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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150841

LARGO HOT WATER SYSTEM THERMAL PERFORMANCE TEST REPORT

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

Under subcontract with IBM, Federal Systems Division, Huntsville, AL

Contract NAS8-32036

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U.S. Department of Energy

U.S. Department of Energy

Solar Energy

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This work was done under the technical management of Mr. Charles N. Thomas, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report presents the thermal performance tests and results on the LARGO Solar Hot Water System under natural environmental conditions. Some objectives of these evaluations are to determine the amount of energy collected, the amount of energy delivered to the household as contributed by solar power supplied to operate the system and auxiliary power to maintain tank temperature at proper level, overall system efficiency and to determine temperature distribution within the tank. The tests and evaluation were performed at the Marshall Space Flight Center solar test facility.

The Solar Hot Water system is termed a "Dump-type" because of the draining system for freeze protection. The solar collector is a single glazed flat plate. An 82-gallon domestic water heater is provided as the energy storage vessel. Water is circulated through the collector and water heater by a 5.3 GPM capacity pump, and control of the pump motor is achieved by a differential temperature controller.

For long range thermal performance tests on the LARGO Solar Hot Water System, see DOE/NASA CR-150842.

17. KEY WORDS

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* Appendix II has been published as a separate volume in the Wyle Test Report, TR-531-19.

1.0 SUMMARY

Thermal performance tests of the LARGO Solar Residential Hot Water System were initiated on September 22, 1977. Results of initial tests revealed that the water flow rate thru the collector was restricted. This restriction was found to be due to a three-way solenoid valve which was located upstream of the system pump. The system manufacturer was informed of the restricted flow condition. Subsequently, the three-way valve and associated piping was modified such that satisfactory flow rates could be achieved. Thermal performance tests were continued on September 28, 1977 thru October 14, 1977 without other system related problems occuring. Additional tests are scheduled. This additional testing phase was scheduled for purposes of obtaining long-thermal performance data on the system.

A summary of performance parameters as determined from operational data on the first phase of testing is presented in Table II.

It is intended that this report will be updated upon completion of the second phase of testing. The final report will be issued as a consolidated document which will include results of both test phases.

2.0 PURPOSE

The purpose of this document is to present the results of tests of the LARGO Solar Hot Water System under natural environmental conditions.

Primary objectives of these performance evaluations are to:

- Determine the amount of energy collected by the system.
- Determine the amount of energy that is delivered to the household as contributed by solar.
- Determine power supplied to operate the system and auxiliary power to maintain tank temperature at proper level.
- Determine overall system efficiency.
- Determine temperature distribution (stratification) within the tank.

The test program was conducted to determine the performance of the system to the evaluation requirements of Reference 3.1 in accordance with Reference 3.2

3.0 REFERENCES

3.1	NBSIR 76-1137	Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program
3.2	Informal Statement of Work (Approved by MSFC)	LARGO Solar Hot Water Heater Test Program
3.3	ASHRAE 93-77	Method of Testing Solar Collectors Based on Thermal Performance
3.4	NBS TN899	Proposed Standards for Testing Solar Collectors and Thermal Storage Devices
3.5	MSFC MMI5300.4C	Metrology and Calibration

4.0 MANUFACTURER

Equipment	Manufacturer	Model No.
Collector	LARGO Solar Systems, Inc. 2525 Key Largo Lane Fort Lauderdale, Florida 33312	HR-410 SR
Residential Electric Water Heater	RHEEM Water Heater, Div. 7600 South Kedzie Avenue Chicago, Illinois 60652	RP-82-2

4.0 MANUFACTURER (Continued)

Equipment	Manufacturer	Model No.
Water Pump	March Manufacturing Co., Inc. 11914 U.S.1 Juno, Florida 33408	809HS
3-Way Water Valve	Automatic Switch Co. Florham Park, New Jersey 07932	8320A85
Controller	Hawthorne Industries, Inc. Solar Energy Division 1501 South Dixie West Palm Beach, Florida 33401	H1503
Solenoid Driver	Del-Sol Control Corp. 11914 U.S.1 Juno, Florida 33408	OA2

5.0 DESCRIPTION OF TEST SPECIMEN

Presented in Figure 1 is a sketch of the LARGO Solar Systems, Inc. Solar Hot Water System which was tested. Major subsystem/components on the "Dump Type" system are designated in the sketch. The system is termed a "Dump Type" because of the draining system associated with freeze protection on the collector.

In the course of testing, it was found that the 3-way solenoid valve caused a large flow restriction down-stream of the pump. Modifications in the piping system and removal of the 3-way valve and bleed line were necessary to achieve satisfactory flow rates.

The modified piping system is shown in Figure 3, where the 3-way valve and the bleed line were replaced by copper tubing and a manual control valve.

The solar collector is a single glazed flate plate, with gross area of 40 Ft^2 and aperture area of 38.25 Ft^2. An 82 gallon domestic water heater is provided as the energy storage vessel which includes a conventional heater element with a maximum power rating of 3.0 KW. Water is recirculated thru the collector and water heater by a 5.3 GPM capacity pump, and control of the pump motor is achieved by a differential temperature controller. Temperature sensors for the differential temperature controller are located at the collector fluid outlet and adjacent to the domestic water heater lower thermostat position.

A second differential temperature controller is employed on the system for purposes of freeze protection. The controller senses temperature at the collector outlet manifold and controls the operation of a solenoid actuated valve to drain water from the system. An automatic air vent is located near the collector outlet to allow air to displace the water in the collector tubes and the piping system upon activation of the drain valve.

5.0 DESCRIPTION OF TEST SPECIMEN (Continued)

Photographs 1 thru 3 show the system components installed on Test Bed #1 at the Solar Test Facility as located at Marshall Space Flight Center, Alabama.

6.0 TEST CONDITIONS AND TEST EQUIPMENT

6.1 Ambient Conditions

Unless otherwise specified in the procedure, the testing will be conducted in natural ambient conditions.

6.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with requirements of Reference 3.5. All sensor output signals are monitored, recorded and processed by the data acquisition system located in Building 4646. A listing of the equipment specifications is provided as follows:

Apparatus/Function	Manufacturer/Model	Range/Accuracy
Platinum Resistance Thermometer/ Collector Fluid Loop Temperature:	Hy-Cal Engineering/ 4135-A	
(1) Collector inlet		50-250°F ±.9°F
(1) Collector outlet		50-250°F ±.9°F
Platinum Resistance Thermometer/	Hy-Cal Engineering/ 4135-A	
(1) Water supply to tank		40-100°F ±.9°F
(1) Tank outlet to load		50-250°F ±.9°F
Flow Meter/	Foxboro/ 1/2-2-8173C1	.23 to 2 GPM ±1% FS
(1) Water flow rate thru collector		
(1) Water flow rate to load	Potter Meter Co./ 1/2-270	0-9 GPM ±1% FS
Electrical Power/	Ohio Semitronics/ PC5-10	
(1) Pump and control system		1.2 KW ±.5% FS
(1) Water heater element	Ohio Semitronics/ PC5-29	0-12 KW ±.5% FS
Pyranometer/Solar Flux Transducer	Eppley/PSP	0-400 BTU/Hr·Ft^2/±3%
Wind Velocity Sensor	Teledyne Geotech/ M1567	.75-65 MPH/±.5%
Wind Direction Sensor	Teledyne Geotech/	0-360°
(6) Thermocouples*/ water temperature profile in tank	Omega/Type T	50-250°F ±3°F
(6) Platinum Resistance Thermometers**/ water temperature profile in domestic water heater tank	Hy-Cal Engineering/ 4125-A	60-250°F ±.9°F

*(6) Thermocouples measurements to be recorded on strip chart recorder, separately.
** This instrumentation was used in the second phase of LARGO System tests.

6.2.1 Instrumentation Designation

The location of instrumentation on the LARGO, Inc. Solar Water Heater System is indicated in Figure 2. A detailed instrumentation list is provided in the Instrumentation and Component List (IP&CL Revision A-15). Instrumentation block diagrams depicting the primary data acquisition set up utilized during these tests are shown in Appendix I. Descriptions of the magnetic tape records from LARGO system operational tests are also provided in Appendix I.

All transducers with the exception of the Eppley PSP pyranometer used in recording test data are calibrated by either NASA or AMC calibration laboratories as required by MSFC MMI 5300.4C. The PSP pyranometer is calibrated by Eppley.

The end-to-end accuracy of data derived from system testing is subject to an error analysis which accounts for all inaccuracies in the transducer, signal conditioning, signal transmission and computer processing methods. Since a formal systems error analysis will not be done, confidence in printout accuracies were established by installing calibrated "parallel" transducers and direct readouts at key points in the system and performing comparison checks from time to time before, during, and after tests. The results of such checks together with a review of the data for anomalies indicates that the data presented is suitable for the purpose intended.

