**FIELD INVESTIGATIONS OF HEATED DISCHARGES
FROM NUCLEAR POWER PLANTS ON
LAKE MICHIGAN: 1972**

by

A. A. Frigo, D. E. Frye, and J. V. Tokar

ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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ABSTRACT

This report contains a partial compilation of thermal-plume field data collected during 1972 by the Energy and Environmental Systems Division of Argonne National Laboratory under the auspices of the Great Lakes Research Program, funded by the U.S. Atomic Energy Commission. Thirty thermal plumes are presented, 15 each for the Point Beach and Palisades Nuclear Power Plants—both located on Lake Michigan. The 1972 data, together with studies performed in previous years, were obtained to demonstrate the variability of plume configurations under a wide range of environmental conditions and collectively are being used to test the validity of several widely used predictive model formulations. General observations of the field data in relation to ambient lake and meteorological conditions are presented here. However, a more detailed analysis of the data will be reported separately.

I. INTRODUCTION

A. General Discussion

This report represents thermal-plume temperature data acquired from 30 field surveys conducted at the Point Beach and Palisades Nuclear Power Plants on Lake Michigan during 1972. The data were gathered as part of the Great Lakes Research Program, funded by the U.S. Atomic Energy Commission and conducted by Argonne National Laboratory, to investigate the biological and physical impact of power-plant cooling-water (waste-heat) discharges to the Great Lakes. A bibliography of the physical research reports issued under this program is listed in Appendix A. A goal of this program has been to work toward developing a methodology to predict a priori thermal-plume behavior resulting from power-plant waste-heat discharges as a function of environmental, engineering,

and operating parameters. The need for such a capability is based largely on three considerations:

- 1) To help predict possible ecological effects associated with heated discharges.
- 2) To assess, and therefore minimize, plume-water recirculation, which could reduce plant efficiency.
- 3) To develop better intake and outfall designs to satisfy water quality standards, or, conversely, to demonstrate the viability of such designs for compliance with such standards.

As is well recognized by thermal-plume investigators, numerous analytical and hydraulic models on various levels of sophistication have been developed and used to predict thermal-plume behavior within a receiving body of water, such as a lake, reservoir, river, estuary, or marine coastal environment. Most of these models have not been sufficiently validated (tested) to warrant general use. Yet present demands for increased power production, together with the manifold circumstances surrounding the regulatory aspects of discharging waste heat, have fostered a kind of pseudo-technology for predicting the influence of waste-heat discharges. Thermal-plume predictive modeling today can best be described as an evolving art requiring much refinement, and refinement can come about only through prototype observations and sequential iteration upon the predictive methods.

There appears to have been little effort expended to demonstrate the viability of plume predictive methods, possibly for the reasons that follow. First, significant expenditures are required to conduct the necessary field surveys, under a wide range of environmental and plant operating conditions, to adequately test model performance. Second, since the lead time between plant design and actual operation is on the order of five to ten years, once a plant becomes operational, rarely is anybody concerned about whether the plume predictions were technically correct.

The thermal-plume data reported upon here were gathered for the primary purpose of validating existing plume models showing promise for large-lake applications (Refs. 1-3) and for obtaining a better physical insight into thermal-plume behavior in response to a wide range of environmental conditions. Details concerning the use of the field data for model testing are discussed in several companion reports (Refs. 3 & 4) and for that reason will not be presented here.

The data presented here represent only a portion of the physical data gathered during the 1972 field season. The 1972 field year concentrated primarily on three major tasks: the acquisition of overall plume temperature data that are presented herein; the acquisition of simultaneous temperature and velocity data in the near-field region (the jet regime), which is reported together with data analysis in Ref. 4; and the collection of long-term near-shore ambient current data, which will be reported with other current data in a forthcoming report.

As was indicated earlier, the plume temperature data were collected at the Point Beach and Palisades Nuclear Power Plants sited on Lake Michigan. A brief description of these plants follows.

B. Point Beach Nuclear Power Plant

This plant is in the town of Two Creeks, Wisconsin, on the western shore of Lake Michigan. Figure 1 is an aerial view of the plant. The plant is a two-unit steam-generating station. The nuclear reactors for each unit are pressurized light-water-moderated and -cooled systems. Each unit has a gross capacity of 523 MWe and a net capacity of 505 MWe. Lake water is brought into the forebay through two 4.3-m-dia pipes buried beneath the lakebed. Water enters the pipes at an intake structure (see Fig. 2), located 533 m offshore, where the lake is about 6.7 m-deep. The intake structure of steel piling, filled with limestone blocks, is in the form of a hollow cylinder standing upright on the bottom. It has an outside diameter of 33.5 m and an inside chamber with a diameter of 18.3 m. The top protrudes about 1.9 m above the high-water level of the lake. Water enters the chamber through void spaces around the limestone blocks and through 0.8-m-dia pipes that penetrate the blocks in a ring at an elevation of 1.5 m above the lakebed. The outer ends of the pipes are covered with 0.03 x 0.05-m bar grating to prevent large fish or debris from entering the intake system. Horizontal water velocities entering the intake are not expected to exceed 0.6 m/sec at full-flow conditions. Corresponding velocity in the intake pipes would be about 1.7 m/sec at full-flow conditions, corresponding to $25.1 \text{ m}^3/\text{sec}$ for full-power operation of each individual unit.

The water is returned to the lake about 50 m offshore through two 10.7-m-wide discharge flumes (one flume per unit). Water depth in the flumes is about 4.2 m. During most of the field year, the second unit was not

Fig. 1. Aerial View of Point Beach Nuclear Power Plant.
ANL. Neg. No. 190-499.

Fig. 2. Schematic of Water-intake Structure at Point Beach Nuclear Power Plant

operational. Late in the summer, however, the second unit was operating at about 12% power and 50% of its rated discharge flow. Unit 2 is geographically the northernmost unit, with its outfall discharging in a northeasterly direction.

C. Palisades Nuclear Power Plant

This plant is near the City of South Haven, Michigan, on the eastern shore of Lake Michigan. Figure 3 is an aerial view of the plant. This plant uses a pressurized-water reactor to produce a maximum gross output of 714 MWe. During the 1972 field year, the plant was operating at a net generating capacity of about 420 MWe. The cooling water is taken from Lake Michigan through an intake crib located 6.1 m below the lake's surface, 1.8 m from the lake bottom, and 1000 m from the shoreline (see Fig. 4). The crib is a 17.4-m-wide, 17.4-m-long, 3.7-m-high box with a steel plate for its top and 0.05-m vertical bars spaced 0.25 m apart around the sides. Water flows horizontally between the vertical bars at a nominal velocity of 0.15-0.18 m/sec and subsequently is diverted to a 3.4-m-dia intake pipe at 2.9 m/sec at full-flow conditions. Full flow for the plant corresponds to $25.6 \text{ m}^3/\text{sec}$. The water is returned to Lake Michigan through a 32.9-m-long discharge canal at the shoreline. The canal is 11.3 m wide at the shoreline outlet and diverges to a width of 28.3 m at the point of discharge. At this point, the water has an average depth of 2.1 m. Early in 1974 the plant will switch from once-through cooling to closed-cycle cooling, using mechanical-draft cooling towers. The conversion was agreed upon during AEC licensing hearings. Details concerning the intake structures of both plants are presented to give perspective to the water-current measurements made near these structures and reported upon within the text.

Fig. 3. Aerial View of Palisades Nuclear Power Plant

Fig. 4. Schematic of Water-intake Structure at Palisades Nuclear Power Plant

II. INSTRUMENTATION, DATA COLLECTION, AND DATA REDUCTION

To adequately define a thermal plume in three dimensions, it is necessary to develop procedures and instrumentation that allow a large area to be covered rapidly while sampling temperature as a function of depth. Techniques for measuring plumes have been developed by the Great Lakes Research Program.⁵ A significant part of the project's effort was the development of a semiautomated system for collecting field data and processing it into the form of an isotherm map.

During the early part of the 1972 field year, an interim acquisition system was used before the completion of the system described below. In the interim system, a commercial digital thermometer⁵ was interfaced with the navigation system, and temperature and range information were fed to an electric typewriter. To gain reliability, flexibility, and speed, an improved acquisition system was developed. The new instrumentation system, mounted on a small boat (see Fig. 5), makes it possible to measure temperature as a function of depth from a moving boat at about 1000 known locations in about 1 hr, typically covering about 5 linear miles. The schematic in Fig. 6 shows the essential components of the system. Figure 7 is a photograph of the system. In essence, our plume measurement system employs submerged temperature-sensing thermistors, digitizing and recording electronics, and positioning and depth-sounding instrumentation.⁶ Analog information proportional to temperature from seven YSI Type 709 linearized thermistors, which are positioned on a submerged boom at 1/2-m intervals to 3 m, is sampled at time intervals measured by a solid-state clock and selected by the operator. The signals from the thermistors are digitized and displayed on light-emitting diodes, printed on paper tape, and recorded on magnetic tape. Each time the thermistors are sampled, information from the clock, the depthfinder, and the positioning equipment are also displayed and recorded.

The visual display is used by the boat operator to determine the position of the plume, the printed paper tape is a backup for the magnetic tape and a place to record observations while the plume is being measured, and the magnetic tape allows the data to be read into the computer without further handling. The printer is an Anadex Type DP650 capable of printing up to two lines of 21 characters per second. The magnetic-tape unit is an incremental digital

Fig. 5. Survey Boat Equipped with Temperature Measuring and Range/Range Equipment

Fig. 6. Schematic of Data-acquisition System

Fig. 7. Data-acquisition System

tape recorder, Model #201, made by Memodyne. A tape reader is part of the laboratory gear that converts this cassette tape into an IBM compatible tape for computer processing. The depthfinder is a digital Datamarine unit, which has been modified to provide binary-coded-decimal (BCD) output for interfacing with the display, tape, and printer units. The positioning system is a Motorola Mini-Ranger, which consists of two shore-based transponders and a receiver/transmitter unit and range console on board the boat. Range information from each transponder is sampled several times per second and displayed and printed at a preselected interval. This information is translated by trilateration into boat position during computer processing. The entire system is powered by storage batteries and requires 6 A at 24 V dc. A high-efficiency commercial inverter (Flite-Tronics PC16 Aircraft Static Inverter) supplies the Mini-Ranger with 117 V ac.

The plume data are read onto the magnetic tape transcribed from the original cassette and, with additional calibration data, are used in a program that has been developed to plot the data. Seven horizontal plots representing data taken at seven depths are plotted by a Calcomp Digital Incremental Plotter. The isotherms and centerlines are drawn by hand on this output. Vertical cross sections of the plume are obtained by identifying, on the horizontal sections, the boat transects of interest. Index numbers associated with the data points are identified and used as input for another computer program, which plots the data in vertical sections. During the 1972 field year, these automated data-collection and -reduction techniques have allowed the acquisition and reduction of about 30 plumes, consisting of about 200 horizontal and 200 vertical sections.

The plume-measurement system described has proved to be highly reliable. We have used this system under all normal conditions without serious malfunction. Problems have arisen, however, when the air temperature was below 0°C , since the boat is essentially open and the solid-state-circuitry temperature specifications are $0\text{--}40^{\circ}\text{C}$. We have also observed difficulties produced by the thermistor time-constant due to the rather high speed (about 3 m/sec) at which the boat travels. In the near field, this time-constant may lead to a shift in the position of the plume interface in the direction of boat travel that must be taken into account when isotherms are drawn. Small-scale features may also be lost as a result of the thermistor time-constant.

During the 1972 field year, the acquisition system was used only for recording temperature, position, time, and depth, but with minor additions to the electronics, other parameters can be measured.

Ambient conditions are routinely measured in conjunction with plume mapping. Ambient lake current is measured with a Bendix Q-15 geomagnetic ducted impeller current meter. Wind speed and direction are measured with a hand-held anemometer on the boat and by a shore-based Meteorology Research, Inc. (MRI), portable meteorological station (see graphs of wind speed and direction in Appendix C). Air temperature, humidity, lake conditions, etc., are also measured with each plume. Table I lists the instrument specifications.

TABLE I. INSTRUMENT SPECIFICATIONS

INSTRUMENT	SENSOR	ACCURACY	THRESHOLD	RANGE	RESOLUTION	TIME CONSTANT	REMARKS
Bendix Q-15 Current Meter	Speed; impeller	$\pm 4\%$ of full scale	0.04 knot	0-1.0 knot; low scale 0-5.0 knots; high scale	0.02 knot; low scale 0.1 knot; high scale	25 sec; low scale 2.5 sec; high scale	
	Direction; vane	$\pm 12^\circ$	-	0-360°	5°	-	Vane has adjustable length; 0.3-3.0 m
Temperature Measurement System	Thermistor	$\pm 0.2^\circ\text{C}$	-	0-50°C	0.1°C	2.5 sec in well stirred water	Thermistor type YSI #709 - water-proofed
Mctorola Mini-Ranger	-	± 3 m	-	0.1-35 km	1 m	-	Accuracy applies to each range measurement. System accuracy varies with position of transponders rela- tive to boat. For most measurements, ± 3 m applies
Data-Marine Depth-Sounder	Model 2301 (Transom mounted)	± 1 ft; low range	2 ft; low range	2 - 99 ft; low range	1 ft	-	
		± 1 fathom; high range	2 fathoms; high range	2 - 99 fathoms; high range	1 fathom	-	
MRI Meteorological Station	Speed; 3 cup anemometer	$\pm 2\%$	0.75 mph	0.75 - 100 mph	0.2 mph	18 ft (response distance)	
	Direction; vane	$\pm 5^\circ$	0.75 mph	0.75 - 100 mph	5°	8 ft (response distance)	
	Temperature; Bi- metallic coil	$\pm 3^\circ\text{F}$	-	-30°+120°F	1°F	unknown	
	Clock	± 60 sec/24 hrs	-	32 Days	-	-	Clock specifications are open to question

Conversion factors:

1 knot = 0.514 m/sec

1 mph = 0.447 m/sec

1 ft = 0.305 m

1 fathom = 1.829 m

 $^\circ\text{C} = (^\circ\text{F} - 32) 5/9$

III. RESULTS OF THE FIELD WORK

A. Introduction to the Data

The results of the thermal-plume measurements at the Point Beach and Palisades Nuclear Power Plants follow. The data are presented in sequence according to date. The thermal-plume drawings show the discharge flume, the shoreline, and the lake bottom where applicable. The intake crib is also shown for the Point Beach plant. In general, each plume data set consists of: the surface isotherm plot, which also contains, in tabular form, pertinent plant and ambient meteorological and lake data; six temperature plots corresponding to the 0.5-, 1.0-, 1.5-, 2.0-, 2.5-, and 3.0-m depth levels; and vertical cross-sectional temperature plots, which are specified on the surface isotherm plot as A-A', B-B', etc. Values of ambient water temperature as a function of depth are contained in Appendix B, as are values of ambient lake current. The time and lake location of current measurement are also specified. Where a thermistor malfunctioned, some plume data sets may be missing from the horizontal plot corresponding to that thermistor depth level. Also, in several vertical cross-sectional temperature plots, and in some horizontal plots, blocks of data appear to be missing. The reason for this is that in some situations the level of the temperature boom had to be raised to avoid possibly catastrophic interaction with the lake bottom. In final explanation of the thermal-plume plots, the barely legible dots in the figures represent actual temperature values at the location indicated and hence also represent the boat path. The data are not legible because the presented figures were substantially reduced in size for presentation purposes from much larger working drawings. The bold dots with accompanying temperature values were placed on the figures to yield readable representative temperatures corresponding to particular locations.

Also included with the plume plots for May 17 and 18, 1972, is the measurement of the outfall velocity at the Point Beach Unit 1 outfall flume. Information as to outfall velocities at the Palisades plant appears in Ref. 4. For all the field trips during the 1972 season, an MRI meteorological station was placed in operation near the appropriate power plant. Graphs showing wind speed, wind direction, and dry-bulb temperature are presented in Appendix C. These graphs can be used to examine the wind velocity and air temperature at times before the plume mapping.

