**Thermal Performance
Experiments on Ultimate
Heat Sinks, Spray Ponds
and Cooling Ponds**

by
R. K. Hadlock

December 1976

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Nuclear Regulatory Commission**

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ULTIMATE HEAT SINKS, SPRAY PONDS AND
COOLING PONDS

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December 1976

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1. SUMMARY

A program of measurement on a Battelle-Northwest (BNW) spray pond has been completed to prove an integrated instrumentation system for application in future field experiments. The measurement programs in the field will produce data of relevance to the design and understanding of performance for ultimate heat sinks as components of emergency core cooling systems. In the absence of active emergency cooling systems, the data will be obtained on analog systems - prime candidates among these are the naturally-occurring hot ponds at Yellowstone National Park and man-made hot cooling ponds at Savannah River National Laboratory as well as spray ponds at various industrial facilities.

The proof experiment has provided data that illustrate the effectiveness of the instrumentation system and also that display interesting site-specific heat transfer processes. The data to be obtained in the field will also be site specific but must be of generic applicability in modeling for design and performance purposes. The integrated instrumentation system will evolve, through modest modifications and substantial supplementation, to provide the requisite data for the more demanding situation of work in and about hot water.

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2. INTRODUCTION

The purpose of the research reported here is to develop approaches for determining the thermal performance of hot cooling ponds and fixed spray ponds that are proposed to be used as ultimate heat sinks in nuclear power plant emergency core cooling systems. The need is derived from the concern that certain elements of the performance are unknown and that information is required for proper design and the design of performance tests to meet the Nuclear Regulatory Commission criteria. Data, site-specific, but of generic applicability, are required for useful modeling directed toward the specification of design and of performance prediction.

Ultimate heat sinks for active emergency cooling systems are not available for study so analogs must be identified for actual measurement programs. These include either naturally-occurring or man-made genuinely hot bodies of water as analogs of nuclear facility cooling ponds and spray ponds at various industrial or power facilities.

Measurement and study programs on these analogs require care and experience in staging and implementation. The requisite expertise is acquired through preliminary measurement effort at a site of convenience so that the field programs may be accomplished with expectation of success.

The research reported here is in response to these criteria and ideas. The remainder of the report includes a description of several accomplished and relevant activities:

- . identification of proper sites and facilities for field measurement programs on analog systems
- . proof-test of an integrated instrumentation system applied to a low-thermal load spray cooling pond

- . analysis of the proof-test data to enable understanding of some aspects of site-specific heat transfer processes
- . identification, through experience and expectation, of instrumentation modification and supplementation required for application to genuinely hot water and the severely-modified atmosphere above.

3. CONCLUSIONS

Completion of the proof experiment, test of the instrumentation system, and identification of suitable sites to be proposed for field experiments, has incorporated and yielded the following conclusions:

- . hot ponds at Yellowstone National Park are proper sites for, at least, a preliminary field measurement program.
- . hot ponds at Savannah River Laboratory are proper sites for following measurement programs if the YNP ponds are found to be inappropriate for further, season-oriented effort.
- . spray ponds at reactor facilities are scarce (many are proposed) and coincidence of spray operation with measurement system availability is doubtful. Further consideration must be given to the identification of routinely-operated spray ponds at other industrial or power facilities as analogs proper for field study.
- . the integrated instrumentation system adequately assesses the low-thermal load BNW spray pond (Figure 1).
- . the integrated instrumentation system requires modest modification and substantial supplementations in view of expected more demanding conditions in and around the vicinity of genuinely hot ponds.

4. SITE SURVEY AND SELECTION

This section is concerned with the identification of candidate sites for field experiments. The measurement programs at these sites shall lead to data volumes relevant to the assessment and prediction of the thermal performance of ultimate heat sinks at nuclear reactors. These sinks provide two principal safety functions stated in the U.S. Nuclear Regulatory Commission Regulatory Guide 1.27, Revision 2 (January 1976) - Ultimate Heat Sink for Nuclear Power Plants. The safety functions are:

- (1) dissipation of residual heat after reactor shutdown and
- (2) dissipation of residual heat after an accident.

Neither of these conditions can usefully be predicted so to be ready with an integrated instrumentation system for measurement on the actual heat sink. Further, especially for the latter case, a measurement program would be impractical because of inconveniences, in particular in consideration of safety aspects. For these reasons, the data to be obtained should be derived from study of experimental analogs. The analog sites must share the characteristic of the presence of large amounts of genuinely hot water if a cooling pond is under scrutiny. For a spray pond, in the absence of a genuinely large heat load, an analog may be achieved for the situation of heat transfer to a relatively cold atmosphere - heat transfer processes more strongly depend on temperature differences than on absolute temperatures.

The NRC Regulatory Guide 1.27 further states:

- The meteorological conditions resulting in maximum evaporation and drift losses should be the worst 30-day average combination of controlling parameters (e.g., dew-point depression, wind speed, solar radiation). The meteorological conditions resulting in minimum water

cooling should be the worst combination of controlling parameters, including diurnal variations where appropriate, for the critical time period(s) unique to the specific design of the sink -

Further,

- The meteorological conditions considered in the design of the sink should be selected with respect to the controlling parameters and critical time periods unique to the specific design of the sink -
- Consider a cooling pond as the sink when the pond temperature may reach a maximum in 5 days following a shutdown. This maximum temperature should coincide with the most severe combination of controlling meteorological parameters for a 1-day period. Therefore, three critical time periods should be considered: 5 days, 1 day, and 30 days (to ensure the availability of a 30-day cooling supply). These three periods need not occur contiguously. They may be combined, however, in the indicated order to produce a synthetic 36-day period which may be used as the design basis for the pond. Alternatively, the worst 36-day consecutive-day period from historical climatological data may be used as the design basis. This period may or may not include the worst 5-day, 1-day, or 30-day period -

Numerical modeling is the useful evaluation tool required to take into account the above mentioned performance criteria and the relevant meteorological and in-water conditions as well as specific plant parameters. The ultimate objective is to produce a generic numerical model which can be modified to fit a specific facility. A viable model fundamentally requires real data, the data will be provided through the field experiments or analog sites.

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Genuinely hot ponds as analogs to ultimate heat sinks are available for study in two categories, i.e., naturally-occurring ponds such as those at Yellowstone National Park (YNP) and man-made ponds at nuclear facilities such as those at the Savannah River National Laboratory (SRL). Spray ponds exist as heat sinks at some nuclear facilities and might be available for study as low temperature analogs to ultimate heat sinks if active.

BNW personnel have assessed characteristics of candidate sites for measurement purposes. This has been accomplished through on-site visits at YNP and SRL for cooling pond analogs and through a literature search, primarily of PSAR's and SAR's, to identify spray pond facilities.

4.1 Hot Ponds at Yellowstone National Park

BNW will assess the heat exchange characteristics of naturally-occurring hot ponds at Yellowstone National Park some time during the months of April-May 1977. The YNP is a site of convenience for the first field experiment, advantages include relatively small logistics requirements in addition to the existence of hot ponds suitable for assessment. Some disadvantage is involved with the expectation that difficulty with a survey of water flows, to include density currents, will be encountered. The experiment on YNP hot ponds will result in useful data and will serve also as a final proof test of instrumentation systems in a hot environment. BNW will propose to accomplish this experiment as required to the National Park Service.

The Park is illustrated on the map in Figure 2 with the hot ponds of interest located in the Midway Group and Firehole River area between Madison and Old Faithful. Various photographs of relevant hot pond features are depicted in Figures 3-5. Quantitative information has been derived, primarily

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through examination of the literature available at the YNP research library and through personal contacts with YNP personnel. The quantitative data for two hot ponds appear in Table 1, Grand Prismatic and Hot Lake are the sites which will be proposed for study to the National Park Service.

