SAFETY EVALUATION BY THE

OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

CATAWBA STANDBY NUCLEAR SERVICE WATER POND

DOCKET NOS. 50-413 AND 50-414

1.0 INTRODUCTION

The Catawba Standby Nuclear Service Water Pond (SNSWP), shown in Figure 1, is an essential part of the ultimate heat sink (UHS) for the Catawba Nuclear Station, providing a back-up water supply in the event of a failure of the supply from Lake Wylie. The pond consists of a small impoundment of Lake Wylie, with two surface thermal outfalls and a single submerged intake. The pond must be capable of supplying cooling water below 92°F for up to 12.5 hours, and below 100°F for 30 days.

Several questions about the adequacy of the pond to provide service water have come to light since the licensing stage:

1. The pond's volume may be smaller than the design, or the volume has diminished because of siltation and sloughing of the banks.

2. Pond temperatures during the last decade have been somewhat higher than expected.

3. Flow of heated water to the pond was supposed to be evenly split between two thermal outfalls. The most current information available (Merschoff, 1995), indicates an uneven split, with approximately 70 percent of the cooling water flowing in the short leg.

4. The design basis heat load may be somewhat different from the heat load used in the licensing phase. Several pieces of correspondence between the staff and the licensee cast some doubt on whether the heat load estimates used in these previous studies are up-to-date. For example, in a letter to NRC (Rehn, 1995), Duke Power Company (DPC) commented that it has revised the heat load curve to take into account mechanical energy and additional heat from the pump motors, but also commented that the total heat rejection, presumable over 30 days, was reduced by 10 percent. This statement alone is not sufficient to judge whether the heat load at critical times has increased or decreased.

To correct any possible problem, the licensee has requalified the operating requirements to allow a higher initial pond temperature, added several feet of depth to increase pond capacity, conducted tests with thermal and dye discharges to the pond, and re-calculated the design basis temperatures. Furthermore, the licensee collected meteorological and pond temperature data on site for a decade, allowing a comparison of the models with the prototype. On September 10, 1996, the licensee submitted four documents for staff review; these are the first four listed under References.

The staff has analyzed the available information and computations by the licensee, and reached the conclusion that it is likely that the pond would perform these functions adequately. The bases for such conclusions are set forth below.

2.0 DISCUSSION AND EVALUATION

2.1 Adequacy of First 12.5 Hours of Operation

The pond is expected to be adequate to supply water below 92°F for the initial period of 12.5 hours. Although the staff did no independent calculations, it reached this conclusion on the basis of a thorough review of the licensee's assessment. The licensee has demonstrated to the staff's satisfaction that: (1) there is adequate lateral and vertical separation between the water intake in the pond and the thermal outfalls; (2) there is strong evidence from thermal tracer tests and engineering calculations for stable stratified conditions in the pond in the initial period; (3) the starting temperature for the design basis is safely below 91.5°F; and (4) the volume of water in the pond is adequate.

The staff assumed that at the start of the design basis event, the water supply to the plant would be unaffected by the hot water being discharged from the two pond outfalls because the intake and outfalls are separated vertically to avoid short-circuiting. Furthermore, the initial pond temperature at the start of the design basis event was chosen by the licensee to be 91.5°F. Maximum temperatures observed in the pond are in the 88 to 89°F range close to the surface, and cooler at depth. These observations are consistent with models of pond performance (described later). Figure 2 shows, among other things, vertical temperature profiles for July 1995. When the initially stratified conditions are taken into account, the vertically averaged temperature would be somewhat lower. At the specified pumping rate for service water, the pond would have a residence time (V/q) of about two days; so this is a safe assumption, even if one assumes an uneven split between the long and short legs of the pond, and a possible breakdown in stratigication

because of pumping (Policastro, 1985). The increased pond level specified in the recent revised limiting conditions of operation (Amendment 152 for Unit 1 and 144 for Unit 2 operating licenses, dated September 20, 1996) would only bolster this conclusion.

2.2 Adequacy to Supply Water Below 100°F for 30 Days

The initial pond temperature is most important for the first 12.5 hours of the design basis accident, and would not have a large effect on the peak pond temperature, which would occur approximately a week later.

The licensee has performed an analysis for the maximum temperature and water loss for the UHS (Baker, 1995a). The model treats the pond as well-stratified. Hot water is discharged to the top layer where it cools by heat transfer to the atmosphere, using the formulation of Edinger and Geyer (1965). It then moves vertically downward, eventually being withdrawn at the bottom and recirculated to the plant. The model does not account for the hydraulics of the top layer, but assumes that the temperature is laterally uniform across the entire lake.

The licensee's choice of the Edinger and Geyer (1965) formulas is likely to be conservative from the standpoint of heat transfer to the atmosphere. The NRC's model for the Catawba Safety Evaluation Report was based on the Edinger and Geyer formula for heat transfer from the pond's surface (Codell, 1980), which has been shown to underestimate atmospheric heat transfer, especially at relatively hot ponds like the SNSWP (Codell, 1980, Policastro, 1985). The Ryan-Harleman (1973) formulation is a more accurate representation of heat transfer from the pond (Policastro, 1985; Codell, 1982, 1986a).

2.3 Steps in the Thermal Analysis

The staff performed the following steps to estimate compliance of the pond with the limiting conditions of operation:

- Modify computer codes to accept meteorological data in formats currently available.
- Compare meteorological data for the short-term record available on site to the long-term record available from Charlotte, North Carolina.
- Revise the models of NUREG-0693 to take into account better formulas for atmospheric heat transfer.
- Acquire pond parameters such as volume, surface area and heat rejection rate.

