

**RESEARCH NEEDS ON WASTE HEAT TRANSFER
FROM LARGE SOURCES INTO THE ENVIRONMENT**

**A report on a conference at Zion, Illinois,
which was supported by the Research Applications
Directorate of the National Science Foundation
Grant GI-30971**

**Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois**

December 1971

PREFACE

The problems of waste heat transfer from large sources into the environment are complicated by rapidly changing environmental values and by uncertainties of benefits, costs, and consequences. Emotion is presently an important force in the decision process, but this must give way to improved knowledge through research and experience.

To identify the priority research and data needs of the nation for rational decisions in this field the National Science Foundation supported a conference of experts during September 20-24, 1971. This is a report on the findings and recommendations of that conference.

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RESEARCH NEEDS ON WASTE HEAT TRANSFER FROM LARGE SOURCES INTO THE ENVIRONMENT

ABSTRACT

A conference was held to evaluate research needs on problems of waste heat transfer from large thermal sources, such as electric generating plants, into the environment. A group of 27 experts from a broad cross section of professional activities reviewed the knowledge of present and projected environmental effects resulting from large injections of waste heat into the environment by means of wet and dry cooling towers and cooling ponds, lakes, and streams. Complicated interactions of the physical, engineering, biological, social, and economic factors are discussed in this report which focuses on key problem areas and suggests needs and directions for further research and action. Various alternatives for waste heat disposal are listed. Alternatives relative to various climatic regimes and local resources in order that environmental consequences might be minimized without excessive delays and costs are reviewed.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

† One of the principal research needs recognized by the interdisciplinary group of experts at the conference is the acquisition of much more environmental data to check and refine existing physical and biological models for calculating the environmental impact of waste heat from large power plant complexes.

† Industries, government agencies, and institutions have compiled a great deal of useful environmental data that should be made available to other scientists for research, for planning and design of observational field programs, and for developing improved mathematical models. A mechanism should be established for an exchange of information. As a result, a strong consensus developed for the establishment of a clearing house or data information center in the power field, such as was done a few years ago in water resources research. The environmental collection center which has been established at Oak Ridge National Laboratory may possibly serve this purpose.

† Comprehensive research programs on the environmental impact from alternative cooling methods, such as cooling towers, ponds, and lakes, are urgently needed. Data on the atmospheric effects are limited and existing mathematical atmospheric models should be tested and then refined as necessary. Detailed climatological data on the lower 500 meters of the atmosphere, vital to understanding the behavior of the rise and dispersion of plumes, are needed.

† The established procedure of once-through cooling for the dissipation of waste heat while being the most economical procedure *per se*, may also have a less total environmental impact at certain sites. Therefore, increased research is recommended to understand fully the biological consequences of this process in streams and large water bodies and to develop more precise technical criteria for the further use of this technique up to its applicable limits. A long period of concerted research effort may be required to

obtain a detailed understanding of thermal effects on biota and the conditions wherein aquatic life and thermal discharge uses are compatible.

† Because of regional variations in topography, climatic conditions, water availability, and adequacy of fuel supplies, research on the various alternatives for waste heat disposal is required for each region. Within each region, the local condition of each site must be carefully evaluated. Useful engineering approximations may be obtained in about five years at many sites.

† Engineering studies are needed to develop improved performance of present cooling devices; new techniques and uses involving waste heat; systems studies of plant sizing, siting, and optimization; and development of alternative power generation, transmission, and utilization systems for conserving energy resources.

† Social research on ways to induce voluntary reduction in the increasing demand for electric power should be given high priority. Public education aimed at reducing power needs similar to programs directed to population should be encouraged.

† The public should be educated into realizing that energy cannot be created without some impact on the environment. At the same time a major problem for industry is to achieve the minimum impact on the total environment at an acceptable cost.

† Proper evaluation of the environmental effects from waste heat require the combined effort of several disciplines. Therefore, team research effort is strongly endorsed to expedite the collection of compatible data and their interpretation for use by regulatory and other agencies.

† Continued support is endorsed for the development of the breeder and fusion reactor systems which are expected to be more efficient than existing nuclear-fuel systems.

† Research on effects from waste heat releases from power complexes of 1000—4000 megawatts or larger in comparison with distributed sites should be conducted.

† The beneficial use of waste heat on a large scale in agriculture, aquaculture, and many other applications is very limited at this time. The major problem is transportation cost of the enormous amounts of low temperature heat available. Research in beneficial uses should continue to be supported.

† Expanded research to develop methods to harness some of the solar energy for heating and electrical uses is endorsed.

† The compilation of bibliographic material and state-of-the-art reports is strongly recommended in order to coordinate and ascertain the exact nature of future research efforts.

† An agency of government should organize a second conference at which representatives of various government agencies, power companies, electric institutes, and research organizations would formulate plans to implement the recommendations of this report.

ZION CONFERENCE

Background

The rapidly growing national need for electrical power has been clearly demonstrated in the past 24 months by power shortages and system failures in the more densely populated areas of the United States. To keep pace with the growing peak demand of a 7 percent increase per year, many new power plant facilities are projected for development in the foreseeable future. In 1970, the total installed capacity of the United States to produce electricity was about 340,000 megawatts and the required capacity in 1990 is estimated to be around 1,260,000 megawatts [*Electric Load and Supply Patterns in the Contiguous United States*, compiled for the workshop by the Chicago Regional Office of the Federal Power Commission, September 1971]. This will require about three times the present capacity with many new sites being developed. Either large cooling towers or large quantities of water or both will be needed, and many new transmission lines will be constructed.

An unavoidable problem with both nuclear and fossil-fuel plants is the dissipation of waste heat produced by the power generation process. In the past, this has been accomplished most frequently by once-through cooling utilizing surface water bodies, which is the most economical procedure. This method is being challenged by some sectors of society, and industry is being forced to consider its environmental impact. The growing national concern with water pollution, including thermal pollution and resulting ecological imbalances, has forced consideration of various alternative means of dissipating heat from the large power plants of the future.

In recent years, the use of large cooling towers with direct heat dissipation to the atmosphere has increased, particularly in Western Europe, and several such installations are now in operation also in the U.S. Very large cooling towers in arrays, either of mechanical draft or natural draft design, and large arrays of cooling ponds represent much more rapid means of releasing heat and moisture to the atmosphere than the release through large natural water bodies. However, the direct atmospheric release of large amounts of heat and moisture immediately raises questions as to the further ecological and meteorological consequences.

Essentially the lack of knowledge of atmospheric effects from large cooling towers, ponds, or reservoirs has not permitted a conclusive scientific decision on the least detrimental means of heat dissipation for new power plants. The ecological effects have never been seriously considered except in streams. Near oceanic areas, the fallout of salt from the use of ocean water in cooling towers may be a problem.

Investigations conducted by industry and governmental agencies have all indicated that atmospheric changes may occur in general, although the type of conditions altered and the magnitude of effects are uncertain. All agree that there may be some increased fog and icing, but the magnitude and the significance of these effects are either not stated or are debatable. The possibility of increased atmospheric turbulence, growth of clouds, production of rainfall and snowfall, severe local storms, and alterations in other weather conditions cannot yet be assessed adequately from mathematical models or observational data. Observations and current studies have shown that observed plumes seed clouds and that rainfall increases are measurable, but detailed supporting data are not available. The effects from plumes will be greatest at night—the most difficult time to measure and record. Thus, climatological studies and application of meteorolog-

ical theory to the problem have been inconclusive and have led to differences in opinion as to atmospheric effects from cooling towers.

Large cooling ponds or channels with spray capabilities have recently been introduced in the Midwest after several years of study in the southern states. The effects from increased invisible moisture in the atmosphere on the social and ecological aspects in the immediate area are not known. Icing on highways is a problem in Minnesota and Wisconsin. The design of power generation plants offshore is also being considered since the heat dissipation at sea is not considered to have any immediate major effects on the environment. However, little is really known about the consequences of these new heat dissipation methods.

Existing studies for government agencies have given little consideration to the biological, social, or legal aspects of the development of large power generation plants. As a result of the large number of complex questions involving a number of disciplines, it appeared appropriate that a workshop-conference should be organized to suggest a national research plan and to enlist the scientific community in solving problems that are most relevant to our society.

Organization of the Conference

A conference was organized by the Illinois State Water Survey through support from the National Science Foundation (GI-30971) to bring together a number of researchers and concerned industrial and government personnel to identify the elements and priorities of a national research effort on the problem of waste heat transfer into the environment. The conference was designed as a workshop in order to allow ample flexibility in developing a plan for future action. The conference was chaired by William C. Ackermann, Principal Investigator, assisted by Glenn E. Stout.

The grant from NSF was supplied from funds under the Energy Resources, Research, and Analysis Program in the Research Applications Directorate. NSF supported the conference as a part of its effort to assist mission-oriented agencies and to interest academic personnel in working on problems that are interdisciplinary and relevant in today's society.

The conference was held at the Illinois Beach Lodge, Zion, Illinois, on September 20-24, 1971, and a preliminary draft of portions of this report was prepared by the participants at that time. All aspects of waste heat transfer into the environment were considered, although little emphasis was given to the beneficial use of waste heat. The 27 participants are listed in Appendix A. Considerable correspondence was carried out with other experts who were unable to attend the conference, and significant contributions were made by those listed in Appendix B. Through the correspondence, current literature, and the participants at the conference, it is believed that much of the current state of knowledge was available for the preparation of this report.

Throughout the discussions, various expressions were used instead of waste heat to describe the problems relating to waste heat transfer into the environment. No general agreement was reached as to whether the proper terminology was waste heat, diffused heat, excess heat, heat rejection, thermal pollution, thermal benefaction, or thermal effects. It appears that each scientific discipline or agency of government has its own preference in describing the same process. Throughout this report waste heat will be used.

RESEARCH PRIORITY AREAS

During the conference it was soon evident that, in spite of the great need for interdisciplinary and supporting research programs, it would be best to describe some of the problems and the proposed research by the various disciplines. The following sections were prepared by participants in each respective field. Background and research needs are presented in this order—social, biologic, atmospheric, hydrologic, and technology/engineering.

