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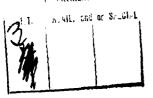
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U.S. ARM	Y ENGINEER RESEARCH AND DEVELOPME	NT LABORATORIES
	FORT BELVOIR VIRGINIA	
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	TASK NO. 1D 643303 D54503	FEB 1 5 1500 DDC-IRA B
	Carrier Air Conditioning Co	mpany
	MILITARY EQUIPMENT DEPART	MENT
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Prepared for

RESEARCH AND DEVELOPMENT PROCUREMENT OFFICE

U.S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

FORT BELVOIR, VIRGINIA

DA-44-009-AMC-1135 (T) **10-643303 D54503** 17.

Submitted by

Military Equipment Department, Carrier Air Conditioning Company

Syracuse, New York

27 September 1965

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1.0 INTRODUCTION

1.1 General

This report is submitted in fulfillment of contract DA-44-009-AMC-1135(T) dated June 2, 1965. In accordance with the requirements of the contract, a detailed engineering design is provided for a 24,000 Btu/hr thermoelectric environmental control unit. The design has been formulated to meet the system requirements described in Exhibit "A", Purchase Description of Request for Quotation No. 65-1816-B dated January 5, 1965 and Amendment No. 1 dated April 26, 1965.

The design presented in this report is a practical one for the application. The analytical and design optimization techniques which are employed have been qualified by previous experience in designing and building thermoelectric systems. Useful experience which was utilized in this study includes the design and development of a thermoelectric air conditioning system for submarines, performed under contracts NObs 77112 and 84598 for the Pureau of Ships, U.S. Navy Department. More recently the first thermoelectric air conditioning and control systems to be sold for a commercial application were developed by Carrier ¹⁶ for installation in the headquarters office building of S.C. Johnson and Son, Inc., Racine, Wisconsin. Twenty-eight complete systems have been in operation for approximately one year. The advantages and proven methods which were utilized in these systems have been incorporated into the environmental control unit design provided herein. The experience gained in these and other similar developments provides assurance that an actual system of the design shown can be built successfully and will perform in accordance with the operational characteristics described.

1.2 System Requirements

The Purchase Description calls for a complete engineering design of a thermoelectric environmental control unit to be optimized for minimum size and weight as well as for maximum efficiency. The design conditions for this system are detailed in the Purchase Description. A brief summary of the design conditions is listed in Table I:

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TABLE I.

Cooling capacity	24,000 Btu/hr
Ambient air temperature	120°F
Supply air temperature	92°F
Coefficient of performance	Minimum of 1.0
Heating capacity	Unspecified, consistent with full reversal of design operating voltage
Maximum dimensions	40 in. wide x 18 in. deep x 66 in. high
Maximum volume	15 cubic feet
Supply air flow	840 to 1,000
Supply air pressure	0.25 in. of water
Control	Provisions for both automatic and manual operation
Power conversion	Solid state without voltage transformation
Main power supply	208 volt, 3 phase, adaptable to both 60 and 400 cps.
Reliability	Capable of continuous operating for 10,000 hours
Maximum noise level	ASHRAE NC-60

1.3 Proposed Work

On February 5, 1965 Carrier Proposal No. MD8512-2 was submitted to USAERDL in reply to the subject Proposal Request. This proposal detailed the work required to meet the specifications of the Purchase Description. No exceptions were taken to these specifications. The proposed work included a complete system analysis in order to provide an optimum design for the subject unit. This work has subsequently been completed as proposed; the exact procedure followed and the results obtained are described in the following sections of this report. Antibiotical and a second secon

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1.4 Summary of Work Completed

In order to formulate the system design, an extensive optimization analysis was carried out. In this analysis, twelve design parameters were optimized for minimum weight and maximum efficiency, four of which describe the TE panel configuration and eight which describe the heat exchanger characteristics. Next, a study was made of the various system arrangements that could incorporate the optimized TE coil into a practical design which would meet the requirements of the purchase description. Consideration was also given to the type of fans which could be utilized with these various system arrangements. Similarly, various methods for controlling the system were studied. From the results of these studies, a final system design was developed as shown in Section 3.0 of this report. Further calculations were then made to determine the performance characteristics of this unit over a complete range of operating conditions. Performance information is contained in Section 4.3.

The system described in Section 3.0 is 28 inches wide by 18 inches deep by 63 inches high, weighs approximately 380 pounds, operates at an overall coefficient of performance (COP) of 1.12, and has a net cooling capacity of 24,000 Btu/hr at design operating conditions. The dual frequency vaneaxial fans selected for the design are well suited to meet the reliability and noise requirements. The power rectifier will furnish 3 phase, full wave d-c power without voltage transformation. The control system will furnish modulated capacity control from full cooling to full heating as required by the system load.

2.0 SYSTEM ANALYSIS

2.1 <u>General</u>

In order to make a complete system analysis, the environmental control unit was divided into three subsystems which, for convenience purposes, can be considered separately. These subsystems consist of the thermoelectric coil, the air handling system, and the control and power conversion system. The thermoelectric coil and the air handling system are very closely related physically. However, for purposes of design, the control and power conversion system may be considered to be independent of the other subsystems so far as physical interrelations are concerned. Some reasons for this include the small size, light weight, and high efficiency of this subsystem. Also, because this portion of the system is physically connected to the other parts by light flexible wire, it is not restricted in its physical location or orientation to the others.

2.2 Thermoelectric Coil

There are 14 major physical and operating parameters that affect the size, weight, and performance of an air-to-air thermoelectric unit. These are:

- 1. Element length
- 2. Element diameter
- 3. Element packing density (ratio of element area to panel area)
- 4. Conductor strap thickness
- 5. Operating current
- 6. Internal fin spacing
- 7. External fin spacing
- 8. Internal fin thickness
- 9. External fin thickness
- 10. Internal fin height
- 11. External fin height
- 12. Fin material
- 13. Internal air velocity
- 14. External air velocity

Because the thermoelectric coil is the heaviest part of the system, it is of considerable importance that this coil be optimized for minimum weight. The system fans also represent a substantial portion of the overall weight, the size and power requirements of which must also be included in this study in order to yield an optimum system. Fortunately, some of the system parameters do not require optimization. For example, the fin material must be aluminum, since it has the highest ratio of thermal conductivity to weight. Also, irom past experience, it is known that the optimum strap thickness is considerably less than the minimum thickness that can be physically handled efficiently. The minimum conductor strap thickness is considered to be 0.020 inches for this system.

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2.2.1 <u>System Optimization Procedure</u>. In order to optimize the remaining 12 parameters, equations were written which describe the system in terms of these parameters. These equations were then programmed into an analog computer and solved while each parameter was varied through a complete range of values. The results were then plotted to show variation in system coefficient of performance over a range of operating current density and for various values of the parameter being varied. An example of this plot is shown in Figure 1. This curve illustrates the significance of parameter variation since it shows the large change in performance that can be expected as a result of changes in internal air velocity. Not all of the parameters have this much effect on system performance or weight. Fortunately, the optimum value of each parameter is somewhat independent of the others and; therefore, this procedure converges on an optimum design quite rapidly. To initiate this procedure, it was necessary to first assume a value for each parameter. Next, for each parameter, calculations were made over the complete range and the optimum parameter value was then used while the next parameter was varied. This procedure continued until all parameters were optimized the first time, then the entire procedure was repeated a second time to insure that all values represented the true optimum. Table II shows these parameters in the order they were optimized, the initial assumed parameter value, the parameter value after the first optimization, and the final value after the second optimization.

TABLE II

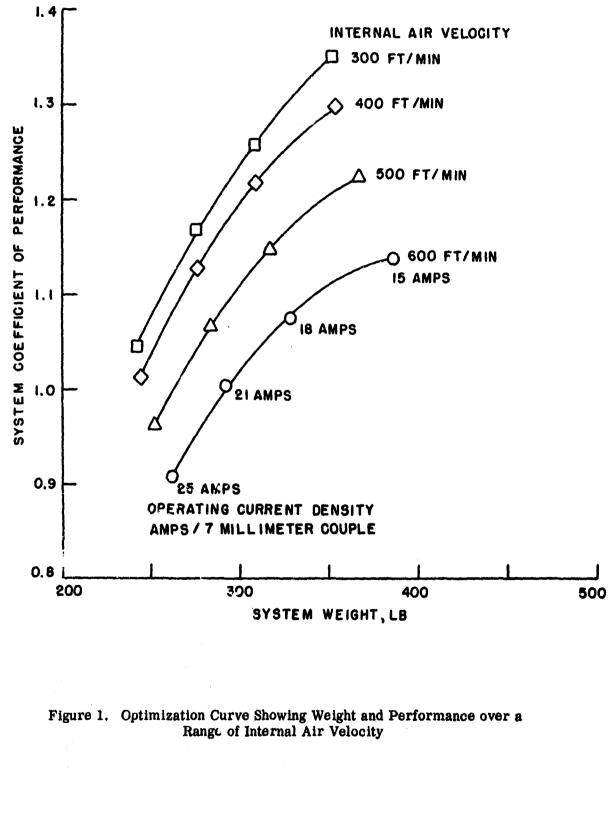
PARAMETER	ASSUMED INITIAL VALUE	VALUE AFTER FIRST <u>OPTIMIZATION</u>	VALUE AFTER SECOND OPTIMIZATION
Packing density (%)	/	50	50
Internal air velocity (ft/min.)	600	300	300
External air velocity (ft/min.)	1000	800	700
Internal fin spacing (fin/in.)	24	28	30
External fin spacing (fin/in.)	24	28	30
Internal fin thickness (in.)	0.010	0.007	0.00 6
External fin thickness (in.)	0.010	0.007	0.006
Internal fin height (in.)	1.00	0.80	0.80
External fin height (in.)	1.00	1.00	1.00

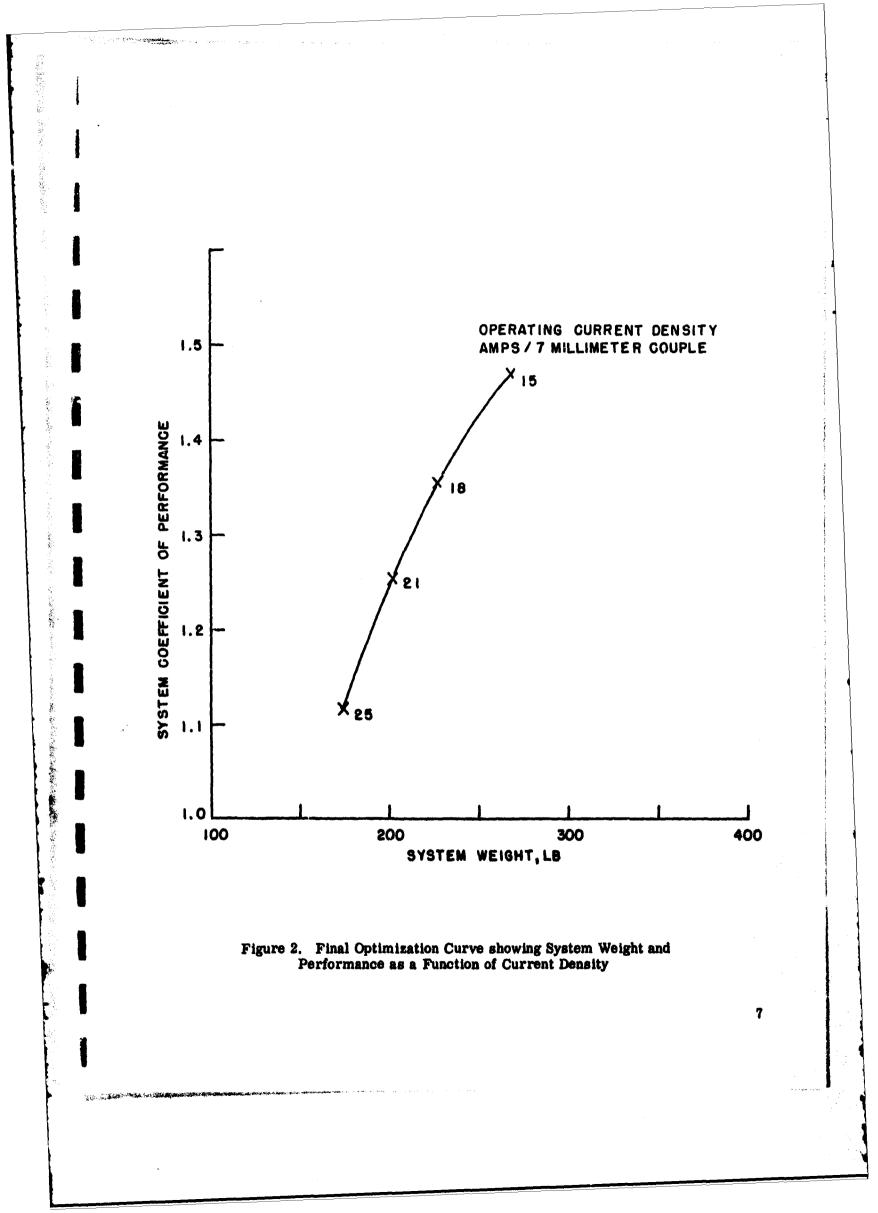
Some of the thermoelectric panel parameters are not shown in Table II. The element length is not included because this value was set up as a variable on the computer program and was varied to give the maximum coefficient of performance for each calculation (the element length was optimized for each solution). The other parameters not shown are element diameter and operating current. Indirectly, these values are combined into the current density and show up as one of the variables on the optimization curve, Figure 1. The element diameter is not actually optimized until the system design is finalized. Figure 2 shows the final results of this optimization procedure. This curve shows the optimum relation between system weight and system performance over the practical range of operating current density.

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It should be pointed out that in this study, reference is always made to overall <u>system</u> weight and <u>system</u> performance, not thermoelectric coil weight or performance. System weight includes the weight of the thermoelectric coil, the weight of the fans (which is calculated as a function of the fan power requirement) and the weight of the unit frame and manifolds which are assumed to equal 50 per cent of the fan and coil weight. System coefficient of performance is defined as the system cooling capacity divided by system power required. System power required includes fan power as well as the power required by the thermoelectric coil. Fan power is calculated from fin pressure drop and air velocity based on an overall fan-motor efficiency of 40 per cent. System cooling capacity is always equal to 24,000 Btu/hr, but is calculated by subtracting the internal fan power from the thermoelectric coil cooling capacity.

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2.2.2. <u>Analog Procedure</u>. The optimization equations and the analog procedure used to solve these equations are essentially the same as those described in detail in Carrier's Proposal No. MD-8512-2. The exact equations and calculations are presented in the original design calculations attached to Copy No. 1 of this report.

2.2.3 <u>Material Parameters</u>. Thermoelectric material parameters used in this study are also the same as described in the reference proposal. These parameters represent average values obtained from actual measurement during fabrication of more than 600 thermoelectric panels built by Carrier, and are based on currently available commercial thermoelectric material. Table III shows the variation in material parameters with temperature.

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104
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TABLE III

Although these parameter values do vary with temperature, they were considered constant at the 152° F value for the optimization calculations. This is justified because the figure of merit is directly related to efficiency and this parameter does not vary with temperature over this range. It is important to note, however, that these variations are taken into account in the final design and the performance calculations described in Section 3, 0 and Section 4.3.

The heat exchanger surfaces utilized in this analysis are a straight fin laminar flow type. The performance characteristics of these surfaces may be found in the original design calculations section.

2.3 Air Handling System

Optimization of the air handling system was accomplished to the greatest extent possible as described in paragraph 2.2.1. Other aspects of this subsystem which were further analyzed include fan efficiency, fan type, system noise level, and air manifold arrangement.

Fan efficiency has a definite relationship to fan type. If dual fans (two fans operating in parallel flow) are used for both the internal and external air streams, these fans would operate at specific speeds of 82,500 and 88,000 respectively:

[specific speed = (rpm) (cfm)^{1/2} / (inch water pressure)^{3/4}]

These specific speed ranges represent an efficient operating condition for vaneaxial type fans. If it were desirable to use forward-curved, squirrel-cage type blowers; two doubleinlet scrolls or four single-inlet units should be used. It was estimated that the overall fanmotor efficiency of the vaneaxial units would be twice that of the squirrel-cage units. Other type blowers available were not considered to be feasible for this system.

In order to meet the dual frequency requirement, it is necessary that fan motors operate at both 60 and 400 cps. Dual frequency motors are available with separate windings within the same motor frame. Also, statically commutated motors have recently been developed which will operate on either frequency; however, information obtained from the manufacturers indicate that these motors are not sufficiently developed to be considered at this time. Thus, it appears that the dual frequency motors are best suited for this application. With these motors, it will be necessary to connect the power to the proper winding terminals depending on the power supply frequency.

With respect to system noise level, it appears that the NC-60 requirement could be met using either type of blower considered. Typically a squirrel-cage blower will generate the greatest noise in the low octave bands where the human ear is less sensitive. Although the vaneaxial fan generates the highest noise levels in the center octave bands, this noise is more readily attenuated with acoustical insulation. In this system, one inch thick fiberglass insulation will be used wherever it will effectively absorb sound or decrease thermal conduction losses.

Probably the most important consideration related to the air handling system is the manifold arrangement. This, in conjunction with the type and number of fans used, largely dictates the size and shape of the overall unit. The possibility exists that the manifolds could be eliminated by going to a cross-flow coil design; however, this presents other problems. In a crossflow design, the coil must be shallow in two directions in order to keep the fan pressure requirements at a reasonable level. Making the coil shallow in two directions on a system of this size results in a long thin coil which is difficult to design into a system. A counterflow coil, being shallow in only one direction, does not have this limitation.

In order to obtain a good manifold arrangement, five possible systems were sketched out and the advantages and disadvantages of each were considered. Systems 1, 2, and 3 were relatively short and wide. A combination of squirrel-cage and vaneaxial fans were used in System 1. System 2 was similar except that it used only vaneaxial fans. System 3 used vaneaxial fans in a somewhat different arrangement than System 2. The major disadvantages of all three systems was large size and poor fan and manifold air entrance arrangements. System 4 was a relatively high and narrow arrangement using all vaneaxial fans. This system was smaller and had considerably better air flow arrangements than the other three systems. From this arrangement it became obvious that System 4 could be made shorter by increasing the coil depth slightly. System 5 includes this change which saved 12 per cent in system volume and 20 per cent in manifold length. The penalty for this saving was a 20 per cent increase in fan power resulting in a three and one-half per cent decrease in system coefficient of performance.

System 5 was then selected as the best fan and manifold arrangement to be incorporated into the final design. The advantages of this system arrangement are pointed out in Section 3.0 of this report.

2.4 Control and Power Conversion System

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The object of the control and power conversion system is to regulate d-c power to the thermoelectric coil in response to a signal obtained from the temperature sensor. In order to provide this power regulation, two step-control methods and five proportionalcontrol methods were considered. The criteria used to evaluate these methods were size, efficiency, reliability, degree of modulation, and cost.

The first method considered was a switching scheme whereby the total current through the thermoelectric coil could be increased in discrete steps by automatically reconnecting the thermoelectric modules from a series to a parallel circuit. The main objection to this method is the increased cost of the coil, since a proportionately larger number of smaller couples would be required if the unit were to operate at full capacity with the modules connected in parallel. Transforming the power to a lower voltage would solve the problem mentioned above, but this could be accomplished only at the expense of transformer weight and power loss. In addition, the specifications stated that power conversion should be accomplished without voltage transformation.

A simple two-step control was considered whereby the voltage to the coil would be increased by switching from half-wave to full-wave rectification. The limited degree of modulation attainable, which in turn affects the system efficiency, is the main dis.dvantage of this method. Also, a special power generator would be necessary in order to operate on half-wave power.

The five types of proportional control systems that were considered include: (1) motor-generator set; (2) magnetic amplifier and rectifier; (3) servo-driven variable transformer; (4) thyratron bridge; (5) silicon controlled rectifier bridge. SCR's and thyratrons can be used in circuits other than the bridge circuits to accomplish proportional power conversion; however, the bridge circuit is more efficient and requires fewer power components.

The SCR bridge control method is easily the best of those considered above. The reasons for this largely involve the small size, high efficiency, and low cost of this system. Reliability information on SCR systems is incomplete at this time, but experience to date indicates this method is at least as reliable as any of the other methods considered. On this basis, the SCR full-wave bridge method was used in the final system design.

3.0 SYSTEM DESIGN

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3.1 Thermoelectric Coil

The final design of the thermoelectric environmental control unit was largely dictated by the results obtained from the system analysis. However, in order to make this design realistic, experience and engineering knowledge require that numerical values obtained from the computer study be somewhat compromised.

It has been well substantiated that there are cooling capacity losses in this type system that are very difficult to calculate. This includes such losses as air leakage, joule heating in electrical wires and connectors, structural heat conduction, ductwork and manifold conduction, thermoelectric material parameter variation, and non-uniform air flow distribution. Added together, these losses equal nearly ten per cent of the system cooling capacity. Consequently, for a net capacity of 24,000 Btu/hr, the system should actually be designed for a capacity of 26,400 Btu/hr. Figure 3 shows the relationship between system weight and system performance when this ten per cent loss factor is included.

