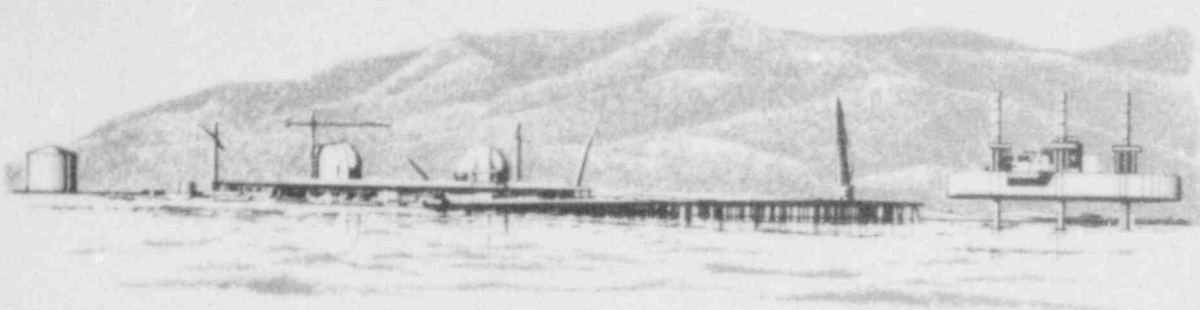

PHASE III THERMAL TOLERANCE STUDIES 1977-1978

SOUTHERN CALIFORNIA EDISON COMPANY

SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3 PROTOTYPE STUDY FOR HEAT TREATMENT

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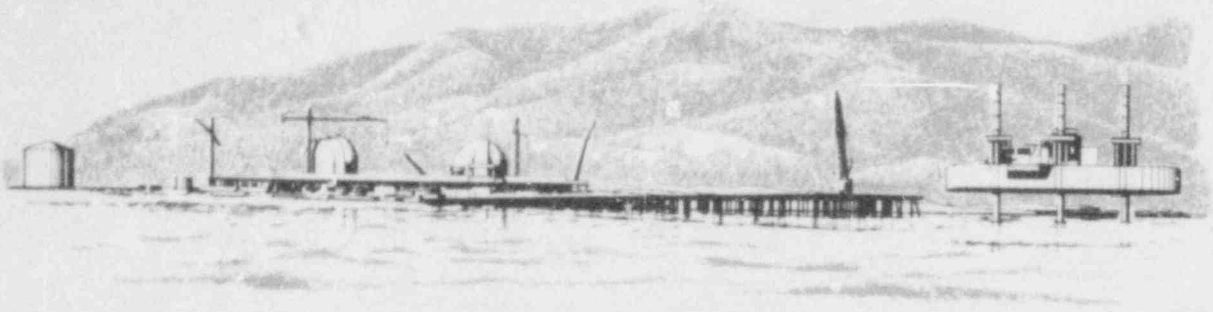

PHASE III THERMAL TOLERANCE STUDIES 1977-1978

SOUTHERN CALIFORNIA EDISON COMPANY

SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3 PROTOTYPE STUDY FOR HEAT TREATMENT PROCEDURES FINAL REPORT DECEMBER 1978

Prepared For
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The San Onofre Nuclear Generating Station Heat Treatment Prototype Study was conducted by scientists from the Lockheed Center for Marine Research (LCMR) in Carlsbad, California. J. W. Graham of LCMR served as principal investigator for the project, assisted by R. E. Thornhill.

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SUMMARY

This report presents the results of a study conducted from April 1977, through December 1978 at San Onofre Nuclear Generating Station Unit 1. As the culmination of a 5-year, 9-part program designed to determine the most environmentally compatible method of heat treatment for San Onofre Units 2 and 3, San Onofre Unit 1 tested a prototype reduced heat treatment cycle developed in previous studies for Units 2 and 3.

It was the aim of the prototype study to schedule heat treatments of 100°F for 105 minutes (screenwell temperature, treating the intake conduit only) according to results of analyses of shell debris, temperature data, and information from computer growth models for the two major fouling organisms. Although most heat treatments were scheduled according to growth model predictions, severe *Balanus* fouling occurring prior to the June 4, July 24, and April 2, 1978 heat treatments did necessitate earlier heat treatment cycles than predicted by the growth model. Also, in October 1977 a large number of mussels which had survived the previous two heat treatments broke loose and impinged on the condenser tubes. As a precautionary measure, the conventional heat treatment procedure was reinstated for one cycle. The survival of

these animals was traced to a calibration error in a temperature recorder which was promptly corrected. No further problems of this nature have occurred, and the reduced heat treatment procedure was reinstated.

Fluctuating intake temperatures triggered severe biofouling conditions during the study, and the influx of shell debris was heavy. Average winter intake temperatures were also considerably above the 4-year baseline average enhancing growth and thus shortening the predicted intervals between heat treatments. Some mussel growth in the discharge conduit was observed, primarily attributable to a 1 month period of reduced load operation permitting discharge temperatures to decline below 80°F. These mussels were subsequently killed by a return to normal operating conditions. At the conclusion of the study, a diver transit and inspection of both conduits indicated no accumulation of fouling resulting from the reduced heat treatment process.

The fouling in the discharge conduit indicates that under some conditions severe growth can occur. Although this growth may eventually be removed by a return to normal operating conditions above 80°F, the current estimates of this length of time are estimated as exposures of 1000 hours at 80°F, 150 hours at 85°F, and 24 hours at 90°F. If these conditions cannot be met, fouling growth in the discharge conduit must be assumed, and a heat treatment should be scheduled.

The prototype study generally confirms in field application the validity of the previous laboratory studies. The temperatures and durations used in the prototype study were adequate to control fouling under most operating conditions experienced at Unit 1. Heat treatment schedules can normally be determined from available temperature and shell debris measurements and the use of a growth model.

Although the results of this study have indicated that the new heat treatment scheme can control fouling under the conditions tested at Unit 1, some caution must be exercised in applying such a scheme to Units 2 and 3. The differences in conduit size and screenwell arrangement alone justify caution in applying the prototype study results. In addition, the problem of instrument calibration encountered at Unit 1 is the type of problem that can happen at any time and indicates that a slightly more conservative approach than was used in the prototype study may be necessary to assure the reliability of operation of the plant.

INTRODUCTION

This study is the final segment of a five year program known as the Thermal Exception Studies for San Onofre Nuclear Generating Station Units 2 and 3. The program encompassed engineering and biological studies designed to optimize the heat treatment procedures for Units 2 and 3 with the intention of setting precise limits on the degree, duration, and frequency of heat treatment operations.

Previous reports have dealt with research into the thermal tolerance of major fouling organisms found at San Onofre (LAS 1975), where laboratory investigations indicated that heat treatment procedures used to control marine fouling could be reduced in both degree and duration. This was followed by a two year conduit simulation study conducted at San Onofre (LCMR 1977) which confirmed the earlier findings as well as presented a method for assessing the timing of a heat treatment operation based on growth models of dominant fouling organisms. This report presents the results of a prototype study, conducted by the Lockheed Center for Marine Research (LCMR) from April 1977 through December 1978, designed to evaluate the effects of a reduced mode of heat treatment at the San Onofre Nuclear Generating Station (SONGS) Unit 1.

Alterations to the normal heat treatment process at SONGS Unit 1 for the purposes of the prototype study were as follows:

1) A reduction of the intake heat treatment temperature by 5°F, from 105°F to 100°F.

2) A reduction in the total heat treatment duration from 4 hours (intake and discharge) to 1.7 hours (intake only).

3) The discontinuation of heat treatment of the discharge conduit.

4) The testing and implementation of a growth model of the Bay Mussel (*Mytilus edulis*) to determine the frequency of heat treatment operations.

The response of the fouling population to these alterations and their effect on plant operations during the prototype study period are discussed in this report.

METHODS-MATERIALS

Data collection efforts were divided into two areas. The first area encompassed an analysis of available plant data including cooling water temperatures and screenwell collection basket shell debris records collected by the operators. These data were representative of the biologically relevant information currently available for analysis of fouling at San Onofre. Analyses were conducted to determine whether these data alone were sufficient to allow heat treatment intervals to be predicted by personnel untrained in biology.

Examples of these data included intake and discharge temperatures monitored continuously on printed paper tape at 5-minute intervals. These records were sub-sampled daily at one hour intervals beginning at 0100 and continuing to 2400 hours. These 24 intake temperatures were then averaged to provide a mean daily intake temperature for analysis. Similarly, plant operational data, which included estimates of the percentage of shell debris and the total weight of the collected screenwell debris were recorded on a daily basis when the collection basket was dumped into a refuse bin. These data are archived for future reference and form the basis for evaluating the impact of fouling on station operations.

Secondly, supplementary data were recorded at frequent intervals by Lockheed personnel to provide more detailed information on the patterns of biofouling settlement and growth within the conduits. This information included analysis of condenser-cleanout debris, estimation of live/dead percentages of shell debris and size measurements of living individuals occasionally found in the shell debris. Analysis procedures for the shell debris data consisted of gathering a quantity of shell debris from a freshly dumped collection basket. Samples were gathered from different areas of the debris pile to reduce variations caused by water flow. For *Mytilus* when present, samples of approximately 100 living individuals were measured to the nearest .1 millimeter by a Vernier caliper. For samples composed principally of *Balanus*, the living individuals would be aggregated into clumps. Several clumps would be collected and the aperture length of each living individual measured (See LCMR 1977 for greater detail). The number of living individuals in each clump was then enumerated and the results expressed in size frequency and clump frequency histograms.

RESULTS AND DISCUSSION

The Prototype Study was initiated on June 5, 1977 with the first reduced heat treatment procedure. Average daily intake water temperatures recorded at the control room of SONGS Unit 1 are presented in Figure 1. The dates of significant temperature and heat treatment events since May 3, 1977 are shown. High ambient temperature peaks above 70°F occurred on June 10, July 24, and August 24, 1977 as well as August 9, August 29, and September 8, 1978. The sharp spike found on October 7, 1977 was artificially induced by tunnel flow reversal during a startup period. Periods of low temperature were more prevalent with sharp declines of 8 to 10°F occurring within the space of a few days. The largest decline occurred during the period from June 10 to June 17 when the temperature decreased over 14°F in seven days.

These fluctuations in temperature are believed to have produced spawning responses in the biofouling communities. Major larval settlement of *Balanus tintinnabulum* occurred during almost every heat treatment interval. Larval settlement of *Mytilus edulis*, not found during the summer months of 1975 in the simulation study (LCMR 1977), were found at varying densities at virtually all times during the summer of 1977. These findings indicate that San Onofre has been exposed to severe biofouling conditions.

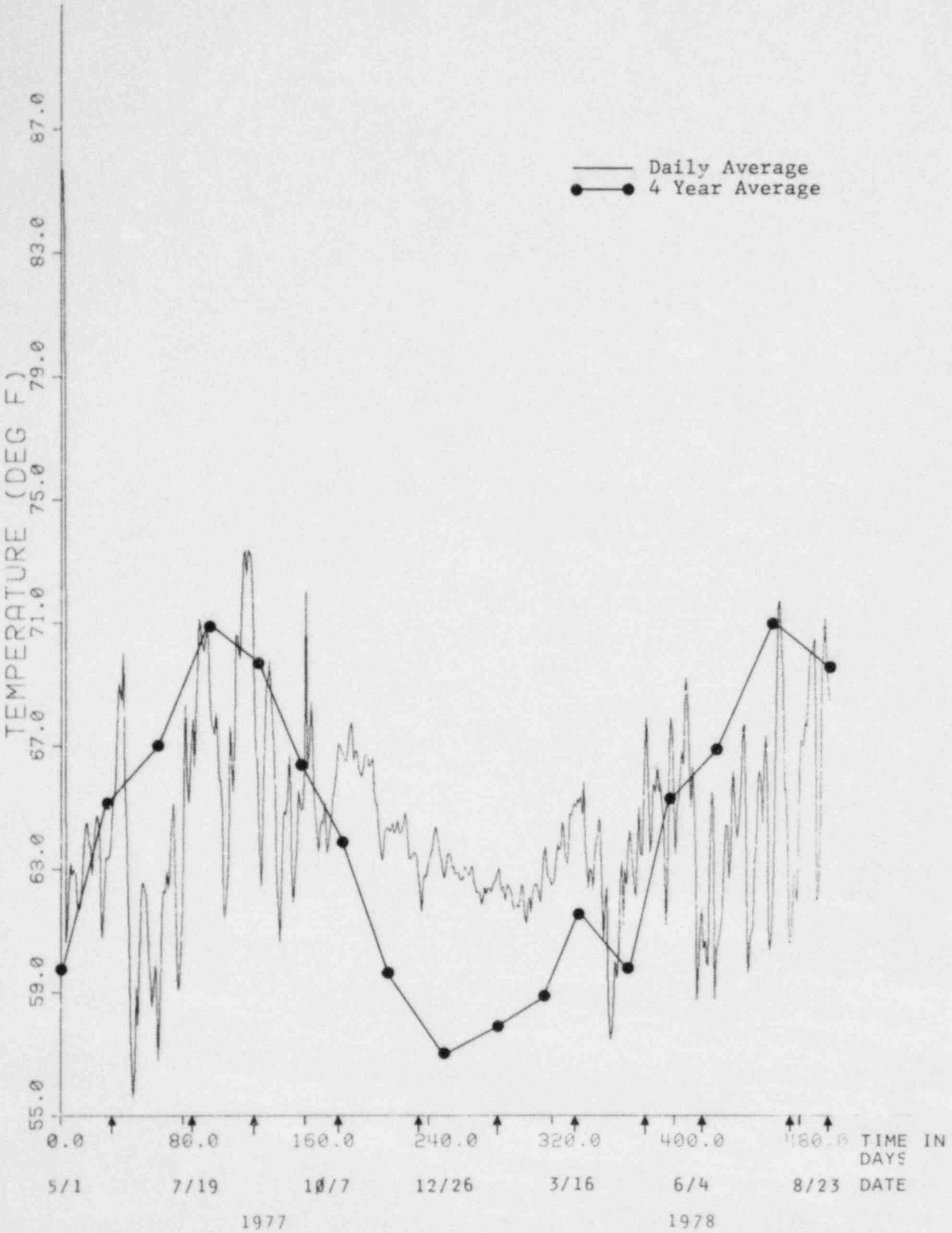

Figure 1. Average daily intake water temperatures recorded at SONGS Unit 1 from May 1, 1977 through September 13, 1978, shown with the four year average water temperatures for the years 1964-1969. Arrows indicate heat treatments.

In Figure 2, the entire history of shell debris influx at San Onofre Unit 1 for the period May 1, 1977 through September 13, 1978 is shown. As a smoothing technique, the daily fluctuations have been processed by a 5-day moving average. The timing of heat treatments are shown as arrows at the bottom of the graph. In almost every case, the heat treatment was followed by a sharp decline in the quantity of shell debris entering the screens.

