General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)
Westinghouse Research Laboratories
Pittsburgh, Pennsylvania 15235

MULTIPURPOSE ELECTRIC FURNACE SYSTEM

R. Mazelsky, C.S. Duncan, R.G. Seidensticker,
R.A. Johnson, J.P. McHugh,
H.C. Foust, P.A. Piotrowski

Final Report
NAS 8-30289

July 23, 1974

Prepared for George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

Westinghouse Research Laboratories
PITTSBURGH, PENNSYLVANIA 15235
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>2. DESIGN MODIFICATIONS AND PRE-DESIGN TESTS</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Furnace Modifications</td>
<td>5</td>
</tr>
<tr>
<td>2.1.1 Intrinsic Heat Loss Reduction</td>
<td>6</td>
</tr>
<tr>
<td>2.1.2 Heater Elements</td>
<td>6</td>
</tr>
<tr>
<td>2.1.3 Suitability of High Temperature Materials</td>
<td>8</td>
</tr>
<tr>
<td>2.1.4 Electrical Insulation of Thermocouples</td>
<td>9</td>
</tr>
<tr>
<td>2.1.5 Modification of Access Port Seals</td>
<td>10</td>
</tr>
<tr>
<td>2.1.6 Pump Line Design</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Helium Package</td>
<td>11</td>
</tr>
<tr>
<td>2.3 Control Package</td>
<td>12</td>
</tr>
<tr>
<td>2.3.1 Introduction</td>
<td>12</td>
</tr>
<tr>
<td>2.3.2 Description of Circuitry Modifications</td>
<td>17</td>
</tr>
<tr>
<td>2.3.2.1 Main Control Board Modifications</td>
<td>17</td>
</tr>
<tr>
<td>2.3.2.2 Auxiliary Control Board Description</td>
<td>20</td>
</tr>
<tr>
<td>2.3.2.3 Control Package Interconnection Modifications</td>
<td>22</td>
</tr>
<tr>
<td>2.3.3 Mechanical Interface Modifications</td>
<td>22</td>
</tr>
<tr>
<td>3. DEVELOPMENT TEST PROGRAM: SUBSYSTEMS</td>
<td>27</td>
</tr>
<tr>
<td>3.1 Development Test Program: Multipurpose Electric Furnace</td>
<td>27</td>
</tr>
<tr>
<td>3.1.1 Furnace Characteristics</td>
<td>30</td>
</tr>
<tr>
<td>3.1.1.1 Furnace Power/Temperature Characteristics</td>
<td>30</td>
</tr>
<tr>
<td>3.1.1.2 Stability of Furnace Characteristics</td>
<td>33</td>
</tr>
<tr>
<td>3.1.1.3 Heat Leveler Temperature Distribution</td>
<td>36</td>
</tr>
<tr>
<td>3.1.2 Furnace Cooling Rate</td>
<td>38</td>
</tr>
<tr>
<td>3.1.3 Three Node Thermal Model of MEF</td>
<td>38</td>
</tr>
<tr>
<td>3.1.4 Furnace Pump-Down Requirements</td>
<td>44</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3.2 Helium Package</td>
<td>45</td>
</tr>
<tr>
<td>3.3 Control Package Performance</td>
<td>46</td>
</tr>
<tr>
<td>4. SYSTEM TESTS</td>
<td>54</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>54</td>
</tr>
<tr>
<td>4.2 Furnace-Control Package System -</td>
<td>54</td>
</tr>
<tr>
<td>Controlled Cool-down Functions</td>
<td></td>
</tr>
<tr>
<td>5. CONCLUSIONS</td>
<td>59</td>
</tr>
<tr>
<td>APPENDIX A -- NEW OR MODIFIED DETAIL</td>
<td>60</td>
</tr>
<tr>
<td>DESIGN DRAWINGS FOR MA-010 FURNACE AND</td>
<td></td>
</tr>
<tr>
<td>HELIUM PACKAGE</td>
<td></td>
</tr>
<tr>
<td>APPENDIX B -- VACUUM LINE TEST DATA</td>
<td>93</td>
</tr>
<tr>
<td>APPENDIX C -- CONCEPTUAL CARTRIDGE</td>
<td>102</td>
</tr>
<tr>
<td>DESIGNS</td>
<td></td>
</tr>
</tbody>
</table>
MULTIPURPOSE ELECTRIC FURNACE SYSTEM

Final Report
NAS 8-30289

ABSTRACT

A multipurpose electric furnace system of advanced design for space applications has been developed and tested. This system is intended for use in the Apollo-Soyuz Test Program. It consists of the furnace, control package and a helium package for rapid cooldown. The system meets or exceeds all the performance requirements of the contract.
1. INTRODUCTION

The Multipurpose Electric Furnace System (MEFS) designed and constructed for Skylab and designated as the M518 facility is an essentially self-contained unit requiring only power (approximately 28 V, DC), a vacuum line (capable of maintaining $10^{-3}$ torr or better in the furnace), and a heat sink (having a thermal impedance of approximately 0.65°C/watt). As a result, any facility capable of meeting these requirements can accommodate this furnace.

Although the MEFS on Skylab met all expectations of performance and reliability, it was apparent that improvement in function could be obtained with some quite specific modifications to parts of the system. Several areas for improvement were identified:

1. The furnace has the capability of operating at higher temperatures. With minor exceptions the materials used in construction are compatible with operation of heaters at approximately 1150°C. This temperature range permits the processing of many new materials that would otherwise be excluded because of temperature limits.

2. Unnecessary heat losses associated with specific assemblies were identified. Significant reduction of these losses would be accomplished by design changes that would have minor impact on construction but which would result in significantly improved performance and efficiency. This reduction in waste power would have a dual impact:

   a) experiments requiring higher temperatures could be performed at equivalent or less power than the M518, and
   b) a larger fraction of the available power could be directed toward doing useful work in the cartridges.
3. The M518 control was designed to provide a linear cooldown rate for samples requiring directional solidification. This results in a nonlinear interface growth velocity, the velocity increasing as solidification proceeds. As a result, only a fraction of the resolidified material experienced near-linear growth rates. The fraction of material that could be regrown at near-linear rates could be significantly increased in the cooldown rate followed a specific nonlinear function. This function could be incorporated with only minor impact on the existing control circuitry.

4. Although the possibility of having a shorted thermocouple must be considered as low, a mechanism for accommodating such a malfunction is desirable. With minor modifications to the control circuitry, this protection could be provided and increased system reliability and safety obtained.

5. The heat capacity of the furnace and its intrinsic efficiency limit the cooldown rate. If the heat loss mechanisms are reduced, the cooldown time is increased. This time becomes a limiting factor in the number of experiments that can be run in a given time. It is apparent that the efficiency of the insulation can be dramatically reduced by the introduction of a heat transfer medium such as helium. This modification necessarily requires the addition of new equipment -- a gas supply system. However, its addition results in a greatly increased utilization of the total MEFS system.

All the above modifications have been evaluated, designed, and constructed. Essentially, a new furnace was constructed within the M518 mockup provided, while the control package was the M518 qualification test unit and appropriate modifications were made to it to provide the new functions. The helium rapid cooldown system had no analog in the M518 system and a new unit was constructed. All
modifications were tested independently and the functions checked against the design goals. Each of the subsystems of the MEFS (furnace, controller, helium/rapid cooldown) were individually checked and evaluated relative to function and design criteria. A test set up was constructed and the total system was run and the performance evaluated. Extensive tests were run and test data compiled so as to verify the function of the incorporated modifications and to define the new system operating parameters. The tests were run in sufficient detail such as to provide a compilation of information suitable for incorporation into the development test report for the MA-010 MEFS.

While the goal of the program was specifically to design, construct and test modifications to an improved MEFS system, additional tasks were requested by MSFC during the course of the program. These included:

1. Evaluation and implementation of cartridge removal concepts consistent with an hermetic system.

2. Interaction with Rockwell International to assure compatibility of dimensions and requirements with the ASTP docking module.

3. Development of a simple thermal analytical model to describe the heat flow of MEFS.

4. Develop preliminary conceptual design of the experiment cartridges for the Principal Investigators to identify feasibility of the experiment performance in the MA-010 and to provide concepts for PI experiment development.

5. Make preliminary evaluation for the feasibility of designing and constructing a flight qualified pulser unit for experiment MA-060.

6. Attend review meetings with RI, MSFC, and JSC to identify any major incompatibilities that may exist between the MA-010 and the Docking Module design.

All aspects of the program were successfully completed.
2. DESIGN MODIFICATIONS AND PRE-DESIGN TESTS

The following sections treat in detail the modifications which were made to the Skylab M518 System in order to meet the requirements of the Apollo-Soyuz Test Program (ASTP). The changes which were made to the configurations of the Multipurpose Electric Furnace (MEF) and Control Package (CP) were relatively minor in scope, however, the performance of these two subsystems was significantly improved. In some instances predesign testing was performed to validate design concepts or material compatibility. Finally, a completely new subsystem, the Helium Package (HP), was designed to permit the rapid furnace cooldown necessary with the compressed ASTP time line.

