ATTACHMENT 3

AECM-82/574

A Survey of Tests and Analyses

On

The Effectiveness of the RHR System in the Pool-Cooling Mode

QUAD-1-82-245
Revision A

A SURVEY OF TESTS AND ANALYSES
ON
THE EFFECTIVENESS OF THE RHR SYSTEM
IN THE POOL-COOLING MODE

Prepared for:

Mark III Containment Issues Owners Group

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1.0 INTRODUCTION

At the request of the Mark III Containment Issues Owners Group, Quadrex Corporation undertook a study of the existing test data and analyses pertaining to the effectiveness of the residual heat removal (RHR) system as a means of thermal mixing within the pressure suppression pool. The purpose of the study was to determine if sufficient data and supporting analyses existed to demonstrate the effectiveness of the RHR system in four plants with Mark III containments (Grand Gulf, Clinton, Perry, and River Bend) without the need for in-plant testing. Specifically, the questions to be addressed are the positions of the RHR suction and discharge and the possibility of short-circuiting and reduced mixing from a lack of suppression pool bulk motion.

The first task was to study the RHR suction and discharge geometry and the orientation of the discharge flow in the four plants. This was done by using drawings and documents supplied by the plants' architect-engineers.

The next task was to review existing test and analysis reports and summarize the pertinent findings that might be applicable to plants with Mark III containments. In some cases, complete reports were available; in other cases, only facts found in public-domain reports could be utilized.

The final task was to draw conclusions regarding the effectiveness of the RHR systems of the four Mark III containments on the basis of the findings resulting from the survey of the existing test and analysis reports.

A summary of the findings is presented in section 2.0, and section 3.0 gives a description of the RHR system suction and return geometries and orientations for each of the four plants. This description is followed by a brief summary in section 4.0 of each test or analysis report reviewed. Section 5.0 presents the conclusions drawn from the available data and information.

2.0 SUMMARY OF FINDINGS

- Short-circuiting of the RHR flow, i.e., the direct flow of some of the RHR system discharge to the RHR system suction line, is not likely to occur.

- After about 15 minutes of RHR system operation, the suction temperature is close to the bulk temperature.

- Operation of one RHR system loop breaks up initial pool stratification at the rate of 1.5 to 1.8°F/min; therefore, a period of 10 to 15 minutes of RHR system operation is sufficient to produce practically uniform temperature distribution in an initially stratified pool.

- Three to four minutes of operation of one RHR system loop can produce an average suppression pool bulk velocity of approximately 0.4 ft/s in an initially quiescent pool.

- The data and analyses reviewed dealt exclusively with the operation of one RHR system loop. No data could be found on the operation of two loops or on the effect of the two loops' discharging in opposite circumferential directions. However, based on considerations of continuity and conservation of momentum, global flow patterns were developed. They show the effectiveness of the existing RHR system suction and discharge arrangements in domestic plants with Mark III containments.

- The concern regarding the effect of opposing RHR system discharges and the claim that each jet will impede the effectiveness of the other in providing suppression pool mixing are without technical bases. Opposing jets produce a different flow pattern but probably afford as much thermal mixing as jets that point in the same direction.

3.0 SURVEY OF RHR SYSTEM SUCTION AND RETURN ARRANGEMENTS

Some of the information presented in this section was obtained from preliminary drawings, and some of the dimensions were estimated and may not be accurate. As far as thermal mixing of the pool is concerned, the main features of the RHR system of interest are:

- Azimuthal location of the discharge nozzles or elbows,
- Direction of the return flow,
- Distance between the discharge nozzle and the pool bottom, and
- Location of the suction strainers and their distance from the discharge nozzles and from the pool bottom.

The above information is summarized in figures 1 through 7 and described below.

3.1 Clinton Power Station, Unit 1

The RHR system return elbows are located at azimuthal angles 275° and 94°; the suction strainers, at 37° and 323° (see figure 1). The discharge flow makes a 55° angle with the radial axis, and both pumps discharge counterclockwise. The discharge points are 14 feet 11 inches from the bottom of the pool and 3 feet 6 inches from the containment shell (see figure 2). The suction strainers are located 8 feet above the pool bottom and 3 feet 11 inches from the containment shell.

3.2 Grand Gulf Power Station

The RHR system return lines have 45° elbows at the discharge ends. The elbows are located at azimuthal angles of 90° and 270° (figure 3) and are pointed in opposite circumferential directions, i.e., one discharges clockwise and the other counterclockwise. The suction strainers are located at 32° and 328°.

The discharge points are at a distance of 14 feet 4 1/2 inches from the bottom of the pool, and the suction strainers are 10 feet 6 inches from the bottom (see figure 4) and 3 feet 10 inches from the containment wall.

3.3 Perry Power Station

The only information available for Perry Power Station is that contained in reference 1. Figure 5 shows the general arrangement of the suction and disharge for one of the RHR system pumps. The azimuthal angle between the suction and discharge points is estimated to be 18°. The discharge point is 16 feet 3/4 inch from the bottom of the pool and 5 feet 3/4 inch from the containment wall. The suction strainer is estimated to be 5 feet above the pool bottom. The locations of the second discharge and suction points are not known.

3.4 River Bend Station, Unit 1

The RHR system return points for pumps A and B are located at azimuthal angles 30° and 310°, respectively (see figure 6). They terminate at 90° elbows pointed in opposite circumferential directions. The discharge flow is tangential. Suction strainers are located at 165° (pump A) and 195° (pump B). Locations of the discharge and suction relative to the pool boundaries are shown in figure 7. The return point is 14 feet from the pool bottom and 2 feet 9 inches from the containment wall. The suction strainers are 3 feet 4 3/4 inches above the pool bottom and 2 feet 3 7/8 inches from the containment wall. These dimensions were obtained from preliminary drawings.

The results of the survey of RHR system suction and return arrangements are summarized in table 3.1. There is a certain amount of variation in the arrangement of RHR system discharge and suction among these four plants. For instance, the azimuthal angle between the two discharge points varies from 80° to 181°; the minimum angle between discharge and suction varies from 18° to 115°; and the distance of the suction strainer from the pool bottom ranges from 3 feet 4 3/4 inches to 10 feet 6 inches.

TABLE 3.1--Summary of RHR system discharge and suction locations

Geometry \ Plant	Clinton	Grand Gulf	Perry	River Bend
Angle between discharges	181°	180°	X	80°
Minimum angle between suction and discharge	48°	58°	~18°	115°
Direction of discharge flow	same	opposite	X	opposite
Distance of discharge from bottom	14'11"	14'4 1/2"	16' 3/4"	14'
Distance of suction from bottom	8'	10'6"	~5'	3'4 3/4"
Distance of discharge from containment	3'6"	X	5'3/4"	2'9"
Distance of suction from containment	3'11"	3'10"	X	2'3 7/8"
Angle of discharge relative to radial	55°	~55°	X	90°

X: Dimension unknown

4.0 SURVEY OF EXISTING TEST DATA AND ANALYSES

In the pool-cooling mode, the role of the RHR system is:

- To mix the water in the pressure suppression pool to avoid any hot spots in the vicinities of the quenchers and to eliminate thermal stratification and

- To remove thermal energy from the pressure suppression pool in a manner that will reduce the temperature uniformly throughout the pool.

The rate of heat removal is proportional to the difference between the temperature at the suction side of the RHR pump and the service water temperature (neglecting energy-transfer mechanisms other than the heat exchanger). It is therefore desirable to withdraw water at the point where the highest temperature exists. However, if the pool is well mixed, it does not make any difference where the suction takes place as long as cold water returning from the RHR heat exchanger is not drawn back in, i.e., as long as there is no short-circuiting.

Another important consideration is the net positive suction head (NPSH), which must be maintained under all postulated conditions to avoid cavitation. Starting with a stratified pool, discharge of the cold water near the surface where the temperatures are higher is desirable. However, there are other considerations, such as pool draw-down and bulk motion of the pool induced by momentum transfer from the discharge jet to the suppression pool.

When two RHR system loops are used in the pool-cooling mode, other questions arise regarding the relative location of the two discharge nozzles, the direction of the jets (same circumferential direction or opposite directions), the angle between the jets and the radial axis, the locations of the suction strainers, and the elevation of discharge and suction points. These questions have been investigated analytically and experimentally (small scale and in-plant tests). In most cases, satisfactory solutions have been found.

A summary of each of the investigations and their major findings follows.

4.1 Perry One-Tenth-Scale Test

A one-tenth-scale model of the Perry Nuclear Power Plant suppression pool was used in this test program. The model included 19 X-quenchers and various structural members, main vents, etc., to simulate the real flow resistance conditions that exist in the actual plant. A simplified sketch of the model is shown in figure 5.

4.1.1 Scaling Factors

The scaling factors were as follows:

Length: 10^{-1},

Area: 10^{-2},

Volume: 10^{-3},

Time: $10^{-1/2}$,

Velocity: $10^{-1/2}$, and

Flow rate: $10^{-5/2}$.

4.1.2 Purpose of the Test

The purpose of the test was to investigate the following concerns:

- Short-circuiting between RHR system discharges and suctions.
- Optimum injection angle for the RHR system discharge jets.
- Bulk pool motion from operation of one RHR system loop.
- Hot spots around discharging quenchers.
- Temperature of the bottom liner of the suppression pool.

The RHR system discharge was simulated by using 50°F water at the rate of 22 gpm (corresponding to 7,000 gpm full scale). Water at 180°F, pumped at a rate of 6 gpm, was used to simulate the discharge of steam through the quenchers. This corresponds to approximately 256 lb/s of condensate in the full scale.

To simulate stratified pool conditions, a linear temperature gradient was established, with a temperature variation of 79°F at the bottom to 91°F at the top.

4.1.3 Summary of Perry One-Tenth-Scale Test Results

a. Test Series 0. Orientation of Discharge Jet

- The optimum jet angle was found to be 55° from the radial axis. In a uniform temperature pool at 47°F, this arrangement resulted in an average bulk velocity of 0.15 ft/s (prototype) in 19 seconds (prototype).

- In a stratified pool (with water temperatures ranging from 91°F at the surface to 79°F at the bottom), a prototype bulk velocity of 0.17 ft/s was established in 25 seconds (prototype) with a 55° jet angle.

- A jet angle of 75° produced considerable backflow and turbulent flow conditions, particularly near the bottom and close to the drywell wall around quenchers 2 and 3 (figure ~). A potentially stagnant region was observed at the bottom near quencher 1.

- No stagnant areas were found for the case in which the jet angle was 55°. Flow patterns and constant velocity lines for this case are shown in figures 8 and 9, which show a considerable amount of turbulent mixing and backflow.

b. Test Series 1. Short-Circuiting

To investigate the possibility of short-circuiting between the discharge and suction of the RHR system, dye was injected in the discharge flow and tracked by movie and still photography. Quenchers 2 and 10 were operated, one at a time. These studies showed that short-circuiting did not occur with or without operating quenchers.

c. Test Series 2. Velocity and Temperature Measurements

A three-dimensional transient temperature distribution, starting with an initially stratified temperature field, is shown in figures 10 and 11. It can be seen that the initial stratification of approximately 12°F is reduced to 1 or 2°F in about 15 minutes.

The temperature at the suction point remained above the discharge temperature of 50°F, indicating that there was no short-circuiting.

The suppression pool water accelerated from zero velocity to an average velocity of 0.4 ft/s in 3 to 4 minutes (prototype values) of RHR system operation.

d. Test Series 3. Velocity and Temperature Measurements with a Quencher Operating

In this series of tests, a jet angle of 55° was used (as in series 2); and quenchers 2, 4, and 10 were actuated, one at a time, to study their effects on the velocity and temperature distributions.

Figure 12 shows the variation of velocity with elevation upstream of the operating quencher (number 2, see figure 5 for the locations of the quenchers). There is a velocity gradient in the vertical direction, particularly between levels 1 and 2 (levels are shown on figure 10) and between levels 2 and 3. In the lower half of the suppression pool, velocities seem to be uniform except near the bottom where backflow occurs. This velocity gradient is more pronounced directly downstream of the jet and diminishes with distance from the jet and with time. Figure 13 shows the variation of velocity with elevation and with time for the case where quencher number 4 is operating. Measurements were taken downstream of the operating quencher. Similarly, figure 14 is a plot of velocity versus time upstream of the jet with quencher number 10 operating.

In figure 15, the temperature of the water at the suction of the RHR system pump is plotted versus time for three tests in test series 3. Temperatures measured at the specified locations at level 4 are also plotted for comparison. It can be seen that the suction temperature is always higher than the discharge temperature of 50°F, thereby indicating that there was no short-circuiting. Also, after about 15 minutes (prototype time) of RHR system operation, the suction temperature stays above the temperature at level 4. Judging from figures 10 and 11, the suction temperature seems to be at or slightly above the bulk temperature of the suppression pool after about 15 minutes of operation of the RHR system.

4.2 Monticello In-Plant Test

The RHR system in the Monticello Nuclear Generating Station has two discharges at azimuthal angles of approximately 74° and 299° and four suction headers at azimuthal angles of 45°, 135°, 225°, and 315° (see figures 16 and 17).