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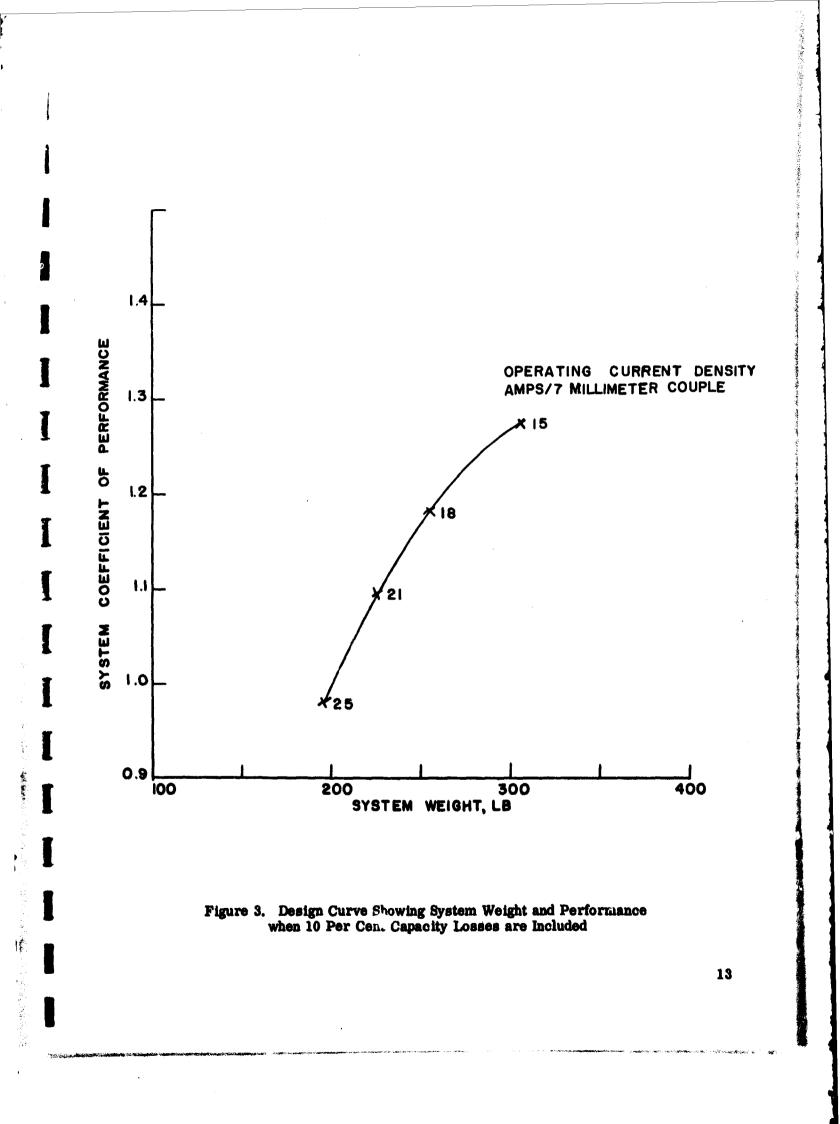
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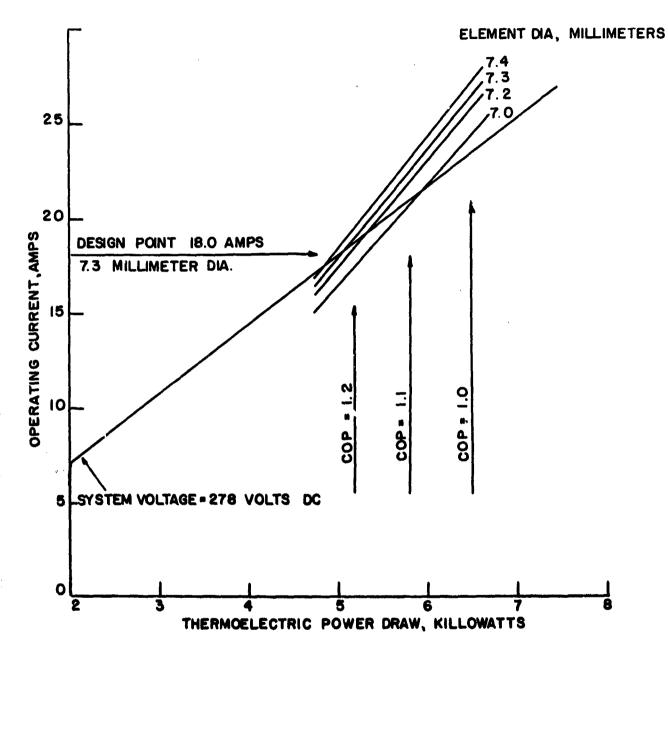
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As mentioned in paragraph 2.2.1, the relationship between operating current and element diameter must be such that the system will operate at 278 volts. A graphical method shown in Figure 4 was used to determine this relationship. As shown on this graph, a single line represents the relationship between operating current, d-c power and voltage (design voltage = 278 volts d-c). The diagonal lines which cross the voltage line represent the relationship between current and power for systems made up of various diameter elements. The vertical lines show the approximate relationship between system coefficient of performance and d-c power draw. Thus, a system COP of 1.20 may be obtained by using 7.3 millimeter diameter elements and the system should operate at 18.0 amperes.

More exact calculations of the system performance later determined that the element diameter should be 6.9 mm. and the system should operate at 17.5 amperes. Reasons for this deviation from the optimum result include:

- (1) Thermoelectric material parameters were considered to be independent of temperature for the optimization calculations.
- (2) Changes in coil depth and air flow velocities were made in order to compact the system as described in paragraph 2.2.





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Figure 4. Graphical Determination of Thermoelectric Element Diameter

3.2 Control and Power Conversion

Although the system analysis determined that an SCR full-wave bridge would provide the best means of supplying power to the thermoelectric coil, a number of considerations must be taken into account before the exact control and power conversions circuit is finalized. The power conversion is accomplished with a 3-phase bridge capable of supplying approximately six kilowatts of d-c power when operated from a 208 volt, 60 or 400 cycle supply. After full-wave rectification and allowing for a 2.5 volt drop across the SCR's, the 208 volt a-c supply converts to 278 volts d-c. The magnitude of the d-c voltage can be controlled by controlling the conduction time of the SCR's. Thus, the main problem was to design the necessary circuitry to control the SCR conduction time in proportion to the deviation from the system set point temperature. Also, the polarity of the output voltage must be reversed as the heat pumping requirement changes from heating to cooling and vice versa. Additional circuitry must be designed for manual operation as well as for over-temperature protection.

Automatic reversing could be accomplished statically by using 12 SCR's in the bridge, or by using a double pole, double throw relay in conjunction with a bridge containing three SCR's and three diodes. The relay method was used because of its simplicity.

The control circuitry includes a firing circuit, a signal shaping network, an amplifier, a temperature sensor and a Schmitt trigger. The Schmitt trigger is used to convert the analog signal from the temperature sensor to a digital signal for operating the reversing relay.

The temperature sensor consists of a thermistor connected in a d-c bridge. The voltage signal from the bridge is proportional to the resistance of the usermistor. The amplifier is required to increase this signal to a workable level.

The signal shaping network is required to provide a dead zone about the set point temperature and also to provide a 180 degree phase shift in the amplifier voltage signal when cooling is required.

The firing circuit controls the conduction time of the SCR's. The SCR's are nonconducting until voltage pulses from the firing circuit are supplied to the SCR gates, at which time conduction begins and continues until the end of a cycle.

Transistors and other semiconductor devices used in this dircuit have characteristics which vary with temperature. Therefore, the circuit is temperature compensated so that temperature change of the control components will not affect the operation of the unit.

A diode bypass of the SCR's is used for manual operation. A relay connects three diodes into the bridge in place of the three SCR's. All of the automatic circuitry is bypassed and maximum power will be supplied to the heat pump.

A thermistor over-temperature protection network was designed to protect the thermoelectric modules from excessively high temperatures that might result from a fan failure. If a thermistor detects a high temperature condition, power to the thermoelectric modules is removed.

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A radio frequency filter was designed and is used in the system for suppression of interference which will be introduced by the switching of the SCR's.

The use of a filter for reducing the ripple at low output voltage was studied. The results of the study indicated that the filter was not worth the extra weight it would add to the system.

3.3 Design Details

The physical system configuration and the design system performance are outlined below:

3.3.1 Physical Configuration

a. Thermoelectric Panels

Element length, 0.087 inch Element diameter, 6.9 mm. Element packing density, 0.45 Conductor strap thickness, 0.020 inch Number of couples, 34 per panel Panel size, 3.625 x 2.540 x 0.177 inches

b. Heat Exchangers

Parameter	Internal HX	External HX
Fin spacing, fin/inch	30	30
Fin material	Aluminum	Aluminum
Fin thickness, inch	0.006	0.008
Fin height, inch	0.80	1.00
Size, inches	5, 25 x 7, 37 x 0, 94	5, 25 x 7, 37 x 1, 04

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c. Thermoelectric Modules

Number of TE panels per module	4
Number of TE couples per module	136
Number of heat exchanges per module	1 internal, 1 external
Size	5.25 x 7.37 x 2.06 inches
Weight	2.67 lb

d. Fans

Parameter	Internal	External
Manufacturer	General Dynamics	General Dynamics
Туре	Vaneaxial	Vaneaxial
Identification	Proposal No. RA-5519	Proposal No. RA-5520
Model No.	9071-A	9092-A
Length, inches	7-1/4	10-1/8
Diameter, inches	8-3/4	11
Weight, lb	13-1/2	28

e. Control and Monitor Fanel

Size	14 x 13 x 4 inches
Weight	5 lb

f. Control and Power Conversion Package

Size	20 x 8 x 4 inches
Weight	16 lb

g. Complete Thermoelectric System (24,000 Btu/hr)

Number of TE modules	60
Number of TE panels	240
Number of TE couples	8160
Number of internal fans	2
Number of external fans	2
Overall size	18 in, deep x 28 in, wide x 63 in, high
Overall volume	18.4 cubic feet
Overall weight	380 lb

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3.3.2 System Performance (Design Point Operation)

a. Thermoelectric Coil

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	Main Power Supply Frequency	
	60 cps	400 cps
Current, amperes d-c	17.5	17.7
Voltage, volts d-c	278	278
Pover draw, kilowatts	4.86	4.92
Cooling capacity, Btu/hr	28,050	28, 230
Coefficient of performance	1.69	1,68
Internal air velocity, ft/min	359	402
External air velocity, ft/min	838	945
b. Internal Fan, Each Unit		
	60 cps	400 cps
Voltage, volts a-c	208	208
Phase	3	3
Current, amperes a-c	0.6	1,5
Power factor	0.85	0.51
Motor efficiency	0.65	0.57
Brake horsepower, hp	0.16	0.21
Power draw, watts	184	275
Sound pressure level, C-scale	70	70
Guaranteed life, hr	3,000	3,000
Expected life, hr	20,000	20,000
Air flow, cfm	510	560
Air pressure, in. of water	1.26	1.43

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c. External Fans, Each Unit

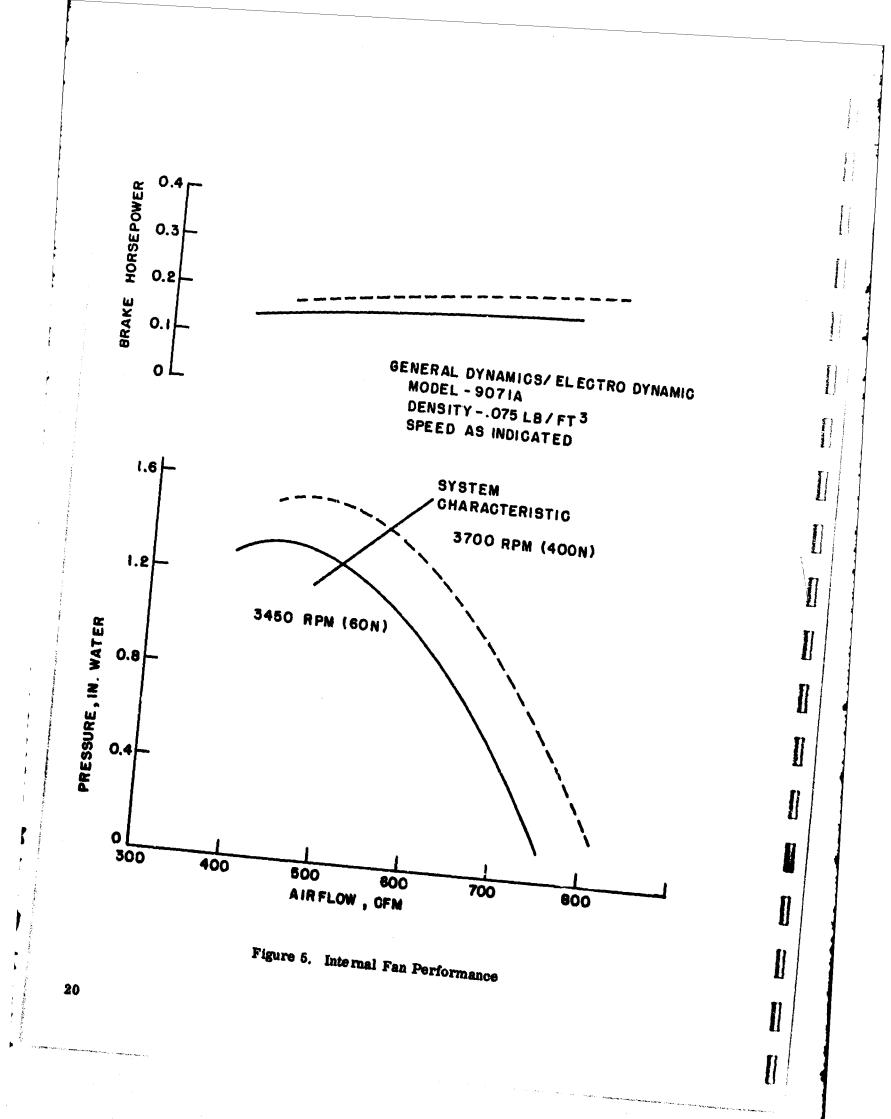
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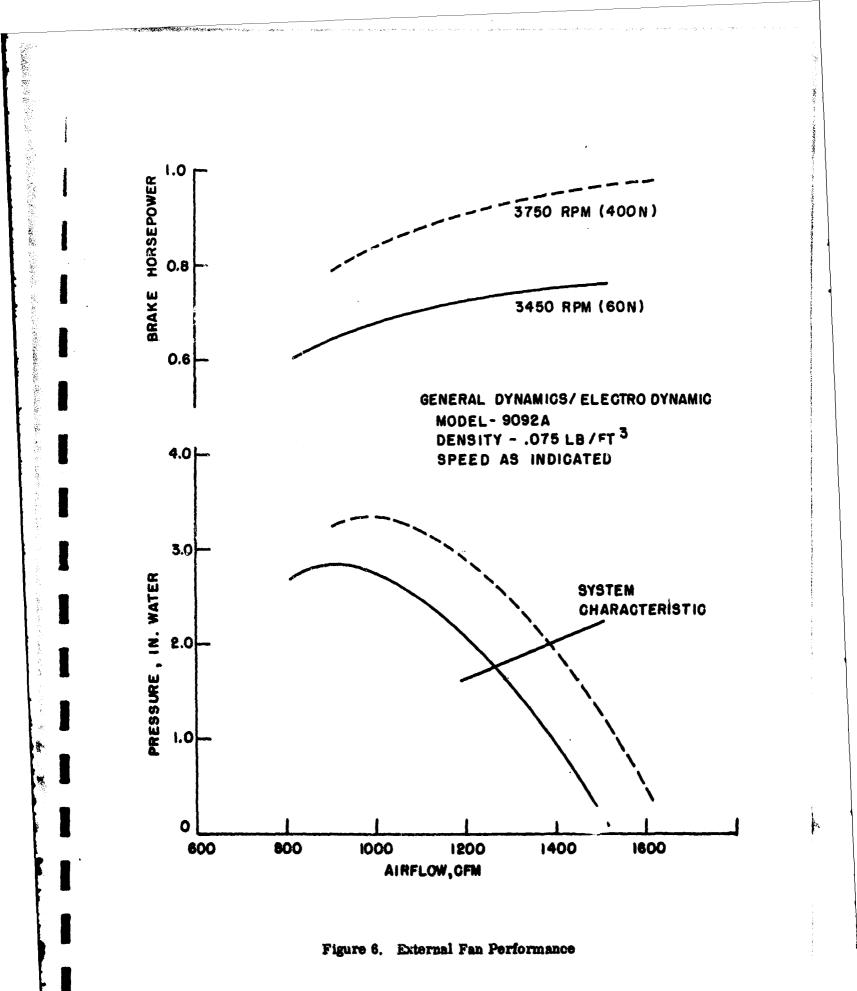
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		Main Power Supply Frequency	
		<u>60 cps</u>	400 cps
Voltage, v	olts a-c	208	208
Phase		3	3
Current,	amperes a-c	2.4	5.3
Power fac	tor	0.90	0.57
Motor effi	ciency	0.70	0.63
Brake hcr	sepower, hp	0.73	0.92
Power dra	aw, watts	780	1090
Sound pre	ssure level, C-scale	80	80
Guarantee	d life, hr	3,000	3,000
Expected	life, hr	20,000	20,000
Air flow,	cfm	1260	1380
Air press	ure, in. of water	1.75	2.00
d. Complete System			
		<u>60 cps</u>	400 cps
Voltage,	volts a-c	208	208
Current,	amperes a-c	19.7	24.4
Power fac	tor	0.99	0.89
Phase		3	3
Power dra	aw, kilowatts	6.84	7.70
Cooling ca	apacity, Btu/hr	26,230	25,800
Overall c	pefficient of	1.12	0.98

Performance curves for the internal and external fans are shown in Figures 5 and 6, respectively. These graphs also show the system characteristic curves.





3.4 Design Drawings

Detailed engineering drawings are included in Appendix A. Most of these are assembly drawings, and the appropriate bill of material for each assembly is shown on the drawing. Exact design details for all special components which are pertinent to the operation of the system are also shown on these drawings.

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Drawing number <u>R-1058-3429</u> shows a thermoelectric panel assembly. In operation, the electrical current will feed into the panel through one of the insulated lead straps then alternately through the n-type and p-type bismuth telluride elements and out the insulated lead strap at the opposite end of the panel. The 34 pairs of elements in each panel are connected in series by means of the 67 insulated conductor straps. The insulated conductor straps are made of a metalized ceramic wafer soldered between a copper conductor strap, and a copper spacer. This sandwich assembly has a dielectric breakdown strength in excess of 4000 volts d-c, and an electrical resistivity in excess of 10^{12} ohms.

Drawing number <u>R-1058-4430</u> shows how four of the thermoelectric panels are soldered in place between the aluminum internal and external air heat exchangers to form a module assembly. This module assembly is the basic building block of the thermoelectric coil. In the complete system, 60 of these modules are stacked in 12 side-by-side banks, each bank five modules high. The current flows through two panels on one side of each module in series, then on through the two panels on the same side of the next module located directly above the first, and so on through the five modules in one bank to the top of the bank. At the top, current flows through a jumper strap to the panel located on the opposite side of the top module and then back down through the same five modules. At the bottom of each bank the current will flow to the next bank of modules and so on in series through all 12 banks.

Drawing <u>R-1058-9434</u> shows the unit framework assembly. The frame is constructed from $1-1/2 \times 1-1/2 \times 3/16$ inch aluminum angle and $1-1/2 \times 1-1/2 \times 1/8$ inch square aluminum tubing welded together. Calculations determined that this size angle would keep the natural frequency of the long structural members well above the rotational frequency of the system fans. Item 26 of this drawing is the internal air supply manifold. These manifolds, as well as the return manifolds, are formed from aluminum sheets insulated with a 3/16 inch layer of free foamed epoxy prior to cutting and forming.

Drawing <u>R-1058-9431</u> shows the system control and monitor panel. This panel mounts into a sealed, recessed compartment on the inside face of the unit such that it may, if desired, be remotely located without resealing the opening from which it was removed. Electrically, this panel is connected to the unit by a single feed-through connector mounted near the bottom of the recessed compartment wall. The system temperature sensor mounted on the face of this panel is detailed on drawing <u>R-1058-3432</u>.

Drawing <u>R-1058-9433</u> shows the power conversion and control package. This package is made up of a two-compartment box designed to confine radio frequency noise generated by the silicon control rectifiers. The free convection fins mounted to the outside of this box are designed to conduct heat away from the power rectifier which is mounted directly adjacent to the fins on the inside of the box. The rectifier mounting blocks are in good thermal contact with the aluminum box, but are electrically insulated from the box by 18 electrically insulated ceramic conductor straps.

Drawing <u>R-1058-4435</u> shows the access cover assembly. This removable cover mounts on the outside face of the unit and is easily removed to allow access to the thermoelectric modules, the internal and external fans and the power rectifier and control package. A fine mesh wire screen prevents dust and dirt from entering the external air inlet, and the outer grill protects the unit from damage. The internal air return manifolds are mounted to the cover such that when the cover is tightened down, it will hold the thermoelectric modules firmly in position.

Drawing <u>R-1058-9436</u> shows six views of the complete environmental control unit along with a sectional side elevation. This drawing shows the mounted location of all the system components described above. The buss-bar which carries the electrical current from one bank of modules to the next is detailed in drawing <u>R-1058-3437</u>.

Drawing <u>R-1058-9439</u> shows a pictorial side elevation of the unit indicating the flow paths of the internal and external air streams.

3.5 Electrical Circuit Diagram

Drawing R-1058-4428 shows the schematic wiring diagram for the system. As shown, the 3-phase, 208 volt, 60 or 400 cycle power feeds into the unit through the main power circuit breaker switch (CB1), through the power rectifier, through the reversing relay (RR), and to the thermoelectric heat pump. Lead wires connect the module selector switch to each of the 12 banks of thermoelectric modules so that the voltage drop across each individual module bank, or across the total coil, may be monitored on the voltmeter (VM).

The same input power feeds through the fan power circuit breaker (CB2) to the internal and external fans, as well as to the control system voltage transformer (TRANS.1). The automatic control network is made up of a temperature sensor circuit, amplifier, Schmitt trigger, signal shaping circuit, and firing circuit. This network picks up a signal from the temperature sensor thermistor (TH1) and feeds a control signal through the pulse transformers (PT1, PT2, PT3) to the gates of the silicon control rectifiers (SCR1, SCR2, SCR3). At the same time, the Schmitt trigger controls the operation of the control relay (CR1) which in turn operates the reversing relay (RR). The system selector switch (SW1) bypasses the automatic control network when it is in the manual heat or manual cool position. In the manual position, the reversing relay and the power rectifier circuit are controlled such that the unit may operate at either full cooling or full heating. During manual operation, the power to the thermoelectric coil bypasses the SCR's and is supplied through the power diodes (D4, D5, D6). The over-temperature protection circuit monitors the signal from the overtemperature thermistors (TH2, TH3, TH4, TH5), and will cut off the power to the rectifiers by operating the control relay (CR2) which in turn will open the main contactor (MC). The over-temperature thermistors are mounted to the thermoelectric coil frame so that they are in good thermal contact with the internal and external air fins.

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3.6 Design Requirements

The design requirements for this system are specified in Section 2 of the Purchase Description as amended by Amendment No. 1. The system design described in Sections 3.2, 3.3, and 3.4 above meets or exceeds all of the specified requirements with the exception of unit volume. The 18.4 cubic foot volume of this design exceeds the 15 cubic foot requirement described in Section 2.2.3 of the Purchase Description.

With regard to certain requirements describing the method of control, variations are made in the exact method specified. However, the same end result is accomplished by means that are considered better than those described. These variations are described below; the section numbers listed refer to those used in the Purchase Description.

Section 2. 4. 2. 2 - Automatic Capacity Control:

With this system design, automatic capacity control is accomplished by modulating the voltage applied to the thermoelectric coil. This modulation is continually proportional from full cooling to full heating. The operation of this control system is described in more detail in Section 4.1.3.3 of this report.

Section 2.4.3.1 - Selector Switch:

The selector switch has only three positions: MANUAL HEAT, MANUAL COOL, and AUTOMATIC.

Section 2. 4. 3. 1. 3 - Off:

Power to the thermoelectric coil is turned off by turning the main power circuit breaker switch to the OFF position.

Section 2.4.3.1.5 - Start:

A special start mode of operation is not provided. With the fast response time and the high heat pumping capacity of a thermoelectric unit during start-up, it appears that a special starting mode of operation should not be required.

Section 2.4.3.2.1 - Inside Fan Motor Switch:

The inside fan will run whenever the fan power circuit breaker switch is on.

