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THERMOCHEMICALLY POWERED HEAT PUMP AND HEAT STORAGE DEVICE

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P.A. STEVENSON, F.E. HAUKE, C. KNAPPENBERGER, K. WEHMEYER

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1.0 INTRODUCTION

In April of 1981, our group began its' initial studies in the use of sodium sulfide as a medium for energy storage. This work culminated in grant proposal CO-0136 to the Department of Energy's Appropriate Energy Technology Small Grants Program which was subsequently accepted and we were duly awarded grant number DE-FG48-81R801058. Work began on this project in October of 1981 and continued through 1982. This report is a summary of the work performed under that grant.

During the first quarter of activity, most of the test equipment was ordered and received. Two major construction projects were completed, laboratory construction and the first prototype test vehicle. Details of the test equipment and prototype design can be found in the second section under the headings of TEST EQUIPMENT, CONSTRUCTION OF FIRST PROTOTYPE and CONSTRUCTION OF SECOND PROTOTYPE. In addition to the construction projects, a literature search for relevant information was begun, and some work was done to develop mathematical models of the processes involved in order to better understand the important design parameters. The results of the literature search are referenced throughout the report and a bibliography is included at the end of the report. The mathematical modeling can be found in the third section, THEORY OF OPERATION and the fourth section CONSTRUCTION CONSIDERATIONS.

During the second quarter of our project, the literature search continued. Also, the major equipment purchases were completed and the first prototype test system debug was almost completed.

The third quarter of operation marked the first major data collection phase of the project. The test equipment was debugged and calibrated and design work on a second prototype unit was started. Because of an equipment failure, we were forced to purchase a new bath temperature regulator which caused a three week schedule delay. In the DETAILED INFORMATION section a discussion of the test results is presented in some detail.

During the forth quarter of operation, more data was collected and the design of the second prototype test unit was continued. The new test unit was designed to take advantage of the information gained from the first prototype and the results of the mathematical modeling. The pressure transducer malfunctioned requiring the purchase of a replacement device.

During the fifth quarter the second prototype test vehicle was completed and limited testing was performed. Detailed information on the design and the test results can be found in the second section, DETAILED INFORMATION, under the subheadings titled DESIGN OF THE SECOND PROTOTYPE and TESTING OF THE SECOND PROTOTYPE. Also during the fifth quarter a materials study was done to determine the effects of sodium sulfide on various metals which might be considered for construction.

2.0 DETAILED INFORMATION

In this section a more complete description of the test equipment, the design and construction of the two prototype test units, and the tests run on them is given. Some results and conclusions of the testing are also included. A description of a materials test to determine the susceptibility of some common construction metals to corrosion from sodium sulfide is also in this section.

2.1 TEST EQUIPMENT

The test equipment used in our project was built around a ten channel data logger with a multiplexing box that expanded the capacity of the data logger to twenty channels. This system, combined with a variety of transducers, was used to monitor the performance and status of the prototype units. Detailed circuit and logic diagrams for the multiplexer, can be found in APPENDIX A, test equipment.

Of the twenty available data channels, twelve were used for temperature measurement within the salt bed itself. Two channels were used for the water reservoir and one channel each was used for each of the temperature baths. The differential temperature across each heat exchanger used two more channels and the pressure transducer and the water reservoir depth indicator each used one channel.

In addition to the data logger, purchased with funds from our grant, and the multiplexer which was designed and built during the first and second quarter of the project, an IBM personal computer was used for data reduction and analysis. A series of computer programs were written to aid in reduction and analysis of data. These programs perform a variety of functions including:

- Reading data from the data logger tapes into the computer.
- Conversion of the raw data into a variety of different dimensional units.
- Listing data files in tabular form.
- Ploting data in graphical form.

In APPENDIX B a more detailed description and listings of all the computer programs can be found.

2.2 DESIGN AND TESTING OF PROTOTYPE UNITS

Two prototype units were built for the purpose of performing operational testing. The first unit was designed to provide basic operating information, however, because of several design flaws, did not perform as well as hoped. Based on the operation of the first unit, a second unit was designed and built which performed much better than the first unit and, in so doing, helped us to establish some design parameters for optimizing the performance of the system.

DESIGN OF THE FIRST PROTOTYPE

The first prototype unit is shown in cross section in figure 2, while figure 1 is a schematic diagram showing the disposition of the some of the transducers. All of the transducers are not shown, to add clarity, but in figure 3, the positions of the temperature probes inside the salt bed are shown.

In the first prototype unit, a water reservoir is maintained to act as an evaporator while the salt is functioning as an absorber and also acts as a condenser when the salt is performing as generator. Lowering the system pressure prevents the salt from dissolving in its own water of hydration as it is heated and also increases the molar concentration of the water vapor thereby increasing vapor diffusion rates. Once again, referring to figure 1, tank (1) is a temperature controlled bath enabling the control of the temperature in tank (2). Calorimetric information is gained by measuring the temperature gradient across the coil (5), and monitoring the flow rate generated by the pump (6). A similar function is provided on the salt side (tank (3) by another water jacket (7), tank (4) and pump (8). The temperature in tanks (1) and (4) is controlled only as a secondary quantity to maintain the proper salt temperature and water reservoir temperature. In addition to the differential temperatures across both heat exchangers, the system, salt temperature and reservoir level are monitored by the data logger system.

Figure 2 gives more information about the actual construction of the first prototype unit. Two plywood boxes, 36 inches on each side were constructed and lined with 3 inches of styrofoam for insulation. Large aluminum vessels were placed inside each box to act as water reservoirs and inside these large vessels, stainless steel cans were suspended to hold the salt on one side and the evaporator/condenser on the the other. Also, a heat exchanger was placed into the large tanks to allow heating and cooling as needed. Heat exchangers were used so that it would be possible to monitor the temperature difference across the exchanger and,thereby, measure the amount of heat added and removed from the system. The stainless steel tanks were sealed and joined by 1 inch I.D. CVPC pipe with a valve in the middle to allow the two tanks to be joined and separated as required.

The heat exchangers were connected to a heater and a refrigeration unit respectively. The heater consisted of a small tank with a bath temperature controller in it that pumped hot water to the side of the system that needed heat during the relevant part of the test. While one side of the system was being heated, the other side of the system was cooled. For cooling, a small refrigerator was modified to allow water to be passed over the cooling coils then into a storage tank where another bath temperature control unit heated the chilled water and antifreeze mixture to the desired temperature than pumped the mixture through the heat exchanger on the appropriate side of the system.

TESTING THE FIRST PROTOTYPE UNIT

Testing of the first prototype unit was accomplished during the third quarter of the project. A considerable amount of time was spent sealing the system against vacuum leaks. Vacuum leaks proved to be one of the most time consuming problems throughout the project. Finally, in June of 1982, a successful test was run using the first prototype test system. Some of the results of that test are shown in figures 4a, 4b , 4c and 4d and are described below.

Figure 4a depicts the temperature variation in degrees Fahrenheit of the temperature control bath (the small circles) and the temperature of the salt bed (the short dashes) versus time in hours. Two important things to notice are that at approximately 160deg F the salt temperature levels off even though the bath temperature continues to rise to about 180deg F. This effect is a result of the hydrated salt changing its stable hydration level. When that level is changing, as it is in figure 4a, the energy which would normally result in a change in temperature, is removing water from the salt crystal lattice structure and then changing that liquid water into water vapor. This heating section of the curve is shown in more detail in figure 4b. If the heating time were increased sufficiently, all the water at this hydration state would be removed and the temperature of the salt would again rise.

During the cooling phase of the test, at about 95deg F, the salt temperature begins to deviate from the temperature of the surrounding water bath. A more detailed view of this phenomenon can be seen in figure 4c. The elevation of the salt temperature above the water temperature at this point is due to the reverse of the process explained above, specifically, the salt is rehydrating and releasing energy in the process. Notice that just past 335 hours the salt temperature suddenly drops to the water bath temperature. This occurs because the water supply for the salt was removed by closing the valve between the salt bed and the water reservoir. With water vapor no longer available to the salt, the rehydration reaction stops and heat is no longer released.

Several problems are obvious after looking at figures 4a and 4c. First, why is the temperature rise only 5deg F, hardly a useful amount of heating for a domestic hot water system, and second, why does the reaction not begin to any significant degree until the temperature falls below 95deg F. Certainly any hot water system needs to operate at well above this temperature and provide heat at a higher rate than was provided by this prototype test system.

Based on theoretical modeling (see THEORY OF OPERATION) the problem was ascertained to be two fold.

The first problem was the slow diffusion rate of water vapor from the evaporator (water reservoir in tank #2) to the salt (tank #3). This was due to the relatively long, narrow pipe connecting the two stainless steel tanks. With only a medium hard vacuum (0.1 - 1.0 psi), the diffusion of the water vapor was just to slow to maintain the reaction at a high enough rate to generate heat at useful rates.

The second problem was that the salt had far to small a surface exposed to the water vapor in relationship to its volume. This caused a further slowing of the reaction rate because it both limited the diffusion of water vapor into the salt and limited the diffusion of heat out of the salt bed into the surrounding water jacket. Slowing the rate of thermal diffusion causes the internal temperature of the salt bed to rise and, thereby, stops the reaction or, at least, slows it down, further limiting the amount of heat released.

Figure 4d shows the temperature gradient along the center axis of the salt bed during the cooling process. It clearly shows that the salt temperatures fall as they get closer to the outside wall next to the water jacket. This indicates that water vapor is not being supplied to this region of the salt bed and that the reaction is being limited.

All of the above concerns led us to the conclusion that a new system needed to be designed and built to improve both water vapor diffusion and thermal diffusion. This new design was completed and tested during the fifth quarter of the project.

DESIGN OF THE SECOND PROTOTYPE

Figure 5 shows the configuration of the second prototype unit. The evaporator/absorber (4) was submerged inside one of the large aluminum water tanks shown in figure 2 for the first prototype test unit and the heat flow was monitored using the same method as described for the first unit. Vacuum was drawn and system pressure was monitored at the top of the chimney although this apparatus is not shown in figure 5.

The heart of the unit shown in figure 5 is a stainless steel tank (5) used to hold the salt (2). The salt tank (5) is open on the bottom and rests on a polycarbonate adapter plate (7). Between the tank (5) and the plate (7) is a rubber seal (not shown) and under the plate (7) is another smaller stainless steel tank (6) which acts as a water reservoir and is also joined to the plate (7) with a rubber seal. A two inch diameter hole in plate (7) connects the two tanks (5) and (6). Plastic screen (not shown) forms a chimney starting at the hole and ending near the top of the large tank (5). The annular space formed between the chimney (3) and the tank (5) is filled with salt and the reservoir (4) is partially filled with water. The amount of water to be added at the start of the test is determined by the hydration state and amount of salt added to tank (5). If the salt added is fully hydrated, no water needs to be added.

Surrounding tank (5) is another tank (8) made of mild steel with a rust resistant coating. Tank (8) is used as a water jacket for both adding and removing heat from the salt bed. It is not stainless steel because it never comes in contact with the salt.

The advantages of this design over the first design are fourfold. First, the diffusion path for the water vapor is far shorter and also has a larger cross section. The second advantage is the much larger surface area available for the water vapor to contact the salt. The third advantage is that the maximum distance from any place in the salt bed to the water jacket is minimized thus allowing for maximum thermal diffusion. Finally, the fourth advantage is that no place in the salt bed is very far from the surface of the salt exposed to the water vapor so the vapor diffusion losses within the salt itself are also minimized.

For the above reasons the performance of the second prototype was expected to greatly improve with respect to the first unit. As will be seen in the next section, a large improvement in performance was realized.

TESTING OF THE SECOND PROTOTYPE

The basic construction of the second prototype test unit was completed during the fourth quarter of the project however vacuum leaks once again were a major problem and took a great deal of time to isolate and fix. Finally, late in the fifth quarter, the system was made operational and a test was completed successfully. The remainder of This section describes the results and conclusions of this test.

Figure 6 shows the relative locations of the temperature probes imbedded within the salt bed. The probes were arrayed in a radial-axial plane of the salt tank. This arrangement was choosen because it took advantage of the axial symmetry of the system and also because it allowed us to study temperature gradients within the salt bed. The descriptions following will refer to the node numbers in figure 6.

Figure 7a is a plot of the water jacket temperature,TBS, and the salt bed temperature, TS7, versus time in hours. This plot gives a profile of the test, namely, the temperature profile of the water jacket. Heat was applied to the water jacket for the first 14 hours of the test. The heater took about 3.5 hours to bring the water jacket to approximate equilibrium at a temperature of 83degC. At about 14 hours into the test the heat source was switched off and the system began to cool. Note that the water jacket temperature cools along a normal exponential cooling curve until it has fallen to just under 60degC at which point the temperature decline stops for 2 to 3 hours and then begins again but at a slower rate, the rate of the salt bed, maintaining a fairly constant temperature difference relative to the salt bed. This indicates that at somewhere near 60degC the rehydration reaction in the salt begins and acts to heat the water jacket.

Figure 7b is a more detailed look at the cooling portion of the test which starts at about 14 hours. This plot shows the temperature of the water jacket (TBS) and the temperature change through the water jacket as a function of the time in hours. Notice here that when the temperature falls to approximately 57degC, the temperature drop across the water jacket begins to increase (increasing negative indicates heat flux out of the jacket) and the rate of cooling is substantially reduced. After approximatelv 2 hours the water jacket temperature begins to fall again but at a much reduced rate. Meanwhile the temperature drop across the water jacket reaches a peak at about 24 hours, maintains that level for about four hours then decreases and levels off again at a reduced value of about -9degC. Since the pump is operating at a rate of about 70 ml/sec, the power output of the system, even at the reduced temperature difference is about 2.7 kw., certainly a significant amount of power. The total heat energy removed from the system during the period starting at 19 hours and lasting through the end of this particular test is nearly 30 kwh., only a small part of which was stored as sensible heat in the salt itself.

Clearly, the second prototype unit far outperformed the first unit. Further evidence of the improved performance of this system is the decrease in temperature gradients within the salt during the test. Figure 7c shows the temperature profiles at points 6, 7 and 8 during the heating phase of the test. Notice that even during the maximum heating period the range of temperature spread between the outside and the inside of the salt bed is no more than 7degC and even that temperature difference does not persist for very long.

Figure 7d shows the temperature profile along the inside of the chimney as a function of time and figure 7e shows the temperature profile inside the salt bed as a function of time. Both of these figures show that the salt bed remains quite uniform. In figure 7d, the temperature at the bottom of the inside wall of the chimney, TS10, is the only temperature to show significant deviation from the other temperatures. This deviation may be a result of the water jacket which, because of construction considerations, did not extend the full length of the salt tank (in figure 5, tank (8) is shorter than tank (5)). This may explain the variations seen in figure 7d.

The second prototype unit performed very well. We continue to run tests to evaluate and characterize it. Several new modifications are being considered to improve its performance but these will not be pursued under this project. In summary, we feel that this second prototype unit was very successful and appears to be the basis for a working design.

2.3 MATERIALS TESTING

During the fourth and fifth quarter of the project a materials evaluation was run to test the effect of sodium sulfide on a variety of common construction metals. Sodium sulfide is highly corrosive and some care is required in choosing the proper materials as they must be strong enough to support a fair amount of weight and pressure loading and they must be able to withstand elevated temperatures and be able to conduct heat reasonably efficiently.

The materials we studied were, aluminum in three different alloys, brass, copper, carbon steel, a mild steel and stainless steel. Two samples of each metal were placed in jars containing dry salt and a salt and water slurry, respectively.

In any form, the salt was found to be very corrosive to all forms of aluminum, copper and brass. Mild steel and carbon steel were only slightly effected by the dry salt but carbon steel was severely effected and mild steel was moderately effected by the slurry. Stainless steel was unaffected by either the dry salt or the slurry.

Although we did not test plastics and coatings, most construction plastics which will stand the temperature requirements (100degC) are unaffected by the corrosive effects of the salt. One very promising approach is an epoxy coating over mild steel. This is quite impervious to corrosion, has almost the same thermal and mechanical characteristics as the mild steel yet it is much less expensive then stainless steel.

3.0 THEORY OF OPERATION

This section introduces some of the theory behind the operation of absorption heat pumps and discusses some of the history, advantages and limitations of them. Several examples are given and many valuable references to other related works are stated (see also the bibliography for additional references).

3.1 THE ABSORPTION HEAT PUMP CYCLE

This section outlines the history of the absorption heat pump and the basic theory of its operation. Also in this section is a discussion of the idealized Carnot heat pump cycle.

BACKGROUND

The absorption heat pump cycle has been described in detail by Perry [26]. The basic process can be described as follows. Heat is supplied to a generator driving the working fluid from a weak absorbent. The working fluid is than condensed during the heat rejection phase of the process in the condenser. The fluid is than transferred to the evaporator which operates at a lower pressure than does the condenser. When heat is supplied to the evaporator the working fluid is vaporized and combines with the strong absorbent during which time the heat of absorption is liberated. The weak absorbent is than transported back to the generator.

Because of the intermittent nature of solar energy and the relatively low temperatures that can be obtained in a domestic solar heating system, some modifications to the above system are in order. These modifications, described in detail by Stanish and Perlmutter [16] and Brunberg [18] involve combining the generator and the absorber into one unit and combining the condenser and the evaporator into another unit. Both of these units than act sequentially to provide the four required functions of the absorber heat pump cycle.

OPERATION

A typical configuration,shown in figure 8,might consist of a bed of salt in contact with a heat source and a heat removal system. The salt acts as a weak absorber while being heated, liberating the working fluid,say water, and then, as a strong absorber while being cooled. During this phase, the salt absorbs the water vapor and liberates both the heat of vaporization and the heat of absorption. In relative close proximity to the generator/absorber is the condenser/evaporator, in this case a water reservoir in contact with a temperature reservoir, permitting heat to be rejected during the generation/condensation phase and supplying heat at low temperature during the absorption/evaporation phase of operation.

Figure 9 illustrates the thermodynamic process used in the heat pump cycle in temperature/composition space. For simplicity, the process is idealized to some extent. Consider point 1 as the starting point, heat is added between 1 and 2 until water begins to leave the salt at point 2. Between 2 and 3, water, which was previously locked in the crystal lattice, is released and vaporized. Process 2-3 requires the system to absorb both the heat of hydration of the particular hydration state and the heat of vaporization of the water. During process 3-4, the heat source has been removed from the generator and the salt, accordingly, cools. The temperature at state 4 has reached a sufficiently low point that the vapor pressure of the salt has fallen below the vapor pressure of the condenser/evaporator and water vapor begins to move from the evaporator to the salt, condensing on its surface and recombining with it to form hydrates again. During this process, the heats of vaporization and hydration are released and may be removed during process 4-1. Clearly, anytime during stage 4-1, heating may begin again causing the absorber to once again become a generator and, similarly, during process 2-3, the heat source may be removed causing a 3-4 type transition to to process 4-1. If heat is not removed during process 4-1, the temperature of the absorber will rise until equilibrium is reached, thus stopping the process. The features described above make this process ideal for use with intermittent heat sources such as solar, where frequent heating and cooling cycles can occur.

CARNOT EFFICIENCY

The efficiency, or coefficient of performance (COP), of a heat pump, is defined as the heat moved to the higher temperature divided by the amount of energy used to cause that move. This effect is shown schematically in figure 10 and mathematically in equation (1).

(1) $$(COP)_h = (Q_c + Q_a)/Q_g$$

The heat moved to the higher temperature source comes from two places, the heat or work supplied to operate the pump and energy from the low temperature heat reservoir. By treating the heat pump as a Carnot heat pump driven by a Carnot heat engine it is easy to find the idealized (COP). Taking the ratio of the energies as being equal to the ratio of the temperatures we can show the reversible (COP) to be given by the relationship shown in equation (2) where all all temperatures are absolute.

(2) $(COP)h = (Ta\ Tg - Tc\ Te) / Tg\ (Ta - Te)$

Table 1 shows some typical values for this equation using temperatures that might be available in a domestic hot water system where the ground is used as a temperature sink.

Tg	Ta	Te=Tc	(COP)h
50	20	10	4.5
50	60	10	1.7
80	20	10	6.6
80	60	10	2.1

TEMPERATURES IN DEG C
Tg = generator temperature
Ta = absorber temperature
Tc = Condenser temperature
Te = Evaporator temperature

TABLE 1

3.2 IRREVERSIBLE ABSORPTION HEAT PUMPS

The following section covers the 'real world' case of heat pumps for which the Carnot assumptions of reversibility do not hold. A more detailed description is also given of the performance of sodium sulfide as the absorber/generator material in a real heat pump.

CALCULATION OF IRREVERSIBLE COP

In actual practice, the COP is quite different from the result calculated using the reversible assumptions of the Carnot cycle. Stanish and Perlmutter [16] show that a system like that shown in equation (3) has a COP which can be expressed as in equation (4).

(3) Solid . nF Solid . (n−p)F + pF

(4) $(COP)h = ([Qc_{1\to3}] + [Qa_{3\to1}]) / [Qc_{1\to3}]$

Several cases are solved by Stanish and Perlmutter. For the inorganic salt hydrates examined, the best performing substances they investigated, the COP was in the range of 1.5 to 1.6. Although the calculation of the COP for sodium sulfide is not available because of a lack of thermodynamic data, it is not unreasonable to assume that the COP for sodium sulfide is approximately 1.5.

SODIUM SULFIDE AS THE ABSORBER/GENERATOR

Sodium sulfide, Na_2S, is very rare in an anhydrous state. The salt readily forms hydrates. Although decahydrate, Na_2S10H_2O, has been reported in the literature [21], it is only stable between 0 and 4.7 deg. centigrade. Much more common is sodium sulfide enneahydrate, Na.S9H.O, which exists at standard temperature and pressure. Na_2S9H_2O is easily reduced at temperatures less than 100 degC to monohydrate, Na_2SH_2O [23]. There is evidence that monohydrate exists at temperatures as low as 85 degC. It has stable intermediate states of $Na_2S4.5H_2O$ and Na_2S5H_2O. In addition to its normal hydrates, Sodium Sulfide delequesces and, when in contact with air, forms oxides, largely thiosulfate and carbonate [22].