Extended safety-relief-valve (SRV) blowdown tests were conducted at Monticello in December 1977 and February 1978. In the first test, the pressure suppression pool was brought to a uniform temperature of 50°F with the help of the RHR system. After a 50-minute wait for the motion of the pool to cease (this waiting period was later determined to be insufficient) the SRV discharging into Bay D (figure 16) was opened and left open for 7 minutes and 55 seconds. The reactor pressure was approximately 1,000 psia, and the steam flow rate varied between 200 to 220 lb/s. The maximum difference between the measured local temperature and the calculated bulk temperature was 43°F (reference 2) for the duration of discharge. In the same period, the maximum temperature difference in the bay of discharge (Bay D, figure 16) was 12°F. This indicated good mixing in that bay, even in the absence of any RHR system flow. Thirty minutes after closure of the SRV, there was a 52°F-temperature variation in the pool from thermal stratification.

The second test was conducted similarly, except that one RHR system loop was used in the recirculation mode (no cooling). The maximum difference between the local and bulk temperatures was reduced to 38°F (reference 2); the maximum stratification was 21°F at 20 minutes after valve closure; and uniform temperature was established throughout the suppression pool after 30 minutes of RHR system operation (in the recirculation mode).

A series of tests were conducted in November 1978 after two modifications were made:

- Forty holes were drilled in the end-cap of one of the quencher arms. The purpose was to enhance the bulk motion of the suppression pool by introducing steam, in the circumferential direction, through the end-cap holes.

- A 90° elbow, terminating at a 10-to-8-inch reducing nozzle, was installed at the end of the RHR system discharge line, oriented tangentially. The purpose of this modification was to impact momentum to the pool and induce bulk motion in the suppression pool. The reduction of the flow area increased the rate of momentum transfer by about 50 percent.

Tests were run with and without the operation of the RHR system. The duration of the SRV blowdown was 12 minutes for the former and 11 minutes for the latter case. The results showed that the end-cap holes did not produce a significant improvement in the suppression pool mixing but that the modification of the discharge nozzle did. In fact, with the RHR system operation, the maximum local-to-bulk temperature was reduced to 15°F; and 6 minutes after SRV closure all temperature readings in the suppression pool were within 5°F.

The Monticello test results indicate:

- Quenchers provide adequate thermal mixing in the bay where they discharge.
- Properly directed, the RHR system discharge jet is an effective means of producing bulk motion and thermal mixing of the pressure suppression pool.

4.3 Caorso In-Plant Test

The geometry of the Caorso RHR system discharge device is quite different from that of the plants with Mark III containments (see figures 18 and 19 for the details). Each of the two 16-inch-diameter discharge lines has a 9.2-foot perforated section with thirty 2-inch holes in two horizontal rows, 180° apart. (The four 20-inch suction lines are located at azimuthal angles of 140°, 164°, 222°, and 235°.)

The locations of the temperature sensors and the activated quencher A are shown in figure 20. The extended SRV blowdown test was conducted with the reactor pressure at 975 psig and an SRV flow rate of 237 lb/s. The initial suppression pool temperature was brought to a uniform 60°F by running the RHR system in the pool-cooling mode. The initial temperature distribution in the suppression pool (just before SRV actuation) is shown in figure 21. The RHR system operation was stopped after a uniform, 60°F suppression pool temperature was established and 4 1/2 hours before SRV actuation. This waiting period was for ensuring that all suppression pool motion had stopped before SRV actuation.

SRV A (figure 20) was actuated and left open for 13 minutes and 7 seconds. Figure 22 shows the temperature distribution and the end of the blowdown. The maximum temperature at this time was 116°F, registered by sensor T13. The sensor T307 on the opposite side of the suppression pool was at 94°F, 15 degrees above its initial temperature, thus indicating the extent of suppression pool mixing caused by the quencher.

After SRV closure, it was 3 minutes and 40 seconds before the RHR system pumps A and C began operating in the pool-mixing mode (no cooling). Stratification began immediately after SRV closure, as can be seen in figures 23 and 25. Figure 24 shows the temperature distribution after 4 minutes of RHR system operation. The maximum temperature difference at that time was only 5°F.

The Caorso test results (reference 3) indicate:

- The X-quencher is an effective device for distributing the thermal energy of the condensing steam over a large volume of the suppression pool.

- The RHR system discharge device used in Caorso is effective in mitigating pool stratification and providing pool mixing. Starting with a stratified pool, it takes only a few minutes of RHR system operation to reach approximately equal temperatures throughout the suppression pool.

4.4 Kuo-Sheng In-Plant Test (Reference 4)

The Kuo-Sheng extended SRV blowdown test consisted of a 9-minute blowdown of one SRV into an initially quiescent suppression pool at a uniform temperature of 90°F. Five minutes into the blowdown, one RHR system loop was put in the pool-mixing mode. At the start of RHR system operations, a 17°F thermal stratification existed; it was reduced to a 2°F stratification after 10 minutes of RHR system operation.

Both the results and the conclusions of this test are similar to those of the Caorso test, in spite of the major differences in the RHR system discharge geometries of the two plants. In both plants, the thermal stratification was reduced at the rate of 1.5 to 1.8°F/min by the operation of one RHR system loop in the pool-mixing mode.

4.5 Thermal Stratification Study of a Mark III Containment Suppression Pool (Reference 5)

The purpose of this study was to determine the effectiveness of one RHR system loop in the thermal mixing of the suppression pool following a design basis accident (DBA).

The suppression-pool and containment data used in the analysis are given in table 4.1, and the RHR system suction and return arrangement is shown in figure 26. Table 4.2 is a summary of the sequence of events analyzed. The analysis starts at 15.5 minutes following the postulated DBA and covers the ensuing 30 minutes. The conditions at 15.5 minutes after DBA are given in table 4.3 and constitute the initial conditions for the analysis. The emergency core-cooling system (ECCS) flow was assumed to be 14,700 gpm for the first 14.5 minutes and 7,800 gpm thereafter. The RHR system flow rate was assumed to be 6,500 gpm (table 4.2). The conditions in the suppression pool at the start of RHR system operation are given in table 4.4. The ECCS and RHR system return temperatures were assumed to be 200°F and 111°F, respectively.

The RELAP4/MOD3 computer program was used to simulate the events and obtain temperature distributions for the pressure suppression pool. A 32-node, half-pool model was used for the first 14.5 minutes; and a 39-node, full-pool model was used for the remainder of the time when the RHR system was in operation.

The results of the RELAP4/MOD3 analysis showed that 15 minutes of operation of one RHR system loop (starting at 30 minutes after DBA) was sufficient to:

- Maintain the peak suppression pool temperature below 166°F (+2°F/-0°F).
- Maintain the average suppression pool surface temperature below 166°F (+2°F/-0°F).
- Decrease the difference between the peak and bulk temperatures of the suppression pool from a maximum of 17°F to 13°F (+2°F/-0°F) and decrease the difference between the average surface and the bulk temperatures of the suppression pool from 15°F to 11°F (+2°F/-0°F).

Another important conclusion, which is supported by the Caorso in-plant test data, was that 5 minutes of operation of a single RHR system loop was sufficient to provide nearly complete breakup of the initial thermal stratification.

Two other observations in reference 5 are either obvious or wrong:

- "Operation of a single RHR system is insufficient to maintain or decrease the rise of the bulk temperature of the suppression pool up to 45 minutes after LOCA."

This should be obvious, since the ECCS is introducing 200°F water at a rate of 7,800 gpm while the RHR system is discharging into the pool at a rate of 6,500 gpm and a temperature of 111°F; the suction temperature for both systems is approximately 155°F.

- "The observed short-circuiting in the RELAP4/MOD3 simulation is conservatively estimated to be between 20% and 40% of the potential short circuiting. Because of the conservative choices for temperature input data to the estimate, it is believed that the actual observed short-circuiting may be less."

This conclusion was reached by calculating a rate of increase of bulk temperature (0.09°F/min), based on computer-calculated suction temperatures and given discharge temperatures for the RHR system and the ECCS, and comparing it with the rate calculated by the computer program (0.21°F/min). The latter was higher, and the conclusion was that short-circuiting occurred. In the absence of any errors (in the computer program or the hand calculations), the two answers should have been the same. Therefore, the discrepancy invalidates either the entire analysis (if the computer program indeed does not conserve energy) or the hand calculations. The hand calculations (appendix H of reference 5) were checked and found to be reasonably accurate (except the wrong ECCS flow rate was used in calculating the maximum rate of temperature rise). However, the conclusion about short-circuiting is without foundation and not supported by test data.

TABLE 4.1.--Mark III 238 suppression pool and containment data

Containment ID	120'
Weir Wall OD/ID (ft)	68'-8"/65'-0"
Weir Wall Thickness	1'-10"
Weir Annulus Width	2'-2"
Weir Annulus Area (ft^2)	482
Obstructed Weir Annulus Area (ft^2)	14
Total Vent Area (horizontal vent) (ft^2)	495
No. Vent Azimuth Locations	40
Vent Azimuth ℄ Spacing on Drywell I.D.	5'-9"
Total No. Vents (3 levels)	120
Vent I.D. (E, F, G)	27-1/2"
Vent Length (D)	5'-0"
Vent Centerlines	Ht. from Basemat
Top Row (J)	12'-11"
Middle Row (M)	8'-5"
Bottom Row (H)	3'-11"
Containment Gross Volume	1,965,000 ft^3
Suppression Pool Volume outside drywell	119,000 ft^3
Water Depth After Drawdown - (Q)	16'-0"
High Water Level (N)	20'-5"

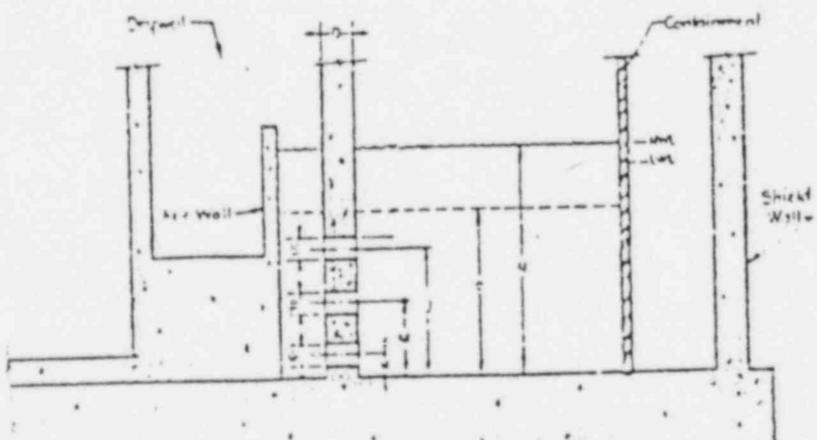

TABLE 4.2.--Sequence of events for ECCS and RHR system activity following LOCA

System Activity	Time (minutes)	Flow Rate (gallons per minute)
1. ECCS Suction & Discharge	0 - 15.5	Pool height and pool thermal stratification at 15.5 minutes are provided by GE
2. ECCS Suction & Discharge	15.5 - 30	14,700 gpm
3. ECCS Suction & Discharge	30 - shutoff	7,800 gpm
4. RHR Suction & Discharge	30 - shutoff	6,500 gpm

TABLE 4.3.--Initial conditions 15½ minutes following LOCA (ECCS)

Water Level (ft)	16.0
Temperature (°F)	
Level IV (Top)	139.5
Level III	138.8
Level II	135.5
Level I (Bottom)	128.0
Flow Rates in Pool	Negligible
ECCS Return Temperature	200.0

TABLE 4.4.--Initial conditions 30 minutes following LOCA (RHR)

Water Level (Ft.)	16.0
Temperature (^{o}F)	
Level III (Top)	165.8
Level II	165.0
Level I (Bottom)	142.7
Flow Rates in Pool	None
ECCS Return Temperature (^{o}F)	200.0
RHR Return Temperature (^{o}F)	111.0

5.0 CONCLUSIONS

The test data and analyses compiled in this report lead to the following conclusions regarding the effectiveness of one RHR system loop in providing mixing within a boiling-water-reactor (BWR) pressure suppression pool:

- Scaled tests at the Perry Power Station demonstrated that even when the suction point is less than 20° degrees from the discharge, no short-circuiting of the flow occurs.
- The same tests demonstrated that, after approximately 15 minutes of RHR system operation, the suction temperature is close to the bulk temperature.
- Both the Perry and Monticello tests indicated the importance of directing the RHR system discharge flow in such a way that suppression pool bulk motion is induced. This bulk motion enhances the uniform distribution of the thermal energy throughout the pool.
- Caorso test results demonstrated that other RHR system discharge devices, such as the sparger design used at Caorso, are equally effective in affording suppression pool mixing. In fact, pool stratification was reduced at about the same rate (1.5 to 1.8°F/min) at Caorso (with a sparger) and at Kuo-Sheng (with a 90° elbow).
- The X-quencher is an effective means of distributing the thermal energy of the condensing steam.

The question of the consequences of having two RHR system discharge elbows facing each other (when both RHR system loops are in the pool-cooling mode) was not directly addressed in any of the reports. That being the main question, it will be discussed in the following paragraphs.

The main concern regarding the effect of opposing RHR system jets is that this arrangement may impede the bulk motion of the suppression pool and adversely affect suppression pool mixing. Regarding the bulk motion of the suppression pool, several points need clarification:

- Circumferential bulk motion by itself is only effective in distributing the thermal energy circumferentially. This type of mixing is necessary when the thermal energy is deposited locally, such as in the case when an SRV is stuck in the open position. However, many other mechanisms contribute to and are essential for thermal mixing:

  - Secondary flow patterns induced by RHR system suction, ECCS suction and return (when operating), quencher discharge, and the turbulence caused by submerged structures and pool geometry.