Measurements Preceding June 5, 1977 Heat Treatment

Measurements and observations began on April 26, 1977 with a conventional full-scale heat treatment of the intake and discharge conduits after a prolonged outage. Following this heat treatment the plant was left in reverse configuration until May 2, 1977 to permit the accumulated shell debris of the intake to be flushed from the conduit. During this period, temperatures greater than 83°F were prevalent in the intake conduit, and were judged sufficient to inhibit the settlement of fouling organisms. When normal flow conditions were re-established on May 2, 1977, the growth model calculations were initiated. The average daily intake water temperatures and their relationship to the calculated growth of *Mytilus* and *Balanus* are shown in Figure 3 with daily records of shell debris found in the collection basket. During the period May 3, 1977 to June 5, 1977 temperatures remained fairly

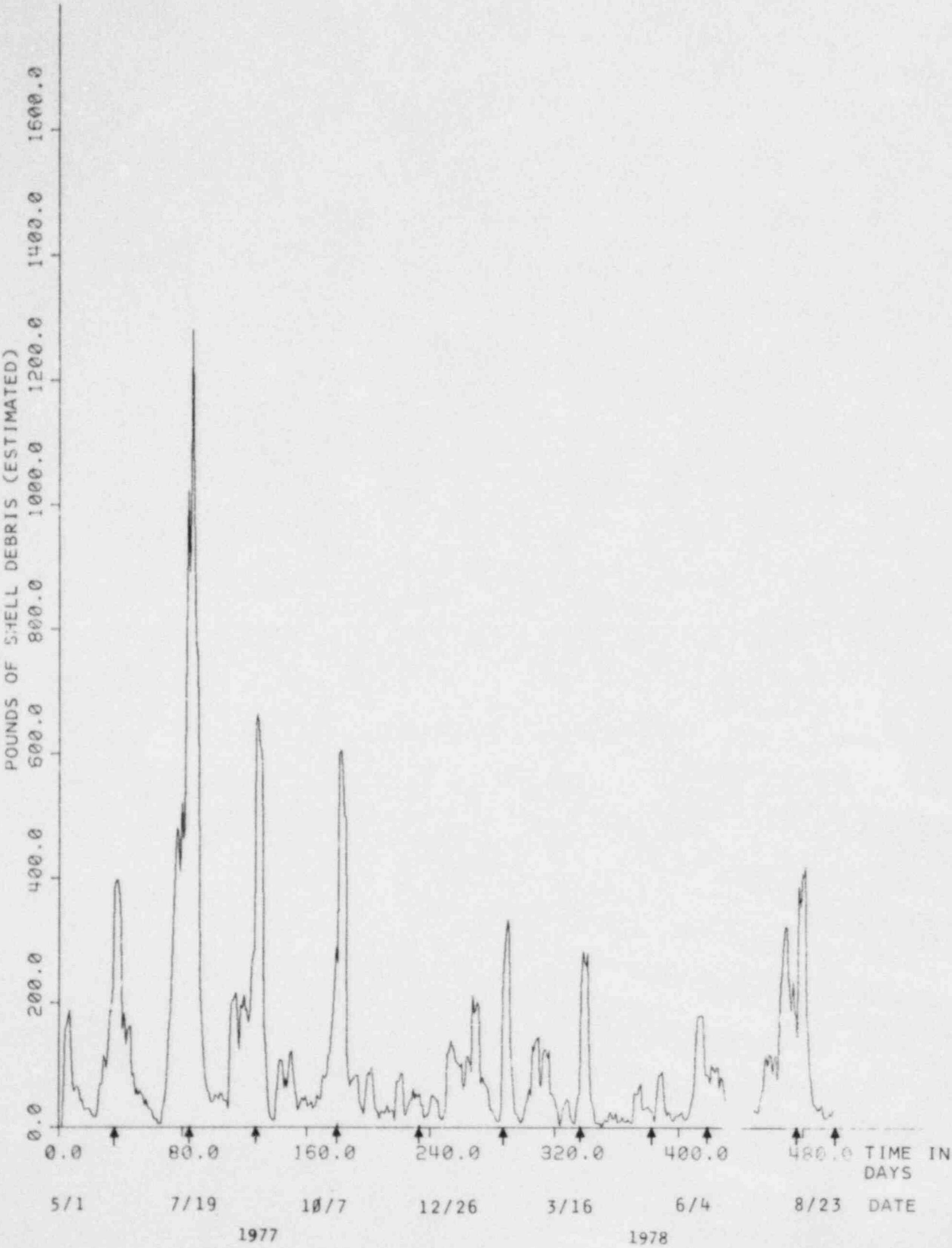

Figure 2. Estimated amount of shell debris in the collection basket shown as five-day moving averages. Arrows indicate heat treatments.

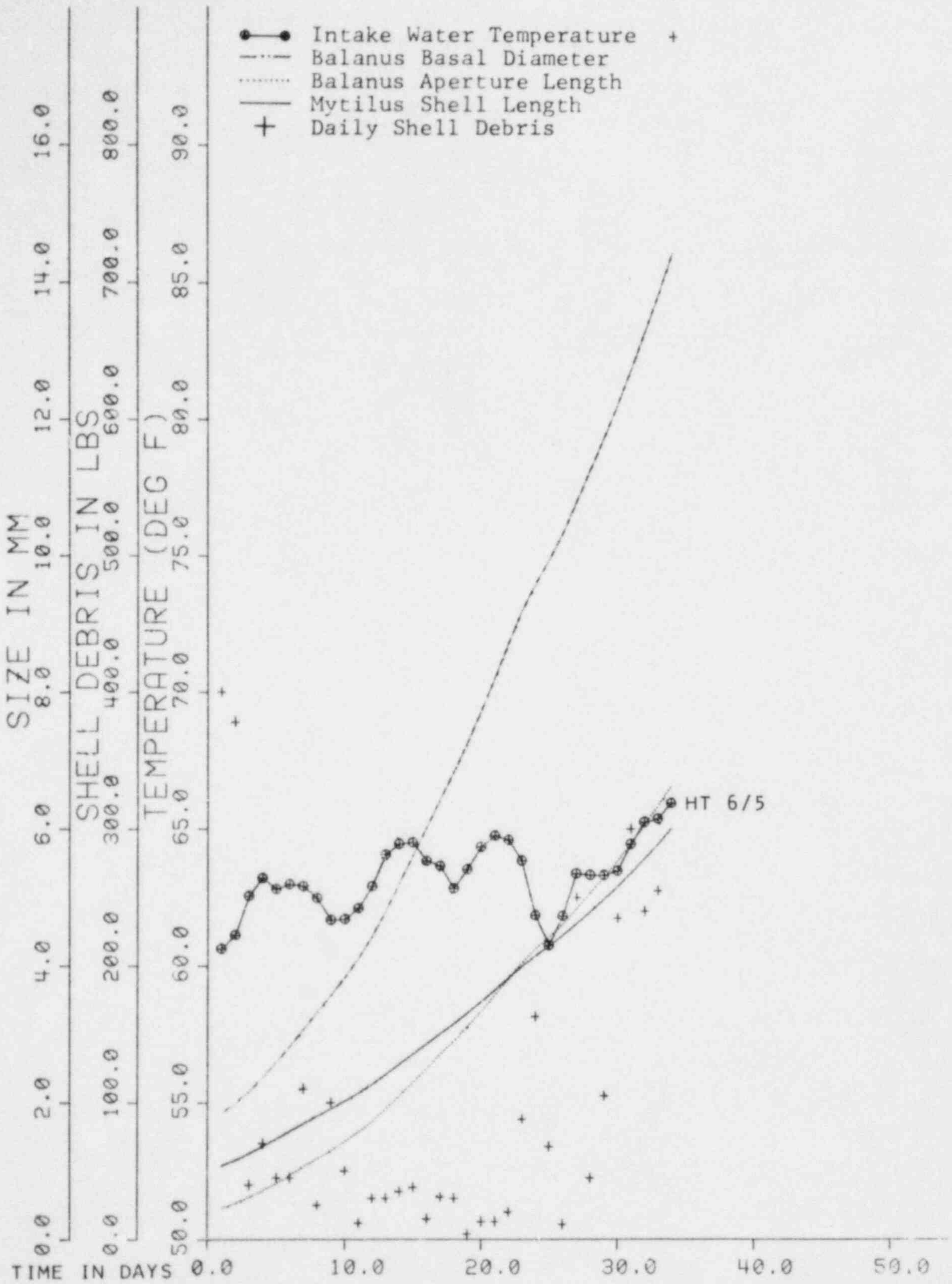

Figure 3. Water temperatures, shell debris, and predicted growth records for the period 5/13/77 to 6/5/77.

stable, increasing slightly overall, with only a single, sharp temperature drop on May 27, 1977. Growth rates also remained stable during this time. Shell debris records (Figure 2) showed a sharp decline in quantity resulting from the heat treatment operations. Low levels of shell debris continued until May 25, 1977 when there was a sharp increase. Concurrently, on May 27, 1977, living *Balanus tintinnabulum* were found in the collection basket. Samples were taken from the collection basket beginning on May 31, 1977 and were subjected to a more detailed analysis (Figure 4). Samples of living barnacles were removed, their aperture lengths measured, and the number of individuals comprising a clump or colony counted. Actual sizes encountered were slightly below the sizes predicted by the model, indicating a settlement time of approximately May 5, 1977. The number of living individuals in an average clump was 2 to 14 individuals/clump. Comparisons with earlier data taken in 1975 and 1976 confirmed that this settling density was extremely high. A rapid rise in shell debris (Figure 3) was also noted during this period.

At that point (May 31, 1977) clear indications of *Balanus tintinnabulum* fouling were present and the supervisor of plant operations was notified. No indications of fouling related problems were apparent in the plant operation other than some trouble with a condenser scrubbing (AMERTAP) system. However,

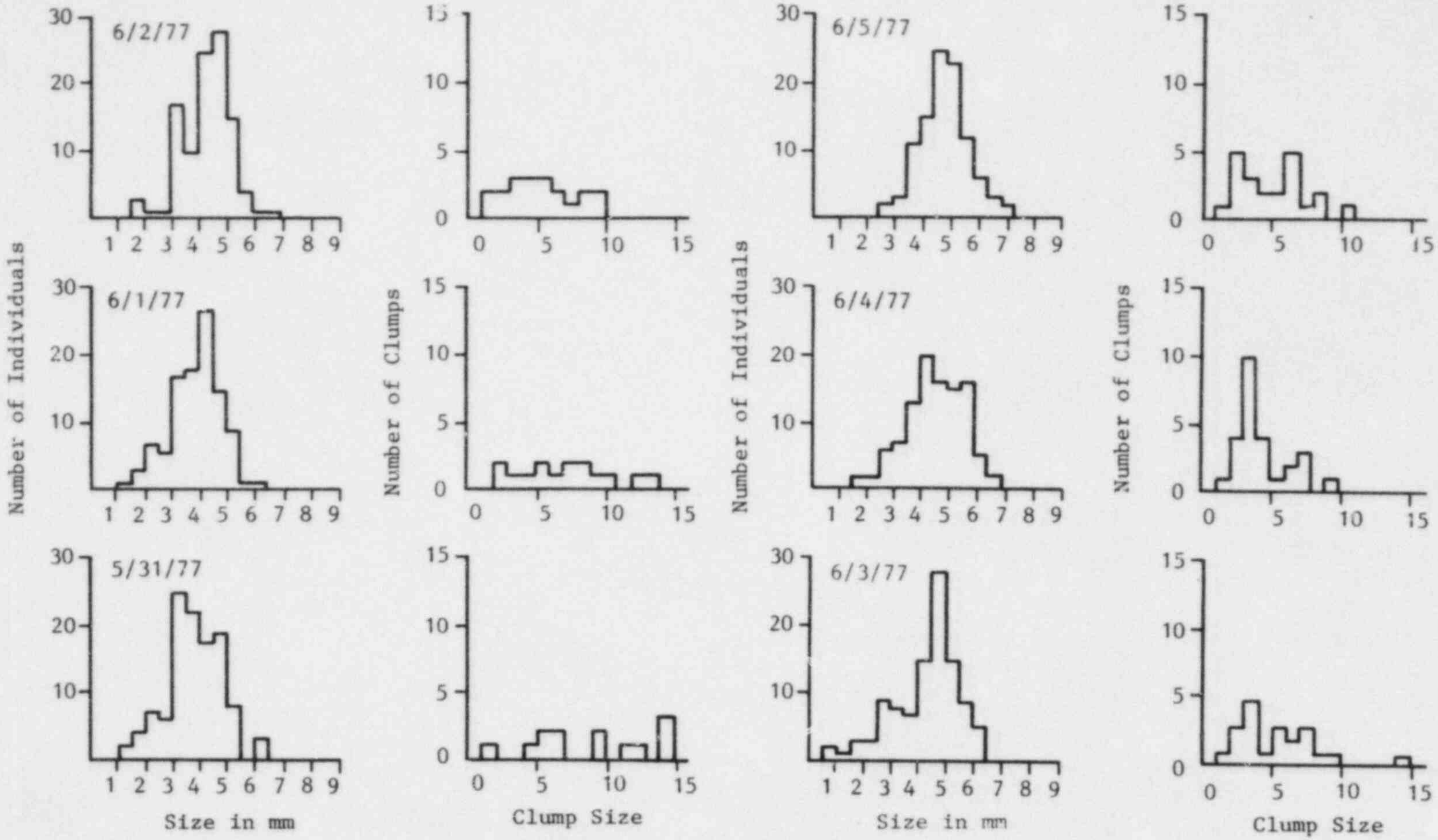

Figure 4. *Balanus tintinnabulum* size frequencies and clump frequencies from collection basket for the period 5/31/77 to 6/5/77.

it was estimated that steady increases in shell debris would take place and that severe trouble could be expected in 5 to 10 days.

Based on this information, a heat treatment was tentatively scheduled for June 5, 1977. First indication of fouling related problems with plant operation was a high condenser back pressure on June 2, 1977 which necessitated a reduction in plant output by 6-7 MWe. Quantities of shell debris were rising, and successive samplings from the collection basket showed little change in the frequency distributions and continued growth through time (Figure 4). Condenser backflushing once per shift started on June 4, 1977. Daily shell debris records peaked at 878 lbs just before the heat treatment operation (Figure 3) on June 5, 1977. The heat treatment was the first of the new series, applied to the intake conduit only for 1.7 hours at a screenwell temperature of 100°F. The operation appeared to be effective against *Balanus tintinnabulum* as shown in the subsequent rapid decline of shell debris (Figure 2) and the disappearance of living individuals in the collection basket.

<u>Measurements Preceding the July 24, 1977 Heat Treatment</u>

The second heat treatment interval is summarized in Figure 5. Again, shell debris quantities dropped rapidly after the preceeding heat treatment and remained very low until July 6, 1977 when they began to rise. During this

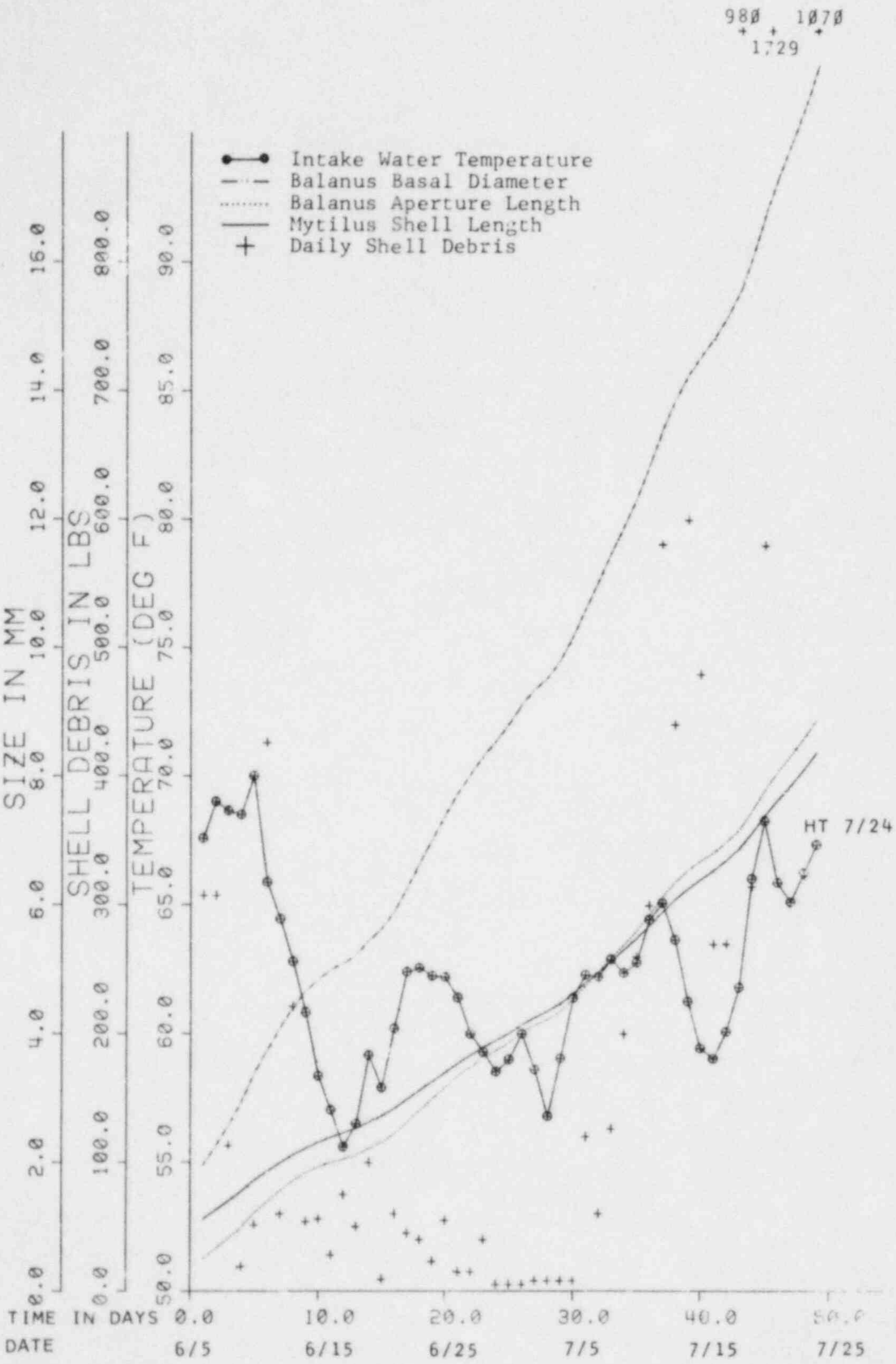

Figure 5. Water temperatures, shell debris, and predicted growth records for the period 6/6/77 to 7/24/77.

period, water temperatures showed wide fluctuations, dropping almost 14°F in 7 days and slowly rising and falling at one week intervals thereafter. These oscillations in temperature exerted a strong influence on the calculated growth rates which are reflected in Figure 5.