One other consideration is that the crystals of sodium sulfide enneahydrate will dissolve in their own water of hydration if heated at atmospheric pressure. U.S. patent number 2,533,163 "Dehydration of Sodium Sulfide", Dec. 5, 1950, describes a technique performed at reduced pressure for removing the water such that the product never "melts in its water of crystallization", and a granular product is obtained. If, during the dehydration process, the temperature of the salt is lowered, water vapor will be reassimilated into the crystals thus releasing both the heat of vaporization of the water vapor and the heat of formation for the particular hydrate being formed. The combination of these two results is approximately one kilowatt-hour of energy liberation per kilogram of dry salt [18].

Figure 11 is a pressure/temperature curve showing the operating space of a sodium sulfide based absorption heat pump. The pressure temperature curve of the phase transition for Na_2S5H_2O is shown displaced by approximately 55 degC from the saturation curve for water [18]. Equilibrium is represented by the solid line connecting points 1,2,3 and 4. The evaporator/condenser is held at 10 deg C at point 1. The resulting vapor pressure over the water, 2, is approximately 0.123 KPa. Since equilibrium exists, the pressure over the salt is also 0.123 kPa, point 3, which requires that the salt be at a temperature of 65 deg C., point 4.

If power is drawn from the salt at some fixed rate, the equilibrium will be disturbed causing the temperature of the salt will be depressed. This none equilibrium is represented by the dashed line connecting points 1',2',3' and 4'. The temperature at point 1' is depressed byTe, the finite temperature difference required to facilitate heat transfer into the evaporator. Because the temperature at 1' is lowered, the pressure is also lower at 2' by roughly 7 Pa/degC. While heat is being removed from the salt. vapor is moving from the evaporator to the salt and the resulting flow causes a pressure drop,P, between 2' and 3'. The pressure drop results from interference with diffusion from inert molecules such as air as well as diffusion losses through the salt itself. Finally, the output temperature, 4', is depressed Ta, by the finite temperature drop required to remove heat from the absorber. Temperature drop Ta is approximately linear with respect to the power being moved through the pump. Not shown in figure 11 is the reversal of process 1',2',3',4' during which heat is added to the salt. This process, however results in an increase in the temperature at 1 through a similar set of arguments to those given in process 1',2',3',4'.

4.0 CONSTRUCTION CONSIDERATIONS

This section discusses some of the practical considerations developed during this project. Discussed is the most likely configuration of the system and some practical considerations for integrating an absorption heat pump into a working system. A discussion of suggested construction techniques is also included.

4.1 SYSTEM OVERVIEW

There are many possible configurations for an absorption heat pump and, to some extent, the configuration chosen is a function of the application for which it will be employed. The system to be described here is based on a low power, low temperature, intermittent heat source such as a small array of flat plate solar collectors and, as a low temperature reservoir, the earth. The application is domestic hot water heating for a single family dwelling, however many of the principles are extendable to other applications such as space heating.

The system may be broken into three major parts, the energy supply, the heat pump and the low temperature heat sink and source. The energy supply will be considered to be solar collectors but could obviously be any other source. One interesting possibility is the use of electric heat where a peak demand pricing system is employed. In other electric installations, the higher efficiency of compressor driven heat pumps would probably make them more desirable than an absorption heat pump. Industrial waste heat could also be used to dehydrate canisters of salt [18] for later use in remote locations.

4.2 HEAT SOURCE AND SINK

Certainly an important factor in successfully operating any heat pump is a source of heat. In addition to a source of heat, a sink must be available for heat rejection during the charging cycle when the salt is being dehydrated. Two techniques will be discussed briefly in this section, direct ground cooling using buried pipes and ground water cooling using wells.

The earth is an obvious place to attach a heat pump. The temperature only a few feet from the surface quickly approaches the yearly climatic mean temperature which, in many temperate areas is very close to the ideal 10 deg C required for a sodium sulfide based absorption heat pump. Because it is so well suited, there have been several projects to evaluate ground cooling, [9], [11], [13], [18]. The intent of this report is to outline a few of the basic design considerations which should be considered for ground cooling.

A buried pipe in close thermal contact with the ground will exchange heat according to equation (5) [25].

(5) $$(T - Te) = \frac{Q'}{2\pi k} \int_{\beta=nr}^{\infty} \frac{e^{-\beta^2}}{\beta} \, d\beta$$

Where:

- T = Outside pipe temperature
- Te= Bulk earth temperature
- Q'= Heat flux per unit length
- r = Pipe radius
- k = Thermal conductivity of soil
- n = $1/2\sqrt{\alpha t}$
- α = Thermal diffusivity of soil
- β = integration variable
- t = elapsed time

Table 2 gives some typical values of the integral in equation (1) for some typical time periods and 1" diameter pipe.

t(hrs.)	Integral
0.50	0.7025
1.00	1.0113
2.00	1.3384
4.00	1.6751
8.00	2.0167

TABLE 2

Solving equation (5) for T ,substituting the symbol I for the value of the integral, and setting Q'=Q/L we can determine the temperature change caused by putting the amount of energy, Q, either into or out of the system described by equation (6).

(6) $$T = Te + Q'I/2k$$

Assuming a mean value of k of 4.98 Kj/hr-m-deg C.,equation (6) yields equation (7).

(7) $$T = Te + (Q'\text{m-degC})/31.3\text{kj}$$

Clearly, in order to limit the temperature rise of the condenser or, the temperature drop of evaporator several hundred meters of pipe are required. This could be an undesirably large amount of pipe and suggests another possibility, the use of ground water as a heat reservoir.

Extensive work has already been done on the use of groundwater heat pumps. Garing and Conner [24] state a rule of thumb that 3 gal./min (11.35 l/min) are required for every 12,000 Btu/hr (12,700 kj/hr.) of heating or cooling required. For a typical domestic hot water system, this number represents approximately the peak energy dissipation rate and is representative of the peak flow rate required

Certainly a host of other possibilities exist. Waste water is an attractive alternative for a heat source, and during cold weather air is a good heat sink. Both of these systems, however, require extensive control systems and alternate sources and sinks.

4.3 HEAT PUMP CONSTRUCTION

Because of the high energy density storage for sodium sulfide (1 Kwh/Kg) [18], a relatively small volume of salt is required. As an example, an 80 gal. water tank for which water is being supplied at 10 deg C requires less than 5 gal. of salt to raise its' temperature 40 deg C, a typical domestic application.

Figure 5 shows a possible design for the heat pump. The water jacket acts as both the heat supply to the generator and the heat sink for the absorber. The salt is arrayed in a manner that allows for both good diffusion of water vapor into the salt during absorption and out of the salt during generation. The salt bed also provides short distances for heat diffusion into and out of the salt. The central chimney provides a short path for water vapor returning to the condenser or arriving form the evaporator.

Materials selection is quite important. Sodium sulfide is very corrosive to aluminum, copper and brass. In its dry state, it does not damage mild steel and stainless steels are quite unaffected by dry salt or, even a slurry of salt and water which does destroy carbon steel. All construction plastics studied appear unaffected including epoxy coatings which might be effectively used with mild steels as a low cost alternative to stainless steel.

Technical grade sodium sulfide is available as flakes which are about 40% water. A 55 gal drum weighs about 400 pounds and in quantities of 1 cost about $125.00 at the time of this publication. The packing density is sufficiently low to allow water vapor into and out of a volume of the material and it seems to serve ideally for the material in an absorption heat pump.

5.0 CONCLUSIONS

We accomplished a great deal more during this project then we had expected to. This was, in part, due to the availability of published information on the subject and, in part, due to the availability of both hardware and technical resources for the asking. It appears that the application of sodium sulfide as an inorganic salt hydrate in an absorption heat pump for use with a solar heating system is very reasonable. More work will be required to optimize the design of the system, however, the prospect of an increase in performance of the system make it very attractive to pursue this work.

We have a considerable amount of hardware built and working at this time and we plan to continue our testing effort to refine its performance and our understanding of the dynamics of the process. There is still more work required in the area of configurational optimization. We feel that the system performance can be improved with some further alterations to the configuration and we hope to find some of these new configurations with further work.

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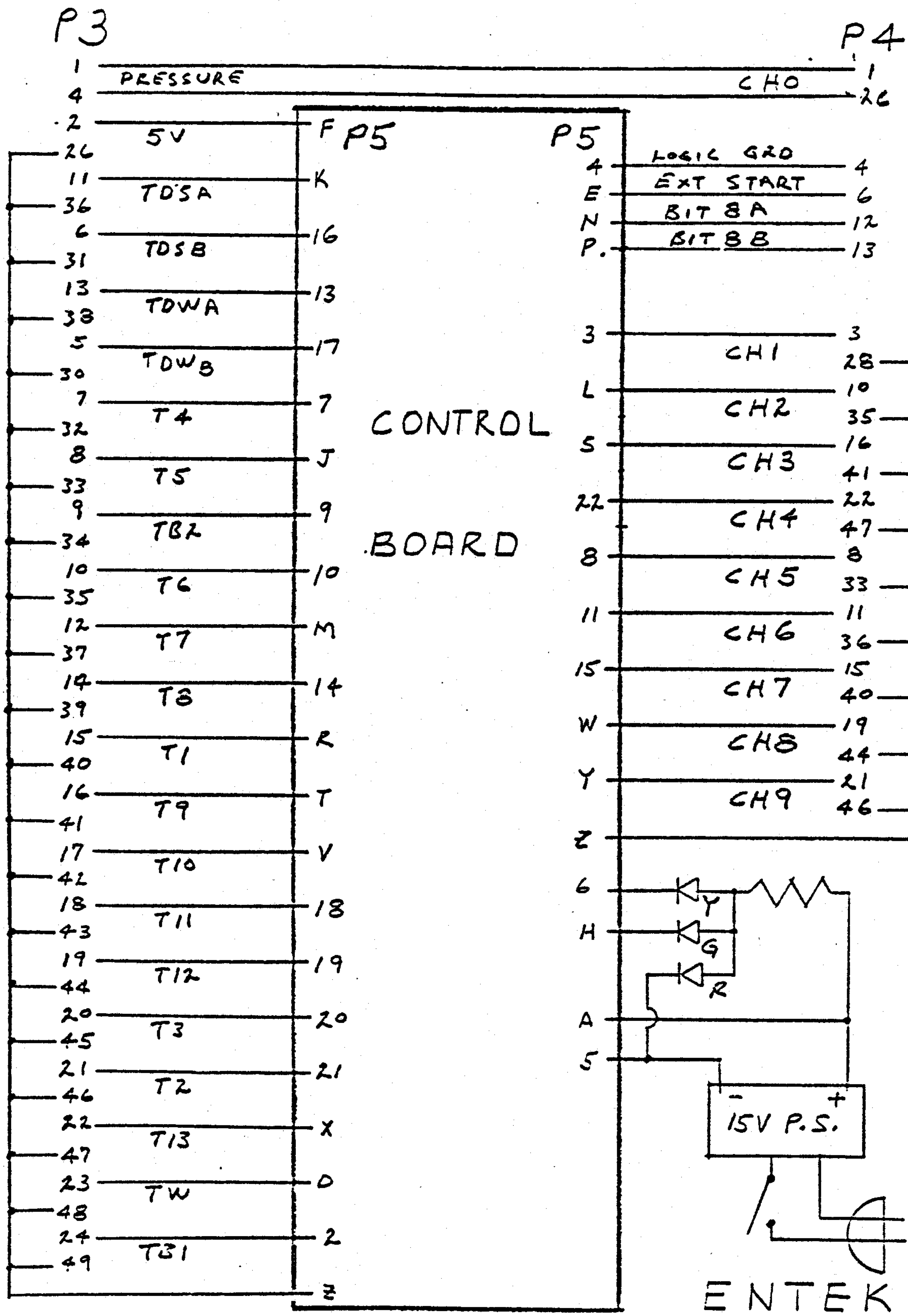
A.0 TEST EQUIPMENT

The configuration of the test equipment used in the experimental work performed during this study is schematically drawn in figure 1. A water reservoir is maintained to act as an evaporator while the salt is functioning as an absorber and also acts as a condenser when the salt is performing as a generator. Lowering the system pressure prevents the salt from dissolving in its own water of hydration as it is heated and also increases the molar concentration of the water vapor thereby increasing vapor diffusion rates. Once again, referring to figure 1, tank (1) is a temperature controlled bath enabling the control of the temperature in tank (2). Calorimetric information is gained by measuring the temperature gradient across the coil (5), and monitoring the flow rate generated by the pump (6). A similar function is provided on the salt side (tank 3) by another water jacket (7), tank (4) and pump (8). The temperature in tanks (1) and (4) is controlled only as a secondary quantity to maintain the proper salt temperature and water reservoir temperature. In addition to the differential temperatures across both heat exchangers, the system pressure, salt temperature and reservoir level are monitored.

All of the system parameters are measured and recorded using a 10 channel data logger. Each channel on the data logger is switched allowing it to measure two different values. This extends the capacity of the ten channel data logger to twenty channels.

The design of the control circuit to perform the multiplexing function is shown in sheets 1 through 7 following this written description. It operates as follows. A single throw double pole relay is located at the input of data logger channels 1 thru 9 which connects either of two sensors to the channel. Data logger channel 0, used to record pressure, is not switched. This gives a total of 19 sensor outputs which can be recorded by the data logger. Switching the relays and taking readings with the data logger are controlled by a programmable timer for which the period between readings can be adjusted from 20 seconds to just over 91 hours. The circuit develops a series of pulses which activate a series of gates that switch the relays, trigger the data logger and record which channels are being measured. The circuit also generates the various voltages needed to drive the sensors.