7.0 TEST REQUIREMENTS AND PROCEDURES

7.1 System Operational Functional Test

Tested by ______________________
Started ______________________
Completed ______________________

7.1.1 Performance Criteria Requirements

Functional tests shall be conducted on the LARGO Solar Hot Water System to determine that major components of the system operate properly after installation on Test Bed No. 1. The system operational functional test shall consist of the following individual tests:

- A system pressure/leakage test.
- An operation test on the freeze protection system.
- An operational test of the system pump/controller.

7.1.2 Test Procedure

1. Install the LARGO Solar Hot Water System on Test Bed No. 1. The system installation is illustrated in Figure 1.

2. Connect the potable water supply to domestic water heater cold water inlet and fill the system. Activate pump and circulate water thru the collector and return to the domestic water heater. Monitor the water flow rate thru the system to assure that the pump is functioning properly (water flow rates of 1 to 5 GPM), then deactivate the pump.

3. Check the system for leaks. If leaks are found, repair them and recheck the system.

4. Activate freeze protection system by application of ice on the freeze protection sensor. The solenoid driver should operate the 3-way valve to drain the system. Allow the freeze sensor to return to a temperature greater than approximately 40°F. The 3-way valve should operate to refill the collector.

5. To check the differential temperature controller, apply power to the controller and monitor pump operation (1 to 5 GPM flow rate is normal). Apply power to the water heater element and monitor water temperature response in the tank. As the water temperature stabilizes, the differential temperature controller should operate to deactivate the pump. The pump controller check out procedure to deactivate the pump may require that the collector aperture be shaded for conditions of high solar insolation.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued

7.1.3 Results of Functional Tests

1. The pump was determined to be functioning properly. However, the flow rate thru the collector circuit was restricted to approximately 0.3 GPM.

2. No leaks were discovered during systems leak tests.

3. The freeze protection sensor/controller did not actuate the 3-way solenoid valve to the normally open condition for circulation of water thru the collector loop. Operation of the system was achieved manually by removing power from the solenoid driver. The freeze protection sensor/controller did not function to operate the 3-way solenoid actuated valve when the sensor was subjected to temperature of 32°F. Also, it was noted that the freeze protection system, would not prevent freezing under conditions of electrical power failure.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.2 System Operational Test

7.2.1 Performance Criteria Requirements

The LARGO Solar Hot Water System shall be tested to experimentally determine the system's operational thermal and performance characteristics. Measurements and data shall be accumulated over an operational period of approximately two weeks (assuming predominately sunny weather) under natural climatic conditions. These tests shall be conducted at the Test Bed No. 1 Facility using a simulated hot water load schedule. Complete weather records will be maintained including total solar radiation incident normal to the collector plane, ambient temperature, wind speed and direction.

Data shall be recorded during system's operation as necessary to evaluate the following performance parameters on a daily basis.

- Total energy collected by the solar system.
- Total energy supplied to operate the system and the auxiliary energy consumed by the domestic water heater.
- Total energy supplied to hot water load as contributed by solar system.
- Overall system efficiency.
- Temperature stratification profile in domestic water heater.

7.2.2 Test Procedure

1. Turn on city water supply to domestic water heater. Apply power to freeze protection controller, pump controller and the domestic water heater. Operate the system for 24 hours under a no-load condition.
2. Tests performed subsequently, shall require that the system be operated during the normal work schedule, Monday through Friday. The system shall be operated continuously under a simulated load condition from 8:00 a.m. until 4:00 p.m.
3. The daily operational hot water loading sequence is as follows:

Time	Operation
0745 Hrs ± 15 Min	Apply power to system
0800 Hrs ± 15 Min	Drain 21 Gal. ± .5 Gal.
1200 Hrs ± 15 Min	Drain 21 Gal. ± .5 Gal.
1700 Hrs ± 15 Min	Drain 21 Gal. ± .5 Gal.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.2.2 Test Procedure (Continued)

The water will be drained from the domestic water heater at the rate of 3 GPM ±0.2 GPM into a graduated container. The container will be accurately marked to indicate from 0 to 35 gallons with subdivisions of 1/2 gallons.

4. Monitor system operation and check for malfunctions or leaks thru the test duration. This operation will be performed at the intervals specified in Procedure 3, above.

5. Throughout the test interval, data will be accumulated on the data system located in Building 4646.

7.2.3 Results of Operational Tests

A list of measured quantities and corresponding parameters which were presented in graphical form is provided in Table I. All test data as recorded on magnetic tape during operational testing were processed after completion of tests and subsequently computer plots were prepared.

System operational performance parameters were evaluated on a daily basis and are summarized as shown in Table II. The methods used in the evaluations are outlined in Paragraph 7.0 of the report.

In the first test phase, temperature stratification measurements were recorded on a strip chart. These measurements were used to prepare graphs to show the temperature profile of the water during the system operation. Graphs of measured temperature profiles in the domestic water heater tank are also presented in Appendix II. Temperature stratification effects which were observed during the tests are delineated below:

- During periods when the system pump is inactive, the axial temperature distribution in the tank shows significant stratification effects. Typical measured transient temperature stratification effects are shown graphically in Figure 4. The upper and lower temperature sensors were plotted as a function of time during overnight storage with the upper tank thermostat and electrical heater element active.

- Typical temperature stratification effects during the proximity of time at which the hot water load occured are shown in Figure 5

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.2.3 Results of Operational Tests (Continued)

It is apparent from this graph that a limited amount of mixing existed in the tank during the time that city water was admitted at the tank bottom and hot water was discharged from the top.

- Circulation of fluid thru the tank by the system pump results in mixing which relaxes the stratification effects which existed prior to activation of the pump. This effect is indicated in Figure 5, where the transient upper and lower tank temperature measurements are plotted.

Test data was recorded over a 24 hour basis to evaluate the overall heat transfer loss coefficient (U_L) of the domestic water heater. This test data consisted of bulk average temperature of water in the tank and the ambient air temperature which are shown graphically in Figure 6 as functions of time. The overall tank heat transfer coefficient was determined to be 9.6 BTU/Hr°F.

8.0 ANALYSIS

Analyses were performed of data obtained from LARGO system tests to evaluate thermal performance parameters. Equations used to evaluate the test data are indicated in the following paragraphs.

Solar Energy Available

The total daily solar energy available was calculated for the interval of time that the LARGO system controller and simultaneously the data acquisition system were active.

$$Q_S = \int_{\tau_1}^{\tau_2} I001 A_c \, d\tau$$

where,

Q_S = Total daily solar energy available

A_c = Gross collector area

I001 = Measured solar insolation

τ = Time

Solar Energy Collected

The quantity of solar energy collected on a daily basis was evaluated by,

$$Q_C = \int_{\tau_1}^{\tau_2} W370 C_p \, (T171 - T170) \, d\tau$$

where,

Q_C = Solar energy collected

W370 = Liquid flow rate

C_p = Specific heat

T171 = Collector fluid outlet temperature

T170 = Collector fluid inlet temperature

τ = Time

Hot Water Load

The total daily hot water loads were evaluated using the equation,

$$Q_H = C_p \sum_{n=0}^{n} M_n (T372 - T371)_n$$

where,

Q_H = Total daily hot water load

8.0 ANALYSIS (Continued)

C_p = Specific heat

M = Mass of water during each load

(T372-T371) = Temperature difference between outlet to load and city water inlet during each load interval

Total Electrical Energy

The total electrical energy was the sum used by the hot water heater element and the pump.

$$Q_E = \int_{\tau_1}^{\tau_2} EP370 d\tau + \int_{\tau_1}^{\tau_2} EP371 d\tau$$

where,

Q_E = Total electrical energy used

EP370 = Electrical power of heater element

EP371 = Electrical power of pump

τ = Time

Overall Heat Transfer Loss Coefficient of Hot Water Tank

This parameter was evaluated by the recording of liquid temperature existing in the tank and the ambient air temperature over night on a strip chart. Temperature sensors used to establish liquid temperature profiles were used to determine a bulk average temperature transient and the overall loss coefficient was evaluated by,

$$U_L = \frac{V_t \rho C_p(\bar{T}i-\bar{T}f)}{\Delta\tau(\bar{T}w-\bar{T}a)}$$

where,

U_L = Overall tank heat transfer coefficient

V_t = Volume of tank

ρ = Density

C_p = Specific heat

$\bar{T}i$ = Initial liquid bulk average temperature

$\bar{T}f$ = Final liquid bulk average temperature

$\Delta\tau$ = Time interval from initial to final conditions

8.0 ANALYSIS (Continued)

$\bar{T}w$ = Arithmetic average temperature of bulk liquid for time interval

$\bar{T}a$ = Arithmetic average ambient air temperature for time interval

TABLE I

List of Measured Parameters

Measurement	Parameter
Solar radiation	BTU/Hr/Ft^2 vs. time of day
Ambient temperature	°F vs. time of day
Wind speed/direction	MPH/direction vs. time of day
Collector inlet temperature	°F vs. time of day in hours
Collector outlet temperature	°F vs. time of day in hours
City water supply temperature	°F vs. time of day in hours
Hot water system outlet temperature (to load)	°F vs. time of day in hours
System temporary shelter temperature	°F vs. time of day in hours
Hot water flow rate to load	GPM vs. time of day in hours
Water flow rate thru collector	GPM vs. time of day in hours
System pump power	Watts vs. time of day in hours
Domestic hot water heating element power	Watts vs. time of day in hours
Temperature stratification profile in domestic hot water tank	°F vs. position in tank