Intake studies were also conducted at the two power plants. Currents were measured near the intake structures using the Q-15 current meter. At the Point Beach intake, water temperature was also measured.

The plume isotherms, both horizontal and vertical sections, shown in the figures were all drawn by hand in which some degree of intuitive judgment and latitude in interpolation was exercised. In most cases, the individuals who participated in plume contouring attempted to interpolate linearly between data points. However, it was not always possible to do so; therefore, some subjectivity is inherent in the data. To test the validity of hand contouring, several people were asked to draw isotherms to several sets of identical temperature data independently. The results of these tests indicated some minor differences between contours drawn by different individuals, and for that matter, for plumes repeated by the same individuals. The inter- and intra-personnel differences between plume drawings, however, showed few significant differences.

Several two-dimensional computer data interpolation and contouring codes are available; one of the most promising was tested with our data. The obvious advantage of using such routines is that individual subjectivity is removed from consideration. The computer routine invariably misinterpolated the temperature values between two somewhat separated data segments, but did reasonably well in fitting the data close to the segments themselves. This kind of behavior also could have been anticipated, since the codified interpolation scheme did not contain the necessary physics describing turbulent heat transport, but rather used an "n" nearest neighbor algorithm. Such an algorithm probably would be suitable for uniformly or even randomly distributed data that are reasonably compacted. However, the plume data were intensively gathered on discrete and widely separated line segments.

An attempt was made to construct a more suitable algorithm of the form

$$T(x,y) = \sum_{i=1}^N a_i f_i(x,y) \quad ,$$

where the functions f_i are given and the a_i are chosen to minimize

$$x = \sum_{\alpha=1}^M \{T(x_{\alpha}, y_{\alpha}) - t_{\alpha}\}^2$$

for the observed temperatures t_{α} at points (x_{α}, y_{α}) . This makes the calculation of a_1 a classical linear-least-squares effort. This attempt seemed to be satisfactory in theory, but proved poor in practice.

For the above and other considerations, it was felt that subjective hand contouring was the best approach to follow. The surface-layer isotherms were constructed first, with the lower-depth isotherms following in consecutive order. The personnel involved in temperature contouring always tried to factor into each succeeding depth level the insight and trends established in the previous levels so that a more consistent set of plume data could be obtained.

The vertical cross sections were drawn independently of the horizontal sections, and close inspection of the vertical and horizontal plots will reveal some minor differences between the two sets in relationship to isotherm positions. Part of the problem is that the vertical sections were constructed by unfolding the point-to-point distances into a straight line. That is, the possibly curved or irregular boat trajectory between any two locations was unfolded as if it were a straight-line trajectory. If there were some minor position error due to range-equipment noise from one point to another, this error would then be incorporated into the vertical section plotting and would tend to increase the distances between locations designated by the cross-section markings. The cross sections selected for presentation were chosen to be closely representative of centerline normal sections proceeding away from the discharge.

The plume centerlines designated on each surface drawing are quite subjective. When the temperatures are not distributed symmetrically in the plume, the term "centerline" loses its meaning. In the near field (the jet regime), where the plume configuration is often tongue-shaped, the centerline is generally drawn to divide the plume symmetrically. Away from the immediate near field, the plume configuration can take an untold number of shapes, making it almost impossible to define a unique centerline. The location selected for the centerline in these reaches of each plume was generally chosen to be the locus of maximum temperatures. Where that was not practical, the centerline was drawn to bisect the area of the highest isotherms. The centerlines should therefore not be interpreted too literally within these somewhat remote plume regimes.

Several general comments seem appropriate regarding the ambient lake and meteorological data presented in block form on each surface-plume drawing. The meteorological data reported were acquired from the boat using a portable Weather Measure three-cup anemometer held about 2 m above the water surface. Wet- and dry-bulb temperatures were measured using a conventional sling psychrometer. The important fact here is that these meteorological measurements were typically gathered over a 5-min period before and after a plume data run, which generally required 40-90 min to complete. Therefore, the meteorological conditions recorded before and after each plume measurement period might not have been representative of the "mean" conditions during the actual plume-measurement period. Anyone interested in using more representative values for wind speed and direction should therefore refer to Appendix C, Figs. 142-157 which summarize in greater detail prevailing wind speed, wind direction and dry-bulb air-temperature data collected several hours before, during, and after each plume-measurement period. The meteorological data reported in Appendix C were acquired from a portable recording station generally located on land and situated as close to the shoreline as possible in an area remote from structures, bluffs, trees, or other factors that could seriously distort the measured parameters.

Basically, the same general comments apply for the ambient current values reported for each surface plume. These current values were obtained either before or after, or occasionally both before and after, each plume-measurement period. Appendix B lists the pertinent data regarding the location, date and time, and current conditions obtained for each plume data set. In most cases, the ambient current data were taken on the upcurrent side of the plume to avoid possible bias due to the discharge dynamics of the plant effluent itself. Because lake currents are both spatially and temporally variable, it is difficult to define "ambient current" from a single measurement. This is demonstrated by the fact that some of the before-and-after ambient current values reported in Appendix B for the same date show significant differences. In such cases, the current values reported on the surface-plume drawings represent average values of before-and-after conditions, or the particular reading thought to be more closely representative of measurement period or more representative of the plume position. Where there was no clear choice between before and after conditions, a range is presented.

B. Presentation of Data

1. Point Beach Nuclear Power Plant: May 17, 1972

The first temperature survey was conducted during the afternoon of May 17, 1972. During the survey, the lake conditions were calm with 0- to 0.3-m waves (see Fig. 8). The meteorological graphs in Appendix C indicate that the wind speed was low the previous night. The wind speed began to increase around 0800. Direction also shifted at this time from westerly to southerly. Also, a sharp increase in air temperature of about 9°C occurred from 1200 to 1400 before the plume mapping.

Fig. 8. Lake-surface Conditions at Point Beach:
May 17, 1972, 1100 Hours

Results of the plume mapping are shown in Figs. 9-12. As can be seen from the figures, the plume moves north in the direction of the ambient current. The ambient current was measured at two locations south of the plant near the shoreline, as indicated in Appendix B. The current speed is fairly constant with location and depth. Ambient lake-water temperature was also measured as a function of depth; values are given in Appendix B. The ambient water temperature was fairly constant, decreasing only slightly with depth in the first 3 m. The plume sections (Fig. 12) indicate that the plume is somewhat deeper on the upcurrent side than on the downcurrent side. The plume interface on the upcurrent side is also better defined. These two features were observed for most plumes where a significant ambient current was present.

Discharge velocities were also measured at the lake end of the Unit 1 discharge flume as a function of position and depth. Results are presented in Table II, along with a definition sketch showing measurement locations. The results of these measurements indicate that slightly higher velocities occur on the north side of the flume and that velocity decreases with depth.

Plume areas within the isotherms at all depths were measured from the drawings and are tabulated in Appendix D. As would be expected for a buoyant effluent, the areas decreased with depth. Appendix E lists the half-depths of the plume and contains a description of the half-depth. For this plume, the half-depth was 1.5 m.

2. Point Beach Nuclear Power Plant: May 18, 1972

One temperature survey was conducted during the afternoon of May 18, 1972. Before this plume mapping, near-field temperature and velocity measurements were conducted near the flume for Unit 1. These data are presented in Ref. 4. Figure 13 shows that lake conditions were quite calm for the survey. Wind was light and variable most of this day and the previous night. Air temperature was relatively constant.

Results of the survey are shown in Figs. 14-17. Ambient current was zero at all levels. The surface drawing (Fig. 14) shows that the plume initially moves straight out from the flume, and then drifts slightly southward, possibly in response to a very low current, below the threshold measuring capability of the Bendix Q-15 current meter. There were no sharp

Fig. 9. Thermal Plume at Surface for Point Beach Nuclear Power Plant: May 17, 1972, 1646-1806 Hours. ANL Neg. No. 190-982.

Fig. 10. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: May 17, 1972, 1646-1806 Hours. ANL Neg. No. 190-992.

Fig. 11. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: May 17, 1972, 1646-1806 Hours. ANL Neg. No. 190-1042

Fig. 12. Vertical Cross Sections for Point Beach Nuclear Power Plant: May 17, 1972, 1646-1806 Hours. ANL Neg. No. 190-1069.

Table II. Discharge Velocity Profile at the
Point Beach Nuclear Power Plant (Unit 1) Discharge Flume

May 17, 1972			May 18, 1972		
Position	Depth (meters)	Speed (cm/sec)	Position	Depth (meters)	Speed (cm/sec)
1	0.3	69	1	0.3	56
1	3.5	57	1	1.5	58
			1	2.7	59
2	0.3	83	2	0.3	93
2	3.5	68	2	1.5	77
			2	2.7	64
3	0.3	90	3	0.3	84
3	3.5	52	3	1.5	73
			3	2.7	60
4	0.3	76	4	0.3	66
4	3.5	42	4	1.5	54
			4	2.7	45
5	0.3	54	5	0.3	46
5	1.5	54	5	1.5	48
5	3.0	33	5	2.7	41
5	3.5	35

Definition Sketch

Fig. 13. Lake-surface Conditions at Point Beach:
May 18, 1972, 1030 Hours

Fig. 14. Thermal Plume at Surface for Point Beach Nuclear Power Plant: May 18, 1972, 1645-1751 Hours. ANL Neg. No. 190-983.

Fig. 16. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: May 18, 1972, 1645-1751 Hours.

Fig. 17. Vertical Cross Sections for Point Beach Nuclear Power Plant:
May 18, 1972, 1645-1751 Hours. ANL Neg. No. 190-1085.

Fig. 17 (Contd.). ANL Neg. No. 190-1083.

temperature gradients on either side of the plume, indicating that if there were any current, it must have been very low. Ambient water temperature dropped by 2°C from the surface to the 3.0-m level, indicating strong stratification, which is to be expected under calm lake and meteorological conditions.

The half-depth of the plume was 1.0 m, which is less than on May 17, 1972. This condition is probably due to the greater buoyancy forces present when temperature stratification is stronger. Plume areas also drop off more rapidly with depth than on the previous day, but are larger at the surface.

As on the previous day, discharge velocity was measured, at the lake end of the Unit 1 flume, with the Ekman-Merz current meter (see Table II). As on May 17, the velocity decreased with depth and was greater on the north side than on the south side of the flume.

3. Point Beach Nuclear Power Plant: May 24, 1972

The plume was mapped three times during the morning hours of May 24, 1972. Lake-surface conditions were fairly calm (see Fig. 18). Winds were light and variable for the time of the plume mapping and during the previous night. What little winds did exist in the morning were mainly out of the north. The wind began to increase later in the day. The air temperature was fairly constant on this and the previous day.

The results of these three surveys are shown in Figs. 19-30. Except for small-scale variations, which could be due to the difference in location of data-collection points and hence slightly different drawing techniques, the plumes look much the same. Ambient current was measured north of the plant, before the plume mapping, and was found to be zero at all levels. Later in the afternoon, a low current with a southward component (see Appendix B) was measured south of the plant. This could explain the slight bending to the south of the plume centerline, particularly for the last survey.

Ambient water temperature varied by as much as 3°C from about 1 km offshore to near the shoreline. This phenomenon was probably due to strong nearshore heating of the surface water. Plume areas within isotherms decreased with depth and were similar for the three surveys. Plume half-depth was found to be about 1.25 m for the two later surveys. Insufficient data precluded an estimation of half-depth for the first survey.

Fig. 18. Lake-surface Conditions at Point Beach: May 24, 1972, Morning

Fig. 19. Thermal Plume at Surface for Point Beach Nuclear Power Plant: May 24, 1972, 0925-1040 Hours.
 ANL Neg. No. 190-979.

Fig. 20. Thermal Plume at 0.5- and 1.5-m Depths for Point Beach Nuclear Power Plant: May 24, 1972, 0925-1040 Hours. ANL Neg. No. 190-1021.

Fig. 21. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: May 24, 1972, 0925-1040 Hours. ANL Neg. No. 190-1018.

Fig. 22. Vertical Cross Sections for Point Beach Nuclear Power Plant: May 24, 1972, 0925-1040 Hours. ANL Neg. No. 190-1088.

Fig. 22 (Contd.). ANL Neg. No. 190-1089.

Fig. 23. Thermal Plume at Surface for Point Beach Nuclear Power Plant: May 24, 1972, 1045-1145 Hours. ANL Neg. No. 190-988.

Fig. 24. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths
For Point Beach Nuclear Power Plant: May 24, 1972,
1045-1145 Hours. ANL Neg. No. 190-1031.

Fig. 25. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: May 24, 1972, 1045-1145 Hours. ANL Neg. No. 190-1040.

Fig. 26. Vertical Cross Sections for Point Beach Nuclear Power Plant: May 24, 1972, 1045-1145 Hours.
ANL Neg. No. 190-1078.

Fig. 27. Thermal Plume at Surface for Point Beach Nuclear Power Plant: May 24, 1972, 1145-1225 Hours. ANL Neg. No. 190-974.

Fig. 28. Thermal Plume at 0.5- and 1.5-m Depths for Point Beach Nuclear Power Plant: May 24, 1972, 1145-1225 Hours. ANL Neg. No. 190-1038.

Fig. 29. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: May 24, 1972, 1145-1225 Hours. ANL Neg. No. 190-998.

Fig. 30. Vertical Cross Section for Point Beach Nuclear Power Plant: May 24, 1972, 1145-1225 Hours. ANL Neg. No. 190-1081.

During the afternoon of May 24, an intake study was conducted at the Point Beach Plant intake crib (see Fig. 2) to measure current and temperature patterns near this structure. A two-point mooring system was used to obtain simultaneous temperature and velocity measurements near the intake crib from the Argonne survey boat. An anchor was located at the stern of the boat on the crib centerline. A bowline was attached to the intake structure. The boat's position was held constant between these two lines. The Bendix Q-15 current meter, with a YSI No. 409 thermistor recording on a Rustrack Model No. 2133 recorder, measured current velocity and temperature as a function of depth at the nine stations shown in Fig. 31. The meter was lowered over the side and suspended at 1-m intervals to the bottom. Results of these measurements are given in Table III. Ambient conditions were measured during the study. Dry-bulb temperature was 12.5°C , the relative humidity was 75%, winds were out of the north at 2-3 m/sec, and sky conditions were clear. Lake conditions were calm with 0.2-m waves heading toward the south. Ambient water temperature was 10.7°C . The ambient current was measured at 1 and 3 m and found to be zero. Plant operating data was reported to be the same as for the morning temperature surveys.

Since the ambient-current speed was so low as to be not measurable, evaluating the results of this study is easier. As can be seen from Table III, the water near the intake shows little or no effect from the intake. Trace amounts of current were noticed at the surface, but there was no indication of currents below 3 m, even though the inlet pipes are located at a depth of about 5.2 m. These results are supported by the experiences of divers who have worked near the intake.

Water temperatures were also measured at each location and depth. Comparing the temperatures measured with the intake water temperature as reported by the Point Beach Plant personnel for the time of the study (11.7°C) indicates a slight discrepancy. The temperatures measured near the intake varied from 12.3 to 14.2°C , with an average of 13.0°C . The reason for this 1.3°C temperature difference between average value measured and plant data is not known, although it is probably a calibration problem.