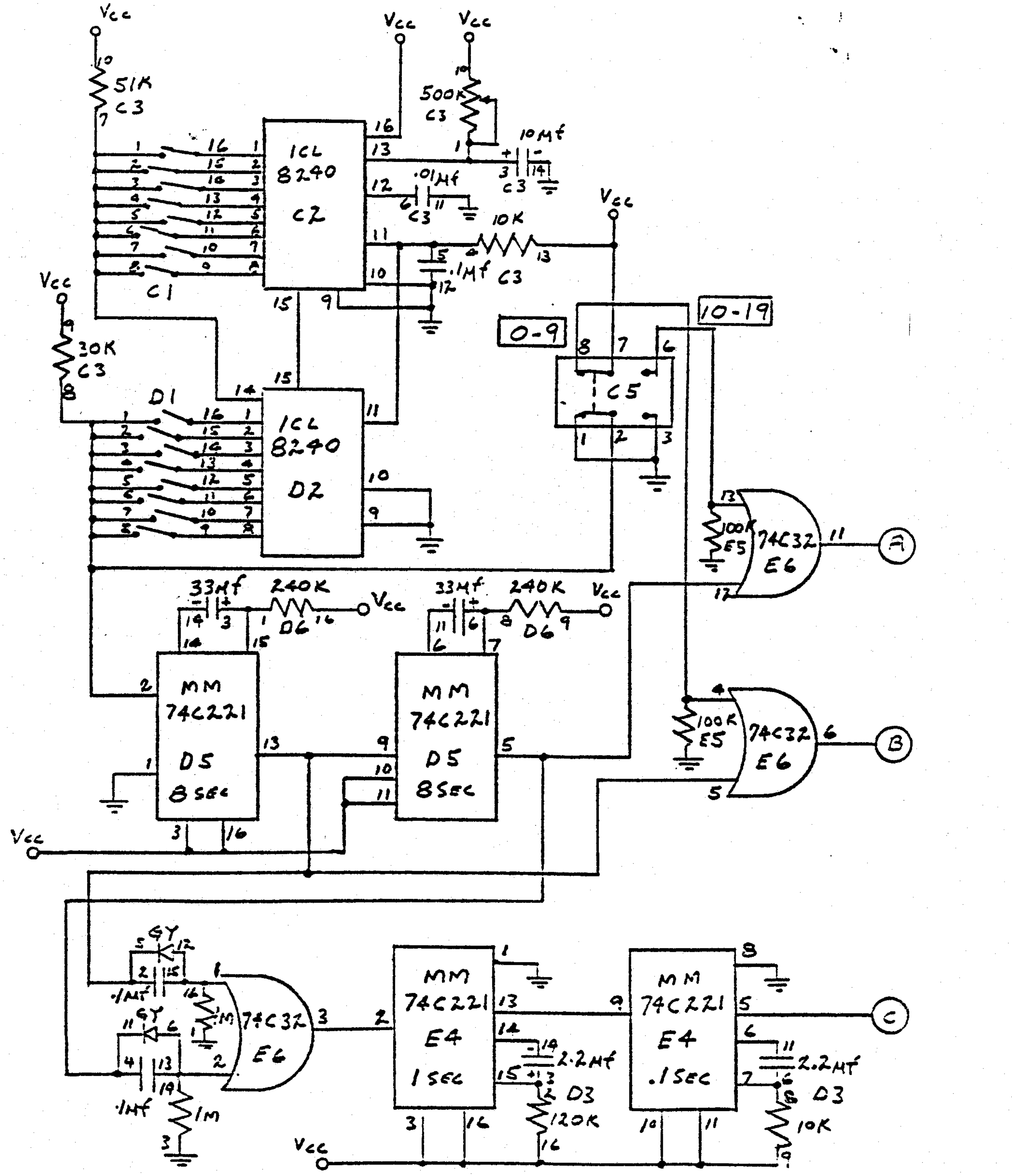
MULTIPLEXER



ENTEK
INSTRUMENTATION SYSTEM
SHEET 2

1-14-83

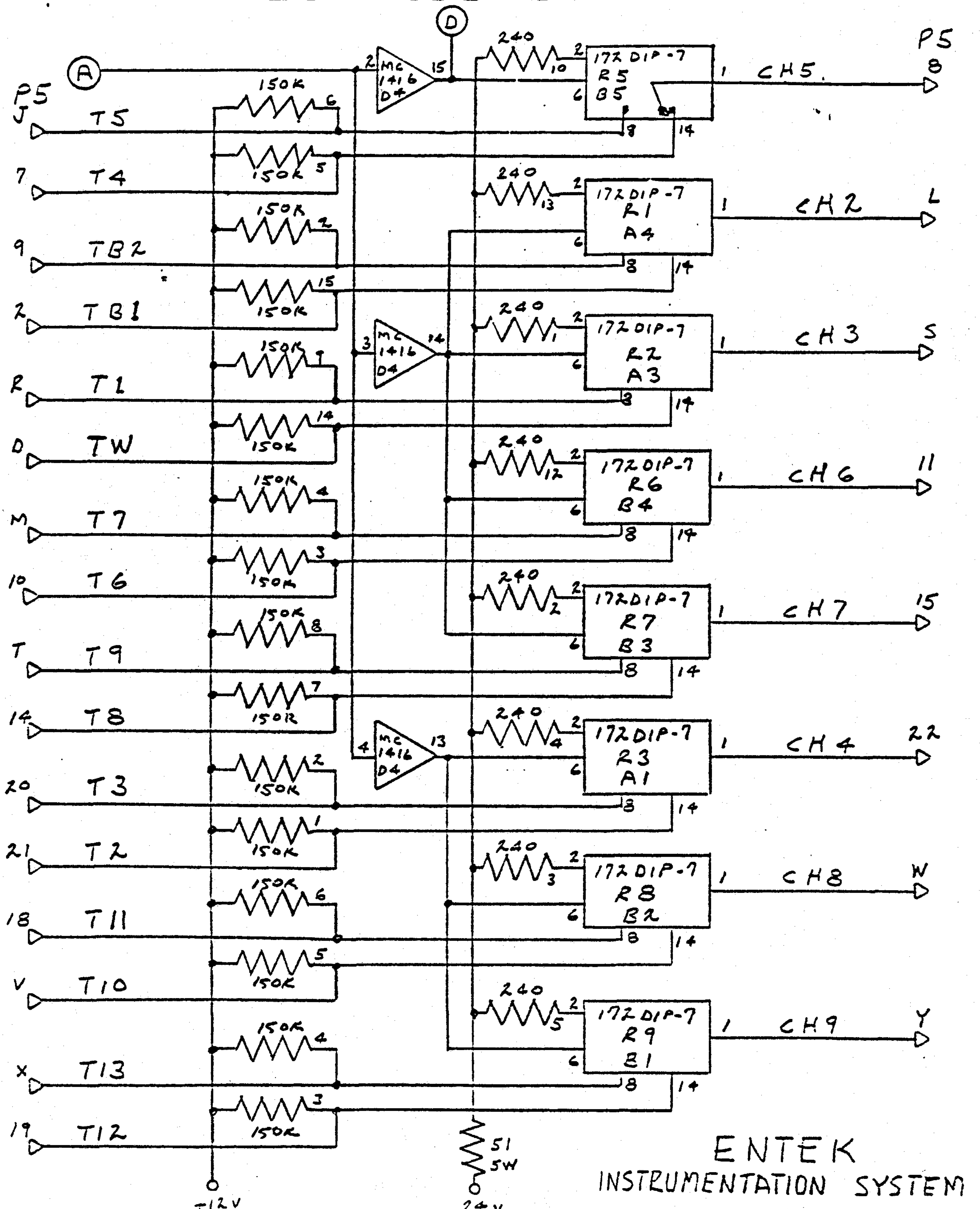
CONTROL BOARD



ENTEK
INSTRUMENTATION SYSTEM
SHEET 3

1-14-83

CONTROL BOARD

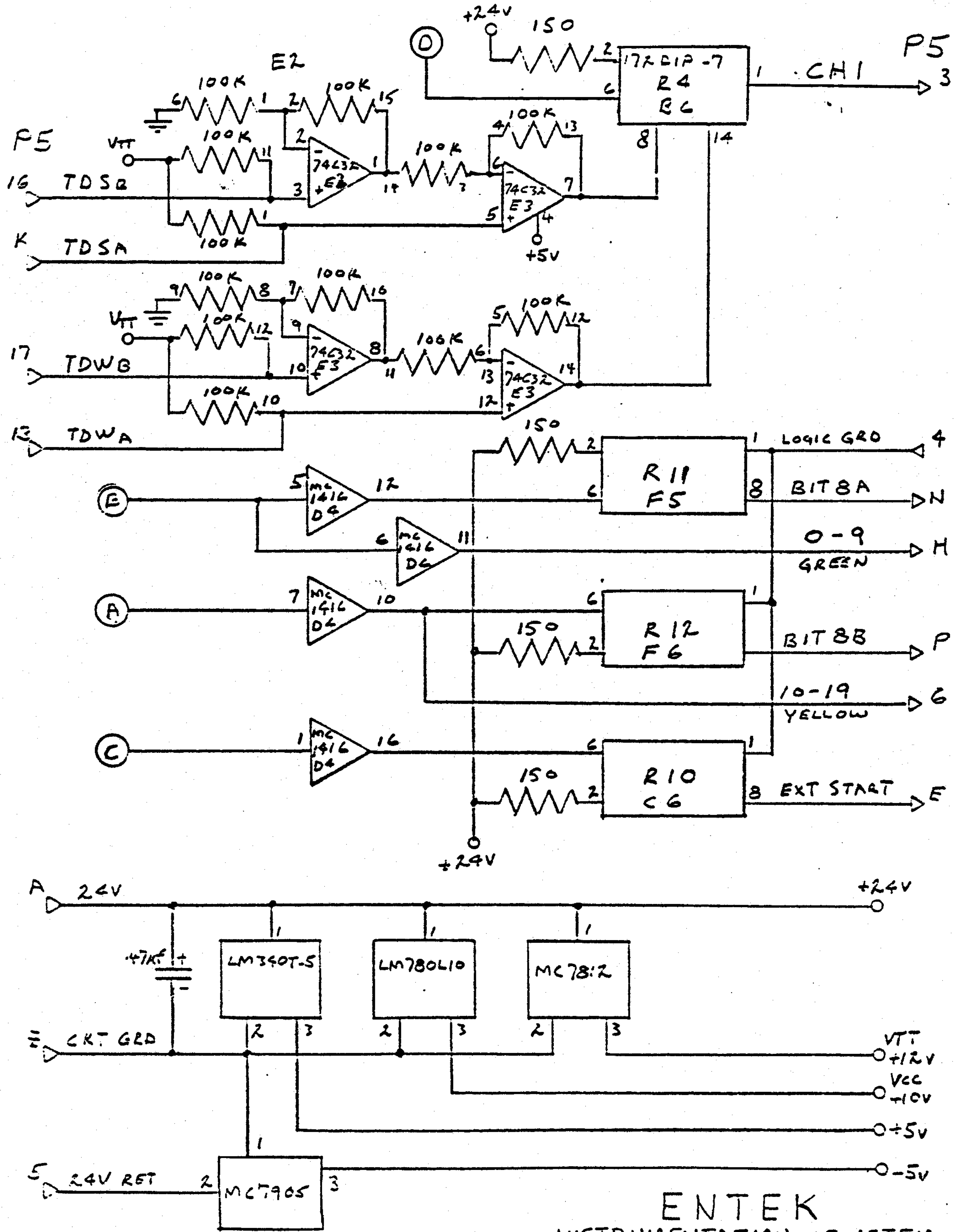


ENTEK
INSTRUMENTATION SYSTEM
SHEET 4

1-16-83

26

CONTROL BOARD



ENTEK
INSTRUMENTATION SYSTEM
SHEET 5

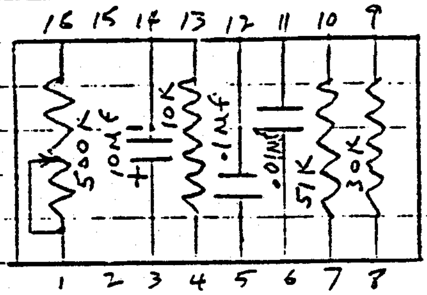
1-12-82

ENTEK
INSTRUMENTATION SYSTEM
SHEET 6

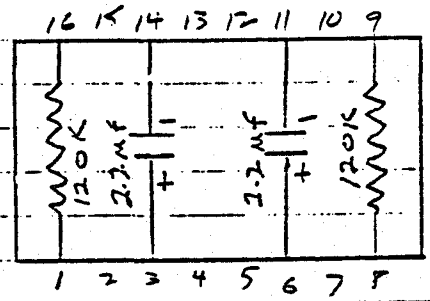
1-16-83

COMPONENT PACKS

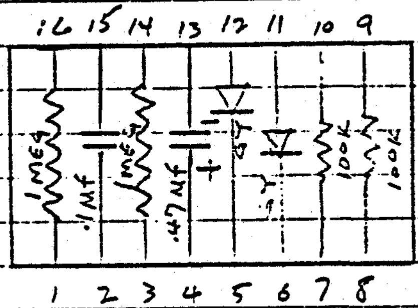
C 3



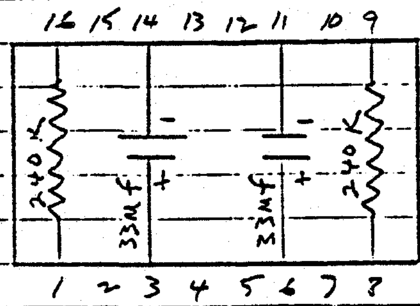
D 3



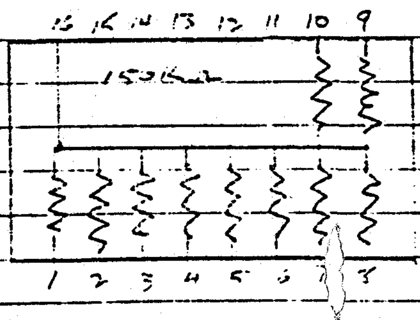
E 5



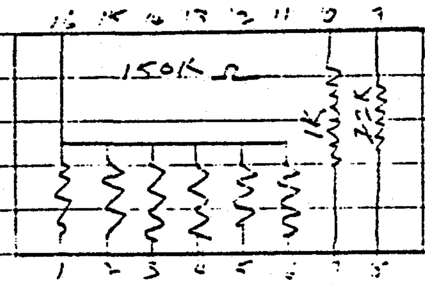
D 6



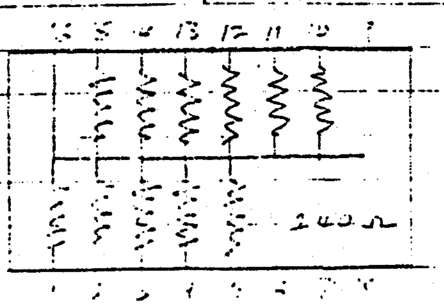
A 2



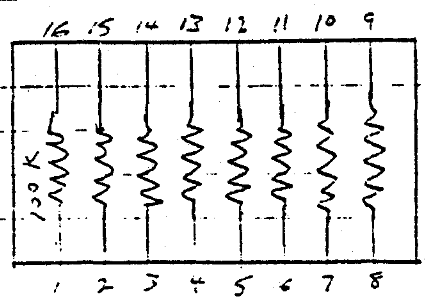
A 5



C 4



E 2



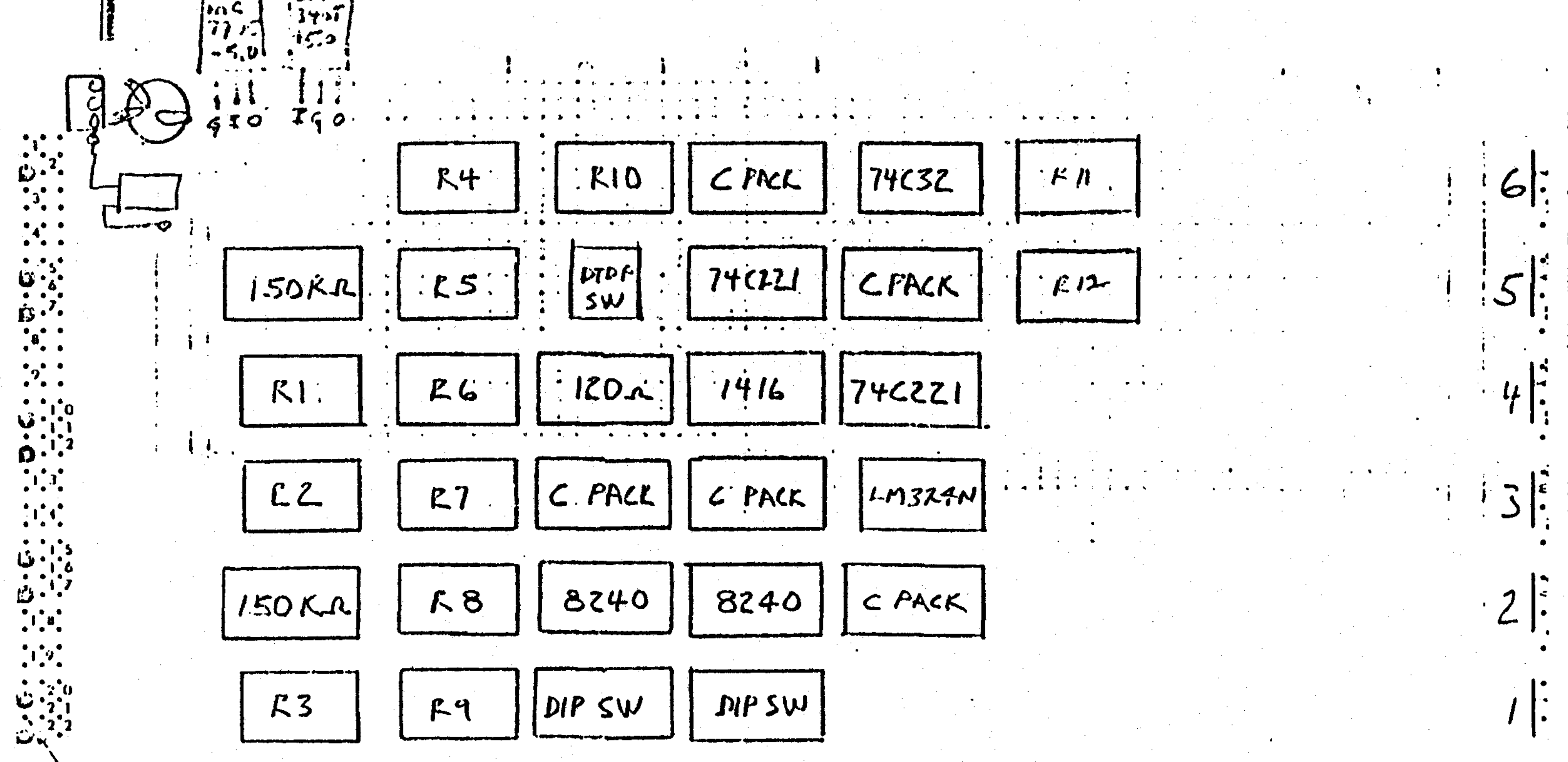
3682 9.6" LONG CARD

COMPONENT SIDE

ENTEK INSTRUMENTATION SYSTEM

SHEET 7 1-16-83

CARD LAYOUT



Zone Letters A,B,C,etc., on ... axis and X, Y, Z on ... axis mark position for 14- or 16-pin DIPs

CAUTION: In any plug contact area on either side of Plugbord, use only those holes having pads. Holes without pads may have insufficient clearance to adjacent circuitry and using them could cause shorting.

NOTICE: Where tin coated circuitry exists, a small percentage of the holes may have solder blockage. This is usually a light "skin" easily penetrated by component leads. In some cases, a soldering iron may be required.

APPLICATION: Intended for use in non-hostile environments up to 200 volts RMS or 300 volts DC.

LA3-P7

B.0 COMPUTER PROGRAMS

The computer programs used to analyze the results collected by the data logger described in APPENDIX A follows this written description and comprises the balance of APPENDIX B. The program is written in Micro Soft Basic for an IBM Personal Computer and performs a variety of tasks including, moving data from the tape cassettes which store the data logger output to flexible diskettes, converting the data to a variety of different units (e.g. temperatures to Centigrade or Fahrenheit), and tabularizing or plotting the data. There are six separate programs, MENU, TAPELOAD, DISKLOAD, CONVERT, CONVCON, TABLE and PLOT. Each of the programs is briefly described below and, on the following pages may be found the listings of each of them.

MENU is merely a control program that allows the selection of the other programs. It performs no actual data manipulation but does act as a conduit for the data which is stored in a two dimensional array named DT.

The program TAPELOAD allows data to be transferred from a data logger tape cassette to a disk. In the process of transferring ,the data is decoded from the ASCII code used by the data logger and stored as a floating point value on disk. The advantage of having the data on disk is in increased speed of access over the tape and in increased storage density.

The purpose of the program DISKLOAD is to transfer data stored in disk files by TAPELOAD into the main memory of the computer.

CONVERT is used to convert the data in memory (supplied by DISKLOAD) from millivolts, as it is stored, to some more appropriate units such as degrees Centigrade for temperature or mm of mercury for pressure. Included in the operation are the appropriate conversion for each transducer being used and any circuitry that is being used with that transducer.

Because of the changes frequently required in this type of study, it is from time to time required that the conversion constants be changed. This is accomplished with the program CONVCON.

TABLE allows the data to be output in either its raw form, millivolts, or in the converted form as a table.

PLOT is a series of routines for plotting the data. There are two basic forms that the data can take, either time series, that is any variable or variables plotted versus time, or pairs of variables plotted against each other.

MENU

```
10 KEY OFF:CLS:COMMON EXST$
20 EXST$=""
30 LOCATE 10,10:PRINT "CHOOSE OPTION STRING (RTN TO END):"
40 LOCATE 12,23:PRINT "1. TRANSFER DATA FROM TAPE TO DISK"
50 LOCATE 13,23:PRINT "2. LOAD DATA FROM DISK INTO COMPUTER"
60 LOCATE 14,23:PRINT "3. CONVERT FILE"
70 LOCATE 15,23:PRINT "4. EDIT CONVERSION CONSTANTS"
80 LOCATE 16,23:PRINT "5. OUTPUT TABLE OF DATA"
90 LOCATE 17,23:PRINT "6. PLOTTING ROUTINES"
100 LOCATE 10,44,1
110 Q$=INKEY$:IF Q$="1" OR Q$="2" OR Q$="3" OR Q$="4" OR Q$="5" OR Q$="6" THEN 1
20 ELSE IF Q$=CHR$(13) GOTO 150 ELSE 110
120 COLOR 15:IF EXST$<>"" THEN PRINT ","+Q$; ELSE PRINT Q$;
130 EXST$=EXST$+Q$
140 GOTO 110
150 LOCATE ,,0:COLOR 7:Q$=LEFT$(EXST$,1)
160 EXST$=RIGHT$(EXST$,LEN(EXST$)-1)
170 ON VAL(Q$) GOTO 180,190,200,210,220,230
180 CHAIN "TAPELOAD"
190 CHAIN "DISKLOAD"
200 CHAIN "CONVERT"
210 CHAIN "CONVCON"
220 CHAIN "TABLE"
230 CHAIN "PLOT"
```

TAPELOAD

```
10 DIM D(20):COMMON EXST$
20 CLS:KEY OFF
30 LOCATE 12.10:COLOR 23:PRINT "MAKE SURE DATA DISK IS IN DRIVE B. HIT ANY KEY T
O CONTINUE":COLOR 7
40 LOCATE ,,0:Q$=INKEY$:IF Q$="" THEN 40
50 REM*****************************************************************
60 REM              READ DATA FROM TAPE. CONVERT AND STORE ON DISK
70 REM*****************************************************************
80 CLS:LOCATE 5.19:PRINT CHR$(218)+STRING$(32.CHR$(196))+CHR$(191)
90 LOCATE 6.19:PRINT CHR$(179)+" FILES ALREADY ON THIS DISKETTE "+CHR$(179)
100 LOCATE 7.19:PRINT CHR$(192)+STRING$(32.CHR$(196))+CHR$(217)
110 PRINT
120 FILES "B:*.*"
130 PRINT:PRINT
140 INPUT"                    INPUT NAME FOR NEW DATA FILE:";N$
150 CLS:LOCATE 10.20:INPUT"PERCENT OF TAPE USED(0-1)";ALPHA:LOCATE 10.60
160 OPEN "COM1:1200.E.7" AS #1
170 OPEN "B:"+N$ FOR OUTPUT AS #2
180 LOCATE ,,0
190 PRINT #1,CHR$(26);                                  'SEND REWIND
200 GOSUB 340
210 PRINT #1,CHR$(17);                                  'SEND READ REQUEST
220 BUFF=-1
230 WHILE LOC(1)<=100
240 FOR J=1 TO 500
250 NEXT J
260 IF BUFF=LOC(1) GOTO 580
270 BUFF=LOC(1)
280 WEND
290 PRINT #1,CHR$(19);                                  'READ OFF
300 A$=INPUT$(100,#1)
310 I=I+1
320 CLS:LOCATE 10,25,0:PRINT "NUMBER OF FILES READ: ";I
330 GOTO 380
340 FOR W=1 TO 750*ALPHA
350 SOUND RND*1200+37,1
360 NEXT W
370 RETURN
380 LOCATE ,,0
390 REM*****************************************************************
400 REM                          CONVERT RAW DATA
410 REM*****************************************************************
420 D(1)=24*VAL(MID$(A$,2,2))+VAL(MID$(A$,4,2))+VAL(MID$(A$,6,2))/60
430 CNT=19
440 D(2)=VAL(MID$(A$,17,1)):D(2)=D(2)+(D(2)=3)-(D(2)=0)
450 FOR K=3 TO 12
460 B$=MID$(A$,CNT,8)
470 D(K)=VAL(RIGHT$(B$,4)+"E-"+MID$(B$,3,1))
480 CNT=CNT+9-(K=7)
490 NEXT K
500 REM*****************************************************************
510 REM                         PRINT DATA TO DISK
520 REM*****************************************************************
530 IF D(5)<>1 THEN 570
540 FOR K=1 TO 12
550 PRINT#2.D(K)
560 NEXT K
570 GOTO 210
580 PRINT#1.CHR$(19):CLOSE
590 REM ****************************************************************
600 REM                          GOTO NEXT PROGRAM
610 REM ****************************************************************
620 Q$=LEFT$(EXST$,1)
630 IF Q$="" THEN CHAIN "MENU"
640 EXST$=RIGHT$(EXST$.LEN(EXST$)-1)
650 ON VAL(Q$) GOTO 660.670.680.690.700.710
660 CHAIN "TAPELOAD"
670 CHAIN "DISKLOAD"
680 CHAIN "CONVERT"
690 CHAIN "CONVCON
700 CHAIN "TABLE"
710 CHAIN "PLOT"
```

DISK LOAD

```
10 REM ********************** LOAD DATA FROM DISK ****************************
20 COMMON EXST$,DT(),N$, NT
30 CLS:LOCATE 5,19:PRINT CHR$(218)+STRING$(34,CHR$(196))+CHR$(191)
40 LOCATE 6,19:PRINT CHR$(179)+" FILES AVAILABLE ON THIS DISKETTE "+CHR$(179)
50 LOCATE 7,19:PRINT CHR$(192)+STRING$(34,CHR$(196))+CHR$(217)
60 PRINT:LOCATE ,,0
70 FILES "B:*.*"
80 PRINT:PRINT
90 INPUT"                    INPUT NAME OF FILE TO BE READ:";N$
100 OPEN"B:"+N$ FOR INPUT AS #2
110 NT=INT(.5+LOF(2)/102)
120 DIM DT(NT+1,12)
130 FOR I=1 TO NT
140 FOR J=1 TO 12
150 INPUT#2,DT(I,J)
160 NEXT J
170 NEXT I
180 CLOSE
190 REM *******************************************************************
200 REM                         GOTO NEXT PROGRAM
210 REM *******************************************************************
220 Q$=LEFT$(EXST$,1)
230 IF Q$="" THEN CHAIN "MENU"
240 EXST$=RIGHT$(EXST$,LEN(EXST$)-1)
250 ON VAL(Q$) GOTO 260,270,280,290,300,310
260 CHAIN "TAPELOAD"
270 CHAIN "DISKLOAD"
280 CHAIN "CONVERT"
290 CHAIN "CONVCON"
300 CHAIN "TABLE"
310 CHAIN "PLOT"
```