TABLE II

Summary of Thermal Performance Parameters

Performance Parameter Test Date, 1977	Total Solar Energy Available, BTU	Total Energy Collected, BTU	Total Electrical Energy Used, BTU	Total Energy Supplied To Hot Water Load As Contributed By Solar, BTU	Overall System Efficiency, %
9-22	78431	35080	1920	30267	39
9-23	64075	29780	1843	18650	29
10-3	82518	39150	5344	36842	45
10-4	78962	35950	1686	37806	48
10-6	41170	10950	1703	10559	26
10-7	63775	24000	1605	25384	40
10-14	79901	36450	1755	34697	43

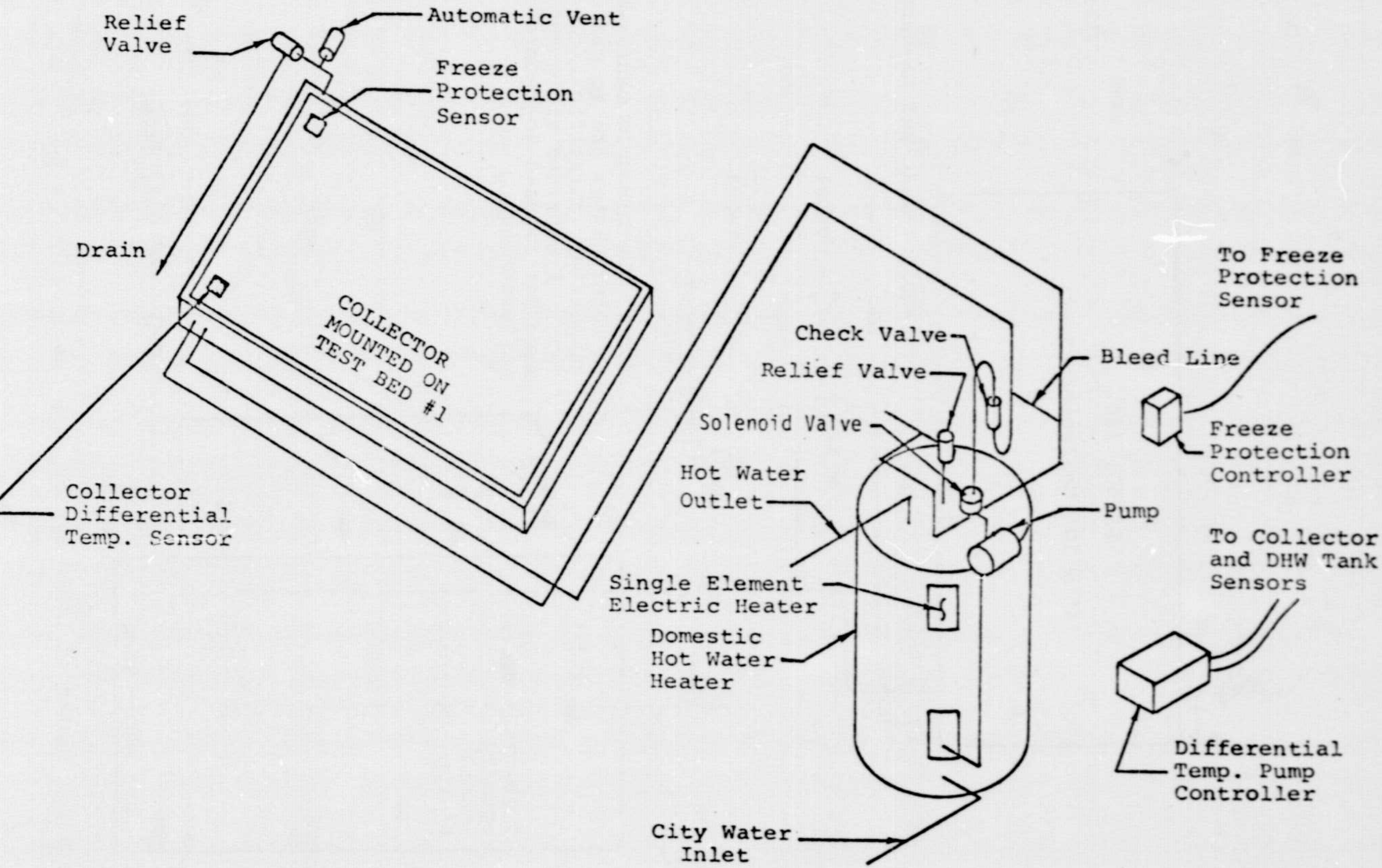

Figure 1. LARGO Solar Hot Water System Installation Schematic

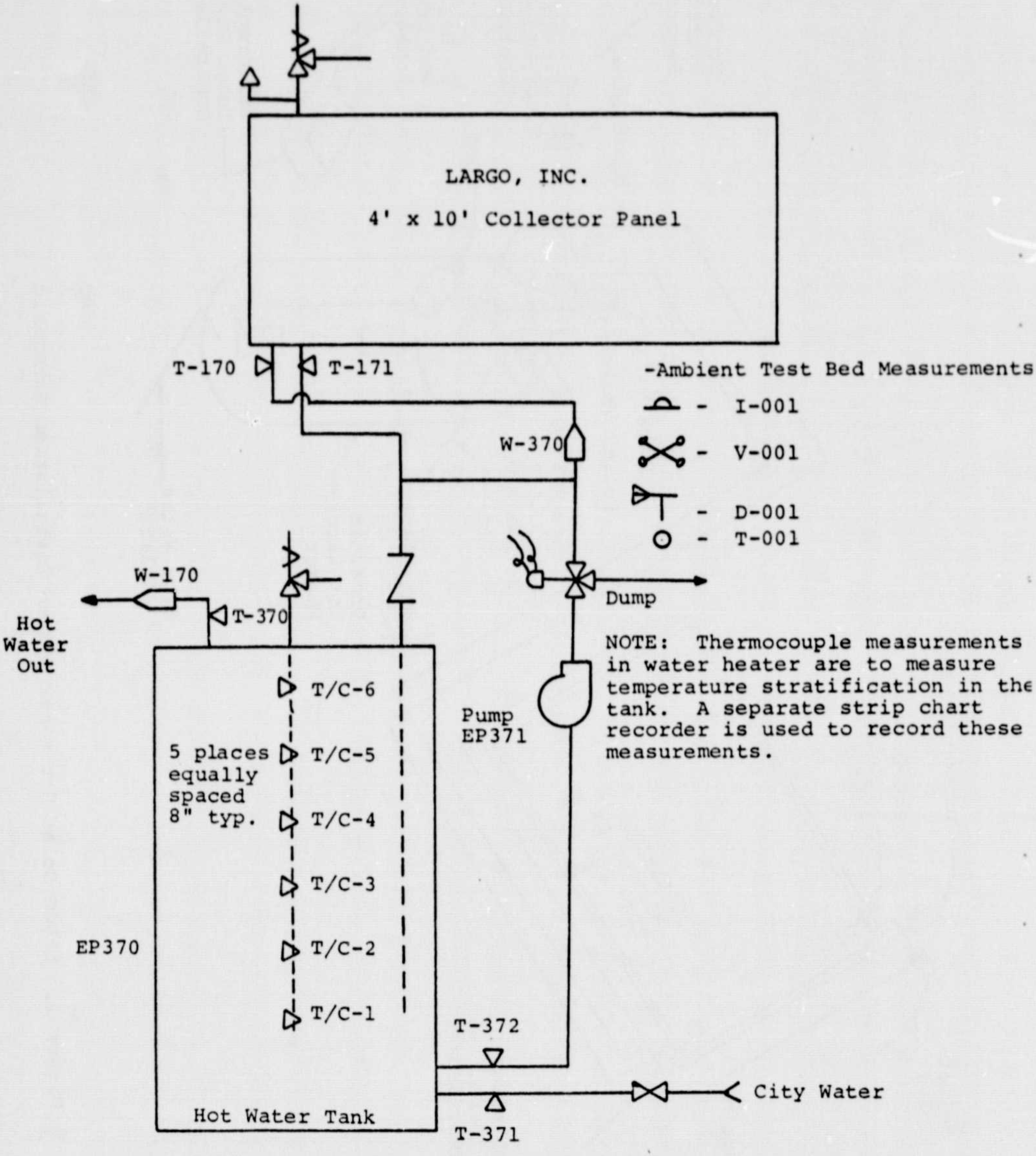

Figure 2. Sketch of LARGO System with Instrumentation Locations.