SOCIAL

From a sociological perspective, the proposed application of new methods (other than once-through cooling) for handling waste heat from electric generation plants may be seen as the application of a new technology which may produce physical effects in the atmosphere and in turn have a variety of social and economic impacts. This proposed application, therefore, has many similarities to planned weather modification efforts.

Relationship to Other Societal Problems

Research results from weather modification studies suggest that the following variables may be relevant in understanding the social response to the proposed use of large cooling towers, lakes, or similar applications.

- 1) *Views of the more powerful or more vocal interest groups and opinion leaders toward the agencies or industries, known to be in support of or proposing to utilize the new technology.* Enemies of the power industry are likely to become active; friends may or may not get involved. Credibility is a key element here.
- 2) *The financial resources and the legal and political sophistication of such interest groups and opinion leaders.* Any long term, effective action requires readily available resources and skills.
- 3) *Anticipated economic impact that would follow the installation of the new technology.* Those anticipating significant economic gain may or may not take action, but those believing that they will suffer economic loss are most likely to make their voices heard.
- 4) *Level of consensus among recognized experts regarding the probable physical effects of the new technology.* Where the experts don't agree, every would-be protagonist can 'pick his preferred expert' and have a fair chance of winning converts to his point of view. Thus, public hearings may have the logical character of an argument among a group of children.
- 5) *The decision makers' perception of public opinion regarding the proposed application.* The real public opinion is seldom known. The decision makers' perception of it will be shaped by the mass media, organized letter and phone campaigns, and the individual decision maker's selective perception from his personal encounters.

- 6) *Mobility of activist groups.* Where organized opposition has emerged in one area, a proposed installation elsewhere may serve as an attraction. On occasion it really is true that it is the 'outsiders' who have stirred up the trouble.
- 7) *Anticipated aesthetic degradation.* The proposed plant with its new technology may be seen as a potential visual blight in and of itself as well as a destruction of otherwise desirable open space or green area.

These are just some of the social factors which may come into play prior to the building of the installation. Once the plant with its waste heat dissipation technology has begun to operate, other considerations may come to the fore. Examples would include the following possibilities.

- 1) Concern about humidity-induced problems such as respiratory problems, paint deterioration and the corrosion of metals, increase in fungus diseases, and personal discomfort attributed to high humidity levels.
- 2) Concern produced by the high visibility of plumes and fog. Plumes from nuclear powered plants may be viewed as hazardous.
- 3) Concern about economic impact such as a negative effect on land values and retail sales attributed to the reputation of near-the-plant and downwind locations.
- 4) Concern about aesthetic degradation.
- 5) Concern about accidents purportedly resulting from plume-induced fog, icing, rain, or snow.

Research Needs

Needs in the social area involve two different major areas of research.

- 1) The research needs related to the matters recounted above can perhaps be best phrased as: What procedures and emphasis can be used to provide an adequate basis for the development of 'informed consent' or 'informed rejection' in communities where new electric generation plants are being proposed?

Since there appear to be many interrelated factors potentially involved in any worthwhile 'informed consent' process, and given the dearth of research on the social implications of new electric generation plants, the most useful research approach initially would be to conduct a series of intensive case studies in communities where the new technology has already been applied and where such installations will be constructed in the next year or two. Where possible, matching communities could be selected where one has once-through cooling, one a cooling tower, and one a man-made lake. Where feasible, careful surveys should be made of initial public opinion and views held by powerful and vocal interest groups. Then the informing and decision processes should be followed in detail. The monitoring of social response to the installation and operation of the plant should be continued for six months to a year.

These case studies should be preceded by observation and informal data collection in various areas in Western Europe where cooling towers have been used extensively for some years. In the U.S. there are only about 15 sites where large cooling towers are in use and most of these have been installed in recent years.

Specific questions to be addressed in the case studies would include: 1) What are the issues that most typically arise? 2) How is information and misinformation relevant to these issues secured and utilized? 3) What are the factors which appear to produce controversy and court suits? 4) What procedures

appear to offer the greatest hope for rational decision making and the fair adjudication of grievances?

2) A second major area of research seems warranted. We need to know to what extent and in what ways is it possible to bring about a *voluntary* reduction in the approximately 7 percent per year increase in the peak consumption of electric power.

This question centers, in large measure, on the basic research question of how daily habit patterns or life style can be altered without the threat or application of legal action. The answers to that issue will apply not only to the use of electric power but also to a whole range of environmental concerns. Here some creative, experimental, non-laboratory pilot studies appear to be in order. A minimum period of two years will be required to get a first approximate answer to the question. This should be collaborative research involving sociologists, economists, and social psychologists.

Both types of research envisioned here, to be successful, will require the active cooperation of the relevant electric power companies.

BIOLOGIC

Waste heat additions to the terrestrial or aquatic environment will exert an influence on the ecosystem. However, it is generally recognized that the direction, the magnitude, and the significance of the effect are not presently understood nor can they be fully defined for any particular ecological complex.

As a consequence of numerous biological phenomena and their responses to environmental variables there is need for comprehensive data and information at all biotic levels as well as on critical members or species of the ecosystem.

Environmental influences, including waste heat increments (in amount or extra duration of exposure), can be expected to elicit changes which may be small and of little populational or species significance, or which may be of great magnitude and marked biological effect. However, these effects must be studied from the purview that they are, or will be, superimposed upon a background of natural population and environmental oscillations in aquatic environments which are of diverse quality, and which are, in addition, modified by regional variations. Since these variations correlate with both short and long time scales, accurate assessment of any ecosystem will correspondingly require study on comparable scales.

Diversity of the natural environment requires a distinction between the major categories of *terrestrial* and *aquatic*, but the latter is further diversified into streams of variable flow velocities and volumes, lake (natural and artificial), estuaries, and other coastal marine waters having variable physical and hydrographic characteristics. These environments each provide the matrix for substantially different ecosystems. Latitudinal and other geographic differences impose a further need for regional studies.

Comprehensive understanding of the aquatic ecosystem can be accelerated by study of existing areas of thermal modification, including river, lake, and estuarine waters. Data obtained through laboratory simulations provide useful information, but it is generally understood that such studies yield supplemental data only and cannot substitute for the profoundly more complex field conditions. It is unrealistic to attempt to evaluate biological effects by utilizing a single environmental variable such as temperature. While multivariate studies are designed to duplicate environmental conditions, this has not been done because of lack of complete information on each environment. Laboratory studies will allow measurement of critical thermal limits and studies of age-class thermal sensitivity and its influence on the

behavior of index species, as well as other biological effects resulting from elevated temperatures. Such studies may provide insight into the range of responses that will be elicited under natural conditions and thereby increase the efficiency of *in situ* environmental research. However, the results obtained must be interpreted within the context of natural environmental characteristics, oscillations, and cycles.

Terrestrial Environments

Mechanisms of transfer of waste heat discharges from large sources into the atmospheric environment include cooling towers of diverse design, lakes, ponds, and sprays. The concerns for ecological effects, resultant from thermal additions, are primarily those beyond the boundaries of the land occupied by the power complex. Significant biological changes may occur within those boundaries as a result of dispersing heat from a given installation. However, loss of productive land for crops, forestry, wildlife, and recreation, among other uses, to accommodate the construction of cooling towers, lakes, or multiple sprays is, in principle, no different from any major land conversion from one use to another. Ecological concern is directed primarily toward external effects, such as the possibility that the installation would stimulate reproduction of harmful insects or plant species which would disperse into neighboring areas.

It is believed that present knowledge is generally adequate for a preliminary assessment of the probable ecological consequences of heat discharge to the environment of terrestrial plants and animals. Because each site, and each anticipated means of heat dissipation, is to some degree unique, an assessment of probable ecological effects should be made as a part of the site selection process and system design.

It is estimated that the effects of heat discharge (including those of associated humidity) on terrestrial organisms will be principally

- 1) *Changes in timing and rapidity of growth of fungal diseases of plants and animals (mostly insects).*

Most fungi are highly dependent upon critical conditions of high humidity and high temperature for spore germination and establishment and, to a lesser extent, for growth of the mycelium or fungal body. If a cooling pond, tower, or spray installation should extend a normal period of saturated humidity by only a few hours when atmospheric temperature is, for example, in excess of 82°F, a fungus infection might be initiated in circumstances where it would not occur in the absence of the power installation. Such an infection might be a rust disease of crop plants or of forest or ornamental trees; similarly, it might be a disease attacking the larvae of harmful insects.

A team of plant and insect pathologists acquainted with the organisms of a particular area can assess the likelihood of significant changes in fungal populations, when provided with meteorological and engineering information on the probability of increased humidity episodes at ground level during each season. In the unlikely event that the cooling installation should significantly increase average humidity at ground level during the entire growing season, a new range of problems may be introduced and would require more intensive research.

- 2) *Changes in evaporation and transpiration due to decreased solar radiation (fog) and increased humidity.*

This effect is likely to be small unless the fog and near-surface humidity produced by a cooling installation are much greater than currently indicated. Computer models to assess evaporation and transpiration, and their effect on seasonal soil moisture and plant growth, currently exist and are being refined. These models can provide reasonably definitive answers to questions raised by the agricultural community and others concerning possible changes in planting or harvest dates.

- 3) *Interference with wildlife migration routes or breeding sites.*

- 4) *Influence of warmer temperatures at the margins of cooling ponds, lakes, rivers, or other heat disposal sites on the habitat or refuge of desirable or pest species or communities.*

This change might permit survival during otherwise unfavorable climatic conditions. Present knowledge should permit assessment of the possibility of this effect under conditions and annual cycles characteristic of a particular site.

- 5) *Changes in precipitation.*

If meteorological analysis should demonstrate this to be likely, the consequences can be assessed by the present methods of comparative ecology and agronomy.

