NASA CR-54770
LAC ER# 8207

MODIFICATION AND MAJOR OVERHAUL OF CRYOGENIC IRRADIATION FACILITY AT PLUMBROOK REACTOR FACILITY

by

LOCKHEED NUCLEAR PRODUCTS

C.A. Schwanbeck, Project Manager

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS3-6210

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FINAL REPORT

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A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

Code: U   Contract: NAS 3-6210

FOREWORD

This final report is submitted to the Lewis Research Center of the National Aeronautics and Space Administration in accordance with the requirements of NASA Contract NAS 3-6210.

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OF CRYOGENIC IRRADIATION FACILITY
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ABSTRACT

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This is the final report on Contract NAS 3-6210 which was implemented for the overhaul, modification, repair and instrument calibration of the equipment used in combined nuclear-cryogenic material studies.

The equipment includes a gaseous phase helium refrigerator system, the test loops with their transfer system, associated instrumentation and appurtenances.

It includes a reliability evaluation of the equipment and a projected maintenance schedule predicated on the results.

Author

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MODIFICATION AND MAJOR OVERHAUL OF CRYOGENIC IRRADIATION FACILITY AT PLUMBROOK REACTOR FACILITY

by

LOCKHEED NUCLEAR PRODUCTS

C. A. Schwanbeck, Project Manager

SUMMARY

This is the final report on a program for the overhaul and maintenance of equipment which has been used for combined nuclear cryogenic studies on structural materials performed at the NASA Plumbrook Reactor Facility.

The equipment consisting of the helium refrigerator, test loops, and transfer system was originally installed during 1962-63 and was subsequently used for numerous long duration tests at room temperature out-of-pile and at 30°R, both out-of-pile and in-pile to 10^{17}nvt, E>0.5 Mev. The resultant cumulative time at near design capacity dictated that the refrigerator expansion engines and engine crossheads should be disassembled for inspection and repaired as necessary.

In addition, a leakage through manual shut-off valves in the cold refrigerant lines and the necessity of removing permanently installed platinum resistance thermometers for calibration or replacement dictated modification of these components.

The use of conventional lubricating oil in the compressor system has caused degradation of effectiveness in the refrigerator heat exchanger indicating that the required oil removal equipment was not performing as designed, so modification of the components in this system was also performed.

Maintenance of the test loop and transfer system was also performed with emphasis on the evacuated enclosures in the former and on the equipment submerged in the quadrant in the latter.

A reliability evaluation of the equipment was performed to provide criteria for the development of a periodic maintenance requirement schedule.

1 INTRODUCTION

This report covers the activities conducted under Contract NAS 3-6210 between the National Aeronautics and Space Administration, Lewis Research Center and The Lockheed-Georgia Company for modification and maintenance of certain government owned experimental equipment located at the NASA Plum Brook Reactor Facility.

The equipment under consideration was initially designed by Lockheed and installed at the Plum Brook Reactor Facility. It has been used to conduct an experimental program investigating the combined nuclear-cryogenic effects on the mechanical properties of engineering materials authorized by Contract NASw-114.

The work authorized by Contract NAS 3-6210 had two primary objectives:

- The performance of a complete maintenance program to correct equipment deterioration caused by about two years of operation.
- The upgrading of the equipment capabilities through modifications based on two years of operational experience.

The scope of work also included preparation of a reliability evaluation of the equipment based on operational experience; providing assistance to NASA personnel in removal of a gamma shield in the reactor port HB-2 required by the contribution from this shield to tungsten activity in the primary reactor coolant water; and revision of both the equipment operational manual and hazards analysis manual to reflect both equipment modifications and shield removal as well as increased familiarity with the test equipment resultant from two years of actual operation.

1.1 TEST EQUIPMENT

The test equipment reworked and modified under this program was designed to permit tensile testing of miniature test specimens in a high flux zone at HB-2 of the Plum Brook Reactor while maintaining the specimen temperature at any level between 30°R and 540°R. The component systems of the test equipment requiring specific action in this task are:

1. The refrigeration system, a gaseous helium refrigerator used to control test specimen temperature.

2. The test loops, a horizontal 5000 lb. capacity universal type testing machine capable of maintaining a test specimen temperature between 30°R and 540°R.

3. The transfer system, a system of tracks and carriages capable of positioning test loops in the high flux zone of HB-2 or the specimen change location and operating under about 20 feet of water in Quadrant "D" which provides biological shielding during reactor power cycles.

4. The specimen change system, which provides shielding for the operator during test specimen changing in irradiated test loops by means of remote handling techniques.

A brief description of each of these systems, as installed, follows.

1.2 REFRIGERATION SYSTEM

Test location temperature control is provided by a closed cycle helium refrigerator with an electrically driven positive displacement compressor, a counter-flow heat exchanger and four reciprocating expansion engines. The refrigeration system was designed and built for this application and is warranted to be capable of maintaining any temperature between 30°R, and room temperature in the test location of the test loops. The refrigeration system has a rated capacity of 1150 Watts with a manifold temperature of 30°R. A schematic of this system is shown in Figure 1. 1.

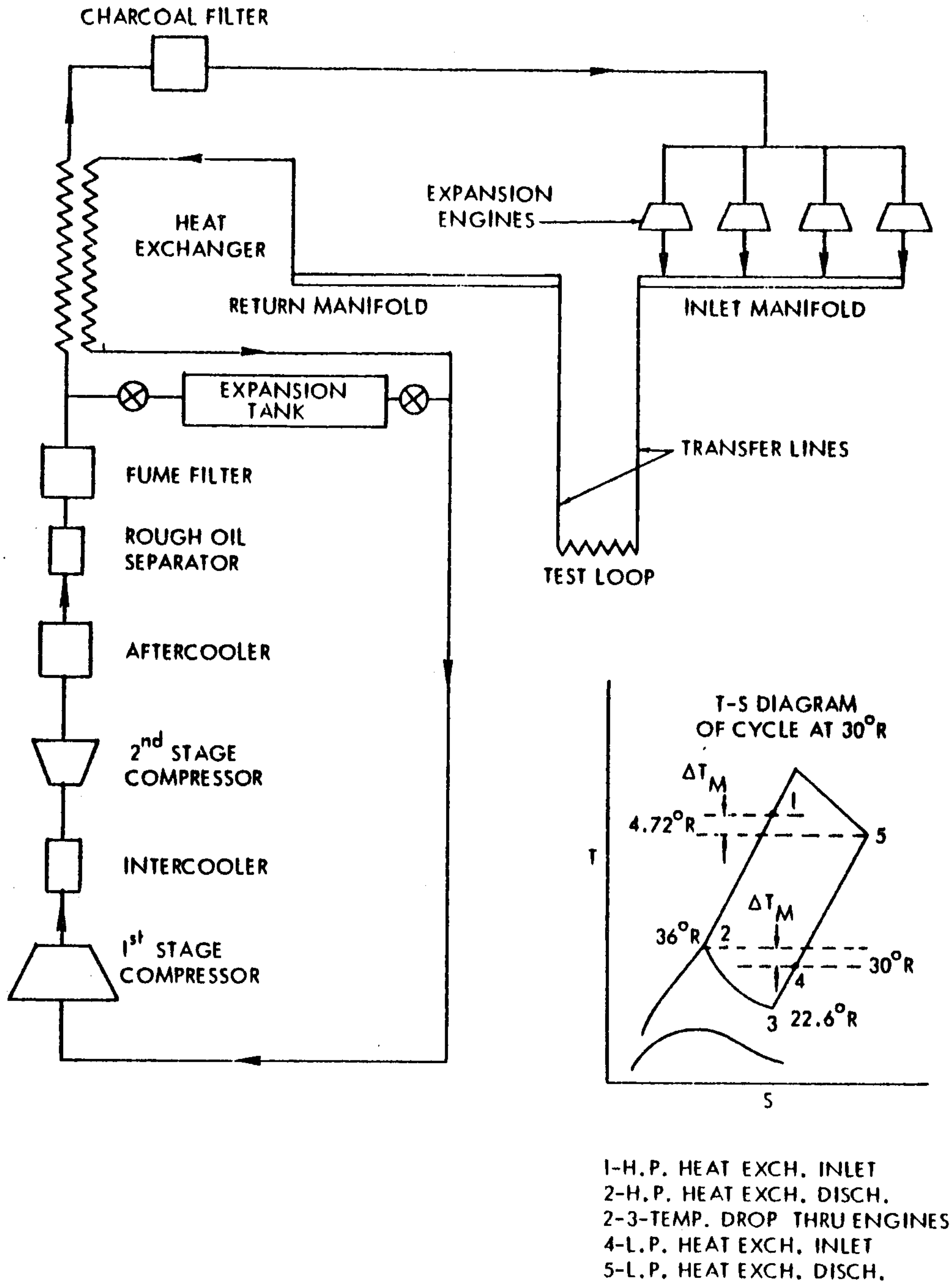


FIGURE 1.1 SCHEMATIC OF SYSTEM

Low pressure ($\approx$50 psia) helium gas is drawn into the suction side of a two stage positive displacement Ingersoll-Rand Compressor and compressed to 300 psia. The heat of compression is removed by water cooling after each compression stage. The helium gas at 300 psia and $\approx$80°F passes through a Trane extended surface counter flow aluminum heat exchanger capable of a 600 lb/hr flow with a duty of 410,000 BTU/hr. With the refrigeration system operating at 30°R, the helium gas leaves the heat exchanger at approximately 37°R and 296 psia. The cold gas enters the expansion engine inlet where it is expanded to $\approx$53 psia in the reciprocating engines. These engines are coupled in pairs to crossheads which drive oil pumps to absorb work from the system. The design specifications for the expansion engines are given below:

Mass Flow (Total)	520 lb/hr
Inlet Temperature	37°R
Outlet Temperature	24°R
Piston Displacement	7.93 ft^3/min
Engine Speed	340 RPM

The heat exchanger and each pair of expansion engines are mounted in evacuated shells filled with powdered perlite to provide insulation.

The refrigerated gas leaving the expansion engines is transferred through vacuum insulated flexible lines to the test location in the tensile-compression test loop. After passing through the test chamber, the gas is returned through a manifold to the low pressure side of the heat exchanger and then back to the compressor suction side. A line heater of 2500 Watt capacity is located in the inlet manifold and each set of transfer lines contains a 100 Watt trim heater to allow operation of the system at any temperature between 30°R and room temperature.

The temperature of the refrigeration system is controlled by two platinum resistance thermometers in each set of transfer lines in the manifold. One sensor is located at the inlet line and one at the return leg.

1.3 TEST LOOPS, TENSILE AND COMPRESSION

The irradiation of specimens using this test equipment in conjunction with the Plum Brook Reactor requires protracted exposures in a high flux zone of the operating reactor with the specimen temperature maintained at the temperature of interest. The irradiations are conducted in a test location adjacent to the beryllium reflector on the north face of the reactor core. Access to this zone is through a 9 in. ID horizontal beam port (HB-2) located approximately 20 feet below the surface of a pool of demineralized water which provides biological shielding during reactor operations. The beam port, which penetrates a high density concrete biological shield two feet thick, the stainless steel pressure vessel and thermal shield, is approximately seven feet in length from its external flange to the high flux test zone. However, the full ID of HB-2 is not available as a test zone as the presence of a gamma shield limits the internal dimensions of the beam port to 6" x ≈6 1/2'.

A special test loop contains a horizontally placed 5000 lb capacity tensile testing machine together with the requisite stress-strain monitoring instrumentation and vacuum insulated refrigerant transfer lines in a 6" OD tubular housing of sufficient length to place the test location in the high flux zone. This test loop is shown in Figure 1.2.

The cryogenic test zone is located at the forward end of the loop. This zone is contained in a removable head with a vacuum insulated annular space between the test zone and the external surface of the head.

The test load is applied to the specimen by a hydraulic cylinder operating through a linkage to a bellows protected actuator rod threaded to the aft specimen holder. The hydraulic fluid is demineralized water. Stress is monitored by a ring type dynamometer with a water-proofed Linear Variable Differential Transformer (LVDT) acting as the deflection sensing unit.

Stainless steel instrument tubes run the length of the test loop to provide protection for leads to non-nuclear instrumentation of a removable nature, such as extensometer, dynamometer and thermocouples.

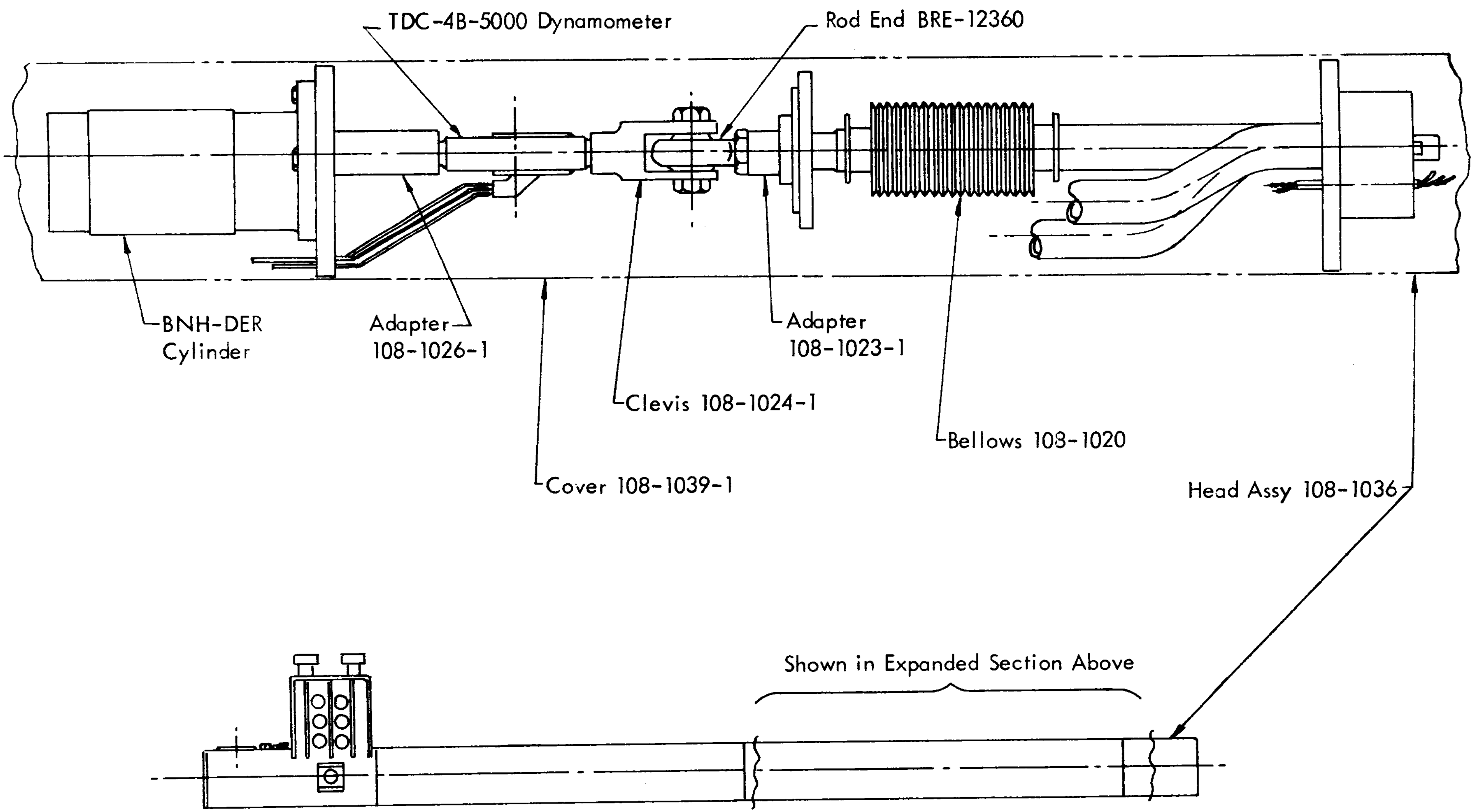


FIGURE 1.2 TENSILE TEST LOOP ASSEMBLY 108-1015

1.4 TRANSFER SYSTEM

To permit insertion and withdrawal of the test loops at the beam port and the hot cave, independently of reactor operations, a special transfer system was installed in Quadrant "D" of the Plum Brook Reactor Facility. The location of this system with respect to the reactor beam port HB-2 and the specimen change hot cave is shown in Figure 1.3. All of the transfer equipment operates under some 20 feet of quadrant water.

The transfer system includes two base tables, fastened to the floor of Quadrant "D", on which are located translating tables capable of movement in the east-west direction. On each of the translating tables there are three sets of tracks on which specially designed carriages travel to transfer the test loops to the desired location. The lateral east-west translation of the transfer tables allows the positioning of any track in proper alignment with the beam port or the hot cave for insertion of the test loop. The north table, associated with the hot cave, has the additional capability of rotation through 180° to enable insertion of the forward end of the test loop into the hot cave. The actuating force for this translation and rotation is provided by a 10HP hydraulic pump, using demineralized water as the working fluid. Mechanical stops are situated at the limits of table travel and movable mechanical stops are so located to insure accurate positioning of the tracks for beam port and hot cave insertion of the test loop.

Each of the carriages which hold the test loops travels on six pairs of grooved wheels on the table tracks. They are moved on the tables by a hydraulically operated rack and pinion gear driven by the 10HP pump. By suitable manipulation, the carriage may be placed on any track of the tables and positioned in front of either the beam port or the hot cave. Limit switches located on the tables are tripped by actuators on the carriages and indicate carriage locations on the tables by means of lights on the control console. Mechanical stops limit carriage travel on the tables.

After a carriage is positioned at the beam port or hot cave, it is advanced and coupled in place. Both the beam port and the hot cave port are protected by 6" gate type valves. On the quadrant side of each valve there is a chevron seal to prevent water flow past the loop during operation. The valves are interlocked with limit switches to prevent opening unless the test loop is in position in the chevron seal to block flow. After coupling the carriage to

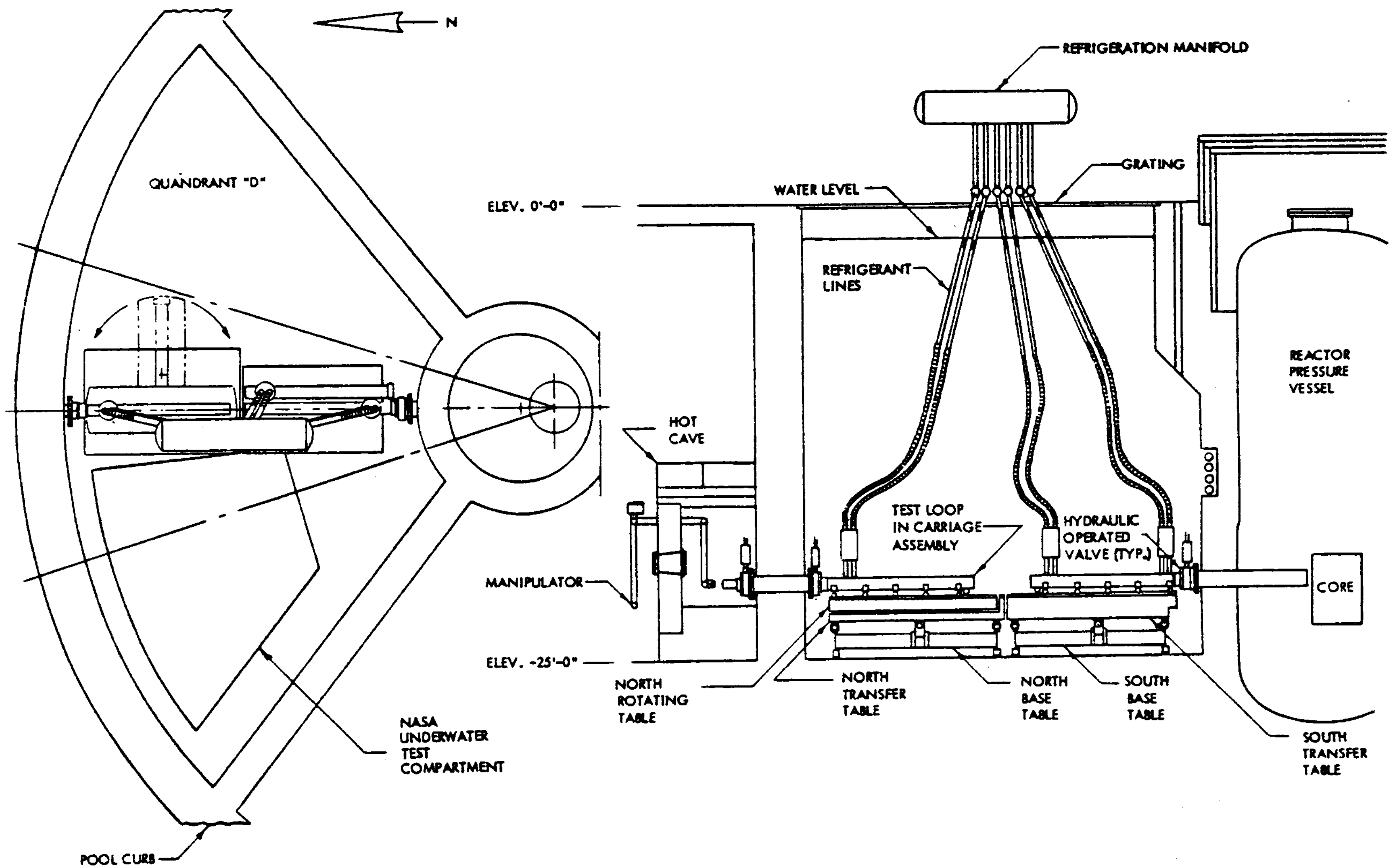


FIGURE 1.3 SAMPLE CHANGE SYSTEM

either valve, the loop is advanced into the beam port or hot cave by a high torque hydraulic motor driven by the 10HP pump. The torque is translated from the motor shaft to a lead screw through a worm-worm gear connection. This lead screw is coupled to a yoke assembly on the carriage which supports the aft end of the test loop. As the lead screw advances the test loop, limit switches on the carriage indicate the loop position by lights on the control panel. An adjustable mechanical stop precludes the possibility of inserting the loop into HB-2 to a point which will restrict the coolant passage between the forward end of the loop and the gamma shield plug. The test loop drive system, during an insertion into the beam port, must overcome a primary coolant pressure of 125 psi and systematic frictions. This requires a thrust force of over 4000 lbs.

Limit switches and mechanical stops have been installed at all places necessary to insure safe operation of the transfer system.

Control of the transfer system is accomplished by the use of solenoid valves, using demineralized water as the actuating fluid, located in a control panel located on the grating over Quadrant "D".

1.5 SAMPLE CHANGE EQUIPMENT

To perform the requisite in-pile tests with a maximum utilization of reactor time, equipment was designed and installed to allow the replacement of a specimen in one test loop during the irradiation of a second specimen in a different test loop. Due to the high activity level of the test loops after several in-pile exposures, this specimen change, as well as routine loop maintenance, was accomplished using remote techniques.

To provide operator shielding during work on the test loops, a hot cave was constructed of high density concrete and lead-filled steel outside of the wall of Quadrant "D" with an access port for the test loop on a radial line with HB-2. This hot cave was equipped with Central Research Laboratory Model 8 Manipulators and specially designed remote handling tools to permit test specimen change and minor loop maintenance. See Figure 1.4.