On July 5, 1977 living *Balanus tintinnabulum* were seen in the shell debris, which had increased to 120 lbs by July 6. The estimated settling time of these individuals was June 12, 1977. In contrast to the previous set, the clump frequency distribution (Figure 6) was clustered below 6 individuals/clump, indicating a moderate set of *Balanus*. From July 7 to July 11, the shell debris rose steadily and the supervisor of plant operations was notified of this increase. By July 13, shell debris exceeded 500 lbs/day and condenser backflushing was started. A heat treatment operation was scheduled for July 23 or 24. During the interval July 14 to 24, shell debris oscillated at high levels, exceeding 900 lbs/day (7/21/77, 1729 lbs/day; and 7/22/77, 1513 lbs/day). Collection basket samples (Figure 6) showed continued growth and little change in clump frequency during that time. The heat treatment on July 24, 1977 was the prototype (i.e., 1.7 hours at 100°F in the screen-well and applied to the intake only). Again, the operation appeared to be effective as living *Balanus* ceased to appear in the shell debris and there was a rapid reduction in the quantity of shell debris (Figure 2).

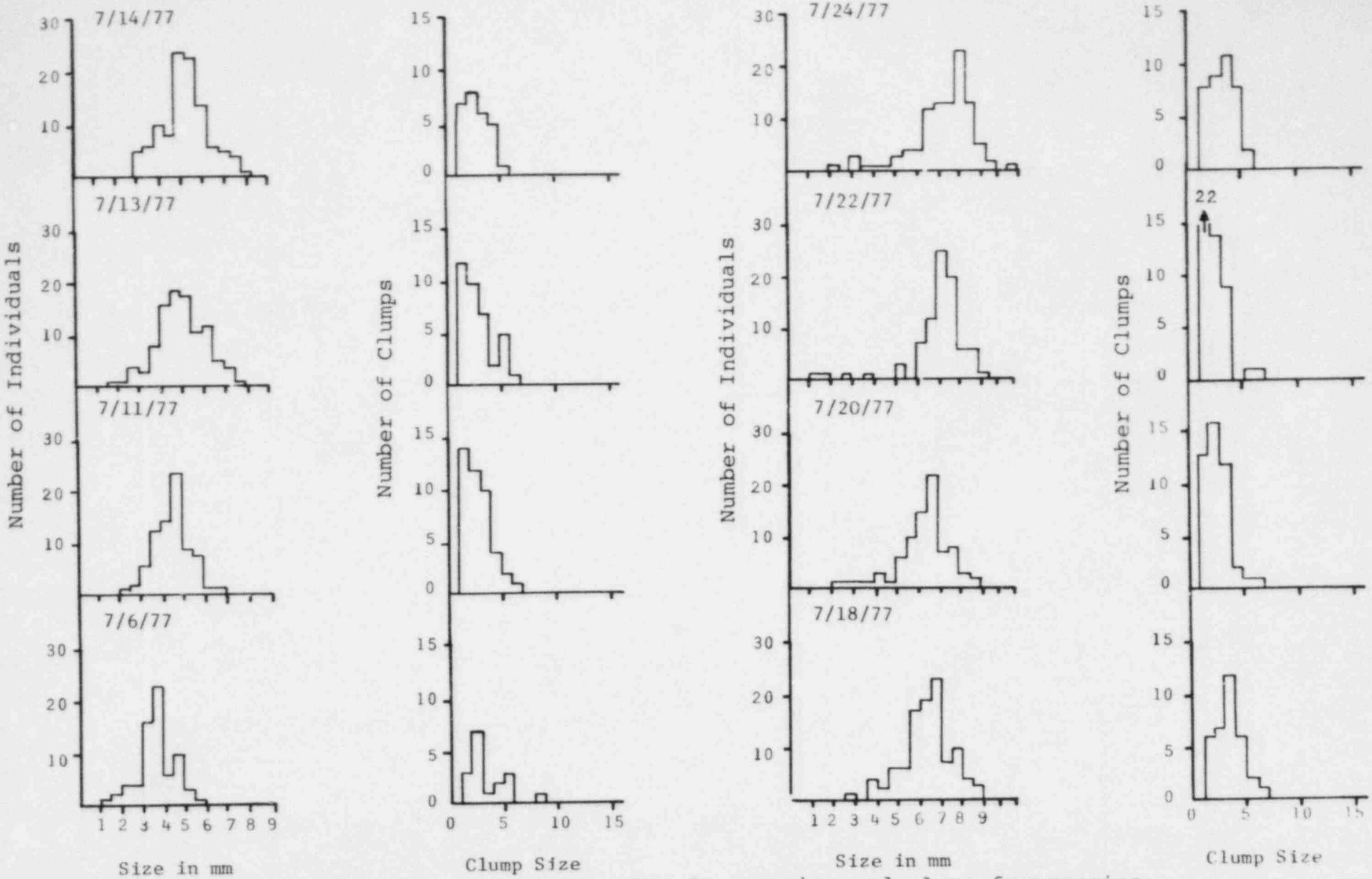

Figure 6. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 7/6/77 to 7/24/77. Approximate date of major settlement estimated at 6/12/77.

Measurements Preceding September 4, 1977 Heat Treatment

The third heat treatment interval is shown in Figure 7. During this period, intake temperatures generally remained high, broken by only a single period around August 15, 1977, when they declined below 65°F. Projected growth was rapid, and relatively constant. Shell debris remained low until August 18, 1977 when it evidenced several sharp rises and falls. By August 22, 1977 living *Balanus tintinnabulum* were observed in the collection basket although they comprised only 15% to 25% of the shell debris present. Samples taken on August 23, (Figure 8) showed a mean size of approximately 4.5 mm with only 1 or 2 individuals/clump. The estimated date of settlement was August 7, 1977 and the small clump size indicated a relatively light set in comparison with the previous ones. The supervisor of plant operations was notified of the situation and it was agreed that monitoring would continue for an extended period before scheduling a heat treatment operation. As expected, the quantity of shell debris rose at a slow but erratic pace over the next few days. On August 31, 1977 the *Mytilus* growth model predicted average sizes greater than the 9.6 mm critical size and a heat treatment operation was scheduled and carried out on September 4, 1977. The remaining collection basket measurements (Figure 8) showed continued growth and little change in the clump frequency. Again, the reduced heat treatment was effective, producing an immediate decline in the shell debris entering the collection basket (Figure 2).

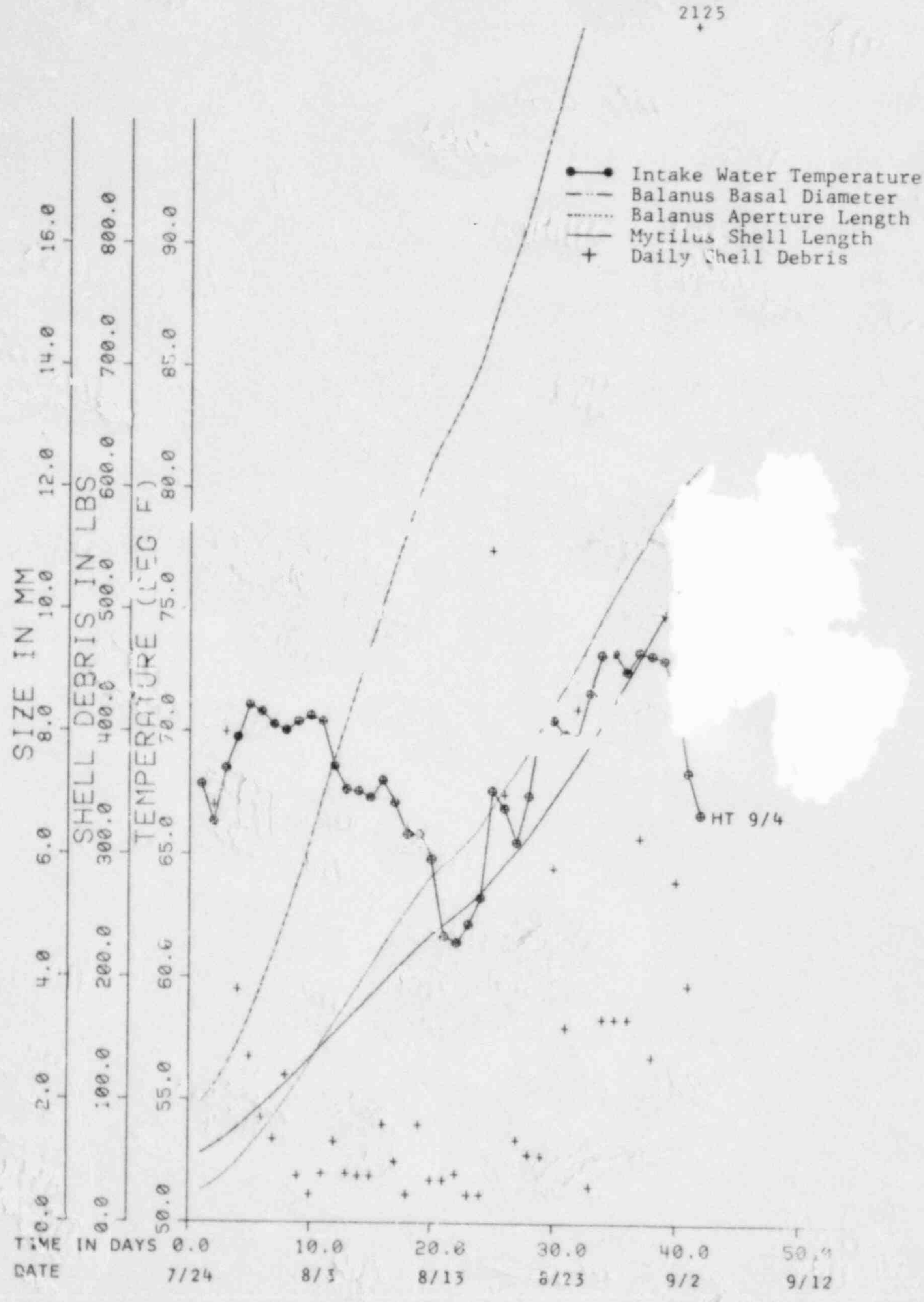

Figure 7. Water temperatures, shell debris, and predicted growth records for the period 7/25/77 to 9/4/77.

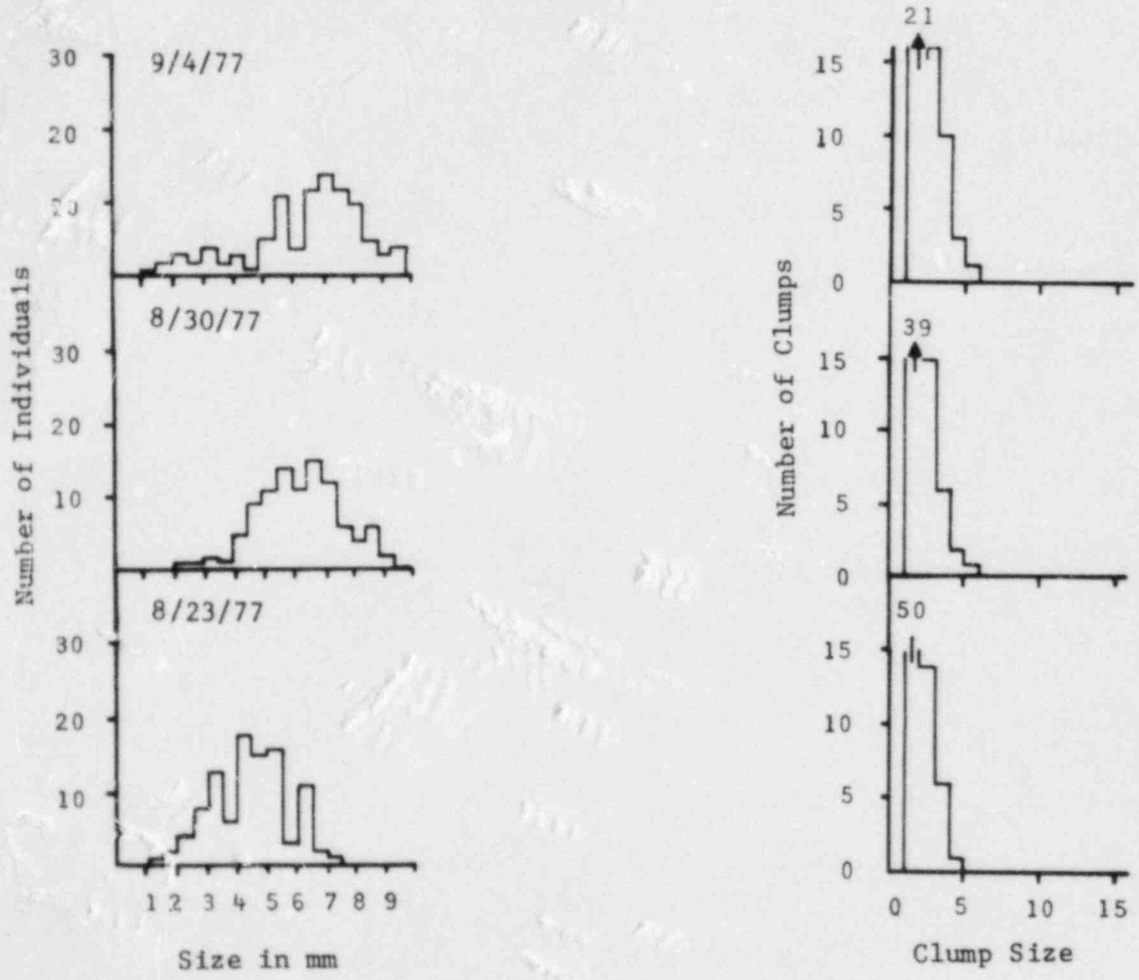

Figure 8. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 8/23/77 to 9/4/77. Approximate date of major settlement estimated at 8/7/77.

Measurements Preceding the October 28, 1977 Heat Treatment

The fourth heat treatment interval is shown in Figure 9. During this interval, water temperatures generally varied between 60° and 70°F. The high temperature on October 7 was caused by restarting the plant during a reverse tunnel configuration and only persisted for a few hours. Sharp fluctuations in temperature gradually decreased during the latter half of the period. An extended plant outage during which the circulating water pumps were periodically out of service (mainly during the earlier part of the outage) lasted from September 9, 1977 to October 7, 1977.

