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METHODS FOR LOW POWER
TEMPERATURE CONTROL

REPORT NO. 1

CONTRACT NO. DA 36-039 SC-90883

DA PROJECT NO. 3B55-03-003-72

FIRST QUARTERLY REPORT
2 JULY 1962 TO 30 SEPTEMBER 1962

to

U S ARMY ELECTRONICS RESEARCH
AND DEVELOPMENT LABORATORY
FORT MONMOUTH
NEW JERSEY

from

ARTHUR D. LITTLE, INC.
ACORN PARK
CAMBRIDGE, MASSACHUSETTS

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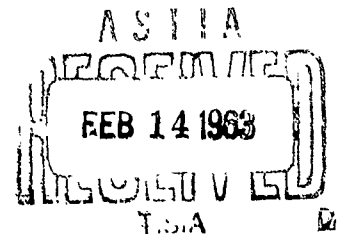
FIRST QUARTERLY REPORT

2 July 1962 - 30 September 1962

"Certain commercial items and materials in this report are identified by code; a separate code sheet is available for U. S. Military Agencies only."

U. S. ARMY ELECTRONICS RESEARCH & DEVELOPMENT
LABORATORY, FORT MONMOUTH, NEW JERSEY

Arthur D. Little, Inc.
Cambridge 40, Massachusetts



METHODS FOR LOW POWER TEMPERATURE CONTROL

REPORT NO. 1

Contract No. DA 36-039 SC-90883
DA Project No. 3B-55-03-003-72

SIGNAL CORPS TECHNICAL REQUIREMENT
SCL-7648, dated 3 November 1961

FIRST QUARTERLY REPORT

2 July 1962 - 30 September 1962

This program covers a continuing study of the methods and techniques to minimize the power requirements necessary to control the temperature of a quartz crystal unit.

- ii -

Arthur D. Little, Inc.

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I. PURPOSE

The purpose of this project is to design, manufacture, and test four types of miniature low-power ovens for regulating the temperature of an IT-cut quartz crystal. The temperature of the ovens is to be controlled by snap-action thermostats.

The types E6, F6G, and G6G ovens must maintain the crystal temperature at 75°C with stability of $\pm 2.5^{\circ}\text{C}$ in ambient temperatures ranging from $+60^{\circ}\text{C}$ to -40°C . The volume of each oven is not to exceed 3 cubic inches. The type E6 oven, which is to have an average power consumption of 500 milliwatts at an ambient temperature of -40°C , is to be designed so that the crystal is accessible. The type F6G oven is to have an average power consumption of 50 milliwatts at an ambient temperature of -40°C , and the crystal may be permanently sealed inside the oven. The type G6G oven is to be identical to the type F6G, except that less expensive thermal insulation is to be considered. The average power consumption of this type of oven may be twice that of the F6G, if necessary.

The fourth oven type, H6, is to maintain within its inner cavity a temperature of 0°C with stability of $\pm 3^{\circ}\text{C}$ at ambient temperatures ranging from 0°C to -55°C . Room for two crystals housed in HC-6/U crystal holders is to be provided inside the inner cavity. The inner cavity has to be accessible. The total volume of this oven type is not to exceed 4 cubic inches, and average power consumption is to be 250 milliwatts at an ambient temperature of -55°C .

Ideally, the warm-up time for all oven types should not exceed 10 minutes.

II. ABSTRACT

An investigation is conducted of methods and devices by which the temperature of a single quartz crystal blank can be maintained at a nominal operating temperature over environmental temperature extremes. Four types of snap-action ovens are studied: a 500-milliwatt oven (Type E6) requiring accessibility to the crystal and operating at $+75^{\circ}\text{C} \pm 2.5^{\circ}\text{C}$ over a -40°C to $+60^{\circ}\text{C}$ ambient; a 50-milliwatt sealed oven (Type F6G) with similar operating requirements; a less-costly, 100-milliwatt sealed oven (Type G6G) with similar operating requirements; and a 250-milliwatt oven (Type H6) requiring accessibility to a temperature-compensated crystal and operating at $0^{\circ}\text{C} \pm 3^{\circ}\text{C}$ over a -55°C to 0°C ambient.

Components for all four types have been chosen, pilot models have been designed, and a test program has been formulated to produce data on the performance of each component.

Tests were begun on pilot models of E6 and H6 ovens to establish performance limits on snap-action thermostats. Thermocouple instrumentation was used in determining temperature of dummy crystals.

Tests were completed satisfactorily on the E6 pilot models, and fabrication of the required five final models has begun.

Chambers for determining outgassing properties of components for the sealed (F6G and G6G) ovens were made, and tests are in progress. Modifications were made to present instrumentation for more expedient testing of insul-

ation or insulation components requiring vacuum.

Investigation was begun on the use of glass shells for the sealed ovens in place of stainless steel as used in the previous contract.

III. SUMMARY REPORT ON THE CONFERENCE
HELD IN CONNECTION WITH THE PROJECT

On 17 July 1962, in Fort Monmouth, New Jersey, Messrs. Owen Layden, Charles Shibla, and Dennis Pochmerski, representing U. S. Army Electronics Research and Development Laboratories and Messrs. Igor Black and John Peterson, representing Arthur D. Little, Inc., met to discuss the objectives and planning of the present project. The most important conclusions reached in the process of the discussion were:

1. It is extremely important to extend the life of the 50-mw oven.
2. Glass should be tried for inside and outside shells of types F6G and G6G ovens.
3. If the increased size of the oven will help to extend the life of the oven, the size requirement may be relaxed.

We discussed with the USAERDL personnel the planning of the program for the project, and agreed on the proposed approach.

IV. FACTUAL DATA

A. Availability and Performance of Snap-Action Thermostats

We contacted companies A, B and C for information regarding the performance, sizes, and availability of the snap-action thermostats.

The snap-action thermostats which may be utilized for our purpose are supplied in two enclosures: in a cylindrical metal can of approximately 5/8 diameter x 5/16 high, or a metal can identical in size and shape to the HC-6/U crystal holder. Hermetically sealed or semi-enclosed thermostats are manufactured. Hermetically sealed thermostats are recommended by all manufacturers for longer life and greater reliability, since while in operation, they are affected less by fumes, dust and impurities in the air than the semi-enclosed type is.

According to manufacturer A, thermostats enclosed in the HC-6/U crystal have poor response because the parts are surrounded by air, which acts as a thermal insulator between the metal case and the actuating bi-metallic disc. The advantage of using a thermostat enclosed in the HC-6/U can is the thermal symmetry which could be achieved between the thermostat and crystal in the E6, F6G, and G6G type ovens.

Because of the space requirements, we will not be able to utilize the glass dewars, designed previously for the E6 type oven, unless we adopt the disc-shaped thermostat. By studying the possible designs for H6 type ovens, it becomes obvious that the disc-shaped thermostat is required for this oven. For

these reasons, we limited our investigations to thermostats of the disc type.

The following table shows the data we obtained from catalogues and by interviews with the manufacturers' representatives.