2.1 Furnace Modifications

The design modifications of the MEF were prompted by two major considerations: the need for higher operating temperatures and the desire for reduced power requirements. The variety of materials experiments proposed for the ASTP mission require temperatures in excess of the \( \sim 1000^\circ C \) limit of the Skylab M518 system. Further, the reduced heat dissipation capability of the ASTP vehicles mandated that these higher temperatures be obtained with no increase in power requirements.

Experience with the M518 MEF suggested that somewhat higher temperature operation would be possible without any modification; however, the power requirements would be excessive. Therefore, the initial thrust of the re-design effort was to reduce the intrinsic heat loss. The predicted performance of the re-designed system was sufficiently
encouraging that even higher temperature operation appeared feasible if it were compatible with the furnace materials, especially the heating elements. Accordingly, the high temperature components of the furnace were carefully evaluated and where necessary, materials were changed or assembly techniques modified to provide reliable operation.

2.1.1 Intrinsic Heat Loss Reduction

a. Analysis of the M518 MEF indicated that one of the significant heat losses was the "piping" of radiation between the heat shields. This loss could be reduced by providing a "mitred" closure of the radiation shields at the colder as well as at the hotter end of the furnace. This type of construction would, in essence, provide a "nested can" shield configuration where the only radiation leaks occurred through the necessary clearance gaps in the shields. The efficiency of the shield system was also increased by using two interstitial shields of 0.0127 mm (0.0005 in.) thick molybdenum foil between adjacent main shields.

b. (Conductive Heat Losses). Conductive heat loss through the heat leveler support tubes was also reduced. In the M518 system, the heat leveler assembly was mechanically supported by three stainless steel (Type 310) gradient tubes 0.875 in. O.D. x 0.016 in. wall. These tubes had a combined thermal conductance of about 0.15 W-cm-K⁻¹ which would result in a conductive loss of about 21 watts with a furnace temperature of 1150°C. In the modified furnace, the wall thickness of the support tubes was cut to 0.008" which would reduce the loss by half.

2.1.2 Heater Elements

The design target maximum temperature of 1150°C for the MEF Heat Leveler mandated a re-examination of the heater elements. The first characteristic considered was the specific loading of the heater wires. This parameter controls the temperature difference between the wire itself and the work piece, e.g. the graphite heat leveler. If the
loading is too large, then the heater wire may be forced to run too hot in order to transfer the requisite power to the work. Several different variations of heater design were investigated including single and multiple ribbon heaters. It was found, however, that the double, non-inductive winding used for the M518 furnace was nearly optimum when the additional constraint of heater resistance was imposed. The specific loading of about 1 $\text{w/cm}^2$ would impose a wire temperature only about 50°C greater than the heat leveler temperature.

The next factor investigated was the suitability of Kanthal A-1 as heater material. Although this material is suitable for use to 1325°C in air, at least one reference does not recommend its use in vacuum at temperatures over 1000°C. This warning is founded in the rapid evaporation of a component (chromium?) from the alloy and verified by tests we performed on bare wires in ultra-high vacuum. Sample filaments burned out after two hours or less at a surface temperature of 1200°C. The heater winding, however, is NOT a bare wire operating in ultra-high vacuum.

A second test was performed with a Kanthal A-1 heater wound on a salvaged M518 heater form. In this geometry, the wire is completely surrounded by high purity alumina. In the test facility, this heater form was filled with a graphite block to simulate the heat leveler and heavily insulated with "Fiberfrax" to reduce heat losses. After 144 hours of operation, the windings were still operating; however, the heater resistances had changed a great deal. Examination of the disassembled unit revealed that evaporation of a volatile component had occurred and the wire itself was seriously degraded.

A further modification of the configuration was considered, namely, embedding the heater wires in high purity alumina cement. The life test was then repeated. The Kanthal was wound on the heater form and fired in air at 1000°C to form a surface oxide. A slurry of

---

1Bockris, et al.
alumina powder (Morganite #961) was applied, air dried, and then fired at 1000°C. Finally, the test set-up was reassembled. After 100 hours of operation at ~1200°C, the heater resistances had changed by only about 1.3%. Since the test time was roughly ten times larger than the anticipated operating requirements, this design was adopted for incorporation in the prototype furnace.

2.1.3 Suitability of High Temperature Materials

Coincident with the requirement of higher temperature operation of the modified furnace, it became necessary to evaluate the higher temperature suitability of the structural materials used in the Skylab furnace design. It was immediately obvious that the only portion of the design which might be doubtful was that part of the structure in close thermal proximity to the heating element. Furthermore, it was clear that the limiting condition was that of the combined effects of graphite, alumina and Type 310 stainless steel as they exist at higher temperature in the Multipurpose Furnace atmosphere and pressure environment. These materials, in the Skylab furnace design, are in direct physical contact.

In order to evaluate the limiting of this materials combination, a series of compatibility tests was carried out under conditions which approximated the Multipurpose Furnace environment. Alumina was promptly shown to be inert in these conditions at the intended temperature. The margin of safe temperature for the graphite-stainless steel combination, however, was found to be uncomfortably small. The intended maximum design temperature for graphite and stainless steel is 1150°C in the modified design. Our tests indicated that this materials combination exhibited no harmful degradation at 1225°C but degraded seriously at 1250°C. Thus, a furnace over-temperature of about 75°C would be allowable insofar as graphite and stainless steel reaction is a concern. While a margin of that value is probably adequate, it was desirable to provide a more comfortable choice of materials.
As a consequence, nickel was proposed as a replacement for the stainless steel and the graphite and nickel combination was evaluated. This combination exhibited no harmful degradation even at 1287°C, and it was deemed unnecessary to extend the evaluation to higher temperatures. The conclusion was that the graphite-nickel-alumina combination was safe to at least 1287°C and that the resulting over-temperature margin of 137°C was more than adequate. As a consequence, the modified Multipurpose Furnace design replaces Type 310 stainless steel with nickel in the temperature-critical areas.

2.1.4 **Electrical Insulation of Thermocouples**

With increased Multipurpose Furnace temperature a predictable consequence is increasingly-reduced thermocouple electrical isolation resistance. This occurrence is a natural property of the magnesia insulation in the prefabricated swaged thermocouples and has the effect of reducing the resistance between the Chromel-Alumel wires and the Inconel sheaths which, in the Skylab furnace, are electrically grounded to the furnace structure. This effect is acceptable at the 1000°C maximum temperature for which the Skylab furnace was designed. Because this effect is strongly temperature dependent, however, it becomes unacceptable at the higher (1150°C) maximum furnace temperature and, as a result, requires compensating design changes.

Greatly increased thermocouple resistance to ground was obtained by electrically insulating the Inconel sheaths from the grounded furnace structure. This was accomplished in the high temperature region by the installation of high purity alumina sleeves and in the low temperature region by Teflon sleeves. Additionally, the control thermocouple Inconel sheaths were electrically connected to the regulated 10 volt supply which biases the control thermocouples. This arrangement in effect applies a guard potential to the sheaths and thus eliminates the effect of the small remaining electrical leakage which exists with the insulating sleeves. The Inconel sheaths of the four measuring thermocouples are allowed to float electrically.
2.1.5 Modification of Access Port Seals

Experience disclosed that the seals of the access ports for the Skylab Multipurpose Electric Furnace were not suitable for repeated use because of the excessive force required for removal. No seal leakage was ever detected. Because rotating and reciprocating seals are used routinely in high vacuum systems, it appeared very likely that the fault with the Skylab furnace was not a fault of design principle but was rather more likely a fault of design detail dimensions. The O-Ring Handbook published by the Parker Seal Company was consulted as an up-to-date authoritative source closely related to both industrial and military applications. Information from this source was used as a guide for determining the design dimensions which were subsequently chosen for the modified seal design.

Analysis of the Skylab furnace seal design shows that it followed exactly the Parker recommendations for static vacuum seal applications (Design Chart 8-2). A static seal would normally be assembled and remain assembled rather than be repeatedly assembled and disassembled as in the case of the access port caps. Accordingly, the furnace design was modified to follow the Parker recommendation for dynamic vacuum seals (Design Chart 8-1). For vacuum applications Parker also suggests the use of O-rings in tandem as is already included in the furnace design. To further minimize the force required for access port cap removal, the modified access port bore is polished to a near mirror-like finish.

In order to verify the modified access port seal design, a simulated test fixture version of the modified access port assembly was built and tested. Obviously, the most stringent requirement was vacuum leak tightness. Mass spectrometer helium leak detector tests were unable to detect any leakage of the seal at 25°C and 120°C under static and dynamic conditions. The leak tests were repeated after hundreds of hours at 25°C and 120°C and after hundreds of mating and
separation cycles. On this basis, the prototype furnace was constructed according to the modified design. The experience with the prototype duplicates the experience with the test fixture.

As a back-up in the event the modified seals had been found to be inadequate, a radically new seal design was developed in conceptual form. The new concept was not developed in full detail, was not built, and is not recommended.

2.1.6 Pump Line Design

The M518 furnace was evacuated by evacuating the chamber in which it was situated. The MA-010 is evacuated through a pump line leading from the furnace through the DM wall to space. The furnace vacuum connection was redesigned to allow for this change. The M518 fitting was replaced by a one-inch diameter elbow terminating in a Gamah fitting which allows the furnace to be easily coupled to the DM pump line.