Section 2. 4. 3. 2. 2 - Outside Fan Motor Switch:

The outside fan motor switch has two positions, ON and AUTOMATIC. The system could possibly be damaged if the external fans were turned off when the unit was operating in the cooling mode, consequently the OFF position was eliminated.

Section 2, 4, 3, 5 - Monitor Lights:

A voltmeter and a thermoelectric module selector switch are located on the control and monitor panel. This provides a means of checking the exact voltage drop across each module bank.

Section 2.4.7 - Thermoelectric Modules:

This unit has 12 module banks each comprised of five identical modules.

4.0 SYSTEM OPERATION

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4.1 Description of Operation

4.1.1 <u>General</u>. The basic subsystems comprising the thermoelectric environmental control unit are: (1) thermoelectric coil, (2) air handling, and (3) control and power conversion. Referring to Drawing <u>R-1058-9439</u>, the air flow paths through the fans, manifolds, and thermoelectric coil are shown. Internal air enters the top of the unit just above the internal fans and passes through the fans into the internal air supply manifolds. It then passes through the thermoelectric coil, up through the six return air manifolds and leaves the unit through the top opening near the outside face of the unit.

External air enters through the outside face of the unit, passes through the protective grill and fine mesh screen straight into the external air fins of the thermoelectric coil. After leaving the coil, air passes downward into the external fans and is discharged through a protective grill near the bottom of the outside face. Thus, the two air streams pass through the coil in counter flow. The internal circuit is under positive pressure and the external circuit under negative pressure so that any air leakage will always be from the internal to the external air stream.

The direction of heat flow through the thermoelectric modules is dependent on the polarity of d-c power supplied to the modules. In the cooling mode, heat is pumped from the internal air stream to the external air stream. In the heating mode, heat is not actually extracted from the external air stream, since the external fans are always off. However, the heat equivalent of the power input is rejected to the internal air stream. Control of the d-c current flow quantity and direction is described in Section 4.1.2.

4.1.2 Control and Power Conversion

4.1.2.1 Manual Operation.

Refer to Drawing R-1058-4428. When the system selector switch (SW1) is in the manual cool position, the manual relay (MAN) is energized, the SCR's (SCR1, SCR2, SCR3) are disconnected from the rectifier bridge, and the diodes (D4, D5, D6) are connected to the bridge. The reversing relay (RR) is in the non-energized cooling position and 278 volts d-c is applied to the thermoelectric heat pump.

With the system selector switch in the manual heat position, manual relay (MAN) is again energized, the reversing relay (RR) is energized to the heating position, and 278 volts d-c is applied to the thermoelectric coil. Also, the fan relay (FR) is energized, cutting the external fans off.

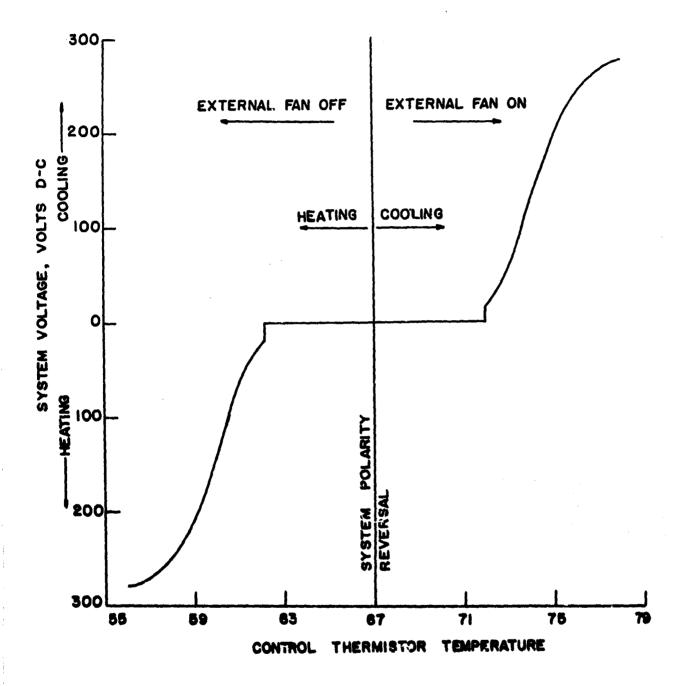
4.1.2.2 Automatic Operation.

In the automatic mode of operation, a small voltage signal is produced by the temperature sensor in proportion to the difference between the set point temperature and the temperature of the control thermistor (TH1). The resistance of the thermistor decreases as the temperature increases, and this causes the voltage at the base of transistor TR1 to increase in proportion to the temperature increase. The voltage signal is amplified by transistor TR2 and then supplied to the reversing network consisting of a Schmitt trigger, a control relay (CR1), and the reversing relay (RR). Simultaneously, this amplified signal is supplied to the signal shaping network.

The amplifier and Schmitt trigger are biased so that the reversing occurs at a set point temperature of $67^{\circ}F$. As the temperature rises above $67^{\circ}F$, the control relay (CR1) is energized, opening its normally closed contacts. Also, the reversing relay is de-energized placing a cooling polarity on the thermoelectric coil, and the fan relay (FR) is de-energized turning on the external fans. As the temperature of the control thermistor drops below $67^{\circ}F$, the control relay (CR1) is de-energized which in turn energizes the reversing relay to the heating position, and the fan relay turns off the external fans.

The signal shaping network provides a dead zone of $\pm 5^{\circ}F$ about the set point temperature. When the control thermistor temperature is in this dead zone, no signal is supplied to the firing circuit, and consequently power is not supplied to the thermoelectric coil. As the control thermistor temperature increases above 72°F, the voltage from the signal shaping network increases continuously until the full cooling signal is produced at 77°F. Conversely, as temperature drops below 62°F, the voltage decreases until the full heating signal is produced at 57°F.

The voltage from the signal shaping network is supplied to the firing circuit which controls the conduction time of the SCR's in proportion to the voltage signal. Controlling the conduction time of the SCR's in turn controls the voltage applied to the thermoelectric coil. Figure 7 shows the relation between the control thermistor temperature and the applied system voltage. The firing circuit used here is a unijunction type. In this circuit, a voltage signal is converted to a time signal by charging a capacitor. Thus, a high signal voltage corresponds to a short charging time which in turn results in a long conduction time.



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4.1.2.3 Over-Temperature Protection.

In the over-temperature protection circuit, the thermistors (TH2, TH3, TH4, TH5) are located to protect the system against over-temperature conditions which could be caused by an inoperative fan or by a blocked air passage. If the temperature of any one of these thermistors exceeds 160°F during operation, then control relay (CR2) is energized, which in turn de-energizes the main contactor (MC) removing power from the thermoelectric coil. Simultaneously, the reset warning light on the control panel will go on indicating an over-temperature condition has occurred. To resume operation after an over-temperature condition occurs, the "reset" button must be depressed.

4.2 Operating Procedure

4.2.1 <u>Automatic Operation</u>. To operate this unit in the automatic mode, the following sequential procedure should be followed:

- 1. Selector switch ... AUTO
- 2. External fan.... AUTO
- 3. Fan power ON
- 4. Main power ON

Both the main power and the fan power indicator lights should be on. The reset light should be out; however, if the reset light is on immediately after the fan power switch is turned on, then the reset button should be pushed.

If during automatic operation, or any mode of operation, the operator wants to check the module operation, the voltage drop across an_J of the 12 module banks may be monitored by setting the module selector switch to the proper module bank number and reading the voltage drop from the meter.

To turn the unit of when operating in the automatic mode, the sequence is:

1. Main power OFF

2. Fan power Oz'F

4.5.2 <u>Manual Operation</u>. To operate the unit in either the manual cooling or the manual heating mode:

1. Selector switch. . . . MAN, COOL OR MAN, HEAT

- 2. External fan.... AUTO
- 3. Fan power ON
- 4. Main power ON

To turn off unit:

- 1. Main power OFF
- 2. Fan power OFF

4.2.3 <u>Manual Fan Operation</u>. In order to operate the internal fans without operating the thermoelectric coil or the external fan, the sequential operations are:

- 1. Selector switch.... MAN. HEAT
- 2. External fan.... AUTO
- 3. Main power OFF
- 4. Fan power ON

To operate both internal and external fans with the thermoelectric coil off:

- 1. External fan.... ON
- 2. Main power OFF

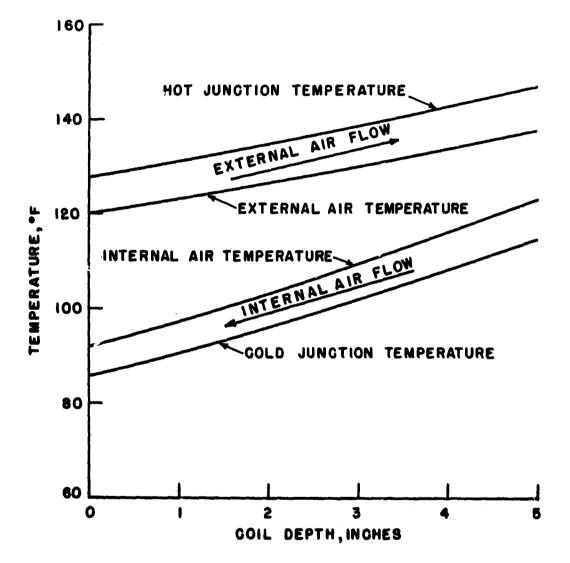
If the inside air temperature is above $67^{\circ}F$ and the outdoor ambient is below $67^{\circ}F$, it may be possible to decrease the inside temperature to $67^{\circ}F$ and control at this temperature without operating the thermoelectric coil. This is possible by operating the internal fans and letting the external fans cycle on and off in the automatic operating mode. To accomplish this:

- 1. Selector switch..., AUTO
- 2. External fan.... AUTO
- 3. Main power OFF
- 4. Fan power ON

To turn the unit off after any manual fan operation, simply turn the fan power switch off.

4.3 Operating Performance

Electronic analog computer calculations were made to determine the performance characteristics of this system at off-design as well as at design conditions. The operating performance at design condition was described in detail in Section 3.3.2. Figure 8 shows the plotted computer solution for the system operating at design conditions on 60 cycle power. This plot shows how the element junction temperature and the internal and external air temperatures vary with coil location.



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Off-design cooling performance was calculated for variations in outdoor ambient temperature, internal supply air temperature and operating voltage. Heating performance was calculated for variation in operating voltage. All calculations were made for both 60 and 400 cycle operation. The system power draw and COP are significantly affected by main power frequency, whereas the change in cooling capacity is insignificant. Figures 9 and 10 show how system capacity varies with ambient temperature and operating voltage for supply air temperature of 72 and 62° F, respectively. In both of these plots, the heating capacity is based on a return air temperature of 50°F. Note that zero amperage curves are shown rather than zero voltage. The reason for this is that when the SCR's are shut off, there is still a back EMF on the system generated by the thermoelectric coil. In certain cases, this generated voltage may exceed 60 volts. Figures 9 and 10 are of primary interest because they give a good representation of how the system will perform under normally expected conditions of operation. It is interesting to note that there is a large range of operation between zero amperage heating and zero amperage cooling. Within this range, the system will control the inside air temperature at the set point temperature of 67°F by simply turning the external fans off and on as required.

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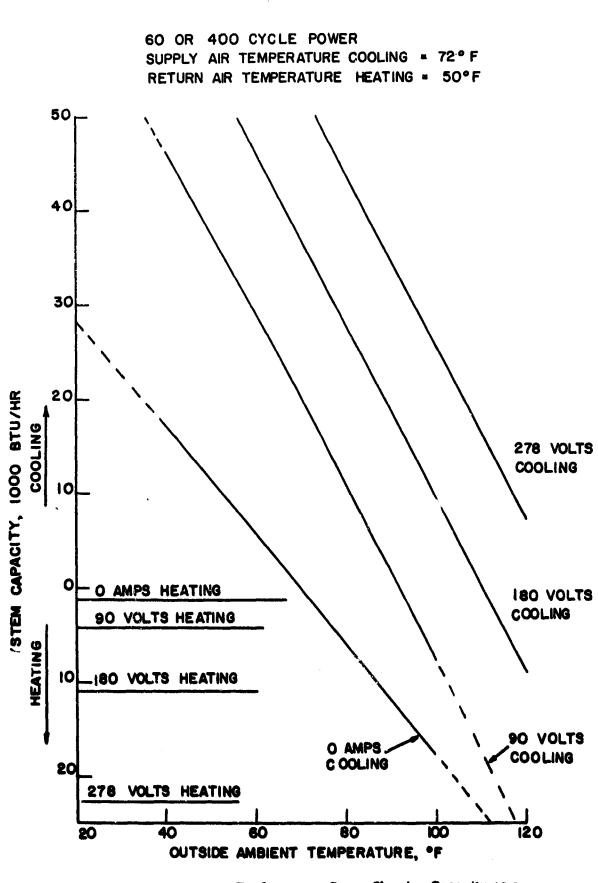
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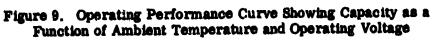
Figure 11 shows how system performance during cooling operation varies with outdoor ambient air temperature and operating voltage. System capacity, power draw and coefficient of performance are all shown for 60 cycle operation and a supply air temperature of $72^{\circ}F$.

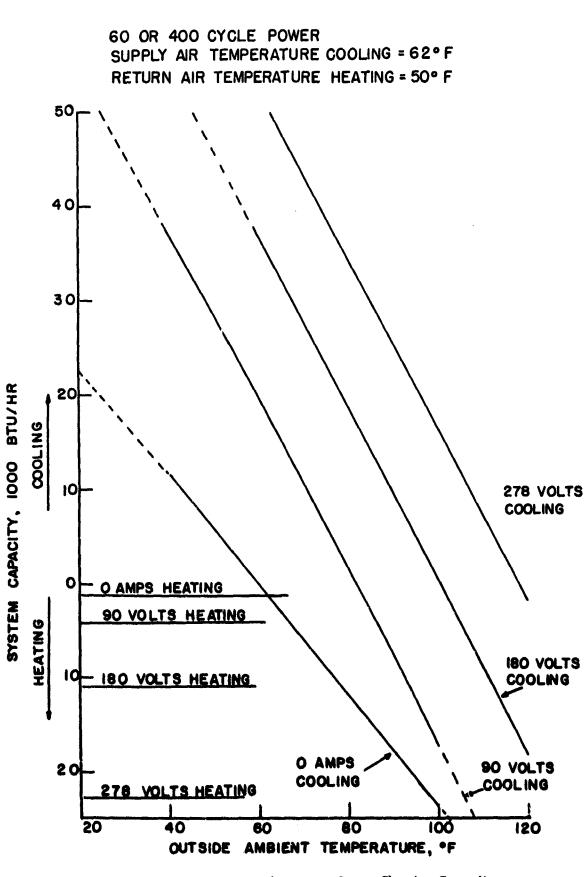
Figure 12 shows the same performance information when the supply air temperature is 62°F, and Figures 13 and 14 show similar curves for the system operating on 400 cycle power.

Figures 15 and 16 show how system performance during full cooling operation varies with outdoor ambient sir temperature and supply air temperature. Again system capacity, power draw, and coefficient of performance may be determined from the plot. Figure 15 represents 60 cycle operation and Figure 16 represents 400 cycle operation. These two plots are of greatest interest because they represent how the system will operate in the manual cooling mode. They also show the system design operating condition.

The exact procedure used to calculate the performance information is located in the calculation section of Copy No. 1 of this report. Tabulated data is also provided which shows such information as operating current, fan power requirements, etc.







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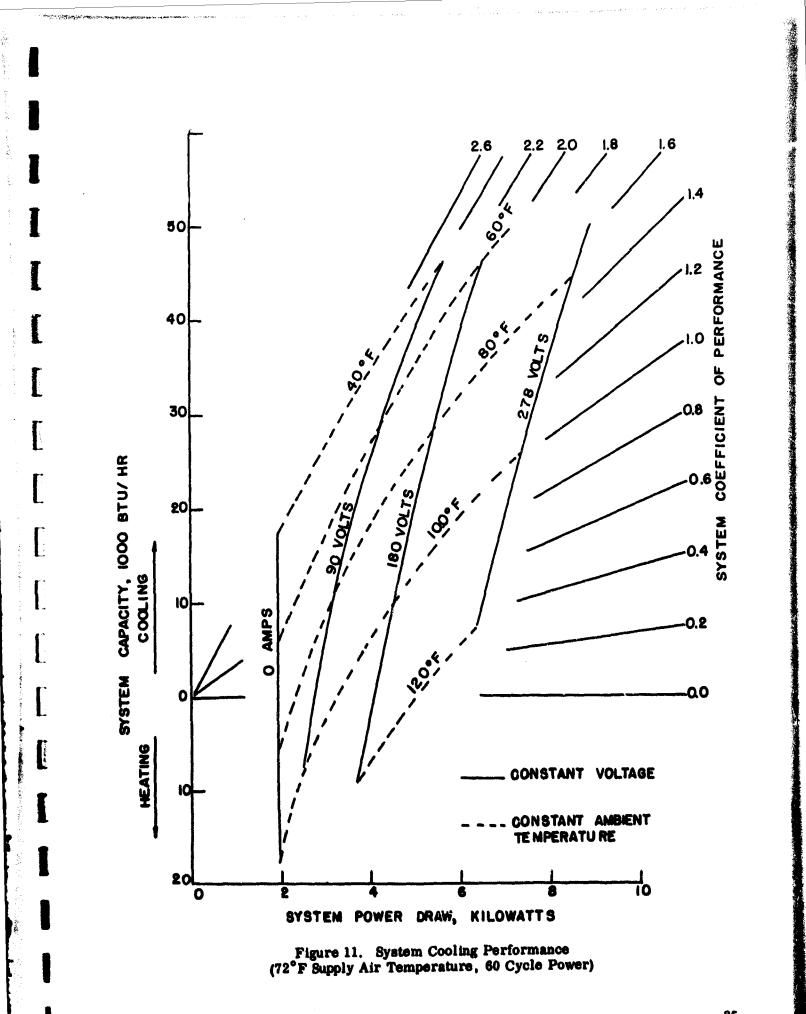
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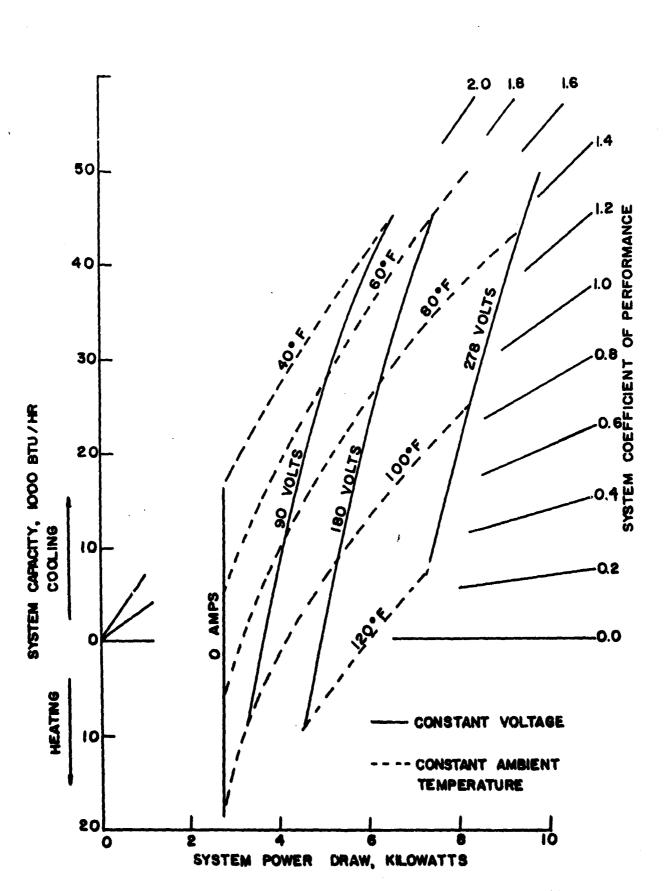
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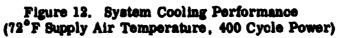
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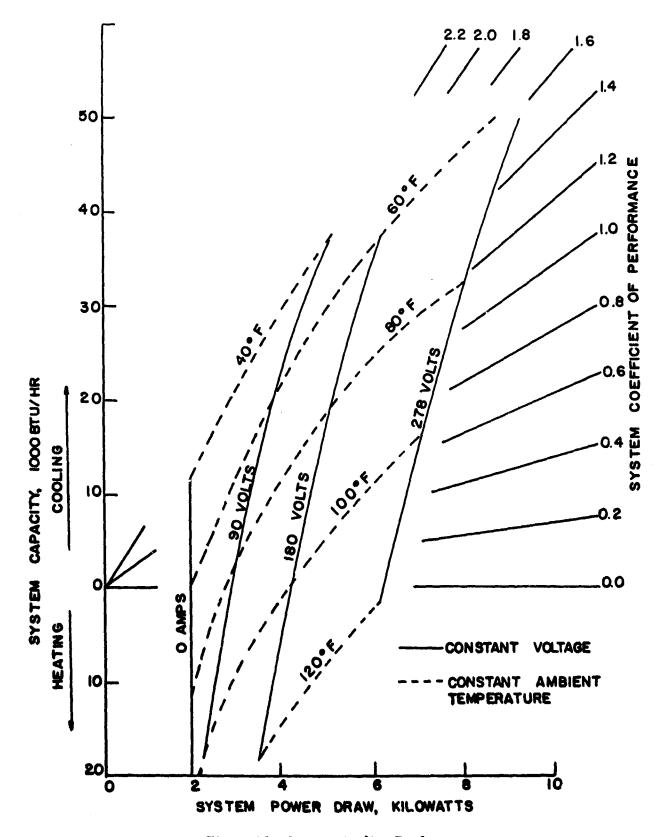
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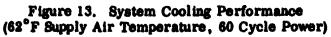
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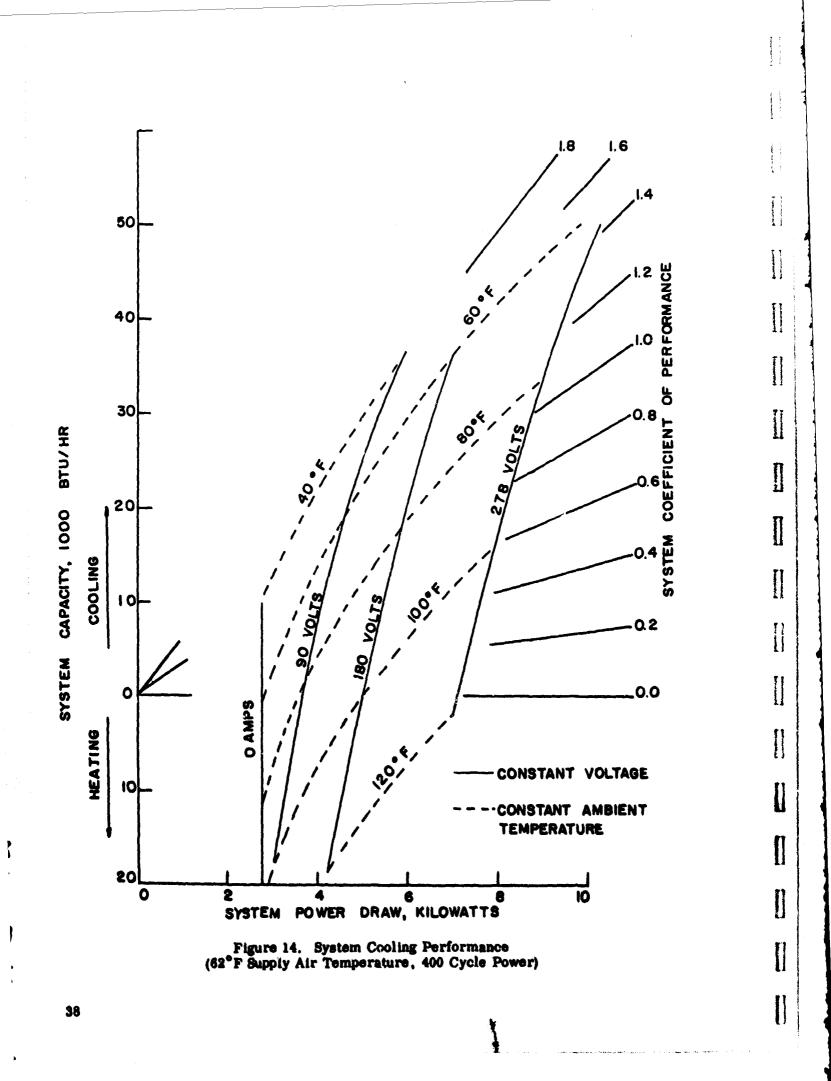
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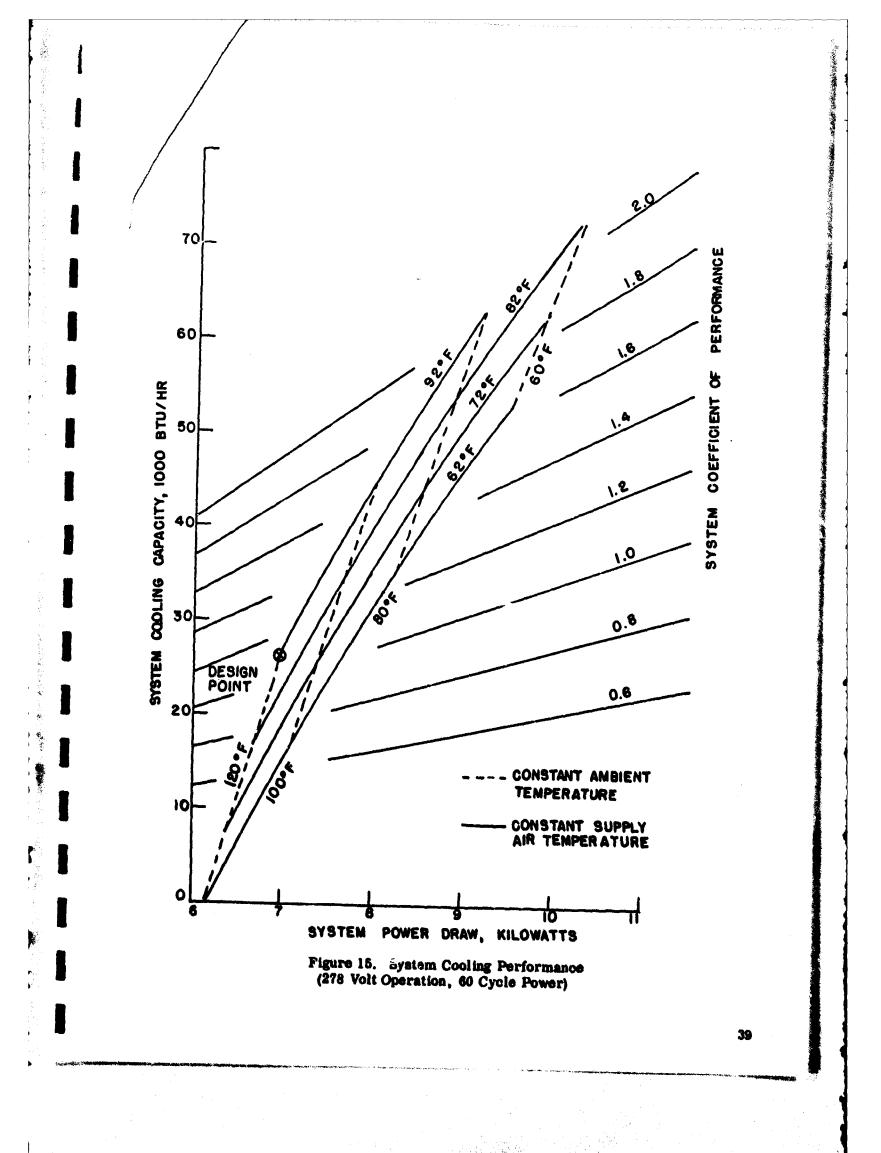