Although additional knowledge remains to be gathered in the above fields, a large scale, intensive ecological research program, directed exclusively to the problems raised by dispersal of waste heat into the terrestrial environment, is not justified at this time. However, ecological investigators are encouraged to keep these problems in mind in the course of their work.

The research needs were identified as follows:

- 1) *Evaluate jointly, the extent and duration of humidity changes and their relation to temperature cycles in the vicinity of planned facilities.* As meteorologists and engineers estimate the statistical probability of an increase in ground-level humidity, temperature, or precipitation for a particular cooling facility, agronomists, plant, and insect physiologists and ecologists should then judge the influence these changes may have on
 - a) The growing season.
 - b) The influence of aerial changes including fog and solar radiation, on transpiration and evaporation of the principal flora or plant communities. Existing computer models designed to assess transpiration and evaporation on seasonally and regionally based soil moisture and plant growth should be coupled with meteorological and engineering predictions relative to cooling facilities.
 - c) The influence these changes may exert on pest, pathogenic, and beneficial organisms which are endemic to the area of the planned cooling facility (e.g., spore germination, fungal growth, insect life cycles, etc.).
- 2) *Evaluate the influence that these changes may have on areas adjacent to those planned for the location of cooling towers or other heat transfer installations.* Evaluation should include the effect on animal refuges or habitats and on useful and pest species whose life cycles might be altered by these local changes.
- 3) *Evaluate the influence of cooling towers which have been in operation both in this country and others (e.g., Western Europe) through comprehensive field studies.* These should include a comparison of essentially identical or equivalent areas with respect to plant and animal communities but which are beyond the immediate influence of the cooling facility.

Aquatic Environments

Concern for the environmental effects of heat transfer to water resources is directly related to the extent of the area involved and the rate of heat dissipation. The geometry of the thermal plume and its gradient, from the source (outfall) to a point of negligible variance from ambient conditions, defines the area of direct influence as well as the magnitude of heat transfer to the aquatic ecosystem. Modeling of thermal plumes is essential to predict the area, volume, and temperatures for proposed cooling water

discharges, and to define the minimum area which must be subject to intensive biological investigation.

Rivers and Streams

Generally accepted and legitimate uses of rivers include navigation, recreation, water supply, hydropower generation, waste water assimilation, agricultural consumption, and the maintenance and support of biotic communities. Regionally there may be varying priorities of one use over another resulting from riparian rights, local developments, and social and economic needs of the area comprising the river system. Each of these uses, in some way, influences the water quality and may result in a beneficial or detrimental effect.

For example, an increase in water temperature could be beneficial to navigation during ice periods; alternately, decreased visibility due to fog formation could exert a limitation on this water use. Further, increased temperature accelerates biochemical oxidation, but, in addition, it develops an added oxygen deficit. This thermal effect could result in a local decrease in water quality, but a more rapid recovery of a deteriorated river system over a greater distance, and ultimately serve to enhance its water quality.

Thus, the interaction of increased thermal levels with other water characteristics must be elucidated within the scope of multiple uses and water quality specifications. The complementary and antagonistic effects consequent to thermal additions to a waterway serving multiple and diverse needs must become understood. Studies to achieve this goal must be regional since hydrographic and biological characteristics of a river system, and the relative priorities of its use, vary on a regional basis.

Comprehensive studies are needed to achieve a balance among various water uses and its conservation. The specification of a thermal standard would result from careful consideration of all constraints imposed by present and future uses in terms of the impact of a thermal increment on its other legitimate uses.

Such understanding is a necessary prologue to resolving the question as to the best environmental route for a thermal discharge, e.g., into a waterway or to the atmosphere.

Based upon the differences in river characteristics and multiple uses, study should be directed as follows:

- 1) *Investigate the biotic, chemical, and physical effects of thermal additions at the immediate point of discharge of warmed water and along the gradient of these effects for the distance influenced.*
 - a) Clarify the thermal effects on biotic populations as they vary with season and volume flow; these must include annual extremes of climatic conditions.
 - b) Determine whether thermally induced changes in the ecosystem are reversible, and the time scale for recolonization as well as the nature and diversity of newly established populations.
 - c) Analyze comparatively the relative intensity of the impact of thermal addition to a river system when contrasted with the impact resultant from use of alternative methods of heat transfer.
- 2) *Through long term studies, elucidate the extent and duration of the impact of thermal addition to the river on water and air temperatures with respect to shifts in the annual averages and their range.*

- 3) *Study the impact of thermal addition to a river system to elucidate its interrelation with other uses of these resources. Such studies should clarify priorities related to social, economic, and conservation needs of the area which depends upon the river system.*

It is noted also that specific biological studies indicated below as research needs for lakes, estuaries, and marine waters are applicable to study of rivers and streams.

Freshwater Lakes, Estuaries, and Marine Waters

Ecosystem responses to thermal increments will be different according to the characteristics of the environment being considered for use in energy production and waste heat transfer.

An accurate assessment of change can be made only with a background of factual information which includes a comprehensive structural and functional description of the ecosystem in question. Within this concept, collection of basic data must be continued for each category of aquatic environment to provide sufficient information for the development of reliable models essential for predictions and planning.

After basic data have been acquired for each category of aquatic ecosystem, the consequences of environmental modification can be more clearly identified.

If with continued engineering development there is a decrease in the thermal discharge into aquatic resources, there will result a smaller modification of the environment. The nature of the biological response may become negligible, or the response may be that of very subtle long term changes which would be evident only through long term detailed study.

The research needs were identified as follows:

- 1) *Study the interaction between temperature and reactivity of chemical constituents of the aquatic environment.* These studies would be essential principally in areas unique with respect to chemical composition, e.g., high salinity. In addition, thermal effects on buffering capacity, chemical reactions, and rates of chemical change should be studied as they relate to thermal alteration of the environment. These needs pertain predominantly to estuarine and marine waters; to areas where effluent brines will be both heated and concentrated; and to areas where chemical pollutants already exist, or may be anticipated to increase.
- 2) *Study community metabolism to provide initial evidence on the impact of thermal additions to each type of aquatic ecosystem.* The relationship between gross productivity and respiration provides a basis for estimating biological change with respect to eutrophication, to increased production, or to a breakdown in energy flow through trophic levels. Information in this category is more quickly obtained and would provide a more rapid assessment of ecosystem modification than other more detailed (but necessary) and time consuming studies.
- 3) *Identify key or index species at the significant trophic levels and species of sport and commercial value.* Variance in response of these species to temperature as a function of age, sex, and past physiological and thermal history must be determined. Essential information must be acquired for:

- a) Thermal tolerance limits and preferences *per se* and with variable temperature histories.
 - b) Fecundity and the influence of chronic thermal increments on it.
 - c) Behavioral responses to changing thermal regimes; these should include social (grouping) behavior, migrations (diurnal and seasonal, vertical and horizontal), predator-prey relations, and parasite-host relations.
 - d) Magnitude of energy turn-over at both natural and increased acclimation thermal levels.
- 4) *Study long term effects of small temperature increments on inter-species competition (expressed in shifting diversity values).*
 - 5) *Study selection by fishes of new positions in thermal gradients and its correlation to food dependence and availability.*
 - 6) *Determine the effect of entrainment of planktonic organisms through cooling systems and its significance on the area ecosystem with respect to trophic relations and species diversity.*
 - 7) *Determine the effect of blow-down on the immediate area ecosystem, with particular reference to the interactions of these concentrated chemicals and temperature.*
 - 8) *Study the influence of thermally based shifts in oxygen saturation levels on metabolism of organisms permanently resident (benthos and periphyton) in the area of thermal discharge.*
 - 9) *Determine the significance of the impact of thermal increments on each of these aquatic resources.* For this a comprehensive study of the ecosystem is essential and should include:
 - a) Primary productivity and biomass.
 - b) Species diversity and population density at each trophic level.
 - c) Energy transfer through trophic levels.
 - d) The nature of the chemical and physical matrix of the system.
 - e) The variations in these concurrent with seasonal and annual cycles.
 - f) Population (species) grouping within and at the interface of (thermal) mixing zones.
 - g) The climatological over-lay as it relates to surface water movements, upwelling, turn-overs, current velocity and direction, temperature modification, and radiant energy availability should be correlated with structural and functional aspects of the described ecosystem.
 - 10) *With the development of artificial lakes, ponds, and impoundments, study their ecological history expressed in the establishment of individual populations and communities.* Such information is not available and it would complement populational studies in natural lakes. These studies would provide a base for predictions concerning future development of artificial lakes for waste heat transfer purposes.

Deep Ocean Water

It has been suggested that nuclear power complexes or their heat discharge facilities could be constructed off shore in the ocean. Buoyancy differences consequent to reactor cooling would result in

deep water entrainment and vertical over-turn of deeper nutrient-rich water inducing artificial upwelling which could increase surface fishery yields. This route of heat transfer would minimize the temperature increase at the sea surface and would enrich this layer to support increased biological productivity. It has been estimated that oceanic areas of natural upwelling represent approximately 1 percent of the total ocean area and produce 50 percent of the fishery production. Some studies are in progress on the physical and biological characteristics of natural and artificial upwelling using sewage outfalls as an analog for nutrient upwelling.

The research needs were identified as follows:

- 1) *Conduct economic feasibility and reliability studies of cooling water outlet structures to provide maximum quantities of nutrient-rich deep water at the surface.*
- 2) *Develop models of the quantities of deep ocean water which would be brought to the surface. The spatial and temporal distribution of warmed waters resulting from each feasible combination of nuclear plant design, discharge configuration, and ocean current patterns must be defined.*
- 3) *Continue to develop and refine physical and biological models, supported by field and simulation study data, to estimate the consequences, and the beneficial use, of deep ocean heat transfer.*

ATMOSPHERIC

The dissipation of waste heat from industrial processing either directly or indirectly occurs in the atmosphere and becomes part of the radiation budget of the planet. The future gigantic demands for power will create great amounts of waste heat for disposal in the atmosphere. Most meteorologic and hydrologic observational programs are not designed to provide the required data to explain the consequences of the transfer of heat and moisture to the air environment. The following material describes some of the needs for baseline surveys, field observations, laboratory, and theoretical studies.