2.2 Helium Package

As used in Skylab, the Multipurpose Furnace was evacuated during the entire time period required for each experiment. The modified furnace, if evacuated, could require as much as twenty hours of passive cooling to reach the allowed touch temperature. For the ASTP mission, cooldown periods of such duration would seriously limit the number of experiments which could be fitted into the permitted time frame. In order to minimize this problem, a helium rapid cooldown system was developed. With this system the time required for cooldown can be reduced to as little as three hours.

Rapid cooling may be provided through selective control of the heat loss of the furnace. For minimum thermal transfer the heat shields described in 2.1.1 require a high vacuum environment, but the thermal transfer will be increased enormously if the vacuum environment is replaced by helium. Fortunately, only a very small amount of helium
is required for this purpose since the order of only 0.01 atmosphere approaches the maximum effectiveness. For the Multipurpose Furnace the volume required to produce 0.01 atm is roughly 0.16 cc He at standard conditions. Within the 0.01 atm range the thermal transfer is weakly dependent upon pressure, and it is consequently not necessary to provide a precise volumetric measure for each dosage. The Helium Package is designed such that successive doses of helium will be provided at slightly reduced volume.

A schematic representation of the Helium Package (HP) is shown in Fig. 2-1. During each experiment prior to rapid cooldown, all HP valves must be closed. Immediately prior to operation of the HP, it is necessary to close the DM valve in the overboard vacuum line to the furnace. To initiate rapid cooldown two valve operations are required: (1) Valve B must be opened momentarily in order to pressurize the Helium Dosage Cavity from the Helium Storage Tube, and (2) Valve A must be opened momentarily in order to release the helium dosage into the furnace. No further valve manipulation is required during the rapid cooldown period.

When cooldown is completed and the allowed touch temperature has been reached, the experiment cycle is completed. Before the furnace may be opened, it should be pressurized to the same value as the Docking Module. This is accomplished with the HP by momentarily opening Valves A and C simultaneously and thus allowing the Docking Module atmosphere to flow into the furnace until the pressure is equilibrated.

2.3 Control Package

2.3.1 Introduction

The Control Package for the Multipurpose Electric Furnace System has been modified to meet a new set of requirements for the ASTP mission. These modifications include several changes of the system
HELIUM DOSAGE
CAVITY

HELIUM STORAGE
TUBE

HOUSING

TO FURNACE
TO HELIUM
STORAGE

TO DM
ATMOSPHERE

OPEN TO DM
ATMOSPHERE

TO FURNACE AND
OVERBOARD VACUUM LINE

HELIUM PACKAGE
SCHEMATIC REPRESENTATION OF HELIUM RAPID COOLDOWN SYSTEM

Fig. 2-1
operating functions and also mechanical modifications to meet new interface requirements. A listing of these modifications and a brief description of each is presented below. In addition to these items, a number of minor electronic component changes have been made to provide additional safety margins in circuitry operation.

1. Increase Maximum Control Temperature -- To facilitate higher temperature experiments, the gain of the control thermocouple amplifier has been altered to permit a maximum controlled heat leveler temperature in excess of 1150°C.

2. Variable Controlled Cooldown Rate -- To provide more constant solidification velocities in the experiments, circuitry has been incorporated to continuously decrease the cooldown rate during the controlled cooldown portion of the experiment. A control is provided to enable selection of the amount of cooldown rate variation.

3. Shorted Control Thermocouple Protection -- To protect the furnace from overheating should the control thermocouple become shorted, an additional shutdown circuit has been incorporated in the control package. This circuit continuously monitors both HOT-1 and HOT-2 measuring thermocouples and automatically shuts off the furnace heaters if either of these thermocouples exceeds a preset limit temperature (nominally set at 1190°C).

4. Mechanical Interface Modifications -- A new mounting mechanism and a new control cable between the control package and furnace have been designed to facilitate the ASTP system configuration. The input power and telemetry cable is being provided by RIC.

The operation of the ASTP Control Package is very similar to the operation of the M518 Control Package. The block diagrams for the two systems are therefore very much the same except for the introduction of the new control functions. The changes are easily identified with reference to the block diagrams shown in Figs. 2-2 and 2-3. In
FURNACE CONTROL SYSTEM

28V

BREAKER

VOLTAGE REGULATOR

REGULATED VOLTAGES

SHUTDOWN SIGNALS

SHUTDOWN RELAY

HEATER

CONTROL T.C.#1

SELECTOR SWITCH

T.C. AMP.

COMPARATOR

OUTPUT SWITCH

SOAK PERIOD TIMER

SOAK PERIOD SELECTION

SHUTDOWN

TEMP. SELECT

FURN. COOL

T.C. OPEN

OVER TEMP.

SHORT

HEAT UP

SOAK

COOL DOWN

END

CLOCK

CONTROLLED COOL DOWN CIRCUIT

RATE SELECTION

RATE RATIO SELECTION

INDICATION FUNCTION
28VDC REGULATED—
REGULATED POWER SUPPLY (ISOLATED) VOLTAGES

MEASURING T.C. OVERTEMP SHUTDOWN

COOL FURNACE INDICATION

MEASURING T.C. K.S

HOT NO 1
A1

HOT NO 2
A2

COLD NO 1
A3

COLD NO 2
A4

SELECTOR SWITCH

DIGITAL READOUT

AMPLIFIED T.C. SIGNALS FOR TELEMETRY 0-5V

THERMOCOUPLE MEASURING AND READOUT
the Furnace Control System block diagram, the "rate ratio selection" is identified as a new input to the controlled cooldown circuit. The "measuring T.C. overtemperature shutdown function" identified in Fig. 2-3 provides the shorted controlled thermocouple protection function. The output of this shutdown circuit provides one of the shutdown signals to the "shutdown relay" shown in Fig. 2-2. All the other functions identified in these figures are the same as those for the M518 system.

2.3.2 Description of Circuitry Modifications

The new system control functions and modifications have been implemented by the addition of a new auxiliary control board, a number of modifications to the main control board, some modification of the control package wiring, and the replacement of two heater selector switches with a control potentiometer on the control panel. Circuitry on the auxiliary control board provides the new functions of "variable controlled cooldown rate" and the "shorted control thermocouple protection". Modifications on the main control board are component value changes and the addition of connection leads to the auxiliary control board.

2.3.2.1 Main Control Board Modifications

Let us first consider the modifications that have been made to the control board. A schematic of this board is shown in Fig. 2-4. The gain of the thermocouple amplifier (A3) has been changed to enable a maximum control temperature (at the furnace heaters) of 1180°C. To accomplish this, resistor R6 has been increased to 445 Ω to reduce A3 gain to give a nominal output voltage of +15 V (+5.00 volts referenced to the +10 V supply voltage) for an input thermocouple voltage of 48.09 mV (corresponding to 1180°C). Resistor R7 has been increased to 2.32 K to maintain a balanced input to A3.

The introduction of the variable cooldown rate function also has required several changes on the main control board. This new
function is being implemented by automatically changing the internal clock rate during the controlled cooldown mode of operation. The internal clock rate of the CP is set by the "Clock Oscillator" circuit comprised of capacitor C6, amplifier A5, transistor Q3, and associated resistors and diodes. The clock rate is determined by the rate of charging and discharging C6 each clock period. For the M518 control package, a precision resistor across pins CE102 and CE103 was used to set the rate of charging C6. This precision resistor has been replaced by a circuit on the new auxiliary control board providing a controlled charging current to C6. During the controlled cooldown mode of operation, the charging current generated by this new circuit gradually decreases to cause the clock rate to decrease accordingly. As the clock rate decreases, the repetition rate of the clock pulses to the cooldown circuit decreases which increases the period between incremental steps out of the D/A converter (A23). Thus, the cooldown rate is decreased.

A more detailed description of this "current source" circuitry is given later.

Resistor R21 has been changed in value and the wiring of counter stage A9 and cooldown selector switch S1 have been changed in conjunction with the new controlled cooldown function. Resistor R21 has been changed to 156 K, to provide a nominal controlled cooldown temperature for 150°C below the soak temperature (i.e., the cooldown rate is controlled by the CP until the furnace temperature drops 150°C below the soak temperature). This temperature range has been changed from 300°C to 150°C to reduce the time required for each experiment and to ease the problems of time scheduling each experiment. The wiring changes to counter A9 and switch S1 maintains the initial controlled cooldown rates of 0.5, 1.2, and 2.4°C/min that were available for the M518 series of experiments.

Other changes on the main control board include:

1. addition of a wire connection (AE105) common with AE41 to permit exitation of the overtemperature caution light by the new overtemperature protection circuit (see section 2.2.2), and
(2) changing of resistor values to provide additional drive to relay K1. This latter modification is provided by changing the values of resistors R38, R39, R40, R43, R37, and R89 to those shown on the schematic.

