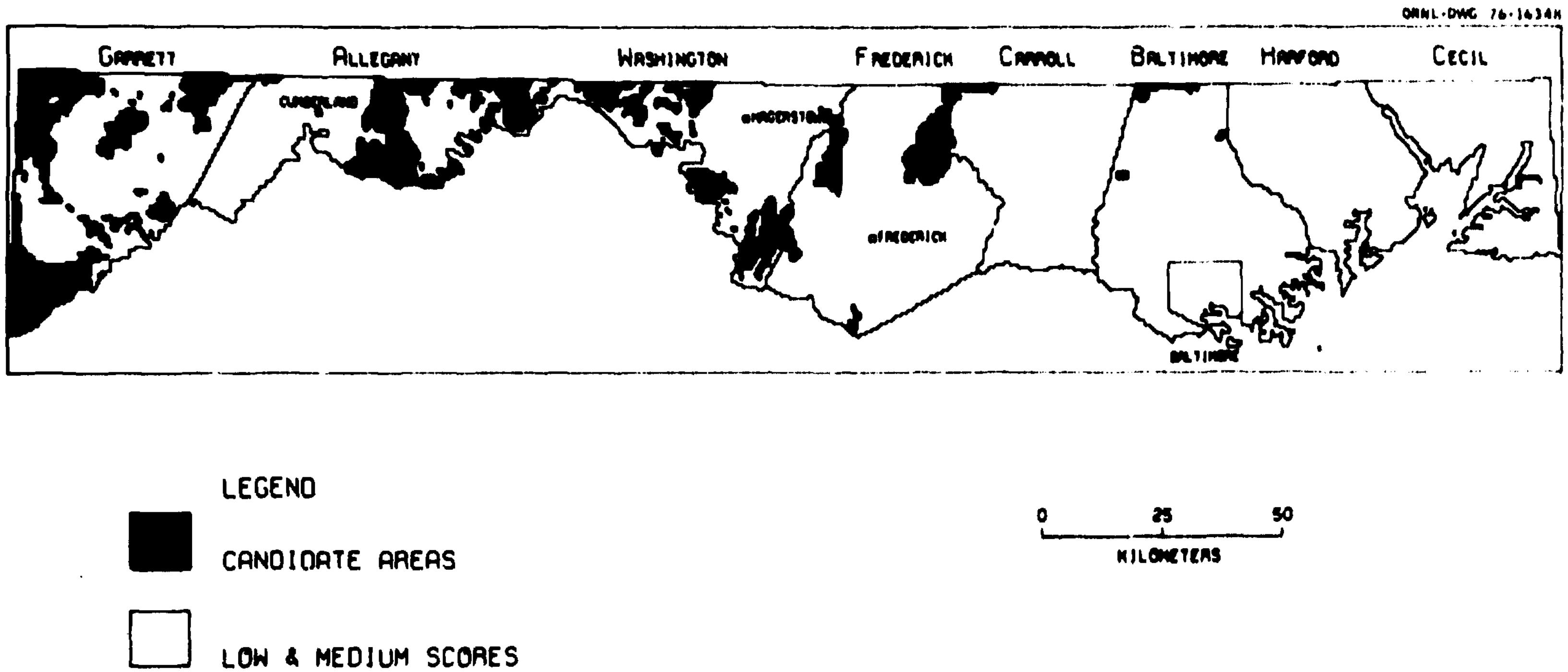

Fig. 3.27. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: Minimization of adverse socioeconomic impact; respondent: Maryland Power Plant Siting Program; number of variables in calculation: 27.

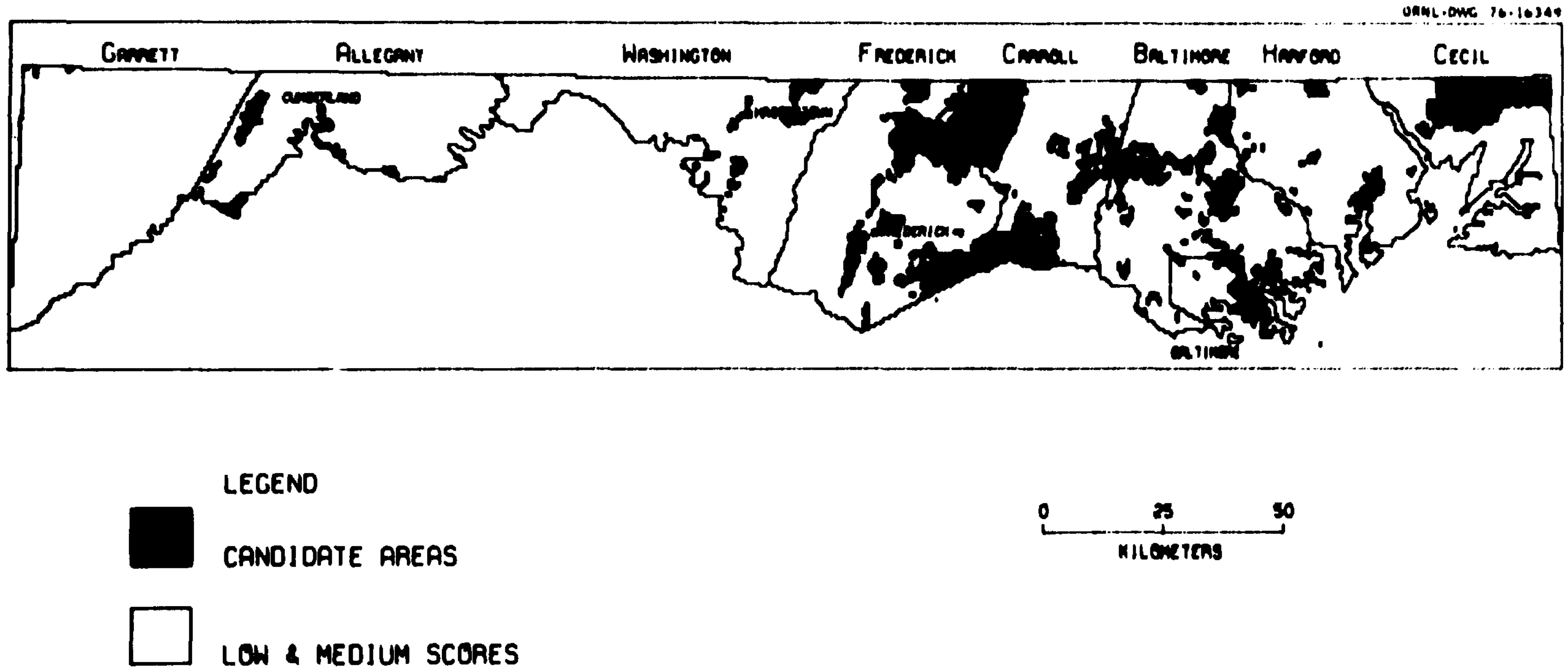

Fig. 3.28. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: Minimization of adverse ecologic impact; respondent: Maryland Power Plant Siting Program; number of variables in calculation: 27.

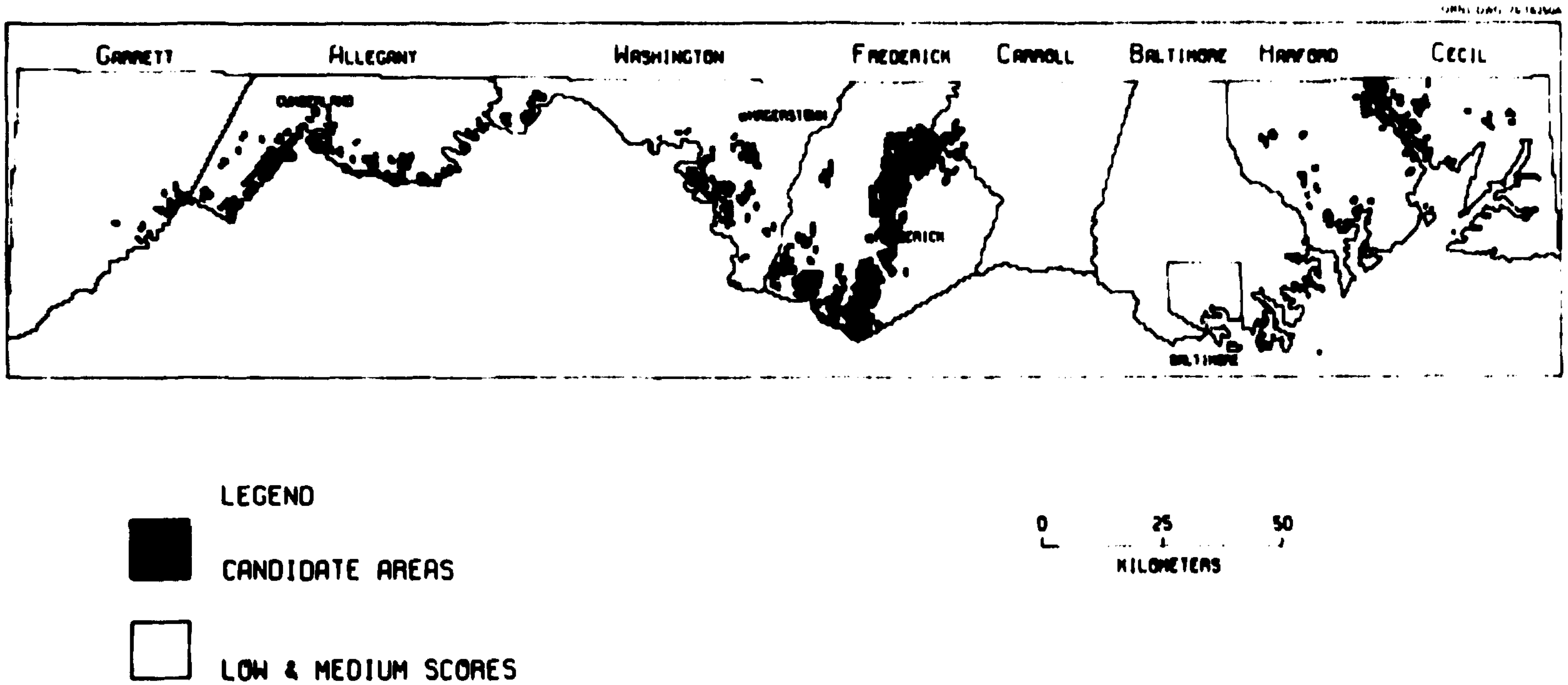

Fig. 3.29. Candidate areas for a fossil-fired power plant with cooling tower in northern Maryland, 1976. Siting objective: Composite of all objectives; respondent: Maryland Power Plant Siting Program; number of variables in calculation: 27.

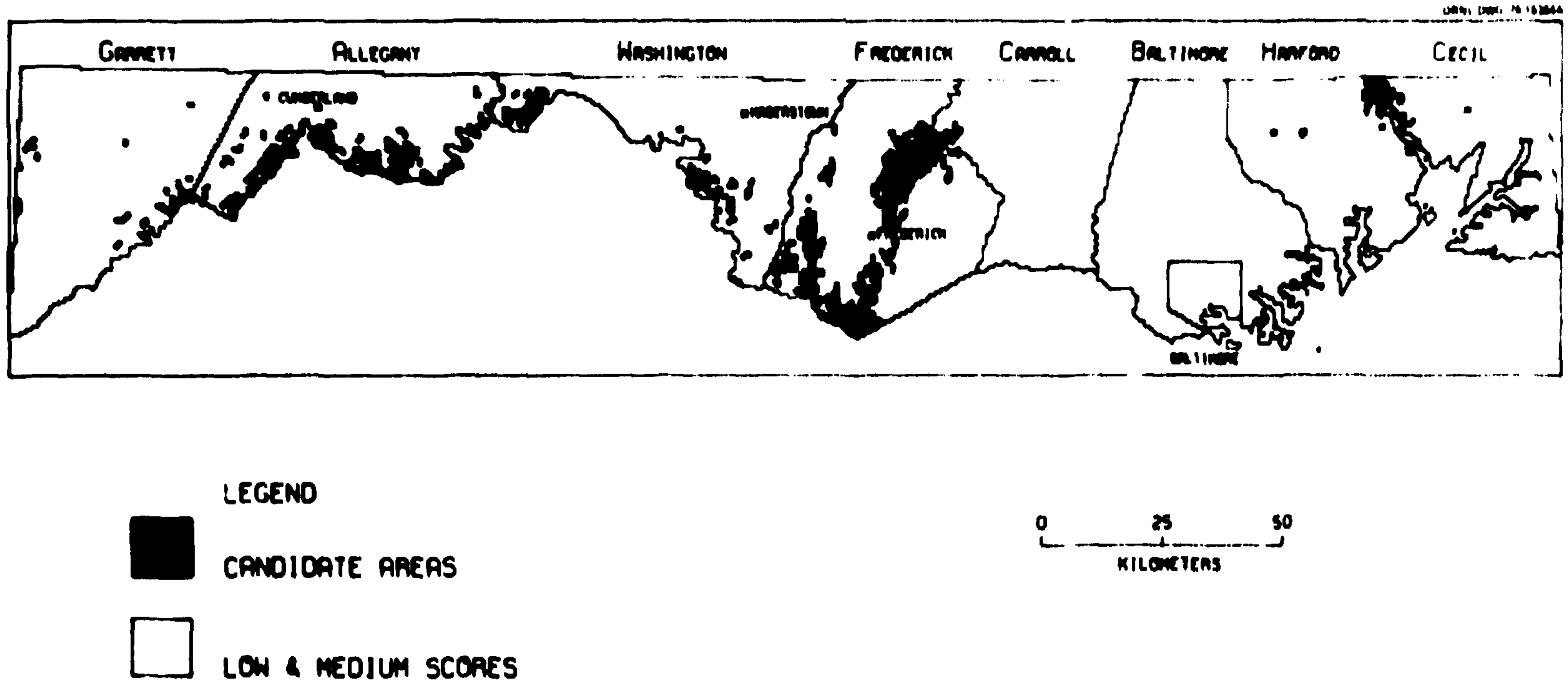

Fig. 3.30. Candidate areas for a nuclear power plant with cooling tower in northern Maryland, 1976. Siting objective: Composite of all objectives; respondent: Maryland Power Plant Siting Program; number of variables in calculation: 27.

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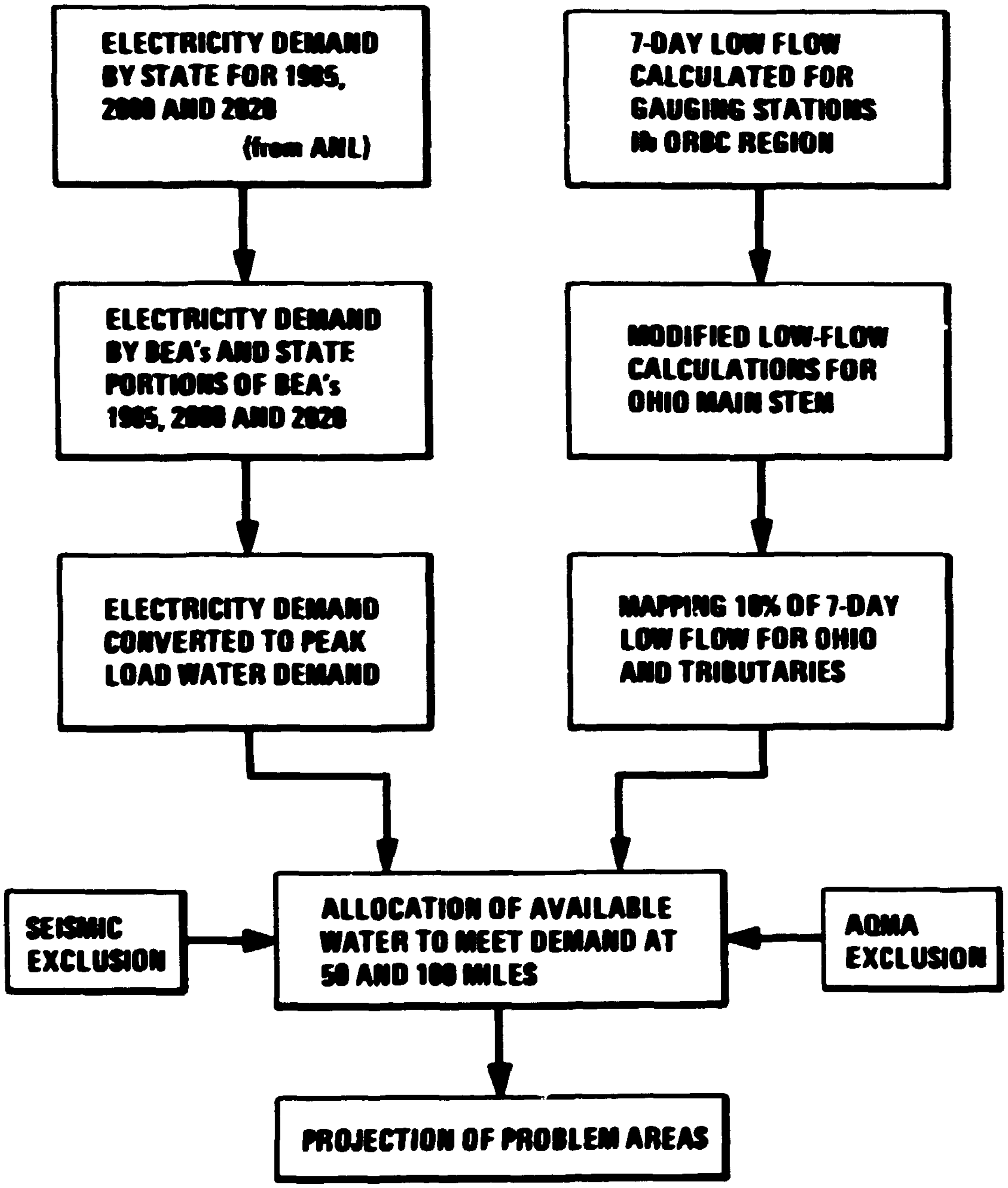

Fig. 3.31. Analysis procedure.

of BEAs (Sect. 3.2). Electricity demand values for the state BEA portions were converted to water consumption estimates under the assumption of a peak load situation and were mapped for the ORBC region. These values represent a worst-case situation in electricity demand. Embedded in the calculations are estimates of technology mixes by states (also provided by ANL) and estimates of water consumption (evaporation only) according to the type of power plant (with a cooling tower option). For a 1000-MW(e) plant, this translates into an average consumptive use of 0.7 m^3/sec (25 ft^3/sec) for nuclear and 0.5 m^3/sec (18 ft^3/sec) for fossil-fired plants.[45]

Parallel to the peak-load analysis, calculations of low stream flow for the Ohio River and its major tributaries were developed by using the WAS model (Sect. 3.3.2). The values were adjusted along the main stem of the Ohio River to reflect the augmentation by reservoirs as calculated by the U.S. Army Corps of Engineers. These flows do not necessarily reflect the actual present flows along the main channel, but rather what is theoretically possible if regulation conditions are ideal and if all proposed reservoirs in the basin are constructed.

For our analysis ORBC designated that only 10% of the 7-day, 10-year low flow should be considered available for energy production. Consequently, 10% of the low flow calculated by the WAS model is shown in Fig. 3.13.

Finally, using the information on demand and water availability, members of our group employed a spatial analysis approach to allocate water to satisfy electricity demand for each forecast year (1985, 2000, and 2020). Counties in which plants would be difficult to site were eliminated from the allocation process. For example, if a county were in a seismic III risk zone[46] (which would restrict nuclear plants) and/or if EPA had designated a county as an AQMA (which would inhibit the siting of fossil-fired plants), the counties affected would be avoided in siting consideration. Only streams capable of sustaining at least one 1000-MW(e) fossil-fired plant [0.5 m^3/sec (18 ft^3/sec)] were considered; reservoir construction to augment flow was not considered.

Starting with the tributaries in the Upper Ohio River Watershed (the Allegheny and Monongahela Rivers), we allocated water to surrounding demand centers (the centers of each state BEA portion), using four different power transmission constraints. The ORBC requested that we examine the possibility of satisfying surrounding demand out to 80.5 (50), 160 (100), 240 (150), and 320 km (200 miles) from the main stem and major tributaries.

Table 3.5 is a sample of the running account system used to keep track of water allocated to satisfy demand. No allocation was made if (1) the running account of available water (base water minus the running total of water consumed) was not sufficient to satisfy the consumptive needs of one plant (of at least 0.5 m^3/sec); (2) the county was excluded from consideration because of seismicity or air quality; or (3) all demand within the transmission distance (i.e., 80.5, 160, 240, or 320 km) was previously satisfied. When available water dropped below the minimum amount needed or when all the surrounding demand areas could not be satisfied, areas were identified as unsatisfied and the corresponding counties on the tributaries were designated as problem areas. Figure 3.32 indicates those counties that, on the basis of our analysis, may experience water availability problems during low flow, assuming that the generating capacity proposed to be on line in 1985 is built and the ORBC adheres to an allocation of 10% of low flow for energy generation.

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45. The consumptive rates for various types of power plants were calculated by Garland Samuels of ORNL; see Garland Samuels, *Assessment of Water Resources for Nuclear Energy Centers*, ORNL-5097 (September 1976).

46. Seismic risk is defined according to NRC as an area for which "costs and time" make it impractical to consider siting a nuclear plant.

Table 3.5. Water allocation—m^3/sec (ft^3/sec)—using running account system to satisfy 1985 demand, 50-mile radius of county, Ohio River

River[a] and county	Base water	Water available	Water allocated	Running total of consumed amount	By state BEA: Portion served	By state BEA: Amount used
Allegheny and Monongahela Rivers			2.66 (93.81)	2.66 (93.81)		
Allegheny (AQMA and population)[b]	15.80 (558)	13.15 (464.19)	0	2.66 (93.81)		
Beaver (AQMA and population)[b]	16.71 (590)	13.77 (486.19)	0	2.66 (93.81)		
Columbiana	16.99 (600)	14.34 (506.19)	4.72 (166.66)	7.38 (260.47)	PA-66	4.34 (153.35)
Jefferson	17.28 (610)	9.90 (349.53)	0	7.38 (260.47)	PA-67	0.38 (13.31)
Belmont	18.41 (650)	11.03 (389.53)	0	7.38 (260.47)		
Monroe	18.97 (670)	11.60 (409.53)	0.14 (4.9)	7.52 (265.37)	WV-64	0.14 (4.9)
Washington	19.54 (690)	12.16 (429.53)	0	7.52 (265.37)		
Muskingum River			0	7.52 (265.37)		
Washington	21.30 (752)	13.78 (486.63)	0	7.52 (265.37)		
Athens	21.49 (759)	13.98 (493.67)	0	7.52 (265.37)		
Meigs	22.09 (780)	14.57 (514.63)	0.21 (7.4)	7.72 (272.77)	OH-52	0.21 (7.4)

[a]Note that each tributary is kept on a separate sheet.
[b]Reason for excluding county.

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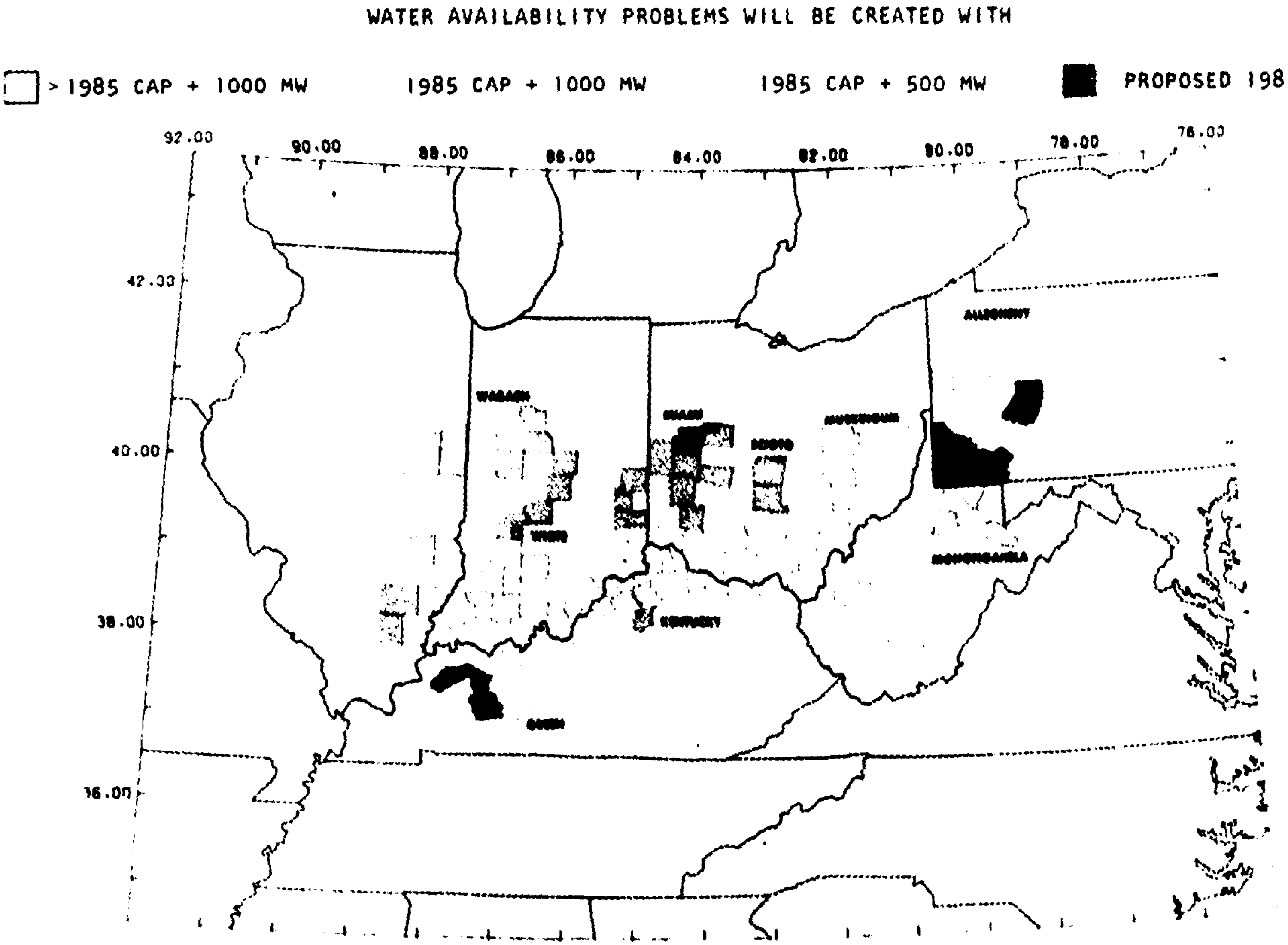

Fig. 3.32. Problem counties along tributaries in the ORBC region where water consumption by 1985 planned electric generating capacity will exceed the volume of water available or where the siting of additional capacity (500 or 1000 MW) will exceed the volume of water available.

Several caveats should be attached to this analysis. First, peak-load demand coinciding with a low water flow situation does not occur often or even uniformly over the entire area considered in the analysis. Also, it is our opinion that it would be more realistic to perform the ORBC analysis using a worst-week peak electricity demand and a worst-week water flow situation instead of a worst-day situation. This analysis is now being performed.

On the other hand, our analysis used water consumption figures easily achieved by present technology; even with a 20% error, the water availability situation will progressively worsen. Countermeasures such as better reservoir regulation, more reservoir construction (an increasingly less feasible option), or more water conservation are indicated. It would appear that the "free lunch," as far as water is concerned, is about over in the eastern United States.

3.4 SOCIAL IMPACT ANALYSIS

E. Peelle[47]

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3.4.1 Approach to Community Assessment

Our approach to social impact analysis is a pragmatic one, combining applied research with direct applications in licensing or regulatory procedures for the NRC and ERDA. Both our research and applications functions derive from the new requirements and policy directions specified in the National Environmental Policy Act of 1969. Sections 1A, 1B, and 1D of Title 1, Section 102, require that we "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences . . . in decision making . . ." (1A); "identify and develop methods and procedures . . . which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making along with economic and technical considerations" (1B); and "study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources" (1D).

Our two applied research projects seek to develop both qualitative and quantitative knowledge at different levels of analysis. These two projects are the ERDA-DTO work on social effects of alternative energy generating technologies and the NRC postlicensing studies of effects on host communities of operating nuclear power reactors. Work is now in progress at the individual, group, and community levels, and efforts are under way to identify and analyze variables for regional social impact assessment. A third project is applications work, which this year has involved preparation and review of environmental impact statements with the Environmental Impact Section. A major expansion of our applications effort occurred this year as a result of formalizing our previously ad hoc participation in

47. Group leader.
48. Consultant.
49. College of Wooster, Wooster, Ohio, Great Lakes College Association student.
50. Consultant, Department of Psychology, University of Tennessee, Knoxville.

NRC impact statements. In addition to nuclear plant assessments, we are involved in assessments of two operating coal-fired generating plants in the Ohio River basin (Clifty Creek and Kyger) as part of the Portsmouth project and assessments of proposed demonstration plants for ERDA-FE.

The dual goals of the group are (1) to develop a broad understanding of the social effects of large energy facilities through practical, exploratory work in which we ask questions in a variety of settings, develop an inclusive list of variables, and specify their relationships and (2) to advance the state of the art by developing methodological tools in our research projects that will lead to continuing improvements in direct applications.

A major focus is the siting of large energy facilities. We approach the problem on many different levels—individual, group, community, and regional—to identify for each level (1) characteristics of acceptable sites and (2) courses of action that minimize adverse social impacts. Mitigation of, or compensation for, externalized social costs at facility sites is a continuing interest and is being developed further in comparisons of mitigation plans at four facility sites (three nuclear and one coal). A principal goal of the NRC studies is to develop siting guidelines for minimizing adverse social impacts.

The Social Impact Assessment Group is also developing the capability for comparing the social impacts of alternative fuels at each stage of the fuel cycle, beginning with generating facilities. To date, the emphasis has been on the nuclear fuel cycle: work on both preconstruction and postconstruction effects of nuclear generating facilities is in progress. Case studies of Plymouth and Waterford (NRC) examine construction and operating effects; the Hartsville project (DIO) examines preconstruction effects. Through the ERDA-DIO work, the group will be broadening its approach by looking at the *coal fuel cycle, beginning with coal generation plants and undertaking parts of the* National Coal Utilization Assessment for the southern region.

Much of the research and applications expertise developed by the Social Impacts Analysis Group has been used by the Socio-political Resource Group, Risk-Impact Panel, Committee on Nuclear and Alternative Energy Systems (CONAES), National Research Council. Elizabeth Peelle is a member of the Resource Group and has drafted the community impact and response sections of the CONAES report.

3.4.2 Social Assessment Research

Postlicensing case studies. Under a grant from the NRC Office of Regulatory Research, the Social Impact Assessment Group completed its first postlicensing case study of two nuclear power plant host communities—Plymouth, Massachusetts, and Waterford, Connecticut. The purpose of this comparative assessment was to analyze the social, economic, and political impacts associated with the construction and early operation of these plants. As the first of its kind, this study provided a unique opportunity to verify the range of impacts that occurred in the two host communities, in contrast to impact statements, which forecast expected impacts. Comparisons and characteristics of the two communities and reactors, along with additional information about the study, were given in last year's report.[51]

Various primary and secondary data were collected and analyzed during the study. These data included open-ended interviews, local and state records, census data, and attitude surveys. Within each community, about 35 open-ended interviews were conducted with local officials, utility personnel, and

51. Elizabeth Peelle et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 132–45.

concerned citizens. In addition, information on the particular nuclear plant, community socioeconomic and political characteristics, and regional demographic and economic trends was also used. Finally, attitude surveys were taken in both communities to determine citizens' (1) attitudes toward the plants and plant effects, (2) satisfaction with their community, and (3) perceptions of the future of their community.[52]

A social impact assessment model (Fig. 3.33) was developed to classify the data for analysis and to structure observed empirical relationships. This conceptual model[53] has three distinct components — inputs, community structure, and impacts. Inputs are defined as those factors introduced into a host community solely as a result of siting a nuclear plant there; that is, they would not exist without the plant. Four such factors are distinguishable: (1) facility characteristics, (2) the licensing and regulatory process, (3) generated revenue, and (4) human resources. Although all these factors are present when siting any nuclear power plant, the relative importance of each varies from case to case.

Facility characteristics refer to the physical plant, the land it occupies, its transmission lines and corridors, cooling system, discharge canals, and ancillary facilities (e.g., a visitor's center). Typically, these characteristics will have some effect on the land use patterns, aesthetic appearance, and natural and human ecology of a host community and the surrounding area. Our assessment of Plymouth and Waterford, however, indicated that this input was of minor significance in these two cases.

Similarly, we did not devote special attention to the second input category, the licensing and regulatory process, which includes all the legal requirements, procedures, and related nonformal activities associated with licensing a nuclear plant. Foremost among these activities are the preparation of an environmental report by the utility, preparation of an environmental impact statement and a safety and radiological analysis by the NRC, and licensing hearings before the Atomic Safety and Licensing Board.[54] The licensing and regulatory process provides the framework within which supporters and opponents of a nuclear plant have the opportunity to argue their competing claims. In both Plymouth and Waterford, this process was essentially routine and did not prove to be significant in explaining the impacts that occurred.

The last two inputs — generated revenue and human resources — were significant and occupied the bulk of our attention. Generated revenue refers to the direct and indirect flow of money into the host community as a result of siting a plant there — property taxes on the plant,[55] local plant-related purchases of goods and services, and growth in employment. In both Plymouth and Waterford, the key economic impact was the enhancement of the community's tax base.

Human resources refer to the in-migrating and commuting populations associated with construction and operation of the plant. The relative proportions of commuters and in-migrants are crucial in determining the type and degree of impacts which a host community experiences. Since both Plymouth and Waterford were located within sizable labor markets, there were very few in-migrants, but substantial numbers of commuting workers.

The second component of the model, community structure, refers to the social, economic, and political structure and service capacity of the host community. Changes in these variables constitute the

52. The questionnaire used in the attitude survey was adapted from C. R. Schuller et al., *Citizens' Views on the Proposed Hartsville Nuclear Power Plant: A Preliminary Report of Potential Social Impacts*, ORNL-RUS-3 (May 1975).

53. Note that this is not a mathematical model, but entirely a conceptual model useful for organizing and classifying data and relationships. The relationships between inputs, community structure, and impacts have not been quantified.

54. Steven Ebbins and Raphael Kasper, *Citizen Groups and the Nuclear Power Controversy*, MIT Press, Cambridge, Mass., 1974.

55. Or, in the case of publicly owned utilities, in-lieu-of-tax payments.

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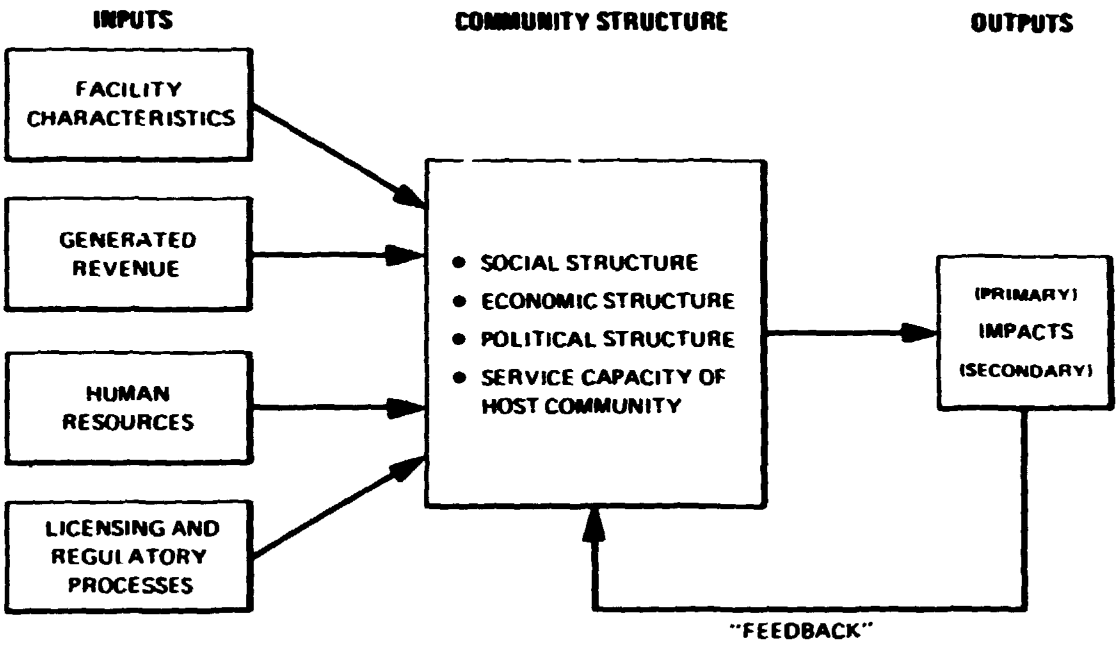

Fig. 3.33. Social impact assessment model.

impacts of the plant and arise from the interaction between the inputs and community structure. We distinguish primary and secondary impacts according to their temporal sequence; thus, a primary impact such as an increased property tax base may lead to a lowering of the existing tax rate, a secondary impact. In this way, impacts may "feed back" on community structure to produce other impacts; hence, the model includes a feedback "loop."

Findings. Construction phase impacts in both Plymouth and Waterford were minor. The only impact of any magnitude identified retrospectively was construction worker traffic. Most workers commuted to the sites from homes in the metropolitan areas, rather than relocating nearer the sites or moving to the host communities. This pattern appears to be typical of "nonremote" sites (i.e., those located within a major labor market). There was little interaction between construction workers and local residents, except for incidental contact in bars, grocery stores, restaurants, and other places of business. Thus, although some construction worker dollars were spent in the host communities, neither plant stimulated significant local commercial activity during construction.

In both Plymouth and Waterford, it is clear that the major impact has been the enormous increases in their tax bases provided by the operating reactors. By 1975 this amounted to about 50% of Plymouth's property tax base and 60% of Waterford's. Both communities have consequently chosen to lower or stabilize existing property tax rates and invest the additional revenue in new public services and facilities. This additional income has enabled the communities to further professionalize public service by hiring new staff and creating new positions in the local government. Both communities created new departments of public works, and town planners have been hired to develop more detailed comprehensive plans.

The relationships of the host communities to neighboring communities have also been affected by the presence of the plants, principally because of the augmented tax base. Neighboring towns have, to varying degrees, resented the favorable tax situations of the two host communities. Efforts have been initiated in both states to redistribute utility tax payments so that a larger proportion will go to other jurisdictions and/or to the states. This sense of distributive injustice has been exacerbated by the transportation of reactor wastes through neighboring communities, a matter now under legal challenge.

The sudden population growth that has occurred in Plymouth since 1968 (the start of plant construction) has been further stimulated by the favorable property tax rate made possible by the plant. Regional growth rates were also increasing at the same time, and Plymouth would certainly have experienced population increases if the plant had not been built. However, it appears that the favorable tax rate in Plymouth made the community a more attractive place to live, a judgment supported by building contractors, citizens, and officials. Waterford, on the other hand, had a history of effective zoning ordinances prior to plant construction which appear to have prevented significant increases in its rate of population growth. Town officials, however, have felt pressure from some local residents to rezone to encourage more rapid growth by making land and housing available to the less affluent.

Finally, attitude surveys and interviews with local officials indicate high levels of support for the nuclear plants in both communities. There were few intervenors in either community, residents expressed little concern over potential environmental and safety hazards; and relations between the communities and utilities are considered mutually beneficial. In view of the substantial economic benefits to both the utilities and the communities, this conclusion comes as no surprise.

The conclusions of the study are based on just 2 of the 61 communities presently (1976) hosting nuclear reactors. There are no comparable published data on these other cases which would enable us to make valid comparisons. These constraints severely restrict the generalizability of this study to other cases.

Nevertheless, we can attempt to place the particular impacts and responses of these two communities in some perspective with the following observations. By cross-classifying the two key input variables (incoming people and generated tax revenues) in a two-by-two table, we see that Plymouth and Waterford fall in cell 2, where generated tax revenues are high and the number of incoming people is low.

Number of incoming people	Amount of tax revenue: Low	Amount of tax revenue: High
Low	1	2
High	3	4

As seen in this study, one result of this input mix of high benefits and low costs, or low amount of disturbance, is a relatively high rate of public acceptance. We expect that no other input combination will produce similar levels of public acceptance since in no other case is the relative benefit–cost ratio as favorable. In cell 1, both are low; in cell 3, benefits are low and costs are high; and in cell 4, both are high. The types of impacts, as well as their magnitudes, vary from cell to cell. We also suspect that local levels of support would vary too, primarily as a function of perceived benefits and costs. Communities falling into cell 3 are prime candidates for mitigation plans which attempt to alter an unfavorable benefit-cost ratio.

A final report on the Plymouth-Waterford study will be issued early in 1977.

Hartsville II. As part of our plan to approach community impact analysis on different levels and with different research designs, the longitudinal Hartsville case study, which began during the planning stage prior to licensing, examines community effects throughout the life cycle of the nuclear facility.