Shell debris remained at low levels until October 13, 1977 and increased slowly thereafter, with living *Balanus tintinnabulum* showing up in the collection basket on October 14, 1977. Samples taken on October 19, 1977 (Figure 10), revealed indications of a moderate set of *Balanus tintinnabulum* on September 21, 1977. By October 21, 1977 predicted *Mytilus* sizes had reached the 9.6 mm critical level, and shell debris levels were still relatively low. A subsequent sample of the collection basket on October 24, 1977 (Figure 10) revealed relatively slow growth and little change in *Balanus* clump size. Although quantities of shell debris remained relatively low, a substantial increase in the condenser back pressure occurred on October 26, 1977. This was caused by a considerable accumulation of living *Mytilus edulis* growing in

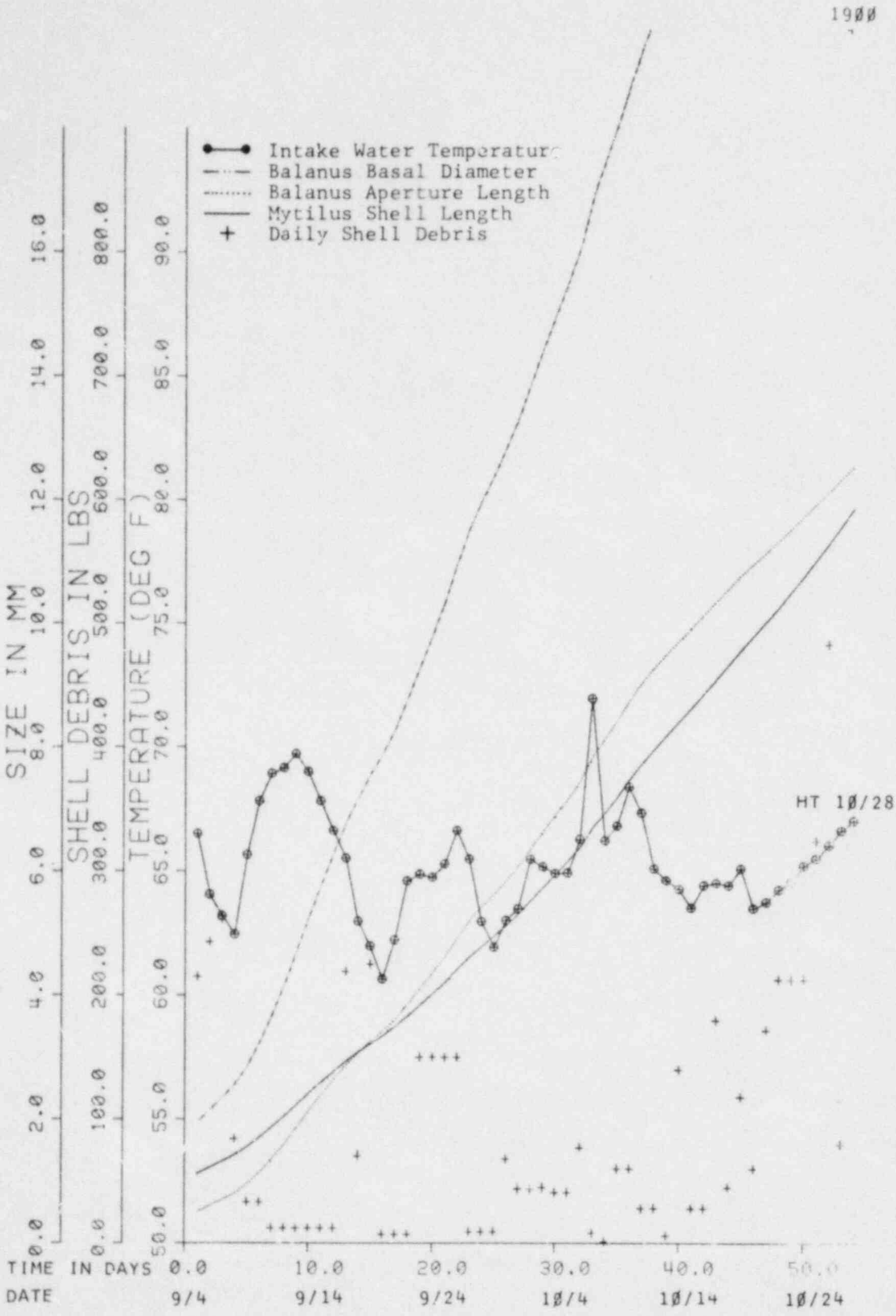

Figure 9. Water temperatures, shell debris, and predicted growth records for the period 9/5/77 to 10/28/77.

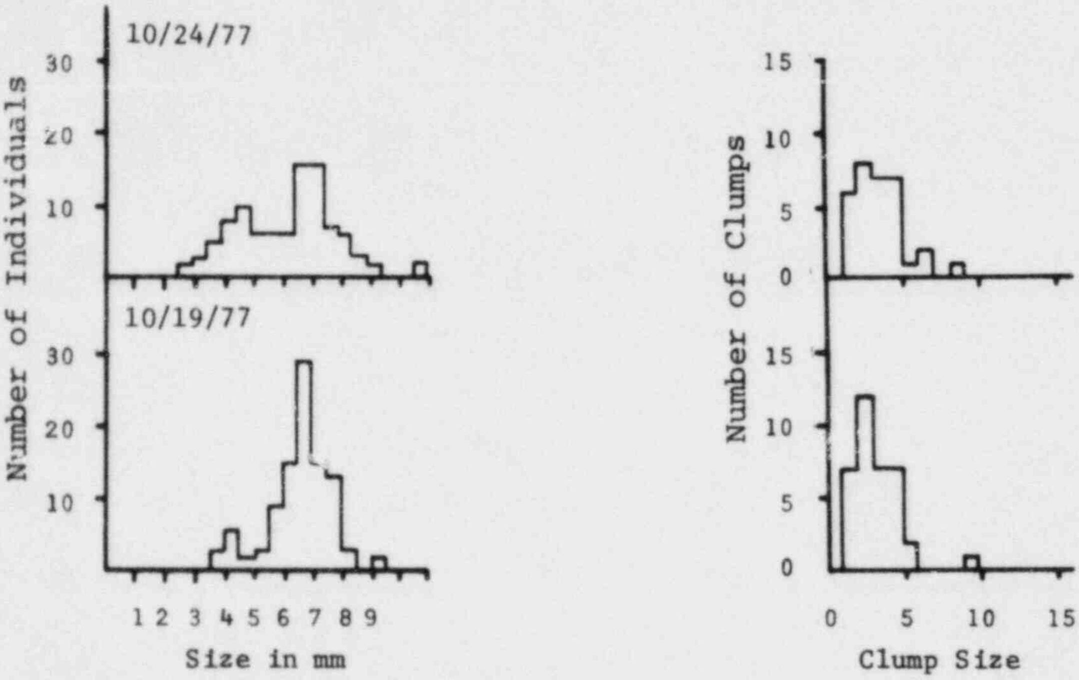

Figure 10. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 10/19/77 to 10/24/77. Approximate date of major settlement estimated at 9/21/77.

the areas between the traveling screens and the condensers breaking loose and blocking the condenser tubes. The heavy influx of *Mytilus* necessitated plant load reduction and condenser entries on an emergency basis to remove shell debris from the condenser tubes.

A sample of the living *Mytilus* extracted from the cleaning of the condenser area was measured and the size frequency distribution graphed (Figure 11). From the data supplied by the growth model, it was clear that this accumulation contained individuals that had settled as early as May 3, 1977 and had survived the 3 previous heat treatment operations. Faced with this information and the necessity of scheduling an immediate heat treatment operation, the conventional 105°F, [illegible] hour, each conduit heat treatment was re-implemented on October 28, 1977.

As it was thought that temperature stratification (i.e., colder water layers enabling some individuals to survive), in the screenwell could account for this unexpected survival, the traveling screens were instrumented with an array of 12 thermistor probes. Using these probes, the temperature profiles of the conduits were charted during the midpoints of the 105°F hold phase of both intake and discharge heat treatment operations. Two factors were immediately obvious. First, the temperatures during the heat treatment were relatively uniformly distributed throughout the conduit, and secondly, actual temperatures measured in the screenwells were about 3 to 5°F lower than those indicated by the readout instrument used by

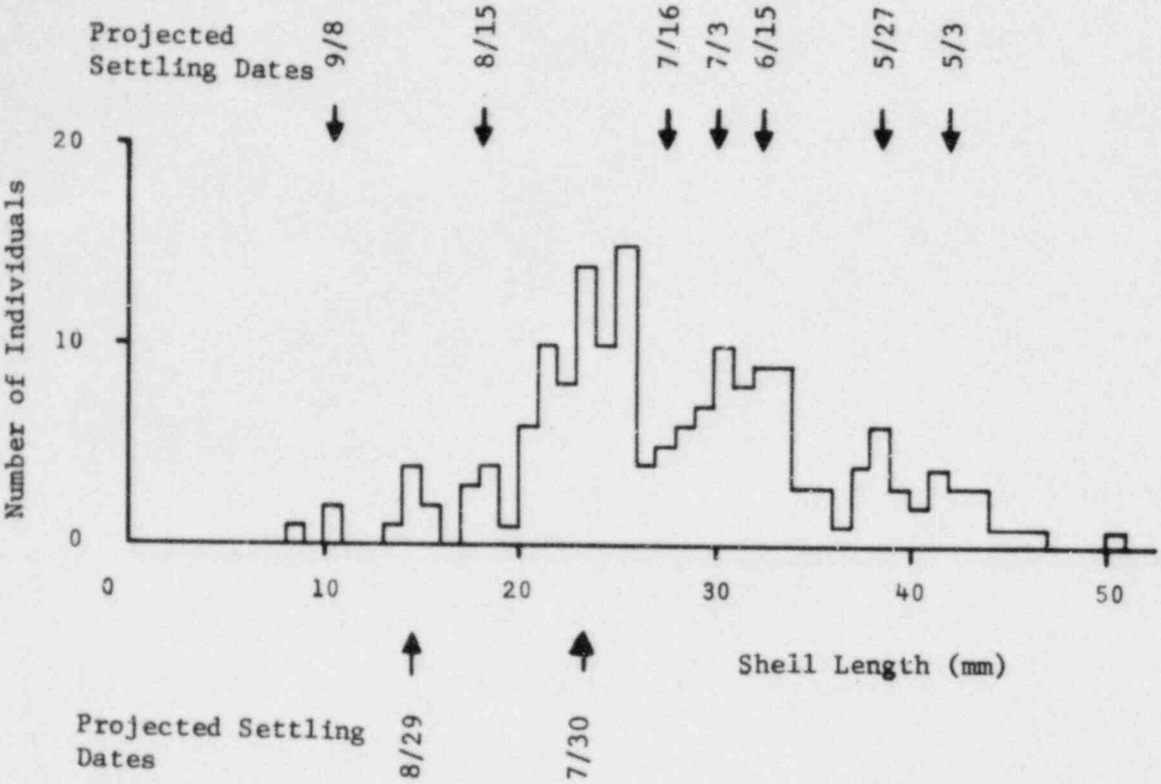

Figure 11. Size frequency histogram of *Mytilus edulis* obtained from the condenser cleanout on 10/26/77 shown with predicted sizes if settlement assumed during major low (top) and high (bottom) temperature events.

the operators to control the heat treatment temperature. This amount of error, if applied consistently to each previous heat treatment, would have led to a 95 to 97°F heat treatment being used instead of the intended 100°F. In the screenwell, *Mytilus edulis* would then have required approximately 6 hours of heat treatment to achieve the desired mortality at a temperature of 95°F. Thus, a minor error in temperature measurement without an accompanying significant increase in application time caused considerable difficulty. Additional evidence of the error in temperature may be found in the complete exclusion of living *Balanus tintinnabulum* from the condenser debris. Evidently the previous heat treatment temperatures were high enough to completely kill the *Balanus* while permitting some *Mytilus* survival.

Using the data available from the *Mytilus* sample in Figure 11 and the growth model, a high degree of correlation was shown between low temperature events as identified in Figure 1 and major size-frequency peaks shown in Figure 11. Two size-frequency peaks were also correlated with major high temperature peaks. This confirmed observations that settlement or spawning is mediated more by temperature changes rather than any specific set temperature (Bayne 1976). Although there is probably some relationship between spawning, settlement, and temperature for *Mytilus* the relationship is still unclear. With regard to *Balanus tintinnabulum*, some settlement has taken place between each of the heat treatment intervals. However, no discernible correlation of settling period with temperature is evident at this time.

Measurements Preceding the December 20, 1977 Heat Treatment

Major events of the fifth heat treatment interval are summarized in Figure 12. The extreme ambient temperature fluctuations ceased and the general temperature trend was downward. As was expected for a period lacking sharp temperature variations, fouling remained at a low level. A few living *Balanus* were found in the shell debris on November 29, 1977, the clump frequency (1-2 individuals per clump) and average size (3.7 mm) were small enough to indicate that a light set had taken place 12-14 days earlier. Although examined periodically, the quantities of living *Balanus* did not appreciably increase beyond sightings of occasional individuals. As scheduled by the growth model, a heat treatment was carried out on December 20, 1977 restoring the reduced mode, intake only heat treatment cycle using the recalibrated temperature recording device. Additionally, a visual inspection was made of the condenser inlets during the condenser cleanout of December 28, 1977.

This inspection revealed a small patch (1-2 sq ft) of dead *Mytilus* on the roof of one of the concrete tunnels. The condition of these mussels were such that they were judged to have been killed during the previous heat treatment of October 28, 1977. Their occurrence in the system after their death was attributed to the location of the patch in a sheltered area not exposed to the full water flow, and to a heavy attachment of byssal threads to the conduit and the exterior of the shells (this patch has subsequently disappeared). No other major fouling was seen in the tunnels.

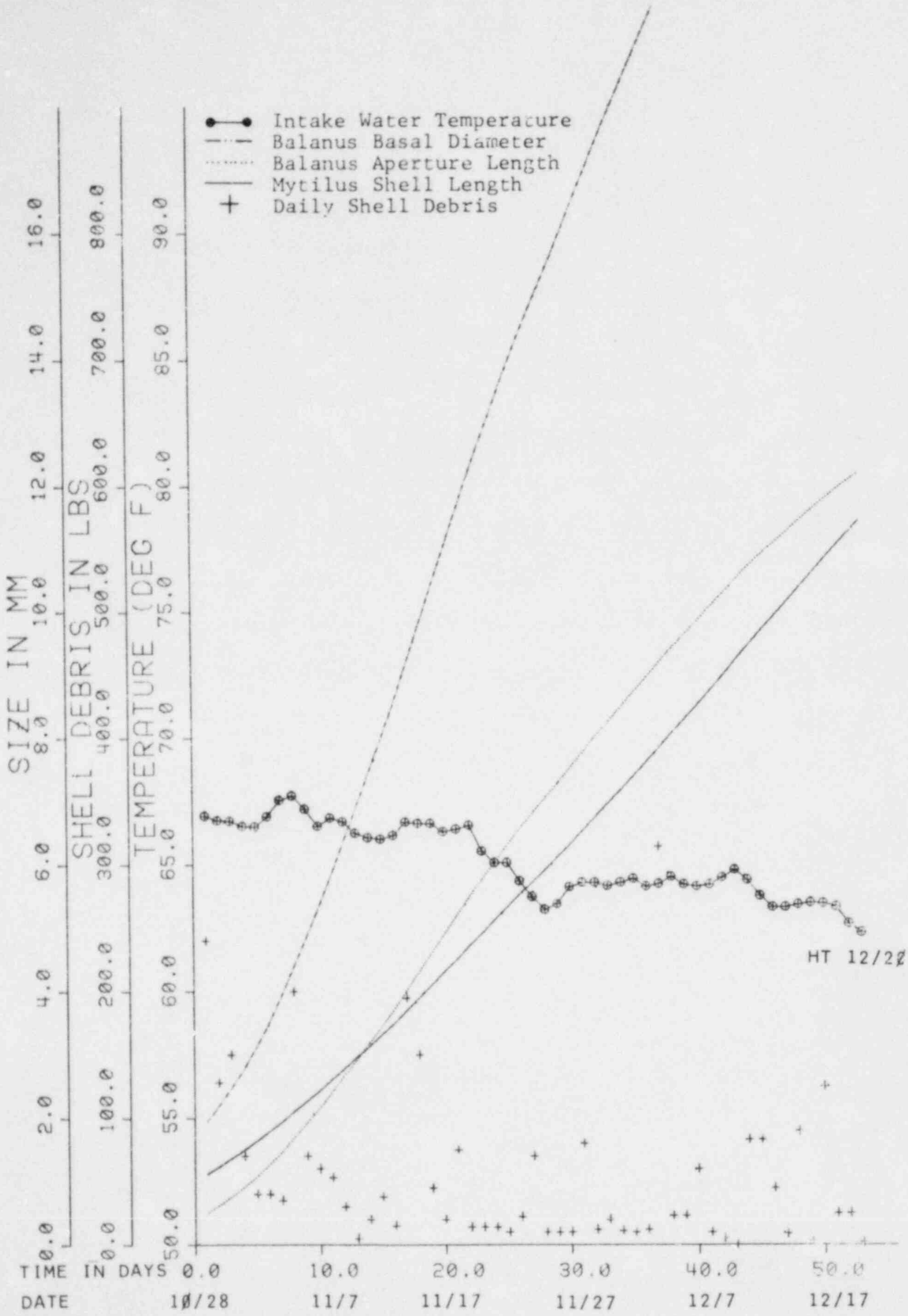

Figure 12. Water temperatures, shell debris, and predicted growth records for the period 10/29/77 to 12/20/77.