2.3.2.2 Auxiliary Control Board Description

The auxiliary control board shown in Fig. 2-5 provides the functions of variable cooldown rate and protection against a shorted control thermocouple. Let us consider the variable controlled cooldown rate function first. This function is provided by resistors R11, R12, R13, R14, R15, R101, diode CR5, and transistor Q1 in conjunction with the clock oscillator circuitry described in section 2.2.1. The output of this circuit is a controlled current from the collector of Q1 (GE4) that sets the clock rate of the control package. The input to this circuit is the output of the D/A converter (A7 on the control board) through potentiometer R101 (10 K, 10 turn) mounted on the front panel. The charging current at the collector of Q1 is determined by the voltage across resistors R14 and R15. This voltage is nominally 3.3 volts during "heat up" and "soak" modes of operation. During the "controlled cooldown" mode of operation, the voltage at the output of A7 (i.e., AE101) increases. This causes the voltage at GE3 to increase and the voltage across resistors R11 and R14-R15 to decrease accordingly. The amount the voltage across R14-R15 decreases as a function of the setting of R101 and the voltage at AE101; the end result being a steady decrease in C6 charging current generated by this circuit throughout the controlled cooldown mode of operation. Test results of this function are presented later in this report.

The "shorted control T.C. protection" circuit is comprised of A1, A2, A3, A4, K2 and associated components. In reality, this circuit is a "measuring thermocouple overtemperature shutdown" circuit that shuts off power to the heaters should either HOT-1 or HOT-2 thermocouples exceed 1190°C. The inputs to the circuit are the amplified
HOT-1 and HOT-2 thermocouple signals. These amplified signals are compared to a trip level voltage of 4.96 volts (derived at the output of voltage regulator A1) by operational amplifiers A2 and A3. Should either input signal exceed 4.96 volts, the output of the corresponding operational amplifier goes low. This causes capacitor C4 to discharge toward the -15 volt rail and causes the output of A4 to switch to the -15 V rail. This energizes relay K2 which shuts off power to the heaters by deenergizing relay K1 (see interconnection diagram Fig. 2-5 and schematic Fig. 2-3). K2 also provides isolation between the control board and telemetry circuitry. At the same time, the overtemperature light is energized through K1 and positive feedback through diode CR3 to latch the circuit in the overtemperature state. Reset of the circuit is accomplished by turning the input power switch off momentarily.

2.3.2.3 Control Package Interconnection Modifications

The new interconnection drawing for the control package is shown in Fig. 2-6. The changes from the M518 system are associated with the following: 1) removal of the heater selection switches and wiring the heater leads to the new auxiliary control board; 2) interconnection of the auxiliary control board to the main control board, K2 relay, power supply connections, connection to potentiometer R101, and connection to HOT-1 and HOT-2 amplified input signals; 3) rewiring of rate selector switch S1; and 4) rewiring of input connector J1 at pins F, G, T, J and H to accommodate the ASTP requirements; and 5) addition of new leads AE101-AE105 to the control board.

2.3.3 Mechanical Interface Modifications

The mechanical interface changes have been made to accommodate hard mounting of the control package to the wall of the ASTP vehicle and cable modification to meet the new system configuration. Two mounting brackets are welded to the base of the control package replacing the old mounting clamp. These are shown in Fig. 2-7. The interconnection cable between the control package and furnace is shown in Fig. 2-8.
Fig. 2-8
This cable has been shortened to meet the new requirements and the vacuum cleaner feedthrough assembly has been removed since it no longer is applicable. The input power and telemetry cable is not shown since it is now the responsibility of Rockwell International Corporation.
3. DEVELOPMENT TEST PROGRAM: SUBSYSTEMS

Three main goals were envisaged for the development test program on the subsystem level:

* Comparison of the MA-010 subsystems with the design criteria;
* Evaluation of the stability of the subsystem characteristics;
* Determination of values for parameters in analytic models of the subsystems.

Each subsystem of the MA-010 system was therefore evaluated and characterized separately. Furnace power-temperature characteristics were evaluated under well-defined laboratory conditions. The control package performance was determined in detail using simulated thermocouple inputs. Finally, the helium package was tested; however, because of the nature of its operation, determination of its performance required operation in conjunction with the Multipurpose Electric Furnace.

3.1 Development Test Program: Multipurpose Electric Furnace

The primary goal of the MEF development test program was to verify that the furnace would operate at a sufficiently high temperature with acceptably low power consumption for the required time period. A subsidiary goal of the testing was to provide empirical values for the parameters in a simple, three node, thermal analysis model of the furnace. One additional task was added as the program developed: the pump-down characteristics of the furnace needed to be characterized in order to completely specify the MA-010 interface with the Docking Module being built by Rockwell International Space Division.

All testing was performed using the heat sink configuration shown in Fig. 3-1. For the initial tests, the heat sink was mounted in
Fig. 3-1—Furnace Test Configuration
a vacuum bell jar which also served to evacuate the furnace. Most of the tests, however, were performed with the furnace mounted in a bell jar which only served to control the external ambient; the furnace was evacuated by a separate system through the pumping line shown in the figure. Although the external ambient could be maintained at any pressure from atmospheric to high vacuum, the actual testing was done with high vacuum (< $10^{-5}$ torr) to ensure that heat transfer from the furnace can was dominated by radiation.

For the testing of the MEF as a subsystem, heater power was supplied by a regulated DC power supply. Individual heater currents were measured using precision calibrated shunts and a L&N K-3 potentiometer which provided 0.01 percent accuracy in the current values. The heater voltages were measured at connection points inside the furnace instrumentation compartment so that no errors were introduced by voltage drops in the leads. A digital electronic voltmeter provided four digit accuracy in the voltage measurements, so that the overall accuracy in the power measurements should have been better than 0.1 percent. This precision was not realized in the earliest measurements because of ground loops and thermal EMF's in the measurement circuitry. Once these problems were recognized and eliminated, consistently reliable measurements of the input power and system temperatures were made to high precision. The high precision of voltage and current measurements also permitted precise monitoring of the heater resistances during the entire test program.

Since one goal of the test program was to evaluate the parameters in a thermal model, it was necessary to measure the various power fluxes in the system, especially the power flux into the heat sink. This was accomplished with the test facility by measuring the temperature drops in the heat sink yoke (see Fig. 3-1) as a function of power using an independent heat source instead of the furnace. This device consisted of a stainless steel plate and heating element which mated with the heat sink. Radiation shielding and insulation was incorporated in a manner so that essentially all the input power to
the heating element was dissipated through the heat sink. In this fashion, the heat flux through the heat sink could be determined by measuring the temperature drops between TC3 and TC's 1 and 2. Since some power is radiated from the collar and arms of the heat sink yoke, this calibration was temperature dependent and this correction was made in evaluating the test data.

3.1.1 Furnace Characteristics

During the entire testing program, the furnace was loaded with "low loss" cartridges similar to the "Standard Cartridge" (Part No. 800C878G01A) used in the M518 program. In order to reduce thermal coupling, the present low loss cartridge was shorter than the "Standard Cartridge" so that it extended up to but not into the heat leveler. Also, it was open at the hot end so that it was evacuated to improve the efficiency of the axial thermal insulation. The power/temperature characteristics of such a configuration were well-known from previous work in the M518 studies so that the net furnace power (net heat loss) could be calculated by subtracting the cartridge losses from the total power input.

3.1.1.1 Furnace Power/Temperature Characteristics

The intrinsic heat loss of the furnace as a function of temperature was one of the most important characteristics measured for the system. All measurements were made with the system in steady state as determined by the absence of temperature drift on a control thermocouple, usually CTC-1. The actual calibration data, however, was expressed in terms of the HOT-1 thermocouple since only the measurement thermocouples are accessible during normal system operation.

The usual technique of measurement was to heat the furnace with a larger power input than required for the desired equilibrium temperature and then reduce the power when the appropriate temperature was reached. As a matter of convenience, it was frequently useful to use the relation
\[ \Delta P = C_1 \frac{dT}{dt} \quad (3.1) \]

\( \Delta P \) = difference between input power and equilibrium power  
\( C_1 \) = heat capacity of heat leveler (about 980 J/°C)  
\[ \frac{dT}{dt} \] = Drift of CTC-1 in °C/sec  

to calculate the power changes needed to bring the furnace into steady state. This technique considerably reduced the time necessary to obtain a given data point and increased the accuracy of the information.

The furnace power/temperature characteristics are shown in Fig. 3-2 which also shows the M518 characteristics for comparison. For quantitative use, the net furnace power losses can best be obtained from the empirical equation

\[ P = (a + bT)^4 \quad (3.2) \]

where the least squares fit for \( a \) and \( b \) (including data for \( T > 1100^\circ C \)) gives

\[ a = 1.0830 \pm 0.0239 \quad (3.3a) \]

\[ b = 1.7403 \times 10^{-3} \pm 2.75 \times 10^{-5} \ . \]

The same power equation fits the total power/temperature curve with the coefficients changed to

\[ a = 1.1372 \pm 0.019 \quad (3.3b) \]

\[ b = 1.7816 \times 10^{-3} \pm 2.05 \times 10^{-5} \ . \]

If only the data for temperatures less than 1100°C is used, then the equation changes slightly and the power measured for temperatures in the vicinity of 1150°C is found to be one or two watts greater than anticipated from the balance of the data. This excess power is probably due to gaseous conduction in the furnace.
Fig. 3-2 - Net power loss
For most of the measurements, the pressure measured in the furnace during the measurements was of the order of $1 \text{ to } 3 \times 10^{-4}$ torr, however, for measurements near 1150°C, the pressure ranged from $7 \times 10^{-4}$ to $1.5 \times 10^{-3}$ torr. Simple calculations of the heat transfer by the residual gas at low pressures (see e.g. Dushman, "Vacuum Technique") indicates that at about 1100°C, the gaseous heat loss as a function of pressure are of the order of

$$P_g = 2 \times 10^3 p \text{ watts (p in torr)} \quad (3.4)$$

Thus, the excess power loss observed is in excellent agreement with that expected from kinetic theory considerations. It also follows that an operational pressure limit for furnace pressure lies about $2 \times 10^{-3}$ torr; otherwise, the gaseous heat losses become excessive.