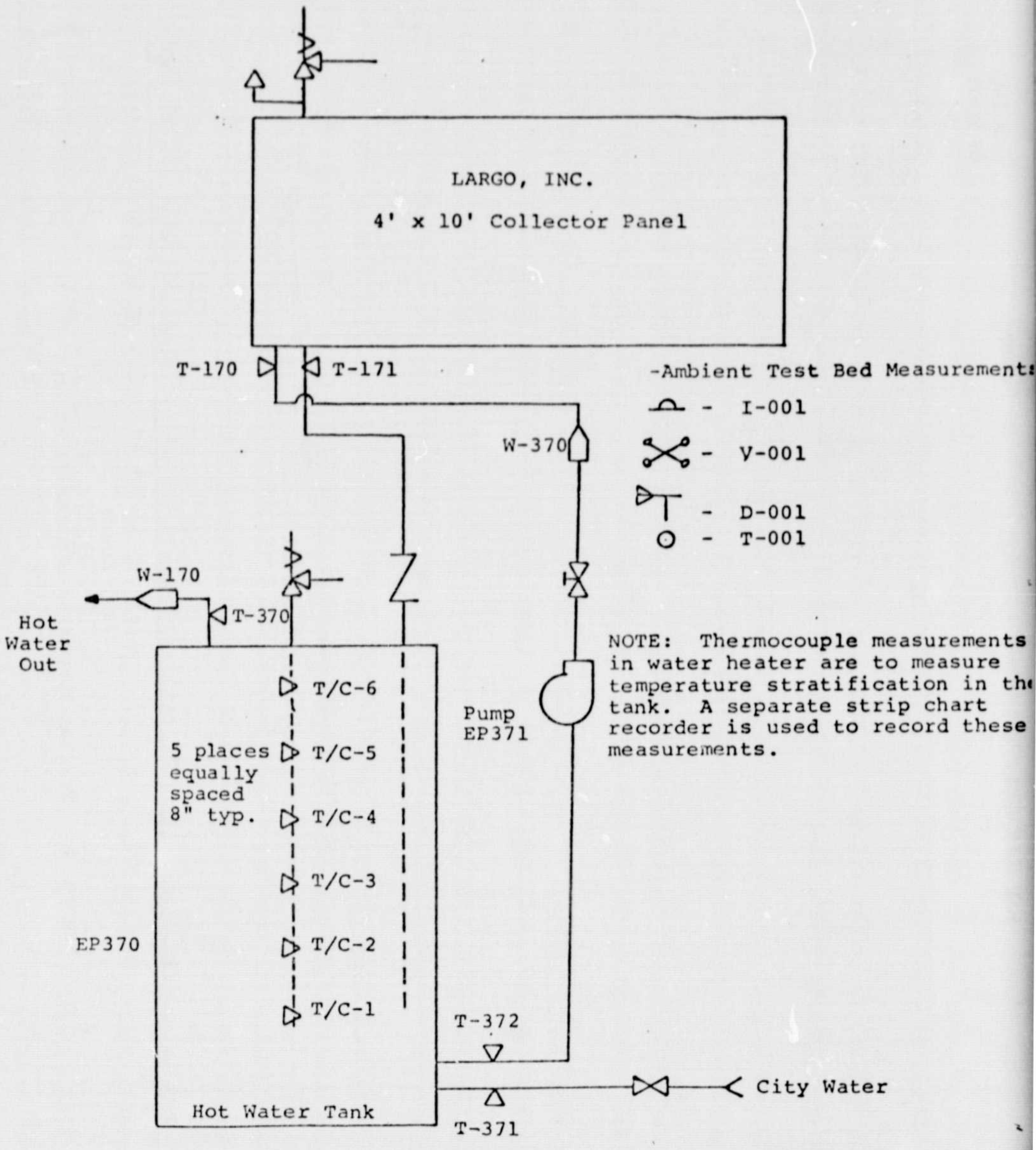

Figure 3. Sketch of Modified Piping on LARGO System with Instrumentation Locations

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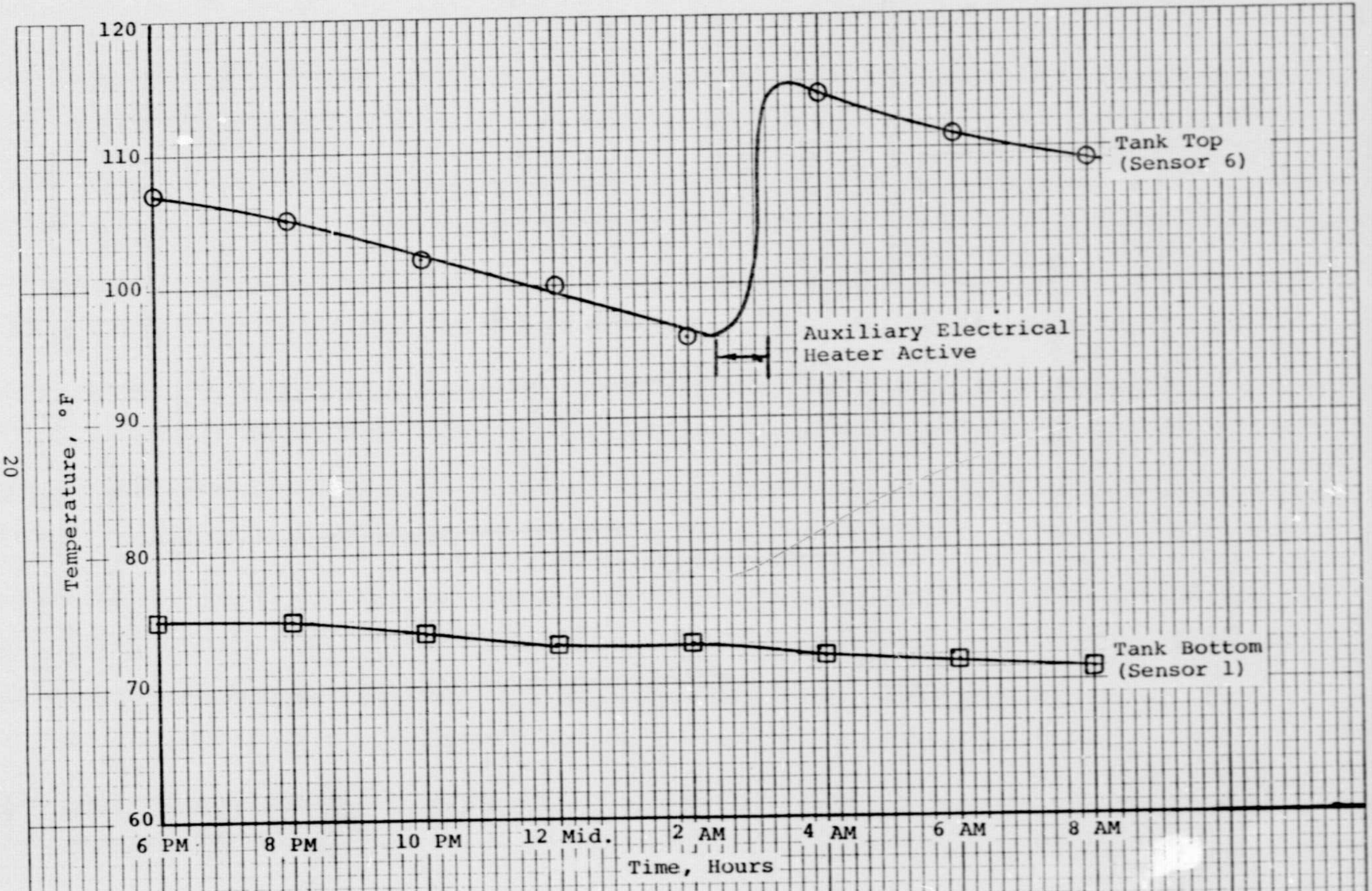

Figure 4. Typical Temperature Stratification Measurements During Overnight Storage