  - Free convection, which is particularly effective in spreading the hot water over the top layer of the pool. The Caorso test, as well as an earlier test at Quad Cities, indicates that, even in the absence of RHR system activity, the temperature on the other side of the pool rises in a very short time after SRV discharge begins.

- The concern that opposing RHR discharge jets will impede pool mixing is a misconception. Whereas it is true that a rigid body subjected to two equal and opposing forces will not move, the same is not always true for a body of liquid. To clarify this point, one may picture a global view of the flow patterns for the two cases, i.e., with two jets in the same direction versus opposing jets. For simplicity, secondary flow patterns will not be shown; and transient effects will be ignored, i.e., steady-state flow rate will be indicated. Taking River Bend as an example, the global flow rates for the cases of jets discharging in the same direction and in opposing directions are shown in figures 27 and 28.

If the discharge jets are pointing in the same direction, the overall flow will be in one direction with the flow introduced at azimuthal angles of 310° and 30° (the locations of return lines) and withdrawn at azimuthal angles of 190° and 165° (suction points). The flow rate for each loop is called $\dot{m}_1$, and the entrained flow is denoted by $\dot{m}_2$.

In the actual case of opposing jets, there are two planes of symmetry at azimuthal angles of 180° and 350°. The planes behave more or less as rigid boundaries. When the two opposing streams meet at these points, they are deflected, as shown in figure 28. Again, each jet induces a flow rate of $\dot{m}_2$; and each loop has a flow rate of $\dot{m}_1$. The flow pattern shown in figure 28 is ideal for suppression pool mixing, since there is not only a circumferential flow but also a flow in the vertical direction to break up any stratification.

At the planes of symmetry, i.e., at azimuthal angles of 350° and 180°, mixing of the two streams takes place. In other words, these two planes act as very effective parallel-flow heat exchangers, providing energy transfer between the two halves of the suppression pool.

This is admittedly a highly simplified presentation of the actual flow, but it serves the purpose of refuting the notion that in some manner two opposing jets will cancel each other's effect and reduce the degree of thermal mixing afforded by the bulk motion of the suppression pool.

Similar flow patterns exist in the Grand Gulf plant and lead to the same conclusion.

To summarize, all of the domestic plants with Mark III containments have RHR system discharge and suction arrangements that preclude short-circuiting and provide effective thermal mixing of the pressure suppression pool. The remarks about the disadvantages of opposing discharge jets, particularly the suggestion that two opposing jets will tend to impede the effectiveness of each other, are without technical basis. Uniform and unidirectional bulk motion is not the only and not necessarily the best way of effecting thermal mixing. Opposing jets provide a different flow pattern, which is equally effective in distributing the thermal energy.

Existing tests and analyses provide sufficient support for the above conclusions; additional testing is not necessary.

References

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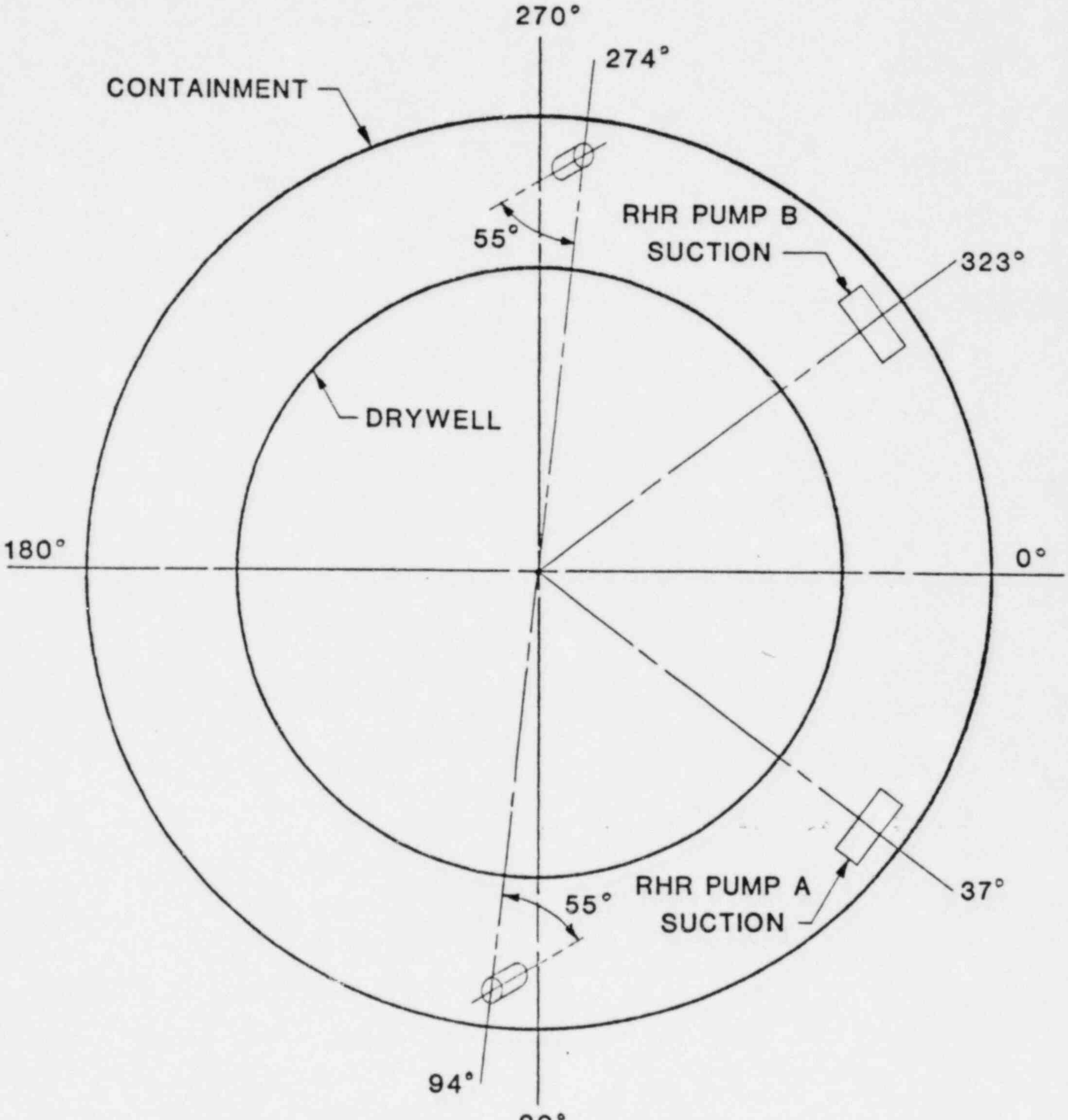
4. Author's notes, taken at the site during the Kuo-Sheng in-plant SRV test.

5. "Mark III Suppression Pool Thermal Stratification Study." Revision 0. EDS Report No. A-77-122. December 5, 1977.