- Scan the long-term meteorological record to determine the most adverse period for temperature and water loss (not the same period).
- Determine if observed and predicted pond temperatures comply.
- Determine likely alternative conceptual models of the pond, and implement them in a computer code.
- Run the codes to determine peak temperature. Make qualitative adjustments to pond parameters to estimate the effects of non-ideal pond hydraulics such as a breakdown in stratification or an uneven flow split between the two thermal outfalls.

2.4 Meteorological Data

The staff acquired meteorological data applicable to the site. As outlined in the methodology the staff developed for UHS analysis (Codell, 1981, 1986b), this required a long-term meteorological record from the Charlotte, N.C. airport and a shorter period of on-site meteorological data.

The offsite data came from the National Climatic Data Center (NCDC, 1993) in CD-ROM format. The NRC cooling pond and spray pond models documented in NUREG -0693 and -0733 were designed for a main-frame computer, using 9-track magnetic tapes. The staff modified the codes to accept a different data format, and took advantage of direct solar radiation measurements that were not generally available from the older data formats.

There were some additional complications to using the new CD-ROM data; it was only possible to read the information on an MS-DOS computer, and the staff was unable to use its Sun UNIX system for this task. In the end, the staff completely reprogrammed a much simpler computer program based on the old one. The staff developed a small program for the PC to extract the meteorological record (listing of this program may be found in NRC document, Accession No. 9611010090), but did most of the computing otherwise on the Sun platform.

An approximately 10-year record existed for on-site meteorological data. In a telephone conference with Duke Power held on August 27, 1996, the staff requested this data for a comparison an offsite record from the airport in Charlotte, North Carolina. The licensee provided only dew point and dry bulb temperature. Comparison of coincident temperatures for the airport and Catawba site are shown in Figures 3 and 4 respectively. There is a clear bias in the dew point data, with higher values coming mainly from the Catawba site. The higher dew point probably can be explained by the proximity of Lake Wylie, which receives the thermal discharges from the plant. There is a less distinct difference in the dry bulb temperatures. On the basis of these correlations, the staff added 1.1°F and 0.1°F to the dew point and dry bulb

temperatures from the airport data, respectively (the average differences between the airport and site data). The licensee did not provide data on wind speed and solar radiation, so there were no corrections made for these parameters. The effects of the differences in any of the parameters appears to be minor.

2.5 Modification of Heat Transfer Models

The original models used in the staff's UHS pond analysis (NUREG-0693) were based on the Edinger-Geyer (1965) heat transfer formulas, which are acknowledged to overestimate pond temperatures, especially for heavily loaded ponds. The staff replaced them with the Ryan-Harleman formulas (1973).

2.6 Acquire Pond Parameters and Heat Loads

The staff revised the pond parameters such as volume, surface area and heat load, from the licensee's performance assessment report (Baker, 1995a). The staff assumed a pond volume of 1.89×10^7 ft^3 and an initial surface area of 1.65×10^6 ft^2, corresponding to an initial water level of 571 ft MSL. These values correspond to the recently revised technical specification limit, and were also the values used by the licensee in their latest evaluation of performance. The staff did not adjust the surface area of the pond for water loss, because it estimated that there would be less than a 1/2 foot drop in water level from all causes at the time of peak temperature.

2.7 Scan Meteorological Record for Most Adverse Periods

The staff developed the program CATU2 (listing of this program may be found in NRC document, Accession No. 9611010090) to scan the meteorological record from Charlotte, North Carolina, from 1961 to 1990 in order to determine the period of highest pond temperature and water loss from evaporation. Peak temperature for an unloaded pond would have occurred at about noon on July 28, 1977. The program then produced an abbreviated table 30 days before and after this period for subsequent analysis with added plant heat loads.

2.8 Partial Validation of Pond Model to Onsite Data

It is interesting to note that the peak unloaded temperatures for a totally mixed pond calculated with the CATU2 model was about 89.6°F. Figure 5 shows measured pond temperatures for the pond in July 1995. The measurement station was not indicated in the figure, but is probably a near-surface location based on the obvious diurnal variations. Figure 2 shows the strong pond stratification for summer months, indicating that there would be high stability and little vertical mixing during this period in the absence of flow. Running the model with the same meteorological data for a shallower

pond to simulate a stratified surface layer showed, as expected, a greater peak temperature; i.e., 89.6°F for a 10 foot thickness, 92.8°F for a 4 foot thickness and 95.5°F for a 2 foot thickness. The model results are qualitatively similar to temperatures observed in the field.

2.9 Rationalization of Models on Basis of Field Evidence and Detailed Model Calculations

Alternative conceptual models of the pond's thermal behavior can be supported by several computational models and field tests:

2.9.1 Thermal/dye tracer test

The licensee conducted a test of the pond with thermal effluent and dye tracer in February 1995 during plant shutdown (Baker, 1995b). The testing was conducted in winter, with heat loads and flow rates considerably lower than the design bases for the UHS, so they were not meant to be a direct simulation of pond performance. The flow rate of heated water through the pond was between 23.8 and 25.4 CFS (cubic feet per second), approximately half of the design basis flow, and was apparently directed entirely to the thermal outfall in the short leg. The tests demonstrated that the heated water spread out over most of the pond surface water, including the long leg, because of stratification, and that there was little short-circuiting between the discharge and intake. Stratification is strongest immediately after the start of the thermal discharge, but there appears to be increased vertical mixing at later times. These tests lend support to the licensee's model of a stratified pond, and diminishes the potential detrimental effects of an uneven flow split between the two thermal outfalls.