CONVERT

```
10 OPEN "CONST" FOR INPUT AS #1
20 DIM CON(23)
30 FOR I=1 TO 23
40 INPUT#1.CON(I)
50 NEXT I:CLOSE
60 COMMON DT().EXST$,N$,NT
70 CLS:LOCATE 2.25:PRINT "FILE BEING CONVERTED "+N$
80 REM ***********************************************************************
90 REM                          CONVERSION ROUTINE
100 REM **********************************************************************
110 CLS:LOCATE 12.20.1:PRINT "TEMPERATURES IN "+CHR$(248)+"C OR "+CHR$(248)+"F (
F/C)?
120 LOCATE 12.51:TP$=INKEY$:IF TP$="" THEN 120
130 IF TP$="C" THEN LOCATE 2.10:PRINT "TEMPERATURES IN "+CHR$(248)+"C"
140 IF TP$="F" THEN LOCATE 2.10:PRINT "TEMPERATURES IN "+CHR$(248)+"F"
150 LOCATE 12.20:PRINT SPC(40)
160 LOCATE 8,20:PRINT "PRESSURE IN UNITS OF:"
170 LOCATE 9,20:L$(1)="  PSI":PRINT "   1. PSI"
180 LOCATE 10,20:L$(2)=" ATMS.":PRINT "   2. ATMS."
190 LOCATE 11,20:L$(3)="IN.H2O":PRINT "   3. IN.H2O"
200 LOCATE 12,20:L$(4)="IN.HG":PRINT "   4. IN.HG"
210 LOCATE 13,20:L$(5)="MM HG":PRINT "   5. MM HG (TORR)"
220 LOCATE 8,42:PR$=INKEY$:IF PR$="" THEN 220
230 LOCATE 3,10:PRINT "PRESSURES IN "+L$(VAL(PR$))
240 FOR I=8 TO 13:LOCATE I,1:PRINT SPC(75):NEXT I
250 LOCATE 8,20:PRINT "UNITS FOR WATER RESEVOIR"
260 PRINT TAB(30) "1. MILLILITERS":L1$(1)="  ML."
270 PRINT TAB(30) "2. GALLONS":L1$(2)="GALLONS"
280 PRINT TAB(30) "3. MM. H2O":L1$(3)="MM.H2O"
290 PRINT TAB(30) "4. IN.H2O":L1$(4)="IN.H2O"
300 LOCATE 8,45:VOL$=INKEY$:IF VOL$="" THEN 300
310 LOCATE 4,10:PRINT "WATER IN RES. IN UNITS OF "+L1$(VAL(VOL$))
320 FOR I=8 TO 12:LOCATE I,1:PRINT SPC(70):NEXT I
330 LOCATE 10,20:PRINT "ANY CHANGES IN THESE UNITS (Y/N)?":LOCATE 10,53,1
340 Q$=INKEY$:IF Q$="Y" THEN 110 ELSE IF Q$="N" THEN 360 ELSE 340
350 REM ******************************************************************
360 REM ================== PERFORM CONVERSION ===========================
370 REM ******************************************************************
380 CLS:LOCATE 10,20,0:PRINT "CONVERTING FILE NOW, PLEASE WAIT"
390 FOR I=1 TO NT
400 IF DT(I.2)=1 THEN DT(I,3)=DT(I,3)*CON(10+VAL(PR$))-3.0538*CON(10+VAL(PR$))/C
ON(11) ELSE GOSUB 630
410 IF DT(I,2)=1 THEN DT(I.4)=CON(8+5*(TP$="C"))+CON(10+5*(TP$="C"))*DT(I.4)*100
0 ELSE DT(I.4)=CON(9+5*(TP$="C"))+CON(10+5*(TP$="C"))*DT(I,4)*1000
420 FOR J=5 TO 12
430 DT(I,J)=CON(6+5*(TP$="C"))+CON(7+5*(TP$="C"))*DT(I,J)*1000
440 NEXT J
450 NEXT I
460 REM ********************************************************************
470 REM                          GOTO NEXT PROGRAM
480 REM ********************************************************************
490 Q$=LEFT$(EXST$,1)
500 IF Q$="" THEN CHAIN "MENU"
510 EXST$=RIGHT$(EXST$,LEN(EXST$)-1)
520 ON VAL(Q$) GOTO 530,540,550,560,570,580
530 CHAIN "TAPELOAD"
540 CHAIN "DISKLOAD"
550 CHAIN "CONVERT"
560 CHAIN "CONVCON"
570 CHAIN "TABLE"
580 CHAIN "PLOT"
590 END
600 REM ********************************************************************
610 REM ===================== VOLUME OF WATER ROUTINE =====================
620 REM ********************************************************************
630 FOR J=1 TO 12
640 READ ML(J).MV(J)
650 IF DT(I,3)<=MV(J) THEN 670
660 NEXT J
670 DT(I,3)=ML(J-1)+((ML(J)-ML(J-1))/(MV(J)-MV(J-1)))*(DT(I,3)-MV(J-1))
680 DATA 0..5.225.1.5.450.114.675.182.5,900,239,1125.290.1350,327.1575,349,1800,
365,2025.391.2250,395,2475.409
690 RESTORE:RETURN
```

```
10 COMMON EXST$
20 OPEN "CONST" FOR INPUT AS #1
30 DIM CON(23)
40 FOR I=1 TO 23
50 INPUT#1,CON(I)
60 NEXT I:CLOSE
70 REM ************************************************************************
80 REM ================ CONVERSION CONSTANT LISTER ========================
90 REM ************************************************************************
100 CLS
110 PRINT " I    CON(I)    DESCRIPTION     VALUE" TAB(40) " I     CON(I)    DESCRIPT
ION    VALUE"
120 FOR J=3 TO 15:LOCATE J,39:PRINT CHR$(186):NEXT J:LOCATE 1,39:PRINT CHR$(186)

130 LOCATE 2,1
140 PRINT STRING$(38,CHR$(205))+CHR$(206)+STRING$(39,CHR$(205))
150 LAB$(1)="TO  DT  DTO1DTO2DDT "
160 LAB$(2)="ML GALMM IN.HO R  RO R1 "
170 LAB$(3)=CHR$(248)+"C"+CHR$(248)+"F"
180 LAB$(4)="PSI  ATM  INH2OMM HGTORR "
190 FOR I=1 TO 23
200 IF I<=10 THEN LABEL$=MID$(LAB$(1),(4*I)-3+((I>5)*20),4):GOTO 230
210 IF I<=15 THEN LABEL$=MID$(LAB$(4),(5*(I-10))-4,5):GOTO 230
220 IF I>15 THEN LABEL$=MID$(LAB$(2),(3*(I-15))-2,3)
230 IF I<=5 THEN CAT$=CHR$(248)+"C" :GOTO 270
240 IF I<=10 THEN CAT$=CHR$(248)+"F":GOTO 270
250 IF I<=15 THEN CAT$="PRESSURE" :GOTO 270
260 CAT$="H2O RES."
270 IF I>12 THEN LOCATE (I-10),40
280 PRINT I TAB(7-(I>12)*40) LABEL$ TAB(17-(I>12)*40) CAT$ TAB(28-(I>12)*40) CON
(I)
290 NEXT I
300 LOCATE 15,1:PRINT CHR$(192)+STRING$(37,CHR$(196))+CHR$(208)+STRING$(38,CHR$(
196))+CHR$(217)
310 LOCATE 16,20:PRINT "TABLE OF RAW DATA CONVERSION CONSTANTS"
320 LOCATE 22,25:PRINT "PRESS ANY KEY TO CONTINUE";
330 Q$=INKEY$:IF Q$="" THEN 330 ELSE PRINT
340 LOCATE 22,20:PRINT SPC(50)
350 LOCATE 18,1:PRINT STRING$(79,CHR$(205))
360 LOCATE 19,25:PRINT "CHANGE ANY CONSTANTS (Y/N)?":LOCATE 19,55
370 Q$=INKEY$:IF Q$="Y" THEN 410 ELSE IF Q$="N" THEN 490 ELSE 370
380 REM ************************************************************************
390 REM ============= CONVERSION CONSTANTS EDITING ROUTINE ==================
400 REM ************************************************************************
410 LOCATE 19,10:PRINT "INPUT I OF CONSTANT TO BE CHANGED THAN THE VALUE (STOP T
O END)"
420 LOCATE 20,20:INPUT "I=";I$
430 IF I$="STOP" THEN 460 ELSE I=VAL(I$)
440 LOCATE 20,30:INPUT "NEW VALUE=";CON(I)
450 LOCATE 20,20:PRINT SPC(50):GOTO 420
460 LOCATE 20,17:PRINT "DO YOU WISH TO VIEW THE LIST AS UPDATED (Y/N)?":LOCATE 2
0,61
470 Q$=INKEY$:IF Q$="Y" THEN 80 ELSE IF Q$="N" THEN 490 ELSE 470
480 REM ************************************************************************
490 REM ===================== SAVE UPDATED CONSTANTS ======================
500 REM ************************************************************************
510 OPEN "CONST" FOR OUTPUT AS #1
520 FOR I=1 TO 23
530 PRINT#1,CON(I)
540 NEXT I
550 CLOSE
560 REM ************************************************************************
570 REM ======================= GOTO NEXT PROGRAM =======================
580 REM ************************************************************************
590 Q$=LEFT$(EXST$,1)
600 IF Q$="" THEN CHAIN "MENU"
610 EXST$=RIGHT$(EXST$,LEN(EXST$)-1)
620 ON VAL(Q$) GOTO 630,640,650,660,670,680
630 CHAIN "TAPELOAD"
640 CHAIN "DISKLOAD"
650 CHAIN "CONVERT"
660 CHAIN "CONVCON"
670 CHAIN "TABLE"
680 CHAIN "PLOT"
```

```
10 DIM OPT(20),T$(20):COMMON DT(),EXST$
20 REM ************************************************************************
30 REM                              OUTPUT MENU
40 REM ************************************************************************
50 FOR I=1 TO 20:OPT(I)=0:NEXT I
60 CLS:LOCATE 1,10,1:PRINT "SELECT ALL OR UP TO 10 INDIVIDUAL CHANNELS FOR DISPL
AY"
70 CH$="PA   DT1  TBW  TRES1TS2  TS4  TS6  TS8  TS10 TS12 H H2ODT2  TBS  TRES2TS
1  TS3  TS5  TS7  TS9  TS11 "
80 PRINT "CH.#        DESC.    LISTING #"
90 FOR I=0 TO 19
100 PRINT " ";I TAB(13) MID$(CH$,1+I*5,5)
110 NEXT I
120 LOCATE 4,50:PRINT "         SALT BED MAP"
130 LOCATE 5,50:PRINT CHR$(218)+STRING$(28,CHR$(196))+CHR$(191)
140 FOR I=6 TO 18:LOCATE I,50:PRINT CHR$(179) SPC(28) CHR$(179):NEXT I
150 LOCATE 19,50:PRINT CHR$(192)+STRING$(28,CHR$(196))+CHR$(217)
160 LOCATE 6,51:PRINT "10      6      1"
170 LOCATE 9,51:PRINT "        7      2"
180 LOCATE 12,51:PRINT "11      8      3"
190 LOCATE 15,51:PRINT "        9      4"
200 LOCATE 18,51:PRINT "12             5"
210 LOCATE 20,50:PRINT CHR$(179)+CHR$(17)+STRING$(3,CHR$(196))+"RADIUS"+STRING$(
3,CHR$(196))+CHR$(180)
220 I=1
230 LOCATE 23,25:PRINT SPC(40):LOCATE 23,25:INPUT "CH.# ,ALL OR STOP:";Q$
240 IF Q$="ALL" THEN 280 ELSE IF Q$="STOP" THEN 290 ELSE IF VAL(Q$)>19 THEN 230
250 LOCATE (3+VAL(Q$)),22:PRINT I
260 OPT(I)=1+VAL(Q$)
270 IF I=10 THEN 290 ELSE I=I+1:GOTO 230
280 FOR I=1 TO 20:OPT(I)=I:NEXT I
290 NOPT=I+(I<>10 OR Q$="STOP"):LOCATE 23,25:PRINT "ANY CORRECTIONS (Y/N)?
"
300 Q$=INKEY$:IF Q$="N" THEN 310 ELSE IF Q$="Y" THEN 50 ELSE 300
310 REM ************************************************************************
320 REM                              FORMAT ROUTINE
330 REM ************************************************************************
340 IF DT(1,5)<1 THEN TF$=" #### " ELSE IF TP$="C" THEN TF$=" ##.# " ELSE TF$="
###  "
350 IF DT(1,5)<1 THEN PF$=" #### " ELSE 370
360 VF$=" #### ":DTF$="###.## ":GOTO 400
370 IF PR$="1" THEN PF$="  #.## " ELSE IF PR$="2" THEN PF$="  .### " ELSE IF PR$
="4"  THEN PF$="  ##.# " ELSE PF$="  ###  "
380 IF VOL$="1" OR VOL$="3" THEN VF$=" ####  " ELSE VF$="  #.## "
390 DTF$="###.# "
400 GOSUB 1050
410 CLS:LOCATE 10,20:PRINT "OUTPUT TO SCREEN OR PRINTER(S/P)?":LOCATE 10,53,1
420 Q$=INKEY$:IF Q$="S" OR Q$="s" THEN 430 ELSE IF Q$="P" OR Q$="p" THEN 770 ELS
E 420
430 CLS:PRINT SPC(30) "FILE NAME: ";N$
440 PRINT CHR$(218)+STRING$(11,CHR$(196))+CHR$(210)+STRING$(65,CHR$(196))+CHR$(1
91)
450 PRINT CHR$(179) TAB(9) "+0" TAB(13) CHR$(186)+" ";
460 IF DT(1,5)<1 THEN PRINT TAB(40) "MILLIVOLTS": ELSE IF NOPT=20 THEN PRINT L$(
VAL(PR$)) TAB(45) "DEG "+TP$: ELSE PRINT TAB(45) "DEG "+TP$;
470 PRINT  TAB(79) CHR$(179)
480 LOCATE 4,1:PRINT CHR$(179)+" HRS." TAB(9) "+10" TAB(13) CHR$(186)+TITLE$ TAB
(79) CHR$(179)
490 IF NOPT=20 THEN 500
500 PRINT CHR$(195)+STRING$(11,CHR$(196))+CHR$(215)+STRING$(65,CHR$(196))+CHR$(1
80)
510 PRINT CHR$(179)+" TIME  RNG "+CHR$(186)+C$ TAB(79) CHR$(179)
520 PRINT CHR$(198)+STRING$(11,CHR$(205))+CHR$(206)+STRING$(65,CHR$(205))+CHR$(1
81)
530 FOR I=1 TO NT STEP 2
540 IF DT(I,2)=2 THEN 570
550 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I,J+2):D(J+10)=(1-999*(DT(1,5)<1))
*DT(I+1,J+2):NEXT J
560 GOTO 530
570 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I+1,J+2):D(J+10)=(1-999*(DT(1,5)<1
))*DT(I,J+2):NEXT J
580 PRINT CHR$(179);
590 PRINT USING"###.## ";DT(I,1);
600 PRINT USING" #  ";DT(I,2);:PRINT CHR$(186)+" ";
610 LOCATE ,15
620 FOR J=1 TO NOPT:K=OPT(J)
630 IF K=1 OR K=11 THEN IF K=1 THEN PRINT USING PF$;D(K); ELSE PRINT USING VF$;D
(K);
640 IF K=2 OR K=12 THEN PRINT USING DTF$;D(K);
650 IF(K>2 AND K<11) OR (K>12) THEN PRINT USING TF$;D(K);
660 IF J=10 AND NOPT>10 THEN PRINT TAB(79) CHR$(179):PRINT CHR$(179) TAB(9) DT(I
+1,2);" "+CHR$(186)+" ";
670 NEXT J
680 PRINT TAB(79) CHR$(179)
690 IF ((I+1) MOD (28/(1-(NOPT=20))))=0 THEN LOCATE 23,20:PRINT "PRESS ANY KEY T
O CONTINUE, ESC TO END PRINTOUT":GOTO 710
700 GOTO 7[illegible]
```

```
550 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I,J+2):D(J+10)=(1-999*(DT(1,5)<1))
*DT(I+1,J+2):NEXT J
560 GOTO 580
570 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I+1,J+2):D(J+10)=(1-999*(DT(1,5)<1
))*DT(I,J+2):NEXT J
580 PRINT CHR$(179);
590 PRINT USING"###.## ";DT(I,1);
600 PRINT USING" #  ";DT(I,2);:PRINT CHR$(186)+" ";
610 LOCATE ,15
620 FOR J=1 TO NOPT:K=OPT(J)
630 IF K=1 OR K=11 THEN IF K=1 THEN PRINT USING PF$;D(K); ELSE PRINT USING VF$;D
(K);
640 IF K=2 OR K=12 THEN PRINT USING DTF$;D(K);
650 IF(K>2 AND K<11) OR (K>12) THEN PRINT USING TF$;D(K);
660 IF J=10 AND NOPT>10 THEN PRINT TAB(79) CHR$(179):PRINT CHR$(179) TAB(9) DT(I
+1,2);" "+CHR$(186)+" ";
670 NEXT J
680 PRINT TAB(79) CHR$(179)
690 IF ((I+1) MOD (28/(1-(NOPT=20))))=0 THEN LOCATE 23,20:PRINT "PRESS ANY KEY T
O CONTINUE. ESC TO END PRINTOUT":GOTO 710
700 GOTO 720
710 Q$=INKEY$:IF Q$="" THEN 710 ELSE IF Q$=CHR$(27) AND Q1$="Y" THEN 50 ELSE IF
Q$=CHR$(27) AND Q1$="N" THEN 1190 ELSE LOCATE 8,1,0
720 NEXT I
730 PRINT CHR$(192)+STRING$(11,CHR$(196))+CHR$(208)+STRING$(65,CHR$(196))+CHR$(2
17)
740 FOR I=CSRLIN TO 23:LOCATE I,1:PRINT SPACE$(79):NEXT I
750 LOCATE 23,20,0:PRINT "HIT ANY KEY TO CONTINUE. ESC TO END";
760 Q$=INKEY$:IF Q$="" THEN 760 ELSE IF Q$=CHR$(27) THEN 1280 ELSE 50
770 LPRINT SPC(30) "FILE NAME: ";N$
780 LPRINT CHR$(188)+STRING$(11,CHR$(172))+CHR$(188)+STRING$(65,CHR$(172))+CHR$(
204)
790 LPRINT CHR$(181) TAB(9) "+0" TAB(13) CHR$(181)+" ";
800 IF DT(1,5)<1 THEN LPRINT TAB(40) "MILLIVOLTS"; ELSE IF NOPT=20 THEN LPRINT L
$(VAL(PR$)) TAB(45) "DEG "+TP$; ELSE LPRINT TAB(45) "DEG "+TP$;
810 LPRINT  TAB(79) CHR$(202)
820 LPRINT CHR$(181)+" HRS." TAB(9) "+10" TAB(13) CHR$(181)+TITLE$ TAB(79) CHR$(
202)
830 LPRINT CHR$(189)+STRING$(11,CHR$(172))+CHR$(189)+STRING$(65,CHR$(172))+CHR$(
206)
840 LPRINT CHR$(181)+" TIME  RNG "+CHR$(181)+C$ TAB(79) CHR$(202)
850 LPRINT CHR$(189)+STRING$(11,CHR$(172))+CHR$(189)+STRING$(65,CHR$(172))+CHR$(
206)
860 FOR I=1 TO NT STEP 2
870 IF DT(I,2)=2 THEN 900
880 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I,J+2):D(J+10)=(1-999*(DT(1,5)<1))
*DT(I+1,J+2):NEXT J
890 GOTO 910
900 FOR J=1 TO 10:D(J)=(1-999*(DT(1,5)<1))*DT(I+1,J+2):D(J+10)=(1-999*(DT(1,5)<1
))*DT(I,J+2):NEXT J
910 LPRINT CHR$(181);
920 LPRINT USING"###.## ";DT(I,1);
930 LPRINT USING" #  ";DT(I,2);:LPRINT CHR$(181)+" ";
940 FOR J=1 TO NOPT:K=OPT(J)
950 IF K=1 OR K=11 THEN IF K=1 THEN LPRINT USING PF$;D(K); ELSE LPRINT USING VF$
;D(K);
960 IF K=2 OR K=12 THEN LPRINT USING DTF$;D(K);
970 IF(K>2 AND K<11) OR (K>12) THEN LPRINT USING TF$;D(K);
980 IF J=10 AND NOPT>10 THEN LPRINT TAB(79) CHR$(202):LPRINT CHR$(181) TAB(9) DT
(I+1,2);" "+CHR$(181)+" ";
990 NEXT J
1000 LPRINT TAB(79) CHR$(202)
1010 NEXT I
1020 LPRINT CHR$(173)+STRING$(11,CHR$(172))+CHR$(173)+STRING$(65,CHR$(172))+CHR$
(174)
1030 GOTO 750
1040 END
1050 REM
1060 REM                 SUBROUTINE FOR TITLE LINE
1070 REM
1080 L$(0)=" PRES":L1$(0)=" H2O"
1090 IF NOPT=20 THEN 1210
1100 TITLE$=" "
1110 T$(1)=L$(VAL(PR$)):T$(11)=L1$(VAL(VOL$))
1120 T$(2)=" DT1":T$(12)=" DT2"
1130 T$(3)=" TBW":T$(13)=" TBS"
1140 T$(4)=" TR1":T$(14)=" TR2"
1150 FOR J=5 TO 10
1160 T$(J)=" TS"+MID$(STR$(1+2*(J-5)),2,2):T$(J+10)=" TS"+MID$(STR$(2*(J-4)),2,2
):NEXT J
1170 FOR J=1 TO NOPT
1180 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1190 NEXT J
1200 GOTO 1230
1210 IF DT(1,5)<1 THEN TITLE$=" P/VOL" ELSE TITLE$=" "+L1$(VAL(VOL$))
1220 TITLE$=TITLE$+"   DT     TB     [illegible]"
1230 REM              [illegible]
```

```
1040 END
1050 REM
1060 REM                    SUBROUTINE FOR TITLE LINE
1070 REM
1080 L$(0)=" PRES":L1$(0)=" H2O"
1090 IF NOPT=20 THEN 1210
1100 TITLE$=" "
1110 T$(1)=L$(VAL(PR$)):T$(11)=L1$(VAL(VOL$))
1120 T$(2)=" DT1":T$(12)=" DT2"
1130 T$(3)=" TB1":T$(13)=" TB2"
1140 T$(4)=" TR1":T$(14)=" TR2"
1150 FOR J=5 TO 10
1160 T$(J)=" TS"+MID$(STR$(1+2*(J-5)),2,2):T$(J+10)=" TS"+MID$(STR$(2*(J-4)),2,2
 :NEXT J
1170 FOR J=1 TO NOPT
1180 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1190 NEXT J
1200 GOTO 1230
1210 IF DT(1,5)<1 THEN TITLE$=" P/VOL" ELSE TITLE$=" "+L1$(VAL(VOL$))
1220 TITLE$=TITLE$+"   DT     TB     TR     TS     TS     TS     TS     TS     TS"
1230 REM                        CHANNEL NUMBER LABELS
1240 C$=" ":FOR J=1 TO (NOPT+10*(NOPT=20))
1250 C$=C$+LEFT$("  "+STR$(OPT(J)-1)+"      ",6-((OPT(J)=2) OR (OPT(J)=12)))
1260 NEXT J
1270 RETURN
1280 REM ************************************************************
1290 REM ===================== GOTO NEXT PROGRAM ========================
1300 REM ************************************************************
1310 Q$=LEFT$(EXST$,1)
1320 IF Q$="" THEN CHAIN "MENU"
1330 EXST$=RIGHT$(EXST$,LEN(EXST$)-1)
1340 ON VAL(Q$) GOTO 1350,1360,1370,1380,1390,1400
1350 CHAIN "TAPELOAD"
1360 CHAIN "DISKLOAD"
1370 CHAIN "CONVERT"
1380 CHAIN "CONVCON"
1390 CHAIN "TABLE"
1400 CHAIN "PLOT"
```