TVA's four-unit Hartsville nuclear power plant is presently under construction near Dixon Springs and Hartsville, Tennessee. Two surveys have been administered and analyzed. The first (Hartsville I) was administered in January 1975 before any work had begun at the site.[1] The second survey (Hartsville II) was administered in August 1975 immediately before limited hearings opened on the final environmental statement (FES). Since a limited work authorization was not granted until April 1976, the first two surveys will serve as an extended benchmark against which future comparisons can be measured.

This year's Hartsville effort focused primarily on the analysis and evaluation of the second Hartsville survey and on comparison of changes between the first and second surveys. The two attitude surveys are part of a continuing multifaceted assessment, funded by ERDA-DTO, of community impacts on energy-related facilities. To date, major emphasis has been placed on attitude research, correlates of support and opposition, and expectations regarding the facility.

The first two surveys asked two major questions: (1) What are the correlates of support and opposition to the nuclear power plant? and (2) How do residents perceive the quality of their lives? Respondents to the Hartsville I survey were reinterviewed for Hartsville II. Of the original 350 respondents, 288 (88%) participated in the Hartsville II survey. This "panel" of 288 respondents was used in comparative analysis of the two surveys. The questionnaire was composed of items which provided information on (1) background characteristics of respondents; (2) measures of perceived quality of life; (3) information level regarding the facility; (4) expectations of changes in the community, including estimates of the likelihood and desirability of events; and (5) support or opposition to the plant.

Support and opposition. A comparison of the level of support and opposition in the two surveys is presented in Table 3.6. Both support and opposition rose slightly in the August survey when "don't know" was not an option: 68% supported the nuclear plant, and 31% opposed it. These responses may be compared with the Harris survey[56] of a national sample in March 1975, in which 63% supported nuclear plant construction, 19% opposed it, and 18% were not sure (see Table 3.6). The proportions remain very similar for three nuclear communities surveyed by Harris, with a slight increase to 23% in those opposed. These results are in general agreement with those from six nuclear referenda held in the fall of 1976 on somewhat different issues, in which the ratio of support to opposition was about 2 to 1.

Looking closer at the levels of support and opposition in Table 3.7, one can compare the answers of specific categories of supporters and opposers from one survey to the next. As can be seen in the diagonal, almost 60% of the panel, 163 individuals, gave the same response in both surveys. Excluding the "no response–don't know" category, we found that almost the exact proportions of support and opposition held in both surveys: 70% indicated some level of support in Hartsville I compared with 69% in Hartsville II; the opposition proportions for the two surveys were 30 and 31% respectively.

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56. Louis Harris and Associates, Inc., *A Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States*, conducted for Ebasco Services, Inc., New York, August 1975.

Table 3.6. Support and opposition (%) to nuclear power plant construction

Survey	Support	Oppose	Not sure
	Harris survey[a]		
National sample	63	19	18
Composite of three nuclear communities	63	23	14
	Hartsville panel sample[b]		
Hartsville I (January 1975)	59	26	15
Hartsville II (August 1975)[c]	68	31	1

[a] Louis Harris and Associates, Inc., *A Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States*, conducted for Ebasco Services, Inc., New York, August 1975, pp. 76–102.

[b] Sample included 288 respondents.

[c] Forced choice.

Table 3.7. Analysis of responses to Hartsville II survey question: "If it were up to you would you permit construction of the TVA Power Plant near Hartsville?"

Response in January	Response in August: "Definitely yes" ($N = 109$)	"Probably yes" ($N = 87$)	No answer ($N = 3$)	"Probably no" ($N = 37$)	"Definitely no" ($N = 52$)	Percent of responses in January ($N = 288$)[a]
"Definitely yes" ($N = 116$)	*85*[b]	25	0	4	2	40
"Probably yes" ($N = 55$)	15	*30*	0	7	3	19
"Don't know" or no answer[c] ($N = 42$)	8	22	*2*	6	4	15
Probably no" ($N = 26$)	0	4	1	*12*	9	9
Definitely no" ($N = 49$)	1	6	0	8	*34*	17
Percent of responses in August ($N = 288$)[a]	38	30	1	13	18	100

[a] $N = 288$ (i.e., the panel of respondents who answered both the January and August surveys).

[b] Numbers in italics refer to respondents whose response was the same in January and August. The total was 163, or 57% of the 288 members of the panel.

[c] The "don't know" alternative appeared only in January; 12 respondents declined to answer in January.

Coal vs nuclear. One additional item that was asked only in the second survey dealt with respondents' preference for coal vs nuclear plants. It was hypothesized that opposition to nuclear power may stem from an opposition to high-technology projects in general. Respondents were asked, "Suppose that the power plant proposed for Hartsville was going to burn coal instead of using nuclear fuel. If it were up to you, would you permit construction of this type of plant?" Results of this item are presented in Table 3.8. The largest proportion of the sample, 107 individuals (38%), would support both types of plants. Only 43 individuals (15%) are opposed to both types of plants. It is interesting to note, however, that the general level of opposition to each plant separately is almost equal (31% for nuclear vs 30% for coal). It may be that a small minority of citizens are opposed to any kind of energy development, but that enough others are opposed to specific technologies that total opposition becomes a substantial minority in any community. This interesting component of energy development opposition will be further explored in subsequent reports.

Expected events. Respondents were asked to rate the likelihood of a list of possible events ranging from "traffic congestion" to "air pollution" to "more jobs." These likelihood estimates were analyzed to ascertain commonalities among items. A factor analysis produced five factors in each survey. Although seven individual items were slightly different across surveys (20 were exactly the same), the individual dimensions represented by the factors were very similar. Likelihood groups (factors) are presented in Table 3.9 in decreasing order of explained variance.

Although the underlying dimensions of the factors did not change significantly, the order of importance of the factors has changed. Most strikingly, the social disruption factor has shifted from fourth to first between the surveys. Since these changes may be artifacts of the data (number of items in each factor, for example), further exploration into the reasons for these shifts is continuing.

Demographics. The demographic characteristics of supporters and opponents of the Hartsville plant were very similar in both surveys. Support for the plant was strongest among business and labor occupations and less pronounced among housewives. In both surveys, the only occupational group in which a majority opposed the construction was farmers. Women tended to oppose the plant more than men in both surveys. In the second survey, some evidence indicated that support for the plant increased as the respondent's place of residence became more urban.[57]

Community satisfaction. Satisfaction with the quality of services available in Hartsville was a common theme in both surveys. Results are presented in Table 3.10. Scale scores ranged from 1.0 (very

57. E. D. Sundstrom et al., *Citizens' Views about the Proposed Hartsville Nuclear Power Plant: A Survey of Residents' Perceptions in August 1975*, ORNL/TM-5801 (1977), p. 42.

Table 3.8. Support of nuclear plant vs support of coal plant

Support nuclear plant	Support coal			Total	
	Yes	Don't know	No	Number	Percent
Yes	107	45	43	195	69
No	29	16	43	88	31
Total					
Number	136	61	86	283	100
Percent	48	22	30		

Table 3.9. Likelihood estimate factors

Hartsville I[a]	Hartsville II[b]
Hazards	Disruptive effects of population growth
Economic growth	Hazards to safety and environment
Community stability: lower costs	Increased business and new facilities
Social disruptions	Attention from outside the area
Community recognition	Economic benefits of growth

[a]The questionnaire used in the attitude survey was adapted from C. R. Schuller et al., *Citizens' Views on the Proposed Hartsville Nuclear Power Plant: A Preliminary Report of Potential Social Impacts*, ORNL/RUS-3 (May 1975).

[b]F. D. Sundstrom et al., *Citizens' Views about the Proposed Hartsville Nuclear Power Plant: A Survey of Residents' Perceptions in August 1975*, ORNL/TM-5801 (1977).

Table 3.10. Satisfaction with local services in Hartsville, Tennessee, 1975

Type of service	Mean rating of satisfaction[a]		Correlation of January with August[b]	T-test of difference	Number of respondents
	January	August			
Public schools	2.4	2.4	0.51	0.88	275
Streets and highways	2.0	2.1	0.38	0.44	286
Police protection	2.5	2.4	0.42	0.69	280
Fire protection	2.2	2.2	0.45	0.14	275
Telephone service	2.1	2.1	0.53	0.15	284
Sewage treatment	2.6	2.6	0.47	0.13	227
Water supply	2.3	2.2	0.37	1.76	265
Zoning laws	2.8	2.8	0.35	0.88	230
Garbage pickup	2.4	2.4	0.29	0.17	239
Housing availability[c]	3.4	3.3	0.46	2.87[b]	280
Medical care	2.6	2.5	0.41	1.44	279

[a]Very satisfied = 1.0, satisfied = 2.0, not sure = 3.0, dissatisfied = 4.0, very dissatisfied = 5.0.

[b]$p < 0.01$.

[c]Three-digit values are 3.43 and 3.25.

Source: F. D. Sundstrom et al., *Citizens' Views about the Proposed Hartsville Nuclear Power Plant: A Survey of Residents' Perceptions in August 1975*, ORNL/TM-5801 (1977).

satisfied) to 5.0 (very dissatisfied). As can be seen from the table. Hartsville residents were generally satisfied with services, and their level of satisfaction did not change appreciably between the two surveys. Only one item showed any significant change. In the second survey, respondents were slightly less satisfied with the availability of housing. A second measure of satisfaction dealt with individuals' neighborhoods. For both surveys, respondents were asked to rate their neighborhoods on a series of seven-point semantic differential scales. Results reported in Table 3.11 show that in the first survey the respondents tended to describe their neighborhoods as private, stable, uncrowded, pleasant, quiet, safe, and pretty. The same people evaluated their neighborhoods as somewhat more noisy, crowded, unpleasant, and changing in the second survey. The number of building permits granted in Hartsville almost doubled between 1974 and 1975 and appears to have doubled again between 1975 and the present.

Summary. Comparison of the two surveys revealed some shifts in individuals' perceptions of the quality of their lives and in the expected likelihood of certain events associated with the plant. Most significantly, however, there has been virtually no change in the proportion of individuals voicing an opinion either in support of or against construction of the facility. It should be noted that no construction had begun at the time of either survey. Further examination of the interests reflected in these surveys must be extended to construction and operation phases, together with an appropriate behavior monitoring program. The evolution of attitudes and community support and opposition will be followed by future surveys, the next of which is scheduled for a few years from now during the peak of construction activity.

Table 3.11. Ratings of characteristics of neighborhoods[a] in Hartsville, Tennessee, 1975

Characteristic	Mean rating		Correlation of January with August[b]	T-test of difference	Number of respondents
	January	August			
Private vs not private[c]		2.7			288
Changing vs stable	6.0	5.0	0.20	6.94[b]	286
People similar to me vs people dissimilar to me	2.3	2.5	0.34	1.32	283
Crowded vs uncrowded	5.9	5.5	0.36	2.70[b]	282
Close-knit vs not close-knit	3.5	3.6	0.31	0.14	278
Unsafe vs safe[c]		5.8			288
Unpleasant vs pleasant	6.5	6.1	0.23	4.63[b]	284
Wealthy vs poor[c]		4.0			286
Noisy vs quiet	5.7	5.3	0.46	3.72[b]	287
Pretty vs ugly[d]	2.5	2.5	0.35	0.73	286

[a] Respondents were asked to make rankings on a seven-unit continuum for each pair of attributes. A score of 1.0 was given for the first member of the pair, and 7.0 for the opposite member. Responses in between were assigned appropriate intermediate scores.

[b] $p < 0.01$.

[c] Asked in August only.

[d] Asked in January as attractive vs unattractive.

Source: E. D. Sundstrom et al., *Citizens' Views about the Proposed Hartsville Nuclear Power Plant: A Survey of Residents' Perceptions in August 1975*, ORNL/TM-5801 (1977).

Hartsville III research plan. A detailed research plan was developed for our Hartsville III work. Two significant departures from previous work are the inclusion of a parallel coal host community (Coaltown), now in final site selection stage, and a shift in focus for both communities from the attitude component to examination of community response and adaptation to perceived or real impacts resulting from the planning, construction, and operation of the particular generating facility.

Figure 3.34 presents the time-series quasi-experimental design for the study as it is currently under way. Inclusion of a coal host community brings us closer to the overall goal of the group — the capability to generalize about impacts across technologies and across stages of the fuel cycle. By adding a coal-fired generating plant to the study, we will be able to (1) examine social and economic impacts common to both technologies and (2) determine those impacts that appear to be unique to the facilities. The second departure — examining local responses to facilities — will be undertaken through a series of interrelated tasks which will establish the linkages between the licensing process, local policy responses, and changes in characteristics of the community (or changes in the relationships of those characteristics). As with the attitude component, the major research innovation of this study will remain the time-series nature of the analysis and the following impacts and responses throughout the life cycle of the facility.

Figure 3.35 lists seven areas of interest that will be examined for each community. They represent a convenient, if artificial, separation of specific tasks and indicate the types of data to be considered.

Generally, however, most of the tasks can be subsumed under two analytical categories: (1) policy formation and implementation and (2) social indicators. Work with social indicators will involve monitoring those areas anticipated to change as a result of the facilities and those areas which local administrators are particularly concerned with (as reflected in local policy decisions) and some general monitoring to pick up any unexpected impacts. Table 3.12 lists some possible indicators which may be used, as well as the general categories of indicators currently being considered. Subsequent refinements of this list will depend on data availability and the nature of the local decisions under consideration.

Policy formation and implementation will be considered under two general conditions. First will be those licensing and siting policy decisions that may affect the type and magnitude of impacts upon a community. Such licensing and design decisions can alter the sequence in which new people or direct financial benefits are introduced into the community. Concomitant with these decisions are those which

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COALTOWN – HARTSVILLE DESIGN

	BASELINE	PRECONSTRUCTION					CONSTRUCTION					OPERATION			
	T_0	T_1	T_2	T_3	T_4		T_5	T_6	T_7	T_8		T_9	T_{10}	T_{11}	T_{12}
1. ATTITUDE SURVEY		0			0	CONSTRUCTION APPROVAL	0			0	OPERATING APPROVAL	0			0
2. ECONOMIC DEMOGRAPHIC	0	0	0	0	0		0	0	0	0		0	0	0	0
3. INSTITUTIONAL CONSTRAINTS		0			0		0			0		0			0
4. SOCIAL/POLITICAL	0	0			0		0	0	0	0		0	0	0	0
5. LABOR FORCE/HOUSING/SERVICES	0	0	0	0	0		0	0	0	0		0			0
6. LICENSING/PERMITS		0		0	0		0		0	0		0			0
7. MITIGATION		0			0		0	0	0	0		0	0	0	0

0 = OBSERVATION

Fig. 3.34. Coaltown-Hartsville design.

Table 3.12. Some social indicator data for time-series analysis

Demographic characteristics	
	Age, sex, race distribution
	Urbanization
	Population density
Economic characteristics	
	Occupational distribution
	Unemployment rates
	Median family income
	Retail and service receipts
	Governmental revenues
	Cost of living
Social structure	
	Voluntary organizations
	Socioeconomic status distribution
Public services	
	Education: student - teacher ratio; per capita expenditure
	Health-care delivery
	Fire, police, sanitation
	Social, counseling
Social - mental health	
	Alcoholism
	Delinquency, suicide
	Divorce, single-parent households
	Crime statistics
	Poverty levels
Attitudes and values	
	Population at large: satisfaction, support - oppose
	Decision makers: expectations, efficacy
Governmental performance	
	Size, professionalization
	Planning bodies, etc.
	Voting: local issues, elections
	Budgets: allocations
	Activities: licensing, regulation
	Federal money as percent of total revenue

affect the responsibility of the utility in mitigating perceived adverse impacts resulting from the introduction of the facility. This second category of policy decisions involves community-level responses to social impacts. These decisions may be made in response to real changes in the social and economic environment, or they can be made in anticipation of impacts. Policies may be designed to encourage growth or minimize changes. These types of responses will be examined in relation to the real changes in community social indicators to determine the effectiveness of policies in dealing with social impacts at the local level.

Social impact analysis model. The preceding description of proposed work presupposes an implicit model for the organization of data and the development of testable hypotheses. Work on the development of a social impact model has been continuing within the group over a period of two years. We use alternative models representing the same basic assumptions, but differing in application and in the emphasis put upon some of the elements according to the needs of specific studies. As shown earlier in Fig. 3.34 (Sect. 3.4.2), we are working toward a systems approach, as reflected in the input output nature of the model used in the postlicensing studies. The current model, which is being used in the Hartsville III project, is presented in Fig. 3.35.

Here the inputs, community context, and outputs are similar to the model presented earlier. However, since Hartsville III will concentrate on the relationship among policy decisions, the facility, and social changes, we have added two additional stages. First, extracommunity siting policy outputs are considered. Early consideration of these policy outputs is very important since they directly affect the rate at which human resources and revenues are introduced into the community. Additionally, siting policy outputs resulting from interactions between the utility and the licensing agency may result in enforced mitigation responsibilities for the utility, which in turn may have an important effect upon the magnitude and direction of impacts. Finally, we have introduced community management strategies (policies) as an intervening characteristic because the selection and implementation of particular strategies serve to modify intracommunity relationships.

Economic impacts analysis. To complement the community level fiscal impacts work done in our postlicensing studies, we are approaching economic impacts from a different angle and stage of the facility life cycle in our Hartsville project. We are beginning a major emphasis on measuring the magnitude and spatial distribution of economic impacts associated with energy facility construction. Toward that end, we have begun analysis at three spatial levels — a construction site (county), an impact region (multicounty area), and a national grid. At the site level, we are constructing a data and analysis book to record the socioeconomic impacts associated with the Hartsville, Tennessee, nuclear power plant. Objectives of the data book are to establish baselines for modeling and monitoring as many socioeconomic dimensions as possible at the site level. To date, we have completed a preliminary analysis of baselines in the retail trade and services sectors for Trousdale County, the location of Hartsville.

At the national and regional levels we have started complementary activities aimed at monitoring the macroimpacts of energy facility construction. Regional science techniques of input output analysis, multiplier analysis, economic modeling, and spatial analysis are being employed to establish a framework for identifying (1) the level and range of socioeconomic impacts by industrial category, (2) regional and multiregional specific impacts by industry, and (3) relative spatial effects from alternative

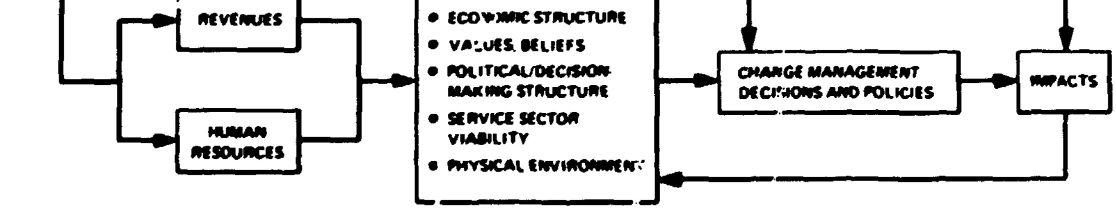

Fig. 3.35. Social impact assessment model for local decision making.

site selection. Regional differences by industry are being measured through a procedure that may be termed a "homogeneous group average requirements technique." in which regions are classified with respect to export or import orientation by two-digit SIC. Such measures will provide (1) a base for allocating macroeconomic impacts to internal and external destinations and (2) a background for measuring regional growth change stimulated by new construction activity.

Hartsville data analysis book: Retail trade baseline. The beginning of our analysis at the construction-site (county) level is represented by the socioeconomic data analysis book. The Hartsville impact area includes a contiguous five-county area surrounding Hartsville, Tennessee, which is located in Trousdale County, northeast of the Nashville-Davidson metropolitan area. To establish a baseline retail activity, we estimated a retail trade model. On the basis of previous experience,[58] we knew that a significant correlation exists between retail service receipts (hereafter referred to as retail receipts) and county levels of population, income, and urban orientation; in fact, these variables explain most of the observed variation in retail receipts at the county level. We have also observed that, with few exceptions, counties tend to remain in relatively constant economic position with respect to these variables. In other words, growth through time in levels of these variables is fairly uniform across all counties.[58] Using this information, we developed a projections model based on relative county positions instead of directly on socioeconomic variables. This change has greatly simplified the information needed to project baseline retail receipts for impact evaluations. Instead of requiring estimates of population, urbanization, income, and other influential variables, we can now project on the basis of relative economic position.

We first analyzed the socioeconomic characteristics of the 95 counties in Tennessee in each census year since 1950. Cluster analysis[59] revealed four main groups of counties having significantly different levels of population, urbanization, income, number of families, and number of families with income below poverty level. Through simple statistical comparisons, we determined that retail employment was significantly different among the four groups. This was an important finding, for it supported our suspicion that retail activity depends on county size as determined by the level of the economic variables (i.e., population, income, number of families, and urbanization).

To establish a baseline projection for each county in the Hartsville impact area, we first determined the cluster group membership of each impacted county. Three impact counties (Trousdale, Macon, and Smith), as well as some other Tennessee counties form group IV; Sumner and Wilson, along with some other counties, make up group II. In all cases the groupings were exclusive and exhaustive of the sample. Our baseline estimate of retail receipts per capita for each impact county is the group estimate of the unique group in which the county is a member. Thus, the first three counties have the same level of estimated and projected retail receipts since they are members of the same group. Retail receipts level by group was calculated with the estimated model:

$$\hat{RS} = 0.2697 + 1.0020\,GI + 0.5948\,GII + 0.3203\,GIII + 0.1705T\,. \qquad (3)$$

$$(7.85) \quad (16.68) \quad (16.57) \quad (12.30) \quad (12.46)$$

$$\bar{R}^2 = 0.6926\,, \qquad Se = 0.1974\,, \qquad F(4280) = 161\,, \qquad DW = 1.82\,.$$

58. C. R. Kerley, *A Model of Functional Area Retail Trade Receipts*, paper presented at the Western Regional Science Meeting, San Diego, Calif., Feb. 27–29, 1976.

59. A. J. Barr et al. *A User's Guide to SAS 76*, SAS Institute Inc., Raleigh, N.C., 1976.

where

$\hat{RS}$ = estimated retail receipts (millions of dollars per 1000 population).
GI = group I = 1.0 if group I.
= 0 if not group I.
GII = group II = 1.0 if group II.
= 0 if not group II.
$GIII$ = group III = 1.0 if group III.
= 0 if not group III.
T = time (1950 = 1. 1960 = 2. 1970 = 3. 1980 = 4).
$\bar{R}^2$ = coefficient of determination adjusted for degrees of freedom.[60]
Se = standard error of the estimate.[60]
F = F ratio.[60]
DW = Durbin-Watson statistic.[60]

Numbers in parentheses are t-values, which test the hypothesis that each b coefficient (number preceding variable in the model) is significantly different from zero at some level of significance (e.g., 0.05, 0.01).[60] Since all t-values in the model are significant at the 0.01 level, the cluster groups are highly significant as variables to explain the variation in retail receipts. In regression analysis the smaller the value of the t significance level, the more powerful the results and the more confidence we can place in the variables as predictors of the dependent variable (i.e., $\hat{RS}$).

Each binary variable can assume values of 1.0 or 0, depending on whether a county is a member of a given group. If the county is a member of group I, then its value will equal 1.0 for GI and 0 for GII and $GIII$. Similarly, counties that are not members of group I will have values of 0 for group I.

We have defined four groups of counties by cluster analysis, but have included only three binary variables in the model. Only three are needed to account for differences in four groups.[60,61] The fourth group is accounted for by the intercept term. Reading from left to right in the model, we estimate retail receipts as the level of group IV (the intercept), plus some larger amount if we are referring to another group. Levels of retail receipts were estimated using adjusted data expressed on a per capita basis. This adjustment purges the data of unwanted correlation due to uniform changes in population and price levels. In Table 3.13 we change the estimates back to unweighted form and to a dollar basis by multiplying by the consumer price index (CPI) and 1000 respectively. The last column is a baseline estimate for the year 1980 in the absence of the upcoming construction activity. Implicit in the projection is the assumption that group membership would not have changed between 1970 and 1980. This assumption is based on observed regularity in group membership for each decade since 1950. As noted earlier, three impact counties are members of group IV. The baseline projection for each of those counties is $1400 per capita in 1980. In Sumner and Wilson Counties, the baseline receipts projection is $2300 per capita. These levels will eventually be compared with actual levels (during construction activity) to determine the longer-term impacts generated by retail receipts in each county. An additional element will be incorporated for the actual comparison; this element is the regression residual, which tells us how well the model fits a given observation unit. Since we obtained a fairly good $\bar{R}^2$, we expect the model to do well in most cases. However, should an impact county vary significantly from its group, the projection and impact measurement will be adjusted accordingly.

60. Potluri Rao and R. L. Miller, *Applied Econometrics*, Wadsworth Publ. Co. Belmont, Calif., 1971.
61. Jan Kemta, *Elements of Econometrics*, Macmillan, New York, 1971.

Table 3.13. Unweighted baseline estimates of retail service receipts ($) per capita in the Hartsville impact area to 1980

	1950	1960	1970	1980
Group II (Sumner, Wilson, and others)[a]	755	1070	1590	2300
Group IV (Trousdale, Macon, Smith, and others)[a]	320	545	900	1400

[a] Only counties in the Hartsville impact area are listed; each group actually includes other counties from the 95-county sample. Table values apply to each county in each group. The table values are equal to those calculated with the model plus adjustments for CPI weighting and dissimilar measurement units for income (millions) and population (thousands). Thus, the table value relationship to the calculated model value in Table $R = \hat{R} \times CPI \times 1000$, where CPI equals 0.73 in 1950, 0.89 in 1960, 1.16 in 1970, and 1.50 in 1980 (estimated).

3.4.3 Social Assessment Applications

Coal utilization assessment. As part of the ERDA DTO RSP national assessment of coal utilization scenarios to 2020, we have been involved from an early stage in the development of the Coal Utilization Assessment (CUA) for the Southeast. Development of the CUA plan has been supervised by ANL. Most of our time was spent in development of the socioeconomic work statement and in meetings with socioeconomic groups from other national laboratories.

The primary output from this effort has been the detailed work plan for 1977. Four major efforts are currently under way as our primary input into the CUA; these tasks will be necessary to complete the cost-effective yet systematic assessment of potential social impacts of alternative coal technology scenarios for the Southeast. These impacts are:

1. Assessment of fuel cycle impacts. Generic social impacts associated with six stages of the coal fuel cycle (extraction, beneficiation, transport, conversion, combustion, and transmission) will be reviewed and assessed. Through systematic reviews of current and past research we expect to extract impacts common to the entire coal fuel cycle and those unique to each stage of the cycle. In this way essential background data collection and analysis will be possible for each scenario.
2. Identification of initial siting criteria. Current and evolving expertise will be used by the siting group to develop and apply socioeconomic criteria in siting choices. Provision will be made for systematic interchanges between the groups and for periodic updating and revision of criteria as more information becomes available.
3. Identification of constraints to coal development. We will identify both institutional and socioeconomic "initial states" that may act to hinder or accelerate coal development at differential rates within the CUA region. State and regional compacts and laws will be examined, together with evaluations of the constraints that may be imposed by existing social or economic conditions. Task three will draw heavily on the results of the two previous tasks.
4. Assessments of sites. To make relative local impact comparisons for alternative levels and types of coal technology development, we will conduct social assessments for the 50 to 150 sites (counties) identified by the siting group for extraction, conversion to liquid or gaseous fuels, and combustion. Sites will be characterized in terms of socioeconomic commonalities and assessed by a limited number of social indicators. Assessments of impacts, mitigation possibilities, and constraints will be based on the three other tasks.

The four major tasks, together with the evaluation of CUA scenario I (base case), are projected for completion by June 1977. Refinement of techniques and assumptions will then be made for subsequent scenarios as needed.

Environmental impact statements. Upon request, the Social Impact Assessment Group prepares and reviews parts of environmental impact statements and/or participates in licensing hearings. Over the past year, the group's involvement in such work has expanded with a growing recognition of the need for social science expertise in impact statement work. Our policy is to distribute work assignments among all members so that each is responsible for at least one environmental impact statement. The purpose of this policy is to provide opportunities for the practical application of research and to suggest further research possibilities for methodological and conceptual development of social impacts assessment at the community level. Group members assigned to a project are expected to continue with the project throughout the impact statement process.

Through October 1976, members of our group have been involved in activities related to ten separate impact statements (nine for NRC and one for ERDA). Projects continuing from last year are Wolf Creek, Sterling, and Greene County; new projects this year for NRC are Montague I and II, Jamesport I and II, Blue Hills I and II, New England I and II, Shoreham, and Fort Calhoun II; the new project for ERDA is the Clifty/Kyger coal-fired generating plants. Activities have consisted of making site visits, preparing social impact sections for the DES and FES, reviewing and commenting on impact statement documents, preparing testimony, and/or testifying. Table 3.14 lists our contributions to the various impact statement projects over the last year; dates given are the time at which major documents were docketed.

The circumstances, issues, and problems related to each of these projects vary. We mention only a few of these differences here. The Blue Hills I and II project represented the first early site review (ESR) by NRC, the purpose of which is to provide preliminary data to NRC on the suitability of the site for a nuclear power plant prior to the applicant's application for a construction permit. For the Wolf Creek, Sterling, and Jamesport I and II projects, we commented on hearing contentions related to potential socioeconomic impacts. In the cases of Sterling and Jamesport I and II, the staff testified before the Atomic Safety and Licensing Board on (1) the impacts on land use planning (Jamesport); (2) the impacts on police, fire, health, and transportation services (Sterling); and (3) the impacts of decommissioning (Sterling). The New England I and II project represents the first staff participation in an impact statement from its inception, and the Shoreham Project is our first operating license impact statement. Finally, the Clifty/Kyger project requires assessment of impacts of two coal-fired generating plants which have been operating for over 20 years. This information is an input to the Portsmouth Gaseous Diffusion add-on draft environmental statement.

In addition to participation in the formal impact statement process, we worked on the development of environmental standard review plans (ESRP) for NRC. The ESRP are to be used as guidelines for preparing impact statements. We participated in briefings given by local management and NRC on problems of impact statement work. A library of materials and data is being developed in support of our activities for the preparation of environmental impact statements.

One important sequel resulted from our participation during the Hartsville hearings reported last year. In 1975, the Social Impacts Analysis Group reviewed the statement on the proposed Hartsville Nuclear Power Plant at the request of NRC's environmental statements project and legal staff. Several significant changes were made in the FES at the suggestion of our staff representative. These changes included a provision requiring the applicant to monitor and semiannually report socioeconomic changes during the construction period to ascertain the effectiveness of the applicant's proposed plan for mitigating expected social and economic costs. In April 1976, the Atomic Safety and Licensing Board issued its ruling in which this revision was adopted officially; Section 201 of this ruling reads

> 17. Within six months of the beginning of construction activities on site, TVA shall develop and submit for NRC review, a program to monitor and evaluate socioeconomic impacts and

Table 3.14. Participation of Social Impacts Analysis Group in environmental impact statement preparation, 1976

Stage[b]	Statement[a]									
	Wolf Creek CP	Montague I and II CP	Sterling CP	Greene County CP	Jamesport I and II CP	Shoreham OL	Blue Hills I and II ESR	New England I and 2 CP	Fort Calhoun II CP	Clifty Kyger CP[c]
ER docketed	5/17/74	7/12/74	12/20/74	9/15/75	9/17/74	1/26/76	8/26/76	9/9/76	1/26/76	
Lab team comments							X	X		
Site visit				X	X		X	X		X
PDES written						X	X		X	
DES docketed	7/3/75	11/5/75	1/5/76	3/11/76	2/13/75					
FES prepared		X	X	X						
FES docketed	10/31/75		6/18/76		10/7/75					
Response to comments			X	X						
Testimony prepared	X		X		X					
ASLB hearings			X		X					
FES issued										
CP or OL issued										

[a] Abbreviations: CP – construction permit; OL – operating license; ESR – early site review.
[b] Abbreviations: ER – environmental report; ASLB – Atomic Safety and Licensing Board.
[c] Addendum to an existing DES for two coal-fired plants.

> the effectiveness of mitigating actions. This program shall include but not be limited to an assessment of effects resulting from primary as well as secondary employment. Continuing information and evaluation shall be provided to the Staff on a semi-annual basis until the third report has been submitted following the issuance of any operating license for the last unit.

We view this as an important contribution of legal precedents requiring the internalization of social costs in direct energy production costs.

Coal conversion project. This work is in support of the Fossil Energy environmental project (Sect. 2.7) for ERDA's Fossil Energy Division, Major Facilities Project Management. Several types of synfuel and combustion processes are being assessed before construction of scaled-up demonstration plants. We function as part of a multidisciplinary team which is reviewing environmental reports on specific plants, developing guidelines for content and procedures for future environmental reports and environmental impact statements, and, in general, formulating the environmental assessment framework to be used before emplacement of a new operating-scale technology.

We have applied the framework and methods developed in our earlier work on nuclear plants to coal conversion facilities. We anticipate some differences in the size and ratio of construction and operating work forces; in the water, coal availability, and transportation requirements of conversion plants; and in the taxation and licensing procedures. Future work on programmatic and site-specific environmental impact statements for coal conversion plants can be expected to clarify the significance of these differences.

3.5 DATA MANAGEMENT AND ANALYSIS GROUP

A. S. Loebl[62]

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3.5.1 Overview

The Data Management and Analysis Group was established for the purpose of accumulating, evaluating, analyzing, and synthesizing information on the social and economic aspects of energy supply and demand. During the past fiscal year, the group has focused on (1) data management research and information research, (2) socioeconomic data management and analysis, and (3) energy data analysis.

The group has concentrated its effort on three related research projects during FY 1976: (1) RUSTIC: Regional and Urban Studies Information Center – a unified socioeconomic analysis and retrieval system; (2) transportation energy conservation data book; and (3) an epidemiological study of Oak Ridge employee (*a*) mortality, (*b*) public health and demographic statistics, and (*c*) analytic dosimetry.

3.5.2 RUSTIC: Regional and Urban Studies Information Center

RUSTIC was created in 1973 to study the problems of demographic information transfer and to determine an efficient means for transferring socioeconomic data to federal, state, and local policy

62. Group leader.
63. Computer Sciences Division.

makers. This work, sponsored by the Office of Environmental Information Systems of ERDA in cooperation with the Information Center Complex of ORNL's Information Division, has become a strong link between ORNL and other federal agencies and provides assistance to state and local policy makers. RUSTIC includes in its library over 3000 reels of computer tape and computer software developed for management and analysis of socioeconomic data bases.[64] Its data collection is available to internal (ORNL) users as well as public, private, governmental, and academic users outside the laboratory through Oak Ridge Associated Universities. During 1976 RUSTIC services were provided on a cost recovery basis to about 20 outside users. Among these users were ERDA's Division of Biomedical and Environmental Research, ERDA national laboratories, HUD, Kentucky Department of Commerce, University of Missouri, University of Texas, City of Gastonia, North Carolina, and the Urban Institute.

Program design. RUSTIC focuses on development of retrieval methods for research applications. RUSTIC has fostered development of data management tools[65,66] and improved data acquisition, maintenance, utilization, and organization with the incorporation in 1976 of 7 software packages and 22 data bases consisting of 61 data files. Data resources acquired during 1976 included files on transportation energy supply; consumption and conservation; facility location, particularly of airports and power plants; human health and vital statistics; regional economic data; socioeconomic surveys of the United States; recent federal census and related data.

The development of the RUSTIC program has (1) mobilized existing and developing information resources to meet expressed needs; (2) provided energy and environmental research and development data; (3) established a responsiveness to energy research and development needs; (4) established factual data base construction; (5) provided resources and guidance in the development, exchange, and use of methods and materials in analysis of social science data; and (6) promoted the development of information networks among ERDA's scientific and technical information services and collaboration with information networks of other federal agencies. This collaboration was accomplished, in part, through participation with the Inter-Laboratory Working Group for Data Exchange.

3.5.3 Transportation Energy Conservation Data Book

Energy end-use analyses by the Data Management and Analysis Group have included development, maintenance, display, and manipulation of data supportive of the program responsibilities of the ERDA Division of Transportation Energy Conservation (TEC).[67] The Data Analysis Branch of TEC contracted with ORNL in January 1976 to prepare a transportation energy conservation data book. The major purposes of this data book are to (1) draw together, under one cover, data from diverse sources, (2) eliminate data inconsistencies, and (3) produce a useful reference document.

The 263-page volume completed in October 1976 contains statistical information on the major transportation modes, overall energy use in the transportation sector, and the energy distribution among transportation modes. Data on past, present, and projected energy use and conservation in the

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64. A. S. Loebl et al., *Regional Information Group Energy, Environmental and Socioeconomic Data Bases and Associated Software at Oak Ridge National Laboratory*, ORNL-TM-5600 (September 1976).

65. N. S. Malthouse, *INDEXGEN: Automated Indexing for Large Bibliographic Document Collections*, M. S. thesis, University of Tennessee, June 1976.

66. N. S. Malthouse, *INDEXGEN: Index Term Generation Heuristics Software Documentation*, ORNL EIS-104 (December 1976).

67. A. S. Loebl et al., *Transportation Energy Conservation Data Book*, ORNL-5198 (October 1976).

transportation sector are presented under six chapter groupings: (1) characteristics of transportation modes; (2) energy characteristics, including energy consumption by source, sector, and energy intensiveness; (3) conservation alternatives; (4) government impacts, including expenditures, regulations, and research; (5) energy supply, including domestic petroleum production, prices, and projections; and (6) transportation demand, including population characteristics and economic determinants.

The compilation is based on a review of past and continuing data-gathering activities of many private and public organizations. Each chapter provides a bibliography of data sources. In a more general bibliography at the end of the book, references that are particularly significant have been annotated. Time series data are presented for transportation and transportation fuel use for one or two decades prior to the oil embargo. Where available, projections of future energy use and the determinants of energy use are also given.

Future editions of the data book that will include data on energy use and conservation at the subnational level and more information on nonhighway transportation modes are planned. Four supplements are scheduled to be published by the end of FY 1977; the first of these was released in November 1976.[68]

A detailed information set supports publication of this document. This set will be continuously improved by (1) review of past and ongoing data collection sources and activities, including research that will provide transportation energy use parameters; (2) collection, monitoring, and updating of data sources identified in step (1); (3) assembly of information into summary form; and (4) development and use of simple analytical tools, using the collected data identified in step (1).

3.5.4 Additional Program Activities

Mortality study of work health hazards to Oak Ridge employees. The FY 1976 effort has focused on an occupational mortality study constituting an epidemiological study of the causes of age-, sex-, and race-specific mortality of Oak Ridge employees at ERDA installations. The study represents a longitudinal analysis of mortality experience and compares the experience of the relevant work force with that of the general population of the United States. The immediate effort of this study has focused on total mortality and mortality from neoplasia for the population employed in the three-plant complex between 1950 and 1970.

The study draws heavily on the established biomedical and environmental research programs at ORNL and Oak Ridge Associated Universities and on the unique computerized information-handling hardware and software systems available at Oak Ridge. Specifically, we have developed the capacity to collect and document demographic-epidemiological parameters and to develop the necessary automated procedures that permit flexibility of analysis. We have coalesced that information, which is conventionally available in raw form from national and subnational sources, and are able to meld it with specific occupational personnel data into a comprehensive system.

Public health and demographic statistics. This program is functionally and administratively located within the Health Physics Division. The purpose of the program is to assess the methodology and available data sources appropriate for use in analytical studies and environmental impact statements concerning the health effects of nuclear power plants.

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68. D. B. Shonka et al., *Transportation Energy Conservation Data Book: Supplement I*, ORNL-5232 (November 1976).

To accomplish this purpose, we have focused on the determination of the public health and demographic data sources of local, state, and federal origin. Received to date are data from the National Cancer Institute (NCI), National Center for Health Statistics (NCHS), and Tennessee Department of Public Health. The NCI provided cancer mortality data aggregated for 1950 to 1969 on a nationwide basis by county and also provided data from the Third National Cancer Survey.[69] NCHS provided data concerning mortality for the United States by county;[70] the State of Tennessee also provided the mortality data by county in published and machine-readable form.

Demographic data including age, sex, race, and socioeconomic structure are available to the program on a county and subcounty level in the 1950, 1960, and 1970 censuses on a nationwide bases.[71] Additional socioeconomic statistics for counties and large cities are available for selected intercensal years from the county and city data books, county business patterns, and other economic censuses of the U.S. Department of Commerce.

One specific contribution of the Data Management and Analysis Group to this program is in the area of data management and analysis. The group analysis focuses on methodology development in the areas of human ecological analysis and classical demographic analysis employing stable population theory and life table techniques. The development of methodology and location of data sources for assessment of the public health impacts of energy production are the central purposes of this interdivisional project.

Analytic dosimetry. Functionally and administratively located in the Health Physics Division, the analytic dosimetry program was established to undertake in-depth review of certain subjects selected by the staff and to serve as a focal point where technical questions could be directed to assist researchers. Organization and development of the Health Physics Information System has been a responsibility of the Data Management and Analysis Group in collaboration with the Information Center Complex of the Information Division. Collaboration between the Energy and Health Physics Divisions under this program has focused on human health effects (as discussed in the two projects above) and health standards for energy production.