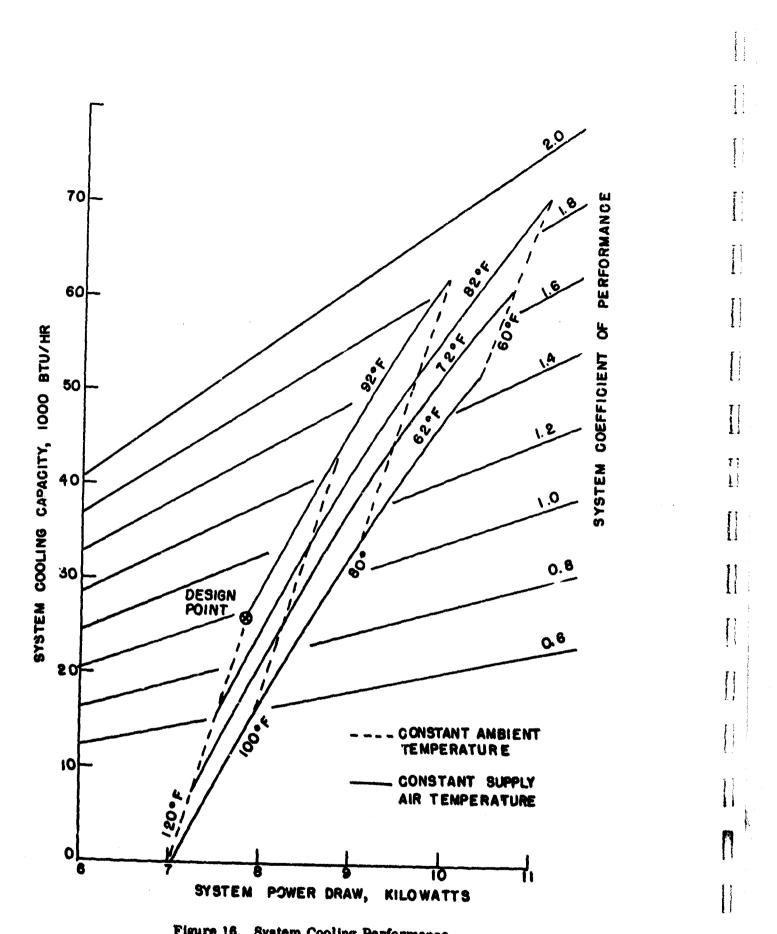
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5.0 MAINTENANCE PROCEDURES

5.1 <u>Thermoelectric Module</u>

A thermoelectric module with a broken junction may either be replaced with a spare module or electrically removed from the circuit while it physically remains in the thermoelectric coil. To replace a thermoelectric module:

- (1) Remove access cover from outside face.
- (2) Identify the bank which contains the defective module.
- (3) Remove the top module in this bank by sliding it up about 1 inch and then out.
- (4) Remove successive modules from the bank in the same manner until the defective module has been removed.
- (5) Replace with a spare module making sure that the module connector pins are properly in place.
- (6) Replace the other modules into the bank, again insuring that all connector pins are properly in place.
- (7) Replace and fasten down the access cover.

If a spare module is not available, then a defective module may be electrically removed from the circuit by the following procedure:

- (1) Remove access cover from outside face.
- (2) Remove the top module as described perviously.
- (3) Remove successive modules from the bank in the same manner until the defective module has been removed.
- (4) After removal of the defective module, replace all other modules into the bank such that each module is one position below its original position.
- (5) Leaving the jumper strap in its original position across the top of the uppermost module, replace the bad module into the top position after removing the connector pins.
- (6) Replace and fasten down the access cover.

5.2 Internal Fan

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in order to remove an internal fan:

(1)	Remove access cover from outside face.
(2)	Remove the internal air baffle from the front of the fans.
(3)	Disconnect fan electrical connector.
(4)	Remove fan mounting bolts and remove fan.
(5)	Replace fan by reversing steps 1, 2, 3, and 4.
External Fa	<u>n</u>
To remove a	an external fan:
(1)	Remove access cover from outside face.
(2)	Disconnect fan electrical connector.
	Remove fan mounting bolts and remove fan.
(3)	Remove fail mounting botts and remove fail.
(4)	Replace fan by rever,, steps 1, 2, and 3. Power Conversion Packag
(4) <u>Control and</u> To remove t	Replace fan by reverais, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package:
(4) <u>Control and</u> To remove ((1)	Replace fan by reverais, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face.
(4) <u>Control and</u> To remove ((1) (2)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan.
(4) <u>Control and</u> To remove ((1) (2) (3)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box.
(4) <u>Control and</u> To remove ((1) (2) (3)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box. Remove screws fastening the control box to the unit
(4) <u>Control and</u> To remove ((1) (2) (3) (4)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box. Remove screws fastening the control box to the unit frame and remove control box.
(4) <u>Control and</u> To remove ((1) (2) (3) (4)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box. Remove screws fastening the control box to the unit
(4) <u>Control and</u> To remove ((1) (2) (3) (4) (5)	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Package</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box. Remove screws fastening the control box to the unit frame and remove control box.
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 (4) <u>Control and</u> To remove 1 (1) (2) (3) (4) (5) To remove 1 	Replace fan by rever, steps 1, 2, and 3. <u>Power Conversion Packag</u> the control and power conversion package: Remove access cover from outside face. Remove one external fan. Remove all electrical connectors from control box. Remove screws fastening the control box to the unit frame and remove control box. Replace box by reversing steps 1, 2, 3, and 4. a printed circuit card from the control and power conversion package Remove cover from package.

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To remove a bad diode or SCR from the rectifier hridge:

- (1) Remove cover from the control box.
- (2) Disconnect lead wires from the defective diode or SCR.
- (3) Remove the defective component and replace with a spare. Care should be exercised to prevent stripping the copper threads. If a torque wrench is available, the components should be torqued to 30 in. -lb.
- (4) Replace the lead wires.
- (5) Replace cover.

5.5 Frequency Changeover

The fan motors and the firing circuit for this system are frequency sensitive. Consequently, they must be wired for the proper supply frequency. On the firing circuit, a jumper wire must be removed when the unit is operated at 400 cycles. This wire is marked as indicated on the schematic wiring diagram. Conversely, when operating on 60 cycle this wire must be connected in position.

The fan motors are dual frequency with a separate set of lead wires for each frequency. Each set of wires is connected to an MS connector. The connectors are clearly marked 60 cycle or 400 cycle. The proper connection is determined by the main power supply frequency.

6.0 MANUFACTURING PROCEDURE

The manufacturing procedure used to process thermoelectric panels consists principally of processing semiconductor elements and insulated conductor straps and assembling them into the panel circuit. Detailed process sheets are available which describe the exact step-by-step procedures that have been developed at Carrier's thermoelectric process development and pilot production facility. The applicable process sheets are included in Appendix B.

7.0 COST ESTIMATE

The Purchase Description requests a cost estimate for fabricating one prototype unit and total costs for producing quantities of 10, 50 and 600 units per buy. A detailed price analysis is presented in Figure 17 to show prototype development costs and an estimate for producing ten units. An explanation is in order for these cost estimates as well as for the larger production quantities.

Input data for the price analysis shown has been obtained from actual experience using existing thermoelectric process development facilities and the manufacturing methods described in the previous section. Existing facilities and procedures are adequate for prototype development and for a limited production to meet the requirements of field trial qualification. After absorption of non-recurring development costs, there would be only minor differences in cost per unit up to the maximum capability of the existing facilities and using the manufacturing procedures described earlier. In other words, after the first unit is developed, whether the additional requirement is for three units, five or ten, only slight cost improvement would be possible. The maximum capability of the facility now in use would be about ten units, considering a reasonable delivery time for fabrication. Therefore, the information presented in the price analysis for producing one and ten units should be regarded as reasonably representative for any number within this range, the major difference for quantities smaller than ten being in material costs. Likewise, to reflect substantial reductions in cost, a scale-up to meet volume production requirements would be necessary. This, of course, is not reflected in the price for a range from one to ten units.

For quantities of 50 and 600 units per buy, increased automation of routine procedures would be employed. High volume operations would justify capital expenditures to reduce labor costs and to improve process yield, both of which are significant percentages of unit cost in small quantities as produced by existing methods. One of the major advantages of producing a small number of units, say three to ten, would be to establish production measures which could be employed for large scale-up in capacity.

It is fully recognized that cost will play a major role in determining the ultimate feasibility of thermoelectric systems. The advantages of reliability, size, weight and performance characteristics will, in the final analysis, have to be related to cost in comparison with a conventional system. Carrier believes that the effect of a scale-up to meet true production requirements will be of major significance in reducing thermoelectric system cost to a level where it is competitive with more conventional systems. We do not

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MILITARY EQUIPMENT DEPARTMENT PRICE ANALYSIS

Purchaser	USAERDL, Fort Belvoir, Va.	Contract No	DA-44-009-AMC-1135(T)
ProjectTh	ermoelectric Environmental Control Unit	Date	September, 1965
Applicable Spe	RFQ No. 65-1816B	Estimated by	
Type Units	Thermoelectric	Checked by	

PRICE ITEMIZATION	Non-Recurring Preproduction Costs (No. Units_0_)	Production Costs (No. Units <u>1</u>)	Production Costs (No. Units 10)
DIRECT MATERIAL			
Raw Material		5,800	
Purchased Parts		4,700	35,100
FACTORY LABOR			
1,900 firs at \$ 3.95 /fir		7,505	
14,500 lirs at \$ 2.50 /lir			36,250
FACTORY OVERHEAD 145 %	L	10,882	52,563
ENGINEERING LABOR			
2.000 lirs at \$6.50 /iir	13,000		
500 1 000 lirs at \$ 5, 25 /lir		2,625	5,250
ENGINEERING OVERIJEAD 85 %	11,050	2,231	4,463
DRAFTING LABOR			
500 Hrs at \$4,25 /llr	2,125		
DRAFTING OVERHEAD 85 %	1,806		
OTHER DIRECT COSTS			
TESTING MATERIALS - COSTS			
(a) Testing Labor: 100 hrs at 3, 95 x 2, 45		968	
(4) Testing Labor: 400 hrs at 2. 50 x 2. 45			2,450
TOTAL MANUFACTURING COSTS	27,981	34,711	183,076
GENERAL & ADMINISTRATIVE EXPENSE 16 %	4,197	5,207	27,461
TOTAL COST	32,178	39,918	210,537
PROFIT 10 %	3,218	3,992	21,054
MISCELLANEOUS COSTS			
(H)			
(b)			
(u)			
TOTAL SELLING PRICE (No. of Unith)	35,196	43,910	231,591
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Figure 17. Detailed Price Analysis

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believe, however, that it is possible, without the experience of prototype development and a limited production for field evaluation purposes, to predict an accurate unit cost for large volume requirements.

It is our belief that no one is in a better position to predict the cost of developing and producing a system of the type described than Carrier. We are the only company to date that has developed and produced a thermoelectric air conditioning system for a commercial application, namely the 28 units provided for the S.C. Johnson application described previously. On the basis of this experience, we believe that a projection of costs to large production quantities would be misleading until after the important first steps of prototype development and limited production for field trial qualification have been completed successfully.

8.0 SUMMARY OF RESULTS

A system analysis has been completed for a 24,000 Btu/hr thermoelectric environmental control unit. In this analysis an electronic analog computer was used to optimize 12 system parameters for minimum weight and maximum efficiency. All important subsystems and sub-system components were also analyzed by weighing the advantages and disadvantages of the design possibilities considered.

From this analysis a design was formulated to meet the system requirements as described in the Purchase Description. A complete set of assembly drawings are provided. The resulting thermoelectric environmental control unit has outside dimensions of 28 inches wide by 18 inches deep by 63 inches high, weighs 380 pounds and will provide 24,000 Btu/hr cooling capacity at an overall system coefficient of performance of 1.12.

Calculations were made to determine the off-design performance characteristics of this system. Performance information is presented in graphical form, and a complete description of how the system operates is included. Operating instructions, maintenance procedures, manufacturing procedures and cost analysis information are also presented.

9.0 RECOMMENDATIONS

On the basis of the results presented herein, it is recommended that development of a prototype unit be initiated. The objectives outlined in the Purchase Description have been met or exceeded by the design provided. Carrier is confident that a successful prototype unit can be built which will be in complete accord with all of the physical and performance characteristics of the design shown. It is estimated that delivery of a completed unit can be made within nine months from the date of contract award. As shown in the price analysis included in Section 7.0, the estimated cost for producing one unit of the type designed is:

None-recurring developmental costs	\$35,196
Production cost	43,910
Total estimated cost	\$79,106

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We will welcome the opportunity of working with USAERDL in developing this unit and believe that it is an important and worthwhile step in the application of thermoelectricity to military requirements.

APPENDIX A

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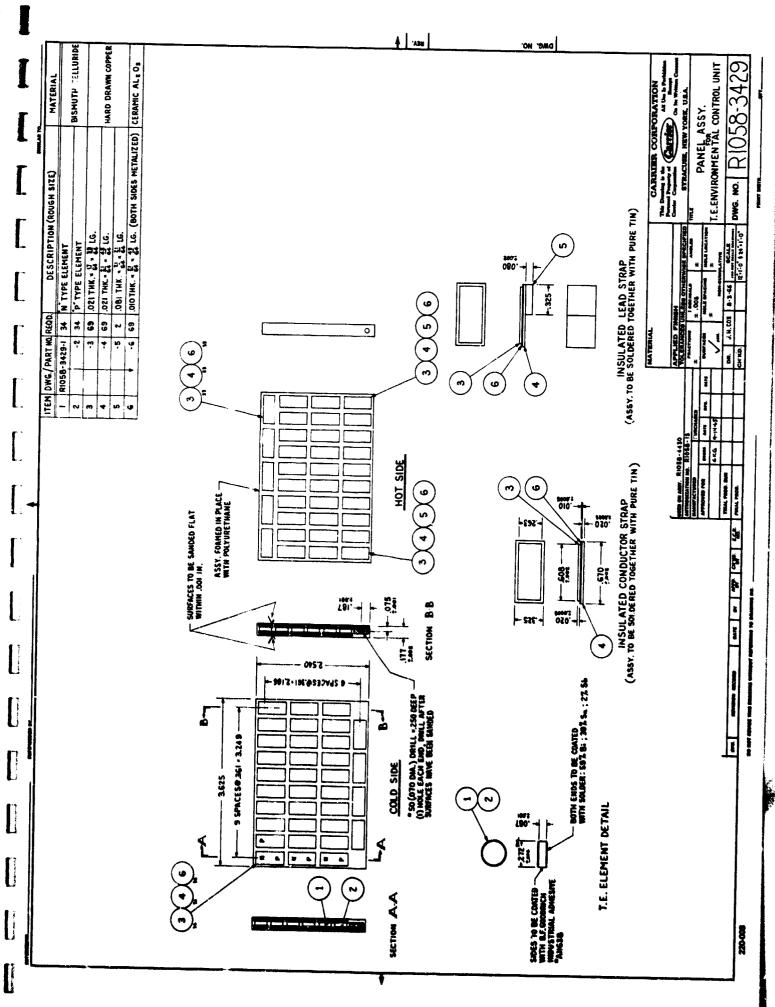
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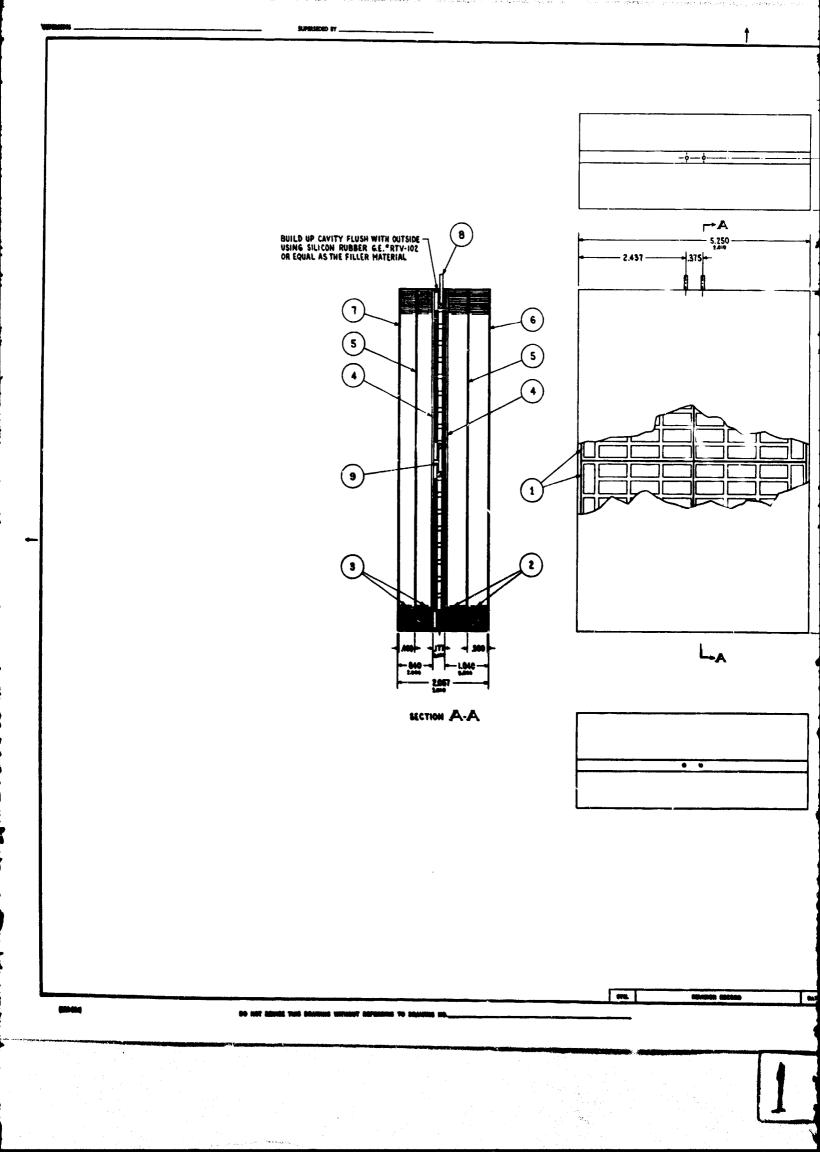
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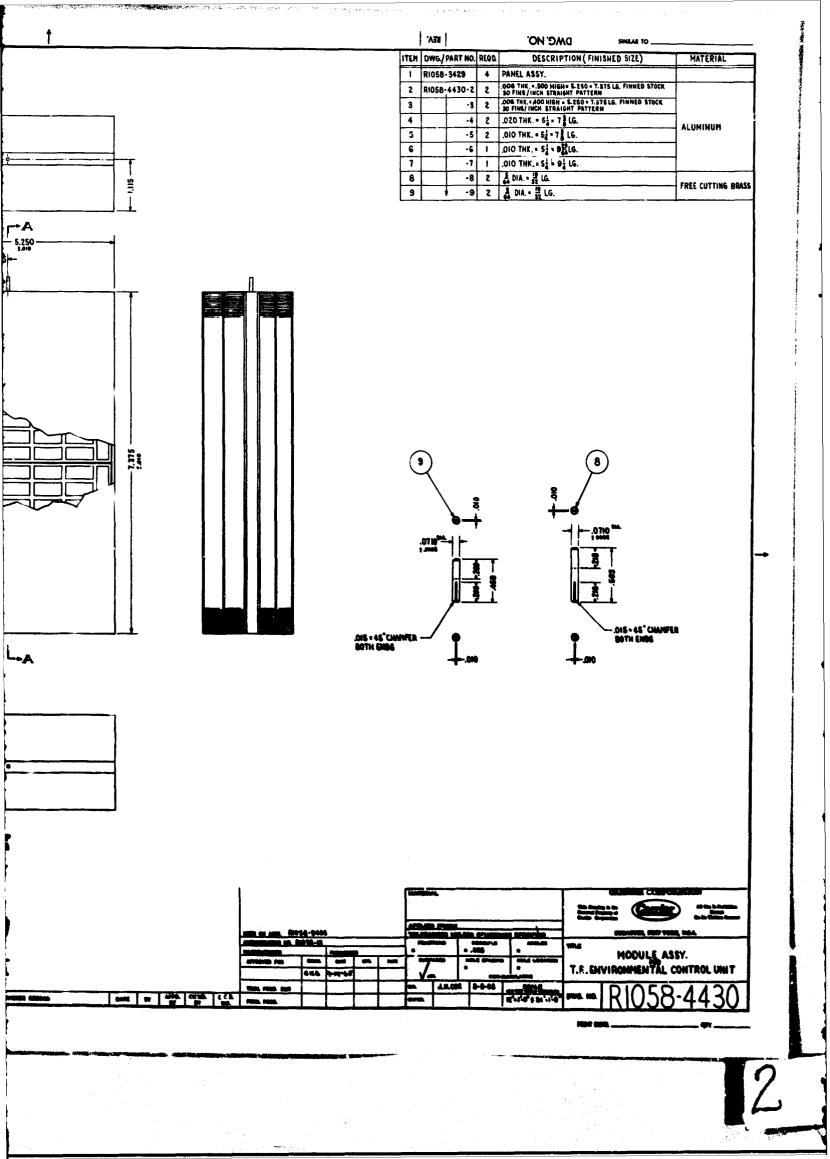
LIST OF ASSEMBLY AND SCHEMATIC DRAWINGS