These hot bodies of water are sufficiently interesting analogs to hot cooling ponds that both should be studied with the integrated instrumentation system. BNW anticipates approximately 2 weeks of work at Grand Prismatic to be followed after a one-week break, by a one-week effort at Hot Lake. The results of these studies may be sufficiently valuable that a second experimental measurement program will be conducted during the warmer months of July and August. In this way, aspects of the seasonal dependence on heat transfer processes will be assessed. Further, heat transfer to the atmosphere should be at a minimum under summertime conditions and this analog to severe heat loading must be examined. A third YNP measurement program should be conducted during the winter (FY 1978) in order to complete the comparative seasonal assessment.

4.2 Hot Ponds at Savannah River Laboratory

In the event that the first measurement program at YNP should establish that the ponds there are unsatisfactory for further measurement, BNW will assess heat exchange characteristics of man-made hot ponds at Savannah River National Laboratory. This will occur during the months of July-August 1977 so as to take advantage of the hot, moist atmospheric conditions which are representative of relative inefficiency in heat transfer from water to air. An advantage with the Savannah River ponds is that assessment of the water temperatures and flows, including density currents, is partially complete through efforts conducted during the summer of 1976 by Savannah River personnel. Further, some aspects of the heat loading are understood and, in part, available for use by BNW. The Yellowstone experience

would assist in reducing logistics uncertainties at Savannah River, located across the continent from BNW. A proposal to accomplish this experiment will be directed to SRL. It is appropriate that both the YNP and SRL proposals be submitted prior to January 1, 1977; the implementation of the SRL proposal, as discussed, will be contingent on early findings at YNP.

The SRL is illustrated on the map in Figure 6. The hot ponds of interest are located to the Southeast of the 100-R reactor and are named Ponds 1 and 2, bisected by a road, and connected through a culvert. These ponds are part of a larger circulation system including Par (P and R) Pond and inter-connecting genuinely hot streams. Figures 7 and 8 illustrate a pond portion and a hot stream and in both cases "steam" rising from the surface partially obscures the view. Ponds 1 and 2 have a depth of approximately 1.5 meters and are 4-5 acres in area. One is active in the sense of being directly in the larger-scale circulation while the culvert-connected pond is "dead", responding to conditions imposed on it through density currents established in the culvert. Temperatures in the streams range as high as 80°C, the pond temperatures are more characteristically in the range 30-60°C.

4.3 Spray Ponds

BNW intends to assess the heat exchange characteristics of a spray pond while it experiences a large heat load. The already-accomplished proof experiment has established the adequacy of an integrated instrument system in establishing mass and thermal exchanges and balances for a small spray pond experiencing a small heat load. The system is transferable to a larger spray system. The analog experimental site will evidently be that of a heat exchanger for routine cooling and may be an installation at a nuclear power plant. In anticipation of at least two major field efforts during FY 1977 on hot ponds without sprays, BNW will propose to accomplish measurement

programs on spray ponds during FY 1978. The proposal will be made for the spray pond effort in the Quarterly Report due April 1, 1977.

BNW personnel have partially completed a survey of the available literature for ultimate heat sink types at existing and proposed nuclear power plants. This information will be utilized in making selections of two spray facilities for the proposed measurement programs in FY 1978. The number of existing spray facilities is small, but many are proposed for future power plants. Further, the likelihood of encountering operating sprays is small. These two factors require attention, in the specification of candidate sites, to other spray systems, i.e., those at fossil fuel power plants and at other industrial installations.

5. THE PROOF EXPERIMENT

This section is concerned with the design, implementation, and analysis of a proof-measurement program. The primary intent has been to proof-test an integrated instrumentation system and, secondly, to acquire data to accomplish both a portion of the proof and a semi-quantitative assessment of some of the more interesting thermal characteristics of a small low-load spray pond. Conveniently, these objectives have been accomplished in a BNW fixed-spray pond which, while experiencing a small heat load, serves as the heat sink for office and laboratory building air-conditioning systems.

5.1 Motivation

The accomplishment of successful field programs is dependent on proper staging including attention given to objectives and aspects of logistics, experiment design, instrumentation integration and function, and the choice of involved personnel. Evidence that this array of inputs will efficiently work in the field, away from the staging site, is obtained through a trial run - a proof experiment. The properly-designed proof experiment may also produce data and ideas of specific relevance to the objectives defined for the field experiments to follow. If, then, the opportunity is available for system proof, the field programs may be approached with enthusiasm and with expectation of success. The further benefit to be derived from the proof experiment is the identification, through actual experience, of system deficiencies, their correction, and a view toward extra potential in data information content.

System proof in a framework of heat transfer, rather than in consideration of possible environmental effects, is the main objective. The purpose of continuing research is to determine the thermal performance of thermally hot cooling ponds and fixed spray ponds to be used as ultimate heat sinks in emergency core

cooling systems. Such real systems are not available for study so the selection of suitable analogs is required. The analogs may include naturally-occurring and man-made hot ponds and spray ponds which transfer heat to a relatively cold atmosphere, thereby simulating substantial convective activity. It is necessary then, that the integrated instrumentation system, applied in the proof experiment, be capable of performing at elevated pond temperatures and be useful for the assessment of the potentially significant effects of sprays. Attention has been given to these criteria as well as to all other more general aspects of the heat transfer problem. Considerable working experience in and about the pond water has been obtained. The proof pond is, of course, not hot - procedures for field experiments must be modified accordingly and certain subsets of instruments will necessarily be modified and supplemented for work in and about genuinely hot water.

5.2 Description

5.2.1 Geometry and Pumping

The proof pond is one of three interconnected shallow bodies of water. Together, these ponds serve as the heat sink for air-conditioning systems in several buildings of the main BNW laboratory and office complex at Richland, Washington. A further spray pond function is that of decoration; the ponds experience only a small heat load. Operational procedures are available to ensure that mean pond water temperature does not exceed approximately 24°C.

The proof pond is illustrated schematically in Figure 9. The depth is nominally 0.56 meters and the longest (North-South) dimension is 55 meters. Nominal water volume is $1.1 \cdot 10^6$ liters with $2.1 \cdot 10^3$ square meter surface area. All walls and the floor of the pond are of sealed concrete construction and seepage is nil. The water surface is characteristically 0.25 meter below the level of the surrounding concrete sidewalk.

On the South end, open gravity-flow pipes connect to another small pond (South pond) of the same nominal depth. To the West, similar connection is made to the third pond (West pond) somewhat larger but of only 0.25 meter depth. Water flows between ponds as required in the maintenance of common surface level.

Aside from the interconnecting gravity flows, water moves in and out of the ponds in response to three separate types of pumping systems. First, water is removed from the proof pond at the south (spray) sump, brought through pumps located in one of the adjacent buildings, and thence returned to the ponds through the sprays. A complication is implicit in this because a sump for sprays also exists in the west pond and this water is then moved by the same series of spray pumps. The spray water is returned to all three of the ponds. This peculiar interconnection, deriving from add-on construction, makes it impossible to directly know the ultimate destination of a (mixed) parcel of water. However, for purposes of mass and thermal budget considerations, the requisite information can be obtained through a combination of measurements and known plant parameters. Secondly, a totally separate pumping system obtains water from the north (condenser) sump and directs this water through air conditioner condenser heat exchangers in another building. The warmed water returns to the proof pond and the south pond in unequal but measurable amounts. A similar system operates totally within the west pond. Note that the spray water does not directly encounter warming by condenser heat exchangers. Thirdly, essentially unmodified Columbia River water is introduced to the proof pond near the north sump. The water is automatically pumped through research-program fish tanks in one of the buildings and into the pond on a schedule which depends on biological requirements. However, the river water is relatively cool and provides makeup for evaporation and drift as well as direct pond cooling if required at times

of thermal stress. In this latter case, provision is available for increasing the pumping beyond that of the automatic mode; if excessive river water is introduced, pond level is maintained through outflow via a stand-pipe. This situation was not encountered during proof measurement episodes. The cool river water, in part, immediately leaves the proof pond through the condenser sump for efficient condenser cooling. Often, the condenser system is operated in the absence of a thermal requirement for spray operation. All spray operation is under manual control on demand based on opinion.