### 3.1.1.2 Stability of Furnace Characteristics

The precision with which the power/temperature characteristics of the MEF can be measured allows the stability of these characteristics to be measured. The effect of continued operation can best be seen from the Table 3-1 which shows the total furnace power losses and heater resistances for temperatures near 1000°C at various times during the course of the testing program. The furnace operating history corresponding to the various dates can be deduced from Fig. 3-3.

#### Table 3-1

<table>
<thead>
<tr>
<th>Date</th>
<th>$T_{\text{HOT-1}}$ °C</th>
<th>$P_{\text{In}}$ watts</th>
<th>$P_{\text{1000}}$ watts</th>
<th>$R$ ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-21-73</td>
<td>992.2</td>
<td>68.87</td>
<td>72.0</td>
<td>3.609</td>
</tr>
<tr>
<td>1-11-74</td>
<td>1000.2</td>
<td>70.96</td>
<td>70.9</td>
<td>3.611</td>
</tr>
<tr>
<td>1-14-74</td>
<td>998.5</td>
<td>71.12</td>
<td>71.4</td>
<td>3.608</td>
</tr>
<tr>
<td>2-12-74</td>
<td>992.6</td>
<td>71.5</td>
<td>72.8</td>
<td>3.611</td>
</tr>
<tr>
<td>5-03-74</td>
<td>996.9</td>
<td>71.4</td>
<td>72.0</td>
<td>3.616</td>
</tr>
<tr>
<td>5-20-74*</td>
<td>992.3</td>
<td>73.02</td>
<td>74.4</td>
<td>3.615</td>
</tr>
</tbody>
</table>

*After furnace flange drilled at WANL.*
Fig. 3-3—Operating history of MEF
The values for the power at 1000°C were extrapolated from the measured input power using the derivative of Eq. (3.2) and the parameters (3.3b). The heater resistances were determined from the individual heater voltages and currents of the two heater sections.

The data in Table 3-1 would indicate that there has been a gradual increase in the power required to maintain a given temperature. Such an increase could result from a slight loss in efficiency of the heat shields due to oxidation of unplated molybdenum components. The severity of this oxidation is a function of both the gas pressure and composition, the temperature of operation and the time at temperature. This effect illustrates the second way in which poor furnace vacuum leads to degraded performance. The first way is gaseous heat conduction discussed in section 3.1.1.1 which is, of course, reversible. The degradation of the radiation shields by oxidation, however, is a permanent change.

It should be pointed out that while there is a measurable deterioration of the furnace power/temperature characteristic, the actual amount of the change is only about 2 watts at 1000°C, and then only after operation for times much longer than expected during the actual mission.

Of equal importance with the power/temperature characteristic is the stability of the heater resistance. Preliminary experiments showed that Kanthal A-1 ablated severely in vacuum without protection. Even when incased in the alumina heater form, the heater resistance changed drastically in five or ten hours of operation. In the present design, the heater wire is additionally incased in high purity alumina cement. The efficacy of this technique is well demonstrated by the data which indicates a negligible increase in heater resistance over the testing period.

Figure 3-3 is a schematic representation of the MA-010 prototype furnace thermal history, and illustrates the number and
frequency of furnace test runs. More quantitatively, the total operating time (furnace power on) was 459.5 hours. Of this total, 133 hours were spent at temperatures exceeding 900°C. This total includes 72 hours above 1000°C, of which the furnace spent 22 hours at 1150°C, with about 3 hours at 1190°C. These totals do not include time spent at elevated temperatures during cooldown when the furnace input power was turned off.

3.1.1.3 Heat Leveler Temperature Distribution

The temperature measured by the control thermocouples (CTC's) and the measurement thermocouples (HOT-1, 2) give an indication of the radial temperature drop which occurs in the heat leveler. This drop is of the order of 5°C at a heat leveler temperature of 550°C and 12°C at 1150°C with low loss cartridges and would be greater with experiment cartridges drawing greater power.

The axial temperature distribution in the heat leveler cannot be determined by the furnace thermocouples so that a special temperature probe was constructed to measure it. This probe consisted of a cartridge similar to the low loss cartridge but have a stack of circular radiation shields extending into the heat leveler cavity. Five thermocouples were spaced along this section; the radiation shields prevented interaction between the thermocouples and also insured that the thermocouples "saw" only a small section of the heat leveler cavity. The results of the measurements are shown in Fig. 3-4. The heat leveler indeed has an extremely constant temperature over about half of its length and the temperature then begins to drop off. The last thermocouple unfortunately was not in the actual cavity but rather in the gradient tube region and as a result measured a much lower temperature than the other four. This data is of importance in calculating the performance of experiment cartridges in that it indicates that the "effective heat leveler temperature" for cartridge design calculations may be five to ten degrees cooler than the measured temperature.
Fig. 3-4—Heat leveler temperature profile
3.1.2 Furnace Cooling Rate

The passive furnace cooling rate was measured with low loss cartridges both under vacuum conditions and with helium added to increase the heat losses. The observed rates as a function of temperature are shown in Fig. 3-5. It should be emphasized that the normal cool rate is valid only for the low loss cartridges; with regular experiment cartridges which conduct appreciable power, the rate will be faster. The effect of cartridges for the helium quenched cooling rates will be very small due to the high heat flux through the gas.

The helium cool rates are labeled on the curve as one dosage, two dosages, and three dosages. These correspond to helium pressures (at room temperature) of about 11 torr, 22 torr and 33 torr respectively. Little difference is found between the 22 torr and 33 torr cases; however, the rate for the 11 torr case is slightly lower than for the higher pressure conditions. If the maximum cooling rate is required, then a second dosage of helium might be called for; more than two dosages produce no improvement.

The cooling rate data can be combined with the power loss data to give the effective heat capacity of the furnace. This parameter turns out to be slightly temperature dependent with a value of

\[ C_p = 960 \text{ J/K at } 700^\circ\text{C}, \quad 1040 \text{ J/K at } 1000^\circ\text{C} \quad \text{and} \quad 1080 \text{ J/K at } 1100^\circ\text{C}. \]

Depending on the accuracy of the calculation, either the temperature dependent value or an approximate value of 1000 J/K could be used. This parameter is also dependent on the cartridges in the furnace and should be measured for each of the separate experiments to provide the best input data for the Three Node TAM (see section 3.1.3).

3.1.3 Three Node Thermal Model of MEF

A three node thermal analysis model (TAM) of the Multipurpose Furnace was developed to predict gross furnace performance both for experiment cartridge development and for use by Rockwell International Space Division in their integrated TAM of the entire Docking Module.
Fig. 3-5—MEF cooling rates
The three node TAM provides a simple and quite accurate means for predicting furnace temperatures and powers for different operating conditions including experiment cartridges other than the low loss cartridges. It does not, of course, provide a detailed modeling of the temperature distribution within either the furnace or the experiment cartridges.

In this lumped parameter model, the heat leveler is Node 1, the heat extractor plate is Node 2, and the outer can is taken as the third node; and appropriate conduction and radiation connections are made between these nodes as shown in Fig. 3-6. The temperature of Nodes 1 and 2 are directly measurable by the HOT and COLD thermocouples; a specially-located thermocouple is used for Node 3.

Although this is a lumped parameter model, the various connections have physical reality which allows some a priori evaluation. For example, K1 represents various conduction paths between the heat leveler and the heat extraction plate such as the support tubes, thermocouples and sheaths, etc. Similarly, the radiation connections can be evaluated by calculating the heat fluxes through the shields. The assumed numbers given in Fig. 3-6 represent these calculated values. The observed values were determined by measuring the various furnace temperatures and heat fluxes and in general the measured values agree well with the anticipated values. The largest discrepancy occurs in K1, the radiation conductance between the heat leveler and the heat extraction plate. This deviation is not unreasonable since the calculated value did not include radiation leakage through the numerous clearance holes in the axial shields required for the thermocouples and current loads.

