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DEVELOPING AN ADEQUATE HYDROTHERMAL MONITORING PROGRAM

By

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As a result of stringent regulatory requirements controlling thermal discharges from power plants, hydrothermal monitoring programs have become essential activities. In addition to being presently required by Federal and State regulations to demonstrate compliance with temperature criteria, such programs play an important role in the selection of the best suited engineering concepts for thermal discharges as well as in the development and validation of mathematical models for temperature predictions. For these reasons, hydrothermal monitoring must now be recognized as an important engineering tool and as an activity that should be carefully coordinated with both the licensing effort and other investigations and engineering activities on a power plant project.

In my talk, I will discuss the various phases of hydrothermal monitoring in the overall picture of a nuclear power plant project, review the impact of regulatory requirements on monitoring programs, and illustrate with examples the application of available monitoring techniques.

Before this discussion, it may be useful to clarify the term "hydrothermal monitoring program" as it will be used here. In a broad sense, such a

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monitoring program includes all short-term and long-term surveys and measurements from the beginning of a power plant project until after the plant is in operation, aimed at defining the hydrodynamic and thermal characteristics of a receiving water body. In other words, hydrothermal monitoring is considered to include not only the preoperational and postoperational measurements designed to determine temperature changes due to plant operation, but also all surveys conducted in the conceptual stage of a project when the feasibility of a once-through cooling water system is investigated and the best suited type of thermal discharge is selected.

In principle, a hydrothermal monitoring program for a power plant with a once-through condenser cooling water system should consist of three phases. Phase 1 includes measurements designed to supply information on all pertinent physical characteristics of the receiving water. Phase 2 includes measurements aimed at establishing baseline conditions in the preoperational stage and developing a rational program for postoperational monitoring. Phase 3 includes measurements designed to determine changes in water temperatures during the postoperational stage and to demonstrate compliance with regulatory requirements.

Figure 1 shows the schedule of a nuclear power plant project with the typical milestones related to obtaining the necessary licenses and discharge permits. The chart shows the three phases of the hydrotherm monitoring program and their relation to those milestones. Phase 1 should start as early as possible and be completed before the application

for the state discharge permit, PSAR, and Environmental Report are filed. Phase 2 should be completed before the FSAR and Final Environmental Report are filed. Phase 3 starts after the plant operates at full load and is completed when compliance with applicable regulations is demonstrated. Limited water temperature monitoring may, however, continue throughout the life of the plant.

Let me now discuss in some detail the scope and objectives of the three monitoring phases. Recognition of these separate objectives is a first step toward developing an adequate hydrothermal monitoring program.

Phase 1 takes place in the conceptual stage of a power plant project. It normally consists of short-term surveys and some long-term measurements.

The information obtained in this phase must be adequate (a) to ensure a good understanding of natural conditions, (b) to enable selection of best suited engineering concepts for condenser cooling water intake and discharge facilities, (c) to supply inputs for mathematical modeling of near-field and far-field temperature changes due to thermal discharges, and (d) to supply data for physical modeling, if required. The quantity and quality of information obtained in this phase must be sufficient on one hand for engineering purposes and on the other hand for obtaining the required discharge permits.

Physical parameters investigated in Phase 1 include current velocities, flow patterns, bottom topography, water temperature variation, thermal stratification, and dispersion characteristics. For tidal waters, additional

parameters to be investigated include tide levels, salinities, and flushing characteristics. It should be emphasized that field surveys required to obtain this information must be carefully designed to suit the proposed discharge system and the natural characteristics of the site so that the data obtained can be used in the mathematical analysis of temperature changes due to thermal discharges.

The required duration of Phase 1 depends largely on site characteristics but, in many cases, it is also influenced by the stringency of temperature criteria that have to be met in a given State. For example, if the requirement is to meet a 1.5 F temperature rise criterion at a specified distance from the discharge structure, it is obvious that very reliable information must be available for an elaborate hydrothermal analysis; hence, more comprehensive surveys are necessary. In general, an adequate duration for this phase is one year so that conditions during four seasons can be investigated. In certain cases, where special conditions exist, more than one year of measurements may be necessary. On the other hand, when certain information is already available, the duration can be shortened.

It should be pointed out that the Phase 1 effort is normally on the critical path of the project schedule since it determines the date when a discharge permit can be obtained and when the PSAR and Environmental Report can be filed. Therefore, this effort should be initiated as early as possible in parallel with conceptual engineering for selection of the best cooling water scheme and most suited type of intake and discharge facilities.

The area of the receiving waters that is covered by the Phase 1 monitoring may be, in certain cases, relatively large, particularly when several cooling water discharge schemes are compared in the conceptual engineering stage. Even after a cooling water discharge scheme has been selected, the area covered by hydrothermal surveys in this phase may be extensive, particularly in tidal waters where flushing rates must be determined by means of dye tracer sudies. In fact, the relatively large area covered by these surveys is often one of the main characteristics of Phase 1, as distinct from subsequent Phases 2 and 3 of the hydrothermal monitoring program where emphasis is shifted from the broader study of physical site characteristics to a more regulatory-oriented determination of temperature changes due to plant operation.

Phases 2 and 3 are very much related, even though they may be conducted at an interval of several years. The objectives of Phase 2 are (a) to establish preoperational baseline conditions for comparison with future, postoperational monitoring, (b) to lay the groundwork for a rational method for assessing temperature changes due to future plant operation, and (c) to enable development of a detailed monitoring program for the postoperational stage.

Phase 3 is the actual implementation of the postoperational monitoring program. Its scope, like the scope of Phase 2, is largely determined by the nature of regulatory requirements controlling thermal discharges in a given State.

Specifically, the type and location of measurements conducted in Phases 2 and 3 depend on the following factors:

a. Regulatory requirements as to a specific size for the mixing zone

b. Existence of well-defined temperature rise and/or maximum temperature criteria

c. Requirements aimed at controlling temperatures in certain zones such as fish passageways or specified biologically sensitive areas

These factors have a great influence on the scope and extent of preoperational and postoperational hydrothermal monitoring. Therefore, they must be considered when we define what an adequate monitoring program is in these phases. To emphasize this point, I will briefly illustrate the wide range of regulatory requirements the power industry has to meet in various states and how they affect the monitoring program.

In certain states, permissible temperature rises are specified together with the extent of mixing zones. A case in point are the present regulations in the State of New York.

<u>For Streams</u>: "The water temperature at the surface of a stream shall not be raised to more than 90 F at any point. Further, at least 50 percent of the cross sectional area and/or volume of flow of the stream, including a minimum of 1/2 of the sur-

face as measured from shore to shore, shall not be raised more than 5 F over the temperature that existed before the addition of heat of artificial origin or to a maximum of 86 F whichever is less, except during periods of the year when stream temperatures are below 39 F ...."