The human effects research has been discussed under the heading of the mortality study of Oak Ridge workers. Our group assisted the Analytic Dosimetry Program in developing a file (within the Health Physics Information System) on health standards of energy production as a basis for review of general and applied problems in this area.

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69. S. J. Cutler et al., "Third National Cancer Survey an Overview of Available Information," *J. Nat. Cancer Inst.* 53, 1565 75 (1974).

70. National Center for Health Statistics, *Standardized Micro-Data Tape Transcripts*, DHEW Publ. No. (HRA) 74-1213 (Revised), Rockville, Md., June 1974.

4. Energy Conservation Section

R. S. Carlsmith

4.1 INTRODUCTION

Energy conservation research investigates ways in which energy is used. The ultimate goal is to present ways in which to use energy more wisely in the context of future scarcities and higher energy prices. Our current research emphasizes conservation opportunities in the residential and commercial sectors. We are also examining electrical energy distribution and use across all sectors of the economy.

Conservation of energy is important to the missions of a number of federal agencies. The various research tasks described in this chapter are sponsored by the Energy Research and Development Administration (ERDA). Department of Housing and Urban Development (HUD). Federal Energy Administration (FEA). and Nuclear Regulatory Commission (NRC).

For the ERDA Division of Buildings and Community Systems and HUD. we are participating in the development of the Annual Cycle Energy System (ACES). which uses a heat pump and a large thermal storage unit to provide space heating. water heating. and air conditioning with very low energy consumption. For ERDA and FEA. we are analyzing the performance of present-day air-to-air heat pumps through experimental tests of commercial units and simulation tests using computer models; these tests will lead to an assessment of the potential costs and benefits of efficiency improvements. Similar programs of experimentation and analysis were carried out on home water heaters and mobile home structures.

Under joint sponsorship of FEA and ERDA, we have continued the development of an engineering-economic model of energy use in the residential sector and are now proceeding to extend the model to the commercial sector. We have used the model to yield information for ERDA regarding the energy and economic impacts of technological developments and to provide estimates to FEA on the results that can be expected from several kinds of energy standards and regulations.

Our programs in community systems include concepts for decentralized energy systems that will supply energy to communities of a few houses to entire towns. The rationale for decentralized energy systems is to conserve energy by converting fuel to heat and electricity near the point of its use; waste heat can be fully used, and losses associated with energy conveyance can be minimized. Our current program for HUD includes assessment of environmental impacts of Modular Integrated Utility Systems (MIUS). The major task of the ERDA-sponsored Community Systems Program is to perform a state-of-the-art survey of technologies appropriate for such systems.

Detailed forecasts of future electricity use on a state-by-state level are being prepared for NRC. The estimates account for changing trends in population, prices, incomes, and other relevant factors for individual states. The NRC will use the forecasts to prepare environmental impact statements on proposed nuclear power plants, which must consider, among other issues, whether there will be a need for additional electric generating capacity.

The Division of Electric Energy Systems of ERDA and the Electric Power Research Institute (EPRI) are jointly sponsoring a series of projects to demonstrate communications technologies for automation of electricity distribution needs. The demonstrations are expected to show the capabilities and limitations of various kinds of equipment. Such equipment can be used to increase power plant load factors, which will in turn reduce the need for new power plants and save fuel.

Finally, for the ERDA Division of Solar Energy, we are helping the ORNL Engineering Technology Division develop cost targets for solar electric technologies. These cost targets are the allowable investment in solar generating plants such that the operating costs of these plants will equal those of conventional generating plants.

4.2 RESIDENTIAL ENERGY CONSERVATION

J. C. Moyers

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R. D. Ellison[1]	A. S. Holman	J. S. Tolliver[1]
H. C. Fischer[2]	E. A. Nephew	D. J. Walukas

The principal objectives of the Residential Energy Conservation Program are (1) to identify end uses in the residential sector where substantial improvements in energy use are attainable; (2) to develop, through detailed research and analysis, feasible technologies and engineering criteria for effecting such improvements; and (3) to promote early commercial implementation of promising conservation measures and technological innovations identified by the research. Because roughly 80% of the total residential demand for energy is for space heating, space cooling, and producing domestic hot water,[3] the greatest potential for energy conservation lies in these areas. Consequently, the main program effort has been to investigate the energy savings attainable by providing better home insulation, improving heating and cooling systems, and improving water heaters.[4-11]

4.2.1 Annual Cycle Energy System

The ACES is an integrated system for providing space heating and cooling and domestic hot water to residences or commercial buildings. Essentially, the ACES consists of a heat pump coupled to a thermal storage unit, which allows the heating and cooling loads of the building to be integrated

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1. Computer Sciences Division.

2. Consultant.

3. Federal Energy Administration, *Project Independence Final Task Force Report: Residential and Commercial Energy Use Patterns, 1970–1990*, vol. I (November 1974).

4. S. E. Beall et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1974*, ORNL-5030.

5. W. Fulkerson et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124.

6. J. V. Wilson, *Energy Usage and Conservation in Mobile Home Heating and Cooling*, ORNL/NSF/EP-91 (August 1976).

7. S. J. Ball, *Experimental Investigation of Retrofit Options for Mobile Homes*, ORNL/TM-5511 (to be published).

8. D. E. Spann and G. G. Slaughter, *An Efficiency Evaluation and Consumer Economic Analysis of Domestic Water Heating*, ORNL/CON-5 (to be published).

9. H. C. Fischer et al., *Summary of Annual Cycle Energy System Workshop I Held October 29-30, 1975, at Oak Ridge, Tennessee*, ORNL/TM-5243 (July 1976).

10. E. C. Hise et al., *Design Report for the ACES Demonstration House*, ORNL/CON-1 (October 1976).

11. H. C. Fischer et al., *The Annual Cycle Energy System: Initial Investigations*, ORNL/TM-5525 (October 1976).

over an annual cycle. In ACES, thermal energy storage (TES) is accomplished by means of an insulated tank of water that provides a source of heat for the heat pump and also functions as a repository for solar energy collected by an auxiliary radiant-convector panel. Solar energy is collected during the winter heating season and is deposited in the TES bin to prevent an excessive accumulation of ice. It is estimated that, on a yearly basis, ACES will consume less than half of the energy required by a conventional system using an air-to-air heat pump and an electric water heater.

ACES demonstration buildings. In view of the desirable energy conservation characteristics of the ACES, an important program objective has been to construct and operate full-scale, prototype installations for demonstration purposes. These demonstrations will be used to test design procedures and to assist in establishing general engineering criteria for ACES applications in various climates. Toward this end, the construction of several demonstration ACES—a Veterans Administration nursing home, a residential demonstration at Richmond, Virginia, and a residential demonstration at Knoxville, Tennessee—has been undertaken by various organizations.

Veterans Administration nursing home.[12] The space heating and cooling system being built by the Veterans Administration to supply a 60-bed nursing home in Wilmington, Delaware, incorporates a 264-kW heat pump, a 566-m^3 ice tank, a solar radiant-convector panel, and a computer system to monitor and control system operation. The computer controls heat storage in and withdrawal from the ice tank, which is located in a separate building, in a way that most economically satisfies space-conditioning demands as governed by both weather and season. The system, designed by V.A. mechanical engineers and consulting engineer Robert G. Werden, is scheduled to begin operation in late 1977.

Richmond residential ACES. At the request and encouragement of the Commonwealth of Virginia, a group of private companies has undertaken to design, construct, and market an ACES residential demonstration house. The house is a two-story, 167-m^2, colonial style structure located in an existing subdivision. The system is not equipped with a solar radiant-convector panel, but will use, instead, a conventional outdoor fan coil as the auxiliary heat sink. The TES bin consists of a wood tank with a vinyl liner. The Residential Energy Conservation Program at ORNL has assisted in the preliminary design of the house by providing calculations of the thermal characteristics of the building and the ACES components and performance. Construction of the demonstration house is nearly complete, and operation is anticipated to begin in late 1976.

Knoxville residential ACES. The ACES demonstration house sponsored by ERDA and HUD is one of three buildings being constructed at a complex on the University of Tennessee campus in Knoxville to demonstrate residential energy conservation. The two other buildings at the complex are a solar demonstration house and a control house employing a conventional space-conditioning system. The control house, built with the same floor plan and thermal envelope characteristics as the solar house and the ACES house, will provide baseline information on the heating and cooling load demands of the experimental buildings.

Design and tests of ACES facility at Knoxville. The ACES demonstration house (Fig. 4.1) was completed in July 1976 and is currently being tested and instrumented in preparation for a test run. The building is a two-level, frame structure with a partial basement and 186 m^2 of living area. The house has three bedrooms, two baths, a living-dining room, kitchen, utility room, and entry hall. The shell is heavily insulated; it has 140 mm of insulation (0.256 $W/m^2 \cdot K$) in the side walls, 305 mm (0.136 $W/m^2 \cdot K$) in the flat ceiling, 229 mm (0.182 $W/m^2 \cdot K$) in the cathedral ceiling, and 152 mm

12. "Heat Pump Gets by with Less Energy by Making Ice Summer and Winter," *Architectural Record* **1976**(11), 133–36 (1976).

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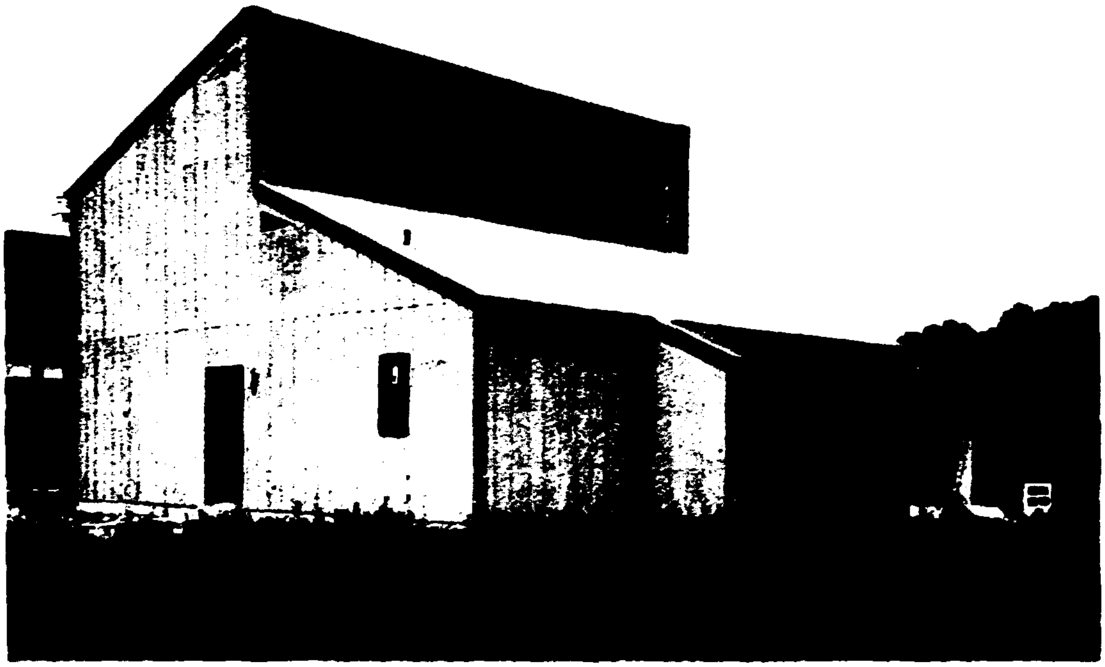

Fig. 4.1. Photograph of the ACES residential demonstration house at the UT campus.

(0.273 W/m^2·K) beneath the floor. The windows are double-glazed, having an overall heat transfer coefficient (U) of 3.29 W/m^2·K. The basement walls and crawl space foundation are of reinforced concrete poured in styrofoam forms, producing a composite wall having a U-value of 0.352 W/m^2·K. Additional details of the construction are given in the design report.[10]

The integrated space heating and cooling system of the ACES house is depicted isometrically in Fig. 4.2, which shows the location and relative size of the system components. The major elements of the system are (1) a high-efficiency heat pump with refrigerant-to-brine heat exchangers on both the evaporating and condensing sides; (2) TES bin on the low-temperature (evaporator) side of the heat pump; (3) a fan coil with forced-air circulation for space heating and cooling; (4) a solar panel that functions as both an auxiliary heat source and a heat sink; and (5) a refrigerant-to-water heat exchanger for heating domestic water and a hot water storage tank.

Ice storage bin. The TES tank of the ACES demonstration house was constructed by pouring concrete into foam-form blocks and coating the inside of the tank with urethane-asphalt to make it leaktight. Unfortunately, the concrete was not poured as a single batch; instead, partial pourings were made on four separate days. Inadequate bonding between the separate pourings resulted in major leaks from the tank when it was filled with water. A 30-mil vinyl liner was later installed in the bin to eliminate the leakage. Future construction of this type of storage bin should require vinyl liners in all cases where a monolithic concrete pour is not possible.

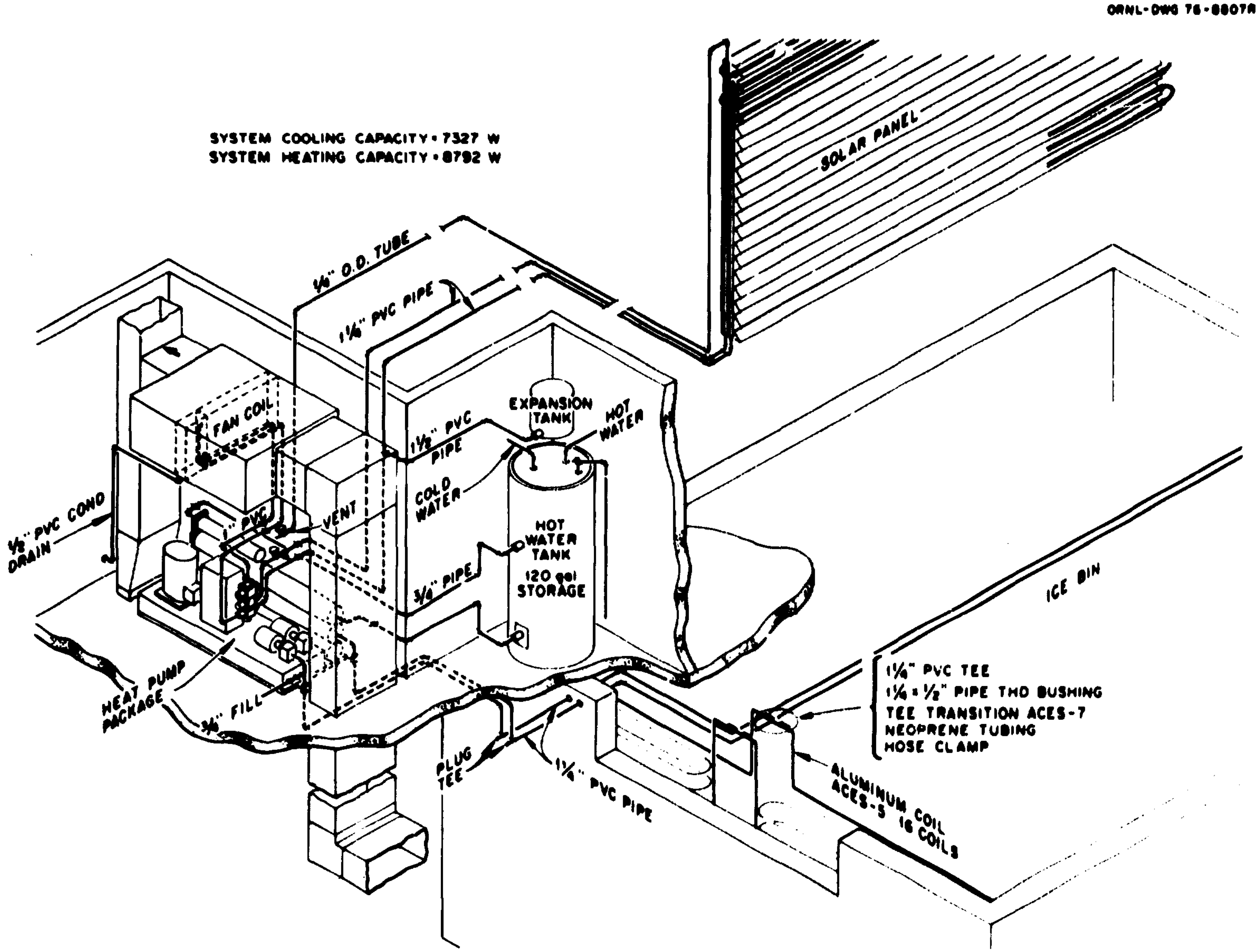

Fig. 4.2. Isometric view of the demonstration ACES.

Control system. The control system establishes or prohibits paths of heat flow between the various ACES components as required to meet the building's energy demands while maintaining the desired energy inventory in the storage bin. Control is effected by such sensor-actuated mechanisms as dampers, valves, and electrical switches. Figure 4.3 illustrates possible paths of controlled transport of heat within the system, including the economy cycle.

The control system requires two types of input information for selection of the desired mode of operation. The first type of input is inhabitant-controlled and is derived from the house thermostat setting and the setting of a four-position season switch. The thermostat setting controls energy deposits in (and withdrawals from) TES to meet present needs, whereas the four-season switch anticipates future needs. The second type of input information is derived from sensors that measure the present ice inventory and temperatures of the living space, the TES bin, the radiant-convector panel, the hot water tank, and the outside air. On the basis of these two sources of information, the control system establishes the proper mode of operation by controlling the compressor, three pumps, the fan, the outside air damper, and six valves.

Data acquisition system. The ACES demonstration facility will be operated in a test record run over a full annual cycle to determine its performance under conditions approximating those of actual occupancy. To assess daily and annual coefficients of performance (COPs) of the system, measurements will be made of the heat flows into and out of the TES bin, the fan coil unit, the water heater, and the solar collector panel. In addition, electrical inputs to the compressor and auxiliary

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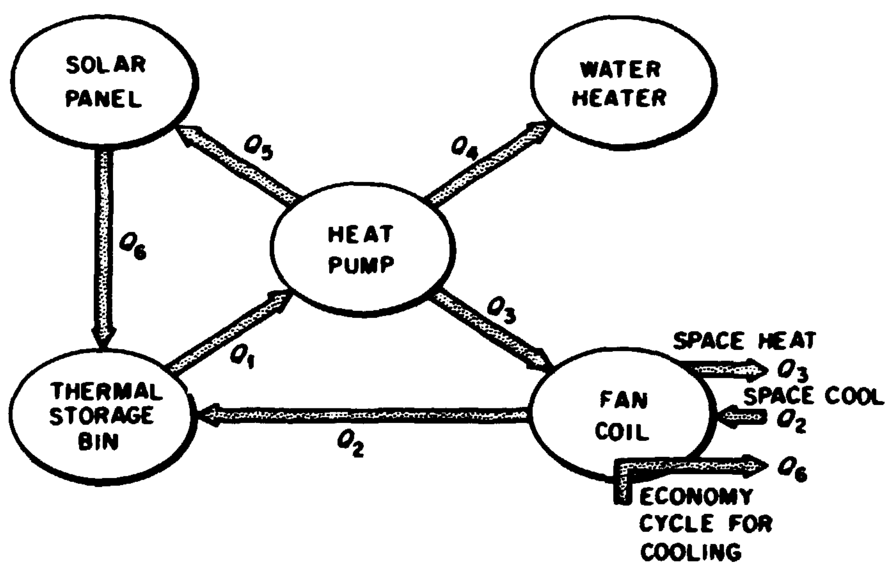

Q_1 - HEAT WITHDRAWAL FROM STORAGE BIN
Q_2 - HEAT DEPOSIT IN STORAGE BIN, SPACE COOLING
Q_3 - HEAT DELIVERY FOR SPACE HEATING
Q_4 - HEAT DELIVERY FOR WATER HEATING
Q_5 - COMPRESSOR WASTE HEAT REJECTION TO ATMOSPHERE
Q_6 - COLLECTED SOLAR ENERGY TO STORAGE BIN

Fig. 4.3. Heat transport paths in demonstration ACES house in Knoxville.

equipment will be measured, and a complete set of outside weather data—wet- and dry-bulb temperatures, barometric pressure, integrated wind speed, wind direction, integrated solar radiation, and precipitation—will be recorded.

Instrumentation is currently being installed in the ACES demonstration house to collect and process these data. The data acquisition and processing system consists of a Hewlett-Packard 9830 calculator with an interface bus which controls a 40-channel analog scanner and a 30-channel digital multiprogrammer. The system includes associated sensors, signal conditioning circuits, and digital multiplier–integrators. The channels will read heat exchanger inlet and outlet temperatures, heat exchanger mass flow rates, the water level in the ice bin, and other operating parameters of the system. This information will be processed automatically and accumulated continuously to yield hourly heat flows among ACES components. The data obtained will be used to determine the performance of the system and individual components.

Preoperational tests. The demonstration system has been tested in several phases. During startup tests, the system was charged and tested for leaks and for proper functioning of the circulators, valves, compressor, and control system. After running the system for a short time in the water heating and nighttime heat rejection mode to build up a small inventory of ice, operation was switched to the air-conditioning mode to test the space cooling components. Following these qualitative tests, a series of quantitative heat balance measurements demonstrated that the COPs of the compressor and of the entire system were within design specifications.

After these tests using the original compressor, an improved compressor and higher-efficiency circulating pumps were acquired and installed in the ACES demonstration facility. A new series of heat balance measurements, performed under the same operating conditions as before, demonstrated that the improved-design components raised the compressor heating COP from 3.0 to 3.5. During preoperational testing, pitting corrosion was detected on the outside surfaces of the finned, aluminum tubing of the ice-bin heat exchanger; the cause of this corrosion is being investigated. To permit continued operation of the ACES system in the demonstration house, the aluminum tubing was bypassed with 25-mm-OD polyethylene tubing serving as the heat exchanger surface; this modification is not expected to produce a significant degradation of system performance. The demonstration ACES is presently in automatic operation under control of the house thermostat and is providing space cooling and water heating services to the building.

ACES components development. *Ice coil design.* The original design of the ice-bin heat exchanger consisted of finned, aluminum tubing arranged horizontally in a serpentine configuration and submerged in the water of the storage bin. A methanol-and-water brine circulates through the tubing to extract heat from or deposit it in the TES bin. Tests were performed to measure the lineal heat transfer coefficient, $\hat{U}$, of the ice-bin heat exchanger tubing during ice buildup. The experimental results (Fig. 4.4) indicate that the ACES heat exchanger tubing behaves as a thick-walled tube, modified by a fin correction factor. The magnitude of the heat transfer coefficient during ice buildup is determined primarily by the thickness of the ice annulus; that is,

$$\hat{U} = [2\pi f_c / (1/h_i r_i) + \ln(r_o/r_i)/K_t + \ln(r_{ice}/r_o)/K_{ice}] \, . \qquad (1)$$

where

r_i = inner radius of the heat exchanger tubing,
r_o = outer radius of the tubing,
r_{ice} = radius of the surrounding ice annulus,

K_t = thermal conductivity of the tubing.
K_{ice} = thermal conductivity of ice.
h_i = convective heat transfer coefficient inside the tube.
f_c = fin correction factor.

The convective heat transfer coefficient, h_i, is a function of the velocity, density, specific heat, and absolute viscosity of the brine and is obtained from the expression $h_i = 12\ Nu\ K/D$. Here, Nu is the Nusselt number characterizing the properties of the brine, K is the thermal conductivity of water, and D is the inside diameter of the tubing. The experimental fin correction factor, f_c, is plotted in Fig. 4.4.

A similar series of tests was performed to measure the lineal heat transfer coefficient of the tubing when the exchanger is operated in the ice-melting mode. It was determined that the fo·m of the calculational model for estimating these heat transfer coefficients is the same as for the ice-forming mode of heat exchanger operation. Here, however, r_w, the radius of the water annulus surrounding the tubing must be used in place of r_i; also, K_{eff}, an effective thermal conductivity of the water layer surrounding the heat exchanger tubing must be used instead of K_{ice}. Essentially, K_{eff} is the thermal conductivity that must be maintained by a motionless fluid in a gap in order to trans:nit

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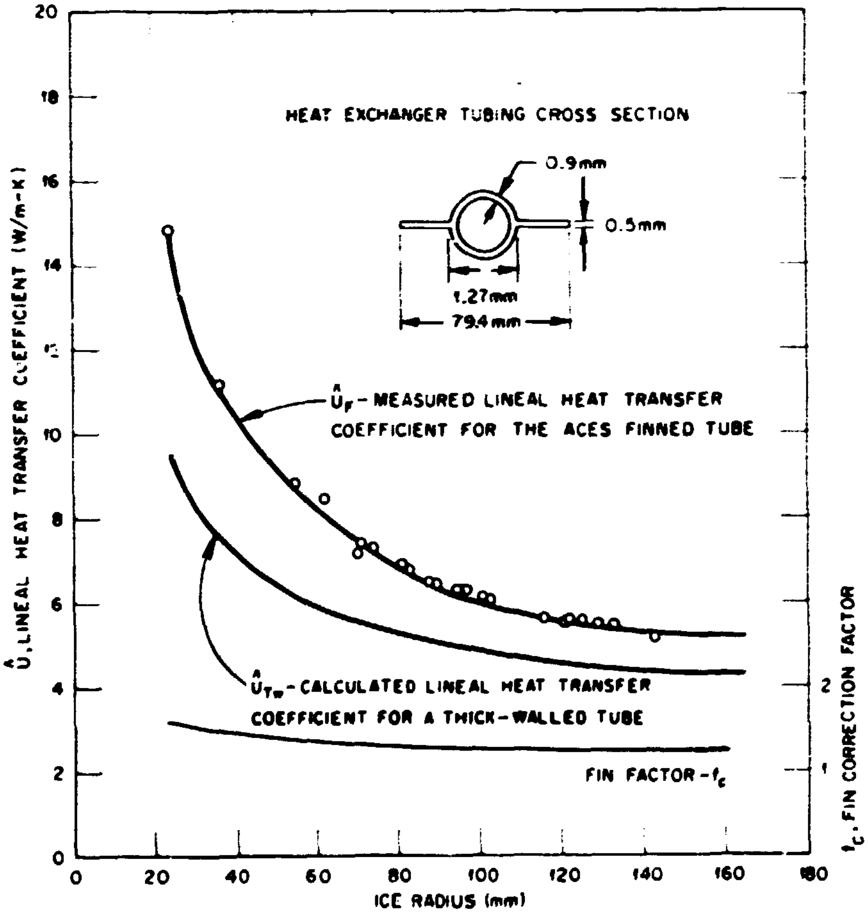

Fig. 4.4. Heat transfer coefficient of ACES heat exchanger tubing surrounded by an annular ice muff.

the same amount of heat as a fluid moving by convection. The experimental fin correction factor that applies during the ice-melting mode of heat exchanger operation was found to be relatively constant ($f_c = 1.2$) over the range of water annulus radii investigated. During ice buildup and ice melting, the heat transfer coefficient varies primarily with the thickness of the ice or water annulus surrounding the finned, aluminum tubing. Heat exchanger tubing slightly larger in diameter, but without fins, could be used to yield the same heat transfer coefficient.

Solar panel design. ACES applications may require a solar panel to collect heat in the winter and to reject waste heat from the compressor in the summer. The solar panel planned for use in the ACES consists of an unglazed array of finned, aluminum tubing mounted on a support frame. The methanol-and-water brine is circulated through the tubing to absorb solar energy, which arrives at the outer surface of the tube by convection of ambient air or by direct radiation.

A test panel (Fig. 4.5) having a 2.32-m^2 collecting surface was operated to measure the design parameters that determine its energy collection performance. The main objective of this investigation was to provide ACES design engineers with a means for estimating the area of collecting surface, or total tube length, that is needed for a solar panel application in any locality where solar and weather data are available. Operating variables monitored during the course of the experiment were the inlet and outlet temperatures of the working fluid, the fluid flow rate, the ambient air temperature, and the level of incident solar radiation. On the basis of these data, empirical equations were developed for predicting energy collection and rejection capacities as a function of panel size.

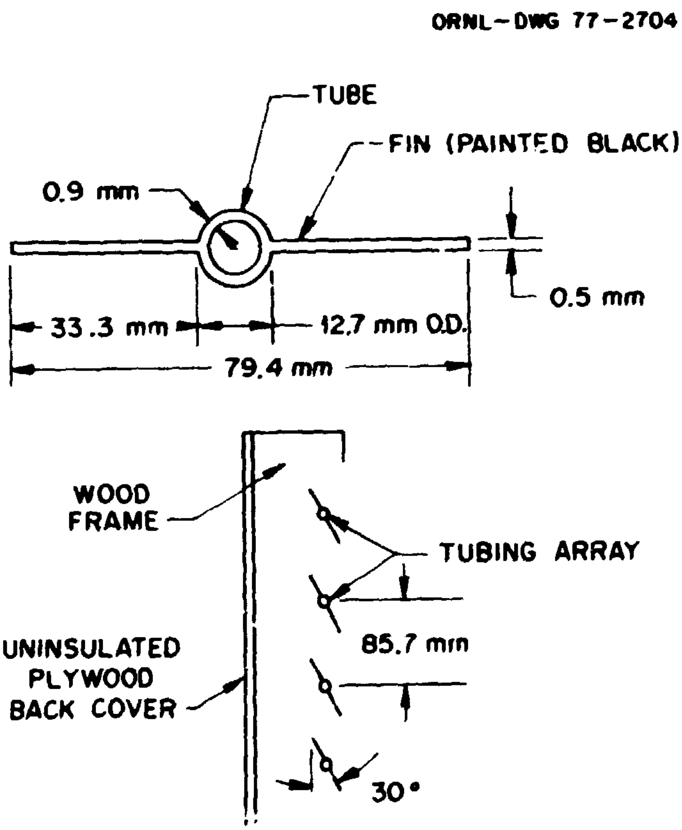

Fig. 4.5. Experimental radiant-convector panel.

For winter daytime heat collection, the empirical equation relating the heat collection rate to panel area is

$$Q_c = AF_c(0.93I/N + 2uT_{aw} - 47.3)\,. \tag{2}$$

where

Q_c = heat collection rate, W,
A = panel area, m^2,
F_c = panel efficiency factor,
I = average solar radiation normal to the panel during the daily heat collection period, Whr/m^2,
N = number of hours in the heat collection period, hr,
u = convection coefficient, W/m^2·K,
T_{aw} = daytime winter average air temperature, °C.

For summer night heat rejection, the empirical equation relating the heat rejection rate to panel area is

$$Q_r = AF_r[2u(T_{as} - T_b)]\,. \tag{3}$$

where

T_{as} = average ambient air temperature on a summer night, °C,
T_b = temperature of the brine in the solar panel tubing, °C.

The convection coefficient, u (W/m^2·K), and the panel efficiency factor, F_r, are obtained from experimental correlations: $u = 7.44 + 4.32S$, where S is the average wind speed (m/sec) and $F_r = 0.0063u$.

Ice bin design. The basic requirements of an ACES ice storage bin are that it can be easily constructed from commercially available materials and that it is watertight, accessible for maintenance, and adequately insulated to prevent undue melting of the stored ice. In addition, the cost of providing interseasonal ice storage must not exceed the present worth of the ice that is beneficially delivered for space cooling over the lifetime of the storage facility. The present worth for 1 m^3 of ice, delivered annually from an ice storage bin over a 20-year period, can be estimated by considering the alternative cost of producing the ice each year at the time it is actually needed.

For example, to produce 1 m^3 of ice in the summer, using a heat pump that has a cooling COP of 2.5, would require an electrical power input of (335 kJ/kg)(897 kg/m^3)/[(2.5)(3600 kJ/kWhr)], or 33.39 kWhr. Assuming that power presently costs 4¢/kWhr and that power costs will escalate at an annual rate of 6% over the next 20 years, the present worth of the ice produced annually over this period of time, discounted at an annual rate of 10%, is

$$33.39 \times 0.04\left(\frac{1.06}{0.10 - 0.06}\right)\left(\frac{1.10^{20} - 1.06^{20}}{1.10^{20}}\right) = \$18.52/\text{m}^3\,. \tag{4}$$

On the basis of this example, expenditures to provide interseasonal ice storage capability are justifiable, providing they do not exceed \$18.52 per cubic meter of delivered ice. Expenditures for interseasonal ice storage are incremental to the base cost of providing an adequately sized, wintertime heat source for the ACES. For this reason, the permissible expenditure for interseasonal ice storage should be compared with the marginal cost of providing additional storage capacity above that required for the heat source alone. Clearly, the development of low-cost TES structures is of crucial importance to the economic viability of the ACES concept.

We have examined several alternative tank structures, all of which show promise of being economically feasible for ACES applications: wood tanks with vinyl liners, cast concrete septic tanks, and steel tanks. Currently, the most complete cost data are available for steel tanks. Cylindrical steel tanks, commercially available in kit form, can be obtained in a variety of sizes. Figure 4.6 illustrates a steel storage tank for ACES which was designed by the Clayton and Lambert Mfg. Co. of Buckner, Kentucky. The confirmed prices for the water tanks, listed in Table 4.1, are for the basic water tank kit

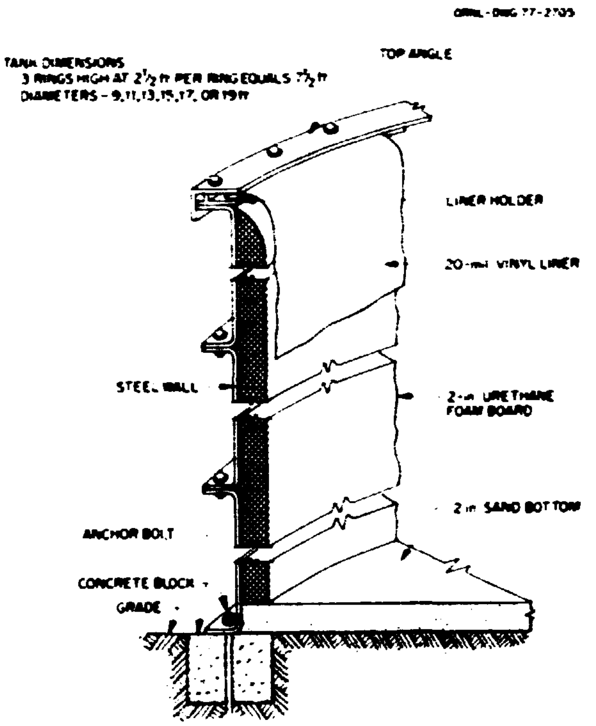

Fig. 4.6. Steel tank design for ACES thermal storage.

Table 4.1. Costs of steel storage tanks for ACES applications

Tank size (ft, in.)		Volume[a] (m^3)	Cost ($)					Cost ($/$m^3$)	
Diameter	Height		Tank kit	Insulation	Assembly	Excavation	Total	Unit	Marginal[b]
9, 6	7, 6	12.80	460	88	160	50	758	59.22	
11, 5	7, 6	18.69	544	106	176	57	883	47.24	21.22
13, 4	7, 6	25.71	623	124	192	66	1005	39.90	17.38
15, 3	7, 6	33.87	713	142	208	76	1139	33.63	16.42
17, 2	7, 6	43.13	804	160	224	87	1275	29.56	14.69
19, 1	7, 6	53.52	893	177	240	100	1410	26.35	12.99

[a]The effective tank volume is calculated on the basis of 50.8-mm wall insulation, a 50.8-mm sand bottom and a 101.6-mm top void.

[b]The average cost per unit volume for storage capacity above that of the next smaller size tank.

with nuts, bolts, mastic for assembly, the vinyl liner, and vinyl extrusion for hanging the liner. The estimated costs of installation, also listed in Table 4.1, are based on assumed costs of $3.98 per square meter of 50.8-mm urethane insulation, $10 per hour for assembly labor, and $1.98 per cubic meter for excavation. Not included in the total costs are delivery costs and expenditures for the tank lid and superstructure. The lid and superstructure costs will vary, depending upon the extent to which the ACES design makes use of the building structure.

Icemaker heat pump.[13] An icemaker heat pump is especially attractive for use in the ACES because of its high COP and because the ice is harvested directly, thereby obviating the need for a complicated ice-bin heat exchanger. A schematic drawing of an icemaker heat pump used in an ACES is shown in Fig. 4.7. The freezing cycle of the icemaker heat pump is terminated when the ice on the evaporator surface is about 6 mm thick to prevent a continuing buildup of ice that would insulate the evaporator surface and lower the COP of the machine. As soon as the compressor is switched off, a solenoid valve opens to connect the gas space in the receiver to the evaporator plate at a point downstream from the expansion valve. This action allows warm (35° C) refrigerant vapor to flow to the evaporator surface, where it condenses. The heat of condensation that is liberated raises the temperature of the evaporator surface from about −6.7 to 0° C. As a result, the ice bond is loosened, and the ice falls off the plate and into the storage bin.

The design objective for an ACES icemaker heat pump is to obtain high energy efficiency rather than to produce food-quality ice. This objective requires that the system produce a maximum heating

13. H. C. Fischer et al., "Application of the Ice-Maker Heat Pump to an Annual Cycle Energy System," paper prepared for presentation at the ASME Winter Meeting, New York, December 1976.

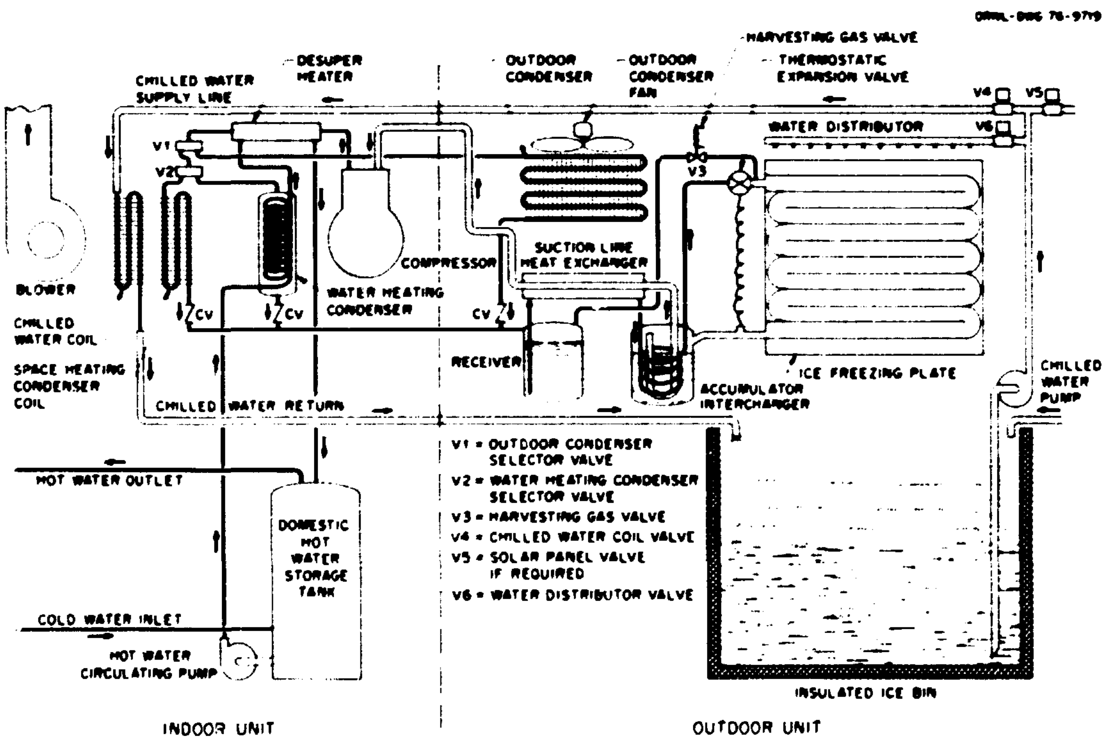

Fig. 4.7. Schematic drawing of the ACES icemaker heat pump.

output at the condenser, operate at an average temperature of −6.7° C or higher, use the compressor only in its design temperature range, and employ a thermodynamic method of harvesting the ice. A high-performance system of this type, when coupled with thermal storage as in the ACES, will provide load leveling capability and help conserve primary energy resources.

An icemaker heat pump test unit has been installed in the Energy Conservation Laboratory at ORNL; operation of the test unit has successfully demonstrated the thermodynamic ice harvesting method. A demonstration house equipped with an icemaker heat pump and TES is being considered for construction at Philadelphia in the coming year by the Korman Corporation, Philadelphia Electric Company, and ERDA.

ACES design manuals. The Energy Conservation Program has initiated contract negotiations with Robert G. Werden and Associates and with the National Environmental Systems Contractors Association (NESCA) to secure their assistance in preparing and publishing two design manuals for use in the application of ACES. The first of these manuals, to be developed by Robert G. Werden and Associates, concerns the design of ACES installations for large commercial buildings. The manual is intended for use by architect-engineers and will require the availability of large computer facilities for design calculations. The manual will provide an authoritative procedure for properly sizing and selecting equipment and distribution systems using the ACES concept. Also to be included are those specifications and analyses dealing with building construction, return on investment, life-cycle costing, etc., which are necessary to provide the architect or engineer with a clear understanding of the economic and energy use advantages that are involved.