Fig. 31. Station Locations for Intake Study at the Point Beach Nuclear Power Plant: May 24, 1972

TABLE III. Results of Current and Temperature Measurements
Made at the Point Beach Nuclear Power Plant
Intake Crib: May 24, 1972

Station	Time	Depth (meters)	Bottom Depth (meters)	Current Speed (cm/sec)	Current Direction (degrees)	Temperature (°C)
1	1344	1.0	7.4	0	-	12.7
1	1345	2.0	7.4	0	-	12.7
1	1347	3.0	7.4	0	-	12.7
1	1348	4.0	7.4	0	-	12.4
1	1352	5.0	7.4	0	-	12.5
1	1353	6.0	7.4	0	-	12.6
1	1354	7.0	7.4	0	-	12.6
2	1358	1.0	7.0	0	-	12.9
2	1359	2.0	7.0	0	-	12.7
2	1400	3.0	7.0	0	-	12.7
2	1401	4.0	7.0	0	-	12.5
2	1402	5.0	7.0	0	-	12.4
2	1403	6.0	7.0	0	-	12.4
3	1424	1.0	7.0	4.4	270	12.7
3	1426	2.0	7.0	2.8	275	12.7
3	1427	3.0	7.0	1.1	275	12.7
3	1428	4.0	7.0	0	-	12.7
3	1430	5.0	7.0	0	-	12.6
3	1431	6.0	7.0	0	-	12.3
4	1438	1.0	8.0	1.7	240	12.7
4	1440	2.0	8.0	0	-	12.5
4	1441	3.0	8.0	0	-	12.5
4	1442	4.0	8.0	0	-	12.5
4	1444	5.0	8.0	0	-	12.6
4	1445	6.0	8.0	0	-	12.6
4	1446	7.0	8.0	0	-	13.0
5	1516	1.0	7.8	1.7	150	13.4
5	1519	2.0	7.8	0	-	13.2
5	1521	3.0	7.8	0	-	12.9
5	1522	4.0	7.8	0	-	12.7
5	1523	5.0	7.8	0	-	12.9
5	1524	6.0	7.8	0	-	13.0
5	1525	7.0	7.8	0	-	13.3
6	1528	1.0	7.5	3.3	150	13.8
6	1530	2.0	7.5	0	-	13.3
6	1532	3.0	7.5	0	-	13.0
6	1533	4.0	7.5	0	-	13.1
6	1534	5.0	7.5	0	-	13.1
6	1535	6.0	7.5	0	-	13.1
6	1536	7.0	7.5	0	-	12.7
9	1544	1.0	7.9	0	-	13.7
9	1546	3.0	7.9	0	-	13.2
9	1547	5.0	7.9	0	-	13.0
9	1548	7.0	7.9	0	-	12.9
7	1603	1.0	7.5	0	-	13.7
7	1605	2.0	7.5	0	-	13.1
7	1606	3.0	7.5	0	-	13.0
7	1607	4.0	7.5	0	-	13.1
7	1611	5.0	7.5	0	-	13.3
7	1612	6.0	7.5	0	-	13.2
7	1613	7.0	7.5	0	-	13.2
8	1616	1.0	7.6	6.1	105	14.2
8	1618	2.0	7.6	0	-	13.5
8	1619	3.0	7.6	0	-	13.4
8	1620	4.0	7.6	0	-	13.5
8	1627	5.0	7.6	0	-	13.3
8	1630	6.0	7.6	0	-	13.4
8	1631	7.0	7.6	0	-	13.2

4. Palisades Nuclear Power Plant: June 13, 1972

Field work began at the Palisades Plant on June 13, 1972. The thermal plume was mapped twice during the afternoon. Lake conditions were calm (see Fig. 32). The graphs in Appendix C show that winds were fairly light and out of the west. The boat anemometer indicated the wind to be out of the southwest. The boat anemometer direction is a short-time average value (about 30 sec); the data in Appendix C represent 1-hr averages. Wind direction and speed were fairly constant from the previous night, although lower wind speeds were recorded on the previous day.

Fig. 32. Lake-surface Conditions at Palisades: June 13, 1972, 1615 Hours and MRI Mechanical Weather Station

As recorded by the MRI meteorological station, the air temperature increased by almost 10°C from 0800 to the time of plume mapping. Figures 33-40 show that the plume was driven north along the shoreline by a fairly strong northward-flowing current. Temperatures as much as 2°C above ambient were noted 4 km from the outfall for the plume mapped from 1516 to 1615. The current velocity is listed on the drawings and also in Appendix B. Higher currents are indicated for the plume mapped later in the day, but the current measurements were at different locations. A pronounced temperature interface existed on the upcurrent side of the plume, as is indicated in both the horizontal and vertical plume drawings. This interface was marked by dead fish and other debris on the surface. Some seemingly anomalous temperatures occur about 1000 m offshore from the outfall. It is possible that this is spurious, perhaps attributable to an equipment malfunction.

After the temperature surveys were completed, the boat was driven back to the jetty at South Haven, Michigan, at 1/2-1 km offshore, with the temperature-acquisition equipment running. Nearshore heating and possible downwelling were noted. The nearshore heating was expected, since the day was bright and hot with a considerable increase in air temperature during the day. In fact, the two surveys indicate that ambient water temperature increased by almost 2°C near the shore.

Although information was sparse in the far-field region for determining the characteristic half-depth of the plume, for both surveys the half-depth was probably less than 0.5 m. Plume areas within isotherms are listed in Appendix D. Areas appeared to decrease fairly rapidly with depth.

5. Palisades Nuclear Power Plant: June 19, 1972

One temperature survey was conducted late in the afternoon on this day. Lake conditions were calm (see Fig. 41), and winds were light and out of the south-southeast. No wind or air temperature data are available from earlier in the day, because the meteorological station was set up just before the thermal-plume mapping.

Fig. 33. Thermal Plume at Surface for Palisades Nuclear Power Plant:
 June 13, 1972, 1242-1443 Hours. ANL Neg. No. 190-962.

Fig. 34. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 13, 1972, 1242-1443 Hours. ANL Neg. No. 190-1007.

Fig. 35. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 13, 1972, 1242-1443 Hours. ANL Neg. No. 190-996.

Fig. 36. Vertical Cross Sections for Palisades Nuclear Power Plant: June 13, 1972, 1242-1443 Hr. ANL Neg. No. 190-1072.

Fig. 37. Thermal Plume at Surface for Palisades Nuclear Power Plant: June 13, 1972, 1516-1615 Hours. ANL Neg. No. 190-978.

Fig. 38. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 13, 1972, 1516-1615 Hours. ANL Neg. No. 190-993.

Fig. 39. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths
for Palisades Nuclear Power Plant: June 13, 1972,
1516-1615 Hours. ANL Neg. No. 190-1029.

Fig. 40. Vertical Cross Sections for Palisades Nuclear Power Plant: June 13, 1972, 1516-1615 Hours. ANL Neg. No. 190-1087.

Fig. 41. Lake-surface Conditions at Palisades:
June 19, 1972, 1700 Hours

Results of the survey (see Figs. 42-45) indicate that the plume was heading north, although there was some indication of possible changing current conditions. (Unfortunately, not enough offshore temperature data were collected to close the 16°C isotherm.) Examination of the lake-current data in Appendix B indicates that there was a fairly strong northward current (010° - 035°) at all levels when measured near the shore and south of the plant in 6.1-m-deep water. Measurements made later in the day, farther offshore, and north of the plant in 12.2-m-deep water indicate an offshore current at the 1-m level (320°) and a southward flowing current (225°) at the 3-m level.

The plume drawings indicate some evidence of upwelling; namely, the temperature of the nearshore surface water was less than that of the offshore surface water. The ambient water showed some stratification, with ambient-water temperatures of 14.9 - 15.6°C at the surface and 12.1 - 14.1°C at the 3-m level. The plume disappears below the 1.5-m level, and plume half-depth was probably less than 1 m. As noted in Appendix D, plume areas decreased rapidly with depth.

Fig. 42. Thermal Plume at Surface for Palisades Nuclear Power Plant: June 19, 1972, 1630-1730 Hours. ANL Neg. No. 190-970.

Fig. 43. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 19, 1972, 1630-1730 Hours. ANL Neg. No. 190-1004.

Fig. 44. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 19, 1972, 1630-1730 Hours. ANL Neg. No. 190-1001.

Fig. 45. Vertical Cross Sections for Palisades Nuclear Power Plant: June 19, 1972, 1630-1730 Hours. ANL Neg. No. 190-1059.

Fig. 45 (Contd.). ANL Neg. No. 190-1065.

6. Palisades Nuclear Power Plant: June 20, 1972

The thermal plume was mapped four times on June 20-twice in the morning and twice in the afternoon-over a 5-hr span. Lake conditions remained relatively calm for all four surveys (see Figs. 46 & 47). For the surveys, winds were moderate and out of the southwest and decreased slightly in magnitude in the afternoon. Winds were fairly light the previous night. The air temperature was relatively constant. The day was marked by fog pockets moving in and out of the area, but meteorological conditions were fairly constant.

Results of the plume mappings are shown in Figs. 48-63. The plume was driven north by a strong northward shore-parallel current. The current was measured at several times, locations, and depths during the day (see Appendix B). Current speed increased during the day. Plume direction and shape were similar for all four surveys. The surface drawings for the morning surveys are almost indistinguishable. Minor differences are probably due to the subjective drawing of the isotherms to different data-point locations. Certain isotherms increased in size from morning to afternoon. This was due to an increase in ambient water temperature (see Appendix B) as the day progressed, due to solar heating of the surface water. Surface-water temperature increased by 0.5°C per hour over the time of the survey. Plume half-depth decreased from 1.25 to 0.3 m (see Appendix E) from the morning to the afternoon. Plume areas decreased rapidly with depth.

7. Point Beach Nuclear Power Plant: July 7-8, 1972

Temperature surveys were conducted at the Point Beach plant on July 7 and July 8, 1972, before and after the shutdown of the Unit 1 reactor in conjunction with fish-behavior studies. The pumps for this unit were also shut down. Echo soundings conducted in conjunction with the temperature measurements, using a fish locator, provided information on the distribution of fish in the thermal plume on July 7 and in the same area in ambient water on July 8. A discussion of the fish behavior during this pre- and post-shutdown period at Point Beach is provided by Romberg et al.⁷

Results of the temperature surveys for the two days are shown in Figs. 64-70. Unfortunately, much of the pertinent lake and meteorological data were not collected. Thus, results of the temperature surveys are provided

Fig. 46. Lake-surface Conditions at Palisades:
June 20, 1972, 1045 Hours

Fig. 47. Lake-surface Conditions at Palisades:
June 20, 1972, 1330 Hours

Fig. 48. Thermal Plume at Surface for Palisades Nuclear Power Plant: June 20, 1972, 1027-1109 Hours
ANL Neg. No. 190-986.

Fig. 49. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1027-1109 Hours. ANL Neg. No. 190-1032.

Fig. 50. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1072-1109 Hours. ANL Neg. No. 190-1008.

Fig. 51. Vertical Cross Sections for Palisades Nuclear Power Plant: June 20, 1972, 1027-1109 Hours. ANL Neg. No. 190-1073.

Fig. 51 (Contd.). ANL Neg. No. 190-1086.

Fig. 52. Thermal Plume at Surface for Palisades Nuclear Power Plant; June 20, 1972, 1100-1200 Hr. ANL Neg. No. 190-972.

Fig. 53. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1100-1200 Hours. ANL Neg. No. 190-995.

Fig. 54. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1110-1200 Hours. ANL Neg. No. 190-991.

Fig. 55. Vertical Cross Sections for Palisades Nuclear Power Plant: June 20, 1972, 1110-1200 Hours. ANL Neg. No. 190-1091.

Fig. 55 (Contd.). ANL Neg. No. 190-1079.

Fig. 56. Thermal Plume at Surface for Palisades Nuclear Power Plant: June 20, 1972, 1330-1425 Hours. ANL Neg. No. 190-984.

Fig. 57. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1330-1425 Hours. ANL Neg. No. 190-1000.

Fig. 58. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1330-1425 Hours. ANL Neg. No. 190-997.

Fig. 59. Vertical Cross Sections for Palisades Nuclear Power Plant: June 20, 1972, 1330-1425 Hours. ANL Neg. No. 190-1092.

Fig. 59 (Contd.). ANL Neg. No. 190-1062.

Fig. 60. Thermal Plume at Surface for Palisades Nuclear Power Plant: June 20, 1972, 1430-1515 Hours. ANL Neg. No. 190-980.

Fig. 61. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1430-1515 Hours. ANL Neg. No. 190-999.

Fig. 62. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: June 20, 1972, 1430-1515 Hours. ANL Neg. No. 190-1002.

Fig. 63. Vertical Cross Sections for Palisades Nuclear Power Plant: June 20, 1972, 1430-1515 Hours. ANL Neg. No. 190-1063.

Fig. 63 (Contd.). ANL Neg. No. 190-1066.

Fig. 64. Thermal Plume at Surface for Point Beach Nuclear Power Plant: July 7, 1972, 1830-2015 Hours. ANL Neg. No. 190-973.

Fig. 65. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: July 7, 1972, 1830-2015 Hours. ANL Neg. No. 190-1035.

Fig. 66. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: July 7, 1972, 1830-2015 Hours

Fig. 67. Vertical Cross Sections for Point Beach Nuclear Power Plant:
July 7, 1972, 1830-2015 Hours. ANL Neg. No. 190-1075.

Fig. 67 (Contd.). ANL Neg. No. 190-1084.

Fig. 68. Isotherms at Surface for Point Beach Nuclear Power Plant:
 July 8, 1972, 1500-1730 Hours. ANL Neg. No. 190-975.

Fig. 69. Isotherms at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: July 8, 1972, 1500-1730 Hours. ANL Neg. No. 190-1037.

Fig. 70 Isotherms at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: July 8, 1972, 1500-1730 Hours. ANL Neg. No. 190-1030.

only for completeness. From the figures for July 7, it is evident that the plume heads almost straight out from the plant, indicating that there was either no ambient current or, at most, a very low current. Examination of Fig. 68 indicates ambient water temperature decreasing with distance from shore. Discussion with Romberg et al. indicated meteorological conditions remained constant for both days, although fog rolled in during the survey on July 8. Ambient water temperature was constant with depth on July 7 and dropped off slightly with depth on July 8 (see Appendix B). Plume half-depth for July 7 was 1.0-1.25 m. Plume areas within isotherms decreased with depth in a way consistent with previous findings.

8. Point Beach Nuclear Power Plant: July 11, 1972

During the afternoon of July 11 at Point Beach, one temperature survey was conducted. Results of the survey are given in Figs. 71-74. This day was marked by a foggy, damp morning, followed by clearing just before the plume mapping. Lake conditions were choppy with 0.3- to 0.6-m waves. During the plume mapping, there was a sharp increase in air temperature, followed by a temperature drop shortly after. Wind speed increased from light to moderate during the morning. Direction changed from southwest to southeast and then to north-northeast during the plume mapping. Winds were calm on the day before. The meteorological data listed on the surface temperature plot for July 11 (see Fig. 71) refer to instantaneous conditions just before plume mapping. Since conditions were changing, refer to Appendix C for information on wind and air-temperature variations.

The plume headed out from the outfall toward the intake crib and then was deflected northward by a west-northwesterly flowing current. Although the current was strong at the 1-m level (see Appendix B), there was no evidence of a sharp temperature gradient on the upcurrent side of the plume. The plume was somewhat deeper than previously noted with the half-depth being about 2.5-2.75 m. Ambient water temperature was well defined and constant with depth, probably due in part to the mixing caused by the choppy lake conditions. Plume areas within isotherms were larger than normal for the Point Beach Plant and dropped off rapidly after 1.5 m.

Fig. 71. Thermal Plume at Surface for Point Beach Nuclear Power Plant:
July 11, 1972, 1245-1355 Hours. ANL Neg. No. 190-964.

Fig. 72. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: July 11, 1972, 1245-1355 Hours. ANL Neg. No. 190-1020.

Fig. 73. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: July 11, 1972, 1245-1355 Hours. ANL Neg. No. 190-1026.

Fig. 74. Vertical Cross Sections for Point Beach Nuclear Power Plant: July 11, 1972, 1245-1355 Hours. ANL Neg. No. 190-1070.

Fig. 74 (Contd.). ANL Neg. No. 190-1067.