<u>Comp- any</u>	<u>Size (inches)</u>			<u>Differ- ential (°F)</u>	<u>Toler- ance (°F)</u>	<u>Type</u>	<u>Avail- ability</u>	<u>Price</u>
	<u>Diameter</u>	<u>Body Width</u>	<u>Width with Terminals</u>					
A	0.620	0.202	0.301	1 - 3	+ - 2	Sealed	3-4 weeks	\$25/ea.
B	0.660	0.300	0.300	2 - 5	+ - 3	"	3 weeks	\$11/ea.
C	0.606	0.215	0.280	2 - 4	+ - 2	"	"	\$10/ea.

None of the companies are willing to support the effort involved in improving the performance of their thermostats until they see a large market for their product. The superior performance of the Company A thermostat was simply the result of the manufacturer selecting the better thermostat from the batch prepared to Company B specifications. The price of the Company A thermostat permits such a careful selection, as well as the calibration indicated by the calibration tags giving the closing temperature and the differential.

Company B, even though not willing to perform such a selection, suggested (independently from Company A) that we buy the thermostats and select the best ourselves.

We purchased three thermostats from each company. The following table shows the temperatures shown on the tags of the thermostats supplied by Company A.

<u>Thermostat</u>	<u>Differential (°F)</u>	<u>Closing Temp. (°F)</u>	<u>Tolerance (°F)</u>
1	3	164.9	-2.1
2	2.7	164.2	-2.8
3	2.8	167.4	+ .4

The space requirements of our design (see Chapter C-1) makes the use of the Company B thermostat impossible. The size, the shape of electrical contacts, and the differential of the thermostats sent to us by Company A are within the limitations we presently believe necessary in the manufacture of the required ovens. We, therefore, decided to test these thermostats in conjunction with the core and the insulation.

B. Electrical Circuit

Figure 1 shows the schematic of the electrical circuit we plan to utilize in all four types of ovens. This circuit will require two snap-action thermostats. In the first experiment, the thermostat which controls the warm-up heater will be set approximately 10 to 15 degrees lower than the required operating temperature of the crystal in order to prevent overshooting the crystal operating temperature. Overshooting would occur because of the continued heat flow (toward the crystal) from those parts of the core which store heat after the warm-up heater is turned off. The thermostat controlling the warm-up heater can have a wide differential and large tolerance of the closing temperature. The calculations show that in the type E6 oven a 5-watt heater is

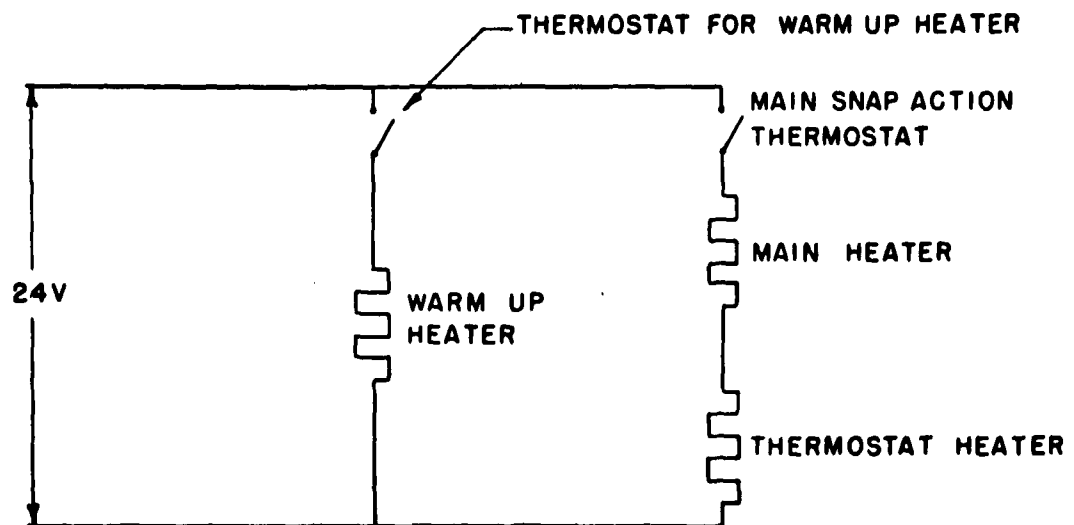


FIGURE 1
SCHEMATIC OF ELECTRICAL CIRCUIT

required to reduce the warm-up time to approximately 10 minutes.

The F6G, G6G, and H6 type ovens will require 1/2 watt, 1-watt and 2 1/2-watt warm-up heaters, respectively.

The main heater may consist of two parts: the major part of the heater will supply the heat to the copper clip around the crystal can, the other (a small portion of the heater) will transmit the heat directly to the controlling thermostat. This arrangement was found previously to be necessary for precision temperature control of the oven.

C. Design of the Ovens

1. Type E6 Oven

Figure 2 shows the proposed core arrangement for the type E6 oven. The crystal can is held by a copper clip around which is wound a heater made of 0.005 inch diameter type 180 alloy wire. If necessary for accurate control of the crystal temperature, a small part of the heater winding may be placed directly on the snap-action thermostat. (See Figure 3). The warm-up heater will be placed either below the crystal-thermostat assembly (Figure 2) or wound directly over the copper clip (Figure 3). The snap-action thermostat controlling the warm-up heater will be placed at the bottom of the core. This arrangement permits the crystal to be placed at the warmest part of the core-- near the top of the inverted glass dewar. The assembled parts described above will be placed inside a micarta shell (Figure 4) very similar in design to the one used in the type A6 oven.