The second design manual, to be developed by NESCA, concerns small buildings—light commercial buildings and residences. The manual is intended for use by HVAC contractors and the system design personnel employed by these contractors. The manual will use a systematic, step-by-step procedure to cover load calculation for heating, cooling, and domestic hot water, equipment selection, distribution system design, and those installation and servicing considerations that are required for proper system design and operation. The design procedures established in the manual will neither assume nor require extensive engineering expertise on the part of the user, nor will they require the use of large digital computers. Thus, the ACES design manual will parallel existing NESCA design manuals which are directed at the same target audience and which relate to existing conventional HVAC systems. ORNL will assist in the preparation of the ACES design manuals by providing information and computer programs that have been developed.

4.2.2 Effects of Thermostat Setting on Energy Conservation Consumption by Residential Heat Pumps

Implicit in previous studies of the effect of thermostat setting on energy consumption[14-18] are the assumptions that efficiency of the heating system is independent of outdoor temperatures and that energy consumption is proportional to the space heating load. These assumptions cannot be applied to a system that consists of a heat pump supplemented by resistance heaters even if indoor temperatures are

14. L. W. Nelson, *ASHRAE J.* 15(8), 41–49 (1973).

15. D. A. Pilati, *The Energy Conservation Potential of Winter Thermostat Reductions and Night Setback*, ORNL NSF EP-80 (February 1975).

16. D. Harrje, "Night Setback and Energy Savings," The Center for Environmental Studies, Princeton University, N.J., unpublished.

17. M. P. Zabinski and A. Amalfitano, *ASHRAE J.* 18(1), 41–46 (1976).

18. David Quentzel, *ASHRAE J.* 18(3), 39–43.

held constant throughout the heating season. If night setback of indoor temperatures is anticipated, much closer scrutiny of the relationship of energy consumption to load is required. The morning recovery period occurs during the coldest part of the day, calling for maximum output from the system when the heat pump's COP is lowest. This effect and the desire for rapid temperature recovery indicate increased use of the auxiliary resistance heaters and might result in an increase, rather than a savings, in total energy consumption.

Heating loads and energy consumption have been calculated for a 140-m^2 single-family detached house having three bedrooms, two baths, and a basement.[19] The same model home as used by Pilati[15] was selected to facilitate comparison. The model home was assumed to have internal loads and occupancy schedules typical of a family of two adults and two children, and hourly weather data[20] for six cities, chosen to span a wide range of climatic conditions, were used. Simulations were run for only the heating seasons in Atlanta, Knoxville, Philadelphia, Seattle, Cheyenne, and Minneapolis. For each city, calculations were made for constant thermostat settings of 22 and 20°C; to examine the effects of night setback, calculations were also made for a daytime temperature of 20°C with temperature lowered to 15.6 and 12.8°C between the hours of 10 PM and 6 AM. The percentage of energy savings compared with consumption at a constant temperature of 22°C is shown in Fig. 4.8 as a function of the average outdoor temperature for the heating season (September through May).

The calculated energy savings in each of the six cities considered have been fitted by the method of least-squares analysis to obtain the curves shown in Fig. 4.8. The figure shows that, over a wide range of climatic conditions, substantial energy savings can be achieved for variable-capacity heating systems by implementing night setback of indoor temperatures.

4.2.3 Heat Pump Analysis and Evaluation

The heat pump analysis and evaluation work this year has been directed at assessing the potential energy savings derived from technological improvements to present-day air-to-air heat pump systems. The project approach is to (1) identify heat pump inefficiencies experimentally and to recommend improvements, (2) evaluate recommended improvements experimentally and analytically, (3) determine the costs associated with the recommended heat pump improvements, and (4) develop the analytical capabilities needed to perform the evaluations. These capabilities include (*a*) a computer simulation that determines heat pump performance as a function of outdoor temperature and (*b*) a procedure for estimating heat pump energy consumption when the heat pump, climate, and building thermal characteristics are specified.

Experimental tests of heat pumps. The purposes of the experimental work are to identify inefficiencies in heat pump systems and components and to verify the computer simulation model. A nominal 3-ton-capacity (10.6-kW output) heat pump, purchased at lowest bid, was installed in the laboratory and instrumented so that system and component performance could be evaluated. The temperature and pressure of the refrigerant were measured at the points shown in Fig. 4.9; the power consumption was measured at the outdoor and indoor units; and the air inlet and outlet temperatures and the air flow were measured at the indoor and outdoor heat exchangers. The test results were

19. R. D. Ellison, *Savings in Energy Consumption by Residential Heat Pumps: The Effects of Lower Indoor Temperatures and of Night Setback*, ORNL/CON-4 (to be published).

20. Copies of the weather data, encoded on magnetic tapes, may be obtained from G. McKay or D. Calloway, National Climatic Center, Federal Building, Asheville, NC 28801.

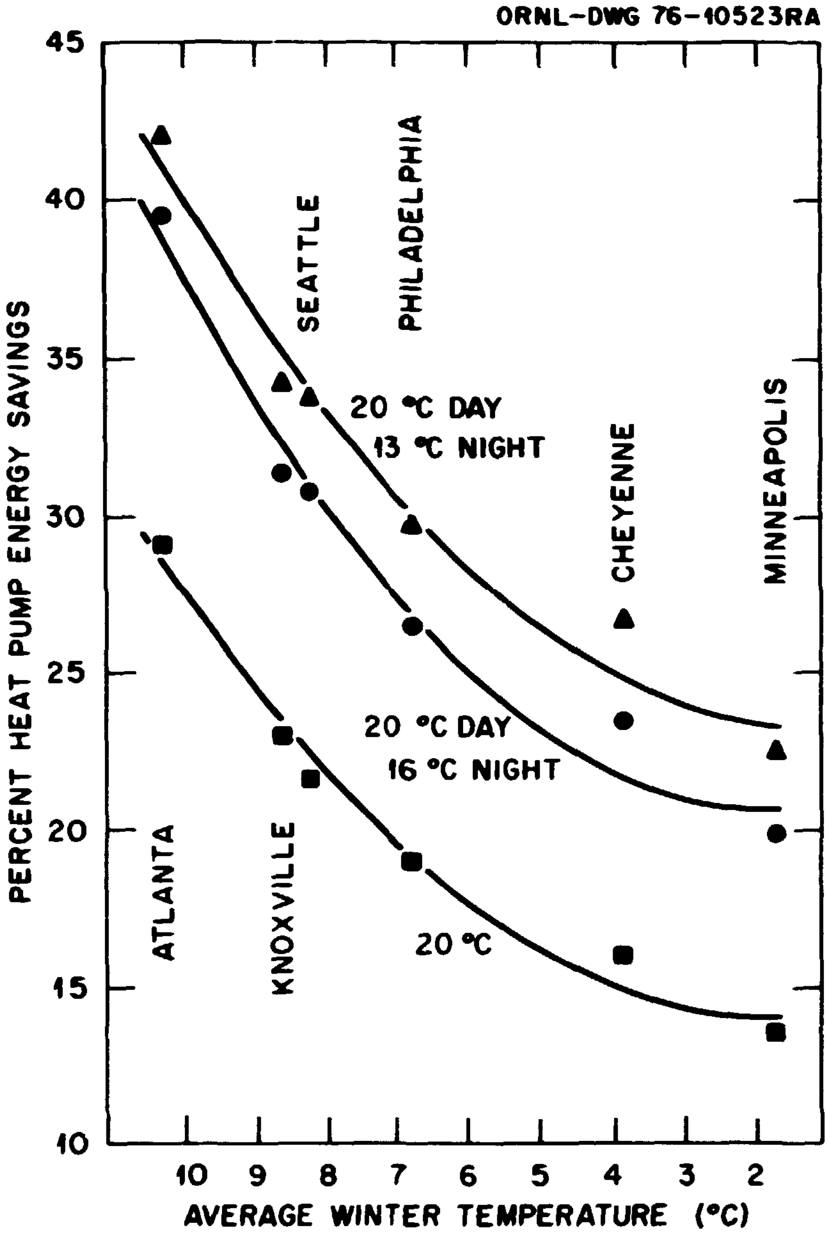

Fig. 4.8. Percentage of energy savings (compared with consumption at 22.2°C) as a function of average temperature for the heating season (September through May).

consistent with the published ratings. Figure 4.10 shows a pressure-enthalpy diagram for a test condition; the numbered points correspond to the location of the experimental measurements. Two system energy losses are depicted in the diagram: (1) the energy loss in the high-pressure side of the reversing valve and (2) the energy loss resulting from compressor inefficiencies.

The fractional reversing valve loss, $L_{rv} = (h_1 - h_7)/(h_1 - h_5)$ (see Fig. 4.10), was measured as a function of the outdoor ambient temperature, T_a. For 30 measurements covering an outdoor temperature range of −16 to +16°C, the experimental correlation was found to be

$$L_{rv} = 0.06281 - 0.00085 T_a \, . \tag{5}$$

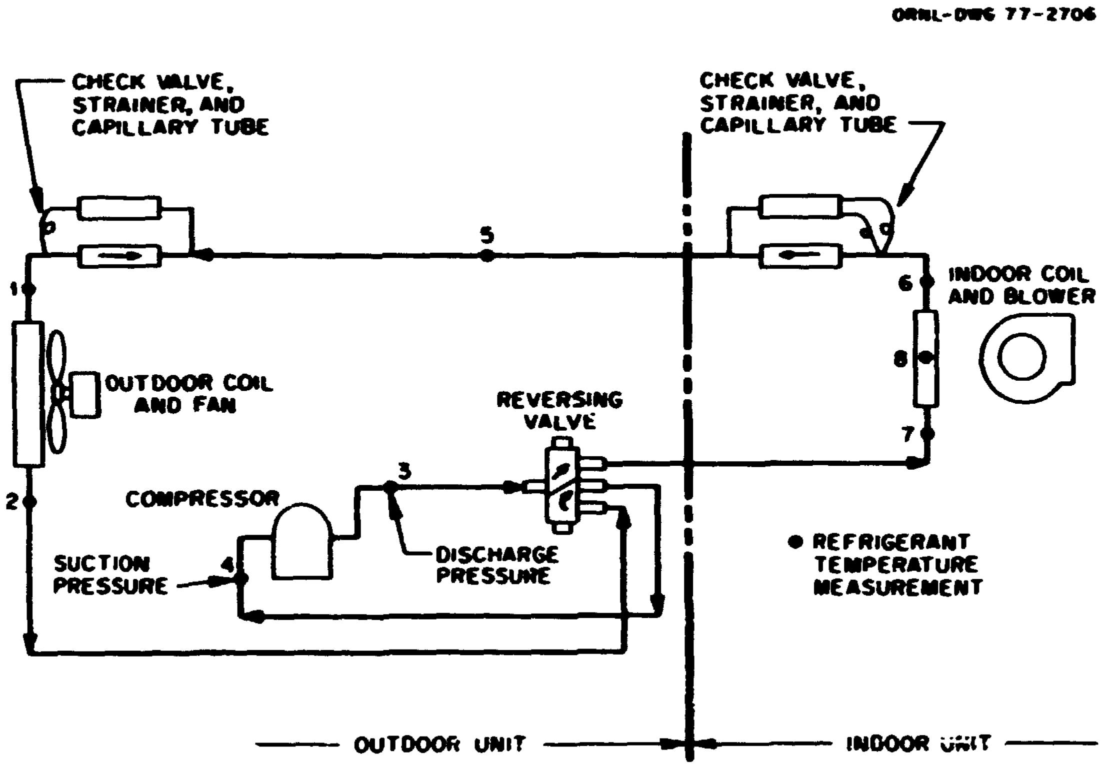

Fig. 4.9. Heat pump schematic (heating mode).

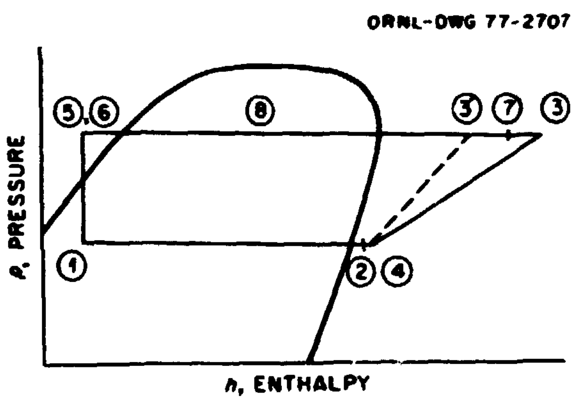

Fig. 4.10. Pressure-enthalpy diagram of a heat pump cycle.

The fractional isentropic efficiency of the compressor, $\eta_c = (h'_2 - h_1)/(h_2 - h_1)$, was also measured as a function of T_a. The experimental correlation, for the −16 to +16°C temperature range, was found to be

$$\eta_c = 0.60234 - 0.01112T_a . \quad (6)$$

From this correlation, it is seen that high isentropic efficiency occurs at low outdoor ambient temperatures (T_a) and considerably lower efficiencies occur in the normal operating temperature range of −4 to +13°C.

Energy losses also occur when the heat pump cycles on and off to meet building heating demands that are lower than the output capacity of the heating system. A modulated heat pump, which continuously matches capacity to demand, requires lower heat transfer rates than a cycling system with the same heat exchangers. The lower refrigerant-to-air temperature differences at the condenser and the evaporator lower the pressure differential for the compressor and thereby increase system efficiency. An investigation is being conducted to determine the potential of a modulated heat pump for energy conservation. Other energy savings can result from better defrost mechanisms, fan motors, or the use of an alternative refrigerant. The technical feasibility of these design improvements is being investigated.

Simulation of residential heat pumps by computer models. A heat pump model is being adapted for use in determining the performance characteristics of heat pump systems having different components and configurations. The computer model will be used as a tool in developing an estimating procedure for predicting the seasonal performance and energy consumption of heat pumps. The model will also be used in the experimental program to identify sources of inefficiencies in current heat pump design and to suggest possible improvements. The heat pump computer simulation activity at ORNL is based largely on a program developed at MIT.[21] The model establishes evaporating and condensing pressures by seeking a mass flow, or pressure balance, for the refrigerant side of the system. The balance is then iteratively refined by subprograms to include air-side effects. The MIT model has been acquired and is currently operational at ORNL.

Seasonal performance of heat pumps. The purpose of developing a procedure for estimating seasonal performance of heat pumps is to allow determination of overall energy consumption when given characteristics of the building, climate, and heat pump performance. The building's thermal losses are assumed to be linear with outdoor temperature (other effects such as solar gains, wind, etc., are averaged) and are zero at 18°C outdoor temperature. The heat pump system performance as a function of outdoor temperature can be obtained from manufacturers' data, laboratory experiments, and the computer simulation model. The temperature at which the heat pump capacity coincides with the building heat demand is defined as the balance point temperature; the balance point is used to determine system performance including the use of supplemental resistance heaters. Average heat loss from a building is proportional to the number of degree-hours. A computer program has been written to calculate degree-hours as a function of outdoor temperature from U.S. Weather Bureau data.

Energy consumption by a heat pump in a given climatic region can be calculated as a function of balance point temperature (or building heat loss characterization). The results of this method compare favorably with those of an hour-by-hour calculation method. Work is progressing for the cooling mode.

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21. C. G. Hiller and L. R. Glicksman, *Improving Heat Pump Performance via Compressor Capacity Control — Analysis and Test*, MIT-EL-76001, Massachusetts Institute of Technology, Cambridge (January 1976).

4.2.4 Other Areas of Residential Energy Conservation

Mobile home energy study. The data obtained from an experimental program[5] to determine the thermal characteristics of mobile homes and the energy savings afforded by various retrofit improvements have now been analyzed. We have developed a computational, two-node, dynamic model of the test mobile home that provides good agreement with temperatures measured during a series of space heating and cooling test runs. Analysis of the space heating test data indicates that energy savings approaching 50% can be achieved by adding storm windows, skirting, and extra insulation to the mobile home structure; the changes would be economical in many parts of the United States. A full description of the experimental program and the analytical findings is available in the literature.[6,7]

4.3 ENERGY DEMAND MODELS

4.3.1 Engineering-Economic Models of Energy Use

Eric Hirst[22]	Jane Cope[23]
Jerry Jackson	William Lin
Steve Cohn	Robert Hoskins[24]
J. H. Carney[23]	Stan Johnson[24]

Our work this past year has been directed at the development, improvement, and application of detailed engineering-economic models that simulate energy uses in the residential and commercial sectors from 1970 through 2000. The purpose of these computer models is to provide FEA, ERDA, and other energy decision makers with analytical tools to study the energy and direct economic impacts of various energy conservation policies, programs, and technologies.

Our efforts presently encompass two major economic sectors—residential and commercial. We began work on our residential energy model in August 1975 and on the commercial energy model in July 1976. The residential sector is defined as those structures (single-family units, apartments, and trailers) occupied by households; group quarters such as dormitories and jails are not considered part of the residential sector. The commercial sector is defined as those structures such as office buildings, schools, hospitals, and stores that house the service sectors of our economy (e.g., retail and wholesale trade, government enterprises, and health services).

Table 4.2 summarizes the key features of the residential and commercial energy models. Perhaps the most important feature is the explicit sensitivity of the models to the major demographic, economic, and technological determinants of residential and commercial energy uses. These factors include (1) population growth, household formation, and housing choices; (2) fuel prices, incomes, employment, and economic activities; and (3) energy efficiencies and capital costs for structures and equipment. Thus, these energy models overcome the limitations associated with econometric models (lack of sensitivity to technological changes) and engineering process models (lack of sensitivity to economic variables).

Because of the features listed in Table 4.2, the energy models are useful for analyzing conservation policies and programs (e.g., fuel taxes, natural gas deregulation, financial incentives for retrofitting homes, appliance efficiency standards) and technological alternatives (e.g., R&D programs to increase

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22. Group leader.
23. Computer Sciences Division.
24. Consultant, Mechanical Engineering Department, University of Tennessee.

Table 4.2 Key features of ORNL energy use models

Explicit	They are sensitive to demographic, economic, and technological determinants of energy uses.
Simulation	They are based on household and commercial firm behavior about purchases and uses of equipment and structures.
Dynamic	They incorporate time features of the lifetimes and behavioral lags of equipment and structures.
Detailed	They calculate many fuel, end use, and building type components for each year for energy use, energy costs, and capital costs.

equipment efficiencies and/or reduce capital costs). The models are also useful in developing detailed, internally consistent forecasts of residential and commercial energy uses to the year 2000.

For each case cited above, the models estimate annual energy use by fuel, end use, and building type. In addition, the models calculate energy expenditures, capital costs for equipment, and costs for upgrading thermal integrity for new and existing structures. These cost figures allow one to develop benefit–cost measures for each policy, program, or technology being considered.

Residential energy use model. The present version (III) of our residential energy model deals with energy use at the national level for four fuels (electricity, gas, oil, and other); eight end uses (space heating, water heating, refrigeration, food freezing, cooking, air conditioning, lighting, and other); and three housing types (single-family, apartments, and trailers). Household energy use for each combination of fuel, end use, and housing type is computed in response to changes in (1) stocks of occupied housing units and new residential construction, (2) equipment ownership by fuel and end use, (3) thermal integrity of housing units, (4) average unit energy requirements for each type of equipment, and (5) usage factors that reflect household behavior.

Version III of the ORNL model[25] differs from the original version[26] in several ways:

1. The original version included only operating costs as explanatory variables for equipment choices. New equipment choices (market shares among fuels) are now functions of both operating costs (fuel prices and equipment efficiencies) and equipment prices.
2. The number of end uses is increased from six to eight. The new end uses are food freezing (split from refrigeration) and lighting (split from other).
3. The original version calculated equipment ownership each year and then inferred new equipment installations indirectly. Version III deals explicitly with future installations of new equipment and then calculates equipment ownership from new installations.

Figure 4.11 is a schematic diagram of our residential model. The demographics submodel calculates stocks of occupied housing units by type for each year of the simulation. On the basis of calculations of household formation and retirements from the existing stock of occupied housing units, new construction requirements are calculated for each year to ensure that the stock of occupied housing units matches demand (the number of households that year).

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25. Eric Hirst et al., *An Improved Engineering–Economic Model of Residential Energy Use*, ORNL/CON-8 (to be published).

26. Eric Hirst, W. W. Lin, and Jane Cope, *An Engineering–Economic Model of Residential Energy Use*, ORNL/TM-5470 (July 1976).

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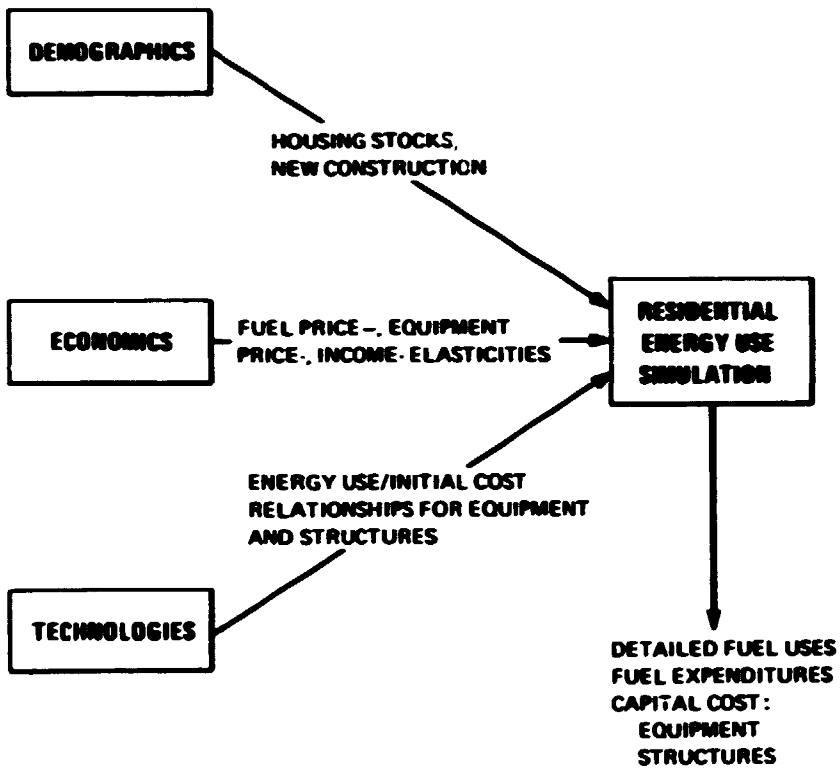

Fig. 4.11. Schematic diagram of ORNL residential energy use model.

The economics submodels[27,28] calculate elasticities (parameters) that determine the responsiveness of households to changes in economic variables—incomes, fuel prices, equipment prices. Elasticities are calculated for each of the three major household fuels for each of the eight end uses. Each fuel price and income elasticity is decomposed into two elements—an elasticity of equipment ownership (E_o) and an elasticity of equipment use (E_u). The first element gives changes in equipment ownership in response to changes in fuel prices, equipment prices, and incomes, and the second gives the responsiveness of equipment use (with ownership held constant) to changes in own-fuel prices and incomes. These submodels calculate a total of 272 elasticities.

The technologies submodels[29,30] evaluate changes in equipment energy requirements and changes in equipment purchase price as functions of alternative designs. Detailed engineering submodels were constructed for gas and electric water heaters and for refrigerators. We synthesized data from a number of sources to infer relationships between equipment energy use and initial cost for the other end uses considered in version III.

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27. W. W. Lin, Eric Hirst, and Steve Cohn, *Fuel Choices in the Household Sector*, ORNL CON-3 (October 1976).

28. Steve Cohn, Eric Hirst, and Jerry Jackson, *Econometric Analyses of Household Fuel Demands*, ORNL CON-7 (January 1977).

29. Robert Hoskins and Eric Hirst, *Energy and Cost Analysis of Residential Refrigerators*, ORNL CON-6 (January 1977).

30. J. D'Acierno, R. Bertolami, and E. Chao, *Energy Consumption in Residential Gas and Electric Water Heaters and Ranges*, ORNL MIT-226 (February 1976).

Figure 4.12 summarizes the outputs from our refrigerator analysis.[39] Each point represents the energy use and initial cost for a particular refrigerator design. Cost figures are synthesized from discussions with manufacturers and other researchers. Results of the analysis suggest that refrigerator energy use can be sharply reduced with only slight increases in refrigerator retail price. For example, the point labeled 1,2,3,4,6,7,8 represents a design that uses 52% less electricity than the reference refrigerator and has a purchase price only 19% higher than the reference unit.

The simulation model combines outputs from the various submodels (Fig. 4.11) with appropriate initial conditions for 1970 and boundary conditions (policy variables) for the 1970–2000 period. Output from the simulation model includes 96 fuel use components (Q_t^{ikm}) for each year (t): 4 fuels (i) × 8 end uses (k) × 3 housing types (m). The model also calculates annual fuel expenditures, equipment costs, and capital costs for improving thermal integrity of new and existing structures at the same level of detail. Each fuel use component is determined in the simulation program as the product of five factors:

$$Q_t^{ikm} = HT_t^m \cdot C_t^{ikm} \cdot \mathrm{TI}_t^{ikm} \cdot \mathrm{EU}_t^{ikm} \cdot U_t^{ik} \ . \qquad (7)$$

where

HT = the stock of occupied housing units,
C = fraction (market share) of households using a particular type of equipment,
TI = thermal integrity of housing units (for space heating and air conditioning only),
EU = average annual energy use for the type of equipment,
U = usage factor.

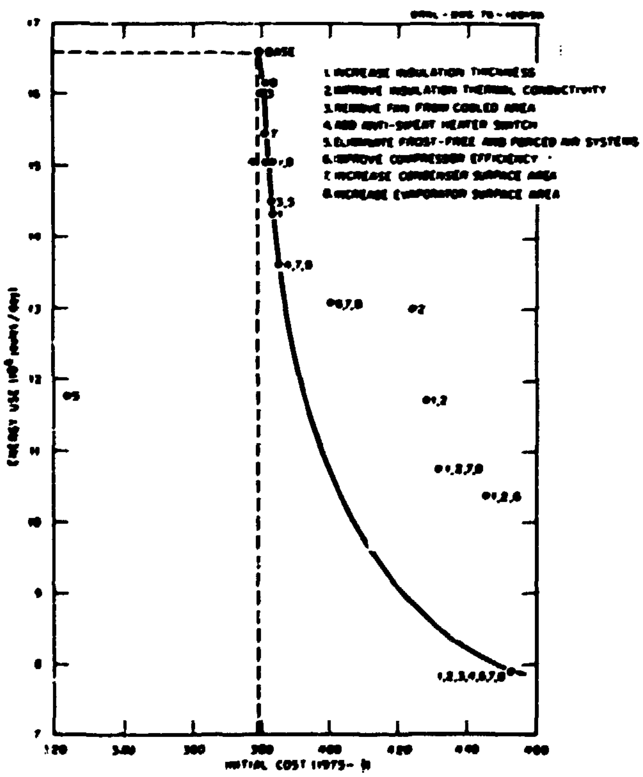

Fig. 4.12. Electricity use vs retail price for a 0.45-m³ (16-ft³) top-freezer refrigerator.

The first version of the residential model was completed in January 1976. Since then we have used this model (and succeeding versions) for our project sponsors. FEA and ERDA, to evaluate various conservation policies and technologies. We also conducted a broad analysis of alternative conservation strategies for the residential sector.[31,32] We are now using the model to support the National Academy of Sciences, Committee on Nuclear and Alternative Energy Systems, in its analysis of energy options for ERDA.

As an example of our use of the model to analyze conservation programs, we briefly review our evaluation of the energy and direct economic impacts of national adoption of the ASHRAE 90-75 thermal standards[33] for construction of new single-and multifamily units. We assume that the standards are fully implemented in 1978 and remain in force through the year 2000.

Figure 4.13 shows how the energy savings increase over time, reaching 0.9 exajoules (EJ or 10^{18} J) per year in 2000, which is equivalent to 3% of the baseline residential energy use in 2000. Most of the savings are in electricity (81% in 2000) because most new space heating installations and all air conditioning installations are electric. Cumulative energy savings for the 1978–2000 period are 10.6 EJ (Table 4.3).

31. Eric Hirst, *Residential Energy Conservation Strategies*, ORNL CON-2 (September 1976).

32. Eric Hirst, *Science* 194, 1249–52 (1976).

33. A. D. Little, Inc., *An Impact Assessment of ASHRAE Standard 90-75, Energy Conservation in New Building Design*, December 1975.

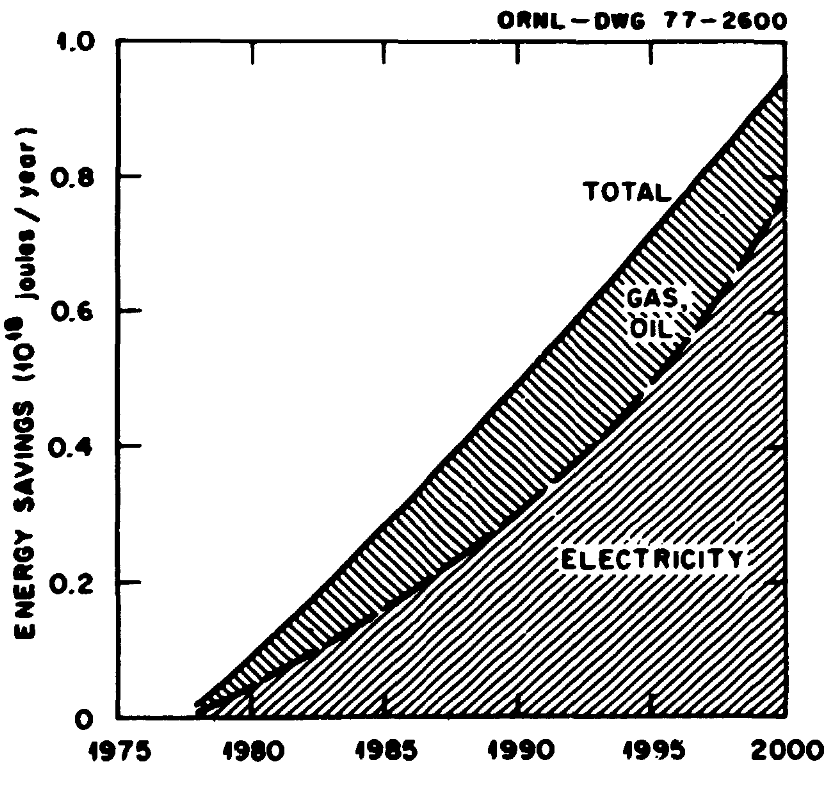

Fig. 4.13. Annual energy savings from adoption of ASHRAE 90-75 thermal standards.

Table 4.3. Cumulative energy and economic benefits of implementing ASHRAE 90-75 in single- and multifamily housing[a]

Cumulative (1977–2000) energy benefits (EJ)	
Electricity	7.28
Gas	1.74
Oil	1.58
Total	10.60
Present worth of 1977–2000 economic benefits at 10% (billion 1975 $)	
Fuels	8.82
Equipment	−0.14
Structures	−3.45
Total	5.23
Benefit–cost = (8.82 − 0.14) 3.45 = 2.5	

[a]Assuming that the ASHRAE thermal standards are implemented in all states starting in 1978 and remain in force for the entire forecast period (through 2000).

Adoption of the ASHRAE 90-75 thermal standards increases capital costs of constructing new residences and reduces operating costs of space heating and air conditioning systems. Figure 4.14 shows changes in capital and operating costs for each year from 1978 through 2000. Between 1978 and 1983, annual outlays for construction exceed annual fuel bill savings; however, after 1983, reductions in fuel bills always exceed annual construction cost increases.

Table 4.3 shows the present worth (in 1977, at a real interest rate of 10%) of the fuel bill reductions and capital cost increases for equipment (due to fuel switching) and structures (due to thermal integrity improvements). The present-worth net economic benefit to society is $5.23 billion (1975 dollars). Comparison of the savings with the increased construction costs shows that the overall benefit–cost ratio for implementation of these standards is 2.5.

The results presented here strongly suggest that adoption of the ASHRAE 90-75 thermal standards for construction of new residences will save money for homeowners and save energy for the nation.

Using the model to evaluate the energy impacts of several conservation programs,[11,32] we found a large range in projected growth of residential energy use: Cumulative energy use from 1975 through 2000 ranges from 650 to 478 EJ in our projections. Our highest forecast shows an average annual growth of energy consumption of 2.5% for this period, as compared with an annual growth of 3.6% from 1950 to 1975. Growth of energy use is almost certain to be slower during the fourth quarter of this century than it was during the third quarter because of slower growth in population and households, changes in fuel price trends, and approaching saturation of equipment ownership for major residential energy uses.

We also found that implementation of strong, cost-effective conservation programs (appliance efficiency standards, thermal standards for new construction, and a retrofit program, coupled with higher fuel prices) could cut residential energy use growth to only 0.4% per year between 1975 and 2000. Under these assumptions, residential energy use in 2000 will be only 10% higher than it now is.

We are continuing to make improvements to our residential energy model. The present version (III) does not endogenously determine changes in equipment efficiencies and in structural thermal integrities. The user must provide inputs to the model on these efficiency changes over time. We are now developing a model that internalizes these efficiency changes as functions of fuel prices, consumer behavior (fuel price and equipment price elasticities[27]), and the technologies affected (energy use vs capital cost[29]).

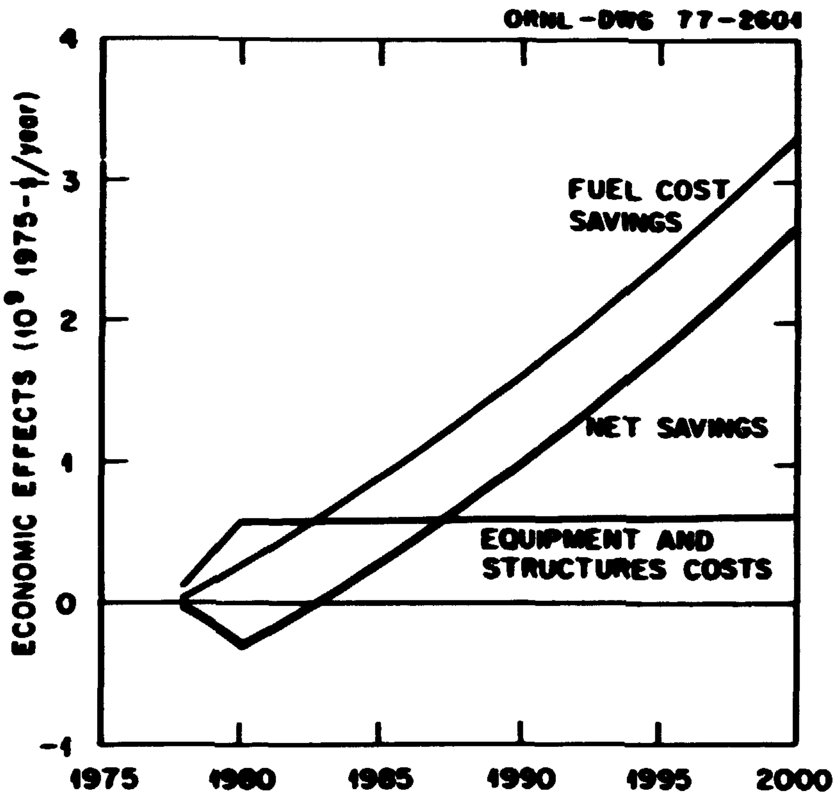

Fig. 4.14. Economic costs and benefits of adopting the ASHRAE 90-75 thermal standards for construction of new residences.

Our engineering submodels are well developed only for gas and electric water heaters and refrigerators. We will continue working on other end uses with a focus on new space heating and cooling technologies such as solar, annual cycle, and total energy systems.

We are currently developing regional residential models for each of the nine census divisions, and may develop similar models for each of the ten FEA regions. Regionalization will allow us to evaluate the impacts on regional energy use of (1) regional energy policies and (2) national policies that differ from region to region in their application because of fuel-price and climatic differences among regions.

Finally, we are involved in several efforts to disseminate the results of our activities, with respect to both methodology development (refs. 25–30, 34–36, and 38) and results (refs. 31, 32, and 37).

Commercial energy use model. The purpose of this project is to develop a comprehensive simulation model of commercial energy use to the year 2000. Detailed annual forecasts will be provided

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34. Eric Hirst, W. W. Lin, and Jane Cope, "Modeling Residential Energy Use," *Eleventh Intersociety Energy Conversion Engineering Conference Proceedings*, vol. 1, Conf. No. 769098, September 1976.

35. Eric Hirst, W. W. Lin, and Jane Cope, "Simulation Model of Household Fuel Uses," accepted for publication in *Applied Mathematical Modeling*, 1977.

36. Eric Hirst, *Energy* 1(1), 33–44 (1976).

37. Eric Hirst, "Residential Energy Use Alternatives to the Year 2000," accepted for publication in *Energy Communications*, 1977.

38. Eric Hirst, W. W. Lin, and Jane Cope, "A Residential Energy Use Model Sensitive to Demographic, Economic, and Technological Factors," accepted for publication in *Quarterly Review of Economics and Business*, 1977.

for five end uses, four fuels, and ten commercial subsectors. The engineering–economic methodology developed for the residential sector is being used to model commercial energy use. This model will then be used to help FEA determine the capital costs and energy savings of various conservation programs.

The basic equation used to evaluate energy use in the model is

$$Q_t^{ikm} = S_t^m \cdot FS_t^{ikm} \cdot TI_t^{ikm} \cdot EU_t^{ikm} \cdot U_t^{ik} \, . \tag{8}$$

where

Q = fuel use,
i = fuel (electricity, gas, oil, other),
k = end use (space heating, water heating, air conditioning, lighting, other),
m = commercial subsector (retail and wholesale trade; automotive repair and services; finance, insurance, and related activities; warehouse activities; public administration; educational services; health services; religious services; nonresidential lodging services; miscellaneous commercial activities),
t = forecast year,
S = stock of floor space, m^2,
FS = fraction of floor space served by a particular fuel–end use combination,
TI = thermal integrity of structures,
EU = average commercial energy use, J/m^2,
U = usage factor.

Each factor determining energy use is calculated in a separate economic or engineering submodel; for example, estimates of the stock of floor space (S) are derived from econometric demand models. Floor space used by commercial establishments is quantitatively related to the price of floor space and to variables that influence the level of economic activity within the commercial subsectors. An initial partial-adjustment formulation was estimated for all ten subsectors. Subsequent research on this submodel will evaluate alternative dynamic specifications of the econometric models and refine the historical floor-space stock data.

Much of our initial work on this model dealt with development of necessary data concerning (1) inventories and additions of floor space (in square meters) by commercial subsectors, (2) energy use figures (in joules per square meter) for each combination of fuel, end use, and building type for 1970, and (3) internally consistent estimates of historical commercial fuel use by fuel (in exajoules per year). With respect to development of consistent historical data on commercial fuel use by fuel, we found large discrepancies among energy trade associations and federal agencies concerning definitions of the commercial sector. We used information from a variety of sources to develop new data series that reflect state-level annual fuel uses (electricity, gas, oil, other) for the commercial sector.[39] These new data series are now part of the ORNL energy use data base and will be used in developing econometric models of commercial energy uses.

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39. Eric Hirst and Jerry Jackson, *Energy* 2(2) (1977).

4.3.2 Econometric Analysis of Energy Demand

W. S. Chern[40]

S. B. Candill[41] G. S. Maddala[41]
B. D. Holcomb[42] C. L. Ng[43]
W. W. Lin M. A. Smith[43]

During the past year, this effort, representing a continuing activity in the study of energy demand, has focused on two major areas. The first area is aimed at improving our understanding of the interrelationships of demands for all substitute energy sources. Specifically, we developed an integrated energy demand model for the combined residential and commercial sector to estimate aggregate demand and demands for individual fuels (electricity, natural gas, and petroleum products). This integrated demand model can be used to analyze a wider range of energy issues than the demand models with which we previously estimated for individual fuels.[44] For example, the present model is capable of analyzing the impact of changes in a particular fuel price on (1) total energy demand and (2) the demand for that particular fuel in the residential and commercial sectors. In addition, we developed another model dealing with space heating energy demand that estimates important elasticities of both utilization rates and saturations for electricity, natural gas, and petroleum products. This model is being used in the residential engineering-economic modeling work described in the preceding section. Both studies were supported by the ERDA Division of Buildings and Community Systems.

Our second area of focus is aimed at developing a regional model for forecasting electricity demand by sector and state. Regional models are necessary because regional forecasts of electricity demand are essential for evaluating the future need for additional electricity generating capacity in a particular region or service area; and a model developed at the regional level can best capture regional variation in the demand structure and thus can provide more reliable forecasts than a model developed for the United States as a whole. This work is sponsored by the NRC. These regional models have been and will be continuously used by the staff of NRC and several national laboratories to prepare the "need for facility" sections of environmental impact statements for nuclear power plants.