2.9.2 Policastro's Model Study

Policastro (1985) studied thermal hydraulics for small, heavily loaded cooling ponds, using two UHS designs in the process, one of which was Catawba. He reached the following conclusions:

a. The ponds may be stratified thermally at the start, with the hottest water at the surface, but once pumping begins, the stratification breaks down. Pumping may produce vertical eddies that destroy the stratification. The pond would become vertically well-mixed, with temperature differences along its length. A one-dimensional lateral plug flow model predicted peak temperatures almost as well as the three dimensional model.

b. Of the three pond-hydraulic models, the totally mixed pond model predicted the highest intake temperature. His example, which was based closely on the heat load and meteorology for Catawba available at the time, predicted a peak temperature with the mixed model at the intake of 98°F. The three-dimensional and one-dimensional lateral flow models predicted 96.?°F and 97.0°F, respectively.

Policastro's analysis assumed that there was an even split between the thermal outfalls. Furthermore, this study did not have the benefit of information on actual pond performance, the results of the thermal/dye tracer tests conducted in 1995 and the most recent estimates of pond parameters and heat loads.

2.9.3 Reconciling Dye/Thermal Tracer Test and Policastro Model

The three-dimensional modeling study of Policastro does not appear to be in full agreement with the field tracer tests. The model study predicts considerable vertical mixing after a period of initial stratification. However, the model study assumed higher flow rate, equal flow from both thermal outfalls, and was simulated for a period considerably longer than the field study. The field study also shows an increased mixing of the thermal layer as the test progressed, especially at locations close to the thermal outfall and intake, consistent with the Policastro model. The Policastro model study might have predicted higher mixing because of strictly numerical factors having to do with coarse discretization of the pond volume. The pond was represented by rectangular blocks 100 ft x 100 ft horizontally, and approximately 1/10 of the pond depth vertically. The irregular shape of the rectangular representation of the pond and the coarseness of the grid probably added considerable dispersion horizontally and vertically to the simulation as a modeling artifact.

The evidence from both studies is useful, but neither is totally conclusive. The staff's best estimate of the likely conditions in the pond would be as follows:

1. There would be initially strong stratification of the pond, causing a spreading of hot water over a large portion of the pond surface. This strong stratification would prevent short-circuiting between the thermal outfall and intake.

2. With time, the stratification would diminish because of vertical and horizontal mixing caused by flow-generated eddies and contact of the plume with the pond borders and bottom. However, the stratification would continue to be effective at promoting a spreading of hot water across the surface of the pond in spite of diminished flow from the second thermal outfall.

3. Stratification would be reinforced by continuing heat rejection to the circulating water. However, at some point the heat load would diminish below the level where discharged water was significantly hotter than withdrawn water, and the effect would be lost.

4. Even if vertical mixing occurs, this is not necessarily bad for heat transfer. The "plug-flow" model, in fact, is very efficient at rejecting heat to the atmosphere. The down side of the "plug-flow" model is that it does not predict effective use of the long arm of the pond under conditions of diminished flow from the second outfall.

2.10 Pond Models of Likely Prototype Conditions

By running several simulations to take into account the uncertainties in the pond behavior, the staff effectively bound the peak temperature. The staff analyzed the pond performance using two sets of models. The first case describes the most favorable conditions. The second case takes into account, in a conservative manner, factors that could degrade performance.

2.11 Base Case Pond Model, Full Pond Available for Cooling

This is the base case, giving full credit of the entire pond volume and area for cooling. The program UHS3CAT2 (listing of this program may be found in NRC document, Accession No. 9611010090) contains three pond hydraulic models: (1) fully mixed pond volume, (2) fully stratified, and (3) plug flow. The fully mixed model assumes that all water in the pond is at a single temperature. There is no physical basis to support this model for the Catawba pond. The fully mixed model usually predicts the worst temperature because it minimizes heat transfer to the atmosphere.

The fully stratified model is virtually identical to the one used by the licensee in their latest evaluation (Baker, 1995a). It assumes that heated water spreads uniformly across the entire surface of the pond, and that the top layer has a uniform temperature. Water in the top layer then moves vertically downward, and is eventually withdrawn by the plant intake. On outward appearance, this model is not very realistic. It does not account for the complex hydraulics of the pond in terms of cooling of the surface layer, breakdown of stratification, and uneven distribution of heat and water to the two legs of the pond. The model used by the licensee for the licensing stage analysis of UHS performance by Ryan and Harleman (1973) is more realistic, allowing for cooling of the top layer as it moves horizontally, and then downwelling of the cooled water to deeper layers. Sill (1995) points out, however, that the assumption of vertical-only transport in the licensee's model usually gives a similar answer to the stratified pond model of Ryan and Harleman, and therefore may be appropriate. The staff agrees with this assessment.

The plug flow model assumes that water leaving the outfalls moves along the pond in plug flow, with no stratification or mixing with water in front or behind, until it reaches the thermal intake. The plug flow model is actually the most optimistic, providing that the entire pond is utilized, because it maximizes heat transfer to the atmosphere, thereby predicting the lowest temperature. Policastro (1985) used a three-dimensional model for the Catawba pond, and concluded that, after an initial period of stratification, vertical eddies would cause stratification to break down, whereupon the plug-flow model would most closely predict the behavior of the pond. Policastro's study did not account for the possible uneven flow split between the outfalls, which would lead to sub-optimal performance.

The pond models were run with 100 percent of the heat load and flow rate, for the 60-day period centered on 12:00 P.M., July 28, 1977, determined from the initial screening of the meteorological data. The 100-percent heat load curve is shown in Figure 6. Initial pond volume was 1.89×10^7 ft^3, with constant pond surface area 1.65×10^6 ft^2. The model was run numerous times, with the starting time changed in 4-hour increments in order to align the peak meteorology and heat load timing, and the highest temperature for each of the three models (mixed, stratified or plug flow) was chosen from all runs.