Atmospheric Data Needs

It will be necessary to collect specialized measurements and analyze data of a nonstandard nature in order to understand the impact of the various cooling systems on the environment. These data requirements, which are the largest felt need, are discussed in the following sections, grouped according to the heat discharge system. Studies for site selection require a different type of data from that required for research to understand the tower effects on the environment.

Natural and Mechanical Draft Wet Cooling Towers

Site and Pre-Operational Surveys. A climatological survey for a period of at least one year should be made prior to site selection to establish its suitability for heat and moisture discharges and dispersion. Local topographic features (hills, valleys, large lakes, etc.) may produce unacceptable environmental conditions. Thus, the climatological surveys should be tailored for each site. Items to be measured routinely and recorded every one or two hours include:

- 1) Air temperature to nearest 1°C
- 2) Moisture content (saturation deficit would be better)
- 3) Wind speed and direction

Ideally, these data should be collected through a depth sufficient to cover the layer through which plume transport and dispersion occurs (500 meters for natural draft towers, 100 to 200 meters for mechanical). A 100- to 200-meter meteorological tower would provide a suitable platform for routine measurements near the ground, the zone of maximum interest. Balloons and aircraft can be used for measurements in the layer above the tower, but on a much lower frequency. Great care must be exercised in extrapolating vertical profiles from the nearest National Weather Service sounding and weather station; for example, the Chicago Midway Airport Environmental Meteorological Sounding Unit data cannot be used to estimate cooling tower fog potential from the Zion, Illinois, power station only 75 kilometers away because of land-lake effects.

In addition, the frequency and extent of fog, freezing fog, and dew should also be measured for several years before the power plant becomes operational.

Post-Operational Data Needs. The data collecting program should continue and be expanded to include the geometrical and physical properties of the visible cooling tower plume. Photographic techniques can be used to measure the geometrical parameters to be correlated with plant, engineering, and meteorological data. The invisible water vapor plume should also be monitored. Radar and weather satellite data can be used to locate areas of precipitation and cloud buildup to see if naturally occurring clouds and rainfall and subsequent mesoscale weather patterns are augmented by the cooling tower effluent.

The surface fog network should be expanded to detect any increase due to the tower plume, remembering that the point of fog produced by the tower may be some distance from the source.

A network of temperature and humidity sensors (with accuracies better than those of hair hygrometers) should be used to detect surface temperature and humidity increases due to heat and water vapor being diffused to ground level. It is expected that these changes will be quite small and well within the natural variations. Documentation of this fact will be needed for regulatory activities.

In addition to these daily observations, intensive observations should be made for short periods (a few hours or days) during typical weather situations representative of all seasons and hours for model verification. These data should include:

- 1) Temperature, humidity, and wind profiles of 1 kilometer for distances up to 10 kilometers upwind and downwind of the cooling towers at the surface.
- 2) Temperature, liquid water content, drop size, and flow rate cross sections at the tower opening and within the visible plume.
- 3) Cross sections of temperature and water vapor in the invisible plume as far downwind as it can be identified.
- 4) Water sample collections to detect drift.
- 5) Nucleating properties of the drift particles.

Mechanical draft towers, because of their lower level of release and the nature of their discharge, are known to have a much greater potential than natural draft units to increase local ground-level fog and humidity. Also, these meteorological changes will occur closer to mechanical units.

Dry Cooling Towers

The heat discharge from such units could trigger an existing instability. Radar techniques should be used to detect changes in clouds and induced precipitation.

Small Cooling Lakes and Ponds

These small lakes are defined as those with less than 1 to 3 acres of surface per megawatt of electrical energy produced. The major local changes to be expected will be in the intensity, frequency, and vertical and horizontal extent of fog, and the creation of freezing fog very near the water's edge. The primary concern to man will be the extent of the induced fog. A large number of expensive optical devices (transmissometers) may be needed to monitor conditions over a large area.

Fog and dew conditions, especially frequency and duration, should be measured at the site before the pond is built, after the pond is built but before its use for a heat sink, and during its use for cooling.

Mesoscale weather effects will be much more difficult to measure and monitor. Radar and weather satellite pictures could be used to detect whether cumulus clouds are generated by large cooling lakes.

Air crossing the cooling lake will be warmer, more humid, and less stable than it would otherwise be. These changes may be small and difficult to measure beyond a short distance from the pond's edge. A program to measure these changes should be initiated, if only to show how small the effect is.

Spray Ponds and Canals

Spray units greatly increase the effective area of evaporating surfaces. They will also increase the frequency and intensity of dew, fog, frost, and icing conditions along the banks or downwind of the canal or lake.

Since spray canals and lakes are very new, their impact on the environment has not been studied. Drift of droplets and invisible humidity may be a problem near the area of the sprays, especially in subfreezing weather. Consequently, the same remarks made for cooling lakes apply to spray ponds and canals.

Once-Through Cooling, Large Lake or Ocean

Because of mixing, a large fraction of the total heat from power plants will be added to the main body of water and later released slowly to the atmosphere, over a large area. Hence, local weather changes will be minor. An increase in local fogginess at the outfall may be detected.

A major research need is to determine the relative magnitude of the two processes in the water which lower plume temperature: turbulent mixing versus atmospheric losses which occur through evaporation, conduction, and radiation for a wide variety of weather conditions and for the various ways of releasing the heated water to the main water body (surface flow, submerged jets, etc.). This matter is described in more detail in the Hydrologic section.

Model Development—Cooling Towers

There is a need for sophisticated mathematical models that can be applied for given sites and meteorological conditions to define the behavior and effects of thermal discharge from cooling towers. Some models currently exist and are in use; however, these models require verification, further development, and generalization. Some plume characteristics and effects have not been modeled to date.

Plumes from Natural Draft Cooling Towers

A model should be able to predict the ascent of the plume, its dimensions as a function of height, and its physical characteristics (temperature, water content, vertical velocity). Models based on cumulus cloud models are being applied to cooling tower plumes with apparently realistic results. Wider evaluation of the capability of these models is needed. In particular, certain parameterizations in the models should receive attention. Both basic cloud physics processes (droplet growth, coalescence, freezing) and the mixing of plume and environmental air (entrainment) are normally handled by empirical parameters taken from cloud modeling experience. Even in the cloud models, parameter values and their dependence on cloud type, geographical region, etc. have not been well established. Examination of the applicability of these parameterizations to cooling tower plume models is needed.

Less advanced than the modeling of natural draft plume rise is the capability for predicting downwind plume behavior and vertical diffusion. This element is critical because it determines when, and to what extent, moisture from a wet plume will exist at ground level. Thus, the determination of ground-fog potential requires accurate specification of vertical diffusion from elevated sources.

Present models and limited field experience are in basic agreement that plumes from tall natural draft towers seldom cause ground-level fog. But the conditions under which fog can occur and their relative frequency are not understood. Models should be developed and tested for specification of ground-level concentration from plumes aloft, especially in inversion conditions. Because of the complicated vertical atmospheric structure that often exists at times of fog potential, a method for handling vertical stability variations may be required. This problem area, of course, is closely related to that of vertical diffusion from industrial stack plumes, and improved models would benefit air pollution areas as well as cooling tower concerns. Field data are needed to refine existing models.

Mechanical Draft Towers

It is generally accepted that mechanical draft towers present a much higher probability of ground-level effects because of the height and nature of the discharge. Verified models for predicting the height of rise of mechanical draft plumes are needed. Effective plume rise from mechanical draft towers is a complicated problem because discharge takes place from towers consisting of lines of individual cells. In turn, a number of towers may be grouped in various ways at large stations. Merging of individual plumes and the net plume rise effect from a complex of towers must be investigated.

A satisfactory model should be capable of defining the relative effects of various tower numbers, spacings, and orientations. Aerodynamic effect of airflow over the towers themselves must probably be considered also in this problem.

Plume Model Applications and Extensions

Given satisfactory models for defining the behavior of plumes from a natural draft tower or a group of mechanical draft towers, there are several critical problems that should be attacked. These problems, in turn, should be the object of new model developments.

A first application, of fundamental importance for power plant design and siting, is delineation of the relative effects of wet and dry cooling towers, plants of various sizes, and various sizes and configurations of cooling towers. For example, it is not clear whether, for a given rate of energy dissipation, the plume from a dry tower in a humid climate is more likely to initiate clouds than the plume from a wet tower. This model application and development must be carried out to determine whether new designs of towers can reduce atmospheric effects, and whether certain effects become critical for plants beyond a given size. Field data are needed before modeling is attempted.

The second related application is evaluation of weather influences on a larger scale than that of the plume. Here, the plume models can serve to define input or boundary conditions, and a different type of meteorological model will be required. Specific questions include:

When and in what conditions can a single cooling tower or a group of cooling towers initiate cloud formation over and downwind of the station?

To what extent will cooling tower effluents contribute to significant cloud development and ultimately to mesoscale precipitation?

On a climatological scale, how will cooling towers or groups of towers influence location and quantity of precipitation?

Is there a critical heat release rate for a given site below which no significant weather effects are produced and above which rainfall increases can be expected?

It seems quite obvious that there is a magnitude of local heat input to the atmosphere that must lead to significant changes in weather—particularly cloud formation and precipitation. The fundamental question, and perhaps the ultimate question to be answered by research into effects of thermal discharge, is the magnitude and space scales of heat input at which such significant effects will occur.