<u>For Lakes</u>: "The water temperature at the surface of a lake shall not be raised more than 3 F over the temperature that existed before the addition of heat of artificial origin, except that within a radius of 300 ft or equivalent area from the point of discharge, this temperature may be exceeded."

<u>For Coastal Waters</u>: "The water temperature at the surface of coastal waters shall not be raised more than 4 F over the monthly means of maximum daily temperatures from October through June nor more than 1.5 F from July through September, except that within a radius of 300 ft or equivalent area from the point of discharge this temperature may be exceeded."

<u>For Estuaries</u>: "The water temperature at the surface of an estuary shall not be raised to more than 90 F at any point, provided further at least 50 percent of the cross sectional area and/or volume of flow of the estuary, including a minimum of 1/3 of the surface as measured from water edge to water edge at any stage of the tide shall not be raised more than 4 F over the temperature that existed before the addition of heat of artificial origin or a maximum of 83 F, whichever is less. However, during July through September if the water temperature at the surface of an estuary before the addition of heat of artificial origin is more than 83 F, an increase in temperature not to exceed 1.5 F at any point of the estuarine passageway as delineated above may be permitted."

These extensive quotes from the New York State regulations have been given here because they illustrate a trend that we see in certain states, a trend toward a uniform administrative definition of temperature criteria and mixing zone boundaries.

Other states have followed a different trend by retaining in their regulations a certain flexibility in terms of defining the extent of the mixing zone on a case-by-case basis. This trend is illustrated by a quote from the Michigan Interstate and Intrastate Water Temperature Standards (August, 1971)

> "Mixing zones for thermal discharges will be established on a case by case basis and will be designed to minimize effects on the aquatic biota in the receiving waters and to permit fish migration at all times. Configuration will be based on the physical characteristics of the receiving water body and the biological importance of the area to be protected such as spawning areas, migratory routes, etc. Within mixing zones other standards than those presented may be applicable but will not interfere with the designated water uses for the area."

At this time, it seems that this latter trend toward greater flexibility in defining the extent of mixing zones is more and more widely accepted by the scientific community. From a monitoring standpoint, this means that no uniform administrative guidelines are applied and that planning the scope of Phases 2 and 3 of the hydrothermal monitoring program is only possible after regulatory agencies have defined their specific requirements. In all likelihood, this will happen at the time when discharge permits are obtained.

This brings again into focus the importance of Phase 1 of the monitoring program. In other words, this emphasizes the need for a sufficiently comprehensive scope of the field studies conducted earlier, in the conceptual stage of the project, to enable a good understanding of all site characteristics. It is only when good, solid information is available that a greater flexibility in regulations can be effectively used.

Insofar as Phases 2 and 3 are concerned, regardless if temperature criteria are administratively established for all sites or on a site-by-site basis, there is one key factor that determines the scope and extent of hydrothermal monitoring, and that is whether the criteria relate to absolute temperatures or termperature rises above ambient water temperature. When only absolute

water temperatures are specified, the monitoring program aimed at proving compliance with regulatory requirements is a relatively straightforward task. When temperature rises above ambient are specified, the crucial question is: What is the ambient water temperature, and how will it be measured? The answer to this question determines largely the scope of preoperational and postoperational monitoring. The definition of ambient water temperature as being the temperature of the water before the addition of artificial heat is relatively simple from a logical standpoint, but it poses serious problems from a practical standpoint. Obviously, the difficulty consists in measuring this ambient temperature once the power plant is in operation so that the actual temperature rise at selected points can be determined.

A practical approach to overcome this difficulty would be, in principle, to select an area in the receiving water that is unaffected by the thermal discharge but is as nearly representative as possible of ambient water temperature in the zone that is affected by the thermal discharge. In a stream or lake, this is relatively easy by selecting a control area outside the thermal plume and where no effect of heat recirculation is expected (Fig. 2). Water temperature measured in the control area can then be used to define the ambient water temperature during the Phase 3 postoperational monitoring. However, during the Phase 2 preoperational monitoring, it must be determined whether water temperatures in the control area are truly representative of those prevailing in the area where temperature changes due to plant operation will be subsequently measured. When this is not the case, due for example to significant depth differences, a possible

correlation of natural water temperatures in the two areas must be investigated. This determination must obviously be made in Phase 2, that is, before addition of waste heat from the plant.

In tidal waters, definition of the ambient water temperature is considerably more difficult, for example, in coastal waters or estuaries (Fig. 3), a control area that would be located in any of the two directions of flow be affected by heat returning with the tide. A control area that would be located at a greater distance offshore may not be representative due to greater depth. For these reasons, considerable attention should be given in Phase 2 to selection of a rational method for defining the ambient water temperature to be used later as part of Phase 3 monitoring. Long-term temperature measurements should be conducted during Phase 2 to establish possible correlations between natural temperatures in the area of regulatory interest and other areas that would be less affected by thermal discharges. It should be emphasized that this effort is not strictly a monitoring one, but that it must be combined with an analytical effort. One objective of analysis is to investigate the relative importance of physical parameters that affect temperature differences between the area of regulatory interest and the control area. Another objective is to filter out any effects of plant heat on temperatures measured in the control area after the plant is in operation.

As part of ambient water temperature investigation, a problem that must be carefully explored during Phase 2 of the monitoring program is the possible existence of physical site characteristics that can affect the results of postoperational measurements. In this category would fall any characteristics that could lead to rapid changes of natural water

temperatures and therefore lead to erroneous conclusions after the plant is in operation.

I will illustrate the effect of such physical characteristics with an example related to natural temperature changes at the surface of a lake. As part of preoperational studies for a nuclear power plant on Lake Ontario, long-term records of water temperatures at several locations were obtained. Out of these records, one piece of information can be singled out in the context of the subject under discussion, and is shown in Fig. 4. This is a summary of average daily temperature profiles between June 1 and August 15 at a point where the lake depth is approximately 40 ft. Of special interest are the rapid temperature changes that occurred from July 20 to August 2. In one case, the temperature change was as much as 25 F in approximately one day. The analysis of data showed that rapid reductions in temperatures, at first only in deeper water and then also near the surface, were due to an upward tilting of the thermocline and a corresponding shoreward flow of cold hypolimnetic water. This upwelling had been generated by an offshore wind as was shown by an analysis of wind data.