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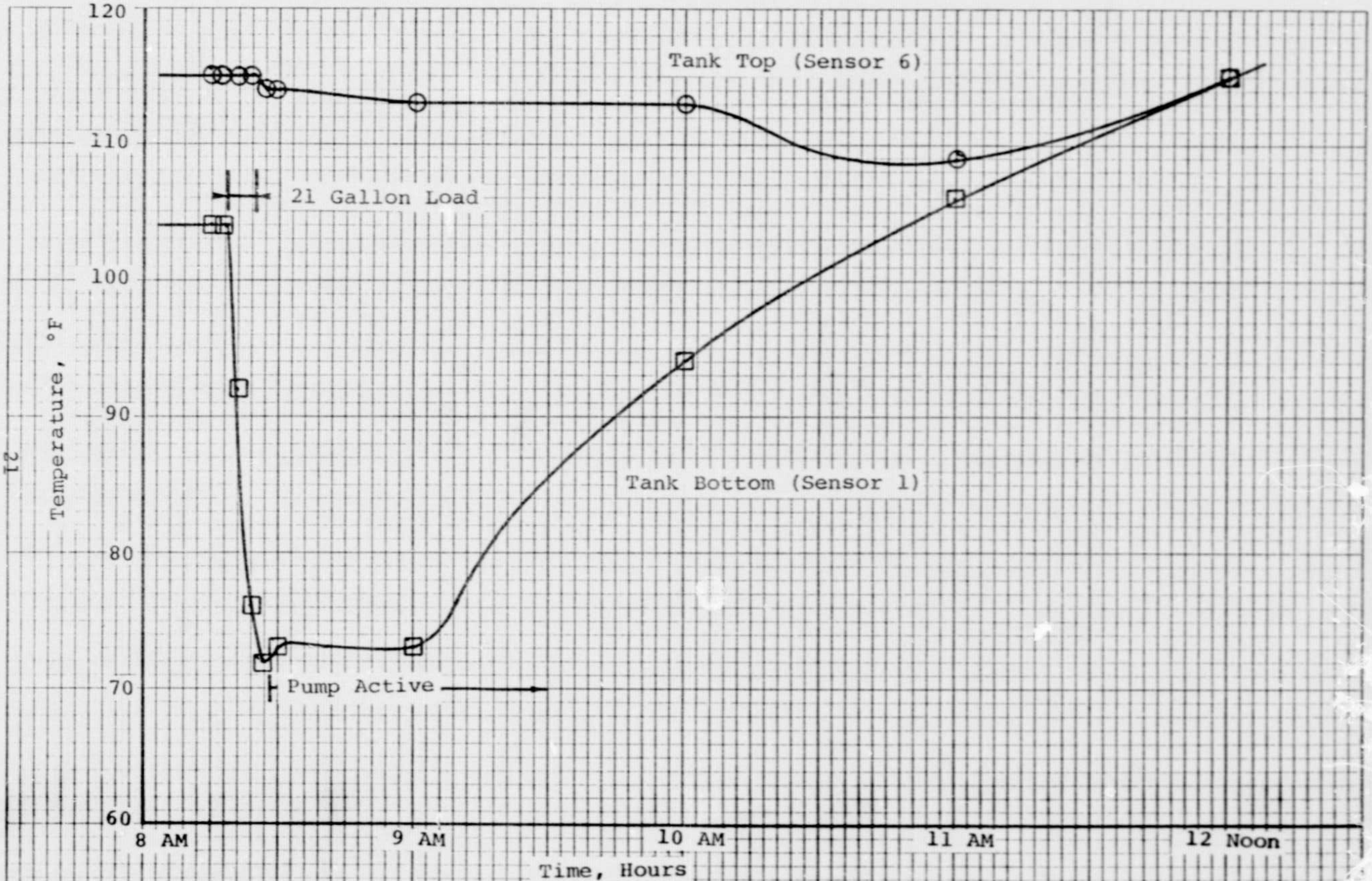

Figure 5 . Typical Temperature Stratification Measurements During System Operation (October 13, 1977)

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46 0703

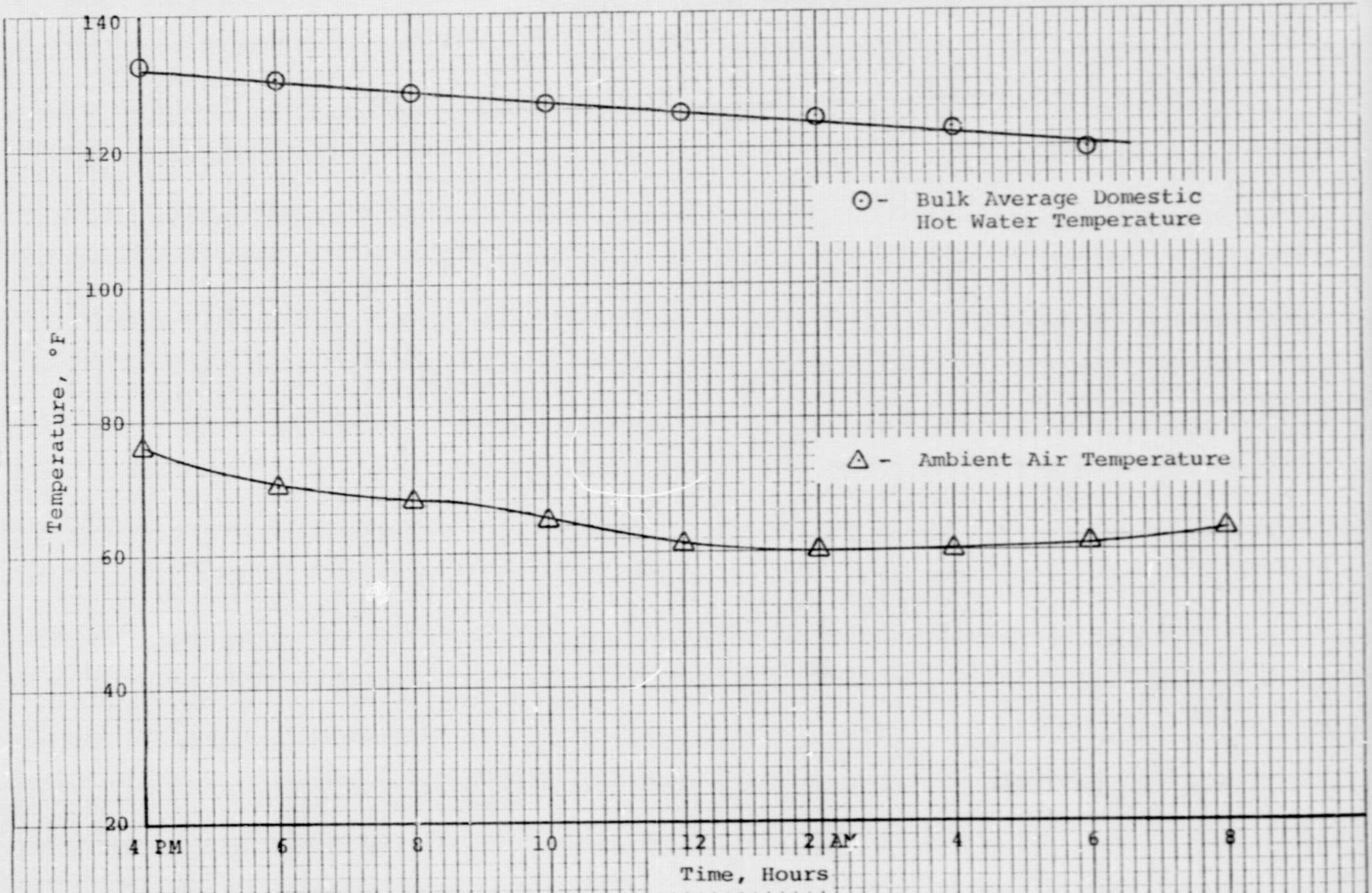
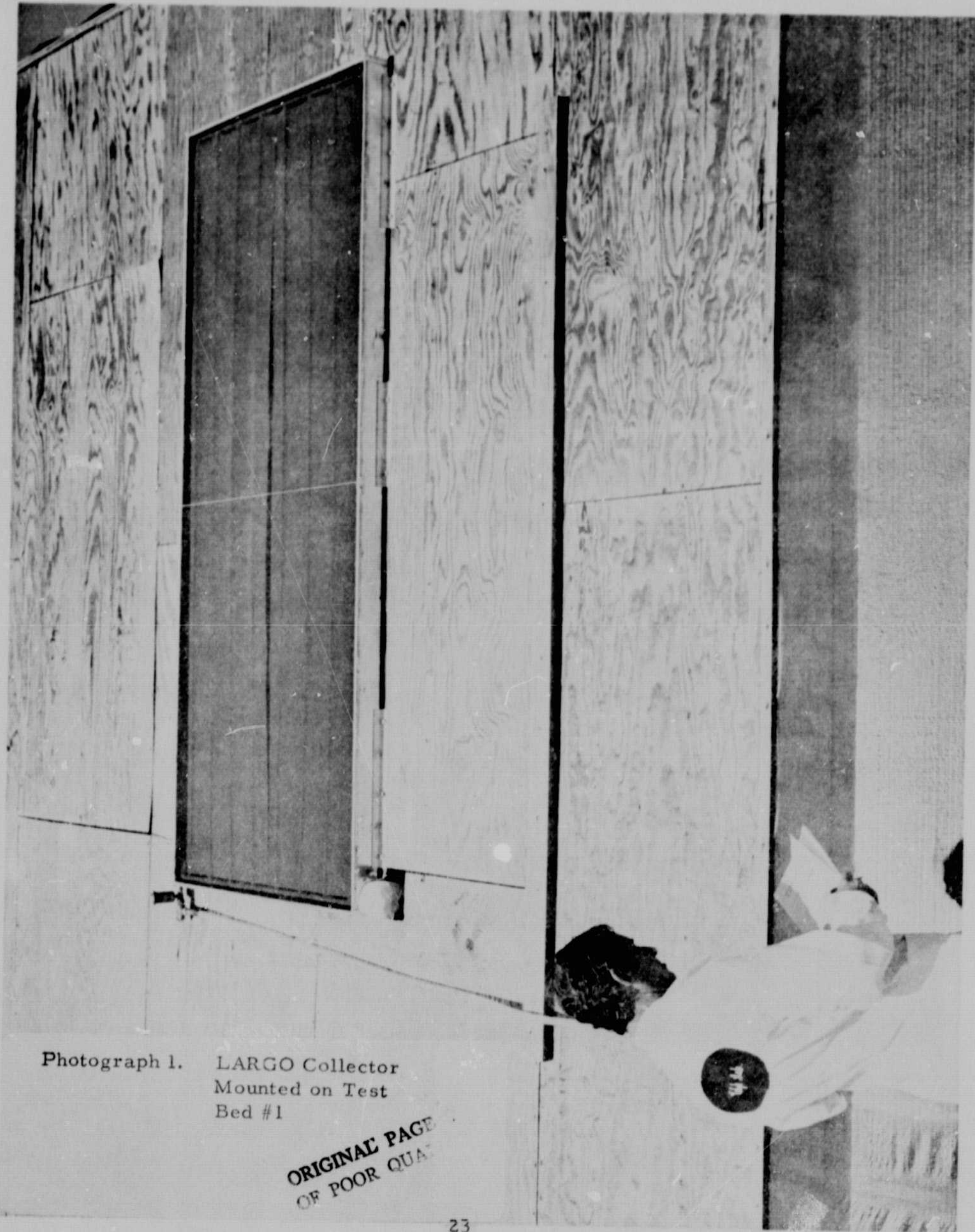