Model Development—Ponds and Reservoirs

The transfer of waste heat from cooling ponds, reservoirs, and spray ponds or canals requires mathematical modeling since there are almost no observational data to predict the possible problems. Also needed are better field data on the fluxes of latent, sensible, and radiant heat to and from cooling ponds and spray canals, and better computer simulations of these fluxes. There is considerable disagreement in the literature on how to estimate these heat exchange rates; the published coefficients vary by a factor of at least 6 or 8. Better predictions of these fluxes will result in better designed cooling ponds (probably smaller) and less consumptive water losses. Since the transfer properties of the atmosphere are affected by the waste heat flux, the mathematical problem is nonlinear and is solved best by the use of numerical computer modeling. As the waste heat diffuses through the atmosphere, large scale atmospheric phenomena are affected. For example, it is important to determine whether the waste heat from an intensive energy production center will influence synoptic conditions. The modeling techniques can help answer questions concerning the optimum size of power plants, the design of monitoring systems, and field research programs. For example, will a 10,000 megawatt plant on a 15,000 acre lake produce a significant weather modification in the mesoscale wind patterns and weather conditions?

Over large lake surfaces (width greater than 10 kilometers and more likely over 50 kilometers), it is possible to simplify the analysis so that the meteorological variables become functions only of height and time. Thus, a one-dimensional air-sea model can be used to estimate waste heat transfer and the proportions of it due to evaporative, radiative, and sensible heat transfer. A surface energy balance is needed, as well as a knowledge of circulations in the water body. Such one-dimensional models are being developed using data obtained in the Barbados Oceanographic and Meteorological Experiment (BOMEX).

Over smaller lakes (width less than 10 kilometers), advection from surrounding land areas is significant, and meteorological variables are a function of horizontal position as well as height and time. In this case it is necessary to use two- or three-dimensional models to simulate the heat transfer from the lake or pond. Again, the surface energy budget and the circulations in the water body must be included in the model. This complicated type of numerical model is currently being developed by only two or three groups in the world. Because of the nonlinearity of the problem, many parameterizations are necessary, and these depend on observational programs. Much cooperation is needed between persons engaged in data collection and persons engaged in the development of models.

The evaporative flux from spray ponds is likely to be somewhat greater than that from conventional cooling ponds. Furthermore, spray ponds are likely to be relatively small per unit of heat discharge. The two- or three-dimensional numerical models developed for conventional ponds can be used to analyze heat transfer from spray ponds. The effect of evaporation of the spray would affect the solution through the equation for the surface energy balance. The interaction between the heat balance and small-scale atmospheric circulation is also important. However, it will probably be necessary to parameterize the evaporation of the spray, because of the complexity of the process.

The interaction of waste heat with the atmosphere at scales larger than 10 or 20 kilometers is also of great interest, because of the possibility that the waste heat and moisture may, for example, augment rainfall or change climate over large regions. We must determine the level of waste heat input that will significantly affect regional or global weather. For this purpose, regional and global general circulation models must be developed and used.

If waste heat is put into the oceans, from which it is then slowly transferred over broad areas to the atmosphere, then coupled ocean-atmosphere models are necessary. The global models that are currently operational require further sophistication in order to satisfactorily answer this question. In particular, the grid scale of the models should be reduced to about 50 kilometers or less in order to account for thermal effects around sources such as Lake Michigan.

HYDROLOGIC

The objective of the physical and analytical studies of thermal discharges is to provide a predictive capability that will allow *a priori* estimates of the temperature and the spatial and temporal distribution of water discharged from power plants. These predictions must be sufficiently accurate to allow an estimate of the possible biological effects of the thermal discharge.

A number of mathematical models describing the dispersion of heated or buoyant discharges are available in the literature. Some of these models attempt to treat the entire discharge while others treat only the near field (jet momentum dominated) or the far field (drift flow). There have also been a number of physical scale modeling studies of either the near field or far field regimes. Unfortunately, there has

been practically no testing or validating of the models with actual field data. The greatest need ??
ea is the acquisition of adequate field data from operating power plants to allow the testing of both ??
mathematical and physical scale models.

In the momentum-dominated near-field region the major modeling difficulties are associated with the boundary conditions, such as the bottom effects, shoreline influences, ambient lake currents, and upwelling conditions, and their effects on the stratification of the heated water.

In the joining region, that which connects the near-field and the far-field regions, the water is usually stably stratified and diffuses primarily by horizontal spreading. None of the available models treat the often observed 'sharp' interface on one side of the thermal plume that appears to be caused by 'gravity-head' spreading against the direction of the ambient lake current.

Dispersion in the far-field region is the most difficult to model because of its dependence upon the ambient lake turbulence, wind-induced surface currents, atmospheric heat transfer rates, and the transient nature of the discharge. To adequately predict the location of various areas of warm water the model must be a transient analysis. A great need exists for data on the ambient turbulence and eddy diffusivities in the water body. The greatest need, however, is a study of the biological significance of this far-field region where temperatures are only 1-1½ °C above ambient. If the region is not biologically significant, then the tremendous effort required to adequately model it will not be needed.

The art of physical scale modeling would be considerably enhanced if provisions were made for testing the modeling results with post-operational data from power plants. The acquisition of this type of data should be encouraged. Instrumentation systems, including simple instruments for measurement of ultra-low velocity in the field, should be developed.

Cooling Ponds

The cooling pond is an alternative to once-through cooling or cooling by use of a cooling tower. Originally, this concept was generally utilized to allow locating the generating station at or near the fuel source, but in recent years the legislative restrictions placed on once-through cooling have further increased the importance of the cooling pond. For definition purposes it is noted that the cooling pond differs from the lake in that it is a water body of comparatively limited acreage, relatively shallow depth, and usually man-made.

The technical literature reveals that some research has been conducted on natural and man-made lakes, but the practical application of this material indicates that additional research is required. The areas that require additional consideration are as follows:

- 1) *Improved techniques for designing and predicting the performance of cooling ponds, including techniques that consider or determine*
 - a) The interaction of the near-field and the far-field effects.
 - b) The effects of wind speed on both the heat transfer mechanism and on the surface distribution of the heated water.
 - c) The effects of the distribution of heated water across the surface of the pond due to differences in water density resulting from temperature differences.
 - d) The significance of possible channeling of the heated water from the discharge source to the intake.
 - e) The interaction of multiple separated heat sources on a common cooling pond.

- f) The total effective surface area of the pond as a result of the consideration of items c) and d) above. This item also refers to the determination of the effective cooling area resulting from adjacent upstream and downstream surface areas not in the primary flow pattern and considers inflow and outflow to the total pond as an additional variable. Additionally, the determination of the equivalent effective area of inlets, bays, etc., outside of the main flow channel should be considered.
 - g) The influence of water depth on cooling pond performance and methods for maximizing benefits of thermal storage capacity in ponds.
- 2) *Improved analytical models which consider hourly weather, solar, and plant heat loads as well as other variables considered in item 1, from which time-history plots of all areas of the pond can be developed.*
 - 3) *Improved analytical techniques to determine the natural and forced evaporative water losses associated with ponds in conjunction with the development of item 2.*
 - 4) *Methods to increase the efficiency of cooling ponds and to reduce the solar radiation by, for example, the introduction of reflective material on the pond surface.*
 - 5) *Complete and meaningful field data to verify the analytical models or to obtain empirical coefficients that can be applied to the analytical equations.*

Spray Ponds/Canals

Spray canals and spray ponds of a large size are relatively new in their application to the dissipation of waste heat. Much has yet to be learned about their design and operation. Areas that need investigation are:

- 1) *Spray pond/canal configuration.* Various design configurations should be analyzed to minimize interference with surrounding structures and natural boundaries. Optimal thermal efficiency with respect to hydraulic, topographic, and meteorologic conditions should be investigated. It may be beneficial to use long narrow canals/ponds laid out in a curvilinear pattern, to best accomplish this.
- 2) *Spray placement.* Spray placement with respect to surrounding sprays is of primary importance, since degradation of efficiency of succeeding downwind nozzles must be considered in the design. Investigation of the degree of this degradation is necessary with the objective of optimizing nozzle density over the pond area.
- 3) *Spray design.* Spray nozzle design parameters which maximize heat transfer per unit of cost and minimize drift problems by controlling drop size and area covered should be established.
- 4) *Drift control.* The amount of drift and the distance it travels downwind should be investigated under various conditions of wind velocity, nozzle height, water pressure, and nozzle type. Various control methods for drift should be investigated, such as drift fences and drop size control devices.
- 5) *Analytical models.* Both thermal and atmospheric models are necessary to establish boundaries on the effects of heat and moisture rejected by this method. Field correlation is necessary. The extent of downwind drift, dew, fog, and icing needs to be established under various atmospheric conditions for the various regions of the country.

TECHNOLOGY/ENGINEERING

In 1970, there were some 340,000 megawatts of installed electrical generating capacity in the contiguous United States. Of a total of about 3400 facilities, about 2400 are either hydroelectric or steam-turbine/internal combustion units which provide relatively small quantities of overall power supply and either release no heat or release heat directly to the atmosphere. The remaining 1000 facilities are steam-electric sources, requiring large inputs of thermal energy and releasing to the environment approximately two-thirds of their basic energy consumption. These generating systems require methods for carrying off excess quantities of thermal energy, normally accomplished by passing large quantities of water through the system and releasing this warmed water back to the environment, usually through streams and lakes.

There are presently many unanswered questions regarding the impact of waste heat on the environment, even at today's levels of water usage. Future electric utility installed capacities are predicted to reach 600,000 megawatts in 1980 and 5,200,000 megawatts in 2050. All of this capacity will require some method for removal of the excess waste heat, with the system so designed as to have minimal effects on the environment, in order to alter it as little as possible.

This section of the report contains the conclusions of the group concerning the engineering and technological areas of the problem and is organized in three broad topical areas:

- 1) Improvements in existing technology
- 2) Energy system analysis
- 3) Improved techniques for power generation

Although the topics within each segment are necessarily far from complete, it is hoped that the points covered provide some direction and guidance for needed research and development. It is also noted that many of the problems mentioned in the previous sections, especially meteorologic and hydrologic, involve engineering problems such as tailoring thermal effects for more favorable environmental impact.