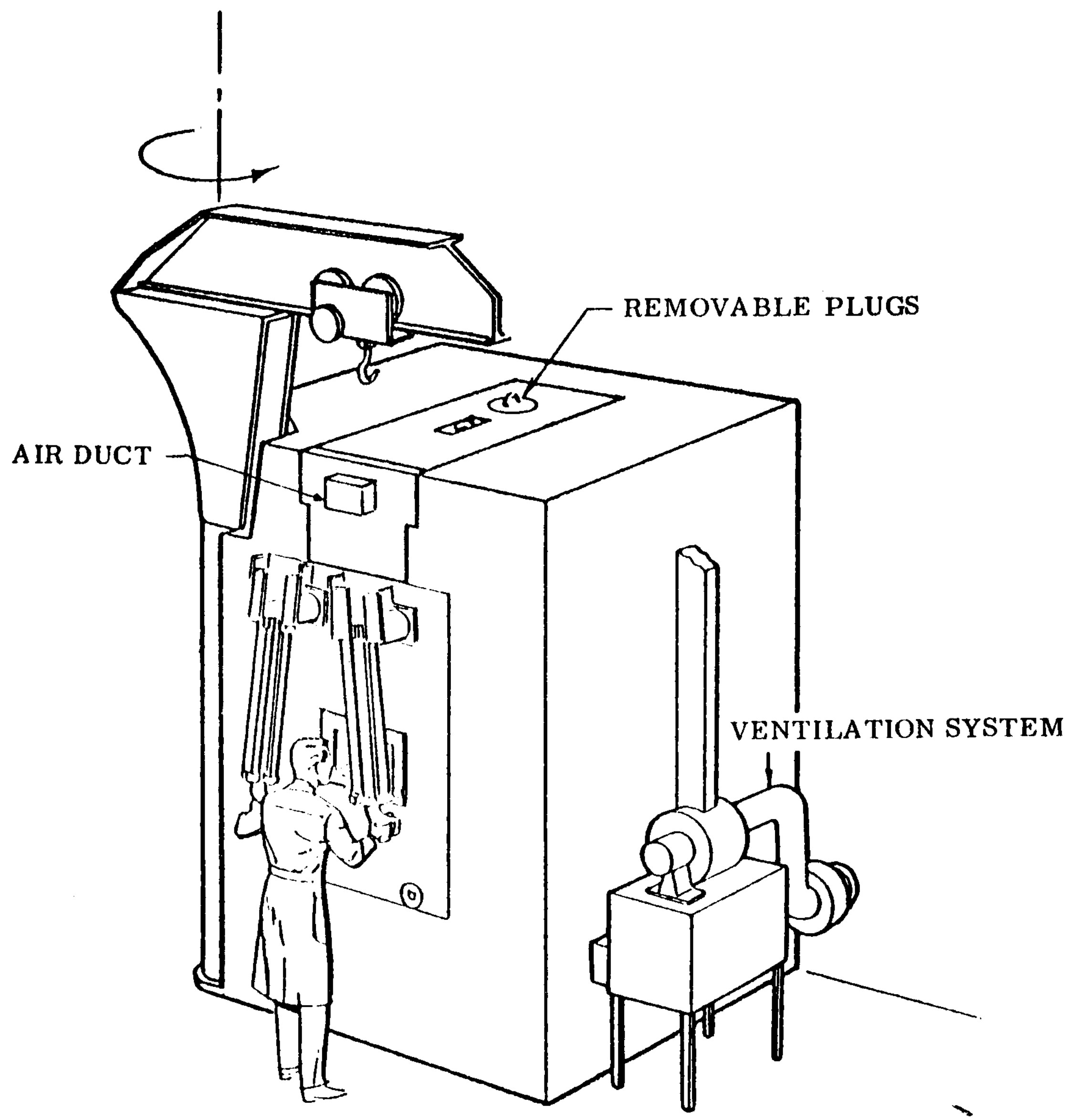


FIGURE 1.4 HOT CAVE - OVERALL VIEW

2 REFRIGERATION MODIFICATION AND OVERHAUL

The following description of the various modifications and maintenances performed on the refrigerator are presented to sequentially conform with the requirements defined in the scope of work and not in the order they were performed. The various tasks were scheduled to utilize personnel and equipment in an effective maintenance program compatible with contract requirements. The resulting modification, maintenance and calibration is described together with the evaluation test results.

2.1 MODIFICATION OF EXTENDED STEM VALVES

These valves are installed as shut-off or isolation valves in the refrigerator manifold system and in the heat exchanger pod. They are normally used when isolation of an engine pod is required and when opening a test loop to replace a test specimen when the refrigerator is operating.

Evidence of gross leakage through these valves has been assimilated during previous testing cycles and effort to eliminate the leakage by installing Arthur D. Little, Inc., replacement parts has been without definitive results. The apparent difficulty in obtaining a positive seal was due to the combination of a rotating stem poppet assembly and the threaded replaceable seat. When leakage occurred at low temperatures the poppet tended to freeze to the seat causing it to back-out of its threaded position.

A number of different modifications to these valves have been considered and it was concluded that a non-rotating stem and relatively soft seat offered the most promising solution.

The valves, shown in Figure 2.1, numbers 18, 20 and 22 in the inlet manifold; 17, 19 and 21 in the outlet manifold; 12, 13, 14 and 15 in the heat exchanger to isolate the expansion engine pods; and 11, also positioned in the heat exchanger enclosure to isolate the manifold, were removed for modification.

The valve poppet, seat and stem were re-designed to incorporate the desired modifications. The originally installed valve concept is shown in Figure 2.2. This valve required rotation of the extended stem which was a relatively thin walled tube (1.50 in. diam. x .035 in. thick wall) which had been filled

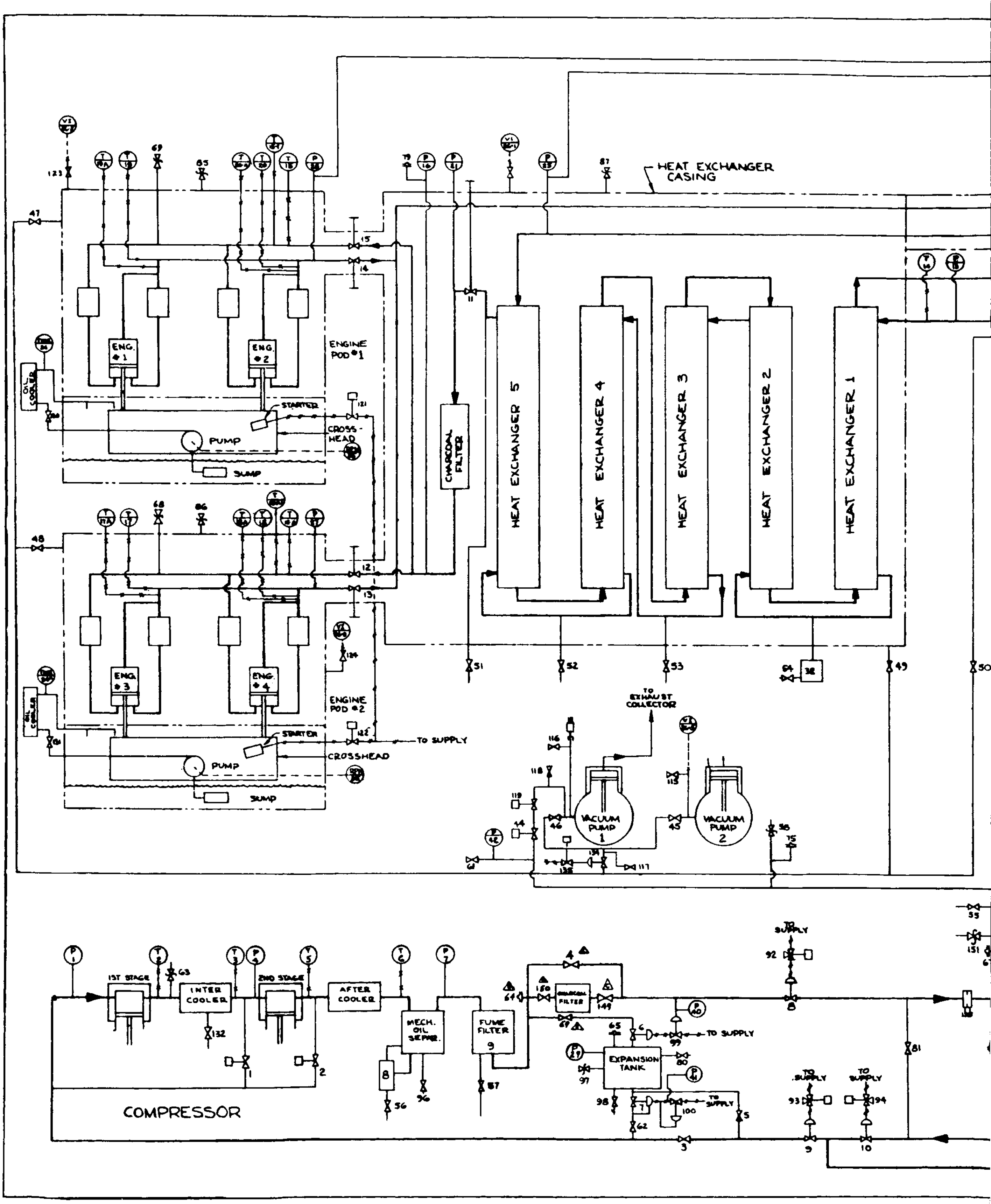
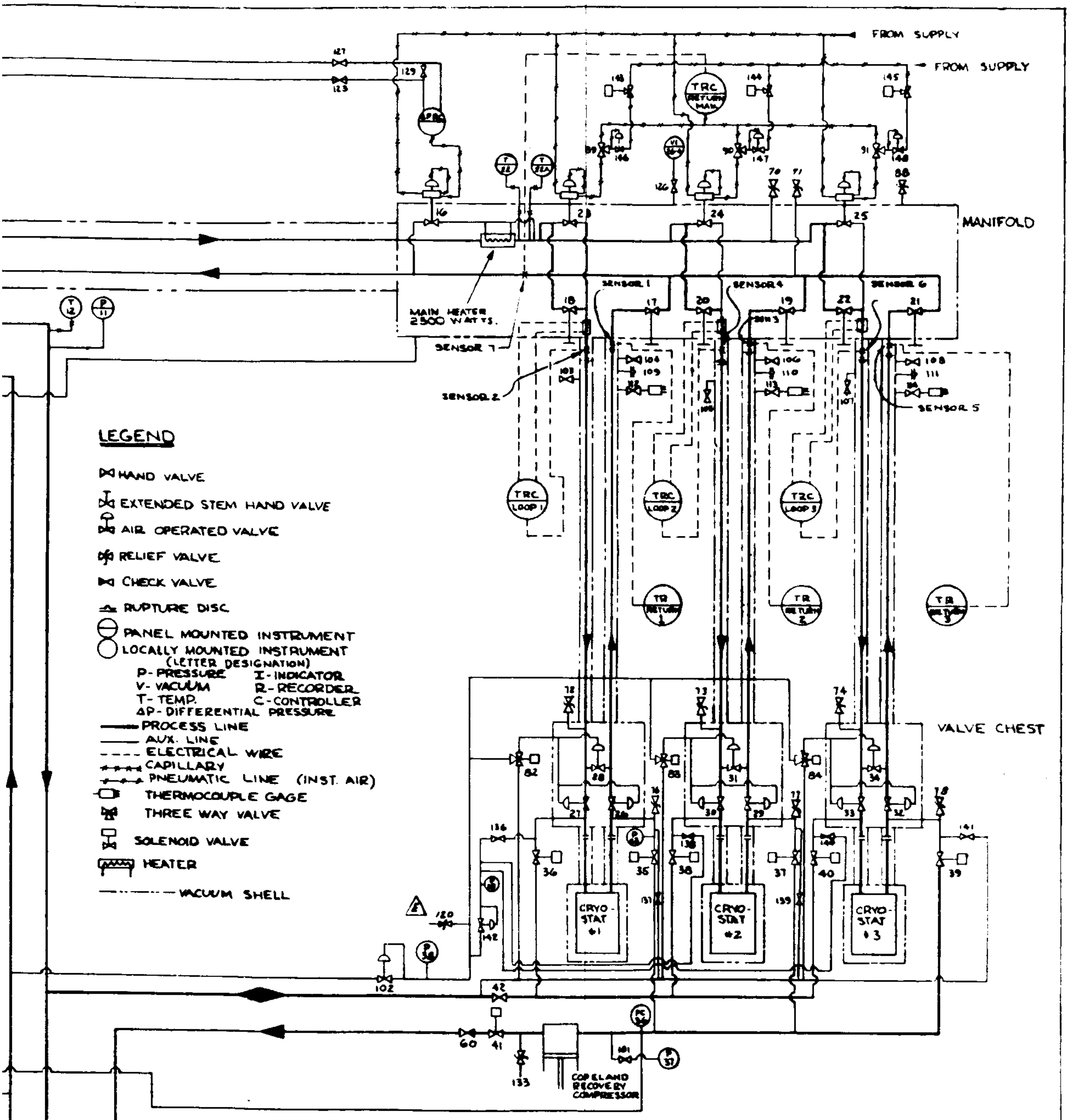


FIGURE 2.1 REFRIGERATOR SYST



NOTES

1. FOR DESCRIPTION OF REFRIGERATOR COMPONENTS SEE TABLE 3 OF DESIGN MANUAL HAZARDS ANALYSIS.
2. " " " INSTRUMENTATION " " 2 OF OPERATION & MAINTENANCE MANUAL
3. " " " CONTROLS " " 5 OF DESIGN MANUAL HAZARDS ANALYSIS
4. " " " VALVES " " 6 OF APPENDIX A OPER. & MAINT. MANUAL
5. FOR COOLING WATER PIPING SEE FIG. 19 OF OPERATION MANUAL.
6. FOR ELECTRICAL WIRING SEE FIG. 18 OF OPERATION MANUAL.

M FLOW SCHEMATIC

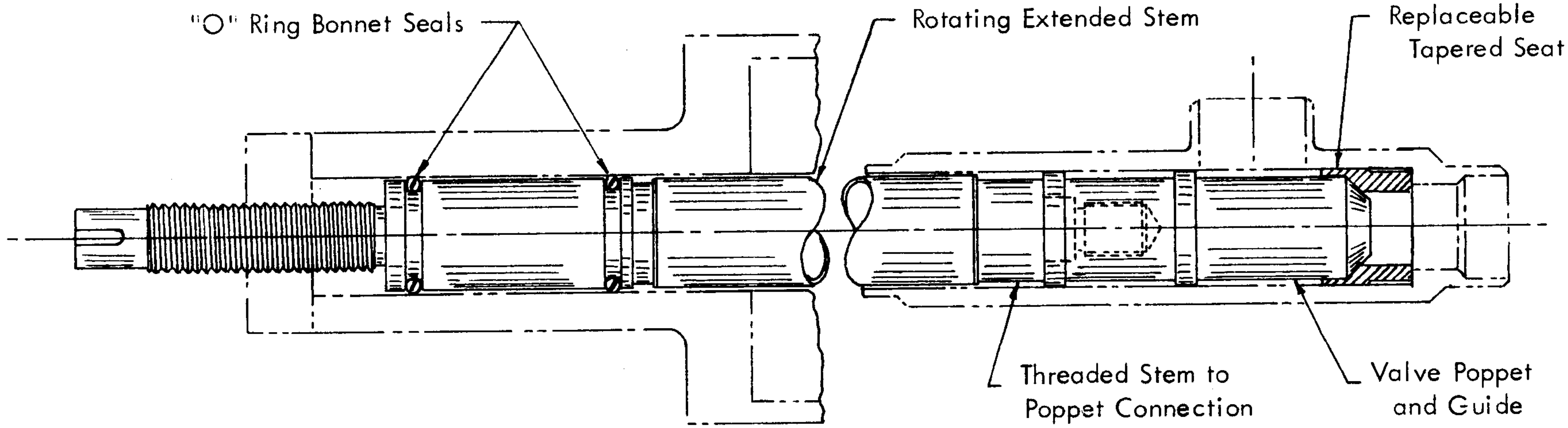


FIGURE 2.2 ORIGINAL EXTENDED STEM VALVE INSTALLATION

with a foamed-in-place material inside the tube to eliminate natural convective heat transfer in the interior of the tube. To permit removal of valve numbers 12, 13, 14 and 15 installed in the heat exchanger, the tubular stems were cut. The latter was an alternative to removing the expansion engine pods to provide the required clearance for removal. This was done after methods for fabricating valves for re-installation had been considered. The design concept required the application of a pinned joint in the center of the stem. An analysis indicated the pinned joint did not contribute appreciably to the conductive heat path and it was considered feasible.

The valve modification concept is shown in Figure 2.3. To incorporate the non-rotating stem concept the valve was modified by providing a threaded actuator isolated from the stem and a keyway between the bonnet "O" ring seals to prevent rotation of the stem when the valve is opened or closed. The seat was also modified to permit the application of a flat Teflon poppet seal. This seal can be replaced, as required, when the refrigerator is not operating.

All the components for this modification were fabricated during the contract period. They were then assembled and the tubular stems were filled with a foamed-in-place closed cell polyurethane. The valves were then installed in the refrigerator system and tested at 30°R to assure positive isolation of the various elements in the system. This test was conducted by opening and closing a pair of the valves in the manifold one hundred times and observing the temperature sensors in the transfer lines to determine if any leakage of cold gas existed. No leakage was evident during these tests. The valve assemblies involved in the test were then disassembled and checked for evidence of damage or wear. No deterioration of any component was apparent so the valves were reassembled with new Teflon seats and reinstalled in the manifold.

2.2 MODIFICATION OF THE REFRIGERATOR COMPRESSOR LUBRICATING OIL REMOVAL SYSTEM

The application of a modified air compressor to the helium refrigeration system required the use of standard compressor lubricating techniques for the cylinders

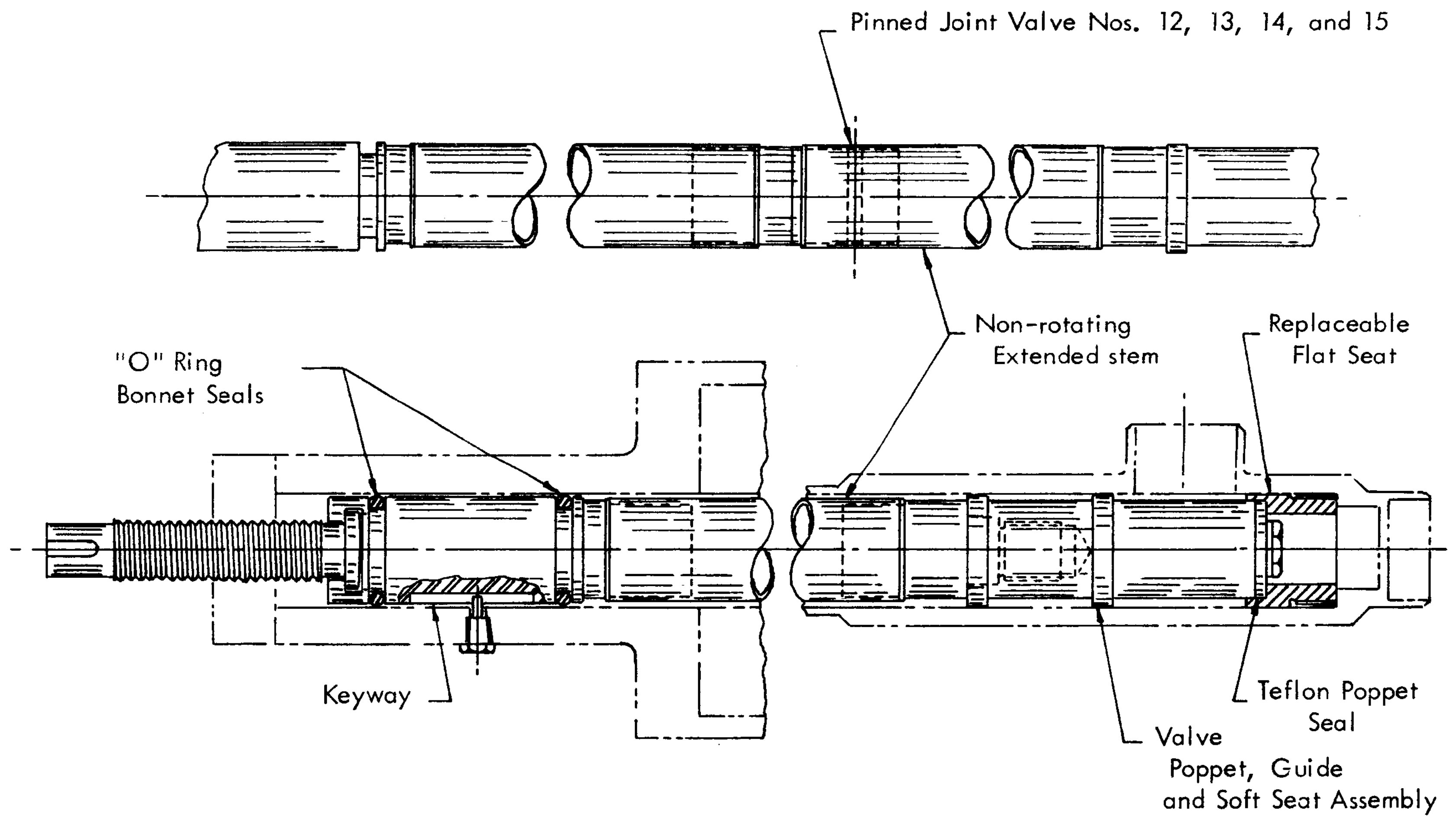


FIGURE 2.3 MODIFIED EXTENDED STEM VALVE INSTALLATION

and valves and a pressurized lubricating system for the hydrodynamic bearings in the isolated crankcase enclosure of the compressor. The latter contributes negligible quantities of oil to the high pressure helium and was therefore not considered in the modification. The former does, however, introduce significant quantities of oil into the effluent stream of high pressure helium, which must be removed to prevent a build-up in the low temperature regions of the refrigerator.

Originally when the system was designed, the compressor lubrication requirements for the pistons and valves were established at 0.10 lbs/hr which is introduced by a positive displacement type lubricator system which distributes it to the pistons. The carry-over was to be removed by the interstage traps and an agglomerator, fume filter, charcoal filter combination positioned downstream of the aftercooler shown in Figure 2.4.

In addition, the migration of compressor lubricating oil was anticipated and provisions were incorporated into the system to permit removal of the oil collected on the heat exchanger surfaces. The removal is accomplished by isolating the heat exchanger from the remaining system and connecting a Freon solvent circulating loop to designated connections. Any oil that may be present on the heat exchanger surface is highly miscible in this Freon solvent and as such is carried with the solvent into the supply container.

The procedure for cleaning the heat exchanger surfaces appears quite straightforward requiring a minimum Freon purging time of three hours, and approximately twelve hours for the initial set-up and subsequent refrigerator helium purge. However, it has proven in practice to be difficult to completely purge the Freon from the system thus causing freeze-out in the expansion engines when the refrigerator is operating.

Any extension of the operating time between oil removal will reduce this possibility which entails the removal of the engines for cleaning.

In addition, the solvent is a relatively high cost item and it is self-evident that the extension of operating time between oil removal will reduce this cost.

After initial evidence of oil in the heat exchanger, as shown by increased pressure differential and reduction in heat transfer, effort to determine the effectiveness of the various oil removal units was undertaken. It was concluded that the agglomerator was not performing its design function of removing 96% of the oil carry-over. As a result an alternate method of sealing the base of the filter units was incorporated, with insignificant results, and subsequently the porous filter elements were replaced with a fiberglass element which only slightly improved the performance of the unit.

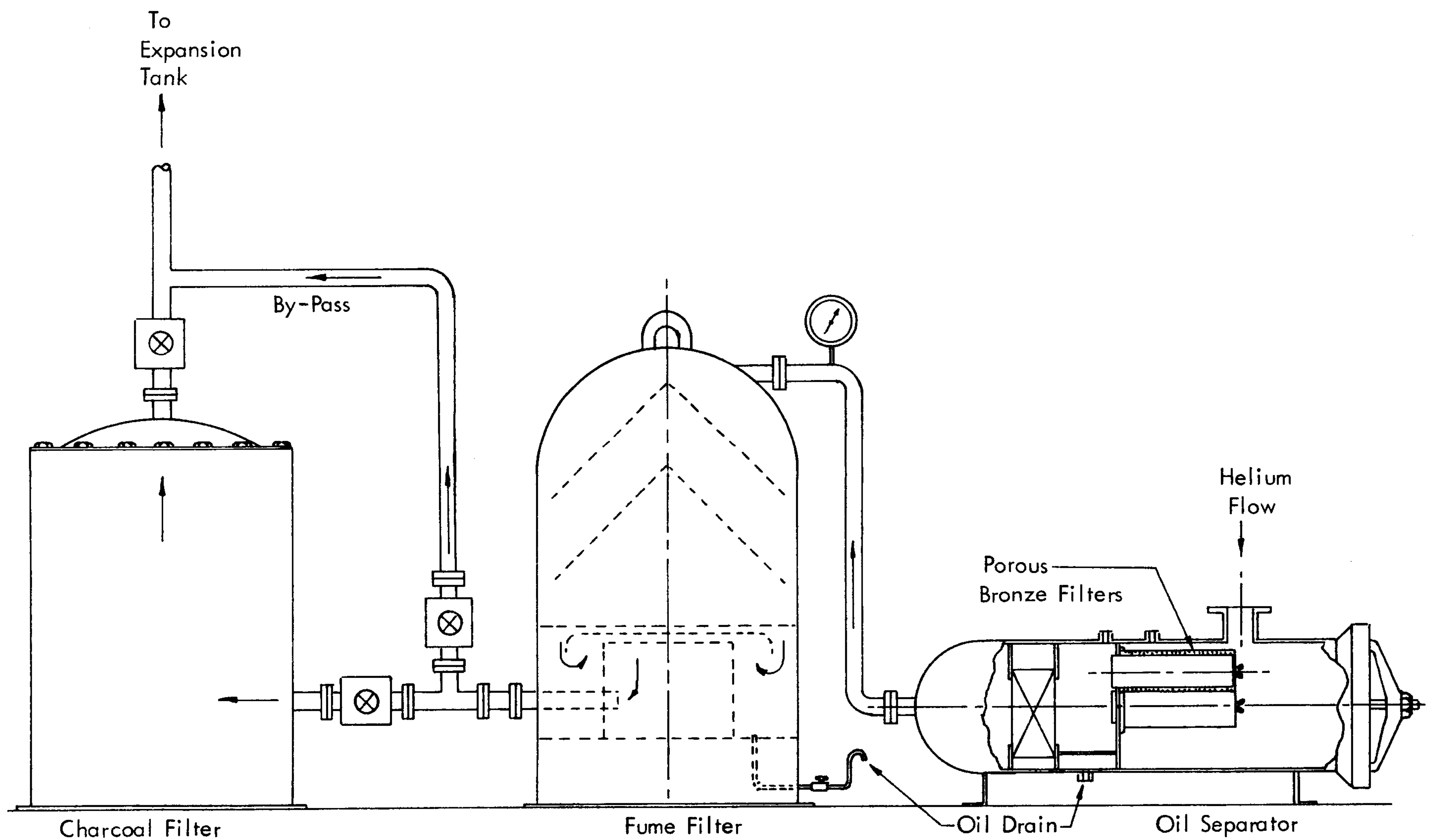


FIGURE 2.4 COMPRESSOR OIL REMOVAL SYSTEM ORIGINAL INSTALLATION

Various filter manufacturers were solicited in an effort to obtain a more adequate oil removal equipment with again, only limited results. Following this, a determination of the helium velocity in the unit was made which indicated that maximum stream velocity existed where the lubricating oil was intended to collect indicating that a modification to alleviate this condition was a requisite to improve its performance.