Figure 6. Plot of Measured Bulk Average Domestic Hot Water Temperature and Ambient Air Temperature Versus Time (9/28/77)



Photograph 1. LARGO Collector Mounted on Test Bed #1

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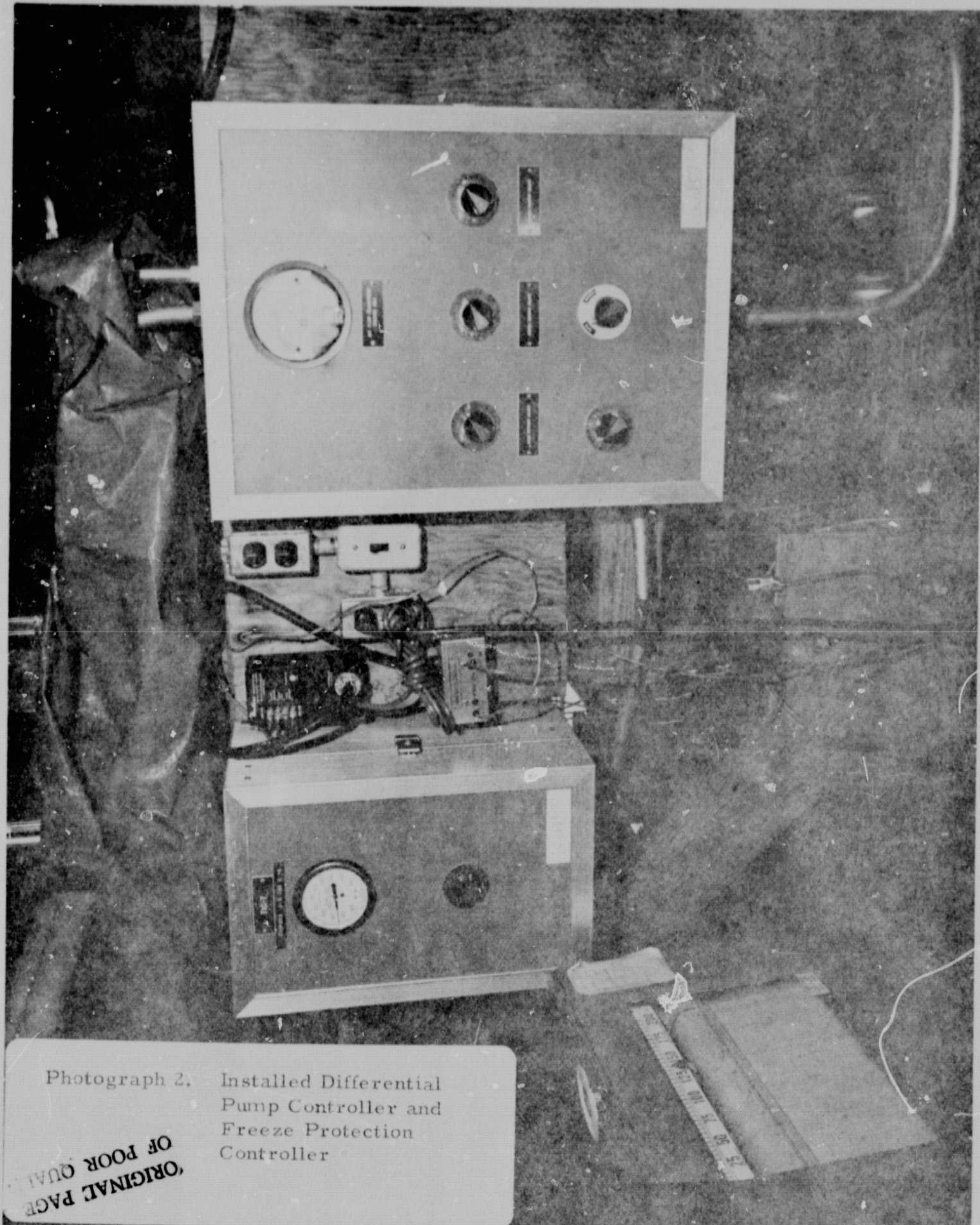

Photograph 2. Installed Differential Pump Controller and Freeze Protection Controller

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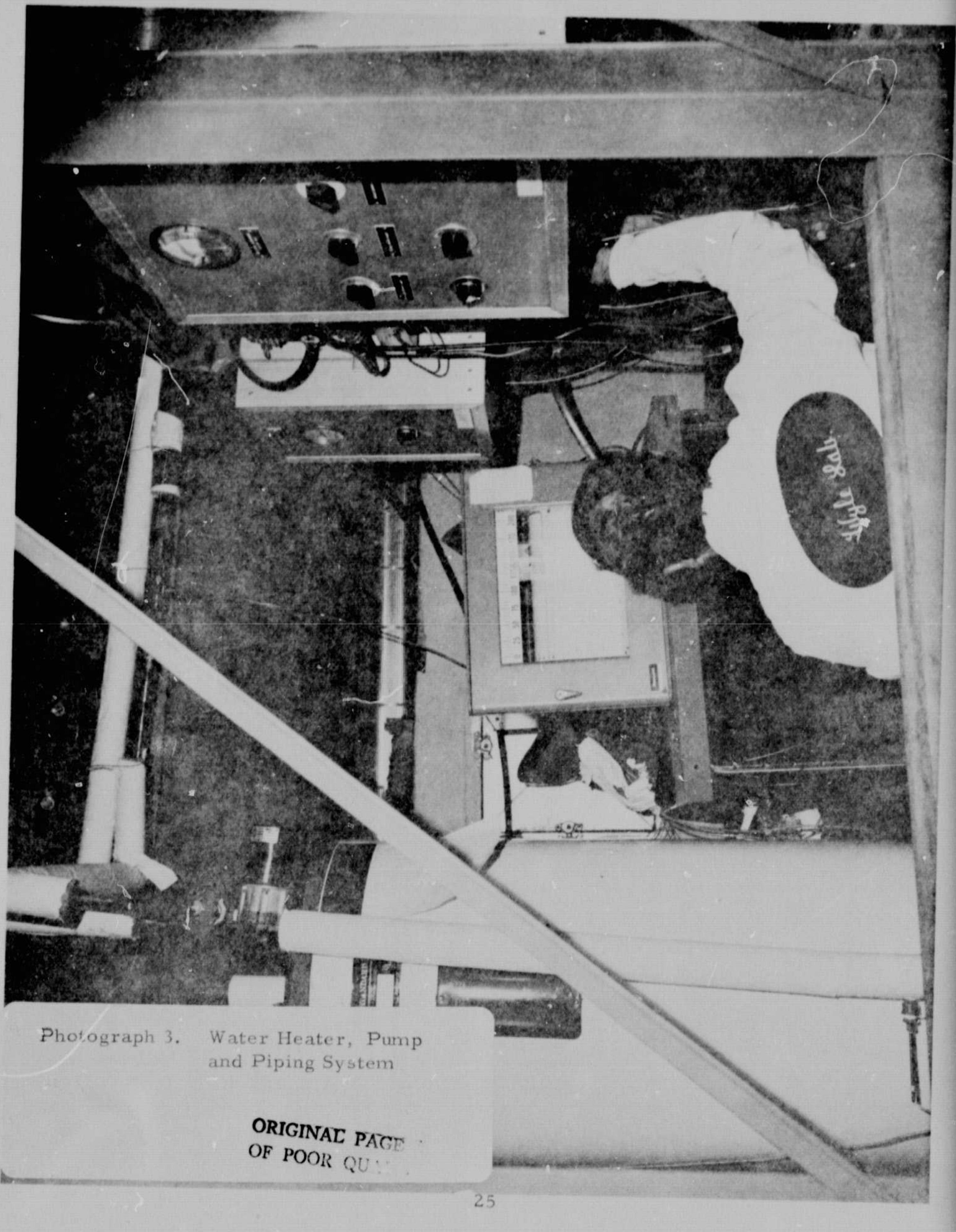

