A Preliminary Proposal

to

American Electric Power Service Corporation

and

Consumers Power Company

for

# AN INVESTIGATION OF THE IMPACT OF POWER PLANT THERMAL DISCHARGES ON THE METEOROLOGICAL ENVIRONMENT

Submitted as a

Michigan Sea Grant Program Research Sub-project

by


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ABSTRACT

It is proposed to establish two networks of meteorological stations near the Lake Michigan shoreline in southwest Lower Michigan to determine if the thermal discharges from mechanical-draft cooling towers at the Palisades Nuclear Power Plant and a once-through lake cooling system at the Donald C. Cook Nuclear Power Plant produce significant effects on local meteorological conditions. The measurement of several meteorological variables will begin two years before the operation of the cooling systems and continue for two years during which they are in operation. The data will be analyzed statistically to evaluate possible meteorological changes which may take place as the result of the operation of the cooling systems. The proposed research would be carried out as part of the multi-disciplinary activities of the Michigan Sea Grant Program.

# I INTRODUCTION

The research proposed is in response to a request initiated by the state climatologist for Michigan in cooperation with Consumers Power Company and Michigan-Indiana Power Company that a 5-year meteorological investigation be conducted near the Palisades (Consumers Power Company) and the Donald C. Cook (Michigan-Indiana Power Company) nuclear power plants. The purpose of the investigation is to determine to what extent the future use of mechanical-draft cooling towers at the Palisades plant and a once-through lake water cooling system at the Cook plant may effect certain meteorological variables and phenomena inland from the plants. Both plant sites are located on the Lake Michigan shoreline in southwest lower Michigan. The Palisades plant is about 7 miles southwest of South Haven and the Cook plant, currently under construction, is about 9 miles southwest of Benton Harbor. They are separated by a distance of about 25 miles.

At the present time, adequate quantitative information on the meteorological effects of waste heat released by nuclear power plants is not available. As a result, any effects are still speculative. The proposed investigation will provide an opportunity to measure and evaluate the effects on the meteorological environment of the two methods of disposing of waste heat.

At both power plants, water from Lake Michigan will be used to cool steam condensers. The lake water will become heated in the process. At Palisades, the heated water will be cooled and recycled by means of an array of mechanical draft cooling towers which, in the process of cooling the water, will discharge a moist heated plume into the atmosphere. At the Cook plant, where a once-through lake cooling system will be used, the heated water will be returned to Lake Michigan. Although the mechanical details of the cooling methods are different, they are similar in that the energy released ultimately reaches the atmosphere.

To investigate the impact of the thermal discharges on meteorological conditions inland, the proposed research includes the following:

1) procuring, installing and operating equipment for measuring temperature, relative humidity, and precipitation on a continuous basis at about 12 locations inland from each plant site and total solar atmospheric radiation, wind velocity and visibility at 3 or 4 locations,
2) monitoring fog, icing, and severe weather conditions,
3) abstracting and tabulating the data obtained,
4) analyzing the data to determine spatial and temporal meteorological variations, and
5) evaluating the results for changes which may have been caused by operation of cooling towers at the Palisades plant and the once-through lake cooling method at the Cook plant.

Measurements will be made through the following two phases of operation at both plants: (1) a period of about 2 years during which cooling towers are under construction at the Palisades site, and the nuclear power plant and cooling systems are under construction at the Cook site, and (2) a period of about 2 years after operation of the power plants and cooling systems begins. The total cost of the 5-year program is estimated at $387,783.

## II BACKGROUND

### Meteorological effects of cooling towers

The increasing concern with plumes from cooling towers in recent years has been mainly due to the increasing number of installations, their size, and the total quantity of water being discharged, both liquid and vapor. Possible impacts of the cooling tower releases on the local environment may be considered to be of two kinds: (1) the presence of water from the towers themselves in the form of plumes, fog, icing, or precipitation and (2) influences on natural condensation and precipitation processes.