As distinct from the period of upwelling, variations in natural water temperature often occurred from day to day. These temperature changes were due to wind stresses inducing surface currents which shifted the overall temperature patterns near the lake surface. It is obvious that a clear understanding of such natural temperature changes and of the physical parameters that control them must be obtained long before the power plant goes into operation. Otherwise, the possible unexpected

occurrence of such natural conditions during postoperational surveys could pose serious problems from a regulatory standpoint.

To conclude the discussion on ambient water temperatures, it should be added that it is conceivable to find occasionally from preoperational studies at a particular site that a reliable determination of the ambient temperature will be all but impossible after the plant is in operation. Should this be the case, the analytical methods and mathematical models developed in the conceptual phase of the project remain the only reliable tool available for determining temperature changes.

For example, if the Phase 2 monitoring should reveal that no adequate temperature correlation with a control area exists, utilization of mathematical models is the only recourse. To make this tool a credible and reliable one, special hydrothermal surveys should be included in the postoperational monitoring program aimed specifically at validating the mathematical model. If certain basic aspects of this model are validated during the surveys, a practical demonstration will have been made that temperature changes determined by the mathematical model are also reliable. Such hydrothermal surveys would have to be tailored to suit the site characteristics and the nature of the mathematical model that was used.

I have mentioned this possibility only to emphasize that, with stringent regulatory requirements and complex site characteristics, hydrothermal monitoring programs and hydrothermal analyses are very much interrelated. These two efforts must be often carried out in parallel throughout the

monitoring program. In fact, the engineering profession and regulatory agencies should recognize that only in a few cases will postoperational monitoring be a simple and neat administrative task. In most cases, it will be a rather elaborate effort combining direct measurements and analyses. The sooner this is recognized, the better and more reliable our monitoring programs will become.

So far in this talk, I have discussed the objectives of the three monitoring phases and the engineering and regulatory problems that have to be considered in planning a program. I will now review briefly the measuring techniques that are used. These include the following:

a. Long-term velocity and temperature measurements

b. Short-term surveys to determine vertical profiles of velocities and temperatures at selected locations

c. Drogue surveys to determine flow patterns

d. Infrared surveys to determine temperatures at water surface

e. Dye tracer studies to determine natural dispersion characteristics and flushing conditions

While the ultimate purpose of hydrothermal monitoring is determination of temperatures and temperature changes in the receiving water body, any technique that addresses itself to water temperature measurement only

is unsatisfactory. The total hydrothermal picture in the receiving waters is usually so complex that looking strictly at temperatures may lead to incomplete or even erroneous conclusions. This is true not only for preoperational studies but also for the postoperational studies in Phase 3, with the exception of routine temperature monitoring that must continue beyond that phase. The best approach in hydrothermal monitoring is a combination of some of the techniques mentioned above. The most adequate combination should be selected to suit the characteristics of the receiving water body and the type of condenser cooling water discharge. Different techniques may be used in the various phases of the monitoring program.

Long-term velocity and temperature measurements are conducted by means of self-contained instruments mounted on underwater towers or attached to buoys. Self-contained current meters measuring speed and direction of flow are usually either of the Savonius rotor or inducted impeller type, both with accuracies of the order of ±3 percent. Savonius rotors have been proved so far to be more reliable but their readings can be misleading in shallow waters where they are affected by orbital movements produced by surface waves. Separate wave recorders and analytical corrections of the readings are therefore necessary with this type of current meter. Inducted impeller meters are a relatively new development, and they are designed to filter out automatically the effect of wave motion, but improvements will be necessary before these instruments can be widely used. Self-contained temperature meters with sensors of various types have usually a sensor accuracy of ±0.2 C.

The overall accuracy of long-term measurements depends both on the sensors and on the output format. Strip chart recorders may sometimes pose problems due to lack of a timing mechanism indicating that the paper is proceeding at the proper speed or due to inadequate time resolution. Photographic outputs that can be processed in the laboratory to digital outputs tend to eliminate human error in processing. However, the quality of the picture is sometimes inadequate and human interpretation of the signals is still necessary. Magnetic tape outputs are intended only for computer processing. This ensures maximum processing speed but involves the risk of difficulties in data reduction if any malfunction has occurred during the recording process.

Lacking at this time in self-contained instruments is some onshore system that would indicate if the sensor is working. When the records are retrieved, it is often found that the instrument was malfunctioning. Frequent servicing and instrument redundancy is presently the method used to minimize this problem. Also, when strip chart recorders are used, these can be mounted above the water surface and can be frequently inspected. A desirable development would be an onshore readout or indication of proper instrument operation.

Short-term hydrothermal surveys represent a practical technique for obtaining temperature and velocity profiles at points of interest in receiving waters. Measurements made by means of portable current and temperature meters off one or several boats enable the investigation of temperature and velocity distribution at several locations in a relatively short period of time. The advantage of this technique is instrument mobility, but a basic requirement that is not always fully satisfied is

the need to accurately determine the position of the boat at the time measurements are made. When temperature conditions tend to change rapidly, such as in shallow waters or in certain tidal water bodies, the time of travel between boat locations may be a critical factor.

When carefully planned, short-term surveys can be usefully combined with long-term measurements at selected locations. For example, correlations may be established between conditions prevailing at the site of the fixed instruments and at other points where periodical measurements are made. Based on such correlations, long-term variation of water temperatures and current velocities at a larger number of locations and depths may be obtained.

In addition to current and temperature meters, short-term surveys may utilize drogues to investigate flow patterns over relatively large areas. Such drogues are normally provided with cables of selected lengths attached to cruciforms that move with the velocity prevailing at the depth where they are immersed. Synoptic flow patterns at various depths can thus be obtained if drogue movement is documented by triangulation or aerial photography. Drogues can also be useful in studying net drift in tidal waters and water movement in stratified systems.

When planning to use drogues in a hydrothermal survey, careful consideration must be given to bottom topography and wind conditions. When the bottom of the water body is irregular, drogues may run aground, and practical means for their retrieval with minimum loss of time must be available. The accuracy of flow patterns is very sensitive to wind effects due to shear at the drogue surface and drag on the small flags that are normally used

to facilitate visual observation. Information on wind speed and direction during the entire survey should be obtained in order to make corrections if necessary. In view of possible wider application of drogues for hydrothermal surveys, it would be desirable to develop improved types of drogues that would be less wind-sensitive.

Infrared surveys are often used to investigate temperature patterns at water surface. Regulatory agencies tend to favor them because, in principle, they enable a rapid temperature measurement over a large area. There is therefore the tendency to consider them ideal tools for verifying compliance with regulations. In actuality, infrared surveys used as the only monitoring technique may be misleading. This word of caution reflects the following considerations: (a) Infrared radiometry measures temperatures in only a fraction of an inch of water near the surface, (b) wind effects may result in significant shifts of surface temperature patterns, and (c) present absolute accuracy of these measurements is ±1 C and the relative accuracy is ±0.5 C.