5.2.2 Spray System

Two main groups of sprays exist in the proof pond. Figure 9 shows the large group of 12 clusters each consisting of five nozzles arranged on a circle of 2.5 meter diameter. In addition, two similar clusters are located near the south end of the pond. The 70 nozzles in the proof pond are supplemented by 140 more nozzles in the other ponds. The 210 nozzles share water from two sumps and the sprays for all of them are driven by common pumps.

When active, sprays disturb approximately half the surface of the proof pond. The nozzles are of a simple brass pipe - elbow configuration. This is partially illustrated in Figure 10. The simple shape is not a result of attention to producing any special type of spray pattern. Characteristically, the spray drops rise to a maximum height about two meters above the pond surface and most of the larger drops are thrown to a distance of about two meters from the nozzles. Because of the proximity of adjacent nozzles, considerable spray interference occurs. Smaller drops tend to fall back to the pond surface closer to the nozzles. Figures 11 and 12 give indication of some of these characteristics. For appearance comparison, Figures 12 and 1 are the same with sprays on, the other with sprays off. Sprays were turned on and off as measurements required.

The spray system is intended to provide requisite water cooling when the ponds experience a maximum thermal loading as a result primarily of solar radiation and condenser heat exchange. Various degrees of cooling efficiency occur; dependent on ambient meteorological conditions, the efficiency may become very small or even negative. This latter (only decorative but perhaps intrinsically humorous) situation can be offset at times of thermal stress through replacement of pond water by cool river water.

5.2.3 Proof Pond Isolation

The proof pond may be studied for mass and thermal budgets as well as other heat exchange properties as if essentially isolated from the other ponds. Where the other ponds influence the behavior of the proof pond, these influences are measured. The primary influence is the water flow, in response to gravity, from pond to pond. The flows and temperatures are both measured and the south and west ponds are found to usually exist at temperatures higher than that of the proof pond. The west pond is very shallow and responds rapidly to daytime radiative loading. The very small south pond experiences a portion of the condenser thermal loading from one of the major office and laboratory buildings. Another peripheral pond influence is the effect on the air flowing over the proof pond, its temperature and moisture character in the first few meters above sidewalk level.

Buildings adjacent to the proof pond provide obstacles and modifications to air flow over the proof pond, and, in fact, shade the pond in the early morning hours. The west tower (Figure 9) instrumentation provides temperature and wind data which especially reflect the influence of an adjacent building rising to about 15 meters above sidewalk level.

These various influences on proof pond measurement data are accepted as "a fact of life" and are given attention in

data examination and interpretation. It is not the intent of the proof experiment to attempt an idealized study in the spirit of, say, classical boundary layer studies. No effort has been devoted to the production of an idealized situation; rather, measurements have been made on what actually exists without choice or modification.

5.3 The Integrated Instrumentation System

The proof pond experiences a small heat load, however it is complex in the array and interconnection of water inlets and outlets. The instrumentation system integrated for proof pond study was, for the former reason, simplified by the fact that the pond is shallow. This implies the absence of substantial temperature stratification; the pond remains rather well-mixed and semi-permanent density currents are absent. Further, modification by the pond of the air above is small and instrumentation specific to the details of convective activity above the pond was not deployed. Considerable attention, however, was given to the measurement of inflow and outflow along with corresponding temperatures so as to enable examination of water mass and thermal budgets. Field experiments shall require some modification of existing systems and substantial additions because of more demanding circumstances of genuinely hot water per se and its thermal interaction with the relatively deep atmosphere above. The modifications and additions are well-defined and are discussed in Section 6.

5.3.1 Water Flow and Temperature Sensors

All proof pond inlet and outlet pipes were fitted with flowmeters which enabled, through manual reading at appropriate intervals, information of total volume flow through pipes over measured time durations. The flowmeters were designed for biological oceanographic work and are illustrated schematically in Figure 13. Also in this figure is shown the smooth,

large-diameter plastic irrigation pipe within which was mounted the meter. Mounted at pipe center, the small meter responds, through turning of the propeller, to water flow. The pipe is sufficiently large in diameter and the water flow is sufficiently rapid to produce a Reynolds number large enough to allow simple calibration procedures. The plastic pipes were butted and sealed against pipe ends at the pond walls. The meters were located to sense water flow representative of that through a long, straight pipe. The propeller turns an indicating counter which was read at appropriate intervals through a small clear plastic window.

Each of the flowmeter pipes was equipped with a water-proofed thermistor bead which provided temperature information and was recorded continuously during intensive periods of data acquisition. The temperature and flow data were found to be smooth in time which then allowed intermittent flow readings and later, useful time-averaging of both data sets.

At two locations in the proof pond, one in the quiet water and the other in water with its surface disturbed by spray, temperature was continuously acquired at two levels. With temperature determination within one centimeter of the pond bottom and of the pond surface at each of these locations, and, with supplementation by temperature available at several other pond locations, pond mean temperatures were deduced.

Both sumps in the proof pond were similarly fitted with bead thermistors. The north (condenser) sump did not require flow determination since all the water drawn through it necessarily appeared at the proof pond and south pond condenser water inlets. These inlets were measured with the flowmeters previously described. The south (spray) sump could not be similarly assessed because of its system interconnection. A plywood flume was constructed to require all flow into the sump

to be smoothly directed through it. The flume flow was then assessed by obtaining flowmeter measurements at several locations over the flow cross-section. Figure 14 shows the flume being placed in position and in position against screening surrounding the sump intake. Plastic sheeting was placed around the screen to prevent water from entering the sump except through the flume.

5.3.2 Air Flow and Temperature Sensors

Three micrometeorological towers, six meters in height were erected at convenient locations (Figure 9) on the sidewalk surrounding the proof pond. Each tower was instrumented at three logarithmically-spaced levels, for some data acquisition at 1.5, 3, and 6 meters and for other data runs at 0.75, 1.5, and 3 meters. The west tower is shown in Figure 15 with the top level of instrumentation at 6 meters. Each level of sensors consisted of a three-component wind speed anemometer and dry bulb and wet bulb thermistors as shown in Figure 16. Solar and long-wave radiation was prevented from affecting the thermistor data by a shield constructed from nested small diameter plastic irrigation pipe. Aspiration was accomplished with a small fan downstream from the wet bulb and dry bulb thermistors.

5.3.3 Air-Water Interface and Spray Sensors

An infrared radiometer was utilized to obtain water surface temperature at various locations in and about the pond. This hand-held instrument was not a primary data source. The information obtained was used solely for comparison with thermistor data.

The water leaving the nozzles to produce sprays was temperature-measured by thermistors in contact with the brass spray nozzles and insulated from the surrounding air. Water flow through the nozzles was obtained from flow measurements made elsewhere in the spray pumping system.

The spray water was also measured for temperature at locations near the pond surface. Thermistors were mounted in small white plastic funnels placed on a towable float which could be moved from place to place in the spray pattern at the pond surface. The entire float and mounted equipment was designed to minimize unwanted effects of solar radiation. Figure 17 shows the float in position on the inactive pond.

