NASA CR 168181

Qualification Testing of Solar Photovoltaic Powered Refrigerator Freezers for Medical Use In Remote Geographic Locations

Final Report

Contract No. DEN 3–240

William J. Kaszeta
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INTRODUCTION

The purpose of this contract was to develop photovoltaic (PV) powered refrigerator/freezer (R/F) systems for use in medical outposts in remote areas of developing countries. At present the three billion people of the less developed world suffer from a plethora of infectious diseases. Because these infections tend to flourish at the poverty level, they are important indicators of a vast state of collective ill health. The concomitant disability has an adverse effect on agricultural and industrial development, and the infant and child mortality inhibits attempts to control population growth.

Vaccination has been used extensively in developed countries over the last few decades for the prevention of a number of important communicable diseases such as poliomyelitis, small pox, diphtheria, and measles. The experiences gained in these countries are now being transferred on a gradually increasing scale to the developing world. However, the application of vaccination in developing countries has met with a number of problems of an economic, operational, and technological nature. One of the main problems consists in the refrigerated storage and transportation of vaccines, the so called "cold-chain". The cold chain is a system for distributing vaccines in the potent state from the manufacturer to the actual vaccination site. Vaccines exposed to elevated temperatures suffer a permanent loss of potency. To remain efficacious most vaccines must be maintained during storage and transport at 4 to 8 degrees centrigrade. For the more sensitive polio and measles vaccines, a -20° centrigrade temperature is recommended for extended storage times.

The available technical solutions to the problem of maintaining the cold chain are mainly based on the presumption that there is a steady supply of electric power, which is frequently not the case in developing countries. The problem is more serious for these countries in that (1) many of them have a hot tropical climate and (2) much of the cold chain equipment produced in developed countries is unsuitable for tropical countries.

The development of effective PV powered R/F units, to be used as peripheral units in the cold chain, is seen by the World Health Organization (WHO) and the Centers for Disease Control (CDC) (U.S. Department of Health and Human Services) as vital to the success of immunization programs in the developing countries. At present 75% of the population that is to be reached by the immunization programs are in areas not served by reliable refrigeration. Dr. Stanley O. Foster, CDC, has estimated that 30,000 refrigeration units will be needed in the next 5 years to support present programs in remote areas where no reliable commercial power supply is available. PV powered R/F units could fulfill this need for remote refrigeration of vaccines.

This report covers the performance measurements of PV powered R/F units tested by Solavolt International under contract DEN 3-240 for the National Aeronautics and Space Administration (NASA), Lewis Research Center (LeRC), Cleveland, Ohio. Two different models of PV

powered R/F units for medical use were tested: module WSR 12-1 from Western Solar Refrigeration, Inc., San Diego, CA (Serial # 04-125), and a model RR-2 from Polar Products, Los Angeles, CA (no serial #).

The requirements for these R/F units have been established as:

- The R/F unit shall be a top opening chest type unit.
- The R/F unit, the compressor/motor/condenser, battery complement, controls, regulator and instrumentation shall be assembled as an integral unit.
- The R/F assembly shall be packaged to provide maximum personnel safety. The design of enclosures and arrangement of components shall provide good ventilation of the battery compartment and compressor, and ease of servicing.
- The compressor motor shall be a DC type and operate at a nominal 12 volts.
- The dimensions of the R/F assembly shall conform to the following:

  - Total maximum height of assembly: 100 cm
  - Total usable storage volume: minimum 60 liters
    maximum 100 liters
  - Freezer compartment usable volume: minimum 20 liters
    maximum 1/3 total R/F volume

- The materials used for the R/F inner and outer liner jackets shall be durable, easily cleaned, and resistant to deteriation from exposure to foods and vaccines. The inner and outer R/F liners shall be sealed together to minimize moisture penetration due to atmospheric and/or temperature induced vapor pressure differences between the environment and the insulation cavity.
- The material for insulation shall be foamed in place polyurethane type and shall be of sufficient thickness to provide adequeate cold retention, minimize compressor energy requirements, and, in general, provide the greatest overall system economic benefit.
- The R/F units shall have a single outer lid which is hinged, self-closing and lockable. The outer lid gasket shall be capable of withstanding normal medical use and provide the necessary sealing to minimize heat leaks.
- The R/F units shall have separate interior lids for the freezer and refrigerator compartments. The interior lids shall be hinged and designed to reduce heat transfer between the compartments and the outer lid.

The Performance Requirements for the refrigerator/freezer are:

- With the R/F unit empty and the complete assembly stablized in a 43°C ambient environment, the assembly shall be capable of achieving refrigerator compartment temperatures in the range of 4° to 8°C (for refrigerator compartment temperature sensing locations given in Figure 1) within 24 hours after compressor startup.

- The R/F unit shall be capable of continuously maintaining refrigerator compartment temperatures in the range of 4° to 8° C (per temperature sensing locations given in Figures 2 and 3) when the refrigerator compartment is filled with a uniformly distributed water load in the ratio of 1/3 liter liquid per liter of refrigerator compartment volume, with an empty freezer compartment, and with the complete R/F assembly in a 43°C environment. Further, the R/F unit shall be capable of meeting this requirement with 70% or less compressor run (on) time.

- The R/F unit shall be capable of freezing a minimum of 2 kg of water every 24 hours with the initial water temperature being 43°C and with the R/F unit operating in a stable cycling mode in a 43°C ambient environment. (See Figure 4)

A full manufacturers description of the R/F units tested is contained in Appendices C and D. The testing established that these two refrigerators can meet the operational requirements but require differing amounts of current (expressed in ampere-hours per day) to maintain proper internal temperatures. This data is summarized in tables contained in Appendices A and B. All temperatures given in this report are in degrees centrigrade.

Both R/F units utilize the same Danfoss Model BD2.5 compressor. The WSR uses a single compressor to cool the freezer and eutectic plate, cooling of the refrigerator section is by means of cold air from the freezer controlled by an air door. The Polar Products R/F unit utilizes two compressors, refrigerator and freezer, with separate controls. Either section could be shut down if not required, but switches to do such are not provided.

The Danfoss compressor is of a hermetic design with an AC motor driven by a 12 volt inverter and has been in use for about 8 years.

TESTING PROGRAM

Initial testing was started on April 22, 1981 following issuance of a contract by NASA-LeRC for Motorola Solar Energy Systems, Inc. and Western Solar, Inc. to jointly manufacture and test a PV powered medical R/F unit in accordance with specifications and requirements established by CDC and NASA, LeRC. The initial testing of the Western Solar R/F unit showed that it did not meet the established performance requirements and the contract was suspended temporarily. Western Solar modified the operation of their R/F unit and satisfied Motorola that the revisions would enable the R/F unit to pass the tests. The major modification was to add a small fan in the refrigerator section to provide circulation while the compressor was running. Motorola had also contactd Polar Products, a R/F manufacturer who had submitted a technically acceptable proposal to the NASA-LeRC RFP in conjuction with another photovoltaic manufacturer who withdrew during contract negotiations. The Polar Products R/F unit when tested for Motorola indicated a good potential for inclusion in the existing contract. Permisson was given to Motorola to test the revised Western Solar R/F and the Polar Products R/F as part of the existing contract.

On October 1, 1981 Motorola Solar Energy Systems, Inc. (a subsidiary of Motorola, Inc.) and SES, Inc. (a subsidiary of Shell Oil Company) formed Solavolt International as a partnership. The Silicon Division of Solavolt assumed all operations and personnel of Motorola Solar Energy Systems including the R/F contract from NASA-LeRC.

In December of 1981 contract work was resumed on the two PV powered R/F units, and was completed on June 6, 1982.

As initially conceived, the testing would consist of two phases.

QUALIFICATION AND ACCEPTANCE

The qualification series of tests were to determine if the selected R/F units were capable of meeting the stated performance and design requirements. The acceptance test was designed to be performed on successive units to establish that their performance was within acceptable limits of the unit subjected to the qualification testing.

During an early June 1982 progress review meeting with NASA-LeRC, an analysis of the power requirements verses ambient temperatures for the two designs indicated the need for additional test data. To augment the data it was agreed to extend the testing to fully loaded refrigerators at 21° and 32°C to determine the average current after stablilization at these temperatures. Collection of this data permits establishing both the loaded and unloaded current requirements for both units as a function of temperature. This information is necessary for proper design of the photovoltaic systems used to power the R/F units in various locations. All of the data taken with the R/F units loaded was taken with the units operating from a battery whose voltage was fixed at 12.0 +/- 0.1 volts by a power supply while the acceptance data was taken from actual array operation of the units.

TEST EQUIPMENT

The testing program utilized the environmental test facility located at the Motorola Government Electronics Group (GEG) facility in Scottsdale, AZ along with a Solavolt supplied data acquisition system. A large GEG Thermotron environmental chamber with 48 in. x 72 in. x 54 in. inside dimensions was used as it is capable of holding both refrigerators at one time. The standard test facility controls and procedures, maintained for MIL-STD testing, were used to provide the specified environment. The data acquisition system consists of a HP-3497A datalogger controlled by an Apple II computer, storing the data on standard Apple minifloppy disks. (See Figures 5 and 6)

Temperature data was taken using thermocouples sheathed in 1/8 inch stainless steel tubing. Fifteen foot long leads of 30 gauge thermocouple wire were used for connection to the datalogger. In order to maintain a good seal and avoid damage to the refrigerators the thermocouple leads were carefully spread out along the R/F edge and taped in place. In order to properly position freezer and empty refrigerator thermocouples, replacement inner lids were fabricated containing 1/8 inch holes to hold the thermocouple sheaths in position. Where surface temperatures were measured, thermal contact was ensured by use of 3M thermal paste. The placement of the thermocouples was as described later in the test requirements.

Figure 5 shows the general schematic for wiring used in the qualification testing. Voltages were measured for each refrigerator by the datalogger as shown in Figure 5. For the Polar Products refrigerator the use of two compressors necessitated the use of two additional current shunts in order to measure the current of each compressor individually. Array currents were measured using the shunt in the Curtis Instruments package. Shunt precision was 0.1%. The shunts introduced a maximum of 25 millivolts error.

The measurement sequence was controlled by a Basic program on the Apple II computer. During a test the Apple II checks the time as maintained by a clock in the datalogger and when the time equals or exceeds the time stored for the next reading a sub-routine is executed. The Apple II then interrogates the datalogger to measure each active channel and transmit the raw readings to the Apple II. For temperatures the datalogger supplies a millivolt reading that is converted into temperature by the Apple II. From the input data the Apple II computes the currents, voltages, insolation and temperatures along with the elasped time and appends the data to individual channel files on the disk. The Apple II also makes a printed copy of the processed data as required, usually 2 or 3 times an hour.

The currents measured by the data system were integrated and used in the calculation of the average current required. Ampere-hour instrumentation was used as a check on the digital data system. The analog current meters on the R/F units indicated the same currents and short term variations as the data system. No analog meter readings were recorded. Compressor currents as high as 7 amperes were indicated during pull downs.

QUALIFICATION TESTING

The qualification testing consisted of four major procedures:

(1) No-load pull down

(2) Ice making

(3) Steady-state (maintenance)

(4) Holdover

These tests are performed at 43°C and utilize a battery/power supply for current. The voltage is held at 12 +/- 0.1 volts. The units are empty for the first two tests and contain bottles of water for the last two tests.

PULL DOWN TEST

The no-load pull down test was performed from 12/10/81 to 12/12/81 for both refrigerators at the same time. For this test the empty refrigerators were stablized at 43° until all thermocouples were within one degree of the target temperature. The "cold/normal" switch was "on" on the WSR for this test. The thermostats on the Polar Products R/F unit were not by-passed.

RESULTS

	Polar Products	WSR
Hours to reach 5° in refrigerator	0.9	22.5
Amp-hours to reach 5° in refrigerator	11.64	144.0
Hours to reach -15° in the freezer	1.7	(1)
Amp-hours to reach -15° in the freezer	17.54	(1)

(1) Never reached.

Plots of the average currents and temperatures are contained in Appendix A for the Polar Products R/F and in Appendix B for the WSR R/F.

The WSR R/F unit requires a longer pull down due to the use of a cold storage eutectic plate. This thermal storage increases the holdover storage time and increases the cycle time. Energy used to cool the unit in pulldown is thus stored in the eutectic plate.

ICE MAKING

For the ice making test each freezer compartment was loaded with 6 plastic flasks called "cold dogs", each containing 350 ml. for a total of 2.1 kilograms of water. The bottles were placed in two rows of 3, one row on top of the other in the WSR, and side by side in the Polar Products (See Fig. 4). The WHO requirement is to freeze at least two kilograms of water in 24 hours, starting with 43° water. Both units under test passed this requirement. Two bottles in each refrigerator (center top and front bottom in the WSR and the two center bottles in the Polar Products, See Fig. 4) were monitored with thermocouples during the test. After 24 hours the refrigerators were opened and all bottles were found to be hard frozen. An analysis of the temperature data indicates that the Polar Products R/F required 8 hours to freeze one center bottle and 10 hours for the other. Likewise the WSR required 10.5 and 20 hours for similar results.

MAINTENANCE TEST

For the maintenance test the refrigerators were loaded with 191 vaccine bottles (two trays of 64 and one tray of 63, See Figures 2 and 3) each containing 30 cc of water. This is the maximum that will fit in these units when the bottles are in the trays from original cases. Thermocouples were placed in the corner bottles (8) and in the middle and top center bottles for a total of 10 thermocouples. Care was taken that the thermocouples did not touch the sides of the bottles. In addition, 3 freezer temperatures, ambient top and rear temperatures, compressor current(s) and voltage were monitored. For the Polar Products both compressors were separately monitored and both the refrigerator and freezer plates were equipped with thermocouples. The WSR eutectic plate was also monitored.

Prior to the start of testing the warm bottles were first preconditioned to the required 4° to 8° range using the R/F units. Minor adjustment of the Polar Products R/F unit control set point had to be made to maintain this temperature range prior to start of testing. This setting of the thermostat was not changed for the duration of the testing. In a like manner the WSR required adjustment of the air door in order to bring all bottles into the acceptable range. The plots in Appendices A and B show that all bottles remained in the desired temperature range.

HOLDOVER TEST

Following the first maintenance test at 43°, the refrigerators were turned off and the temperatures monitored for an additional 48 hours to determine the warm up rate for each refrigerator when loaded. This temperature data is contained in Appendices A and B.

ACCEPTANCE TESTING

For the acceptance testing the test set-up was changed such that the R/F units were operated from a PV system. This necessitated measurement of array currents and insolation during the tests. The test set up was rewired as shown in Figure 6.

Two photovoltaic arrays, each consisting of 5 Motorola MSP43A40 40 watt modules wired in parallel, were installed on the facility roof directly above the environmental chamber. Each array was connected to the system with 25 feet of #6 gauge cable. The array was facing due south and inclined at 22° from the horizontal for the April/June test series. An Eppley model PSP Pyranometer (serial #13644F3) was mounted coplainar with the array and connected to the datalogger with shielded cable. Each array was connected to a Solavolt model MSR12S10 voltage regulator and a set of batteries in the chamber.

Three Delco model 2000 batteries (new) were used with the Polar Products refrigerator and four with the WSR refrigerator. The number of batteries was chosen to meet the requirement that the batteries fit within the R/F unit. Due to very high insolation during the April/May tests, the batteries reached full charge every day and the array current was then limited by the voltage regulators.

The acceptance testing was performed on each R/F unit at 43°, 32° and 21° C with the R/F units operating from a photovoltaic system. The 43° C testing utilized a photovoltaic system consisting of ten 40 watt photovoltaic modules and two voltage regulators, requiring separate test runs on the R/F units. For the 32° and 21° testing each R/F unit was operated from a photovoltaic system consisting of five modules and one voltage regulator with the units tested simultaneously. For this test the R/F units were thermally stablized at the selected ambient prior to starting the test.

The acceptance testing was performed with both of the compartments empty. Thermocouples were placed at top, center and bottom of both the freezer and refrigerator compartments. Testing was continued until each unit had reached stable cycling conditions for at least 3 compressor cycles. Plots were made of the measured parameters and used for calculating the results tabularized in Appendices A and B.

LOADED MAINTENANCE TESTING

In order to determine the power consumption of the R/F units when fully loaded, two additional test runs were made on each unit. The R/F units were reloaded with the vaccine bottles used in the earlier maintenance and holdover tests and were run in both 32° and 21° C ambients until three stable compressor cycles were obtained. No adjustments were made to the controls on the R/F units. Temperatures and currents were monitored and plotted. The R/F units were operated off a 12.0 volt power supply that was buffered by a battery. Fixed voltage operation was chosen so that the data obtained could be directly compared with 43° ambient data taken in the qualification testing.

Collection of this data indicated some differences in the operation of the two R/F units. The WSR R/F unit consumed additional current when loaded as compared to the data collected at the same temperatures in the unloaded acceptance tests. In comparison the Polar Products R/F unit consumed less current when loaded as compared to the unloaded acceptance data. This data is presented in the tables of calculated data in Appendices A and B.

COMMENTS

The samples of both R/F units met the design goals set forth in the WHO requirements in the introduction. However, the refrigerator manufacturer made minor changes in their units with such changes being reported to and approved by NASA/LeRC. Neither unit utilized hinges on the inner lids, the Polar Products unit did not have lockable outer lid latches, and the freezer volume of the WSR box is 17.6 liters.

In several cases the ambient temperature as measured at the rear or top of the unit under test appears to increase out of specification (nominal +/- 1°) while the compressor is running. This was found to be due to the local heating caused by the compressor/condenser. A check of a separate record of chamber temperature for 43° C acceptance tests showed that the overall chamber temperature was within 1/2° F (1/4° C) and steady during test. Air flow in this chamber is from top to bottom, with measurement for control being taken on the air leaving the chamber at the bottom.

The high thermal mass in the eutectic plate of the WSR R/F represents a time constant of 1-2 days. For high precision measurements a test should allow at least 3 time constants for stablization. Data collected by WSR indicates that the slightly higher current consumption measured on the WSR R/F when loaded was due to the lack of full stablization.

The relatively rapid cycling rate of the Polar Products unit indicates that improvements in the control settings to increase the differential would improve performance. At the point this became known, adjustments were not made as it was deemed preferable to maintain testing continuity.

CALCULATIONS

Pages A-3 and B-3 summarize the data taken in the testing. The data for "Full" R/F units is taken from the plots of maintenance data gathered during qualification testing for the 43° data and from the 32° and 21° loaded maintenance tests for their respective temperatures. The "Empty" data are taken from the 3 acceptance tests. The duty cycles were calculated directly from the stored digital data. The differentials are taken from the temperature plots under steady cycling conditions. The "Full" data is taken at 12.0 +/- 0.1 volts while this "Empty" data is taken during operation from an array.

CONCLUSIONS

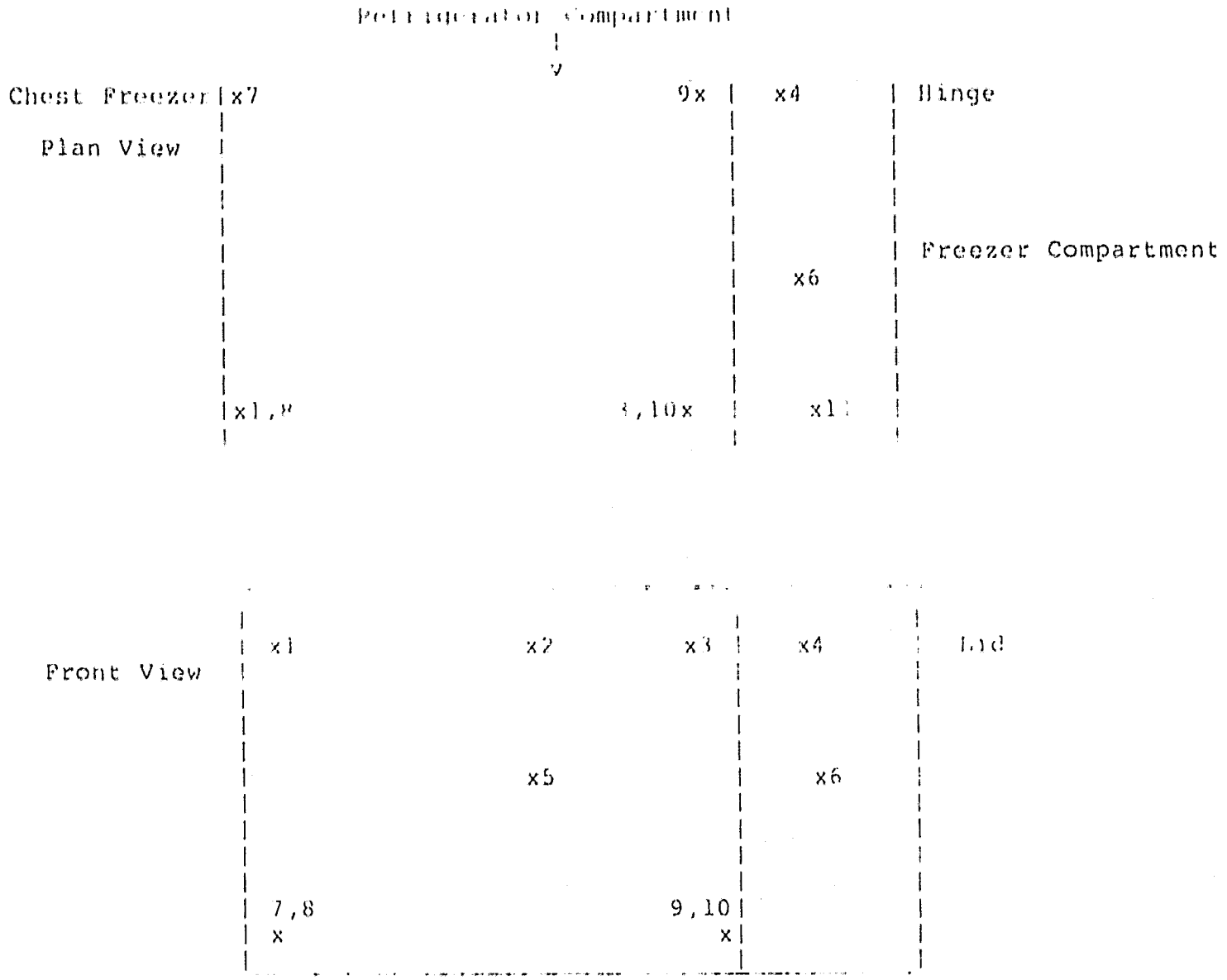
1. Both R/F units meet the major WHO requirements.