Measurements Preceding the February 12, 1978 Heat Treatment

During this period, the average water temperatures remained at approximately 63°F (Figure 13), a value considerably warmer than the 56 to 57°F (Figure 1) normally expected during this period. Shell debris remained at low levels throughout the period with some increases due to storm activity. No living *Balanus* were encountered, and the heat treatment cycle occurred as scheduled on February 12, 1978. The warm temperatures encountered during this period considerably reduced the projected interval between heat treatments for the winter months. A visual condenser inlet tunnel inspection performed during the condenser cleanout of February 26, 1978 revealed no major fouling buildup on the walls.

Measurements Preceding the April 2, 1978 Heat Treatment

During this period, water temperatures remained stable, increasing slightly throughout the 49 day period (Figure 14). No *Balanus* settlement was recorded throughout this period, but the warm temperatures maintained a rapid potential *Mytilus* growth. Occasional large peaks of shell debris were due to offshore storm action which also resulted in the entrainment of large quantities of drift seaweed. This seaweed acts as a scouring agent, thus knocking large quantities of dead shell debris off the conduit walls.

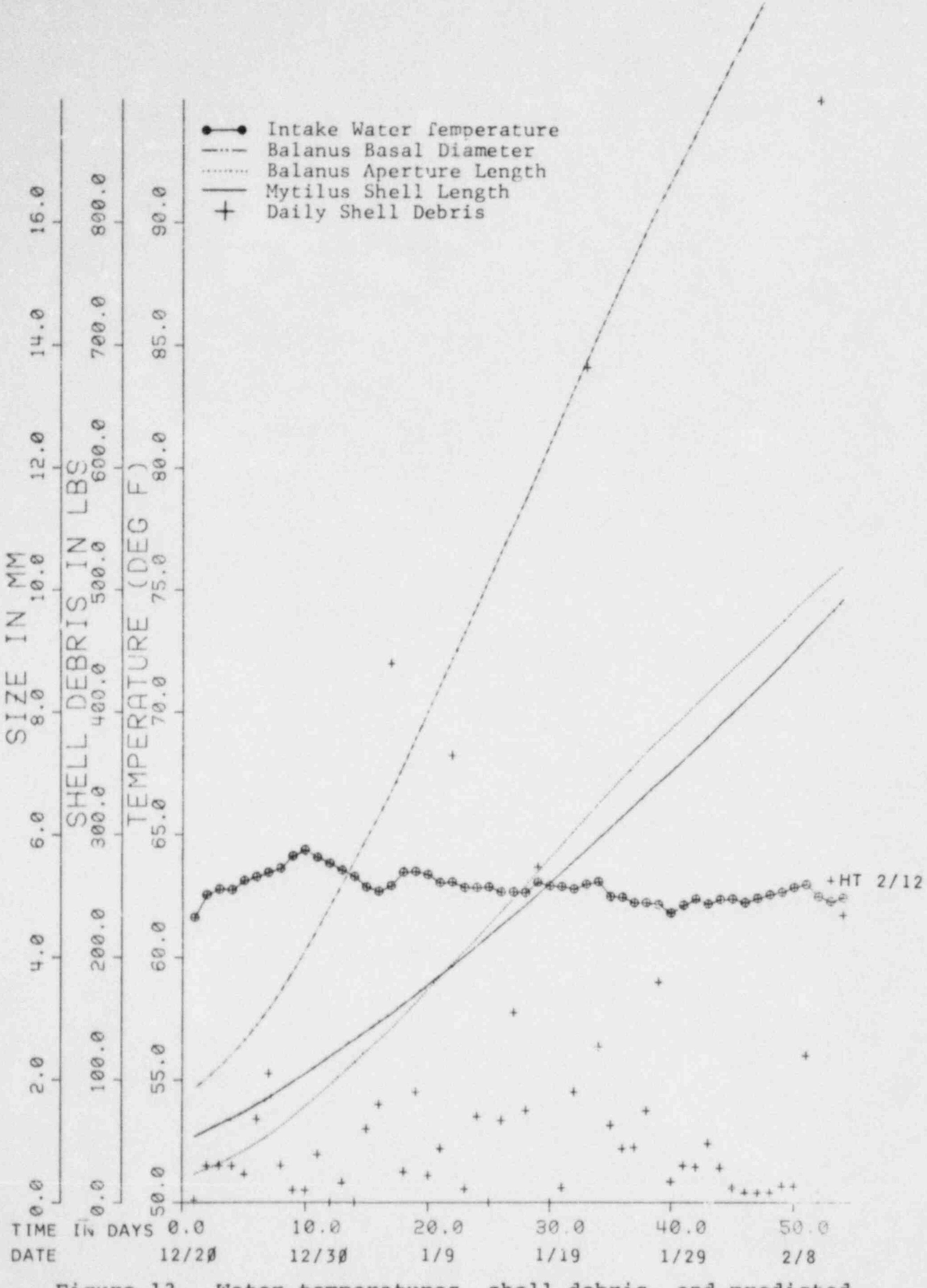

Figure 13. Water temperatures, shell debris, and predicted growth records for the period 12/21/77 to 2/12/78.

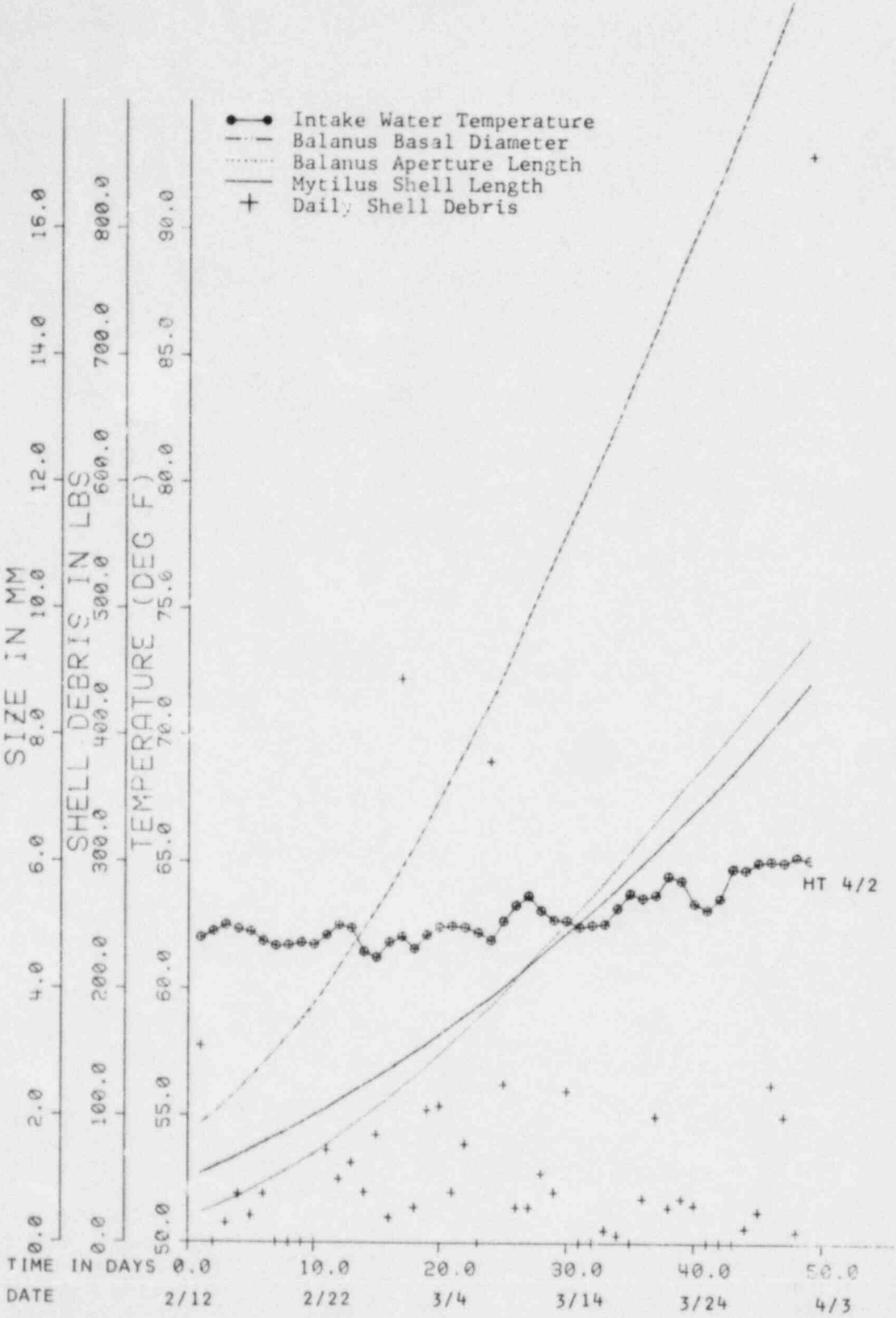

Figure 14. Water temperatures, shell debris, and predicted growth records for the period 2/13/78 to 4/2/78.

Otherwise, conditions remained stable with the heat treatment occurring on April 2, 1978. This heat treatment was 3-5 days earlier than was scheduled by the growth model due to plant operational requirements.

Measurements Preceding the May 17, 1978 Heat Treatment

The eighth heat treatment interval is shown in Figure 15. During this period, temperatures dropped steadily, reaching a low of 57.5°F on April 23, 1978 and then began an upward trend. Short-term temperature variations also increased noticeably over those encountered in the two previous heat treatment intervals.

Living *Balanus* appeared in the collection basket on May 8, 1978. Samples taken at that time (Figure 16) show a mean size of 3.3 mm in aperture and a clump size of 8-10 individuals. This information suggested that a heavy set of *Balanus* had taken place somewhere between April 18, and May 1, 1978. Successive samples taken on May 11, 15, and 17, 1978 (Figure 16) showed growth to be rapid with clump size remaining at 6-8 individuals. Due to this influx, a heat treatment was carried out on May 17, 1978.

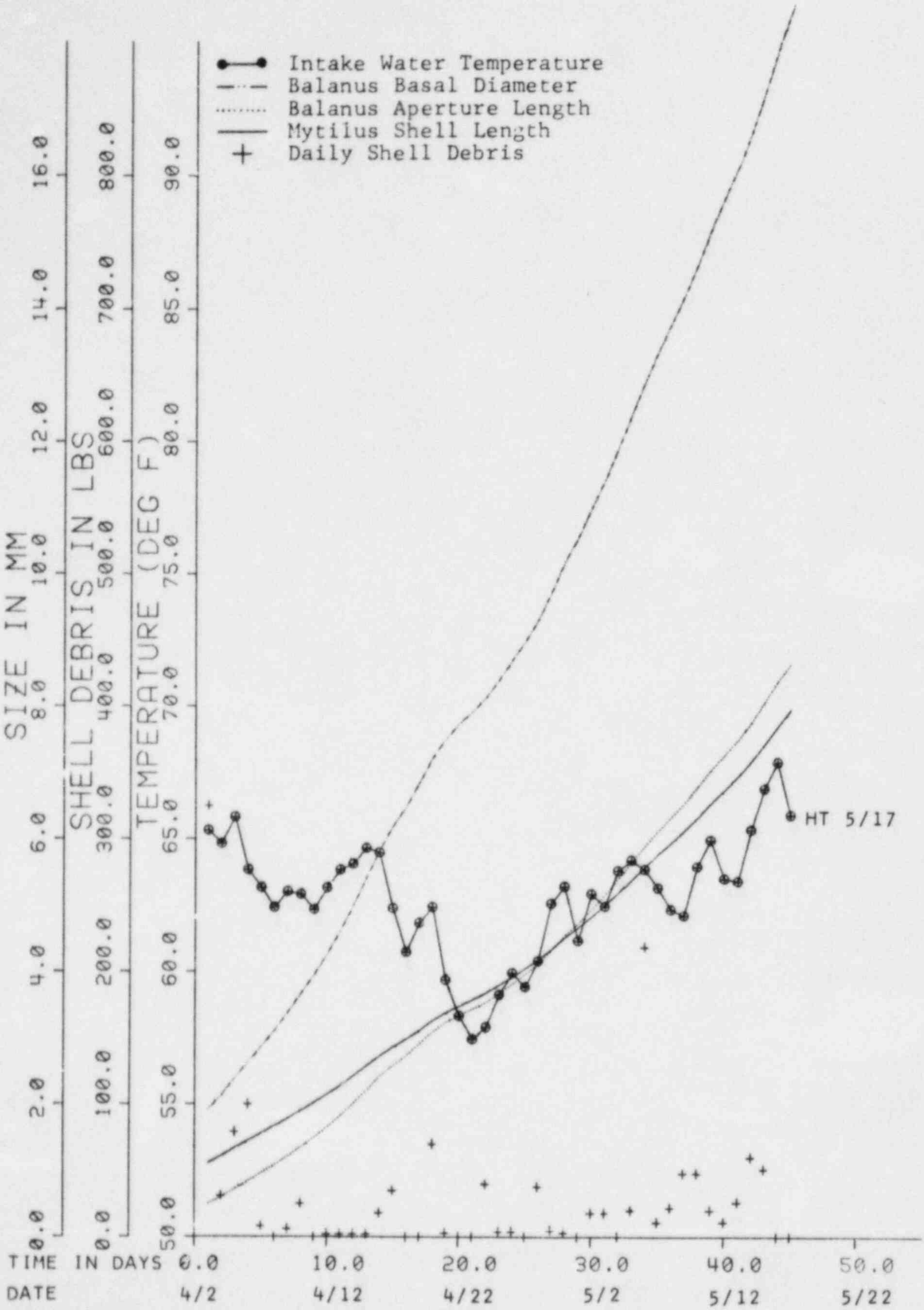

Figure 15. Water temperatures, shell debris, and predicted growth records for the period 4/3/78 to 5/17/78.