The performance of the furnace can be calculated by numerical solution of the following simultaneous differential equations.

\[
\frac{dT_1}{dt} = \frac{1}{C_1}(P_{IN} - P_1 - P_2 - PK1 - PK2) \quad (3.5a)
\]

or

\[
\frac{dT_1}{dt} = \frac{1}{C_1}(-P_1 - P_2 - P_3 - PK1 - PK2) \quad (3.5b)
\]
**THREE NODE THERMAL MODEL**

![Diagram of Three Node Thermal Model](image)

<table>
<thead>
<tr>
<th>Path Description</th>
<th>Assumed $\text{WK}^{-1}$</th>
<th>Observed $\text{WK}^{-1}$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$ Conductive Paths</td>
<td>0.025</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>$K_2$ Experiment Cartridge</td>
<td></td>
<td>8.0(-3)</td>
<td>(1)</td>
</tr>
<tr>
<td>$K_3$ Gas Conduction in Helium Quench</td>
<td>0.50</td>
<td>0.36/0.49</td>
<td>(2)</td>
</tr>
<tr>
<td>$K_4$ Conductance through Furnace Chamber Cover</td>
<td>0.181</td>
<td>0.100</td>
<td>(3)</td>
</tr>
<tr>
<td>$K_5$ Heat Sink Conductance</td>
<td>1.54</td>
<td>1.13</td>
<td></td>
</tr>
</tbody>
</table>

$$P = K(T_i - T_j)$$

$$P = \kappa(T_i^4 - T_j^4)$$

<table>
<thead>
<tr>
<th>Conductance Type</th>
<th>Assumed $\text{WK}^{-4}$</th>
<th>Observed $\text{WK}^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa_1$ Radiation Conductance from Heat Leveler to Heat Extractor Plate</td>
<td>1.31(-12)</td>
<td>9.7 (-12)</td>
</tr>
<tr>
<td>$\kappa_2$ Radiation Conductance from Heat Leveler to Furnace Chamber Cover</td>
<td>1.14(-11)</td>
<td>7.95(-12)</td>
</tr>
<tr>
<td>$\kappa_3$ Radiation Conductance from Furnace Chamber Cover to Ambient</td>
<td>3.36(-9)</td>
<td>2.16(-9)</td>
</tr>
<tr>
<td>$\kappa_4$ Radiation Conductance from Instrumentation Compartment Cover to Ambient</td>
<td>5.15(-10)</td>
<td>5.15(-10)</td>
</tr>
</tbody>
</table>

**Notes:**

(1) Observed value for low loss cartridge.
(2) Values for one or two dosages respectively.
(3) Change in value due to geometrical factor.
\[ \frac{dT_2}{dt} = \frac{1}{C_2}(P_1 + P_2 + P_4 + PK_1 - PS - PK_4) \]  

(3.6)

\[ \frac{dT_3}{dt} = \frac{1}{C_3}(PK_2 - P_4 - PK_3) \]  

(3.7a)

\[ \frac{dT_3}{dt} = \frac{1}{C_3}(PK_2 + P_3 - P_4 - PK_3) \]  

(3.7b)

where the P's refer to heat fluxes through the conductance connections and the PK's to the heat fluxes via the radiation connections.

Equations 3.5a and 3.7a apply during the heat up and soak times whereas 3.5b and 3.7b are valid during the helium quench. During the heat up, the input power is constant, while in the soak period, \( \frac{dT_1}{dt} \) is set at zero and the input power is calculated as a variable. The model as illustrated is applicable to the test configuration, Fig. 3-1, used to measure furnace performance in the laboratory. In order to calculate the performance of the system in the docking module, the model must be changed very slightly by connecting the radiative conductance \( k_1 \) to Node 2 rather than to ambient. Although this changes Eq. 3.6 slightly, the values of the individual connection elements are not affected.

The model was tested by performing a furnace run with known input powers during the heat-up and soak phases. Following the soak phase, the furnace was cooled passively to 700°C when helium was admitted to accelerate the cooldown. Figure 3.7 shows the calculated temperatures as solid lines with the observed values as data points. Generally, the agreement is excellent; however, a deviation in the transient response of T3 indicates a slightly larger heat capacity is required for Node 3 if greater accuracy is necessary. Under steady state conditions, the predicted furnace losses agree within 0.5 watt with the values calculated from Eq. 3.2. This agreement, of course, depends on having a good representation of the cartridge conductance \( K_2 \) which must be evaluated for every experiment.
Low Loss Test Cartridge

Temperature °C

Time Hours

- Calculated T1, T2, T3
- Observed T1
- Observed T2
- Observed T3

Fig. 3-7—Observed vs predicted furnace temperatures
3.1.4 Furnace Pump-Down Requirements

An adequate vacuum must be maintained in the furnace during operation for the reasons discussed in section 3.1.1.2. Because of the structure of the furnace, coupled with the experimental procedural and time line requirements, the demands on the pumping line are more severe than would be the case with a simple laboratory vacuum system.

The internal structure of the furnace contains a very large surface area. For example, the fired graphite heat leveler will readily absorb large quantities of gas, including water vapor, when the furnace is opened to the atmosphere, as is required for cartridge loading. When the furnace is subsequently heated, outgassing occurs in several bursts as different species with different energies of binding are desorbed. This behavior is clearly illustrated by the pressure vs temperature curves in Appendix B. The pumping line must have sufficient capacity to handle these bursts of outgassing in order to prevent the pressure in the furnace from becoming excessive during heat up.

Early in the program, Rockwell contemplated the use of a section of 3/8" O.D. pump line in the DM. Our early tests, with a 28" section of 3/8" line in the system, showed this configuration to be inadequate, as shown in Appendix B. We replaced the 3/8" line with 26" of 3/4" O.D. line which was satisfactory. Later, a one-inch pumping line was designed by Rockwell. As an addendum to this contract, a detailed mock-up of the Rockwell design was constructed and tested. Our test results are shown in Appendix B and prove the one-inch line to be entirely adequate to meet the furnace vacuum requirements, although the margin of safety was quite small.
3.2 Helium Package

The detailed design drawings for the helium package (HP) are contained in Appendix A. The prototype HP, including the associated lines, was leak checked while evacuated. Both the storage and dosage cavity were also leak checked while pressurized to 300 psi.

Functional testing of the HP requires its use in conjunction with the furnace. These test results are included with the furnace tests in section 3.1.2.
3.3 Control Package Performance

A number of tests were performed on the modified control package to verify and characterize the operation of the new control functions. These tests were made on the control package itself with the use of simulated thermocouple signals, a dummy heater load, an oscilloscope, a dc power supply, a precision 5-digit digital voltmeter, and a counter.

The first test performed was to obtain a calibration curve of true control temperature on control thermocouple CTC-1 (or CTC-2) vs soak setting. This curve was obtained by setting the control potentiometer at specific points and then adjusting the simulated CTC-1 signal to obtain a 50-50 heater waveform (i.e., 50% output power). The simulated TC signal was then measured and the corresponding TC temperature was recorded from the new reference tables for Chromel-Alumel thermocouples. The resulting temperature calibration curves are shown in detail in Figs. 3-8, 3-9, 3-10, and 3-11.

The calibration of the "shorted control TC protection" circuit was checked by simulating HOT-1 and HOT-2 thermocouple signals and measuring the input voltages at which each caused K2 to be energized. These trip levels occurred at 48.48 mV and 48.45 mV corresponding to HOT-1 and HOT-2 temperatures of 1190°C and 1189°C respectively. For each case it was verified that K1 and heater power was shut off and that the overtemperature light was energized.

A series of tests were then performed to determine the performance of the variable rate controlled cooldown function. For all of these tests, the CTC-1 thermocouple signal was continuously adjusted to maintain a 50-50 output heater waveform throughout the controlled cooldown period. Measurements were made of the change in millivolts of the CTC-1 signal and the period of the clock oscillator every five minutes during each cooldown test. The millivolts change
Fig. 3-8. TRUE CONTROL TEMPERATURE vs. SOAK SETTING (0-250)
Fig. 3-9. TRUE CONTROL TEMPERATURE VS. SOAK SETTING (250-500)
Fig. 3-10. TRUE CONTROL TEMPERATURE VS. SOAK SETTING (500-750)
Fig. 3-11. TRUE CONTROL TEMPERATURE VS. SOAK SETTING (750-1000)
was transferred into a corresponding linearized CTC-1 temperature change to obtain the set of curves shown in Fig. 3-12. This shows the controlled temperature variation from soak temperature \( T_{\text{CTC-1}} - T_{\text{soak}} \) as a function of time and "rate ratio" potentiometer settings. One might note that the initial cooldown rate setting for all these tests was 2.4°C/min. If initial cooldown rates of 1.2 or 0.6°C/min are selected, the curves would be identical except that the time scales would be increased by factors of 2 and 4, respectively. It should also be noted that the visible irregularities (particularly for the 000 pot setting curve) do not really exist but are a result of drafting errors used to obtain the curves.

Another useful set of curves is shown in Fig. 3-13. This figure shows the normalized cooldown rate vs cooldown temperature as a function of rate ratio potentiometer settings. Definitions of normalized cooldown rate and cooldown temperature are given on the curve.
NORMALIZED COOLDOWN RATE = (RATE INITIAL / RATE T1)

NORMALIZED COOLDOWN RATE
VS. COOLDOWN TEMPERATURE \( \Delta T_X \)
\( (\Delta T_X = T_X - T_{SOAK}) \)

RATE RATIO
POT SETTINGS

0.00
5.00
17.00
25.00
30.00

SOAK TEMPERATURE

\( \Delta T_X (\degree C) \)
4. SYSTEM TESTS

4.1 Introduction

The control package and the helium package both interact with the furnace independently. That is, the control functions are in an "off" mode whenever the helium package function is utilized. Therefore, the system tests of significance are furnace-helium package and furnace-control package. The furnace-helium package system is discussed in section 3.1.2. The furnace-control package system is discussed below in terms of a system test of the controlled cooldown function.