2. Both R/F units have essentially the same full-load current consumption. Although the Polar Products R/F unit does require more current in an unloaded condition, this condition is not applicable to real usage.

3. The dual compressor design of the Polar Products R/F unit evaluated offers some potential increase in reliability.

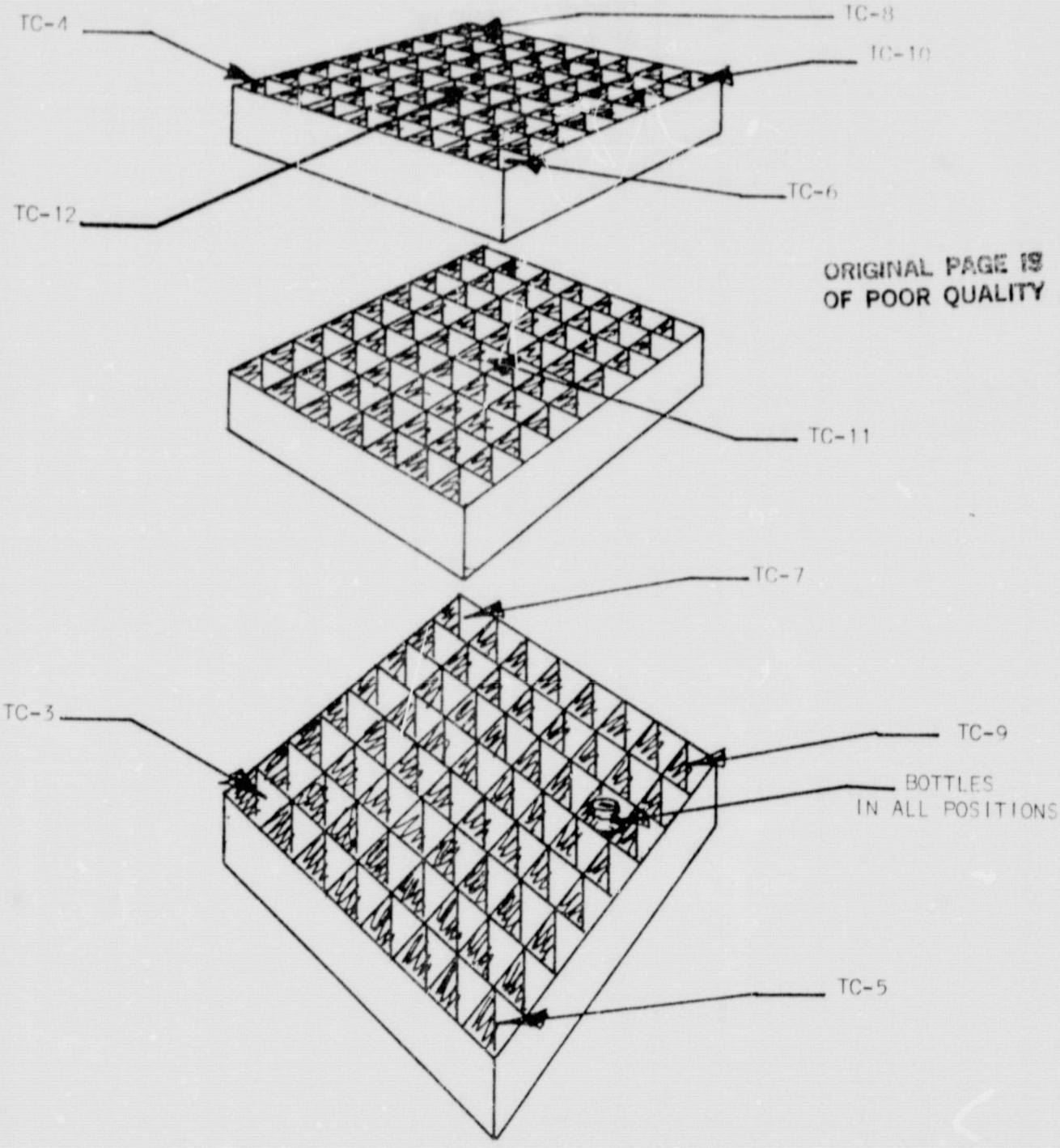
4. The eutectic cell utilized in the WSR R/F unit has experienced some problems but WSR seems to have taken corrective action to minimize these problems on future units.

5. The testing performed does not provide complete characterization of the R/F units. There appears to be some effect of voltage on current consumption and the partial load performance was not evaulated. Further characterization of these would require extensive additional testing.



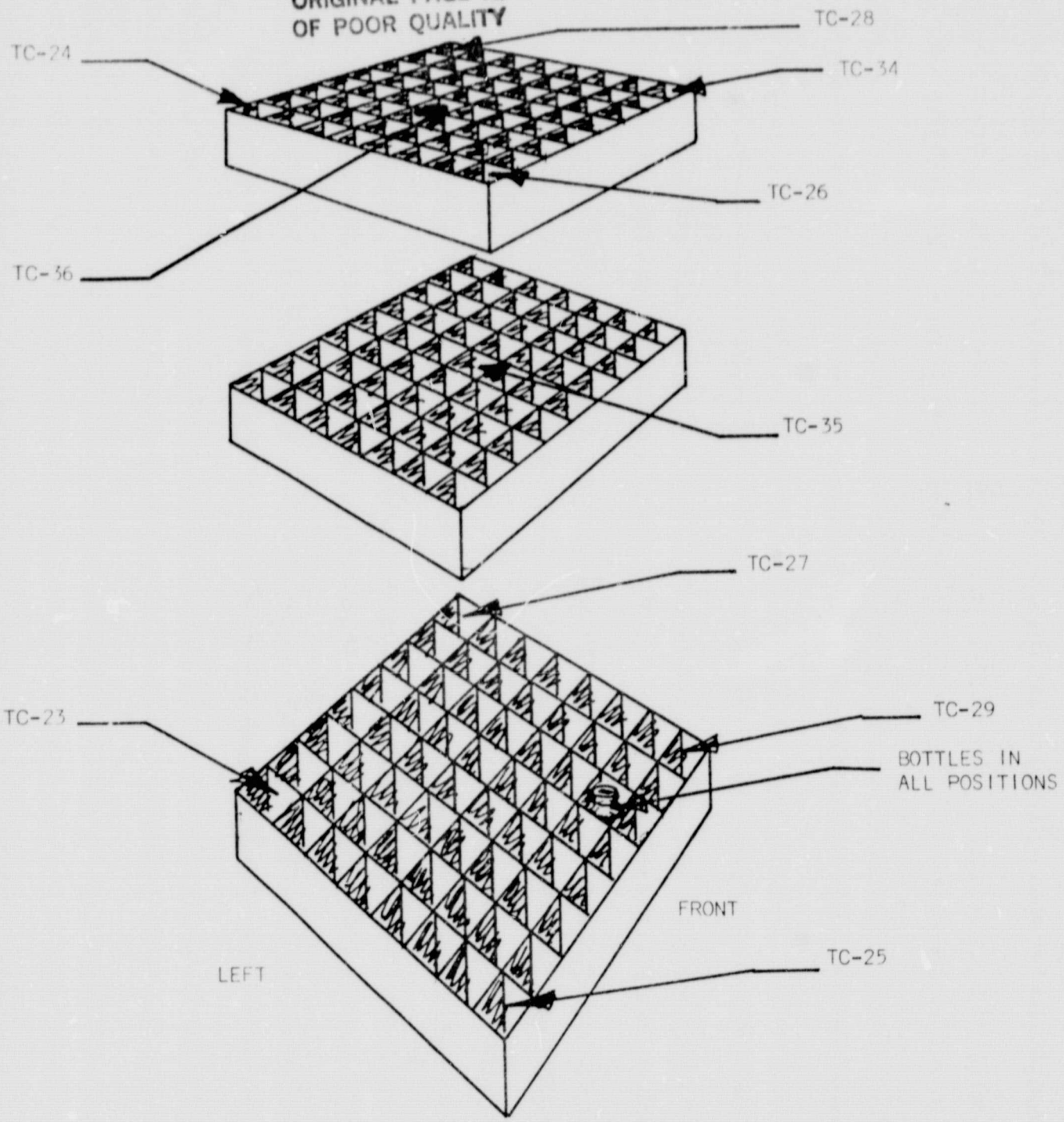
TEMPERATURE SENSING LOCATIONS

Fig. 1



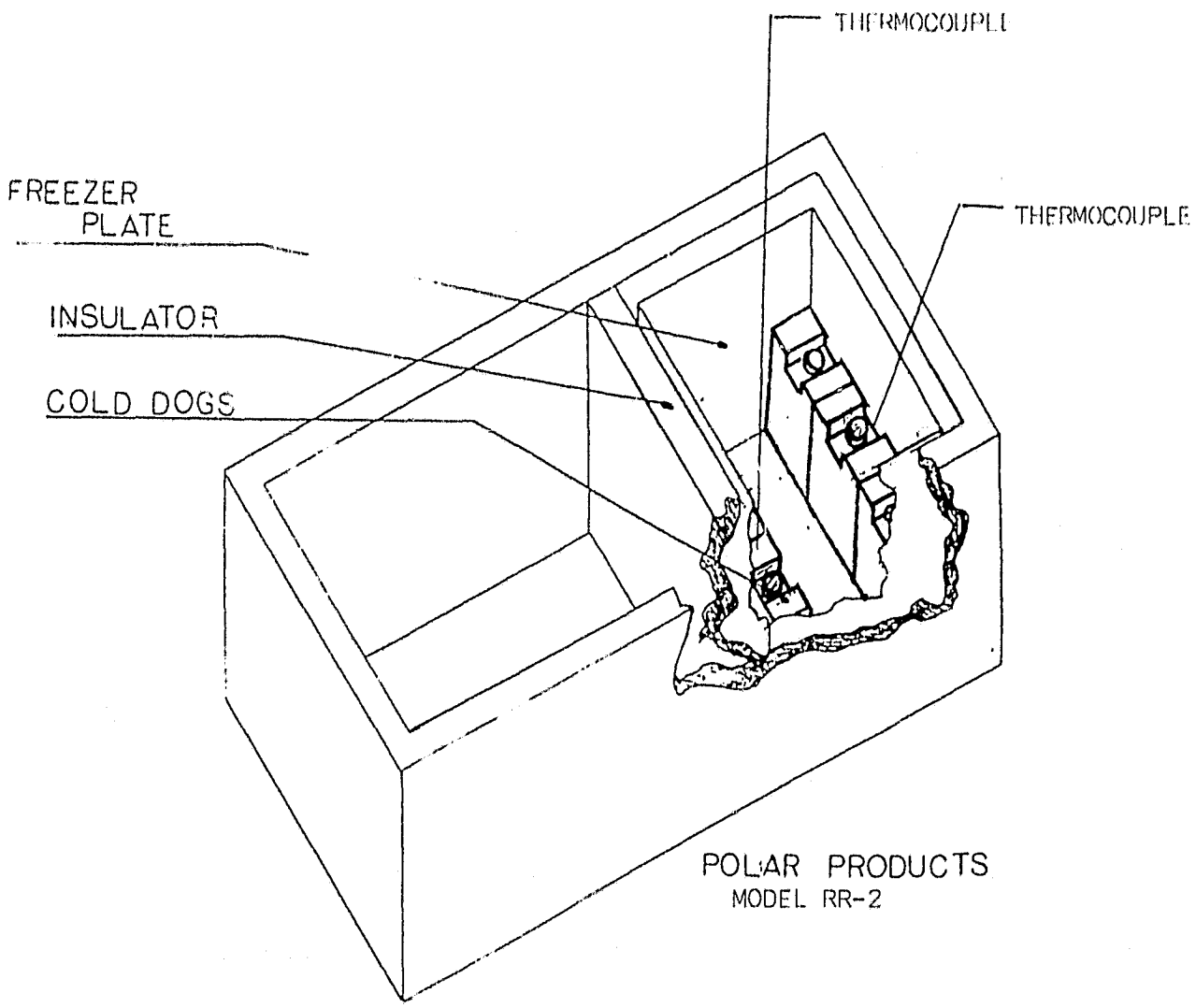
POLAR PRODUCTS RR-2
PLACEMENT OF THERMOCOUPLES IN BOTTLES
LOADED MAINTENANCE TESTS

FIGURE 2



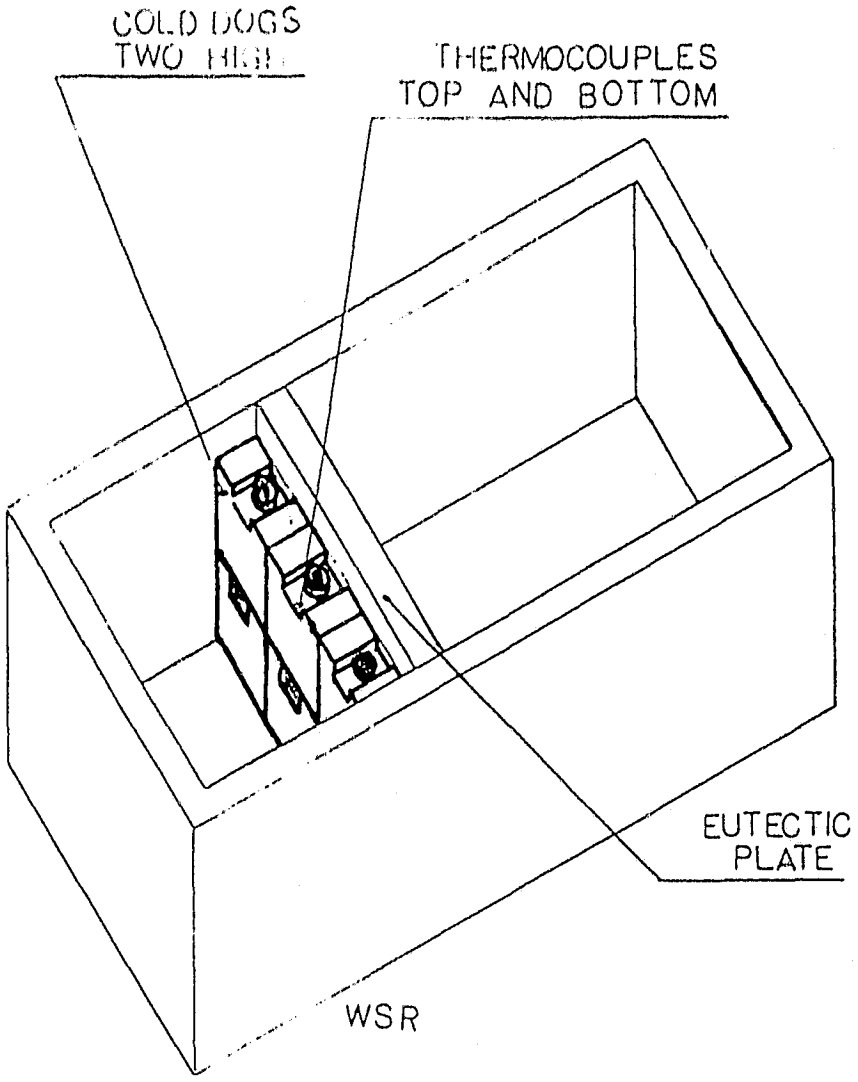
WESTERN SOLAR REFRIGERATION 12-1
PLACEMENT OF THERMOCOUPLES IN BOTTLES
LOADED MAINTENANCE TESTS

FIGURE 3



LOCATION OF "COLD DOGS"
AND THERMCOUPLES

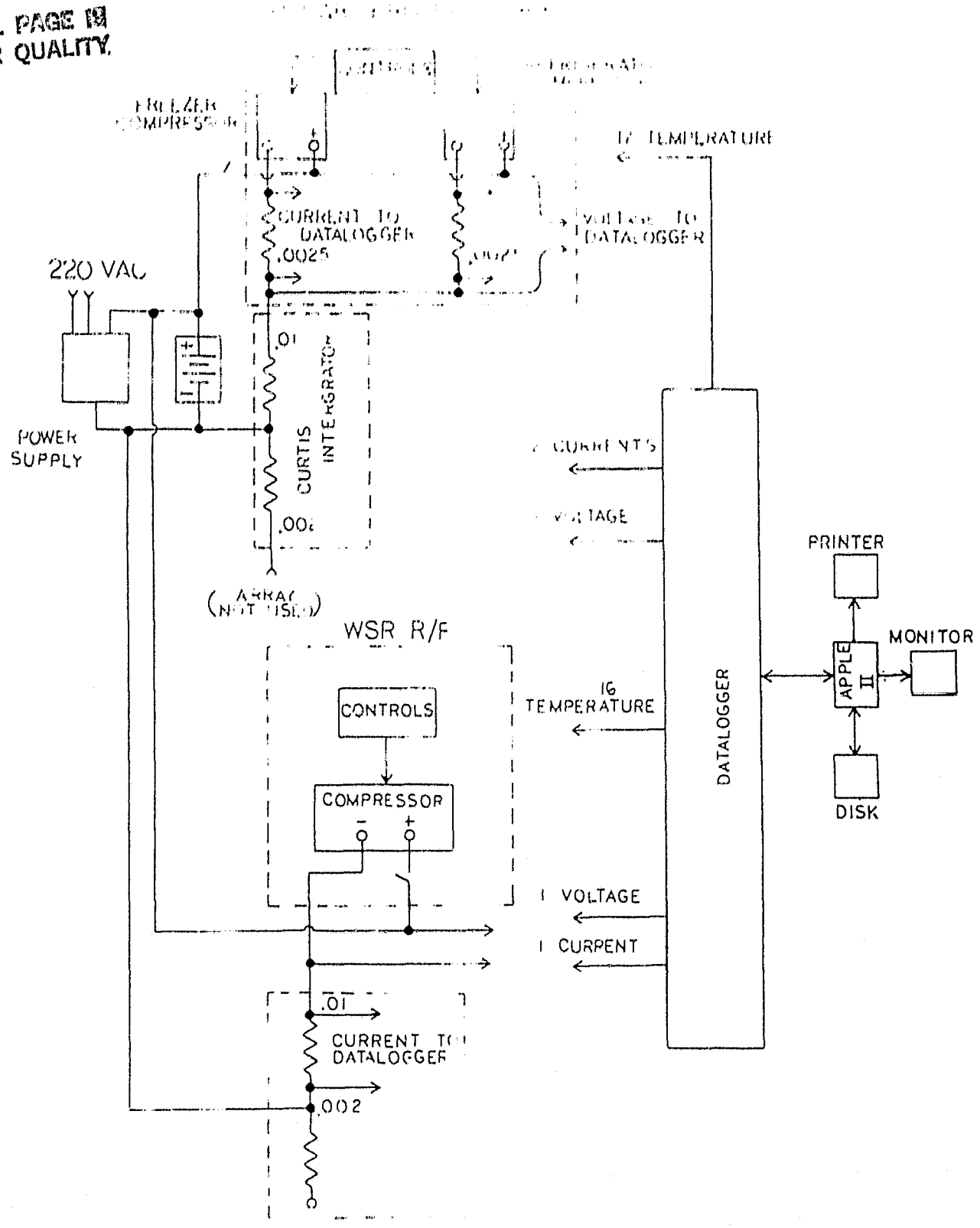
FIGURE 4A



MODEL 12-1

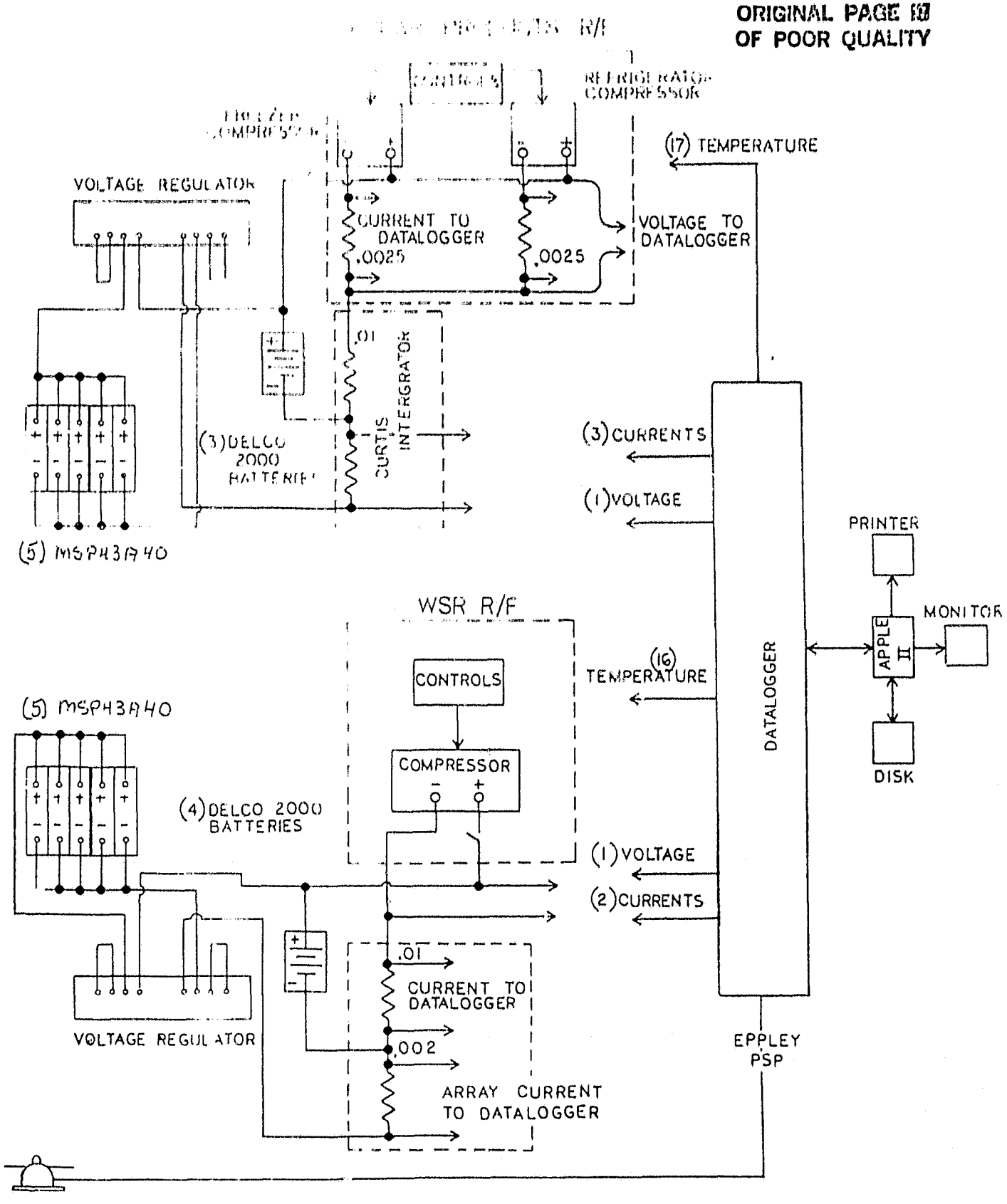
LOCATION OF "COLD DOGS"
AND THERMOCOUPLES

FIGURE 4B



QUALIFICATION TESTING WIRING

FIGURE 5



ACCEPTANCE TESTING WIRING

FIGURE 6

APPENDIX A

POLAR PRODUCTS, INC

CALCULATED DATA AND SUMMARY

[illegible] PRODUCTS, INC.