2.12 Degraded Pond Performance

The staff considered additional factors such as pond thermal hydraulics and uneven flow split between the two thermal outfalls. These factors were taken into account in a qualitative sense, since it would have required a considerable expenditure of effort to develop full models of the necessary phenomena. For the degraded case, the staff analyzed only flow and heat rejection from the thermal outfall in the short leg of the pond, with 75 percent of the heat load and flow rate, and 50 percent of the total pond surface area used in the previous analysis. This case allows some credit for the surface area beyond the short leg, but conservatively ignores the considerable cooling that would occur for the remaining 25 percent of the flow from the second thermal outfall.

2.13 Results

For the base case, the model predicted peak pond temperatures of 98.5, 95.6 and 93.5°F for the mixed, stratified and plug flow models, respectively.

For the degraded case, the model predicted peak pond temperatures of 102.6, 100.0 and 97.2°F for the mixed, stratified and plug flow models, respectively.

The staff does not attach any significance to the result from the mixed model. Field studies and detailed numerical modeling support the stratified and plug flow models only. On the basis of these results, therefore, the peak pond temperature at the intake would remain below 100°F.

3.0 CONCLUSIONS

The performance of the Catawba SNSWP appears to be adequate. Water temperature will stay below 92°F for the first 12.5 hours following the design basis accident, and below 100°F for up to 30 days. Where possible, the model results were compared to observed results from field tests for flow and temperature and found to be acceptable.

The modeling study considered in a conservative manner the possible degradation of the cooling efficiency caused by an unequal flow split between the two thermal outfalls. Furthermore, the results took into consideration a somewhat higher average dry bulb and dew point temperatures at the site over those for the Charlotte airport location. It is likely that the elevated temperatures at the site reflect heat added to the environment from plant operation. This increase would be less of a factor several days after a plant shutdown, so including the effect is conservative. The maximum temperatures calculated also include perfect alignment of meteorological conditions leading to highest temperature with the peak effect of the heat load, and therefore reflect a worst case.

There is no possible adverse impact on cooling water temperature from raising the minimum pond level by increasing the height of the weir. This could only improve conditions by increasing the pond volume and residence time, and increasing the separation between the surface discharges and the submerged intake.