To accomplish this, the unit, as installed, was disassembled and a large diameter filter assembly was designed and incorporated into the unit. (See Figure 2.5). Some of the features included were redirecting the flow over an inlet baffle to preclude previously existing flow impingement on the filter elements and the routing of the flow through four large diameter fiberglass filter elements which are in series with each other.

The results of the modification were then evaluated by operating the compressor in a closed loop system with the expansion tank and obtaining volumetric measure of the oil collected in the system. The oil removed was in excess by an order of magnitude of that removed by any previous modification, and the unit removed approximately 90% of the oil collected in all the oil removal system.

This increase in oil removal in the agglomerator decreases the oil removal requirement of the fume filter quite drastically thus enabling it to operate more efficiently. This, in turn, reduces the amount of carryover oil into the heat exchanger.

The improvement, though significant, still does not meet the 96% removal criteria established in the system design, but the substantial increase in oil removal by the agglomerator indicates the operating time between freon purging of the system will be extended appreciably.

2.3 REFRIGERATOR ENGINE POD EQUIPMENT

The overhaul of the refrigeration equipment contained in the engine pods was initiated early in the maintenance program. The disassembly and inspection was scheduled to coincide with a pre-established visit of representatives from Arthur D. Little, Inc. They observed the disassembly and inspection phase of the maintenance.

2.3.1 Overhaul of the Refrigerator Crosshead Assemblies

The crosshead assemblies are positioned in the bottom of the engine pods and connected to the engines by tensile rods for the valves and pistons. The crossheads convert the linear motion of the pistons to a rotary motion which is used to operate a gear type oil pump to dissipate the engine work. The shaft connected to the pump also has provision for the inlet and exhaust valve cam installation. The stuffing boxes incorporated in the

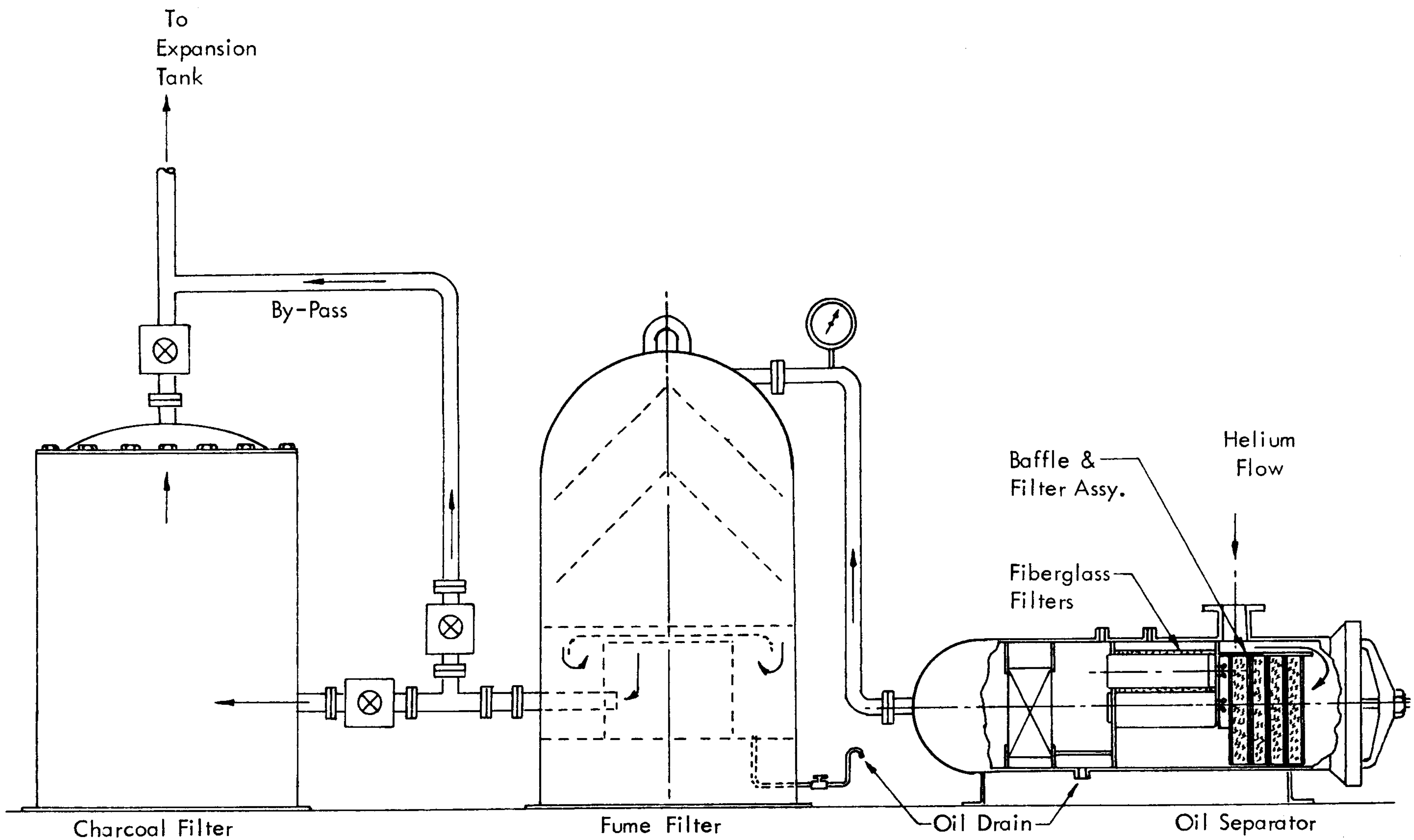


FIGURE 2.5 COMPRESSOR OIL REMOVAL SYSTEM MODIFIED INSTALLATION

top of the crosshead assembly seal the crankcase from the helium flow through the engines.

Two expansion engines are connected to each crosshead to minimize equipment size and operational problems as well as minimize pulsations in the gas pressure. The piston of each engine is connected to a slipper which in turn actuates a connecting rod attached to the shaft rotary eccentric. The possibility of this slipper introducing non-aligned loading into the piston rod was considered as a possible cause of the short operating life of the piston rods.

The crossheads were removed, disassembled and significant dimensions checked against the drawing requirements. The comparison of these dimensions did not indicate that significant wear had occurred; however, there were indications that the clamping arrangement for the piston rod in the slipper could cause substantial misalignment when transmitting the load from the piston rod into the slipper. By modifying the clamp to eliminate the evident misalignment, good alignment was obtained. Subsequently, the clamps were modified for all the engines, the stuffing boxes were rebuilt and the crossheads reassembled.

2.3.2 Overhaul of the Expansion Engines

The four expansion engines in pod nos. 1 and 2 were removed and completely disassembled. A dimensional inspection of all engine components that are subject to wear was made and there were no components which exceeded the dimensional operating tolerances.

Each component was then individually inspected for evidence of wear which would not necessarily be evident in the dimensional inspection and the valve tensile rods were straightened to assure alignment. Distance pieces were inspected to determine perpendicularity and the piston gas seal, which is a labrinth type, was inspected. In all instances, the components were within operating tolerances. The "O" ring seal grooves were inspected and polished and the rod sheaths were inspected to establish their serviceability. After determining that all of these components were in satisfactory operating condition, the engines were reassembled with new piston rods and gaskets being installed. The new rods were installed due to evidence of wear at the slipper connection of the existing rods. Careful leak testing was performed for a period of eight hours on each engine. This was accomplished by submerging the engine in water and imposing helium pressure on all engine cavities that would normally require pressure integrity during operation. When this test established pressure integrity of each of the engines, they were removed from the tank, dried and reinstalled in the engine pods.

Operation of the engines during component testing and subsequently during the calorimeter tests indicated that performance was in conformance with the refrigerator operating characteristics.

2.4 CALIBRATION OF REFRIGERATOR TEMPERATURE AND PRESSURE GAUGES

The calibration of the temperature and pressure gauges in the refrigerator console were checked so that the temperatures can be ascertained for trouble shooting purposes.

2.4.1 Description of Temperature Gauges

The temperature sensors are of the gas thermometer type. Such thermometers operate on the principal that under conditions where Charles' law is valid, the temperature of a measured quantity of gas can be deduced from the measured gas pressure. The thermometers under discussion consist of a precision Bourdon gauge to which a gas filled bulb is connected by means of a capillary tube. The system is filled at a known temperature with a gas at a certain pressure, depending on the desired range for the gauge, and is then sealed off. The gauge is then calibrated at temperature check points other than that at which it was filled. The thermometers are helium filled Foxboro Class IIIB in two ranges, 0-300°R and 0-600°R, with 5 in. indicator dials and were furnished by the Foxboro Company, Foxboro, Massachusetts. The 0-600°R gauges are equipped with double electric contact attachments for sounding an alarm if the temperature decreases or increases beyond certain limits during refrigerator operation.

2.4.1.1 Location and Use

Table 1 gives the locations of the gas thermometers which were checked. The location point numbers are shown in Figure 2.1. In general, the

TABLE 1

REFRIGERATOR TEMPERATURE GAUGE LOCATIONS

POINT *	LOCATION	RANGE (°R)	ALARM CONTACTS**
15	Inlet, Engines #1 & #2	0-600	Yes
15-1	Inlet, Engines #1 & #2	0-300	No
15 A	Inlet, Engines #3 & #4	0-600	Yes
15 A-1	Inlet, Engines #3 & #4	0-300	No
17	Exhaust, Engine #3	0-600	Yes
17 A	Exhaust, Engine #3	0-300	No
18	Exhaust, Engine #4	0-600	Yes
18 A	Exhaust, Engine #4	0-300	No
19	Exhaust, Engine #1	0-600	Yes
19 A	Exhaust, Engine #1	0-300	No
20	Exhaust, Engine #2	0-600	Yes
20 A	Exhaust, Engine #2	0-300	No

* See Figure 2.1

** Not used during normal operation

thermometer bulbs are placed in a well in the center of the refrigerant flow at the locations indicated with approximately 20 feet of capillary to the indicating gauge on the control panel.

A small temperature differential across an engine may indicate leakage of helium past either the intake or exhaust valves or across the piston to the low pressure side and will result in inability to obtain design conditions.

A small temperature differential with normal gas pressures may be accompanied by slow engines and will indicate excessive friction, possibly due to frozen impurities or metal particles in the helium refrigerant.

A sudden loss of temperature differential may indicate a malfunction in the valve assembly such as a broken spring or separated valve mount and rod.

2.4.1.2 Purpose of Calibration Check

The gas thermometers in this system are not used to monitor primary temperatures such as test specimen temperatures. They are, however, used as a means of monitoring the condition of components such as the expansion engines. While their response time is slow they are still an acceptable method of obtaining approximate temperatures. Past experience had indicated occasional erratic action as well as longer than normal response times and in one specific instance, an apparent erroneous reading.

Under the best conditions gas thermometers can develop leaks over extended periods of operation which would result in atmospheric gases entering the bulbs at low temperatures and thus changing the calibrations. In this application, there is also the possibility of physical damage to the extended capillary and to the gauge with the possibility of wear in the gauge linkage. In the gauges with electric contacts, there is the possibility of damage to the contacts, particularly to the contact arms during adjustment.

2.4.1.3 Procedure and Results

The bulbs on the 12 thermometers which were checked were removed from their operating positions and submerged in LN_2 and allowed to reach equilibrium while the temperature indicated at the gauge was noted. Except for the 0-300°R thermometer at the exhaust position of engine number 2, all of the thermometers read within 5°R of the set point temperature (139.5°R). The errors appeared to be random and were attributed to wear in the gauge linkages rather than to leakage. These thermometers were re-set as closely as possible to the set point by adjusting the gauge needle rather than re-evacuating and filling.

The electric contact points of the 0-600°R gauges were checked and found to be operative.

The 0-300°R thermometer at the exhaust of number 2 engine showed a full scale reading when submerged in LN_2 so it was evacuated and leak tested. There appeared to be a leak but it could not be located on the accessible portion of the thermometer system. The thermometer was filled with helium at LN_2 temperature to a pressure corresponding to this set point on the gauge and sealed off. Its' performance gradually deteriorated and it was concluded that leaks existed in the portion of the capillary which is not readily accessible. Since this gauge functions mostly in a redundant capacity, its repair and the attainment of the original read-out capability of the system would not justify the major effort that would be involved and the gauge has been marked "inoperative".

2.4.2 Calibration of Refrigerator Pressure Gauges

The pressure gauges in the refrigerator system are of the Bourdon tube type. Where the gauges are used to measure the pressure in the low temperature gas stream the pressure tap is positioned to provide a sufficient length of tubing to the gauge thus precluding the low temperature effects on the gauge. The gauges calibrated are mounted in the refrigerator operating panel and at appropriate locations in the compressor building.

The gauges were calibrated by connecting the gauge to a pressure chamber which included a calibrated (Heise) gauge, and comparing incremental pressure increases with those on the test gauge. The results indicate the percent error for the full-range of each gauge tested, and are shown in Table 2.

TABLE 2

REFRIGERATOR PRESSURE GAUGES LOCATION AND CALIBRATION

Point*	Instrument	Range	Purpose	Full Scale Calibration-Percent Error
1	Pressure Gauge	0-200 psi	Measures compressor suction pressure	1.0 %
4	Pressure Gauge	0-200 psi	Measures second stage compressor suction pressure	0.25 %
7	Pressure Gauge	0-400 psi	Measures second stage compressor discharge pressure	0.5 %
11	Pressure Gauge	0-200 psi	Measures compressor suction pressure	0.0 %
13	Pressure Gauge	0-400 psi	Measures compressor discharge pressure	0.6 %
16	Pressure Gauge	0-400 psi	Measures inlet gas pressure to all expansion engines	0.6 %
21	Pressure Gauge	0-400 psi	Measures inlet pressure to charcoal filter	0.29 %
25	Pressure Gauge	0-200 psi	Measures heat exchanger (cold end) gas return pressure	0.57 %
27	Pressure Gauge	0-200 psi	Measures exhaust gas pressure from #3 & #4 expansion engines	1.0 %
28	Pressure Gauge	0-200 psi	Measures exhaust gas pressure from #1 & #2 engines	0.0 %

* See Figure 2.1

2.5 PRESSURE TESTING AND VERIFICATION OF PRESSURE RELIEVING DEVICES

Pressure relieving devices are incorporated into the refrigerator system to prevent excessive pressures in any segment of the system. The relief valves are, in general, of the spring loaded type and are pre-set to open when the pressure exceeds the set value; however, those protecting the vacuum insulating spaces are closed and sealed by atmospheric pressure and will open when the internal pressure is sufficient to overcome the weight of the poppet.

Several valves are supplemented by rupture discs which are essentially a thin metal diaphragm which is designed to fail at a pressure well below the pressure of the weakest component in the system it protects. The discs are incorporated into the system where cold gas may be trapped which can warm-up and cause excessive pressure and, as indicated, they are used as a positive pressure relieving device in parallel with the relief valves. This arrangement has been incorporated into the system where the failure of the relief valve would permit pressure to exceed the rupture pressure of components.

2.5.1 Pressure Relief Valves

Tables 3 a, 3 b and 3 c list the pressure relief valves that were removed from the system and tested to establish if the cracking pressure was as prescribed. Each valve was connected to a regulated nitrogen gas pressure source with suitable adapters and the pressure was then increased until the valve opened. This pressure was then recorded as the cracking pressure in the table.

2.5.2 Rupture Discs

The rupture discs were inspected in an effort to determine if the discs had sustained excessive strain which implies incipient failure. If the latter condition was evident the discs were replaced; all others were considered satisfactory.

2.6 MODIFICATION OF REFRIGERATOR RESISTANCE THERMOMETER INSTALLATION

The six primary temperature sensing devices (Figure 2.1), platinum resistance thermometers,

TABLE 3 a

PRESSURE RELIEVING DEVICES - LOCATION AND TEST PRESSURE

Valve No.	Purpose	Type	Size	Location	Pressure Setting	Test Cracking Pressure	Remarks
58	System Evacuation Piping Warm-Up Protection	Relief Valve	3/4" IPS	CV* 0+00 Level	65 psia	67 psia	
75	Auxilliary to Valve 58	Rupture Disc	1/2" IPS	CV* 0+00 Level	75 psia	Insp. (ok)	
63	Compressor 1st Stage Helium Pressure Relief	Relief Valve	1 1/4" IPS	Compressor Building	165 psia	167 psia	
64	Compressor Charcoal Filter Upstream Press. Safety Disc	Rupture Disc	1" IPS	Compressor Building	365 psia	Insp. (ok)	
97	Helium Expansion Tank Pressure Relief	Relief Valve	1" IPS	Compressor Building	345 psia	350 psia	
65	Auxilliary to Valve 97	Rupture Disc	1" IPS	Compressor Building	375 psia	Insp. (ok)	
151	Helium Inlet Piping Warm-Up Protection	Relief Valve	1" IPS	CV* 0+00 Level	345 psia	348 psia	
67	Auxilliary to Valve 151	Rupture Disc	1/2" IPS	CV* 0+00 Level	365 psia	Insp. (ok)	
66	Helium Return Piping Warm-Up Protection	Rupture Disc	1" IPS	CV* 0+00 Level	200 psia	Insp. (ok)	
68	Expansion Engine Helium Inlet Pressure Relief Pod #1	Relief Valve	1/2" IPS	CV* 0+00 Level	365 psia	365 psia	

* CV - Containment Vessel

TABLE 3 b

PRESSURE RELIEVING DEVICES - LOCATION AND TEST PRESSURE

Valve No.	Purpose	Type	Size	Location	Pressure Setting	Test Cracking Pressure	Remarks
69	Expansion Engine Helium Inlet Pressure Relief Pod #2	Relief Valve	1/2" IPS	CV* 0+00 Level	365 psia	365 psia	
70	Helium Inlet Manifold Header Pressure Relief	Relief Valve	1/2" IPS	CV* 0+00 Level	75 psia	77 psia	
71	Helium Return Manifold Header Pressure Relief	Relief Valve	1/2" IPS	CV* 0+00 Level	75 psia	76 psia	
72	Inlet Transfer Line #1 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	75 psia	70 psia	
73	Inlet Transfer Line #2 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	75 psia	70 psia	
74	Inlet Transfer Line #3 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	75 psia	78 psia	
76	Cryostat #1 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	65 psia	70 psia	
77	Cryostat #2 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	65 psia	70 psia	
78	Cryostat #3 Warm-Up Protection	Relief Valve	1/2" IPS	CV* 0+00 Level	65 psia	70 psia	
79	HX to Manifold Piping Warm-Up Protection	Rupture Disc	1/2" IPS	CV* 0+00 Level	365 psia	Insp. (ok)	

* CV - Containment Vessel

TABLE 3 c

PRESSURE RELIEVING DEVICES - LOCATION AND TEST PRESSURE

Valve No.	Purpose	Type	Size	Location	Pressure Setting	Test Cracking Pressure	Remarks
85	Pod #1 Insulation Space Pressure Relief	Relief Valve	3" IPS	CV* 0+00 Level	N.C. to Atmosphere	16.2 psia	
86	Pod #2 Insulation Space Pressure Relief	Relief Valve	3" IPS	CV* 0+00 Level	N.C. to Atmosphere	16.2 psia	
87	HX Insulation Space Pressure Relief	Relief Valve	3" IPS	CV* 0+00 Level	N.C. to Atmosphere	16.2 psia	
88	Manifold Insulation Space Pressure Relief	Relief Valve	2" IPS	CV* 0+00 Level	N.C. to Atmosphere	16.2 psia	
109	Pressure Relief of #1 Transfer Line-Valve Chest Insulating Space	Rupture Disc	1" IPS	CV* 0+00 Level	35 psia	Insp. (ok)	
110	Pressure Relief of #2 Transfer Line-Valve Chest Insulating Space	Rupture Disc	1" IPS	CV* 0+00 Level	35 psia	Insp. (ok)	
111	Pressure Relief of #3 Transfer Line-Valve Chest Insulating Space	Rupture Disc	1" IPS	CV* 0+00 Level	35 psia	Insp. (ok)	
120	Pressure Relief of Valves For Pneumatically Operated Supply System	Relief Valve	1/2" IPS	CV* 0+00 Level	65 psia	66 psia	
133	Outlet Pressure Relief Recovery Compr. System	Relief Valve	3/4" IPS	0-25 ft. Level	115 psia	116 psia	

* CV - Containment Vessel

in the refrigerant supply lines were removed and the refrigerator was modified to allow accessibility for future recalibration. The six sensing devices were replaced with the same or like devices calibrated to NBS standards by accepted techniques.

The purpose in recalibrating the sensors was to correct for any physical changes which might have occurred in the sensors in the approximately three years of operation. Such changes would be due to the extended temperature cycling and possibly due to the impingement of particulate matter in the flowing helium and conceivably due to physical damage during original installation. Although the original intent was to place these sensors near the head of the test loops in the irradiation field, the actual location in the transfer line manifold, as shown in Figure 2.6, does not require consideration of radiation effects on the sensor resistances.

A method of removing the permanently installed sensors was established and the assemblies were removed from the transfer lines. The sensors were sent to Rosemount Engineering Company for calibration during the modification of the enclosures. The results were subsequently compared with original calibration data.

The sensor in the manifold return line was not replaced or recalibrated because of the major effort in disassembly and reconstruction which would have been required to do so. This was considered reasonable in view of the minor changes evident in the sensors which had been recalibrated and that this sensor measures the return temperature to the heat exchanger which is not essentially in maintaining the test specimen temperature. The latter is maintained by varying mass flow through the test loop so that the inlet and outlet sensor temperatures are stabilized at calibrated temperatures.

2.6.1 Original Construction

As shown in Figure 2.6 and Figure 2.7, the sensors were mounted in wells in the individual vacuum-powder insulated lines between the manifold inlet and outlet headers and the transfer line swivel joints with the sensor in the center of the helium flow and with the sensor axis at a 45 degree angle to the helium line.