4.2 Furnace-Control Package System -- Controlled Cooldown Function

A number of tests were performed to verify the operation of the variable rate cooldown function in a complete system configuration. These tests were all run with "low loss" cartridges in the furnace. For each test run, a "soak setting" of 835 was used which yielded a control thermocouple CTC-1 "soak" temperature of 960°C. The corresponding heat leveler HOT-1 thermocouple temperature during soak was measured at 952.5°C. The first set of tests were run with a "cooldown rate" selection of 2.4°C/min and the "rate ratio" setting was used as a variable. Measurements of CTC-1 and HOT-1 thermocouple signals were made at specific time intervals from the beginning to the end of each controlled cooldown period.

The results of the first set of tests are shown in Fig. 4-1 with HOT-1 temperature plotted as a function of time and "rate ratio" setting. The plot of HOT-1 vs time is of particular interest since this is more representative of the temperature-time profile seen at the hot end of the experiment cartridges than that obtained by plotting...
CONTROLLED COOLDOWN TEMP. VS. TIME

Soak Setting - 835
Cooldown Rate Setting - 2.4°C/min

Fig. 4-1
control thermocouple CTC-1 vs time. One might note that there is a delay of several minutes between the start of controlled cooldown and when HOT-1 temperature starts to decrease at the desired rate. This delay is caused mainly by the thermal mass of the heat leveler and the resulting thermal time delay between CTC-1 and HOT-1 thermocouples. After this delay, however, the variable rate cooldown function performed very well as one can see by comparing this set of curves (Fig. 4-1) to those generated when testing the control package by itself (see Fig. 3-12).

Two other figures are presented to demonstrate operating characteristics of the combined system. The first of these (Fig. 4-2) compares CTC-1 temperature and HOT-1 temperature for one of the test runs. This plot clearly shows the temperature differential between HOT-1 and CTC-1, the thermal lag between HOT-1 and CTC-1, but most importantly the good tracking between these two temperatures. Therefore, since we know that the control package provides very smooth programmed temperature control of CTC-1, then HOT-1 temperature will be controlled similarly. The second figure (Fig. 4-3) shows the results of two controlled cooldown test runs with a cooldown rate setting of 1.2°C/min instead of 2.4°C/min. The results of these tests are virtually identical to those shown in Fig. 4-1 except that the time scale is increased by a factor of two (2), as it should be.
CONTROLLED COOLDOWN TEMP. VS. TIME

Soak Setting - 835
Cooldown Rate Setting - 2.4°C/min
Rate Ratio Setting - 700

Fig. 4-2
CONTROLLED COOLDOWN TEMP. VS. TIME

Soak Setting - 835
Cooldown Rate Setting - 1.2°C/min

Fig. 4-3
5. CONCLUSIONS

The results of both the subsystem and system level testing demonstrated that the MA-010 prototype MEF System characteristics met all the design goals for the equipment. At the conclusion of the test sequence, it was found that unanticipated deformation had occurred in the spacer (gradient) tubes. Subsequent analysis revealed that this problem arose from tolerance build-up which caused mechanical interference at high operating temperatures and this problem has been corrected in the flight design.

Under an addendum to this contract, the feasibility of constructing a flight-qualified pulser unit for experiment MA-060 was established.

*(WANL DRM Nos. DA-0112 and DA-0114.)*
APPENDIX A -- NEW OR MODIFIED DETAIL DESIGN DRAWINGS FOR MA-010 FURNACE AND HELIUM PACKAGE
**TABLE 1: DIMENSIONS**

<table>
<thead>
<tr>
<th>SLIDE SIZE</th>
<th>W/SLICE MIN.</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

**TABLE 2: MATERIALS**

<table>
<thead>
<tr>
<th>PART</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM</td>
<td>304L STAINLESS STEEL</td>
</tr>
<tr>
<td>FITS</td>
<td>TYPICAL MATERIALS (TYPICAL)</td>
</tr>
<tr>
<td>SEAL</td>
<td>BUTTERFLY (TYPICAL)</td>
</tr>
<tr>
<td>RINGS</td>
<td>304L SS</td>
</tr>
<tr>
<td>SPARKS</td>
<td>304L STAINLESS STEEL</td>
</tr>
<tr>
<td>BOLT</td>
<td>400 ALLOYED SS</td>
</tr>
<tr>
<td>NUT</td>
<td>ALUMINUM NUTER GAL.</td>
</tr>
<tr>
<td>PADS</td>
<td>304L SS</td>
</tr>
</tbody>
</table>

**PARTS LIST**

<table>
<thead>
<tr>
<th>PART</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALVE</td>
<td>500C889</td>
</tr>
</tbody>
</table>
NOTE: SLOTS SMALL ANGLE MEASURED AS SHOWN COUNTERCLOCKWISE TO LOCK

DETAIL 'B' ENLARGED TYPE

THD RELIEF

Note: Unless otherwise specified, remove all burrs and break all sharp edges. Do not machine chamfer internal corners. Do not re.

1 - This drawing replaces RED drawing 723 6412.

2 - Unless otherwise specified, remove all burrs and break all sharp edges. Do not machine chamfer internal corners. Do not re.

3 - Tag IDENT part no. 1 serial no. per P2045-95, see table column.  

UNLESS OTHERWISE SPECIFIED REMOVE ALL BURRS AND BREAK ALL SHARP

EDGES. DO NOT MACHINE CHAMFER INTERNAL CORNERS. DO NOT RE.

1 - THIS DRAWING REPLACES RED DRAWING 723 6412.
### TABLE I

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>Specification 1</td>
</tr>
<tr>
<td>Item 2</td>
<td>Specification 2</td>
</tr>
<tr>
<td>Item 3</td>
<td>Specification 3</td>
</tr>
</tbody>
</table>

### SECTION A-A

- **Figure A**: Detailed view of the assembly showing parts A, B, C, and D, with dimensions X, Y, and Z.
- **Figure B**: Exploded view with parts labeled 1 through 10.

---

**Notes**:
- All dimensions are in millimeters unless otherwise specified.
- Assembly should be completed within 24 hours of receipt.
- Parts A and B are manufactured by XYZ Corporation.
GROUPS 1, 2, 3, 4, 5, 6, 7, 8
HEAT SHIELD ASS'YS.

TABLE 1

<table>
<thead>
<tr>
<th>GROUP NO</th>
<th>PART NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2222-0001</td>
</tr>
<tr>
<td>2</td>
<td>2222-0002</td>
</tr>
<tr>
<td>3</td>
<td>2222-0003</td>
</tr>
<tr>
<td>4</td>
<td>2222-0004</td>
</tr>
<tr>
<td>5</td>
<td>2222-0005</td>
</tr>
<tr>
<td>6</td>
<td>2222-0006</td>
</tr>
<tr>
<td>7</td>
<td>2222-0007</td>
</tr>
<tr>
<td>8</td>
<td>2222-0008</td>
</tr>
</tbody>
</table>

SPOT WELD PER
MATERIAL

MATERIAL WELDED TO MOLD

EAT 5 N160A

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.

WEIGHT 1550 LB.
TABLE 1

<table>
<thead>
<tr>
<th>GROUP NO.</th>
<th>PART NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3956185013</td>
</tr>
</tbody>
</table>

**TABLE 1**

**HEATER WIRE SLEEVE**

**PART NO.** 3956185013

**HEATER WIRE**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WIRE RETURN (E-NUITS)</td>
</tr>
<tr>
<td>2</td>
<td>90° 90° 90° 90° WIRE TURN AROUND</td>
</tr>
<tr>
<td>3</td>
<td>180° 180° 180° 180° WIRE TURN AROUND</td>
</tr>
</tbody>
</table>

*Insert A wire into slot shown. Bend wire 90° following hole. Then wire intersects slot shown at opposite end of item 1. Bend wire 90° for return trip to slot shown. Insert B wire into slot shown & follow same procedure.*

**FULL HEATER WINDING**

- Fill heater winding with a blank of water & solids mix (non-flammable material) before installing sleeve.

**CHECK CONTINUITY & RESISTANCE OF EACH WINDING AFTER COATING:** Elements A & B SLIDE BACK.

**ORANGE WIRE AFTER WINDING & BEFORE INSPECTION PER TESTS**

**EACH WIRE** is approximately Jeet long, no welds or splices permitted in hot zone.

**HEATING ELEMENTS A & B - 76 WATTS EACH.**

**T-TAG PART NUMBER & SERIAL NUMBER PER BILL. SEE TABLE 2.**
1. UNLESS OTHERWISE SPECIFIED, FEATURES SHOWN AXIAL TO CENTER ARE:

- TO A @ 0.002

2. GRAPHT|E: FURNISHED BY ULTRA CARBON COMP.

BAY CITY, MICH.

3. UNLESS OTHERWISE SPECIFIED, REMOVE ALL BURRS AND BREAK ALL SHARP EDGES. (ID MAX RADIUS OR CHAMFER, INTERNAL CORNER (ID MAX R.