Improvements in Existing Technology

Evaporative Cooling Towers

It is believed that the performance of cooling towers has not yet been fully exploited. Research is needed to reduce the plume or fog from mechanical and natural draft towers. The presence of plume or fog is objectionable for aesthetic reasons, as well as for its production of high humidity, poor visibility, icing of surrounding property, etc. Suggestions for future research are as follows:

- 1) *Investigation of electrostatic eliminators.*
- 2) *Investigation of after-heating and the effectiveness of the combined wet-dry tower.*
- 3) *Investigation of the effect of seeding.*
- 4) *Investigation of the variation in the shape, design, and baffling of the air intakes and outlets (for example, to develop a vertical plume by tangential air inlets).*
- 5) *Investigation of the effect of intermittent release of air discharge (puffing, torus-shaped cloud discharge, etc.).*

6) *Investigation of the effect of stainless steel wire mesh, plastic particulate parts, etc., for control of drift.*

Research is needed to develop a reliable method for measuring drift from a mechanical or natural draft cooling tower. It is reported that a laser beam scattering method is being used, but information is incomplete on its applicability and accuracy.

Research is needed to reduce drift, particularly from wet mechanical draft cooling towers, but also from natural draft towers. Present guarantees for cooling towers call for less than 0.2 percent of the tower circulating rate, but this is sufficient to cause appreciable deposits on surrounding objects. Baffles in which the discharge air flow is changed in direction are now used, but other means such as stainless steel mesh, different baffle design, plastic particulate shapes, etc. should be investigated.

Dry Cooling Towers

For some time dry cooling has had an application in the petroleum and petrochemical industry to disperse waste process heat where the temperature reaches 200-400°F. It is only recently that there has been application in the power industry where the temperature reaches 80-100°F. The power industry has some major obstacles to overcome before dry cooling systems come into widespread use. An obstacle will be the cost of large steam turbines which have yet to be designed for the high back-pressure. At present, dry cooling tower structures are much more expensive than other methods of cooling, at least when the final temperature must be as low as possible. Research to reduce this economic disadvantage is necessary. Deserving of investigation are areas such as improved fin design and materials, roughness treatment, transition and turbulence control, use of swirl flow, liquid additives, suspensions, vibration, electrostatic fields, fluid injection, and suction/blowing boundary layer controls.

Although the indirect system using an intermediate heat transfer fluid seems best suited for large plants at present, further attention should be given to the system which condenses the turbine exhaust by direct cooling with air. This involves some rather difficult fluid handling problems due to the low pressure and high specific volume of the turbine exhaust.

Not to be overlooked is the significance of establishing large heat islands and their effect on the environment. Finally, consideration of the effect of dry cooling on the total available energy picture must be ascertained. In most U.S. climates, dry cooling results in poorer efficiencies and therefore greater fuel usages.

Combined Cooling Methods

The needed techniques to determine the individual performance and physical effects on the environment of various cooling methods have been discussed. There is also a need to investigate the possible advantages of combining cooling methods, and, if there indeed are advantages, to develop methods to determine optimum combinations. It must be recognized that regional considerations would be an important variable in these investigations. A typical combination that might be considered is the use of spray channels in combination with a cooling pond. The spray channel would most likely be operated only when peak generating loads and waste heat output are the largest.

Continued investigation is also suggested in the following areas:

- 1) *Combined wet and dry towers.*

- 2) *Dry towers with spray cooling of the inlet air*
- 3) *Fan assisted dry and wet natural draft towers*
- 4) *Dry tower and a cooling pond*

Other Waste Heat Transfer Methods

Possible alternatives to lakes, ponds, towers, etc. which have not yet been invented would be welcome innovations. These would have to be analyzed from both an engineering and economic basis. However, conceptual studies including order-of-magnitude considerations might be useful.

Evaluation and development of once-through cooling systems should be continued in order to seek out the best possible solutions to the problems and questions of environmental waste heat. New methods for improving the performance of once-through cooling systems, such as new techniques of dispersal or tailoring of plumes and jets, should be pursued.

Underground water sources and sinks could provide a waste heat transfer system. This must be considered from both a water source point of view and a point of view toward groundwater stability. Technically, there is a severe heat transfer problem regarding thermal ground loading. Unfortunately, due to the large quantities of water involved, this aspect has a very low priority.

Beneficial Uses of Waste Heat

Heated fluids discarded at 80 to 100°F in summer and 45 to 55°F in winter do not have many uses, and are expensive to transport any distance to a point of use. Power stations can reject heat at higher levels (300-380°F) for useful purposes, as for example urban heating and cooling, but the electrical generation of the power station, for which purpose the plant was constructed, is significantly reduced. Two definite advantages in doing this are in cost sharing and in overall conservation of natural resources.

More efficient sewage treatment may be attained by applying waste heat in this process, since an 18°F rise in temperature approximately doubles the biochemical reaction rate. Final treated sewage effluent, which has been treated for phosphate removal, may also be employed satisfactorily for cooling condenser water in a cooling tower, as has been done at Amarillo, Texas, over the past 10 years. A better quality effluent in respect to organic decomposition and increased oxygen content should be discharged to the stream as a result of aeration provided in the cooling tower. There are several areas of incomplete information on the use of sewage effluent for cooling, and these require research work described as follows.

- 1) Applying untreated sewage to the condenser water may cause fouling of heat exchange and cooling tower surfaces; research is needed to determine the minimum and required preliminary treatment of the sewage to make this process practical.
- 2) Research is needed to determine at which point in the sewage treatment process the heat addition would be most beneficial to the treatment process.
- 3) Research is needed to determine if the drift and vapor from a cooling tower utilizing sewage effluent may contain pathogenic organisms which could provide a health hazard to the surrounding area. Olfactory acceptability must be determined.

Investigations are needed on other beneficial uses, such as using warm water in the process industries, in greenhouses, in aquaculture to increase yield, in irrigation of field crops, and in a variety of heating

applications (soils, highways, etc.). Although the economic problem associated with transport and use of large volumes of warm water are formidable, continued attention to such concepts is warranted in order to fully utilize every bit of our energy.

Energy Systems Analysis

The increasing emphasis on environmental impact of power plant waste heat discharges requires the establishment of planning and design guidelines with analytical techniques for evaluation and decision making. This must go beyond optimization of individual components and determination of effects. The technique of evaluating the consequence of particular directives, the evaluation of alternatives, and the procedure of optimization are embodied within systems analysis and operations research (dynamic programming, etc.). It is felt that much can be done in energy systems approach along this line. The approach should include technical, economic, ecological, and sociological factors as they apply to system identification, modeling, optimization, and evaluation.

It is extremely important that realism and feasibility be properly recognized. However, at the same time the approach might very well consider the sensitivity of assumptions *a priori* to their complete validation to the extent that potential effectiveness can be estimated and priorities can be developed.

Two levels of systems are identified here for purpose of illustration. First, there is the problem of optimal siting, sizing, and design of an electrical power complex in order to meet the current and projected demand in a definite region. This complex would include existing plants, modifications, and new installations with appropriate time delay. While emphasis is on a limited scale, attention should be given to interfacing with the external system as simulated on an impedance basis such as supply and demand of fuels, tie-in to the power grid, and responses of adjacent environments. Particular emphasis would be on the influence of the waste heat discharges of the complex on the environment in terms of the mode of heat rejection. Constraints might include daily and average temperatures, water oxygen content, humidity, fog, and the like.

Secondly, a larger total energy system might be studied. This would incorporate other energy sources besides electric power and would interpret demand on a more fundamental level such as requirements for heating, transportation, industry, etc. In addition, the sizing, siting, and design of an interactive demand should be included. This could allow for demand shifts and incorporation of more efficient overall utilization and total environmental and social impact evaluation. For example, beneficial uses of waste heat such as in sewage treatment and other processes might then become attractive. Other energy users would share in the system directly, and means for charging costs would be more easily defined.

All of this requires incorporation of models and value judgments which require continuing study outside of systems analysis. However, the systems approach yields information itself, as noted above, and should be developed concurrently. As data become available, models can be improved, and evaluations made regarding environmental impact. In this connection, the team effort is essential. The systems analysis team should include members cognizant of economic, sociological, biological, and meteorological effects, as well as engineers. It is anticipated that the technologists would lead the team since the emphasis is on management of technology. However, interaction with the larger thermal-discharge-effects community is also essential. It is recommended, therefore, that conferences and proceedings of that community include a program on systems analysis. This will insure the highest level of realism in the systems approach and impart to the community at large the current state of affairs. Finally, since the principal objective is a means for decision making, the utilities and government should be involved on an advisory basis with the techniques being made available as developed.

Improved Techniques for Power Generation

At present, modern fossil-fuel steam electric generating plants operate at approximately 32-38 percent efficiency in converting fuel to electrical energy, and most nuclear-fuel plants operate at about 32 percent. Thus, about two-thirds, of the total energy expended is not converted to electrical energy and must be dissipated to the environment. This section indicates areas of research and development needed to increase the efficiencies of power production in order to reduce any further degradation.

Improved Efficiencies of Existing Systems

Improvement in the efficiencies of fossil-fuel generating systems over the present percentages would reduce consumption of dwindling natural resources, and decrease the amounts of waste thermal energy.

Increases in the efficiencies of nuclear-fuel steam supply systems from the present 32 percent to about 40 percent through the use of gas-cooled or breeder reactors would also reduce the amounts of waste heat to the environment.

Development of the Breeder Reactor Systems

Breeder reactor systems, which essentially produce as much fission fuel (plutonium-239 or uranium-233) as is consumed (uranium-235), will provide a vitally needed stop-gap measure to conserve natural resources of nuclear fuels, while other power sources are being developed. In addition to the conservation of fuel, these reactors may operate at considerably higher efficiencies than are typical today, thereby releasing less waste heat to the environment.

Development of Open Cycle—Combustion Magnetohydrodynamic Generator Systems

In the magnetohydrodynamic (MHD) concept, the energy contained in a very hot stream of electrically conducting gas is converted directly into electrical energy. A small amount of 'seed' material such as cesium or potassium carbonate, must be injected into the combustion chamber to make the gas stream a good conductor. The charged particles of the heated gases pass through a magnetic field, generating an electrical current. Efficiencies in this system may increase significantly, substantially lowering the amount of waste heat which must be discharged. In addition, topping and/or bottoming cycles can be considered to obtain greater efficiencies. Much research and development are needed to make this a practical system, and it is important that this be done. In addition to utilizing the higher temperatures for improved thermal efficiency, MHD may also allow a more favorable fuel choice. The open-cycle system may be able to use fuels now unsuitable for air pollution reasons. Environmental effects should be investigated simultaneously.