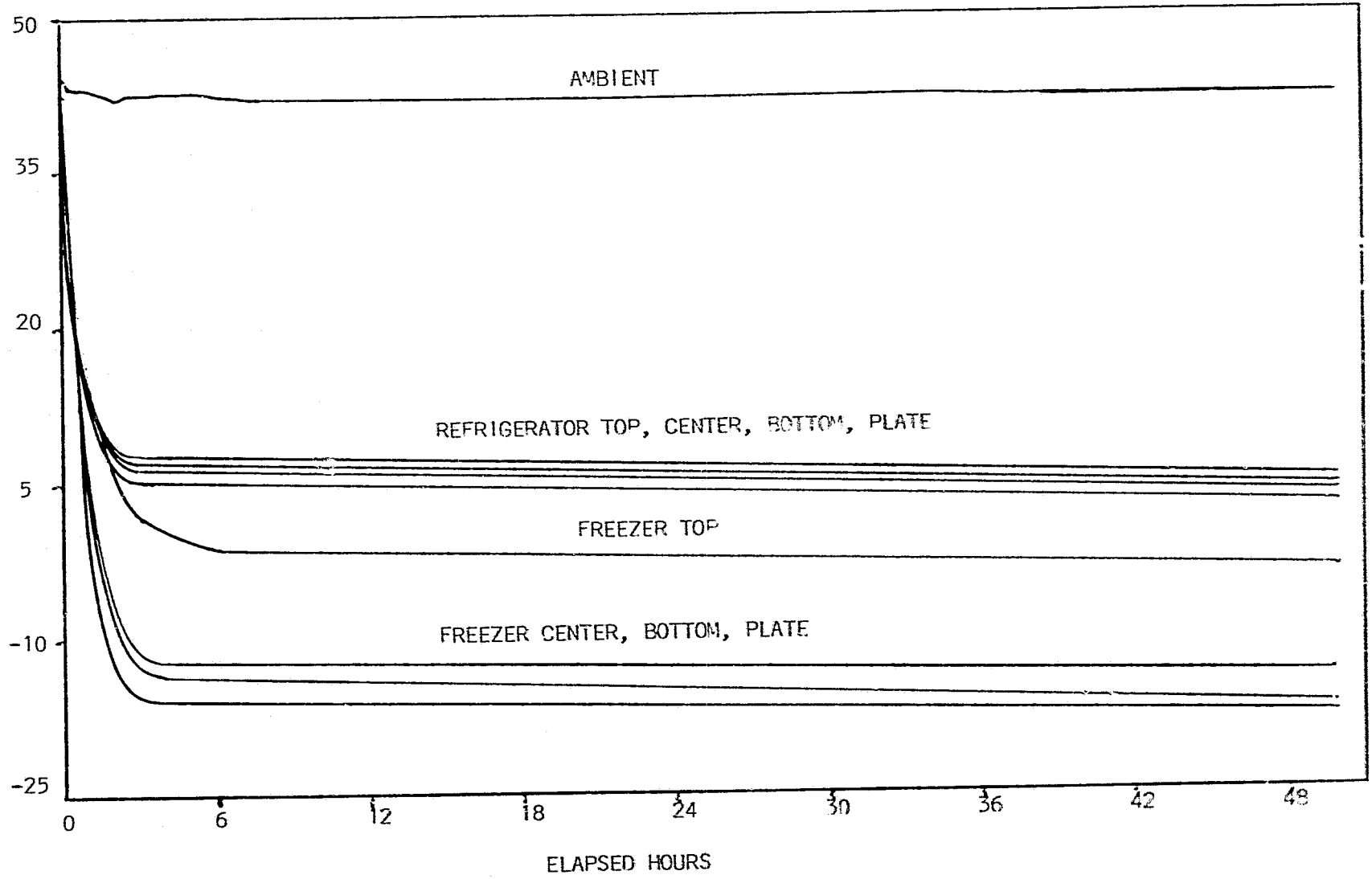
MODEL NR-2

CALCULATED DATA

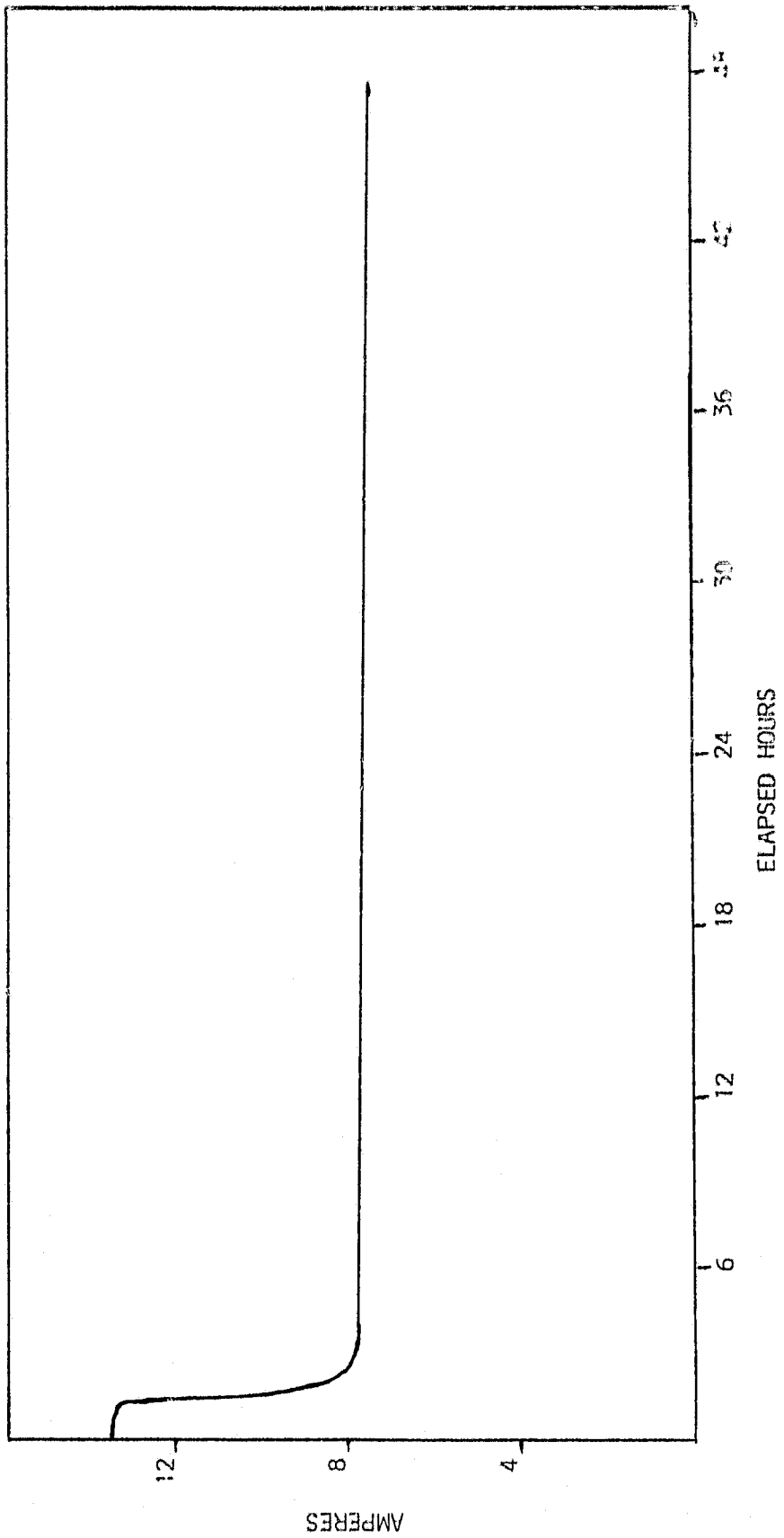
	TEMPERATURE	FULL	EMPTY
AVERAGE AMPERE-HOURS/DAY	43 Deg	59.9	82.6
	32 Deg	42.3	55.0
	21 Deg	32.4	26.2
FREEZER DUTY CYCLE (%)	43 Deg	23.8	32.8
	32 Deg	23.9	26.7
	21 Deg	11.7	18.8
REFRIGERATOR DUTY CYCLE (%)	43 Deg	18.4	17.3
	32 Deg	9.7	9.0
	21 Deg	6.5	4.3
FREEZER DIFFERENTIAL (FREEZER EMPTY)	43 Deg	11.5	8.0
	32 Deg	9.2	9.0
	21 Deg	9.0	9.0
REFRIGERATOR DIFFERENTIAL	43 Deg	0.20	2.4
	32 Deg	0.30	3.0
	21 Deg	0.65	3.0
FREEZER CYCLE TIME (HOURS)	43 Deg	1.37	0.86
	32 Deg	1.22	1.12
	21 Deg	1.52	1.33
REFRIGERATOR CYCLE TIME (HOURS)	43 Deg	0.61	0.74
	32 Deg	1.08	1.32
	21 Deg	2.36	4.00

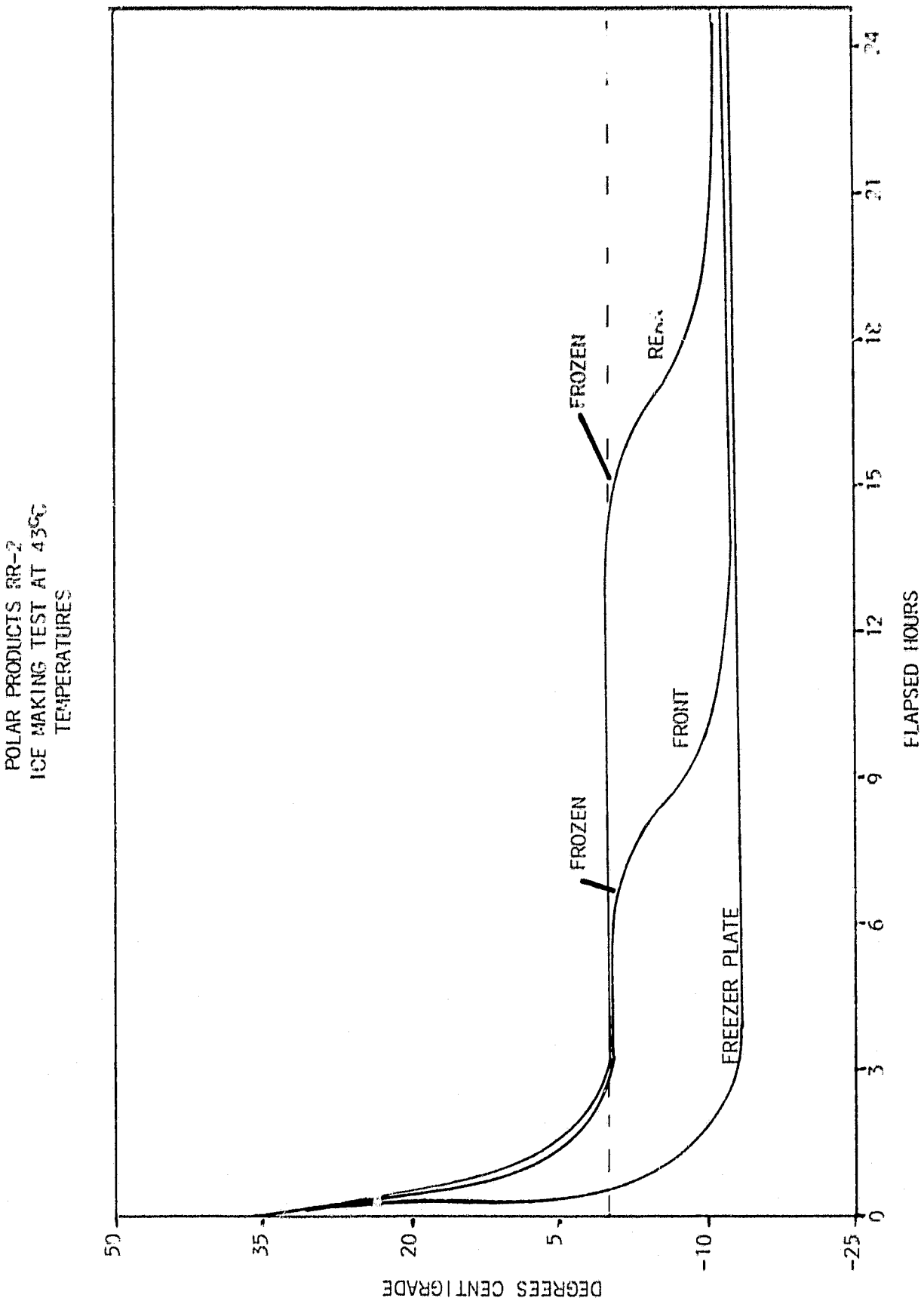
NOTE: Refrigerator differentials are measured in bottles when loaded, in air when empty.

POLAR PRODUCTS RR-2
NO-LOAD PULL DOWN AT 43°C AMBIENT
TEMPERATURES

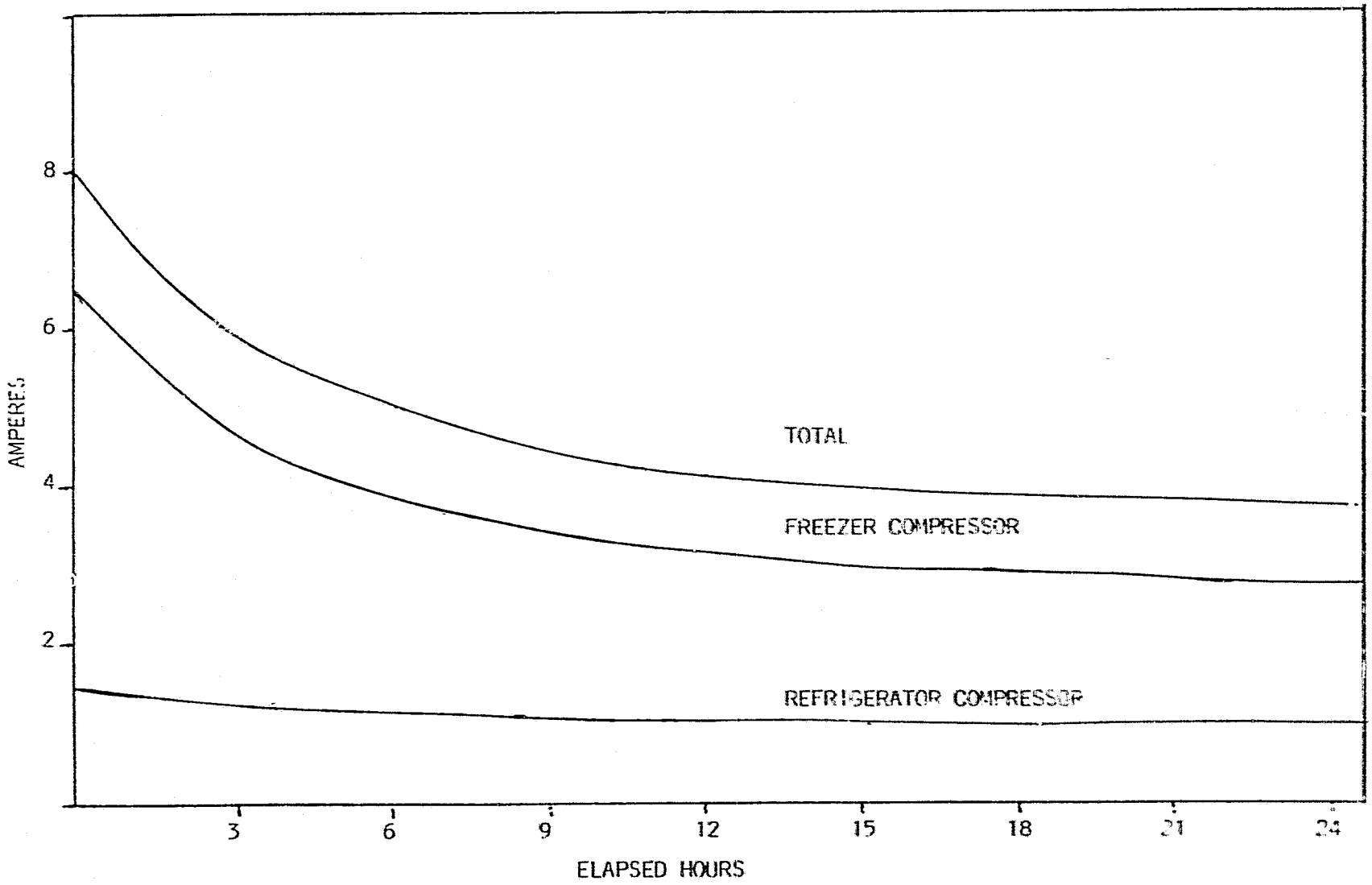


POLAR PRODUCTS RR-2
NO-LOAD PULL DOWN AT 43°C
AVERAGE CURRENT (TOTAL)