Aggregate and end-use energy demand studies for the United States. *Aggregate energy demand.*[45] The study deals with the estimation of energy demand for the combined residential and commercial sector in the United States. The demand components include space heating, air conditioning, cooking, clothes drying, and water heating, but exclude the transportation use of energy. The model consists of two parts: (1) the determination of aggregate end-use demand for energy (Q) as a function of the weighted energy price (P), personal income (I), and the numbers of heating and cooling degree-days; and (2) the estimation of market-shares for electricity, natural gas,

40. Group leader.
41. Consultant, University of Florida.
42. Computer Sciences Division.
43. GLCA–Oak Ridge Science Semester students, Denison University, Ohio.
44. G. S. Gill et al., *Energy Div. Annu. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 40–51.
45. W. S. Chern, *Energy Demand and Interfuel Substitution in the Combined Residential and Commercial Sector*, ORNL-TM-5557 (September 1976).

and petroleum products as functions of personal incomes, degree-days, and the prices of electricity (P_1), natural gas (P_2), and oil (P_3). The model was estimated by using data from 48 states for 1971 and 1972.[46] Relevant elasticities were computed at sample means. Since the model was estimated from cross-sectional data, the resulting elasticities are generally interpreted as long-run elasticities.

The aggregate-demand elasticities were computed to be −0.70 with respect to energy price (P) and 0.47 with respect to income (I). The estimated price elasticity is below unity, implying that an increase in total consumer expenditure on energy could be expected as the price of energy rises. Furthermore, since the estimated income elasticity is well below unity, raising incomes would not result in a proportional rise in end-use energy demand in the residential and commercial sectors.

Another set of demand elasticities was estimated for the demands for individual fuels. The estimated price elasticities for the demands for electricity, natural gas, and petroleum products are −1.46, −1.50, and −1.60 respectively. These results indicate that the demands for individual fuels are all elastic with respect to their own prices in the long run. In the case of electricity, one obvious implication is that a substantial reduction in electricity demand growth may be anticipated as a result of increases in the real price of electricity. Of course, changes in electricity prices are often accompanied by changes in the prices of natural gas and oil, thus resulting in interfuel substitutions. The impact of these interfuel substitutions could be evaluated by the estimated demand elasticities with respect to the prices of substitutes. The results show that there are significant interfuel substitutions, especially between natural gas and petroleum products.

From the standpoint of conserving energy, it is of great interest to know the aggregate-demand elasticities with respect to individual fuel prices. For comparison, the model was extended to deal with demand for primary energy (i.e., energy sources used to produce fuels for end use). Let q_i be the total amount of fuel i consumed at the point of end use in the residential and commercial sectors. To allow for a proper comparison of the fuels having different end-use efficiencies, we define net end-use energy consumption, Q_i, as $Q_i = q_i \eta_i$, where η_i is the end-use efficiency factor for fuel i. Total primary energy, M, is then defined as $M = \Sigma Q_i(e_i/\eta_i)$, where e_i is the input−output coefficient measuring the amount of primary energy required to produce a unit of fuel i for end use.

Electricity is more efficient at the point of end use than are natural gas and petroleum products. It is assumed that the end-use efficiency factor (η_i) is 1.0 for electricity (which does not allow for potential gain from increased use of heat pumps in the future) and 0.55 and 0.50 for natural gas and petroleum products respectively. However, Robert Herendeen and Clark Bullard of the University of Illinois at Urbana-Champaign have estimated that it takes 3.8 Btu of primary energy[47] to produce 1 Btu of electricity, whereas it takes 1.1 and 1.2 Btu of primary energy[48] to produce 1 Btu of natural gas and petroleum products respectively. Thus, when the direct and indirect use of energy in producing end-use fuels is accounted for, electricity is shown to be the least efficient fuel for many major end uses.

The estimated price elasticities for aggregate primary and end-use energy are compared in Table 4.4. Although the electricity price elasticity (−0.33) is much higher than the natural gas and oil price elasticities for primary energy demand, it is the lowest (−0.05) of the three price elasticities for end-use energy demand. The implication is that raising the prices of oil and natural gas has greater potential for conservation of end-use energy than raising electricity prices. However, when the

46. Data were obtained from the U.S. Bureau of Mines, Edison Electric Institute, American Gas Association, National Climatic Center, and U.S Department of Commerce.

47. This factor does not take into account the contribution from hydroelectric sources that require no fuel.

48. These efficiencies do not include allowances for present or future import of oil or gas or for production of oil or gas from coal or shale, in which case the value would be about 1.7.

Table 4.4. Comparison of estimated price elasticities for total residential and commercial end-use and primary energy

Type of demand	Electricity price	Gas price	Oil price
End-use energy	−0.054	−0.264	−0.270
Primary energy	−0.330	−0.157	−0.224

primary sources of energy are considered for the residential and commercial sector, raising electricity prices is more effective for energy conservation than raising the prices of natural gas and petroleum products. However, this conclusion says nothing about the type of primary source energy saved by raising electricity prices. Thus, since most electricity is produced from coal, raising electricity prices may be less effective in reducing demands for oil and gas than raising oil and gas prices, even for the residential and commercial sectors.

Space heating demand for energy. Space heating is the most important energy end use in the residential sector. In 1970, space heating accounted for 56% of the total energy used by households. The purpose of this study is to develop a model of space heating demand in the residential sector for the major fuels, that is, electricity, natural gas, and petroleum products. The model consists of two parts: The first part determines the average usage per heating customer, and the second deals with the proportion of occupied housing units using a particular fuel for space heating. Specifically, the model embodies several significant features: (1) estimates of both energy usage and fuel choice for space heating; (2) the inclusion of appliance prices as explanatory variables in the fuel-choice model; (3) marginal prices of electricity rather than the commonly used average price for both the usage and the fuel-choice equations; and (4) the lack of a rigid constraint in the fuel-choice model that cross-price saturation elasticities with respect to a given fuel price be identical. The model was estimated from data collected from 48 states in 1970.

The model was used to estimate usage and saturation elasticities (Table 4.5).[49] The usage elasticity measures the extent to which the average heating usage of a particular fuel responds to changes in its price. On the other hand, the saturation elasticity is defined as the percentage change in the proportion of housing units that use a particular fuel for heating that results from a 1% change in fuel prices. The results show that the price elasticity of usage for all three fuels is near unity. In all cases, the estimated usage elasticities are smaller than the own-price elasticities of saturation. Although there exists no other estimate of usage elasticity with which to compare our results, our estimates of saturation elasticities are generally within the range estimated by other studies.[50-52]

The sum of usage and saturation elasticities gives the total elasticity for space heating demand. The total own-price elasticity for natural gas is −1.89, and the total own-price elasticity for petroleum products is −2.05. For electricity, the total own-price elasticity appears to be much larger than that estimated for the aggregate demand for all purposes. These results, therefore, imply that space heating demand for electricity is much more sensitive to price changes than other end-use

49. W. S. Chern and W. W. Lin, "Energy Demand for Space Heating: An Econometric Analysis," to be published in the proceedings of the American Statistical Association Annual Meeting, Boston, Mass., Aug. 23–26, 1976.

50. M. Baughman and P. Joskow, *Land Econ.* 51, 41–69 (1975).

51. W. W. Lin, Eric Hirst, and Steve Cohn, *Fuel Choices in the Household Sector*, ORNL CON-3 (October 1976).

52. J. W. Wilson, *Q. Rev. Econ. Bus.* 1, 7–27 (1971).

Table 4.5. Estimated usage and saturation elasticities for space heating[a]

Type of fuel	Electricity price	Gas price	Oil price
	Usage elasticities		
Electricity	−0.95	b	b
Natural gas	b	−0.81	b
Petroleum products	b	b	−0.98
	Saturation elasticities		
Electricity	−3.59	0.85	1.78
Natural gas	0.46	−1.08	0.28
Petroleum products	0.24	1.78	−1.07

[a]Computed at sample means.
[b]No cross price elasticities are estimated, because they are identically zero

demands of electricity. This sensitivity results perhaps from the high substitutability of other fuels for the space heating.

Regional forecasting model for electric energy. The principal objectives of this work are to (1) quantify the relationship between electricity demand and its causal factors, (2) provide a credible computer-based model that can be used to forecast demand for electric energy by end-use sector on a state basis, (3) develop alternative scenarios reflecting potential policy strategies and actions, and (4) provide estimates of future power needs for environmental impact statements related to nuclear power plants.

Structure of the model. To cope with the problems associated with the declining block rate structure and the interdependence of electricity price and prices of natural gas and oil, we have developed a simultaneous equation system in which both electricity demand and price are endogenously determined. Mathematically, the demand equation for a given state i and a given sector j can be written as

$$E_{ijt} = \alpha_{ij} + (1 - \lambda_j)E_{ij,t-1} + \beta_j P_{ijt} + \gamma A_{ijt} + \mu_{ijt} \,. \tag{9}$$

where

t = time period,
E = quantity of the electricity sale,
P = average price of electricity,
A = vector of exogenous variables,
μ = error term.

Also, α and β are unknown coefficients and γ is a vector of coefficients to be estimated. Equation (9) is dynamic, as derived from the partial adjustment model, where λ is known as the adjustment coefficient.

The average price of electricity is theoretically determined by the relevant rate schedule and the level of consumption. Historical data on rate schedules are incomplete and still not in a usable form.

However, the level and slope of the rate schedule are presumably related to the underlying cost structure. Therefore, we assume

$$P_{qt} = \delta_q + \epsilon_j E_{qt} + \theta_j B_{qt} + v_{qt} \ . \qquad (10)$$

where B is a vector of exogenous variables, v is the error term, δ and ϵ are coefficients, and θ is a vector of coefficients to be estimated.

Relevant exogenous variables differ from sector to sector as detailed in Table 4.6. Most of the exogenous variables listed in Table 4.6 should be self-explanatory. In the residential sector, the ratio of population to number of residential customers is used to measure the impact of household size. In the commercial sector, per-capita personal income and population are used to measure indirectly the level of commercial activities. The dummy variables for states are included because the models are estimated for the region while allowing the constant term to vary from state to state. The number of natural gas customers is included to measure the impact of the availability of natural gas.

Relevant exogenous variables in the price equation include (1) costs of fuels used by electric utilities; (2) costs of operation, maintenance, capital depreciation, and taxes in generation, transmission, and distribution; (3) capacity utilization; and (4) state dummies.

Equations (9) and (10) are structural equations that are simultaneously estimated for each sector by the two-stage least-squares (2SLS) procedure. For forecasting, it is more efficient to use the reduced-form equations, expressing endogenous variables as a function of lagged endogenous and all exogenous variables. These reduced-form equations are derived from the structural equations.

Estimated electricity demand functions for the South Atlantic Division. To gain a greater efficiency in estimation, we estimated the structural equations for each of the residential, commercial, and industrial sectors by census division. The model for the South Atlantic Division has been estimated by the 2SLS procedure using state data for 1955–1974.

Table 4.6. Exogenous variables in the demand equation by sector[a]

Residential	Commercial	Industrial
Price of natural gas	Price of natural gas	Price of natural gas
No. 2 oil price	No. 2 oil price	No. 6 oil price
Per-capita personal income	Per-capita personal income	Coal price
Number of customers	Population	Gross National Product
Ratio of population to number of customers	Heating degree-days	Value added in manufacturing
Heating degree-days	Average July mean temperature	Wage rates of manufacturing employees
Average July mean temperature	Number of natural gas customers	Number of natural gas customers
Number of natural gas customers	State dummies	State dummies
State dummies		

[a]All price, income, and value variables are expressed in real terms.

Only the highlights of the regression results in terms of the estimates of long-run demand elasticities are presented in Table 4.7.[53] We have confirmed in the econometric analysis that electricity demands in all three sectors are, in general, sensitive to economic, demographic, and climatic factors. The reduced-form equations, as derived from the structural equations, were used to forecast electricity demand and price during the sample period. The computed mean-square percentage forecasting errors are all less than 5%, indicating a very good performance of the model.

Preliminary forecasts of electricity demand for the South Atlantic Division: 1975–1990. The estimated econometric model for the South Atlantic Division has been used to forecast electricity demand for each of the seven states in this division. To make forecasts, we must estimate the future values of all exogenous variables in the model. The projected growth rates of population, residential customers, real per-capita incomes, value added in manufacturing, and price and income deflators are all based on the projection made by the Bureau of Economic Analysis (BEA)[54] and other public sources.[55,56]

We developed three scenarios for fuel prices and costs of electricity generation, transmission, and distribution. In the *base case*, we used Hudson and Jorgenson's projections[57] of the prices of natural gas, refined petroleum products, and coal. Hudson and Jorgenson project that the price of natural gas in current dollars will increase by 7.1% annually for the period 1974–1980, 5.9% for 1980–1985, and 6.5% for 1985–1990; oil price will increase by 5.3% annually for the period 1974–1980, 6.2% for 1980–1985, and 5.8% for 1985–1990; and coal price will increase by 7.4% for the period 1974–1980, 6.9% for 1980–1985, and 6.0% for 1985–1990. In the *low-price case*, the real prices of fuels and the real costs of electricity generation, transmission, and distribution are assumed to remain at the 1974 level. In the *high-price case*, we assume that the growth rates of all price and cost components in the base case will be doubled in real terms.

53. W. S. Chern et al., "Future Growth in Electric Power Demand in the South Atlantic Region," paper to be published in the proceedings of the Third Annual UMR-MEC Conference on Energy, University of Missouri–Rolla, Oct. 12–14, 1976.

54. U.S. Bureau of Economic Analysis, *Survey of Current Business* (April 1974).

55. National Planning Association, *Regional Economic Projections: 1960–85*, Report 73-R-1, Washington, D.C. (1973).

56. Federal Energy Administration, *National Energy Outlook* (February 1976).

57. E. A. Hudson and D. W. Jorgenson, *Bell J. Econ. Manage. Sci.* 5, 461–514 (1974).

Table 4.7. Estimates of long-run demand elasticities—South Atlantic Division

Sector	Fuel price			Consumer income	Number of residential customers	Population	Heating degree-days	July mean temperature	Value added
	Electricity	Natural gas	Oil						
Residential	−1.20	0.11		0.76	0.96		0.19	0.60	
Commercial	−0.85	0.14		1.38		1.11		0.19	
Industrial	−1.75	0.15	0.22						0.81

Projected annual growth rates for the period 1974–1990 are presented in Table 4.8. On the basis of these preliminary forecasts, we offer the following conclusions.

1. Electricity demand will continue to grow in all sectors and in all states in the South Atlantic Division. However, the rates of growth will be considerably lower than those observed in the 1950s and 1960s. As forecast in our base case, the total electricity demand in this region will grow at a rate of 6.2% per year for the period 1974–1990, as compared with 9.7% for 1955–1970 and 8.6% for 1970–1973.
2. The forecast rates of growth in electricity demand vary considerably from state to state: Florida has the highest rate and West Virginia has the lowest. These variations suggest that the forecasts at the national level should not be used as the basis for making energy policies at the regional or state levels.
3. Electricity demand is found to be sensitive to changes in fuel prices and costs of generating, transmitting, and distributing electricity. The results show that, for the South Atlantic Division, doubling the growth rates for all fuel prices and electricity costs in real terms will reduce total electricity demand by 14% as compared with the base case.

Table 4.8. Forecasts of annual growth rates of electricity demand by sector and state, South Atlantic Division, 1974–1990

State	Case[a]	Sector: Residential	Sector: Commercial	Sector: Industrial	Total
Delaware	B	5.0	4.8	3.0	4.0
	L	5.8	5.4	3.9	4.7
	H	4.2	4.2	2.2	3.2
Maryland[b]	B	5.2	6.8	2.0	4.8
	L	6.1	7.5	2.9	5.6
	H	4.3	6.1	1.2	4.0
Virginia	B	6.1	7.2	4.3	6.1
	L	7.1	8.0	5.2	6.9
	H	5.2	6.5	3.5	5.2
West Virginia	B	4.1	4.6	4.2	4.2
	L	5.2	5.4	5.6	5.5
	H	3.1	3.8	2.8	3.1
North & South Carolina	B	6.7	6.7	6.7	6.7
	L	8.1	7.7	8.1	8.0
	H	5.3	5.6	5.4	5.4
Georgia	B	6.5	6.6	5.5	6.2
	L	7.1	7.3	6.7	7.0
	H	5.2	5.9	4.2	5.1
Florida	B	7.4	8.4	5.6	7.5
	L	8.2	9.0	6.4	8.2
	H	6.7	7.9	4.9	6.8
Regional total	B	6.6	7.2	5.3	6.4
	L	7.5	7.9	6.5	7.3
	H	5.6	6.5	4.2	5.4

[a] B = base case, L = low-price case, and H = high-price case.
[b] Includes the District of Columbia.

4. Electricity demand, particularly in the residential and commercial sectors, will grow at a faster rate for the South Atlantic Division than for the nation as a whole. This higher growth rate is a result of higher growth rates of population and number of residential customers as projected. We recognize that these projections do not include many factors such as the potential increases in the use of solar heating and non-price-induced conservation or policy impacts which could drastically change our estimates of future demand for electricity.

Future research. In our continuing effort, we will develop a similar regional model for the other eight census divisions. In addition, we will carefully validate our models further and perform a broader sensitivity analysis on other exogenous variables such as changes in population growth and climatic condition. Furthermore, we will attempt to incorporate additional features in our forecasting model to deal with the impacts of natural gas availability and energy conservation measures.

4.4 COMMUNITY UTILITY SYSTEMS PROGRAMS

W. R. Mixon

W. J. Boegly, Jr.[58]	J. O. Kolb
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Our activities in community utility systems programs began in 1972 with participation in the multiagency MIUS program under the direction of HUD. The MIUS concept uses a relatively small plant located within a housing development or community to provide electricity, space and water heating, space cooling, solid and liquid waste treatment, and potable water. Analytical efforts to date indicate that MIUS has the potential to meet most of the program goals.

1. Fuel consumption is reduced by using waste heat from electrical generation and energy recovered from solid waste to provide space heating and cooling and water heating.
2. Natural resources conservation includes the reuse of treated liquid waste for nonpotable purposes such as irrigation and cooling water.
3. Technology to minimize adverse environmental impact of onsite systems is currently available; problems related to thermal pollution, disposal of solid waste, plant siting, and the use of long transmission lines can be eliminated.
4. MIUS can be installed near appropriate users in phase with actual demands of community development or renewal; thus, the impact of local restrictions on housing construction due to a lack of utility service (primarily sewage treatment) can be eliminated.
5. The total cost to the nation for utility services, on a marginal cost basis, can be reduced for large multi-family developments, especially if conventional utilities would require long water or sewage transmission lines.

To serve the needs of any specific community, the MIUS concept allows considerable flexibility in the services to be included, the type of ownership, and the relationship to conventional utility systems.

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58. Environmental Sciences Division.
59. Consultant.

MIUS is not proposed as a competitor or a complete substitute for conventional utilities, but there are a significant number of applications for which MIUS would be of public benefit and should be considered as an option.

During the past year, other agencies have initiated programs to evaluate, develop, and demonstrate decentralized community energy systems because of their potential for energy conservation. The ERDA programs in which we have become involved include Advanced Technology-Mix Energy Systems (ATMES), Coal-Using Integrated Community Energy Systems (ICES), and District Heating from Nuclear Central Station Plants. In general, the ERDA programs extended the MIUS concept to include a wider range of community types and sizes, emerging and advanced technologies, and more emphasis on interconnection with the conventional electric utility grid. Expertise in MIUS technologies has also led to participation in the analysis of thermal storage for the Office of Technology Assessment (OTA). The following subsections describe Energy Division participation and progress in each program.

4.4.1 Modular Integrated Utility Systems

The MIUS program is aimed toward the development, demonstration, evaluation, and ultimate widespread application of a new option for providing community utility services. If plants are located near appropriate consumers and utility subsystems are integrated, waste heat from electrical generation, and possibly from solid waste incineration, can be economically used for domestic heating and cooling. Reduced fuel consumption is a critical national goal, but developing communities also face increasingly serious problems related to the adequate treatment and disposal of liquid and solid wastes which must not be neglected. Many communities, faced with the task of upgrading existing waste disposal facilities and the growing need for new environmentally acceptable capacity, have imposed building moratoriums. The MIUS concept addresses these problems by integrating solid and liquid waste treatment with the electric thermal subsystems.

To date, most activities in the MIUS program have been part of the first of three major phases. Phase I includes the evaluation, development, and testing of major components and subsystems; testing of limited subsystem integration techniques; and assessment of the MIUS concept. The ORNL responsibilities in phase I have consisted primarily of evaluating major component and subsystem technologies, providing conceptual design and systems analysis, and assessing the consequences of widespread application. Also included are detailed design activities for a coal-fired MIUS test unit, described separately in Chap. 5.

During 1976, phase I activities were essentially completed by the publication of technology evaluations and system analyses. Phase II the demonstration and evaluation of MIUS in full-scale applications was formally initiated by site selection and the start of a conceptual design for a MIUS demonstration. The ORNL responsibilities in phase II include system design review, preparation of an environmental statement, and completion of a followup evaluation of actual environmental effects. The objective of phase III is to achieve implementation of the MIUS concept by the private sector.

Technology evaluations and systems analysis. Major components and subsystems of utility technologies were evaluated with respect to possible applicability to the MIUS concept. Emphasis was put on technologies that could be used on a development site and that were in the appropriate size range to serve communities of about 100 to 3000 dwelling units. In several cases, extension of the analysis by comparing candidate MIUS technologies with the more conventional municipal-sized systems was appropriate. Technologies were evaluated with respect to status of development, capital and operating costs, consumption of resources, and possibilities of integration with other MIUS subsystems. The last 5 of the 14 technology evaluation and system analysis studies planned for publication were published during 1976, and major conclusions are described below.

Initial MIUS and conventional systems comparisons. Reference 60 presents the results of a preliminary study comparing the economics, fuel requirements, and environmental impacts of MIUS and conventional energy systems. The primary analytical effort was placed on determining the costs and energy requirements associated with several methods of supplying electricity, space heating, domestic hot water, and air-conditioning services to hypothetical garden and high-rise apartment models; no associated commercial or industrial installations were considered. The study was also limited to a site having a climate similar to that of Philadelphia, Pennsylvania. A total of eleven cases, or models, were considered, and all models were evaluated on the basis of present (early 1972) marginal cost and fuel energy requirements.

The objective of this first comparative analysis was to provide preliminary information on feasibility of the MIUS concept and to help determine requirements for additional modeling and analyses. Results indicated that primary fuel requirements of MIUS were from 22 to 45% less than those of conventional systems, depending on the type of conventional system used for comparison, if the overall efficiency of conventional electric generation, transmission, and distribution is 30%. Based on a marginal cost analysis, the annual costs of services from MIUS were found to be in about the same range as those from most conventional systems.

Near-term MIUS concepts. The main purposes of this analysis[61] were to (1) illustrate the possible and recommended options for incorporating commercially available technologies into a typical MIUS and (2) describe the possible methods of integrating utilities. Examples were discussed for all community services—power generation, space heating and cooling, domestic hot water, potable water, fire protection water, and liquid and solid waste treatment and disposal. The final selection of the various subsystems used in a MIUS will depend on many factors such as climate, population density, total population, consumer mix and demands, local geology and topography, and local resources such as water, natural gas, oil, and land; therefore, no one illustrated configuration could be considered an optimum for a particular installation. Reference 61 represents a good introduction to MIUS concepts using current technology.

MIUS and conventional systems comparison for an existing development. The purpose of this study[62] was to evaluate a MIUS in the realistic framework of an existing housing development having a conventional utility system. Previous model studies have used hypothetical layouts that simplified analyses but that were not representative of real situations. In this study, an existing housing development, consisting of the buildings listed in Table 4.9, was selected, and the conventional utility system was analytically replaced by a MIUS using the same utility service requirements. Electrical heating and cooling loads, based on building characteristics, occupancy, and weather, were also determined analytically. Lifestyles of the inhabitants were not changed; only the methods of providing the same utility services were altered.

The evaluation was based on a MIUS configuration in which no effort was made to optimize the utility system, although some variations were studied. The study was not intended to represent the best possible application of a MIUS, but rather to apply a representative MIUS model to one existing site. The technologies used are representative of commercially available components as of about mid-1973.

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60. Garland Samuels et al., *MIUS Systems Analysis—Initial Comparisons of Modular-Sized Integrated Utility Systems and Conventional Systems*, ORNL/HUD/MIUS-6 (June 1976).

61. Garland Samuels and W. J. Boegly, *MIUS Technology Evaluation—Preliminary Subsystem Recommendations for Near-Term Concepts*, ORNL/HUD/MIUS-17 (May 1976).

62. E. C. Hise et al., *MIUS Systems Analysis—Comparison of MIUS and Conventional Utility Systems for an Existing Development*, ORNL/HUD/MIUS-20 (June 1976).

Table 4.9. Description of buildings in the Walden development model used for analysis

Building type	Number of stories	Number of buildings	Total enclosed floor area (m^2)	Total number of dwelling units
Garden apartment	3	4	45,400	410
Townhouses		63	9,100	63
Motel	4	1	8,400	212
Restaurant, bar	1	1	100	
Office	5	1	7,000	

and the climate is that of Chicago, Illinois. The criteria used for evaluation were fuel consumption, the dominant environmental impacts, and costs to the country (i.e., the present marginal cost of providing incremental services as of January 1972).

Results indicate that MIUS would require about 17% less fuel than would the conventional utility systems (including fuel for conventional electric generation). Onsite incineration of solid waste with heat recovery in MIUS was not found to have a significant effect on fuel savings. Economic analyses using present marginal cost for incremental services (as of January 1972) indicate that to construct, own, and operate a MIUS costs more than would be required to serve the same development conventionally. The total net difference in annual owning and operating costs was about $180 per 100 m² of total enclosed floor area. However, the economic advantages of allowing development to proceed in areas where utilities services are limited were not considered.

Environmental effects of using MIUS were an increase in carbon monoxide, hydrocarbons, and nitrous oxide emissions, but a reduction in sulfur dioxide and particulate emissions. In any case, MIUS use would not exceed Federal Air Quality Standards, and the local air quality would not be markedly changed by MIUS use from that when conventional utilities were used. Impact due to onsite liquid waste treatment results mainly from the release of effluent at a different point from that of the large conventional system since the degree of treatment obtained by small plants is the same as, or higher than, that obtained by larger plants.

Thermal energy conveyance. Thermal energy produced by a MIUS can be distributed at moderate temperatures, and low-pressure steam or water is most adaptable as an energy transfer medium. Reference 63 discusses the types, cost, and performance of several types of conduits for thermal energy conveyance. Conduits applicable to water conveyance of thermal energy produced in a MIUS were evaluated from data on characteristics and economic factors related to district heating and cooling systems for housing developments.

Many different types of conduit and methods of construction are used in existing thermal energy conveyance systems. Types that are most prevalent, both in older systems that are still in operation and in more recent installations that include improvements in methods and materials, are illustrated and discussed. Information on long-term performance is included, where available, from inspection reports on various types of conduit in existing systems. The conduit was treated in much greater depth than the other aspects of a thermal energy conveyance system, and special emphasis is placed on estimates of the installed cost of several commercially available types of conduit.

63. J. L. Meador, *MIUS Technology Evaluation — Thermal Energy Conveyance*, ORNL-HUD-MIUS-22 (May 1976).

Effects of MIUS thermal energy storage (TES) and incinerator options. Reference 64 is one of a series of evaluations undertaken to determine the applicability of various currently available technologies to MIUS. We completed a parametric systems analysis that illustrates the economics of integrating TES in a MIUS model for cases with and without solid waste incineration and waste heat recovery. Annual and seasonal energy demand profiles are included to show that the time when waste heat is available does not coincide with the time when it can be used. Results are based on hypothetical consumer and MIUS models that have been used in previous analyses at ORNL—a 720-unit garden apartment complex, Philadelphia climate, and a hypothetical MIUS design providing complete utility services.

The analysis indicates that a significant savings in fuel consumption can accrue from the storage of excess waste heat for subsequent use during periods when the available heat from the engine-generators is not adequate to satisfy the demand. Use of the heat energy available from the incineration of solid wastes can result in a fuel savings of up to 5% per year if a water storage vessel of 470-m^3 capacity is used. A vessel of this size is capable of storing 42 GJ of heat energy from an initial temperature of 70° C to a final temperature of 93° C. The breakeven cost of the fuel (natural gas), at which the value of the fuel saved equals the estimated annual owning cost of the TES facility, was shown to be of the order of $7.95 per 100 m^3.

Three possible incinerator options were analyzed to determine the net annual costs of each for disposal of the 1.62 Gg of solid wastes per year. The analyses indicate that, up to a natural gas cost of about $8.83 per 100 m^3, the lowest cost option was for the case of incineration with no heat recovery and no TES. However, if the fuel cost exceeds $8.83 per 100 m^3, incineration with heat recovery and 42 GJ of TES should be considered. These conclusions hold equally for incineration with no supplemental fuel and with 20% supplemental fuel requirements.

Environmental evaluation of MIUS demonstration. In April 1976, the issuance of a grant for conceptual and preliminary MIUS designs to serve a part of the new town of St. Charles, Maryland, was publicly announced, and MIUS program activities in the demonstration phase were formally initiated. Energy Division participation includes (1) review and analysis of design concepts prepared by the developer and his contractors, (2) preparation of an environmental statement before construction, and (3) completion of a followup evaluation of actual environmental and community effects from MIUS construction and operation.

During the early stages of MIUS concept design, efforts concentrated on familiarization with the demonstration site and the collection and analysis of published documents and other available data describing the environment in and around St. Charles. An extensive site visit, which included inspections of St. Charles facilities and the surrounding area, discussions with various State and local government officials, and visits to local educational institutions involved in ongoing environmental research efforts at St. Charles, was completed in July 1976.

One aspect of the environmental evaluation task is the identification of potential MIUS impacts to ensure that pre- and postconstruction monitoring is adequate. The identification of impacts and overall planning of onsite monitoring requirements proceeded as conceptual design information became available. The major potential environmental impacts are expected to be (1) the effects of engine exhaust and incinerator emissions on air quality and (2) the disposal of treated liquid waste.

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64. C. L. Segaser, *MIUS Systems Analysis—The Effects of Thermal Energy Storage and Solid Waste Incineration Options on MIUS Cost and Fuel Consumption*, ORNL/HUD/MIUS-26 (July 1976).

4.4.2 Advanced Technology-Mix Energy Systems

In March 1976 ORNL initiated work on the technology survey task of the ATMES program. The program is funded by ERDA through Argonne National Laboratory, the leading lab for community systems programs.

The ATMES program is concerned with conserving energy and scarce fuels by introducing new methods of energy supply to American communities. A major objective is to translate emerging technologies from the research stage to a meaningful level of commercialization in real communities. The ATMES program is developing innovative ways of combining current and advanced technologies into integrated energy-conserving systems that could furnish any or all of the energy-using services for a community. These systems typically would consist of the equipment and processes needed to provide such services as electricity, space heating and cooling, water heating, solid and liquid waste treatment, and intra- and interbuilding transportation, material transfer, and communications. The key goals of the ATMES program are to identify, evaluate, develop, demonstrate, and deploy advanced energy systems that will optimally meet the needs of certain types of communities.

The technology survey task consists of three subtasks as discussed in the following subsections.

Subtask 1: Selection and evaluation criteria. The objective of subtask 1 is to develop criteria for the systematic selection and evaluation of major components, subsystems, and concepts to be considered in the synthesis of community systems. Technologies considered were those applicable to three community sizes, as characterized by electrical requirements of 2, 20, and 100 MW(e). Initially, existing community characterizations and conceptual system designs from the MIUS program provided inputs. At a later stage, continuing inputs are expected from the ATMES community characterization and conceptual design tasks.

Criteria used to select technologies for further consideration included such factors as the functional requirements for use in community systems, degree of integration with other candidate components and subsystems, and size or capacity as based on community size and reliability requirements for multiple units. Selected technologies were categorized according to three time frames of development: current technology that is commercially available, near-term technology considered ready for demonstration by 1980, and long-term concepts that may not be proven feasible until after 1980.

Evaluation criteria consist of technical performance, economic, and other data required to simulate and evaluate the use of a particular technology in a complete community system. Evaluation criteria include, where applicable, such factors as (1) type of fuel or other resource required and efficiency of its use, (2) status of development and potential for improvement, (3) reliability and operator requirements, (4) engineering performance characteristics, (5) major manufacturers and retailers, (6) capital, maintenance, and operating costs, (7) required site characteristics, (8) social and economic problems, and (9) effluents and other environmental impacts.

Subtask 1 was essentially completed in FY 1976. A draft selection and evaluation criteria report was submitted for program review and later revised in response to review comments. Additional submittals included a listing of organizations working on selected advanced technologies and a rating method used to prioritize the generic technologies to be evaluated.

Subtask 2: Technology data collection. The objective of subtask 2 was to collect and catalog available data and information pertinent to those technologies having potential application to ATMES. This subtask includes a survey of literature and discussion with manufacturers, R&D organizations, architect-engineers, etc., to identify and list specific technologies with respect to the three time frames of interest.

A prioritized listing of technologies to be evaluated, by time frame and functional category, was completed; functional categories included (1) prime movers, (2) electric generators, (3) heat recovery equipment, (4) thermal distribution, (5) central heating components, (6) central chiller components, (7) individual HVAC and water heating, (8) thermal and electric storage, (9) solid waste treatment, (10) liquid waste treatment, and (11) heat rejection. Data collection activities of this subtask will continue to provide input to subtask 3.

Subtask 3: Technology evaluation and characterization. Included in subtask 3 was the evaluation of candidate component and subsystem technologies with respect to applicability in community systems by fully characterizing the selected technologies with respect to stat. of development, cost, performance, emissions, use of resources, and other evaluation criteria required to support other program tasks.

Work in subtask 3 first concentrated on currently available technologies. Since a large data base currently exists for these technologies, efforts required were primarily to update existing data and to account for recent developments.

Summary. The output of the technology survey task consists of technology evaluation data reports, which include a brief technical summary in the form of data sheets plus thorough documentation of backup information that is suitable for publication as a topical report.

A draft technology evaluation of unitary air-to-air heat pumps was submitted on June 25 to illustrate the proposed data sheet format and to provide the initial distr bution of current technology data. Through September 1976, additional draft evaluations of diesel-er gine prime movers and water-to-air heat pumps were completed; evaluations of gas and dual-fuel prime movers, central absorption chillers, solid waste pyrolysis, and revisions to air-to-air heat pump and diesel engine evaluations in response to review comments were near completion. Evaluations of gas turbines, electric generators, heat recovery equipment, central heating boilers, and TES are in progress. This task is proposed to continue through FY 1977.

4.4.3 District Heating from Nuclear Central Station Plants

A technology evaluation and a cost analysis of piping systems for transport and distribution of thermal energy and for end-use equipment within apartment buildings were completed. This effort was our contribution to a joint study with the Engineering Technology Division to determine the economic feasibility of using heat from central station nuclear power plants to supply thermal energy to large industries and residential-commercial developments. The scope of this study included the cross-country transport of moderate-temperature (up to 215°C) steam or hot water over distances of up to 24 km to an industrial complex or to the point of connection with a distribution system for a residential development. Transport conduits were sized to supply up to 10^3 kg/sec of steam for industrial process heat or 293 Mw(t) to meet the peak thermal demand of the residential development model.

The energy transport capability of high-temperature water (HTW) has been compared with that of intermediate-pressure steam for many years. Steam systems predominate in big cities of the United States, whereas HTW systems are invariably proposed for new and upgraded systems in European countries. Comparisons of maximum transport distances for steam and HTW, based on maximum velocities and other design parameters used and recommended for operating systems in the United States, and consideration of operation and maintenance problems tend to favor the use of HTW. For large-diameter (0.6- to 1.5-m) conduits, the maximum transport distance of HTW is not limited by pressure drop to the degree that normally occurs with medium-pressure (2.4 MPa) steam. Our comparisons of costs and the thermal energy transport capabilities of some steam and condensate vs

HTW systems are being completed. The data will compare installed cost per unit of energy vs the maximum distance of transport. When completed, the results will also be included in a paper for the ATMES evaluations.

For this study, a regular array of garden apartment buildings that has been used in previous MIUS program analyses was considered to be representative of the magnitude and distribution of thermal demands in residential-commercial developments. Each apartment building had six apartments per floor, and the reference block consisted of 240 two-story buildings (2880 apartments). The effect of housing density on piping cost was determined by considering one- and three-story buildings, and the effect of climate was determined by considering a range of thermal energy demands. Table 4.10 shows estimated costs for the HTW and chilled water distribution systems for the various conditions considered. These results indicate that distribution system costs are not a strong function of peak energy demand or housing density. A 43% reduction in heating demand reduces costs by about 8 to 16%, and a 50% increase in housing density (from two- to three-story buildings) decreases costs by about 22 to 28% for HTW and 14 to 20% for chilled water. The largest cost change, a 76% increase, resulted from a 50% reduction in housing density (from two- to one-story buildings).

Costs for HTW and chilled water distribution systems were also estimated for up to twelve interconnected reference blocks. It was found that the capital cost per apartment increased as the number of apartments served increased; that is, no economy of scale was evident for up to 35,000 apartments.

Another capital cost element considered was for equipment within the apartment buildings to provide space heating and cooling and water heating. Costs were estimated for three types of building service equipment: (1) district systems, consisting of two-pipe hot or chilled water piping, fan coil units, and a central building heat exchanger and storage tank for potable hot water; (2) central building systems, consisting of a central boiler in each building for space and water heating plus electric air conditioner units in each apartment; and (3) individual apartment systems, consisting of an individual electric furnace, a water heater, and an air conditioner in each apartment.

Table 4.10. Cost estimates for HTW and chilled water distribution systems for the reference block of 240 apartment buildings

Peak energy demand (MJ/apt)	Distribution system cost ($/apt) for building heights of		
	One story	Two stories	Three stories
HTW, ΔT = 56°C, 149°C supply			
17.9		358	261
25.3		385	286
31.6	702	398	311
HTW, ΔT = 111°C, 177°C supply			
31.6		360	259
Chilled water, ΔT = 8.3°C			
15.8		236	187
18.5		253	206
21.1		263	225

Table 4.11. Comparison of capital costs for district and conventional building service equipment for space heating and cooling and water heating

System type	Cost for two-story building ($/apt)	Remarks
District piping	1800	16% more for one story, 7% less for three stories
Central building	2460	8% more for one story, 2% less for three stories
Individual apartment equipment	1480	Not sensitive to building size

The resulting cost comparisons are shown in Table 4.11. Costs are not total capital costs since common equipment costs were not included and district and central building systems do not include thermal energy meters. Engineering Technology Division staff will combine these capital cost elements to other costs, such as costs for pumping stations, energy and equipment at the central station plant, and heat exchangers, to determine the total cost of delivered energy to industrial and residential consumers. Final results were not available at the end of this report period.

4.4.4 Thermal Energy Storage for Solar Application

A draft report[65] analyzing the costs and performance characteristics of devices for storing thermal energy produced by solar collectors was completed in February 1976 at the request of OTA. The work was performed in cooperation with the Engineering Technology Division and is intended to serve three functions; it will be used (1) as part of a draft paper giving an overview of solar technology; (2) as a basis for (*a*) preparing preliminary designs for a variety of solar systems and (*b*) assisting in the selection of several baseline designs that will be subjected to detailed technical and economic analysis; and (3) as a source document by the team that will perform the detailed analysis.

The TES devices that we considered were those suitable for applications defined by the product of solar energy conversion, the type of load, and solar collector temperature ranges. The systems studied are capable of producing both electricity and space conditioning for three types of loads: (1) a single-family detached residence, (2) an apartment complex of 100 units, and (3) a city of 30,000, containing single-family residences and apartment complexes. Collector temperatures are in four ranges: (1) 38 to 121°C (used for space heating and single-cycle air conditioners and organic Rankine low-temperature turbines); (2) 149 to 204°C (used for dual-cycle air conditioners and low-temperature turbines); (3) 204 to 316°C (using fluids heated by parabolic trough collectors to run Rankine turbines); (4) 427 to 538°C (using fluids heated by heliostats to run closed-cycle gas turbines and steam Rankine turbines).

The solar-to-thermal-electric conversion systems needed to provide the domestic electricity, domestic hot water heating, and the space heating and cooling for the three load types in the prescribed temperature regimes will require subsystems capable of storing from 60 to 36×10^5 kWhr of thermal energy. Some specific storage subsystems proposed for initial selection in the various temperature regimes are described in the following subsections.

Low-temperature TES subsystems. Water is the obvious selection as a heat storage material in the low-temperature (38 to 121°C) regime. Water can be stored in a variety of tanks fabricated from various

65. C. L. Segaser, *Solar Thermal Energy Storage Subsystems*, ORNL TM-5758 (to be published).

materials, including wood, concrete, fiberglass, steel, and other metals. One of the available phase-change materials (PCM) could be selected as an alternative to water if space is at a premium, but it will be more expensive. Several inorganic and organic salts, salt hydrates, and eutectics have been investigated as potential TES materials for space and hot water heating. Of these materials, $Ba(OH)_2 \cdot 8H_2O$ appears to have the most desirable characteristics of the PCM in the low-temperature regime.