PUMP CAPACITY 5050 GPM

FIG. 1 LOCATIONS OF RHR SUCTION AND DISCHARGE

CLINTON POWER STATION

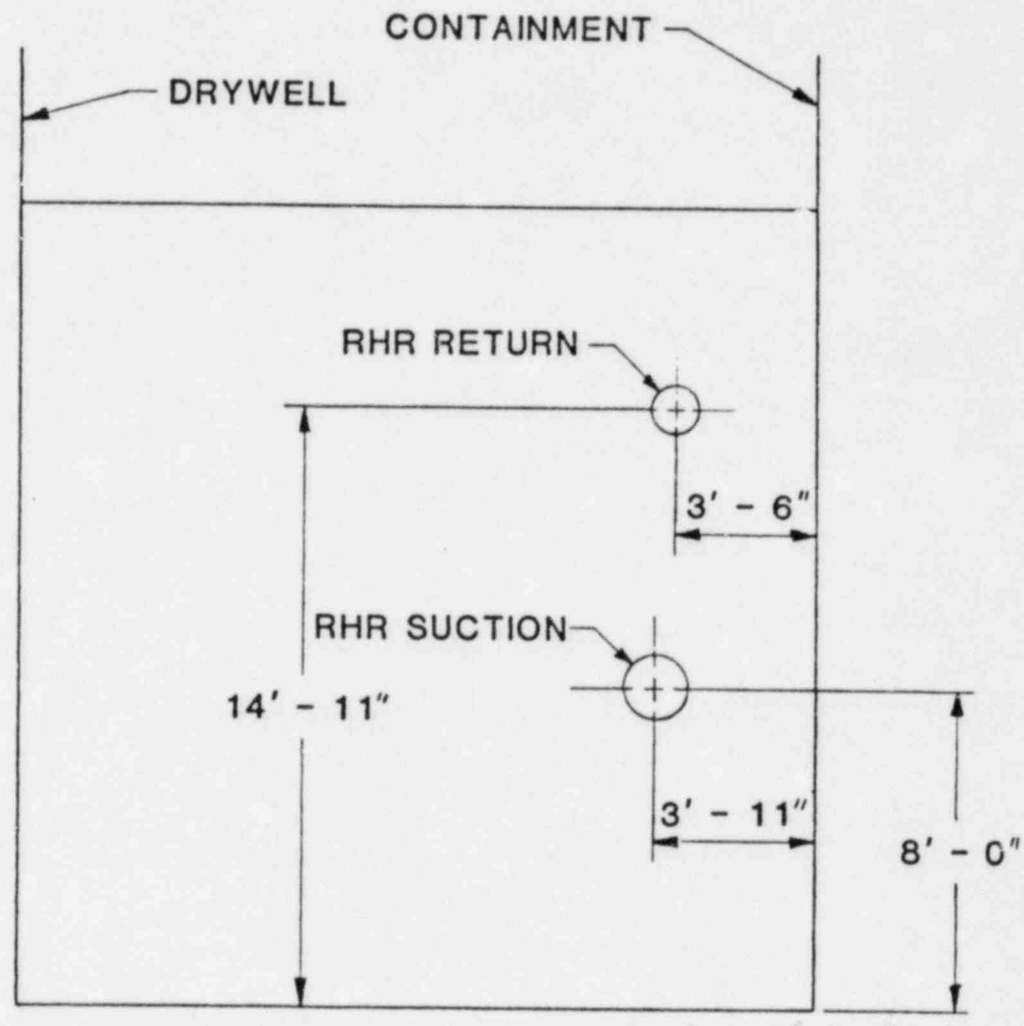


FIG. 2 ELEVATIONS OF RHR SUCTION AND DISCHARGE

CLINTON POWER STATION

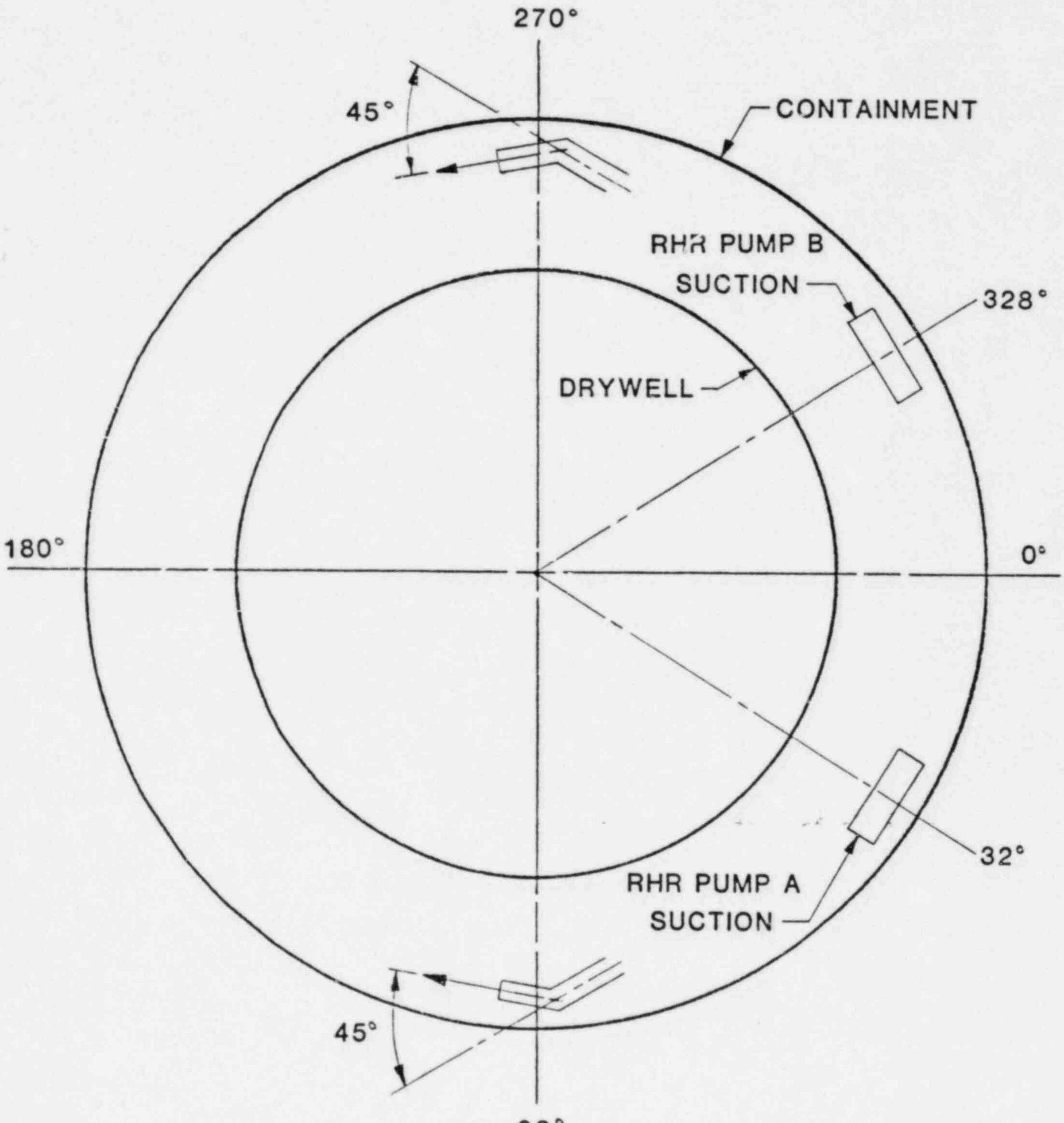


FIG. 3 LOCATIONS OF RHR SUCTION AND DISCHARGE

GRAND GULF POWER STATION

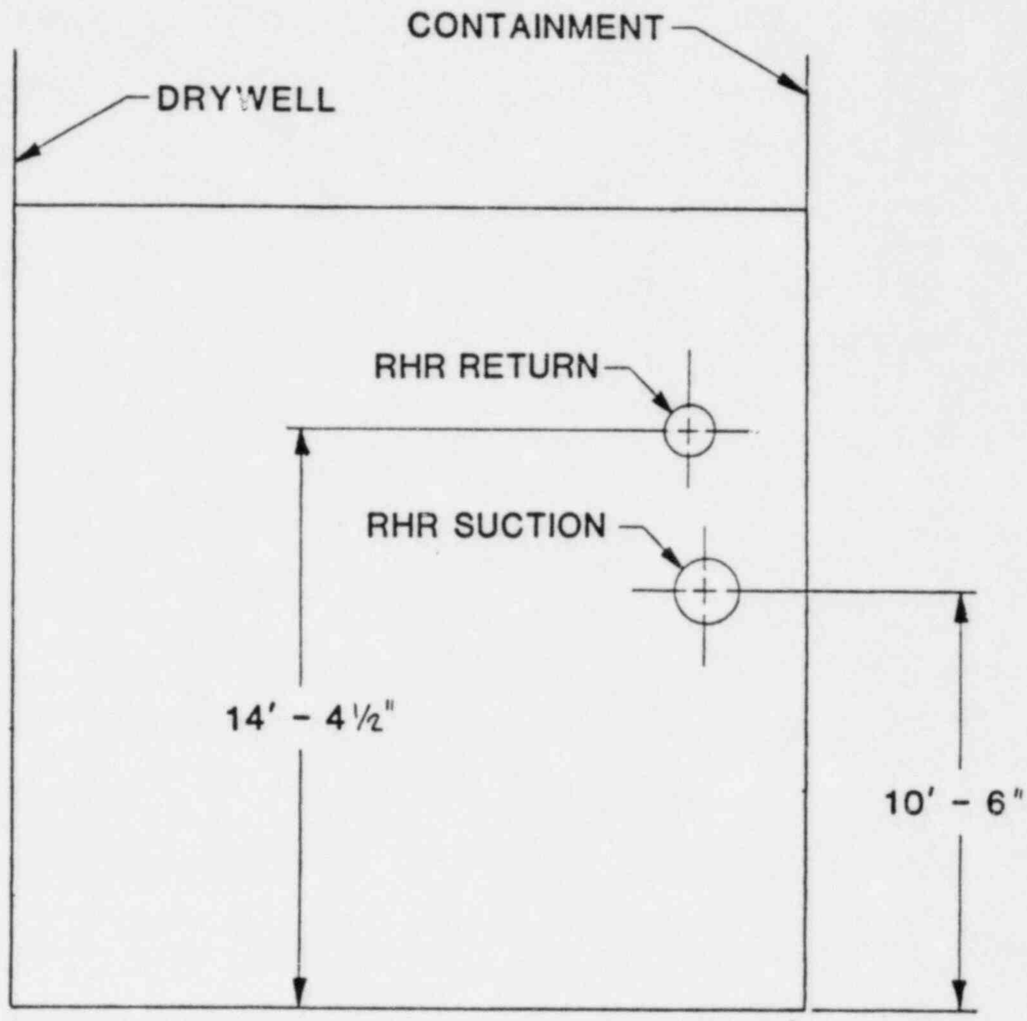


FIG. 4 ELEVATIONS OF RHR SUCTION AND DISCHARGE

GRAND GULF POWER STATION

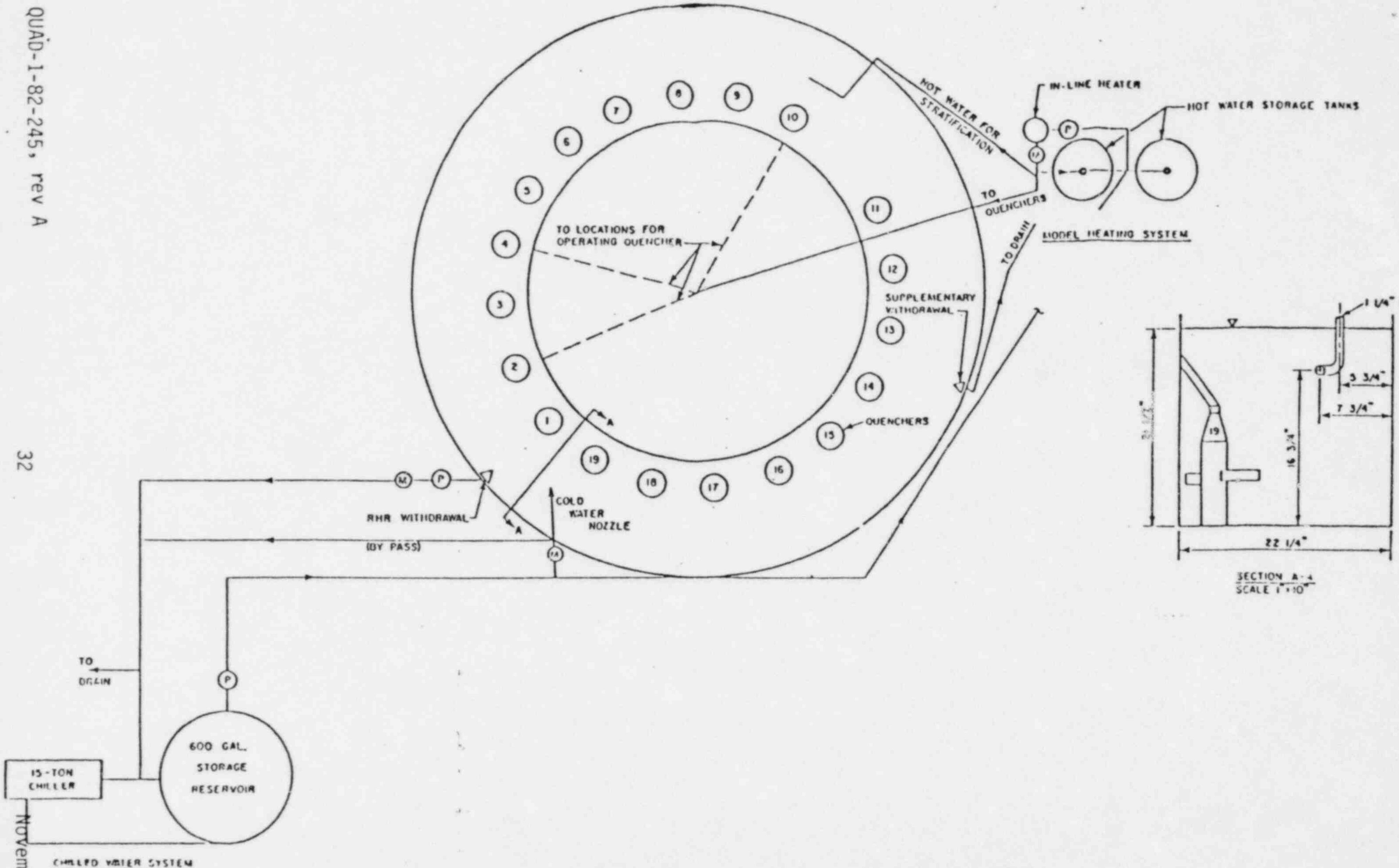
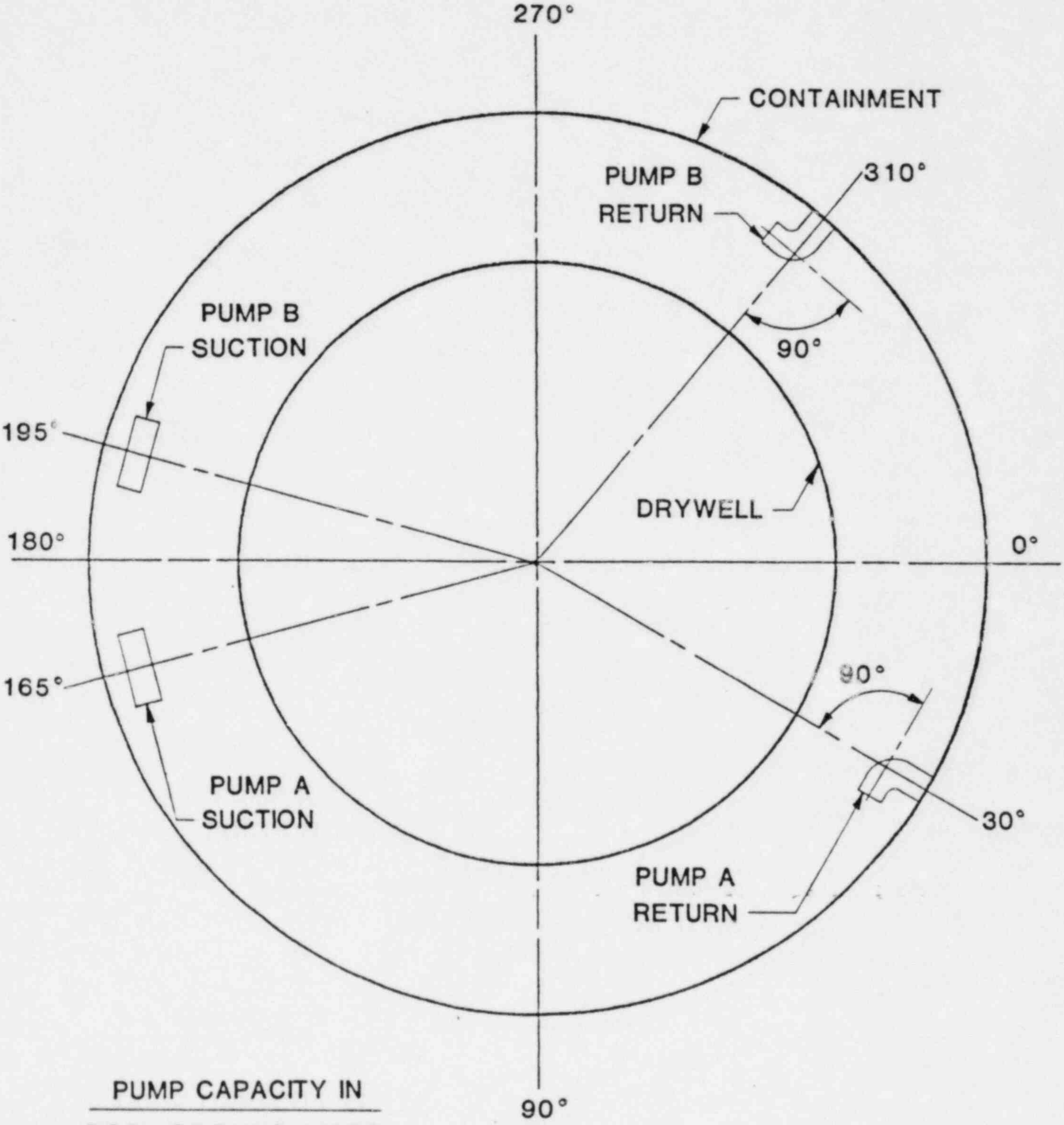


FIG.5-LOCATION OF RHR SUCTION AND DISCHARGE

PERRY POWER STATION (MODEL)



PUMP CAPACITY IN POOL COOLING MODE	
PUMP A	5050 GPM
PUMP B	5050 GPM

FIG. 6 LOCATIONS OF RHR SUCTION AND DISCHARGE

RIVERBEND (PRELIMINARY)