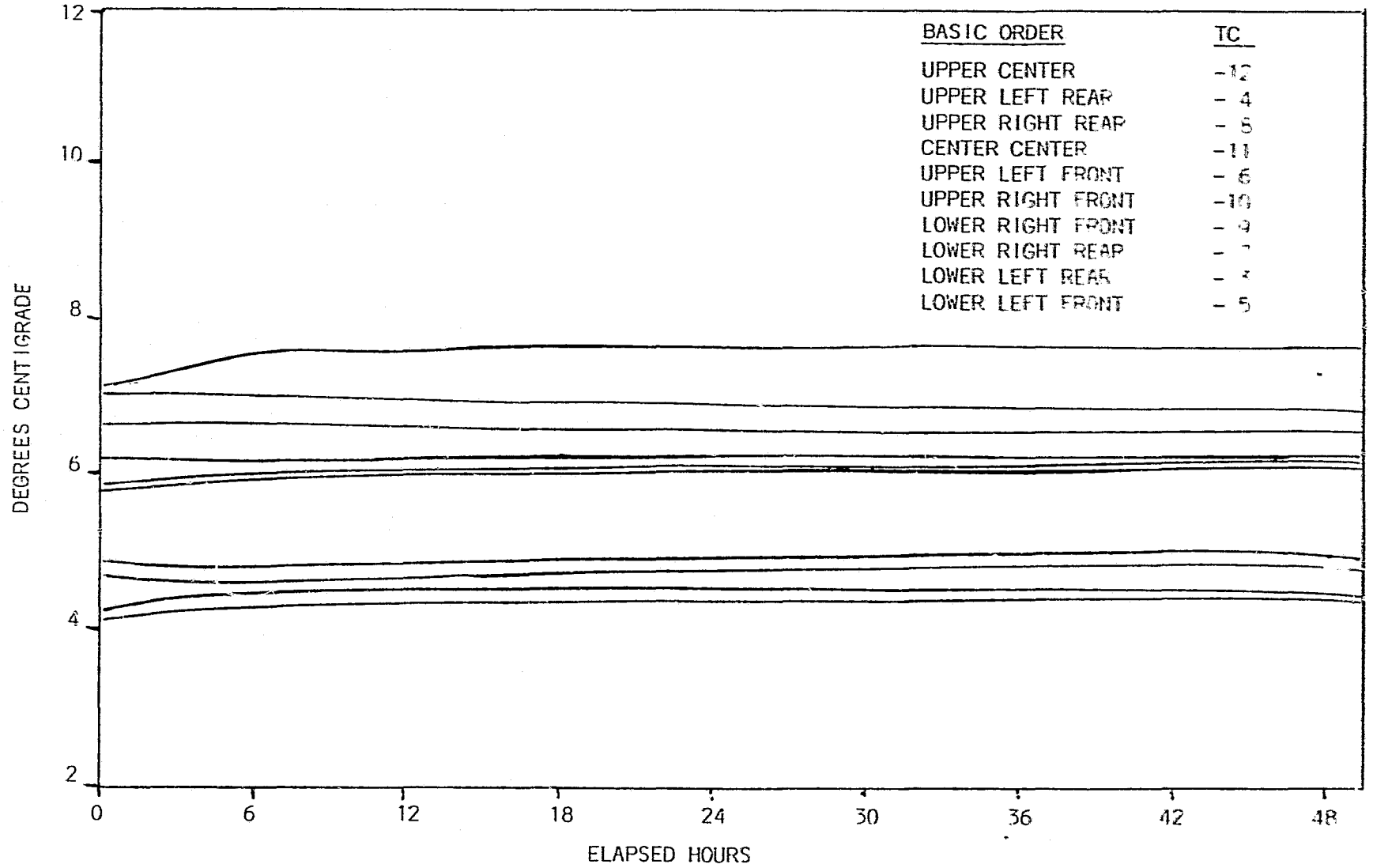



POLAR PRODUCTS RR-2
ICE MAKING TEST AT 43°C
TEMPERATURES
DEGREES CENTIGRADE
50
35
20
5
-10
-25
0
3
6
9
12
15
18
21
24
ELAPSED HOURS
FROZEN
FROZEN
FRONT
FREEZER PLATE