5.3.4 Radiation Sensors

Net radiometers were used to assess, at all important wavelengths, the net radiation at a level 1.5 meters above the quiet water surface and 1.5 meters (approximate) above the sprays. In addition, pyranometers were used, in a net configuration, to assess the short-wave radiative contributions. Figure 18 shows some of this radiation equipment in place over the proof pond. In addition, an extra net radiometer was located away from the pond over a grass surface.

5.3.5 Drift Sensors

Fresh photographic film was horizontally exposed to drift droplets downwind from the proof pond on rare occasions when wind conditions produced discernable drift. Only the larger droplets, diameter larger than about 25 micrometers, make impressions on the film; this is not a result of any failure of the film technique, but because smaller droplets evaporate, relatively because of large surface to volume ratio, before reaching any sensor in the ambient air. The use of a commercially available droplet size spectrometer, with size capability from 0.5 micrometer up, assisted in this conclusion - it has not been possible to quantitatively distinguish between background levels of aerosols and particles on the one hand and drift droplets on the other with this device.

The film technique incorporates the exposure of a series of film plates arranged on a line downwind from the sprays.

Realistic gradients of number populations for several diameter size ranges have been obtained.

5.3.6 Signal Handling and Recording

All data have been recorded digitally on incremental computer-compatible magnetic tape with the exception of the flowmeter data and the drift results. The bulk of the data are then precisely time-registered with respect to each other, a necessary criterion if, for example, eddy-flux computations were to be useful or required. For the proof experiment per se such computations are not useful because the low-load pond does not exhibit sufficiently interesting behavior. However, it is anticipated that the field experiments on genuinely hot ponds will require this capability. The radiation data have also simultaneously been recorded on strip-charts.

The digital entries on magnetic tape are representative only of voltages. Signal conditioning for conversion to engineering units is not required because of the need for computer handling anyway; further, the likelihood for inaccuracy in results increases with increasing electronic circuitry. The voltages representative of meteorological and water parameters may all be recorded in one second of time with immediate repeat scans continuously. Flexibility is available through switch-selectable intervals between scans ranging from one second through several values to one hour. The total number of recording channels available is 75 which is sufficient for the proof experiment and for the field experiments. Figure 19 is a photograph of the display, digitizing, and recording equipment. Visual display is available for any desired input channel on command and auxiliary display is also available, for any channel, on an accurate and calibrated digital voltmeter for check purposes during and before data acquisition runs.

5.4 System and Sensor Characteristics and Calibration

Where appropriate and possible, sensors and systems were calibrated in laboratory circumstances. Some calibration procedures involved comparison against National Bureau of Standards (NBS) - traceable items. Other procedures involved comparisons for internal system consistency and performance. During the period of data acquisition runs, attention was given to the maintenance of system stability and comparison checks. Table 2 includes a schedule of calibration activity. A system of Quality Assurance documentation for calibration and other program elements including personnel, procedures, and peer review has been established.

5.4.1 Flowmeters

The flowmeter counter increases by 10 counts per propeller revolution and the propeller rate increases linearly with water speed above a threshold of 10 centimeters per second (less than the flows measured in the proof experiments) in the range up to 7.9 meters per second. The manufacturer provides a general calibration curve in this range which was used for data analysis in the proof experiment. Reliance on the provided calibration was established through an additional calibration procedure. Flows in the pipes containing the centered flowmeters, for the proof experiment, were sufficiently large to produce Reynolds numbers in the range 10^4 to 10^6 , an indication of developed turbulence with characteristic dimension on the order of centimeters or less. For this condition, the meter is removed from direct wall influence and flow measurement at the pipe center is representative of flow across the pipe cross-section. The boundary layer is thin and no strong time-averaged speed profile exists along a pipe diameter. The question remains concerning representativeness of the flowmeter measurement and its accuracy (correspondence with manufacturer's calibration). The quiet proof pond was used

as a tow tank during an interval when the spray and condenser pumps were turned off. A pipe, with an internally-mounted flowmeter, and mounted on a wheeled cart, was towed along the smooth bottom. The course was 30 meters long and the towing was accomplished in times ranging from 25 to 90 seconds. Both directions were run with the flowmeter located at the 3/4 point along pipe length. For flow through the longer end to the meter, no displacement of the results from the manufacturer's calibration was noted. An approximate (constant) 7.5 centimeter per second decrease from the manufacturer's calibration was discovered for the case of water entering the pipe from the short end. The meter, of course was running backwards; in the proof experiment all inlets and outlets run in the same direction at all times. Several more runs were made with induced large-scale turbulence on the order of 10's of centimeters characteristic dimension. This was done by towing the tube in the wake of the person pulling it. In this case, departures of up to 30 centimeters per second were found. For the cases of proper orientation of pipe and meter, the maximum departure of manufacturer's calibration and experimentally-determined results, was 9%. It was concluded that the flowmeters provide accurate and representative measures of pipe flow (for large Reynolds numbers) as well as for flow in an open channel.

5.4.2 Sump Flume

Measurements were made, using a previously described flowmeter, in the constructed flume to enable assessment of flow into the south (spray) sump. Fifteen locations were chosen in a cross-section near the screen and approximately 1 meter by 0.56 meter in dimension. The results for two data acquisition runs were separately averaged for computations and the results were both within 10% of the value of 208 liters per second deduced, with assumptions, for sump flow from plant parameters. Assumptions were that the south sump and the sump

in the west pond were drawing equally and that the pumps were operating at rated capacity. It was concluded that the sump flow assessment was accurate and representative and that the values near 208 liters per second should be used in all further considerations.

5.4.3 All Thermistors

The same type of bead thermistor was deployed for all pond and wet bulb and dry bulb temperatures. The voltage versus temperature characteristic is given in Figure 20 for the very simple electrical configuration also illustrated there. The curve is very nearly linear, and for periods on the order of minutes or 10's of minutes, in the absence of large temperature excursions, the voltages, rather than the temperatures, may be computer-averaged.

All pond thermistors were water-proofed when attached to cables and tested in a precision temperature-controlled bath. Among those to be used in the proof experiment, only one was found to differ from the rest by more than 0.1°C over the range 10 to 40°C . This one was discarded and the remainder were checked, in the bath against NBS-traceable thermometers, and found to agree within 0.1°C . Several thermistors of equal performance were prepared as spares.

The spray temperatures obtained by the thermistor-equipped float were checked for representativeness by obtaining early-morning data prior to any possible solar radiation influence. The data showed that no discernable effect of solar radiation occurred for midday conditions. The thermistors were located in white plastic funnel throats constricted so as to require a continual flow of spray water past the thermistor but not to cause substantial water back-up in the funnel.

Wet bulb (water proofed) and dry bulb thermistors were checked against each other (the wet bulb in dry condition) and

against NBS-traceable thermometers, after being mounted in the in-house constructed aspirated shields. This was accomplished in quiet laboratory air, inside a large box to minimize perturbations. All agreement was within 0.2°C . This information was not as easily obtained as it was for a stable liquid bath.

The time constant for the bead thermistor is on the order of one second in air moving in excess of 1 meter per second. The water-proofed and wet-wicked thermistors exhibit time constants on the order of 10 seconds. It was concluded that the thermistors provide accurate measurements of air and water temperature.

The wet wicked thermistors were checked for output against a calibrated aspirated thermistor psychrometer after installation and wetting with distilled water at the proof pond. The correspondence between these devices was within 0.3°C over intervals of a few minutes for instantaneous values.

Radiation shields were checked for performance through a procedure of alternate shading and exposure to direct sunlight under severe conditions - sun high in the sky and reflection from a shiny surface below. With aspiration, no periodicity could be detected in the resulting trend-removed data. Without aspiration, of course, the results were totally unacceptable. It was concluded that the thermistors provide representative as well as accurate temperature information, sufficient for considering logarithmically-spaced temperature profiles over six meters.