Development of Closed Cycle—Nuclear Magnetohydrodynamic Generator Systems

The increasing use of nuclear energy suggests the significance of a gas-cooled reactor with an MHD device in a closed loop. However, the lower temperatures of the current nuclear devices suggest that a non-equilibrium operation is essential. Here, internal electrical currents elevate electron temperature of the seed-material ionization. The nonequilibrium is maintained through ineffective collisions of particles. Both MHD systems are subject to important problems such as end and surface effects, instability, and materials degradation, which all require continuing research.

Development of Fusion Reactor Systems

Fusion, whereby the nuclei of light elements fuse to form a heavier element and also release energy, could ultimately solve the problem of natural resources and scarcity of fuels. Efficiencies are potentially the greatest of any thermal system because of the high temperatures involved. The most significant problem at present is fusion plasma containment.

Development of Solar Energy Utilization

The impingement of solar energy on the surface of the earth is a massive energy source yet untapped. Development of economical methods to harness this energy will provide a complete combustion-free system which will not add any extra thermal energy to the environment, but will merely delay its re-radiation while also directing it into productive usages. Development should be directed toward small-scale use on a household level, and toward central power station use as a supplement to major power sources.

Development of Methods for Flattening Peaks of Energy Usage

Development of items such as rechargeable fuel cells in the house which could be recharged at off-peak hours (overnight) would allow for a slower growth rate of power sources and would provide more efficient utilization of available facilities. Methods for reducing consumption of electrical power during prime times may be developed by such means as premium billing rates, storage facilities for off-peak energy, storage of 'cold' refrigerant, etc.

Development of Improved Transmission and Dispatching Techniques

Development of improved methods for electrical power transmission, particularly over long distances, and improved reliability of transmission facilities, will reduce the attendant heat load rejected to the environment. Further, the initiation of a national integrated network of power dispatching will further reduce the number of generating facilities required, and will allow generating facilities to be operated at a higher fraction of their capacity.

MANAGEMENT OF RESEARCH EFFORT

An orderly development of research on the atmospheric impact of waste heat is needed to supplement the research on the impact on the aquatic portion of the biosphere. The atmospheric impact is not yet a universally perceived field of research, probably because potential problems are not necessarily recognized as existent problems. However, because a large increase in the quantity of waste heat appears inevitable over the next several decades, regardless of social and technological developments which might decrease projected rates of this increase, it is a peculiarly opportune time to assess this atmospheric impact, in order that reasonable technological (and social) choices may be made before we haphazardly perform inadvertent experiments because we might be using anything less than our best available knowledge.

Coordination

Since this is a nascent field of research, no strongly organized or coordinated efforts are presently under way. Coordination of research efforts is highly desirable, and could best be undertaken by an *ad hoc* organization, probably a committee under the sponsorship of National Science Foundation, Office of Science and Technology, or National Academy of Engineering. This committee would act principally as a resource to identify work already performed, to pinpoint project areas in which efforts would be directed fruitfully, and to prevent duplication of effort in those areas where a surplus of competence exists. It should be an active committee made up from the community of both the sponsors and the performers of research work; i.e., several federal agencies, universities, and other research organizations, the 'concerned' public, and the electric generating companies. Committee staff should be maintained at an absolute minimum, and membership on the committee rotated to prevent degeneration of the committee function to organization of effort according to an outmoded research plan.

Some of the required research efforts currently identified can be performed by individuals or by relatively small groups. Individual studies should be coordinated to insure compatibility of data. The need for larger studies of 'Big Science,' involving several research institutions, should be borne in mind as smaller studies are completed. From this would come integrated studies, such as one for the Chesapeake Bay area, or one of the Lake Michigan or East Coast power generating regions, or an off-shore installation.

Team Approach

Numerous studies have been conducted on various aspects of the environment, and data presently exist on many topics as viewed from specific scientific disciplines. However, few investigations have been directed to an understanding of the environment as an integrated whole, where physical-chemical-biological-atmospheric and human balances are subtly reciprocal and deeply interdependent. To reach an understanding of the interaction of all environmental qualities with respect to the impact of waste heat transfer to the environment, it is essential that groups of scientists of diverse competencies interact in such studies. Large scale comprehensive studies which recognize the relationships between the physical, chemical, and biological aspects of the environment are necessarily interdisciplinary and require the competence of each of the scientific disciplines.

In a societal setting, contributions of sociologists and economists are also essential as are those of the law which mediates in justice when natural resources and their use support the needs and technological advances of any nation.

The research needs indicated in this report can only be met by individuals or groups of specialists operating as a team.

Program Direction

'Big Science' will be required for major integrating aspects of the waste heat problems. But large projects create problems of their own in several areas, including program direction and control so that the objectives are achieved with a minimum of effort.

Perhaps the best way to assemble a research team to attack complex, multidiscipline scientific investigations is to form a team from existing research groups and/or individuals from industry, universities, consulting firms, and government agencies.

The project leader will be expected to define the problem to be investigated, to select the procedures and techniques needed to solve the problem, and to select qualified people and/or groups that have the scientific knowhow to solve specific items. The project leader, in addition, will be expected to exert leadership to insure that all phases are completed; control of money could be his most effective technique. The success of the project will depend in no small way on his ability.

Furthermore, individual scientists and engineers will be required to submerge the desire to 'do his own thing' and work within the overall framework of the project. There must be frequent exchanges of ideas between the project leader and the scientists so that the project can be modified as new knowledge is generated.

Regional Efforts

Since natural resources and environmental characteristics vary discontinuously within each continental land mass, technological changes and resource use will exert differential effects according to the region where they are introduced or used. Heat transfer into the aquatic or terrestrial environment at low latitudes in the United States will interact with the multiple parameters of those environments in a manner substantially different from that at higher latitudes. Correspondingly, areas of greater aridity will respond with effects different from those of high water supply areas (Great Lakes region) under the same environmental modification or intrusion.

The annual variation in flow volume and single direction of flow, characteristic of rivers and streams, make them hydrographically substantially different from lakes, ponds, and coastal marine waters. Similarly, the latter differ significantly among themselves with respect to hydrographic and chemical characteristics. Associated with these physical, climatological, and geological differences as a correlate of geographic range, biological communities show complementary variations representing adaptation to each environmental type.

Thus, to elucidate and define the impact of waste heat transfer to the environment it is essential that study be conducted within the context of each environmental category. Regional studies to elucidate the effect of heat transfer to the aquatic or terrestrial environments must be conducted at high and low latitudes, and for river, lake, and marine aquatic environments to predict the impact of heat addition on the whole environment.

It appears likely that in accord with environmental differences there will be a need to transfer waste heat by different cooling facilities. Those exerting the least impact on each environmental type should become the heat transfer route of choice on a regional basis, and within the context of regional resources.

Data Acquisition, Availability, and Transfer

A considerable body of environmental data on many water resources now exists in this country. Laboratories at many levels of government have historically monitored selected water quality parameters in areas of different regional and environmental characteristics. In addition, private and contract laboratories have conducted particularized studies in a diversity of natural water resources; the latter have increased greatly in recent years. To acquire this information considerable financial resources, both public and private, have been expended through the energies of countless competent scientists and supporting personnel. It is most likely that the baseline data which now exist would permit first-stage modeling of ecosystems and reasonable predictions concerning the responses of aquatic biota to artificial thermal increments. Continued collection of monitoring data to outline gross ecosystem characteristics, as well as continuing and new field and experimental studies to elucidate thermal effects, when added to existing data, will make possible first-level biological models and provide the basis for sound predictions.

Much of this information remains in the form of catalogued records and intra-agency reports to regional, municipal, and government laboratories. Similarly, reports to contractors from studies conducted by scientific laboratories, both university and proprietary, hold a wealth of environmental data. This is presently not available because it has not reached the conventional scientific literature.

To achieve the common goal of understanding the environment, this information must become available. Only in this way will environmental management of waste heat transfer become attainable more rapidly. In addition, the growing public challenge to the real need for intensified study and to the conclusions drawn from numerous current studies (of diverse origins) may be averted. Environmental problems are science-based and socially important problems; where solutions may exist, they should be vigorously sought.

Every effort must be expended to acquire, collate, and analyze these data to accelerate understanding of environmental responses to waste heat additions and to present comprehensively the baseline from which contemporary studies can accurately evaluate the impact of current and future water resource use. Contributions of data to a central data center for environmental research would provide the neutral ground and objective synthesis to resolve the large problems which now exist in environmental management.

LIST OF RESEARCH TOPICS

On the basis of the recommendations of the assembled group, the correspondence, and the reports listed below, a list of important research topics was developed. The list is subdivided according to subject matter such as social, biologic, atmospheric, hydrologic, and technology/engineering. No attempt was made to establish a priority listing since most topics would rank rather high. It was obvious that a strong need prevails to develop the background data and to collect new data. Such information is needed to test the mathematical models that have been developed to describe the environmental condition from releases of waste heat into air and water and to establish criteria for regulatory agencies. Natural variations in air and water must be established before stringent restrictions are established. The following reports were consulted:

Electric Power and the Environment. A report sponsored by the Energy Policy Staff, Office of Science and Technology, Executive Office of the President, August 1970.

The Effects and Control of Heated Water Discharges. A report to the Federal Council for Science and Technology by the Committee on Water Resources Research, Problem Area Task Group, November 1970.

Program Plan on Thermal Discharges and Effects. The Thermal Program Task Force, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL-TM-3107, Preliminary Draft, August 17, 1970.

During the planning phase and subsequent to the conference a number of reports which had limited distribution or had been released very recently were uncovered. This also suggests the importance and urgency of the problem. These were reviewed and used to help prepare this list of research topics requiring early action by scientists and engineers.