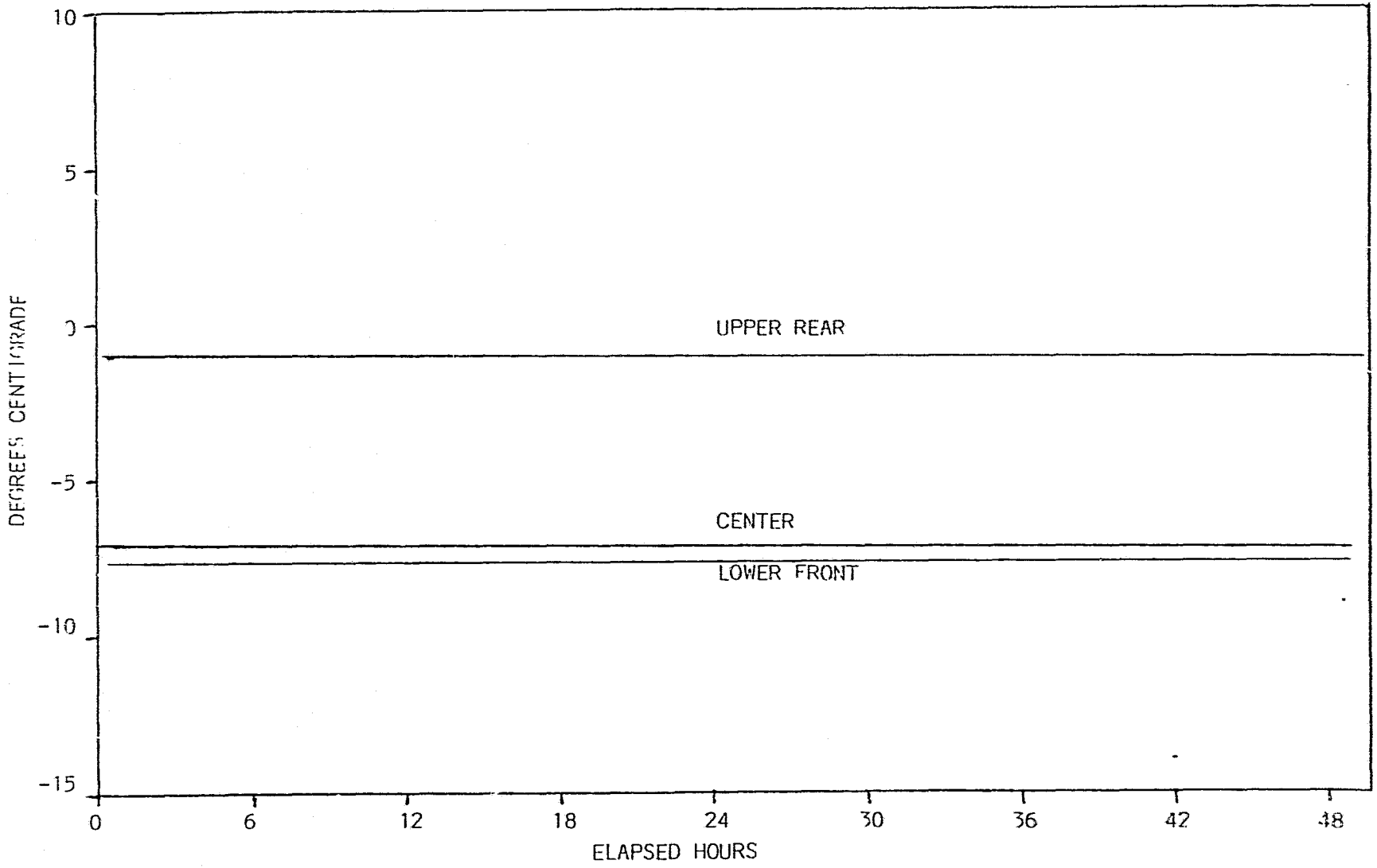
POLAR PRODUCTS RR-2
ICEMAKING AT 43°C
AVERAGE CURRENTS



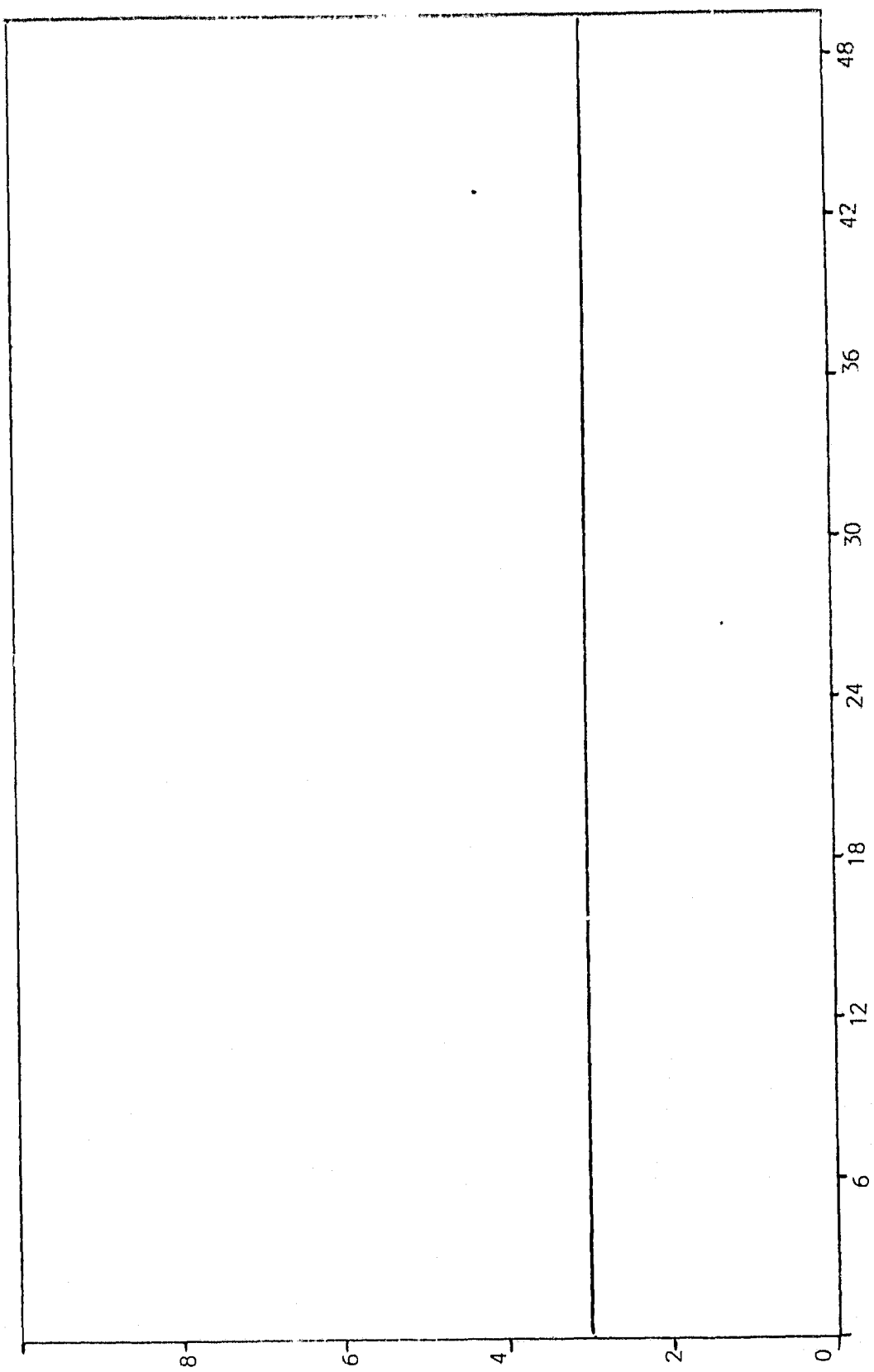
POLAR PRODUCTS RR-2
LOADED MAINTENANCE AT 43°C AMBIENT
BOTTLE TEMPERATURES



POLAR PRODUCTS RR-2
LOADED MAINTENANCE AT 43°C AMBIENT
AVERAGE FREEZER TEMPERATURES

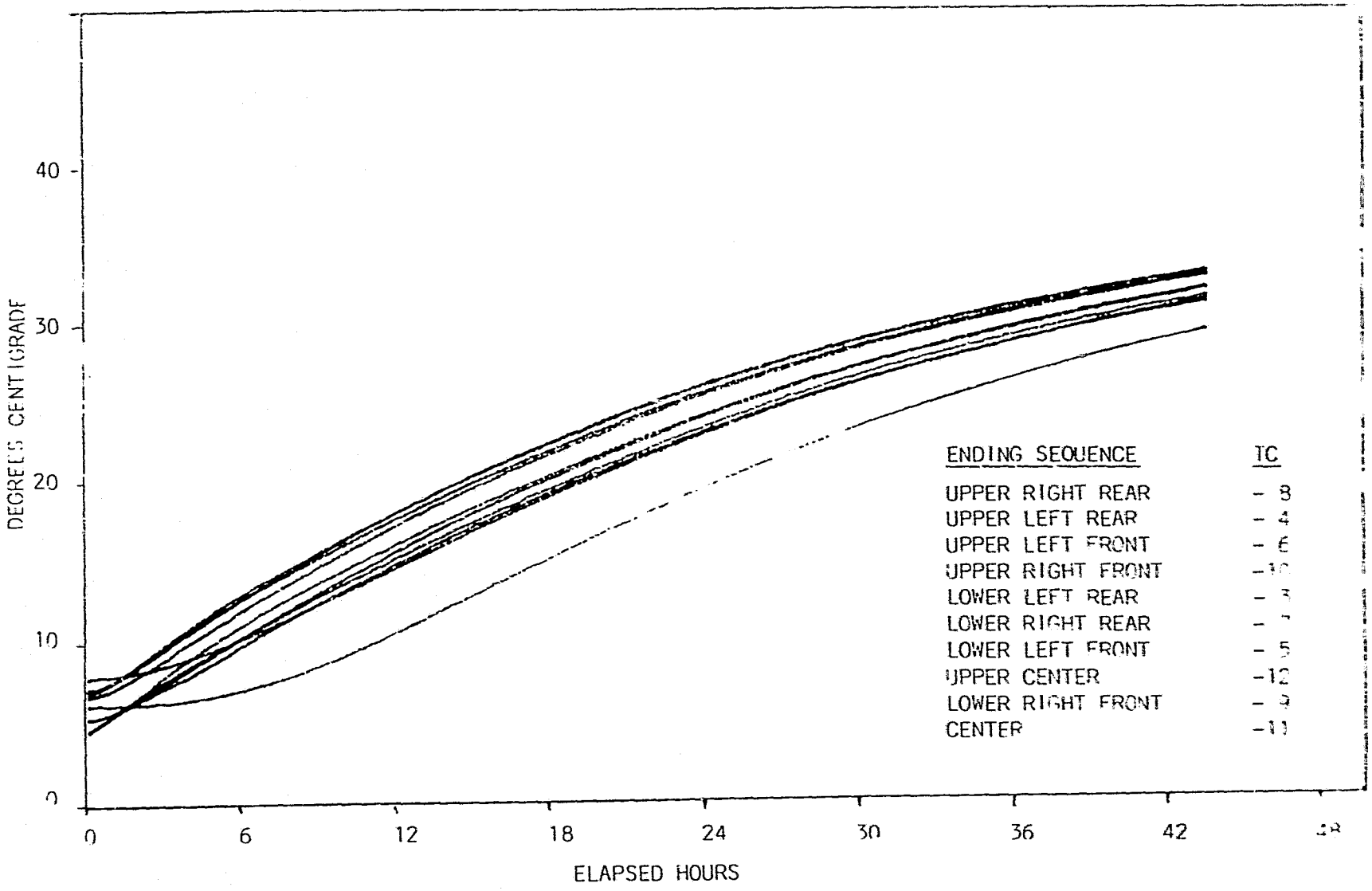


POLAR PRODUCTS RR-2
LOADED MAINTENANCE AT 43°C AMBIENT
AVERAGE CURRENT

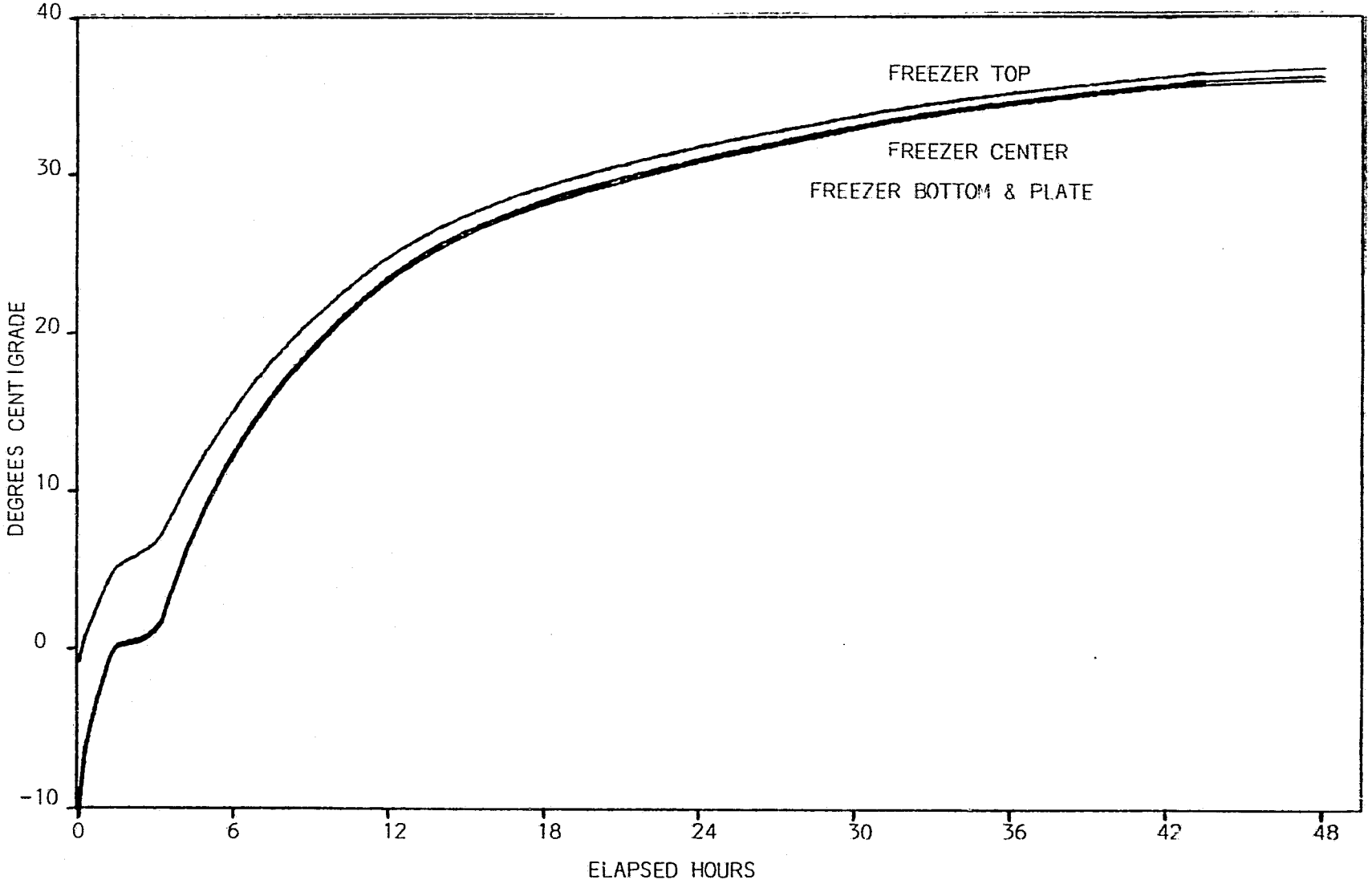


HOLDOVER

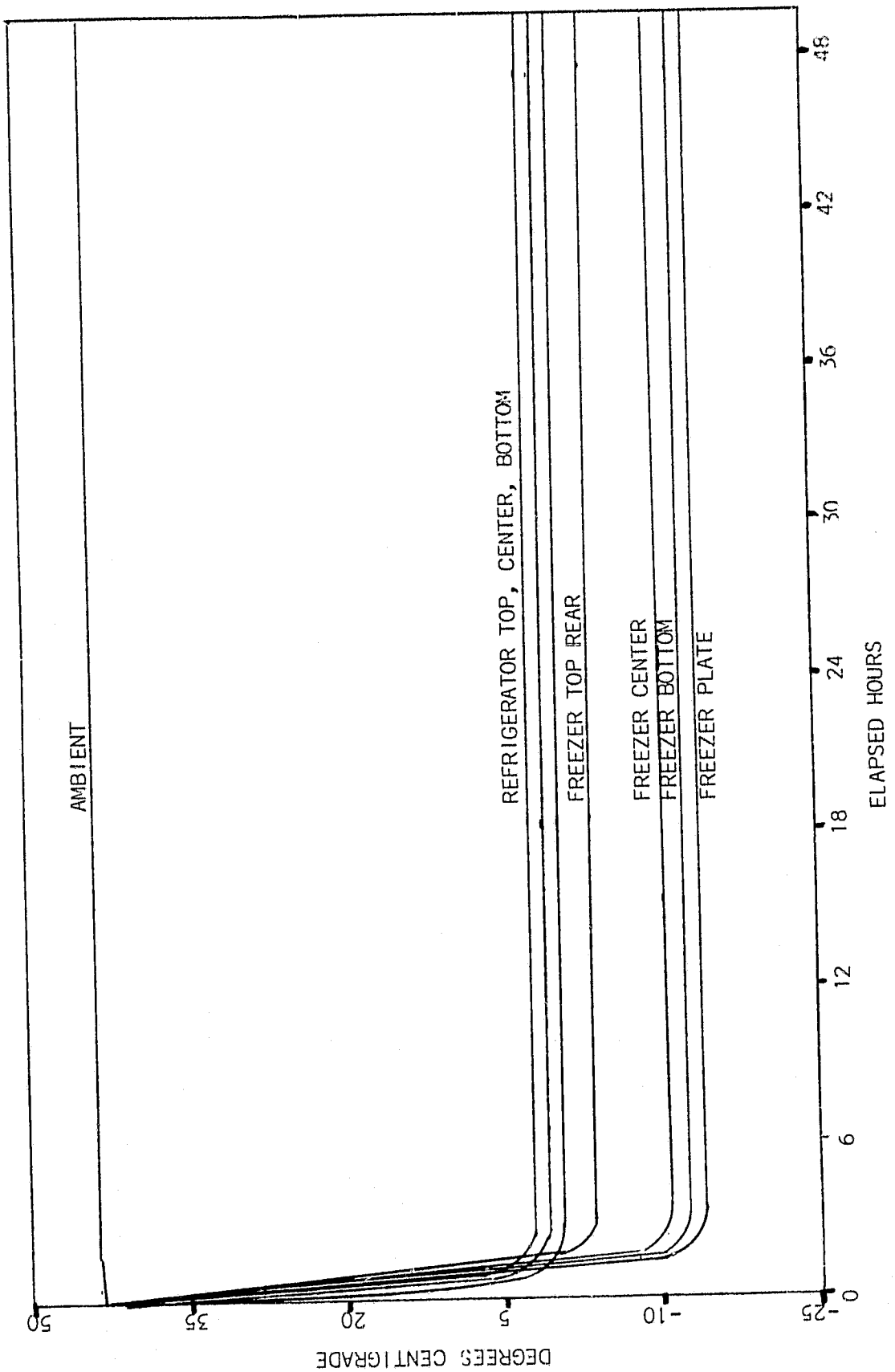
BOTTLE TEMPERATURES



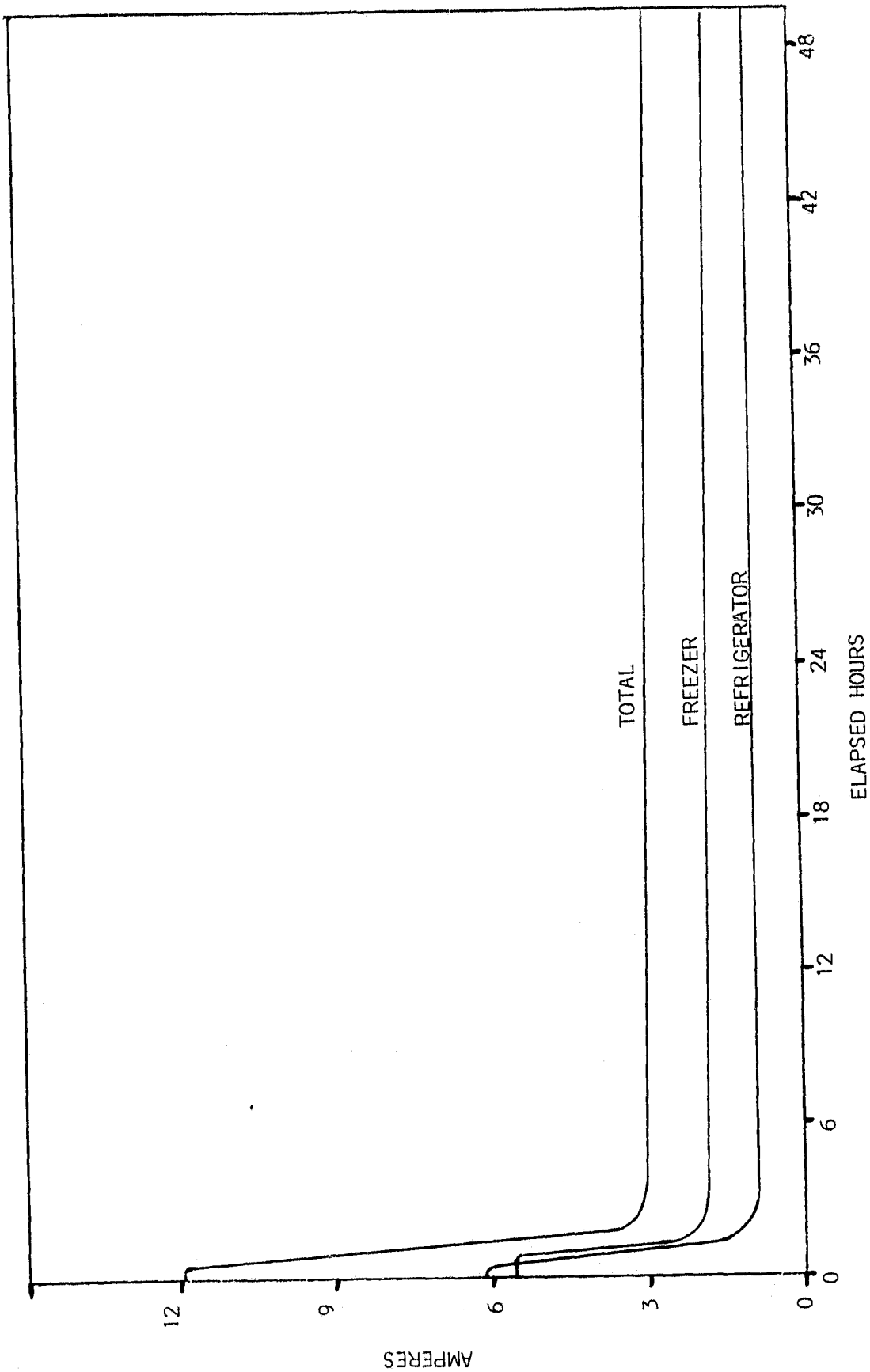
POLAR PRODUCTS RR-2
HOLDOVER AT 43°C
FREEZER TEMPERATURES

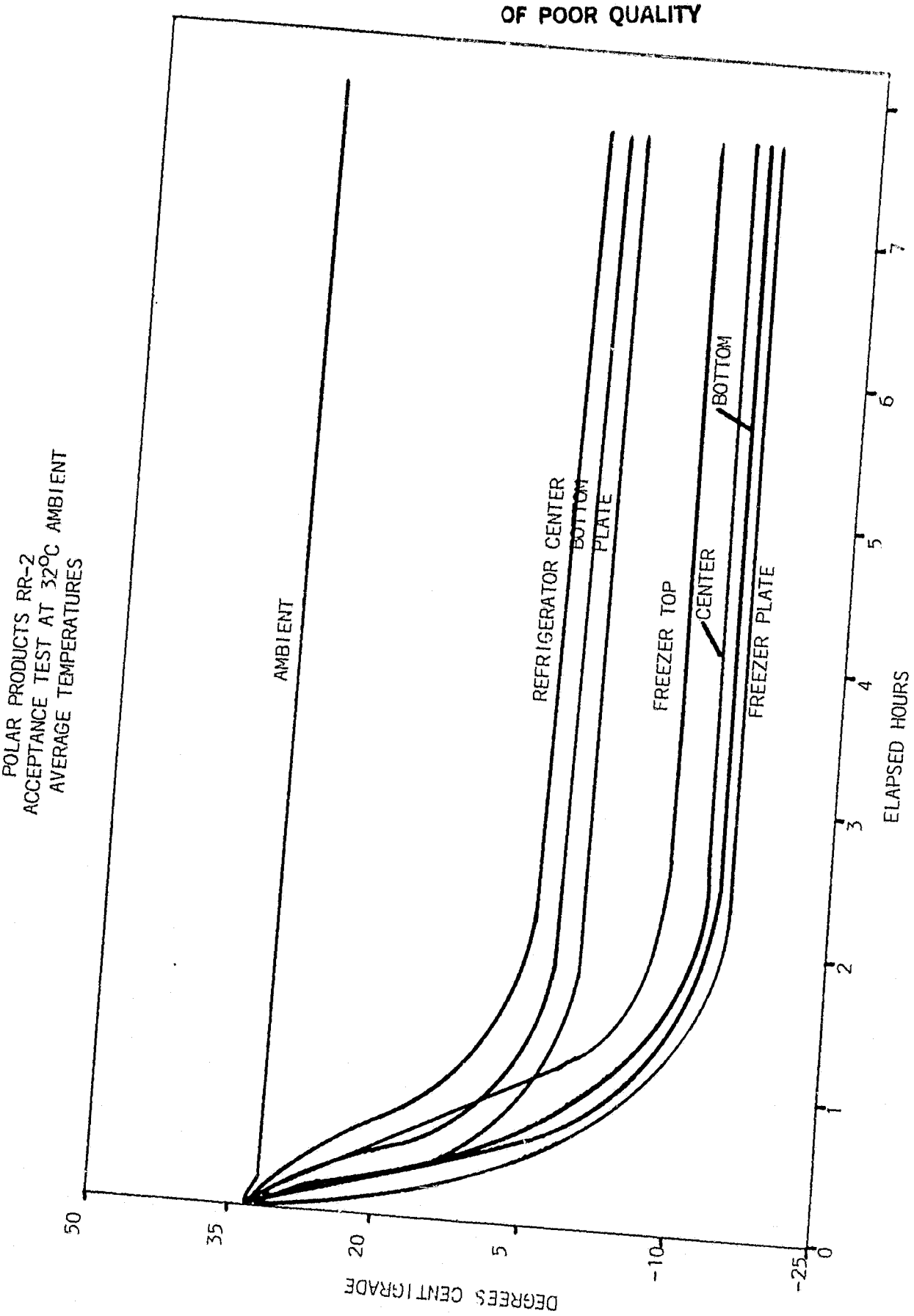


POLAR PRODUCTS RR-2
ACCEPTANCE TEST AT 43°C AMBIENT
AVERAGE TEMPERATURES

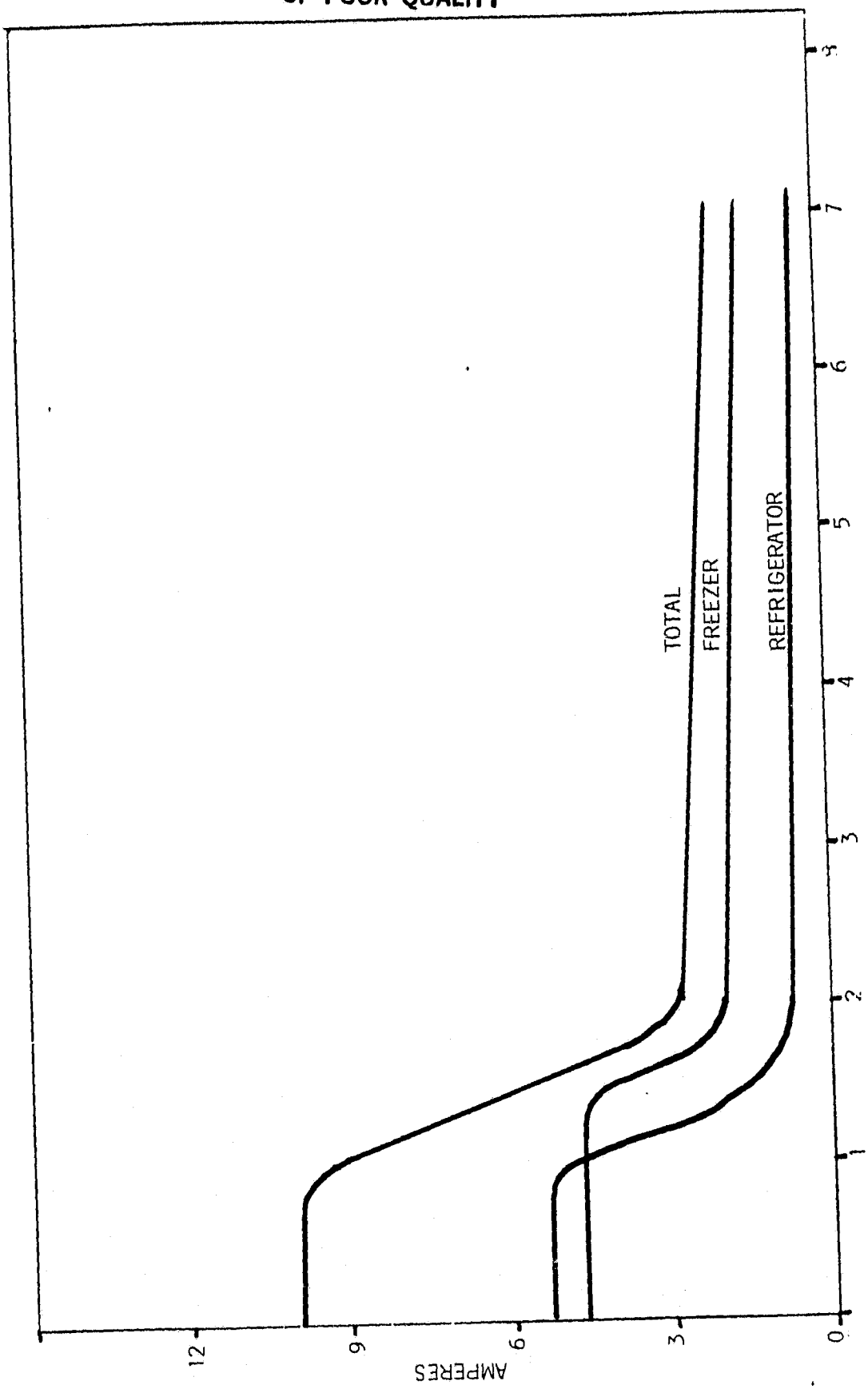


POLAR PRODUCTS RR-2
ACCEPTANCE TEST AT 43°C AMBIENT
AVERAGE CURRENTS

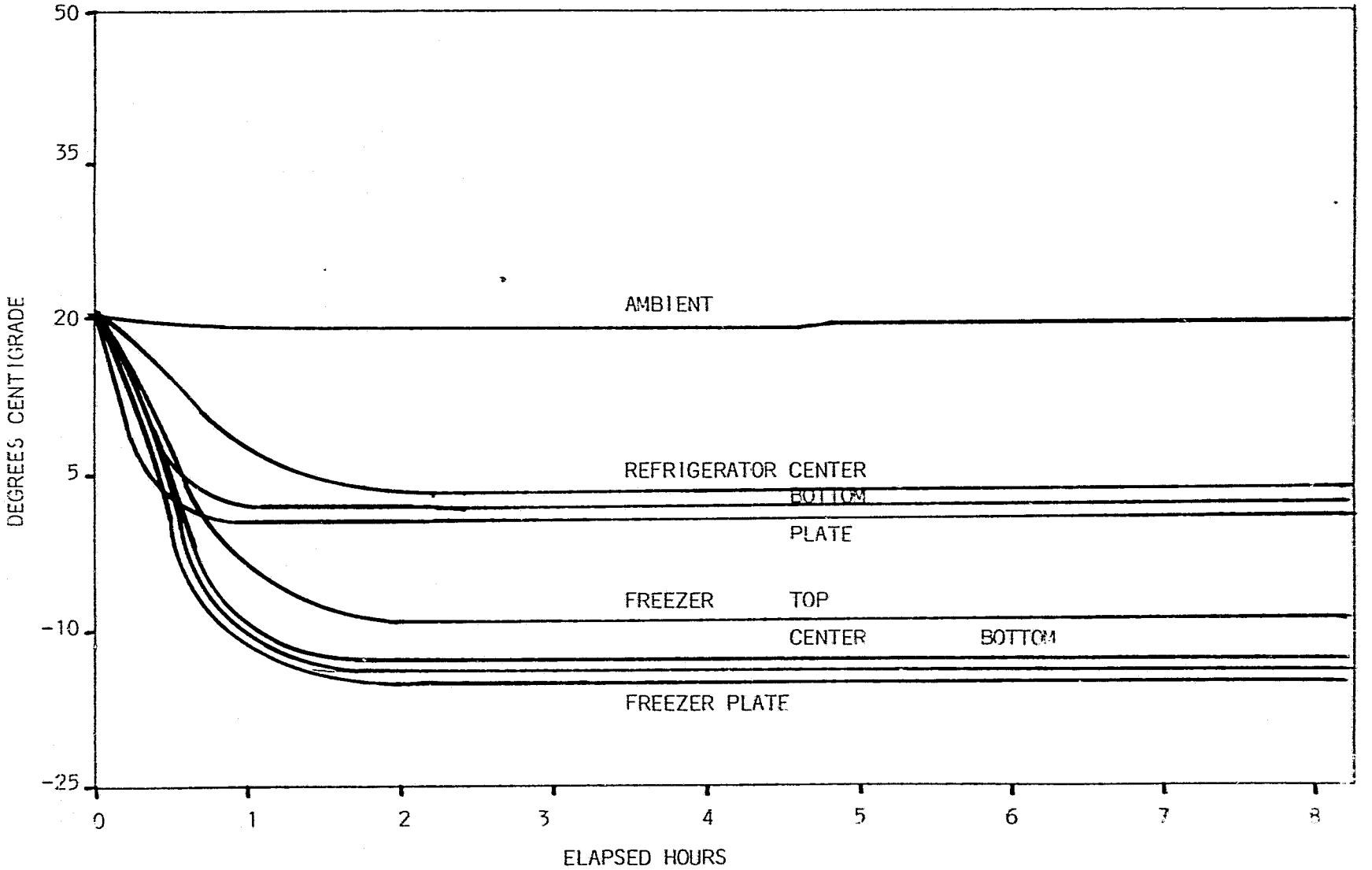




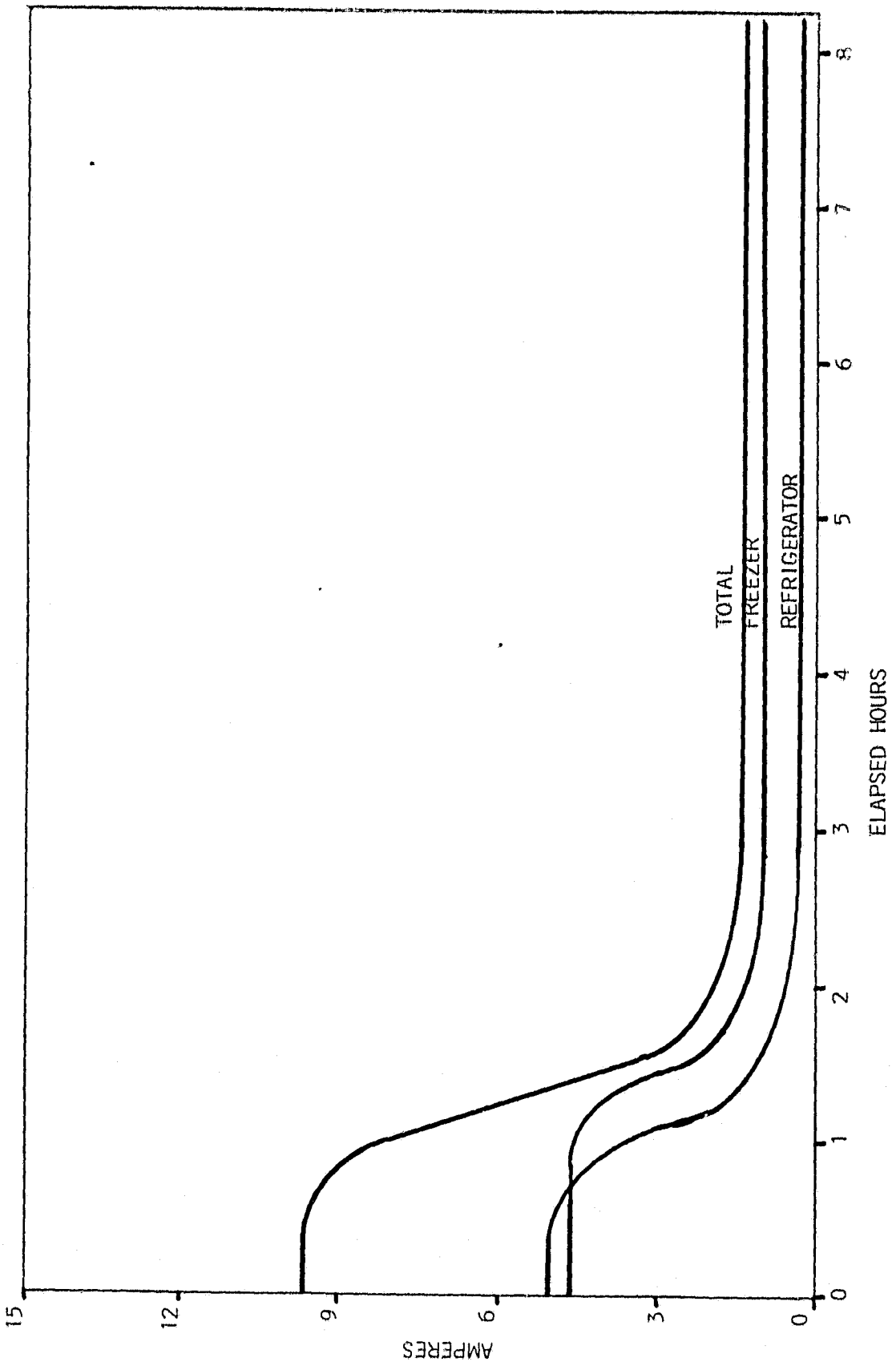
POLAR PRODUCTS RR-2
ACCEPTANCE TEST AT 32°C AMBIENT
AVERAGE CURRENT



POLAR PRODUCTS RR-2
ACCEPTANCE TEST AT 21°C AMBIENT
AVERAGE TEMPERATURES



POLAR PRODUCTS RR-2
ACCEPTANCE TEST AT 21°C AMBIENT
AVERAGE CURRENTS



WESTERN SOLAR REFRIGERATION, INC.

CALCULATED DATA AND SUMMARY

WESTERN SOLAR REFRIGERATION, INC.