To be meaningful, infrared surveys should be combined with short-term or long-term monitoring at several locations in the area under study. This would not only significantly improve the accuracy of the survey, but would also enable an understanding of actual hydrothermal conditions which would be impossible based on just the infrared survey.

Dye tracer studies are a very useful tool in hydrothermal investigations. For example, they are indispensable for determining flushing characteristics of tidal water bodies; in other words, for defining the rate of heat return

to the near-field area of a thermal discharge. This is a critical parameter that controls the design of discharge structures that must meet stringent temperature criteria. Dye tracer studies are also used to determine dispersion characteristics of the receiving waters and, in addition to temperature measurements, they can be very helpful in determining warm water recirculation rates at an operating power station.

A meaningful interpretation of results obtained from dye tracer studies is only possible when the studies are combined with current measurements so that the flux of dye can be determined.

Considerable care should be exercised in using measured dye concentrations or dye flushing rates in hydrothermal analyses, since there is a basic difference between dye and heat in that dye is relatively conservative whereas heat is lost to the atmosphere. This important difference, as well as density effects, must be reflected in adequate adjustments of all dye measurements.

In combining fluorescent dye tracer surveys with other measuring techniques, it is important to plan the survey such that dye concentrations can reach a steady state. Precautions are necessary during dye concentration measurements to enable accurate interpretation of results. For example, water temperatures should always be determined during the survey since fluorescence is temperature dependent and adequate corrections to the fluoremeter readings are therefore necessary when significant water temperature differences are found. Also, when dye is injected in the

circulating water flow of an existing unit, it is necessary to avoid using chlorine for biofouling control, since it reacts with the dye and reduces its fluorescence.

After this brief discussion of measuring techniques used in hydrothermal monitoring programs, I will give two examples of preoperational studies for nuclear power plants where various techniques were combined.

The first example relates to the James A. FitzPatrick Nuclear Power Plant of the Power Authority of the State of New York. The plant is located on Lake Ontario. Condenser cooling water will be discharged into the lake through a diffuser tunnel designed to meet the New York State regulations, specifically a temperature rise of 3 F at the lake surface outside an area equivalent to a 300 ft radius circle. The scope of preoperational hydrothermal monitoring is illustrated in Fig. 5 and included the following:

1. Continuous recordings of water temperatures and current speed and direction at two locations in the vicinity of the intake and discharge structures for two five-month periods in two consecutive years. These measurements were made by self-contained temperature and current meters mounted at various depths on two underwater towers.

2. Intermittent surveys off boats to determine temperature profiles at various locations.

3. Determination of current patterns at various depths by means of drogues tracked by aerial photography.

4. Determination of surface temperature patterns by means of airborne infrared radiometry.

The information obtained from these various types of monitoring techniques was essential for hydrothermal analysis, hydraulic model testing, and development of engineering concepts for intake and discharge structures meeting regulatory requirements. Compliance was verified for both static lake conditions and wind-induced currents in an easterly and westerly direction.

The second example relates to the Shoreham Nuclear Power Station of Long Island Lighting Company. The plant is located on Long Island Sound. Condenser cooling water will be discharged through a multiport diffuser pipe designed to meet the New York State criteria for coastal waters, specifically for a temperature rise of no more than 1.5 F from July through September and 4 F from October through June outside an area equivalent to a 300 ft radius circle.

In addition to supplying basic information on the receiving waters at the site, the preoperational hydrothermal monitoring was an integral part of the approach used in designing the diffuser to meet the required criteria. Specifically, hydrothermal surveys were a part of a three-pronged approach that included mathematical modeling, hydraulic model testing, and field surveys. This is considered to be an example that

illustrates clearly the important role of hydrothermal monitoring in the conceptual stage of engineering.

The preoperational hydrothermal field studies included the following:

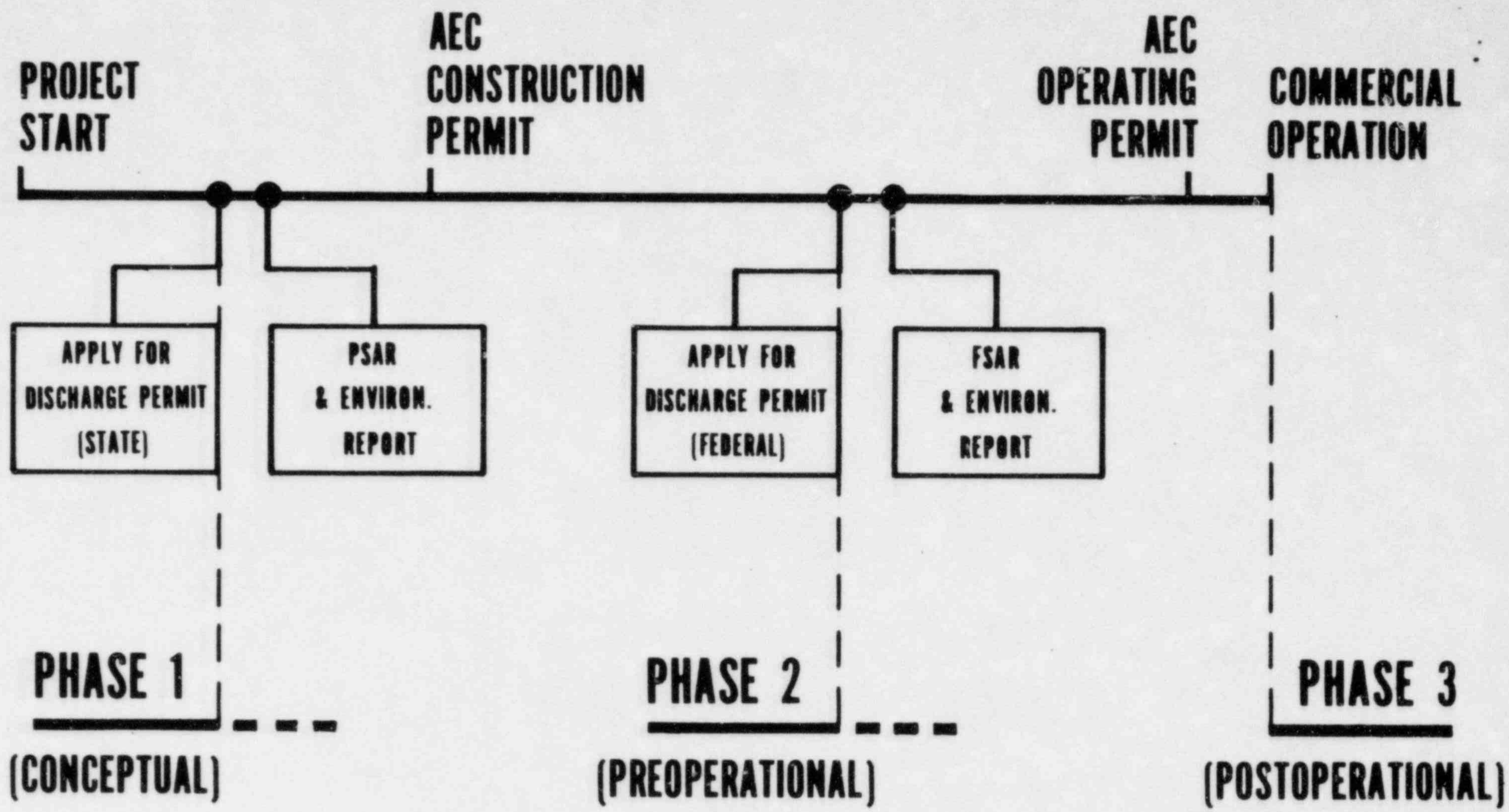
1. Continuous recordings of water temperatures and current velocities during the summer months of one year at three offshore locations, using self-contained instruments suspended from anchored buoys (Fig. 5). Tide levels were also continuously measured during that period.