General

- 1) Develop an information center on thermal effects which would utilize existing information centers such as STORET, USGS, and the Smithsonian Information Exchange, but would also provide supplementary capabilities not otherwise available—such as bibliographies, state of the art and review papers, public records, and legislation.
- 2) Convene a conference of experts and develop a manual on standard methods for instrumentation and methodology for data gathering of air and water temperature sensing to improve practice and mutual acceptability of data.
- 3) Arrange with electric and water utilities, local health groups, and academic communities to provide basic data and information to repositories for scientific utilization.
- 4) Immediately increase federal and private funding to collect basic data and to conduct studies to improve knowledge on problems which might result as large quantities of waste heat are discharged into the environment.
- 5) Investigate and model the regional impact of multiple-site thermal discharges and combined effects from other industrial effluents in air and water.

Social

Although this committee accepted the Federal Power Commission projections and did not focus specifically on research related to reducing the growth rate in energy use, it recommends continued national attention to this question as a means of reducing waste heat problems as well as for other reasons.

- 1) Develop accurate information to educate the public on the various alternatives of the waste heat problem in the various regions of the country.
- 2) Assess current and projected social, legal, and economic impact of waste heat and its control in cooperation with the electric power companies.
- 3) Conduct studies on the future daily habit patterns of mankind to ascertain whether his growing demand for electricity will continue.
- 4) Make an economic analysis of the role of requirements for pollution control expenditures, including waste heat, as a factor in decisions about site locations for new industries.
- 5) Develop a mechanism to improve the utilization of confirmed research into the regulatory process, especially in the fish and game program.

Biologic

Data are needed, in a total context, on the biological effects of heat and heat changes on freshwater streams, lakes, estuaries, and the oceans. The terrestrial environment should also be considered.

- 1) Make a mathematical analysis, based on existing data, of the biological effects of thermal change, in streams, lakes, estuaries, and the ocean.
- 2) Provide continued data input, as rapidly as it becomes available, from field and experimental studies to refine and evaluate mathematical models.
- 3) Define the area of thermal influence through plume modeling in lakes, estuaries, and coastal marine waters.
- 4) Identify sport and commercial species, rare and endangered species, and key or index species at each trophic level. Studies should include the influence of thermal additions on navigation, orientation, social behavior, and predator-prey relations.
- 5) Improve the basis for specifying general status (health) and directional change of the ecosystem, species succession, and indicator occurrence.
- 6) Make field studies and models of thermal effects on overall lake metabolism.
- 7) Conduct laboratory studies on effects of heat addition on fish diseases, parasites, competitors, and food chains leading to man.
- 8) Determine thermal optima, thermal tolerance range, and shifts in tolerance limits for key species at each trophic level and their relationship to differential thermal histories.
- 9) Elucidate the thermal requirements and the temperature tolerance range of aquatic populations and communities as a basis for management decisions.

- 10) Obtain data on natural temperature exposures and optimum temperatures for aquatic communities and key species as a function of age and life history stages.
- 11) Determine the effects of sublethal temperature and other environmental stresses as they relate to fish and supporting ecosystems.
- 12) Study the trophic levels, their balance (homeostasis), diversity, and population dynamics.
- 13) Determine the effects of thermal additions on eutrophication rate and concurrent synergistic changes accelerating it.
- 14) Study the interaction of temperature and temperature increments with other physical, chemical, and biological factors in determining biological effects.
- 15) Determine the effects of thermal increments on fecundity, gonadal maturation, osmoregulation, and temperature adaptation of key species.
- 16) Study the biological responses to concentrated and dispersed thermal effluents into streams, lakes, estuaries, and oceans.
- 17) Study the synergistic effects between temperature and radiation in (radiation) sensitive cell renewal systems.
- 18) Study the thermal effects on solar radiation sensitivity of aquatic organisms, populations, and communities, related to seasonal variations and corresponding biological oscillations.
- 19) Study the thermal effects on radionuclide and stable element concentration in different organisms and their intra-organismic localization.
- 20) Study the biological significance of the far-field region of thermal discharges (that region where the temperature is only 1-1/2°C above ambient).
- 21) Determine the extent and significance of delayed or persistent thermal effects on organisms outside of the detectable mixing zone.
- 22) Conduct field studies on condenser passage effects on entrained organisms.
- 23) Study the advantages and disadvantages of cold water fisheries versus conversion to warm water fisheries with the appropriate supporting ecosystems.
- 24) Study the development of populations and the ecosystem in new (artificial) lakes.
- 25) Identify and assess supporting food chains at the trophic levels of the ecosystem, and study trophic level dynamics-homeostasis, diversity, and productivity.
- 26) Evaluate the environmental effects of cooling towers with respect to the duration of their operation.
- 27) Study the fine structural effects of temperature in fish.
- 28) Study the effects of underlying physiological and biochemical mechanisms, induced by thermal increments, including DNA repair, mutation rates, and genetic recombinations.

Atmospheric

- 1) Study the performance of wet and dry towers, cooling lakes, and spray canals under various climatic conditions.
- 2) Test the models of the dynamic behavior of moist plumes which permit prediction and understanding of movement and plume dynamics, interaction with other plumes, and incidence of initiation of cloud formation and precipitation.
- 3) Study drift loss from cooling towers and spray ponds considering size and distribution of droplets for prediction of deposition patterns.
- 4) Develop a low-level sounding technique and subsequently collect climatic-type data on the lowest 500 meters of the atmosphere.
- 5) Conduct regionalized studies on the heat and water budgets and the environmental effects of prototype cooling ponds, spray ponds, and lakes. Such studies should be preceded by baseline investigations and followed by evaluation and modeling of the air and water environment.
- 6) Model the consequences of increased evaporative losses on the hydrologic cycle of the region.
- 7) Study the partitioning of heat loss from the water surface by evaporation, conduction-convection, and radiation, as dependent upon wind, humidity, and size of water body.
- 8) Improve the models on the turbulent diffusion and boundary-layer processes in air and water bodies.
- 9) Model the organization of mesoscale convective activity which may be influenced by relatively local inputs of heat and moisture.
- 10) Model and evaluate the local (less than 10-20 kilometers) effects of heat and moisture from cooling towers, ponds, and heated water injections into large water bodies. Included here are ground icing, visibility reduction by fog, and initiation or intensification of rain, snow, and storms through convective activity. All processes and effects require evaluation as a function of climatic region.
- 11) Model the long-term, large-scale climatic effects from many power plants, such as for the projection in 2050.

Hydrologic

- 1) Collect improved background water temperature data in streams, lakes, estuaries, and the oceans, to be obtained by a combination of networks, by regression and simulation techniques, and by site measurements immediately following the decision to erect a new power plant.
- 2) Collect data on natural temperature variation and its effects due to mixing (such as occur in

areas of upwelling, downwelling, overturn, and stream mouths) in order to place artificial additions in perspective.

- 3) Test and evaluate existing mathematical models with field data. Improve or develop new models as needed to provide temperature prediction capability of sufficient accuracy for biological evaluations.
- 4) Study the relative importance of mixing and surface heat loss in determining temperature decline under different weather conditions.
- 5) Develop an experimental program to acquire field data needed to test mathematical models.
- 6) Investigate the feasibility of large-scale use of cooling water from groundwater sources for use in wet cooling towers.
- 7) Study and quantify the ambient turbulence of large bodies of water. Develop predictive methods for the resulting dispersion characteristics. Develop relationships for the interaction between wind and the surface current.

Technology/Engineering

- 1) Improve and standardize field methods and instrumentation for measuring air and water.
- 2) Continue research and development for improved power plant efficiencies, heat storage and controlled release, design of discharge outfalls, and flow regulation.
- 3) Conduct studies of siting of large power plants as a means of minimizing problems associated with waste heat transfer to the environment.
- 4) Evaluate design, cost, efficiencies, advantages, and disadvantages of cooling systems (towers, ponds, etc.).
- 5) Devise methods for coping with the concentrated mineral effluent arising from tower blow-down.
- 6) Give consideration to additional incentives for optimizing the waste heat transfer process, such as spinning discs, etc.
- 7) Conduct feasibility studies for using waste hot water for desalting natural, highly mineralized : water resources.
- 8) Improve the design of drift eliminators in cooling towers and spray ponds.
- 9) Examine advanced design heat transfer surfaces including high surface-to-volume configurations for wet and dry towers.
- 10) Evaluate the large number of methods of augmenting heat and mass transfer for possible use in cooling towers, and examine the possibility of fundamental changes in thermal/fluid design of these devices.
- 11) Study solubility of dissolved gases and liquids as a function of thermal effects.
- 12) Study effects of discharged biocides, corrosion inhibitors, and other additives.

- 13) Institute a continued, but modest, research and development effort in the beneficial use of waste heat so that suggested practical applications are evaluated.
- 14) Study the most effective method of 'floating' a warm water discharge.
- 15) Develop methods to utilize solar energy for major power use.

It is assumed that vigorous research and development programs will be continued for advanced methods of power generation such as breeder reactors, magnetohydrodynamics, and fusion. However, this committee did not directly address itself to these problems.

APPENDIX A

LIST OF PARTICIPANTS

Conference on Research Needs for Waste Heat Transfer
from Large Sources into the Environment

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APPENDIX B

LIST OF CORRESPONDEES

The desire to hold the conference at an early date led to a short time interval between the initiation of the proposal and the conference; therefore conflicts occurred whereby proposed attendees were unable to attend. The planning during the summer vacation season for an early fall conference created additional problems. Invited participants who were unable to attend were asked to submit a letter outlining some of the research needs in his particular area of interest. Likewise, some authors of recent manuscripts or articles were solicited for comments that were pertinent to future research needs. In addition, some of the participants of the MIT Summer Session on Engineering Aspects of Heat Disposal from Power Generation were invited to submit their ideas as to the most critical areas of research.

We wish to acknowledge the contribution of the following persons whose ideas have been incorporated into this report:

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