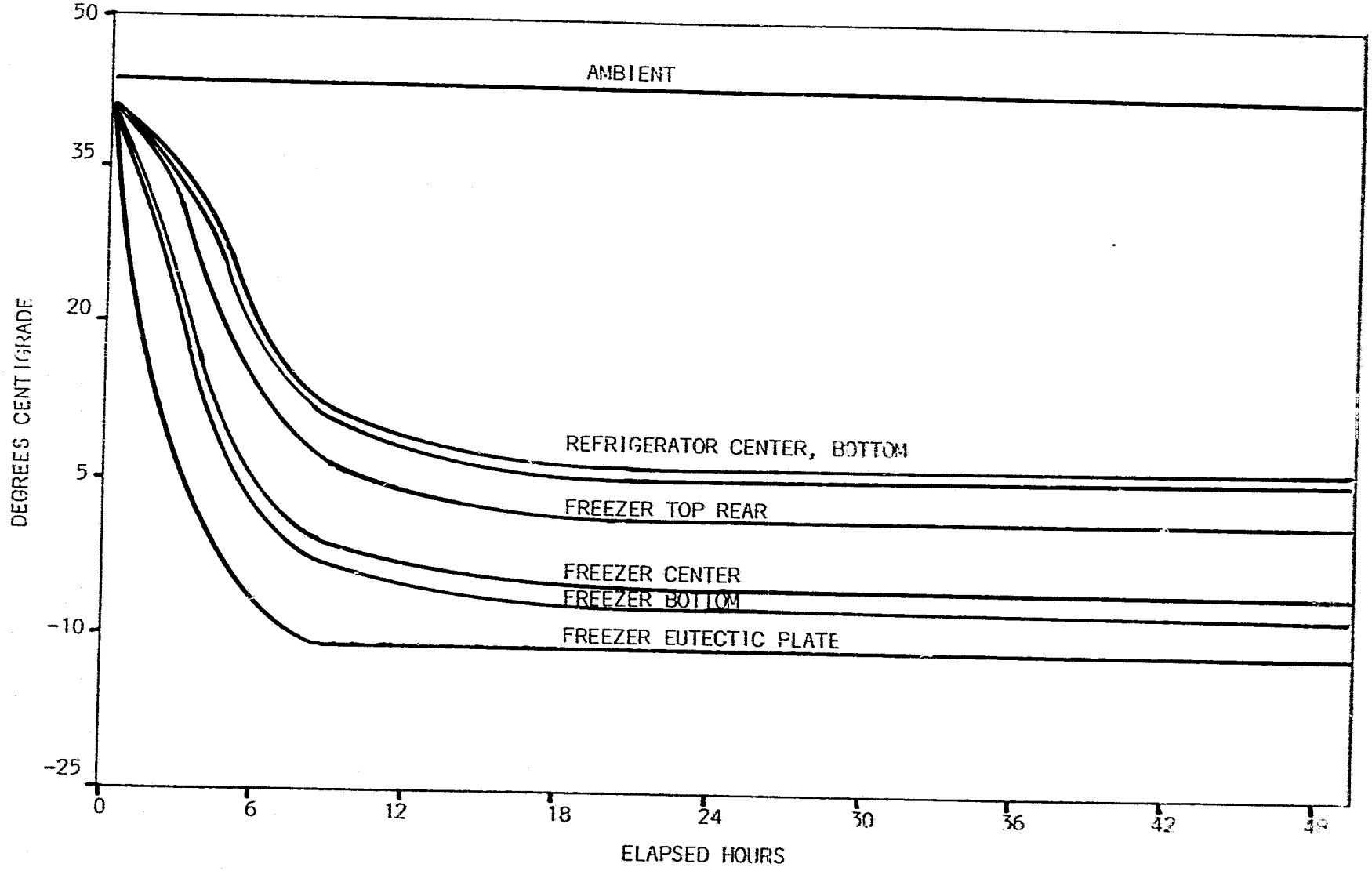
MODEL 12-1

CALCULATED DATA

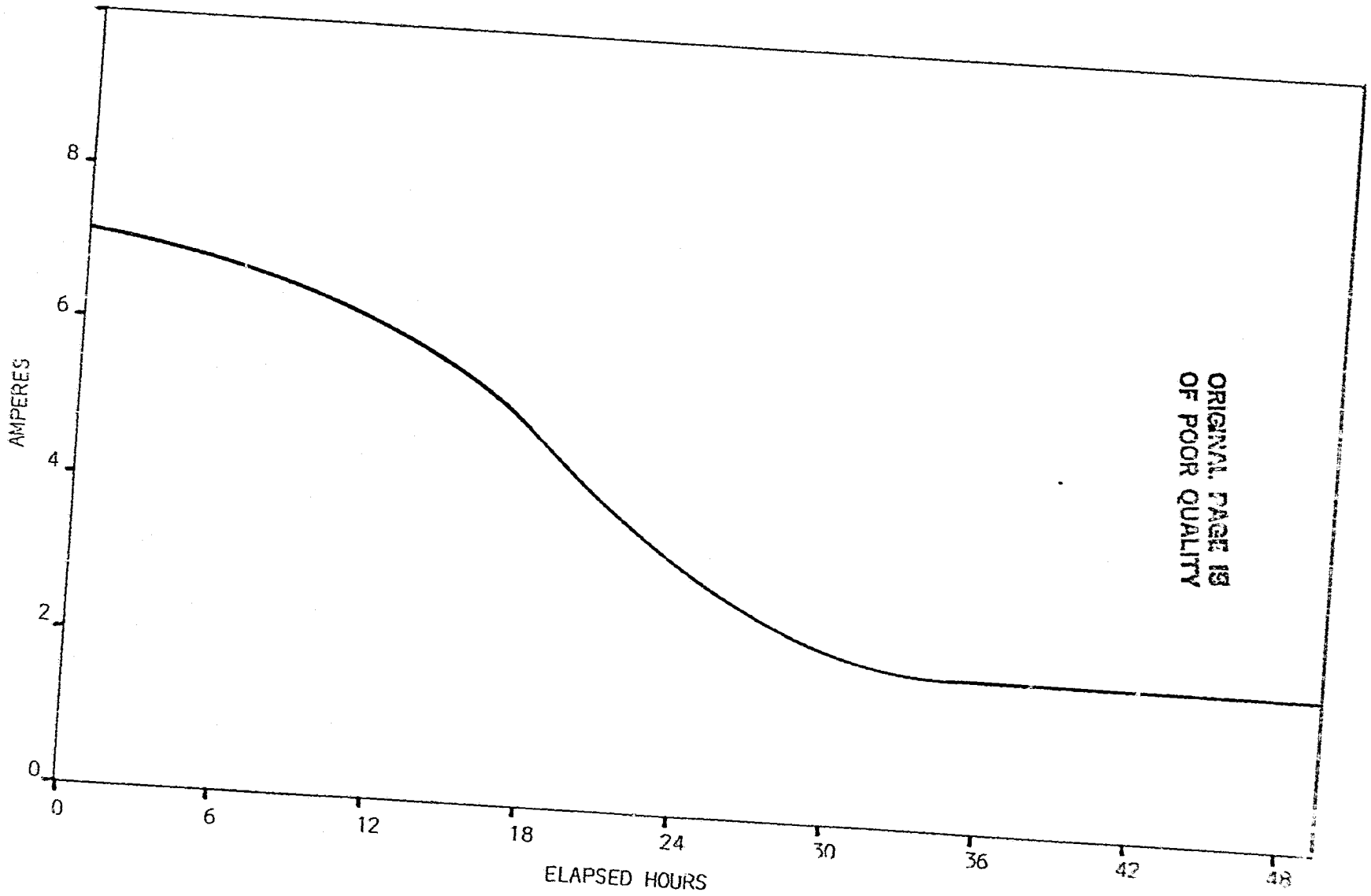
	TEMPERATURE	FULL	EMPTY
AVERAGE AMPERE-HOURS/DAY	43 Deg	62.1	50.0
	32 Deg	30.0	29.2
	21 Deg	32.5	19.7
REFRIGERATOR/FREEZER DUTY CYCLE (%)	43 Deg	38.0	35.0
	32 Deg	24.4	29.4
	21 Deg	22.2	11.6
FREEZER DIFFERENTIAL (FREEZER EMPTY)	43 Deg	1.1	0.7
	32 Deg	0.9	1.0
	21 Deg	0.9	1.0
REFRIGERATOR DIFFERENTIAL	43 Deg	0.2	0.2
	32 Deg	0.1	0.2
	21 Deg	0.1	0.1
CYCLE TIME (HOURS)	43 Deg	9.6	8.1
	32 Deg	8.3	11.5
	21 Deg	10.2	10.1

NOTE: Refrigerator differentials are measured in bottles when loaded, in air when empty

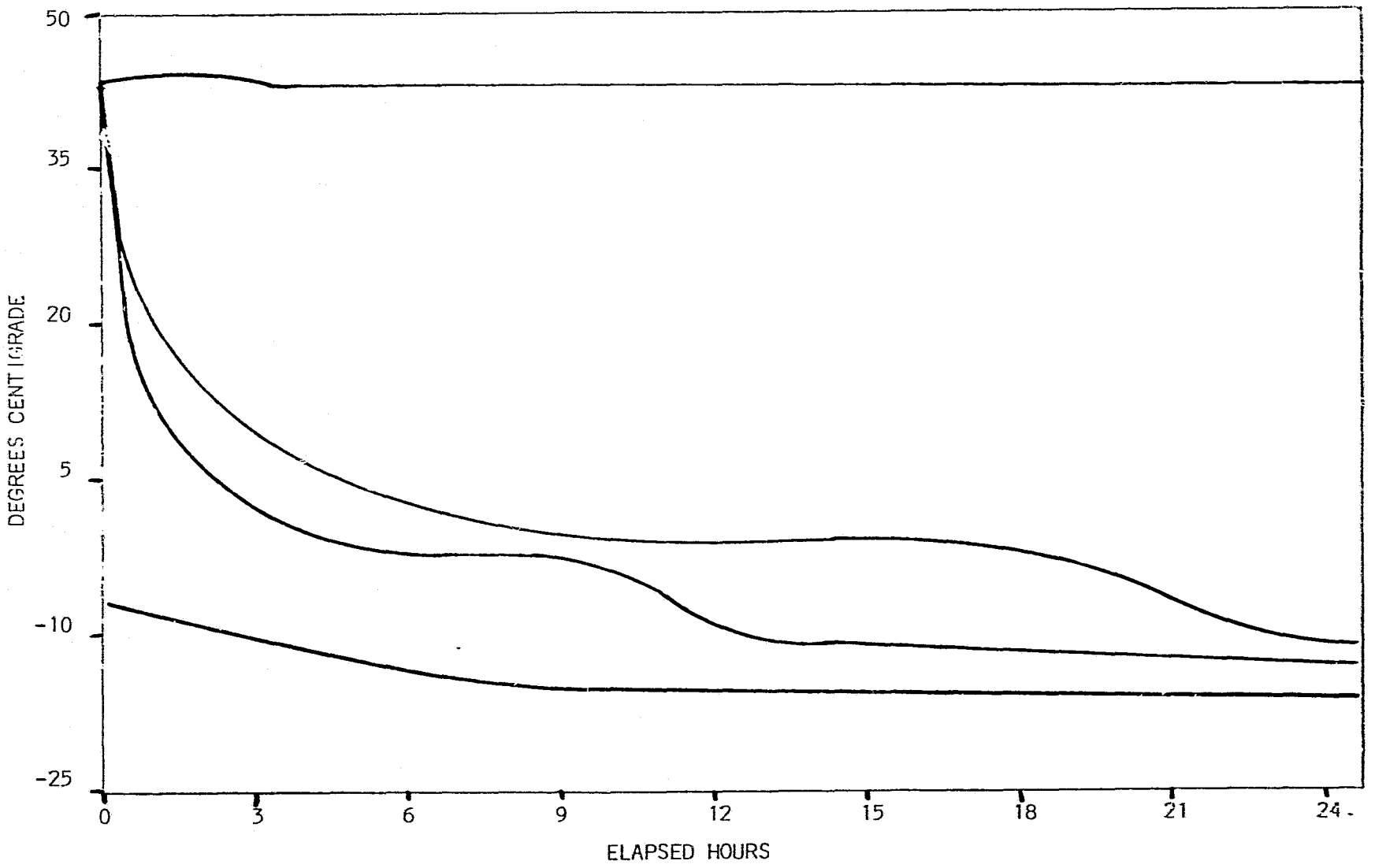
WESTERN SOLAR REFRIGERATION 12-1
NO-LOAD PULL DOWN AT 43°C AMBIENT
TEMPERATURES



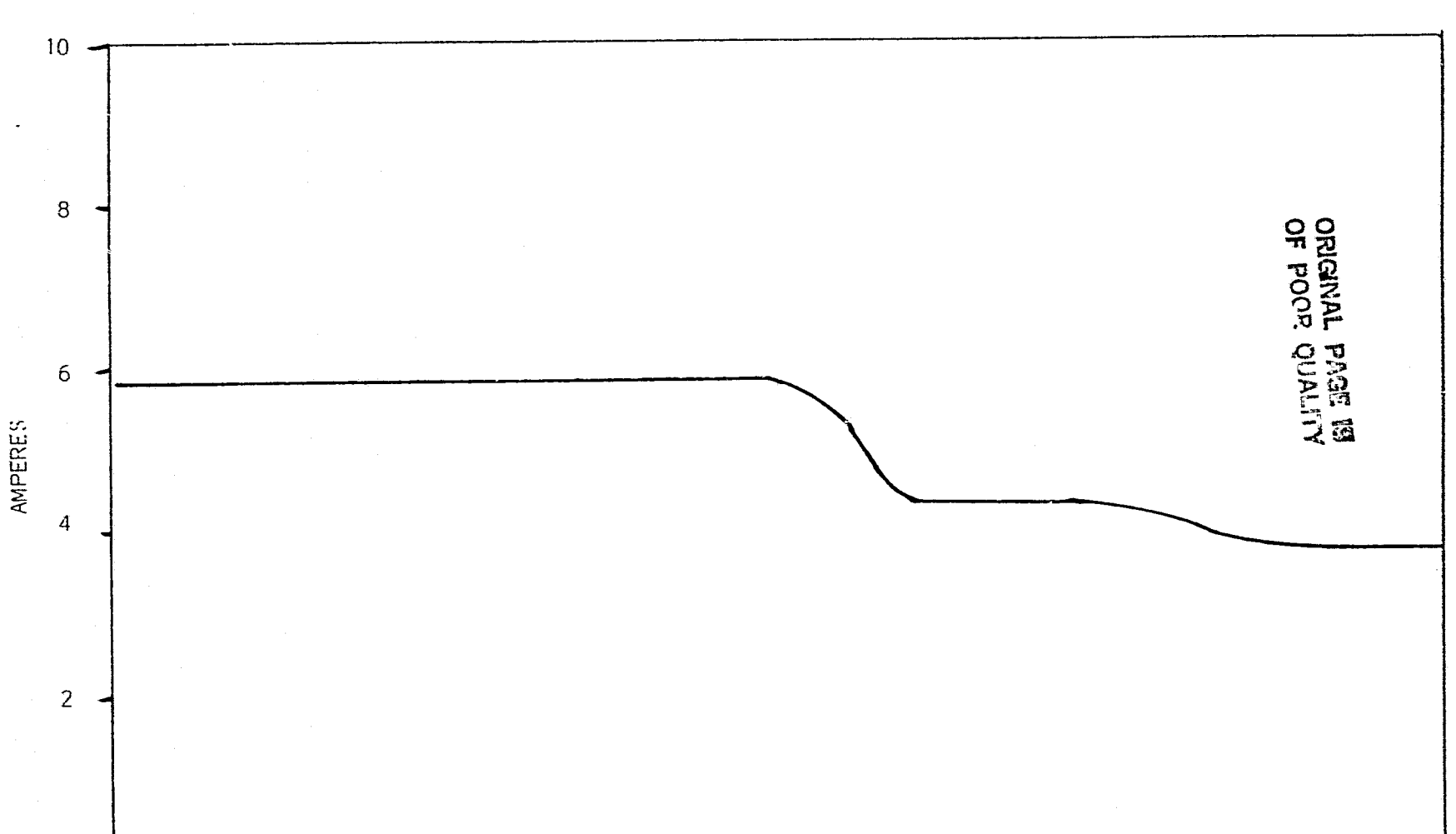
WESTERN SOLAR REFRIGERATION 12-1
NO-LOAD PULL DOWN AT 43°C AMBIENT
AVERAGE CURRENT