SECTION A-A

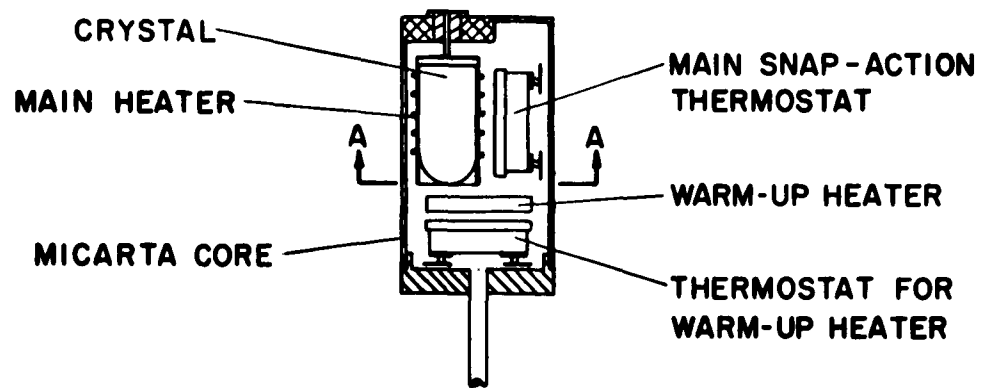


FIGURE 2

CORE ARRANGEMENT FOR E 6 TYPE OVEN

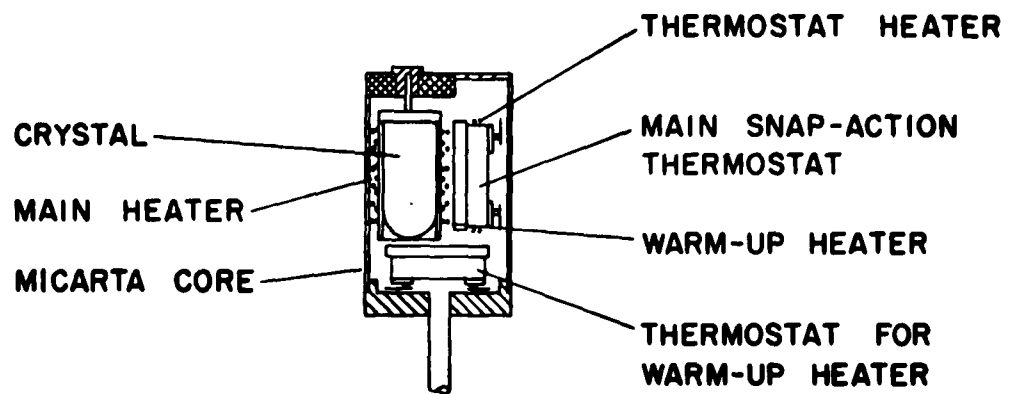


FIGURE 3
 ALTERNATIVE CORE ARRANGEMENT
 FOR E 6 TYPE OVEN

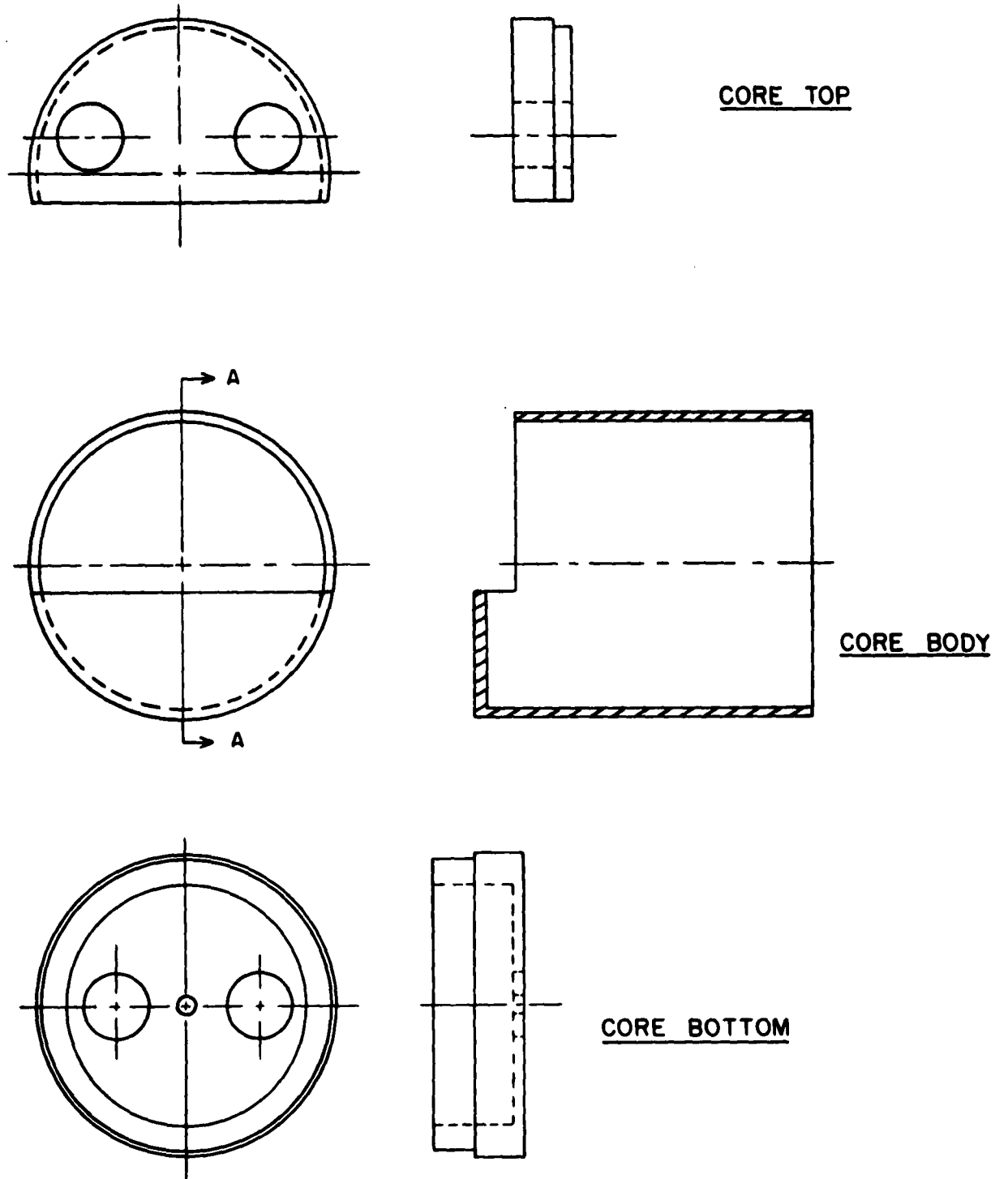


FIGURE 4 MICARTA CORE SHELL
FOR TYPE E6 OVEN

This arrangement permits us to use a glass dewar identical to the one designed for type A6 oven (Figure 5). Six dewars of this design have been ordered from Company D.

2. Type H6 Oven

Figure 6 shows the proposed core arrangement for type H6 oven. An electrical heater of 0.005 inch diameter type 180 alloy wire is wound around the copper clip, which has a cavity intended to hold two size HC-6/U crystal cans. If necessary for accurate control of the crystal temperature, a part of the heater winding may be placed directly on the snap-action thermostat, as shown in Figure 6. The warm-up heater will be wound on the outer side of the main heater.

The thermostat controlling the warm-up heater will be placed below the main-snap-action thermostat.

It is possible that the thermostat for the warm-up heater will also require a part of the winding to be placed directly on its body. If the initial tests of the pilot model indicate such a requirement, the correct number of turns will be placed on the thermostat. This assembly is of the correct size to be placed within the glass dewar shown in Figure 5. However, no space is left for the micarta shell used in the type E6 oven.

The pilot model of type H6 oven will not, therefore, have a micarta shell. If tests prove the need for a shell, a new glass dewar will be designed.