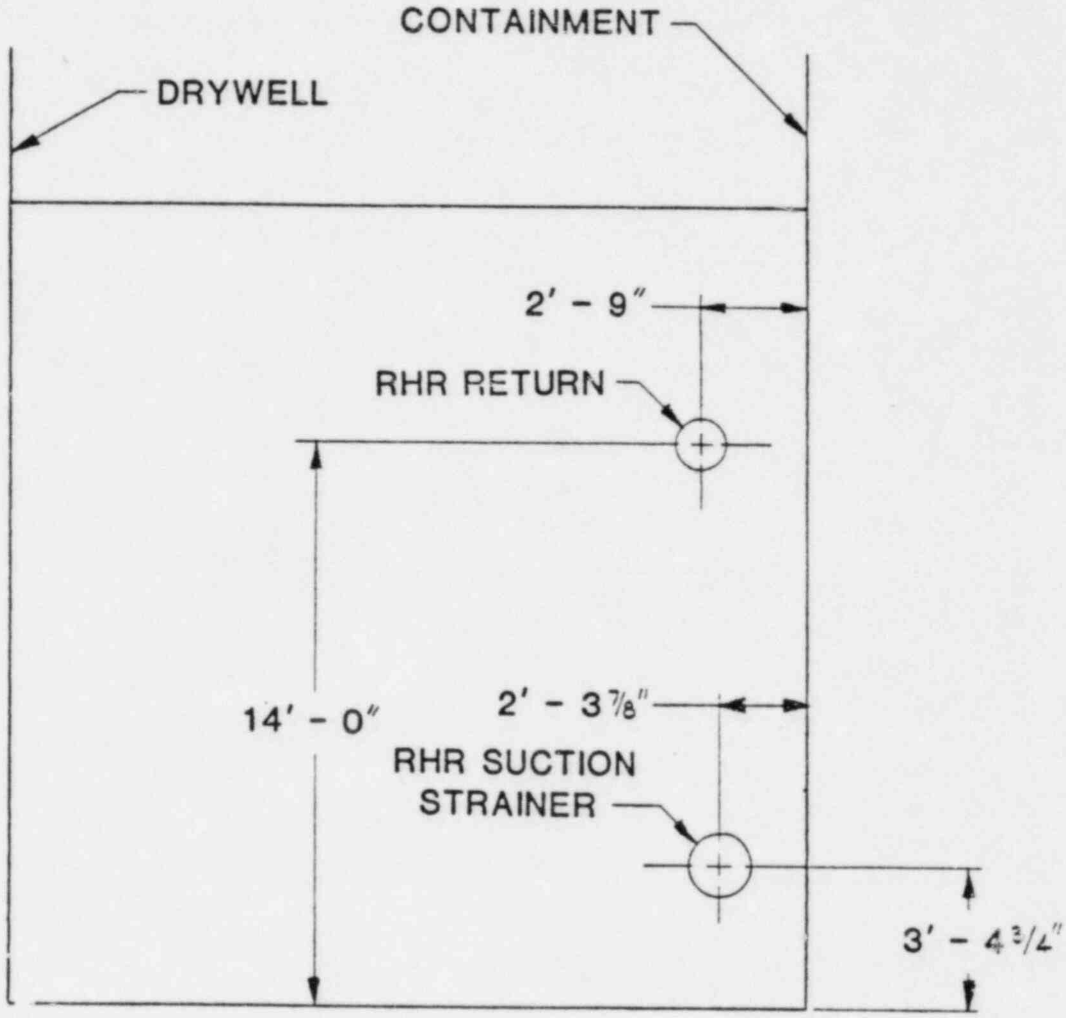
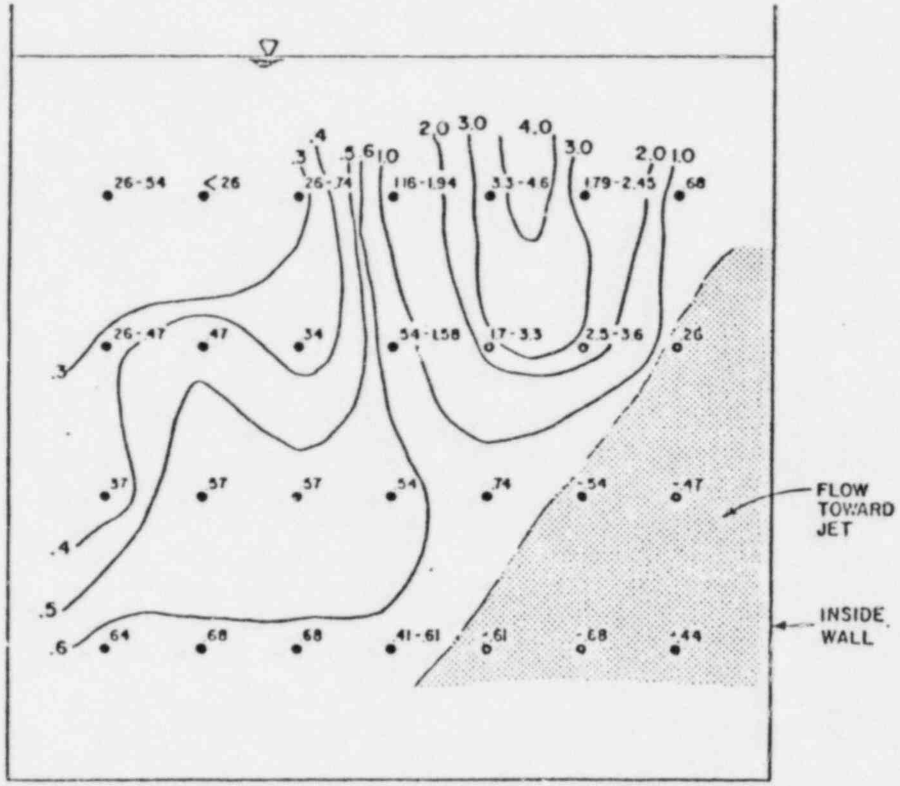
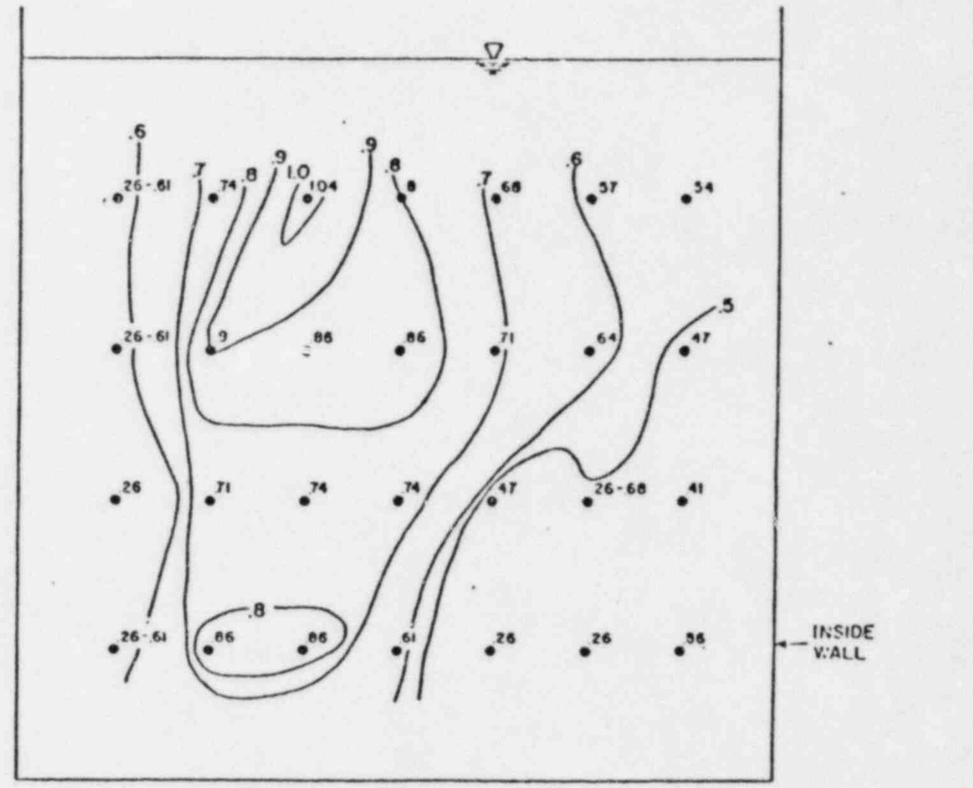


FIG. 7 ELEVATIONS OF RHR SUCTION AND DISCHARGE

RIVERBEND (PRELIMINARY)



VELOCITIES MEASURED BETWEEN THE JET AND QUENCHER No. 1



VELOCITIES MEASURED BETWEEN QUENCHERS No. 1 AND No. 2

JET ANGLE 55°

FIG.8-VELOCITY FIELD FOR JET ANGLE OF 55 DEGREES

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POINT VELOCITIES AND ISO-VELS - TEST O D	
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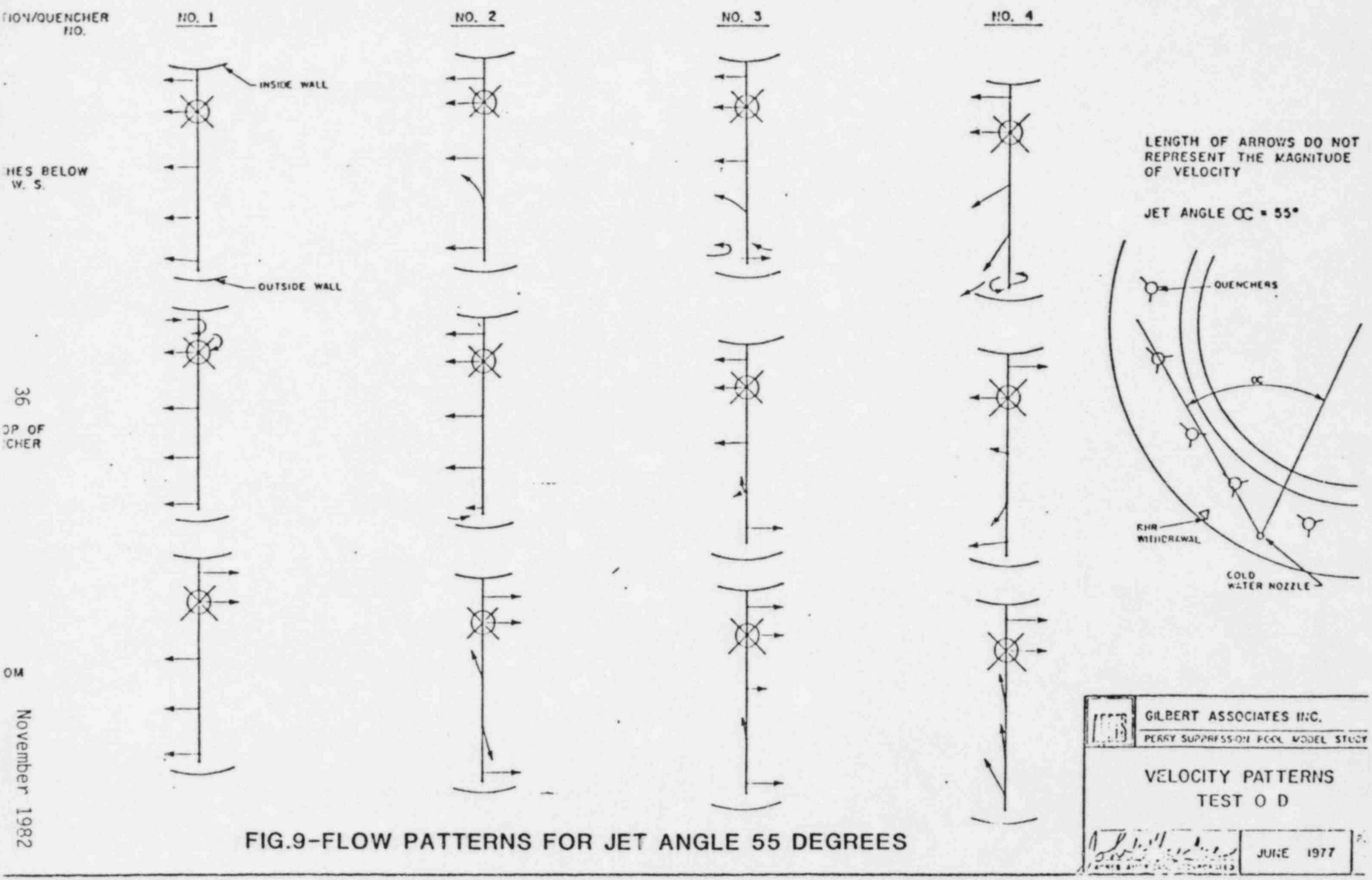