9. Point Beach Nuclear Power Plant: July 13, 1972

A temperature survey was conducted at Point Beach early in the evening on July 13, 1972, following a temperature and velocity study of the near-field region of the plume.⁴ Results of the survey are shown in Figs. 75-78. Winds were fairly strong out of the west on July 12, but calmed down and shifted to the north during the night before the temperature survey. A significant drop in air temperature occurred from July 12 to July 13. Winds were light most of July 13, with direction swinging from north to south at 1200 hours. Winds were fairly light during the plume mapping, and direction was out of the south according to the MRI meteorological-station data. The anemometer on the boat recorded an instantaneous wind direction of 135° before plume mapping. Air temperature was constant during plume mapping. Lake conditions were calm for both studies.

The plume appeared to bend toward the south, although data in the far-field region are missing in certain areas. The current speed is low, and the direction is onshore at the 1-m level and southerly at the other levels. The plume drawings show an anomaly north of the plant. Namely, just north of the plume, the lake water is colder than somewhat further north. Thus, the ambient-water-temperature values reported are uncertain. The ambient water temperatures reported in Appendix B give evidence of significant stratification. Plume half-depth was found to be 0.25-0.5 m, which is very shallow for Point Beach. Areas within isotherms were somewhat smaller than normal, but decreased in a way consistent with previous findings.

10. Palisades Nuclear Power Plant: July 17, 1972

The thermal plume was mapped once during the afternoon of July 17 at the Palisades Plant. Lake conditions were marked by 0.3-1.0-m swells (see Fig. 79). Winds, as recorded by the MRI meteorological station, were fairly light on the average and out of the south, but the wind was gusty and conditions were somewhat rough before the survey. The boat's anemometer indicated instantaneous gusting of the wind with a southwesterly direction, particularly before the survey. Conditions improved later in the day. No wind data are available from the previous day.

Fig. 75. Thermal Plume at Surface for Point Beach Nuclear Power Plant: July 13, 1972, 1805-1903 Hours.
 ANL Neg. No. 190-985.

Fig. 76. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: July 13, 1972, 1805-1903 Hours. ANL Neg. No. 190-1022.

Fig. 77. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: July 13, 1972, 1805-1903 Hours. ANL Neg. No. 190-1019.

Fig. 78. Vertical Cross Sections for Point Beach Nuclear Power Plant: July 13, 1972, 1805-1903 Hours. ANL Neg. No. 190-1093.

Fig. 79. Lake-surface Conditions at Palisades:
July 17, 1972, 1520 Hours

According to the operating data received from the Palisades Plant personnel, the plant load was changing on the day of the survey. The plant load reported is zero for July 16, 194 MWe for July 17, 415 MWe for July 18, 420 MWe for July 19, and constant for an extended period thereafter. The load data reported by the power-plant personnel are only the daily average load. Hence, the reported value of 194 MWe for July 17 is probably an average of a load that increased during July 17 from 0 to 415 MWe. The cooling-water flow rate through the condensers remained constant during the changing plant load at $25.6 \text{ m}^3/\text{sec}$. Although the plant load was increasing, a temperature difference of 7.6°C across the condensers occurred before the temperature survey. Comparing this to the temperature difference for days when the load was steady at about 420 MWe indicates that the plant load at the time of the survey was close to the maximum allowable operating load of 420 MWe. This information should be kept in mind when analyzing the results of this survey.

As seen in Figs. 80-83, the plume was driven north by a strong northward shore-parallel flowing current. A sharp upcurrent temperature interface is produced by the strong current. The plume is similar to the plume mapped under similar lake-current conditions on June 20. Lake-surface conditions were rougher on July 17 than on June 20. Ambient water temperature was well defined and constant with depth to the 3-m level (see Appendix B). Due to the moderately rough lake conditions, the top 3 m was well mixed, accounting for the constancy of ambient temperature with depth. Plume half-depth was found to be about 1 m. Plume areas, which decreased rapidly with depth, appeared to be slightly smaller than normal for Palisades. This could be due to the fact that the power level was coming up from zero. Unfortunately, a problem developed with one of the thermistor probes leading to an incompleteness in the 0.5- and 1.0-m level data (see Fig. 81).

11. Palisades Nuclear Power Plant: July 18, 1972

Following a morning and afternoon of heavy thunderstorms, a temperature survey was conducted at the Palisades Plant during the evening of July 18. Winds out of the south were fairly strong during the morning and early afternoon. The wind shifted gradually to the north through the west. The wind then died down and became very light and variable for the temperature survey. The weather cleared up, and conditions became calm. The air temperature was constant for most of the day.

The results of the plume mapping are shown in Figs. 84-87. The lake conditions were calm (see Fig. 88) following the rough conditions present earlier in the day. There was no measurable ambient lake current, but the plume did appear to drift slightly to the north. Ambient water temperature was well defined, dropping off slightly with depth. The plume was shallow with a half-depth of 0.5-0.75 m. Plume areas decreased rapidly with depth. Unfortunately, the 1.0-m thermistor probe malfunctioned, eliminating all the data at that level.

12. Palisades Nuclear Power Plant: July 19, 1972

Winds continued to be light and variable following the temperature survey on July 18. These conditions prevailed the following day also, when another temperature survey was conducted following a near-field temperature

Fig. 80. Thermal Plume at Surface for Palisades Nuclear Power Plant:
 July 17, 1972, 1600-1655 Hours. ANL Neg. No. 190-971.

Fig. 81. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: July 17, 1972, 1600-1655 Hours. ANL Neg. No. 190-1005.

Fig. 82. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: July 17, 1972, 1600-1655 Hours. ANL Neg. No. 190-1009.

Fig. 83. Vertical Cross Sections for Palisades Nuclear Power Plant: July 17, 1972, 1600-1655 Hours. ANL Neg. No. 190-1076.

Fig. 83 (Contd.). ANL Neg. No. 190-1068.

Fig. 84. Thermal Plume at Surface for Palisades Nuclear Power Plant:
 July 18, 1972, 1952-2055 Hours. ANL Neg. No. 190-968.

Fig. 85. Thermal Plume at 0.5- and 1.5-m Depths for Palisades Nuclear Power Plant: July 18, 1972, 1952-2055 Hours. ANL Neg. No. 190-1003.

Fig. 86. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: July 18, 1972, 1952-2055 Hours. ANL Neg. No. 190-994.

Fig. 87. Vertical Cross Sections for Palisades Nuclear Power Plant: July 18, 1972, 1952-2055 Hours. ANI. Neg. No. 190-1061.

Fig. 88. Lake-surface Conditions at Palisades: July 18, 1972,
1842 Hours

and velocity study.⁴ Although sky conditions were cloudy as compared with clear for the previous survey, the air temperature was significantly higher on July 19. According to the MRI data (in Appendix C), the air temperature increased from about 22°C at 0600 to 33°C at 1100 and then dropped to about 29°C during the temperature survey. This temperature of 29°C is about 3.5°C higher than that recorded on the boat and hence recorded on Fig. 89. The value recorded on the boat was measured offshore and near the lake surface while the MRI meteorological station is land-based, though close to the shoreline. As seen in Figs. 89-91, the plume was similar in behavior to the plume mapped on July 18. Lake conditions were also similar (see Fig. 92). Although winds were very light the previous evening when there was no measurable current, on this day a current was present. In fact, the current was measured in both the morning and afternoon and had a southward direction. Both the plume survey and the near-field study did not seem to be significantly influenced by this current, although the plume did drift slowly southward. The plume data were obtained with the thermistor boom at a depth of 1.5 m; thus no measurements are available below the 1.5-m level. Data collection with the boom at this level was done because several of the higher-level thermistor probes were malfunctioning and most of the significant data were anticipated to be at a depth of less than 1.5 m. Therefore, the low-level probes were raised to collect the shallower temperature data. Unfortunately, we were still unable to collect 0.5-m level data. Data relating to ambient water temperatures at the depths measured are given in Appendix B.

As on the previous day, the plume was very buoyant, although the estimated half-depth of 0.75-1.25 meters was greater than on July 18. The half-depth had to be estimated since values of $\theta/\theta_0 < 0.5$ were not available due to a lack of data in the far-field region of the plume. Plume areas appear to be smaller than on July 18 which seems consistent with the greater half-depth. Isotherm areas decreased rapidly with depth for this very buoyant plume.

13. Palisades Nuclear Power Plant: August 7 and 8, October 11, 1972

Rough weather conditions or the after-effects of these conditions usually mean high winds and large waves. The effect these conditions have on the channel-type shoreline outfall at the Palisades Nuclear Power Plant is quite marked. Instead of being pushed out into the lake and floating on the

Fig. 89. Thermal Plume at Surface for Palisades Nuclear Power Plant:
 July 19, 1972, 1546-1710 Hours. ANL Neg. No. 190-981.

Fig. 90. Thermal Plume at 1.0- and 1.5-m Depths for Palisades Nuclear Power Plant: July 19, 1972, 1546-1710 Hours. ANL Neg. No. 190-1036.

Fig. 91. Vertical Cross Sections for Palisades Nuclear Power Plant: July 19, 1972, 1546-1710 Hours. ANL Neg. No. 190-1096.

Fig. 92. Lake-surface Conditions at Palisades: July 19, 1972, 0942 Hours

surface, the plume is trapped in the nearshore area by breaking waves and moved along the shore by large, wave-induced longshore currents. (Current Speeds of 0.8 m/sec have been measured).

On August 7 and 8 and October 10, 1972, rough weather conditions (see Figs. 93 and 94) made it difficult to use a small boat. Mapping the thermal plume required an alternative plume-mapping technique. A plume under these rough conditions may be only several hundred meters wide, even at a considerable distance from the outfall. For this reason, a technique was developed whereby plume dimensions could be estimated from temperature data collected by wet-suited swimmers carrying ordinary laboratory thermometers. The swimmer or swimmers typically began at the plant outfall and floated, walked, and swam along with the longshore current. At intervals measured along the shore, hand signals were used to relay water temperature to shore based personnel. The results of the three mappings are shown in Fig. 95. Distance offshore was estimated on August 7 and 8 and was measured with an optical rangefinder on October 10. Ambient water temperature was measured by swimming to the upcurrent side of the plume and then into ambient water or by driving some distance from the plume on the upcurrent side and recording the temperature of the lake water at that position. Current was measured in this nearshore zone by timing drogues over a fixed distance. The plumes measured in this way differ markedly from plumes measured with the standard boat techniques on calmer days. Locations up to 6.8 km from the plant outfall appear to be affected in some instances by water at least 1°C above ambient. Temperature was not measured as a function of depth. However, due to the high degree of turbulence in the zone of breaking waves, the plume is probably well mixed to the lake bottom, at least in water depths of 2-3 m. Thus, the plume is layered laterally, rather than vertically, and constrained to mix with ambient water only along its offshore side.

The direction of the plume changed by 180° from August 7 to August 8. This change was caused by a 180° change in current direction, as indicated in Appendix B. From the wind data in Appendix C, it is seen that wind direction changed from northwesterly to west-southwesterly between plume mappings. The northerly wind component helped set up the shore-parallel southerly current on August 7, and the southerly wind component caused the current and hence plume direction to be changed to northerly on August 8. The wind

Fig. 93. Lake-surface Conditions at Palisades: August 7, 1972, 1945 Hours

Fig. 94. Lake-surface Conditions at Palisades: August 8, 1972, 1530 Hours

Fig. 95. Thermal Plume at Surface for Palisades Nuclear Power Plant:
August 7, 1972, 1730-1900 Hours; August 8, 1972, 1415-1745 Hours;
October 11, 1972, 1410-1630 Hours

and lake current data for the morning of August 9 showed that another wind shift occurred, shifting the current to southerly. Thus it was expected that the plume would once again be heading south along the shore. Although a detailed plume mapping was not conducted on August 9, several measurements confirmed the southward-moving plume.

14. Palisades Nuclear Power Plant: August 15, 1972

On August 15, current-speed measurements were made at the Palisades intake crib with the Bendix Q-15 current meter. Scuba divers held the meter in place at the center of each of the four sides of the intake structure at the midpoint between the top and bottom of the structure. (A schematic of the structure is shown in Fig. 4.) Results of these measurements are presented in Table IV. Winds for the study were out of the east-southeast at 2.5 m/sec. Air temperature was 21°C, relative humidity was 77%, and sky conditions were cloudy. Lake-surface conditions were slightly choppy with 0-0.3-m waves (see Fig. 96). Water visibility, which was important for proper current-meter placement, was 3.5 m. The water-surface temperature, as measured near the intake, was 10.7°C. Ambient current was essentially zero; this aids in the interpretation of results, since there is no effect of ambient current. Plant operating data were obtained from the Palisades plant personnel. For the intake study, the plant was operating at 420 MWe. The discharge flow rate was 25.6 m³/sec, and, according to the plant data, the intake water temperature was 15.6°C and discharge temperature was 25.0°C.

Comparing the mean measured intake water speed (25.4 cm/sec) with the predicted value (15-18 cm/sec) (Ref. 8) indicates that the predicted value is too low. This discrepancy may be due to the presence of considerable riprap around the base of the intake structure. The riprap, in effect, reduces the vertical dimension of the intake structure by about 1 m and thus increases the speed of the incoming water.

The divers observed a number of fish (mostly perch) swimming in and out of the intake structure without being noticeably influenced by intake current. The scuba divers were also able to swim away from the intake with little effort.

TABLE IV. Results of Current Measurements Made at the Palisades Nuclear Power Plant Intake Crib: August 15, 1972

Station	Time	Location	Current Speed (cm/sec)
1	1420	North side	24.4
2	1427	East side	25.6
3	1433	South side	24.4
4	1437	West side	27.2

Fig. 96. Lake-surface Conditions at Palisades: August 15, 1972, 1320 Hours

15. Point Beach Nuclear Power Plant: September 6, 1972

On September 6, a new and more advanced data-acquisition system was used for the first time to collect data to determine the isotherm locations. This day also marked the first time that Unit 2 was operational, although at a much lower power level than Unit 1. Lake-surface conditions were choppy at the start of the survey (see Fig. 97) and became rougher as time progressed. Winds, which were out of the south-southwest, increased in intensity from light winds that were less than 0.5 m/sec during the preceding night to almost 7 m/sec during the plume mapping. Winds were light the previous day also. Air temperature remained constant for periods before and after plume mapping.

Results of the temperature survey are shown in Figs. 98-101. No data are available at the 2.0-m level because of a thermistor malfunction. Also, anomalies are apparent in the vertical cross sections (see Fig. 101). This is especially true of the 0.5-m probe, which appeared to be reading as much as 0.6° high on some occasions. The error was inconsistent and hence could not be corrected. There were probably some problems with the new data-acquisition-system channel for this probe, since the probe had functioned properly in the past.

The plume from the two outfalls quickly merged into one plume and was pushed north by the northward-flowing current, which decreased rapidly with depth (as is noted in Appendix B). The ambient water was fairly well mixed with depth, as would be expected for the rough lake conditions. Plume areas decreased rather slowly with depth, particularly in the first 1.5 m of water. Plume half-depth reflected this and was 1.5-2.0 m.

16. Point Beach Nuclear Power Plant: September 9, 1972

On the days before the temperature survey conducted on September 9 at Point Beach, lake conditions were rough and no temperature surveys could be conducted. On September 8, we were able to drop drogues equipped with temperature recorders off the end of the Unit 1 outfall flume and track them using transits. The temperature data obtained using these drogues was used to study the time-temperature history of the condenser cooling water being discharged from the power plant. The results of this experiment are discussed in Ref. 9.

Fig. 97. Lake-surface Conditions at Point Beach:
September 6, 1972, 1007 Hours

Fig. 98. Thermal Plume at Surface for Point Beach Nuclear Power Plant: September 6, 1972, 1115-1300 Hours. ANL Neg. No. 190-967.