Much of the current knowledge concerning possible effects of cooling towers is summarized in a report by Huff _et al_. (1971), who carried out an investigation to assemble and evaluate information on potential effects of cooling tower effluents on atmospheric conditions. Since their work is very relevant to the proposed research, the following sections of their summary and conclusions based on a literature review are abstracted verbatim:

> Fog and Icing
>
> "In the literature, more attention has been given to fog and icing associated with plumes from evaporative cooling towers than to any other weather effects. A primary reason for this is that such effects are readily observable and immediately troublesome. However, there still has been too little done to define these effects accurately. The majority opinion appears to be that fog and icing are us-

ually minor problems with natural-draft towers employing evaporative cooling, since these towers usually extend to heights of 350 feet or more into the atmosphere so that the plume seldom, if ever, sinks to ground level. Mechanical-type towers release their effluent at a much more turbulent condition due to fan-forced ejection, so that there appears to be a high probability of tower-induced fog and icing at or near the ground on occasions. However, the frequency of such occurrences cannot be assessed accurately with existing observational data.

Clouds and Precipitation

Quantitative data on the effects of cooling tower plumes on clouds and precipitation were found to be extremely meager in the published literature. Occasional observations of light drizzle or snow attributed to tower effluents have been reported. Also, there have been several reports of tower plumes contributing to cloud formation downwind; apparently, these are usually stratus-type clouds and observations of cumulus developments have been rare. A few mathematical calculations have been made to determine the cloud and precipitation producing potential of cooling tower plumes, but no meteorologically acceptable analyses have been made to assess quantitatively the possibility that these plumes augment precipitation and cloud systems associated with naturally occurring storms.

Severe Weather

A search was made for any observed and/or calculated effects of tower plumes on severe weather events, such as thunderstorms, hail, tornadoes, and heavy rainstorms. Very little was found and this was of a highly speculative nature. However, from consideration of atmospheric physics and dynamics, one would expect that any severe weather event resulting from cooling tower effluents would be attained only through a triggering or stimulation effect. That is, the additional heat and/or moisture fed into a developing storm cloud could conceivably produce an imbalance that would result in intensif.ication into a severe weather effect, if any, must be strictly conjectural at this time.

In general, we conclude from available information in the literature that a very distinct void exists in our knowledge of the effects of cooling tower plumes on clouds and precipitation with regard to both initiation and stimulations of these weather events. From climatological observations and cloud physics research it is known that cumulus clouds and rain showers or thunderstorms can be triggered by small inputs of energy. Consequently, it is extremely important that research be initiated to combine existing knowledge of plume and cloud properties into mathematical models that will provide reliable quantitative estimates of the plume effect on downwind clouds and rainfall."

At the Palisades site, mechanical-draft cooling towers about 62 feet high will be built near sand dunes, which reach a height of about 140 feet above lake level. The dunes drop off abruptly to an elevation about 20 feet above lake level at a distance of approximately 2400 feet east of the shoreline. A major highway, Interstate 196, parallels the shoreline in a NNE-SSW direction about 1 mile east of the plant site. In the vicinity of the plant site, I-196 runs on top of, and slightly east of the dunes.

In an evaluation of environmental effects of cooling towers for the Palisades site, Koss and Altomare (1971) concluded the following:

1) Fogging and icing effects induced by the cooling towers are negligible throughout the off-site area.
2) Although meteorological conditions conducive to aerodynamic downwash do occur frequently at the site, particularly during winter, the visible plume will usually dissipate before reaching I-196.

The above conclusions are based on an analysis of 4.5 years (1949-1953) of surface weather observations obtained at Muskegon County Airport, which is located about 70 miles north of the Palisades site and about 3.5 miles inland from Lake Michigan. The authors assume that because of the proximity of both sites to the shoreline, wind, temperature, thermal stability and fog regimes at both locations are similar.

The quantitative and continuous measurements of visibility proposed as part of this investigation will provide information on fog frequency and intensity before and during operation of the cooling towers. This information will also enable the validity of the assumptions and conclusions described above to be tested.

Conditions occasionally exist along the Lake Michigan shoreline which could respond with enhanced cloud growth and possibly precipitation to the addition of heat and water (in the form of either vapor, liquid drops or ice crystals). The added heat may augment the natural convection process that gives rise ultimately to condensation at the lower temperatures aloft. In conditions of convective instability, which are common near the shoreline in late fall and early winter, the natural release of latent heat in the condensation process would be increased by the moisture in the saturated plume. Under such conditions precipitation could be initiated or intensified.

## Meteorological effects of lake cooling

For several reasons, significantly different meteorological effects of lake and atmospheric dissipation of waste heat are likely. One reason is the temporal and spatial stability of the meteorological properties of Lake Michigan. Its day-to-day fluctuations in temperature, for example, are much less than those of the atmosphere. In addition, with lake cooling, the heat is released over a longer time period than with cooling towers. According to Hanna (1971) the energy flux per unit area into the atmosphere with a lake cooling method is about three orders of magnitude less than the energy flux from the top of a cooling tower.