2. Periodic water temperature measurements at water surface and near the bottom, during each of the four seasons over a three-year period to determine the natural thermal stratification in the discharge area. Water salinities were also measured at those times.

3. A dye dispersion study to determine natural circulation patterns and flushing characteristics in the discharge area. The study was conducted over a 10-day period during late summer. Fluorescent dye was released continuously from five small dinghies located along a line approximating the position of the proposed diffuser pipe (Fig. 6). The resulting distribution of dye was measured at a number of predetermined transects by means of a boat-mounted, underwater sampling system. During the dye survey, current meters were located at two points along the dye discharge line.

To conclude my talk, I would like to emphasize the key role that hydrothermal monitoring programs can have in influencing the thinking of the engineering profession, the scientific community, and regulatory agencies with regard to waste heat disposal in general. As we all know, at this time, regulatory agencies tend, in many cases, to favor closed-loop cooling water systems where waste heat is released directly to the atmosphere. We believe, however, that sooner or later a more balanced approach to the problem of waste heat control will be adopted. We believe that it will be recognized that, in certain cases, thermal discharges into water bodies may represent the best option available, one that may result in the least total impact on the environment. It is also to be expected that temperature criteria will evolve on a site-by-site basis rather than on the basis of rigid numerical standards. It is in promoting such a trend that comprehensive hydrothermal monitoring can make a major contribution.

If preoperational and postoperational monitoring are meaningfully related and if the available techniques are adequately used, hydrothermal monitoring can help immeasurably in refining the predictive methods presently available, enhancing the credibility of engineering predictions, and promoting greater flexibility in existing regulations. The power industry, the engineering profession, instrumentation manufacturers, and regulatory agencies have a common interest in focusing on hydrothermal monitoring as an important task whose successful resolution may have a bearing on the broader issues of thermal discharge control and power plant siting.