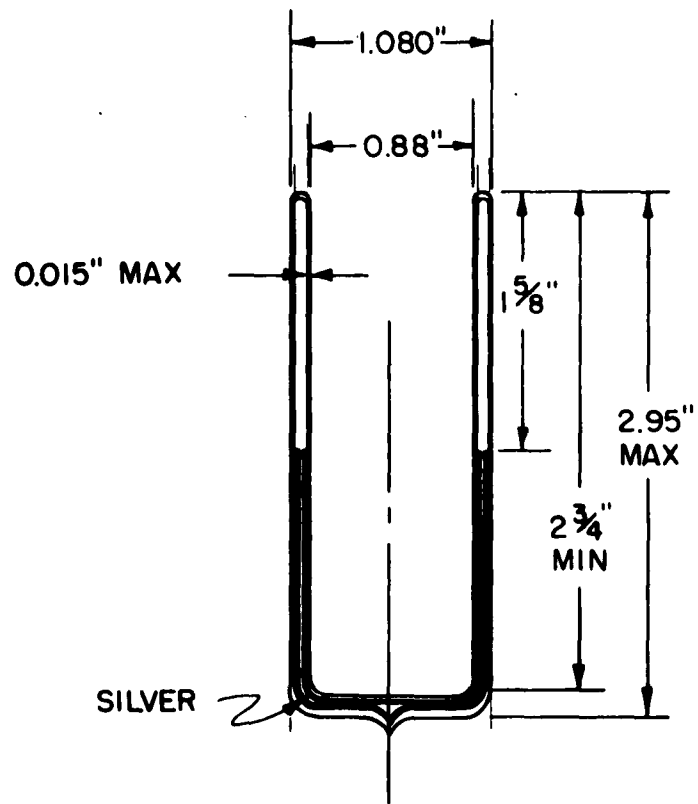
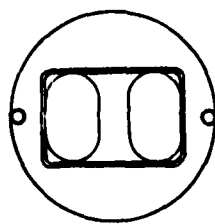


FIGURE 5
MINIATURE PYREX DEWAR



SECTION A-A

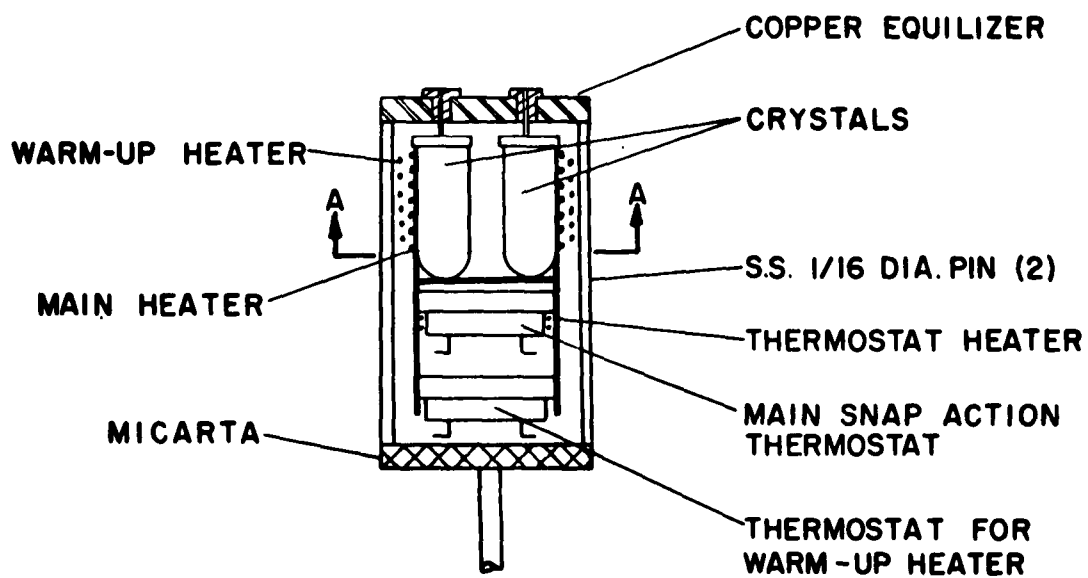


FIGURE 6
CORE ARRANGEMENT FOR TYPE H6 OVEN

3. Type G6G

a. Core

Presently, we plan to utilize the core described in Chapter IV-C-1 and shown in either Figure 2 or 3. The micarta shell will be replaced by a stainless steel or a glass inner shell.

b. Insulation

We are considering two types of insulation for type G6G oven; evacuated powder and evacuated fibers.

The success of the powder insulation will depend to a great degree on the success of the suspension design. We have already proposed a suspension scheme under Contract DA 36-039 SC-87297. However, if it is to be used in an operational oven, it will require further improvements. Figure 7 presents two other possible suspension schemes.

Scheme (a) shows the two stacks of 0.008-inch thick glass mat washers keeping the inner shell from moving along the axis of the cylinder. A narrow band wound around the circumference of the cylinder prevents the transverse movement of the cylinder axis and places the inner shell centrally inside the outer shell.

The remainder of the insulation space will be filled with evacuated powder. Scheme (b) shows two thin plastic pins which position the inner shell centrally inside the outer shell. The insulation space is filled with powder.

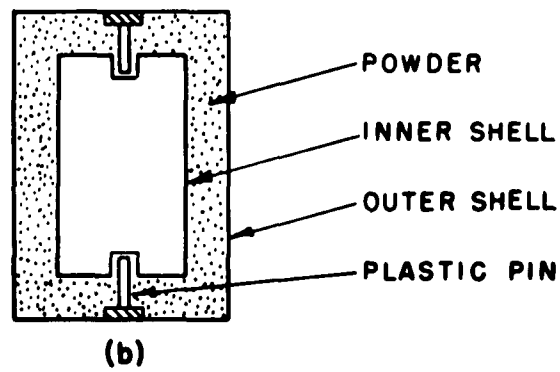
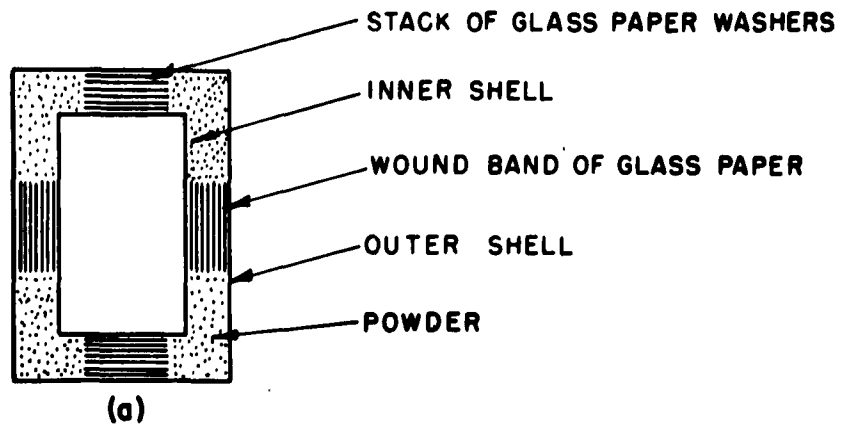


FIGURE 7
 SCHEMES OF THE SUSPENSION OF THE TYPE G6G OVEN

Because of the difficulty in positioning the core in relation to the outer shell in a powder insulation, we will investigate two other types of evacuated insulation schemes (Figure 8) which do not require any special suspension system:

- (1) 0.008-inch thick glass mat is wound around the inner shell in full length of the shell. The outside diameter of the windings is identical to the inside diameter of the outer shell. Stacks of washers made from the same glass paper will be placed on both ends of this pack. The diameter of the washers is the same as the inside diameter of the outer shell.
- (2) Microfiber glass wool will be packed into the insulation space.

c. Shell

We have under consideration two types of material to be used for the inner and outer shells of the insulation system:

- (1) Stainless steel shells allow the oven volume to be kept to the required size. However, the soldered joints needed to make electrical connections from the core to the outside, and the pinch-off procedure for sealing may cause the shells to lose vacuum.
- (2) Glass shells may keep the vacuum for a longer time than the stainless steel shells, but by using them we cannot make the oven of the required size (i. e. , under three cubic inches.)