The heat from a once-through cooling system is ultimately released to the atmosphere mainly by long-wave radiation and the turbulent transfer of latent and sensible heat. Meteorological considerations involved with this system of cooling are that the discharge of heated water, on a large enough scale, may increase atmospheric instability in the first few meters enough to play a significant role in determining turbulent transfer processes, wave generation, growth, and hence, water currents, temperature and precipitation regimes, and to some extent, cyclonic activity.

In this regard, both theoretical and experimental work has shown that if the water is warmer than the air passing over it (unstable, or lapse condition) the air-water interaction process is significantly intensified compared to a warm air over cold water (stable, or inversion) situation. A given wind speed, for example, is much more effective in causing wave generation and growth in a lapse conditions than in an inversion condition because of the enhanced transfer of momentum. For a given wind speed in a lapse condition, an upward transfer of heat and water vapor from the water occurs which is proportional to vertical difference in temperature and water vapor, respectively.

It may be expected, therefore, that by discharging enough heated water into Lake Michigan, lapse conditions would be increased, which could result in an increase in cloudiness and precipitation, particularly snowfall on the eastern shore of the lake during late fall or winter. McVehil and Peace (1966) and Petterssen and Calabrese (1959), for example, studied the intense snowfalls on the lee side of the lake during outbreaks of Arctic air. The latter demonstrated the effect of the warm water in perturbing the synoptic pressure pattern and causing cyclogenesis.

## III PROPOSED RESEARCH

Measurement program

Meteorological equipment for a total of 25 surface stations in the vicinity of the Palisades and Donald C. Cook nuclear power plants will be procured, installed, and operated for a 4-year period. Thirteen of these will be installed in the Palisades area and 12 in the Cook area. Each station will consist of the following:

1) a standard weather shelter
2) a standard recording (weighing) rain and snow gage
3) a hygrothermograph for recording both temperature and relative humidity.

The stations will be located at various distances in easterly, northeasterly, and southeasterly directions inland from the plant sites. The greatest density of stations will be within four miles of the plant sites, with the farthest station located about 10 miles inland in each of the three directions.

At each plant site and at the station located 10 miles east, wind velocity and total solar and atmospheric radiation will be measured.

Visibility will be measured at three locations on a quantitative and continuous basis. Tentative locations are

1) at the Palisades site near I-196
2) at the Cook site near I-94
3) at the Palisades 10-mile station.

## Data Processing

Since a large amount of data will be collected and statistical techniques involving considerable computation will be used, all computations will be done on the University of Michigan IBM 360/67 computer facility. The meteorological data, initially recorded on strip charts, will be digitized using a strip chart digitizer and put on magnetic tape. Once the data are on magnetic tape, they will be readily accessible not only for the analysis for this investigation, but also for use in other research efforts that would find the data of value.

Initially, temperature and relative humidity will be routinely printed out every three hours, in addition to the daily maximum and minimum of each. Hourly values and daily totals of precipitation will be obtained. Hourly average of visibility will be available when it decreases to less than 3 miles. Hourly averages of wind speed and direction and solar atmospheric radiation will also be printed out.

## Data Analysis

Within the four-year observation period there will undoubtedly be natural variations in the local meteorology. Any effects of the cooling methods will be superimposed upon the natural variations. The basic problem is to determine which changes may be due to the cooling methods and which changes occurred naturally. It is realized that under some conditions, there may be a substantial margin of error in making such a determination.

In order to increase the conclusiveness of the results of this investigation, two different analytical approaches will be pursued: 1) a climatological-statistical approach and 2) a physical-statistical approach. Although these methods will be applied to a particular location in this investigation, they will have general applicability, once they are formulated, to other investigations.

The climatological-statistical approach. With the climatological-statistical approach, any changes in the local climate are detected by statistically comparing the two years of network data obtained before the cooling tower and lake-cooling go into operation with the data of the two subsequent years. For this approach, several years of weather observations available for existing climatological stations in the vicinity are required to establish the confidence one can place in the conclusions derived.