5.4.4 Wind Speed Anemometers

The instruments used were three-component propellers mounted orthogonally to each other as shown in Figures 15 and 16. These are used at BNW in a variety of projects. Prior to the proof experiment they were cleaned and all bearings were replaced. Wind tunnel tests were not performed but the small

DC generators were driven with a synchronous motor and found to be satisfactory. These devices have characteristics of response, threshold, and distance constant which are of such quality to make them acceptable as sensors for data to be utilized in turbulence studies. This assertion assumes achieving proper exposure for the sensors. In the proof experiment the wind sensors were deployed only for mean wind information and profiles. The wind direction, of course, may be deduced from the three orthogonal speed components. It was concluded that the wind sensors provide adequately accurate and representative wind information.

5.4.5 Net Radiometers and Pyranometers

The radiometers were checked against each other for common conditions of exposure and calibrated against the pyranometers utilizing standard techniques. The results were consistent with expectation and it was concluded that these devices provide accurate and representative measurements of radiation.

5.4.6 Drift Sensors

Kodak Professional Line Copy film was exposed to drift droplets and images were permanently recorded as colored spots on an otherwise undisturbed film. As mentioned previously, droplets were assessed for diameters ranging from about 25 micrometers on up in size to about 200 micrometers. For the meteorological conditions available, no larger droplets were observed and evaporation apparently prevented the assessment of smaller droplets. The spots on the film were counted for film areas established prior to exposure through examination by measurement under a microscope. The film spot size does not correspond with the actual droplet size; a laboratory procedure of calibration, incorporating the trapping of liquid water drops in silicone oil, established an approximate ratio of 2 for spot size versus droplet size. It was concluded that this technique of exposure, calibration, and analysis is adequately accurate and representative for droplets in the size range specified.

5.4.7 Data Digitizing and Recording

The signal handling and recording equipment was tested and adjusted to correspond with NBS-traceable laboratory standards. It was concluded that the equipment provides accurate representation of sensor signals.

5.5 Measurement Program Schedule

The bulk of the data acquisition was accomplished through a series of data runs during which nearly all of the instrumentation systems were functioning simultaneously. Those data runs ranged in duration from about 2 hours to 24 hours during August and September 1976. The intent was to produce assessment of all reasonably possible physical and meteorological processes and to establish simultaneous time-series of data from which processes of interest could be extracted and examined. Table 2 includes a schedule of the main periods of intensive observation.

A first procedure involved relatively short runs of 2-3 hours duration in order to establish the usefulness of the integrated instrumentation system in verification of mass and thermal budgets for short (5 minute) intervals. It was anticipated that, for short intervals, the proof pond should exhibit essentially steady-state conditions for mass balance, since the pond surface does not rise nor fall appreciably on any time scale. The mean pond temperature may change, however, by an order of Celsius degrees over periods of tens of minutes or hours. A relatively severe test of the pond instrumentation, then, is accomplished through comparison of data analysis results with expected results.

Secondly, after the previously described requirement had been met, the information available led to an intent to acquire data over periods of 24 hours. For these runs, incorporation of the effects of diurnal variation as well as the condition of sprays on versus sprays off, were considered of interest.

It was not convenient, nor realistic, to acquire manual readings of the flowmeters during these long runs.

Interspersed at various times, among the major data runs, were special data acquisition efforts. These were designed to provide additional information, i.e., temperature distribution in the spray patterns at the pond surface and some assessment of drift characteristics.

5.6 Measurement Results

5.6.1 Mass Balance

The severe test of accuracy and representativeness in the data produced by the various flowmeters (Figure 21) is obtained through calculations which should result in evidence of the proof pond water mass balance. This analysis has been performed on data from several experiment runs, two of these, representative of all, are discussed here. Tables 3 and 4 list the calculation results for a daytime and a nighttime run during spray operation. All flows into the proof pond have been summarized and compared to the total outflow for a 5-minute period during which the flows were quite constant. The residuals, which may represent loss from the pond through evaporation and drift, are small. This is in accordance with expected results for this short time interval. They are also small by comparison with most of the individual inflows and outflows. There is a potential invalidity with the addition and subtraction of large numbers to obtain a residual, which even though small, is intended to retain physical significance. However, it may be concluded that small residuals have significance relative to flowmeter accuracy and representativeness because of their correspondence with expected results. The pond surface was not observed to rise nor fall during the data acquisition runs. The larger of the two residuals corresponds to a potential pond surface fall of 0.25 centimeters in five minutes, therefore, the small residuals are considered significant with respect to the instrumentation capability.

5.6.2 Thermal Budget

The heat inputs and outputs (Figure 22) may be calculated from the mass flow data and the temperature, relative to mean pond temperature, measured at various locations throughout the water. A useful pond mean temperature is established as a reference through averaging of many water temperatures. In addition, the net radiometer data establish thermal interaction between pond and surroundings through radiative transfer. Tables 3 and 4 also list the results of calculation with respect to the thermal budget for both a daytime and nighttime run. The residuals here are not small; this is in accordance with expectation since there exists a trend in the pond mean temperature during the day and during the night.

The large residual in the daytime data implies proof pond heating of 0.21°C over the 5-minute period which is consistent with the longer time-scale observation of the mean pond temperature trend during the early afternoon. Note that solar radiation and warm condenser water are the two largest contributors to pond warming as expected. Further, however, the spray water is heating, rather than cooling, in its transit through the air. Mean spray heating, over the spray pattern is approximately 0.9°C . This unusual circumstance is apparently attributable to a combination of influences including small wet bulb depression, high ambient air temperature and intense radiative loading. The wind speed is sufficient to locally purge the spray volume of very moist air, however, relatively severe ambient conditions prevent substantial evaporative cooling of the drops. It is possible that this condition is reflected in the small mass balance residual for evaporation and drift.

The nighttime thermal budget is quite different, here the spray droplets are cooling by 0.8°C as they pass through the relatively cool ambient air. The heat residual implies proof pond cooling in the amount of 0.06°C over the 5-minute period.

This observation is again consistent with the trend exhibited on longer time-scales. The spray cooling is seen to be the largest contributor to pond cooling.

The flowmeter, thermistor, and net radiometer data combine to provide results that are consistent as expected with other observations. The evidence (during only one experiment run) of spray heating is surprising, however the data accuracy and representativeness is such to enable assertion of the validity of the observation. It is concluded that spray operation may become purely decorative for conditions of small wet bulb depression, high ambient temperature, and intense solar loading. The data obtained on 8/30/76 (Table 2) show spray cooling of 2.8°C , and the wet bulb depression is 8°C .

5.6.3 Temperature Profiles

The proof pond thermally affects the air over it primarily as a result of spray-air interaction. The effects of the quiet pond on the air are less. Moisture is added to the air through evaporation and the heat required to produce the evaporation is extracted from the ambient air and is provided, as well, by radiation especially during daytime hours. The affected air is expected to be confined to the first few meters in height above the pond. Thermal loading of the pond is quite small. The pond mean temperature may at times be as much as 20°C lower than the ambient air temperature but rarely is excess of the air temperature. The existence of interesting pond-induced thermal structure in the air above is, therefore, doubted. Excess pond temperature would occur during early evening hours or shortly after the passage of an atmospheric cold front.