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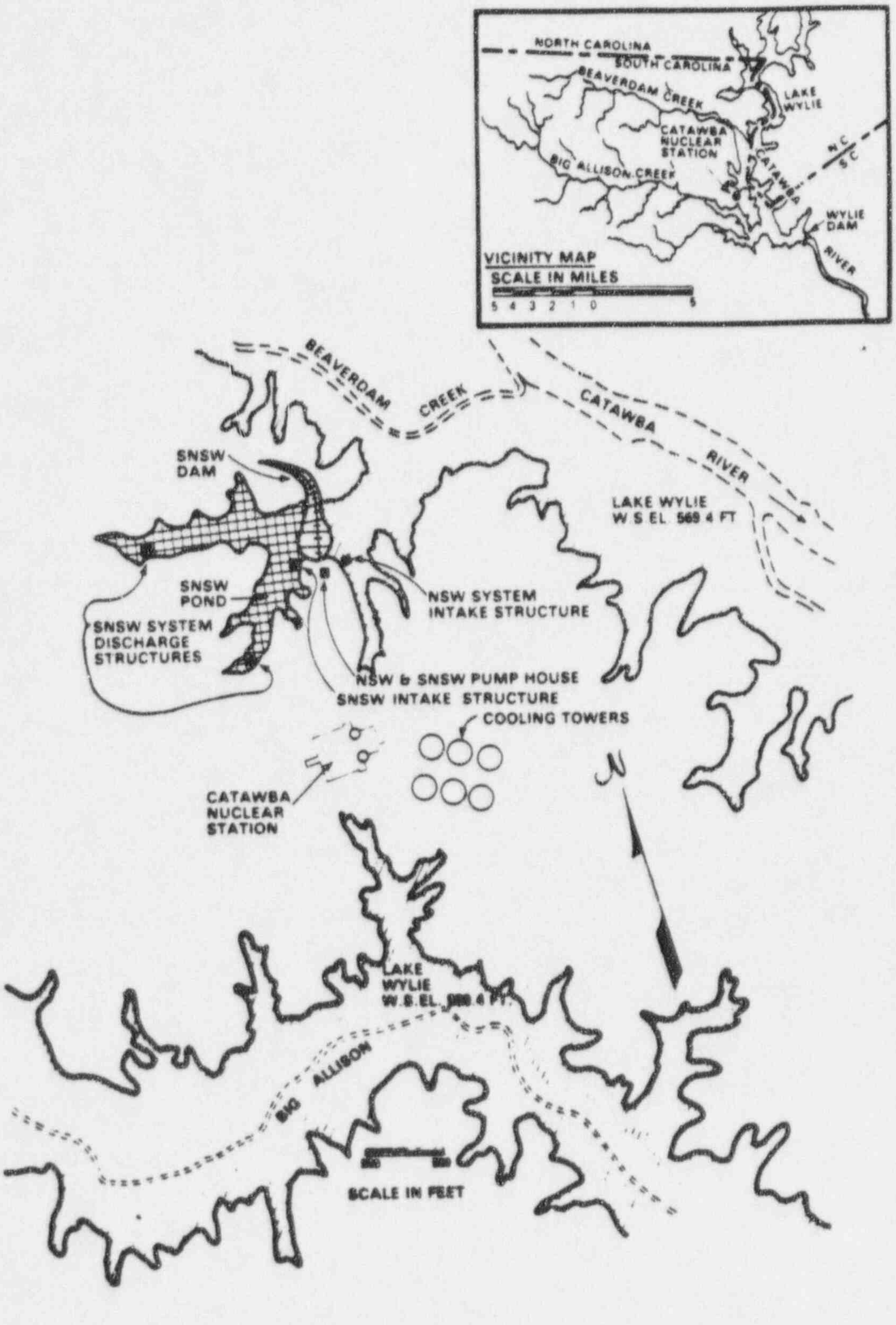
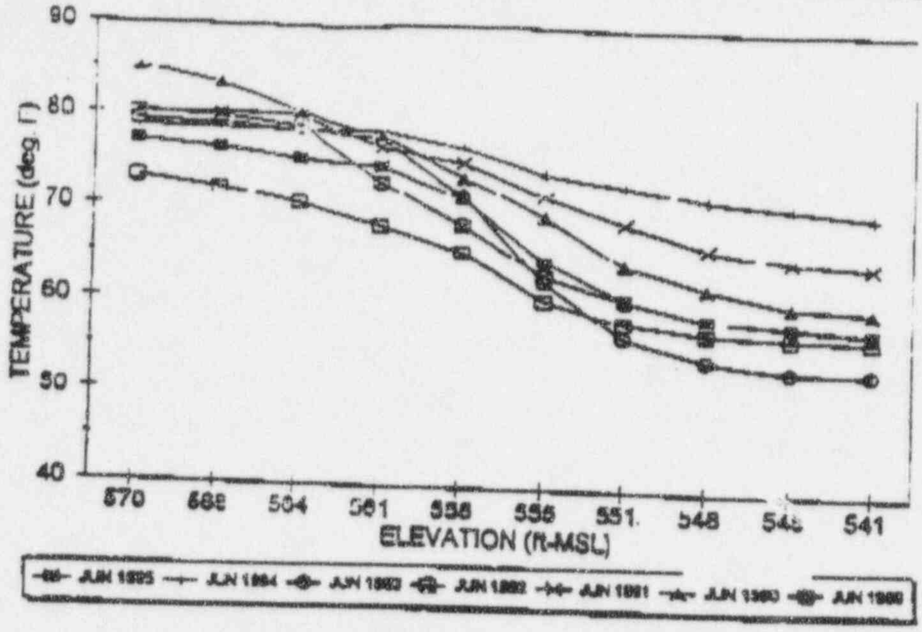
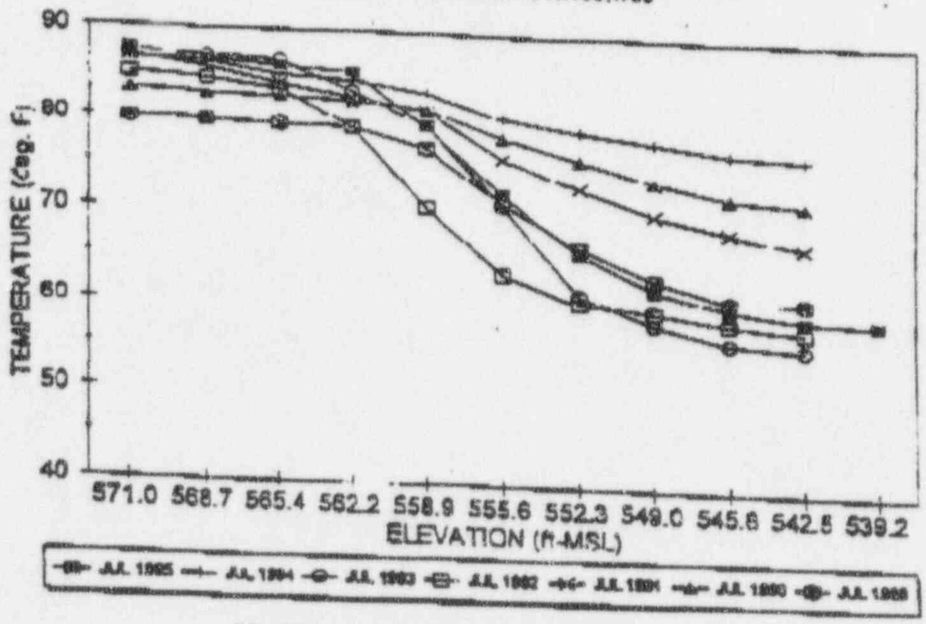