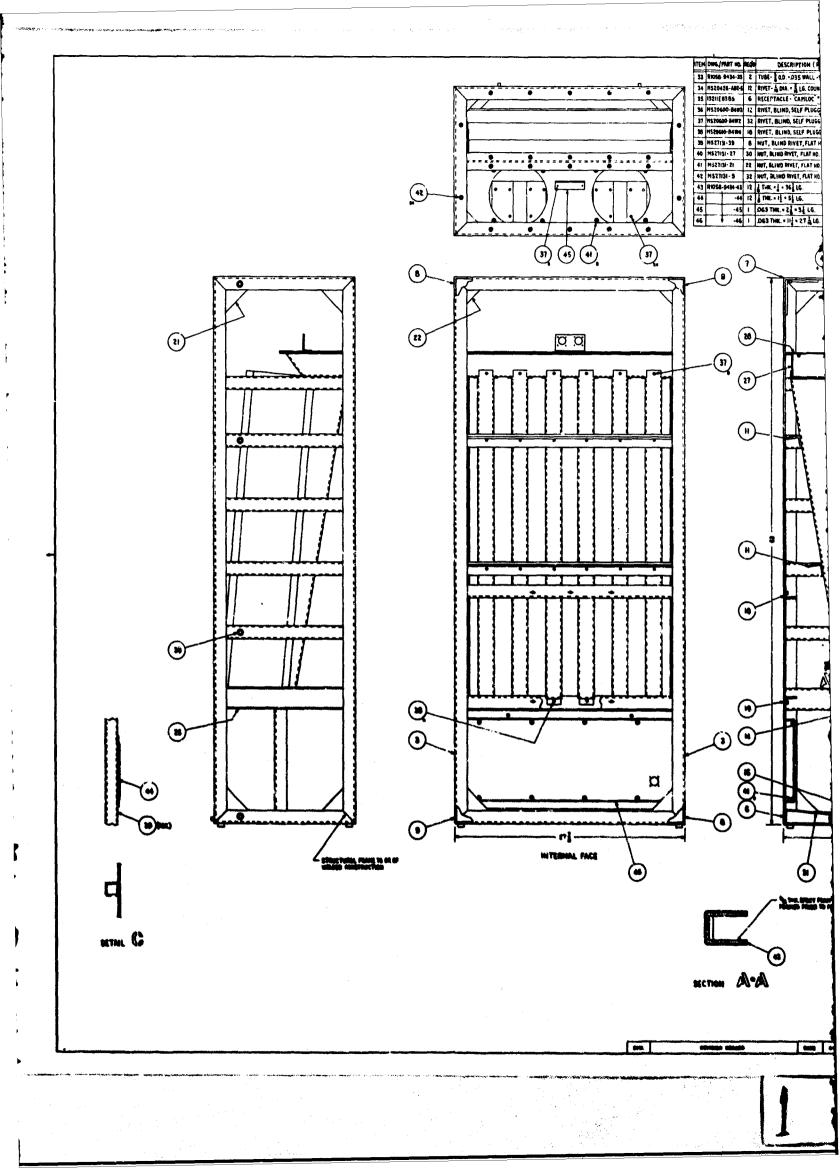
1.	R1058-3429	Panel Assy. for T. E. Environmental Control Unit
2.	R1058-4430	Module Assy. for T. E. Environmental Control Unit
3.	R1058-9434	Frame Assembly for T. E. Environmental Control Unit
4.	R1058-9431	Control and Monitor Panel for T. E. Environmental Control Unit
5.	R1058-3432	Temperature Sensor Assembly for T. E. Environmental Control Unit
6.	R1058-9433	Power Conversion & Control Package for T. E. Environmental Control Unit
7.	R1058-4435	Access Cover Assembly for T. E. Environmental Control Unit
8.	R1058-9436	Unit Assembly for T. E. Environmental Control Unit
9.	R1058-3437	Module Receptacle for T. E. Environmental Control Unit
10.	R1 058-9439	Air Flow Diagram for T. E. Environmental Control Unit
11.	R1058-4428	Schematic Diagram Control and Power Supply for T. E. Environmental Control Unit

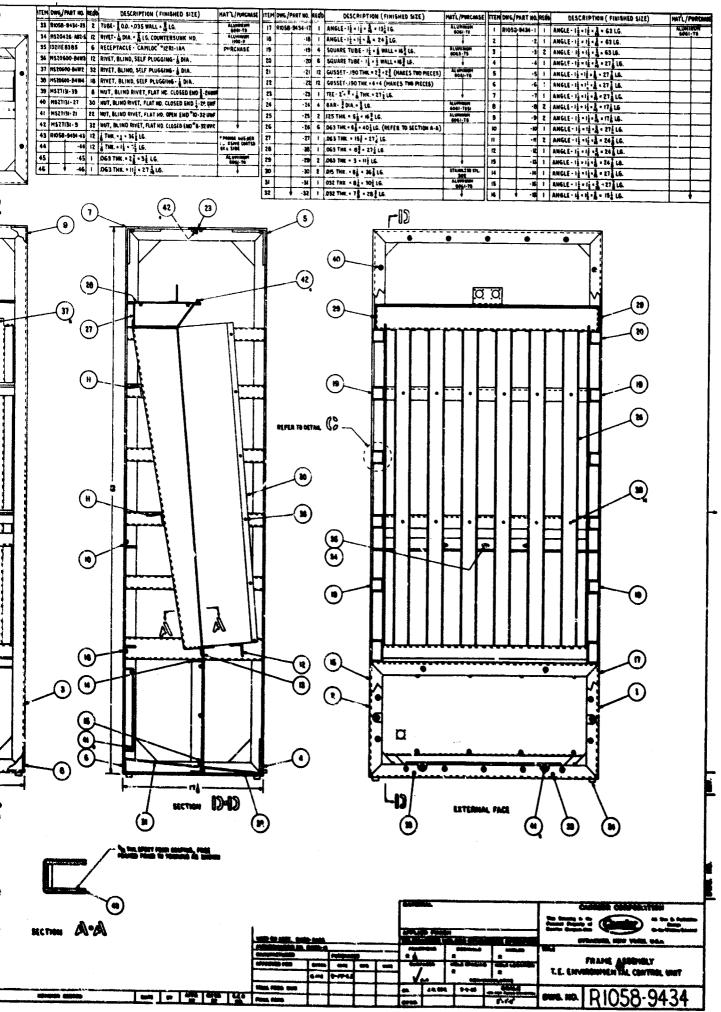
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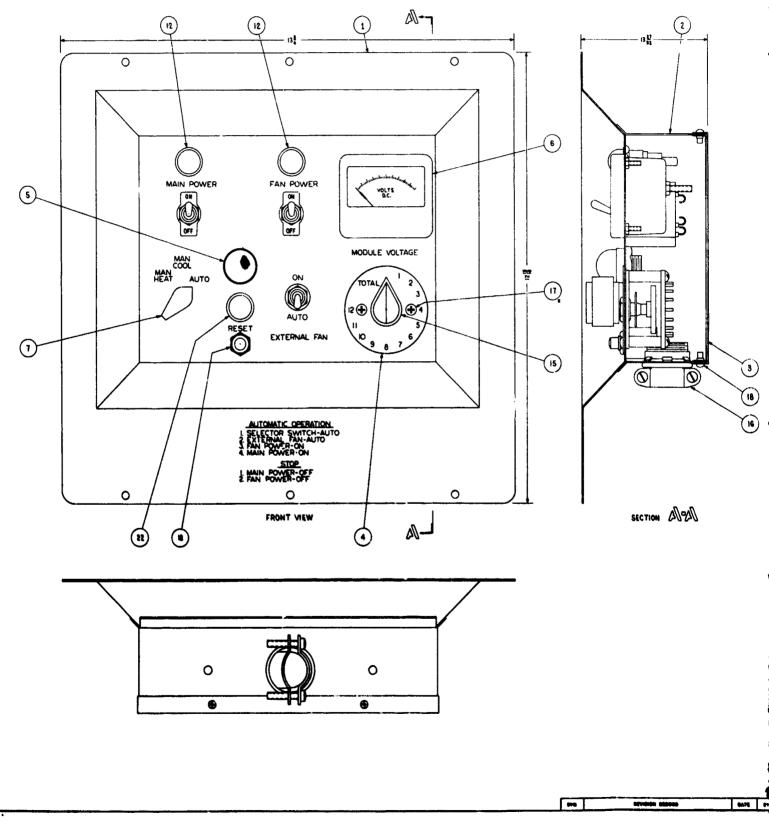


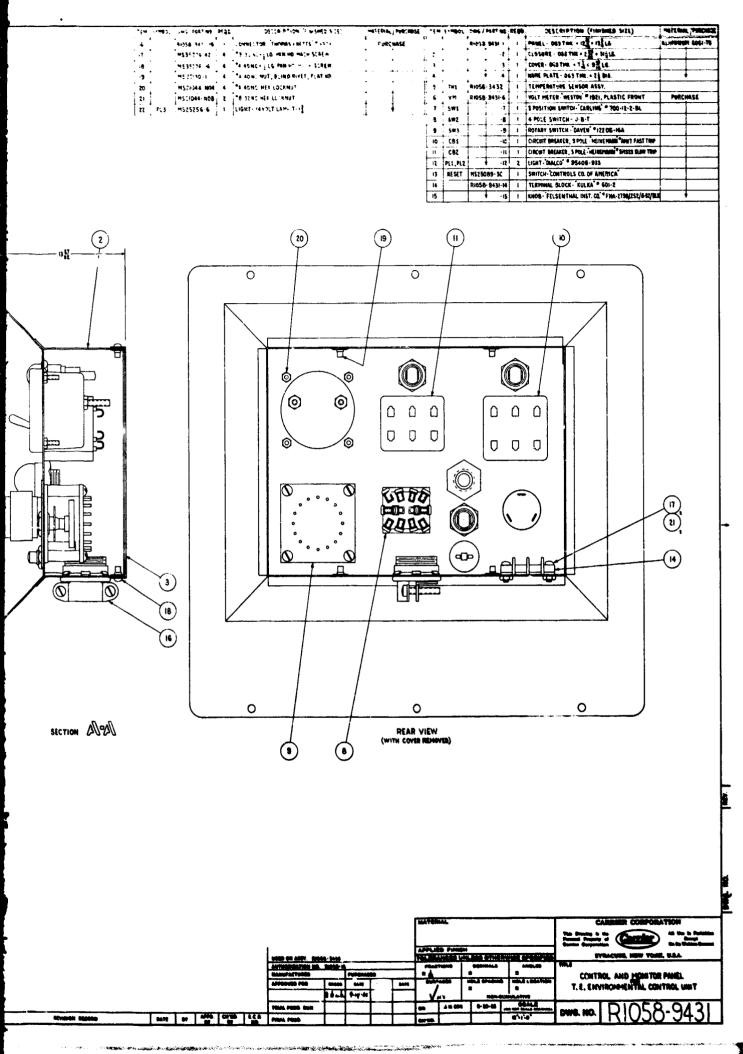




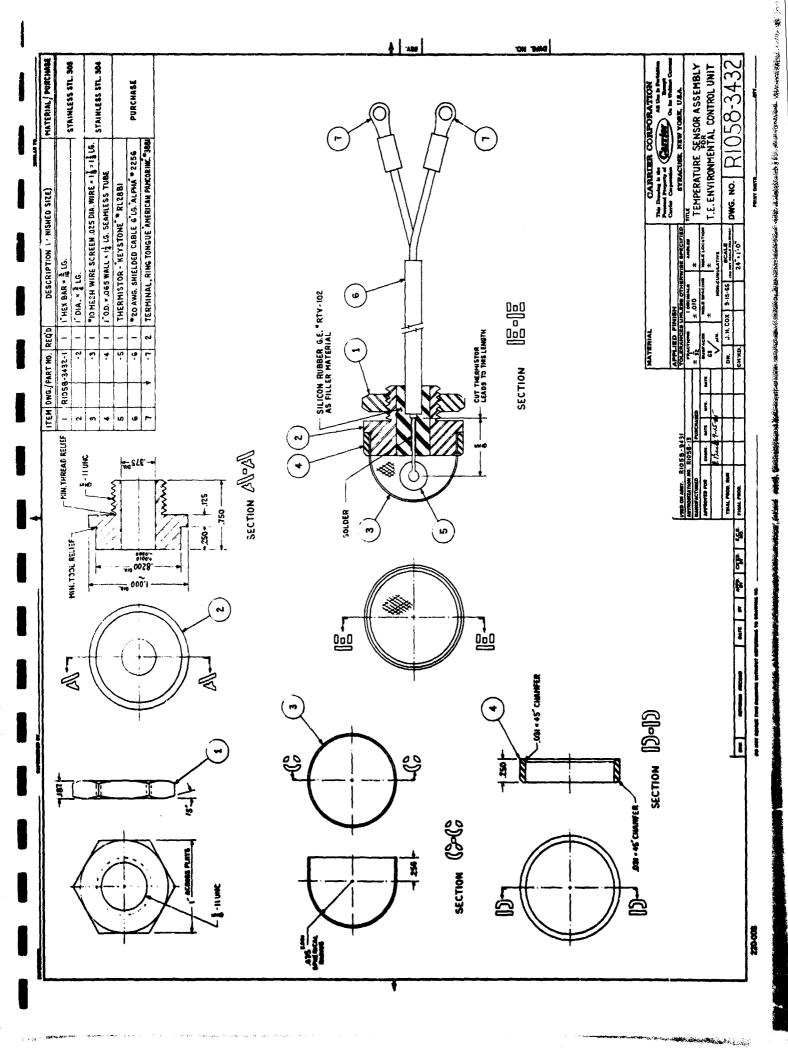


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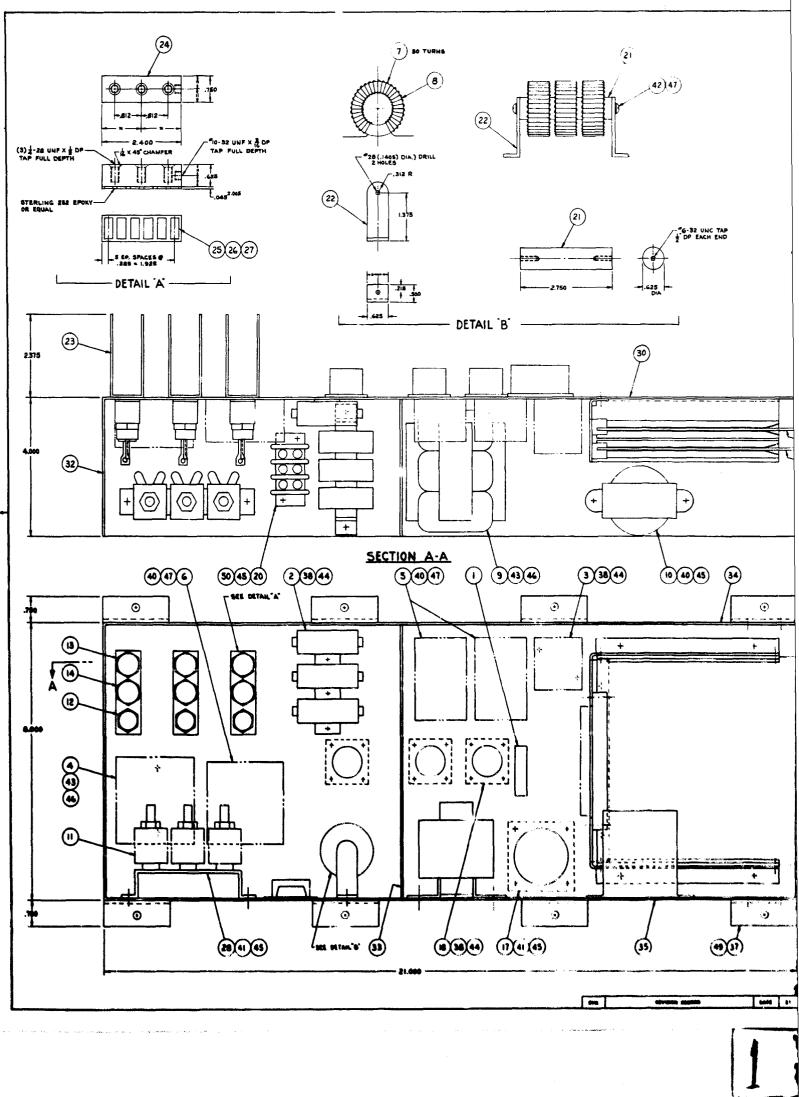


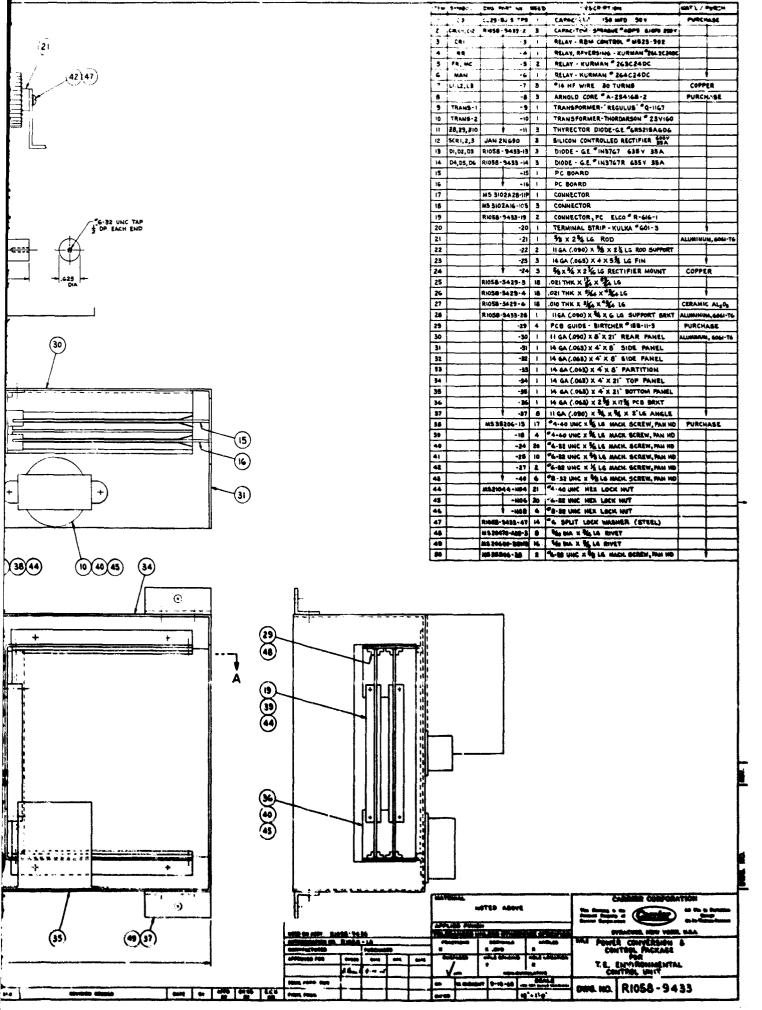


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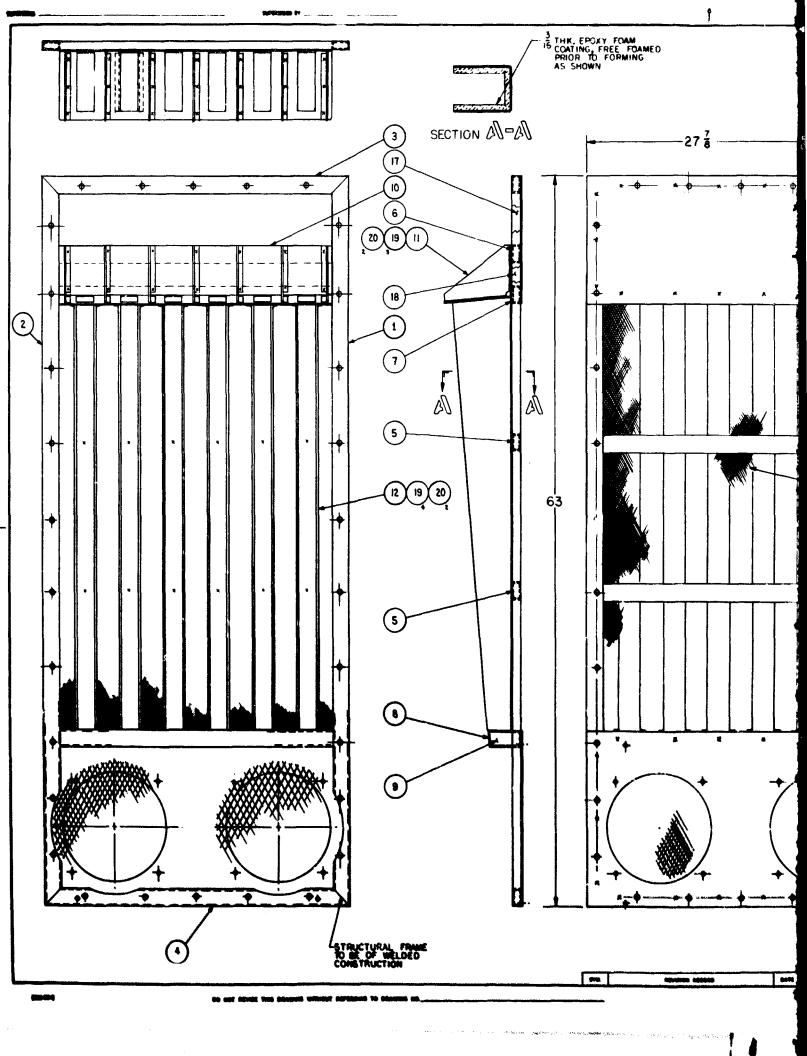