Temperature profiles from the three 6-meter meteorological towers are exhibited in Figures 23 and 24. Note that three of the four charts are for instrumentation placed at the 6, 3, and 1.5 meter levels above the sidewalks. The fourth set of

profiles is for the 3, 1.5, and 0.75 meter levels, which were taken after realization that most of the thermal influence occurs close to pond surface. Comparison of temperature profiles for sprays on and off is contained in Figure 23. The averaged wind is similar in both cases and the north tower experiences the major thermal effect of the pond with wind essentially from the south. With sprays on, the bottom temperature on this tower decreases as expected. This is also true, to a lesser extent, for the south tower. For both towers, the bottom wet bulb temperature is increased, again as expected. Effects are small at the upper two levels. The west tower exhibits, for both wet bulb and dry bulb temperatures, the influence of the west pond which exists at elevated temperature with respect to the proof pond. The elevated wet bulb at three meters on the west tower has been determined to be an accurate measurement. Apparently, moist air lifts from the west pond surface level before it intercepts the west tower. West tower measurements are further greatly influenced by the proximity of a tall building. Wind data show large departures in flow through the west tower by comparison with the flow at the north and south towers.

A comparison for general day and night conditions is presented in Figure 24. The wind conditions are not similar for the two cases but the profiles, however, are in agreement as expected in both cases. The nighttime dry bulb profiles show temperature decrease with height with some evidence of the pond further cooling the air at the north tower bottom level. Moisture is enhanced at the bottom levels on the north and south towers and, again, the west tower experiences west pond and building effects (the wind for this nighttime case is somewhat similar to that for the two previously discussed cases).

The daytime situation in Figure 24 is quite different, primarily due to the different wind situation. Here the west

tower is expected to exhibit the displayed dry bulb decrease at the bottom level (0.75 meters). Moisture enhancement at the lower levels for the north and south towers is primarily attributable to flow off the pond as well as from nearby irrigated fields. The west tower does not substantially experience building effect but is influenced at all levels, now, by the proof pond sprays.

The tower instrumentation has produced data which are in alignment with expected results and are of sufficient quality to enable detailed calculations if required or appropriate.

5.6.4 Diurnal Data Runs

All components of the integrated instrumentation system, with the exception of drift sensors and flowmeters, were operated continuously to provide a view of changing influences and pond parameters. Both sets of data presented in Figures 25 and 26 were obtained under clear sky conditions for maximum conditions of radiative exchange. The first case is for continuous operation of the sprays, the second contains only an 8-hour interval of spray operation for comparison purposes. The two cases are not strictly comparable since the general weather conditions were quite different.

Figure 25 illustrates various temperature and wind data plotted versus time as half-hour averages, for the hours through the diurnal cycle. The cycle contains an afternoon of high ambient temperature combined with substantial wet bulb depression ($\sim 10^{\circ}\text{C}$). This large value is the primary influence on substantial spray cooling of approximately 3°C , during the afternoon. The spray cooling is delineated by shading between the nozzle temperature and float (spray) temperature traces. It is seen that the spray water closely approaches the wet bulb temperature. The mean pond temperature and the nozzle temperature are essentially the same throughout the cycle. River water enters the proof pond at a lower temperature than

that of the mean pond at all times and the condenser water is always warmer than the mean pond. The bumps on some of the lines are due to the influence of nearby automatic irrigation sprays, (note that even the spray temperature is affected). Even though spray cooling is small during the morning hours, pond cooling occurs as a result of spray operation through the entire cycle.

A low-demand cycle is illustrated in Figure 26. Here the sprays are on only during the afternoon and early evening hours and the amount of spray cooling is relatively small, primarily because the wet bulb depression is only approximately 5°C. The cooling of spray water is only about 1°C at the most. The spray water temperature does not approach the wet bulb temperature.

5.6.5 Spray-Pattern Temperature

The spray is assessed for temperature near the proof pond surface with thermistors mounted in collecting funnels fixed to a towable float as shown in Figure 17. It may be located at any desired position with respect to a spray nozzle or spray cluster. Data have been collected to ascertain the variation of temperature in the spray pattern, and thereby the spray cooling, as well as to verify that solar radiation does not adversely affect the measurements. The spray clusters at the north end of the proof pond are schematically illustrated in Figure 27 as is a cluster where the 5 dots represent the location of 5 nozzles per cluster. Temperature data appear in the figure at locations, with respect to the clusters, where the measurements were made. The two data sets relative to the group of clusters are for meteorological conditions similar to those encountered during major data acquisition runs. Cooling of the spray water occurs in each case, and cooling is more substantial, in the interfering spray pattern, closer to the cluster. At the periphery of the pattern, when the larger drops fall to the water surface, the cooling is less.

Thermal exchanges produce less cooling in larger drops because of increased volume to surface area ratio.

The effect of interference is seen; where temperatures show that the cooling of the spray water is less between rows of clusters. This effect is likely a result of somewhat increased local wet bulb temperature in the interior of the spray field. Variations of cooling between corresponding locations is probably attributable to ventilation differences rather than variation among spray nozzle temperatures.

Also illustrated in Figure 27 are temperature data for a single cluster isolated from the rest only in the sense of the relative wind direction. It is established that maximum spray cooling occurs nearest the nozzles when the smallest droplets fall to the water surface.

Earlier sections of this report required spray cooling data as input to heat budget consideration. For those purposes, a mean cooling data base was established by locating the float at what appeared to be a location of mean cooling. The location chosen is consistent with the findings in this section.

5.6.6 Drift Determination

Only drift droplets in the diameter range from about 25 micrometers on up were assessed. As previously described, smaller droplets evaporate before reaching the film sensors. A droplet size spectrometer did not give data for smaller droplets for the same reason.

For mean wind speed in the range 0 to 3 meters per second, the film technique produces data suitable for calculations. The calculations showed less than 1 cubic centimeter per second leaving the pond. Some of the data are listed in Table 5. This small amount, for itself, cannot be of consequence in either a thermal or water budget consideration. The drift, which was believed to evaporate before reaching the sensors,

may be much larger in magnitude. This larger amount will not contribute substantially to the pond water thermal budget but could be important with respect to the mass budget. The evaporated drift can be assessed with air moisture sensors as evaporation.

It has not been possible to assess drift with the film technique under conditions of higher wind speeds. This is not a fault with the technique but rather with the absence of high winds during the times of experimental convenience. Visual observations at other times has shown considerable modification of spray patterns with the wetting of the sidewalks surrounding the proof pond.

The film technique is promising for future work - it displays an expected gradient in number population, for each size range, downwind from the pond. Further, it exhibits the expected gradient in number population for droplet size at a given location downwind from the pond.

5.6.7 Specific Measurement Conclusions

- . The integrated instrumentation system is capable of assessing each of the heat transfer components of consequence. This conclusion is based on calibration results and, significantly, on the achieving of mass balance and reasonable thermal budget, through data analysis, for cases of apparent nearly steady-state conditions.
- . For constant pond depth, the flowmeter and plant parameter data combine to produce the expected mass balance; accuracy and representativeness have been achieved in these measurements.
- . For constant mean pond temperature, the flowmeters, thermistor, and radiometer data combine to produce the expected thermal balance; accuracy and representativeness have been achieved in these measurements.

- . The heat load on the pond as a result of circulation of the water through the air conditioning heat exchangers is small, in fact comparable to the solar load during mid-day hours.
- . The spray water characteristically cools in the range 1 to 4°C, approaching the wet bulb temperature at times, in its transit from nozzle to pond surface. The amount of cooling is a strong function of the dry bulb versus wet bulb difference, a less strong function of dry bulb versus water temperature, and not related to wind speed in any obvious way except insofar as cooling efficiency decreases sharply for no wind at all. Winds of less than 1 meter per second is sufficient to purge the spray space of saturated air.
- . Cooling in the horizontal spray pattern is strongly dependent on radial distance from the nozzle. For wind in excess of approximately 1 meter per second, cooling is greatest near the nozzle and decreases out to the edge of the spray pattern where the large drops fall. This observation is in accordance with the expectation that large drops experience less evaporative cooling due to reduced surface area per unit mass. Some evidence is also available that spray from adjacent nozzles has less cooling efficiency than that from isolated nozzles.
- . It has been observed, for dry bulb versus wet bulb difference about 5°C or less, that on a hot bright afternoon, the sprays may become very inefficient, in fact, heat up slightly during transit through the air. The other condition of interest for this observation is that the dry bulb versus water temperature difference is small.