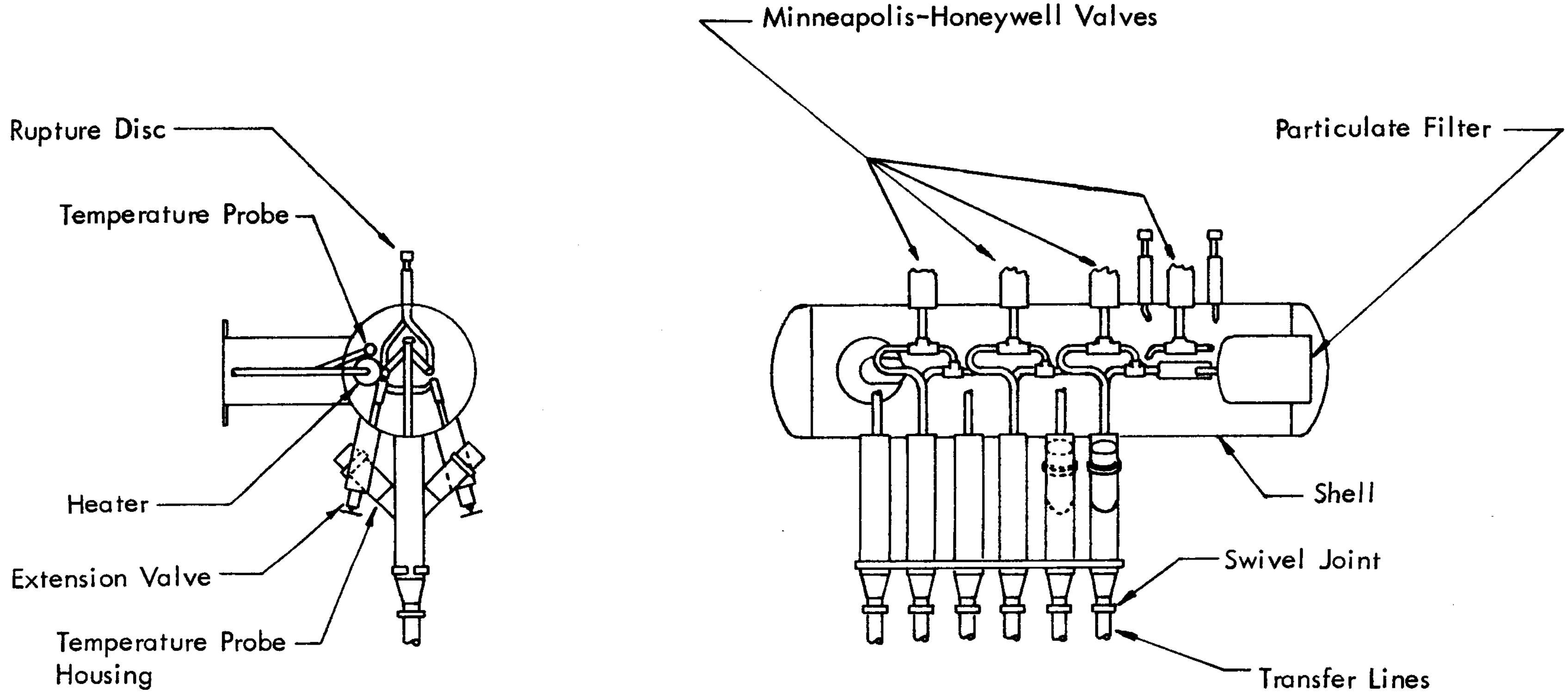


FIGURE 2.6 MANIFOLD INSTALLATION

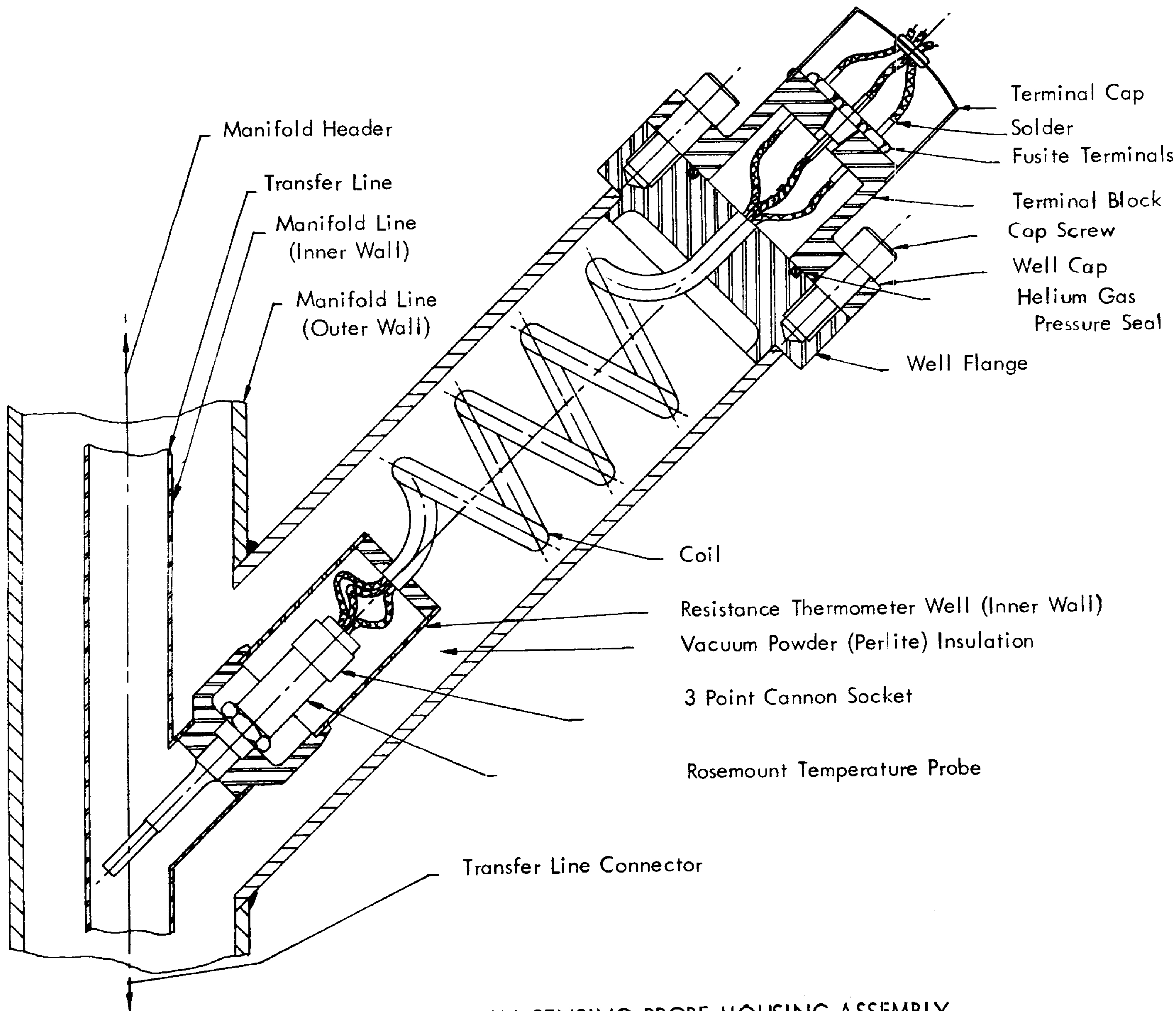


FIGURE 2.7 ORIGINAL SENSING PROBE HOUSING ASSEMBLY

The individual sensor including its 3 pin connector was enclosed in the helium pressurized volume as were the leads, mostly in a helical coil enclosure, from the sensor to Fusite connector feed thrus in the terminal block. The helium was sealed from atmospheric pressure by an O-ring seal between the terminal block and the housing assembly flange. The Fusite connectors were protected and the leads were supported by the terminal cap.

This construction reduced the heat leak to the sensors, permitted fast initial assembly, and allowed good vacuum and helium sealing and good support and protection of the sensor and leads. The construction, however, did not permit convenient removal and replacement of the sensors because the enclosure and tubing were seal welded in place as the assembly was progressively fabricated.

2.6.2 Modification

Alternative modifications were considered which would permit convenient removal and replacement of the sensor while maintaining low heat leak to the sensor.

The first alternative considered was to extend the inner tube all the way to the housing assembly flange with appropriate flange, helium seal, and lead terminals mounted as originally. This would have allowed very easy removal of the sensor after removal of the terminal block, while maintaining the vacuum insulation. However, calculations of the conductive heat leak indicated an order of magnitude increase over the original to about 15 watts per sensor and this alternative was abandoned in favor of the somewhat more complex arrangement shown in Figure 2.8 (and in Lockheed Drawing Nos. 108-220 and 108-223).

This arrangement eliminates all conductive heat leak except that through the lead wires between the inner tube flange and the outer tube flange. Essentially, the modification consists of replacement of the small diameter coil lead enclosure and solder vacuum seal at the flange with Teflon and Kovar seals, breaking the leads with the additional feed-thrus.

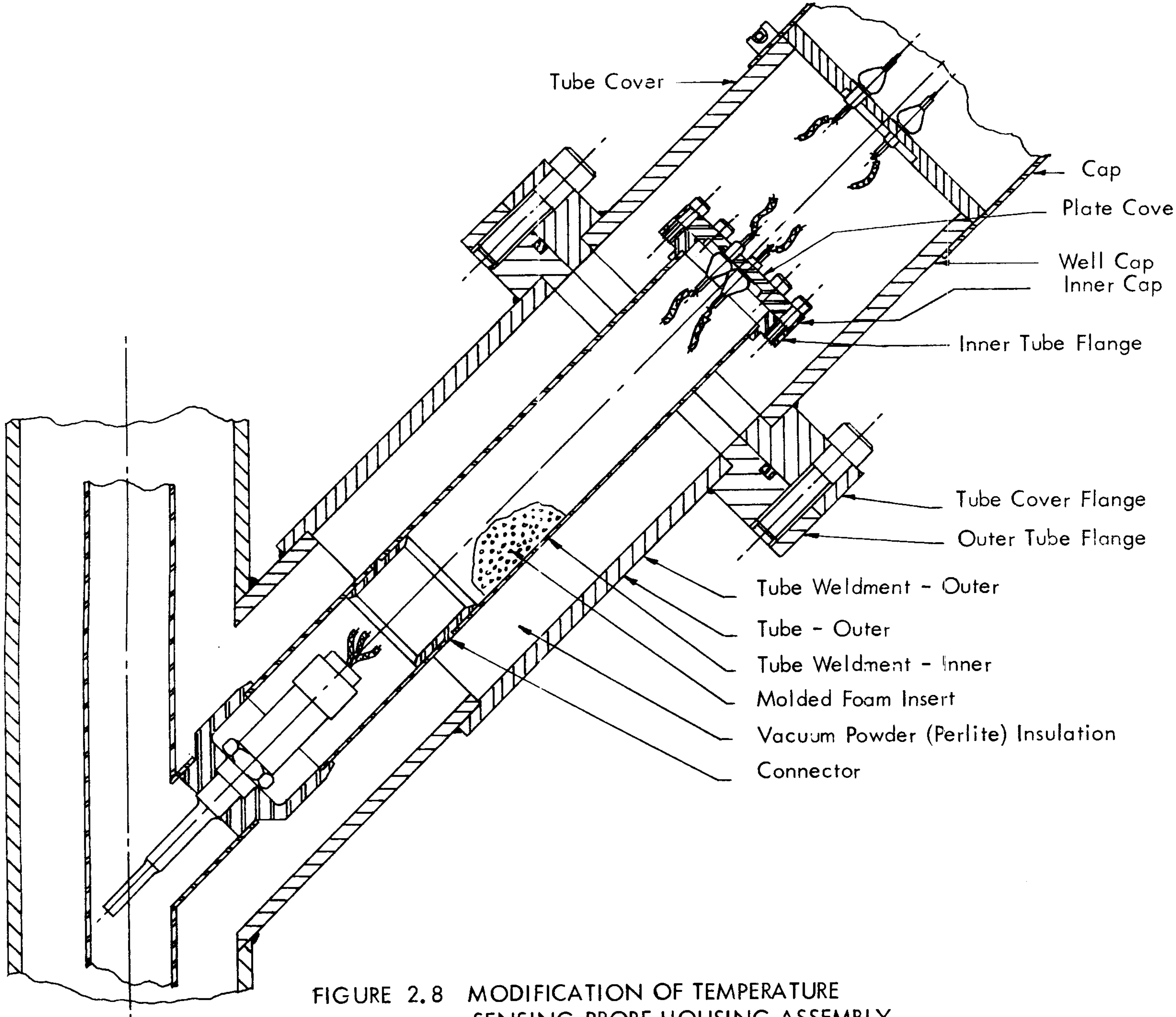


FIGURE 2.8 MODIFICATION OF TEMPERATURE SENSING PROBE HOUSING ASSEMBLY

Although not indicated in the figure, the leads within the inner tube are helically extended in length and most of the enclosed volume of the inner tube is filled with a molded foam insulation insert. The leads between the inner and outer volumes are also extended to facilitate assembly as well as to reduce heat leakage.

The Kovar type seals were used to replace the Fusite seals in order to reduce space requirements for the feed-thrus and at the same time, maintain integrity during thermal cycling.

Modification procedure consisted of the following steps:

1. Construct scaffolding (over empty quadrant).
2. Remove original sensors by cutting the housing assembly.
3. Fabricate inner and outer wall assemblies by machining and welding.
4. Test feed-thru terminals.
5. Leak test the inner and outer tube assemblies individually after constructing a special fixture for testing the outer tube assemblies.
6. Repair leaks.
7. Temperature cycling testing of the inner tube assemblies to LN_2 temperature and leak testing and repairing leaks in these assemblies.
8. Weld inner and outer tube assemblies into place.
9. Pressure test manifold, locating leaks at nozzles and repairing leaks that appeared in outer tube assemblies.
10. Wire (with extended lengths where desirable).

11. Install sensors in manifold housings.

12. Check resistance to ground ($>$200 megohms)

13. Make molded foam inserts.

14. Replace cracked or apparently damaged feed-thrus.

15. Make final assembly.

16. Test with refrigerator operating.

2.6.3 Sensor Description and Calibration

The resistance thermometers used are: Open Wire Sensor, Temperature, Platinum Resistance Type, Rosemount Engineering Company, Type 152-84.

They are designed for use in the range -435°F to $+500^{\circ}$F and use a precision platinum resistance element supported by a light cage and exposed to the working fluid. The element is generally protected by a stainless steel guard tube with additional support of the platinum tip. The exposed element construction affords extremely fast response in fluid media and is suitable for use in helium in the flow conditions of this facility.

External parts are of stainless steel and the sensors are individually vibration tested.

They are stability tested to withstand 50 consecutive temperature shocks from boiling water to LN_2 temperatures. Insulation resistance exceeds 10 megohms at 100 volts D.C.

The leads are of low-temperature-coefficient-of-resistivity and the sensors are operated with a current (≈ 2 ma) sufficient to eliminate the need to consider thermoelectric effects yet low enough that self-heating is negligible. A third lead to the platinum element eliminates most of the effects of variation in lead resistance.

A basic Wheatstone Bridge arrangement is used to determine the sensor resistance for temperature determinations. The change in resistance with temperature is automatically balanced with the position of the balancing motor indicated on a recorder as ohms. This reading is converted to temperature from individual sensor calibration sheets or curves.

Figure 2.9 shows the sensor numbers and positions on the helium flow schematic along with the serial numbers of sensors after equipment modification. Table 4 shows the old sensor serial numbers along with the new serial numbers and the last calibration dates of the sensors in use after equipment modification.

All calibrations (or recalibrations) were by Rosemount Engineering Company utilizing equipment with calibration directly traceable to the National Bureau of Standards. Applicable test data is on file at Rosemount Engineering Company. Specific calibration data are shown in Appendix A.

Sensors 2 (Ser. No. 467), 5 (Ser. No. 392) and 6 (Ser. No. 391) were calibrated by the "NBS-Corruccini Three Point Method" reported in NBS-CEL Project No. 8131 by R. J. Corruccini. The remaining sensors were calibrated at an earlier date by an older, two point technique that is sufficiently accurate for this application of the sensors.

The accuracy required for the experimental program is $\pm$ 1°R so that a calibration accuracy of $\pm$ 0.1°R is considered adequate and $\pm$ 0.05°R desirable.

The three calibration temperatures and corresponding resistors are shown on the calibration sheets for Sensors 2, 5 and 6 along with an FSC factor and DRM factor for the particular sensor. The FSC factor is the ratio of the difference in resistance between the extreme calibration temperatures for the sensor divided by the same difference for the secondary standard resistance. The DRM factor is the error (in ohms) at the third calibration point.

The sensors not used previously were not recalibrated since there was no possibility of strain or other damage after their original calibration and since the older calibration technique used by Rosemount Engineering Company was sufficiently accurate.

A comparison of the original calibration data with the current calibration was made by interpolating the current resistance value into the original resistance data. The results showing the magnitude and direction of variation in temperature are shown in Table 4 a.

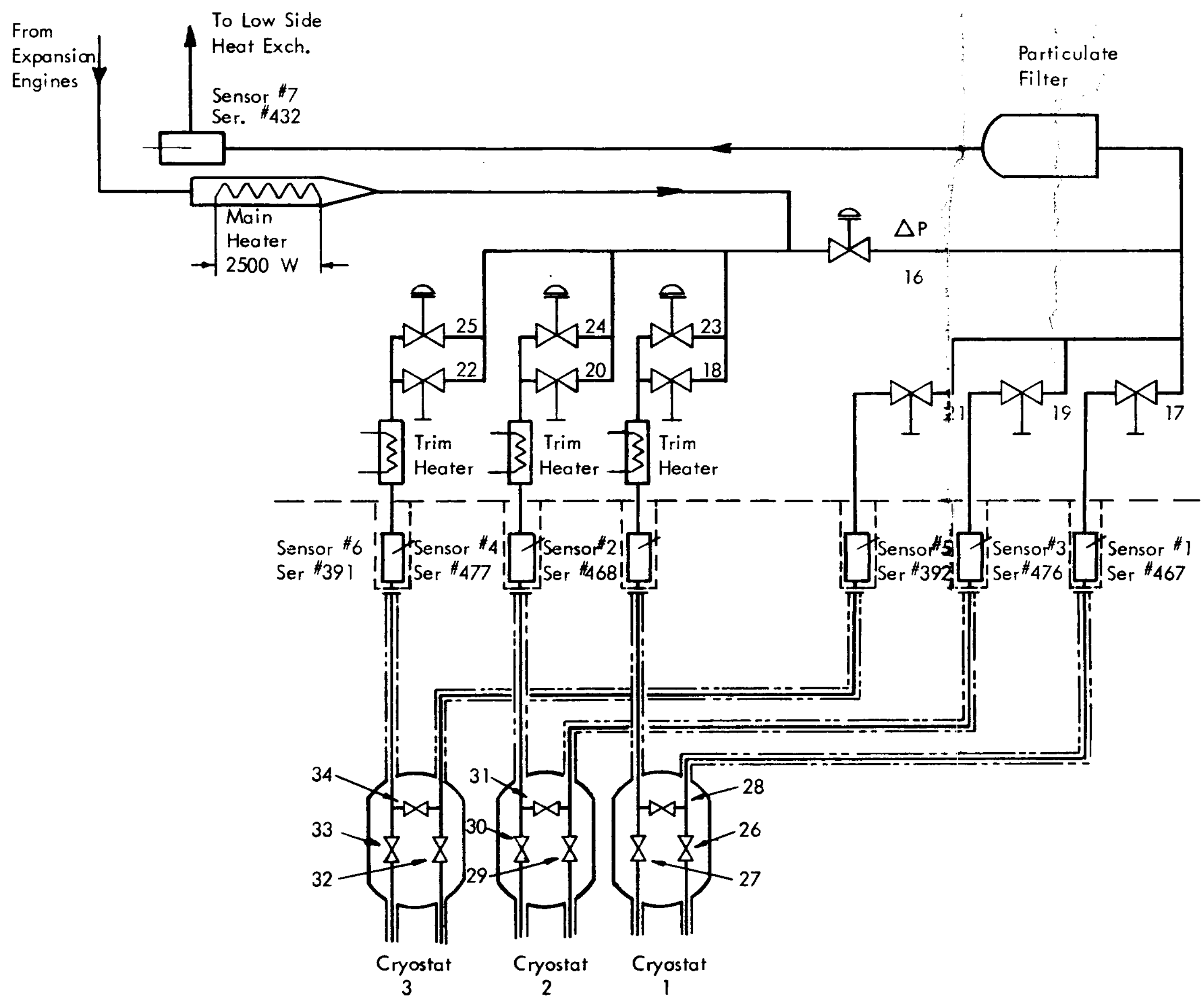


FIGURE 2.9 MANIFOLD HELIUM FLOW SCHEMATIC

TABLE 4

PLATINUM RESISTANCE TEMPERATURE SENSOR POSITIONS

Sensor No.	Sensor Position	Old Serial No.	New Serial No.	New Calibration Date
1	Loop #1 Return	389	467	11-03-61
2	Loop #1 Inlet	392	468	05-06-65
3	Loop #2 Return	388	476	01-25-62
4	Loop #2 Inlet	468	477	01-25-62
5	Loop #3 Return	391	392*	05-06-65
6	Loop #3 Inlet	384	391**	05-06-65
7	Manifold Return***	432	432	11-03-61

* No guard
** ADL fabricated guard
*** Not replaced or re-calibrated

TABLE 4 a

VARIATION IN TEMPERATURE CALIBRATION OF PREVIOUSLY CALIBRATED PLATINUM RESISTANCE THERMOMETERS

Orig. Calib. Temp. °R	Change in Temperature New Calibation in °R		
	Serial No. 391	Serial No. 392	Serial No. 468
30	+ 0.36	+ 0.29	+ 0.45
140	+ 0.22	+ 0.15	+ 0.22
560	+ 0.39	+ 0.46	+ 0.51

The new calibrations on those sensors which were used previously were compared to the old calibrations. The sensors serial numbered 391 and 392 showed differences of less than 0.5°R in the range 25°R to 35°R while the sensor serial numbered 468 showed negligible differences. Although perhaps coincidental, the former two sensors were used previously without guards while the latter was used with a protective guard. The sensor probe guard is a fine mesh screen installed over the perforated tube that protects the wound platinum wire sensor element. This guard was originally incorporated by Arthur D. Little, Inc., to prevent additional failures caused by stream borne particulate matter since the replacement of a sensor required extensive repair effort on the manifold. It has since been concluded that the early failures were the result of residue in the system that persisted through the cleaning processes that followed fabrication and assembly of the refrigerator.

2.6.4 Conclusions and Expected Performance

The equipment modification as described permits ready access to the temperature sensing devices in the helium transfer lines while maintaining low heat leak, maintaining the original sensor placement and maintaining the integrity of the electrical measurement circuit.

Any one of the sensing devices can be removed and replaced in a limited time, after breaking the manifold insulating vacuum.

Procedure for sensor removal is as follows with replacement being the reverse:

1. Shut off helium.
2. Break manifold vacuum.
3. Remove outer tube cover.
4. Remove inner cap.
5. Remove molded foam insert.

6. Disconnect 3 pin connectors.

7. Remove sensor

Based on the required accuracy of the primary temperature measurement and the comparison between old and new calibrations the sensors can be used for approximately two years of normal operation without further recalibration.

The refrigerator system was operated subsequent to making this modification and a thermocouple was placed on the outer tube enclosure cap to measure the temperature of the cap. When the system was operating at 30°R, the indicated temperature was 55°F.

2.7 CALORIMETER TESTS OF THE REFRIGERATOR SYSTEM

The calorimetric test of the refrigeration system was performed at various temperature levels. These tests included the heat leak in the system through the transfer lines and valve chest, but no actual test loops. The latter was simulated by using available calorimeters which permitted the application of varied measurable heat loads. Tests were performed at various temperatures to determine the refrigeration available to maintain the specimen at the designated temperature with return temperatures of 30.8°R, 150°R, 340°R and 572°R.

2.7.1 Theoretical Performance Characteristics

The refrigeration at these temperatures is nearly equivalent to the mass flow times the change in enthalpy of the refrigerant. In the positive displacement cycle used to provide this refrigeration, mass flow is a function of the exhaust pressure and temperature of the expansion engine and the rpm at which the engine is operated. To more clearly describe this, a general operating condition was assumed and an analysis performed to indicate the limitations and characteristics of this type of refrigeration system, as shown in Figure 2.10.

To obtain the total refrigeration provided by the expansion engines, the following conditions were assumed:

Engine inlet pressure, P_2	300 psia
Engine exhaust pressure, P_3	50 psia
Engine inlet temperature, T_2	540 to 36°R

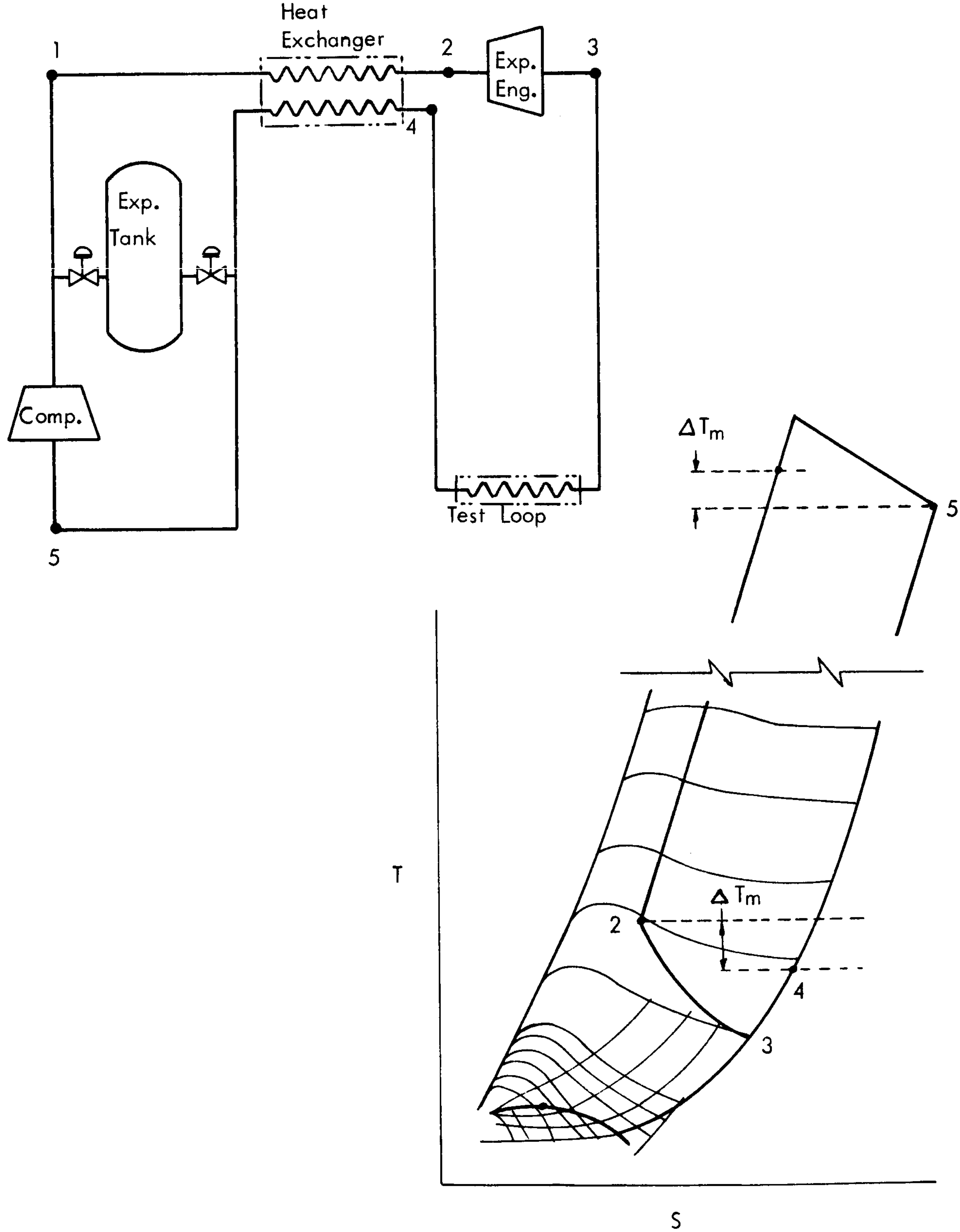


FIGURE 2.10 REFRIGERATION CYCLE

Using these values, the work done by the engines was determined by the following relationship:

$$W_E = (h_2 - h_3) = \frac{k}{k-1} RT_2 \left\{ \left(\frac{P_3}{P_2} \right)^{\frac{k-1}{k}} - 1 \right\} \eta$$

Where: $k = \frac{C_p}{C_v}$

This work represents the total refrigeration in the cycle although the adiabatic irreversible effects (throttling) may contribute negligible refrigeration below the inversion temperature of the gas. The expansion efficiency of the engines (η) was assumed to be 75 per cent throughout the temperature range of the analysis.