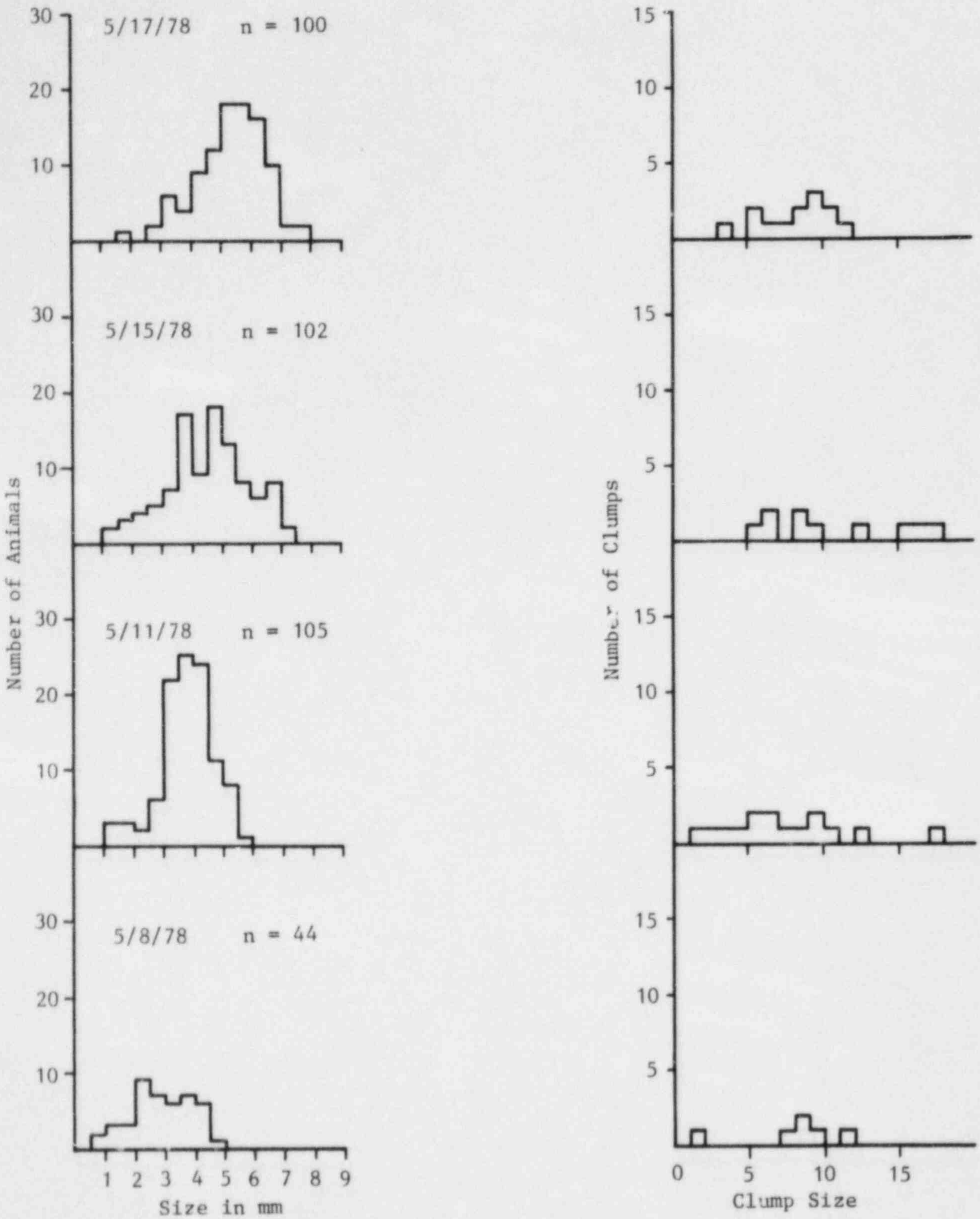

Figure 16. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 5/8/78 to 5/17/78. Approximate date of major settlement estimated at between April 18, and May 1, 1978.

Measurements Preceding the June 23, 1978 Heat Treatment

During this period water temperatures were extremely erratic, showing several highs and lows (Figure 17). The general temperature trend was warming slightly until a sharp declince occurred on June 11, 1978. The effect of this decline on the growth model caused a general flattening of the growth curve slope.

Living *Balanus* appeared in the collection basket on June 15, 1978, and samples were taken and measured on June 16 and 19, 1978. These measurements are summarized in Figure 18, and suggest a moderate settlement of *Balanus* about May 29, 1978. Shell debris records during this period are erratic, peaking at over 300 lbs/day on June 11, 1978 and then for some unknown reason dropping off. However, *B~lanus* were still abundant in the collection basket and as a precautionary move a heat treatment was accomplished on June 23, 1978. On July 3, 1978 the condenser water boxes were opened for cleaning and a visual condenser inlet tunnel inspection was made of the south condenser halves. The inspection revealed that all concrete surfaces were free of major fouling.

Measurements Preceding the August 20, 1978 Heat Treatment

This interval was characterized by wide daily temperature variations (Figure 19). These variations alternately acceler-

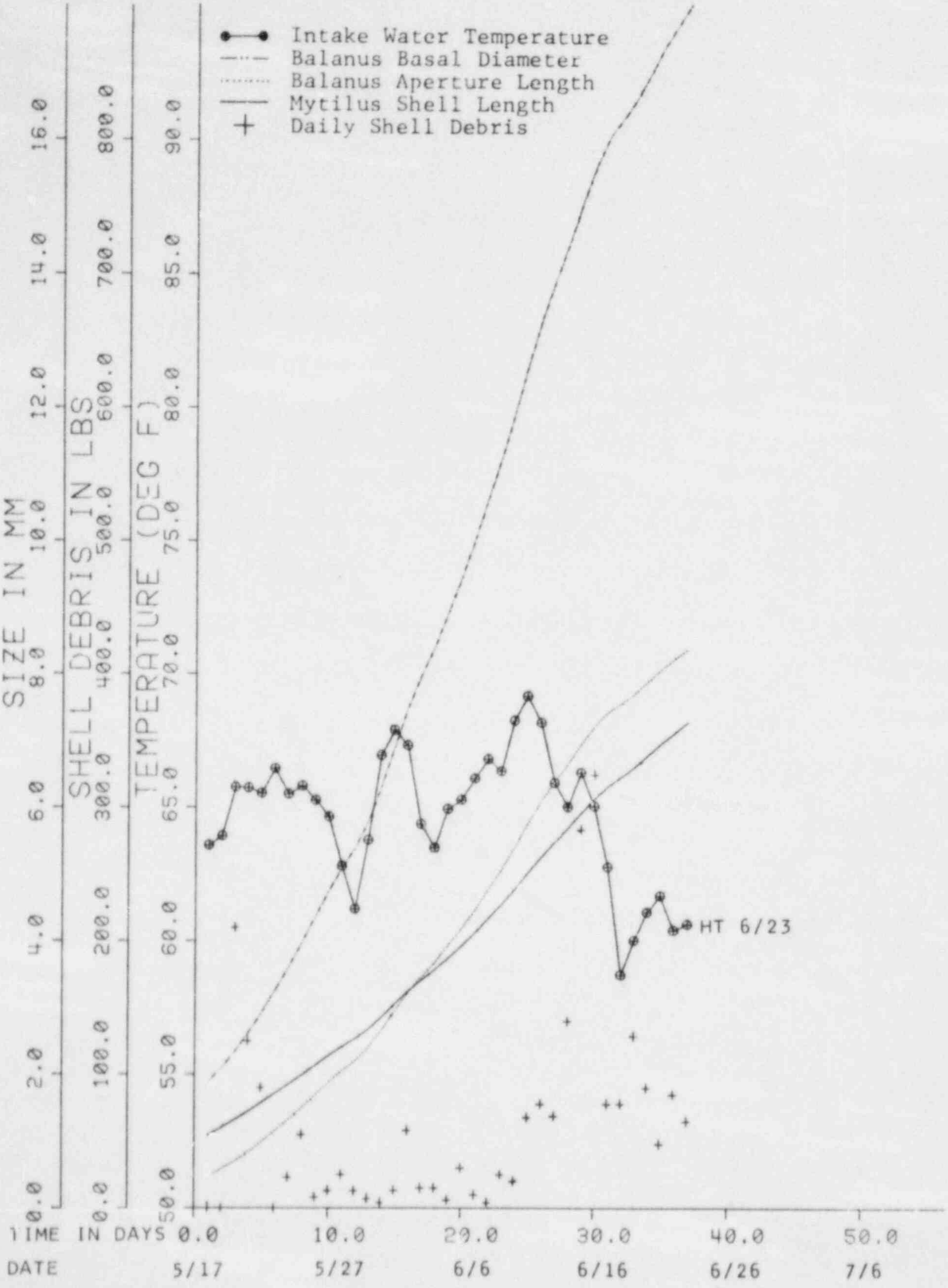

Figure 17. Water temperature, shell debris, and predicted growth records for the period 5/18/78 to 6/23/78.

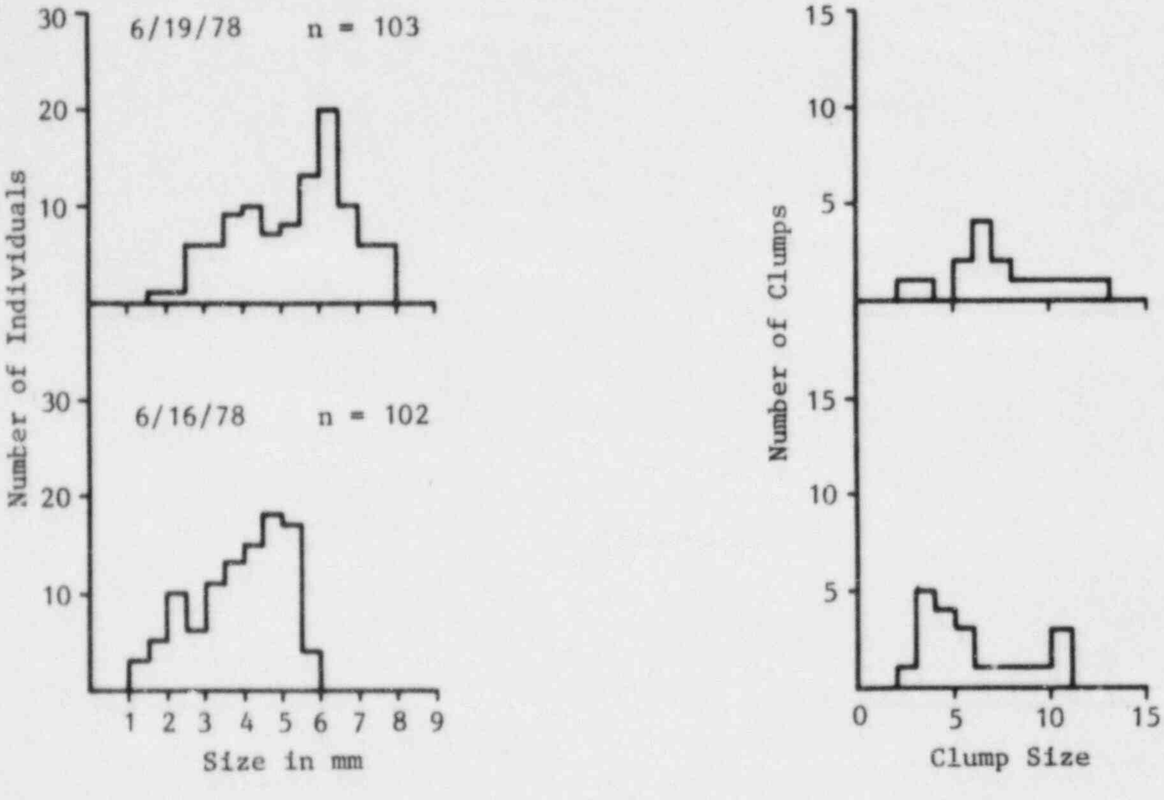

Figure 18. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 6/16/78 to 6/19/78. Approximate date of major settlement estimated at May 29, 1978.

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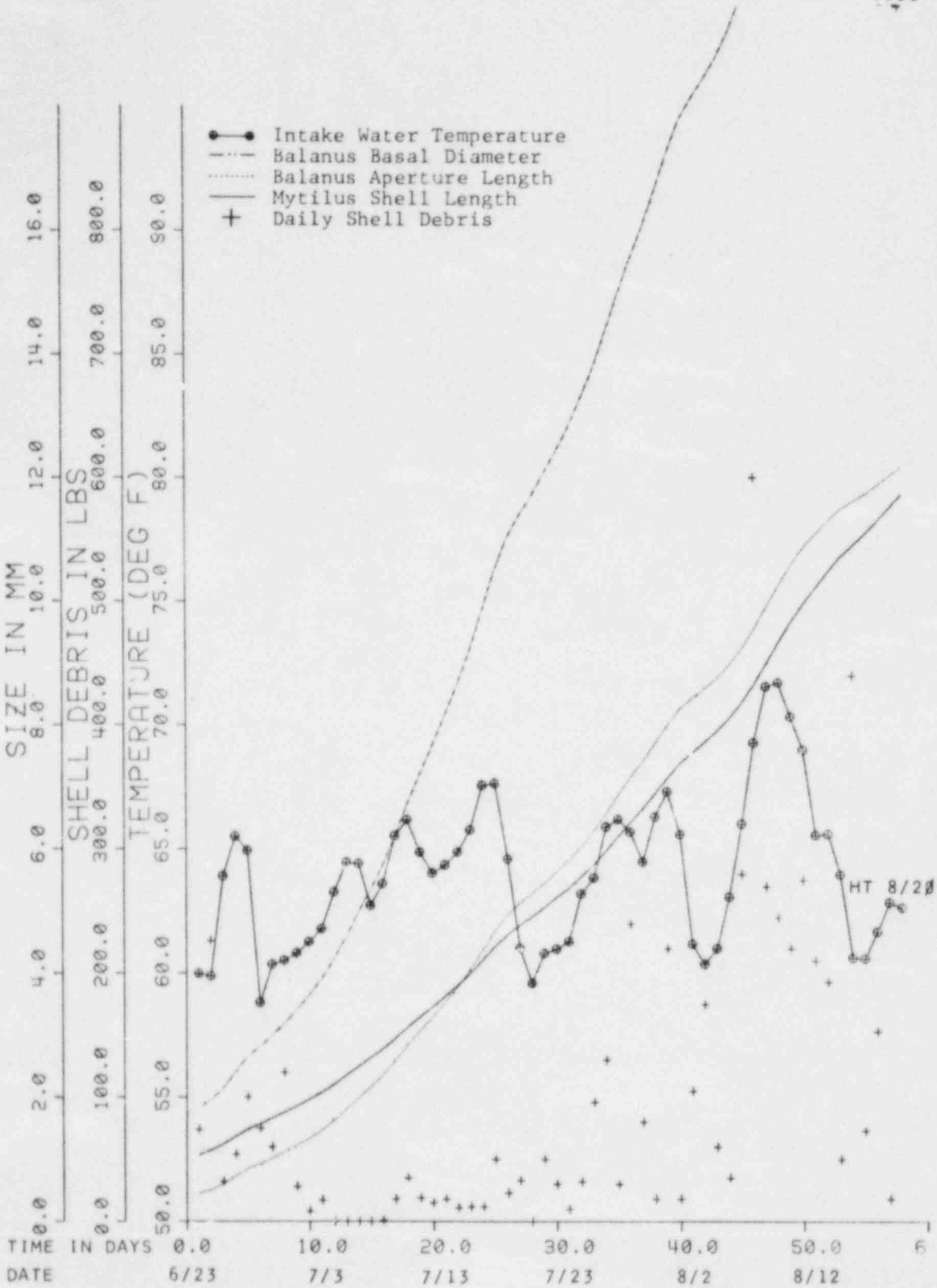

Figure 19. Water temperatures, shell debris, and predicted growth records for the period 6/24/78 to 8/20/78.

ated or retarded the growth rates producing a wavy growth curve. Shell debris dropped to low levels by July 2, 1978 and remained low until July 25, 1978. Examinations of the shell debris on July 27, 1978 failed to disclose living individuals. Living *Balanus* appeared in the collection basket subsequently and samples were taken on August 9, 11, and 14, 1978. The results are plotted in Figure 20, and indicate a light settlement around July 9, 1978.