- . A small amount of drift has been observed for light winds (stronger winds have been unavailable or have occurred at times of inconvenience). Measurement of total drift has not been possible because the smaller droplets (less than about 25 micrometer diameter) evaporate before reaching any sensor. The measurements do show a gradient in the drift field leading downwind from the pond edge for several drop size ranges from about 25 micrometers diameter on up. The technique of using photographic paper is satisfactory for the larger sizes.
- . The micrometeorological towers display data which are consistent with other data. The moist air from the pond(s), the proof pond "sees" the other ponds, is confined to within about 2 meters from the pond surface as seen in the data from the pond edge towers.
- . Diurnal effects are displayed in the data as expected.

6. REQUIRED INSTRUMENTATION MODIFICATIONS AND ADDITIONS

The integrated instrumentation system used in the proof experiment was designed with a view toward future application to experimental programs on genuinely hot ponds and high-thermal load spray ponds. The resulting equipment array can, therefore, be applied as required and as appropriate to these more ambitious measurement efforts. Modest modification and some substantial equipment additions will be required. Part of this requirement is due to expected greater thermal influence of the pond on the air, i.e., the production of convective structure.

6.1 The Effect of Hot Water on Immersed Sensors

Thermistors employed in the proof experiment are designed to stably operate to a temperature of 150°C . The housings and water-proofing materials as well as cabling must be given attention to withstand, for periods up to weeks, immersion in water of temperatures up to 100°C .

Hot, and deep, ponds are likely to be temperature and salinity stratified and density currents may occur. Therefore, temperature and deduced flow information is required at greater depths. Thermistor chains are to be constructed for this purpose. Small amounts of biodegradable dyes will be suggested for additional flow information.

6.2 The Effect of Hot Water on Air Sensors

None of the tower instrumentation and radiation sensors are directly affected by the proximity of hot water in considerations of reliability. The net radiometers may require heating to avoid the equivalent of dew formation on their sensing windows. The deployment and/or mounting of these sensors requires more attention. It will not be possible to wade about a hot deep pond for installations and, in fact, the pond edges may be dangerously hot and weak (a thin crust may cover boiling water

at YNP). The use of a boat for any experimental purposes, on a genuinely hot pond, is not considered reasonable.

6.3 Additions to the Instrumentation System

To avoid the dangers inherent with working in the vicinity of hot water and, yet to obtain the requisite data on thermal transfer, other instrumentation subsystems are proven and available.

6.3.1 Acoustic Sounding

A BNW monostatic acoustic system is available for the Ultimate Heat Sink work and will be deployed near the pond edge to assess continuously, thermal structure in the atmosphere to heights of approximately 500 meters. This remote sensing system is deficient in that no data are required for the first few tens of meters above ground level and, therefore, needs to be supplemented by other systems.

6.3.2 Tethered-Balloon System

A BNW tethered-balloon system is available and has the capability of accurately assessing temperature and air moisture in the first few hundred meters of the atmosphere. In particular, with multi-point tethering, telemetry soundings may be carefully controlled in the first 100 meters.

6.3.3 Raft System

A raft, capable of supporting a 5-meter tower and to serve as a support for thermistor chains will be constructed. Towable, the raft will be controlled for position through rope lines to safe spots on shore. In addition, the deployment of radio-controlled model boats as platforms for thermistors will be investigated.

6.3.4 Plenum Fill Equipment

Certain items of equipment from the dismantled experiment have recently been obtained for dedicated application to the Ultimate Heat Sink work. These include signal conditioning

and equipment control subsystems along with recording and sensor (especially useful in hot water) items.

6.3.5 System Synergism

The above mentioned systems will integrate to produce an instrumentation system capable of safely acquiring data required for a heat transfer study involving large quantities of genuinely hot water. The primary added assessment capability is with sensing of convective structure in, over and about the pond. It is anticipated that spectral analysis techniques, applied to temperature and wind data, will be useful in this respect.

7. BIBLIOGRAPHY

All literature relevant to the work of this report is contained in three general sources:

1. R. L. Drake, A Review and Evaluation of Information on the Thermal Performance of Ultimate Heat Sinks: Spray Ponds and Cooling Ponds, BNWL-B-446, Battelle, Pacific Northwest Laboratories, Richland, WA, 280 pp., 205 references, September 1975.
2. U. S. Nuclear Regulatory Commission, Regulatory Guide 1.27, Revision 2, January 1976.
3. Various Utilities, Preliminary Safety Analysis Reports and Safety Analysis Reports. Prepared for the USNRC, various dates.

8. APPENDIX A

Figures

FIGURE 1. The quiet BNW proof spray pond, two spray nozzle clusters at the south end are not shown. The west pond appears beyond the proof pond.

FIGURE 2. A portion of Yellowstone National Park including the area of interest for hot ponds located between Madison and Old Faithful.

FIGURE 3A. Grand Prismatic photographed from an adjacent boardwalk. The view is severely obscured by "steam" and thin crust over hot water makes direct approach dangerous on some sides.

FIGURE 3B. Opal Pond, a receptor for outflow from Grand Prismatic. The Park Ranger has experienced no difficulty in approaching pond edges.

100

100

FIGURE 4A. Outflow from Opal Pond et al to the Little Firehole River.

FIGURE 4B. The small hot pond is easily and safely approached.

FIGURE 5A. A larger hot pond with firm and safe edges.

FIGURE 5B. Circle Pond, isolated but of small thermal capacity.

FIGURE 6. The Savannah River National Laboratory including the area of interest for hot ponds located between the 100-R and 100-P reactors.

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FIGURE 7. A portion of a hot pond at Savannah River Laboratory.

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FIGURE 8. Hot waterfall in a man-made stream at Savannah River Laboratory.

FIGURE 9. Schematic view of the proof pond illustrating spray cluster arrays, sumps, interconnection to other ponds, and the relative locations of the three meteorological towers.

FIGURE 10. Some detail of the spray nozzle arrangement in a cluster.

FIGURE 11. Spary pattern photographed against a tall building background. The apparent instability of water flow near the nozzle is in result of pumping pulses.

 

FIGURE 12. The active BNW proof spray pond - this view should be compared with that of Figure 1.

FIGURE 13A. A flowmeter pipe in place at the condenser water inlet to the proof pond. The small window, to allow reading of the flowmeter counter is visible near left end.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

FIGURE 13B. Schematic, exploded view of flowmeter configuration.

FIGURE 14A. Spray sump with surrounding metal screen and flume in place. The screen is wrapped with plastic sheeting, during measurement, to require all water to flow through the flume.

FIGURE 14B. Placing the flume in position at the spray sump. A cluster of spray nozzles appears in the background.

FIGURE 15. West tower in foreground with north tower visible on the far pond side.

FIGURE 16A. Sensitive anemometry and radiation shield for thermistors at tower top level.

FIGURE 16B. Schematic view of thermistor radiation shield.

FIGURE 17. The float for temperature determination of cooled spray water in place on the quiet pond.

FIGURE 18. Pyranometers in the foreground over quiet water and a net radiometer over sprays. A tower for routine wind determination is mounted on the building roof.

FIGURE 19. Digital data logging and digital and strip-chart recording systems.

FIGURE 20. Temperature versus voltage characteristics for all thermistors.

FIGURE 21. Components of mass balance.

FIGURE 22. Components of thermal budget.