It is evident that the mass flow (G lb/hr) must be determined to establish the total refrigeration. This was done by assuming that the engine valve timing throughout the stroke did not significantly effect the total displacement volume during a revolution of the engine, so displacement was determined by the following:

Stroke 1.81 inches

Piston Diameter 2.75 inches

Speed 330 rpm

for 4 engines displacement $= (4) \dfrac{1.81\ (0.7854)\ (2.75)^2\ (330)\ 60}{1728} = 492.69 \dfrac{ft^3}{hr.}$

After determining the displacement it was applied to establish the mass flow as follows:

$$\frac{\text{displ.}\ \frac{ft^3}{hr.}}{V_3\ \frac{ft^3}{lb}}$$

Recognizing that the specific volume is a function of both temperature and pressure, values were obtained from the Table of Thermodynamic Properties of Helium, NBS Tech. Note 154A Jan. 1962. The mass flow, so determined, for an engine speed of 330 rpm and effluent pressure and temperature, previously established by the change in enthalpy through the engines, is plotted in Figure 2.10.1 b. The specific volume varies from that determined by ideal gas relationships, which indicates a deviation from ideal gas laws.

When this became evident, the relationship of C_p, C_v and k with respect to temperature and operating pressures was determined from the tabulated values as follows:

$$C_p = \frac{\Delta H}{W \Delta T}$$

$$C_v = \frac{\Delta U}{W \Delta T}$$

These values are plotted in Figure 2.10.1 a. relative to temperature and pressure.

The heat exchanger requirements were established from an early design study and the values were assumed to be valid. The values are plotted in Figure 2.10.1.c. The total refrigeration available to dissipate heat leak and gamma heating is the difference between the engine work and the refrigeration required to pre-cool the compressed gas to the engine inlet temperature. Inasmuch as the specific volume and temperature of the gas are nearly inversely proportional until significant changes occur in the specific heats, the total refrigeration is nearly constant. The heat exchanger requirements with temperature dependent properties of the Prandtl and Reynolds numbers which, in turn, changes the required Δt to effect the heat transfer.

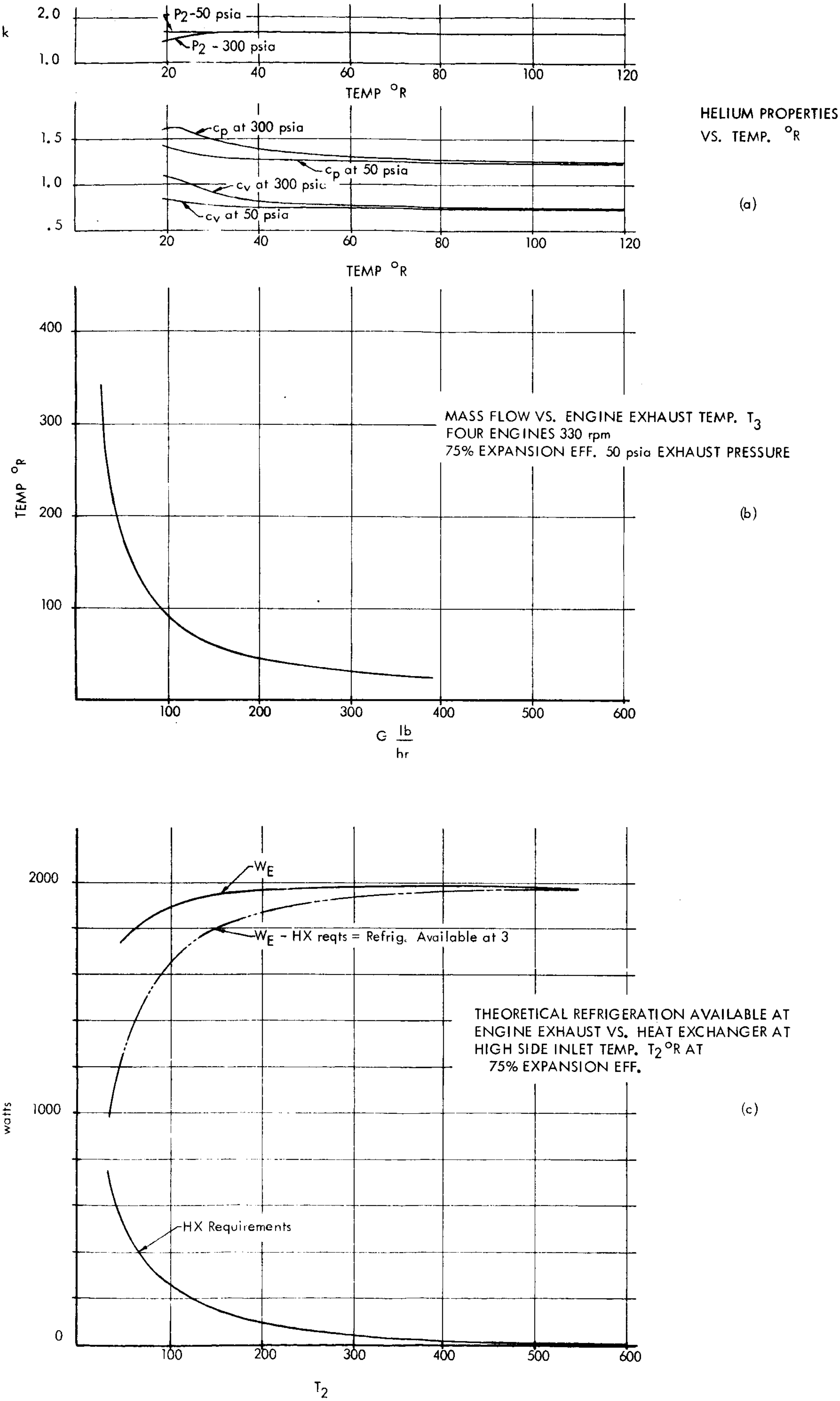


FIGURE 2.10.1 REFRIGERATOR PERFORMANCE RELATIONSHIPS

It is evident that the test loop refrigeration available diminishes throughout the operating temperature range and the Δ t, across the test loop, will increase for a given load as the temperature increases.

The example presented is intended to define general operating characteristics and does not reflect actual performance, in which the various parameters can be altered to effect optimum refrigeration for test requirements.

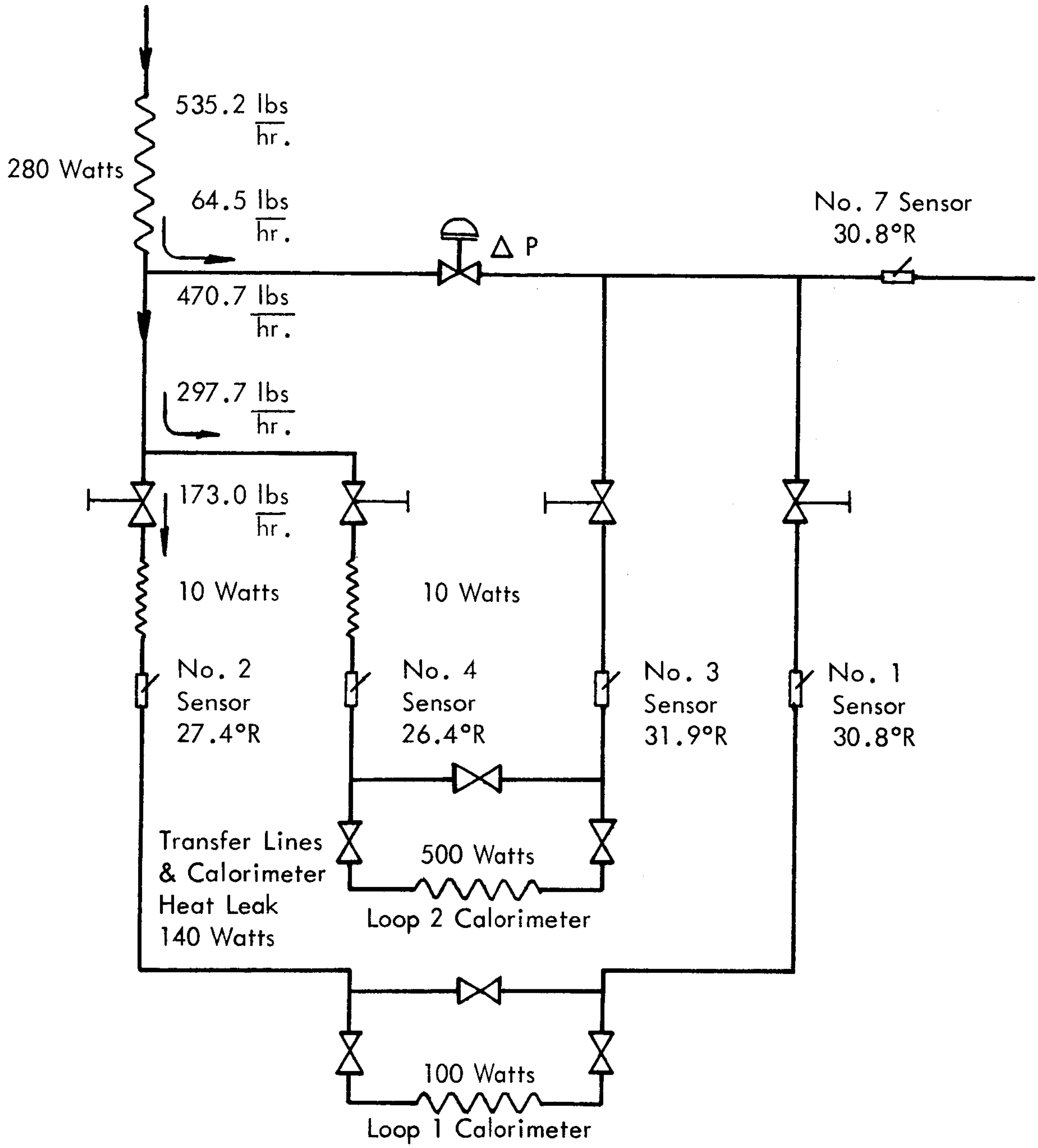
The calorimeter test was performed by simulating the heat leak and test loop load with a calorimeter which is essentially a thermally isolated electric heater which provides a measurable heat load.

2.7.2 Calorimeter Tests and Results

A schematic diagram of the system and individual schematics of each heater condition in the tests with observed data is presented together with available refrigeration at the designated temperature levels in Figures 2.11, 2.12, 2.13 and 2.14. The results indicate a slightly higher engine expansion efficiency in all cases and a substantially reduced heat leak at the higher temperatures; however, it also reflects the increasing Δ t between the inlet and outlet sensors required to obtain maximum refrigeration. Careful load application with the various heaters will permit minimizing this so better temperature control can be maintained at the test specimen.

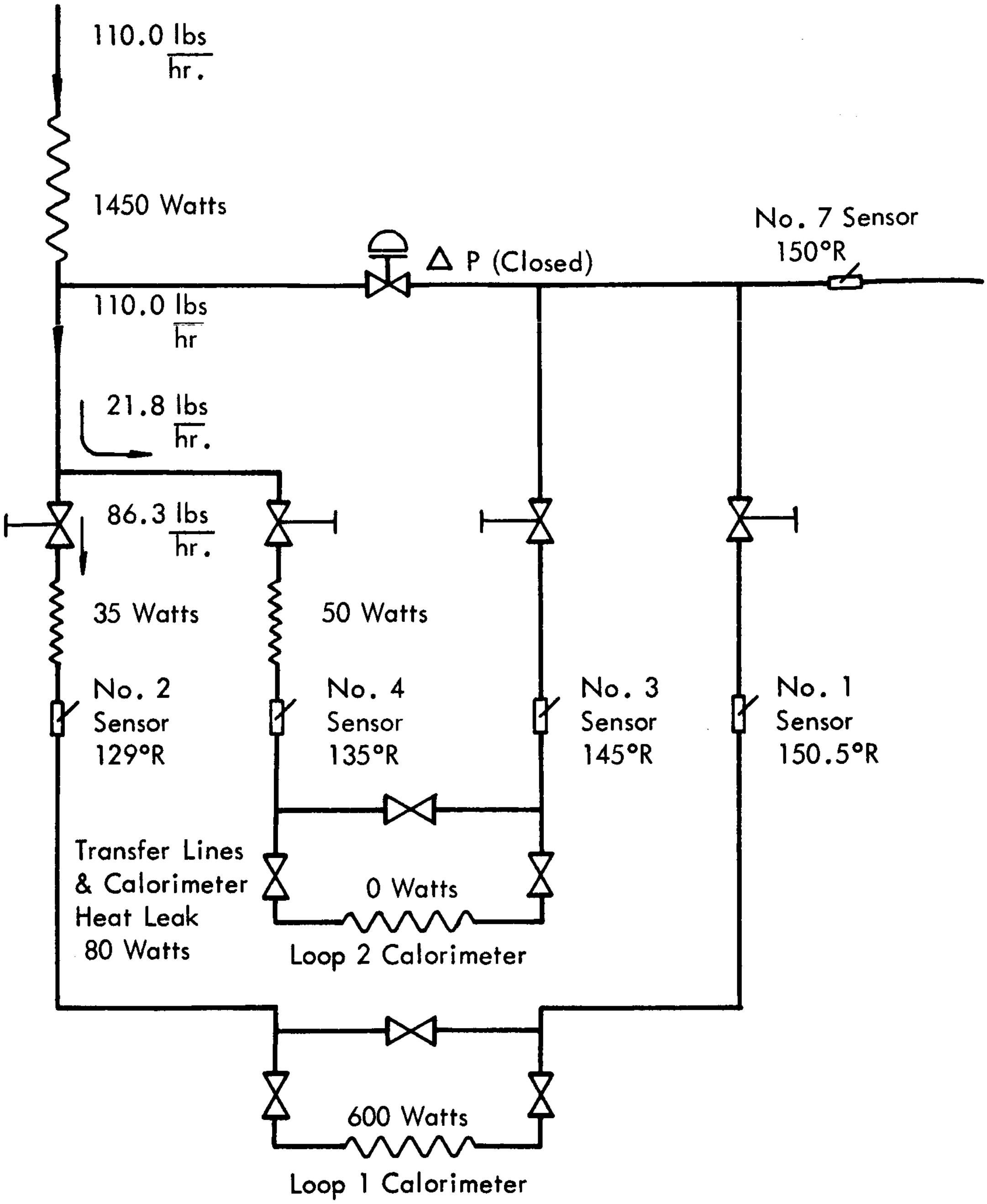
The calorimeter testing of the refrigerator was performed by substituting a thermally isolated heater in place of the tensile test loop. The heat leak into the transfer lines and calorimeter from the external environment was previously measured by stabilizing the refrigerator temperature with a measurable load on the main heater while the transfer lines and calorimeter were isolated, by valves, from the system. Then, by opening the valves and stabilizing the system at equivalent conditions by reducing the power input to the main heater, the reduction in power input was considered equivalent to the heat leak in the transfer lines and calorimeter enclosures. To verify this value, the lines and calorimeter were isolated again by the valves and refrigerator stabilized by increasing the power to the main heater.

The heat leak of a set of transfer lines and the calorimeter was 140 watts at 30°R and 80 watts at 150°R and considered negligible at 340°R.



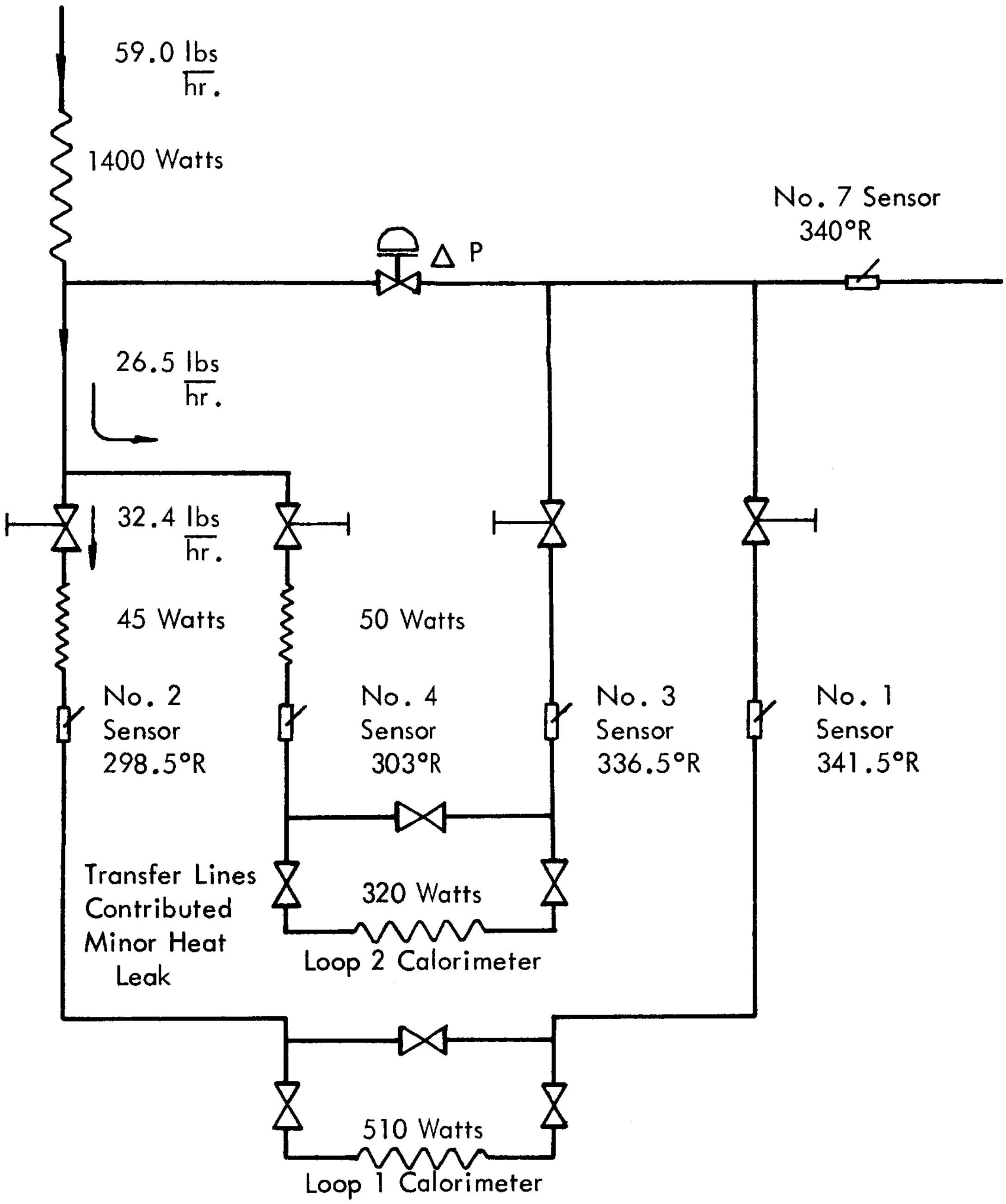
Compressor	
Suction Pressure	48.7 psia
Discharge Pressure	299.7 psia
Expansion Engines	
Speed	330 rpm
Inlet Pressure	284 psia
Exhaust Pressure	59.7 psia
Total Watts Refrigeration	1180

FIGURE 2.11 REFRIGERATOR CALORIMETER TEST 30°R



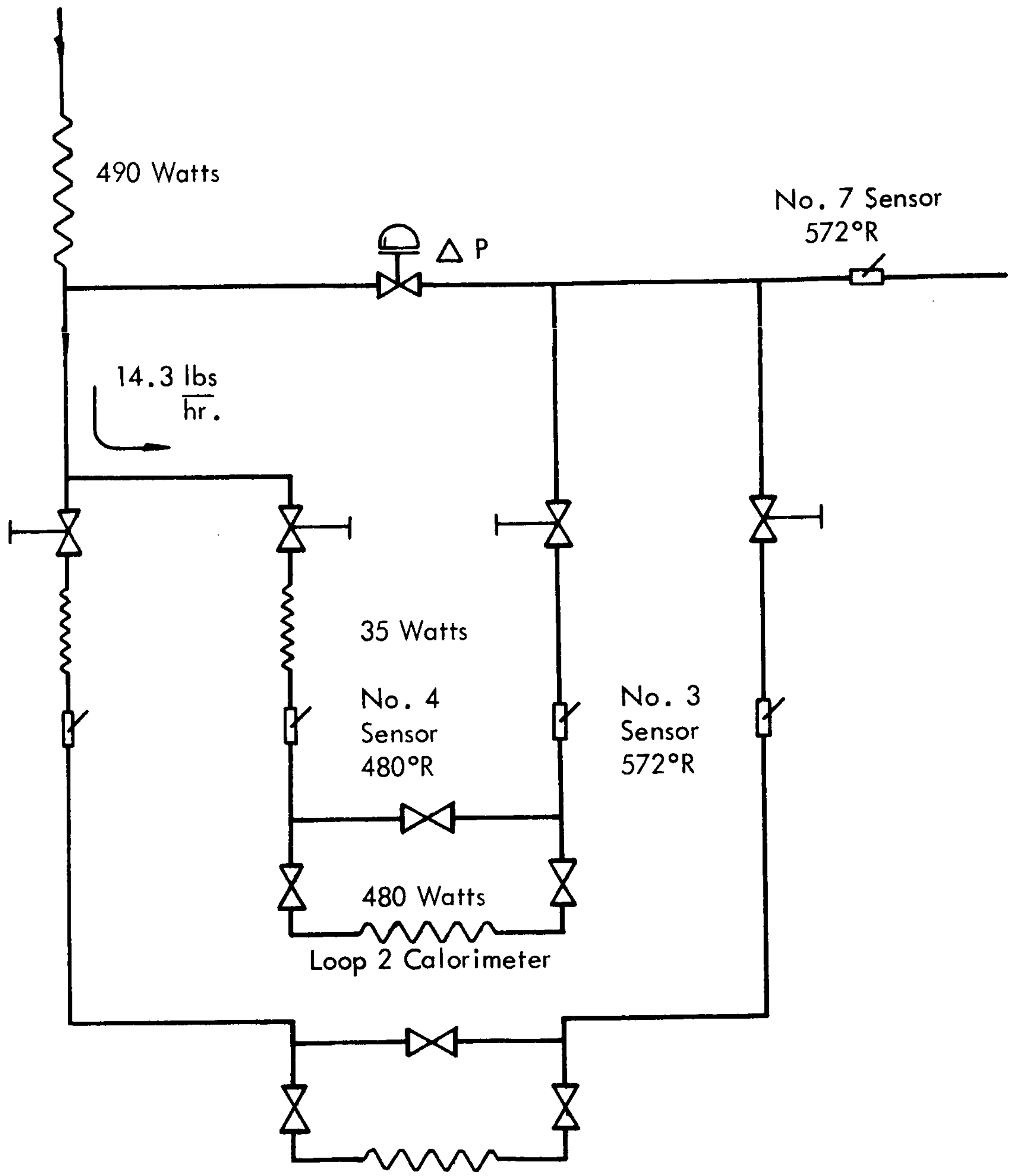
Compressor		
Suction Pressure	47.7	psia
Discharge Pressure	299.7	psia
Expansion Engines		
Speed	290	rpm
Inlet Pressure	298.7	psia
Exhaust Pressure	50.7	psia
Total Watts Refrigeration	2295	

FIGURE 2.12 REFRIGERATOR CALORIMETER TEST 150°R



Compressor		
Suction Pressure	47.7	psia
Discharge Pressure	279.7	psia
Expansion Engines		
Speed	310	rpm
Inlet Pressure	274.7	psia
Exhaust Pressure	48.7	psia
Total Watts Refrigeration	2325	

FIGURE 2.13 REFRIGERATOR CALORIMETER TEST 340°R



Compressor		
Suction Pressure	34.7	psia
Discharge Pressure	209.7	psia
Expansion Engines (2 Only)		
Speed	325	rpm
Inlet Pressure	209.7	psia
Exhaust Pressure	34.7	psia
Total Watts Refrigeration	1005	

FIGURE 2.14 REFRIGERATOR CALORIMETER TEST 540°R

After establishing the heat leak into the calorimeter and transfer lines, tests to determine the refrigeration capacity were performed by applying measurable heat loads to heaters in the system so that the return temperature would stabilize at the predetermined level. The Δt recorded for each calorimeter and its associated lines indicates the mass flow that is routed through the loop and it is evident that the total mass flow from the expansion engines is distributed relative to the heater load in the test loops if the return temperature is maintained at a constant temperature. The latter relationship was used to corroborate the recorded data by performing a heat balance.