Fig. 99. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: September 6, 1972, 1115-1300 Hours

Fig. 100. Thermal Plume at 2.5- and 3.0-m Depths for Point Beach Nuclear Power Plant: September 6, 1972, 1115-1300 Hours. ANL Neg. No. 190-1028.

Fig. 101. Vertical Cross Sections for Point Beach Nuclear Power Plant: September 6, 1972, 1115-1300 Hours. ANL Neg. No. 190-1060.

Fig. 101 (Contd.). ANL Neg. No. 190-1077.

Winds finally began to die down during the afternoon of September 8. During the night preceding the September 9 experiments, winds were light and out of the west-northwest, shifting to northeast on the morning of September 9. According to the MRI instrument, winds then shifted to the south and began to increase at 1300 hours, just before the plume mapping. A sharp drop in air temperature occurred in the early morning hours, and then temperature leveled off for the experiments.

On September 9, both reactor units were again operating. Lake conditions were choppy, as seen in Fig. 102. Near-field velocity and temperature measurements were taken in the morning and afternoon. Results of this experiment are found in Ref. 4. Both wind direction and lake current were changing during the near-field study. (Wind charts are shown in Appendix C.) The direction shifted from northeast to southeast, and lake current dropped from 15 cm/sec at the 1-m level to 0, as shown in Appendix B. Following this experiment, the thermal plume was partially mapped. Problems with the new data-acquisition system developed and culminated with a total system failure during the far-field mapping of the plume. Hence, the results shown in Figs. 103-106 are incomplete. The data available are presented for completeness. For the data presented, the 0.5- and 2.0-m data were again sporadically higher than expected—a problem also noted on September 6.

The lake current was zero, but the plumes from the two units were bent slightly to the north. Ambient water temperature decreased slightly at the 2.5- and 3.0-m levels, although it was fairly constant in the top 2.0 m. Since data were missing from the far-field region, plume half-depths could not be evaluated. Plume areas for the few closed isotherms in the near-field region are given in Appendix D. Some of the isotherm areas increased with depth; this could be indicative of the data-acquisition-system problem. These increasing areas were not felt to be due to natural phenomena.

17. Point Beach Nuclear Power Plant: September 12, 1972

This day presented a contrast to the normal plant-operating conditions that affect the plume at Point Beach. Unit 2 was operating at low power, as it had been since coming on line, but Unit 1 was being reduced in power to make some in-plant repairs. The Unit 1 load during the morning hours was constant at about 265 MWe, which is less than for most of the preceding

Fig. 102. Lake-surface Conditions at Point Beach:
September 9, 1972, 1440 Hours

Fig. 103. Thermal Plume at Surface for Point Beach Nuclear Power Plant: September 9, 1972, 1525-1630 Hours. ANL Neg. No. 190 966.

Fig. 104. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: September 9, 1972, 1525-1630 Hours

Fig. 105. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: September 9, 1972, 1525-1630 Hours. ANL Neg. No. 190-1034.

Fig. 106. Vertical Cross Sections for Point Beach Nuclear Power Plant: September 9, 1972, 1525-1630 Hours. ANL Neg. No. 190-1090.

surveys. At 1400 hours, the load had been reduced to 219 MWe, at 1500 hours the load was 133 MWe, at 1600 hours it was 29 MWe, and finally at 1700 hours, the load had been reduced to zero, where it stayed for at least the rest of the day. For the entire day, the discharge flow rates remained constant at $24.7 \text{ m}^3/\text{sec}$ for Unit 1 and $13.8 \text{ m}^3/\text{sec}$ for Unit 2.

Winds were light and variable on September 12, as they had been on the previous day. September 11 was marked by foggy and drizzly weather conditions. Air temperature increased during the day and reached its maximum value during the temperature survey conducted on this day. Lake conditions for the survey were glassy calm as shown in Fig. 107.

The results presented in Figs. 108-111 show that upwelling conditions existed. The isotherms drawn offshore were not drawn without data, as seems to be the case when examining the surface drawing. Actually, data exist east of these isotherms, but were omitted due to drawing-size limitations. Lake current was measured before and after the survey.

Although not much information can be gleaned from these data, there is an opportunity to look at a plume under changing load conditions. The reduction in power level from about 50% to 0% of full power took place during the experiment. Remnants of the plume (note the pocket of water with temperature greater than 15°C) apparently drifted to the south. It was hard to define ambient water temperature; hence a considerable ambient temperature range is reported in Appendix B. The ambient temperature decreased rapidly with depth, showing significant stratification.

18. Point Beach Nuclear Power Plant: September 29-30, October 1, 1972

On these three days, studies similar to those conducted on July 7-8, 1972, were conducted at the Point Beach Plant. The object of the experiment was to obtain temperature data and fish-location data in the area near the power plant before and after the shutdown of the Unit 1 reactor. The results of the biological aspects of this experiment are discussed by Romberg et al.⁷ The shutdown also provided a chance to look at a Point Beach plume under a smaller plant load than normal and a chance to look at the plume from Unit 2.

Lake conditions were similar on the three days, with swells running at 0.3-0.6 m (see Figs. 112-114). For the three days, ambient water

Fig. 107. Lake-surface Conditions at Point Beach: September 12, 1972,
1634 Hours

Fig. 108. Thermal Plume at Surface for Point Beach Nuclear Power Plant: September 12, 1972, 1409-1602 Hours. ANL Neg. No. 190-977.

Fig. 109. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: September 12, 1972, 1409-1602 Hours. ANL Neg. No. 190-1025.

Fig. 110. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: September 12, 1972, 1409-1602 Hours. ANL Neg. No. 190-1013.

Fig. 111. Vertical Cross Sections for Point Beach Nuclear Power Plant: September 12, 1972, 1409-1602 Hours. ANL Neg. No. 190-1080.

Fig. 112. Lake-surface Conditions at Point Beach:
September 29, 1972, 0930 Hours

Fig. 113. Lake-surface Conditions at Point Beach:
September 30, 1972, 1030 Hours

Fig. 114. Lake-surface Conditions at Point Beach:
October 1, 1972, 0945 Hours

temperature was well defined and constant with both location and depth (see Appendix B). Records of wind speed, wind direction, and air temperature are presented (as previously stated) in Appendix C. Winds for September 29 were moderate and out of the northwest for the time of the temperature/fish-location survey. During the night preceding the survey, moderate winds were blowing out of the north-northwest. The air temperature was constant showing no abrupt changes. Similar to the preceding day, on September 30, the winds remained out of the northwest, as did air temperature. At about 0300 hours on October 1, the winds became light and shifted to the southwest. The winds then picked up and shifted to the south-southeast at the beginning of the temperature survey conducted on this day. The air temperature also increased at this time.

Results of the three temperature surveys are presented in Figs. 115-126. On September 29, the plumes from the two outfalls quickly merged into one plume and then moved toward the south. The current direction, measured with the Q-15 current meter, was to the northwest. The indicated current speed was low, in fact, less than the rated threshold for the current meter. These data are not consistent with the observed plume direction, the amount of centerline bending, and the sharp temperature interface north of the plume. Current data were also available from a Braincon in-situ current meter. Current speed measured by this instrument was about 10 cm/sec, with a direction of 180° . This information looks more reasonable for the plume pictured and analysis of the plumes of September 29 should probably use those measurements, even though the Q-15 data are given in Fig. 115 and Table VI (App. B). Plume half-depth for this survey was found to be 1.5-2.0 m. As previously found, plume areas decreased with depth (see Appendix D).

On September 30, only Unit 2 was in operation. Due to a thermistor malfunction, data are missing from the 3.0-m level. This small plume was driven around toward the southeast by a southeast offshore current. On October 1, under similar plant operating conditions as the previous day, the heated water flowed directly north-northeast out and away from the outfall. This direction agrees with the current direction. On October 1, both the 2.5- and 3.0-m thermistor malfunctioned. Isotherm areas for these plumes are listed in Appendix D. Plume half-depth was about 1.5 m for September 30 and 1.25 m for October 1.

Fig. 115. Thermal Plume at Surface for Point Beach Nuclear Power Plant: September 29, 1972, 1545-1705 Hours

Fig. 116. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: September 29, 1972, 1545-1705 Hours

Fig. 117. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Point Beach Nuclear Power Plant: September 29, 1972, 1545-1705 Hours. ANL Neg. No. 190-1024.

Fig. 118. Vertical Cross Sections for Point Beach Nuclear Power Plant: September 29, 1972, 1545-1705 Hours. ANL Neg. No. 190-1094.

Fig. 118 (Contd.). ANL Neg. No. 190-1064.

Fig. 120. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: September 30, 1972, 1140-1248 Hours. ANL Neg. No. 190-1041.

Fig. 121. Thermal Plume at 2.0- and 2.5-m Depths for Point Beach Nuclear Power Plant: September 30, 1972, 1140-1248 Hours. ANL Neg. No. 190-1033.

Fig. 122. Vertical Cross Sections for Point Beach Nuclear Power Plant:
September 30, 1972, 1140-1248 Hr.
ANL Neg. No. 190-1071.

Fig. 123. Thermal Plume at Surface for Point Beach Nuclear Power Plant: October 1, 1972, 1116-1226 Hours. ANL Neg. No. 190-963.

Fig. 124. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Point Beach Nuclear Power Plant: October 1, 1972, 1116-1226 Hours. ANL Neg. No. 190-1014.

Fig. 125. Thermal Plume at 2.0-m Depth for Point Beach Nuclear Power Plant: October 1, 1972, 1116-1226 Hours. ANL Neg. No. 190-1016.

Fig. 126. Vertical Cross Sections for Point Beach Nuclear Power Plant:
October 1, 1972, 1116-1226 Hours. ANL Neg. No. 190-1082.

19. Palisades Nuclear Power Plant: October 10, 1972

Lake conditions at Palisades on October 10 were relatively calm with 0-0.3-m waves. The MRI meteorological station was set up at 1000 hours on October 10, so wind and air temperature data before this time are not available. For the period from 1000 hours through the completion of the experiment conducted on October 10, winds averaged about 2 m/sec and were out of the south-southeast. As seen in Appendix C, the wind was constant.

A near-field study of the velocity and temperature structure of the thermal plume was conducted from 1025-1550 hours. Results of this study are discussed in Ref. 4. A temperature survey of the entire plume was made following this near-field study. Results are presented in Figs. 127-130. The plume goes straight out from the discharge before being pushed north by a northward, slightly offshore current (note the 14°C isotherm). The current was only measured before the near-field survey, but since meteorological conditions were unchanged, the current probably did not change much later in the day. The current did, however, vary in direction with depth. As seen in Appendix B, the current at the 3- and 5-m levels had components of direction to the south. The ambient water temperature was 12.9°C and was constant with depth. The surface plume areas were somewhat smaller than normal for Palisades. The characteristic half-depth of this plume was 1.25 m.

20. Palisades Nuclear Power Plant: October 13, 1972

October 13 was marked by somewhat rough lake conditions and cloudy sky conditions. Lake conditions were very rough for several days preceding October 13. In fact, it was impossible to get out on the lake on October 11 and 12 because the waves were running about 2 m. Winds were strong on these two days, running as high as 11 m/sec on October 11. On October 12, the winds were out of the north-northwest and finally began to lessen in speed during the early morning hours of October 13. Direction also switched to the east and then to the southeast. During the temperature survey on October 13, the winds began to pick up again swinging around to the south-southwest. The wind speed reported on the surface-plume drawing (see Fig. 131) appears to be higher than that from the MRI data in Appendix C. This is because the wind speed reported on the drawing was measured with the boat anemometer following the temperature survey and corresponds to the Appendix C value for wind speed at

Fig. 127. Thermal Plume at Surface for Palisades Nuclear Power Plant: October 10, 1972, 1625-1748 Hours. ANL Neg. No. 190-969.

Fig. 128. Thermal Plume at 0.5-, 1.0-, and 1.5-m Depths for Palisades Nuclear Power Plant: October 10, 1972, 1625-1748 Hours. ANL Neg. No. 190-1010.

Fig. 129. Thermal Plume at 2.0-, 2.5-, and 3.0-m Depths for Palisades Nuclear Power Plant: October 10, 1972, 1625-1748 Hours. ANL Neg. No. 190-1015.

Fig. 130. Vertical Cross Sections for Palisades Nuclear Power Plant: October 10, 1972, 1625-1748 Hours. ANL Neg. No. 190-1074.

times past 1200 hours. The air temperature was relatively constant during the 24 hr preceding the survey.

Results of this temperature survey are presented in Figs. 131-134. Due to an equipment malfunction, no data for the 2.5-m level were collected. Also, in the vertical section A-A', some of the isotherms are shown drawn with dotted lines. The thermistor boom had to be raised to avoid contact with the lake bottom; hence the location of the vertical isotherms is somewhat uncertain.

As can be seen from the drawings, the plume is driven north by a shore-parallel, northward-flowing current. The upcurrent plume interface was very well defined with a temperature change over this narrow interface of almost 5°C. The plume was also considerably deeper on this side of the plume. This phenomenon was usually found when a sharp interface occurred on one side of the plume. The ambient water was very well mixed over the depth measured. In fact, at any one level, the ambient temperature could be accurately recorded to 0.1°C and the variation between the surface and the 3.0-m level was only 0.2°C. This was due to the strong mixing caused by the rough lake conditions. The surface plume areas were noted to be the smallest, particularly in the far-field region, of any plume mapped at Palisades using the data-acquisition system. This was due to the increased dilution caused by the rough lake conditions. The plume half-depth of 1.25-1.5 m was the largest of any plume mapped for which sufficient data were available for determining this value. Again, this is due to the increased mixing, in this case with depth, caused by the rough lake conditions.

21. Palisades Nuclear Power Plant: February 22, 1973

One last plume figure is presented in this report. This is a photograph of the discharge water at Palisades on February 22, 1973. As can be seen in Fig. 135, the water extended about 200 m into the frozen lake. What is particularly interesting about this photograph is that, although the discharge flow rate was 24.6 m³/sec, the plant load was zero. Evidently, the subsurface water entering the intake was sufficiently warm to maintain an unfrozen region off the discharge.

Fig. 131. Thermal Plume at Surface for Palisades Nuclear Power Plant: October 13, 1972, 1015-1155 Hours. ANL Neg. No. 190-987.

Fig. 133. Thermal Plume at 2.0- and 3.0-m Depths for Palisades Nuclear Power Plant: October 13, 1972, 1015-1155 Hr. ANL Neg. No. 190-1012.

Fig. 134. Vertical Cross Sections for Palisades Nuclear Power Plant: October 13, 1972, 1015-1155 Hours. ANL Neg. No. 190-1095.

Fig. 135. Palisades Nuclear Power Plant: February 22, 1973.
ANL Neg. No. 190-716.

IV. DISCUSSION OF RESULTS

A. General Comments

Although not discussed anywhere else in this report, both the ambient surface current-direction and wind-direction vectors were plotted. In most cases, the currents were directed to the right (clockwise) of the wind by about $10-35^{\circ}$, except for the situations in which the wind direction and shoreline direction made this impossible. In general, the relationship between wind and current was qualitatively consistent with Ekman's elementary theory for coastal regions. A separate report on correlation of current observations with wind data is in preparation.

Another significant issue relates to the dynamical nature of plumes. Consider the group of plume measurements performed on the same date (three plumes at Point Beach on May 24, two plumes at Palisades on June 13, and four plumes at Palisades on June 20). On May 24, three plumes were measured essentially back-to-back under stable ambient meteorological and lake conditions described as calm. The three plumes show obvious differences in their geometrical configurations. A closer look at the three reveals, however, that they are not so dissimilar with respect to the areas within certain isotherms or half-depths along their centerlines (see Appendixes D and E). One obvious explanation for the contour differences rests in the way the data were gathered, i.e., the boat trajectory and the number of passes made within certain reaches of the discharge. The isotherms for each plume clearly reflect the data available; the more intensive the data within a region, the more plume detail is permitted. Another explanation is that, even though the ambient conditions are reported calm, there nevertheless must have been some ambient current drift southward along the shoreline. This is evidenced by the relatively sharp plume-temperature gradients north of the discharge (the speculated upcurrent side) and the elongated isotherms south of the discharge (the speculated downcurrent side). Appendix B shows the ambient current speed to change from 0 cm/sec at 0900 hours on May 24 to 1.7 cm/sec southward at 1648 hours; therefore, lake conditions may have been somewhat variable. Variable lake conditions imply variable plume conditions as well. Probably the best interpretation of the contour variability of the back-to-back plumes rests with a combination of the above arguments for this date.