FIGURE 23. Wet bulb and dry bulb temperature profiles for sprays on and off.

FIGURE 24. Wet bulb and dry bulb temperature profiles for night and day.

FIGURE 25. Temperature traces through a diurnal cycle, the shaded region emphasizes spray cooling. Representative wind speeds and directions are determined from the north tower middle level (3 meters).

FIGURE 26. Temperature traces through a diurnal cycle, sprays on only between 1200 and 2000 hours. Representative wind speeds and directions are determined from the north tower top level (for this case 3 meters).

FIGURE 27. Cooled spray temperature difference in the vicinity of the north-end spray clusters. Temperature difference distribution for an "isolated" cluster is shown below.

9. APPENDIX B

Tables

Table 1. Proposed Candidate Hot Ponds at YNP

	<u>Grand Prismatic Spring</u>	<u>Hot Lake</u>
Location:	Midway	Firehole Drive (Black Warrior)
Character:	Pond fed by spring at depth	One of a series of 4 connected lakes
Shape:	Nearly circular	Irregular oval
Size:	~100 meter diameter	~300 x 100 meters
Depth:	Deep pit, shallow surroundings	A few meters
Temperature:	60 - 90 °C	40 - 65 °C
Access:	Pathways nearby, most of perimeter dangerous	Pathways nearby, safe direct approaches
Stream Discharge:	$4 \cdot 10^{-2}$ cubic meters per second	$4 \cdot 10^{-1}$ cubic meters per second
Isolation:	Other proximate hot ponds (Opal, Turquoise, etc.)	Other proximate hot lakes (Firehole, etc.)
Other Comments:	Boiling at center. Colorful algae growth near edges. Surface usually obscured by "steam". Stable in appearance and performance.	Inflow from Black Warrior Lake (65°C), Outflow 40 C into Tangled Creek. Geese nest adjacent to cooler portions. Stable in appearance and performance.

Table 2. Schedule of Calibration and Date Acquisition Activity

<u>Date/Interval Ending</u>	<u>Nature of Activity</u>	<u>Comments</u>
3/19	Test and adjust digitizing and recording system	Test tape produced and computer-dumped for simulated inputs
3/31	First design and test of thermistor circuitry	Preliminary concepts for sensitivity and range, "zero" self-heating
5/3	Preliminary design for integrated instrumentation system	
5/31	All expense purchases completed. All rental agreements initiated	Flowmeters, magnetic tapes, thermistors, etc. Radiometry
6/1	BNW permissions obtained	Safety, operations, facilities
6/9	Thermistor prototype radiation shield tested	Influence of direct solar radiation
7/14	Wet bulb and dry bulb compared with standard aspirated thermistor psychrometer	
7/16	Pond thermistors tested in controlled bath	
7/19	All temperature shields constructed and compared in laboratory	
7/27	All instrumentation cabling tested, anemometry calibrated. Digital system calibrated.	
7/30	Pond installations complete, preliminary trial runs	
8/2	First sensor comparisons on site	
8/13	Receive droplet size spectrometer	On loan
8/14	Full system operational, first test tape. Strip-chart system and amplifiers calibrated.	

Table 2. (Cont'd)

<u>Date/Interval Ending</u>	<u>Nature of Activity</u>	<u>Comments</u>
8/14	Calibration of flowmeters	
8/17	First general data run.
Flume calibration
1220-1420 PDT	All parameters measured
for analysis leading to
first calculation run
8/20	General data run, day
time. Flume calibra-
tion. IR surface
readings 1120-1350 PDT	Mass and thermal
balance, sprays on
at 1223 PDT
8/23	General data run, night
time. IR surface
readings 1955-2300 PDT	Mass and thermal balance,
sprays off at 2140 PDT
8/24	Radiometer calibration
complete	
8/26	Final establishment of
validity of all temp-
erature measurements	Intercomparisons for
various conditions, check
against aspirated ther-
mistor psychrometer
8/27	Measure temperature
distribution in sprays
24-hour data run
1000 PDT 8/27-1000 PDT
8/28
Film drift calibration | Towable float

Sprays off, on, then off,
small spray cooling |
| 8/30 | General data run
1140-1515 PDT. Test
of droplet size
spectrometer | Mass and thermal balance,
sprays on. Not useful
for proof experiment |
| 8/31 | Measure temperature
distribution in sprays.
24-hour run 0700 PDT
8/31 - 0700 PDT 9/1
Film drift assessment
(twice) | Early morning to avoid
possible effects of sun-
shine. Sprays on
throughout. |
| 9/1 | 24-hour run 1600 PDT
9/1 - 1600 PDT 9/2 | Sprays on, off, then on |
| 9/20 | Film drift assessment
(twice) | |
| 9/22 | Retest of droplet size
spectrometer | Not useful for proof
experiment |

Table 3. Mass and Thermal Data, Daytime Run
1246-1250 PDT, 8/20/76

Mass Balance

Flow In (liters/second)		Flow Out (liters/second)	
West Pond	26.5	Condenser Sump	66.5
South Pond	36.5	Spray Sump	191.1
River	21.8	Evaporation	
Condenser	38.0	Drift	
Sprays	138.7		
	<u>261.5</u>		<u>257.6</u>
			+E+D

Evaporation plus Drift = 3.9 liters/second

Thermal Budget

Heat In (kilocalories/second)		Heat Out (kilocalories/second)	
West Pond	103.4	River	43.6
South Pond	75.0	Condenser Sump	39.9
Condenser	167.2	Evap (Spray), Drift	
Sprays	124.8	Evap (sfc)	
Radiation	380.0	Sensible Heat	
	<u>848.4</u>		<u>83.5</u>
			+E+D+S

Evaporation plus Drift plus Sensible Heat =
764.9 kilocalories/second (pond warming)

Table 5. Number of Drift Droplets per 40 mm² Area on Film;
15, 5 Minute Exposure 8/31/76, 9/20/76

| True Droplet
Diameter
(micrometers)	Distance from Proof Pond Edge (meters)							
	<u>0.15</u>	<u>1.37</u>	<u>2.59</u>	<u>3.81</u>	<u>5.03</u>	<u>6.25</u>	<u>7.47</u>	<u>9.29</u>
25<d<50	14,5	7,2	2,0	1,0	0,0	2,0	0,0	0,0
50<d<75	43,25	23,33	23,17	17,7	5,4	1,5	2,5	0,0
75<d<100	50,27	23,30	22,20	17,6	9,10	9,8	4,5	0,3
100<d<125	7,18	13,10	7,3	5,5	4,4	2,1	2,1	0,2
125<d<150	5,7	1,4	4,1	0,1	1,2	1,1	0,0	0,1
150<d<175	2,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
175<d<200	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 4. Mass and Thermal Data, Nighttime Run
2102-2106 PDT, 8/23/76

Mass Balance

Flow In (liters/second)		Flow Out (liters/second)	
West Pond	28.5	Condenser Sump	39.6
South Pond	34.5	Spray Sump	191.1
River	17.0	Evaporation	
Condenser	30.5	Drift	
Sprays	138.7		
	<u>249.2</u>		<u>230.7</u>
			+E+D

Evaporation plus Drift = 18.5 liters/second

Thermal Budget

Heat In (kilocalories/second)		Heat Out (kilocalories/second)	
West Pond	22.8	Sprays	111.0
South Pond	10.4	Radiation	36.0
Condenser	83.3	River	58.0
		Condenser Sump	19.8
		Evap (Spray), Drift	
		Evap (sfc)	
		Sensible Heat	
	<u>116.5</u>		<u>224.8</u>
			+E+D+S

Evaporation plus Drift plus Sensible Heat =
108.3 kilocalories/second (pond cooling)

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