Figure 1 - Catawba Nuclear Service Water Pond

Figure 2 - Vertical Temperature Profiles in Catawba Pond



TEMPERATURE PROFILES, CNS SNSW POND:
7/95,7/94,7/93,7/92,7/91,7/90,7/89



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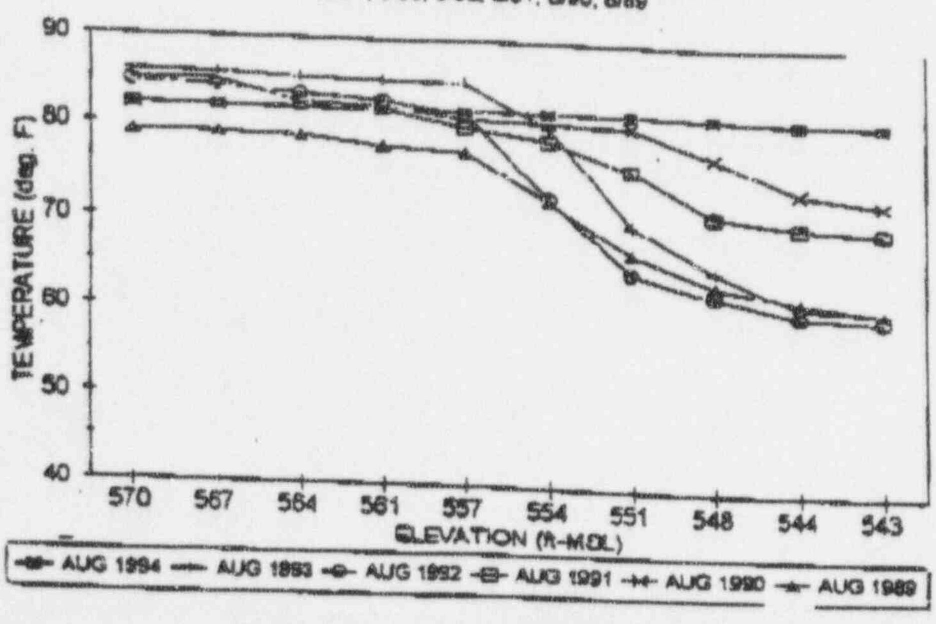


Figure 3 - Comparison of Meteorological Data from Charlotte N.C. and Catawba Site, Dew Point Temperature

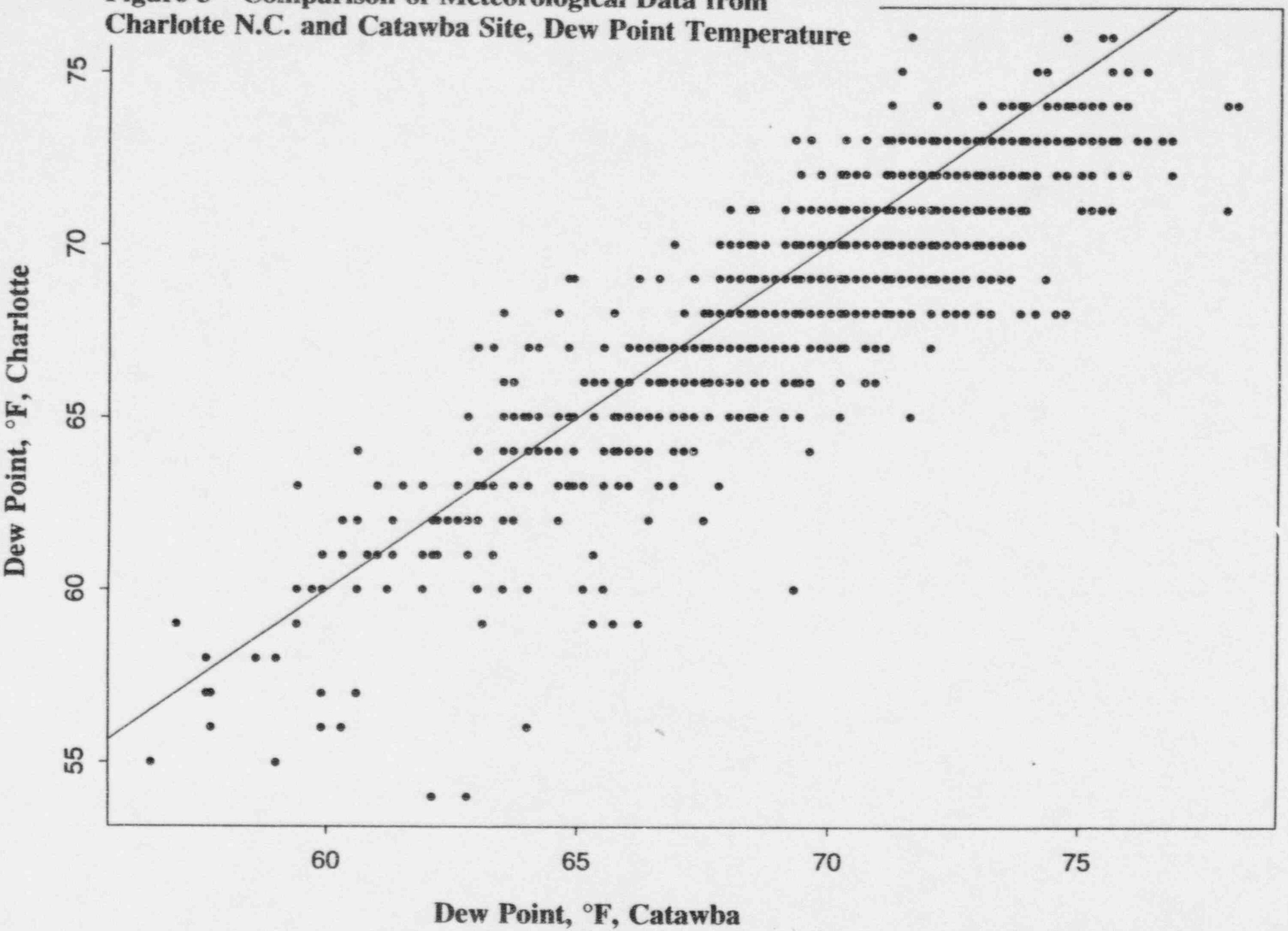
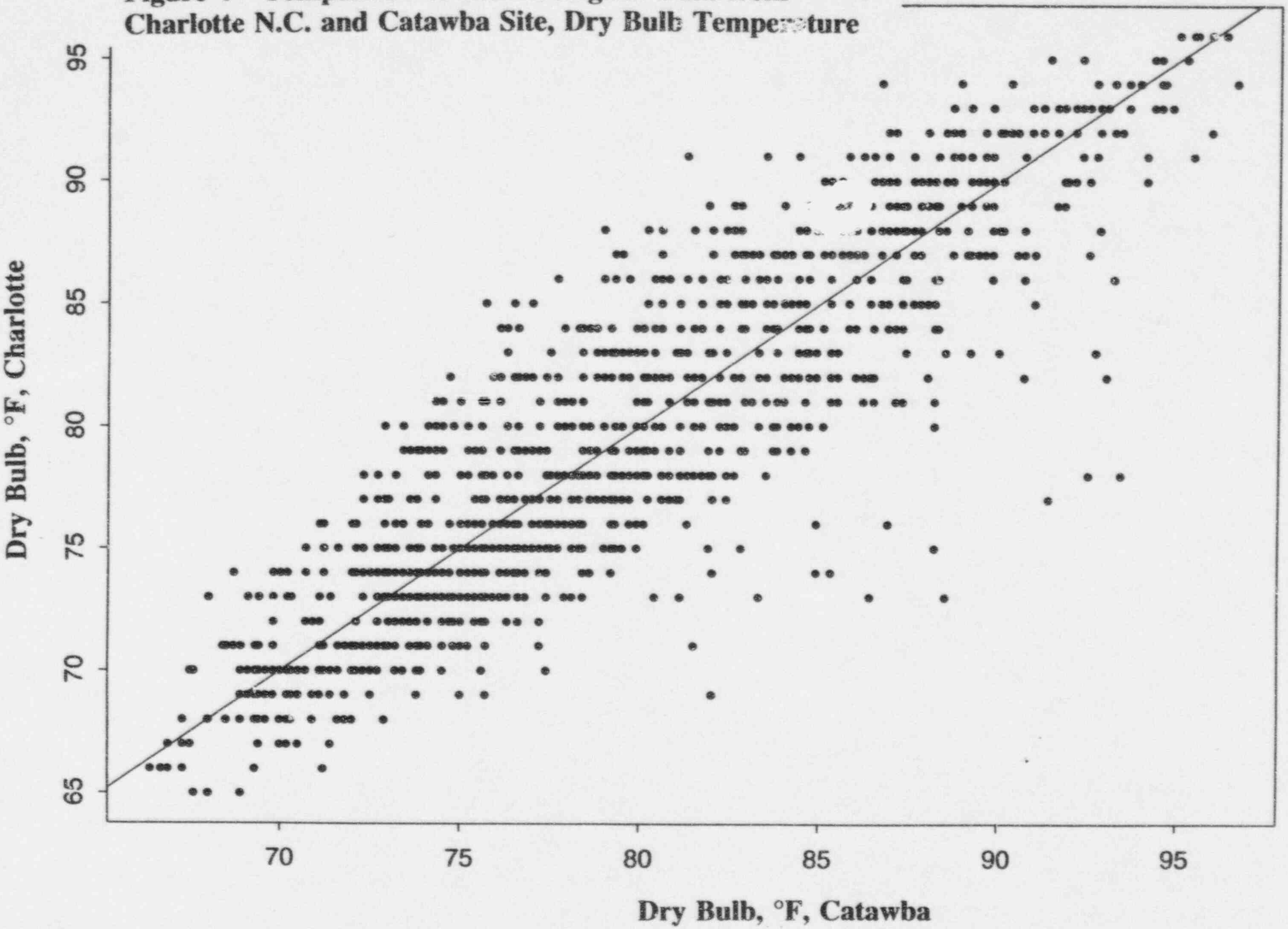