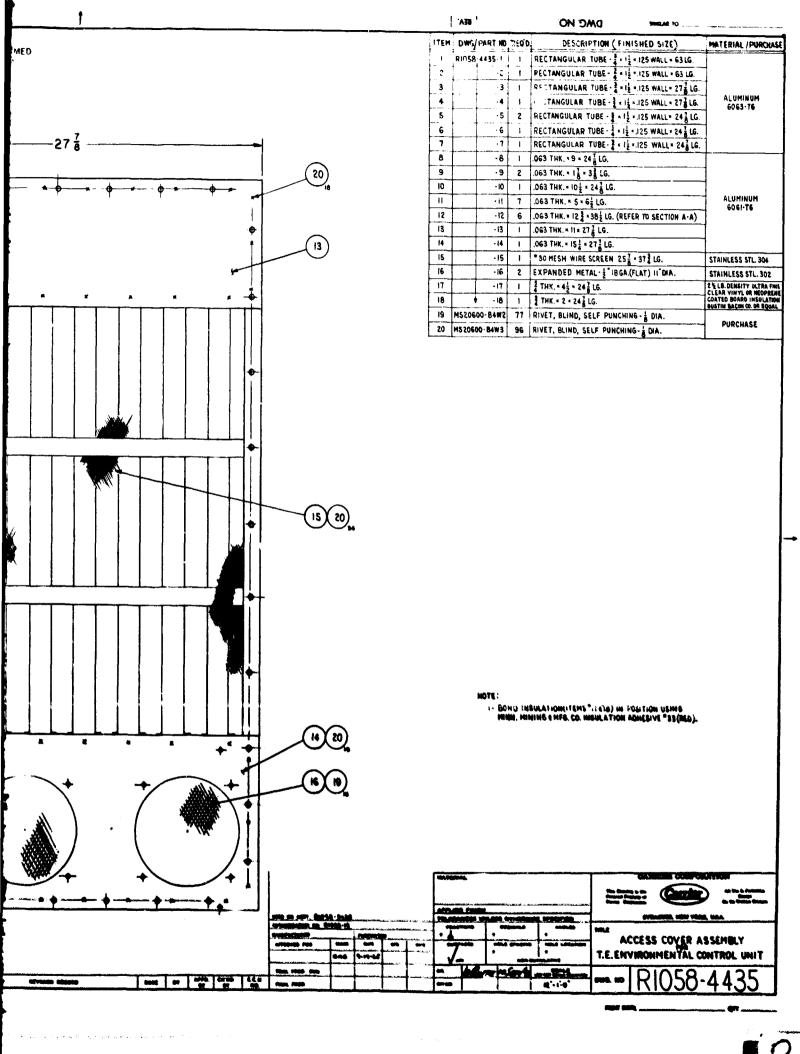
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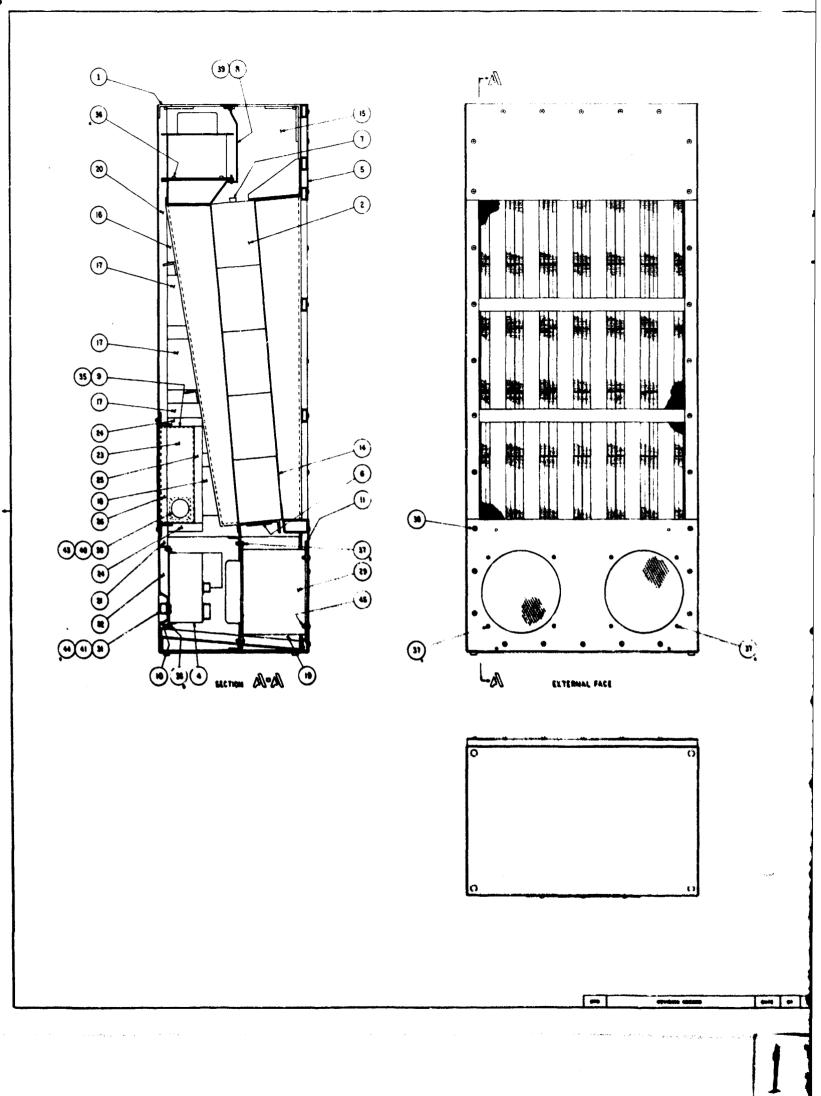
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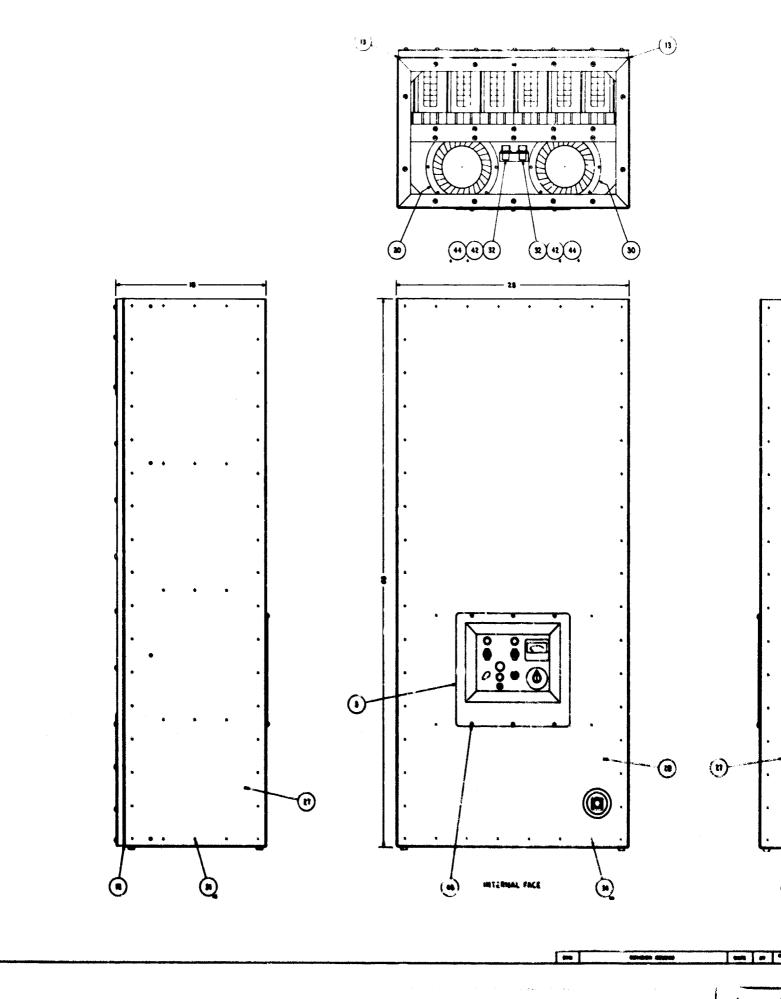
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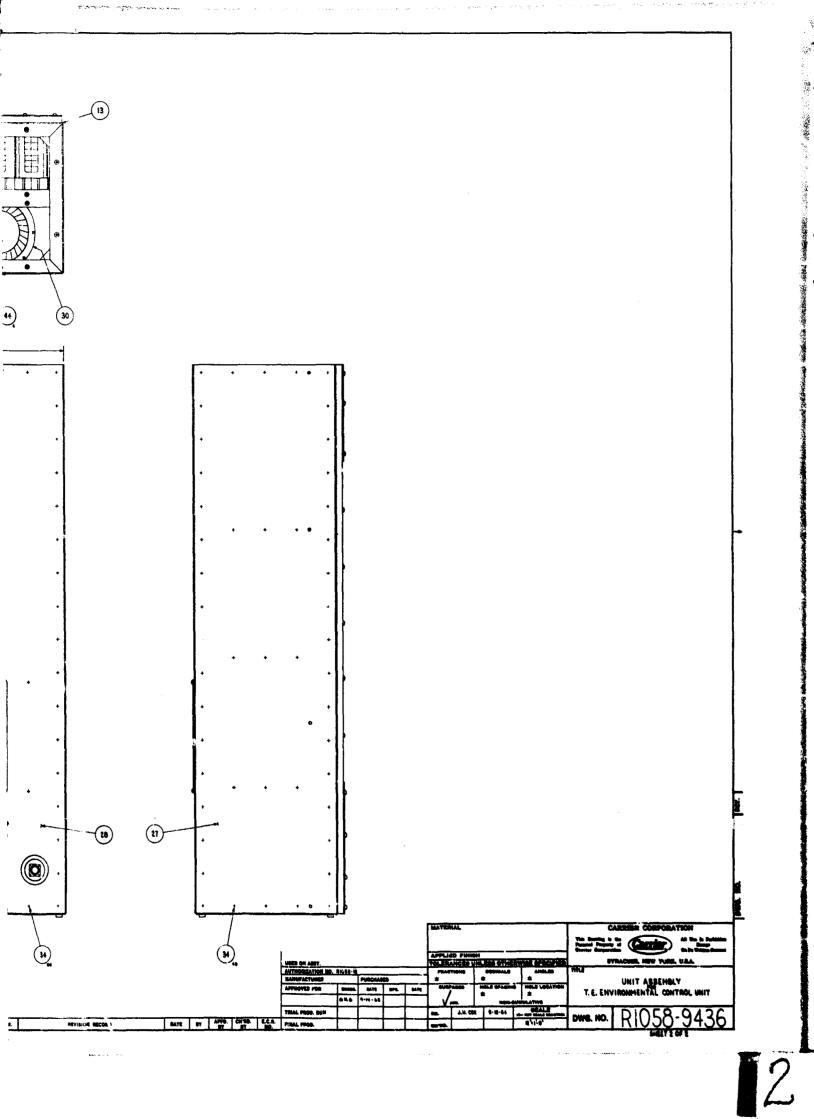


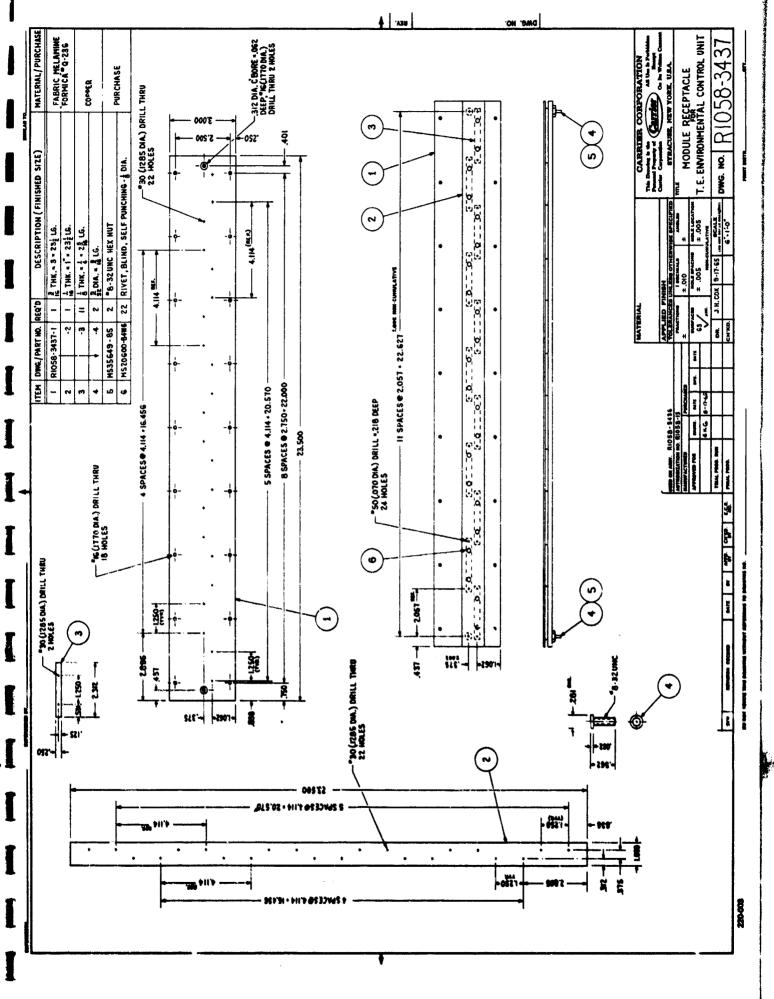


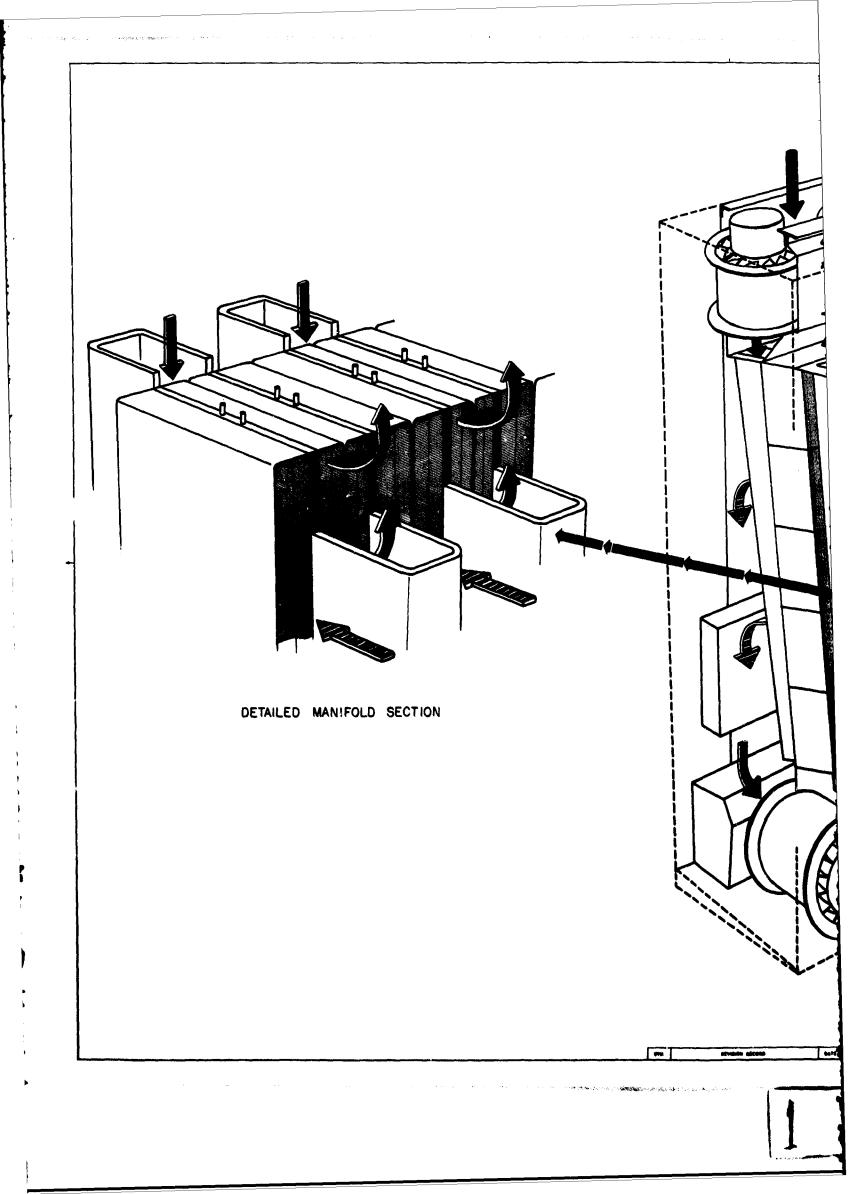
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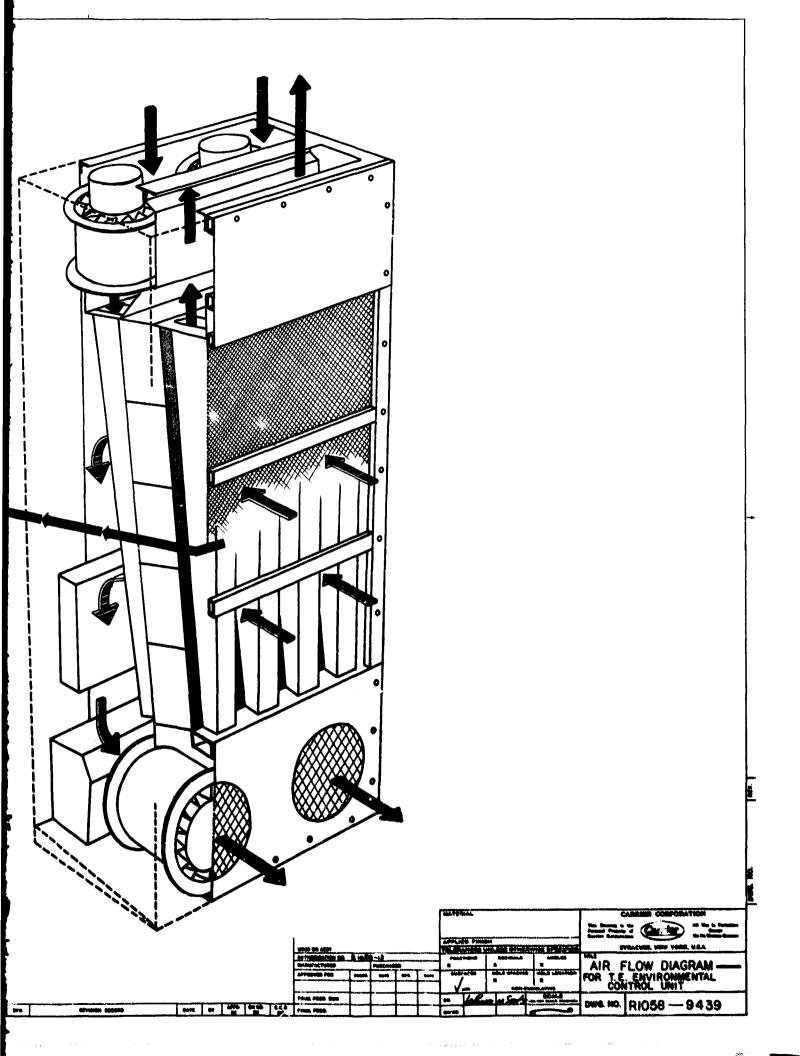
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Ø		6 R1058-3437 I MODULE RECEPTACLE 7 R1058-2438 IZ JUMPER STRAP 8 R1058-2436 I 040 THK - NG - 24 LG. 9 -9 I 040 THK - NG - 24 LG. 10 -10 D40 THK - 18 D4A. 11 -11 Z LTHK - 11 D4A.	ALUHINUM 6061-T6
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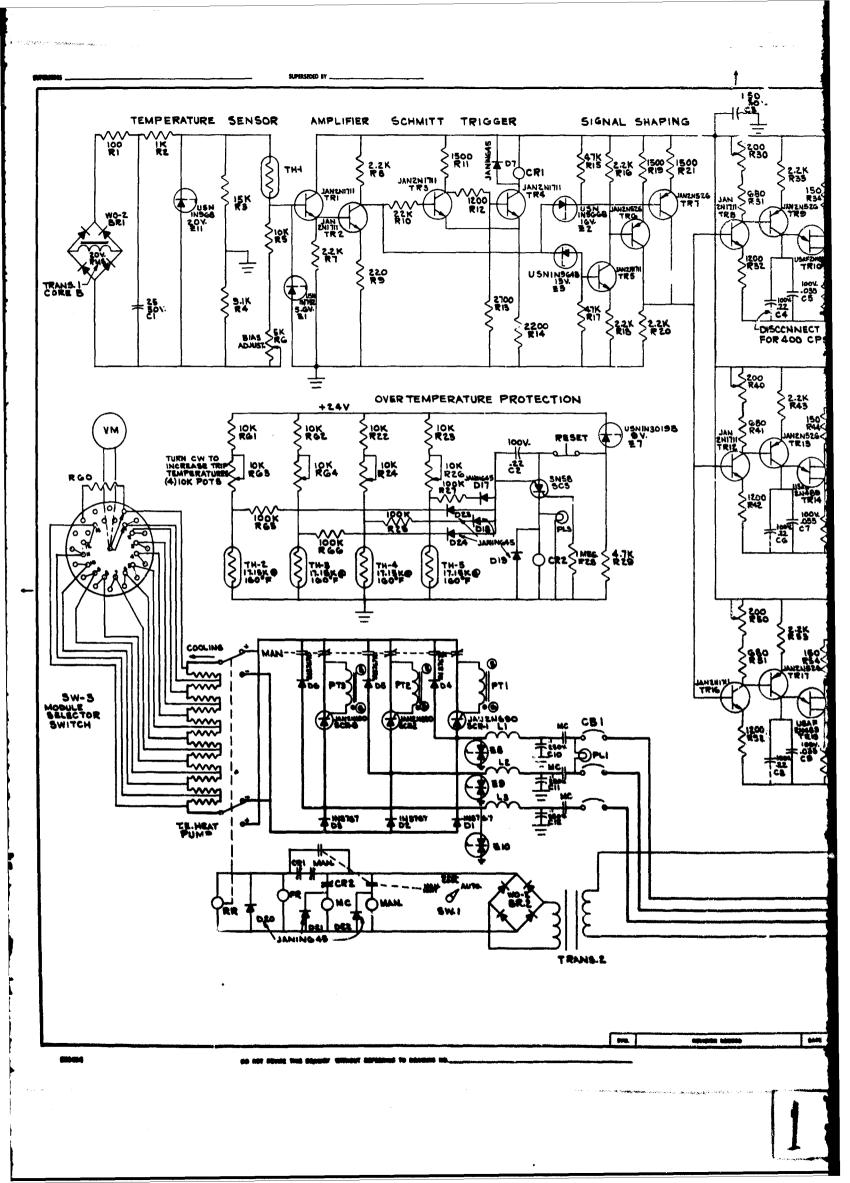