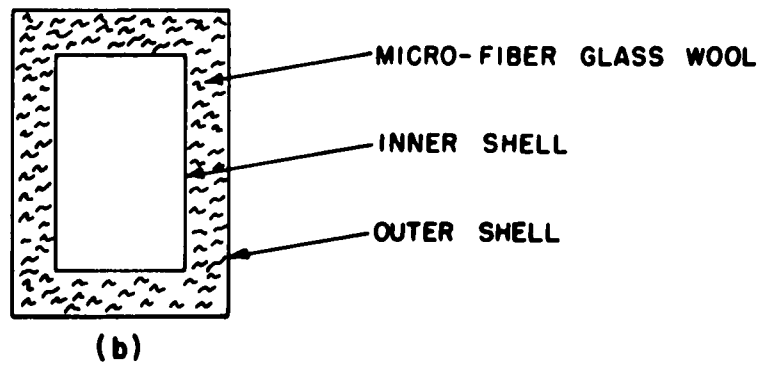
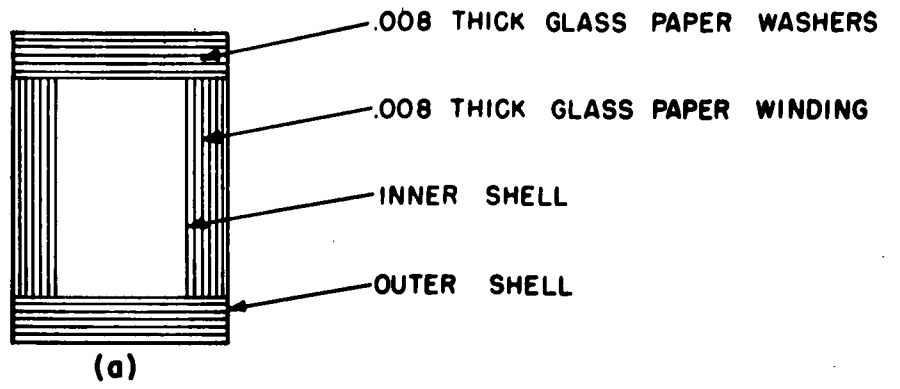


FIGURE 8

NEW INSULATION SCHEMES FOR TYPE G6G OVEN

Pilot models made of the above materials will be manufactured and tested. We already acquired the glass tube bases with metal through pins, which we will use for electrical connectors, and we ordered the glass tubing for inner and outer shell. We will use ovens No. 3385-5 and No. 3385-6 to study the problems of the stainless steel ovens.

4. Type F6G

a. Core

Presently we plan to utilize the core described in Chapter IV-C-1 and shown in Figures 2 and 3. The micarta shell will be replaced by a stainless steel or a glass inner shell.

b. Insulation

We plan to use insulation of the same type that is used in the ovens of type B6 developed under last year's contract for USAERDL. (See quarterly report No. 1, 15 May 1961 - 14 August 1961 Cont. DA 36-039 SC-87297). The outgassing properties of this insulation are presently investigated and are reported in Chapter D-4 below. Until these investigations are completed no other work will be done on the insulation components.

c. Shell

All considerations about the shell materials described in Chapter C-3c will apply to this oven.

D. Testing of the Ovens and Oven Components

1. Tests of Glass Dewars

We tested three glass dewars made by Manufacturer D to the specifications presented in Figure 5. The simulated core described in the Quarterly Report No. 1 (15 May 1960 - 14 August 1960), Cont. DA 36-039 SC-85328 was placed inside the dewars. The dewars require the following heat inputs to the electric heater on the core when the steady state temperature of 85°C is reached (as read by the thermocouple on the simulated core) and when the ambient temperature in the cold chest is -55°C :

Dewar A 520 milliwatts

Dewar B 480 milliwatts

Dewar C 425 milliwatts

We received Dewar A from the manufacturer on 21 August 1961 and tested it for the first time on 4 October 1961. It exhibited a heat loss of 362 milliwatts. During the 12-month period, the heat loss increased 40 per cent.

Figure 9 shows the plot of the heat loss vs. time for Dewar A. The deterioration of the insulation is proportional to elapsed time. Assuming that the heat conduction along the glass inner wall and the radiation heat transfer across the vacuum space are independent of the time, the increase in the total heat transfer must be due to the increased gas conduction. Since the gas conduction is directly proportional to the pressure of the gas for free molecular flow condition, we can deduce that the gas pressure was increased in direct