Photograph 3. Water Heater, Pump and Piping System

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APPENDIX I

LARGO SYSTEM MAGNETIC TAPE

RECORD DESCRIPTIONS

AND

DATA ACQUISITION SYSTEM BLOCK DIAGRAMS

Magnetic Tape Description

Computer magnetic tapes of data recorded in LARGO system tests will be supplied to IBM in addition to the information contained in Appendix II. A description of the DDP-224 computer log tapes is provided below:

1. 7 tracks, 556 BPI and odd parity.
2. Each file in the tape contains one day of test data. The test data are in 1201-word records for succeeding daily tests.
3. The DDP-224 computer is a 24-bit word machine. Sets of two test data are packed into one word. The first ten bits contain the raw count of the first test data, bits 13 through 22 contain the raw count of the second test data. The first of each 1201 words gives the validity and record count. The remaining 1200 words contain 2400 test data in the order of ascending number.
4. Table I-A depicts the pulse code modulation (pcm) number, the coefficient for 4th order engineering unit-raw count conversion and the title of each sensor used for M/N 1B system test.

Block Diagrams of Data Acquisition Setup

Block diagrams of the data acquisition setup are depicted in Figure I-A.

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TABLE I-A

LISTING OF INFORMATION NECESSARY TO CONVERT MAGNETIC TAPE DATA TO ENGINEERING UNITS

```
1- 3- 4
  2       0.E+00     1.E+00     0.E+00     0.E+00     0.E+00
      TIME,HR
  3       0.E+00     1.E+00     0.E+00     0.E+00     0.E+00
      TIME,MIN
149    -4.32E+00  0.36E+00     0.E+00     0.E+00     0.E+00
D001  WIND DIRECTION M/NI D001                        DEGREE
104   -7.507E+000.625E+00      0.E+00     0.E+00     0.E+00
I001  SOLAR FLUX, TOTAL M/N1 I001                     BTU/HR.FT2
 64     -1.2E+00   0.1E+00     0.E+00     0.E+00     0.E+00
RH001 REL HUMID, AIR, M/N1 OUTSIDE RH001              PERCENT
150   -0.548E+02+0.397E+00+0.462E-04+0.385E-08+0.166E-11
T001  TEMP, AIR, AMBIENT OUT SIDE T001                DEGREE F
133   -0.72         0.06
V001  VELOCITY, WIND M/N1 V001                        MPH
105   +0.578E+02+0.18 E+00+0.923E-05+0.501E-09+0.403E-13
T170  LARGO COLLECTOR INLET TEMP       T170           DEG F
290   +0.578E+02+0.18 E+00+0.923E-05+0.501E-09+0.403E-13
T171  LARGO COLLECTOR OUTLET TEMP      T171           DEG F
328   +0.578E+02+0.18 E+00+0.923E-05+0.501E-09+0.403E-13
T370  LARGO WATER OUTLET HEATER TEMP   T370           DEG F
292   -0.548E+02+0.397E+00+0.462E-04+0.385E-08+0.166E-11
T371  LARGO CITY WATER INLET TEMP      T371           DEG F
331   +0.578E+02+0.18 E+00+0.923E-05+0.501E-09+0.403E-13
T372  LARGO W/H OUTLET TO COLLECTOR    T372           DEG F
269   -.1530E+00+.127 E-01
W370  LARG COLLECTOR INLET FLOW        W370           GPM
270    -.078E+00+.6 0 E-02
W170  LARG WATER HEATER OUTLET FLOW    W170           GPM
 11   -.1200E-00+.1 00E-01
EP370 LARG WATER HEATER POWER          EP370          KW
312   -.1200E-01+.1000E-02
EP371 LARG PUMP POWER                  EP371          KW
124   +0.578E+02+0.18 E+00+0.923E-05+0.501E-09+0.403E-13
T351  TEMP PORTABLE WATER TO STOR      T351           DEG F
```

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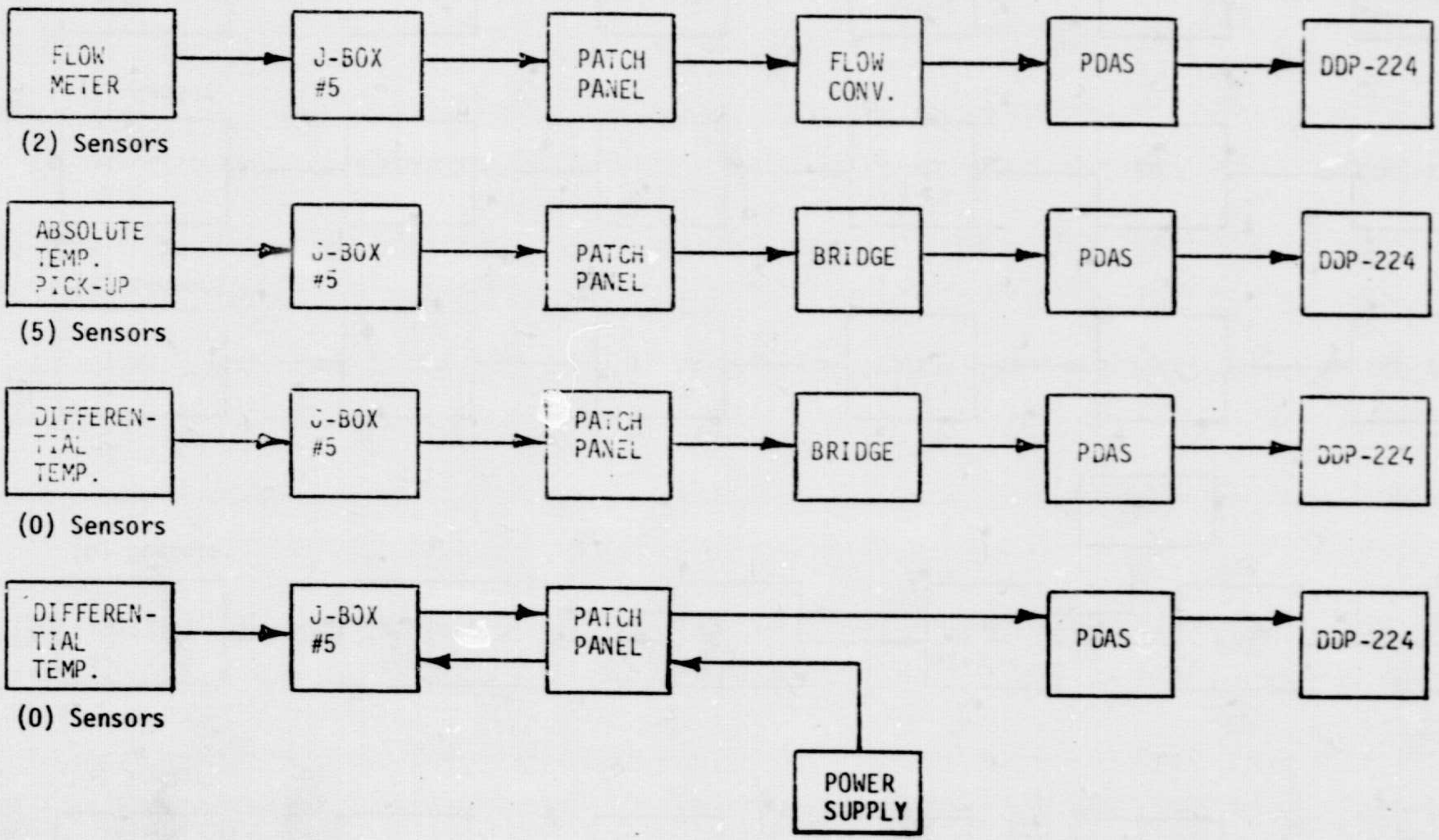