PHASES OF HYDROTHERMAL MONITORING FOR NUCLEAR POWER PLANT

FIG. 1

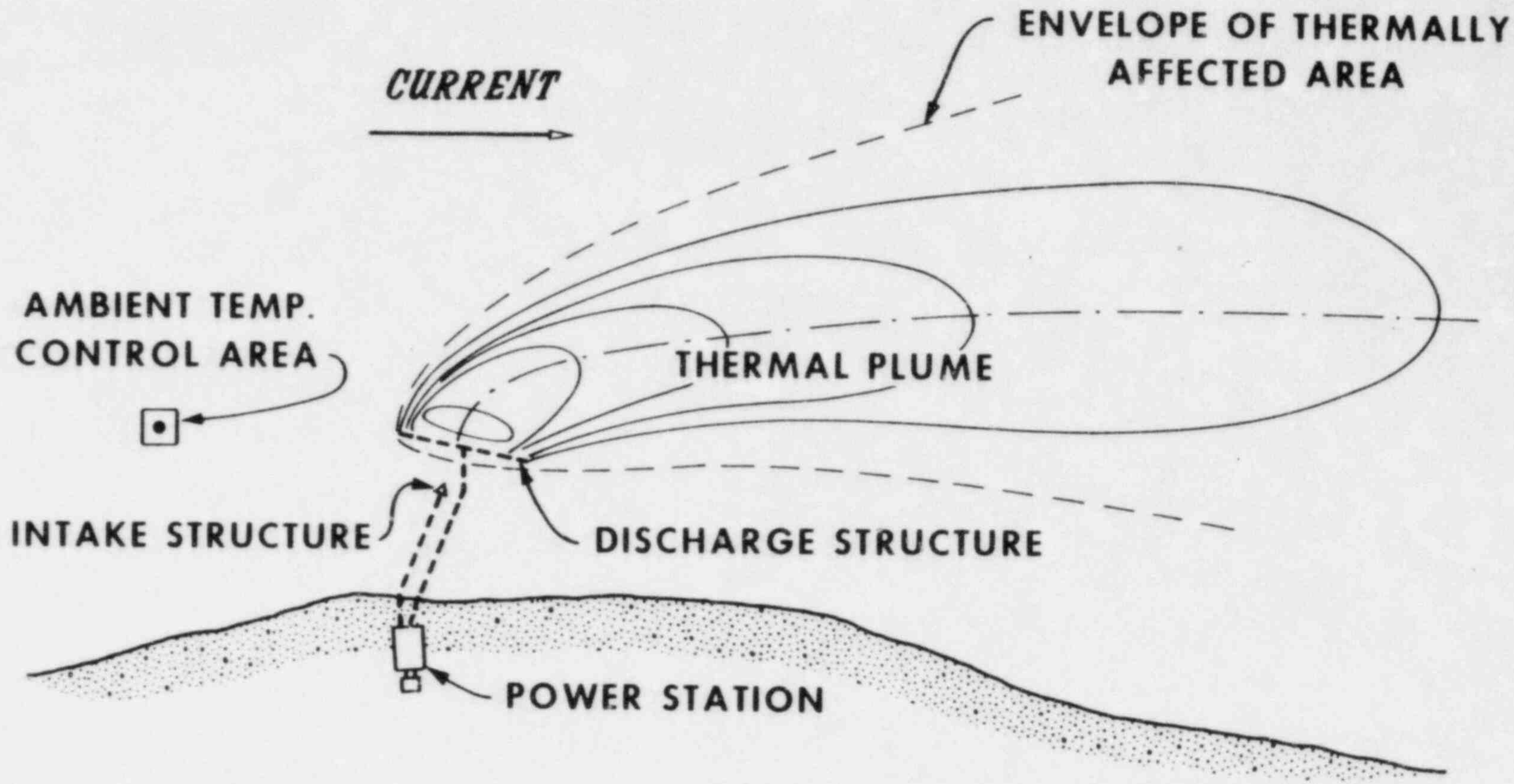


FIG. 2