FIG.9-FLOW PATTERNS FOR JET ANGLE 55 DEGREES

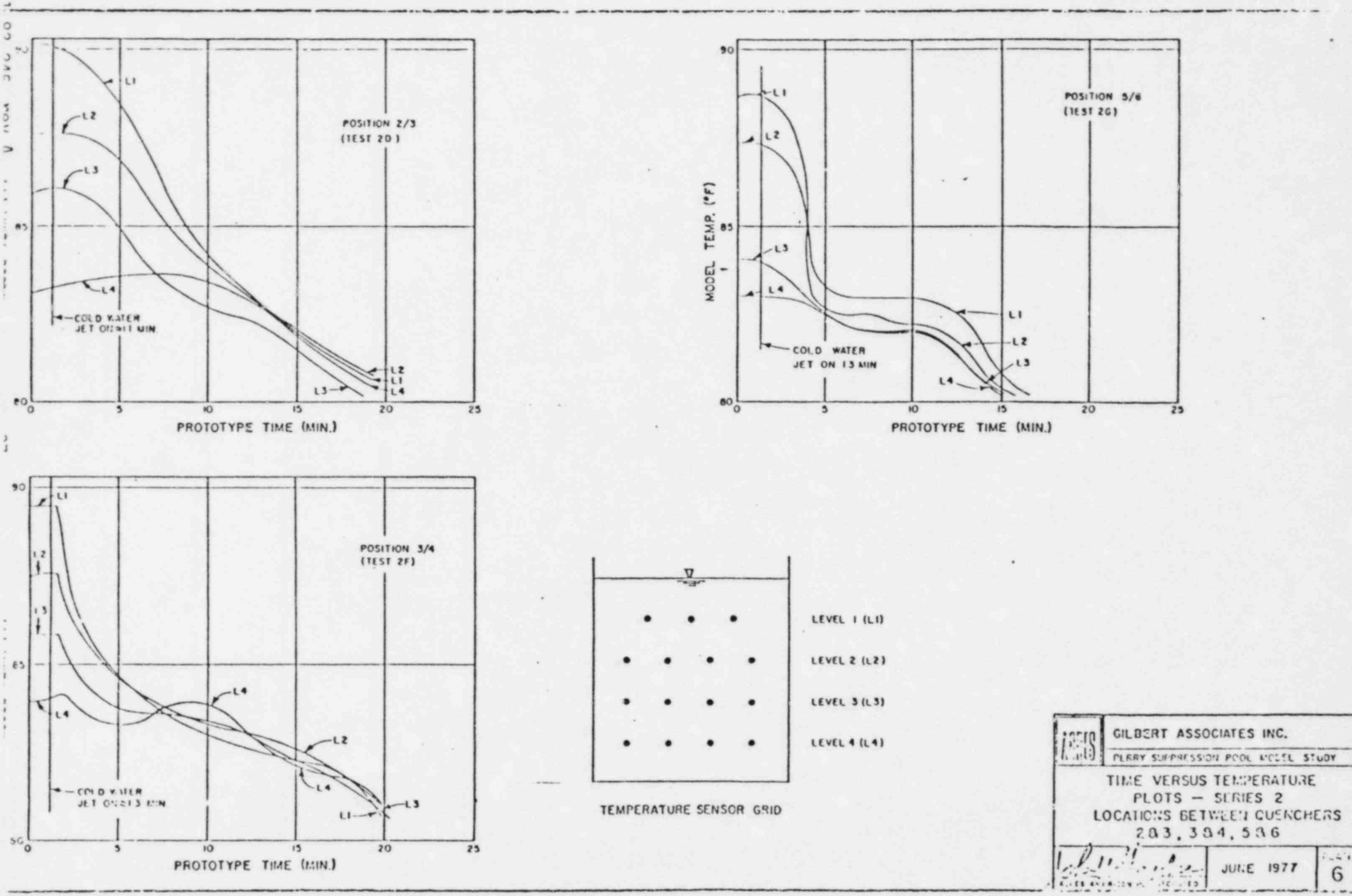


FIG.10-POOL THERMAL MIXING

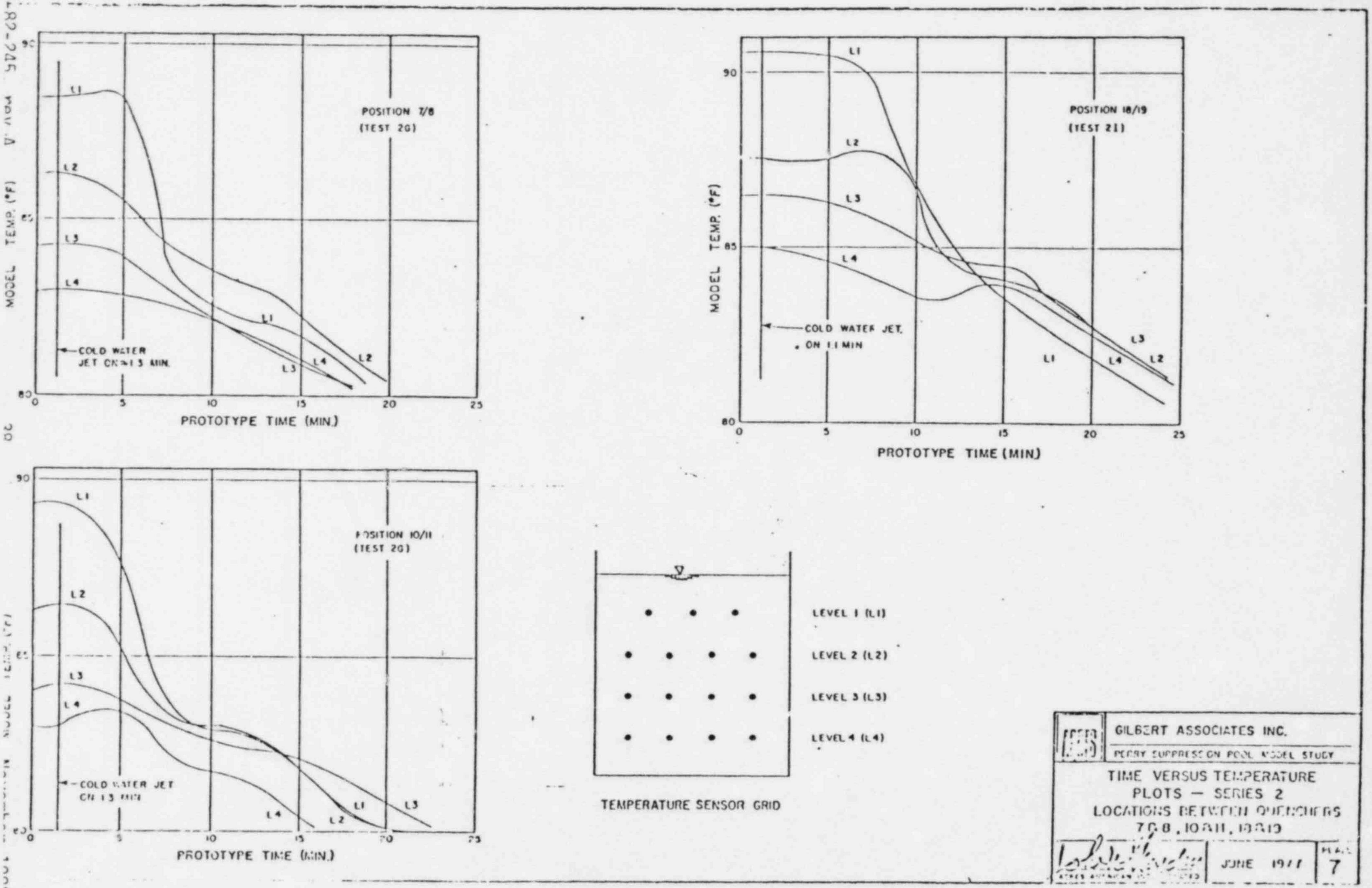


FIG.11-POOL THERMAL MIXING (CONT'D)