Figure 1-A. Block Diagram of Primary Data Acquisition System for LARGO System Test

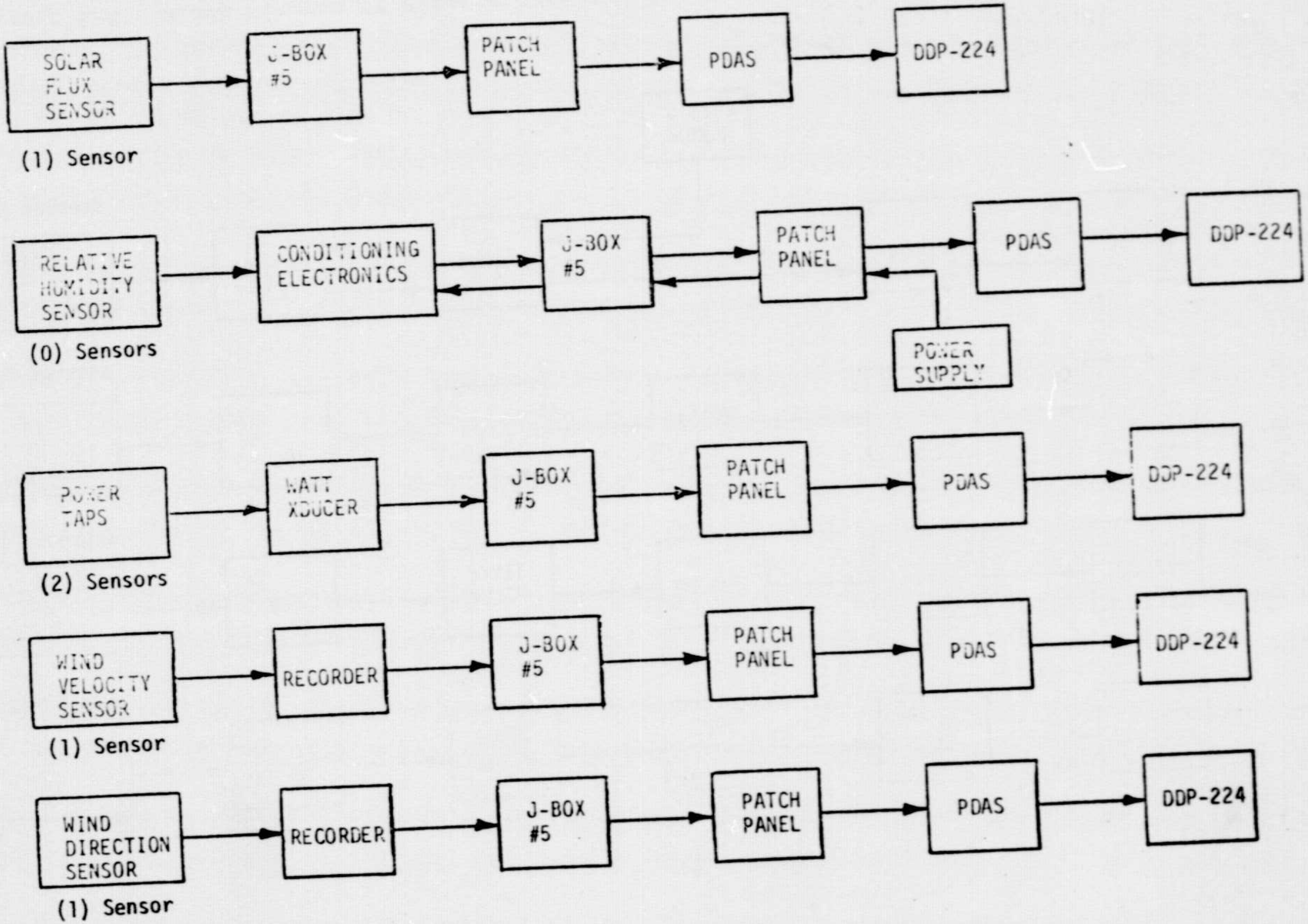

Figure 1-A (Continued)

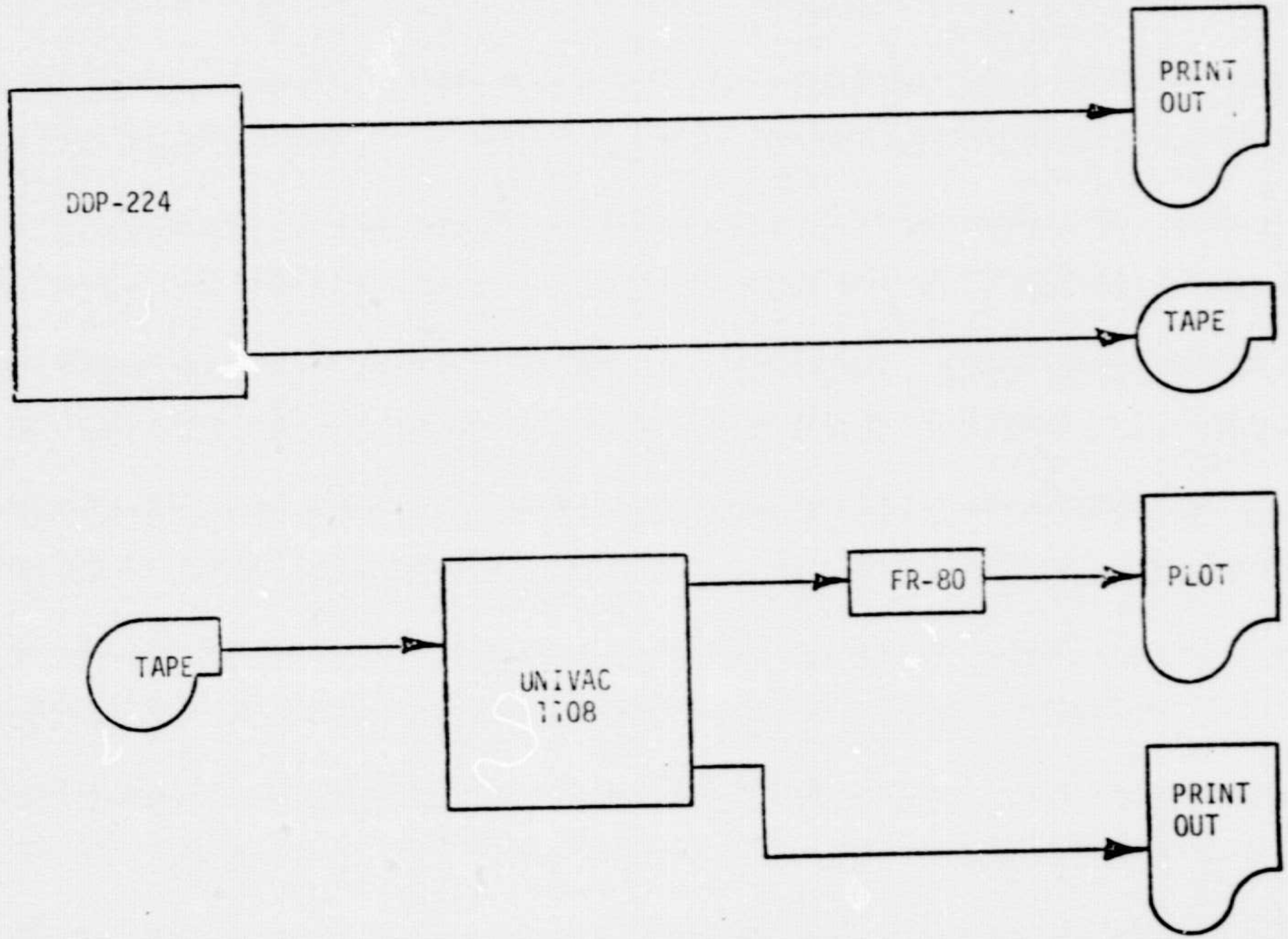

Figure 1-A (Continued)

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