Due to the indications that the settlement was relatively light (i.e., a small clump size and relatively large individuals), it was decided that immediate action could be postponed until the scheduled heat treatment cycle occurred. As expected, shell debris increased slowly, leveling off at roughly 100 to 300 lbs/day with occasional higher peaks. A heat treatment was done on August 20, 1978, 58 days after the previous cycle.

Measurements Preceding the September 13, 1978 Heat Treatment

During this short 24 day period, temperatures peaked at over 70°F (Figure 21), thus greatly accelerating growth. Shell debris declined swiftly from the previous heat treatment and remained at low levels throughout the interval. The heat treatment cycle was initiated considerably earlier than expected due to a planned 2-3 month outage for plant refueling and repair. During the repair periods, biofouling control is

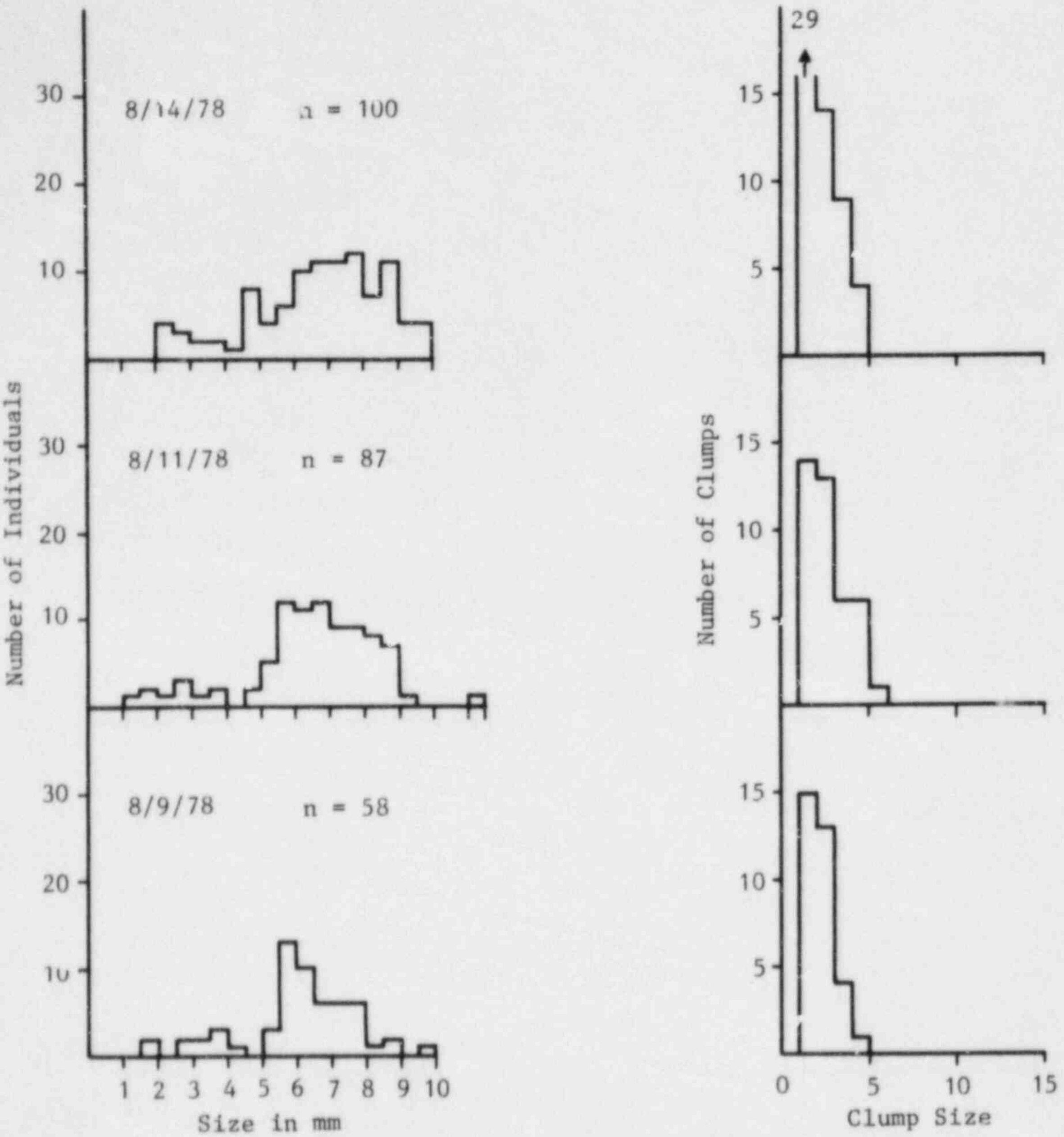

Figure 20. *Balanus tintinnabulum* size frequencies and clump frequencies from the collection basket for the period 8/9/78 to 8/14/78. Approximate date of major settlement estimated at July 9, 1978.

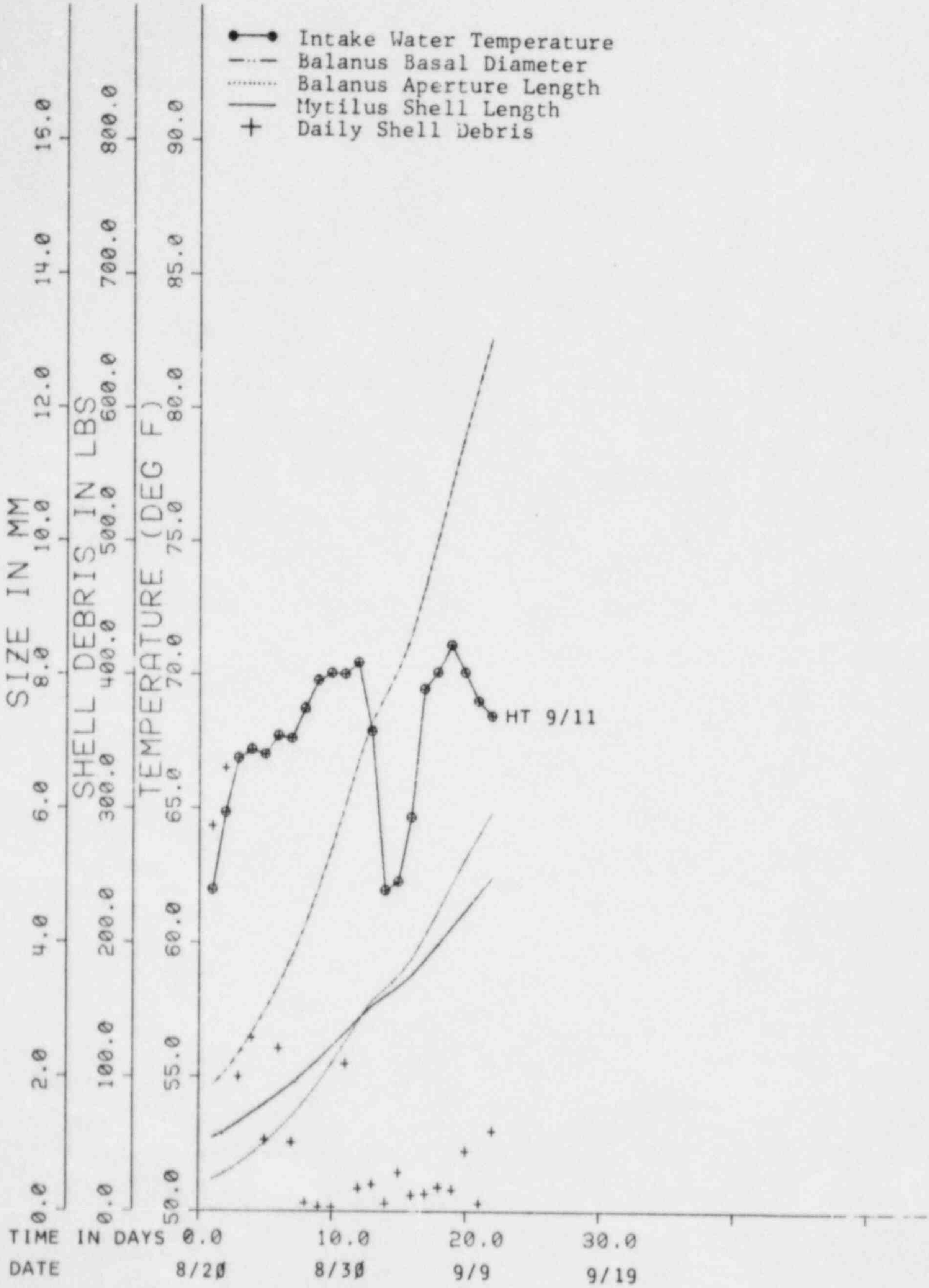

Figure 21. Water temperatures, shell debris, and predicted growth records for the period 8/21/78 to 9/11/78.

not possible and it is common practice to conduct a heat treatment just before taking the unit out of service. This process has been previously effective in minimizing fouling problems in the conduits.

Maintenance operations on the circulating water pumps allowed unrestricted access to the pump outlet and condenser inlet areas on September 20, 1978. Inspection of these areas revealed no major buildup of fouling. As expected, the small barnacle *Chthamalus fissus* was present in great abundance, forming a monolayer over the concrete surface.

Fouling Conditions in the Discharge Conduit

Except for a single heat treatment exposure of 105°F (screenwell temperature) for 2 hours on October 28, 1977, the discharge conduit was not treated. In the final 12 month period there was no need for treatment of the discharge conduit. Temperature conditions in the discharge conduit remained relatively stable until June 1, 1978 when the plant was operated under reduced load. Hourly discharge conduit temperatures are plotted in Figure 22 for the period June 1, 1978 through September 13, 1978.

For the interval June 1 through July 3, temperatures were below 80°F except for comparatively brief periods. During this period, fouling growth was assumed to occur in the discharge conduit, but it was expected that this growth would be gradually removed when the plant regained full load and the

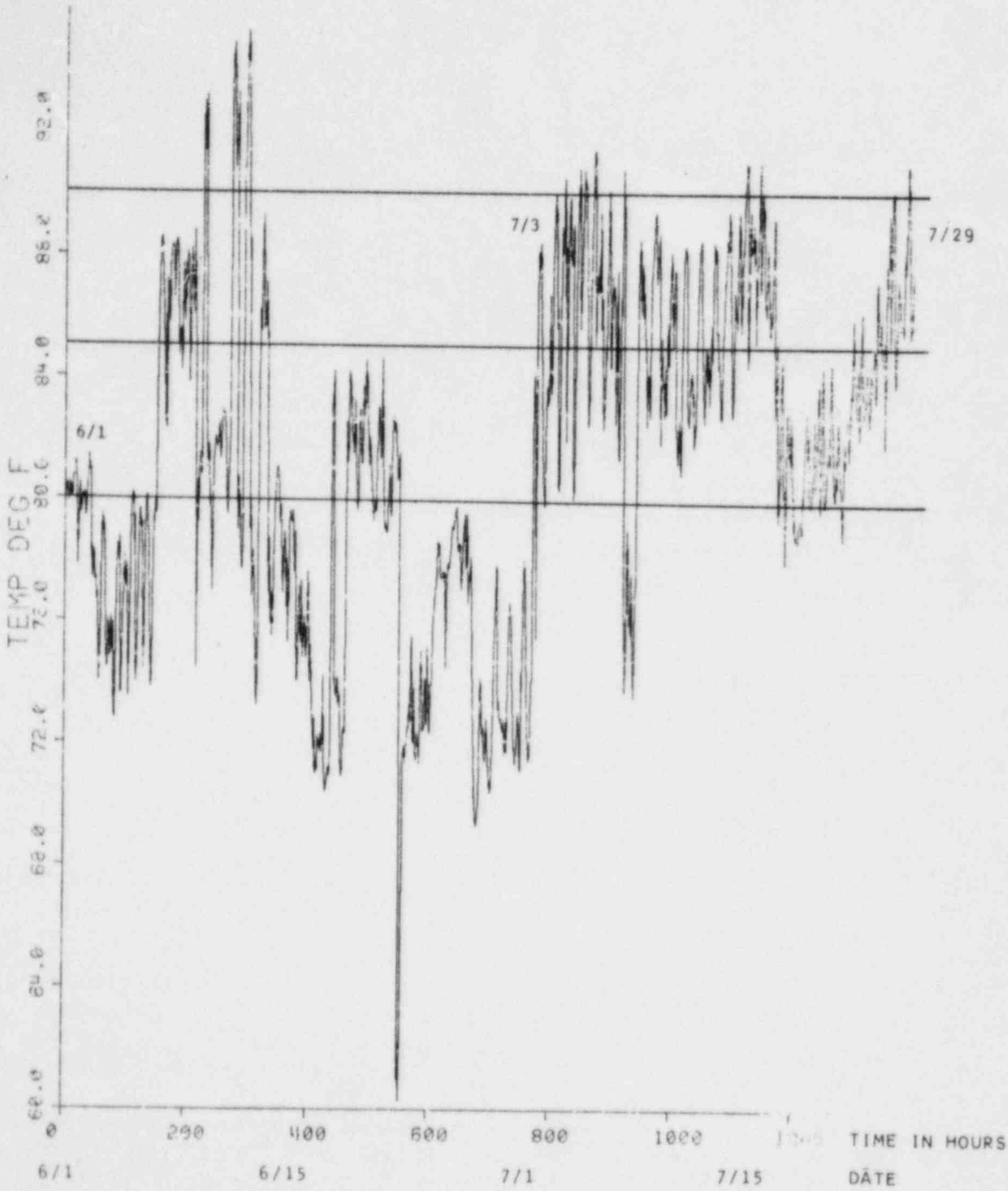

Figure 22. Hourly discharge conduit water temperatures. Beginning 0100 hours on June 1, 1978 and ending at 0900 hours on September 13, 1978. (Continued).

Figure 22. Continued.

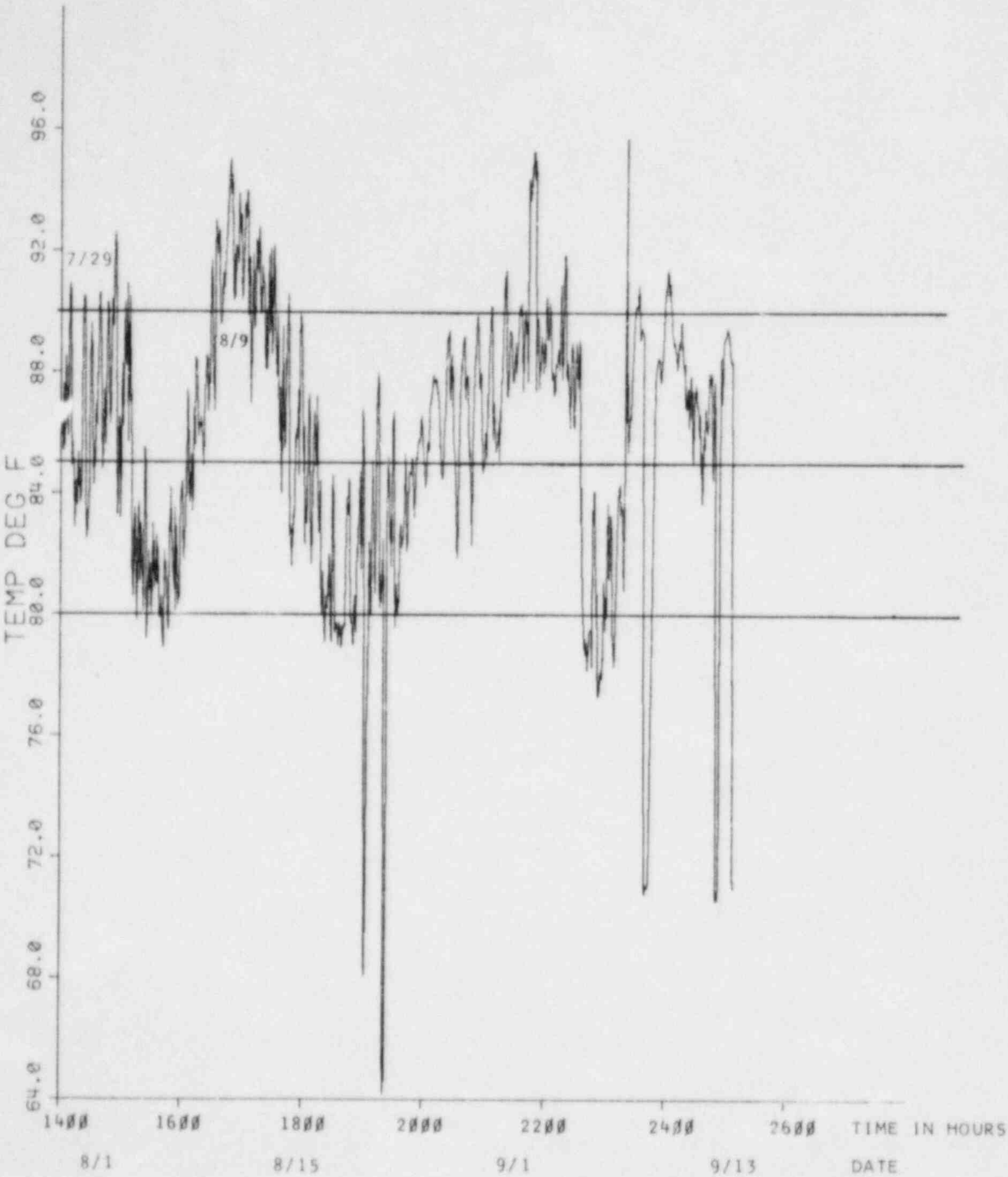

Figure 22. Hourly discharge conduit water temperatures. Beginning 0100 hours on June 1, 1978 and ending at 0900 hours on September 13, 1978.

discharge conduit resumed its normal temperature elevation above ambient. On July 3, 1978 the plant returned to full load operations with diurnal temperature cycles varying at approximately 85°F. A normal high ambient temperature event occurred on August 9, 1978 causing discharge conduit water temperatures to rise in excess of 90°F for 44 hours. This length of exposure was assumed to be lethal to all *Mytilus* in the discharge conduit.