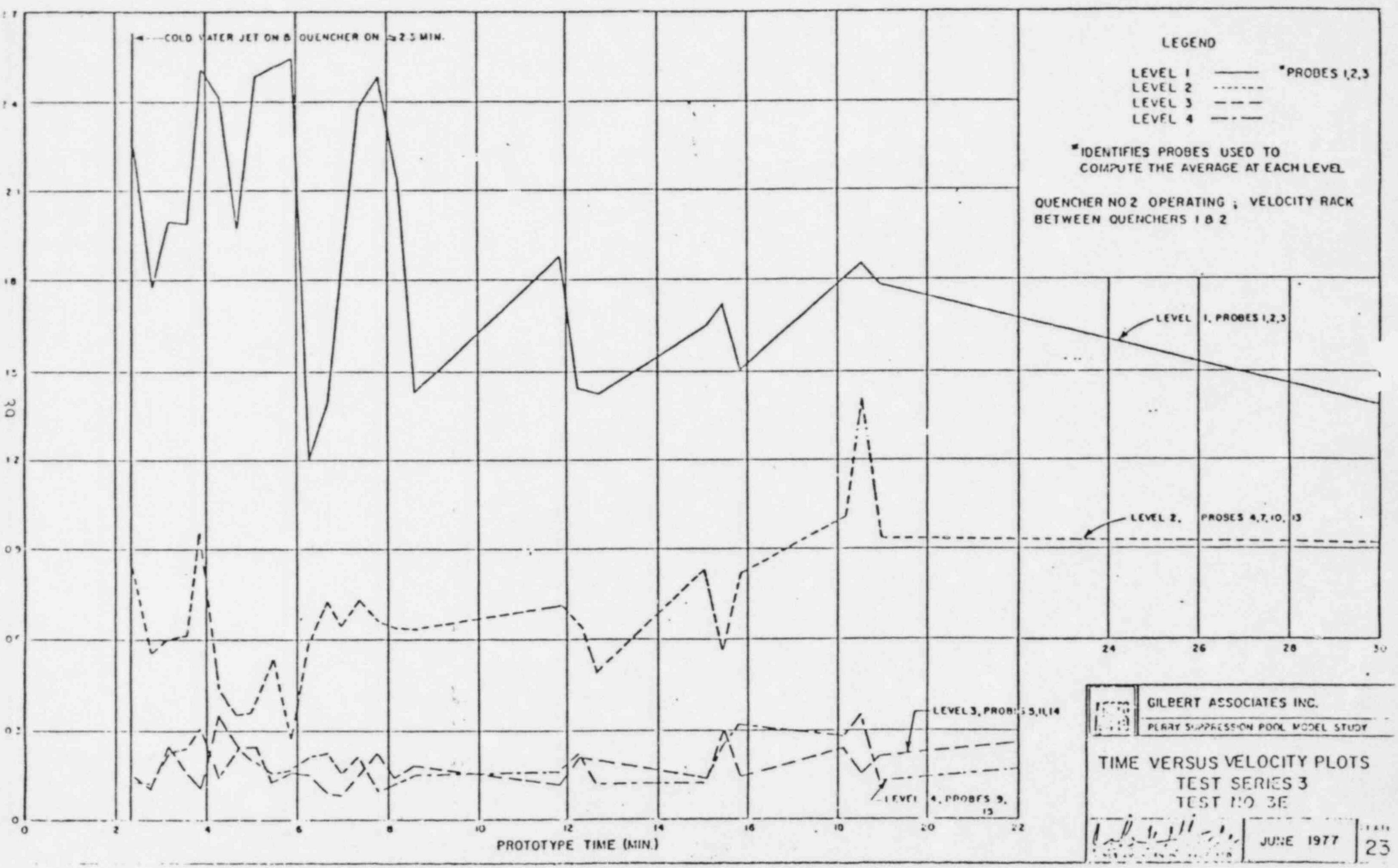


FIG.12-VARIATION OF VELOCITY WITH DEPTH AND WITH TIME

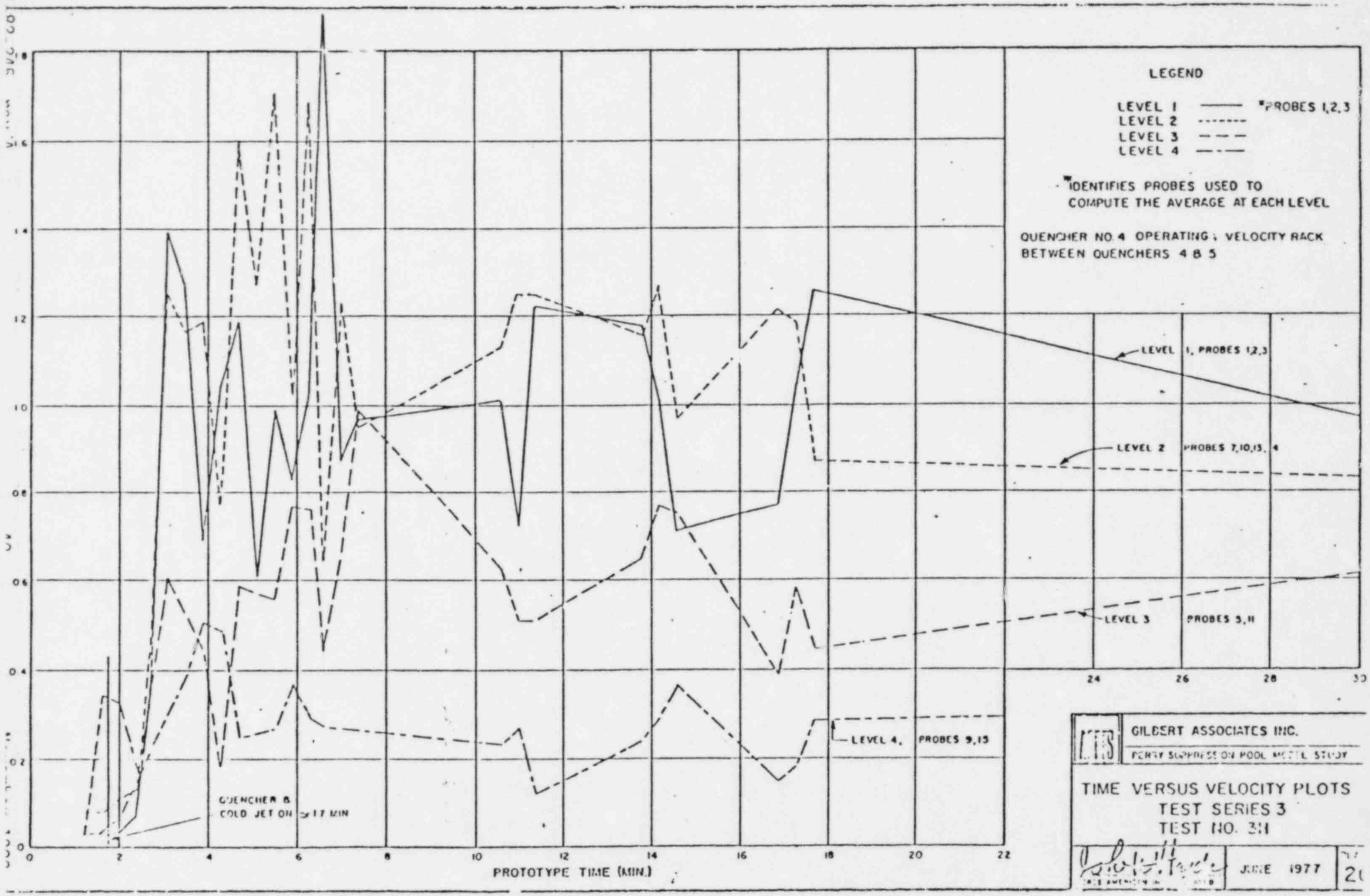


FIG.13-VELOCITY VARIATIONS OF OPERATING QUENCHER NO.4

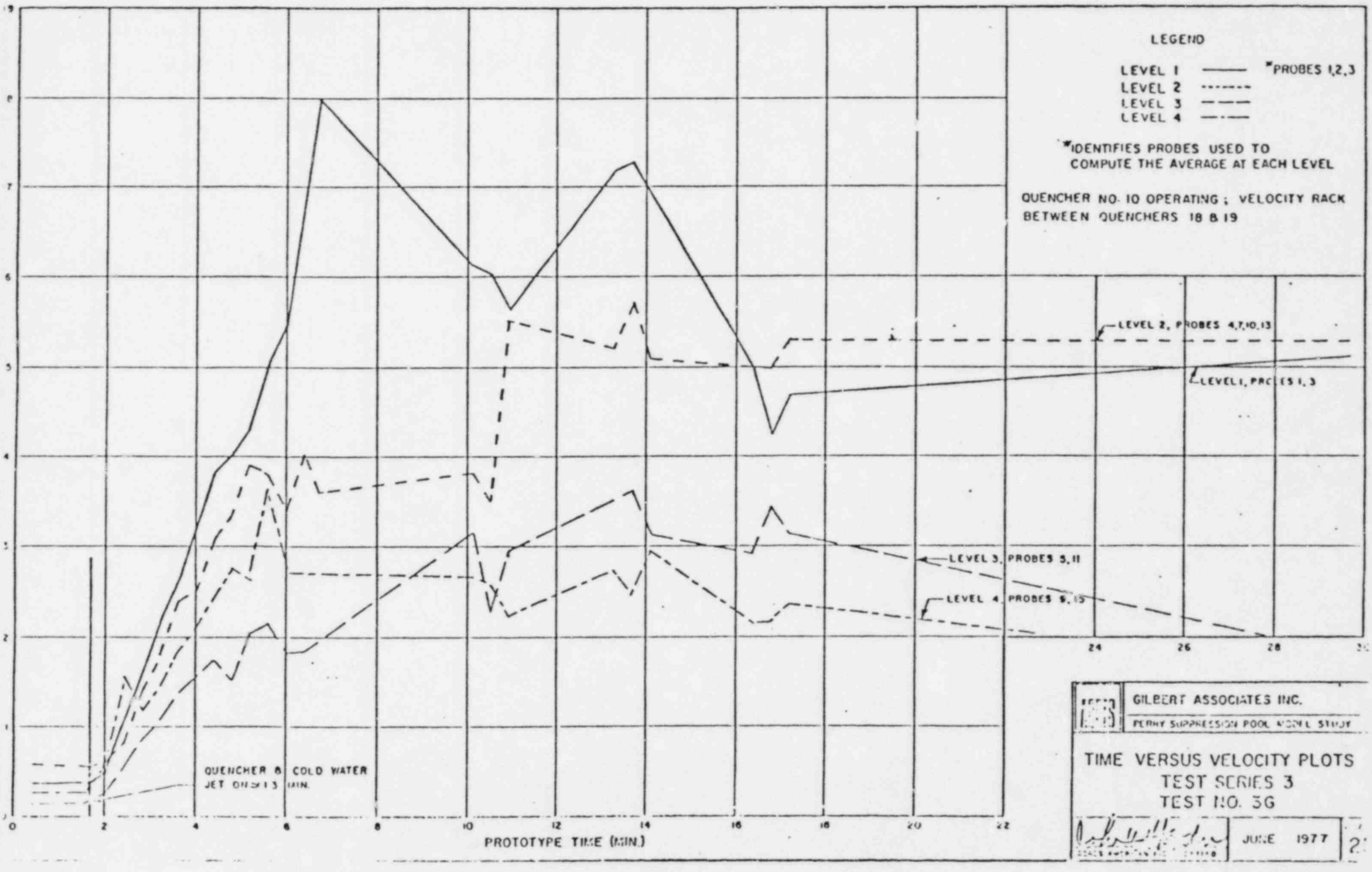


FIG.14-VELOCITY DISTRIBUTION UPSTREAM OF THE JET

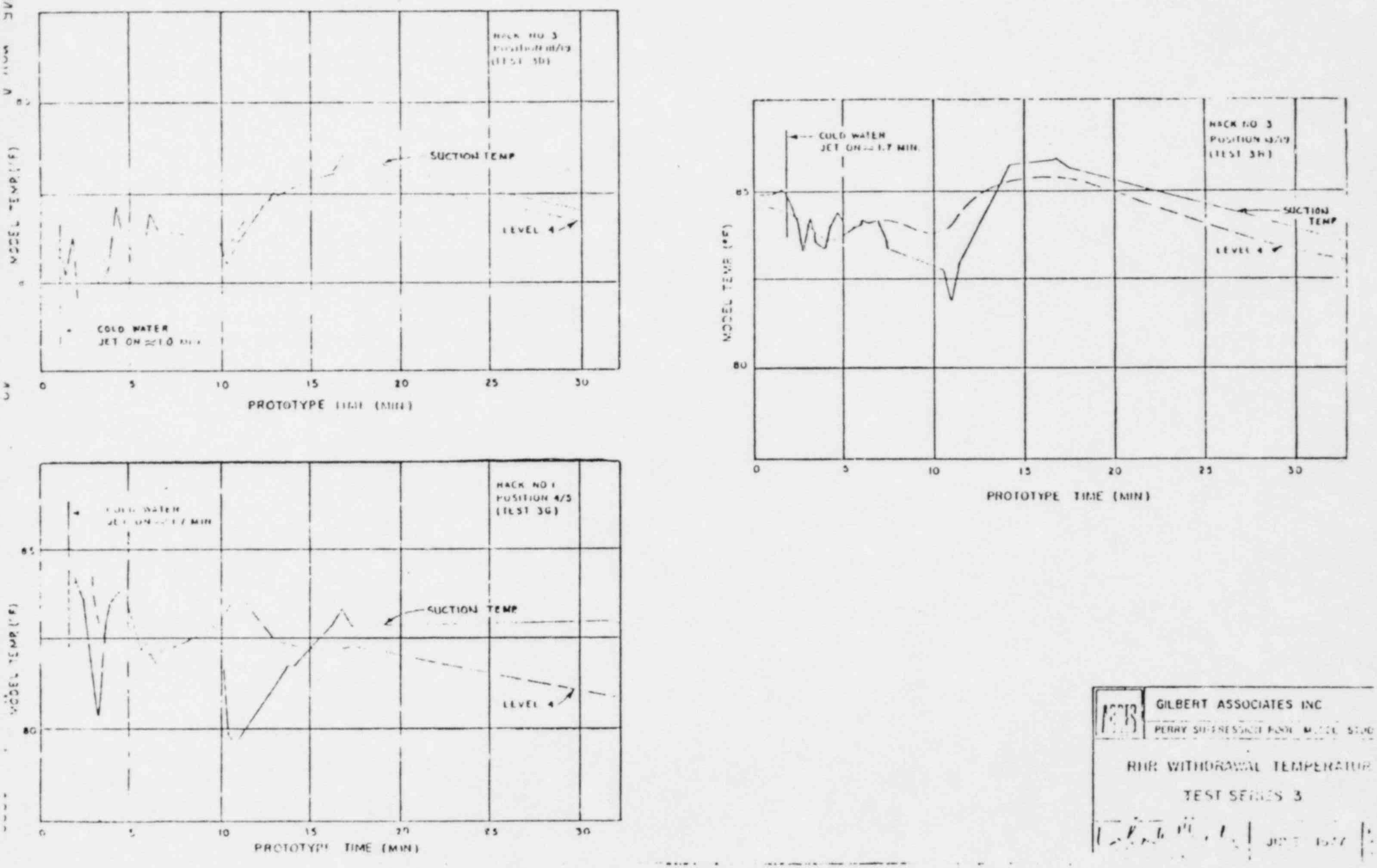


FIG.15-VARIATION OF SUCTION TEMPERATURE WITH TIME

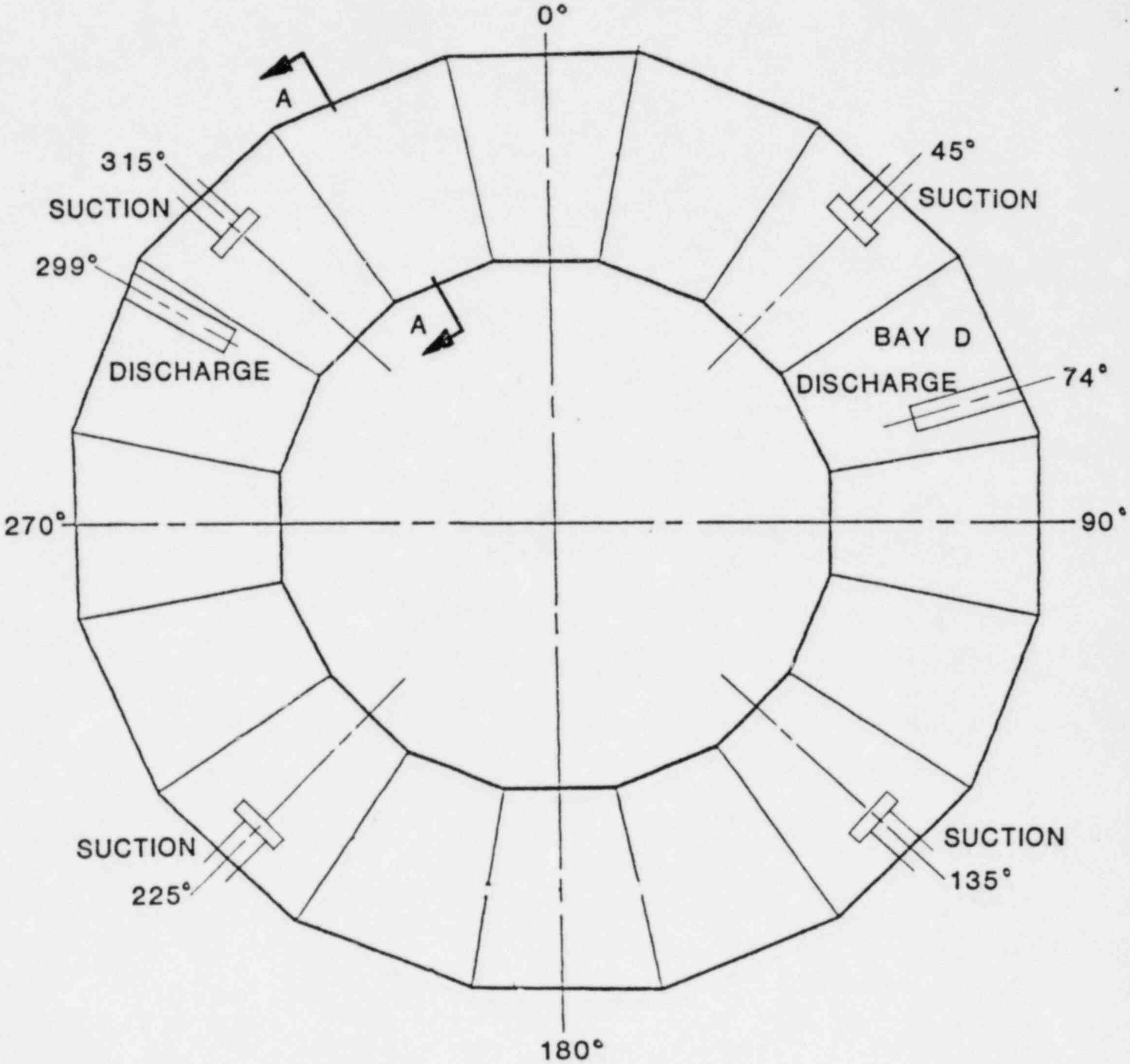
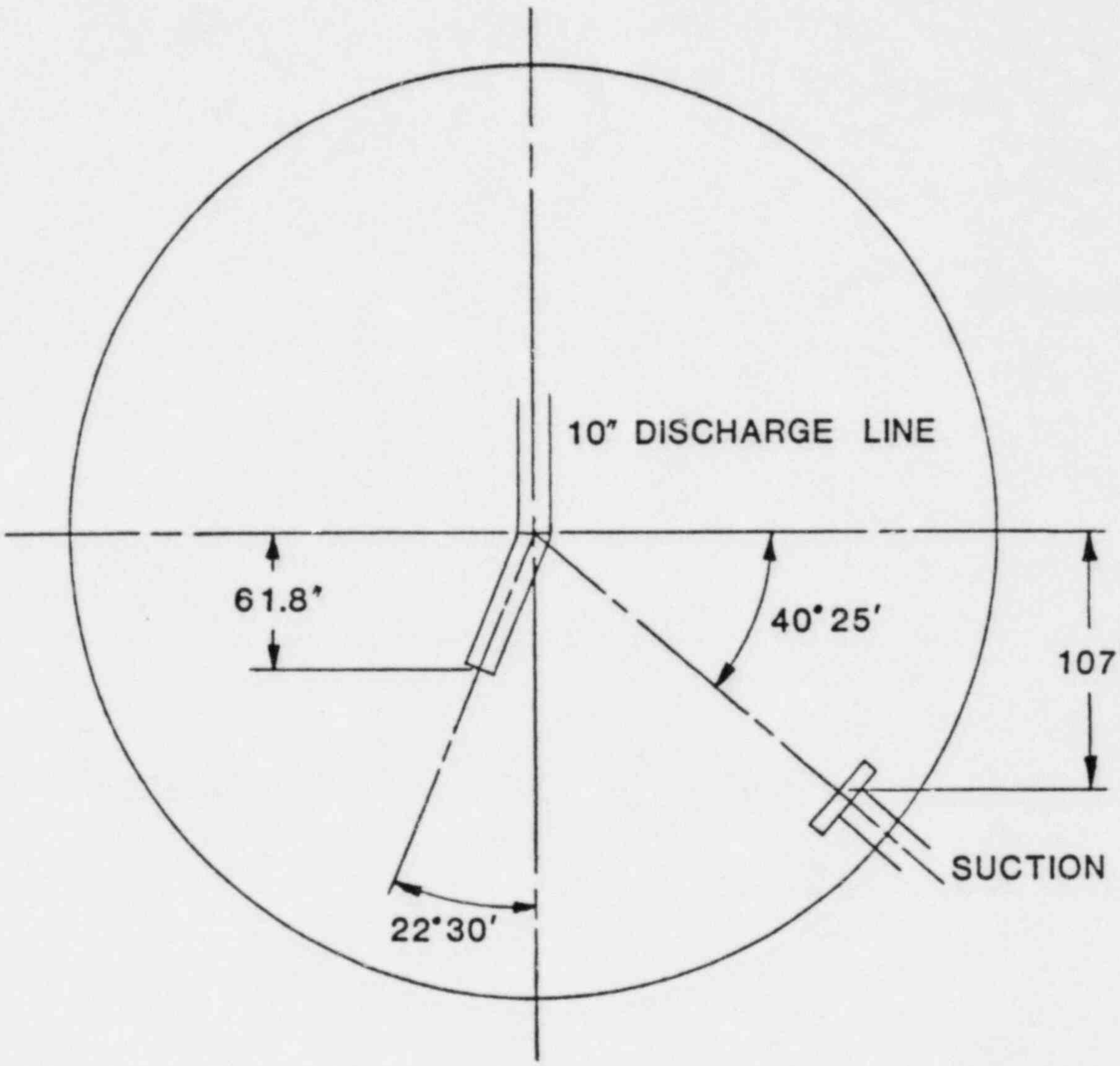