Intermediate-temperature TES subsystems. We recommended one of the commercially available heat transfer oils for initial selection as a TES material in the intermediate-temperature (149 to 316°C) regime. The physical properties of the fluids are similar, but none of the fluids equals the TES capability of water. The heat transfer oils, however, can be used at temperatures approaching the upper range of the intermediate-temperature class of materials without resorting to pressurized containment. Of the heat transfer oils, Caloria HT-43, a petroleum-derived oil produced by EXXON, has the highest heat storage capability.

A heat transfer salt developed by Dupont in the 1930s, HITEC, is also suggested for selection as a potential material for solar energy storage in the intermediate-temperature regime. A white, granular solid eutectic mixture of inorganic salts, HITEC is composed of 53% potassium nitrate (KNO_3), 40% sodium nitrite ($NaNO_2$), and 7% sodium nitrate ($NaNO_3$). The melting point of fresh HITEC is 142°C. An upper limit to the useful operating temperatures for HITEC is imposed by thermal decomposition, which becomes severe at about 500°C.

High-temperature TES subsystems. For solar energy conversion applications in the high-temperature (427 to 538°C) regime, a PCM using the heat-of-fusion of an inorganic salt is recommended. The heat storage capabilities of some selected inorganic salt mixtures useful for solar energy storage in the high-temperature regime were compared. Strictly on the basis of heat storage capability, sodium hydroxide (NaOH) was judged to be superior to the others.

Sodium hydroxide has the attribute of being abundantly available in large quantities, and it is relatively inexpensive. Several progress reports relating to the design and application of systems using sodium hydroxide have been issued. Because of the comparatively large amount of experience gained from sodium hydroxide systems to date, this system is proposed for initial selection as a means of storing solar energy at high temperatures.

4.4.5 Coal-Using Integrated Community Energy System

In April 1976, the ERDA Division of Buildings and Community Systems contracted with the Mathtech Division of Mathematica, Inc., to analyze coal-using systems as producers of energy for community consumption and to develop a methodology for the determination of the optimum coal-using ICES for a given community. The first phase of this project is scheduled to terminate in May 1977 if project milestones are successfully met. The Energy Division is contributing technical management assistance to the ERDA technical project officer for this project.

Project scope and objectives. The scope of this project includes the characterization and optimization of combinations of all technologies, existing and emerging, required to provide community energy demands using coal as the primary fuel. Technologies of interest include the (1) primary conversion of coal to fuel, electricity, or thermal energy; (2) secondary conversion of coal-derived fuels to useful energy; (3) storage and distribution of all forms of fuel and energy; and (4) end-use conversion of coal-derived fuels, electricity, or thermal energy to satisfy user loads. Vehicular transportation and heavy industry demands are excluded. The objective of the technology analysis task is to consider and evaluate technological problems (availability of technology); environmental impact;

initial investments (monetary and resources); operational costs (monetary and resources); and efficiency of energy use under full- and semiload conditions.

The community analysis task is to characterize community service and energy demands by zones for buildings and services and to collect existing data on energy and service demand profiles. The profiles are to show the time-dependent nature of the demands for illustrative and testing purposes in the formulation of the optimization program.

The objective of the system synthesis and optimization task is to provide community planners and system designers with a useful tool with which they can (1) select fuel and energy forms and (2) perform preliminary sizing of equipment and subsystems of a coal-using ICES for a specific community. The basis for selecting an optimum coal-using ICES configuration includes overall energy use, initial investments, operating costs, or combinations of these factors. The results of the optimization procedure can be applied to new community development or to retrofitting an existing community. Purchase and sale of energy and fuel to adjacent markets is also to be included in the optimization procedure.

The final task is to develop a detailed plan for the demonstration of an optimum coal-using ICES and to propose future research for development of improved coal-using ICES.

Status. The first assignment completed was a program plan that translated the work scope into manageable subtasks and elements, allocated manpower requirements, and established project schedules and milestones. Work is now progressing in the four tasks, and working relations are being established between Mathematica, Inc., and its subcontractors. Since no major milestones have been met in the project, it is premature to evaluate its chance of success. Results of the coal-using systems analyses will be integrated into the ATMES technology evaluation effort.

4.5 ELECTRIC ENERGY SYSTEMS

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J. H. Holladay[66] W. E. Lever[67]
M. J. Roberts[66]

This program was initiated to provide technical assistance to the Division of Electric Energy Systems (DEES) of the ERDA Office of Conservation. Emphasis is placed on the transmission, distribution, and use, rather than generation, of electric energy. This mission coincides with the missions of DEES and the Electrical Systems Division of EPRI, and the initial projects of the program activity are funded through branches of these organizations.

4.5.1 Field Demonstrations of Communication Systems for Distribution Automation

The distribution systems of electric utilities are essentially passive systems that receive electricity from transmission lines or directly from generators and distribute it to residential, commercial, and industrial users. The equipment, as presently specified, must be capable of handling the expected

66. Instrumentation and Controls Division.
67. Computer Sciences Division.

peak loads and withstanding many emergency situations without any active management or supervision. Obviously, a managed or supervised system could result in the more optimized use of the equipment by shifting and deferring loads in response to changes, and continuous monitoring of the system status could improve the reliability through more refined maintenance and repair. One of the required elements to implement such supervised or automated distribution is a communication system that will report the system status to a central supervisory location and send the requisite commands back to the action points in the system. Such a communication system can also be used for remote meter reading, load control, and collection of information on system energy usage. To foster the development of the communications required for automated distribution, ERDA and EPRI are funding field demonstrations of communication equipment.

Communication systems that use the existing telephone network, a radio system, or a carrier frequency imposed on the power distribution lines are potentially feasible. Although equipment for each of these systems has been designed and manufactured in pilot quantities by several manufacturers, no system has had sufficient in-service testing to fully qualify it. In this program six manufacturers will supply equipment to six utilities, which will install and operate the equipment for a year-long test. The project will consist of four power-line carrier systems of different frequencies and modes of operation, one telephone network system, and one radio system. Each manufacturer will be teamed with a utility for the demonstration. The utilities are located in different regions of the country and will use the equipment on overhead and underground distribution circuits in urban, suburban, and rural areas.

The manufacturers are funded by either ERDA or EPRI (three each) to supply a system for bidirectional communication to about 750 points in the host utility system. The utilities support the project by supplying the required manpower for equipment installation and the personnel for carrying out the test program for a minimum period of one year. The tests are expected to demonstrate the inherent capabilities and potential limitations of the equipment in achieving effective communication by individual and mass addressing between a utility control location and a variety of devices such as switches, transformers, capacitors, fault detectors, and individual customer meters. The system will handle (1) distribution automation (e.g., remote operation and status reporting of capacitor bank switches, line reclosers, sectionalizing switches, and transformer taps); (2) load control (simulated or actual shedding of load); and (3) metering (total accumulation, time-of-day, peak, and demand).

The Oak Ridge National Laboratory has been selected by ERDA and EPRI to provide data coordination for the project to assure the comparability of the tests. In addition, ORNL will provide technical analysis and monitoring of the three ERDA-funded tests.

The initial tasks in this project, to review the equipment and program plans of the six manufacturers and the experimental plans of the manufacturer–utility teams and to make recommendations on the data required to properly assess the equipment performance, are well under way. Two reports, one on the equipment and one on the experimental plans, will be issued during the first quarter of FY 1977 along with the recommendations on data.

Review of the three ERDA-funded manufacturers will be extended beyond the review required for the data coordination project. This extended review will be directed toward identifying the problems expected in the large-scale manufacturing of the equipment and those that will need to be solved for full implementation of distribution automation in a utility. In addition, we will conduct a more detailed examination of the technical options chosen by the manufacturers.

4.5.2 Participation in US–USSR Superconducting Power Transmission Cooperation

Oak Ridge National Laboratory has participated in one of the scientific and technical cooperations between the United States and the Soviet Union in the field of energy since the inception of the cooperation. H. M. Long was a member of the U.S. Organizing Committee of the Exchange on Superconducting Power Transmission in 1972 and has served on the committee since then; he was named leader of the committee in January 1977. His participation will continue, and he will lead a topical working group on cryogenic dielectrics which he organized to develop and implement cooperation in this technical area. The topical working group is composed of industrial representatives who are involved in dielectric development and who can provide an in-depth assessment of Soviet capability in this area.

4.6 COST TARGETS FOR SOLAR ELECTRIC POWER PLANTS[68]

T. D. Anderson[69] L. C. Fuller[69]
H. I. Bowers[69] S. I. Kaplan
J. G. Delene[69] J. V. Wilson[69]

Solar energy is widely proposed to be a major source of bulk electricity by the year 2000. In gauging the probable rate and extent of solar electricity's penetration into U.S. utility systems, cost targets provide a useful criterion for the approach to economic competitiveness by this new technology.

As defined in this study, a cost target is the allowable investment in a solar generating plant such that its operating cost will equal that of a competing conventional generating plant under the conditions of the chosen demand mode. Such modes are grouped by duration of demand during a daily cycle and range from base load (essentially continuous) through intermediate loads (about 15 to 70% capacity factor) to peaking load (under about 15% capacity factor). The choice of conventional power plant to satisfy a particular demand mode is dominated by economic considerations; for example, short load cycles favor low-capital-cost plants, whereas base-load plants require low variable (fuel and O&M) operating costs.

Using the method described in ref. 70, the capital and other nonfuel costs of various types of conventional steam–electric plants were estimated for commissioning in CY 2000. Self-consistent sets of nominal and high values for fuel contributions to power costs were developed by (1) using forecast prices for nuclear fuel as a base and (2) selecting capacity factors for each plant type from the national energy-system mix embodied in the ERDA Planning and Analysis Office projection (moderate low case).[71] Each fueled system was postulated to be the most economic electricity producer at the mean value of its normal capacity factor range, and fuel prices were computed so as to realize this relationship.

68. Work performed in the Engineering Technology Division.
69. Engineering Technology Division.
70. Energy Research and Development Administration, *CONCEPT: A Computer Code for Conceptual Cost Estimates of Steam-Electric Power Plants, Phase IV User's Manual*, ERDA-108 (June 1975).
71. *Total Energy, Electric Energy and Nuclear Power Projections, United States*, WASH-1139 (1) (February 1975).

Mean operating costs (in dollars per electrical kilowatt-hour), using a 15.5% fixed charge rate on capital, were then developed for the various types of plants:

Annual nuclear operating costs [$/kW(e)]

$$= 0.155(CC) + FOM + VOM(8760)f + VFC(8760)f + FFC\,. \qquad (11)$$

and

Annual fossil-fueled operating costs [$/kW(e)]

$$= 0.155(CC) + FOM + VOM(8760)f + VFC(8760)f\,. \qquad (12)$$

where

CC = capital cost, $/kW(e)
FFC = fixed fuel charge, $/kW(e) per year,
FOM = fixed O&M charge, $/kW(e) per year,
VFC = variable fuel cost, $/kWhr(e),
VOM = variable O&M cost, $/kWhr(e),
f = capacity factor.

Two categories of solar electric plant were studied—fuel displacement and capacity displacement plants. Fuel displacement plants operate whenever weather conditions permit, and their output is used by the utility system in lieu of the highest-cost plant output then in service. The worth of such solar power is the same as the incremental cost of producing the power it replaces—that is, the variable operating cost of the plant. Hence, the cost target for the solar unit is the investment one could make in the unit such that its fixed charges would equal the cost of the displaced power.

Capacity displacement plants imply the presence of sufficient storage and other backup capacity, if necessary, to provide the same reliability and continuity of output as the units they displace. The cost target for a capacity-displacing electric plant is the investment that one could make in the plant so that the annual fixed charges would equal the annual operating cost for a competing conventional plant. Figure 4.15 displays the cost targets for capacity-displacing solar plants in terms of high and nominal conventional plant operating costs for the year 2000 for various capacity factors.

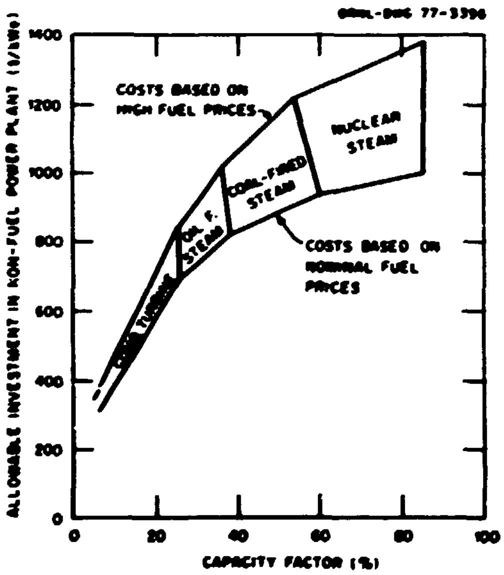

Fig. 4.15. Cost targets for capacity-displacement solar electric plants.

5. High-Temperature Power Conversion Systems

A. P. Fraas

5.1 INTRODUCTION

An important step that can be taken to reduce our national fuel consumption is to increase the efficiency of the thermodynamic cycles. Few realize that a major reason why U.S. coal consumption did not increase rapidly during the past century was an increase in the thermal efficiency of steam plants by a factor of about 10. Unfortunately, there has been no further increase since about 1950 because at that time we reached the upper practicable temperature limit for the steam cycle — about 540°C (1000°F). Reaching higher thermal efficiencies will require going to higher temperatures, and this in turn implies the use of other working fluids. The leading candidates for advanced thermodynamic cycles are (1) gas turbines running on air or helium and (2) potassium or cesium vapor topping cycles superimposed on a conventional steam cycle. Work on both closed-cycle gas turbines and alkali-metal vapor topping cycles is under way in the Energy and Engineering Technology Divisions.

These high-temperature thermodynamic cycles may be coupled to fossil, fission, or fusion energy sources. The work in 1976 has been centered on fluidized-bed coal combustion systems, which will permit the direct combustion of coal (since sulfur emission can be controlled). The fluidized-bed coal combustion system appears to be well suited for coupling to either gas turbines or alkali-metal topping cycles. In either case the peak temperature (and hence the cycle efficiency) is limited by (1) sulfur retention considerations that restrict the fluidized-bed operating temperature to 870 to 930°C (1600 to 1700°F), (2) corrosion considerations, and (3) the rapid drop in the strength of structural materials with increasing temperature; each of these three factors appears to limit the peak operating temperature of the heat transfer matrix to about 870°C (1600°F).

However, many complex and subtle problems must be solved before commercially viable power conversion systems can become a reality. The following sections outline some of these problems and the steps being taken to solve them.

5.2 FLUIDIZED-BED COAL-BURNING GAS TURBINE

A. P. Fraas

S. J. Ball	M. E. Lackey	J. J. Tudor
R. S. Holcomb	J. T. Meador	M. E. Whatley

A major element of the program carried out at ORNL for the Department of Housing and Urban Development (HUD) (see Sect. 4.5) is the study of Modular Integrated Utility Systems (MIUS). These are total energy systems, that is, power plants designed not only to produce the electricity required for a housing complex of up to 1000 units but also to use the waste heat from the thermodynamic cycle for domestic hot water and building heating in the winter and absorption air conditioning in the summer.

The MIUS installation will also provide for disposal of solid wastes and sewage treatment. When severe shortages of natural gas and fuel oil began to limit the construction of new housing developments in 1973, ORNL proposed that a gas turbine might be coupled to a fluidized-bed coal combustion system to meet MIUS requirements. This system would permit the use of the high-sulfur coal that constitutes about 90% of the coal reserves of the United States in the region east of the Mississippi and north of Memphis, where 75% of our urban population dwells.

As a result of conclusions reached in the Concept Feasibility Study,[1] ORNL received approval from HUD and ERDA in February 1975 to proceed with the conceptual design and cost estimate for a fluidized-bed coal combustion system as a heat source for a gas turbine suitable for MIUS applications.

5.2.1 Detailed Design of the Coal-Burning Gas Turbine Experiment

The detailed design of the experiment and the procurement of certain long-lead items have proceeded during the past year. The major part of the design effort has been directed to the furnace, gas turbine, and heat exchangers.

System flow sheet. A flow sheet indicating the principal components of the system and the design operating temperatures is presented in Fig. 5.1. The fluidized-bed furnace, economizer, and air preheater are incorporated in the furnace unit; the remaining components are commercial equipment

1. A. P. Fraas, *Use of Coal and Coal-Derived Fuels in Total Energy Systems for MIUS Applications*, ORNL-HUD-MIUS-27 (April 1976).

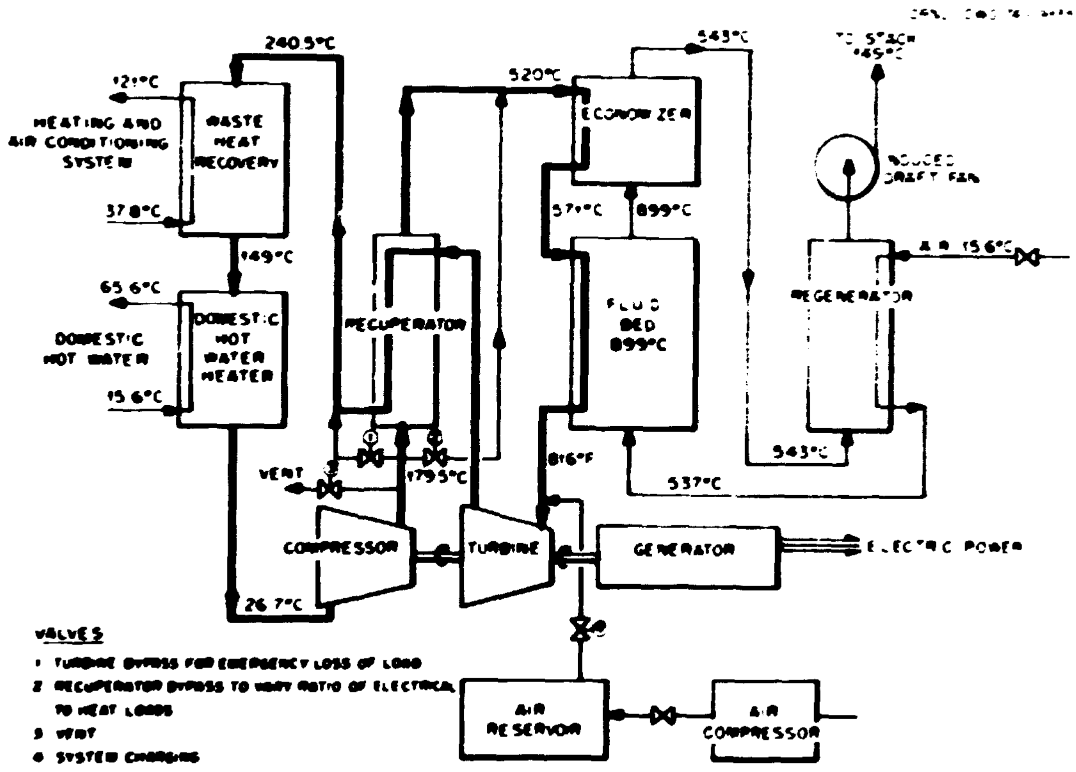

Fig. 5.1. Flow sheet showing the coupling of the major components of the fluidized-bed coal combustion system to a closed-cycle gas turbine for MIUS application.

items with some modifications to suit the requirements of this particular system. Since the gas turbine and compressor unit, recuperator, waste heat recovery heat exchanger, and domestic hot-water heater, along with the connecting ducting, operate with ordinary air, which is essentially free of moisture and dust, there should be relatively little difficulty from corrosion or deposition in these components. Not shown in Fig. 5.1, but included in the combustion air system, is appropriate dust removal equipment, including (1) a cyclone separator between the economizer and the regenerator and (2) a baghouse in the exhaust from the regenerator to the induced-draft fan. Also, a forced-draft fan is used on the inlet air to reduce the power requirements for pumping the combustion air because the pumping power for 15°C (60°F) air is roughly two-thirds as great as that for the hot combustion products.

Furnace design. The principal elements in a fluidized-bed coal combustion system of the type envisioned are shown in Fig. 5.2, which shows a vertical section through the 1.8-m(6-ft)-square reference design furnace. Air from the large plenum at the bottom is blown upward through orifices in the bed plate, through a 0.6-m(2-ft)-deep fluidized bed, and upward to the top of a plenum chamber above the bed, where most of the particles lifted out of the bed have a chance to settle out and fall back into the bed. The hot combustion gases then flow upward through an economizer region, where they give up much of their heat to the turbine air entering the heater.

About a dozen different designs were considered in an effort to evolve a layout that would best meet the boundary conditions, fairly detailed layout and analytical studies were carried out for four of these designs. The various designs and the basic problems involved are discussed in ref. 2.

Assembly and subassembly drawings of the reference design furnace were prepared with sufficient detail to estimate the furnace cost and prepare shop fabrication drawings. A bid package including these drawings and the specifications was prepared and sent with a request to bid to 17 prospective vendors. Of the two bids received, the low bid was found to represent a satisfactory proposal.

A review of the program, emphasizing the prospects for commercial implementation of the coal-burning gas turbine system, was held at ERDA, Office of Fossil Energy, Division of Coal Conversion and Utilization (ERDA-FE) in early September. As a result of the review, ERDA-FE program managers suggested that the commercial prospects of the system would be enhanced if the furnace were built by an experienced furnace manufacturing firm according to its own design for suitable volume production to meet future demand. Consequently, ERDA-FE directed ORNL not to place the order for the furnace on the basis of the low bid that had been received, but rather to cancel the order and make plans to prepare performance specifications and obtain designs from furnace manufacturing firms. This course of action will be followed, and the performance specifications will be prepared when additional funds are received.

Turbine-generator unit. A survey of turbine-generator units having outputs of 300 to 1000 kW(e) was carried out last year by contacting vendors and talking with leading gas turbine experts. The survey identified the AiResearch model 831-200 gas turbine-generator unit as a design suitable for coupling to a fluidized-bed coal combustion system employed as a heat source. Two of the units, which are available from the Air Force on loan for experimental use, were chosen as the basis for the system design.

An engineering study was performed by AiResearch to examine the feasibility of modifying the 831-200 gas turbine for closed-cycle operation. It was concluded that the turbine could be made suitable for closed-cycle use by (1) replacing the seals with the improved seals that AiResearch has used in later model engines, (2) replacing the thrust bearing with one designed for the higher thrust loading being used in a unit that produces a higher power output, and (3) providing a high-pressure compressor inlet

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2. A. P. Fraas et al., "Design Study for a Coal-Fueled Closed Cycle Gas Turbine System for MIUS Applications," *Record of the 10th Intersociety Energy Conversion Engineering Conference*, IEEE Catalog No. 75 CHO 983-7 IAB (August 1975).

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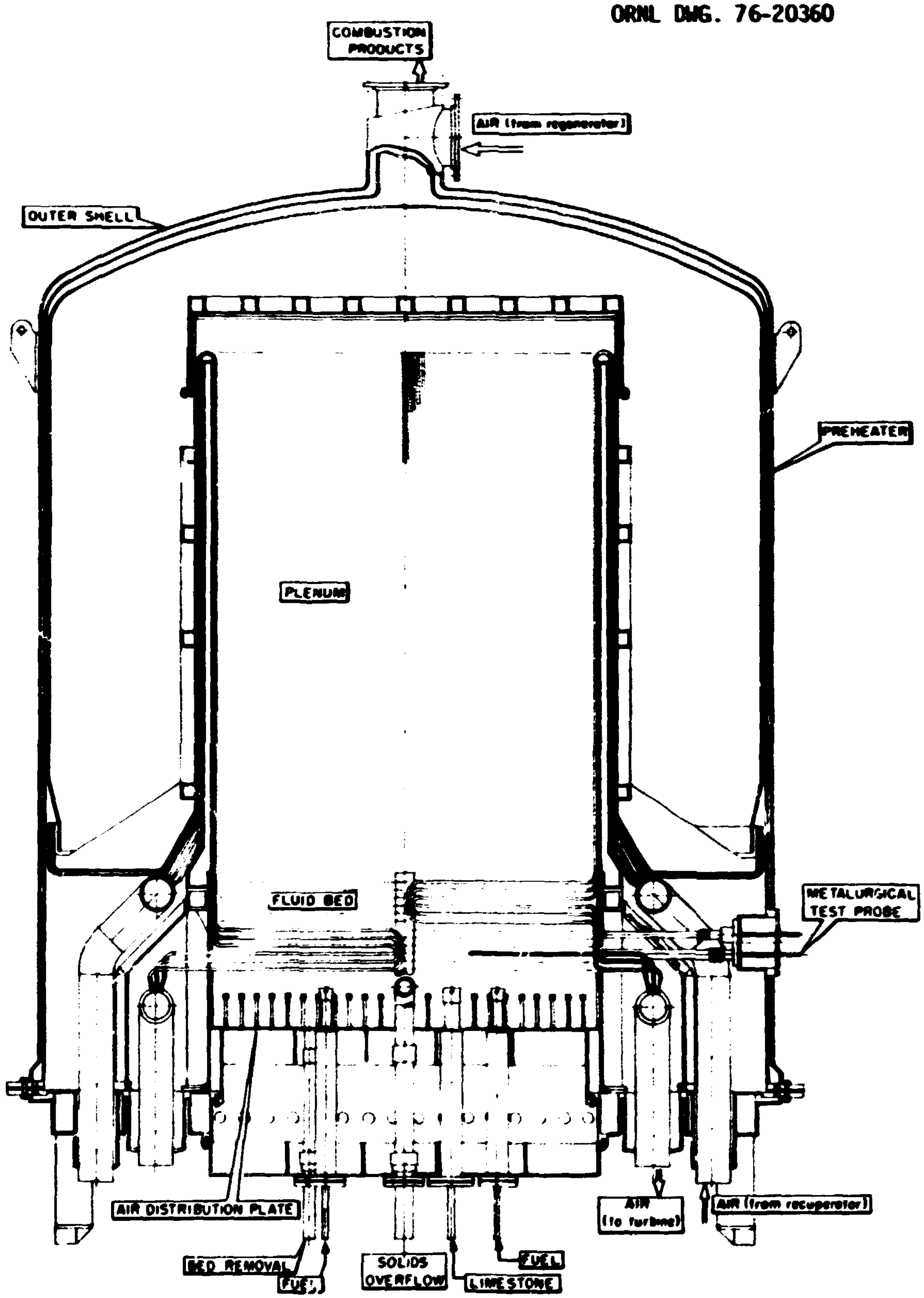

Fig. 5.2. Cross section of the reference design fluidized bed.

plenum. Performance calculations indicated that the best overall performance using this system would be obtained at a speed of about 80% of the original design speed; there should be no vibration problems at this speed of operation.

Recuperator design. The engineering study on the 831-200 gas turbine included the performance analysis of the AiResearch truck gas turbine recuperator core modules for closed-cycle operating conditions. Turbine cycle calculations were done for recuperator designs composed of four, six, or eight modules. The six-module design, which yielded an acceptable pressure drop and heat transfer effectiveness, has been selected as the reference design. The six core modules will be packaged in a cylindrical pressure vessel to form the recuperator for the closed-cycle system. This recuperator design offers the possibility of a considerable cost reduction when the core modules are placed in volume production. The material presently used for the modules is 347 stainless steel, but development of a unit made of the less expensive 400 series stainless steel is in progress.

Regenerator design. A regenerator is employed to transfer heat from the flue gas to the incoming combustion air. This heat transfer increases the thermal efficiency by reducing fuel consumption, and the hot air provides better conditions for burning the fuel and improves the combustion efficiency. A study to determine a regenerator design having high reliability and ease of maintenance at minimum cost was performed. Three types of heat exchangers were included in the study: (1) ceramic core rotary regenerators, (2) metallic core rotary regenerators, and (3) fixed surface heat exchangers of a variety of heat transfer matrices. The ceramic core regenerator material was found to be susceptible to corrosion from sulfur trioxide and did not appear to offer good reliability. The metallic core regenerators in commercial production presented two problems resulting from operation at a higher pressure difference between the air and the flue gas than that found in conventional furnaces: (1) inadequate strength of the separator sheet between the high- and low-pressure sections and (2) excessive air leakage across the rubbing seals. A fixed surface heat exchanger of the bar and plate type of construction appeared to offer the best design for the application. A number of vendors were contacted, and two proposals were submitted. The proposed design with the lower cost was selected as the reference design. It consists of a specially built stainless steel heat exchanger placed in series with a production-model low-carbon steel heat exchanger. The flue gas temperature will be reduced to about 538° C (1000° F) in the stainless steel unit, and the flue gas will be cooled to about 149° C (300° F) in the carbon steel heat exchanger.

Waste heat exchangers. Heat is recovered from the turbine exhaust air in a waste heat exchanger, designed to supply water at about 132° C (270° F), and a domestic water heater, designed to heat water to 62° C (150° F). The waste heat exchanger is designed for a maximum air inlet temperature of 427° C (800° F). The design selected was a finned-tube crossflow heat exchanger having carbon steel finned tubes in the high-temperature section and copper tubes with aluminum fins in the low-temperature section. The domestic water heater will also employ copper tubes with aluminum fins in a crossflow design. The commercially available tube bundles will be installed in a specially fabricated cylindrical shell for the closed-cycle system.

Ash handling system. The preliminary design of the ash handling system was completed, and components were sized and selected. Recommendations for the preferred type of each component were obtained in discussions with several vendors, and a flow sheet incorporating the recommended components was prepared. The option of having the system designed and supplied by a system engineering firm was explored. Discussions were held with a firm that supplies complete systems; the cost estimate for providing the design and the total system indicated that this approach would be more expensive than continuing the design work at ORNL and purchasing the individual components.

5.2.2 Bench Tests

Test work is continuing on a fluidized-bed cold flow model and the coal feed system.

Cold flow model. A number of tests were conducted with a 1.2-m(4-ft)-square, 3-7-m(12-ft)-high Lucite model of the fluidized-bed furnace. A photograph of the model with the bed region filled with limestone is shown in Fig. 5.3. Areas of testing include fluidizing velocity, pressure drop, air distribution, coal mixing rate, and tube vibration. The fluidizing velocity tests indicate that it should be possible to operate the furnace at about one-third of the full-power air flow rate. The coal mixing data show that adequate horizontal mixing of the coal should be obtained from the four coal feed nozzles at one-third of the full-power air flow rate. Tube vibration was found to have a frequency range of 20 to 50 Hz, but low amplitude. The natural frequency of a full-length furnace tube was measured and found to be 15 Hz with no support under the horizontal U-bend portion; results of the vibration test led to the decision to provide supports at the ends of the horizontal U-tubes.

Coal feed system. Tests have been conducted on components of three different coal feed systems, and some endurance testing has been done on the system selected as the reference design. The vibrator-eductor unit, which employs a vibrating feeder to feed coal in four streams to air-driven eductors, was tested; after trying several air flow settings, we found that the coal feed rate is not split equally among the four streams over the range of the vibratory amplitude to give the desired range of total coal feed rate. After spending considerable effort to obtain equal flow in the four streams without success, development work on this type of coal feed splitter was discontinued.

Unfavorable results were obtained from a coal feeding test run on the Iron Fireman pneumatic screw feeder. Part of the transport air from the blower circulated back along the screw feeder and caused the screw to be only partially filled with the finely crushed coal, thus producing a coal feed rate of only half of the maximum feed rate required when the screw was running at full speed. The Iron Fireman feeder was considered unsatisfactory for feeding coal to the furnace.

A coal feed system consisting of a gravity flow splitter that feeds four air ejectors for transporting the coal has been tested; this system has been found to give four streams that can be kept within ±5% of the mean coal flow rate over the entire operating range, and the results are repeatable. A series of batch-flow tests giving a total running time of 175 hr was run on this system, and no operating problems were encountered. The system has been selected as the reference design coal feed system and is currently being installed in a new test facility that will operate continuously with the objective of running a 1000-hr endurance test.

5.2.3 Supplemental Studies

A group of supplemental studies in support of the coal-fired gas turbine program was requested by ERDA-FE, and the studies were initiated upon receipt of funds in March 1976.

Reliability. A report[3] on the analysis of the reliability of a MIUS powered by four coal-fired gas turbine systems was completed in July and submitted to ERDA-FE and HUD for review. The study indicated that this type of MIUS system would be available to meet the electric demand except for about 15 hr per year.

Alternate cycle performance. A report[4] on the performance of the coal-fired gas turbine system with alternate cycle conditions was completed in September and submitted to ERDA-FE and HUD for review.

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3. Garland Samuels, *Reliability Considerations for a Coal-Fired Modular Integrated Utility System*, to be published as ORNL HUD MIUS report.

4. Garland Samuels and W. M. Wells, *Alternate Operating Conditions and Systems for the Coal-Fired Modular Integrated Utility System*, to be published as ORNL HUD MIUS report.

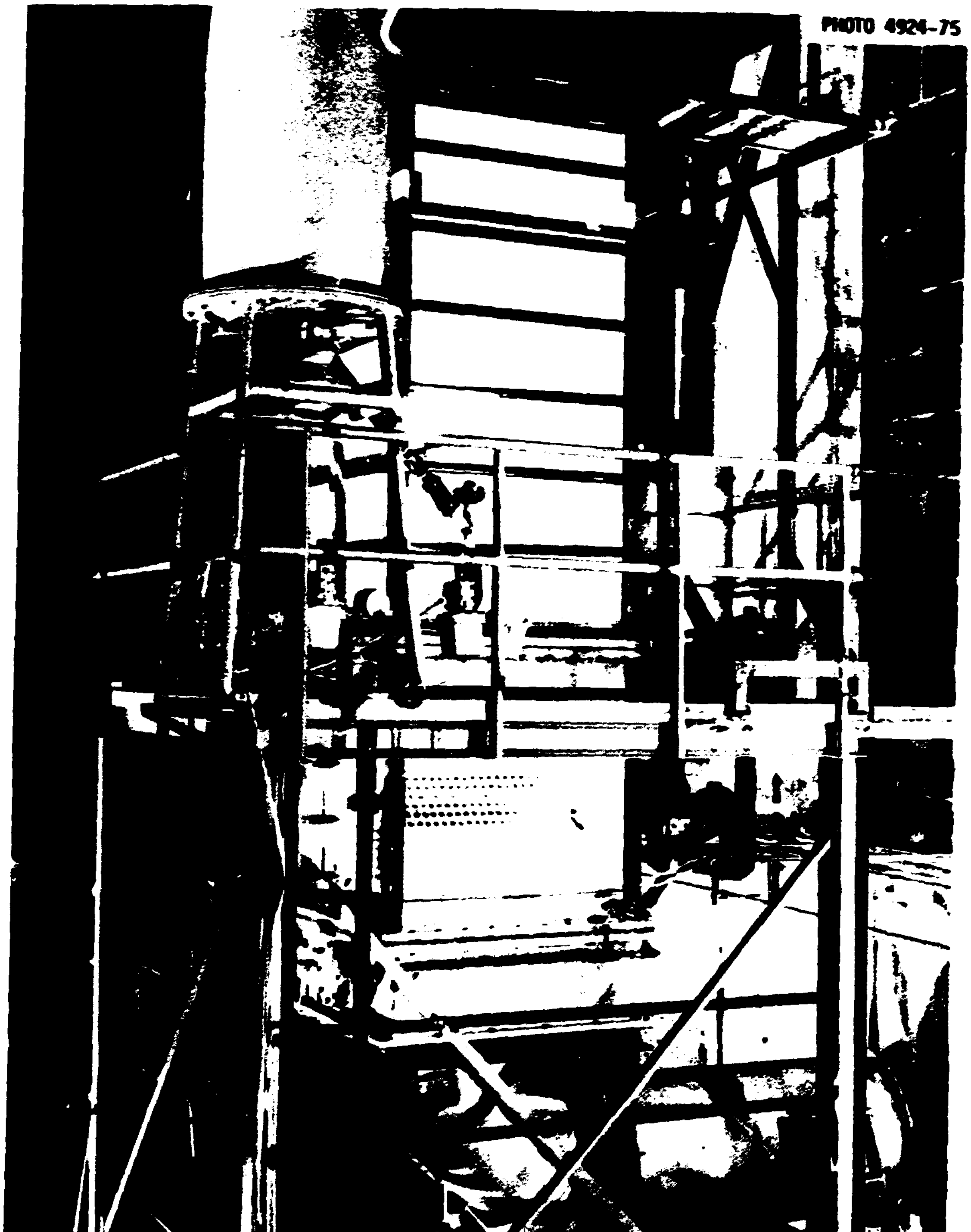

Fig. 5.3. Cold flow test model of fluidized-bed furnace.

Economic comparison. A report is in preparation on the economic comparison of the coal-fired gas turbine system with two alternative energy systems: (1) central station pressurized fluidized-bed electric power plant with air-to-air heat pumps in apartments; (2) central station pressurized fluidized-bed electric power plant with a central heating boiler for the apartments.

Heat transfer test. A heat transfer test was run on an air-cooled tube in the FluiDyne Engineering Corporation fluidized-bed test furnace at a bed temperature of 900° C (1650° F) over a range of fluidizing velocity of 0.2 to 0.6 m/sec (0.8 to 2.2 ft/sec). The results are being analyzed, and a report will be prepared.

Fireside corrosion test. A corrosion test on 16 specimen tubes made up of eight different metal alloys or coatings is scheduled to be run in the FluiDyne fluidized-bed furnace, beginning October 1976 and continuing for a period of 500 hr. The tube wall temperature will be held between 815 and 870° C (1500 and 1600° F).

5.3 ALKALI-METAL VAPOR TOPPING CYCLE

A. P. Fraas

R. S. Holcomb	R. L. Graves	R. E. MacPherson	R. H. Guymon
D. H. Lloyd	M. E. Lackey	J. J. Tudor	G. Samuels

A conceptual design study, initiated at ORNL under the NSF-RANN program early in 1971,[5] indicated that a potassium-steam binary vapor cycle plant having a gas-fired, supercharged potassium boiler would give a thermal efficiency of over 50% and capital costs similar to those for a conventional coal-fired steam plant. The most vital questions were considered to be cost, performance characteristics, and reliability of the potassium boiler. The conceptual design study indicated that such a boiler might best be designed around a set of perhaps 100 tube bundle and burner modules; ORNL proposed that one such full-scale module be built and tested to establish its performance characteristics, cost, and reliability. A program to carry out this project was initiated in July 1972 under the NSF-RANN program, and the boiler and burner module were constructed in 1973.

Work on the potassium vapor cycle was halted in February 1974 because of uncertainties in funding responsibility associated with the transfer of this category of work from NSF to the ERDA-FE. After a year's hiatus, work on installation of the potassium boiler for tests with water was resumed in April 1975 after receipt of the final installment of NSF funds. Funds to resume work on tests with potassium were received from ERDA-FE at the end of November 1975, and fabrication of the required components was initiated. Installation and operation of the water test and design and fabrication of the potassium test components have proceeded in 1976.

5.3.1 Test of the Potassium Boiler Using Water

Installation of the gas-fired boiler module system for water tests was completed in July. A photograph of the tube bundle after it was hung in the equipment tower and before the shroud and furnace shell were placed around it is shown in Fig. 5.4. There were difficulties during startup with the pilot light and with combustion air bypassing the main burner. Both problems were corrected and the system judged suitable for the water tests.

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5. A. P. Fraas, *Preliminary Assessment of a Potassium-Steam-Gas Vapor Cycle for Better Fuel Economy and Reduced Thermal Pollution*, ORNL/NSF-EP-6 (August 1971).

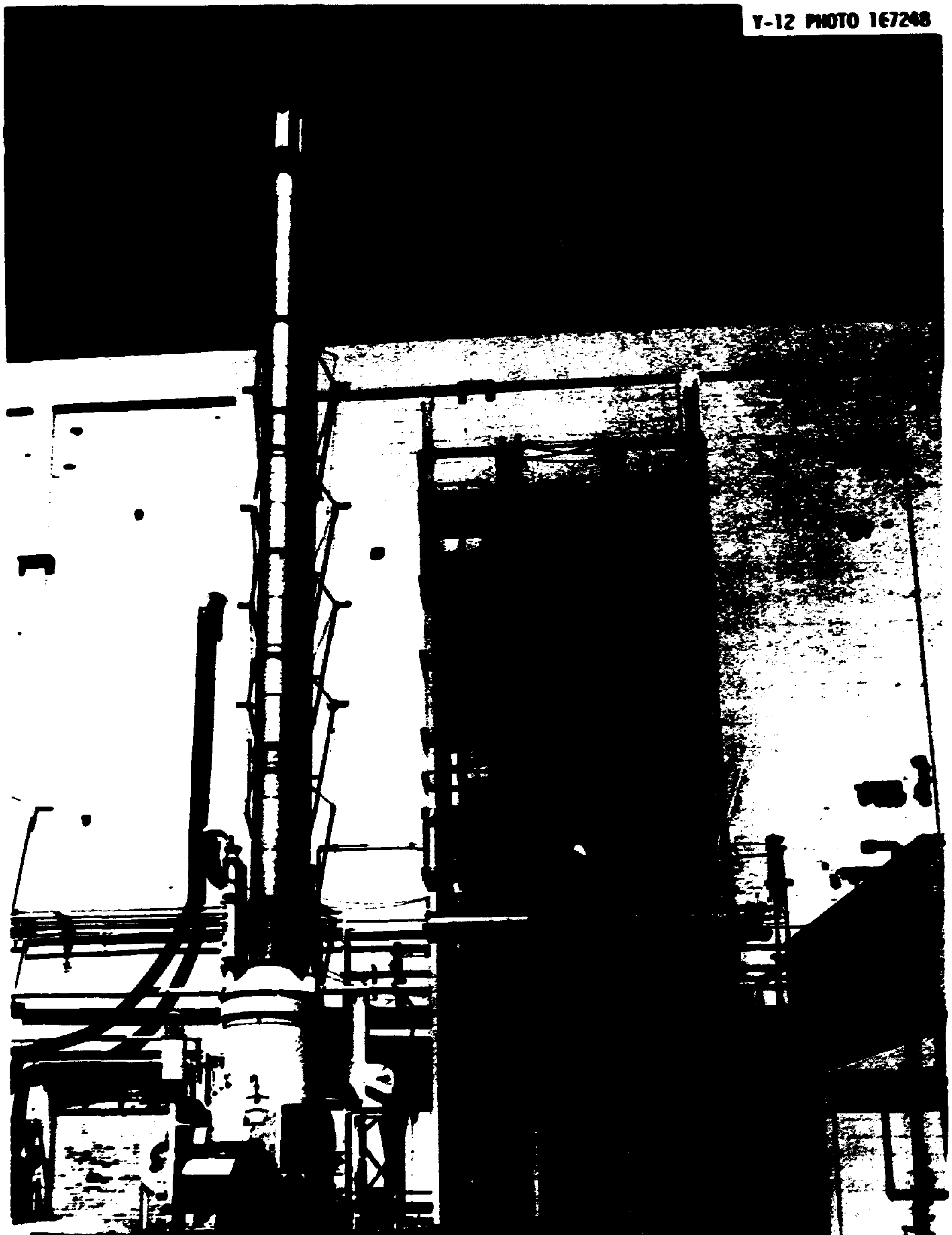

Fig. 5.4. Potassium boiler module installed in equipment tower.