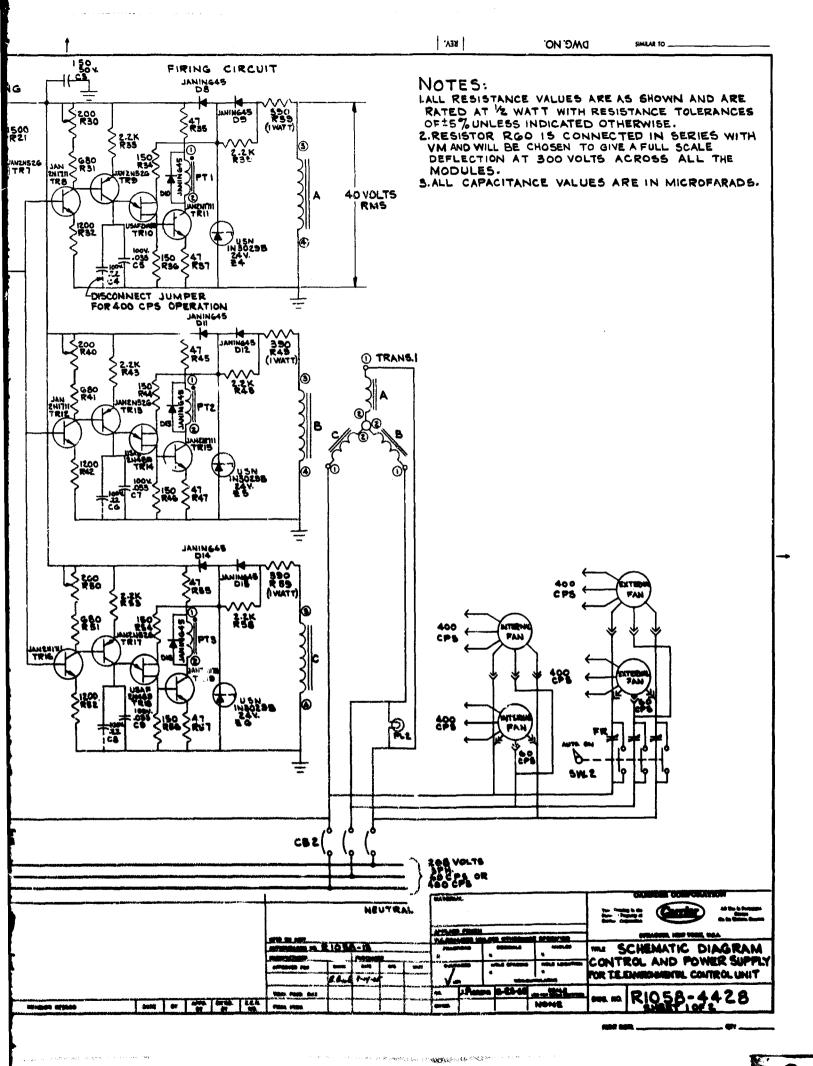












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APPENDIX B

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PROCESS SHEETS

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R-1058-1225	Polishing Thermoelectric Encapsulated Wafers
R-1058-1192	Tinning of Thermoelectric Elements
R-1058-1185	RF Bonding of Ceramic Sandwiches
R-1058-1299	Thermoelectric Panel Assembly
R-1058-1226	Foaming of Thermoelectric Panels

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CW KD.				g ma ch ine	/8	Lei'	are Mounting Thermoelectric meterial mounted in fixture Adjustable angle vise			la. Note:	Dismond blade,	AST	TOLERANCES UN	FRACTIONS	PACES	/ ain.		•
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Gree Bucket with Handle Set of Carrier's (Drawing M1058-3202) Martinia, Encapeulated Thermoelectric Encapeulated	99.956 Nethanol					MANUFACTUREDR1058	7	HASED
Preparing Polishing Compound 1 Micron Al 1. The one (1) materon Al203 can be purchased from Geoscience or Linds as certified. 1 Micron Al 2. Add 1260 gas of the powdered Al203 to the one (1) gailon polyethylene bottle. 1 Micron Al 3. Add 1260 gas of the powdered Al203 to the bottle and hand agitate the contents thoroughly. 1 Micron Al 3. Add 1260 gas of the powdered Al203 to the bottle and hand agitate the contents thoroughly. 1 Micron Al 4. Place on roliers of agitator and allow to rotate until ready for use. 1 Micron al 5. Kaep lid on powder container when not mixing. Room dust will contaminate the Al203 and cause scratches later on. POLISHID ENCAPE	One Bucket with Set of Carrier'	: Handle s (Drawing #R1058-320)	(S			capsulate	i Thermoel	
Preparine Polishing Compound 1. The one (1) aisron Al203 can be purchased from Geoscience or Linde as certified. 2. Add 1200 gas of the powdered Al203 to the one (1) galion polyethylene bottle. 3. Add 1300 cc of deionized water to the bottle and hand agitate the contents thoroughly. 4. Place on roliers of agitator and allow to rotate until ready for use. 5. Aeep lid on powder container when not mixing. Room dust will contaminate the Al203 and cause scratches later on. POLISHID PMG. NO.		1 1 1				Macron	1203, Dei	
1. The one (1) misron Al203 can be purchased from Geoscience or Linde as certified. 2. Add 1260 gms of the powdered Al203 to the one (1) gallon polyethylene bottle. 3. add 1900 sc of deionized water to the bottle and hand agftate the contents thoroughly. 3. add 1900 sc of deionized water to the bottle and hand agftate the contents thoroughly. 4. Place on roliers of agitator and allow to rotate until ready for use. 5. deep 11d on powder container when not mixing. Room dust will contaminate the Al203 and cause scratches later on. POLISHLD 0. <	-	ng Compound						
 2. Add 1260 gas of the powdered Al₂0₃ to the one (1) gallon polyethylene bottle. 3. add 1900 ec of deionized water to the bottle and hand agitate the contents thoroughly. 3. add 1900 ec of deionized water to the bottle and hand agitate the contents thoroughly. 4. Place on roliers of agitator and allow to rotate until ready for use. 5. Keep lid on powder container when not mixing. Room dust will contaminate the Al₂0₃ and cause scratches later polifiely e.K.APE on. 		mieron Al203 can be or Linde as certified	purchased.					
3. add 1900 cc of deionized water to the bottle and hand agiture the contents thoroughly. agiture the contents thoroughly. CARRIER CARRIER CARRIER CARRIER CARRIER CARRIER CARRIER for use. 4. Place on roliers of agitutor and allow to rotate until ready for use. Ant use is readed water to the bitting. Room of agitutor use. 5. Keep lid on powder container when not mixing. Room dust will contaminate the Al203 and cause scratches later container container the Al203 and cause scratches later container the Al203 and cause scratches later container container the Al203 and cause scratches later container the Al203 and cause scratches later container container the Al203 and cause scratches later container c		us of the powdered Al ₂ ⁴ Methylene bottle.	to to			31	arri	
4. Place on roliers of agitator and allow to rotate until ready for use. 5. Keep lid on powder container when not mixing. Room dust will contaminate the Al ₂ O ₃ and cause scratches later on. CAUTION DNG. NO.		of deionized water to contents thoroughly.	o the bot	tle and	hand	CARRIE	R CORPO	RATION
5. Keep lid on powder container when not mixing. Room dust will contaminate the Al2 ⁰ 3 and cause scratches later on. ENCAPE ENCAPE ENCAPE ENCAPE ENCAPE ENCAPE CALITION	Place ready	bliers of agitator and 180.	allow to	o rotate	until	· · · ·	SE. NEW YORK EN EXCEPT ON IT	. U.S.A. 6 WRITTEN CONSENT
		1 powder container when container when containing the $\lambda_1 2 0_3$	n not mis and cause	cing. R(scratch	oom nes later	Od	ENC THERMO	ELECTRIC W.FERS
CH. DWG. NO. R1058-1225						AUTIO	ALL DIMENSIC	NS GIVEN IN INCHES SCALE DRAWING.
CH. CH. DWG. NO.						OR.		SCALE
DWG. NO.						CF.		
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		SUPERSTURY			DEN. NO. LUDO				;
Operati	Operating Precedure	re leve			JOB NO.	REQ.	. NO.		
C. Prei	Preparing PR-1	.1 S.S. Lap.			APPROVED FOR	ENGRG.	DATE	MFG.	DATE
-		linerums duet and and months do			SAMPLE UNIT				
÷		2022	• • • • •		TRIAL PROD. RUN-"EX."				
2.	Insert	the five conditioning gears.			FINAL PROD.				
ç		Renlace duet car "id and comev duet	ran into nosition	0 a 1 t 1 0 1	Pilet Operations	JEG	12163		
		TH MATCH THE TIT		*11777780	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	LENSIONS AF	• •	0°0005	
т. т		Secure some 26.5 micron lapping com for finishing copper streps (Drw. N	ompound mixture. No. R1058-1196)	re. used 96).	ANGULAR ±	-	MACHINING ±		
	Shake t	ily and pour r		nts over	HOLE SPACING & LOCATION 1	on ±		NON-CUMULATIVE	ILATIVE
	the con	not w	the	compound however		-	PURCHASED		
Ŷ	Set	Set top lapping plate into position sustaining bar.	and set	against	MATERIAL Encapsulated Thermoelectrie 1 Micron Al203. Deionized	Thermo. 1203. De	telectric Deignized	te Wafers, d Water	, , ,
6.		wit switch, then reostat			FINISH				
	and then	art machine by slowly	turning the r	the reostat to					
	full power.	over.					/ •	(
2.		Add vigorously mixed lapping compound	through	the small		2 <i>11</i>	101	\sim	
	opening	openings in the top of the upper pl		ទ	<i>y</i>		$\left \right\rangle$	N	
	tioning	compound u		scratches are				20	
	Lenove:	removed irow both the upper and low	ower plates.						
8.		When conditioning has been completed tioning gears and clean in Triclene	, remove D. Wrap	the condi- in paper	SYRACU SYRACU		RK. U.S.A	L. CONSENT	
	and store.	ore.							
6	9. Clean t of oil gear me the buc	Clean the machine thoroughly with 1 of oil and lapping compound must by gear mechanism and plates. The Tri the bucket provided.	h Triclene D. A be removed from Triclene D will). All traces from the upper dll drain into		POLISHING THERMOELECTRIC ENCAPSULATED WAFERS	LRMOELECT ED WAFERS	ICTRIC IRS	
					CAUTION	ALL DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	DO NOT SCALE DRAWING.	VEN IN INC DRAWING.	HES.
					DR.			SCALE	
					CH.				
REQ. USED	USED ON ASSEN.	REVISION	DATE BY	APPE'D CHECKED	DWG. No.	R1058-1225	-1225		

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Derating	Operating Precedure	None				JOB NO.		RE	REQ. NO.		
	Turn of machine					AFPROVED	ED FOR	ENGRG.	DATE	MFG. D	DATE
Ā						SAMPLE UNIT	L				
้า		Unit bucket of oil. compound and Triclene D	Trielene		into a drain	TRIAL PROD. RUN-"EX."	RUN-"EX."				
	af aufficient	sise that large		of wat	of water can	FINAL PROD.					
	sever.					Pilet Or	Operations	JEG	1/2/69		
12.	1 1 2	foregoing precedure is necessary		only with new	Neu	TOLERANCE	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	IENSIONS A		0°0005	
		plates and/or if a cresh occurs which damages	hich das	4.ges	the	ANGULAR ±		MAI	MACHINING ±		
	plates wh	plates with scratehes and gouges				HOLE SPACI	HOLE SPACING & LOCATION #	ont		NON-CUMULATIVE	TIVE
D. Prepa	uring the St	Preparing the Stainless Steel Plates with	h Pellon Paper	Papel	£.a	MANUFACTU	MANUFACTUREDR1058-2187	-	PURCHASED		
.	Clean the	Clean the plates with fresh Triclene D.	Re D.	ltw bru	and wipe dry.	MATERIAL Enge	ML Encapsulated Ther 1 Mcron Al203,	Ther 1203.	Thermeelectric .203, Detonized	ic Wafers. ed Water	•
.	Using a k	Using a knife or other sharp edge.	split	the back	the backing	FINISH					
		. Discard the backing.		3							
i.	Carefully	Carefully place the edge of the pellon papar near the	ellon pa	par' n	ear the		Ü	TTE	rier		
•	edge of t paver to	of the bottom lapping plate surface. Align the to the plate and press the paper into position	surface. Daner in	to poi	Align.the Position					λ	
	with the palm of	palm of the hand. Moving hand slowly from	g hand slowly from	lowly	from		THIS DRAWING IS THE PERSONAL PROPERTY OF	IS THE PERS	ONAL PROPE	RTY OF	
	paper up	upward with the other hand,	the paper can be	Jenali Mer Cal			CARRIER		CORPORATION	NO	
	If air is	pressed into proper position without an encapsulation. If air is trapped, however, lift paper slowly to the point of eir bubble and then unness into notifion	out an e paper sl	Incaps Lowly	to the	שרר מ	STRATCHER FORSIDDEN EXCEPT ON ITS WRITTEN CONSENT	EN EXCEPT O	M ITS WRITT	EN CONSENT	
				1001	• 110 14	TITLE					
4	Repeat the holes in polishing vert tear	Repeat this same procedure for the top plate. I holes in the paper as are indicated for addition polishing compound. Funch from the paper side. Yest tear in the cellon paper or loosing of the	* to e o	op plate. Puncy for addition of paper side, to paper sing of the pape	Punch out on of the , to pre-		POLISHING THERMOELECTRIC ENCAPSULATED WAFERS	ISHING THERMOELECTR ENCAPSULATED WAFERS	OELECTI MAFER:	RIC S	
						CAUT	TION	ALL DIME DO N	DO NOT SCALE DRAWING.	ALL DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	vi vi
						DR.				SCALE	
						Ğ					
-					_	DWG.	NO	R1058-1225	25		
neq. USED O	USED ON ASSEM.	REVISION	DATE	ž	APPRO CHECKED						

Operating Fromdure Note Note Note Note Note 4. Cound the holes. Sever against ustraining bar. Sever against networking bar. APPENOVED FOR Ended NATE on the page of each loce to place into place. Sever against networking bar. APPENOVED FOR Ended NATE on the page of each loce to place into place. Sever against networking bar. APPENOVED FOR Ended NATE on the page of each loce to be place into place. Sever against networking bar. APPENOVED FOR Ended NATE on the place into place. Sever against networking bar. APPENOVED FOR Ended NATE on the place into the place into the place on the place into place. Sever adainst adainst adore aleaseried procedure. APPENDOVED FOR Ended NATE on the place into the place on the		1	•	SUPERSEDES			PRO	PROJ. NO. 1058	ENG	ENGR. NO.	
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 Pour one quart of deionized water on the paper of each plates und lower top plate into plates into position and lower top plate into plates for the plates with reno. Num. TX. Pour part of contents from the one (1) gallon bottle into the plates with reno. Num. TX. Pour part of contents from the one (1) gallon bottle into the plates with reno. Num. TX. Four the machine using afore described. Start the machine using afore described. Run the machine using afore described. Run the machine for 15 minutes adding compound period. Leally. Run the machine for 15 minutes adding compound period. Leally. Run the machine for 15 minutes adding compound period. Run the machine for 15 minutes adding compound period. Run the machine for 15 minutes adding compound period. Run the machine for 15 minutes adding compound period. Run the machine is now ready to polate the thermoellectric element. Run the machine is used for the first time there. Run a now rements the machine is used for the first time that dy or when the paper apper advised out, pour claining the gear the policin paper. Place elements or waters to be politihed into the holes for the first time that any or when the paper apper advised out, pour the machine is used or the first time that any or when the paper apper advised out, pour the machine is used or the first time that any or when the paper apper advised use. Place elements or waters to be politihed into the holes for the first time that any or when the policin paper. Place elements or waters to be politihed into the holes that any one machine is any of the carriers. Place elements or waters to be politihed into the holes that any of the tarrent. Rubber advised or the tarrent. Place elements or waters to be politihed into the holes that advised			around the	holes.					ENGRG.		DATE
7. Four set poise into plate intoplat into plate into plate into plate into pla		ter,		•			<u></u>	APLE UNIT			
Event part of contents from the one (1) gailon both a into place. Inthe Period 6. Pour part of contents from the one (1) gailon both a into place. Start Dettia place Start Dettia place 7. Start the machine using afore described. Nacuna ± Nacuna ± 7. Start the machine using afore described. Nacuna ± Nacuna ± 7. Start the machine using afore described. Nacuna ± Nacuna ± 8. un the machine for 15 ninutes adding compound period. Nacuna ± Nacuna ± 9. Machine is now ready to polish the tharmoelectric alements Nacuna ± Nacuna ± 9. Machine is now ready to polish the tharmoelectric alements Nacuna ± Nacuna ± 10. Each periad the machine to using dionized vater instand of frieter aliand of frieter along Nacuna ± Nacuna ± 10. Each periad the machine to used out, pour classing the gaine that duy or when the paper appears driad out, pour the tharmoelectric from point out, pour that duy or when the paper appears driad out, pour transments are reasoned user. Set the carriers into position, equally along the gear transments are reasoned user or means a machine to be pollabled into the holes 1. Each periad there are both plates thoroughly vetting the gear transment are reasoned user to be pollabled into the holes Calling the machine to the plate that a due to the holes 2. Set the carriers to be pollabled into the holes Out and		~	Pour one	wart of deionized water	ទ័ត្	1 1 1 0 1 0		AL PROD. RUN-"EX."			
 Four part of contents from the one (1) gailon bottle into a one (1) quart bottle/spout. Add compound to the plates onerense second a conservation by the plates of the plates the plates the point of the plates the plate the plates th			top plate		ito position dinst sustain	and ing	<u> </u>	AL PROD.			
0. Four parts from the one (1) quart between the ore (1) quart strom the one (1) quart and compound to the plates interments from the one (1) quart between the orea to measure a construction of the plates into a construct and compound to the plates interments from the machine using afore-described procedure.	••••••••••••••••••••••••••••••••••••••		14				_	lot Operation	JEG	17/63	
 Y:a the holes heretofore described. 7. Start the machine using afore-described procedure. 8. Run the machine for 15 minutes adding compound period. 8. Run the machine for 15 minutes adding compound period. 9. Bachine for 15 minutes adding compound period. 9. Bachine is now ready to pollah the tharmoelectric element wirker. 9. Bachine is now ready to pollah the tharmoelectric element wirker. 9. Bachine is now ready to pollah the tharmoelectric element wirker. 9. Bachine is now ready to pollah the tharmoelectric element wirker instead of the creating. 10. If a creat occurs and the paper is torn, repeat this procedure, items D1 - 9, using deionized water instead of triclere D for cleaning. 11. Each peried the machine is used for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper appeare for the first time that day or when the paper. 9. Each period or waters to be pollahed into the holes of the carriers. 9. Place elements or waters to be pollahed into the holes of the carriers. 9. Place elements or waters to be pollahed into the holes of the carriers. 9. Place elements or waters to be pollahed into the holes of the carriers. 9. Place elements or waters to be pollahed into the holes. 9. Place elements or waters to be pollahed into the hole		.		of contents from the or quart bottle/spout. Ad	d compound	n bottle to the p		LERANCES FOR ALL D	IMENSIONS AF		
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 But the machine for 15 minutes adding compound period- ically. Hachine is now ready to polish the thermoelectric element ically. Hachine is now ready to polish the hermoelectric element is finish in the same and the paper is torn, repeat this pro- ceeture, items D 1 - 9, using defontsed water instead of Trielene D for cleaning. If a crash occurs and the paper is torn, repeat this pro- ceeture, items D 1 - 9, using defontsed water instead of Trielene D for cleaning. Reach period for the first time that day or when the paper appeare dried out, pour cistonised water over both plates thoroughly wetting the pellon paper. Set the carriers into position, equally along the gear rime. Place elements or wafers to be pollshed into the holes of the carriers. Place elements or wafers to be pollshed into the holes of the carriers. Place elements or wafers to be pollshed into the holes. Place elements or wafers to be pollshed into the holes. Place elements or wafers to be pollshed into the holes. Place elements or wafers to be pollshed into the holes. Place elements or wafers to be pollshed into the holes. 							W	NUFACTURED R105			
 9. Machine is now ready to polish the thermoelectric element Encapeulated T 2 Micren Al2 0. If a crash occurs and the paper is torn, repeat this proceedure, iteas D1 - 9, using deionised water instead of Trielene D for cleaning. 9. Machine is now ready to polish the thermoelectric element research of Trielene D for cleaning. 9. Machine is now ready to polish the thirst instead of Trielene D for cleaning. 9. Machine is now ready to polish the thirst instead of Trielene D for cleaning. 9. Machine is now ready to paper appear of the first time that day or when the paper appear dried out, pour deionised water over both plates thoroughly wetting the gear the pellon paper. 9. Set the carriers into position, equally along the gear time. 9. Place elements or wafers to be polished into the holes of the carriers. 9. Place elements or wafers to be polished into the holes of the carriers. 9. Place elements or wafers to be polished into the holes of the carriers. 		0	Run the ma	whine for 15 minutes at	lding compou	nd perio	• • •	TERIAL			
 9. Machine is now ready to polish the thermoelectric element item of the curve item ALZ control of the sum of the paper is torn, repeat this processime. Items D 1 - 9, using deionized water instead of Trielene D for cleaning. 20. If a crash occurs and the paper is torn, repeat this processime. Items D for cleaning. 2. Set the carriers into position, equally along the gear time. 3. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes of the carriers. 4. Use a carriers. 5. Place elements or wafers to be polished into the holes of the carriers. 6. Durion of the carriers. 			ically.					Encapsulated	Thermoel		. . .
10. If a crash oscurs and the paper is torn, repeat this procedure, items D 1 - 9, using defonited water instead of Trielene D for cleaning. FINISH Polishing Thermoelectric Encapeulated Wafers Polishing Thermoelectric Encapeulated Wafers 1. Each peried the machine is used for the first time that dvy or when the paper appears dried out, pour cleaning water over both plates thoroughly wetting the pellon paper. Polishing Thermoelectric Encapeulated Wafers 1. Each peried the machine is used for the first time that dvy or when the paper appears dried out, pour cleaning water over both plates thoroughly wetting the pellon paper. Polished into the first time that dvy or when the paper appears dried out, pour cleaning the pellon paper. 2. Set the carriers into position, equally along the gear rise. Polished into the holes 3. Place elements or wafers to be polished into the holes of the carriers. Polished into the holes 3. Place elements or wafers to be polished into the holes of the carriers. Polished into the holes 9. Place elements or wafers to be polished into the holes Poliskin Revesion 9. Place elements or wafers to be polished into the holes Poliskin Revesion		0		I now ready to nolish th	thermosle	atria al	ament.	I MICLON A	1203, Uei		5
20. If a crash occurs and the paper is torn, repeat this pro- codure, items D 1 - 9, using deionized water instead of Trielens D for cleaning. 9, using deionized water instead of Trielens D for cleaning. Pollathing Thermoelectric Encapsulated Wafers Pollathing thermoelectric Encapsulated Wafers Pollathing Thermoelectric Encapsulated Wafers Pollathing thermoelectric Encapsulated Wafers Pollathing Thermoelectric Encapsulated Wafers Pollate third out, pour catonised water over both plates thoroughly wetting the pellon paper. 2. Set the carriers into position, equally along the gear rime. Pollates thoroughly use the second of the carriers. 3. Place elements or wafers to be pollated into the holes of the carriers. Pollates 9. Place elements or wafers to be pollated into the holes POLLSHIM BRCAPS 9. Place elements or wafers to be pollated into the holes POLLSHIM BRCAPS 9. Place elements or wafers to be pollated into the holes POLLSHIM BRCAPS			4. 11. s					ISN			
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Pollathing Thermoelectric Encapeulated Wafers 1. Each period the machine is used for the first time that day or when the paper appears dried out, pour day or when the paper appears dried out, pour closenting the paper appears dried out, pour distontsed water over both plates thoroughly wetting the sellon paper. 1. Each period the machine is used for the first time that day or when the paper appears dried out, pour day or when the paper appears dried out, pour distontsed water over both plates thoroughly wetting the sellon paper. 2. Set the carriers into position, equally along the gear rise. 3. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes of the carriers. 9. Place elements or wafers to be polished into the holes of the carriers. 9. Place elements or wafers to be polished into the holes of the carriers. 9. Place elements or wafers to be polished into the holes of the carriers.			Triclene I) for cleaning.				C	arr	ier)	
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that day or when the paper appears dried out, pour cetomised water over both plates thoroughly wetting the pellon paper. CARRIER snacus snacus the pellon paper. 2. Set the carriers into position, equally along the gear rise. ITHE 3. Place elemente or wafers to be polished into the holes of the carriers. POLISHIN ENCAPS 3. Place elemente or wafers to be polished into the holes of the carriers. POLISHIN ENCAPS 3. Place elemente or wafers to be polished into the holes of the carriers. POLISHIN ENCAPS	ويوري والم	.		, the module of a line of the	in the fine			THIS DRAWIN	G IS THE FERSO	MAL PROPERTY OF	
Contrad water over both plates thoroughly wetting Status the pellon paper. ALL WEE is romanose 2. Set the carriers into position, equally along the gear ITTLE 2. Set the carriers into position, equally along the gear ITTLE 2. Set the carriers into position, equally along the gear ITTLE 3. Place elements or wafers to be polished into the holes POLLSHIN 3. Place elements or wafers to be polished into the holes POLLSHIN of the carriers. REVISION DR. MED ON ASSEL BY DWG. NO.			-	when the paper appeal	s dried out	- Dour		CARRII	ER CORP	ORATION	
2. Set the carriers into position, equally along the gear rime. TITLE 2. Set the carriers into position, equally along the gear of the carriers. Place elements or wafers to be polished into the holes of the carriers. 3. Place elements or wafers to be polished into the holes. PLACE elements or wafers to be polished into the holes. 3. Place elements or wafers to be polished into the holes. CAUTION 0. The carriers. CAUTION 0. The carriers. DR. 0. The carriers. DR. 0. THO NASEL DNG. NO.			deionised the pello:	both 1		wetting		SYRAC	USE. NEW YO	RK. U.S.A.	
Time. PollSHIM 3. Place elements or wafers to be polished into the holes of the carriers. POLISHIM 3. Place elements or wafers to be polished into the holes of the carriers. ENCAPS 0 f the carriers. CAUTION 1 DR. 1 DWG. NO.			Set	nto position.	pelly along	the					
3. Place elements or wafers to be polished into the holes of the carriers. ENCAPS of the carriers. ENCAPS of the carriers. CAUTION DR. DR. DR. NG. NO.			rims.					HSTIO	ING THERM	OELECTRIC	
of the carriers. CAUTION CAUTION CAUTION CR. CH. DWG. NO.		~	Place	usfers to be				ENCAL	PSULATED	WAFERS	
USED ON ASSEL			of the				2				
USED ON ASSEN. REVISION DATE BY APPER DWG. NO. R1058-1225							0	AUTIO	ALL DIMEN	SIONS GIVEN IN I DT SCALE DRAWIN	NCHES. G.
USED ON ASSEN. REVISION DATE BY APPEND CHICKED DWG. NO. R1058-1225							ğ			scal	ш
USED ON ASSER. REVISION DATE BY APPRID DWG. NO.							IJ				
			N ASSER.	REVISION	+-		_	WG. No.	R1058	-1225	