Because of the importance of fog and precipitation in the investigation, special attention will be devoted to a study of their climatology. Observations of fog at stations near the shoreline are available for Benton Harbor Airport and Muskegon County Airport, so that ten years of data of fog occurrences at these two stations can be used to establish a climatology for fog. This information is essential for evaluating the significance of the visiometer data.

Another source of potentially valuable information is the WSR-57 radar located at Chicago. This radar can detect precipitation in the form of rain or snow with good resolution over this section of the Lake Michigan shoreline. It will help in studying situations in which the cooling processes may initiate or intensify precipitation. Following the climatological-statistical approach, a climatology of the locations of thunderstorm cell development, for example, can be determined with radar and other information. A statistical analysis of the data will then be made to determine any changes during the 4-year period.

The physical-statistical approach. The climatological-statistical approach deals mainly with conditions averaged over many days. It is likely that the cooling processes will only have a significant effect for particular kinds of conditions. Unless these conditions occur quite frequently, the climatological-statistical approach may be unable to give definitive answers because of the small number of samples. In these cases, the physical-statistical methods are probably preferable.

In the physical-statistical approach one deals with the actual unaveraged observations. Utilizing well-established physical laws one tries to relate the observed changes in the meteorological parameter of interest, say temperature, to parameters which cause the temperature changes, such as thermal radiation. Relationships will be determined from the meteorological conditions for the first two years before the cooling processes go into effect. These same relationships can then be used to predict what the observed conditions should be in similar situations for the two years with cooling in progress. One can then compare statistically the predictions with the actual observed data and evaluate statistically whether the effects can be attributed to inaccuracies of the method or to actual effects of the cooling processes.

## Schedule of Activities

### A. First Year

The meteorological instrumentation will be ordered. Most equipment has a 60 to 90-day delivery time. A technician whose home is in the general area of the nuclear power plants will be hired. Requests will be made of property owners in the areas near the sites for permission to locate stations on their land. Once the equipment arrives, all hygrothermographs will be compared and calibrated with standard techniques of measuring temperature and relative humidity. The visiometers will also be compared under various visibility conditions. All shelters and meteorological equipment will then be installed in the field. Concurrently, the logistics of data processing will be established and precipitation and fog climatologies for Benton Harbor and Muskegon will be examined. A progress report describing the first year's activities will be prepared.

### B. Second Year

Recordings at the stations will continue. Data will be processed and tabulated. Computer programs for data processing and analysis will be developed. A progress report summarizing the second year's activities will be prepared.

C. Third and Fourth Years

The third year will be the first year of the complete operation of the cooling systems. Time lapse cameras for photographing the cooling tower plumes will be installed and operated. Recording, processing and analysis of the meteorological data from the stations will continue. Progress reports containing data tabulations and analyses will be prepared each year.

D. Fifth Year

Data processing and analysis will be completed. A final report describing the results of the analysis will be prepared.

## IV SCIENTIFIC PERSONNEL

The investigation will be under the co-direction of Edward Ryznar, Research Associate, and Dr. Dennis G. Baker, Assistant Professor of Meteorology, Department of Meteorology and Oceanography.

Mr. Ryznar is currently involved in a research project entitled, "An Investigation of Atmospheric Diffusion in the Vicinity of the Enrico Fermi Atomic Power Plant". It is sponsored by the Detroit Edison Company and directed by Professor Donald J. Portman.

Dr. Baker is currently involved in an investigation under the Sea Grant Program to study the heat budget and general air-sea interaction processes of Grand Traverse Bay. His research is under the direction of Dr. Edward C. Monahan, Associate Professor of Meteorology.

They will be assisted by graduate and undergraduate students and technicians.

# BIOGRAPHICAL DATA

Edward Ryznar

Education:

BS, Meteorology, University of Wisconsin, June, 1953
MS, Meteorology, University of Michigan, June 1958

Positions Held:

Weather Officer, USAF, August, 1953 - November, 1956
Weather Officer, Michigan Air National Guard, June, 1957 - September, 1961
Assistant in Research, University of Michigan, Research Institute, January, 1957 - September, 1957; Research Assistant, September, 1957 - June, 1959; Graduate Research Assistant, June, 1959 - July, 1960; Assistant Research Meteorologist, University of Michigan, Meteorological Laboratories, Department of Engineering Mechanics, July, 1960 - July, 1963.