2.7.3 Heat Balance Test Verification

A thermodynamic heat balance was performed by establishing the flow requirements to dissipate the load through the transfer line and calorimeter system and then going back through the trim heater and the main heater arrangement to establish the effluent temperature of the expanded helium gas at the engine exhaust. The temperature at this point was, in turn, related to engine rpm and to tabulated specific volume data to determine the credibility of the data obtained. A typical evaluation is shown below for loop 1.

Heat Load -	lines and calorimeter heat leak	140 watts
	calorimeter heater	100 watts
	Total	240 watts

Inlet temperature	$27.4^{o}R$	Inlet pressure	59.70 psia
Outlet temperature	$30.8^{o}R$	Outlet pressure	48.70 psia

The change in enthalpy (ΔH) of the gas between the inlet and outlet conditions was obtained from a helium property table with double interpolation.

$$\Delta H = 4.73 \frac{BTU}{lb} \text{ and } 240 \text{ watts } (3.41) \frac{\frac{BTU}{hr}}{\text{watts}} = 818.4 \frac{BTU}{hr}$$

$$G = \frac{818.4 \frac{BTU}{hr}}{4.73 \frac{BTU}{lb}} = 173.0 \frac{lb}{hr}$$

The ΔH for the conditions observed in loop 2 was determined as $7.33 \frac{BTU}{lb}$.

The total heat load between loop 2 sensors was 640 watts; therefore:

$$640\ (3.41) = 2182\ \frac{BTU}{hr}$$

and

$$\frac{2182\ \frac{BTU}{hr}}{7.33\ \frac{BTU}{hr}} = 297.7\ \frac{lb}{hr}$$

This indicates that the flow through the loops must be $470.7 \frac{lb}{hr}$.

In addition, gas flowing through the manifold by-pass must be sufficient to reduce the temperature of the effluent gas from loop 2 from 31.9°R to 30.8°R and the temperature entering the by-pass was estimated at 26.0°R which appears reasonable relative to the recorded loop inlet temperatures. The enthalpy balance indicates that:

$425.7 \frac{BTU}{hr}$ must be removed by the 26°R by-pass gas; therefore, the mass flow through the by-pass ΔP valve is:

$$G_2 = \frac{297.7\ \Delta h_2}{\Delta h_1}$$

Δh_1 from 26.0°R at 60.00 psia to 30.8°R at 50.00 psia $= 6.60 \frac{BTU}{lb}$

Δh_2 from 31.9°R at 60.00 psia to 30.8°R at 50.00 psia $= 1.43 \frac{BTU}{lb}$

The total mass flow in the system is therefore:

$173.0 \frac{lbs}{hr}$ through loop 1

$297.7 \frac{lbs}{hr}$ through loop 2

64.5	$\frac{lbs}{hr}$	through by-pass
535.2	$\frac{lbs}{hr}$	Total Mass Flow

The test results for the other temperature levels were similarly evaluated to determine the credibility of the test data. They all indicate that there is some loss in refrigeration between the engine exhaust and the inlet to the main heater in the manifold assembly but provide acceptable heat balance. In addition, the determination of mass flow is compatible with theoretical values within normal experimental error. The application of an inductive type wattmeter and determination of mass flow from previously recorded values at similar operating conditions can introduce errors in applied heat load and total refrigeration available. The latter is a function of all the performance characteristics of the engines including valve leakage, sleeve and piston conditions, which will vary with relative wear during engine component life. The total estimated error could be as much as $\pm$ 5%.

The mass flow distribution indicated was established by analytical methods relating load to refrigeration requirements and total flow to the previously measured mass flows to ascertain the credibility of test results.

The test performed at 540°R indicates a reversal of heat transfer in the heat exchanger and though refrigeration is available, it will be progressively reduced as the return temperature increases.

A summary of the calorimeter test results are shown in Table 5 and Figure 2.15.

TABLE 5

SUMMARY - REFRIGERATOR CALORIMETER TEST RESULTS

Test Temperature	$30^{o}R$	$150^{o}R$	$340^{o}R$	$540^{o}R$
Mass Flow G $\frac{lbs}{hr}$	≈ 520.0	≈ 110.0	≈ 59.0	≈ 14.3
Main Line Heater (Watts)	280	1450	1400	490
Loop 1 Heater (Watts)	10	35	45	0
Loop 1 Calorimeter (Watts)	100	600	510	0
Loop 1 Heat Leak (Watts)	140	80	0	0
Loop 2 Heater (Watts)	10	50	50	35
Loop 2 Calorimeter (Watts)	500	0	320	480
Loop 2 Heat Leak (Watts)	140	80	0	0
Total Watts Refrigeration	1180	2295	2325	1005

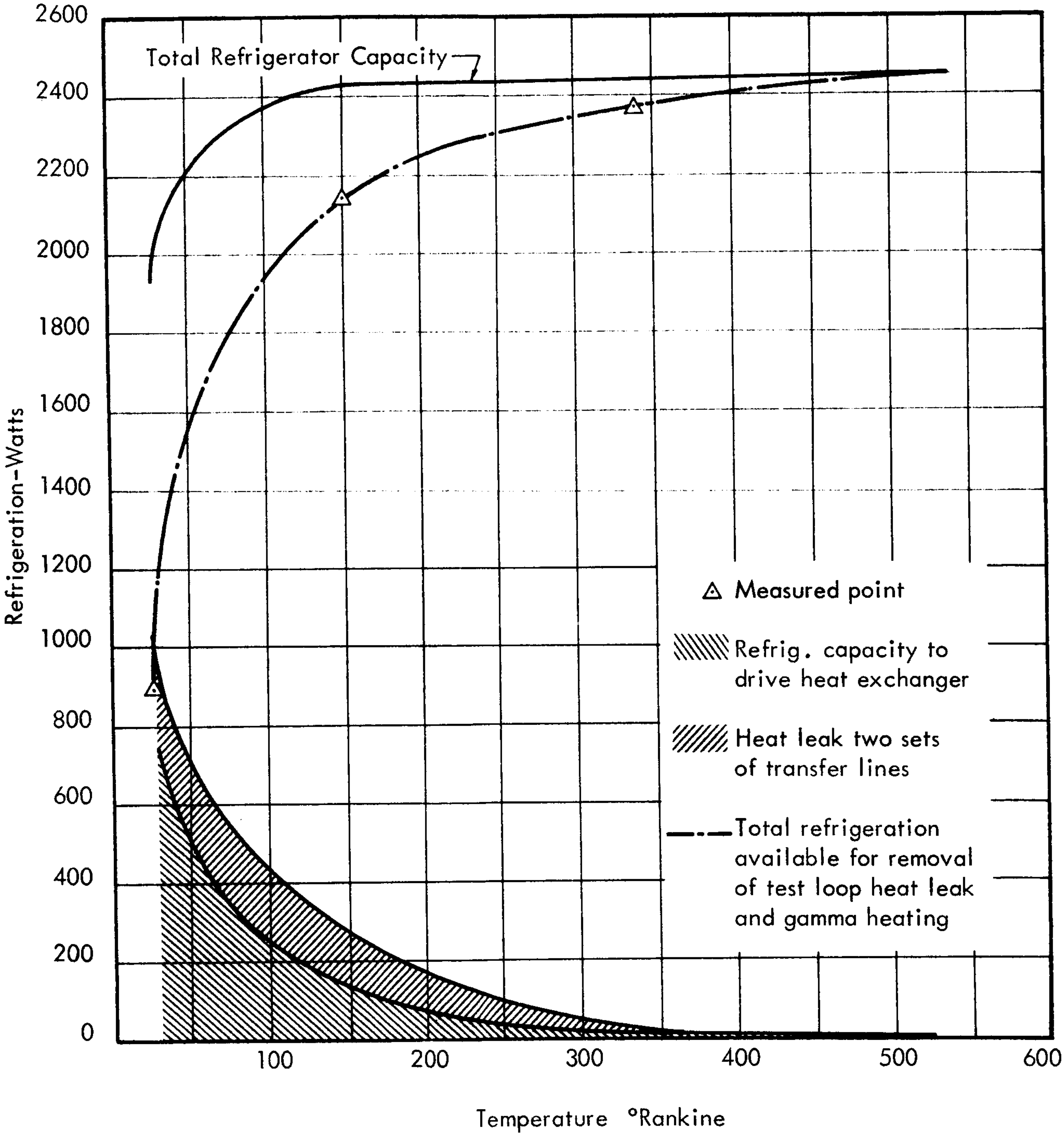


FIGURE 2.15 CALORIMETRIC REFRIGERATION CAPACITY WITH RESPECT TO GAS TEMPERATURE

3 TEST LOOPS

The Government supplied test loops, briefly described in Section 1.3 of this report, had been used extensively prior to the inaguration of this contract. This prior usage had caused some loop deterioration. The correction of this condition was the objective of Section B of Exhibit "A", Scope of Work, in Contract NAS 3-6210.

3.1 IRRADIATION HISTORY

Three of the loops had histories of in-pile exposure to the Plum Brook Reactor field which formed radioactive isotopes within the structural materials. The resultant activity imposed the requirement of remote handling and/or shielding of the forward portion of these loops. The irradiation history of each loop and head assembly is given in Table 6.

TABLE 6
IRRADIATION HISTORY OF TEST LOOP AND HEAD ASSEMBLIES

Loop No. 201-	Head No. 201-	Total Dose* ($x10^{17}$nvt)		Date of Latest Irradiation	Measured Level of Activity and Date of Measurement
		Thermal	Fast		
001	Prototype	0	0	N. I.	-
002	007	19.3	62.4	12-19-64	160 R/hr, 02-24-65
003	008	12.4	40.0	03-25-64	25 R/hr, 05-25-65
004	010	25.4	81.9	12-19-64	N. M.
005	009	0	0	N. I.	-

* at the test specimen location
N. I. not irradiated
N. M. not monitored

3.2 RE-EVACUATION OF TEST LOOP HEAD ASSEMBLIES

As mentioned in Section 1.3, the test loop heads contain an evacuated insulating annular space between the cryogenic test zone and the outer surface. The quality of the vacuum in this annular space is subject to gradual but progressive deterioration due to age and irradiation induced off-gassing. Development of techniques for the periodic re-evacuation of these heads as a cost saving method was part of the scope of work in this project. One of the five test loop head assemblies, listed in Table 6, as the prototype associated with test loop 201-001, has a permanent evacuation tube and valve arrangement which permits re-evacuation at any time. The other four heads, however, are not so equipped since this arrangement would interfere with insertion into the beam port. These four heads must have evacuation tubes installed prior to evacuation and pinched off and seal welded after evacuation. As Table 6 shows, three of these heads have extensive irradiation histories and must be handled by remote means.

The head assemblies are made essentially from 300 series stainless steel and have a total weight of about sixteen and half pounds. The most active radio-isotope formed from thermal neutron activation of the elements contained in stainless steels is Manganese 56. However, Mn^{56} has a half-life of only 2.56 hours and can be permitted to decay to a low level before working on the test loops. The principal activity in the test loops a few weeks after the most recent irradiation is from Cobalt 60, with photon energies of 1.17 and as 1.13 Mev (gamma) and a half-life of 5.25 years, and Tantalum 182, with energies of 1.13 and 1.22 Mev and a 115 day half-life. Smaller, but significant, contributions to the activity come from Cr^{51} and Fe^{59}, with half lives in the order of a month.

3.2.1 Evaluation Testing of Head Assemblies

The initial effort in the test loop head re-evacuation technique was to determine the insulation characteristics of the head relative to the vacuum pressure in the space surrounding the test chamber. The data obtained would then be used to establish the relative condition of all the test loop heads.

The test loop head currently installed and used on the prototype loop was used in obtaining the data. It was selected because it had never been irradiated and the evacuation tube included a bellows seal type vacuum valve.

To obtain the data the vacuum space was originally vented to the atmosphere and the test cavity was filled with liquid nitrogen (140°R). After temperature stabilization the level of the liquid in the head was measured and normal boil-off to the atmosphere proceeded until the level was reduced by 2 inches. The time required for the LN_2 level to be reduced 2 inches was recorded. This test was repeated at various vacuum pressures in the insulating space and the time recorded in each instance. The data so obtained is shown in Figure 3.1 indicating a time of 10.25 minutes at 760 mm Hg to 44 minutes at 1.8×10^{-5} mm Hg. The boil-off rate did not increase significantly after a pressure of 1×10^{-3} mm Hg had been obtained in the insulating space.

The data was converted into heat leak by determining the volume of LN_2 in a 2 inch depth of the obround test cavity. This is approximately 23 in.^{3} which is approximately 0.1 gallon and using the following value for LN_2:

$$6.8 \ \frac{\text{lbs}}{\text{gal.}}$$

$$86.0 \ \frac{\text{BTU}}{\text{lb}} \quad \text{latent heat of vaporization}$$

The heat required to boil-off this quantity of LN_2 is then -

$$0.1 \text{ Gal.} \ (6.8) \frac{\text{lb}}{\text{Gal}} \ (86.0) \frac{\text{BTU}}{\text{lb}} = 58.5 \text{ BTU}$$

To obtain consistent heat leak rates this was related to each recorded time increment as follows:

$$\frac{58.5 \text{ BTU } (1) \text{ hr } (60) \text{ min.}}{\text{Time (min)}} \times \frac{1}{3.41 \ \frac{\text{BTU}}{\text{Watt}}}$$

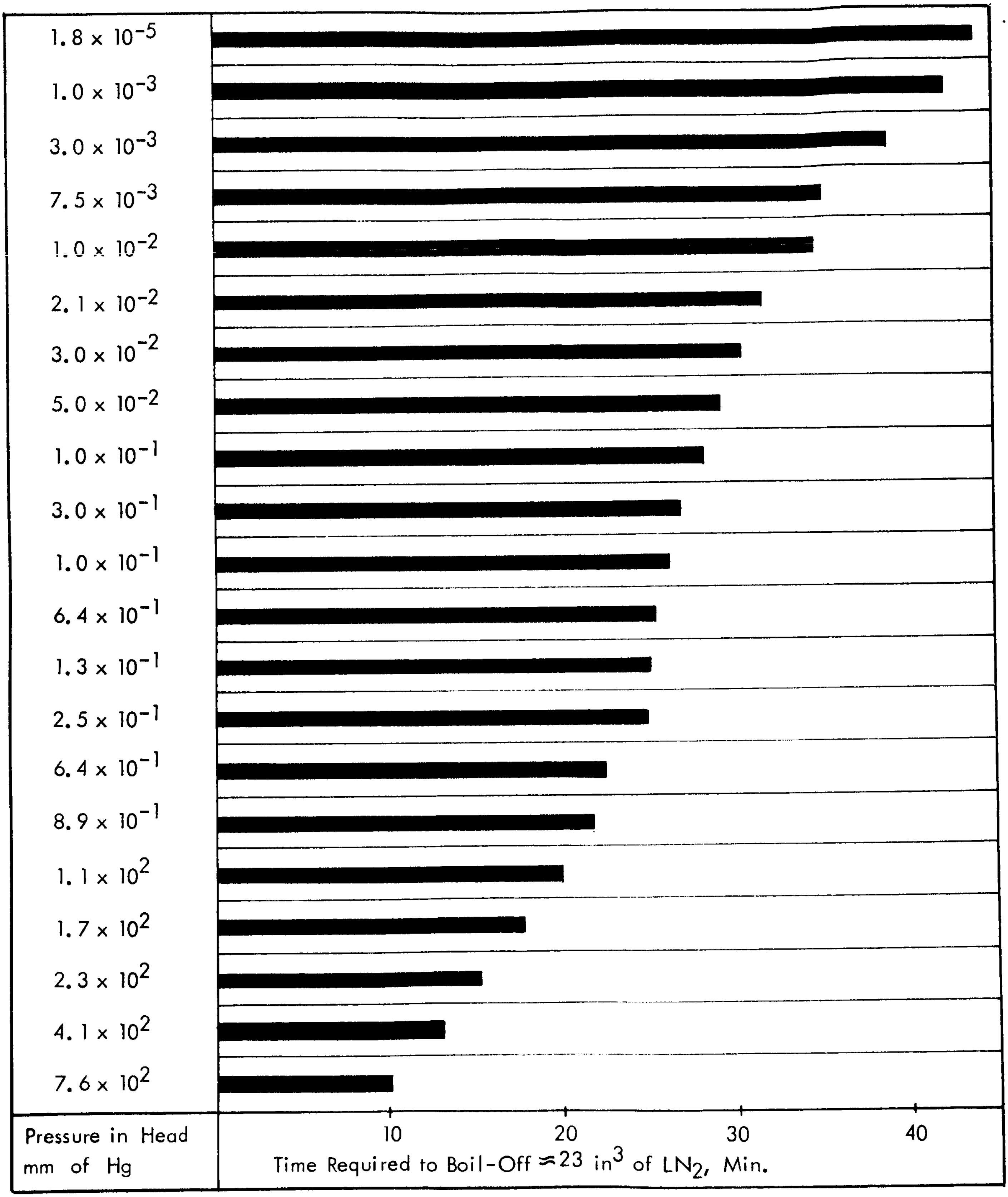


FIGURE 3.1 DEPENDENCE OF BOIL-OFF TIME FOR ≈ 23 in^3 LIQUID NITROGEN ON PRESSURE IN ANNULAR SPACE OF PROTOTYPE HEAD

The results of this evaluation are plotted in Figure 3.1.1 showing the reduction in heat leak from the test performed at atmospheric pressure.

The data obtained and evaluated is used only as a criteria for determining the relative condition of other heads tested in a similar way. The measurements as made were not intended to provide definitive results but only a working criteria to establish the relative condition of irradiated heads.

The conditions in which data was obtained for the boil-off heat leak criteria differ significantly from those in which the test heads are used. The greater Δ T between room temperature and 30°R and room temperature and LN_2 which exists in application is only one consideration and the possibility of the presence of helium in an irradiated head exists; in addition, the thermal characteristics of the system and the presence of an ionized gas in the vacuum space will increase the heat leak substantially. The reduction in heat leak shown, was established to provide a test criteria and should not be extrapolated to determine total heat leak in a test head when used for irradiation testing.

3.2.2 Remote Handling Techniques

As previously stated, and as shown in Table 6, three of the test loop head assemblies are radioactive and must be handled by remote means. The second phase of the development of evacuation techniques, therefore, was devoted to investigation of remote handling methods for installation of evacuation tubes, evacuation, and cutting-off and sealing the evacuation tubes.

3.2.2.1 Evacuation Tube Removal Fixtures

The development of remote techniques for installing evacuation tubes on the irradiated heads was performed using mock-ups with a geometrical configuration similar to that of the actual heads. A milling table was installed in the hot cave, described in Section 1.5 of this report, to permit removal of the existing sealed evacuation tube and mechanical preparation of the mock-up head for installation of the new evacuation tube. This equipment, shown in Figure 3.2, consists of an adjustable track with a clamping fixture to allow accurate positioning of the head in the hot cave. A drill motor on a magnetic stand was equipped with a 4 in. circular saw blade for cutting off the sealed tube flush with a tangential plane of the head. After the cut-off operation had been accomplished, the saw was replaced with a reamer to size the tube orifice for proper fit of a bushing to be installed as a source of filler metal for a welded tube to head connection. The reamer was replaced with a spot face for final machining of the mock-up head.

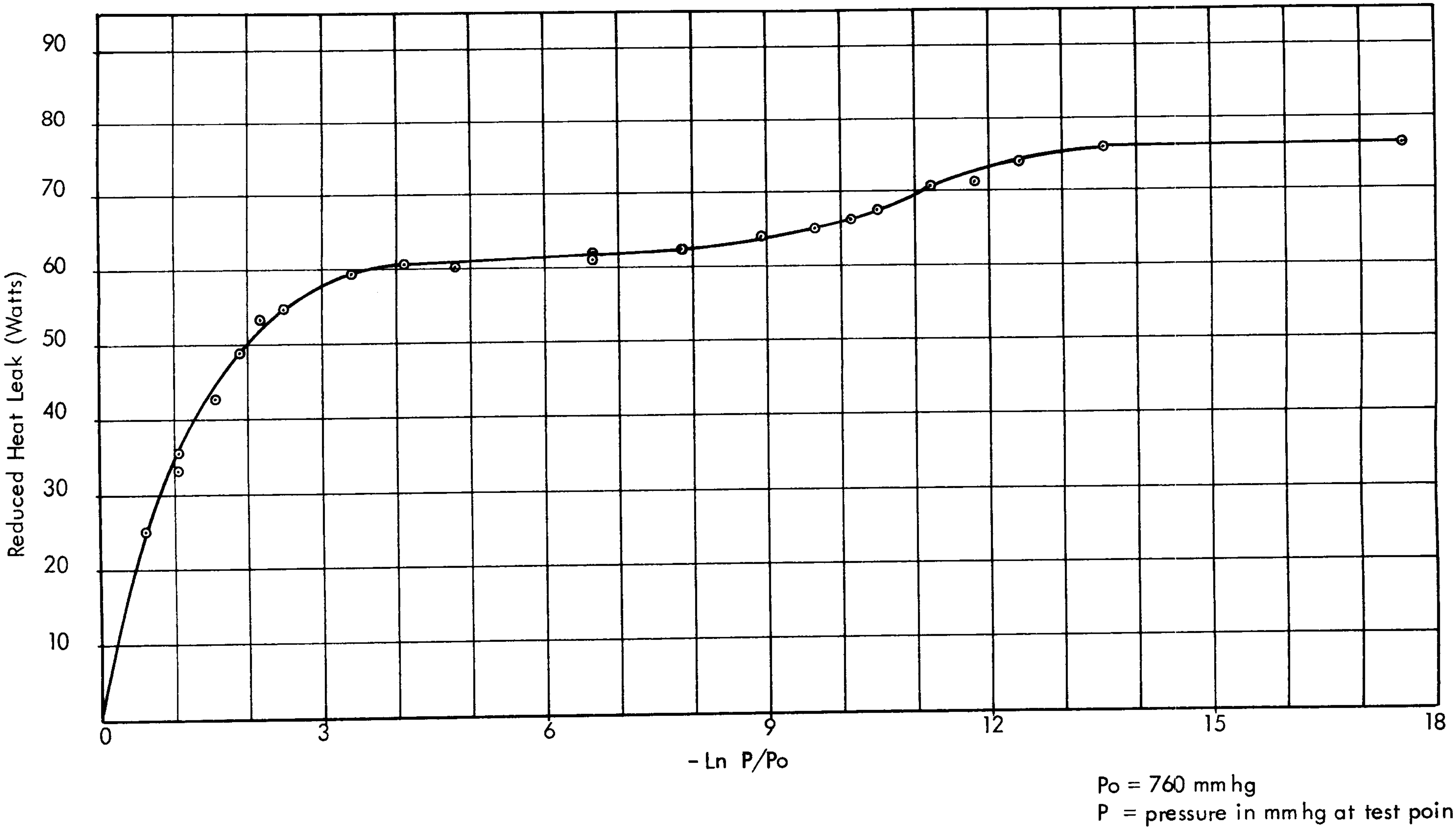


FIGURE 3. 1. 1 REDUCED HEAT LEAK VS PRESSURE IN INSULATING SPACE

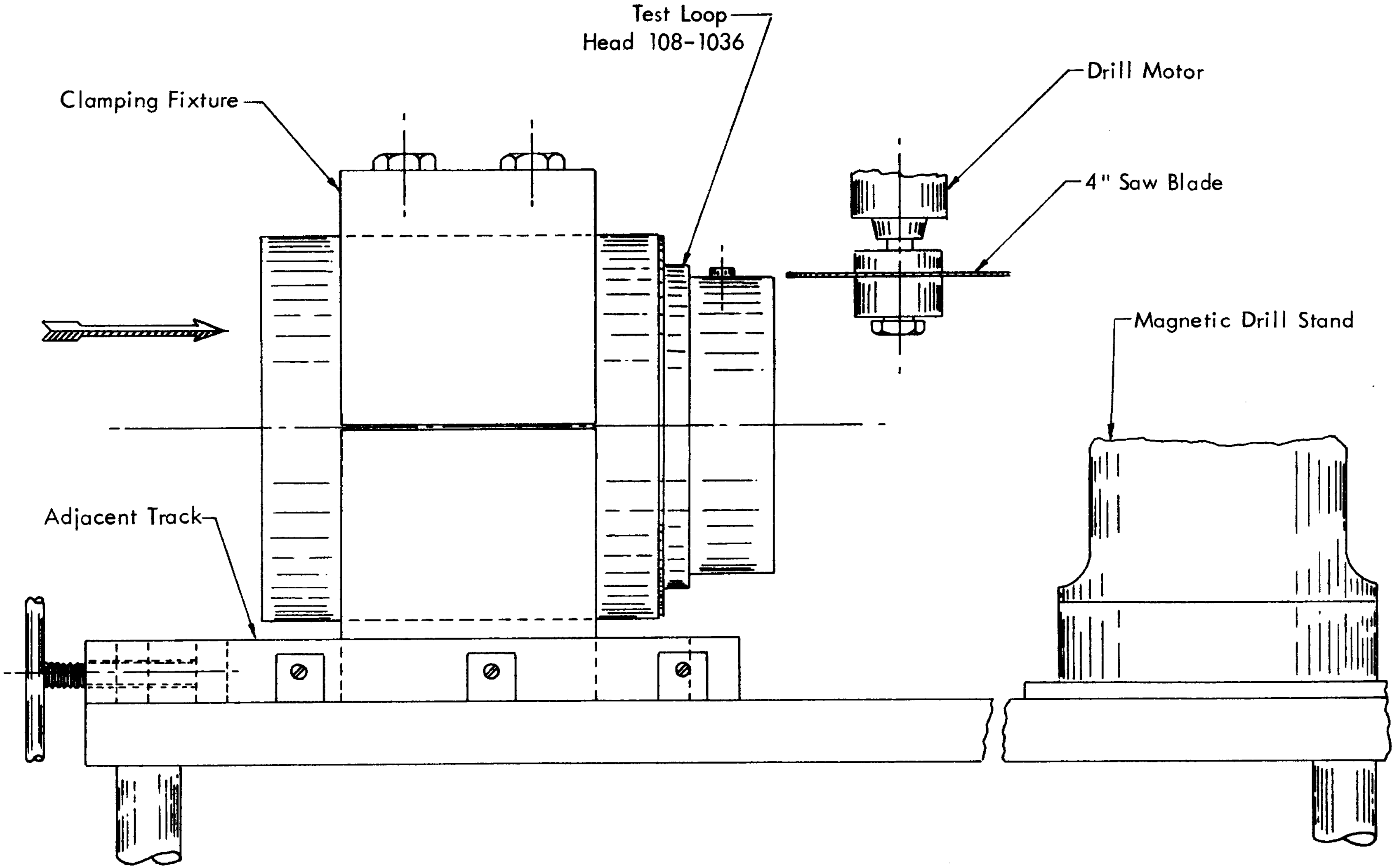


FIGURE 3.2 REMOTE HANDLING FIXTURES TEST LOOP HEAD EVACUATION TUBE CUT-OFF

3.2.2.2 Evacuation Tube Welding Fixture

A welding fixture for remote installation of the evacuation tube, shown in Figure 3.2.1, was then installed in the hot cave for joining the evacuation tube to the mock-up head. Figure 3.2.1 also shows the joint design, which includes a bushing prejoined by heliarc welding to the tube. The jig permits the rotation of a heliarc torch around the evacuation tube to fuse the bushing to the head. A short focal length 8X viewing lens was used outside the hot cave viewing window to permit operator control of the welding operation. A satisfactory weld, showing no leakage when tested with a helium mass spectrometer leak detector, was obtained on the mock-up head before any rework of actual heads was undertaken.