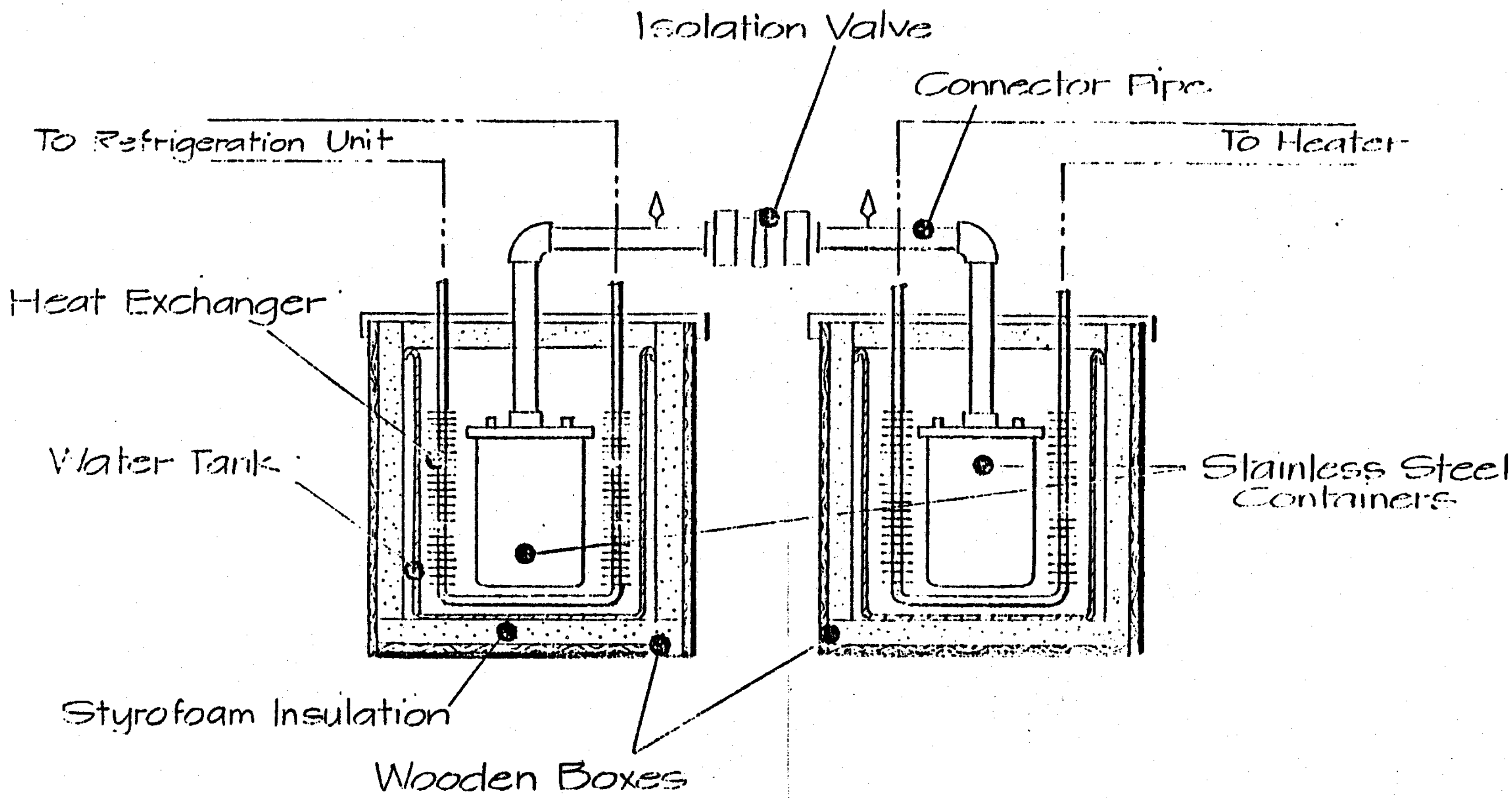
PLOT

```
10 DIM T$(20),OPT(20):I=0
20 CLS:KEY OFF:CLOSE
30 DEFINT I-K
40 COMMON DT(),EXST$,NT,PR$,VOL$,TP$,L$()
50 REM **********************************************************************
60 REM ========================== RANGE DATA ============================
70 REM **********************************************************************
80 CLS:LOCATE 10,34:PRINT "RANGING PLOT"
90 DIM MAXY(20),MINY(20):M1=0:M2=0
100 FOR I=1 TO NT:IF M1=1 AND M2=1 THEN 190
110 IF DT(I,2)<2 AND M1=0 THEN 120 ELSE IF M2=0 GOTO 150 ELSE 180
120 FOR J=1 TO 10:MINY(J)=DT(I,J+2):MAXY(J)=DT(I,J+2):NEXT J
130 MINT(1)=DT(I,1):MAXT(1)=DT(I,1)
140 M1=1:GOTO 180
150 FOR J=11 TO 20:MINY(J)=DT(I,J-8):MAXY(J)=DT(I,J-8):NEXT J
160 MINT(2)=DT(I,1):MAXT(2)=DT(I,1)
170 M2=1
180 NEXT I
190 FOR I=1 TO NT:I1=1-(DT(I,2)>1):JJJ=-10*(DT(I,2)>1)
200 IF DT(I,1)>MAXT(I1) THEN MAXT(I1)=DT(I,1)
210 IF DT(I,1)<MINT(I1) THEN MINT(I1)=DT(I,1)
220 FOR J=3 TO 12
230 JJ=JJJ+J-2
240 IF MAXY(JJ)<DT(I,J) THEN MAXY(JJ)=DT(I,J)
250 IF MINY(JJ)>DT(I,J) THEN MINY(JJ)=DT(I,J)
260 NEXT J
270 LOCATE 12,33:PRINT "COMPLETED:";:COLOR 15:PRINT USING"###.#":100*I/NT;:PRINT
 "%":COLOR 7
290 NEXT I
290 REM **********************************************************************
300 REM ========================== PLOT SELECT ============================
310 REM **********************************************************************
320 CLS:LOCATE 10,20:PRINT "PICK THE TYPE OF PLOT:"
330 LOCATE 12,22:PRINT "1. SELECTED VARIABLES VS TIME"
340 LOCATE 13,22:PRINT "2. PAIRED VARIABLES"
350 LOCATE 14,22:PRINT "3. CONTOUR OF SALT TEMPERATURES"
360 LOCATE 20,25:PRINT "ESC TO RETURN TO MAIN MENU"
370 LOCATE 10,42,1:Z$=INKEY$:IF Z$=CHR$(27) THEN PRINT "RETURN TO MENU"
380 IF Z$=CHR$(27) THEN CHAIN"MENU" ELSE IF Z$="1" OR Z$="2" OR Z$="3" THEN 420
ELSE 370
390 REM **********************************************************************
400 REM                                OUTPUT MENU
410 REM **********************************************************************
420 FOR I=1 TO 20:OPT(I)=0:NEXT I
430 CLS:LOCATE 1,25,1:PRINT "SELECT CHANNELS TO BE PLOTTED"
440 CH$="PA   DT1  TBW  TRES1TS1  TS3  TS5  TS7  TS9  TS11 H H2OOT2  TSR  TRES2T
S2  TS4  TS6  TS8  TS10 TS12 "
450 PRINT "CH.#          DESC.   LISTING #"
460 FOR I=0 TO 19
470 PRINT " ";I TAB(13) MID$(CH$,1+I*5,5)
480 NEXT I
490 LOCATE 4,30:PRINT "                SALT BED MAP"
500 LOCATE 5,50:PRINT CHR$(218)+STRING$(23,CHR$(196))+CHR$(191)
510 FOR I=6 TO 18:LOCATE I,50:PRINT CHR$(179) SPC(23) CHR$(179):NEXT I
520 LOCATE 19,50:PRINT CHR$(192)+STRING$(23,CHR$(196))+CHR$(217)
530 LOCATE 6,51:PRINT "10       6      1"
540 LOCATE 9,51:PRINT "         7      2"
550 LOCATE 12,51:PRINT "11       8      3"
560 LOCATE 15,51:PRINT "         9      4"
570 LOCATE 18,51:PRINT "12              5"
580 LOCATE 20,50:PRINT CHR$(179)+CHR$(17)+STRING$(3,CHR$(196))+"RADIUS"+STRING$(
3,CHR$(195))+CHR$(180)
```

```
150 FOR J=11 TO 20:MINY(J)=DT(I,J-8):MAXY(J)=DT(I,J-8):NEXT J
160 MINT(2)=DT(I,1):MAXT(2)=DT(I,1)
170 M2=1
180 NEXT I
190 FOR I=1 TO NT:I1=1-(DT(I,2)>1):JJJ=-10*(DT(I,2)>1)
200 IF DT(I,1)>MAXT(I1) THEN MAXT(I1)=DT(I,1)
210 IF DT(I,1)<MINT(I1) THEN MINT(I1)=DT(I,1)
220 FOR J=3 TO 12
230 JJ=JJJ+J-2
240 IF MAXY(JJ)<DT(I,J) THEN MAXY(JJ)=DT(I,J)
250 IF MINY(JJ)>DT(I,J) THEN MINY(JJ)=DT(I,J)
260 NEXT J
270 LOCATE 12,33:PRINT "COMPLETED:";:COLOR 15:PRINT USING"###.#";100*I/NT;:PRIN
 "%":COLOR 7
280 NEXT I
290 REM ********************************************************************
300 REM ======================== PLOT SELECT ==============================
310 REM ********************************************************************
320 CLS:LOCATE 10,20:PRINT "PICK THE TYPE OF PLOT:"
330 LOCATE 12,22:PRINT "1. SELECTED VARIABLES VS TIME"
340 LOCATE 13,22:PRINT "2. PAIRED VARIABLES"
350 LOCATE 14,22:PRINT "3. CONTOUR OF SALT TEMPERATURES"
360 LOCATE 20,25:PRINT "ESC TO RETURN TO MAIN MENU"
370 LOCATE 10,42,1:Z$=INKEY$:IF Z$=CHR$(27) THEN PRINT "RETURN TO MENU"
380 IF Z$=CHR$(27) THEN CHAIN"MENU" ELSE IF Z$="1" OR Z$="2" OR Z$="3" THEN 420
ELSE 370
390 REM ********************************************************************
400 REM                              OUTPUT MENU
410 REM ********************************************************************
420 FOR I=1 TO 20:OPT(I)=0:NEXT I
430 CLS:LOCATE 1,25,1:PRINT "SELECT CHANNELS TO BE PLOTTED"
440 CH$="PA   DT1  TBW  TRES1TS1  TS3  TS5  TS7  TS9  TS11 H H2ODT2  TBS  TRES2T
S2  TS4  TS6  TS8  TS10 TS12 "
450 PRINT "CH.#        DESC.    LISTING #"
460 FOR I=0 TO 19
470 PRINT " ";I TAB(13) MID$(CH$,1+I*5,5)
480 NEXT I
490 LOCATE 4,50:PRINT "        SALT BED MAP"
500 LOCATE 5,50:PRINT CHR$(218)+STRING$(28,CHR$(196))+CHR$(191)
510 FOR I=6 TO 18:LOCATE I,50:PRINT CHR$(179) SPC(28) CHR$(179):NEXT I
520 LOCATE 19,50:PRINT CHR$(192)+STRING$(28,CHR$(196))+CHR$(217)
530 LOCATE 6,51:PRINT "10      6      1"
540 LOCATE 9,51:PRINT "        7      2"
550 LOCATE 12,51:PRINT "11      8      3"
560 LOCATE 15,51:PRINT "        9      4"
570 LOCATE 18,51:PRINT "12             5"
580 LOCATE 20,50:PRINT CHR$(179)+CHR$(17)+STRING$(3,CHR$(196))+"RADIUS"+STRING$
3,CHR$(196))+CHR$(180)
590 ON VAL(Z$) GOTO 600,700,800
600 I=1
610 LOCATE 23,25:PRINT SPC(40):LOCATE 23,25:INPUT "CH.# ,ALL OR STOP:";Q$
620 IF Q$="ALL" THEN 660 ELSE IF Q$="STOP" THEN 670 ELSE IF VAL(Q$)>19 THEN 610
630 LOCATE (3+VAL(Q$)),22:PRINT I
640 OPT(I)=1+VAL(Q$)
650 IF I=10 THEN 670 ELSE I=I+1:GOTO 610
660 FOR I=1 TO 20:OPT(I)=I:NEXT I
670 NOPT=I+(I<>10 OR Q$="STOP"):LOCATE 23,25:PRINT "ANY CORRECTIONS (Y/N)?
"
680 Q$=INKEY$:IF Q$="N" THEN 810 ELSE IF Q$="Y" THEN 420 ELSE 680
690 GOTO 810
700 I=1:LL$(0)="X":LL$(1)="Y"
710 LOCATE 23,25:PRINT "SELECT Y";RIGHT$(STR$((1+I)\2),1);" THEN X"+RIGHT$(STR$
(1+I)\2),1);" (STOP TO END):                    "
720 LOCATE 23,57:INPUT"",Q$
730 IF Q$="STOP" THEN 770 ELSE IF VAL(Q$)>19 THEN 710
740 LOCATE (3+VAL(Q$)),22:PRINT LL$(I MOD 2)+RIGHT$(STR$((1+I)\2),1)
750 OPT(I)=1+VAL(Q$)
760 IF I=10 THEN 770 ELSE I=I+1:GOTO 710
770 NOPT=I+(I<>10 OR Q$="STOP"):LOCATE 23,25:PRINT "ANY CORRECTIONS (Y/N)?
"
780 Q$=INKEY$:IF Q$="N" THEN 810 ELSE IF Q$="Y" THEN 420 ELSE 780
790 GOTO 870
800 CLS:COLOR 23:LOCATE 10,20,0:PRINT "THIS OPTION IS NOT YET AVAILABLE":FOR I=
 TO 5000:NEXT:COLOR 7:GOTO 320
810 IF Z$="1" THEN 820 ELSE 870
820 MAXY=MAXY(OPT(1)):MINY=MINY(OPT(1)):MAXX=MAXT(1):MINX=MINT(1)
830 FOR I=2 TO NOPT
840 IF MAXY<MAXY(OPT(I)) THEN MAXY=MAXY(OPT(I))
850 IF MINY>MINY(OPT(I)) THEN MINY=MINY(OPT(I))
860 NEXT I:GOTO 950
870 IF Z$="2" THEN 880 ELSE 320
880 MAXY=MAXY(OPT(1)):MINY=MINY(OPT(1)):MAXX=MAXY(OPT(2)):MINX=MINY(OPT(2))
890 FOR I=3 TO NOPT STEP 2
900 IF MAXX<MAXY(OPT(I+1)) THEN MAXX=MAXY(OPT(I+1))
910 IF MINX>MINY(OPT(I+1)) THEN MINX=MINY(OPT(I+1))
920 IF MAXY<MAXY(OPT(I)) THEN MAXY=MAXY(OPT(I))
930 IF MINY>MINY(OPT(I)) THEN MINY=MINY(OPT(I))
```