Operating Procedure 4. Pour a thir ever each o		2			PROJ. NO. 1058			
	sedure	None			JOB NO.	REC	REQ. NO.	
	a thin lower of the bloc	le nolishtne		composited mixture	APPROVED FOR	ENGRG.	DATE MFG.	G. DATE
	over each of the valers.	entrand E			SAMPLE UNIT			
S. Sat +	ton plate into position and secure		acainst t	the retain-	TRIAL PROD. RUN-"EX."		-+	-
ing	SP Files His Postston				FINAL PROD.			-
					Pilot Operations	JEG	1/7/63	-
6. Turn of th	Turn on lap and while waiting the 10 seconds of the switch, pour polishing compound into	g the 10 seconds g compound into 1		warm up period the holes of	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	NENSIONS AI CIFIED	RE ± 0.0005	05
the t	top plate.				ANGULAR Ì	MAC	MACHINING ±	
7. Slowly	Slowly increase the speed of	the machine until		operating	HOLE SPACING & LOCATION ± MANUFACTURED H1058-2187 PURCHASED	ION ± S-21E7 PU		NON-CUMULATIVE
8. Perio	Periodically add polishing compound to aforementioned holes in the top plate	-	the wafers via	s via the	MATERIAL Encapsulated 1 Micron A	psulated Thern Micron Al202.	Thermoelectric	te Wafers d Water
						2		
9. Establia minutes cleaned continue to the p	Establish the surface removal rate by minutes and measure the thickness of cleaned in deionized water. Using th continue polishing until the surface to the proper dimension.	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	polishing f our or five s rate per has been b	ng for five five pieces. per minute, eer brought	NSINF	arr	rier	
10. A minimum Walters to from the in laber to 3.0 =	A minimum of 1.5 mils must be removed from walers to insure removal of the surface dan from the waferizing process. Any extra rem in labor and material, so attempt to contro to 3.0 - 3.5 total required surface removal	b removed from ex the surface dama, any extra remo tempt to control surface removal.	each lage, loved bl all	side of the resulting is costly processes	THIS DRAWING IS THE PERSONAL PROPERTY OF CARRIER CORPORATION SYRACUSE. NEW YORK, U.S.A. ALL USE IS FORBIDDEN EXCEPT ON 175 WRITTEN CONSENT	is the perso R CORF ISE. NEW YO	THIS DRAWING IS THE PERSONAL PROPERTY OF CARRIER CORPORATION SYRACUSE. NEW YORK. U.S.A. SF IS FORBIDDEN EXCEPT ON 175 WRITTEN COI	r DNBENT
11. When with sheet	When polishing has been completed, wash n with deionized water and cover completely sheet to keep room dust from settling on the pellon paper.	<u>D</u>	wash machine letely with a ng on and con	ine thoroughly th a plastic contaminating	TITLE PULISH ENCA	LISHING THER ENCAPSULATED	PULISHING THERMOELECTRIC ENCAPSULATED WAFERS	0
					CAUTION	ALL DIMEN DO N	DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	IN INCHES. VING.
	-				DR.		sc	SCALE
					CH.			
INTER ON ACCOM	REVISION	DATE		APPE'D CHECKED	DWG. NO.	R1058-1225	1225	

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			SUPERSTOCS			PROJ. NO. RIO58	EN	ENGR. NO.		
perst1	Operating Procedure	e	Hand Timing			JOB NO.	RE	REQ. NO.		
2 8	Equipment					APPROVED FOR	ENGRG.	DATE	MFG.	DATE
Ļ	. Tvecters	15			•	SAMPLE UNIT				
CV.		Scott paper towels	tomils			TRIAL PROD. RUN-"EX."				
m	3. Safety glasses	seals.		(FINAL PROD.				
Ŧ		a corp. onic s	neuroru vory, mouer u-cuum aturasour uitmaennic soldering not Model 1147	c Retteration		Pilot Operation	AFK	B/1/11		
''NO	5. Propen	e tore	Propane torch Bolder: 504 BA: 304 Bn: 24 Sh (see Dr	mwing R1058-1197)	. (2	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	IMENSIONS A ECIFIED	1		
А	5	Solder	Fot	, ,		ANGULAR ±		MACHINING ±	.	
	1. Set the	e sold	Set the solder pot control dial at	54. This should		HOLE SPACING & LOCAT	LOCATION ±		NON-CUMULATIVE	ILATIVE
I		solde.	give a solder temperature of 440 + 1	10°F.		MANUFACTURED	Ā	PURCHASED		
ર્ચ હ		a prop	Using a propage gas torch, melt the the mot. until the level of the molt	B1Sn solder int en material is	iust	I A	Drawing RlC	F1058-1197		
	albove	the un	trasonic heads.			ente	r Drawlp	R LIOSE	1812-1	
ň		off an	Scrap off any oxidation residue which might have	ch might have						
I		durin	formed during the solder melting pro	ocess.		FINISH				
-4		e gene:	Set the generator power dials at 50.							
ŝ	5. Temper	sture	Temperature on the built-in dial the	8 1				•	/	
		pprox	read approximately 400 F, 50 F 1636 	turn accurat			110	ISI		
9	6- One et	a time	e. the the transducers.	. Bush the foot					λ	
,			switch and adjust the phase dial for	the highe	tch	/				
		ble.	available. Shut off this transducer	and tune the	ther.	THUS DRAWIN	THIS DRAWING IS THE PERSONAL FROPERTY OF	WAL FROFE	RTY OF	
r-	7. Pack 5	С В В	Pick up an element with the tweezers	, holding t	vertically	CARRIER		CORPORATION	NO	
			and the parrow side at right angle t	to the front of the a tun transducer heads	theads	STRACUSE	USE. NEW Y	NEW YORK, U.S.A.		
			and measure remaining space between	the e	d the	ALL USE IS PORE	IS PORSIDDEN EXCEPT ON ITS WRITTEN	HILL MULT	EN CONSENT	
))			TITLE				
æ	8. Adjust,	art.	Adjust, W Toocening the screws in the	holding brac	t, to		•		1	•
	give a tinned	give a spacing of timmed are thick.	spacing of 20 mils more than are thick. Tighten screws.	the elements to	be	Tinning o	of Thermo	Thermoelectric Elements	c Elen	ents
			1100 200			CAUTION	IOD VIL DINE	ALL DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	/EN IN INC	HES.
			Item A-6 added			DR.			SCALE	
		•••	Item C and D added	-		CH.				
		H H	Butire	\$/1/63 JBC JEC	; JEG					
	UNDER ON ASSAULT		REVISION	GIATA YR THE TANK	P CHECKED	DWG. NO.	X1070-1192		TTT • AQU	

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						.ON BOL		REQ. NO.		
8	Inspect the	Inspect the element just used for setti		aŭs.		APPROVED FOR	ENGRG.	DATE	MFG.	DATE
	and if the	if the epoxy has expanded a crack,	, discard the piece.	the piec		SAMPLE UNIT				
C. TL	Timing					TRIAL PROD. RUN-"EX."				
						FINAL PROD.			·	
่า	-	Timing may now begin by picking up an element as described	an element	as desc	ribed					
	evitch.	LINEIT ELEMENT DESVEEN VIE NEWAS AND PUBL 1005 Slowly move element while under the solder, ba	neaus and j mder the sc	solder, b	beck	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	DIMENSIONS /	ARE ±		
	heads. At	and foreig always remaining vithin the area of the two heads. After fame seconds. Hift piece from solder and	ece from sc	oi the two folder and	d then	ANGULAR ±	W	MACHINING ±		
	-	remove foot from switch.				HOLE SPACING & LOCATION 1	VTION ±		NON-CUMULATIVE	LATIVE
તં		Inspect both sides of the element and	d if tinning is	ng 16 not	ţ	MANUFACTURED		PURCHASED		
ĸ		Lay tinned element on a clean tovel.	There is no need	no need						
	to whit w	to whit until solder has solidified.								
4		When tirming has been completed, leave solder pot at temperatures heretofore set.	we solder]	pot "on"		FINISM				
4	Maintenance of Put	Ĕ								
4		Periodically, muple the liquid and have chemi performed to ascertain changes in composition.	have chemical emposition.		analysis)			\mathbf{r}	
ನೆ		If there is an indicated change in the Bi, content of more than 5%, the solder should	a n	and Sb removed		CARRIER	F	RE PERSONAL PROFERTY O	NON	
	from the]	from the pot and discarded.				SYRA		ORK. U.S.A		
ň	•	To remove solder, set the entire pot as stand or blocks shout 6" off the table.	8	mbly on a Tern screv in		ALL USE IS	L430X3 N3QQ	ON ITS WRITT	EN COMSENT	
	rear of p	rear of pot and catch molten solder in a		sr cup		nrLE				
	(two may be need screw to normal,	(two may be beeded). When completed return emptying berev to normal.	return en	jtying		Timing of	Thermoelectric Elements	e ctr ic I	Lement	-
						CAUTION	DO ALL DIME	ALL DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	VEN IN INC	HES.
						DR.			SCALE	
	<u> </u>					CK.				
	URED ON ASSERT.	REVISION	DATE	0.2447	CHECKED	DWG. No.	R1058-1192	2611	Rev. III	

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			PROJ. NO. R1058	ENG	ENGR. NO.	•
Operating Procedure	are nobe		JOB NO.	REQ.	REQ. NO.	
			APPROVED FOR	ENGRG.	DATE MFG.	G. DATE
			SAMPLE UNIT			
2 1/2 kw Inducti	2 1/2 kw Induction Heater. Lepel or Equivalent		TRIAL PROD. RUN-"EX."			
Automatic Firtur	Automatic Firturine. Drawine R1058-0175 and -0	-02013	FINAL PROD.			
			Pilot Operations	JEC	2/8/63	_
Tuesers			TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	KENSIONS AI CIFIED	E± 1%	
Plux. Keeter 154	Plux. Lester 1544 diluted 1:1 with Keeter		ANGULAR ±	MACH	MACHINING ±	
104 Intener			HOLE SPACING & LOCATION 1	TON ±	NON	NON-CUMULATIVE
Tin Plated Coppe	Tin Plated Copper Pleces and Ceramic Wafers per	r drawings.	MANUFACTURED X	54	PURCHASED	
B. Start (b			MATERIAL CODDOF Straps Drawing R1058_2181		. and spacers, carr	ters, Carrier Carrier
			Drawing R1058-1141			
1. Turn on cool	Turn on cooling water to RF generator.					
2. Adjust air s	Adjust air supply to hold down fixture to	to 20-25. pei.				
		,		I'Y C	rior	
	Sat start switch on "much buttom"		5			
5. Turn on RF g to warm up.	generator power. Wait 10 minutes	es for generator	CARRIER CARRIER	F	CORPORATION	
6. Set start sv	Set start switch on "foot" switch control.		ALL USE IS FORDIDER	DEN EXCEPT ON		CONSENT
7. Push foot sw provided. P	Push foot switch and set grid to read 250 provided. Power dial to be set at full sc	250 on the meter 11 scale.	Jun			
			RF BONDING OF	CERAMIC	SANDMICHES	ន
	Type flux used	DEC 49	CAUTION	ALL DIMENS	ALL DIMENSIONS GIVEN IN INCHES. DO NOT SCALE DRAWING.	N INCHES. VING.
	2 C-5 "shaking" to "vipe" 1/2 3 1-0 "28 +0 20-25!" D/1	24/64 REZ JEG	DR.		3	SCALE
	C-13 Use of theesers	<u>.</u>	Ğ			
	REVISION	DATE BY APPED CHICKED	DWG. NO.	R1058-1185		Rev. II

		Sacasara				PROJ. NO. R1058		ENGR. NO.			II FV
Le d	Operating Procedure	none				JOB NO.		REQ. NO.			
				ho have	t	APPROVED FOR	R ENGRG.	G. DATE	MFG.	DATE	
×.	Ine induction I on the autometi	Ine induction neating syste will continue to the parton so on the automatic timer. Which for components shown on Carrier	ments show	n on Car	rier	SAMPLE UNIT					
	drawing R1058-	drawing R1058-3181 is approximately 16 seconds at	seconds at	a grid set-	set- ·	TRIAL PROD. RUN-"EX."	x.''				581
	ting of 250.					FINAL PROD.					[[-1]
10.	Terediately un	I mediately upon conclusion of the heating cycle (red light	ing cycle	(red lig	ht	Pilot Operations	ons JEG	k/8/63	}		r\$0
	goes off), the	the compressed air is turned automatically on	automatic	utomatically on	٩	TOLERANCES FOR ALL DIMENSIONS ARE ± UNLESS OTHERWISE SPECIFIED	L DIMENSION	s are ±	1%		าษ
	the plated tin.	the summer to a point before u	ry between	between the 12	and	ANGULAR ±	-	MACHINING	+		
	7 mm pieces and	me pieces and may also be a function of	of the com	the compressed	air	HOLE SPACING & LOCATION ±	4			NON-CUMULATIVE	91
	temperature. The cycle	The cycle can be adjusted on the clock-timer the circuit	l on the cl	OCK-LING	L	MANUFACTURED	x	PURCHASED	ED		NC DN
	-			:		MATERIAL GODDA	r strans	and	Cers.	Carrier	<u> </u>
ц.	Immediately up fingered holde:	Immediately upon completion of the cooling cycle, the fingered holder will rise and slide can now be moved.	ling cycle. 1 now be mov	the three wed.	0	Drawing R105 Drawing R105	E R1058-3181, c	eran	Carr	ier	
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ř.	nove the silue are directly o	are directly over the discharge air holes							7		
13.	Puch foot evit	Push foot switch provided and an air blast will		push the not	iot		N N N	arrie	`		
	sandwiches out	sandwiches out of their slots into a trough and		finally into	Into	'			λ		
	a metal container where	nor whore they will finally wiches may also he namoved :	y cool		tem)-						
	foot svitch is	fout svitch is not used.				THIS DR	F	ERSONAL PRO	DERTY OF		
14.	After the oper	After the operator has become familiar with the aforeguing	with the a	foreguir	ъ В	CAR	CARRIER CORPORATIO		NOIL		
	procedure, he	procedure, be then can load the empty sid	side of the fixture the mattine and cool	e of the fixture malting and cooling	1100	TC VIT NEE 18 FO	ALL USE IS FORBIDDEN EXCEPT ON 175 WRITTEN CONSENT	T ON ITS WR	J. T. ITTEN CONSE	(MT	
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	are always rea	are always ready for bonding as the completeness in the fixture	npleted ones	s are							
						RF BONDING OF CERAMIC SANDWICHES	C OF CERA	MIC SAI	NDWICHEN	S	-
15.	When the muchi on "push butto	When the muchine is not in use, the start on "push button" to avoid accidental trip	start switch tripping of	should be the foot	be set t switch						
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 Operating Procedure Rone Hone ABerfety Precautions 1. Operator abould remove all rings and if worn, wrist wat to avoid possible coupling with the R.F. coll by the metallic objects. 2. Care abould be used to hold tweezers away from the R.F. when it is energized. 3. All flux spillage should be cleaned up immediately with tricleme solvent. Use care not to breathe fumes and we protective hand covering. 4. Do not brethe flux fumes that may escape from sandwich during bonding process. 	None					Ō			
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6. Lay top cross pieces on lat i.eft lead strup is always n B. Starting with p-type, set s Set all n-type eloments int Set all n-type eloments int into tentring of each elo Adjust centring of each elo Adjust centring of each elo Adjust centring of each elo into transite. Chec into transite. I. Set top of matrix plate on the lattice settions. Chec into transite. I. Set nuts on bolts. Tighten into transite.		& ~ ¢		iop cre land : ting wi	sss pi strap								ی بر بر		
 Left land strupt is allowing negative. First claments will <u>threefore</u> be pubye. Restring with petrye, at all pryre claments into position, alternating checkerboard style. Ret all ardype claments into position in the remaining alternate spaces. Adjust centring of each element with tweezers. Majust centring of each element with tweezers. Ret all ardype claments into position in the remaining alternate spaces. Majust centring of each element with tweezers. Ret all ardype claments into position units of claments. Ret sport and with plate on unbracked panel. Cure must be used to fit the rubber cublions between the texts parties. Ret must so bolds. Tighten must be used to fit before treaching unter the texts build tight. Tighten remaining unter the texts of the texts. With a socket versely, draw unte up stud. With a socket versely, draw unte up stud. With a socket versely, draw unte up stud. With a socket versely, draw unter up stud. With a socket versely, draw and tight. Tighten remaining unter the text control of the text of text of the text of text of the text of text of the text		8. 4		lead - ting vi	trap	eces	on lat	tice a	ind fil	_	ition				
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