The June 13, Palisades data consisting of two plumes taken essentially one after the other do show somewhat different temperature contours. Clearly, however, ambient conditions did change considerably over the period when the plumes were measured; therefore dissimilarities should be expected. Similarly, the four Palisades plumes taken on June 20 also show some minor contour dissimilarities. However, the two earlier plumes taken very close in time are characteristically much more similar than the two plumes taken several hours later, even though the reported ambient current conditions changed significantly between the first and second plume and remained essentially the same between the three remaining plumes. The point that we believe must be made is that a thermal plume is an ever-changing entity responding to turbulent lake and meteorological conditions, all of which are not well understood in their own right. The concept of a plume being a steady-state thing is an oversimplification. Plume modelers often use the concept of a steady-state plume in reporting plume field data only because there is as yet no practical alternative.

B. Data Plotted on Asbury-Frigo Curve

The surface areas of the thermal plumes presented in this report were measured using a planimeter as previously discussed and are listed in Appendix D. These data are displayed on the Asbury-Frigo Data Plot (Ref. 10) in Figs. 136 and 137. Figure 138 shows a schematic defining pertinent parameters for the data plot.

Figure 136 for the Point Beach data, show that the data group consistently below the Asbury-Frigo curve, indicating that the discharge from this plant apparently exhibits better mixing than most of the power plants originally studied by Asbury and Frigo. This result agrees with the results of a similar treatment given earlier Point Beach data in Ref. 11. The better mixing of the Point Beach discharge water is probably due in part to its fairly high discharge velocity.

Figure 137 compares the data for Palisades to the Asbury-Frigo curve. The data groups on the high side of the Asbury-Frigo curve. This could be due to the lower velocities at the end of the diverging channel outfall causing less mixing with ambient water. Also, sand bars in front of this shoreline discharge help to force the plume to float more readily on the surface and

X

Fig. 136. Asbury-Frigo Data Plot of Fractional Excess Temperature vs. Ratio of Surface Area to Discharge Flow Rate, Showing Point Beach Data Presented in the Present Report

Fig. 137. Asbury-Frigo Data Plot of Fractional Excess Temperature vs. Ratio of Surface Area to Discharge Flow Rate, Showing Palisades Data Presented in the Present Report

Fig. 138. Schematic Defining Pertinent Parameters for Asbury-Frigo Data Plot

hence spread out over a larger surface area. Some of the data groups fall below the curve — namely, the data for July 17, August 7, August 8, October 10, October 11, and October 13. For all these cases except October 10, the lake conditions were rough and currents were fairly high. Thus the smaller plume areas were probably due, at least in part, to a higher degree of mixing due to the increased ambient lake turbulence.

A more complete correlation of the isotherm areas with lake conditions and outfall geometry is presently underway, and will be reported in the future.

C. Centerline Temperature Decay

Surface fractional excess temperature is plotted as a function of the logarithm of centerline distance from the outfall in Fig. 139. Fractional excess temperature is defined as

$$\theta/\theta_0 = (T_C - T_A)/(T_D - T_A),$$

where

T_C = centerline temperature,

T_A = ambient temperature,

and

T_D = discharge temperature.

All the surface data from the Palisades and Point Beach Power Plants are included, except for the following dates at Point Beach:

- a) July 8, September 30, and October 1, 1972: Unit 1 was shut down.
- b) September 9, 1972: Due to a malfunction of the recording instrumentation, plume mapping was not completed.
- c) September 12, 1972: Power for Unit 1 was being reduced.

The data at both plants indicate that in a region between 200 and 1000 m from the discharge, the centerline temperature decay is a function of the inverse of the cube root of the centerline distance. This result is contrary to the commonly made assumption that centerline temperature decays as a function of the inverse of the square root of the centerline distance.¹² Beyond 1000 m, both sets of data indicate the centerline temperature falls faster than in the first 1000 m, but still not nearly as fast as an inverse-square-root relationship would suggest. However, the error bars (one standard deviation on each side of the plotted point) are quite large beyond 1000 m, and there is considerable uncertainty in the data at this end. This uncertainty is, in part, due to an uncertainty in the value of the ambient temperature that results in greater variability at small fractional excess temperatures.

In the region between 10 and 200 m, the Point Beach data follow the same kind of decay pattern as in the range 200-1000 m; however, the Palisades data show a less rapid decay (in terms of distance) over this interval. The Palisades data also show a smaller drop in centerline temperature for a given distance, over the entire range of data. This result may be explained qualitatively by considering the geometries of the plant discharges, the depth of the receiving lake water, and the discharge velocities. The Point Beach outfall is ~11 m wide and ~4 m deep and enters the lake where the depth is slightly greater than 3 m. The Palisades discharge is ~30 m wide and 1 1/2-2 m deep and enters the lake where the depth is less than 2 m. Due to horizontal entrainment, the wide, shallow plume discharged initially at Palisades results in a less rapid influx of ambient water to the plume centerline, and thus a less rapid temperature decay in terms of distance from the outfall than the deeper, and more narrow, and swifter-flowing Point Beach discharge.

Fig. 139. Plot of Centerline Excess Temperature vs Centerline Distance from the Outfall for the Point Beach and Palisades Nuclear Power Plants

APPENDIX A

Previous Program Reports

Previous Program Reports

- (1) Asbury, J. G., Effects of Thermal Discharges On the Mass/Energy Balance of Lake Michigan, ANL/ES-1 (July 1970).
- (2) Silberman, E. and Stefan, H., Physical (Hydraulic) Modeling of Heat Dispersion in Large Lakes: A Review of the State of the Art, ANL/ES-2 (Aug. 17, 1970).
- (3) Asbury, J. G., Grench, R. E., Nelson, D. M., Prepejchal, W., Romberg, G. P., and Siebold, P., A Photographic Method for Determining Velocity Distributions within Thermal Plumes, ANL/ES-4 (Feb. 1971).
- (4) Asbury, J. G. and Frigo, A. A., A Phenomenological Relationship for Predicting the Surface Areas of Thermal Plumes in Lakes, ANL/ES-5 (April 1971).
- (5) Abu-Shumays, I. K., Phillips, D. L., and Prastein, S. M., "Thermal Plume Data Acquisition, Documentation and Initial Analysis," Proceedings of the 14th Conference of the International Association of Great Lakes Research, Toronto, Ontario, April 19-21, 1971, p. 495.
- (6) Romberg, G. P., Prepejchal, W., and Nelson, D. M., "Thermal Plume Measurements," Proceedings of the 14th Conference of the International Association of Great Lakes Research, Toronto, Ontario, April 19-21, 1971, p. 625.
- (7) Birchfield, G. E., Wind-driven Currents in a Large Lake or Sea, ANL/ES-6 (July 1971).
- (8) Tokar, J. V., Thermal Plumes in Lakes: Compilations of Field Experience, ANL/ES-3 (Aug. 1971).
- (9) Nakatani, R. E., Miller, D., and Tokar, J. V., "Thermal Effects and Nuclear Power Stations in the U.S.A.," International Atomic Energy Agency Transactions, Vienna, 1971, IAEA-SM-146/30, p. 561.
- (10) Asbury, J. G. and Frigo, A. A., "A Phenomenological Relationship for Predicting the Surface Area of Thermal Plumes in Lakes," Transactions of the American Nuclear Society, 1971 Winter Meeting, October 17-21, 1971, Volume 14, No. 2, p. 461.
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- (12) Policastro, A. J. and Tokar, J. V., Heated Effluent Dispersion in Large Lakes: State-of-the-Art of Analytical Modeling, Part 1. Critique of Model Formulations, ANL/ES-11, (Jan. 1972).

- (13) Hughes, T. H., Birchfield, G. E., and Matthies, M. T., A Compilation of the Average Depths of Lake Michigan and Lake Ontario on a Two-minute Grid, ANL/ES-10 (Jan. 1972).
- (14) Frigo, A. A., "Prediction of Surface Plume Areas Associated with Heated Discharges into Large Lakes - A Phenomenological Model," Proceedings of the 15th Conference of the International Association of Great Lakes Research, Madison, Wisconsin, April 5-7, 1972, p. 583.
- (15) Hoglund, B. M. and Spigarelli, S. A., "Studies of the Sinking Plume Phenomenon," Proceedings of the 15th Conference of the International Association of Great Lakes Research, Madison, Wisconsin, April 5-7, 1972, p. 614.
- (16) Policastro, A. J., "State-of-the-Art of Analytical Modeling of Heated Effluent Dispersion in Large Lakes," Proceedings of the 15th Conference of the International Association of Great Lakes Research, Madison, Wisconsin, April 5-7, 1972, p. 642.
- (17) Center for Environmental Studies and Environmental Statement Project, Summary of Recent Technical Information Concerning Thermal Discharges into Lake Michigan, Argonne National Laboratory for the Environmental Protection Agency Region V, Enforcement Branch, Contract Report 72-1, (Aug. 1972).
- (18) Frigo, A. A. and Frye, D. E., Physical Measurements of Thermal Discharges into Lake Michigan: 1971, ANL/ES-16 (October 1972).
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- (20) Policastro, A. J. and Paddock, R. A., "Analytical Modeling of Heated Surface Discharges with Comparisons to Experimental Data," paper presented at the 1972 Annual Meeting of AIChE, November 26-30, 1972, to be published (Heat Transfer Symposium Series, 1973).
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- (22) Paddock, R. A., Tokar, J. V., and Policastro, A. J., "Analysis of Data Taken in the Near-Field Region of a Surface Thermal Discharge with Comparisons to Analytical Model Predictions," paper presented at the 16th Conference of the International Association of Great Lakes Research, Huron, Ohio, April 1973.
- (23) Frye, D., Frigo, A., and Hoglund, B. M., "Data Collection and Reduction Techniques Used for Investigating Thermal Discharges," paper presented at the 16th Conference of the International Association of Great Lakes Research, Huron, Ohio, April 1973.

- (24) Frigo, A. A., Frye, D. E., and Siebold, P., "Temperature and Velocity Measurements in the near-Field Region of Thermal Plumes," Proceedings of the 16th Conference of the International Association of Great Lakes Research, Huron, Ohio, April 1973.
- (25) Policastro, A. J. and W. Dunn, Chapter 13: "Heated Surface Discharges -- Mathematical Models and Similarity Principles," Chapter 14: "Heated Surface Discharges -- Application and Verification of State-of-the-Art Near-Field Models," Heat Disposal in Power Plant Siting, Joint Center for Graduate Study, Richland, Wash., August 20-24, 1973.
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- (27) Paddock, R. A., Policastro, A. J., Frigo, A. A., Frye, D. E., and Tokar, J. V., "Temperature and Velocity Measurements and Predictive Model Comparisons in the Near-Field Region of Surface Thermal Discharges, ANL/ES-25 (Oct. 1973).

APPENDIX B

Ambient Water Data

TABLE V. Ambient Water Temperature Data

<u>Location</u>	<u>Date of Survey (1972)</u>	<u>Time of Survey</u>	<u>Ambient Water Temperature (°C)</u>						
			<u>Surface</u>	<u>0.5-m Depth</u>	<u>1.0-m Depth</u>	<u>1.5-m Depth</u>	<u>2.0-m Depth</u>	<u>2.5-m Depth</u>	<u>3.0-m Depth</u>
Point Beach	May 17	1645-1806	7.9-8.5	7.8-8.5	7.8-8.5	7.8-8.5	7.7-8.5	7.5-8.3	7.2-8.3
Point Beach	May 18	1645-1751	9.5-9.8	9.2-9.6	8.5	8.3	7.7-8.3	7.6-7.8	7.5-7.7
Point Beach	May 24	0925-1040	10.7-13.7	10.5-13.1	NA	10.2-12.9	10.0-11.6	10.0-11.5	10.0-11.4
Point Beach	May 24	1045-1145	11.9-13.8	11.7-13.7	11.7-13.7	11.7-13.7	11.3-12.6	11.1-12.1	11.1-12.1
Point Beach	May 24	1145-1225	11.0-13.4	10.9-12.4	NA	10.9-12.4	10.8-12.2	10.8-12.2	10.8-12.1
Palisades	June 13	1242-1443	14.5-16.5	14.0-14.5	13.5-14.5	13.0-14.0	12.8-13.6	12.7-13.6	12.6-13.5
Palisades	June 13	1516-1615	15.8-17.0	13.7-15.5	12.6-15.5	12.5-15.3	12.4-14.5	12.3-14.1	12.3-14.1
Palisades	June 19	1630-1730	14.9-15.6	14.9-15.6	14.3-15.4	13.5-15.3	12.6-14.7	12.5-14.3	12.1-14.1
Palisades	June 20	1027-1109	14.5-14.7	14.5-14.7	13.9-14.7	13.7-14.7	13.6-14.7	13.6-14.7	13.6-14.7
Palisades	June 20	1110-1200	14.9-15.6	14.8-15.3	14.6-15.1	14.2-15.0	13.9-14.8	13.6-14.8	13.6-14.7
Palisades	June 20	1330-1425	15.8-16.0	15.3-15.8	15.0-15.6	14.8-15.5	14.7-15.2	14.6-15.1	14.6-15.1
Palisades	June 20	1430-1515	16.7-17.2	15.2-16.3	14.7-15.5	14.4-15.5	14.3-15.5	14.1-15.5	14.0-15.5
Point Beach	July 7	1830-2015	11.3-11.5	11.3-11.5	11.2-11.5	10.9-11.4	10.8-11.4	10.8-11.4	10.8-11.4
Point Beach	July 8	1500-1730	12.7-14.8	12.6-13.9	12.6-13.7	12.6-13.5	12.5-13.3	12.2-13.3	12.0-13.2
Point Beach	July 11	1245-1355	10.9-11.5	10.9-11.5	10.9-11.4	10.9-11.4	10.8-11.4	10.6-11.4	10.4-11.4
Point Beach	July 13	1805-1903	13.3-13.7	13.0-13.5	12.2-12.7	11.2-11.7	11.0-11.7	10.6-11.3	10.4-11.1
Palisades	July 17	1600-1655	22.2-22.5	22.2-22.5	NA	21.8-22.4	22.2-22.5	22.0-22.5	22.1-22.5
Palisades	July 18	1952-2055	22.0-22.5	22.0-22.5	NA	21.5-22.3	21.7-21.9	21.5-21.9	21.5-21.9
Palisades	July 19	1546-1710	23.5-24.5	NA	22.1-23.7	21.3-22.5	NA	NA	NA
Palisades	Aug 7	1730-1900	11.3	NA	NA	NA	NA	NA	NA
Palisades	Aug 8	1415-1745	12.5	NA	NA	NA	NA	NA	NA
Point Beach	Sept 6	1115-1300	15.0-15.8	15.4-15.9	15.2-15.4	15.0-15.3	NA	14.7-15.3	14.7-15.3
Point Beach	Sept 9	1525-1630	14.5-16.9	15.1-16.9	14.6-16.7	14.6-16.5	15.2-16.7	14.3-16.0	14.2-15.3
Point Beach	Sept 12	1409-1602	12.1-15.1	10.7-12.8	10.3-12.1	9.9-11.7	9.7-11.5	9.5-11.2	9.1-11.1
Point Beach	Sept 29	1545-1705	11.2-11.7	11.2-11.8	11.2-11.8	11.2-11.8	11.2-11.8	11.2-11.8	10.8-11.7
Point Beach	Sept 30	1140-1248	11.1-11.9	11.0-11.7	11.0-11.7	11.0-11.7	11.0-11.6	11.0-11.6	NA
Point Beach	Oct 1	1116-1226	11.5-11.7	11.5-11.7	11.3-11.6	11.3-11.5	11.1-11.3	NA	NA
Palisades	Oct 10	1625-1748	12.9-13.3	13.0-13.3	13.0-13.3	12.7-13.0	12.8-13.0	12.7-13.0	12.7-13.0
Palisades	Oct 11	1410-1630	13.5	NA	NA	NA	NA	NA	NA
Palisades	Oct 13	1015-1155	12.6-12.7	12.7	12.7	12.7	12.6-12.7	NA	12.5