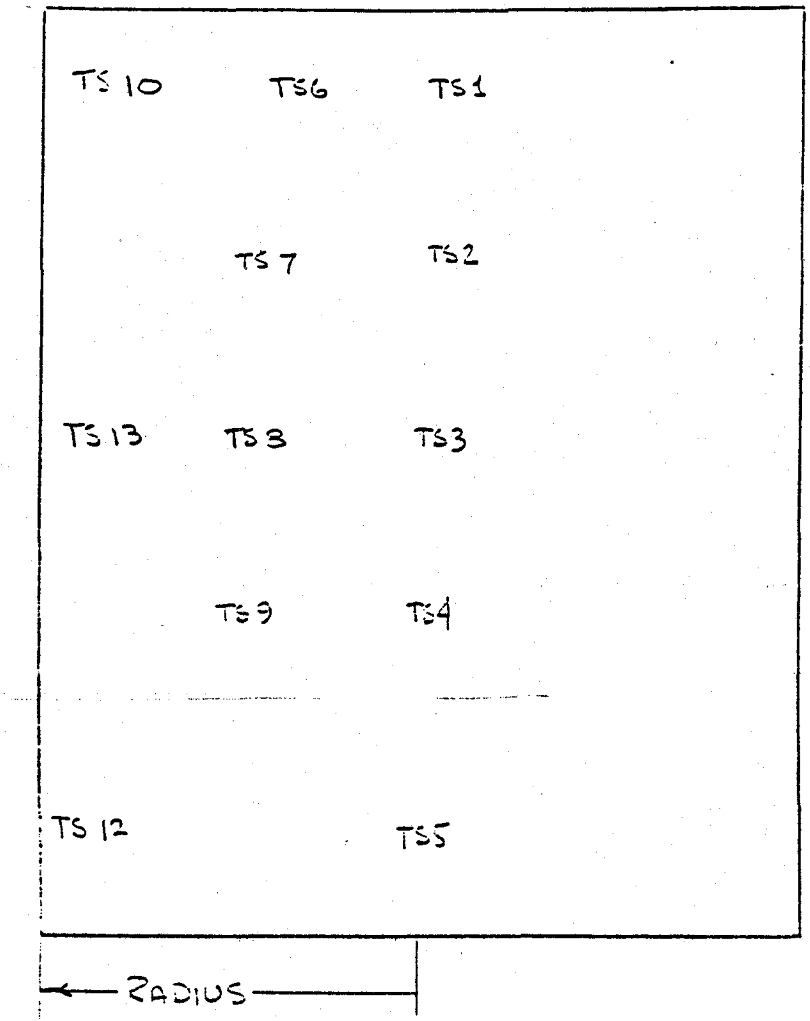
```
760 IF I=10 THEN 770 ELSE I=I+1:GOTO 710
770 NOPT=I+(I<>10 OR O$="STOP"):LOCATE 23,25:PRINT "ANY CORRECTIONS (Y/N)?
"
780 Q$=INKEY$:IF Q$="N" THEN 810 ELSE IF Q$="Y" THEN 420 ELSE 780
790 GOTO 870
800 CLS:COLOR 23:LOCATE 10,20,0:PRINT "THIS OPTION IS NOT YET AVAILABLE":FOR I=1
 TO 5000:NEXT:COLOR 7:GOTO 320
810 IF Z$="1" THEN 820 ELSE 870
820 MAXY=MAXY(OPT(1)):MINY=MINY(OPT(1)):MAXX=MAXT(1):MINX=MINT(1)
830 FOR I=2 TO NOPT
840 IF MAXY<MAXY(OPT(I)) THEN MAXY=MAXY(OPT(I))
850 IF MINY>MINY(OPT(I)) THEN MINY=MINY(OPT(I))
860 NEXT I:GOTO 950
870 IF Z$="2" THEN 880 ELSE 320
880 MAXY=MAXY(OPT(1)):MINY=MINY(OPT(1)):MAXX=MAXY(OPT(2)):MINX=MINY(OPT(2))
890 FOR I=3 TO NOPT STEP 2
900 IF MAXX<MAXY(OPT(I+1)) THEN MAXX=MAXY(OPT(I+1))
910 IF MINX>MINY(OPT(I+1)) THEN MINX=MINY(OPT(I+1))
920 IF MAXY<MAXY(OPT(I)) THEN MAXY=MAXY(OPT(I))
930 IF MINY>MINY(OPT(I)) THEN MINY=MINY(OPT(I))
940 NEXT I
950 CLS:LOCATE 10,20:PRINT "THE DEFAULT LIMITS ON THIS PLOT ARE:"
960 LOCATE 11,25:PRINT "X AXIS:";MINX;" TO ";MAXX
970 LOCATE 12,25:PRINT "Y AXIS:";MINY;" TO ";MAXY
980 LOCATE 19,25:PRINT "DO YOU WISH TO CHANGE ANY OF THESE VALUES?"
990 LOCATE 20,30:PRINT "1) CHANGE NEITHER"
1000 LOCATE 21,30:PRINT "2) CHANGE BOTH"
1010 LOCATE 22,30:PRINT "3) CHANGE ONLY THE Y AXIS"
1020 LOCATE 23,30:PRINT "4) CHANGE ONLY TIME AXIS"
1030 LOCATE 19,67,1:Q$=INKEY$:IF Q$="1" THEN 1040 ELSE IF Q$="2" OR Q$="3" OR Q$
="4" THEN GOSUB 1830 ELSE 1030
1040 GOSUB 1610         'DRAW GRID
1050 ON VAL(Z$) GOTO 1060,1170
1060 FOR J=1 TO NOPT
1070 FOR I=1 TO NT
1080 IF OPT(J)>10 AND DT(I,2)>1 THEN YP=DT(I,OPT(J)-8):XP=DT(I,1):GOTO 1110
1090 IF OPT(J)<11 AND DT(I,2)<2 THEN YP=DT(I,OPT(J)+2):XP=DT(I,1):GOTO 1110
1100 GOTO 1140
1110 X=56+((XP-MINX)/(MAXX-MINX))*560
1120 Y=164-((YP-MINY)/(MAXY-MINY))*152
1130 IF X<639 AND Y<164 AND X>56 AND Y>8 THEN CIRCLE (X,Y),J
1140 NEXT I
1150 NEXT J
1160 GOTO 1290
1170 FOR J=1 TO NOPT STEP 2
1180 FOR I=1 TO NT
1190 IF OPT(J)<11 AND OPT(J+1)<11 AND DT(I,2)<2 THEN YP=DT(I,2+OPT(J)):XP=DT(I,2
+OPT(J+1)):GOTO 1240
1200 IF OPT(J)<11 AND OPT(J+1)>10 AND DT(I,2)<2 AND DT(I+1,2)>1 THEN YP=DT(I,2+O
PT(J)):XP=DT(I+1,OPT(J+1)-8):GOTO 1240
1210 IF OPT(J)>10 AND OPT(J+1)<11 AND DT(I,2)>1 AND DT(I-1,2)<2 THEN YP=DT(I,OPT
(J)-8):XP=DT(I-1,OPT(J+1)+2):GOTO 1240
1220 IF OPT(J)>11 AND OPT(J+1)>11 AND DT(I,2)>1 THEN YP=DT(I,OPT(J)-8):XP=DT(I,O
PT(J+1)-8):GOTO 1240
1230 GOTO 1270
1240 X=56+((XP-MINX)/(MAXX-MINX))*560
1250 Y=164-((YP-MINY)/(MAXY-MINY))*152
1260 IF X<639 AND Y<164 AND X>56 AND Y>8 THEN CIRCLE (X,Y),1+.5*(J-1)
1270 NEXT I
1280 NEXT J
1290 GOSUB 1370             'TITLE LINE ROUTINE
1300 LOCATE 1,35-LEN(N$)/2:PRINT "FILE NAME:"+N$
1310 LOCATE 23,(40-LEN(TITLE$)/2):PRINT TITLE$
1320 Q$=INKEY$:IF Q$="" THEN 1320 ELSE IF Q$=CHR$(27) THEN CHAIN"MENU"
1330 SCREEN 0,0,0:GOTO 320
1340 REM ***********************************************************************
1350 REM ================= SUBROUTINE FOR TITLE LINE =======================
1360 REM ***********************************************************************
1370 L$(0)=" PRES":L1$(0)=" H2O"
1380 TITLE$=" "
1390 T$(1)=L$(VAL(PR$)):T$(11)=L1$(VAL(VOL$))
1400 T$(2)=" DT1":T$(12)=" DT2"
1410 T$(3)=" TBW":T$(13)=" TBS"
1420 T$(4)=" TR1":T$(14)=" TR2"
1430 FOR J=5 TO 10
1440 T$(J)=" TS"+MID$(STR$(1+2*(J-5)),2,2):T$(J+10)=" TS"+MID$(STR$(2*(J-4)),2,
):NEXT J
1450 IF Z$="2" THEN 1510
1460 FOR J=1 TO NOPT
1470 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1480 NEXT J
1490 TITLE$=TITLE$+"VS TIME (IN HOURS)"
1500 RETURN
1510 FOR J=1 TO NOPT STEP 2
1520 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1530 TITLE$=TITLE$+" VS "
1540 TITLE$=TITLE$+LEFT$((T$(OPT(J+1))+"      "),6-((OPT(J+1)=1) OR (OPT(J+1)=11
...
```

```
[illegible] THEN YP=DT(I,2+O
T(J)):XP=DT(I+1,OPT(J+1)-8):GOTO 1240
1210 IF OPT(J)>10 AND OPT(J+1)>11 AND DT(I,2)>1 AND DT(I-1,2)<2 THEN YP=DT(I,OPT
(J)-8):XP=DT(I-1,OPT(J+1)+2):GOTO 1240
1220 IF OPT(J)>11 AND OPT(J+1)>11 AND DT(I,2)>1 THEN YP=DT(I,OPT(J)-8):XP=DT(I,O
PT(J+1)-8):GOTO 1240
1230 GOTO 1270
1240 X=56+((XP-MINX)/(MAXX-MINX))*560
1250 Y=164-((YP-MINY)/(MAXY-MINY))*152
1260 IF X<639 AND Y<164 AND X>56 AND Y>8 THEN CIRCLE (X,Y),1+.5*(J-1)
1270 NEXT I
1280 NEXT J
1290 GOSUB 1370               'TITLE LINE ROUTINE
1300 LOCATE 1,35-LEN(N$)/2:PRINT "FILE NAME:"+N$
1310 LOCATE 23,(40-LEN(TITLE$)/2):PRINT TITLE$
1320 O$=INKEY$:IF O$="" THEN 1320 ELSE IF O$=CHR$(27) THEN CHAIN"MENU"
1330 SCREEN 0,0,0:GOTO 320
1340 REM ****************************************************************
1350 REM ================= SUBROUTINE FOR TITLE LINE =======================
1360 REM ****************************************************************
1370 L$(0)=" FFED":L1$(0)=" H2O"
1380 TITLE$=" "
1390 T$(1)=L$(VAL(FR$)):T$(11)=L1$(VAL(VOL$))
1400 T$(2)=" DT1":T$(12)=" DT2"
1410 T$(3)=" TBW":T$(13)=" TBS"
1420 T$(4)=" TR1":T$(14)=" TR2"
1430 FOR J=5 TO 10
1440 T$(J)=" TS"+MID$(STR$(1+2*(J-5)),2,2):T$(J+10)=" TS"+MID$(STR$(2*(J-4)),2,2
):NEXT J
1450 IF Z$="2" THEN 1510
1460 FOR J=1 TO NOPT
1470 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1480 NEXT J
1490 TITLE$=TITLE$+"VS TIME (IN HOURS)"
1500 RETURN
1510 FOR J=1 TO NOPT STEP 2
1520 TITLE$=TITLE$+LEFT$((T$(OPT(J))+"      "),6-((OPT(J)=1) OR (OPT(J)=11)))
1530 TITLE$=TITLE$+" VS "
1540 TITLE$=TITLE$+LEFT$((T$(OPT(J+1))+"      "),6-((OPT(J+1)=1) OR (OPT(J+1)=11
)))
1550 IF J+1<>NOPT THEN TITLE$=TITLE$+" AND "
1560 NEXT J
1570 RETURN
1580 REM ****************************************************************
1590 REM ======================== GRID ROUTINE ============================
1600 REM ****************************************************************
1610 SCREEN 2
1620 LINE(56,4)-(56,164):LINE-(616,164)
1630 FOR J=4 TO 164 STEP 16:LINE(54,J)-(58,J):NEXT J
1640 FOR I=56 TO 616 STEP 56:LINE(I,162)-(I,164):NEXT I
1650 FOR J=4 TO 164 STEP 16
1660 FOR I=56 TO 616 STEP 8
1670 PSET (I,J):NEXT I:NEXT J
1680 FOR I=56 TO 616 STEP 56
1690 FOR J=4 TO 164 STEP 4
1700 PSET(I,J):NEXT J:NEXT I
1710 L=1+INT(LOG(MAXX)/LOG(10)):L=L-(L<1)
1720 TIMEFMT$=STRING$(L,"#")+".####"
1730 TIMEFMT$=LEFT$(TIMEFMT$,5)
1740 FOR X=5 TO 75 STEP 7:LOCATE 22,X:PRINT USING TIMEFMT$:MINX+(MAXX-MINX)*(X-5
)/70:NEXT X
1750 L=1+INT(LOG(MAXY)/LOG(10)):L=L-(L<1)
1760 YFMT$=STRING$(L,"#")+".#####"
1770 YFMT$=LEFT$(YFMT$,6)
1780 FOR Y=1 TO 21 STEP 2:LOCATE Y,1:PRINT USING YFMT$:MAXY-((MAXY-MINY)*(Y-1)/2
0):NEXT Y
1790 RETURN
1800 REM ****************************************************************
1810 REM ==================== EDIT PLOT LIMITS ============================
1820 REM ****************************************************************
1830 IF O$="4" GOTO 1860
1840 CLS:LOCATE 1,1:PRINT "Y AXIS:";MINY;" TO ";MAXY:LOCATE 10,30:INPUT "MIN Y,
MAX Y:",MINY,MAXY           'CHANGE Y
1850 IF O$="3" THEN RETURN ELSE 1870
1860 CLS
1870 LOCATE 2,1:PRINT "TIME";MINX;" TO ";MAXX:LOCATE 11,30:INPUT "MIN TIME, MAX
TIME:",MINX,MAXX
1880 RETURN
```