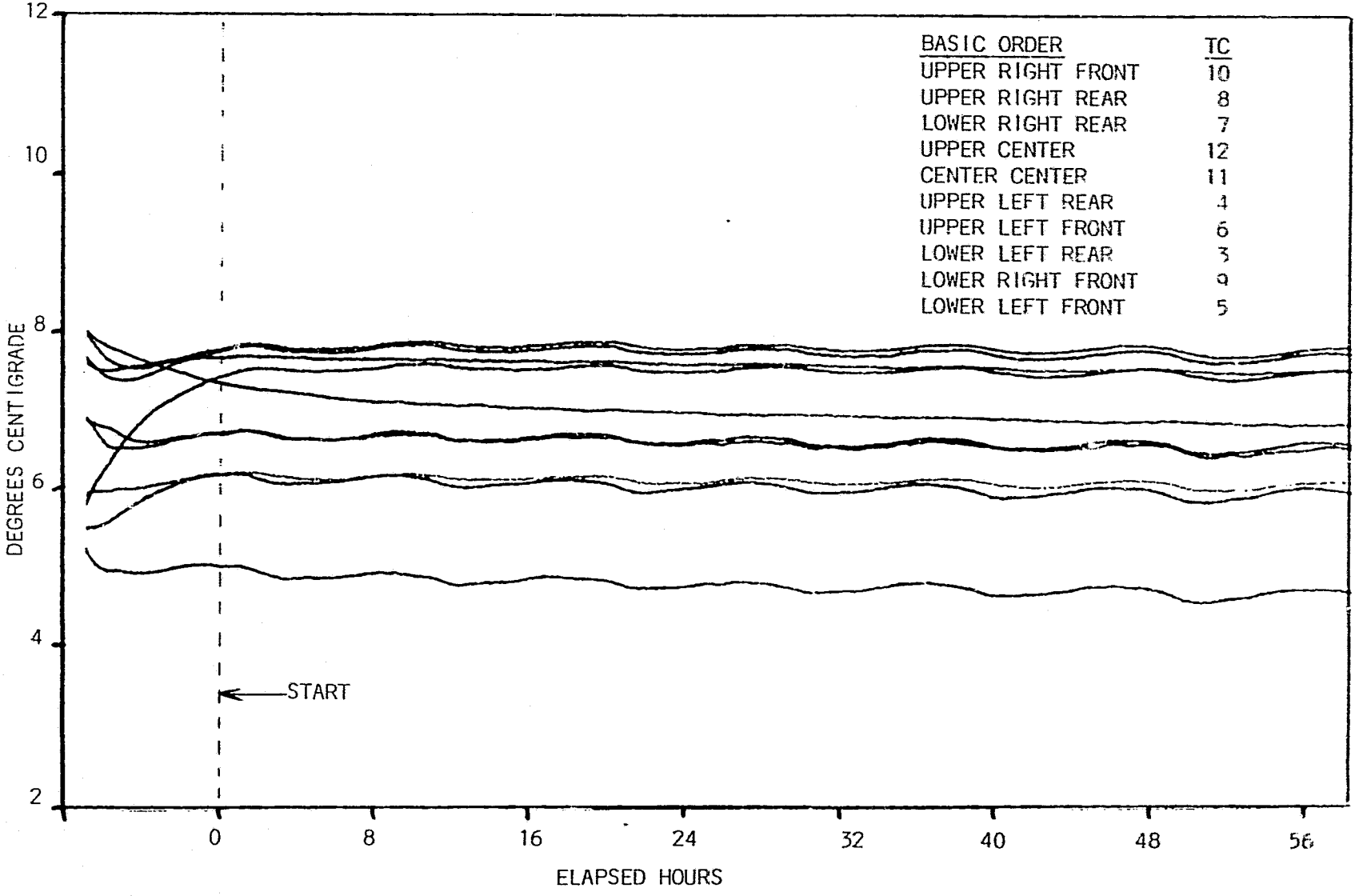
WESTERN SOLAR REFRIGERATOR 12-1
ICE MAKING AT 43°C
TEMPERATURES



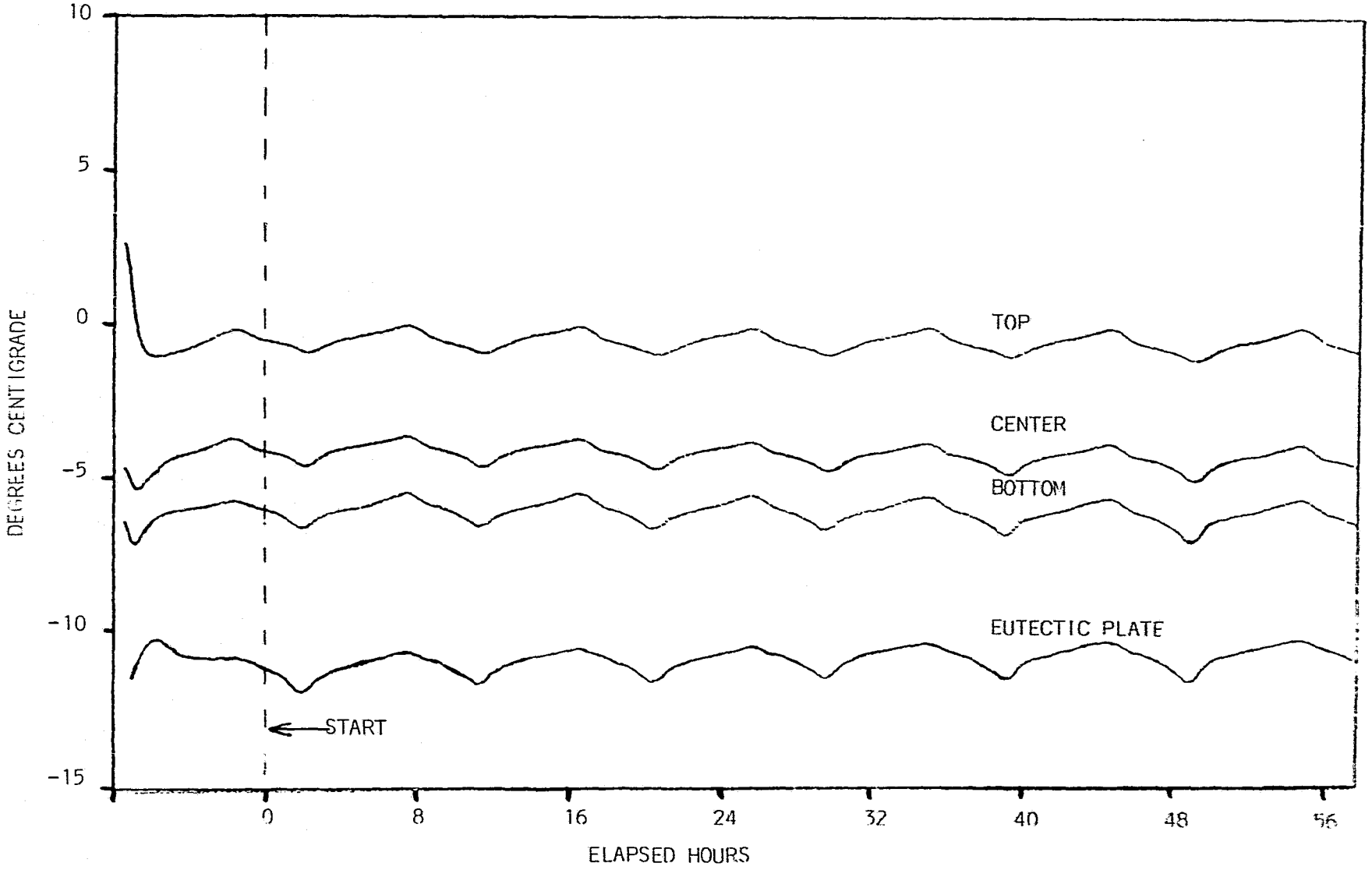
WESTERN SOLAR REFRIGERATION 12-1
ICE MAKING AT 43°C
AVERAGE CURRENT



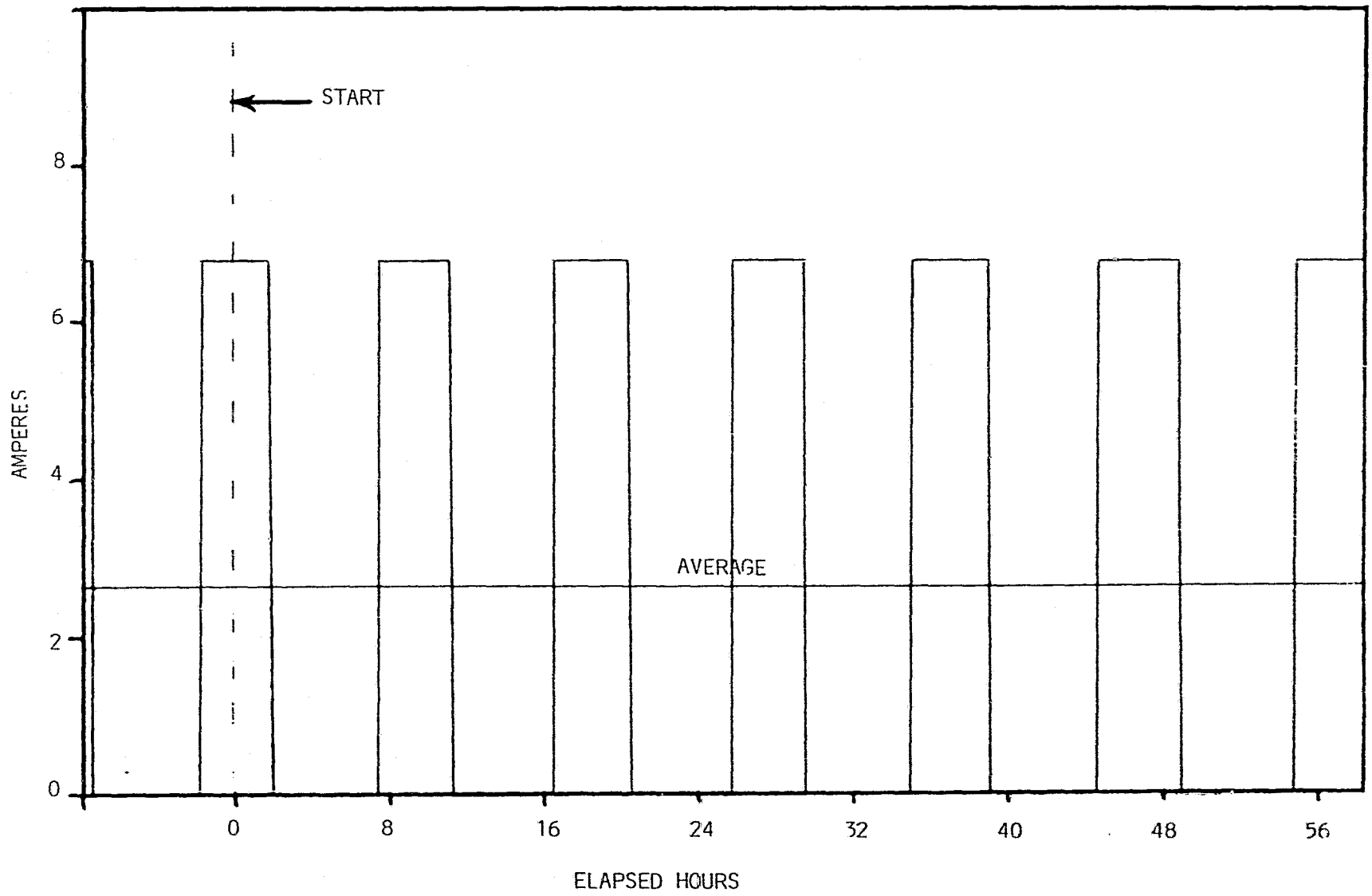
WESTERN SOLAR REFRIGERATION 12-1
LOADED MAINTENANCE AT 43°C AMBIENT
FREEZER TEMPERATURES



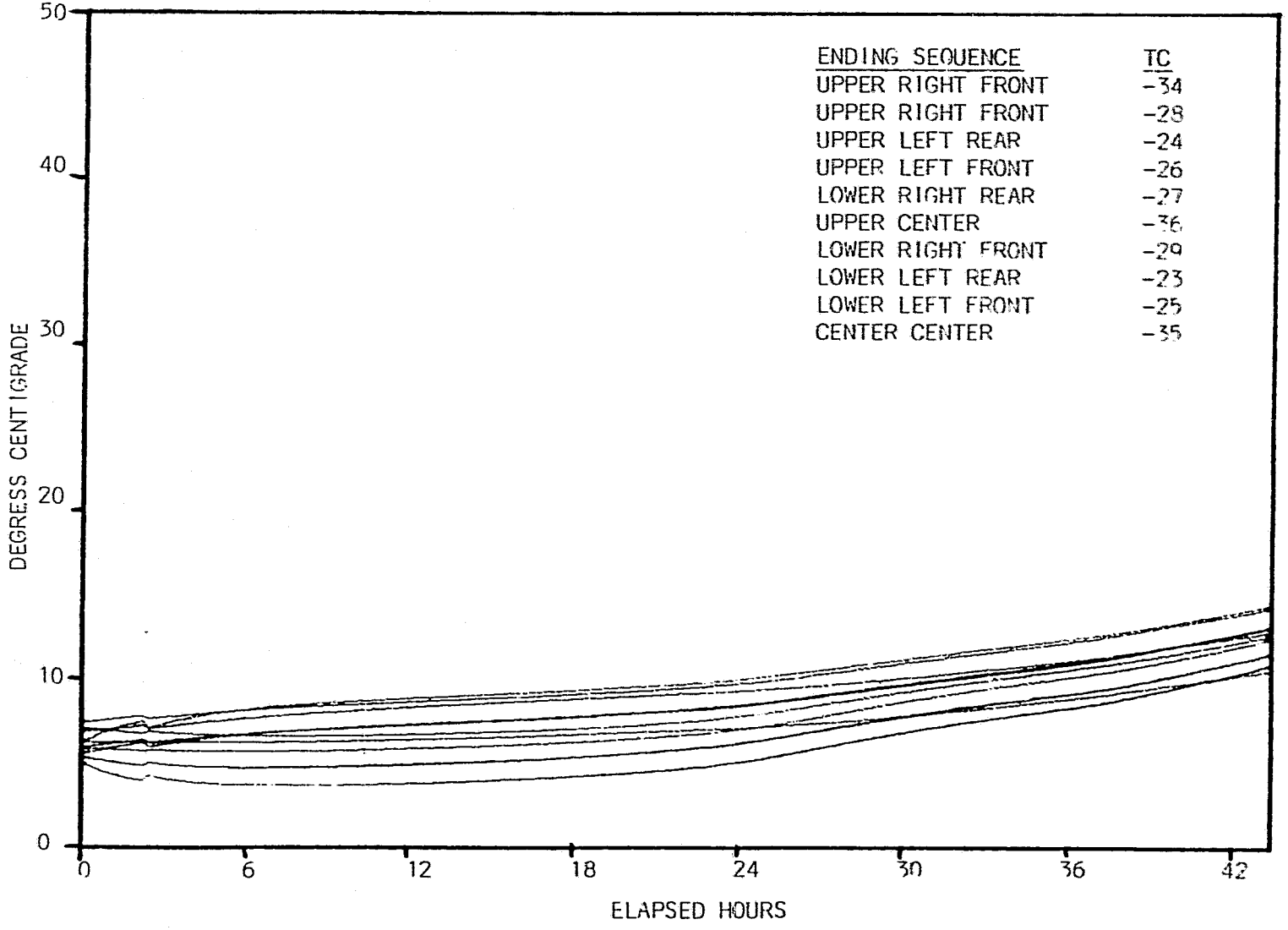
WESTERN SOLAR REFRIGERATION 12-1
LOADED MAINTENANCE AT 43°C AMBIENT
FREEZER TEMPERATURES



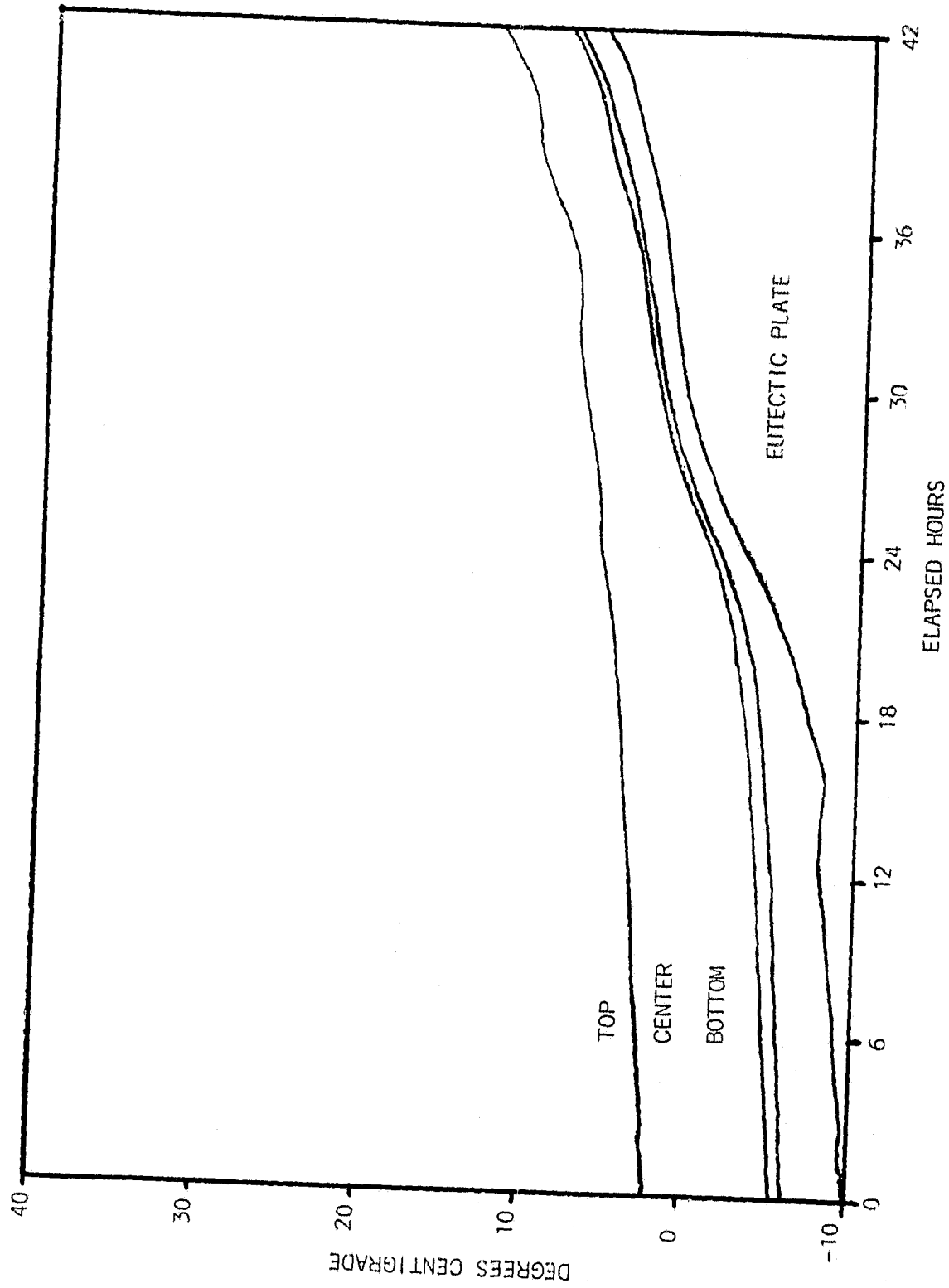
WESTERN SOLAR REFRIGERATION 12-2
LOADED MAINTENANCE AT 43°C AMBIENT
COMPRESSOR CURRENT & AVERAGE CURRENT