Argon is supplied at two points in each of the bottom liquid headers to promote boiling nucleation when operating with potassium in the boiler. One objective of the water tests was to determine whether the argon is properly distributed so that the flow in each tube is sufficient to promote nucleation. A method was devised for measuring the argon flow rate to the individual tubes of the boiler: Water and argon are removed from a point about 3 m (10 ft) down the boiler tube and passed through a flask, where the argon is separated from the water and the collection rate is measured. The water is returned to the boiler tube so that there is essentially no net disturbance in flow at the entrance or exit of the boiler tube. Results from a representative sample of the tubes indicate that an adequate argon flow is present in each of the tubes.

One matter of concern that can affect the boiler integrity is the temperature distribution in the tube bundle as the burner is turned on and the system brought to boiling. Analysis of the startup conditions indicated that, once the temperature of the liquid in the boiler tubes was only slightly higher than the liquid temperature in the downcomers, a thermal circulation current would be set up if the boiler drum were filled with liquid to a level above the outlet of the boiler tubes. This liquid flow would tend to equalize the temperature in the tube bundle and prevent any high thermal stresses from differential thermal expansion. The temperature distribution observed during boiler startup indicated that good liquid circulation was present: the maximum temperature difference between the tubes in the outer row and the tubes in the inner row was only about 25°C (45°F), and the downcomer temperature was running between the temperatures of the inner and the outer tube row. The temperature of the outer tube row gradually rose to about the same temperature as the inner row as the water temperature rose to the boiling point.

5.3.2 Test of the Potassium Boiler Using Potassium

After the boiler test with water is finished, the boiler module and test system will be modified for operation with potassium. The principal modification that will be required is the addition of a vapor condenser, vapor piping, and a fill and drain system. The work during 1976 has consisted of design and some fabrication of these components and system modifications.

Potassium condenser design and fabrication. A potassium condenser built for the space nuclear electric power program will be used in the potassium boiler test. A set of aluminum reflectors that was intended for operation at a temperature lower than that required for the boiler test has been removed. An enclosure providing for heat removal by natural convection of air has been designed, and most of the related drawings have been completed. Design of the potassium vapor piping connecting the boiler to the condenser has been completed. Fabrication of the condenser enclosure, air ducts, and the vapor piping has been started.

Potassium fill and drain system. A fill and drain tank with connecting piping, electric heaters, vacuum system, and argon system will be installed for the potassium test. The detail drawings of the fill and drain tank have been completed, and the remaining system design is almost finished. Fabrication of the cylindrical portion of the tank is under way, and the heads have been ordered.

5.4 COAL-FIRED ALKALI-METAL TOPPING CYCLE

During the past several years, studies of alkali-metal power systems have shifted from gas- or oil-fired systems to units designed to use coal as a fuel in a fluidized-bed combustion chamber. These conceptual studies have included both potassium and cesium as the working fluid and have considered both atmospheric and pressurized furnaces.

The current work on this concept, which is just getting under way, is an extension of previous studies[6] and has two objectives: (1) to determine the relative merits of cesium and potassium as the topping cycle working fluid when used with fluidized-bed coal combustion systems with both atmospheric and pressurized furnaces; (2) to evolve a reference design for a full-scale potassium or cesium boiler coupled to a fluidized-bed furnace.

Work to date has been directed toward parametric cycle analyses for cesium and potassium for various boiler and condenser temperatures and on preliminary designs of the fluidized-bed–boiler units for three types of furnace—atmospheric, supercharged [3 to 5 atm (3×10^5 to 5×10^5 Pa)], and high-pressure combined-cycle [6 to 10 atm (6×10^5 to 10×10^5 Pa)]. Flow sheets for these three furnace pressure regimes are shown in Figs. 5.5–5.7.

The high-pressure system (Fig. 5.7) has the potential for giving the best cycle efficiency, and it permits the use of a deeper fluidized bed without excessive pressure losses, which depend on the ratio of the pressure drop across the bed to the bed pressure. The higher pressure also permits a higher power output from a given size furnace, but it does lead to a much more complex coal feed system. Also, at an operating pressure of 6 to 10 atm (6×10^5 to 10×10^5 Pa), the furnace pressure is greater than the vapor pressure of either potassium or cesium and may cause serious creep buckling problems in the vapor drums and manifolds. The turbocharged [3 to 5 atm (3×10^5 to 5×10^5 Pa)] furnace retains most of the advantages of the higher pressure system and alleviates the creep buckling problems.

Cesium has several advantages over potassium. The maximum temperature being considered for the alkali-metal system is 840°C (1540°F); at this temperature the vapor pressure of cesium is 3.9 atm (4×10^5 Pa), as compared with 2.0 atm (2×10^5 Pa) for potassium. This pressure will reduce the buckling

6. A. P. Fraas, *Energy Div. Ann. Prog. Rep. Dec. 31, 1975*, ORNL-5124, pp. 170–87.

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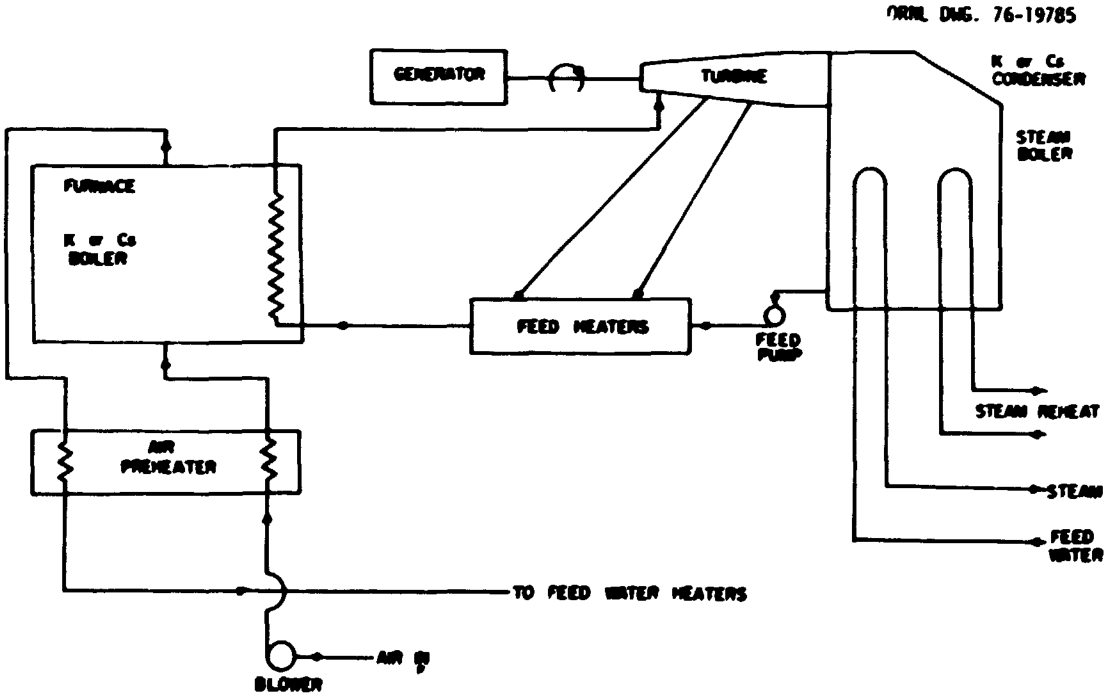

Fig. 5.5. Flow diagram for an atmospheric fluidized-bed combustion system.

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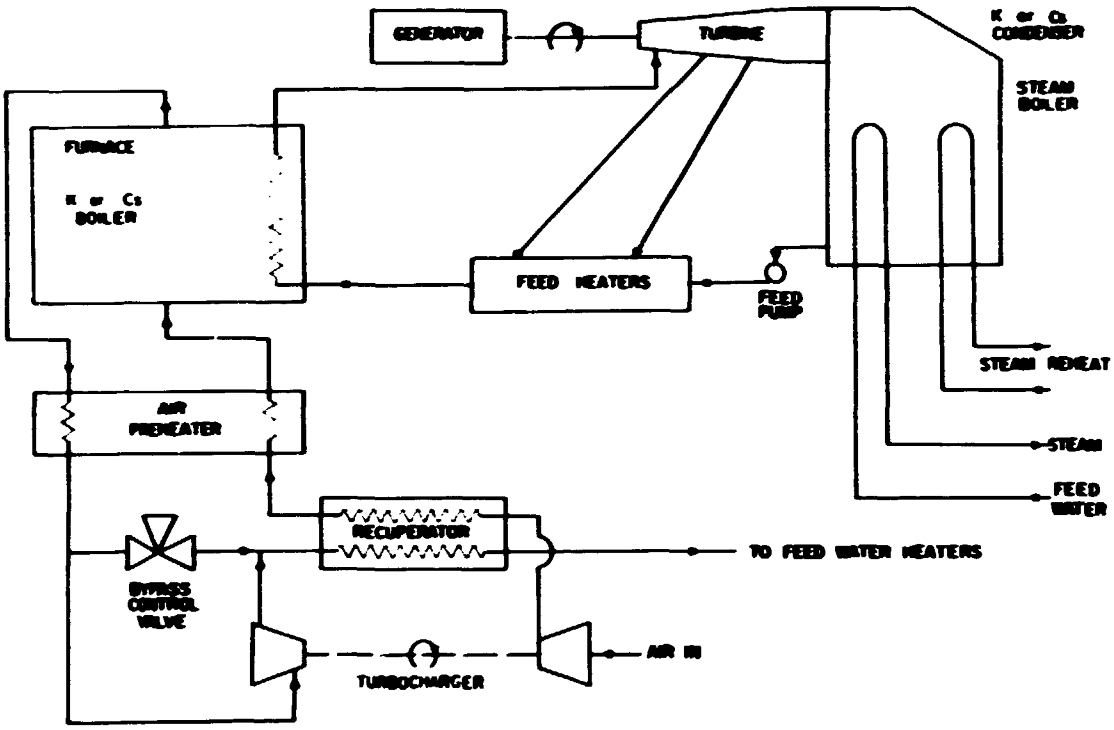

Fig. 5.6. Flow diagram for a turbocharged (3 × 10⁵ to 5 × 10⁵ Pa) fluidized-bed combustion system.

ORNL DWG. 76-19784

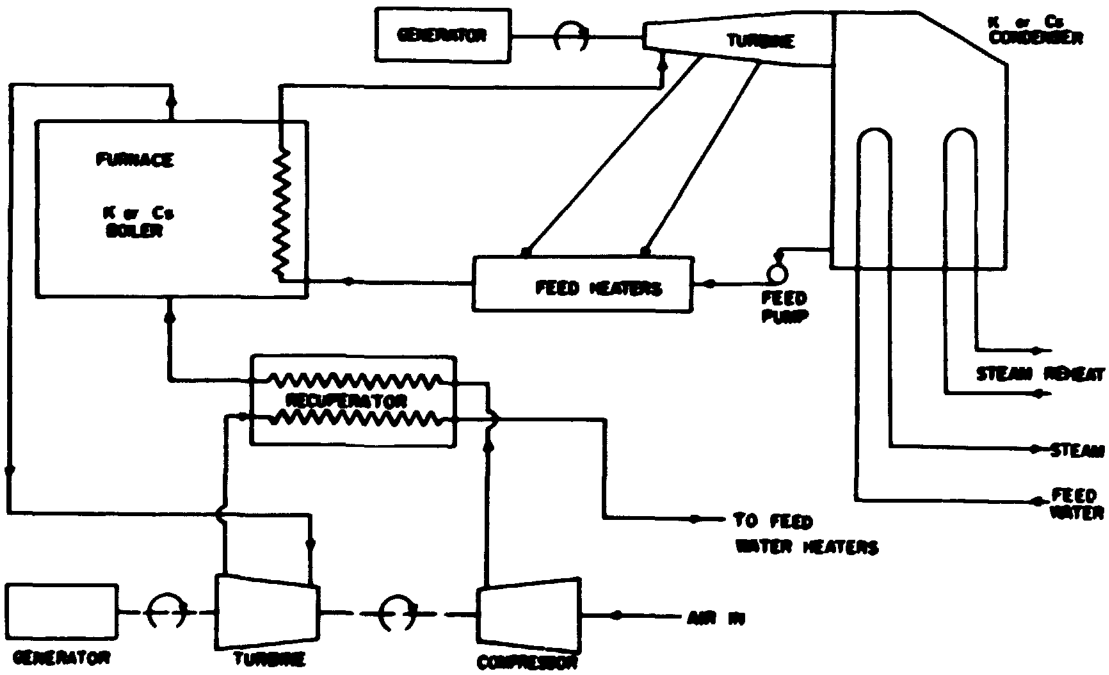

Fig. 5.7. Flow diagram for a high-pressure (6 × 10⁵ to 10 × 10⁵ Pa) fluidized-bed combustion system.

stress on the vapor drums and manifolds of the pressurized furnace system. Also, the vapor flow rate for cesium is only 60% of that required for potassium, which could therefore reduce the size of the entire piping system. Furthermore, with regard to the turbine design, the thermodynamic properties of cesium are preferable to those of potassium. The disadvantage of cesium is its higher cost.

6. Low-Temperature Heat Utilization Program

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6.1 INTRODUCTION

The work of the Low-Temperature Heat Utilization Program during the past year has been mainly concerned with geothermal and solar energy applications. The general objective of the geothermal-related studies is to develop commercially useful technical and cost information on components and systems for converting heat from geothermal sources to useful work. This work consists of both analytical and experimental activities currently concentrated on developing improved heat transfer surfaces for condensers in Rankine or supercritical conversion cycles using fluorocarbons as working fluids. This work is a collaborative effort between the Engineering Division and the Engineering Technology Division, the latter Division being responsible for performing the heat transfer experimental activities.

Solar energy activities are associated with the ERDA Ocean Thermal Energy Conversion (OTEC) Program in providing technical and management assistance in the planning, execution, and analysis of the heat exchanger development program. The development of large, high-performance, low-cost heat exchangers has been shown to be one of the critical needs in establishing the viability of the OTEC concept. This heat exchanger application, although essentially free from thermal stresses, is subject to the uncertainties of biofouling and corrosion and to the many problems encountered with equipment much larger than has ever before been designed for or operated at very low temperature differences. Both the geothermal and the solar programs are concerned with the development of advanced-design heat exchangers for use in low-temperature energy conversion cycles. Thus, much of the experimental and analytical work is mutually complementary.

6.2 GEOTHERMAL ENERGY CONVERSION

Most of the past year's geothermal energy conversion activities have been concerned with operating the test loop and correlating the condensing heat transfer data. The test loop has been operating

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successfully without any major problems since its completion in 1975.[5] We have also begun to apply experimental heat transfer data to the design of a large condenser for the Raft River Geothermal Demonstration Project.

The book *Geothermal Energy as a Source of Electric Power*,[6] although written in 1975, was published and distributed this past year.

6.2.1 Heat Transfer

Most of the working fluids that have been shown to be attractive for the conversion of geothermal heat to electricity[6] have relatively poor heat transfer characteristics. Since current cost analyses of geothermal power plants show the heat exchangers as representing from one-third to one-half of the total plant direct cost, our program, aimed at improving the heat transfer effectiveness and reducing the cost of these units, has a high payoff potential. The approach adopted in our current efforts to improve heat exchanger performance with these fluids is based on heat transfer developments from our former seawater desalting program using fluted (Gregorig surface) condenser tubes. Later we plan to investigate (1) problems associated with improving the working fluid heat transfer coefficients in the evaporator or boiler and (2) means to increase the brine- or water-side coefficients for both boilers and condensers.

Condensation experiments. The specific objective of the current condensation experiments is to obtain data on a number of different Gregorig-type heat transfer surfaces (tubes) with several working fluids so that the effects of geometry and fluid properties may be quantified. The resulting correlations can then be used to design geothermal power plant condensers of optimum performance for a given working fluid.

The condensation test loop completed last year has been used to obtain data for five fluorocarbons on five types of tubes as shown in Table 6.1. Condensation coefficients are computed from Wilson plots ($1/U$ vs $1/V^{0.8}$, where U = overall coefficient and V = cooling water velocity) over a Q/A (heat transferred/unit area) range of about 5000 to 30,000 W/m^2 (1600 to 10,000 Btu/hr·ft^2). The physical characteristics of the tubes (nominally, 2.54 cm OD and 1.2 m long) are summarized in Table 6.2, and the pertinent physical properties of the fluids are summarized in Table 6.3. The heat transfer performance is shown in Fig. 6.1, where h, the condensation coefficient, is plotted vs heat flux, Q/A. The relative performance is better illustrated in Fig. 6.2, in which the ratio of the condensing coefficients (tube E/tube A) is plotted vs heat flux for four of the fluids evaluated. The improved performance is more pronounced at low heat fluxes and varies from a factor of 5.4 for R-22 at low flux to <2 for R-114 at high flux. It should be noted that the heat transfer area used for both h and Q/A is the total outside tube surface area.

Analysis and correlation. In an effort to understand and describe more fully the important factors affecting the experimentally observed condensation heat transfer performance, we initiated analytical and correlation investigations. Smooth-tube data were transformed to nondimensional form and compared with accepted models and correlations. These data are shown in Fig. 6.3 as a plot of the reduced heat transfer coefficient vs Reynolds number. In this form, data from all the fluids tested group in a rather tight band despite the rather wide spread in individual values (see Table 6.3). Such a tight band indicates that the nondimensional groups employed account for the governing mechanisms of heat

5. W. Fulkerson et al., *Energy Div. Ann. Prog. Rep., Dec. 31, 1975*, ORNL-5124.

6. S. L. Milora and J. W. Tester, *Geothermal Energy as a Source of Electric Power*, MIT Press, Cambridge, Mass., 1976.

Table 6.1. Test matrix for geothermal condensation experiments

Fluid	Tube[a]				
	A	B	C	D	E
R-114[b]	X	X	X	X	X
R-21	X				
R-22	X			X	X
R-11	X	X	X	X	X
R-113	X	X		X	

[a]X = test completed

[b]The R-114 tests were completed in 1975

Table 6.2. Characteristics of tubes

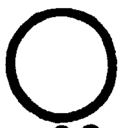
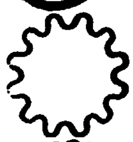
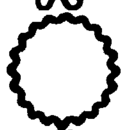
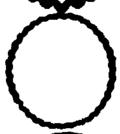
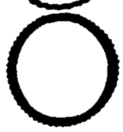
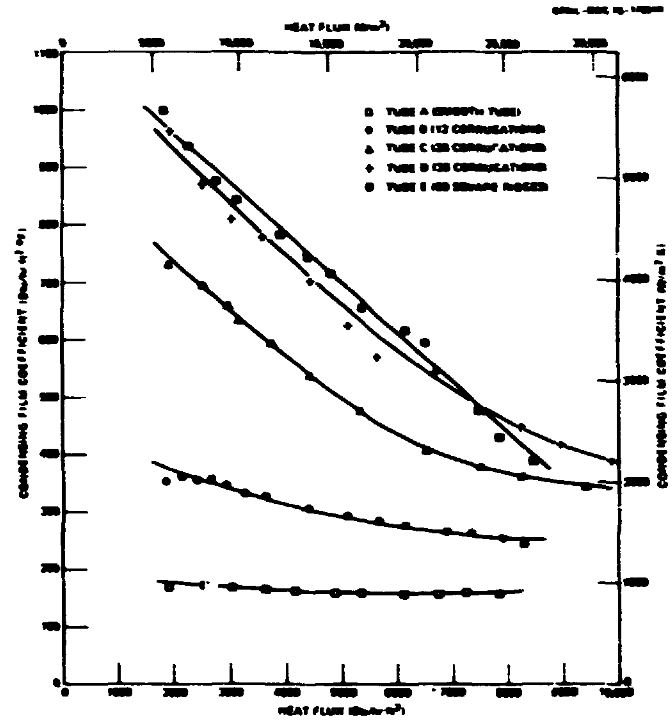
Cross section	Tube designation	Material	External perimeter (cm)	External surface area (m^2)	Number of flutes
	A	Aluminum	8.00	0.0973	0
	B	Al. brass	11.94	0.1295	12
	C	Al. brass	8.90	0.0967	20
	D	CuNi (90:10)	8.90	0.0967	36
	E	Aluminum	12.71	0.1381	60

Table 6.3. Comparison of fluid properties at 38°C (100°F)

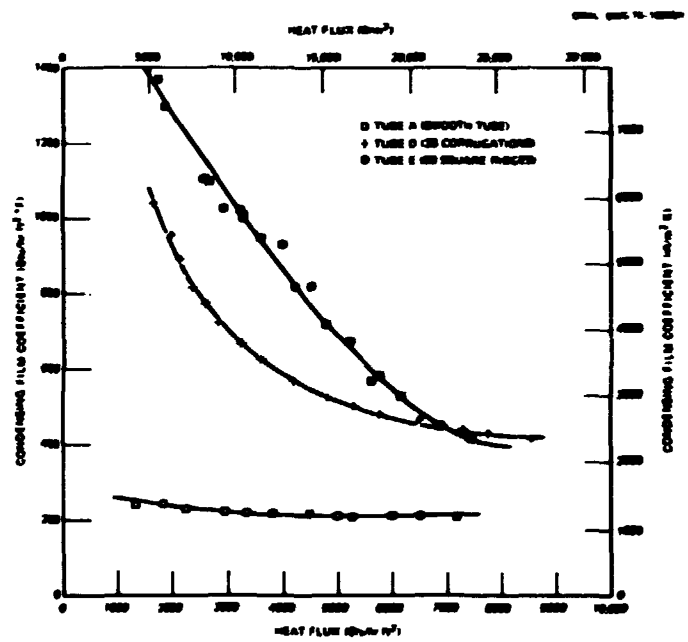
Refrigerant number	Formula	P_{sat} [Pa (psia)]	k [W/m·K (Btu/hr·ft·°F)]	μ [Pa·s (lb$_m$/ft·hr)]	ρ [kg/m^3 (lb$_m$/ft^3)]	h_{fg} [J/kg (Btu/lb$_m$)]	C_p [J/kg (Btu/lb$_m$)]	σ [N/m (lb$_f$/ft)]
11	CCl_3F	161,750 (23.46)	0.0839 (0.0485)	3.696×10^{-4} (0.894)	1445.01 (90.209)	175.01×10^3 (75.24)	895.98 (0.214)	0.167 (1.14×10^{-3})
21	$CHCl_2F$	276,070 (40.04)	0.1018 (0.0588)	2.836×10^{-4} (0.686)	1335.3 (83.36)	221.249×10^3 (95.12)	1063.45 (0.254)	0.01625 (1.11×10^{-3})
22	$CHClF_2$	1,452,040 (210.6)	0.0815 (0.0471)	1.835×10^{-4} (0.444)	1141.09 (71.236)	169.426×10^3 (72.84)	1310.47 (0.313)	0.00645 (0.44×10^{-3})
113	$C_2Cl_3F_3$	72,260 (10.48)	0.0725 (0.0419)	5.701×10^{-4} (1.379)	1534.41 (95.79)	149.934×10^3 (64.46)	971.34 (0.232)	0.01721 (1.18×10^{-3})
114	$C_2Cl_2F_4$	316,120 (45.85)	0.0613 (0.0354)	2.94×10^{-4} (0.71)	1416.19 (88.41)	123.07×10^3 (52.91)	1042.51 (0.249)	0.01053 (0.72×10^{-3})
600a	C_4H_{10}[a]	496,700 (72.04)	0.102 (0.059)	1.45×10^{-4} (0.35)	534.70 (33.38)	309.59×10^3 (133.1)	2625.12 (0.627)	0.0089 (0.61×10^{-3})
717	NH_3[b]	1,461,000 (211.9)	0.452 (0.261)	1.232×10^{-4} (0.298)	583.07 (36.4)	1111.36×10^3 (477.8)	4848.31 (1.158)	0.0234 (1.20×10^{-3})
718	H_2O[b]	6,550 (0.950)	0.628 (0.363)	6.53×10^{-4} (1.58)	993.14 (62.00)	2412.06×10^3 (1037.0)	4178.43 (0.998)	0.06992 (4.79×10^{-3})

[a]Tests planned with this fluid, isobutane.

[b]Shown for comparison.



(R-11)



(R-22)

Fig. 6.1. Condensation heat transfer coefficients for R-11 and R-22.

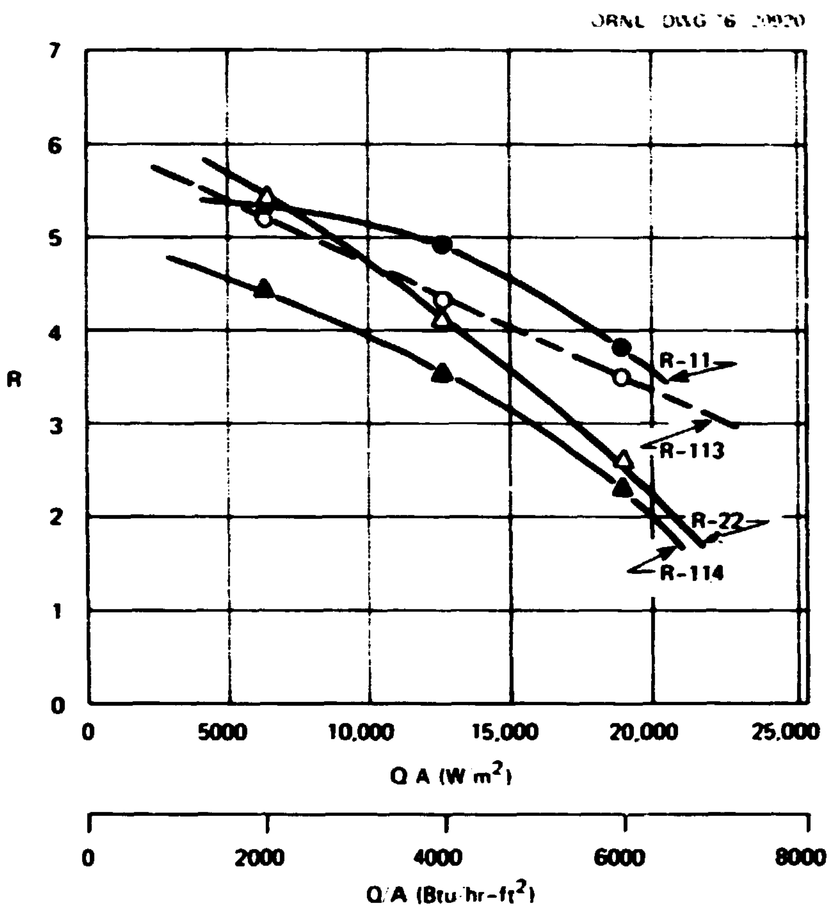


Fig. 6.2. Fluted-tube heat transfer enhancement plot of R, ratio of condensation coefficients; $h_{tube\ E}$ to $h_{tube\ A}$ vs heat flux, Q/A.

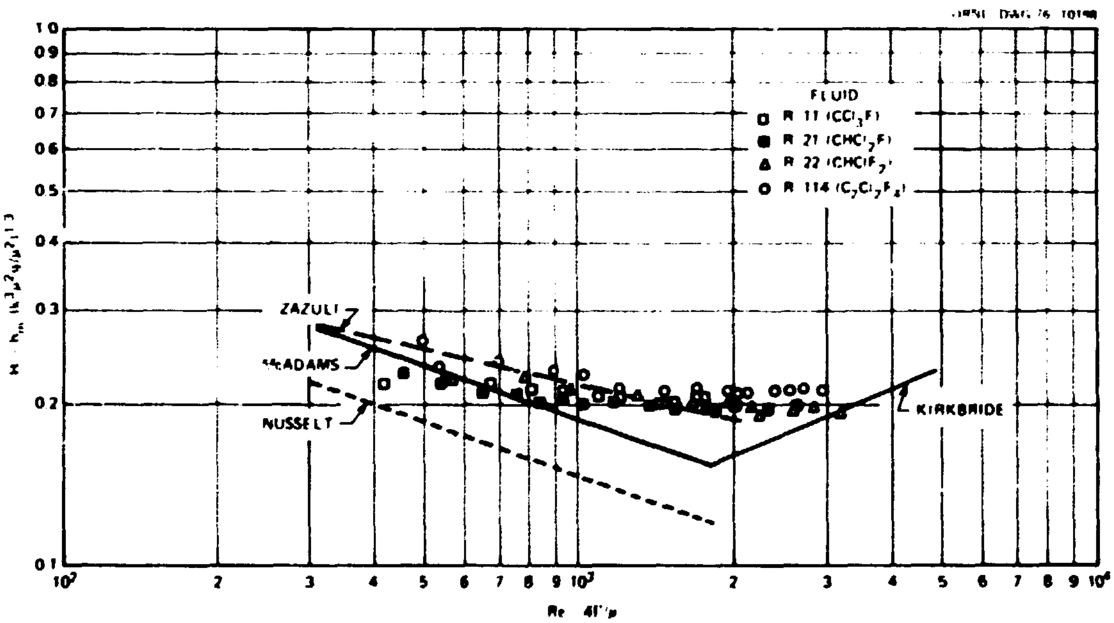


Fig. 6.3. Vertical smooth-tube (A) condensation data—standard nondimensional coordinates (Γ = condensate flow rate at bottom of tube per foot of tube periphery).

transfer. The data band lies considerably above the Nusselt (analytical) prediction and somewhat above the McAdams (experimental) correlation over much of the test range. A correlation by Zazuli[8] which purports to account for ripple effects in the condensate film seems to be in better agreement with the data.

When the same nondimensional approach is applied to data from some of the fluted tubes (see Fig. 6.4 for tube B data), data groupings for different fluids are not nearly as tight. In addition, the data lie far above the Zazuli correlation level. Both observations reinforce the view that, with the fluted tubes, another mechanism comes into play which (1) augments condensation heat transfer and (2) is not adequately accounted for in the standard nondimensional groups. Such effects are consistent with results of previous investigators (working primarily with water) who attributed their findings to surface tension drainage effects on contoured surfaces.

Based on previous work, a first-order analysis of the film condensation and channel drainage situations was developed for fluted tubes within certain operating ranges. From this analysis came a modified set of governing nondimensional groups which attempts to account for surface tension drainage forces acting circumferentially on the condensate film forming on the fluted tube surface. First-order characterization of the surface geometry is presented as the square of the flute spacing (p^2) in the nondimensional ordinate of Fig. 6.5. Application of the first-order model to data from tube B gives the plot presented in Fig. 6.5. It is clear that the data band in Fig. 6.5 is considerably tighter than that in Fig. 6.4 and considerably closer to the prediction-correlation line. Development, refinement, and verification of models such as that described above are key steps in providing reliable design information for geothermal power plant applications.

7. W. H. McAdams, *Heat Transmission*, 2d ed., McGraw-Hill, New York, 1942, p. 269.
8. S. S. Kutateladze, *Fundamentals of Heat Transfer*, Academic Press, New York, 1962, p. 307.

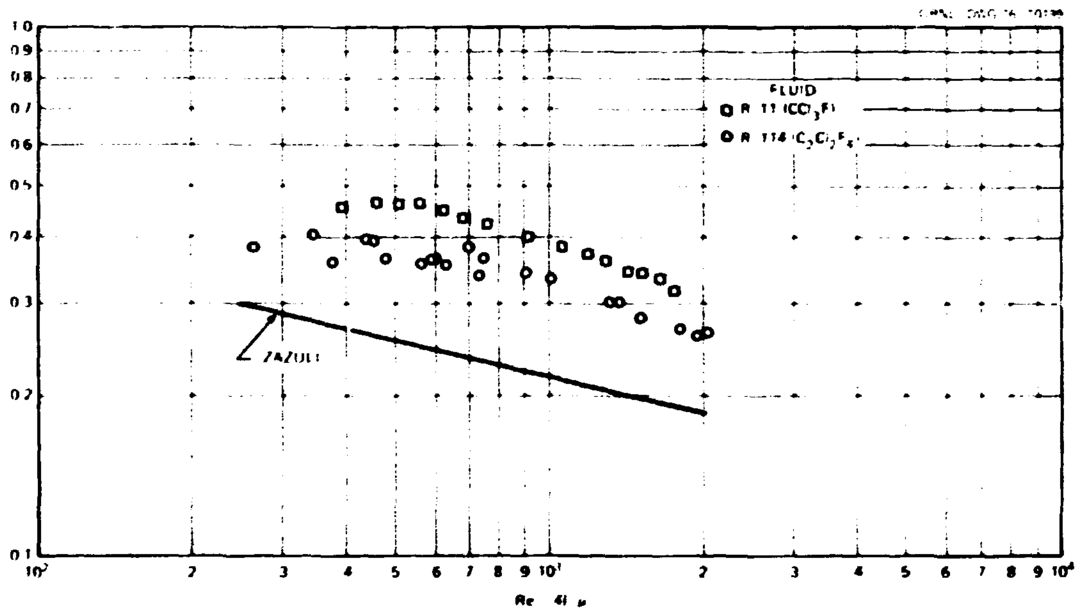


Fig. 6.4. Fluted-tube (B) condensation data—standard nondimensional coordinates.

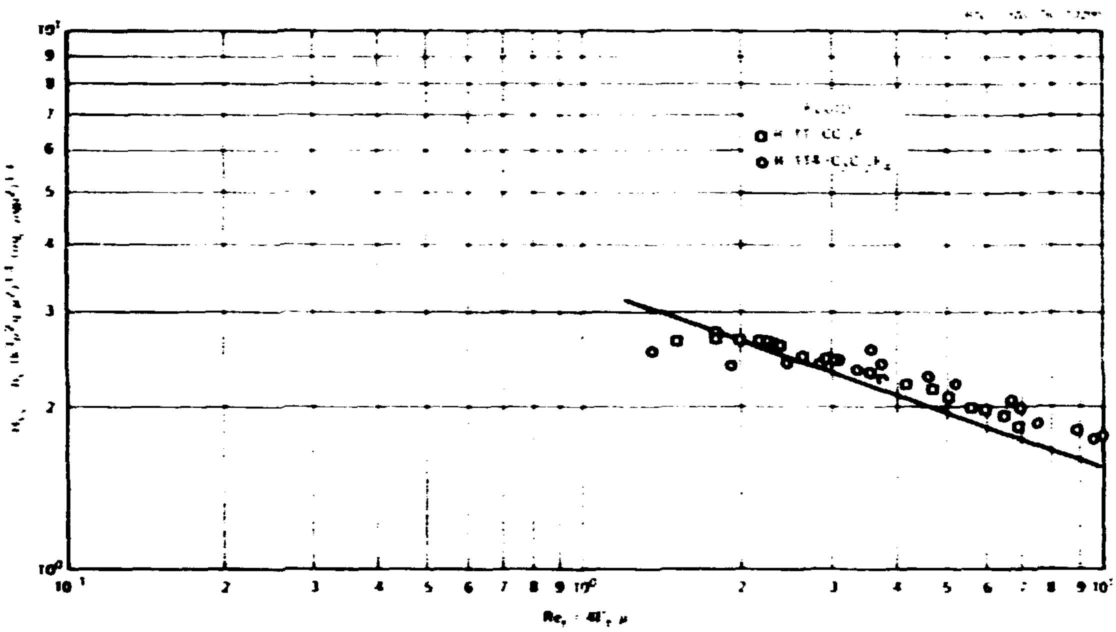


Fig. 6.5. Fluted-tube (B) condensation data—modified nondimensional coordinates.

6.2.2 Cycle Analysis

Although the condensation experimental and correlation work has not progressed to the point that it can be used as the basis for commercial condenser designs, some work has been done to determine the possible range of ultimate economic impact for the application of these enhanced tubes. The example from ref. 6 for the 150° C, 100 MW(e) case, as summarized in Tables 14, 15, and 18 of that reference, may be used to illustrate the potential benefits. In this case, using a conventional smooth tube condenser, the overall heat transfer coefficient was 727 W m^{-2}·K (128 Btu hr·ft^{-2}·°F) at a heat flux of 8960 W m^{-2}·K (2840 Btu hr·ft^{2}). At this heat flux, the ratio of condensing film coefficients for tube E to those for tube A varies between 4 and 5 for the four fluids tested. Assuming the same tube wall and water film resistances, this would translate to an overall coefficient of about 1476 W m^{-2}·K (260 Btu hr·ft^{-2}·°F), or an improvement of a factor of about 2. Thus, the condenser heat transfer area can be reduced by this factor. The number of tubes (same length and diameter) required is reduced by even a larger factor since tube E has about 60% more heat transfer area than does tube A. If the tubes were of equal cost, the condenser cost could decrease by over a factor of 3, giving a maximum savings for the 100-MW(e) plant of nearly \$5 million in direct equipment costs, or more than \$10 million if the associated indirect cost factors as used in the example from ref. 6 are included.

6.3 OCEAN THERMAL ENERGY CONVERSION

Work on this project began in February 1976 in providing technical assistance in program planning, preparation of requests for proposals (RFP), proposal review, and contract monitoring relative to the development of advanced heat exchangers for OTEC application. In addition, several ad-hoc assignments, including a site survey for a core test facility, bottoming cycle analysis, planning and conducting meetings, and initiating a subcontract for a review of heat transfer enhancement literature, were completed.

6.3.1 Development of Advanced-Design Heat Exchangers

As part of the effort to provide technical assistance to the ERDA-OTEC program, several preliminary analyses of heat exchanger concepts and computational work were begun. The two baseline OTEC system studies that were completed by Lockheed[9] and TRW, Inc.,[10] indicated that the plant capital cost would have to be reduced for this concept to become economically competitive by the early 1990s. Further, a large portion of the reductions might come from the use of advanced-design heat exchangers since they represent over one-half of the total direct cost. Thus, to achieve substantial plant cost reductions, dramatic improvements (with acceptable pressure losses) will be required in heat transfer effectiveness, which can in turn be translated into heat exchanger cost reductions.

Figure 6.6 was prepared to illustrate the potentials and limitations in advancing OTEC heat exchanger performance as an input to establishing program development goals. Increasing the overall heat transfer coefficient allows the heat transfer area to be decreased at constant operating temperatures and thus should give a smaller, less costly unit. Increasing the coefficient may be accomplished by (1) improving the ammonia coefficient, h_{NH_3}, (2) improving the seawater coefficient, h_{sw}, or (3) reducing the tube wall and/or fouling resistances. The baseline designs indicated that an overall coefficient of 2270 W/m^2·K (400 Btu/hr·ft^2·°F) is possible with relatively clean titanium tubes. Shifting to aluminum tubes would give about a 12% improvement, but even increasing the h_{NH_3} by a factor of 4 [to 34,000 W/m^2·K (6000 Btu/hr·ft^2·°F)] would only give an additional 29% improvement in the overall coefficient.

The biggest gains are available by improving the h_{sw}. For the case shown for aluminum, doubling the seawater coefficient would increase the overall coefficient by about 40% at the same h_{NH_3}, and an improved h_{NH_3} of 34,000 W/m^2·K (6000 Btu/hr·ft^2·°F) would yield an overall improvement of about a factor of 2. Also, if for this case the fouling resistance [baseline value = 5.3×10^{-5} m^2·K/W (0.0003 hr·ft^2·°F/Btu)] could be decreased by a factor of 2, a total heat transfer improvement over the baseline design of a factor of 2.6 could be achieved. Improvements in h_{NH_3} to values of 34,000 to 56,800 W/m^2·K (6000 to 10,000 Btu/hr·ft^2·°F) appear possible by using fluted tubes for the condenser and/or evaporator and a nucleation enhancement or high-flux surface for the evaporator.