THE TEST VEHICLE

FIGURE 2



PROTOTYPE 1
TEMPERATURE PROBES

FIGURE 3

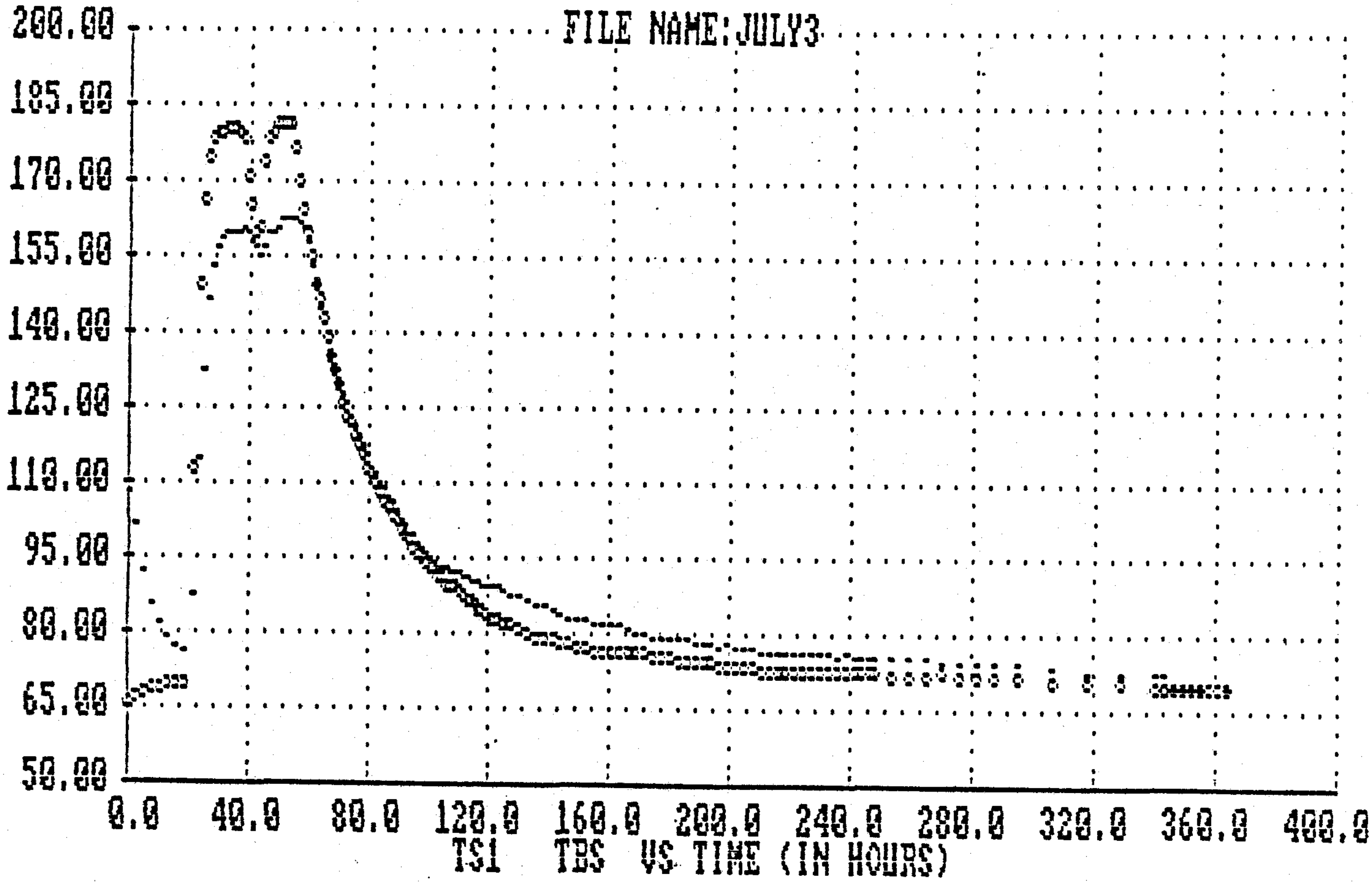


FIGURE 4a

TEMPERATURE VS TIME

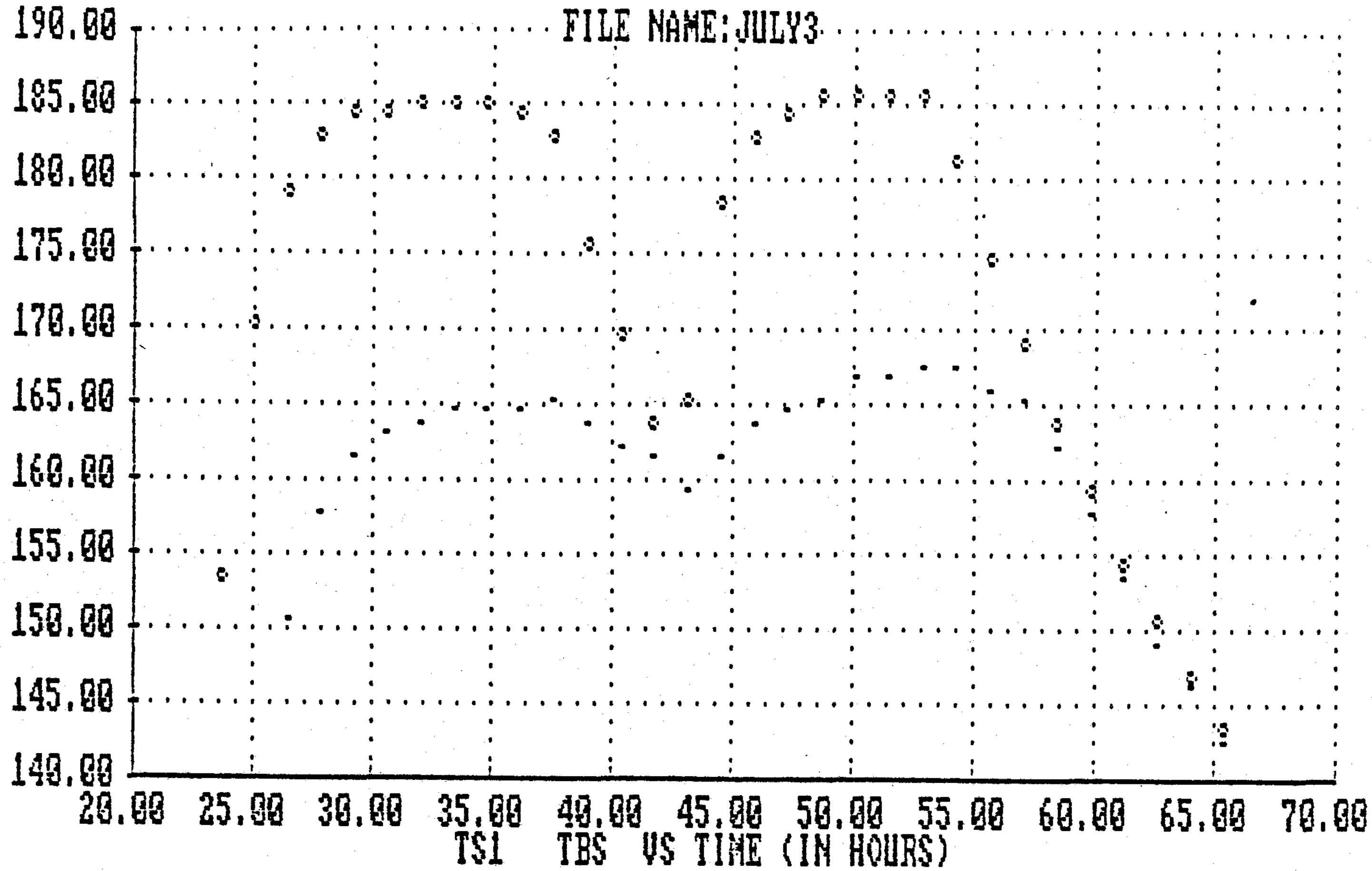


FIGURE 4b

TEMPERATURE VS. TIME

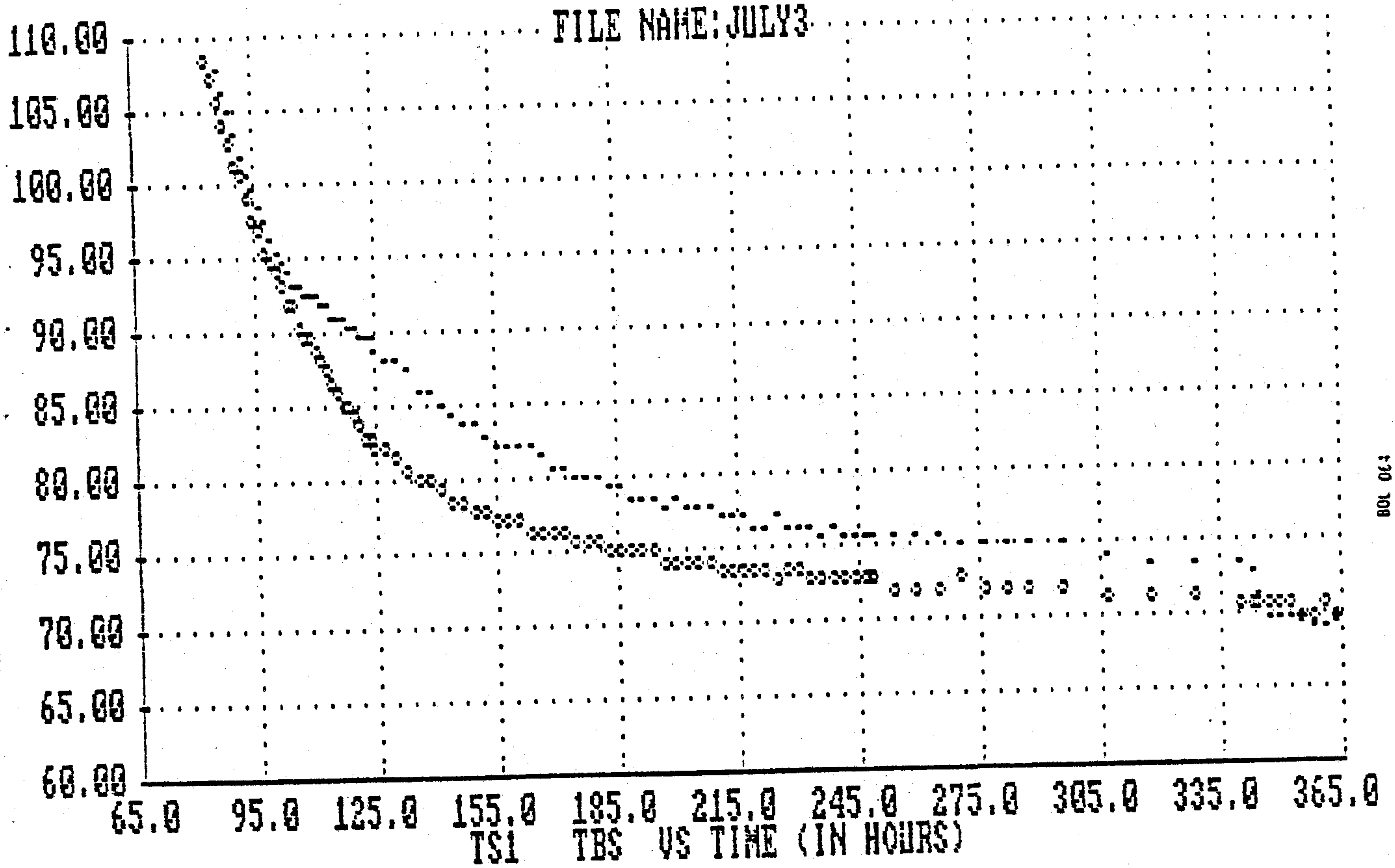


FIGURE 4c

TEMPERATURE VS TIME

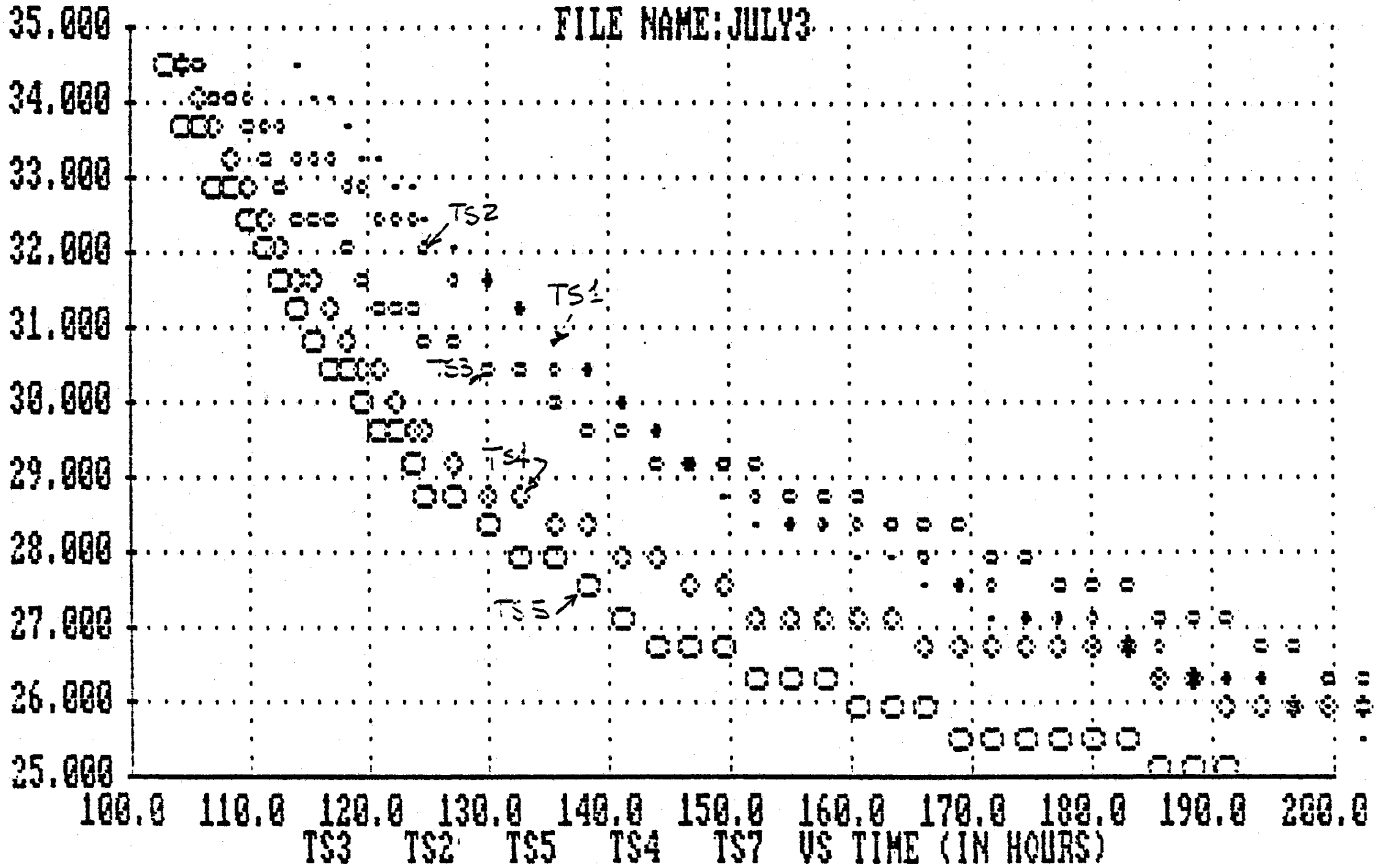
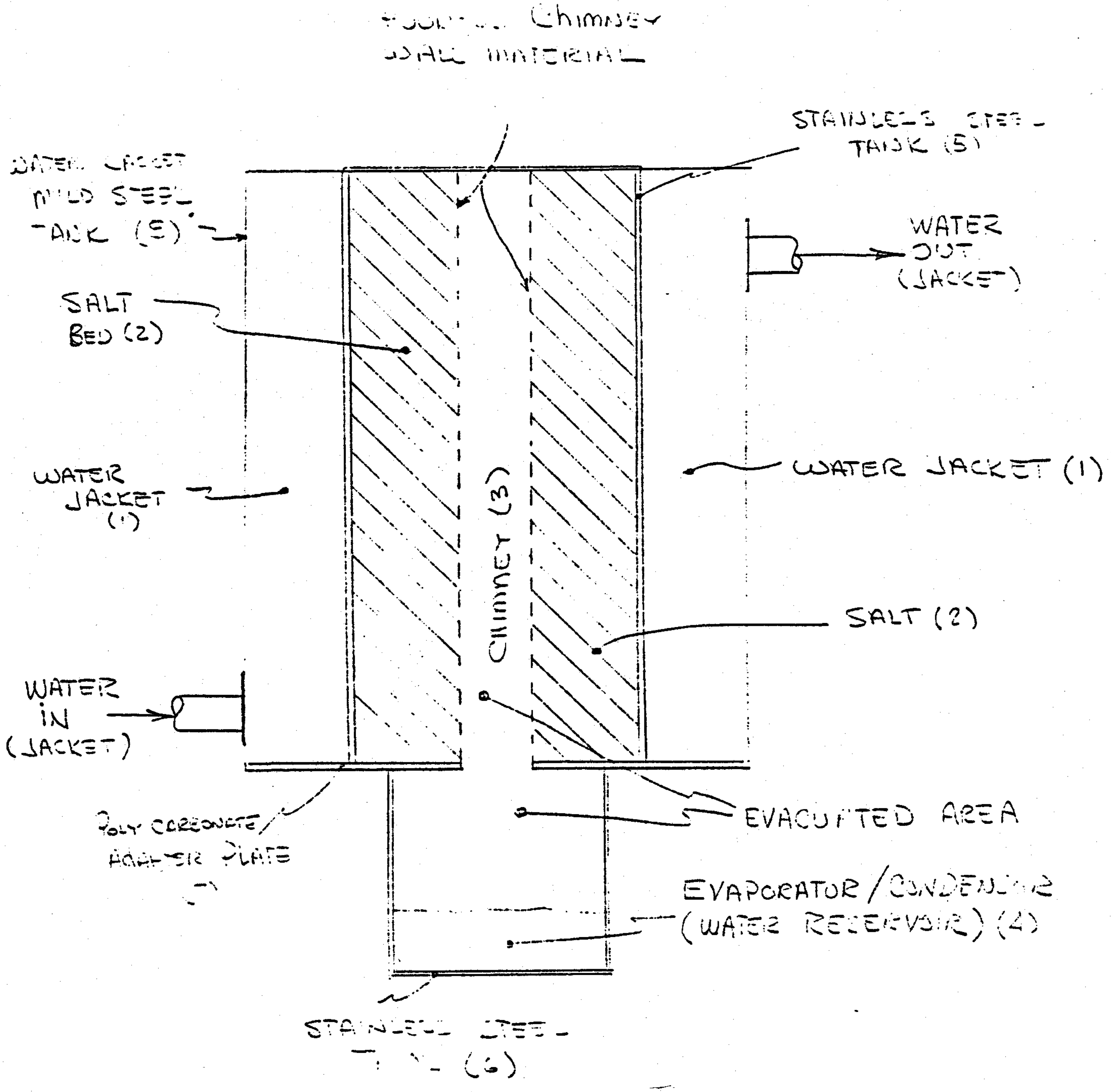
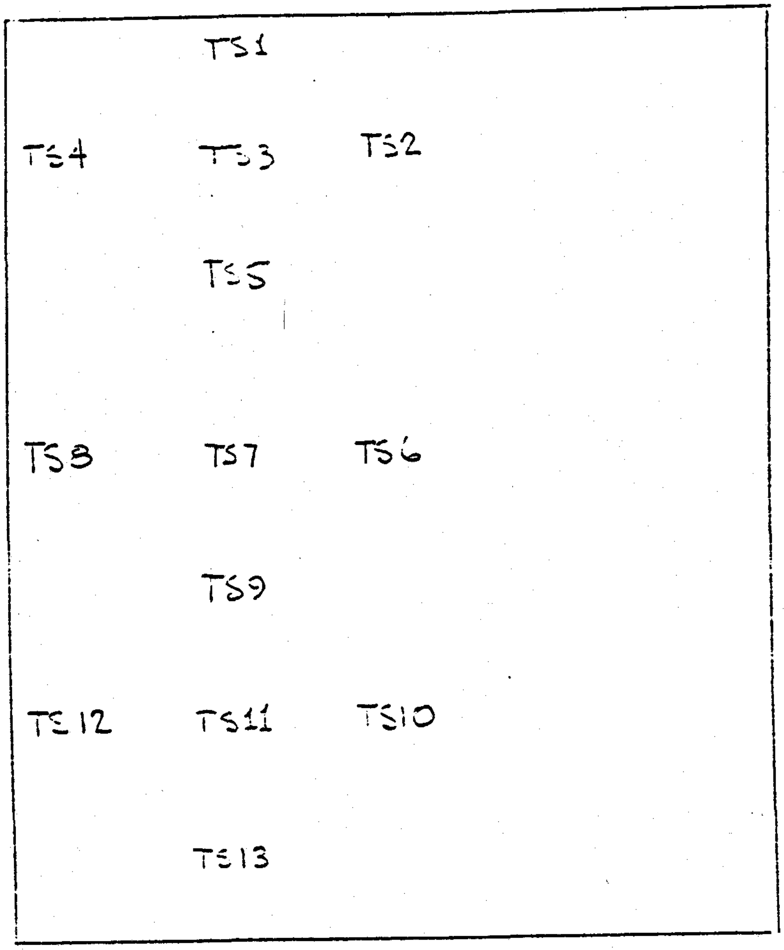

FILE NAME:JULY3
35.000
34.000
33.000
32.000
31.000
30.000
29.000
28.000
27.000
26.000
25.000
100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 190.0 200.0
TS3 TS2 TS5 TS4 TS7 VS TIME (IN HOURS)
TS2
TS1
TS3
TS4
TS5

FIGURE 4d



OPERATING CONFIGURATION

FIGURE 5



PROTOTYPE 2
TEMPERATURE PROBES

FIGURE 6

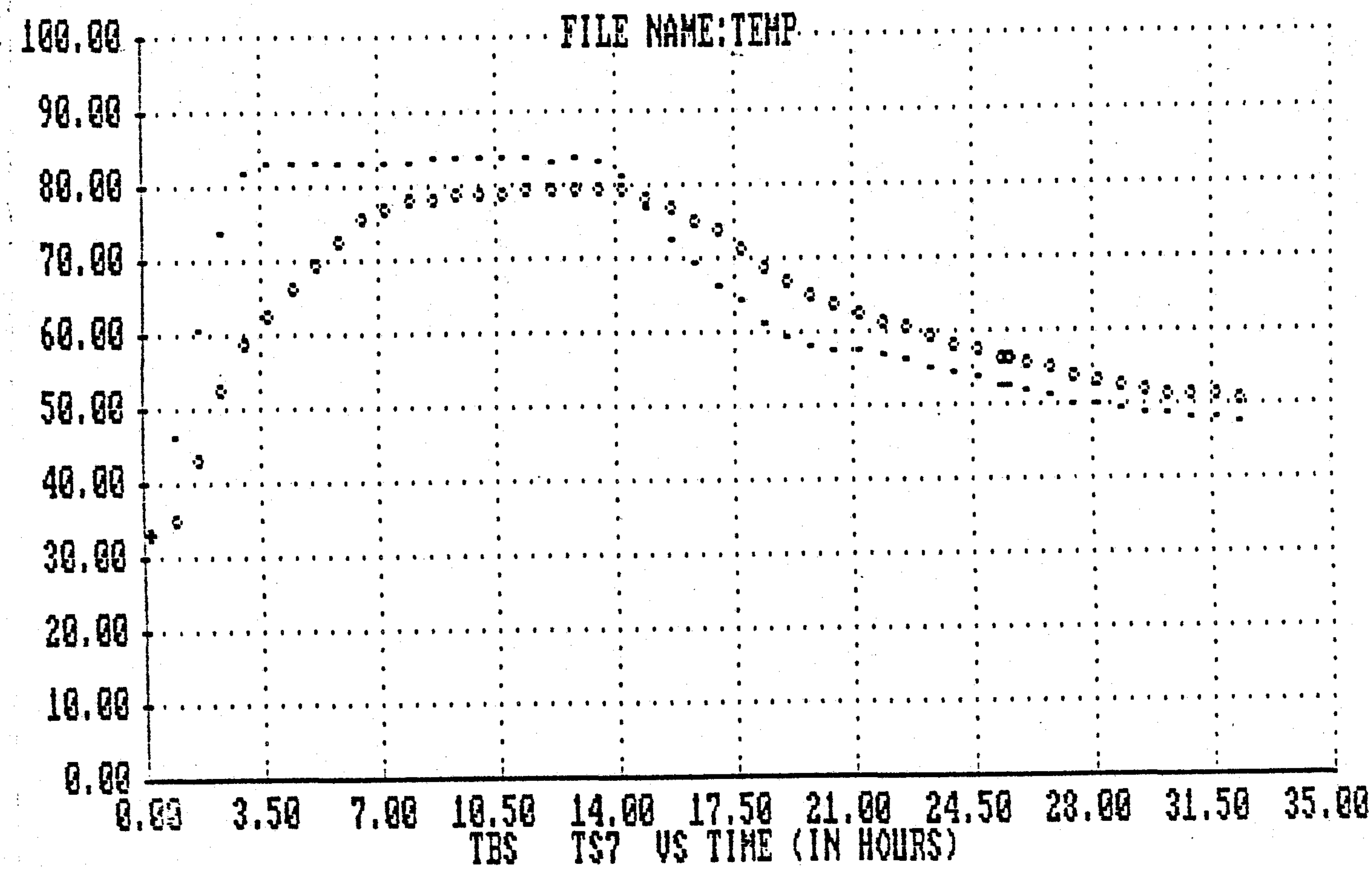

FILE NAME:TEMP
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
3.50
7.00
10.50
14.00
17.50
21.00
24.50
28.00
31.50
35.00
TBS TS7 VS TIME (IN HOURS)

FIGURE 7a

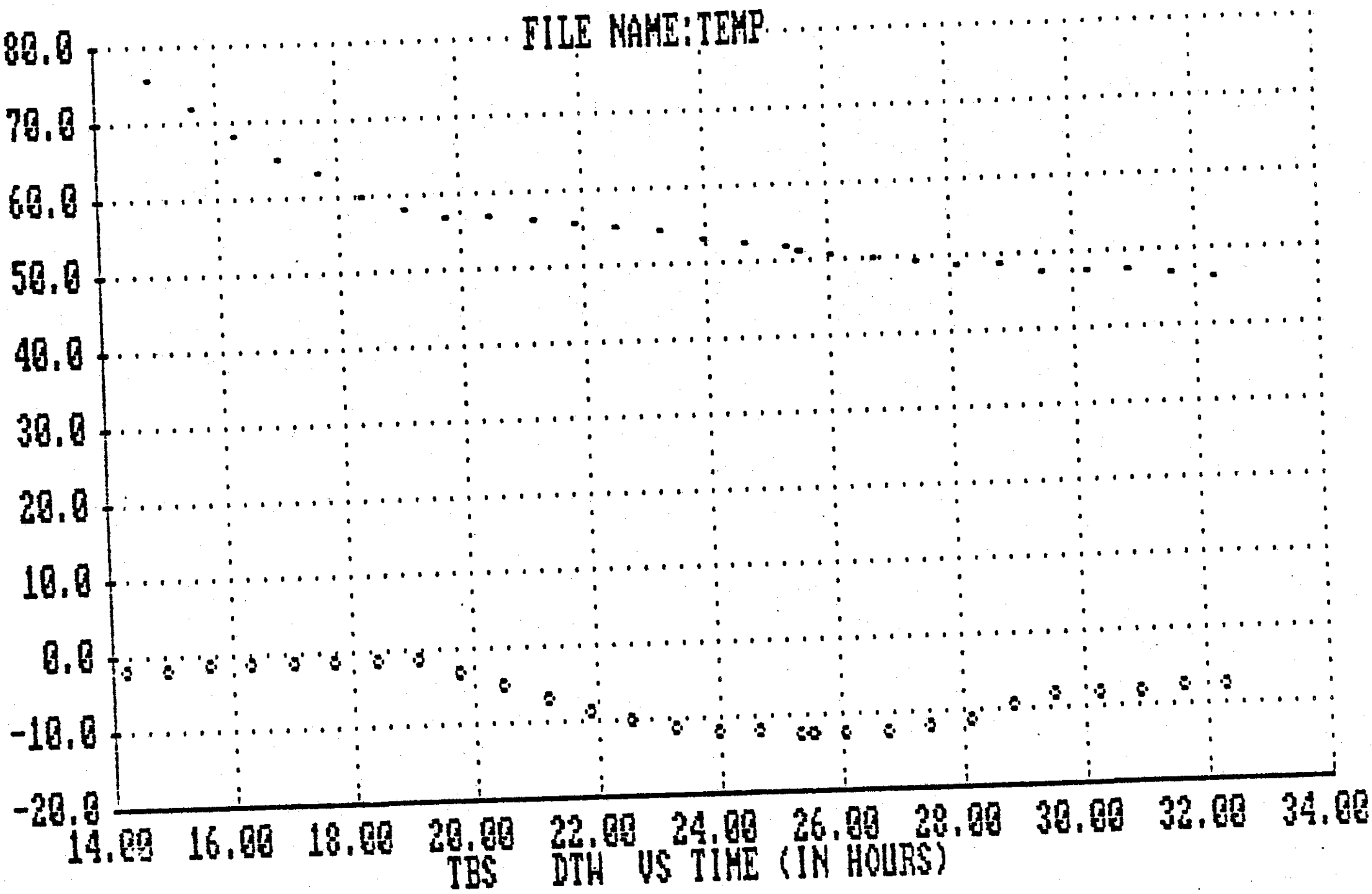
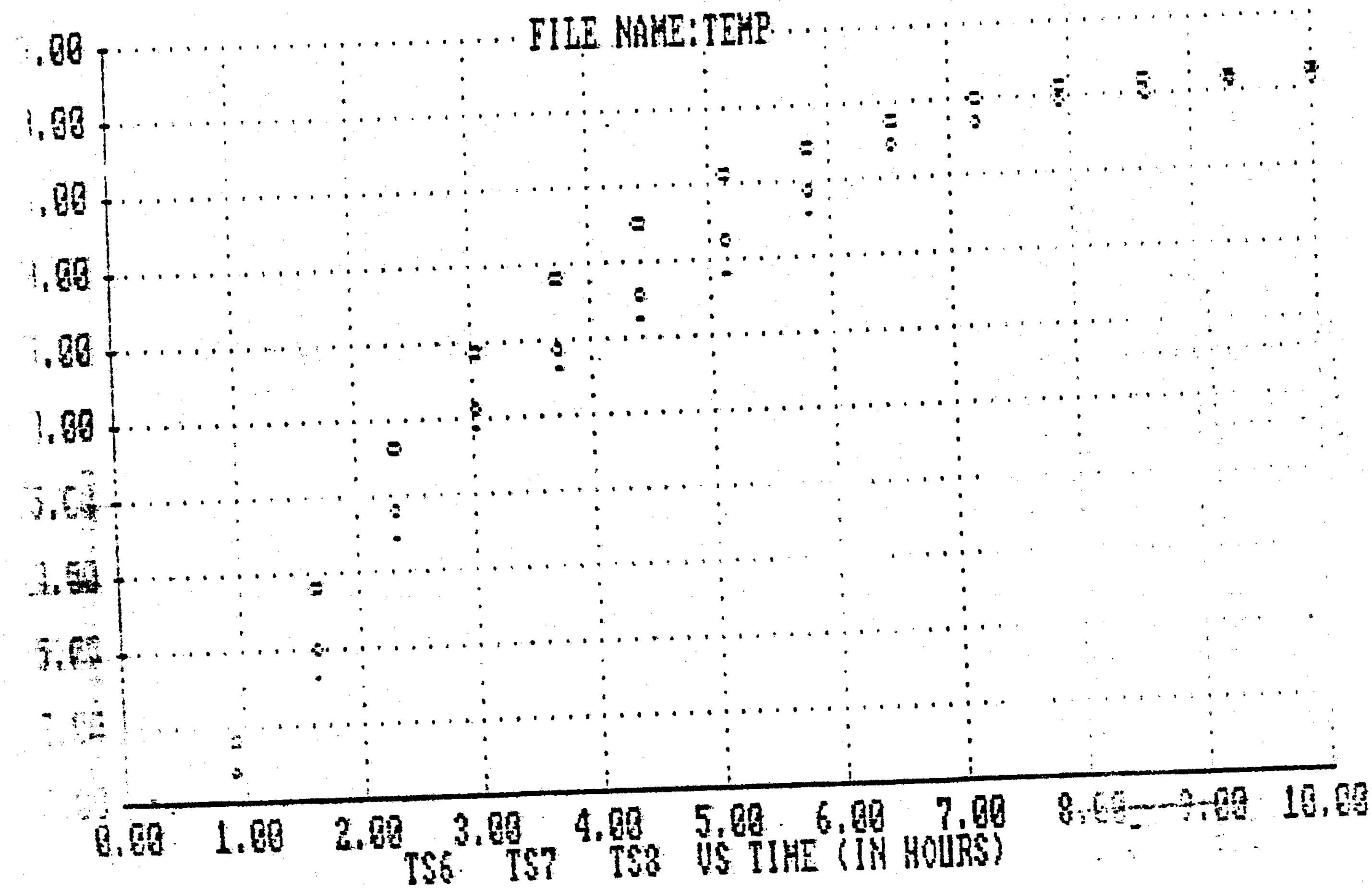

FILE NAME:TEMP
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
14.00
16.00
18.00
20.00
22.00
24.00
26.00
28.00
30.00
32.00
34.00
TBS DTW VS TIME (IN HOURS)

FIGURE 7a



FILE NAME:TEMP
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
10.00
TS6 TS7 TS8 VS TIME (IN HOURS)