MONITORING OF AMBIENT WATER TEMPERATURES IN STREAMS OR LAKES

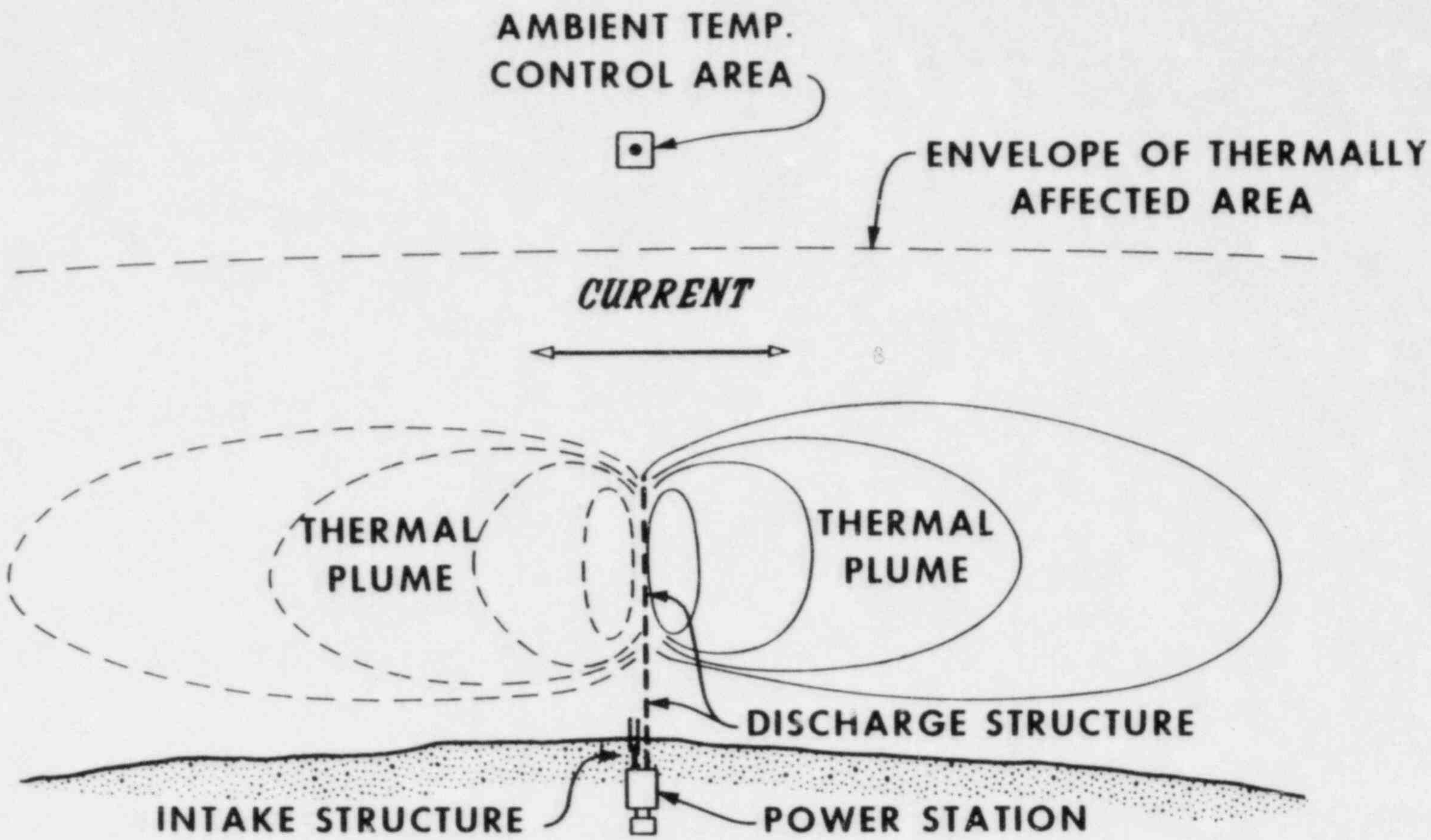
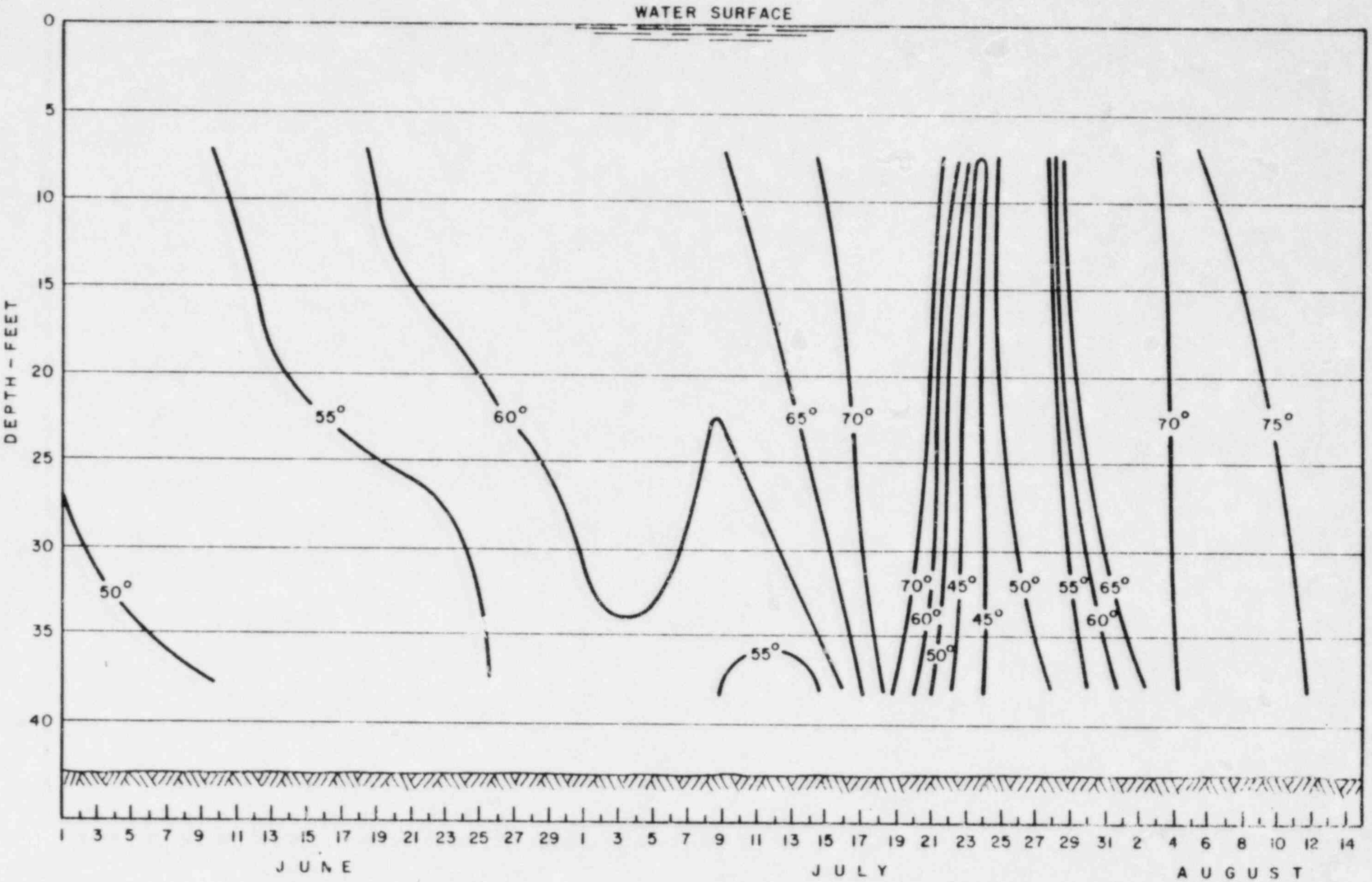