Figure 4 - Comparison of Meteorological Data from Charlotte N.C. and Catawba Site, Dry Bulb Temperature



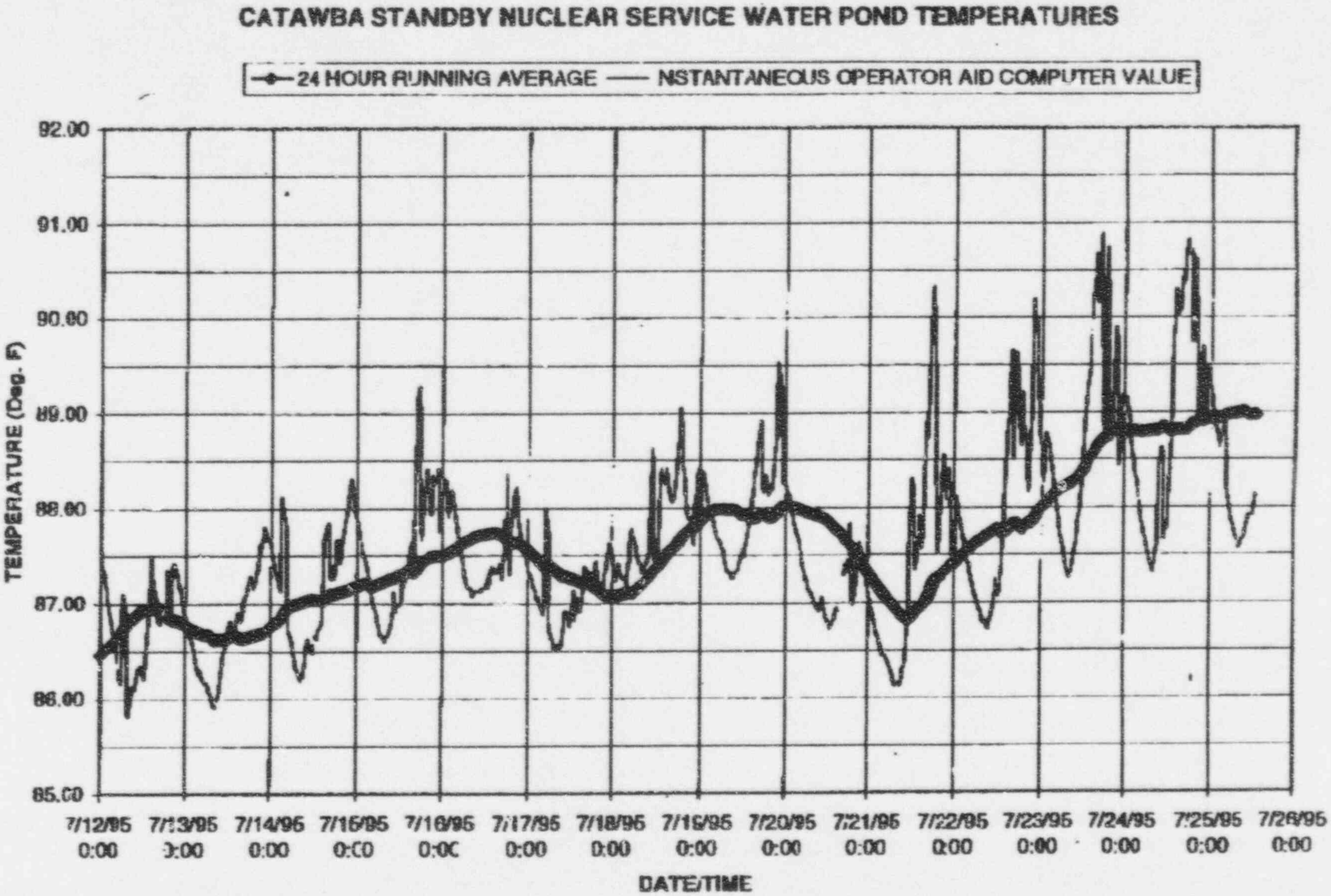


Figure 5 - Measured Pond Temperature

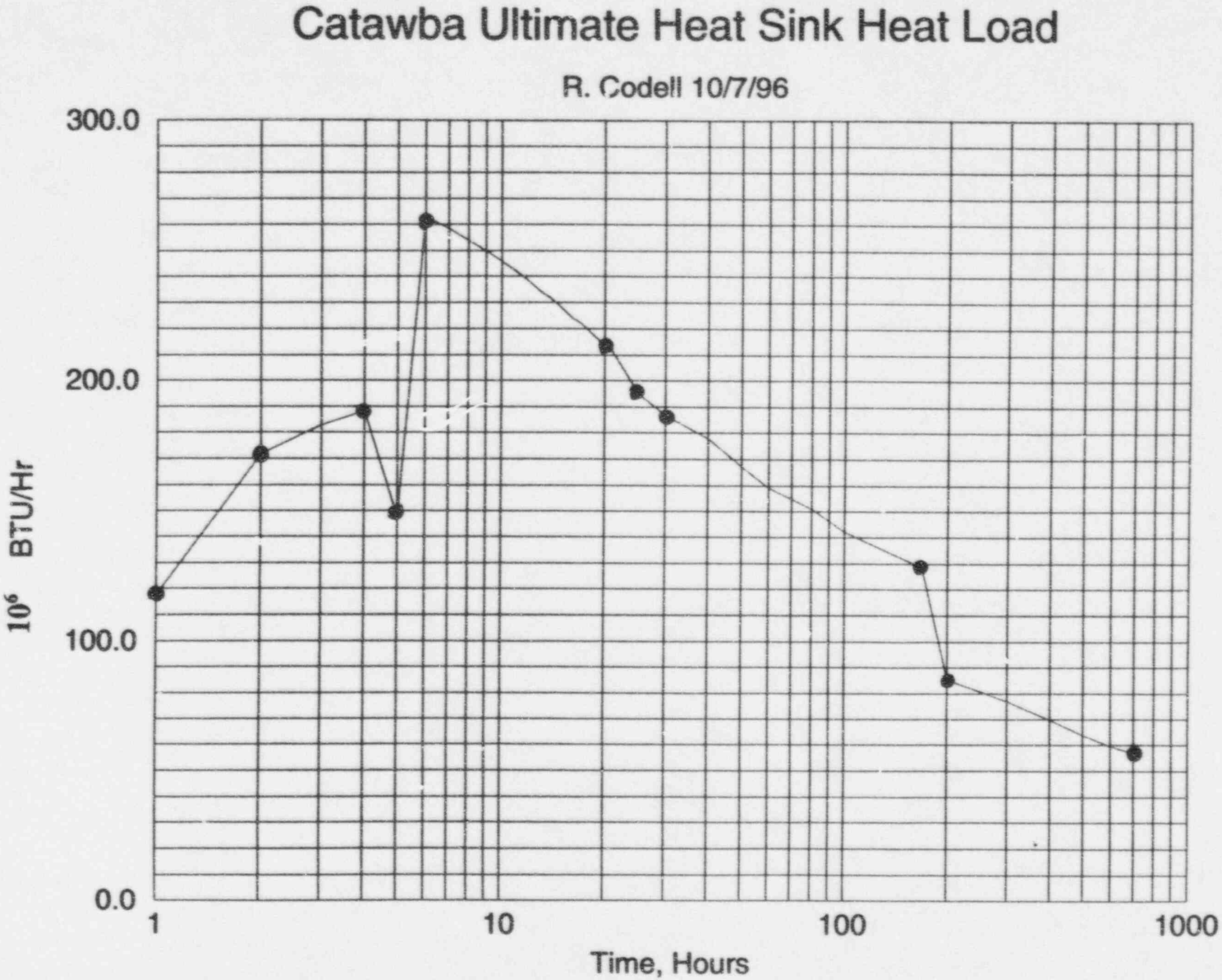


Figure 6 - Heat Load for Catawba UHS Analysis