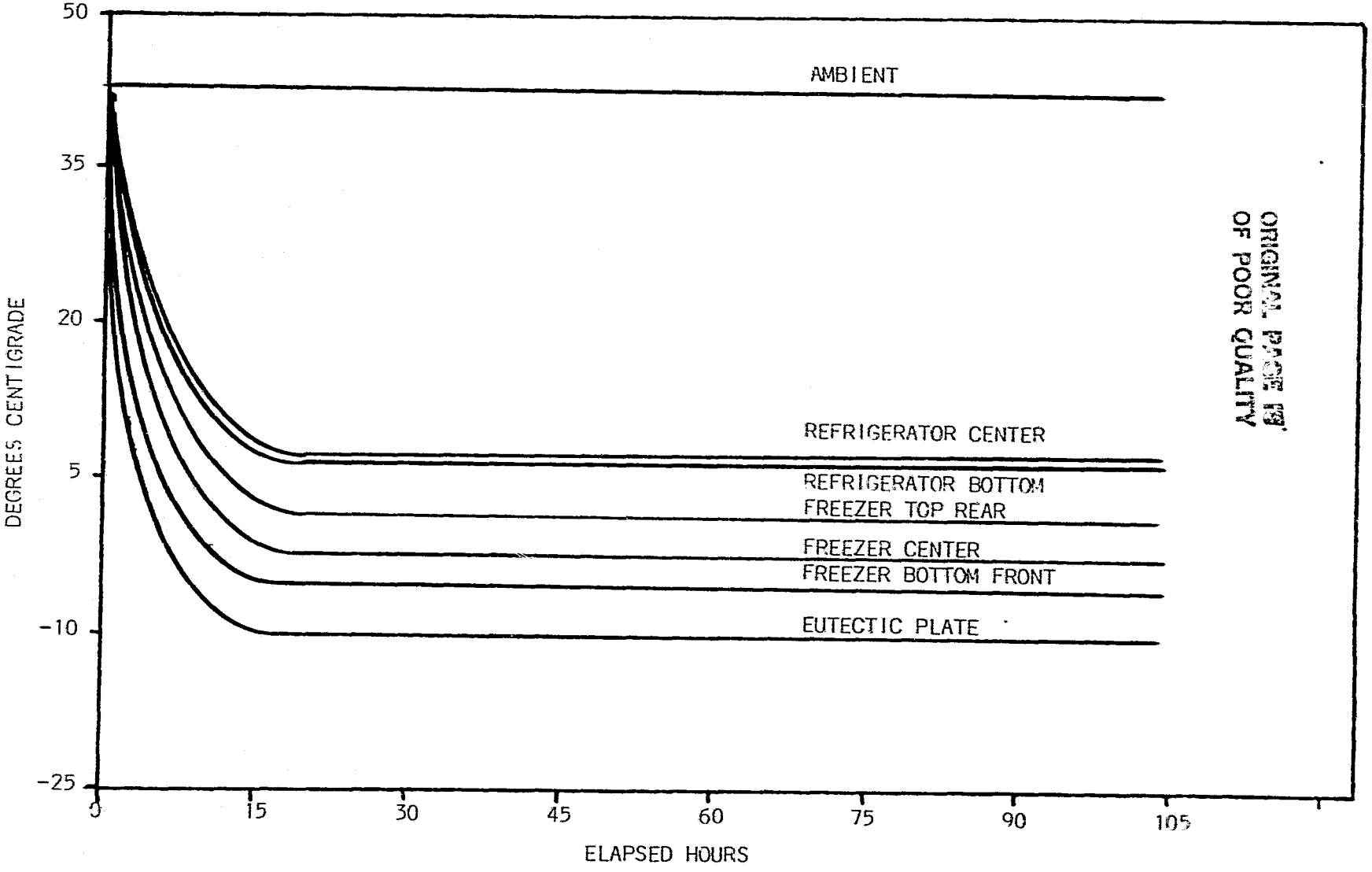
WESTERN SOLAR REFRIGERATION 12-1
HOLDOVER AT 43°C AMBIENT
BOTTLE TEMPERATURES



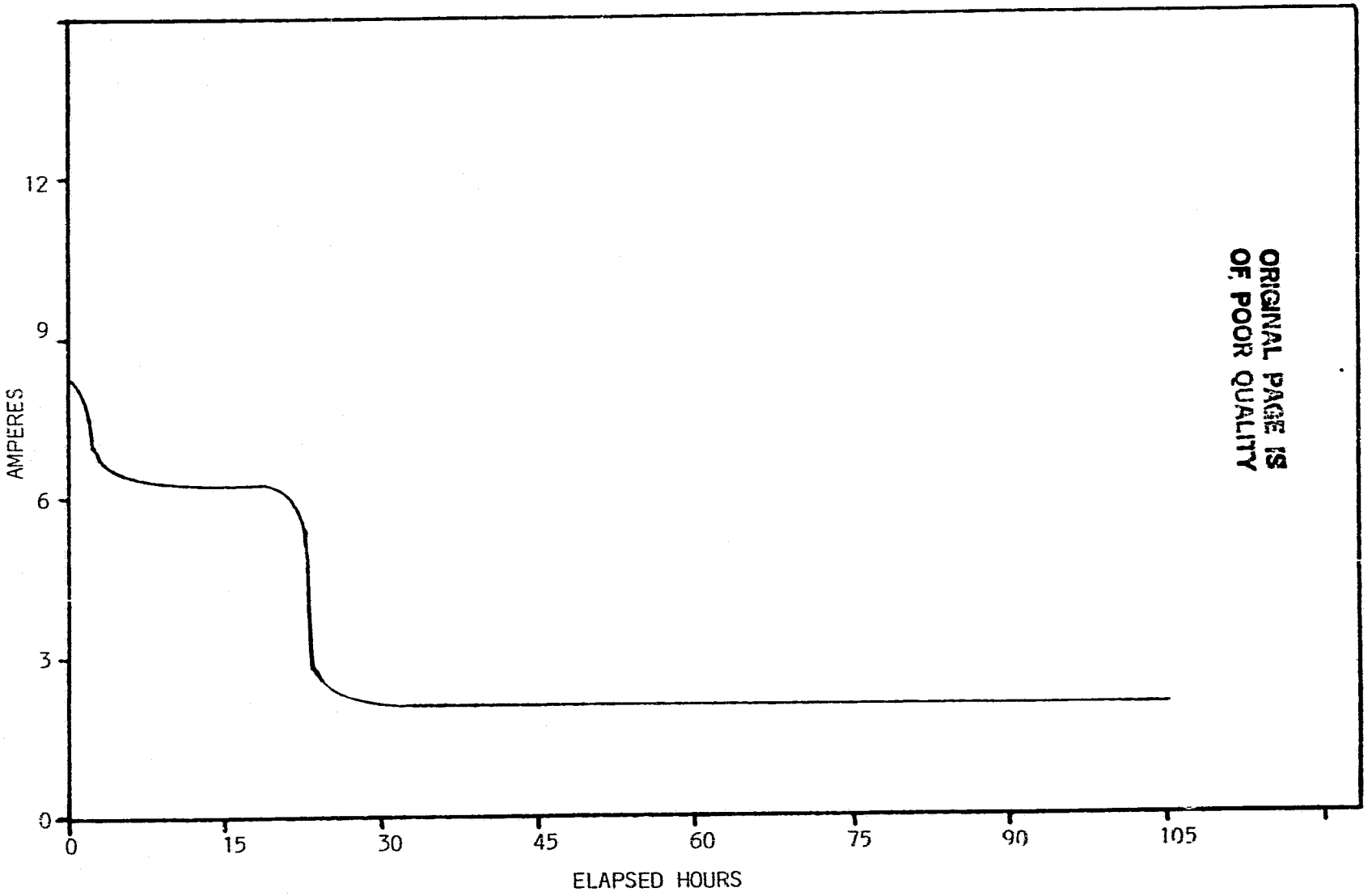
WESTERN SOLAR REFRIGERATION 12-1
HOLDOVER AT 43°C AMBIENT
FREEZER TEMPERATURES



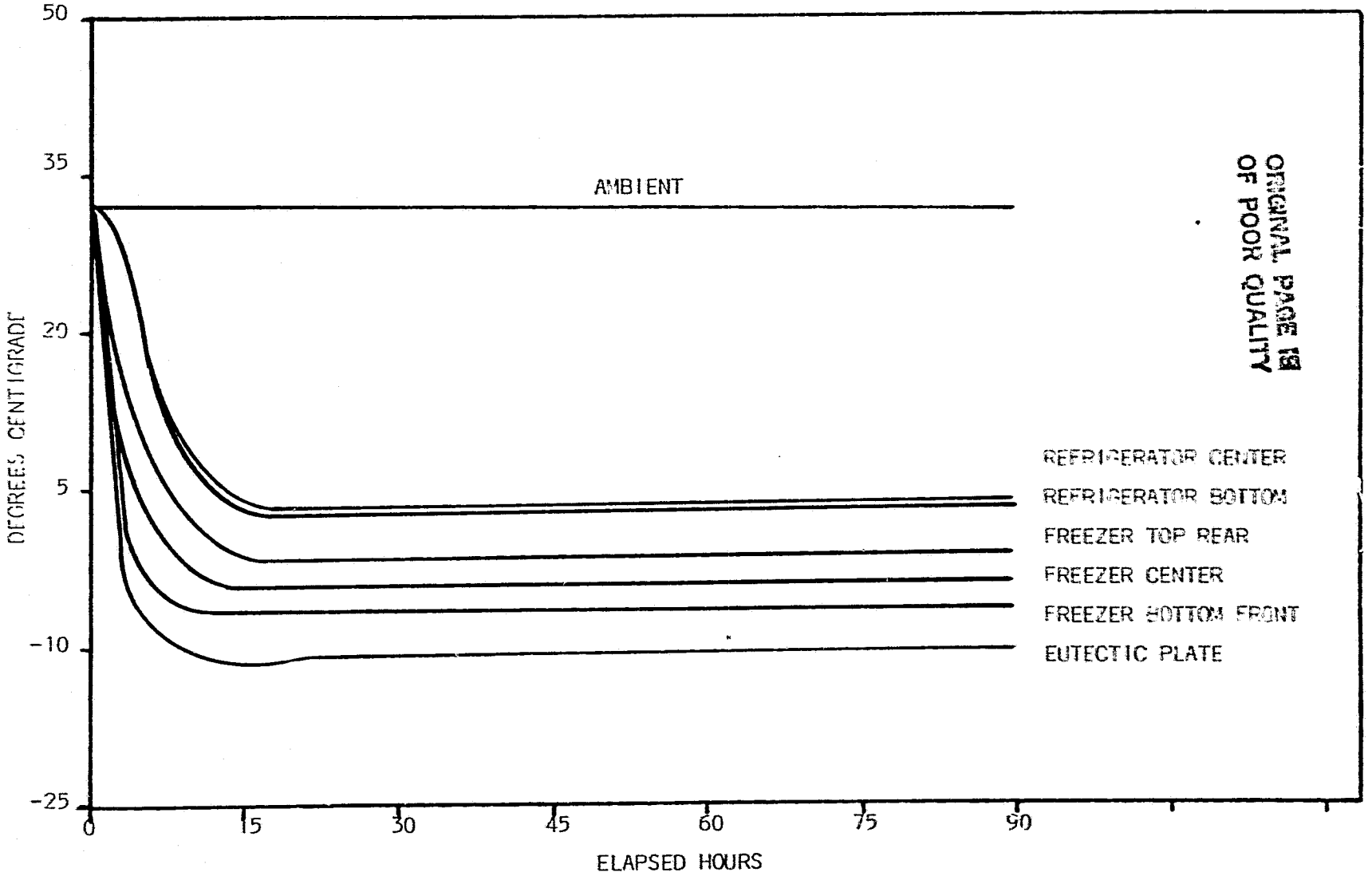
WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 43°C AMBIENT
TEMPERATURES



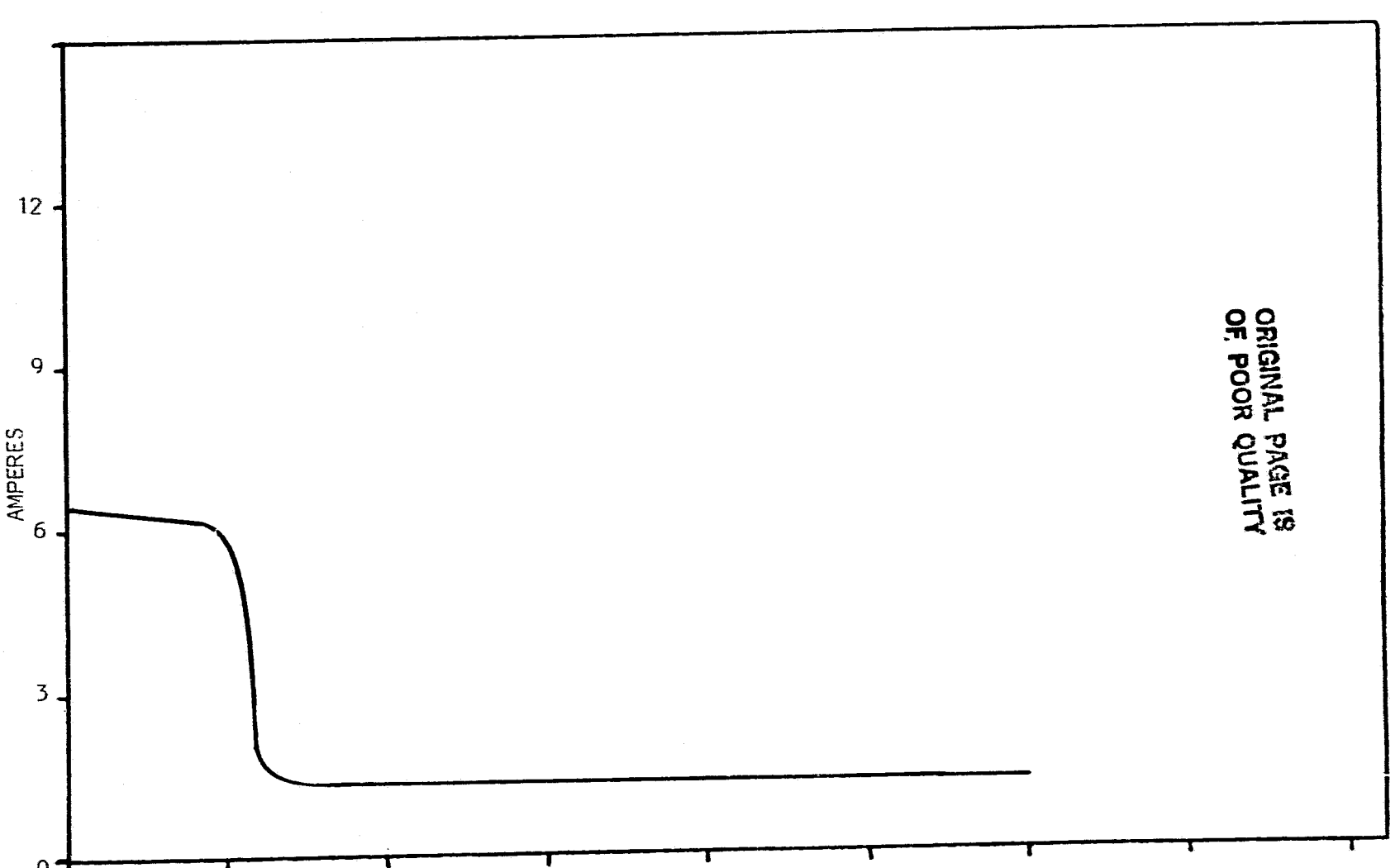
WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 43°C AMBIENT
AVERAGE CURRENT



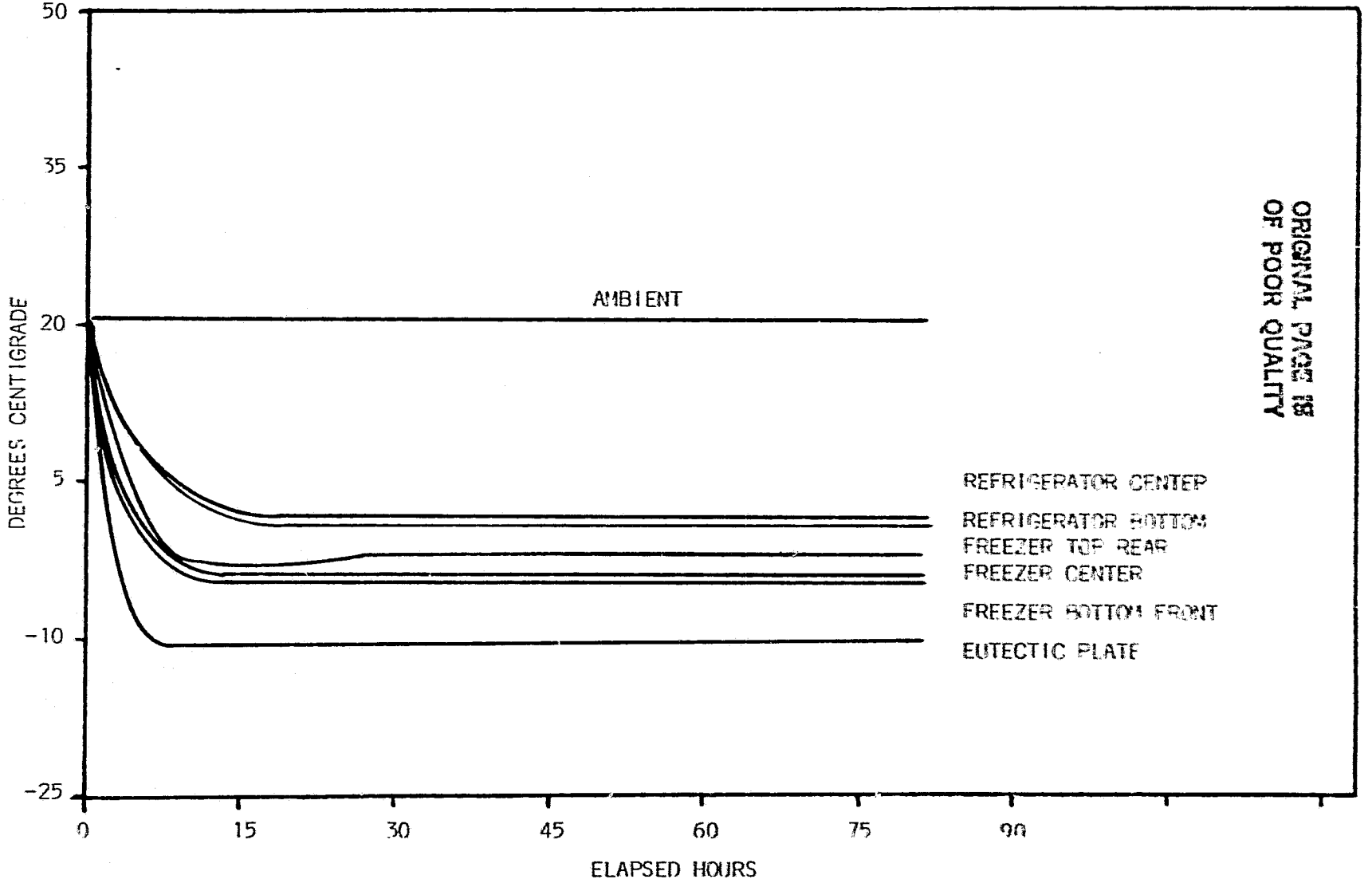
WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 32°C AMBIENT
TEMPERATURES



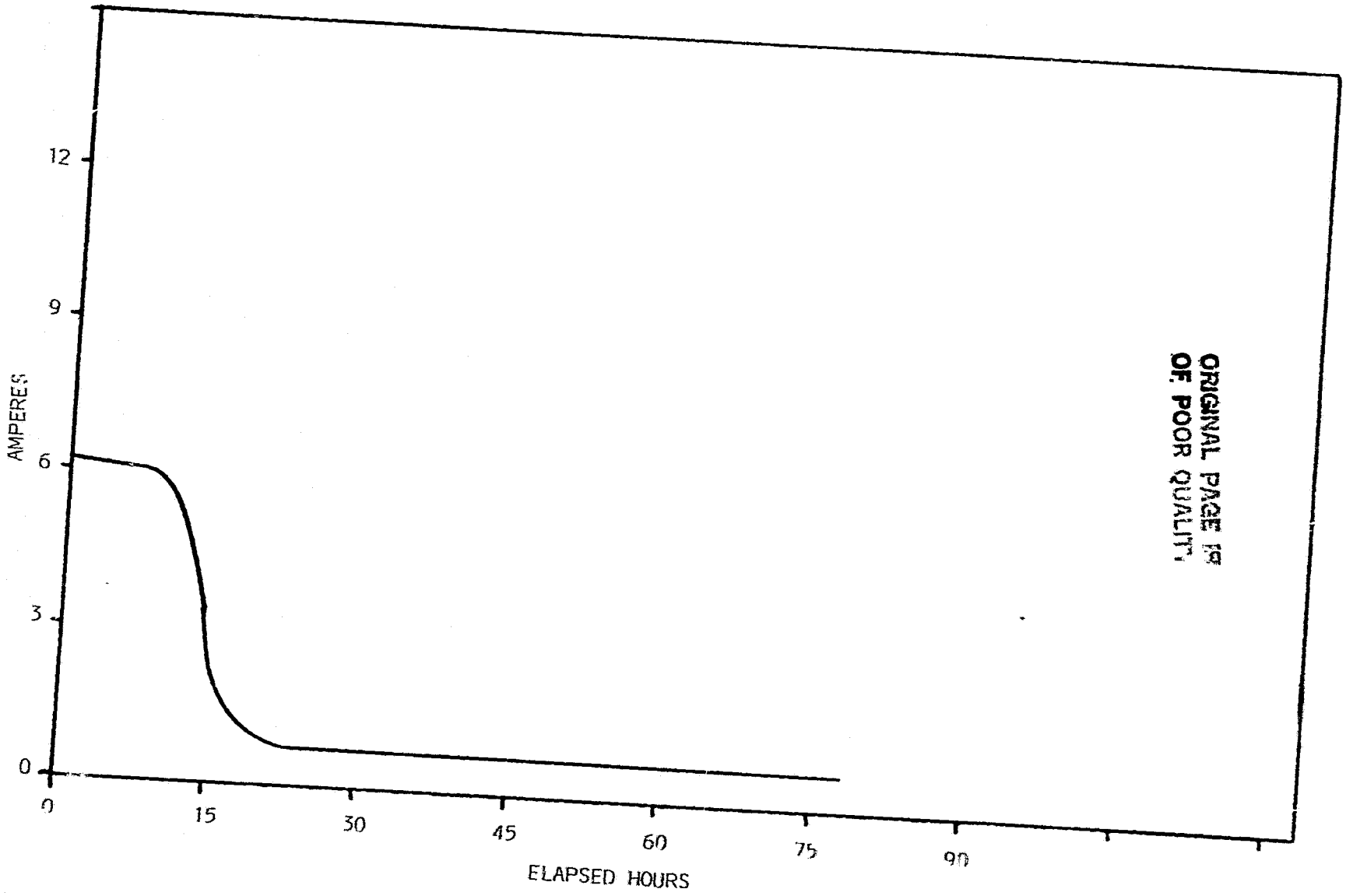
WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 32°C AMBIENT
AVERAGE CURRENT



WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 21°C AMBIENT
TEMPERATURES



WESTERN SOLAR REFRIGERATION 12-1
ACCEPTANCE TEST AT 21°C AMBIENT
AVERAGE CURRENT



POLAR PRODUCTS

SPECIFICATIONS

MODEL RR-2

Dimensions:		102 cm Height 71 cm Deep 96.5 cm Wide
Capacity:	adjustable	127 Liters max as either all refrigerator or freezer 20 liters min for either refrigerator or freezer in comb.
Weig. :	72 kg net	91 Kg. export shipping weight

Materials:

Molded polyethylene cabinet
All stainless latches and hinge
Aluminum base with caiked epoxy finish
Steel casters

Electrical:

Voltage regulator/battery charger	
Load disconnect threshold	11.0+/IV
Load reconnect threshold	13.0+.3V
Float voltage	14.1+.2V
Maximum power diversion to auxiliary load	30 amps
2 step charging sequence	constant current constant voltage float
Temperature compensated charger	-30 MV per ^{o}C

Charging is configured for automotive type lead calcium batteries. For other batteries consult factory for adjustments.

SALES OFFICE: 680 STONE CANYON ROAD, LOS ANGELES, CALIFORNIA 90077 USA PHONE 213-476-0082

SPECIFICATIONS (continued)

Fuse Protection:

Main circuit; 30 amp, automatic reset
Compressor; 8 amp, buss type

System is reverse polarity protected.

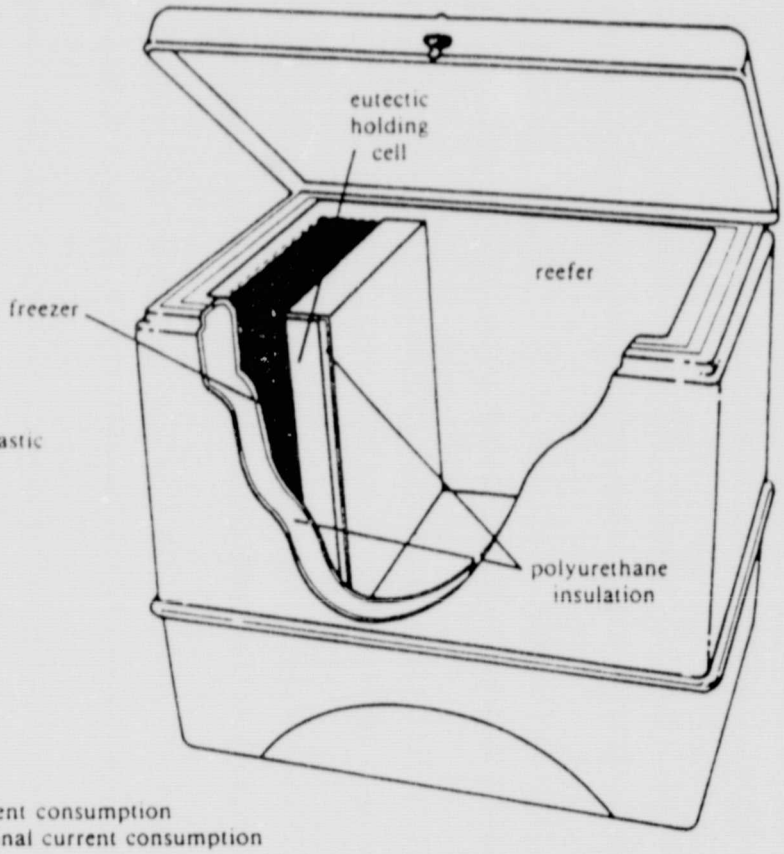
Refirgeration System & Performance:

Two independent refrigeration circuits-
Minimum voltage requirement for compressor 11.0 VDC-
Running current, each compressor under 4.8 amps-
Recommended system voltage input can range from 15 to 22 VDC-
Freezer temperatures can be adjusted to as low as -25o C in 43o C ambients-
Maximum ice production is 6 kg. per 24 hours in 43o C-
Holdover time; at 43o C ambient is 12 hours for -2o C-
Temperature rise (8o to 10o C) measured at last point-
Energy consumption per 24 hours at 43o C is 62 amp perhours box empty; 54 amps hours box full-
Per 24 hours at 25o C consumption is under 22 amp hours-

With our efforts of continued product improvement, we reserve the right to make any changes or modifications without prior notice.

All units are thoroughly tested prior to shipment. Because of our ridged quality control and engineering excellence we are able to offer a 5 year limited warranty. RR-2 is warranted against any defects in material or workmanship under designed use for a period of five (5) years on all parts and one (1) year on labor.

Specifications



Dimensions
- External: L 82.0 × H 91.0 × D 67.0 cm.
- Freezer Interior: L 9.5 × H 40.0 × D 46.5 cm
- Reefer Interior: L 49.5 × H 40.0 × D 46.5 cm

Capacity
- Freezer: 17.6 liters
- Reefer: 93.2 liters

Weight
- 55 kg.

Materials
- Durable thermo-plastic and fiberglass-reinforced plastic cabinet designed for use in hostile environments
- Chromed brass and stainless steel hardware
- Magnetic gasket for positive seal
- Steel casters
- Foamed in-place polyurethane insulation

Electrical Protection
- Under-voltage cutout: 10.8 VDC ± .2 VDC
- Over-voltage cutout: 15.5 – 16.0 VDC
- Over-current cutout: 10.0 amperes nominal
- Reverse voltage protection

Refrigeration System
- Compressor: 12 VDC at 5.5 amperes nominal current consumption
- Condenser fan motor: 12 VDC at .5 amperes nominal current consumption
- Condenser: air-cooled single pass
- Evaporator: eutectic holdover cell, approximately 1800 BTU at – 11°C.

Performance Requirements
- Operable from 11.5 – 15.5 VDC at 6.0 amperes nominal current consumption
- Power consumption not exceeding 20 ampere hours per 24 hours when operated at an ambient temperature of 24°C
- Freezer temperature regulation to – 7°C ± 2½° and regulatable to within 2°
- Reefer temperature regulation to 3°C and regulatable to within 2°

A full in-house quality control program is maintained to assure highest standards of reliability. All units are tested for 72 hours prior to shipment, and carry a one year warranty.

Western Solar Refrigeration

Western Solar Refrigeration, Inc.
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San Diego, California 92101
Tel: (714) 235-6002
TLX: 182 754 HQ LJLA