TABLE VI. Ambient Lake Current Data

Location	Date (1972)	Time	Lake Location ^a		Bottom Depth (meters)	Measurement Depth (meters)	Current	
			x (meters)	y (meters)			Speed (cm/sec)	Direction (degrees)
Point Beach	May 17	1535	248	31	N.A.	1	9.4	005
		"	"	"	"	1	7.2	000
		"	"	"	"	2	6.6	240
		1555	232	136	N.A.	1	8.9	355
		"	"	"	"	2	7.8	355
		"	"	"	"	3	7.2	000
Point Beach	May 18	1345	-22	44	2.0	All Levels	0	-
		1616	991	1112	N.A.	All Levels	0	-
Point Beach	May 24	0900	-711	468	N.A.	All Levels	0	-
		1648	298	958	"	1	1.7	225
		"	"	"	"	3	0	-
Palisades	June 13	1210	2327	1315	13.1	1	13.3	012
		"	"	"	"	3	11.1	010
		1620	4189	1134	12.2	1	6.7	010
		"	"	"	"	3	12.2	020
		"	"	"	"	5	12.2	035
		1655	4797	1060	4.0	1	22.7	000
Palisades	June 19	"	"	"	"	3	14.9	000
		1540	-833	279	6.1	1	11.1	015
		"	"	"	"	3	11.1	010
		1753	-1841	222	6.1	1	17.7	005
		"	"	"	"	3	13.8	020
		1815	2995	844	12.2	1	15.5	320
Palisades	June 20	"	"	"	"	3	11.1	225
		1015	-615	514	6.1	1	15.0	025
		"	"	"	"	3	12.7	018
		1215	-595	1034	12.8	1	19.9	020
		"	"	"	"	3	20.5	010
		1235	-664	497	6.1	1	27.7	030
		"	"	"	"	3	19.4	010
		1530	2262	384	4.9	1	27.1	025
		"	"	"	"	3	21.0	010
		1550	2383	1039	11.6	1	17.7	020
		"	"	"	"	3	19.9	005

^aCoordinate system shown in Figs. 140 and 141.

TABLE VI (Contd.).

Location	Date (1972)	Time	Lake Location ^a		Bottom Depth (meters)	Measurement Depth (meters)	Current	
			x (meters)	y (meters)			Speed (cm/sec)	Direction (degrees)
Point Beach	July 7	-	-	-	-	-	N.A.	N.A.
Point Beach	July 8	-	-	-	-	-	N.A.	N.A.
Point Beach	July 11	1205	-197	755	9.0	1	15.0	300
		"	"	"	"	3	6.6	270
Point Beach	July 13	1215	189	1063	10.5	1	6.6	180
		"	"	"	"	3	9.4	180
		"	"	"	"	5	3.9	200
		1720	-155	922	N.A.	1	2.2	245
		"	"	"	"	3	5.5	180
		"	"	"	"	5	2.8	200
Palisades	July 17	1520	-333	579	8.0	1	11.1	035
		"	"	"	"	3	9.4	050
		"	"	"	"	5	5.5	025
		1705	2337	232	4.5	1	19.4	030
		"	"	"	"	3	8.3	040
Palisades	July 18	1842	-936	355	6.0	1	0	-
		"	"	"	"	3	0	-
Palisades	July 19	0850	-890	252	5.5	1	7.7	190
		"	"	"	"	3	4.4	180
		1453	-977	371	6.5	1	10.0	170
		"	"	"	"	3	5.5	230
		"	"	"	"	5	2.8	260
Palisades	Aug 7	1700	200-m south of plant, 30-m offshore		1.2	0	80.0	205
Palisades	Aug 8	1400	1200-m north of plant, 5-m offshore		0.5	0	64.3	025
		"	1200-m north of plant, 30-m offshore		1.8	0	47.2	025
Palisades	Aug 9	1000	200-m north of plant, 5-m offshore		0.5	0	66.0	205
Point Beach	Sept 6	1007	560	634	8.2	1	18.8	020
		"	"	"	"	3	9.4	020
		"	"	"	"	5	2.8	330

^aCoordinate system shown in Figs. 140 and 141.

TABLE VI (Contd.).

Location	Date (1972)	Time	Lake Location ^a		Bottom Depth (meters)	Measurement Depth (meters)	Current	
			x (meters)	y (meters)			Speed (cm/sec)	Direction (degrees)
Point Beach	Sept 9	0950	-1229	892	7.3	1	15.0	180
		"	"	"	"	3	11.1	180
		"	"	"	"	5	7.2	160
		1440	-1186	806	7.3	1	0	-
		"	"	"	"	3	2.8	170
		"	"	"	"	5	3.3	185
Point Beach	Sept 12	1233	-673	407	6.1	1	2.8	165
		"	"	"	"	3	3.9	155
		"	"	"	"	5	0	-
		1634	-415	423	6.1	1	0	-
		"	"	"	"	3	0	-
		"	"	"	"	5	0	-
Point Beach	Sept 29	1752	60	849	9.1	1	2.2	300
		"	"	"	"	3	3.3	300
		"	"	"	"	5	2.2	290
Point Beach	Sept 30	1338	130	1045	9.1	1	2.8 - 6.6	090 - 130
		"	"	"	"	3	3.3 - 5.0	140
		"	"	"	"	5	5.0 - 6.1	140
Point Beach	Oct 1	1237	-653	918	9.1	1	8.3	020
		"	"	"	"	3	2.8	000
		"	"	"	"	5	0	-
Palisades	Oct 10	0840	236	498	5.8	1	8.9	345
		"	"	"	"	3	2.8	250
		"	"	"	"	5	5.0	215
Palisades	Oct 11	1330	300-m north of plant, 25-m offshore		1.5	0	60.0 - 80.0	025
Palisades	Oct 13	0855	-495	346	4.9	1	11.1	010
		"	"	"	"	3	5.6	025
		"	"	"	"	4	10.0	055

^aCoordinate system shown in Figs. 140 and 141.

Fig. 140. Coordinate System at Palisades Nuclear Power Plant

Fig. 141. Coordinate System at Point Beach Nuclear Power Plant

APPENDIX C

Ambient Meteorological Data

Wind-speed, Wind-direction, and Air-temperature Data

Figures 142-157 are a Calcomp representation of meteorological data collected during the field experiments conducted at the Point Beach and Palisades Nuclear Power Plants during 1972. The data were collected with a Meteorology Research, Inc. (MRI), mechanical weather station, Model 1071 (Fig. 32). The analog records of wind speed, wind direction, and air temperature produced by this instrument are manually digitized at hourly intervals. A single data point on the Calcomp plot represents an average of the chart recorded over the following hour. The plotted points were then connected by straight lines to help visually to show trends in the data. In certain instances, the wind-direction data can be somewhat misleading. Some large direction changes appear to occur when the change was actually only from a value near 360° (top of graph) to a value near 0° (bottom of graph).

Fig. 142. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: May 16, 1972 (1700) - May 18, 1972 (1600)

Fig. 143. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: May 22, 1972 (1700) - May 24, 1972 (1600)

Fig. 144. Wind-speed, Wind-direction and Air-temperature Data for Palisades: June 12, 1972 (1818) - June 14, 1972 (1800)

Fig. 145. Wind-speed, Wind-direction and Air-temperature Data for Palisades: June 19, 1972 (1600) - June 21, 1972 (1500)

Fig. 146. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: July 10, 1972 (1200) - July 12, 1972 (1200).

Fig. 147. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: July 12, 1972 (1200) - July 13, 1972 (2000)

Fig. 148. Wind-speed, Wind-direction and Air-temperature Data for Palisades: July 17, 1972 (1600) - July 19, 1972 (1600)

Fig. 149. Wind-speed, Wind-direction and Air-temperature Data for Palisades: August 7, 1972 (1700) - August 9, 1972 (1700)

Fig. 150. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: September 5, 1972 (1800) - September 7, 1972 (1800)

Fig. 151. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: September 7, 1972 (1800) - September 9, 1972 (1800)

Fig. 152. Wind-speed, Wind-direction and Air-temperature Data for Point Beach: September 9, 1972 (1800) - September 11, 1972 (1800)

Fig. 153. Wind-speed, Wind-direction and Air-temperature Data for Point Beach:
September 11, 1972 (1800) - September 12, 1972 (1800)

Fig. 154. Wind-speed, Wind-direction and Air-temperature Data for Point Beach:
September 28, 1972 (1900) - September 30, 1972 (1900)

Fig. 155. Wind-speed, Wind-direction and Air-temperature Data for Point Beach:
September 30, 1972 (1900) - October 1, 1972 (1300)

Fig. 156. Wind-speed, Wind-direction and Air-temperature Data for Palisades:
October 10, 1972 (1000) - October 12, 1972 (1000)

Fig. 157. Wind-speed, Wind-direction and Air-temperature Data for Palisades:
October 12, 1972 (1000) - October 14, 1972 (1000)

APPENDIX D

Plume Areas as a Function of Isotherm and Depth

TABLE VII. PLUME AREAS AS A FUNCTION OF ISOTHERM AND DEPTH

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: May 17, 1972 (1646-1806)

Isotherm, C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
17.0	9.49 x 10 ²	7.50 x 10 ²	-	-	-	-	-
16.0	2.04 x 10 ³	1.50 x 10 ³	1.00 x 10 ³	1.00 x 10 ³	-	-	-
15.0	5.05 x 10 ³	2.50 x 10 ³	2.00 x 10 ³	1.50 x 10 ³	-	-	-
14.0	8.85 x 10 ³	4.50 x 10 ³	3.25 x 10 ³	2.50 x 10 ³	-	-	-
13.0	2.49 x 10 ⁴	1.93 x 10 ⁴	5.50 x 10 ³	4.75 x 10 ³	-	-	-
12.0	5.27 x 10 ⁴	3.75 x 10 ⁴	1.98 x 10 ⁴	1.30 x 10 ⁴	-	-	-
11.0	1.24 x 10 ⁵	9.70 x 10 ⁴	3.83 x 10 ⁴	2.90 x 10 ⁴	2.15 x 10 ⁴	9.37 x 10 ³	-
10.0	4.05 x 10 ⁵	3.55 x 10 ⁵	3.40 x 10 ⁵	1.23 x 10 ⁵	3.23 x 10 ⁴	2.24 x 10 ⁴	1.51 x 10 ⁴

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: May 18, 1972 (1645-1751)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
17.0	4.87 × 10 ²	8.41 × 10 ²	5.64 × 10 ²	5.04 × 10 ²	-	-	-
16.0	1.75 × 10 ³	2.16 × 10 ³	1.74 × 10 ³	1.54 × 10 ³	-	-	-
15.0	7.21 × 10 ³	5.64 × 10 ³	3.79 × 10 ³	2.63 × 10 ³	-	-	-
14.0	1.10 × 10 ⁵	1.60 × 10 ⁴	1.15 × 10 ⁴	6.04 × 10 ³	4.45 × 10 ³	-	-
13.0	6.61 × 10 ⁵	6.58 × 10 ⁴	4.00 × 10 ⁴	1.55 × 10 ⁴	6.24 × 10 ³	2.62 × 10 ³	-
12.0	-	-	3.73 × 10 ⁵	1.03 × 10 ⁵	1.35 × 10 ⁴	3.87 × 10 ³	-
11.0	-	-	-	-	2.70 × 10 ⁴	5.12 × 10 ³	1.06 × 10 ³
10.0	-	-	-	-	6.75 × 10 ⁴	1.96 × 10 ⁴	2.06 × 10 ³
9.0	-	-	-	-	-	1.01 × 10 ⁵	7.74 × 10 ⁴

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: May 24, 1972 (0036-1040)

Isotherm, C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	5.98 x 10 ²	5.00 x 10 ²	<div>↕ Malfunctioned ↕</div>	-	-	-	-
19.0	1.97 x 10 ³	1.00 x 10 ³		-	-	-	-
18.0	4.10 x 10 ³	2.00 x 10 ³		1.25 x 10 ³	-	-	-
17.0	1.13 x 10 ⁴	4.25 x 10 ³		2.25 x 10 ³	-	-	-
16.0	9.52 x 10 ⁴	1.08 x 10 ⁴		5.25 x 10 ³	-	-	-
15.0	3.20 x 10 ⁵	5.25 x 10 ⁴		9.00 x 10 ³	3.20 x 10 ³	4.57 x 10 ³	2.06 x 10 ³
14.0	-	-		4.93 x 10 ⁴	9.01 x 10 ³	6.87 x 10 ³	4.56 x 10 ³
13.0	-	-		-	-	-	6.31 x 10 ³

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: May 24, 1972 (1045-1145)

Isotherm C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
21.0	4.63 x 10 ²	3.60 x 10 ²	2.88 x 10 ²	3.72 x 10 ²	-	-	-
20.0	1.69 x 10 ³	1.27 x 10 ³	6.73 x 10 ²	6.24 x 10 ²	-	-	-
19.0	4.70 x 10 ³	2.65 x 10 ³	1.75 x 10 ³	1.20 x 10 ³	-	-	-
18.0	9.18 x 10 ³	6.50 x 10 ³	2.99 x 10 ³	2.71 x 10 ³	-	-	-
17.0	2.61 x 10 ⁴	1.13 x 10 ⁴	-	4.50 x 10 ³	-	-	-
16.0	6.44 x 10 ⁴	2.60 x 10 ⁴	-	6.00 x 10 ³	4.51 x 10 ³	-	-
15.0	3.10 x 10 ⁵	-	-	1.70 x 10 ⁴	8.01 x 10 ³	3.37 x 10 ³	1.81 x 10 ³
14.0	-	-	-	-	1.15 x 10 ⁴	5.62 x 10 ³	3.31 x 10 ³

TABLE VII (Contd.).

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: May 24, 1972 (1145-1225)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	4.47×10^2	-	Malfunctioned	-	-	-	-
19.0	1.97×10^3	-		-	-	-	-
18.0	6.51×10^3	-		1.00×10^3	-	-	-
17.0	2.48×10^4	-		1.50×10^3	-	-	-
16.0	1.25×10^5	-		4.50×10^3	4.01×10^3	-	-
15.0	4.47×10^5	-		1.98×10^4	5.51×10^3	2.87×10^3	-
14.0	-	-		-	6.84×10^3	3.61×10^3	8.12×10^2

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 13, 1972 (1242-1443)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
21.0	1.20×10^4	2.70×10^3	3.37×10^3	6.67×10^2	-	-	-
20.0	5.28×10^4	1.00×10^4	4.70×10^3	2.67×10^3	-	-	-
19.0	1.78×10^5	1.87×10^4	1.00×10^4	5.33×10^3	-	-	-
18.0	8.63×10^5	3.14×10^4	1.40×10^4	7.33×10^3	-	-	-
17.0	-	7.47×10^4	2.80×10^4	9.33×10^3	-	-	-
16.0	-	-	5.67×10^4	2.13×10^4	7.33×10^3	-	-
15.0	-	-	-	3.67×10^4	1.73×10^4	-	-
14.0	-	-	-	-	-	4.20×10^4	2.93×10^4

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 13, 1972 (1516-1615)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
21.0	3.78×10^4	5.37×10^3	2.03×10^3	-	-	-	-
20.0	1.88×10^5	1.80×10^4	8.70×10^3	5.33×10^3	-	-	-
19.0	1.26×10^6	3.87×10^4	1.80×10^4	8.00×10^3	-	-	-
18.0	-	1.11×10^5	2.47×10^4	1.20×10^4	-	-	-
17.0	-	-	7.14×10^4	2.00×10^4	-	-	-
16.0	-	-	1.09×10^5	4.00×10^4	-	-	-
15.0	-	-	-	-	5.67×10^4	1.60×10^4	1.53×10^4
14.0	-	-	-	-	-	-	1.10×10^5

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 19, 1972 (1630-1730)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
19.0	3.39×10^4	7.62×10^3	6.12×10^3	2.25×10^3	-	-	-
18.0	2.36×10^5	1.69×10^4	7.62×10^3	4.50×10^3	-	-	-
17.0	3.85×10^5	5.26×10^4	1.09×10^4	6.00×10^3	-	-	-
16.0	-	-	4.96×10^4	8.00×10^3	-	-	-
15.0	-	-	-	1.17×10^5	6.00×10^3	-	-

TABLE VII (Contd.).