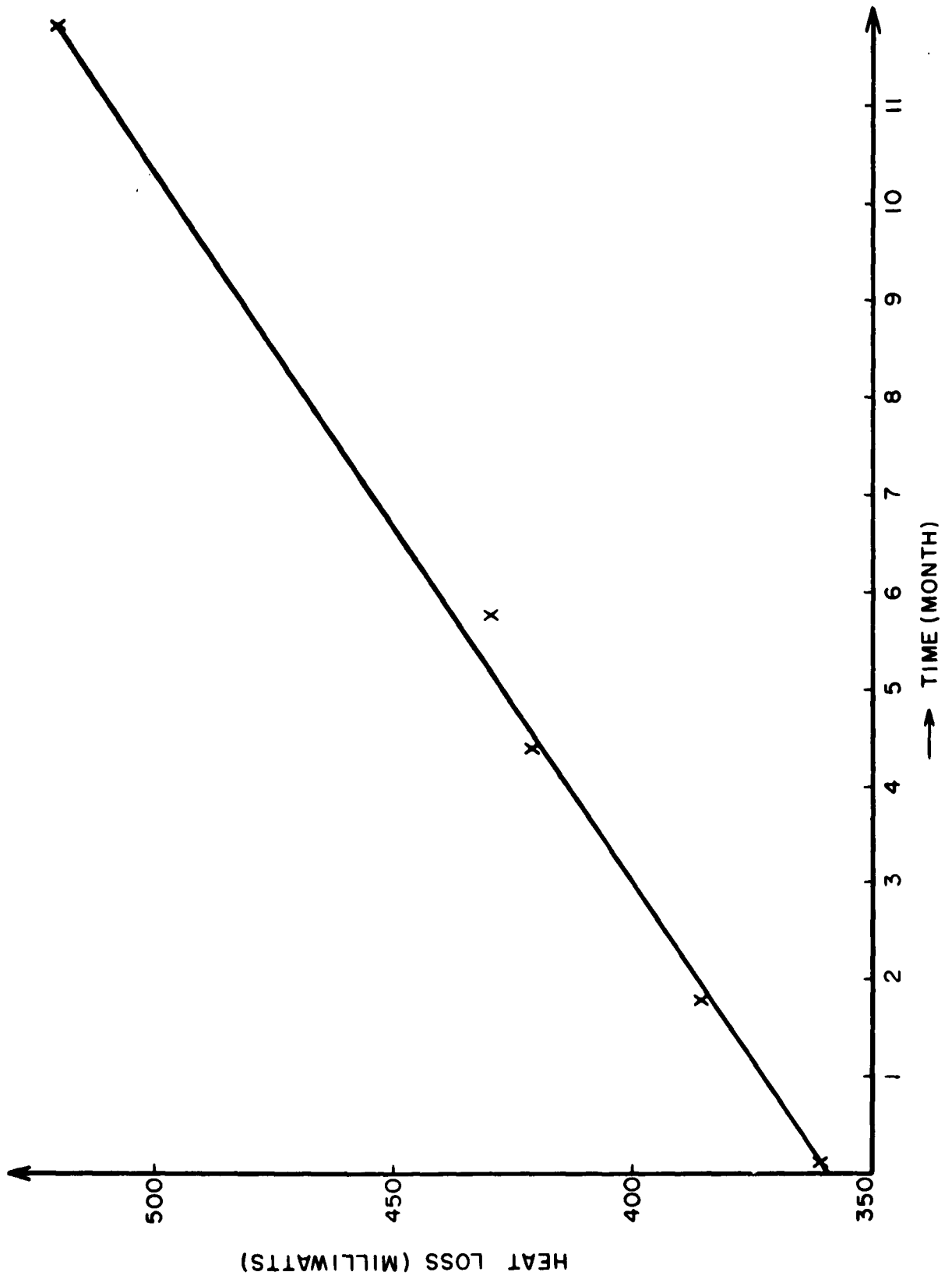


FIGURE 9
 PLOT OF HEAT LOSS VS. TIME FOR DEWAR A

proportion to the elapsed time. This relationship is characteristic of the process of gas diffusion through a solid wall (in this case, glass).

This conclusion proves that the dewars were thoroughly outgassed before sealing; consequently, no further outgassing took place. The only possible way to decrease the diffusion process is to increase the thickness of the walls; however, this is not possible in view of our desire to keep the heat conduction along the inner wall at a minimum.

2. Test of a Simulated Core for Type E6 Oven

At the suggestion of the manufacturer, before ordering thermostats we investigated the requirements for the snap-action thermostat stipulated by our design. We manufactured a core similar to the one shown in Figure 2. The only changes were that: a) we did not install the warm-up heater circuit; b) manufacturer A supplied the dummy of the snap-action thermostat with a thermocouple attached to the switch disc; and c) instead of the crystal, a thermocouple was installed in the crystal can. The simulated core was placed into Dewar A. During the test we controlled the heater input to keep the temperature of the thermostat (indicated by one thermocouple) constant, independently of the ambient temperature. (The temperature of the simulated crystal was indicated by the second thermocouple). The results of the test are shown below:

<u>Temperature (°C)</u>	<u>Temperature of Thermostat (°C)</u>	<u>Temperature of Simulated Crystal(°C)</u>
-55	84.1	83.7
30	84.3	84.1

The results indicate that the temperature of the simulated crystal was 0.2°C lower than that of the thermostat at 30°C ambient temperature, and that the crystal temperature dropped 0.4°C lower than that of the thermostat at -55°C ambient temperature. On the basis of experience in manufacturing type A6 oven, we could have expected this result. (See Contract DA 36-039 SC-87297 final report). The test indicates that the crystal has a better thermal coupling with the ambient temperature than the snap-action thermostat. When we remove the thermocouple leads from the thermostat, its thermal coupling to the ambient temperature becomes even poorer, and the spread between the temperature of the thermostat and that of the crystal may increase. From present indications, however, we may expect that the variation will still be within the limits of our tolerances ($\pm 2.5^\circ\text{C}$) on the control temperature of the crystal.

3. Test of a Simulated Core for Type H6 Oven

Adopting much the same procedure that we used with the simulated core for type E6 oven, we manufactured and tested a simulated core for type H6 oven. We manufactured the core according to the design described in Section C-2 and presented in Figure 6, except that: (a) we did not install the warm-up heater and its control; (b) a thermocouple was attached to the disc of the switch on the snap-action thermostat; and (c) two dummies were used instead of the two crystals. Both of the dummies contained a thermocouple inside the crystal cans. We used one metal and one glass crystal can. The snap-action

thermostat was cemented to the bottom of the copper clip. Figure 10 presents the view of the manufactured core. The core was placed into the glass Dewar A. The results of the test are recorded below:

<u>Ambient Temperatures (°C)</u>	<u>Temperature of the Thermostat (°C)</u>	<u>Temperature of the Crystal (°C)</u>	
		<u>Metal</u>	<u>Glass</u>
-55	1.3	+ 2.2	0.8
-10	-0.1	- 0.8	-0.5

The results show that the temperature of the crystal is 0.4°C lower than that of the thermostat at ambient temperature of -10°C, and that the temperature gap increases to 0.5°C at the ambient temperature of -55°C as indicated by the thermocouple encased into the glass can. The temperature of the crystal is 0.7°C lower than that of the thermostat at ambient temperature of -10°C, but the temperature of the crystal is 0.9°C higher at the ambient temperature of -55°C as indicated by the thermocouple encased into the metal can. When we remove the thermocouple leads from the thermostat, its thermal coupling to the ambient temperature becomes even poorer, and the spread between the temperature of the thermostat and that of the crystal may increase. We believe that a separate heater attached directly to the thermostat body will be necessary to control the crystal temperature within $\pm 3^\circ\text{C}$.

4. Tests of the Outgassing Properties of the Components for Type F6G Oven

We began the experimental investigation of the outgassing properties of the materials which may be used in the insulation space of type F6G ovens. These materials are: a) aluminum foil, b) polyester mat, and c) insulated electrical wire.



FIG. 10. SIMULATED CORE FOR TYPE H6 OVEN

We designed and manufactured a special vacuum manifold which simplifies and facilitates the testing of the components requiring vacuum pumping on the cold chest. Figure 11 presents the view of the manifold installed on the cold chest. The cold chest was modified to adopt the manifold. We plan to utilize the same manifold later for expedient evacuation and testing of the pilot models and final ovens of the F6G and G6G types.

The manifold permits simultaneous evacuation of four separate vessels. Each vessel can be detached or exchanged and re-evacuated without loss of vacuum on the other three vessels. The manifold has a special port which permits the use of the helium leak detector without interruption of the test.