Improvements possible in the h_{sw} are illustrated in Table 6.4 and Fig. 6.7 and indicate that a factor of about 2 (at constant pumping power) should be achievable. If the plant design is optimized for these improved heat exchangers, the overall effect may be still greater, but it would be sensitive to the actual cost of the heat transfer surface and especially to the premise that the surfaces could be maintained in a "clean" condition.

Thus, the results of this preliminary analysis indicate that achieving the following heat exchanger development goals is highly desirable to ensuring the economic viability of the OTEC concept:

1. Improve seawater-side heat transfer coefficient by a factor of about 2 while maintaining acceptable water-side pressure losses and tube cost.
2. Improve ammonia-side coefficient by a factor of 3 to 5.
3. Develop a cost-effective biofouling control or cleaning system to maintain the fouling resistance between 2.6 and 5.3×10^{-5} m^2·K/W (0.00015 and 0.0003 hr·ft^2·°F/Btu).
4. Qualify aluminum as a heat exchanger material.

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9. L. C. Trimble et al., "Ocean Thermal Energy Conversion System Study Report," pp. 3–20 in *Proceedings, Third Workshop on Ocean Thermal Energy Conversion, Houston, Tex., May 8–10, 1975.*

10. R. H. Douglas, "Ocean Thermal Energy Conversion: An Engineering Evaluation," pp. 22–36 in *Proceedings, Third Workshop on Ocean Thermal Energy Conversion, Houston, Tex., May 8–10, 1975.*

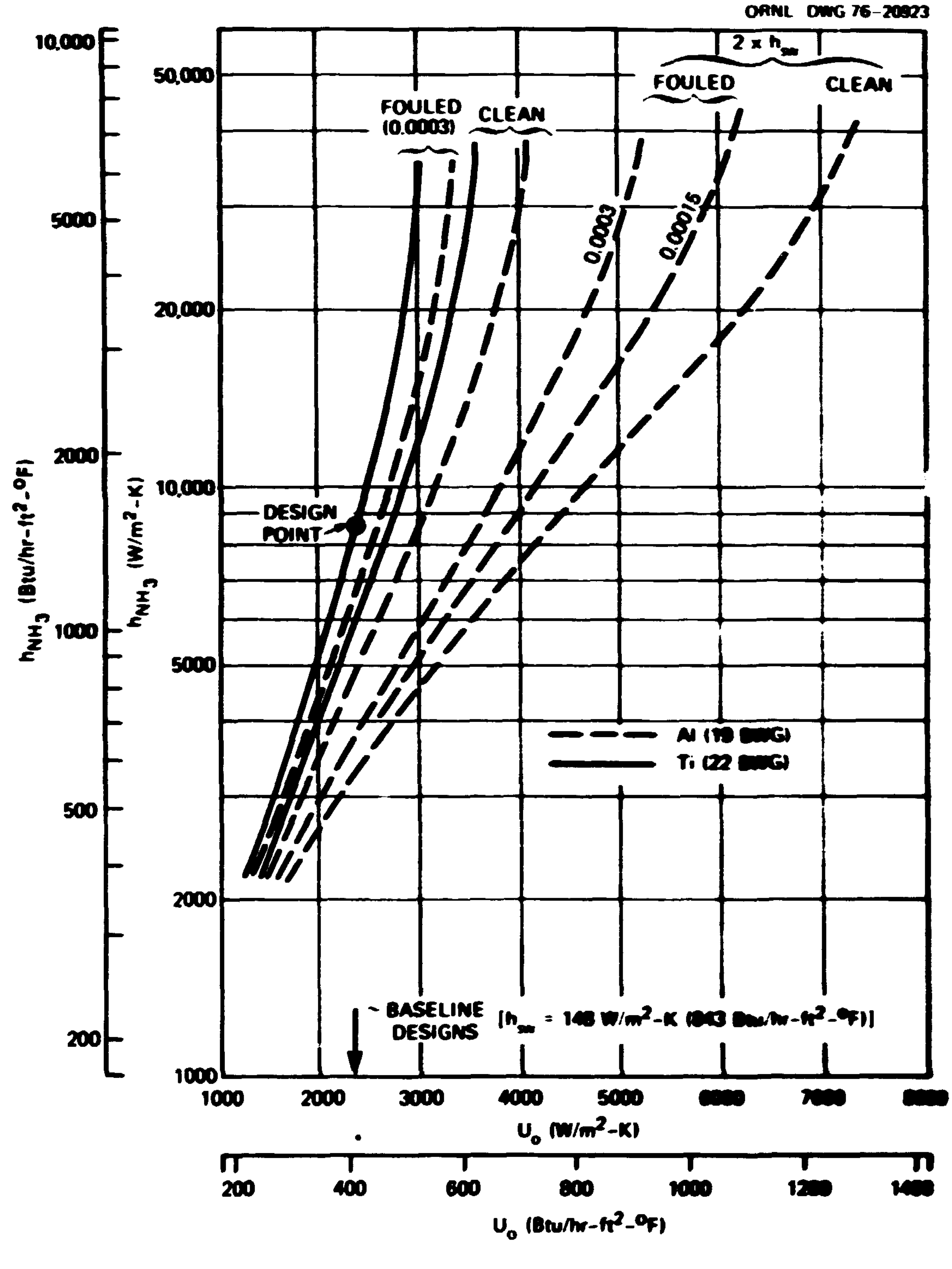

Fig. 6.6. OTEC heat transfer potentials and limitations; plot of ammonia-side heat transfer coefficient vs overall heat transfer coefficient.

Table 6.4. Approximate performance comparison of internally finned tubes

Investigator	Type	Tube No.	Inside diameter [cm (in.)]	Fin height [cm (in.)]	Number of fins	A_{finned}/A_{smooth}	$Re_l = 20{,}000^{a,b}$		$Re_s = 20{,}000^{a,c}$
							h_{finned}/h_{smooth}	f_{finned}/f_{smooth}	$(h_{finned}/h_{smooth})_P$
Bergles	Spiral	3	2.50 (0.986)	0.20 (0.078)	16	1.66	2.6	2.6	2.3
Watkinson	Spiral	18	3.04 (1.196)	0.45 (0.178)	8	1.63	2.3	2.0	1.9
Watkinson	Spiral	19	3.15 (1.240)	0.08 (0.032)	50	1.54	2.3	3.1	1.6
Bergles	Axial	4	1.41 (0.554)	0.15 (0.060)	10	1.60	1.9	2.1	1.5

[a] All heat transfer coefficients, *h*, and friction factors, *f*, are based on the tube inside diameter.

[b] Each dimensionless *h* and *f* in columns 8 and 9 can be interpreted as the performance ratio of the given finned tube to a smooth tube of the same inside diameter at a given volume flow.

[c] The dimensionless *h* in column 10 is the ratio of finned tube heat transfer coefficient to smooth tube (with same inside diameter) heat transfer coefficient at a given pumping power (chosen here to be that pumping power corresponding to a smooth-tube Reynolds number of 20,000).

Sources: A. E. Bergles et al., *Investigation of Heat Transfer Augmentation Through Use of Internally Finned and Roughened Tubes*, Report DSR 70790-69, MIT Engineering Projects Laboratory, 1970.

A. P. Watkinson et al., *AICHE Symp. Ser.* 69(131), 94–103 (1973).

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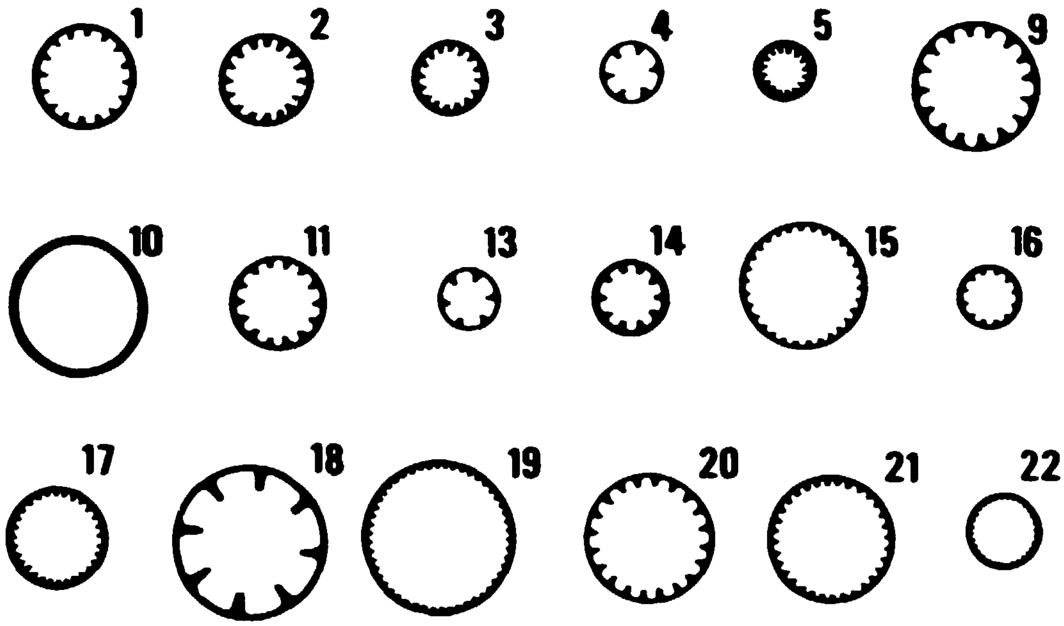

Fig. 6.7. Cross section of inner fin tubes tested by Watkinson. (Bergles tube 3 cross section is similar to the Watkinson tube 20 cross section, and Bergles tube 4 is similar to Watkinson tube 14.)

To provide a rapid estimate of the effects of various design parameters on the size of shell and tube OTEC heat exchangers, a set of equations was developed to define tube length, number of tubes, and tube bundle diameter.

The general equation for tube length is

$$L = 900 \frac{C_p \rho V}{U_o} \left(\frac{d_i^2}{d_o}\right) \ln \left(\frac{\Delta T_1}{\Delta T_1 - \delta t}\right) . \quad (1)$$

and for seawater inside the tubes,

$$L_{sw} = 55 \times 10^3 \left(\frac{V}{U_o}\right) \left(\frac{d_i^2}{d_o}\right) \ln \left(\frac{\Delta T_1}{\Delta T_1 - \delta t}\right) . \quad (2)$$

where

L_{sw} = tube length for seawater,
C_p = specific heat of seawater, Btu/lb/°F,
ρ = water density, lb/ft^3,
V = water flow velocity, ft/sec,
U_o = overall heat transfer coefficient, Btu/hr·ft^2·°F,
d_i = tube inside diameter, ft,
d_o = tube outside diameter, ft,
ΔT_1 = inlet approach temperature difference, °F,
δt = seawater temperature change, °F.

This equation is illustrated graphically in Fig. 6.8 for a seawater velocity inside the tubes of 1.5 m/sec (5 ft/sec) (typical for an optimized plant) for two tube diameters and three values of ΔT_i with δt = 1.1°C (2°F), or for three values of ΔT_m (log mean ΔT between seawater and ammonia). Thus, if the heat transfer development goals are achieved, the likely range of tube lengths is from 1.5 to 4 m (5 to 15 ft).

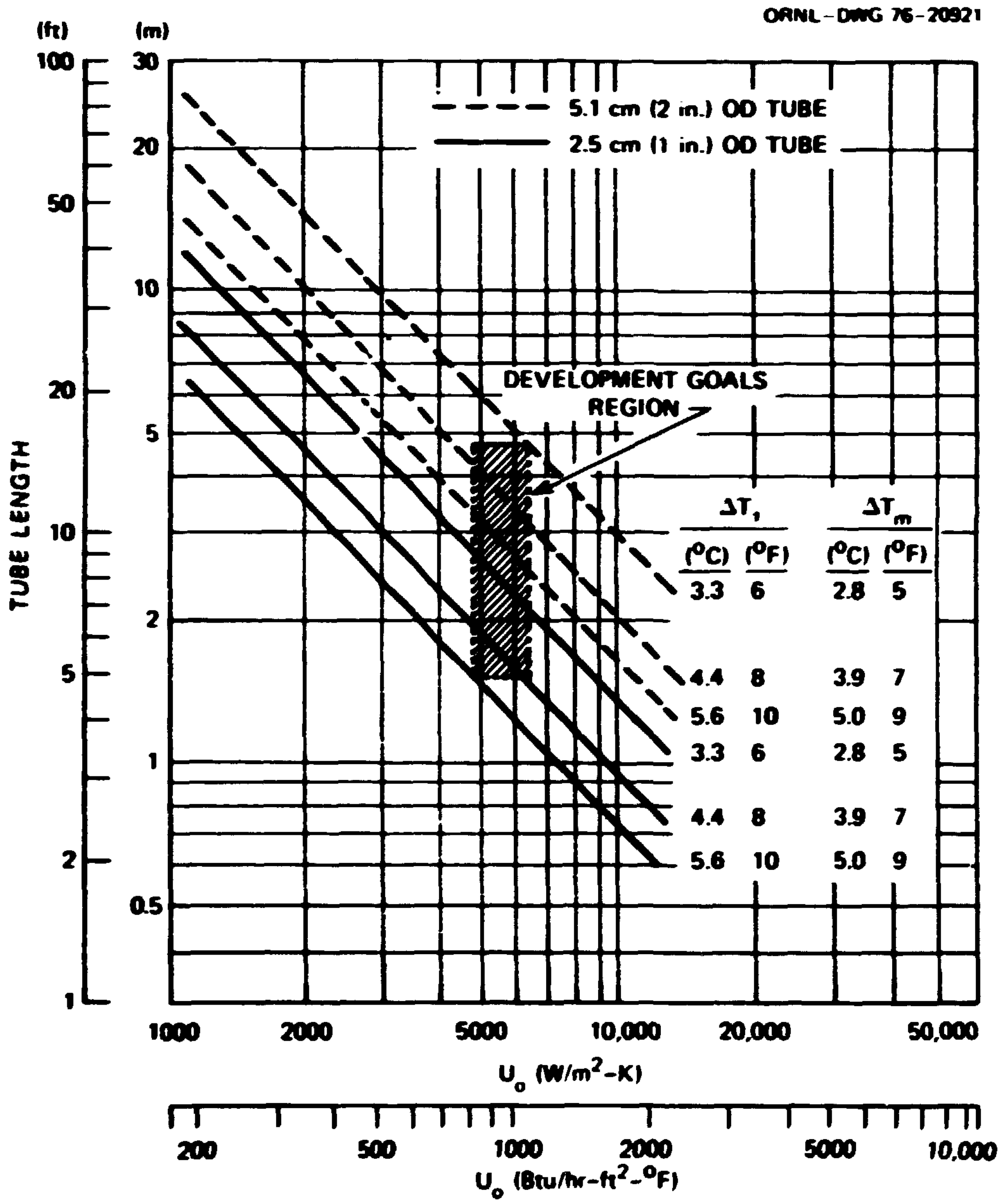

Fig. 6.8. OTEC shell and tube heat exchanger tube length for seawater velocity of 1.5 m/sec (5 ft/sec) and δt of 1.1°C (2°F) as a function of the overall heat transfer coefficient and several values of temperature drop.

The number of tubes required may be determined from the following relationship:

$$N = 20 \frac{MW(e)}{\eta} \left(\frac{1}{V\delta t d_i^2}\right) . \tag{3}$$

where

$MW(e)$ = net electrical plant power.
η = overall cycle efficiency.

The tube bundle diameter (assuming no vapor lanes or other nondrilled areas) and thus an idea of the heat exchanger shell diameter can be estimated from

$$D = 1.05 P d_o \sqrt{N} . \tag{4}$$

where

P = ratio of tube spacing to tube diameter.

Figure 6.9 gives the number of tubes and the tube bundle diameter as a function of the power module size for two values of tube size and δt at a fixed seawater flow velocity and cycle efficiency. It may be noted that the tube bundle diameter is nearly independent of the tube diameter and that both D and N are sensitive to the seawater temperature change and velocity.

Program planning and analysis. Technical assistance was provided in developing the OTEC heat exchanger development program plan. This plan calls for a phased development of several ammonia evaporator and condenser concepts: (1) single-tube or laboratory investigations; (2) bench-scale or core tests, 1.17×10^6 W (4×10^6 Btu/hr) [equivalent to 0.03 MW(e)]; (3) early ocean tests for (*a*) 1 MW(e) (equivalent—no turbine) and (*b*) 5 MW(e) (complete system); (4) full-size prototype, about 25 MW(e); and (5) full-station prototype, about 4 × 25 MW(e).

Four of these phases are noted on Fig. 6.9 (arrows), illustrating the increase in heat exchanger size as a function of power. Not shown in Fig. 6.9 is the parameter size range for the 1.17×10^6 W (4×10^6 Btu/hr) [0.03 MW(e)] core test size; values for a seawater velocity of 1.5 m/sec (5 ft/sec) are shown below.

d_o	δt = 1.1°C (2°F)		δt = 2.2°C (4°F)	
	N	D [m (ft)]	N	D [m (ft)]
1	410	0.7 (2.2)	205	0.5 (1.6)
2	93	0.6 (2.1)	46	0.5 (1.6)

The primary evaporator concepts being investigated under a number of ERDA contracts are (1) sprayed thin-film evaporation (horizontal smooth tube); (2) sprayed thin-film evaporation (high-flux surface); (3) thin-film evaporation on outside vertical fluted tube; (4) pool boiling with nucleation promotion; and (5) two-phase, forced-flow boiling inside tubes. Although the main efforts are directed at the shell and tube configurations, some work is planned for the plate-fin and panel concepts. Condenser types being developed are horizontal or tilted smooth-tube and vertical fluted-tube design. For both heat exchangers, some work has been started on seawater (single-phase) heat transfer enhancement.

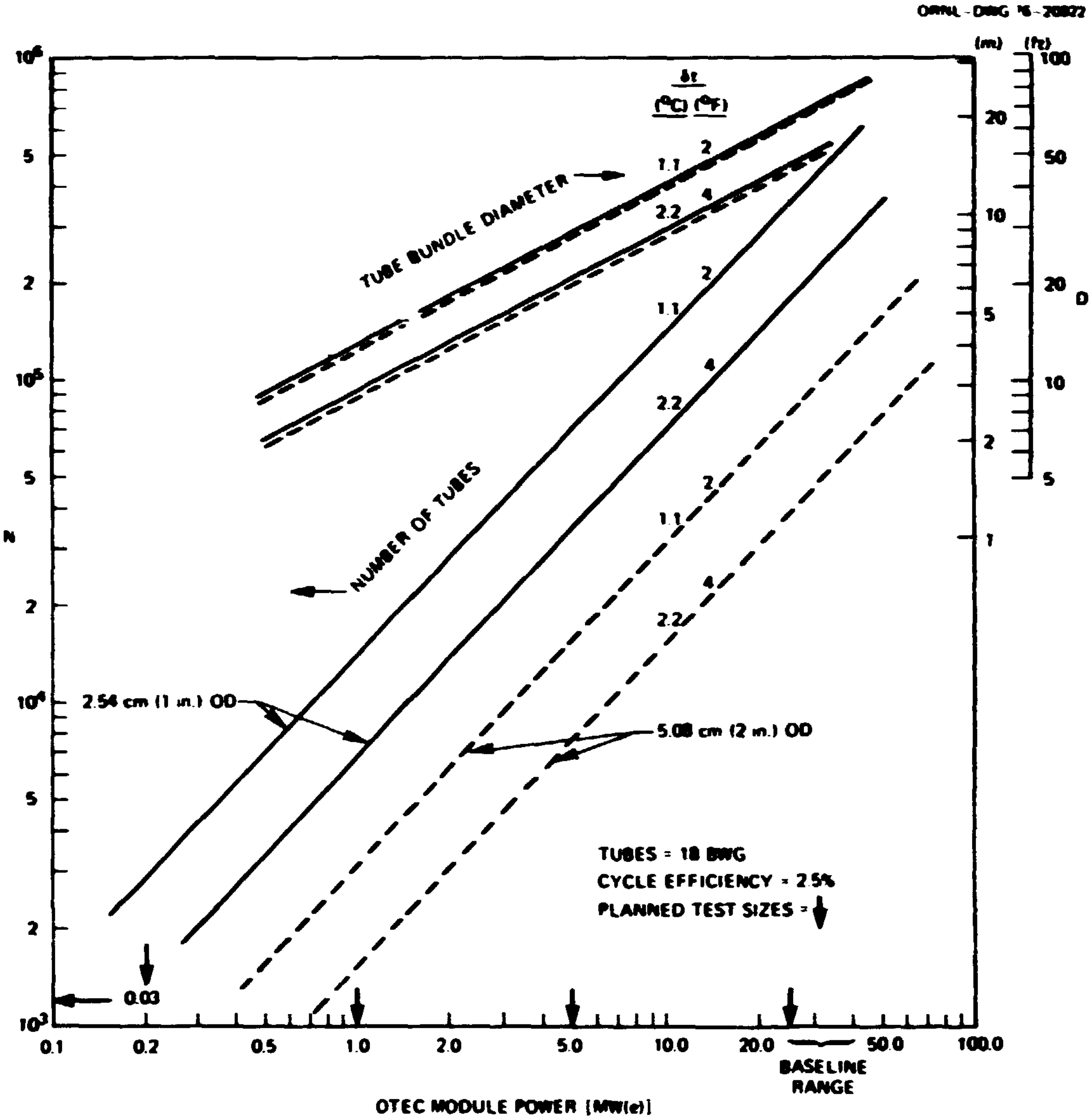

Fig. 6.9. Size of OTEC heat exchangers as a function of power level at two tube diameters and two values of seawater temperature drop (rise), δt. Cycle efficiency is taken to be 2.5%, and water velocity is 1.5 m/sec (5 ft/sec) to establish the relationship for the number of tubes, N.

In addition to the heat transfer studies, work under other ERDA contractors is beginning on hydraulic problems, materials work, alternative working fluids, and design and producibility of large units.

Subcontracting assistance. Assistance has been provided in preparing and reviewing the technical work scopes for RFP packages and reviewing the work proposals in the area of heat transfer. A total of 14 visits were made to eight contractor sites to review and monitor the progress of OTEC heat transfer R&D projects. Four other visits were made to provide assistance to the biofouling and corrosion program, and seven programmatic review visits were made to Washington, D.C.

6.3.2 Special Studies

Several special studies have been started. These include development of an OTEC system optimization model and computer program, surveys of specialized heat transfer literature, and a preliminary examination of the current state of the art in the use of ammonia bottoming cycles for conventional power generation.

System optimization program. As implied in some of the above discussion, an OTEC plant operating at maximum cost effectiveness will require rigid optimizations and trade-offs between some eight or more variables: seawater temperatures, water pumping power, heat transfer geometry, working fluid temperature and pressure drops, and component efficiencies. Figure 6.10 illustrates some of the interrelationships among the components of an OTEC plant. Work has been in progress to develop a model and program of wide flexibility to aid in optimizing the many design and operating variables of the various OTEC concepts and system variations.

Aside from its obvious help in designing OTEC plants, the program will be a valuable tool for the ERDA-OTEC administration in allocating funds and technical effort among competing concepts and in assuring that adequate effort is placed in specific areas of uncertainty, including not only heat transfer and biofouling but fabrication, logistics, and requirements for instrumentation and control.

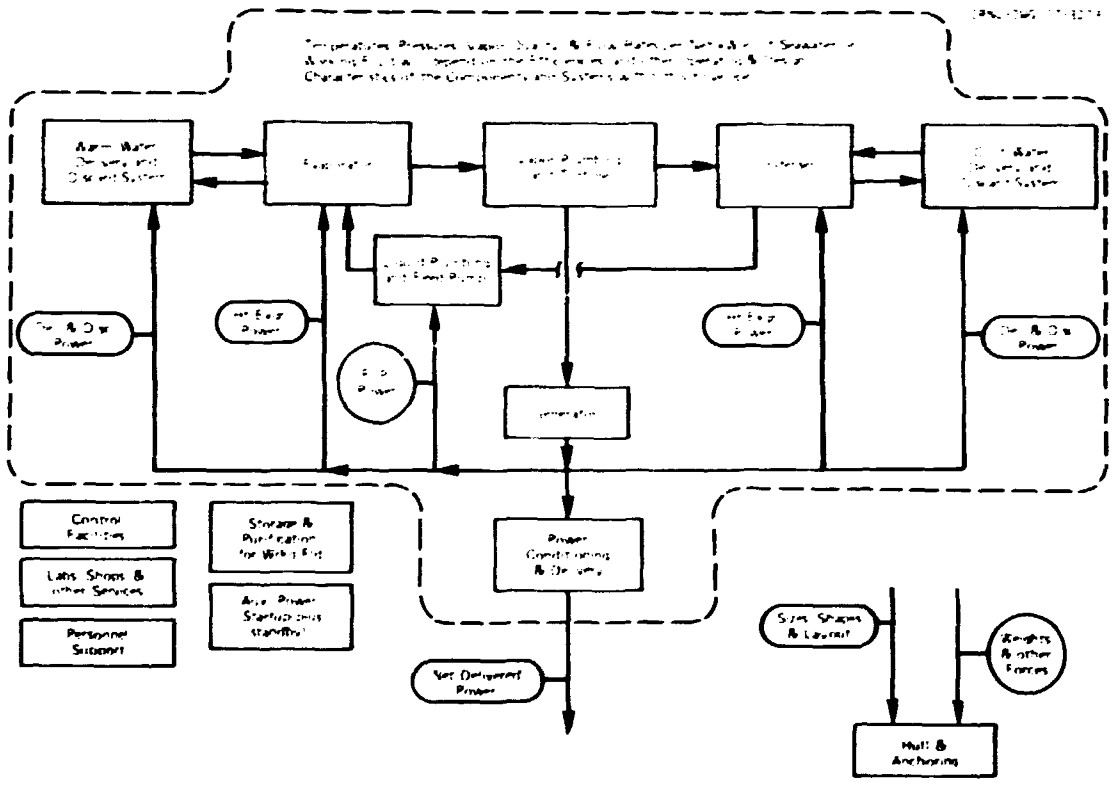

Fig. 6.10. Major interrelationships between the components and systems of an OTEC plant. *(The feed pump would be eliminated in an open system.)*

The suggested optimization program includes

1. Establishment of a generalized model that will fit all reasonable OTEC concepts.
2. Establishment of an internally complete and consistent set of independent variables.
3. An algorithm or set of algorithms for computing the values of dependent design and operating variables from a set of values for the independent variables.
4. Computation of corresponding capital and operating costs.
5. Computation of the corresponding value of the criterion — presumably the cost of net power.
6. Determination of the optimum value of the criterion and its location in the independent-variable vector space.
7. Calculation of sensitivities of the criterion to variations in values of independent and dependent variables near its optimum.

Work on several of these factors is in progress, but to complete the work, particularly incorporation of realistic cost data, it has been recommended that a workshop be held for the various contractors (perhaps as many as eight) who have also been working on this problem.

Literature reviews. Under subcontract to Iowa State University, work was started on a literature survey and discussion paper on single-phase heat transfer as applied to the seawater side of OTEC heat exchangers; this work is scheduled for completion in January 1977.

A review of the literature on ammonia boiling and condensing was also started. The technical literature was reviewed back to 1930, and only a few pertinent papers were found; most of these are in Russian and are currently being translated.

The Nuclear Desalination Information Center literature abstract computer tapes were reactivated, and several topical searches were run to extract information believed to be applicable to the OTEC heat transfer program.

7. Publications and Oral Presentations

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J. J. Tudor, *Evolution of a Conceptual Design for a Coal-Fired Fluidized Bed Combustion Furnace for a MIUS Closed-Cycle Gas Turbine* (to be published).

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———. *Indices, A Technique for Using Large Spatial Data Bases*, ORNL RUS-15 (April 1976).

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M. E. Whatley, *A Review of Information Relevant to Tube Corrosion in a Gas-Cooled, Coal-Fired, Atmospheric-Pressure, Fluidized-Bed Furnace* (to be published).

D. L. Wilson, *CELNDX: A Computer Program to Compute Cell Indices*, ORNL RUS-14 (January 1976).

J. V. Wilson, *Energy Usage and Conservation in Mobile Home Heating and Cooling*, ORNL NSF EP-91 (August 1976).

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S. L. Yaffee, *Simulation and Analysis of Political Interaction in Regional Systems*, ORNL RUS-23 (July 1976).

7.2 ORAL PRESENTATIONS

D. J. Bjornstad, "Public Ownership of Energy Facilities: Implications for State and Local Revenue," presented to the National Association of Tax Administrators, Nashville, Tenn., Oct. 20, 1976.

W. J. Boegly, Jr., "International Experiences with Dual Distribution Systems," presented at the AWWA Dual Distribution Systems Seminar, New Orleans, La., June 20, 1976.

W. S. Chern, "A Market Shares Approach to Modeling Energy Demand," presented at the Western Economic Association Annual Conference, San Francisco, Calif., June 23 27, 1976.

J. E. Dobson, "The Beneficiaries of Economic Growth in the Gatlinburg, Tennessee Area, 1930 1973," presented at Annual Meeting, Association of American Geographers, New York, Apr. 12, 1976.

R. C. Durfee et al., "Assignment of ERTS and Topographical Data to Geodetic Grids for Environmental Analysis of Contour Strip Mining," presented at American Congress on Surveying and Mapping, Annual Meeting, Washington, D.C., Feb. 21 22, 1976.

H. C. Fischer, "Application of the Ice-Maker Heat Pump to an Annual Cycle Energy System," presented to the American Society of Mechanical Engineers Winter Meeting, New York, December 1976.

———, "The Development of the Ice-Maker Heat Pump," presented at the American Society of Heating, Refrigerating, and Air Conditioning Engineers Annual Meeting, Seattle, Wash., June 27, 1976.

———, "The Potential of the Annual Cycle Energy System for Rural Iowa," presented at the Iowa Association of Electrical Cooperatives, Des Moines, Iowa, Dec. 2, 1976.

———, "Potential of the Ice-Maker Heat Pump for Agricultural Applications," presented at the Farm Electrication Council, Inc., Symposium on Electrical Energy for the Food Chain, St. Louis, Mo., Sept. 16, 1976.

———, "Solar-Assisted Heat Pumps," presented at the Solar Energy Seminar, Refrigeration Service Engineers Society, Mesa Community College, Mesa, Ariz., Dec. 4, 1976.

———, "Thermal Storage Applications of the Ice-Maker Heat Pump," presented at the Pennsylvania Electric Association Meeting, Harrisburg, Penn., Sept. 16, 1976.

A. P. Fraas, "Application of the Fluidized-Bed Coal Combustion System to the Production of Electric Power and Process Heat," presented at the AIChE Meeting in Kansas City, Mo., Apr. 11 14, 1976.

———, "Boiling Heat Transfer Problems in a Tokamak," presented at the 16th National Heat Transfer Conference of the American Institute of Chemical Engineers, St. Louis, Mo., Aug. 8 11, 1976.

———, "A New Approach to a Fluidized-Bed Steam Boiler," presented at the American Society of Mechanical Engineers Winter Annual Meeting, New York, Dec. 5 10, 1976.

Eric Hirst, "Energy Conservation Options: Households and Transportation," presented to Tennessee Society of Professional Engineers, Oak Ridge, Tenn., June 28, 1976.

———, "Energy Conservation: Potential vs Actual Savings," presented in Argonne National Laboratory Series on Controversial Energy Issues, Argonne, Ill., Sept. 28, 1976.

———, "Energy Conservation Potential of Urban Mass Transit," presented at 55th Annual Meeting of Transportation Research Board, Washington, D.C., Jan. 19 23, 1976.

———, "Modeling Residential Energy Use," presented at Eleventh Intersociety Energy Conversion Engineering Conference, Lake Tahoe, Calif., Sept. 13, 1976.

———, "The ORNL Residential Energy Use Model," presented to California Energy Commission, Sacramento, Calif., June 14, 1976.

———, "Residential Energy Use Alternatives to the Year 2000," presented at National Science Foundation Workshop on Long-Run Energy Demands, Mitre Corp., McLean, Va., June 9 10, 1976.

———, "Residential and Transportation Energy Conservation Measures and Policies," presented at Duke Power Company seminar "The Three E's—Energy, Environment, and Economics," Lake Hickory, N.C., July 29, 1976.

E. C. Hise, "Energy Conservation in Buildings," presented at the Southern Interstate Nuclear Board Conference, Sarasota, Fla., Dec. 8-10, 1976.

———, "Heat Balance and Efficiency Measurements of Central, Forced-Air, Residential Gas Furnaces," presented at the American Society of Heating, Refrigerating, and Air-Conditioning Engineers Symposium, Chicago, Ill., Feb. 13-17, 1976.

———, "The Potential for Energy Conservation Technology Transfer," presented at the Southern Interstate Nuclear Board Meeting, Winston-Salem, N.C., May 24, 1976.

———, "Residential Demand Reduction through Efficiency," presented at the Institute of Gas Technology Symposium on Changing Gas Demand Factors and Their Impacts over the Next Ten Years, Chicago, Ill., Feb. 26, 1976.

R. S. Holcomb, "Fluidized-Bed Combustion," presented at the American Chemical Society 28th Southeastern Regional Meeting, Gatlinburg, Tenn., Oct. 27-29, 1976.

A. S. Holman, "Adding Insulation to Your Hot Water Heater," presented at Save Energy Seminar, Oak Ridge Civic Center, Oak Ridge, Tenn., Sept. 30, 1976.

———, "Annual Cycle Energy System Computer Simulation Program," presented at the Richmond, Virginia, Chapter of the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Richmond, Dec. 6, 1976.

R. B. Honea, "Assignment of ERTS and Topographical Data to Geodetic Grids for Environmental Analysis of Contour Strip Mining," presented at seminar on "The Future of Surface Mined Lands," Natural Bridge State Resort Park, Slade, Ky., Apr. 14-16, 1976; also presented at the Mid-Southeast Chapter Fall Meeting and Conference of the Association for Computing Machinery, Gatlinburg, Tenn., Oct. 1, 1976.

C. R. Kerley, "A Model of Functional Area Retail Trade Receipts," presented at the Western Regional Science Meeting, San Diego, Calif., Feb. 27-29, 1976.

R. L. Kroodsma, "Analysis of Transmission Line Routes—A Case Study," presented at Mid-Appalachia College Council, Oak Ridge Social Science Program, Oak Ridge, Nov. 10-12, 1975.

———, "Breeding Bird Populations of Power Line Rights-of-Way on the Oak Ridge Reservation," presented at Ecological Society of America Conference, New Orleans, La., June 1976.

———, "Ecological and Social Aspects of Transmission Line Routing," presented at Mid-Appalachia College Council, Oak Ridge Social Science Program, Oak Ridge, Mar. 22-26, 1976.

A. S. Loebl, "Issues of Concern to the Effective Exchanges, Joint Development and/or Acquisition of Computer Software in an Interorganizational Program," presented at the Annual Meeting of the Association of Public Data Users, Atlanta, Ga., Aug. 29, 1976.

———, "The Regional and Urban Studies Information Center of the Regional Information Group," presented at the American Society for Information Service Conference on National Energy and Environmental Information Resources, Oak Ridge, Tenn., May 19, 1976.

R. N. Lyon, "Direction and Prospects for Successful Accomplishment of the OTEC Heat Exchanger Program," presented to the National Academy of Engineers, Washington, D.C., June 3, 1976.

———, "Thermal Electric—Geothermal," presented at AIChE Symposium on Energy Conservation and Alternate Sources, Oak Ridge, Tenn., Sept. 21, 1976.

T. J. Mattingly, Jr., "The Hartsville Project: A Second Look at the Effects of a Proposed Nuclear Power Plant," presented at Mid-Appalachian College Consortium, Oak Ridge Associated Universities, Oak Ridge, Tenn., July 12, 1976.

J. W. Michel. "Geothermal Energy Program Summary," presented to ERDA DGE, Washington, D.C., June 27, 1976.

———, chaired National American Chemical Society Session on Thermochemical Production of Hydrogen, New York, Mar. 8, 1976.

———, "Ocean Thermal Energy Conversion," presented at Energy Production and the Environment (Special Training Session), Oak Ridge Associated Universities, Oak Ridge, Tenn., June 29, 1976.

———, "OTEC Heat Exchanger Development Goals," presented at the OTEC-PNL Biofouling and Corrosion Review Meeting, Seattle, Wash., Oct. 14, 1976.

———, "Progress Summary of ORNL's Geothermal Energy Projects," presented at ERDA Geothermal Coordinating Meeting (Ogle's Committee), Livermore, Calif., July 20, 1976.

———, "Thermal Electric - Ocean Thermal," presented at AIChE Symposium on Energy Conservation and Alternate Sources, Oak Ridge, Tenn., Sept. 21, 1976.

———, "Thermal Gradient Energy Sources," presented at Energy Conservation (Special Training Session), Oak Ridge Associated Universities, Oak Ridge, Tenn., Aug. 6, 1976.

W. R. Mixon, "The Modular Integrated Utility System (MIUS) as a Potential Influence on Community Development," presented at the Fifth Annual Environmental Pollution Symposium, Menlo Park, Calif., May 12-13, 1976.

W. R. Mixon and C. L. Segaser, "Energy Conservation Potential of Modular Integrated Utility Systems (MIUS)," presented at the 11th Intersociety Energy Conversion Engineering Conference, State Line, Nev., Sept. 12-17, 1976.

Elizabeth Peelle, "Evaluating the Nuclear Debate," presented at American Association for Advancement of Science Session on Energy Policy and the Future of Nuclear Power, Boston, Mass., Feb. 20, 1976.

———, "Internalizing Social Costs in Power Plant Siting: Some Examples for Coal and Nuclear Plants in the United States, presented at American Nuclear Society Session on Socioeconomic Issues for Nuclear Power Plants: A World View, Washington, D.C., Nov. 19, 1976.

———, "NEPA: What It Is, How It Works," presented to Mid-Appalachian College Consortium students at ORAU conference, Mar. 22, 1976.

———, "People Impacts Compounded: Gillette, Wyoming, Responds to Energy Development," presented to Environmental Sciences Division, ORNL, Dec. 9, 1976.

———, "Social Effects of Large Energy Facilities," presented to Robertsville Junior High class, Oak Ridge, Tenn., Nov. 12, 1976.

———, "Social Effects of Nuclear Power Plants," presented at Energy Division Information Meeting, Apr. 26, 1976.

———, "Social Effects of Nuclear Power Plants," presented to Chemical Technology Division, May 13, 1976.

———, "Social Effects of Nuclear Power Plants in Developing Countries," presented in Argonne National Laboratory International Atomic Energy Agency training course, Apr. 2, 1976.

———, "Social Impact Work at ORNL," presented at Impact Research Conference, University of Wyoming, Laramie, July 22, 1976.

———, "Social Impacts Assessment: Progress and Projects," presented to Argonne National Laboratory Environmental Statements Project, Apr. 1, 1976.

———. "Social Impacts of Nuclear Power Plants: A Typology," presented to Clinch River Breeder Reactor Project Research Group, University of Tennessee, Knoxville, May 14, 1976.

———. "Socioeconomic Effects of Operating Reactors on Two Host Communities: A Case Study of Pilgrim and Millstone," presented at Atomic Industrial Forum Conference on Land Use and Nuclear Facility Siting, Denver, Colo., July 20, 1976.

B. J. Purdy, "Social Impact Assessment, a Case Study," presented to MACCI members at ORAU, Oak Ridge, Tenn., Mar. 24, 1976.

———. "Social Impact Assessment, a Case Study of Two New England Communities," presented at a Workshop on Social Science and Energy Policy, Vanderbilt University, Department of Environmental Engineering, May 11, 1976.

———. "Socioeconomic Impacts of Nuclear Power Plant Siting, a Case Study of Two New England Communities," presented at the American Sociological Association Annual Meeting, New York, August 1976.

P. L. Rice, "An Econometric Model of the Petroleum Industry," presented at the Eastern Economic Association Second Annual Convention, Bloomsburg, Pa., Apr. 15–17, 1976.

S. W. Schwenterly et al., "AC Dielectric Performance of Helium-Impregnated Multi-Layer Plastic Film Insulation," presented at IEEE US USSR Joint Symposium, Brookhaven National Laboratory, July 1976.

A. H. Voelker, "Techniques for Incorporating Environmental and Social Elements in Resources," presented to the Knoxville Technological Society, Knoxville, Tenn., September 1976.

D. P. Vogt and D. J. Bjornstad, "Distributional Effects of the Fiscal Impact of Power Plant Siting," presented to the Eastern Economic Association Second Annual Convention, Bloomsburg, Pa., Apr. 15–17, 1976.

D. P. Vogt et al., "An Overview of MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment," presented to the Seventh Annual Pittsburgh Conference on Modeling and Simulation, Pittsburgh, Pa., Apr. 26–27, 1976.

D. J. Walukas, "Residential Energy Conservation Program," presented to the National Management Association, Nashville Chapter, Dickson, Tenn., Aug. 13, 1976.

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