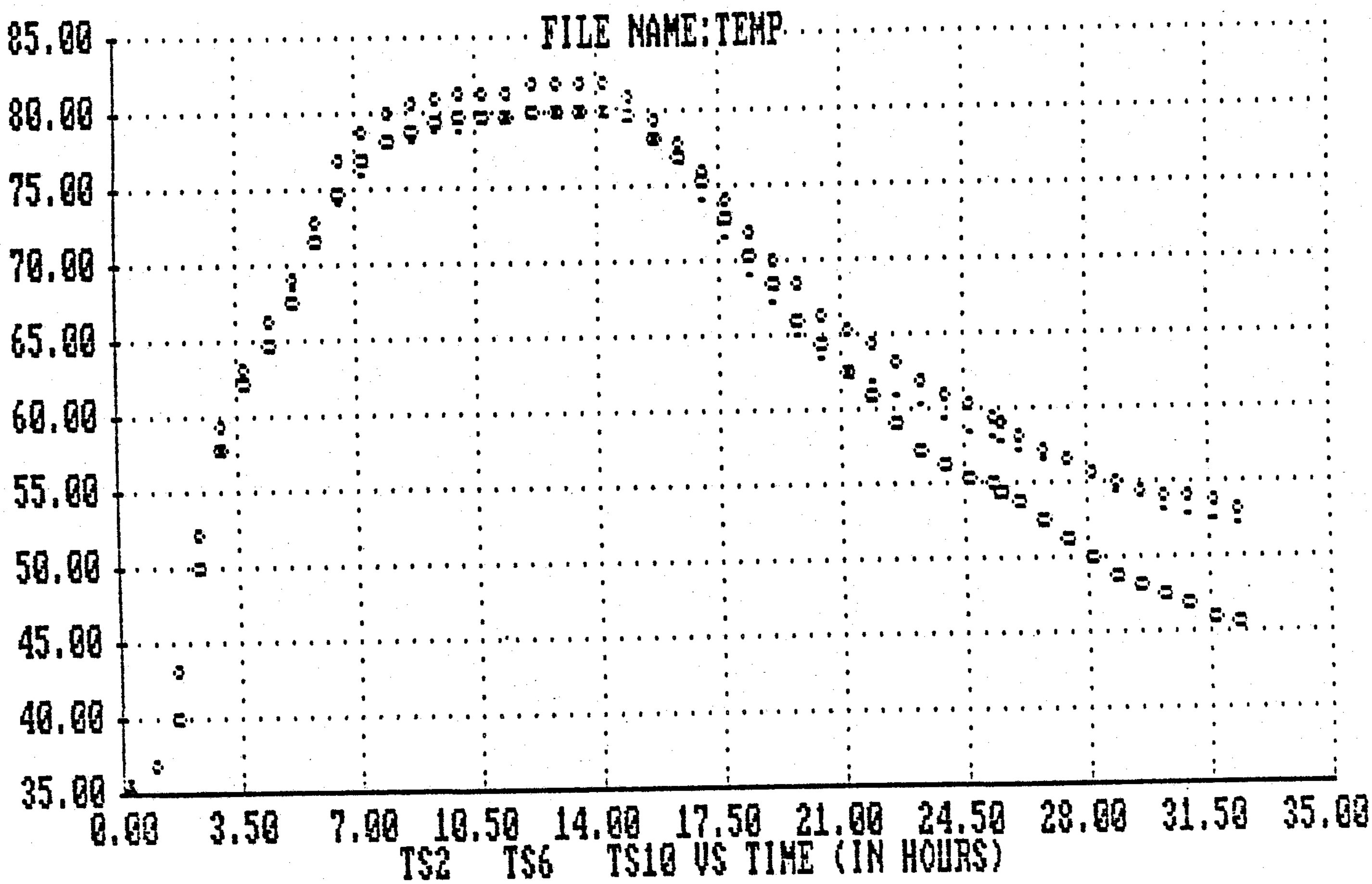

FILE NAME:TEMP
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
0.00
3.50
7.00
10.50
14.00
17.50
21.00
24.50
28.00
31.50
35.00
TS2 TS6 TS10 VS TIME (IN HOURS)

FIGURE 7a

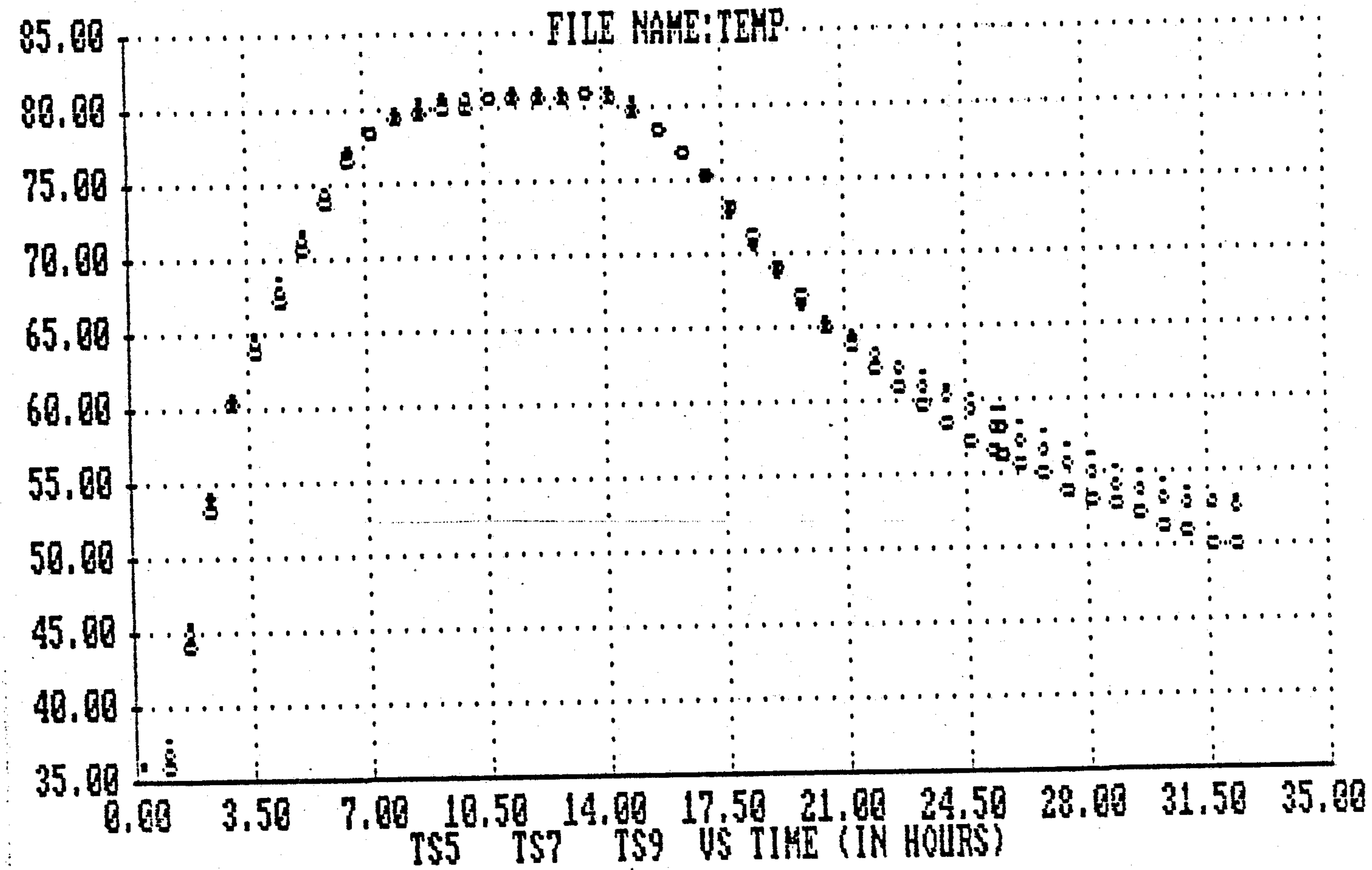

FILE NAME:TEMP
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
0.00
3.50
7.00
10.50
14.00
17.50
21.00
24.50
28.00
31.50
35.00
TS5 TS7 TS9 VS TIME (IN HOURS)

FIGURE 7e

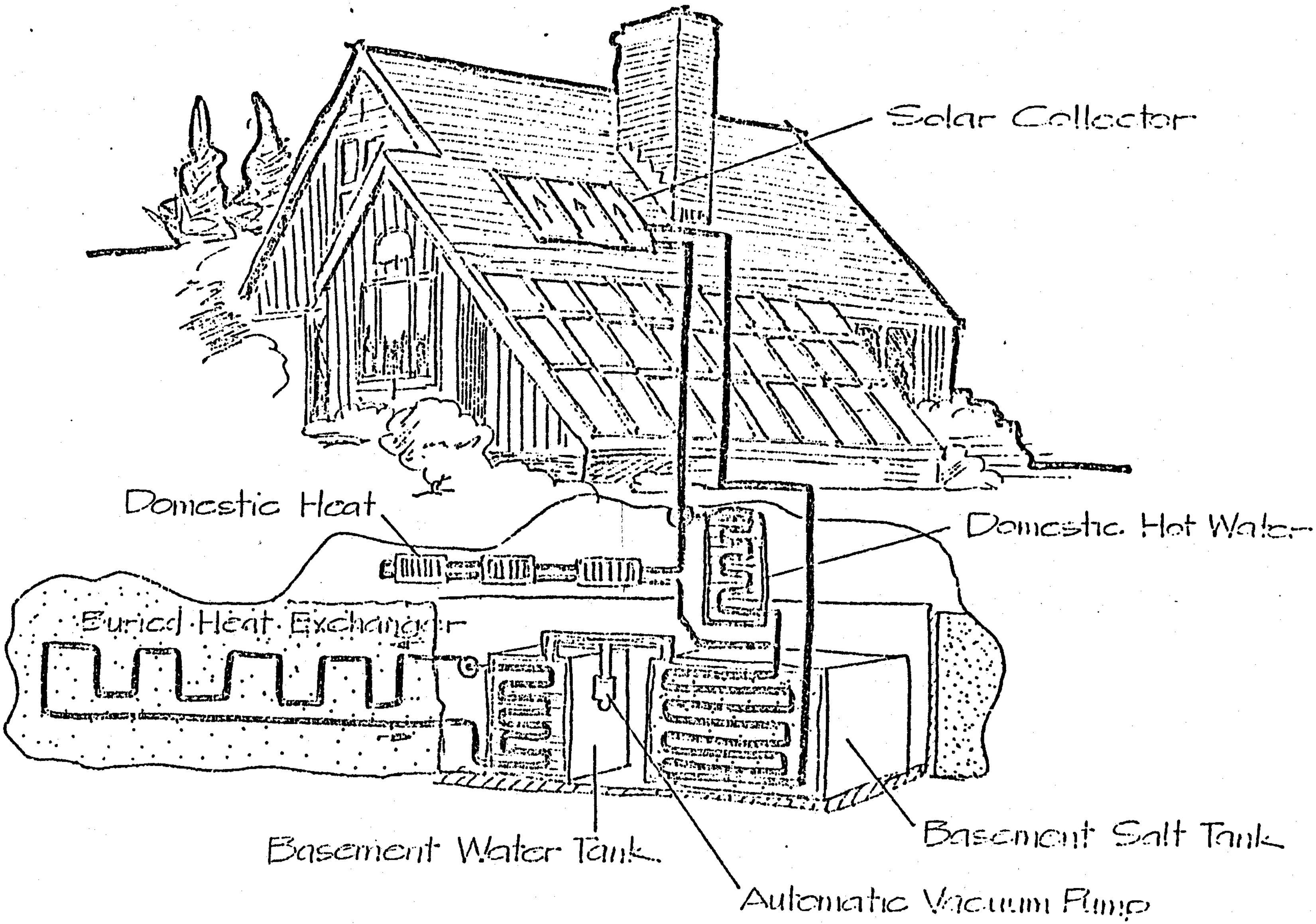
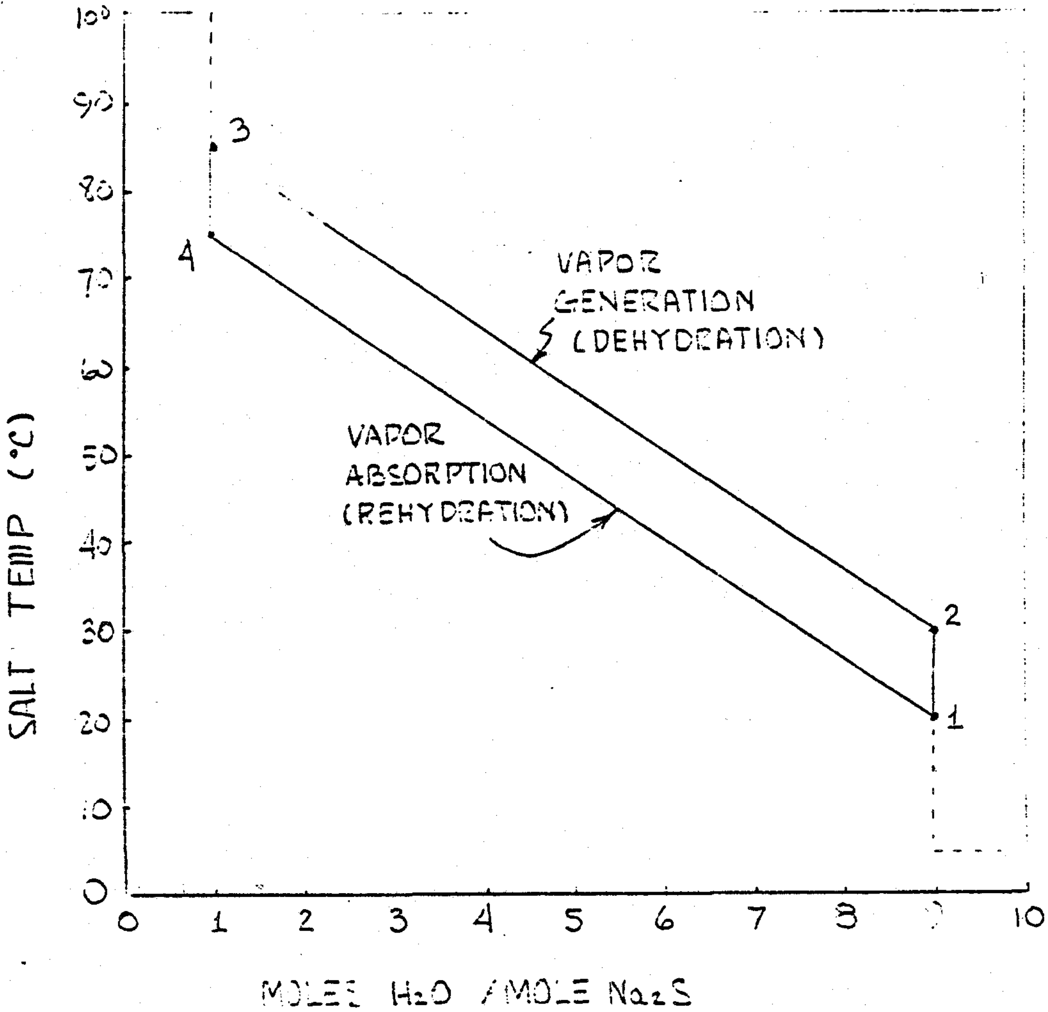
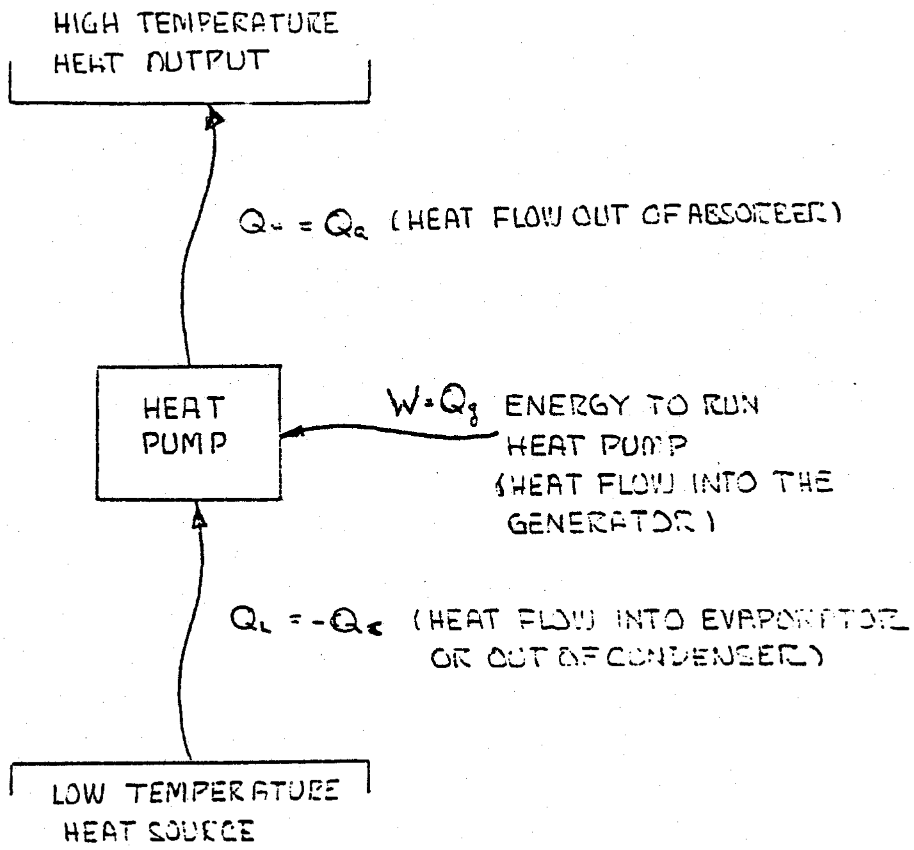

Solar Collector
Domestic Heat
Domestic Hot Water
Buried Heat Exchanger
Basement Water Tank
Basement Salt Tank
Automatic Vacuum Pump

Figure 8



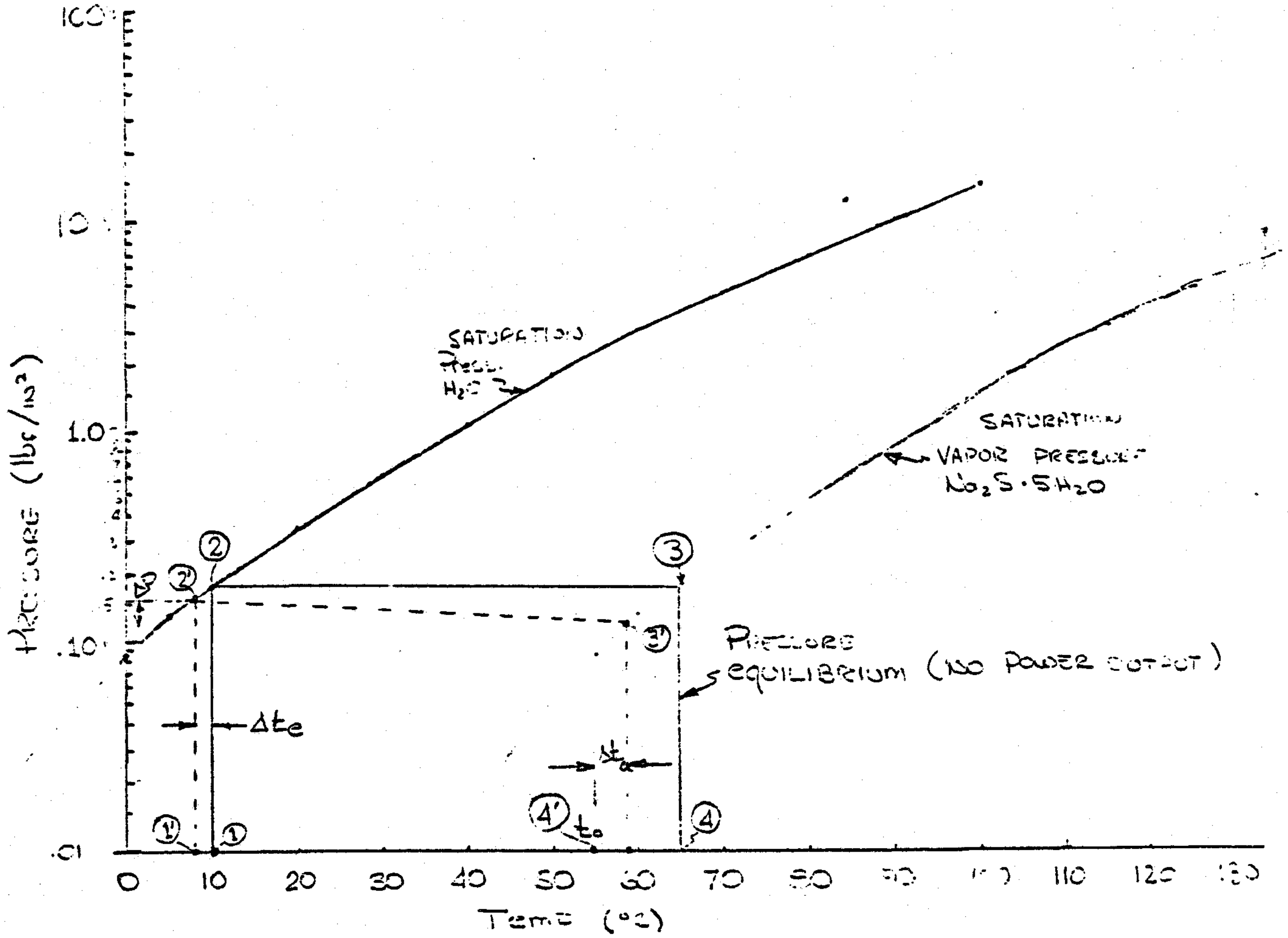
TEMPERATURE / COMPOSITION
CYCLE

FIGURE 9



CARNOT HEAT PUMP

FIGURE 10



Δt_e = [illegible] temperature drop at the [illegible]

$\Delta P = \Delta P_{sat} - \Delta P_{[illegible]}$

Δt_a = [illegible] temperature drop at the [illegible]
(includes temperature gradients in the [illegible] material)

FIGURE 11

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