Present Position:

Research Associate, University of Michigan, Department of Meteorology and Oceanography

Scientific Societies:

Professional Member, American Meteorological Society, 1956 -

Publications:

1960 (With D. J. Portman, and F. C. Elder), Research on energy exchange processes, Summer 1960 Proceedings, Fourth Conference on Great Lakes Research, Great Lakes Research Division Pub. No. 7, University of Michigan, Ann Arbor, 1961, pp. 96-109.

1961 (With F. R. Bellaire), Scintillation and visual resolution over the ground, 1959 experiments, The University of Michigan Institute of Science and Technology, Report No. 2900-293-T, 28 pp.

1961 (With D. J. Portman), Thermodynamic studies of a snow cover in northern Michigan. U.S. Army Snow, Ice and Permafrost Research Establishment, Research Report 74, 73 pp.

1962 (With D. J. Portman, F. C. Elder and V. E. Noble), Some optical properties of turbulence in stratified flow near the ground, J. Geophys. Res. 67, 8, July. pp. 3223-3235.

1963 Visual resolution and optical scintillation in stable stratification over snow, J. App. Meteor., 2, 4, pp. 526-530.

1964 (With D. J. Portman, F. C. Elder, and V. E. Noble), Visual resolution and optical scintillation over snow, ice and frozen ground, U.S. Army Cold Regions Research and Engineering Laboratory, Res. Rpt. No. 111, Part I, 31 pp.

1964 (With D. J. Portman), Some wind stress computations from Lake Michigan Tower Data, (Abstract), Proceedings of Seventh Conference on Great Lakes Research, Great Lakes Research Division Pub. No. 11, University of Michigan, Ann Arbor, p. 321.

1965 (With D. J. Portman and F. C. Elder), Visual resolution and optical scintillation over snow, ice and frozen ground. U.S. Army Cold Regions Research and Engineering Laboratory Res. Rpt. No. 111, Part II, 44 pp.

1965 (With D. J. Portman) The atmosphere near the earth's surface, Systems Engineering Handbook, ed. by R. E. Machol, McGraw-Hill, New York, 5-11 to 5-14.

1965 Dependency of optical scintillation frequency on wind speed, App. Optics. 4, 11, 1416-1418.

1968 (With D. J. Portman and A. Waqif), Laser scintillation caused by turbulence near the ground. U.S. Army Cold Regions, Cold Regions Research and Engineering Laboratory, Res. Rpt. No. 225, 115 pp.

1970 (With D. J. Portman and M. A. Walter), An investigation of atmospheric diffusion in the vicinity of the Enrico Fermi Atomic Power Plant, ORA Report 31486-1-P, University of Michigan, Ann Arbor, Michigan, 31 pp.

1971 (With D. J. Portman), An Investigation of Heat Exchange, International Indian Ocean Expedition, Meteorological Monographs, Number 5, East-West Center Press, Honolulu, 78 pp.

## BIOGRAPHICAL DATA

Dennis G. Baker

**Education:**

| | | | |
|---|---|---|---|
| Harvard | AB(cum laudi) | Physics | 1960-1964 |
| M.I.T. | MS | Meteorology | 1964-1967 |
| M.I.T. | Ph D. | Meteorology | 1967-1970 |

**Experience:**

| | |
|---|---|
| National Center for Atmospheric Research Boulder, Colo. | summer 1966, 1968 |
| Teaching Assistant, Department of Meteorology, MIT | 1966-1970 |
| Assistant Professor of Meteorology, Univ. of Michigan | Sept. 1970 to present |

**Honors:**

| | |
|---|---|
| Associate Editor of the Journal of Applied Meteorology | 1971 - present |

**Professional Memberships:**

American Meteorological Society
American Geophysical Union

**Publications:**

A Study of the Squall Line of 10 May 1964
Proceedings, 12th Conference on Radar Meteorology, October 17-20, 1966, Norman, Oklahoma, pages 398-404.

Use of Time-Space Conversions with Beta-Scale Data
Thermal Convection: A Colloquium, March, 1967, NCAR-TN-24 pages 497-504.

A Study of High pressure Ridges to the East of the Appalachian Mountains - Ph D. thesis, Sept. 1970.

## ESTIMATED COSTS

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|---|---|---|
| First Year Approximately | $130,000 | |
| Second Year Approximately | 63,000 | |
| Third and Fourth Approximately | 69,000 | each |
| Fifth Year Approximately | 58,000 | |
| Total Budget (five years) Approximately | 389,000 | |

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