<table>
<thead>
<tr>
<th>PARTS LIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE NO.</td>
</tr>
<tr>
<td>14683</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NEXT ASSEMBLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwg Code No.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

| INFORMATION CATEGORY | A |
### Parts List

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>DESCRIPTION</th>
<th>CODE No.</th>
<th>PART OR IDENTIFYING No.</th>
<th>MATERIAL</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HEAT SHIELD</td>
<td>800C884-H01</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>2</td>
<td>HEAT SHIELD</td>
<td>800C884-H02</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>3</td>
<td>HEAT SHIELD</td>
<td>800C884-H03</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>4</td>
<td>HEAT SHIELD</td>
<td>800C884-H04</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>5</td>
<td>HEAT SHIELD</td>
<td>800C884-H05</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>6</td>
<td>HEAT SHIELD</td>
<td>800C884-H06</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>7</td>
<td>HEAT SHIELD</td>
<td>800C884-H07</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
<tr>
<td>8</td>
<td>HEAT SHIELD</td>
<td>800C884-H08</td>
<td>-00</td>
<td>N/A</td>
<td>800C884</td>
</tr>
</tbody>
</table>

3. REMOVE ALL BURRS / BREAK ALL SHARP EDGES. OBO MAX R. ARCH. INT. CORNERS. OBO MAX R.

2. HEAT SHIELDS, IT5-5, 7/48 SHALL BE GOLD PLATED TO .0001-.0001 THICKNESS PER P597993, AND POLISHED TO A BRIGHT METALLIC FINISH.

1. TAG IDENT PART NO. SERIAL NO. PER P29457-1 SEE IDENT COLUMN.

---

**Diagram:**
- **X** - DIA.
- **A** - DIA.
- **0.005 THK. STA. 7,000 A**
- **0.004 TOTAL**
- **250 X 0.004 TYP.**

**Text:**
- "ON ITS 5, 6, 7/48 ONLY, REMOVE GOLD PLATING PER P597993 FROM THIS SIDE ONLY. TYP. 4 PLACES."
1. HEATER HOUSING BOTTOM FLANGE

PARTS LIST

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>SERIAL NO.</th>
<th>MATERIAL</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>800C883</td>
<td>800C883</td>
<td>HEATER HOUSING BOTTOM FLANGE</td>
<td>MULTIPURPOSE ELECTRIC FURNACE SYSTEM</td>
</tr>
</tbody>
</table>

Westinghouse Astronuclear Laboratory

- UNLESS OTHERWISE SPECIFIED
- FEATURES SHOWN COPLANAR TO DATUM
- ARE 0.005 DIA

- TAG IDENT PART NO. & SERIAL NO.
- PER P294517-1, SEE IDENT COLUMN.

- UNLESS OTHERWISE SPECIFIED
- REMOVE ALL BURRS & BREAK ALL SHARP EDGES .010 MAX RADIUS.
- CHAMFER, INTERNAL CORNERS .010 MAX R.

- TOLERANCES - DO NOT SCALE
- 2PL DEC 3PL DEC ANGLES .005
- .005 R .002 R .0005 AC500

- C294517-1 IDENT INFORMATION CATEGORY

- CODE NO. 14683 800C883
**REVISIONS**

**PARTS LIST**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>CODE</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BAFFLE TAB</td>
<td>800C882.001</td>
<td>Mo</td>
</tr>
<tr>
<td>2</td>
<td>BAFFLE TAB</td>
<td>800C882.002</td>
<td>Mo</td>
</tr>
<tr>
<td>3</td>
<td>BAFFLE TAB</td>
<td>800C882.003</td>
<td>Mo</td>
</tr>
<tr>
<td>4</td>
<td>HEATER BAFFLE TAB</td>
<td>800C882.004</td>
<td>Mo</td>
</tr>
</tbody>
</table>

**NOTES**

2. UNLESS OTHERWISE SPECIFIED, REMOVE ALL BURRS & BERRY ALL SHARP EDGES .002 MAX. RADIUS OR CHAMFER.

1. MARK PART NO. & LOT SERIAL NO. ON CONTAINER PER P2945/1-1 SEE IDENT. COLUMN.

---

**Westinghouse Astronautical Laboratory**

**FURNACE CHAMBER**

MULTIPURPOSE ELECTRIC FURNACE SYSTEM
1. Tag ident part no. 1.
   See ident column

2. Unless otherwise specified, remove all burrs, break all sharp edges, chamfer internal corners.

3. Unless otherwise specified, features shown coaxial to datum (A) are 0.003 DIA.

THIS IS NOT A MATING THREAD—REQ FOR HEAT TRANSFER CHARACTERISTICS ONLY.

LIST OF MATERIALS

<table>
<thead>
<tr>
<th>STN</th>
<th>ITEM NO.</th>
<th>NOMENCLATURE OR DESCRIPTION</th>
<th>PART OR IDENTIFYING NO.</th>
<th>MATERIAL</th>
<th>SPECIFICATION</th>
<th>ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HEAT TRANSFER TUBE
FURNACE CHAMBER
MULTIPURPOSE ELECTRIC FURNACE SYSTEM

Westinghouse Astronuclear Laboratory
Pittsburgh, Pennsylvania

DATE: 1-25-73
REVISION: 7
CHECKED: 6/19
DESIGN: S.F.
ANALYSIS: S.F.

This is not a mating thread. Required for heat transfer characteristics only.

1. Tag ident part no. 1.
   See ident column

2. Unless otherwise specified, remove all burrs, break all sharp edges, chamfer internal corners.

3. Unless otherwise specified, features shown coaxial to datum (A) are 0.003 DIA.

The drawing shows a diagram of a heat transfer tube furnace chamber for a multipurpose electric furnace system.
I

TABLE I

TABLE I

I

TABLE I

I

TABLE I

I

TABLE I
APPENDIX B — VACUUM LINE TEST DATA

The following graphs illustrate the performance of a variety of pump line configurations. In all cases, the pump line terminated in a vacuum bell jar maintained at a pressure of about $10^{-5}$ torr. The pressure scale on all the graphs refers to the pressure in the furnace.

Curve 1 in Fig. B-1 illustrates pumping performance with a section of 3/8" O.D. tubing in the pump line. This is clearly unsatisfactory. Replacing the 3/8" line with 3/4" O.D. line improves the pump line performance substantially. The effects of furnace outgassing become quite clear when these curves are compared with Curve 3, which is an almost vertical line on the left side of the graph. Curve 3 illustrates the performance of the 3/4" configuration when the preconditioned furnace has been maintained with a helium atmosphere and not opened to the air before pump down.

The data in Fig. B-2 corresponds to the 3/4" pump line configuration with a 21/64" x 1-1/2" long constriction placed in the line. Curve 4 dramatically illustrates the multiple outgassing bursts during furnace heat-up.

Figures B-3 through B-7 illustrate the results of a series of five consecutive runs using a detailed equivalent of the 1" DM pump line. The dotted curves denote pressure and the solid curves denote heat leveler temperature. In all cases, except run 4, the furnace was opened to the atmosphere for 5 minutes immediately preceding the pump down. The 3/8" constriction is a simple orifice in a thin plate, and has no noticeable effect on the pump line performance. What is
Fig. B-1—Furnace pump down rates under various conditions

1. 20" of 3/8" O.D. Copper Tubing in Pump Line. Furnace Open to Air for 10 Minutes Prior to Test.
2. 26" of 3/4" O.D. Copper Tubing in Pump Line. Furnace Open to Air for 15 Minutes Prior to Test.
3. As 2, but with Helium Atmosphere in Furnace.
Fig. B-2—Furnace pump down rates with 2/164" diameter × 1 1/2" long constriction in 3/4" O. D. pump line.
Fig. B-3—Run 1, 3/8" constriction in pump line
Fig. B-4—Run 2, without 3/8" constriction in pump line
Fig. B-5—Run 3, 3/8'' constriction in pump line
Fig. B-6—Run 4, 3/8" constriction in pump line, after opening furnace to air for 20 hours
Fig. B-7—Run 5, 3/8" constriction in pump line
more pronounced is the gradual improvement in vacuum as the furnace is conditioned with three consecutive high temperature runs (Figs. B-3, B-4 and B-5). After run 3, the furnace was left open to the atmosphere for 20 hours. Run 4, Fig. B-6, is a preconditioning run. This was followed by run 5. Note in all cases the multiple outgassing bursts during heat-up. Figure B-5 demonstrates the performance with maximum pre-conditioning and Fig. B-7 shows the performance with minimum pre-conditioning.
APPENDIX C -- CONCEPTUAL CARTRIDGE DESIGNS

As an addendum to the principal task of this contract, preliminary conceptual designs were to be developed for certain of the experiment cartridges.

Of the six original experiments chosen for the Multipurpose Furnace on the ASTP mission, three apparently require cartridges very similar to cartridges used for experiments in the M518 series of experiments of Skylab. Three of the experiments, however, apparently required somewhat more complex designs. In order to clarify the requirements for these experiments in more detail than was available from the proposals, a meeting was arranged by NASA between the principal investigators, Westinghouse, and MSFC personnel. The objectives of the experiments were discussed in detail and the general requirements for the experiment cartridges were agreed on. At this stage of the program, however, detailed requirements were not determined (e.g. exact material composition, precise ampoule dimensions, etc.). As a result of this conference, Westinghouse was directed by MSFC, as an additional task on the present program, to develop conceptual designs for possible experiment cartridges for the three experiments. The following figures and discussions represent these conceptual designs.

While the designs themselves should illustrate the general configuration of the cartridges, they should not be construed to be accurate assembly drawings. Many mechanical details such as the latching and sealing mechanisms depend on design decisions yet to be made on the Multipurpose Furnace itself. Specific thermal design requires more effort than was intended for this task. Nevertheless, while the final cartridge designs may differ in detail from those presented here, they will probably depart but little in general configuration.