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 20, 1972 (1027-1109)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	8.62×10^3	4.87×10^3	2.37×10^3	7.50×10^2	-	-	-
19.0	5.04×10^4	1.86×10^4	1.44×10^4	3.25×10^3	-	-	-
18.0	1.21×10^5	3.21×10^4	2.24×10^4	7.75×10^3	-	-	-
17.0	2.21×10^5	7.14×10^4	2.96×10^4	1.43×10^4	-	-	-
16.0	-	-	1.49×10^5	7.83×10^4	-	-	-

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 20, 1972 (1110-1200)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	1.86×10^4	8.37×10^3	4.12×10^3	2.25×10^3	-	-	-
19.0	8.11×10^4	2.24×10^4	1.06×10^4	4.75×10^3	-	-	-
18.0	2.11×10^5	3.09×10^4	1.81×10^4	8.25×10^3	-	-	-
17.0	3.61×10^5	6.04×10^4	3.04×10^4	1.58×10^4	-	-	-
16.0	-	3.77×10^5	1.77×10^5	7.13×10^4	2.05×10^4	3.25×10^3	4.25×10^3

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 20, 1972 (1330-1425)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
21.0	3.49×10^4	8.12×10^3	4.12×10^3	2.25×10^3	-	-	-
20.0	1.01×10^5	1.89×10^4	7.87×10^3	4.00×10^3	-	-	-
19.0	2.77×10^5	4.31×10^4	1.59×10^4	6.75×10^3	-	-	-
18.0	-	9.46×10^4	2.94×10^4	1.25×10^4	4.50×10^3	-	-
17.0	-	-	6.13×10^4	3.08×10^4	1.10×10^4	-	-
16.0	-	-	-	-	5.43×10^4	1.33×10^4	1.25×10^3

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: June 20, 1972 (1430-1515)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
21.0	3.02×10^4	4.37×10^3	2.37×10^3	1.00×10^3	-	-	-
20.0	1.27×10^5	1.76×10^4	6.12×10^3	3.00×10^3	-	-	-
19.0	3.16×10^5	5.66×10^4	1.86×10^4	6.00×10^3	-	-	-
18.0	-	1.44×10^5	3.41×10^4	1.63×10^4	9.25×10^3	3.50×10^3	-
17.0	-	-	-	4.95×10^4	1.63×10^4	8.25×10^3	5.00×10^3
16.0	-	-	-	-	1.36×10^5	6.45×10^4	3.50×10^4

TABLE VII (Contd.).

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: July 7, 1972 (1830-2015)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
17.0	4.36×10^3	3.75×10^3	2.75×10^3	-	-	-	-
16.0	2.26×10^4	1.13×10^4	5.00×10^3	-	-	-	-
15.0	8.43×10^4	3.78×10^4	1.60×10^4	3.25×10^3	-	-	-
14.0	3.02×10^5	1.00×10^5	4.78×10^4	1.93×10^4	6.01×10^3	-	-
13.0	-	-	2.04×10^5	5.80×10^4	2.48×10^4	1.46×10^4	6.94×10^3
12.0	-	-	-	-	2.66×10^5	8.28×10^4	3.52×10^4

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: July 11, 1972 (1245-1355)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	6.22×10^2	3.84×10^2	3.84×10^2	3.60×10^2	-	-	-
19.0	2.06×10^3	9.37×10^2	7.69×10^2	7.45×10^2	-	-	-
18.0	6.54×10^3	3.96×10^3	2.77×10^3	1.68×10^3	-	-	-
17.0	2.01×10^4	1.20×10^4	7.50×10^3	4.25×10^3	-	-	-
16.0	6.90×10^4	5.75×10^4	1.85×10^4	1.25×10^4	-	-	-
15.0	1.37×10^5	1.33×10^5	8.48×10^4	3.13×10^4	1.45×10^4	-	-
14.0	-	-	-	-	8.68×10^4	3.81×10^4	1.61×10^4
13.0	-	-	-	-	-	-	9.28×10^4

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: July 13, 1972 (1805-1903)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	5.59×10^2	5.40×10^2	5.04×10^2	3.12×10^2	-	-	-
19.0	1.48×10^3	1.56×10^3	7.45×10^2	4.68×10^2	-	-	-
18.0	3.51×10^3	3.33×10^3	2.74×10^3	2.05×10^3	-	-	-
17.0	8.04×10^3	5.15×10^3	4.17×10^3	3.03×10^3	-	-	-
16.0	2.97×10^4	1.03×10^4	0.20×10^4	4.48×10^3	-	-	-
15.0	-	1.08×10^5	5.23×10^4	1.05×10^4	-	-	-
14.0	-	-	-	1.80×10^4	9.01×10^3	-	-
13.0	-	-	-	-	1.18×10^4	4.12×10^3	-
12.0	-	-	-	-	-	7.87×10^3	3.06×10^3

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: July 17, 1972 (1600-1655)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
29.0	3.12×10^3	-	-	-	-	-	-
28.0	1.09×10^4	-	-	-	-	-	-
27.0	3.12×10^4	6.12×10^3	-	-	-	-	-
26.0	6.86×10^4	1.61×10^4	7.50×10^3	-	-	-	-
25.0	1.48×10^5	6.61×10^4	3.00×10^3	-	-	-	-
24.0	4.39×10^5	2.02×10^5	1.28×10^4	-	-	-	-

TABLE VII (Contd.).

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: September 6, 1972 (1115-1300)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
25.0	4.31×10^2	3.12×10^2	-	3.72×10^2	Malfunctioned	-	-
24.0	6.46×10^2	5.28×10^2	-	4.56×10^2		-	-
23.0	1.81×10^3	1.76×10^3	-	6.24×10^2		-	-
22.0	4.95×10^3	3.80×10^3	-	1.80×10^3		-	-
21.0	1.33×10^4	1.00×10^4	-	3.28×10^3		-	-
20.0	3.43×10^4	3.23×10^4	1.15×10^4	5.57×10^3		-	-
19.0	7.14×10^4	1.07×10^5	4.20×10^4	8.75×10^3		-	-
18.0	-	-	8.80×10^4	1.87×10^4		-	-
17.0	-	-	-	-		-	-
16.0	-	-	-	-		-	8.55×10^2

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: September 9, 1972 (1525-1630)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
25.0	-	-	2.76×10^2	-	-	-	-
24.0	3.51×10^2	4.20×10^2	6.73×10^2	1.73×10^2	-	-	-
23.0	9.02×10^2	6.72×10^2	1.38×10^3	3.12×10^2	-	-	-
22.0	5.06×10^3	2.92×10^3	2.86×10^3	5.76×10^2	-	-	-
21.0	9.81×10^3	7.04×10^3	5.60×10^3	1.42×10^3	-	-	-
20.0	-	-	1.11×10^4	3.17×10^3	-	-	-
19.0	-	-	1.57×10^4	4.68×10^3	-	-	-
18.0	-	-	-	1.20×10^4	-	-	-

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: September 29, 1972 (1545-1705)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
20.0	3.35×10^2	3.17×10^2	3.75×10^2	3.07×10^2	-	-	-
19.0	1.52×10^3	1.12×10^3	8.17×10^2	4.25×10^2	-	-	-
18.0	3.15×10^3	2.35×10^3	1.39×10^3	8.87×10^2	-	-	-
17.0	7.53×10^3	4.89×10^3	3.04×10^3	1.73×10^3	3.76×10^3	-	-
16.0	2.30×10^4	1.53×10^4	5.52×10^3	3.13×10^3	4.51×10^3	-	-
15.0	5.32×10^4	4.05×10^4	1.18×10^4	7.00×10^3	6.51×10^3	-	-
14.0	2.12×10^5	1.89×10^5	5.65×10^4	1.83×10^4	1.00×10^4	4.87×10^3	-
13.0	6.16×10^5	6.08×10^5	5.20×10^5	1.96×10^5	8.28×10^4	5.96×10^4	8.56×10^3

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: September 30, 1972 (1140-1248)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
14.0	2.93×10^3	2.16×10^3	-	-	-	-	Malfunctioned
13.0	1.59×10^4	1.10×10^4	4.25×10^3	-	-	-	
12.0	5.80×10^4	4.93×10^4	2.85×10^4	-	-	-	

TABLE VII (Contd.).

Power plant: Point Beach Nuclear Power Plant
 Date and time of survey: October 1, 1972 (1116-1226)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
15.0	2.87×10^2	2.69×10^2	2.40×10^2	-	-	Malfunctioned	Malfunctioned
14.0	3.49×10^3	1.59×10^3	1.06×10^3	-	-		
13.0	9.18×10^4	8.26×10^3	3.51×10^3	-	-		
12.0	-	-	-	8.30×10^4	2.26×10^4		

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: October 10, 1972 (1625-1748)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
22.0	3.37×10^3	3.12×10^3	2.12×10^3	1.00×10^3	-	-	-
21.0	8.87×10^3	4.87×10^3	3.37×10^3	1.50×10^3	-	-	-
20.0	1.50×10^4	7.37×10^3	5.62×10^3	2.25×10^3	-	-	-
19.0	2.37×10^4	1.19×10^4	6.87×10^3	3.25×10^3	-	-	-
18.0	4.62×10^4	1.66×10^4	8.87×10^3	4.00×10^3	-	-	-
17.0	1.21×10^5	4.14×10^4	1.24×10^4	5.00×10^3	-	-	-
16.0	1.99×10^5	8.41×10^4	2.56×10^4	6.75×10^3	-	-	-
15.0	3.45×10^5	2.60×10^5	3.37×10^4	8.75×10^3	-	-	-

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: October 11, 1972 (1410-1630)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
22.0	3.79×10^3	No Data	No Data	No Data	No Data	No Data	No Data
21.0	1.04×10^4						
20.0	1.28×10^4						
19.0	2.26×10^4						
18.0	3.36×10^4						
17.0	5.87×10^4						

Power plant: Palisades Nuclear Power Plant
 Date and time of survey: October 13, 1972 (1015-1155)

Isotherm, °C	Plume Area within Isotherm, (m ²)						
	Surface	0.5-m Depth	1.0-m Depth	1.5-m Depth	2.0-m Depth	2.5-m Depth	3.0-m Depth
22.0	2.12×10^3	-	-	-	-	Malfunctioned	-
21.0	4.37×10^3	-	-	-	-		-
20.0	6.95×10^3	4.12×10^3	-	-	-		-
19.0	1.29×10^4	6.87×10^3	2.87×10^3	-	-		-
18.0	2.31×10^4	1.06×10^4	5.12×10^3	-	-		-
17.0	4.53×10^4	2.76×10^4	6.87×10^3	3.50×10^3	-		-
16.0	6.18×10^4	4.59×10^4	1.24×10^4	6.25×10^3	-		-
15.0	1.33×10^5	1.19×10^5	3.74×10^4	1.73×10^4	-		-
14.0	2.81×10^5	2.74×10^5	2.38×10^5	1.41×10^5	4.35×10^4		-
13.0	1.54×10^6	1.50×10^6	1.45×10^6	1.47×10^6	1.31×10^6		8.88×10^5

APPENDIX E

Centerline Temperature Half-depths

Centerline Temperature Half-depths

by

J. M. Kyser

Centerline temperature half-depths ($D_{1/2}$) were evaluated from the temperature-depth profiles for the 1972 Point Beach and Palisades thermal plumes. Temperature half-depth is defined as the depth at which the local excess temperature equals one-half the surface excess temperature.

The shape of a typical half-depth profile taken at Point Beach or Palisades is shown in Fig. 158. Generally, the half-depth increases sharply from the discharge, then decreases as the excess temperature ratio decreases. $D_{1/2}$ tended to level off for values of excess temperature ratio greater than 0.4.

Table VIII lists the half-depth as a function of excess temperature ratio and a characteristic value of $D_{1/2}$ representing the half-depth of the far-field plume.

Fig. 158. Typical Half-depth Profile

TABLE VIII. PLUME HALF-DEPTH AS A FUNCTION OF EXCESS TEMPERATURE RATIO

LOCATION	DATE OF SURVEY (1972)	TIME OF SURVEY	CHARACTERISTIC HALF-DEPTH (METERS)	HALF-DEPTH (METERS)			
				$\theta/\theta_o = .5$	$\theta/\theta_o = .4$	$\theta/\theta_o = .3$	$\theta/\theta_o = .2$
Point Beach	May 17	1646-1806	1.5	1.75	1.25	1.3	1.5
Point Beach	May 18	1645-1751	1.0	0.75	0.75	1.0	—
Point Beach	May 24	0925-1040	—	1.75	1.0	—	—
Point Beach	May 24	1045-1145	1.25 - 1.5	1.0	1.0	1.25	—
Point Beach	May 24	1145-1225	1.25	1.0	1.0	1.25	1.25
Palisades	June 13	1242-1443	.3	0.3	—	—	—
Palisades	June 13	1516-1615	—	0.3	—	—	—
Palisades	June 19	1630-1730	—	0.5	0.7	—	—
Palisades	June 20	1027-1109	1.25	0.4	—	.8	1.25
Palisades	June 20	1110-1200	0.75	0.3	0.25	0.5	0.75
Palisades	June 20	1330-1425	—	0.25	0.3	—	—
Palisades	June 20	1430-1515	0.3	0.28	—	0.5	—
Point Beach	July 7	1830-2015	1.0 - 1.25	2.5	1.0	1.0	1.0
Point Beach	July 8	1500-1730	—	—	—	—	—
Point Beach	July 11	1245-1355	2.5 - 2.75	1.75	2.4	2.9	3.0
Point Beach	July 13	1805-1903	.25 - .5	1.2	0.5	0.3	0.3
Palisades	July 17	1600-1655	1.0	0.6	0.5	0.9	—
Palisades	July 18	1952-2055	0.5 - 0.75	0.75	—	—	0.5
Palisades	July 19	1546-1710	0.75 - 1.25	—	—	—	—
Palisades	Aug 7	1730-1900	—	—	—	—	—
Palisades	Aug 8	1415-1745	—	—	—	—	—
Point Beach	Sept 6	1115-1300	1.5 - 2.0	1.6	1.5	1.9	—
Point Beach	Sept 9	1525-1630	—	—	1.5	—	—
Point Beach	Sept 12	1409-1602	—	—	—	—	—
Point Beach	Sept 29	1545-1705	1.5 - 2.0	2.0	1.25	1.25	2.25
Point Beach	Sept 30	1140-1248	1.5	0.9	1.0	1.25	1.75
Point Beach	Oct 1	1116-1226	1.25	1.25	1.25	1.25	1.25
Palisades	Oct 10	1625-1748	1.25	—	—	—	1.25
Palisades	Oct 11	1410-1630	—	—	—	—	—
Palisades	Oct 13	1015-1155	1.25 - 1.5	1.1	1.2	1.3	1.5

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