Figure 12 shows the special glass chambers which have been designed and are presently in use for tests of the outgassing properties of the materials that we plan to use in the insulation space of type F6G oven. The photograph shows from left to right: a) multiple-layer insulation system consisting of the aluminum foil and the polyester mat spacer, produced earlier for one of the pilot models, and placed into the test chamber in the identical shape and amount that will be used in the actual oven; b) an empty test chamber identical to the two containing the test materials is attached to a port of the manifold, to serve as a reference; and c) ceramic-coated wire.

Figure 13 presents the history of the evacuation process of the three glass chambers during the one week of the continuous pumping. The dynamic vacuum on the test chambers improved daily until it reached a plateau at the

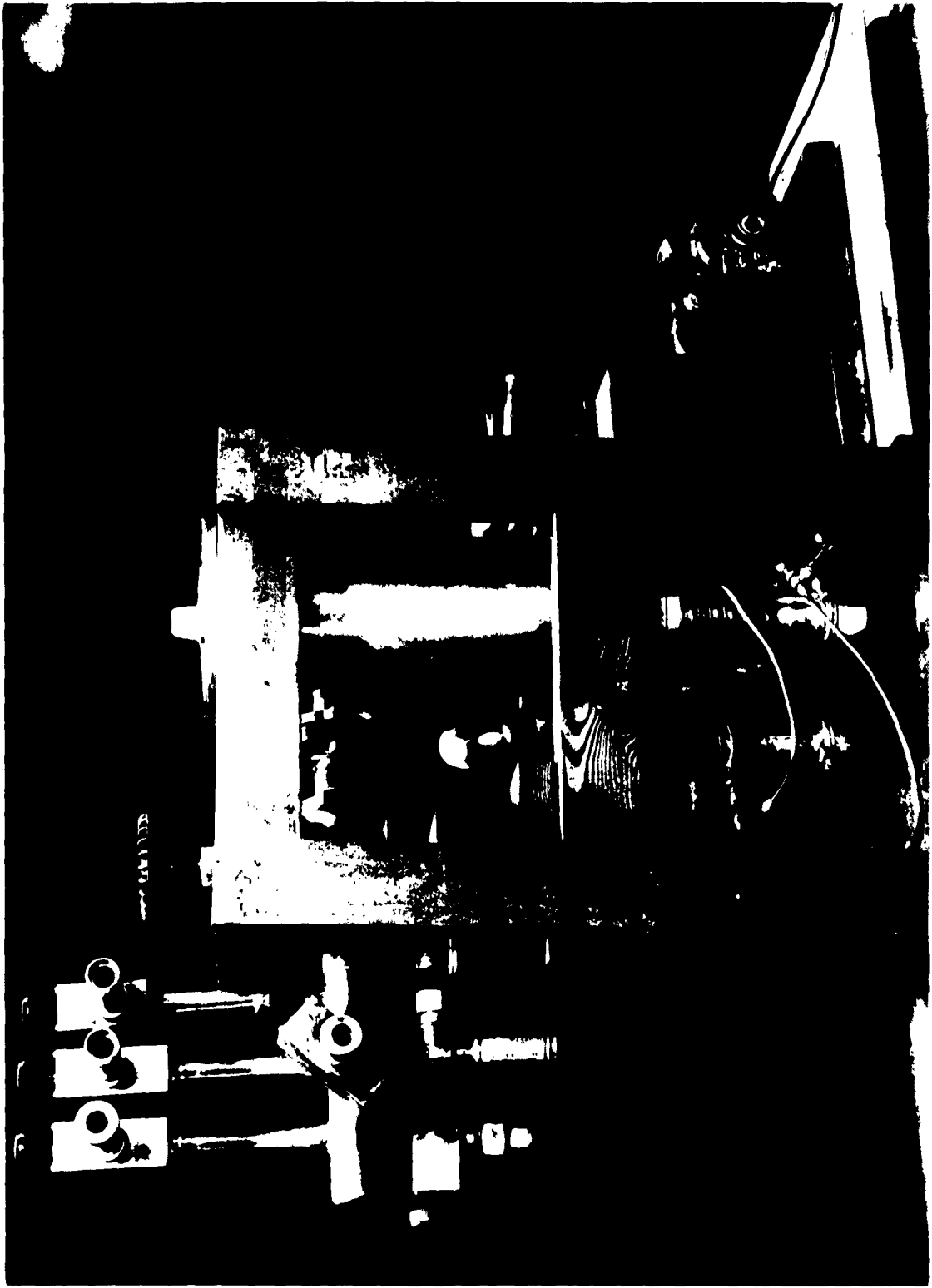


FIG. 11. NEW VACUUM MANIFOLD



FIG. 12. CHAMBERS FOR TESTING COMPONENTS OF INSULATION SYSTEM FOR TYPE F6G OVEN

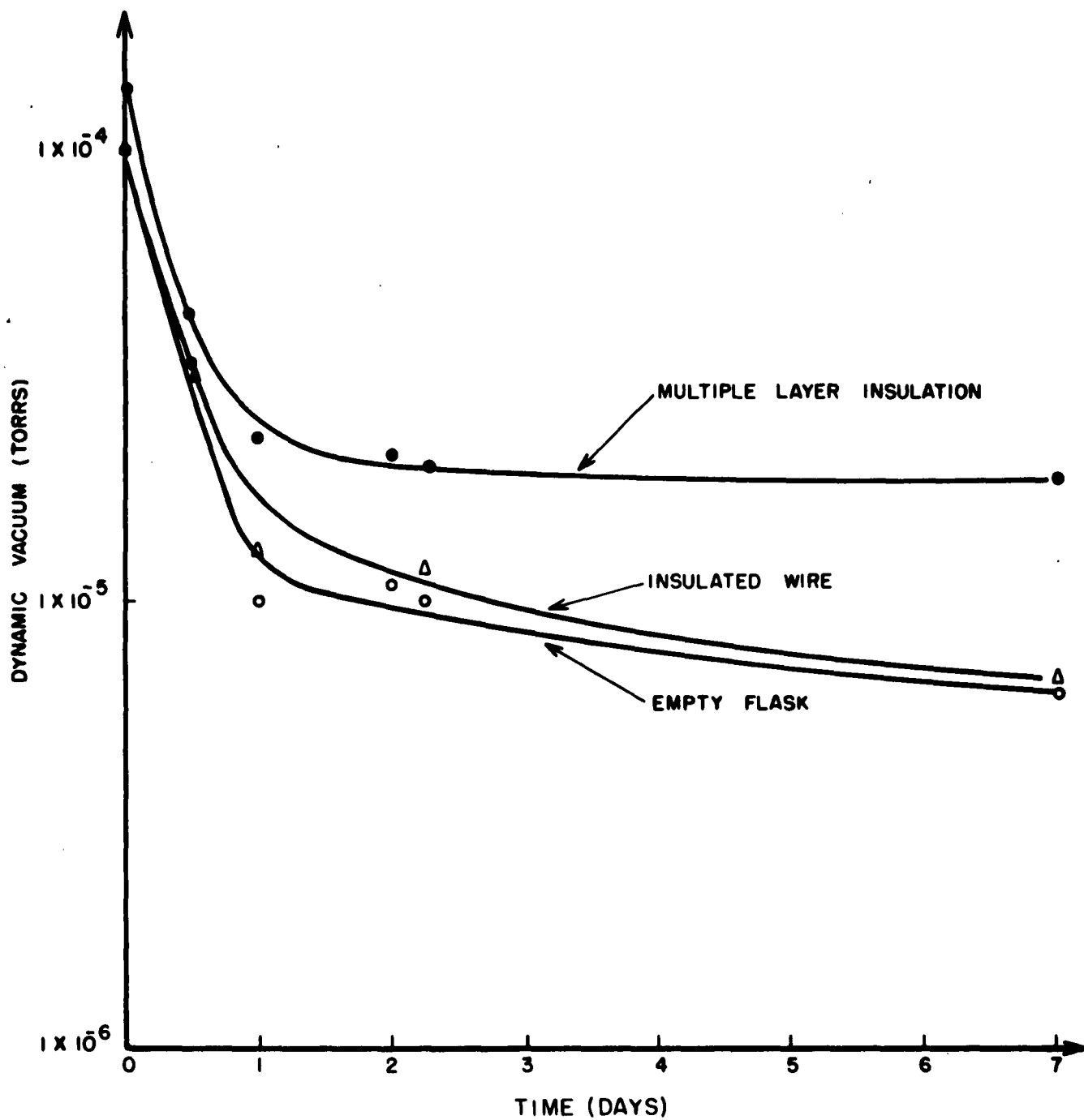


FIGURE 13 PLOT OF DYNAMIC VACUUM VS. ELAPSED TIME FOR THREE GLASS TEST CHAMBERS

following values:

Empty flask	6×10^{-6} Torr
Flask with wire	7×10^{-6} Torr
Flask with insulation	2×10^{-5} Torr

No appreciable improvement was made during the following week. We plan to seal all three test chambers and to measure static vacuum as long as the range of the ionization gauge permits.

At this time no final conclusions can be reached regarding the outgassing properties of the materials. There are indications, however, that at least two or three weeks of pumping are necessary to reach a high vacuum in the system, and that the ceramic-coated wire compares favorably with the multiple-layer insulation system.

V. CONCLUSIONS

1. The performance and the size of the snap-action thermostat manufactured by Company A will suit our requirements.
2. The glass dewar designed for type A6 oven is suitable for oven types E6 and H6 also.
3. Only slight modification of the micarta core shell designed for type A6 oven is necessary for the type E6 oven.
4. A new core design is required for type H6 oven.
5. Deterioration of the vacuum in the glass dewar, which serves as insulation for types E6 and H6 ovens, is directly proportional to the elapsed time. The useful life of the dewar is expected to be more than one year.
6. No problems are expected in the manufacturing and in the temperature control of the crystal in type E6 oven.
7. We expect that the control of the crystal temperature over the ambient temperature range may present a problem in type H6 oven. We believe presently that the control problem can be solved by attaching the portion of the heater directly to the thermostat body.
8. We believe that we should use either glass mat or glass wool to insulate type G6G oven inexpensively rather than the powder insulation.

9. Further testing is necessary before a final conclusion on the outgassing properties of the materials placed within the insulation space of type F6G oven may be reached. At present, it seems that the ceramic-coated wires should prove useable inside the insulation space.

VI. PLAN FOR FURTHER WORK

1. We plan to begin testing to establish the life expectancy and the temperature stability of the snap-action thermostats.
2. We will perform acceptance testing on all new glass dewars received from manufacturer.
3. We plan to test a completely assembled pilot model of type E6 oven.
4. We plan to finish manufacturing of the components such as metal covers, core shells, heaters, etc. , for the final models of type E6 oven.