3.2.2.3 Mock-Up Vacuum Chamber Testing

Concurrently with the above work on techniques for machining and welding, evacuation and sealing techniques were investigated. For this investigation, test chambers with a volume of approximately 70 in.^{3}, equivalent to the volume of the annular space in the actual heads, were constructed for these tests. The chambers were evacuated as shown schematically in Figure 3.3. The initial tests were intended only to demonstrate the feasibility of the operational system, and the furnace shown in Figure 3.3.1 was not used in the first two tests.

The first test chamber was evacuated through a 1/8 in. OD nickel evacuation tube. The lowest pressure obtainable in this chamber was 6×10^{-5} mm of Hg. The evacuation tube was crimped closed and sealed by inert gas welding. There was a slight increase in chamber pressure at cut-off and after 48 hours, the chamber pressure had increased to 50.0×10^{-3} mm hg.

A second chamber was similarly evacuated through a 1/4 in. OD stainless steel tube. The pressure in this chamber reached a steady state of 8×10^{-6} mm of Hg. There was no increase in pressure during sealing and the chamber pressure after 48 hours was less than 20.0×10^{-3} mm hg.

On the basis of these tests, the 1/4 in. OD stainless steel evacuation tube was used in the third test, which simulated actual evacuation techniques proposed for the heads. The chamber used in this test was equipped with an ionization gauge

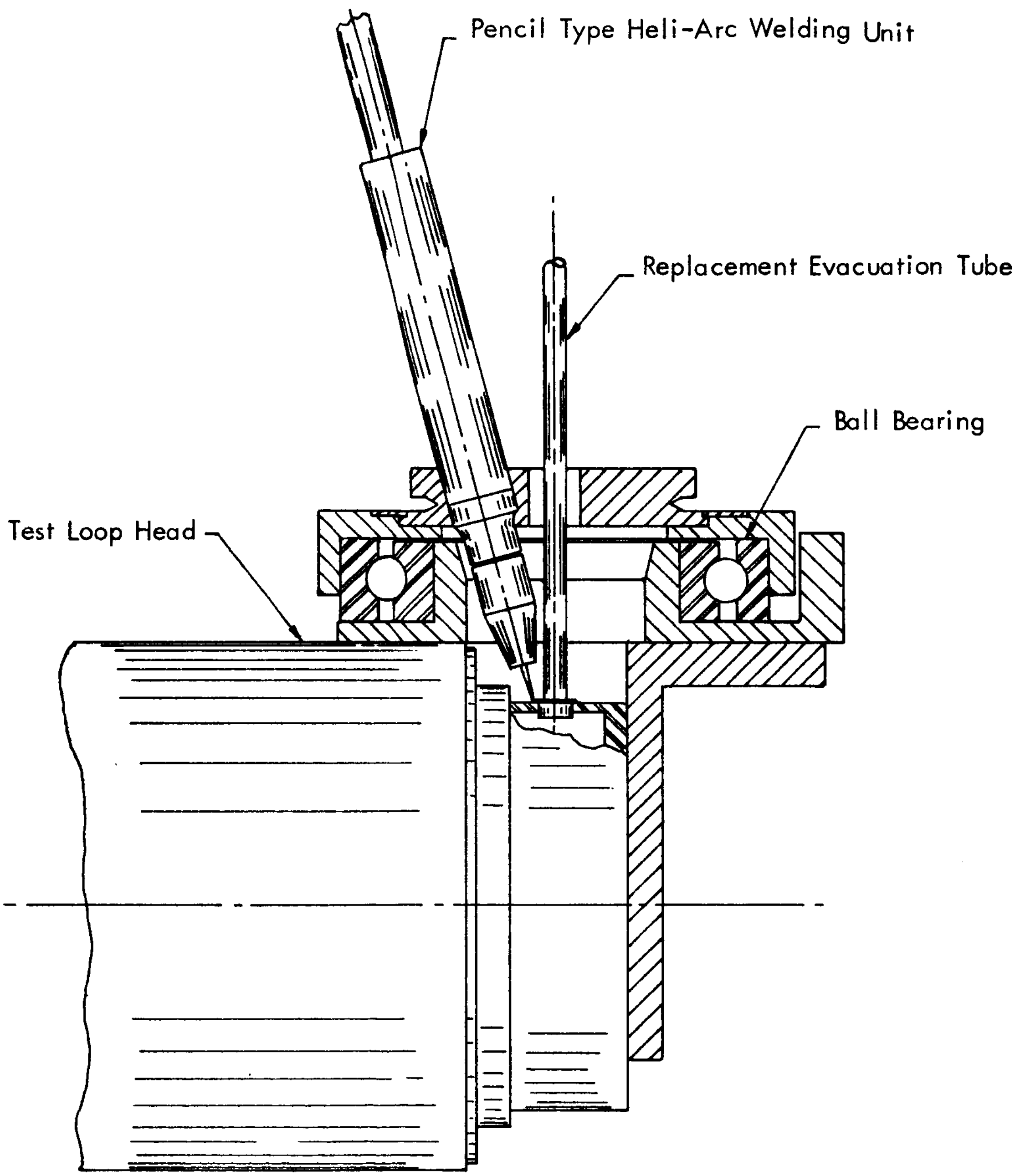


FIGURE 3.2.1 REMOTE HANDLING WELDING FIXTURE
TEST LOOP HEAD EVACUATION TUBE

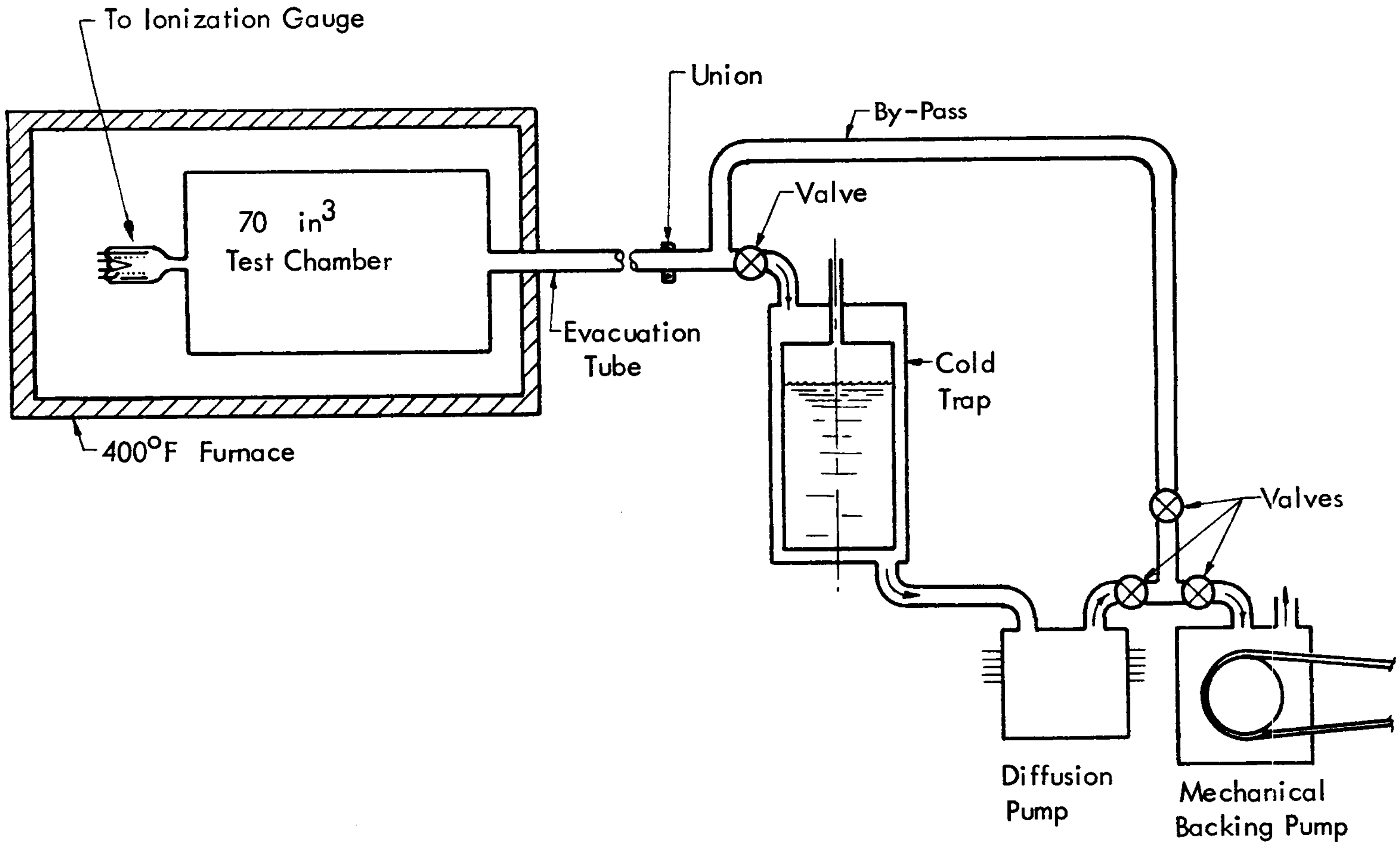


FIGURE 3.3 SCHEMATIC DIAGRAM OF EVACUATION METHOD TEST SYSTEM

welded to the side of the chamber, rather than as shown in Figure 3.3, to permit installation of the chamber in a furnace modified as shown in Figure 3.3.1.

The modification of the bake-out oven, which was a commercially available unit, consisted of fabricating and installing a flush type door and test loop head support cradle track assembly. The former modification was to maintain an elevated temperature in the test head during tube seal-off as well as to eliminate the space required for opening the door so the oven could be placed and used in the hot cave. The latter modification provided the required support and handling characteristics necessary for the remote handling requirements of irradiated test loop heads.

The 1/4 in. OD evacuation tube, about 10 inches in length, was connected to the pumping system union by some five feet of 3/4 in. OD tubing, also to permit installation of the chamber in the furnace. The test chamber was heated to 400°F to accelerate off-gassing and held at this temperature during continuous evacuation for approximately three weeks. The average pressure for the final week and a half of evacuation was 5×10^{-6} mm of Hg, with occasional peaking of the pressure due to off-gassing. The evacuation tube was crimped closed and the pump system shut down. The chamber was then at 400°F with an internal pressure of 3.4×10^{-5} mm of Hg. The evacuation tube was then sealed off by heliarc welding and the chamber allowed to cool to room temperature. The chamber reached room temperature in two hours at a pressure of 2.3×10^{-6} mm of Hg. The chamber pressure was monitored for 52 days, with the results as shown in Figure 3.4.

3.2.2.4 Head Evacuation With Remote Handling

After successful completion of evacuation tube installation, volume evacuation and sealing the evacuation tube on a mock-up basis, re-evacuation of actual heads by remote techniques was undertaken. Head 201-009, which had not been irradiated, was selected to provide a final check-out of the equipment using a head which could, if necessary, be repaired by non-remote methods.

Head 201-009 was machined and equipped with a 1/4 in. OD stainless steel evacuation tube as described above for the mock-up. It was leak tested with a mass spectrometer at room temperature and 400°F and then the head was placed in the modified furnace and held at 400°F during evacuation. However, an indication of a leak developed during evacuation and the head was removed for inspection. Leaks

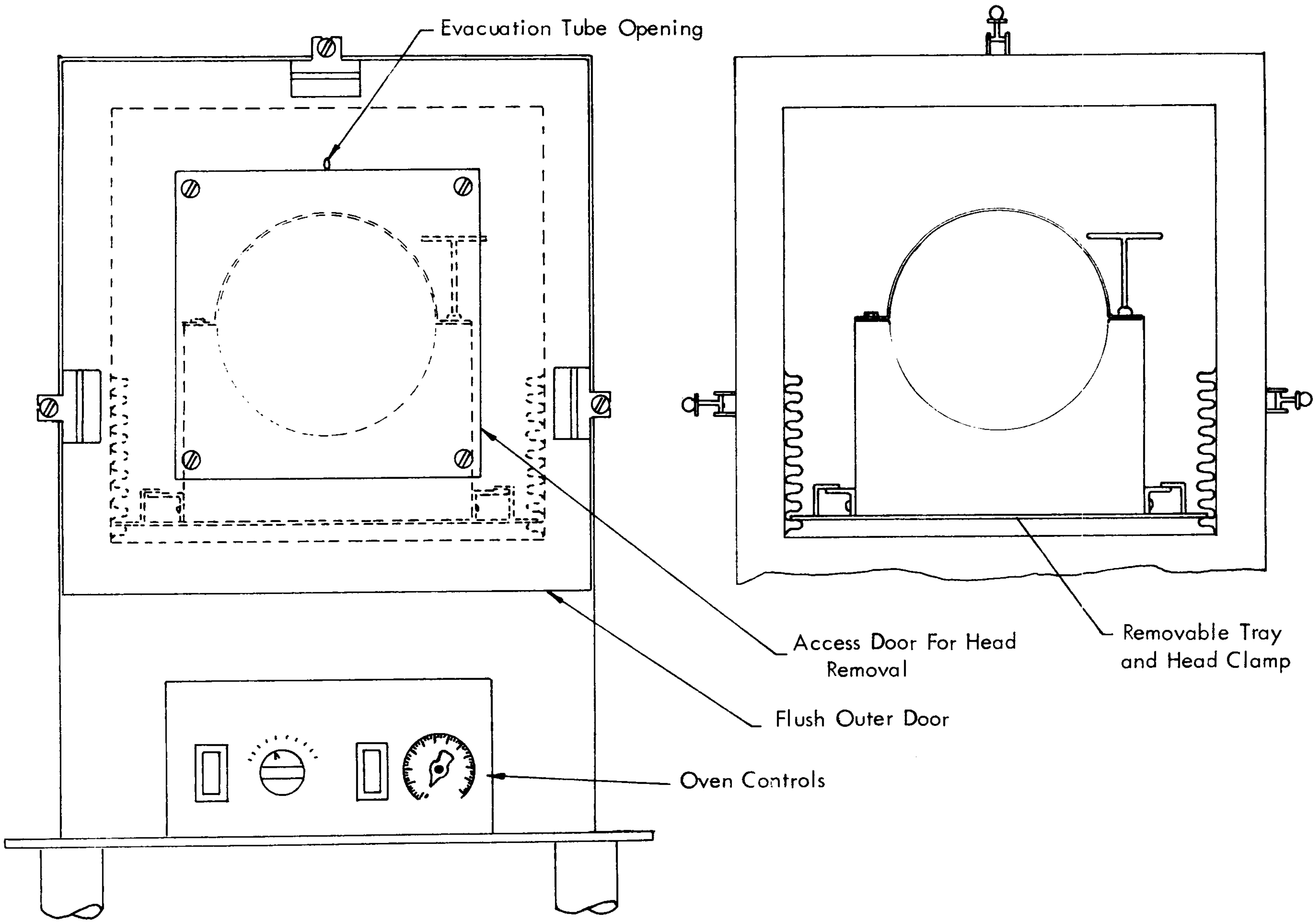


FIGURE 3.3.1 VACUUM BAKE-OUT OVEN MODIFICATION FOR REMOTE HANDLING TEST LOOP HEAD

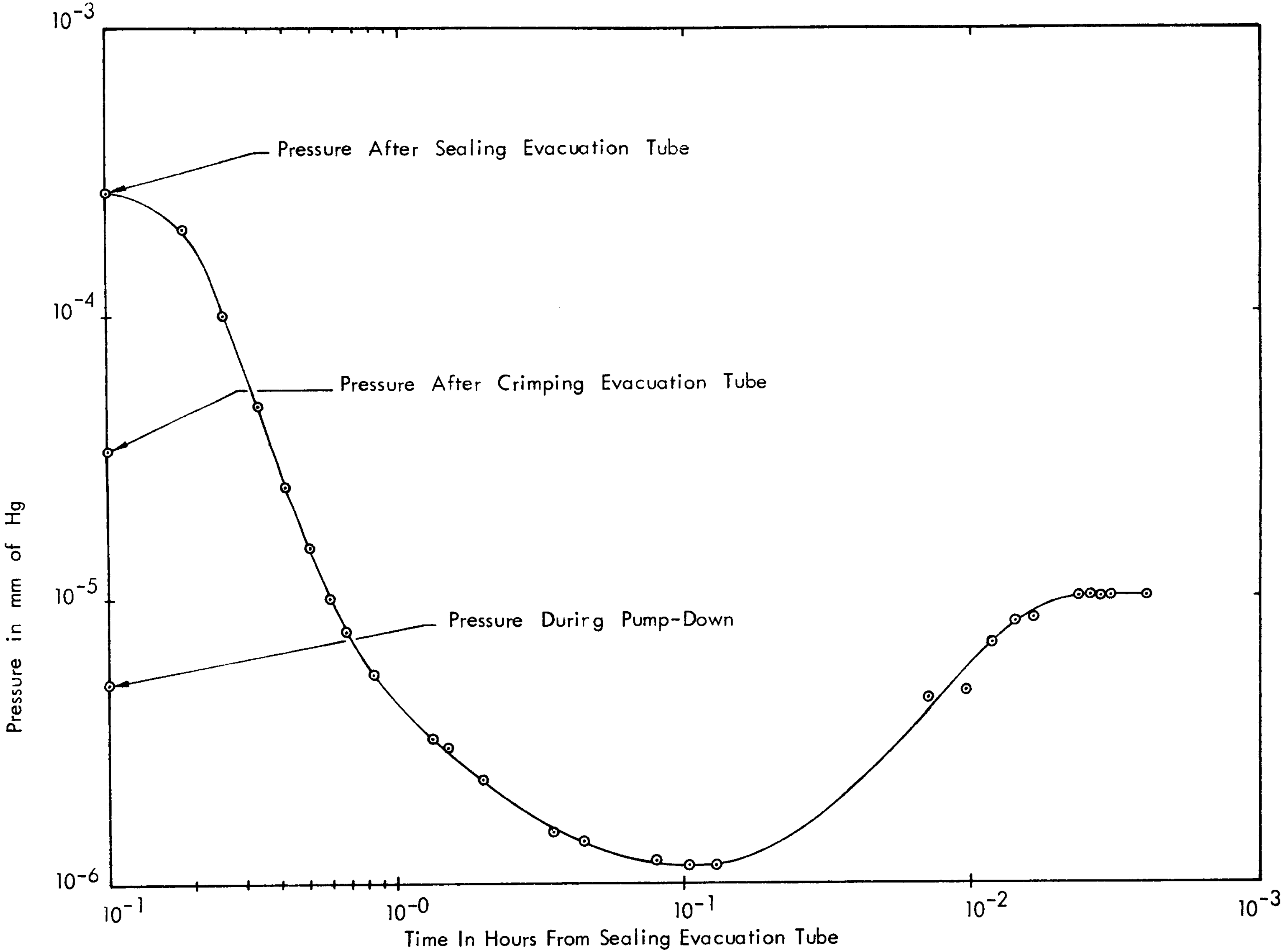


FIGURE 3.4 PRESSURE IN TEST CHAMBER AFTER SEALING EVACUATION TUBE

were discovered in the seating face of the head and were repaired by electron beam welding. The head was then reinstalled in the furnace in the hot cave and the evacuation procedures were resumed. The pressure in the annular space stabilized at 4 x 10^{-6} mm of Hg. The evacuation tube was then crimped and sealed with a heliarc torch. A liquid nitrogen boil-off test was performed immediately after sealing and the 23 in.^{3} volume earlier described was evaporated in 44 minutes. The boil-off test was repeated after four days with no significant difference in the results. This is considered to be an adequate demonstration of the suitability of these techniques for remote evacuation of the annular space of the test loop heads.

Work has been initiated, but not completed, on the evacuation of irradiated heads.

The irradiated test loop head from loop 3 was placed in the hot cave and prepared for re-evacuation. Initially the existing evacuation tube was cut-off using the fixtures previously described. A new evacuation tube was fabricated and placed in the hot cave, and then the welding fixture was attached to the head. The tube was welded into place and subsequently, the head was placed in the bake-out oven and the tube connected to the vacuum table. The head insulating space was evacuated for five days but the pressure would not decrease below 10^{-4} mm Hg indicating a leak. Evacuation was terminated and leak testing initiated. The leak was located in the bellows region of the test loop head. This leak was not evident during pre-evacuation leak testing at room temperature or at 400°F. In addition, the leak could not be detected at room temperature even after the evacuation attempt until the temperature of the cavity was rapidly reduced to 140°R by the use of LN_2.

3.3 INSPECTION AND REPAIR OF TEST LOOPS

As noted in Table 6, Section 3.1, three of the test loops and the associated heads have rather extensive histories of exposure to neutron environments. Since the neutron field attenuates rather rapidly in the primary coolant water, only the forward section of the loop sees a high flux and the head assembly is the principal contributor to test loop activity. Loop 201-002 and head 201-007 were monitored on 24 February 1965 after a total accumulated dose of 19.3 x 10^{17}nvt (thermal). The head had a gamma activity of 160 R/hr; the forward bulkhead measured 22 R/hr with the same monitoring equipment. Thus, the head assemblies contributing some 85 to 90% of the total long half-life isotope activity of the test loops.

A written procedure for transporting the irradiated test loops to a controlled working area in the hot laboratories and performing necessary disassembly and repair work was prepared to insure compliance with Plum Brook Health Safety procedures. The procedure was approved by the NASA Project Engineering Office on 10 May 1965.

In accordance with this procedure, a dummy head was substituted for the irradiated heads on the test loop during transfer and handling to reduce the specific activity of the loop to an acceptable level. With the dummy head installed, the existing transfer cask provided adequate shielding for personnel access aft of the bulkhead with the loop in the position shown in the lower illustration of Figure 3.5. Access to the forward face of the bulkhead was allowable for periods of short duration under continuous Health Safety monitoring.

Each irradiated loop was transferred to the hot laboratory area in accordance with the above mentioned procedure and the solid cover covering the forward portion of the test loop was removed. The dynamometer load cell was removed for replacement. The hydraulic actuator cylinder was removed, decontaminated, disassembled and completely overhauled. All parts were thoroughly inspected and, if necessary, repaired or replaced. New actuator seals were installed and the actuators were reassembled and leak tested.