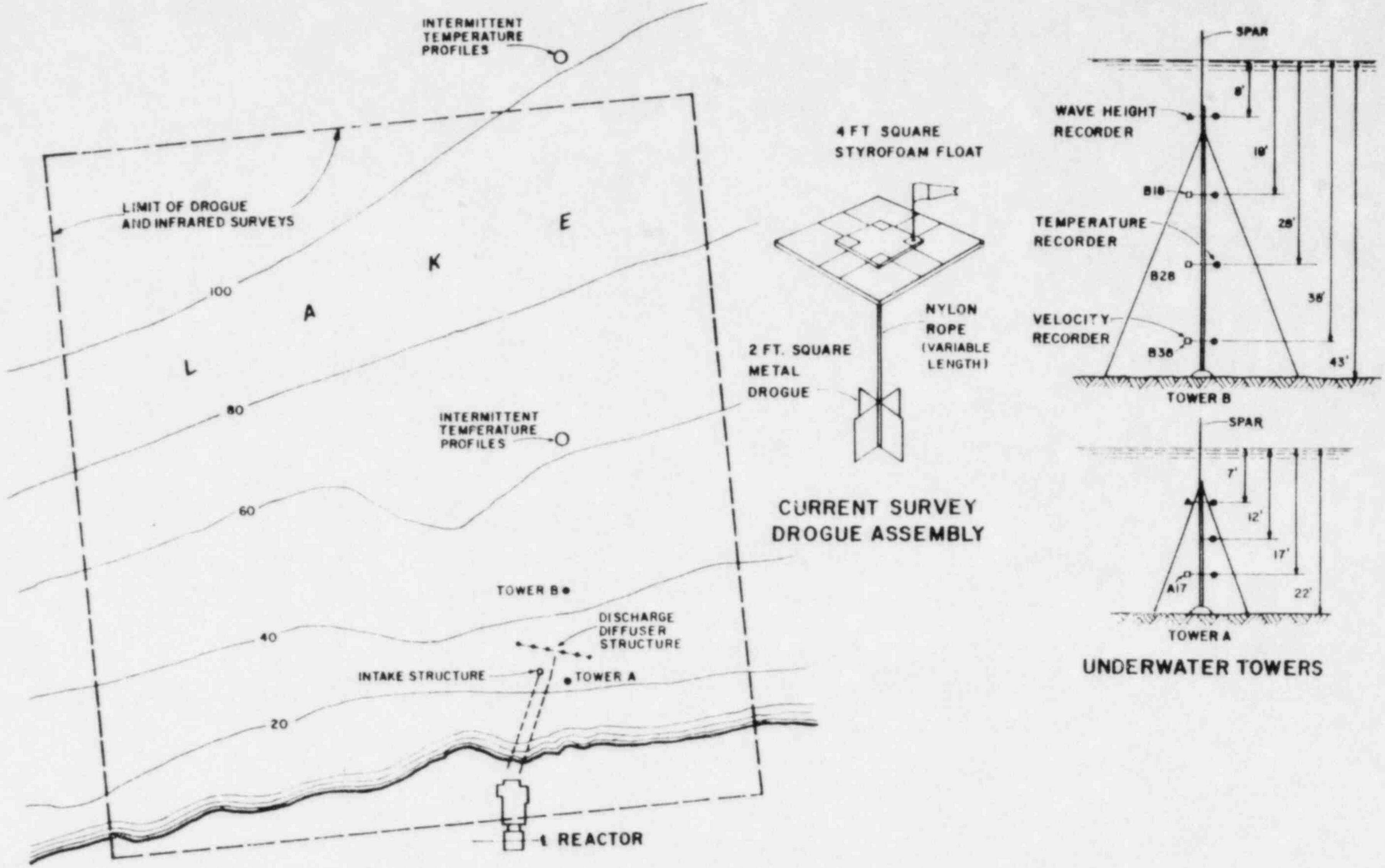
FIG. 3

MONITORING OF AMBIENT WATER TEMPERATURES IN COASTAL WATERS



DAILY TEMPERATURE PROFILES IN LAKE WATER

FIG. 4



CURRENT AND TEMPERATURE SURVEY IN LAKE WATER

FIG. 5

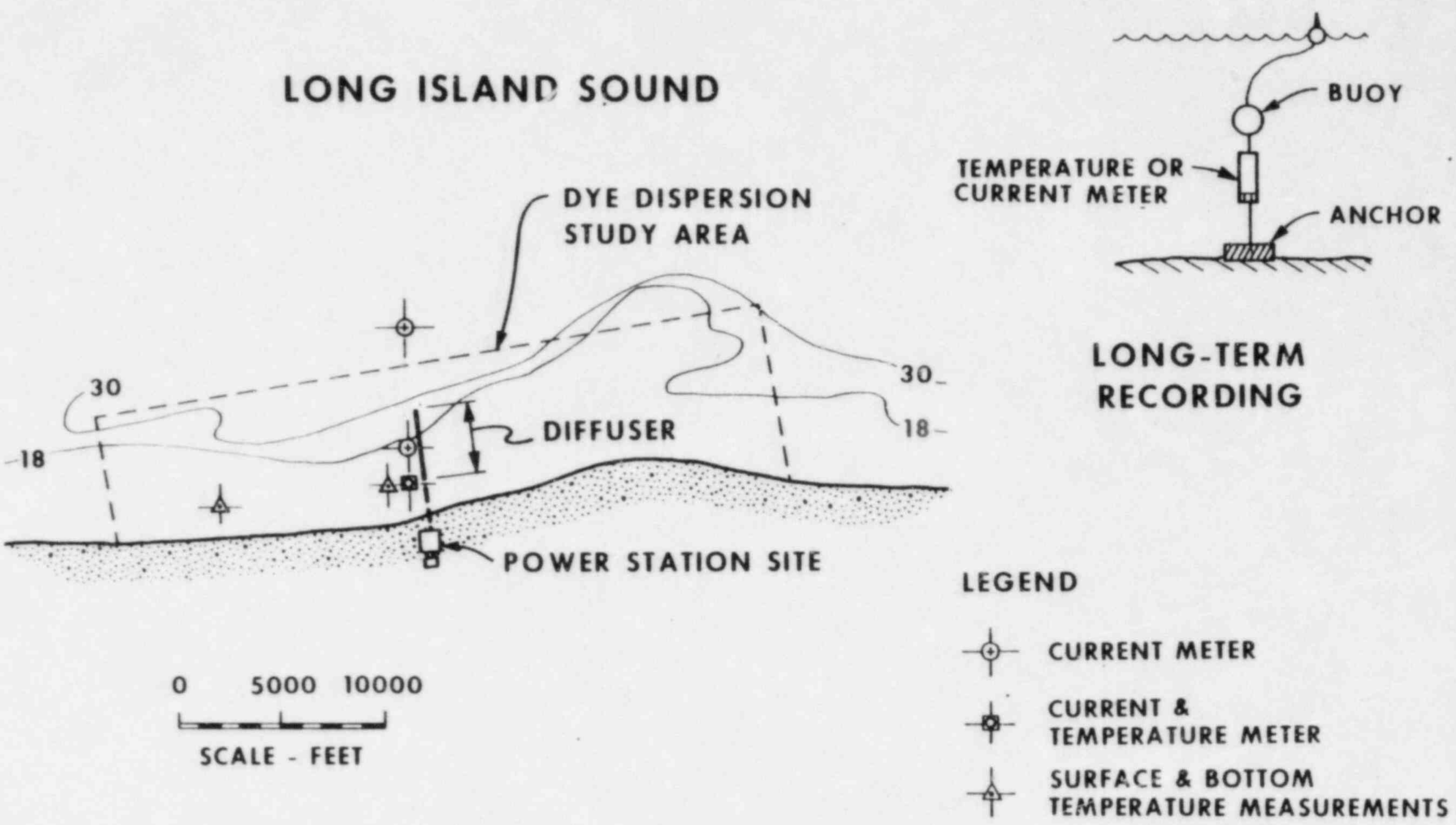
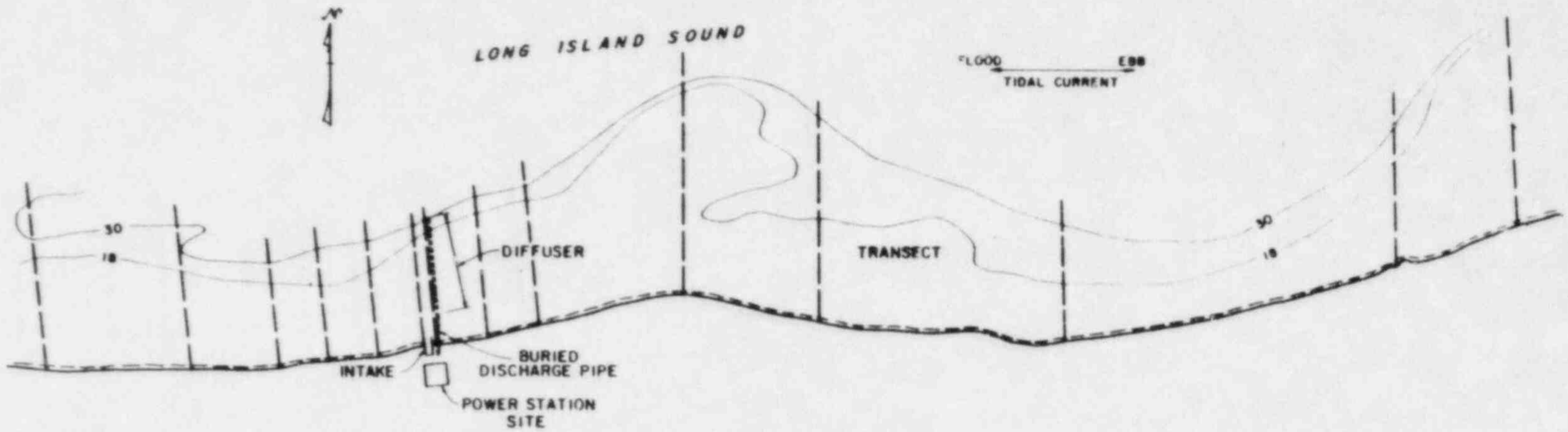


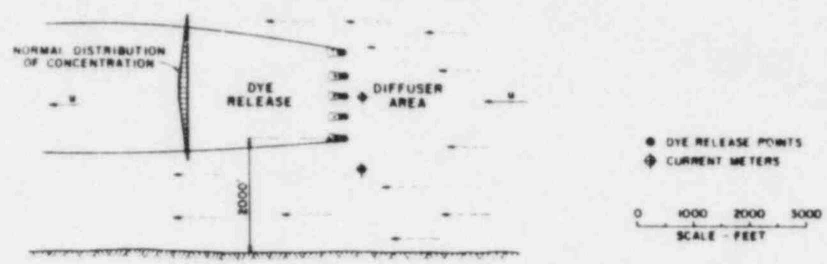
FIG. 6

EXTENT OF MONITORING PROGRAM AT COASTAL SITE



LOCATION OF DYE CONCENTRATION MEASUREMENT TRANSECTS

0 2500 5000 7500 10,000
SCALE - FEET



SIMULATION OF DIFFUSER DISCHARGE PATTERNS BY DYE RELEASE

FIG 7

DYE DISPERSION STUDY