FIG. 16 RHR SUCTION AND DISCHARGE LOCATIONS



VIEW A-A

FIG. 17 RHR SUCTION AND DISCHARGE ARRANGEMENT

FIGURES 18-25

(SEE PROPRIETARY FILE)

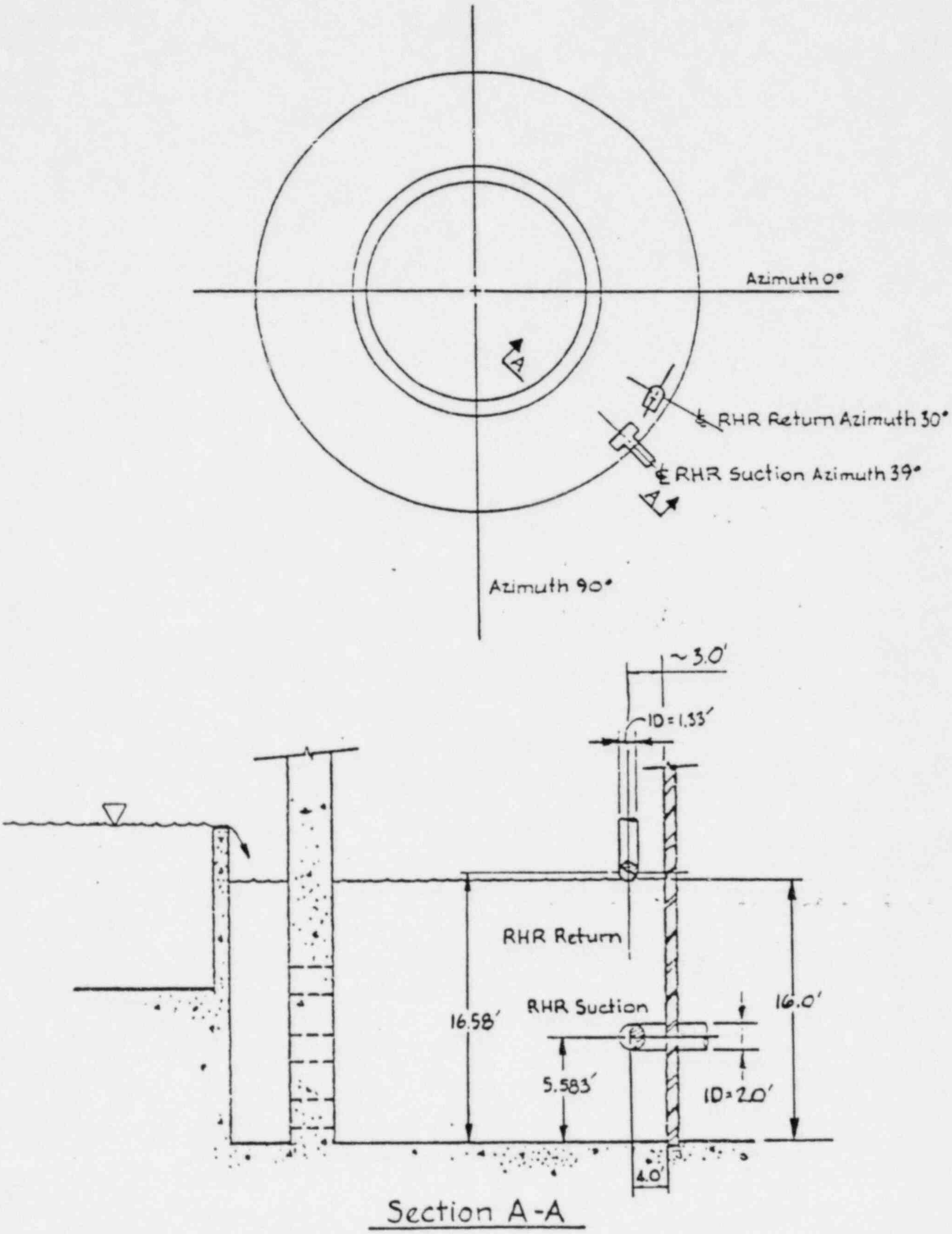


FIGURE 26

RHR RETURN AND SUCTION DETAIL

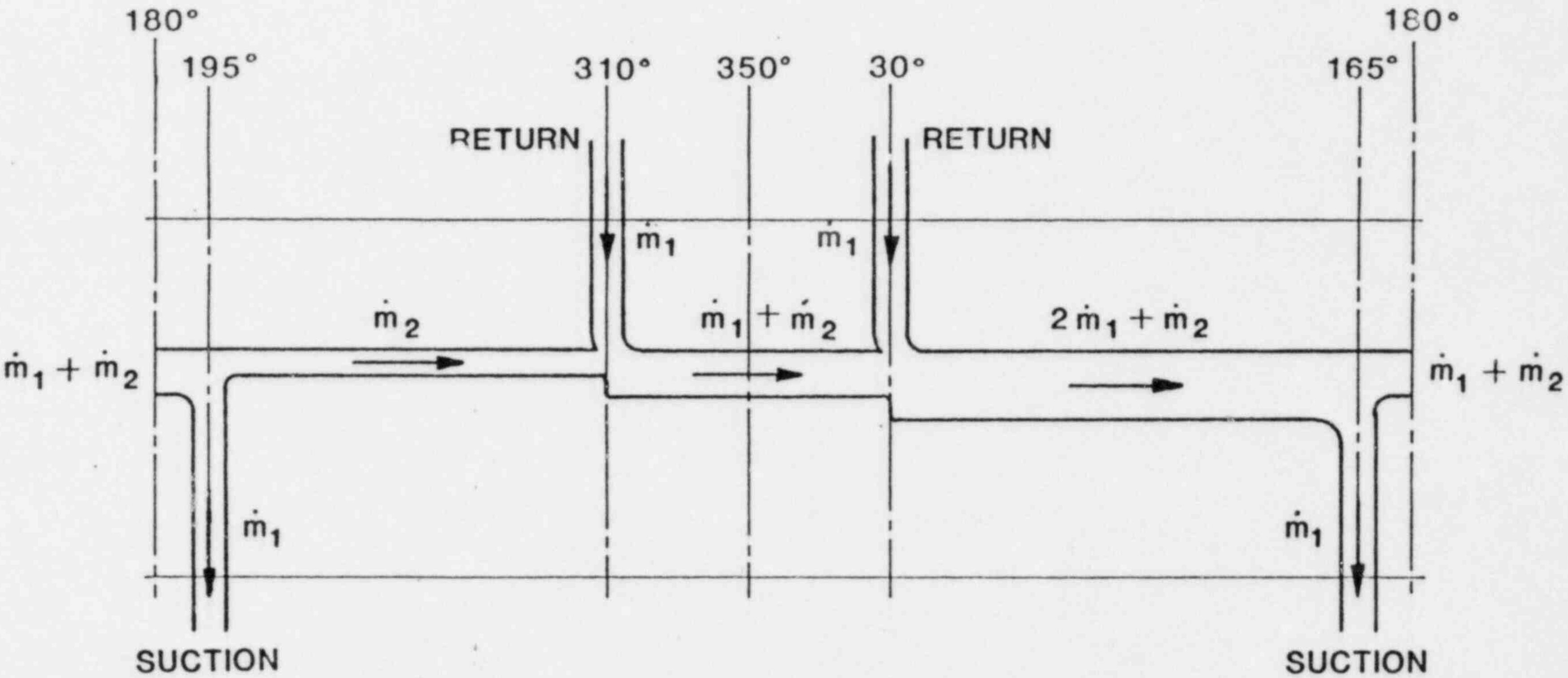


FIG. 27 GLOBAL FLOW FOR DISCHARGE JETS POINTING IN THE SAME DIRECTION

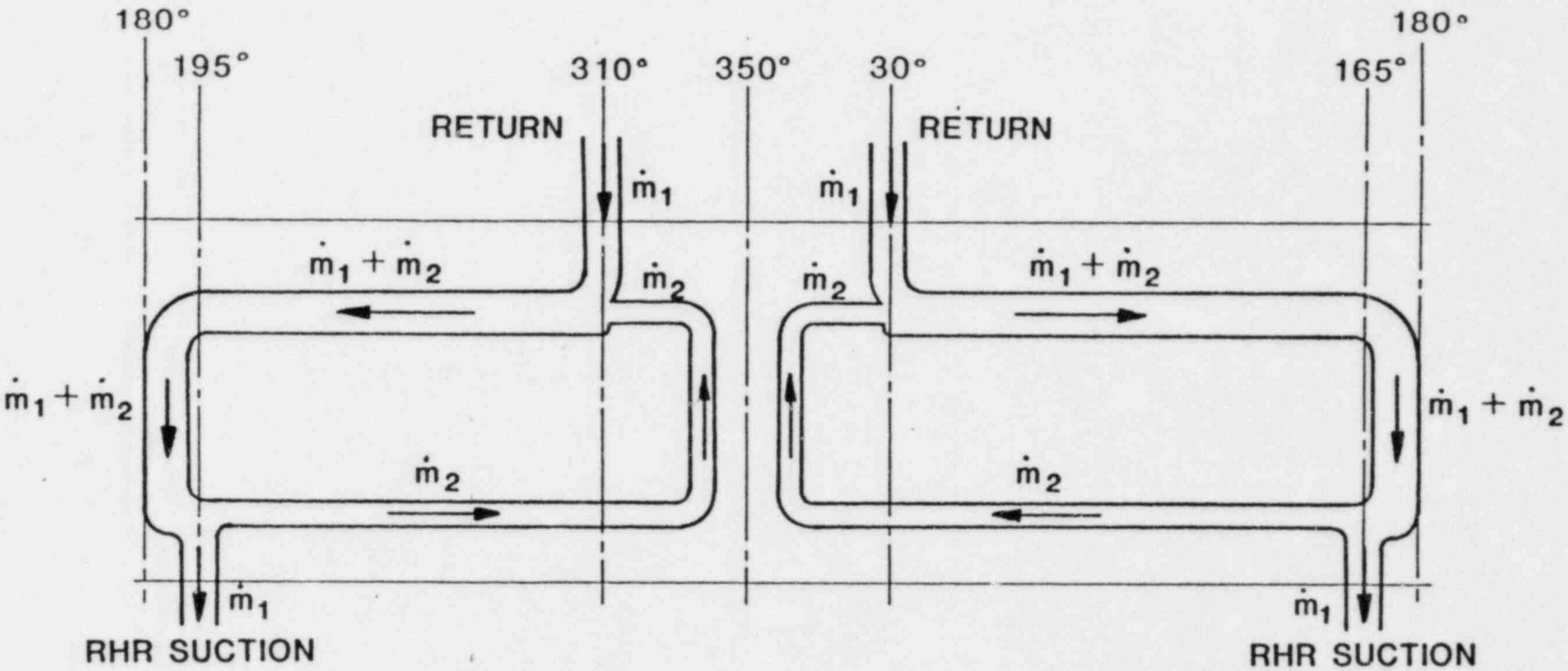


FIG. 28 GLOBAL FLOW FOR THE CASE OF OPPOSING DISCHARGE JETS