5. We plan to manufacture and test a completely assembled pilot model of the type H6 oven.
6. The testing of the outgassing properties of the materials for oven types F6G and G6G will continue.
7. The glass model of the type F6G oven will be manufactured and the testing of the latter will begin.
8. The stainless steel core from oven #3385-3 will be placed in the glass chamber (see Figure 12) and its outgassing properties will be tested.
9. We plan to manufacture and begin testing of the pilot model of type G6G oven.

VII. IDENTIFICATION OF KEY PERSONNEL

Key technical personnel who have taken part in the work covered by this report, with the approximate man-hours performed by each, is given in the following tabulation. A brief description of the background of each person is given in the remaining pages of this section.

<u>Name</u>	<u>Approximate Man Hours</u>
Igor A. Black	142
Anne Everest	109
John Peterson	400

In addition to the man-hours in this list, approximately 50 man-hours were expended by supporting personnel.

MR. IGOR A. BLACK

Mr. Igor A. Black was educated at Munich Institute of Technology, Munich, Germany, and Massachusetts Institute of Technology, where he received an S. M. degree in Mechanical Engineering. While at Massachusetts Institute of Technology he was associated with Sloan Automotive Laboratories, where he was chiefly concerned with thermodynamic studies and experimental methods and techniques, as applied in the field of internal combustion engines. He has had two years of practical experience in tool and automatic machinery design. At the Western Company, he was responsible for design, manufacture and field testing of mobile-oil-well fracturing and acidizing equipment, gaining considerable experience in power plants, power transmissions, hydraulic equipment and controls.

Since joining the staff of Arthur D. Little, Inc., Mr. Black has been engaged principally in development of low-temperature equipment, such as the design, manufacturing and testing of a new helium liquefier, of an equipment for X-ray diffraction studies at 4K, of a tensile testing chamber at temperatures below liquid nitrogen level.

Recently he completed a study on the feasibility of a new approach to development of high-efficiency insulation for cryogenic equipment and designed a thermal conductivity test apparatus.

MISS ANNE EVEREST

Miss Everest graduated in 1956 from Boston University's College of Industrial Technology with a B. S. in Aeronautical Engineering. She joined Arthur D. Little, Inc., in July, 1956.

She has been primarily concerned with the evaluation and development of thermal protection systems for use at extreme low temperatures and for use at temperatures up to 4000^oF. Miss Everest has supervised the laboratory testing of the thermal conductivity of multiple layer and powder insulation; explosive characteristics and compressibility of powder insulation; radiation characteristics of various surfaces.

At the 1959 Cryogenic Engineering Conference in San Francisco, Miss Everest presented a paper on "The Behavior of High Magnesium Content Aluminum Alloys at Room and Liquid Nitrogen Temperatures". This paper summarized her research of the mechanical and metallurgical changes occurring in the Al-Mg alloys at low temperatures.

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		ATTN: SELRA/NRC, E. Jakubowics	1

This contract is supervised by the Solid State and Frequency Control Division, Electronic Components Department, USAELRDL, Fort Monmouth, New Jersey. For further technical information, contact the Project Engineer, Mr. Charles L. Shibla, Telephone 53502325 (New Jersey Area Code 201).

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