Following this exposure, discharge temperatures remained within 80 to 89°F until September 13, 1978. Significant events during this period were a tunnel reversal and intake heat treatment on August 20, 1978 followed by another on September 13, 1978. In the latter heat treatment period, under the reverse tunnel mode of operation, a large influx of *Mytilus* was noticed. During the course of the heat treatment over 2,000 lbs of shell debris was collected. A sample of this debris was collected and measured (Figure 23) showing the majority of the debris to be approximately 27 mm in length. On October 13, 1978, 30 days after the influx of shell debris was recorded, an inspection of the discharge conduit was made by a diver. Traversing the entire length of the discharge conduit, the diver found narrow bands of matted shell debris in some areas. Close examination of this material disclosed that it was composed of the shells of dead *Mytilus*.

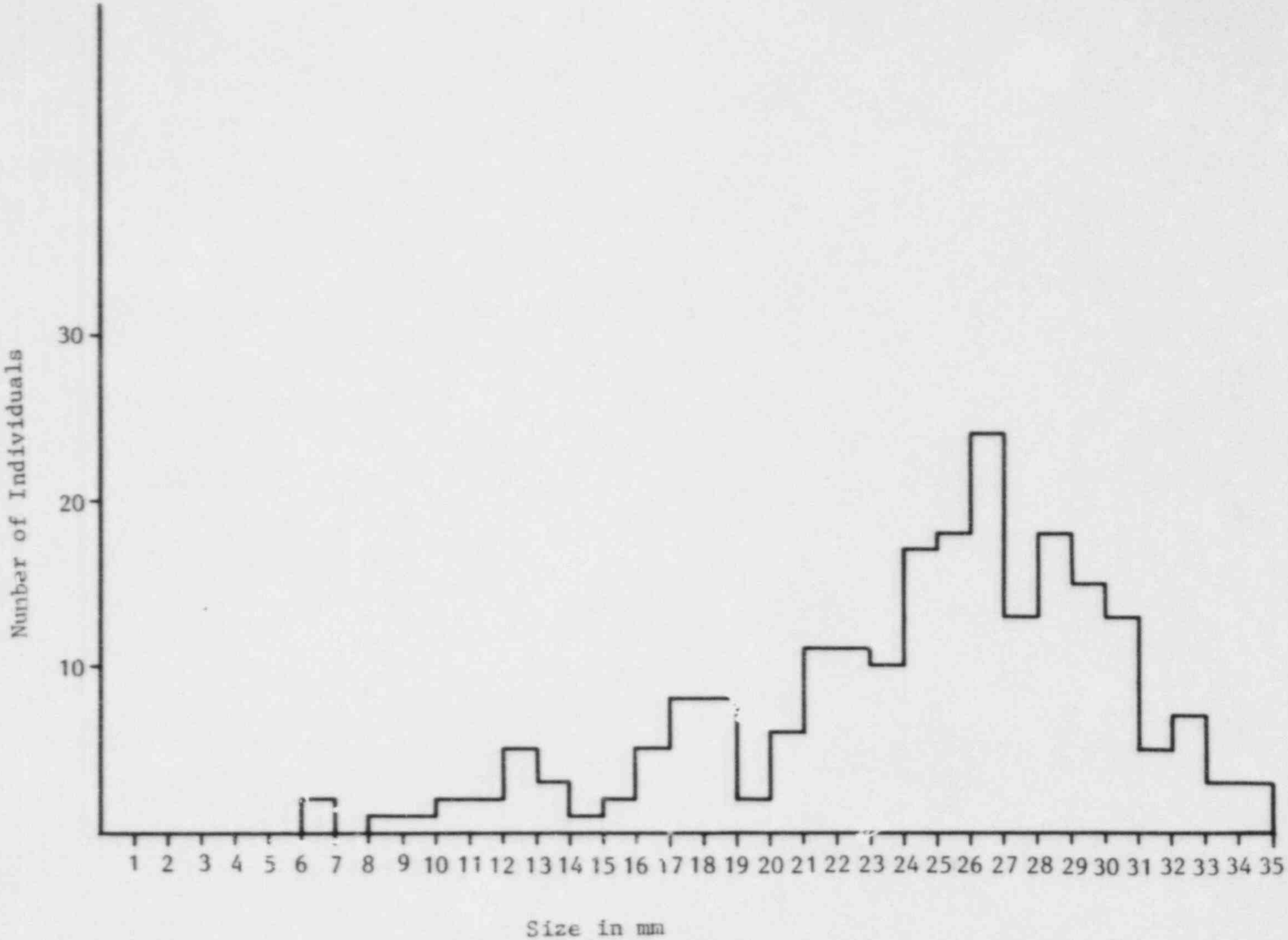

Figure 23. Size frequency histogram of *Mytilus edulis* obtained from the collection basket during the heat treatment on 9/12/78.

Although the growth model cannot be used with accuracy within the temperature range of the discharge conduit, settlement in early June is strongly indicated.

Two points are clearly illustrated. First, that under suitable low temperature conditions, *Mytilus* can occur and grow in the discharge conduit. Second, that this growth will eventually be killed by an exposure to operating conditions above 80°F. The current estimates of this length of time are derived from data presented in the Phase 1 Final Report (LAS 1975) and are estimated as exposures of 1000 hours at 80°F, 150 hours at 85°F, and 24 hours at 90°F. If these exposure conditions cannot be met, fouling growth in the discharge conduit must be assumed.

CONCLUSIONS

During the 17 month period from April 1977 through September 1978, eleven heat treatment operations have been conducted at San Onofre Unit 1. Ten of these operations were programmed to use the reduced heat treatment cycle of 1.7 hours at 100°F in the screenwell while only treating the intake conduit. The sole exception occurred on October 26, 1977, when it was found that a large number of *Mytilus* growing in the area between the traveling screens and condenser tubes had survived three previous heat treatments. This survival was traced to an error in the temperature recorder used to determine heat treatment temperatures such that the actual temperatures used since the start of the program may have been 95 to 97°F instead of 100°F. The nature of the thermal tolerance response for *Mytilus* is such that minor errors in temperature yield a logarithmic response in the durations necessary for biofouling control, thus the heat treatments based on the error in the recorder system were ineffective against *Mytilus* growth in the screenwells. Due to this problem, a full scale heat treatment of the intake and discharge was performed on October 28, 1977. The recorder was replaced with a new unit and the problem has not recurred. Since then, the discharge conduit has not been heat treated for almost a full year of operation.

On September 18, 1978, San Onofre Unit 1 was shut down for refueling. This allowed a routine structural conduit inspection to be made by divers on October 13, 1978. Prior to the inspection, the divers were asked to pay special attention to any fouling in the conduits. The inspection revealed that the discharge conduit had some quantity of dead *Mytilus* shell present. This buildup was attributed to a one month period of plant operation under reduced load, which lowered the average temperature of the discharge conduit well below 80°F. Subsequent exposure to full load conditions did eventually result in the death of these *Mytilus* without additional heat treatment. However, their growth rate was rapid and a conservative approach to the discharge heat treatment cycle is suggested. Using data derived from the Phase 1 Final Report (LAS 1975), current estimates of the length of time for ambient discharge water temperatures to prove lethal to *Mytilus* are exposures of 1000 hours at 80°F, 150 hours at 85°F, and 24 hours at 90°F. Similar low discharge temperature periods may be encountered during severe winters; if these periods are followed by plant outages, severe fouling could develop. Therefore, during the initial phases of new plant startup, when continuous high temperature operation cannot be maintained or during periods of low ambient water temperatures, occasional heat treatments of the discharge may be necessary. The frequency and timing of these treatments will have to be flexible and should be determined from operational monitoring of plant conditions.

Inspection of the intake conduit by the divers indicated no fouling buildup on the surfaces, as well as the absence of living fouling organisms. This indicates that the reduced heat treatment approach maintained adequate conduit cleanliness during this period.

Rebuilding and maintenance of the main circulating water pumps allowed free access to the pump outlet/condenser inlet conduits on September 20, and October 5, 1978. These areas were inspected previously during condenser cleaning operations on December 28, 1977, February 26, and July 3, 1978. Some buildup of the small barnacle *Chthamalus fissus* was evident in these areas. This condition was predicted by the conduit simulation studies previously done at San Onofre Unit 1 (LCMR 1977), and some degree of increased coverage was anticipated. Although covering a greater area than before, the maximal thickness of the buildup was less than 1 inch, and as expected, averaged less than 1/4 inch over most of the conduit surface. The increased thickness was caused by a living monolayer of *Chthamalus* forming over a thick layer of debris and protecting the layer from erosion.

Extensive diver exploration of the screenwell and gate structures was done by a hardhat diver. The diver reported only a small patch of living *Mytilus* adjacent to one of the gates, survival of which was attributable to water flow patterns creating a sheltered pocket during a heat treatment. All other areas within the screenwell/gate structure area were reported free of living fouling organisms. These findings indicate that the reduced heat treatment mode of operation over the last year was effective in maintaining cleanliness of the screenwell and intake conduit areas.

Intervals between the heat treatment cycles, while extended over previous practice, have been shorter than anticipated due to a combination of heavy *Balanus* fouling and warmer than normal winter temperatures. However, the growth model has generally performed as expected throughout this period, and the process of using it to predict heat treatment intervals is feasible. Although interference by barnacle fouling is still a problem, a potential solution is shown in Figure 24. In this method, *Mytilus* growth is used to determine the heat treatment interval until the presence of barnacles is noted in the collection basket. When this happens, and the quantity of living barnacles rises above 50%, heat treatment decisions are made on the basis of shell debris quantities and relative abundance of the barnacle. A more detailed explanation of the calculations and the process may be found in an earlier report (LCMR 1977).

In conclusion, use of available plant data and the growth models proved generally sufficient to schedule intake heat treatments before fouling interfered with plant operations or give

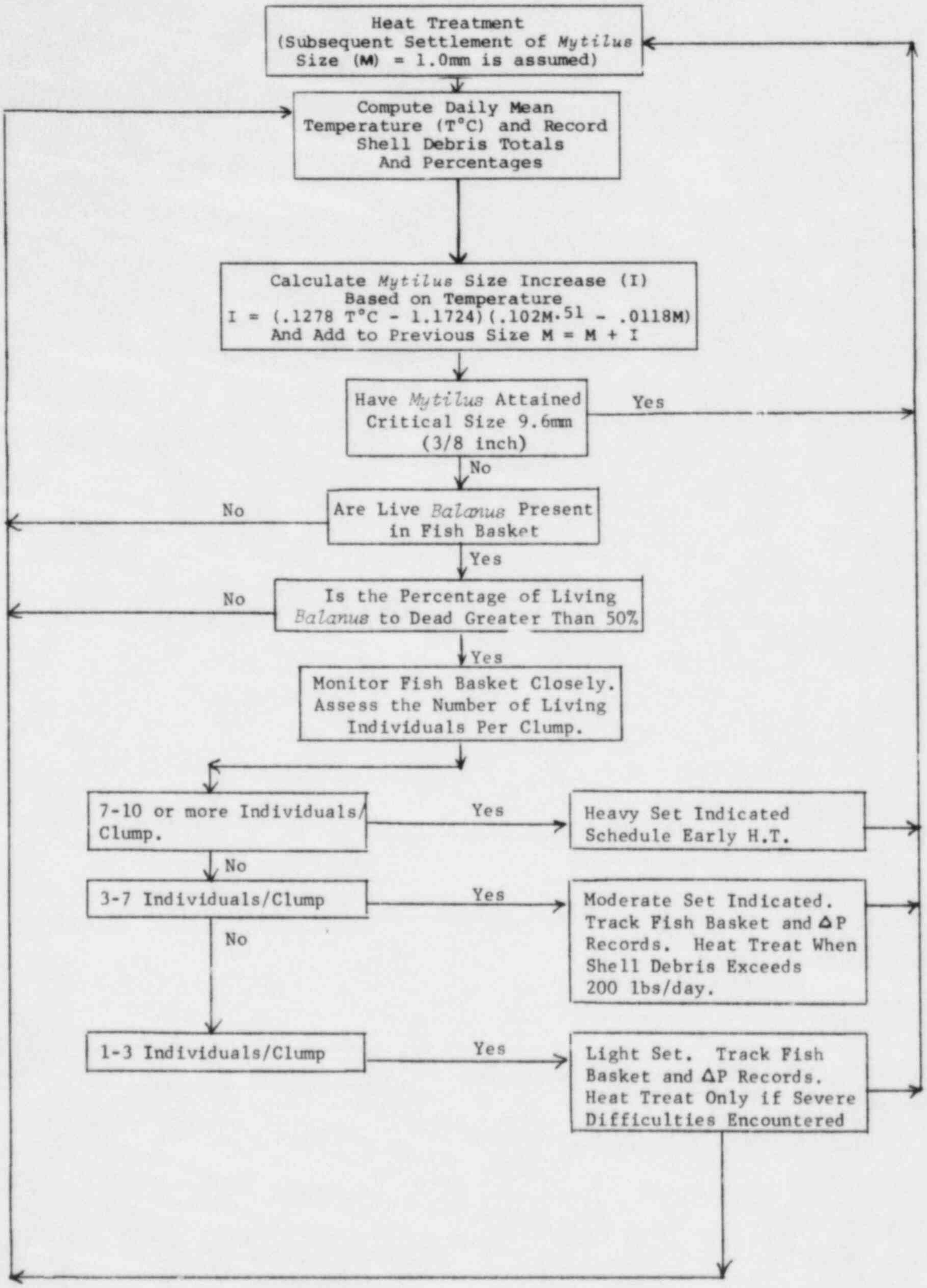

Figure 24. Daily heat treatment decision flowchart.

notice of potential fouling problems. Although the results of this study have indicated that the new heat treatment scheme can control fouling at Unit 1 under most conditions, some caution must be exercised in applying such a scheme to Units 2 and 3. The differences in conduit size and screen-well arrangement alone justify caution in applying the prototype study results. In addition, the problem of instrument calibration encountered at Unit 1 is the type of problem that can happen at any time and indicates that a slightly more conservative approach than was used in the prototype study may be necessary to assure the reliability of operation of the plant.

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