The interior of each test loop was completely inspected for signs of equipment deterioration. This inspection included testing for leak tightness using a helium mass spectrometer. Leaks were found in the protection tube for the extensometer leads at the aft end of loop 201-002. The faulty section of the tube was replaced with new tubing heliarc welded in place. Reinspection showed no leak in the replacement tube. Leaks were also discovered in the extensometer feed-thrus at the forward bulkhead in both loop 201-002 and 201-004. Initial attempts at replacement of these feed-thrus were only moderately successful due to the difficulty of obtaining a leak free joint between the bulkhead and the feed-thrus in the limited working time permissible at the forward face of the bulkhead. The heat required for joining in the allotted time caused cracking in the ceramic portion of the feed-thrus. This was overcome by prefabricating a leak free joint between a stainless steel extension tube and the feed-thru. This permitted installation on the loop with the soldering heat remote from the ceramic portion of the feed-thru. A satisfactory joint could then be obtained between the extension tube and the bulkhead.

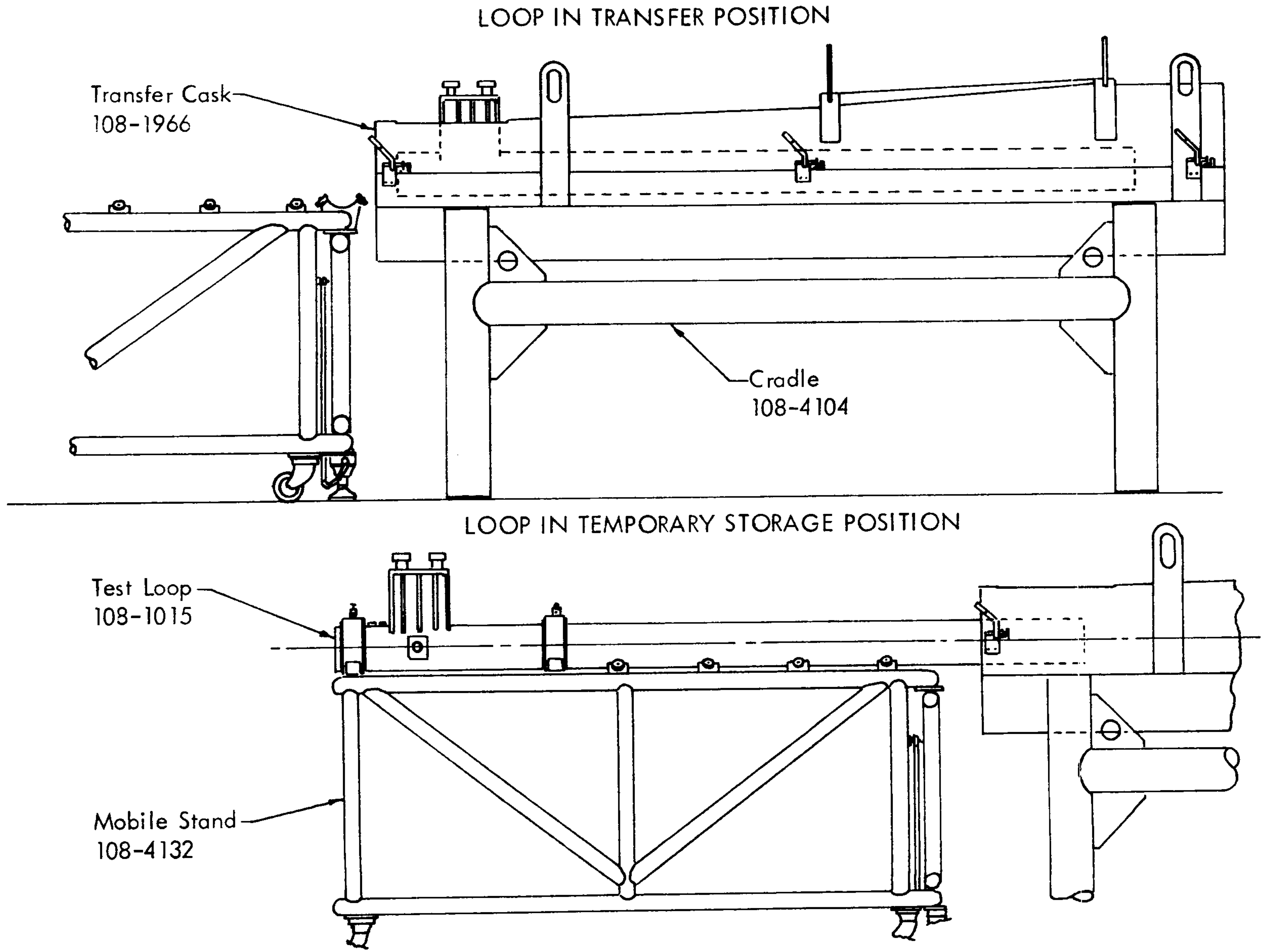


FIGURE 3.5 TEST LOOP TRANSPORT AND TEMPORARY STORAGE ARRANGEMENT

The dynamometer and actuator were reinstalled and all joints were leak checked. The system was given an operational check-out and the solid cover and dummy head replaced. The test loop was then returned to Quadrant "D" following the approved procedure.

One of the loops, loop 201-002, was found to have a cracked carbon alignment bushing at the forward end of the pull rod. Since the replacement of this bushing required more time that would be feasible for personnel exposure at the forward face of the bulkhead, this was done by remote techniques in the hot cave.

Special tooling was designed and fabricated to remotely remove the cracked bushing and install a new bushing.

The three irradiated test loops - 201-002, 201-003 and 201-004 - are now considered to be equivalent to their original operational condition.

3.3.1 Dynamometer Calibration

The load sensing dynamometers were removed from test loops 2, 3 and 4 and replaced with dynamometers that had been previously calibrated. In addition, the dynamometer which was removed from loop 2 was recalibrated as a check on the performance of the dynamometers as used in the recently completed test phase of Contract NASw-114.

The dynamometer rings of those removed from loops 2 and 4 were severely pitted which may affect the mechanical action of the ring and consequently the characteristics of the transducer.

Dynamometer number 177 which had been used since February of 1964 was considered representative of all the dynamometers that were used throughout the testing program and was recalibrated as a check on the calibration which was made in February of 1964 and used in the reduction of the test program data. The remaining dynamometers were not recalibrated, primarily due to their high level of contamination.

Three dynamometers which had been rebuilt were calibrated, as has been the practice of calibrating components prior to their use.

These dynamometers were calibrated (or recalibrated) in tension against a Morehouse proving ring which had been calibrated earlier by the National Bureau of Standards. The load source was an Instron tensile testing machine and the test set-up is shown in Figure 3.6. The calibrations were over the range 0-5000 pounds and the sensitivities of the dynamometers were established in mv/lb.

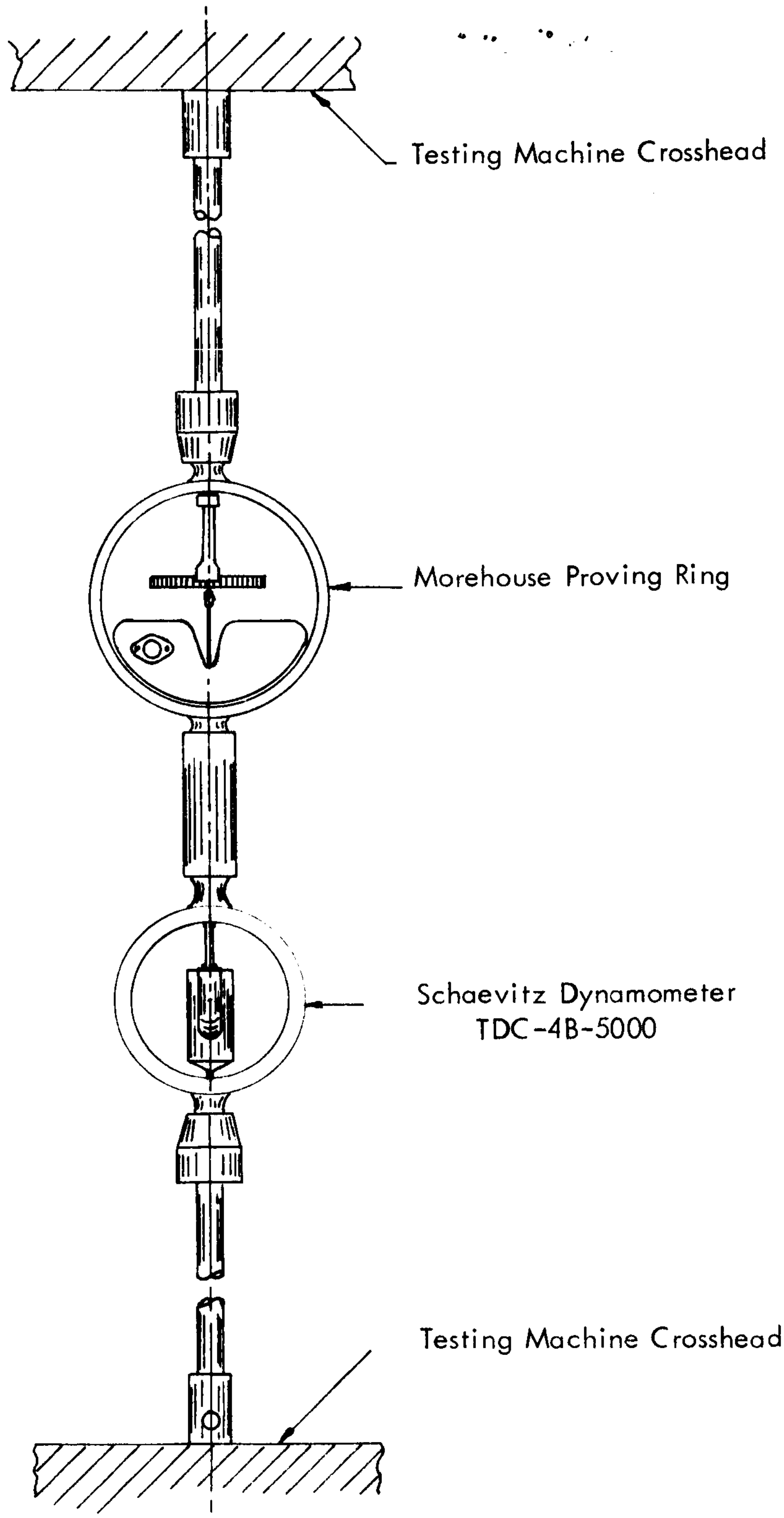


FIGURE 3.6 LINKAGE FOR SERIES CALIBRATION OF LOAD SENSING TRANSDUCER (TENSION)

The detailed procedure for the dynamometer calibrations was as follows:

1. Decontaminate dynamometers.
2. Decontaminate electronic test equipment.
3. Move dynamometers and test equipment to Instron in hot cell area.
4. Check out Morehouse Proving Ring.
5. Make test set-up carefully centering in Instron.
6. Take no-load reading on proving ring.
7. Carefully apply test load to test set-up with the Morehouse ring set to include the no-load connection.
8. Calibrate test equipment.
9. Record mv deflection.
10. Increase load taking readings at approximately 200 lb. intervals to 5000 lbs.
11. Repeat with decreasing loads.
12. Repeat with various appropriate recorder ranges.

The recalibrated sensitivity of dynamometer number 177 is 9.99 lb/mv compared with the previous calibration of 10.24 lb/mv which was obtained with a different Morehouse ring under somewhat different test conditions. The difference between the old and new calibration is well within the range of test values generally experienced in dynamometer calibrations and is not of statistical significance at a reasonable confidence level.

The sensitivity of the dynamometers was established from fitting the calibration data to a linear equation by the method of least squares.

The standard deviations in the calibration data are indicated in Table 7. They were established as follows:

$$S = \sqrt{\frac{\sum_{i=1}^{N} \left(X_i - \bar{X}\right)^2}{N - 1}}$$

where: X_i = value of each calibration point

$\bar{X}$ = value established by least squares method

The data from the new dynamometers indicate a negligible non-linearity in the various full scale voltage settings, with the sensitivity decreasing at the higher voltages. The cause of the variation of the sensitivity with load may be either mechanical or electrical but is not of a magnitude to warrant further investigation.
Altogether, the test data indicate that satisfactory performance from these dynamometers can be expected. However, as a precaution against possible changes due to the rather severe operating environment, it would be desirable to recalibrate the dynamometers after approximately a year in operation.

The new and old dynamometer locations in the test equipment under consideration are indicated in Table 7 along with the new dynamometer calibrations.

TABLE 7

DYNAMOMETER LOCATIONS AND CALIBRATIONS

Test Loop	Old Dynamometers	New Dynamometer and Tension Calibration		Standard Deviation	
2 (201-002)	177	M 1	12.53 lb/mv	M 1	0.072 lb/mv
3 (201-003)	179	M 2	9.85 lb/mv	M 2	0.061 lb/mv
4 (201-004)	178	M 3	10.79 lb/mv	M 3	0.104 lb/mv

All of the dynamometer calibration data is shown in Appendix B. Table 4 in this appendix shows the recalibration data for dynamometer number 177. Tables 1 a, 1 b, 1 c; 2 a, 2 b, 2 c and 3 show the data for dynamometers M 1, M 2 and M 3. Table 5 shows the Morehouse ring calibration data from the National Bureau of Standards.

4 TRANSFER SYSTEM - GENERAL

The equipment incorporated into the transfer system of the test facility includes the transfer tables, the test loop carriages and the valves used as access ports in the reactor beam port and hot cave. Peripheral seals compatible with the outside diameter of the test loop are incorporated into the remotely actuated gate valves used for this application. These seals isolate the reactor primary coolant water from the quadrant and the quadrant water from the hot cave working area when the test loop is inserted into the reactor or hot cave respectively.

The transfer tables permit the alignment of the test loop carriage with the appropriate access port for insertion or any track of one table with any track on the other table for transfer of the loop from one table to the other. The north table is also capable of rotating to properly orient the carriage assembly for insertion into the hot cave or transfer to the south table for eventual insertion into the reactor beam port. The carriage transfer is accomplished with a dual double acting hydraulic cylinder arrangement which is connected to a rack which rotates a pinion gear attached to a transverse shaft located as shown in Figures 4.1 and 4.2. Engagement of a hydraulically actuated clutch mechanism will permit the rotation of a gear on the selected track which will, in turn, engage the fixed rack on the bottom of the carriage to transport the carriage longitudinally from one table to the other. The tables as shown in Figures 4.1 and 4.2 have fixed stops and hydraulically actuated carriage stops to permit accurate positioning of the carriages on the tracks. In addition, hydraulically actuated track alignment stops are provided to permit selective track alignment when traversing the table. Fixed stops are also provided to limit the tranverse motion and on the north table fixed stops are incorporated to limit rotational travel. Rotation of the north table is accomplished by the application of a remotely operated linear hydraulic actuator connected to a chain sprocket arrangement attached to a rotating table support stanchion.

The maintenance effort in the transfer system was initially directed toward the overhaul or replacement of that hydraulic equipment associated with this system that is

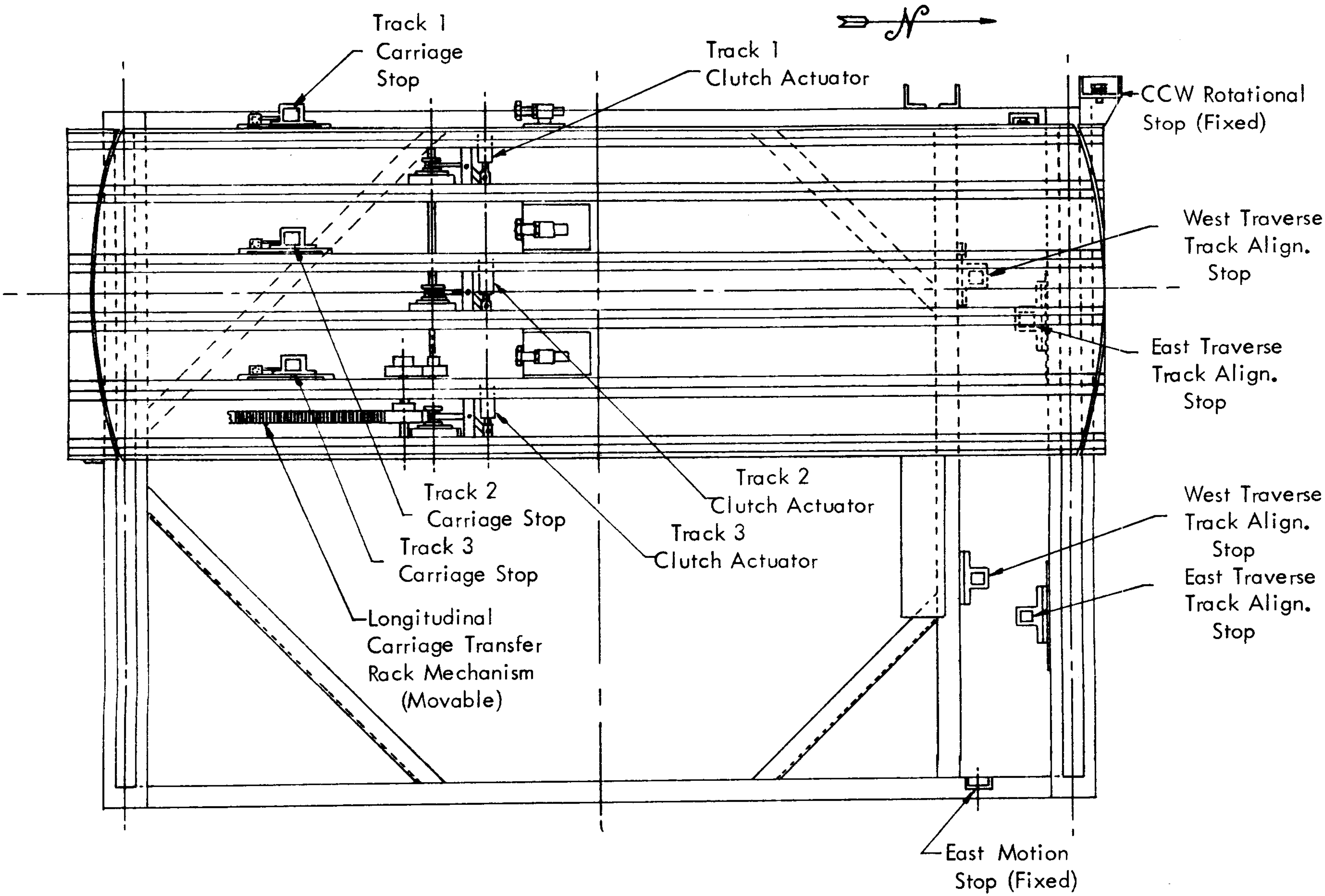


FIGURE 4.1 TRANSFER SYSTEM NORTH TABLE - PLAN VIEW

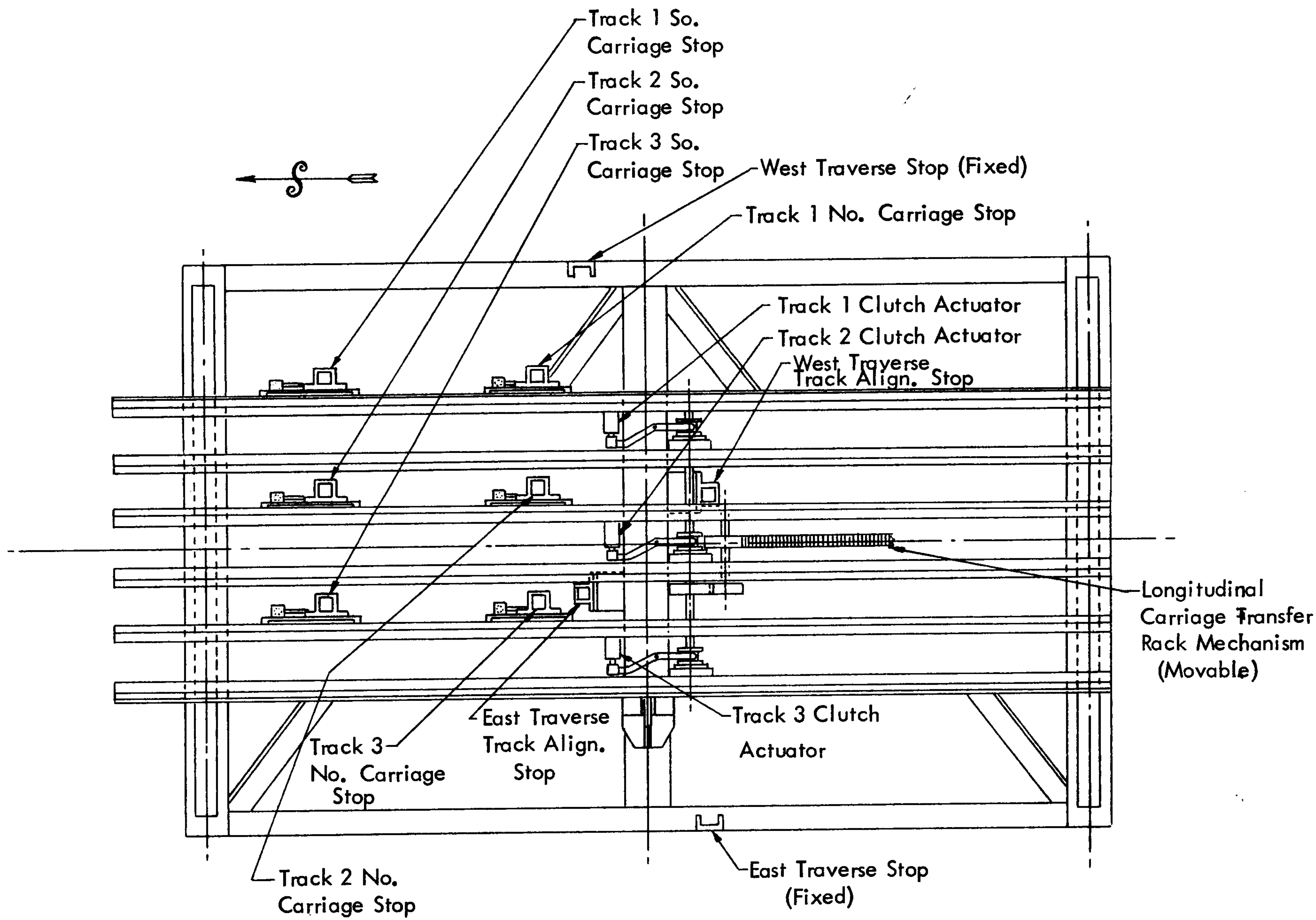


FIGURE 4.2 TRANSFER SYSTEM SOUTH TABLE - PLAN VIEW

normally submerged in approximately 20 feet of water when the reactor is in operation. It is apparent that maintenance periods exist only when the quadrant is drained.

4.1 TRANSFER TABLE MAINTENANCE

The system includes all the necessary tubing and fittings associated with the operation of:

15 double acting hydraulic actuators for the table stops.

6 double acting hydraulic actuators for clutch mechanism operation

4 double acting hydraulic actuators for the longitudinal carriage transfer

2 double acting hydraulic actuators for transverse motion of the table

1 double acting linear actuator for table rotation

The relative positions are shown in Figures 4.1 and 4.2.

Inspection and testing of this tubing was performed and all that appeared to be leaking or damaged was replaced and subsequently leak tested. In addition, the hydraulic actuators were removed from the table stops, clutch mechanism and longitudinal carriage transfer system. Each was disassembled, when possible, inspected and all seals replaced. When corrosion seizure of parts prevented disassembly, the actuators were replaced. All repaired actuators were reassembled and leak tested with the replacement units. They were subsequently reinstalled in the system and the system was then leak tested.

Actuators replaced are as follows:

4 longitudinal carriage transfer actuators

South table track 3 clutch actuators
North table track 1 clutch actuator
North table track 2 clutch actuator
North table track 3 clutch actuator

The longitudinal carriage transfer actuators were replaced with units fabricated from stainless steel to minimize the external corrosion evident on the assemblies that were removed. The clutch actuators that were replaced, could not be disassembled due to corrosion seizure of the caps and snap-rings which held them in place.

The actuators that are used for transverse movement of the tables and rotation of the north table were not removed but were disconnected, inspected and tested in place.

After reassembly of the transfer table systems and the adjustment of the limit switches, they were performance tested and operated satisfactorily.

The limit switches associated with this part of the transfer system are an important element in the proper operation of the remotely controlled operations, yet by their very nature of required sensitivity, are susceptible to misalignment or damage when maintenance is performed in the quadrant. It has, therefore, become a standard practice to determine proper operation of these switches any time the quadrant is drained and personnel enter the quadrant.

The inspection and test of these switches is normally performed just prior to the time the quadrant is refilled.

4.2 TEST LOOP CARRIAGES - GENERAL

There are 4 test loop carriage assemblies in the test facility. The purpose of the carriage as shown in Figure 4.3 is to support the test loops on the transfer tables and contain a coupling ring for positive connection to the coupling mechanism on the hot cave and beam port access valves. They also provide a worm screw drive system powered by a hydraulic motor to insert and withdraw the test loop from either the beam port or hot cave. The lead screw is maintained in tension throughout the insertion or withdrawal of the test loop. The loop is positioned in a yoke by a trunnion and the yoke is supported on track-guided, needle type bearings. These bearings support and guide the test loop when it is inserted into the hot cave or beam port position. The yoke bearing arrangement is designed to sustain the moment that is applied during insertion of the loop against the primary water pressure.

Initially the bearing races were fabricated from a type 440C stainless steel, which

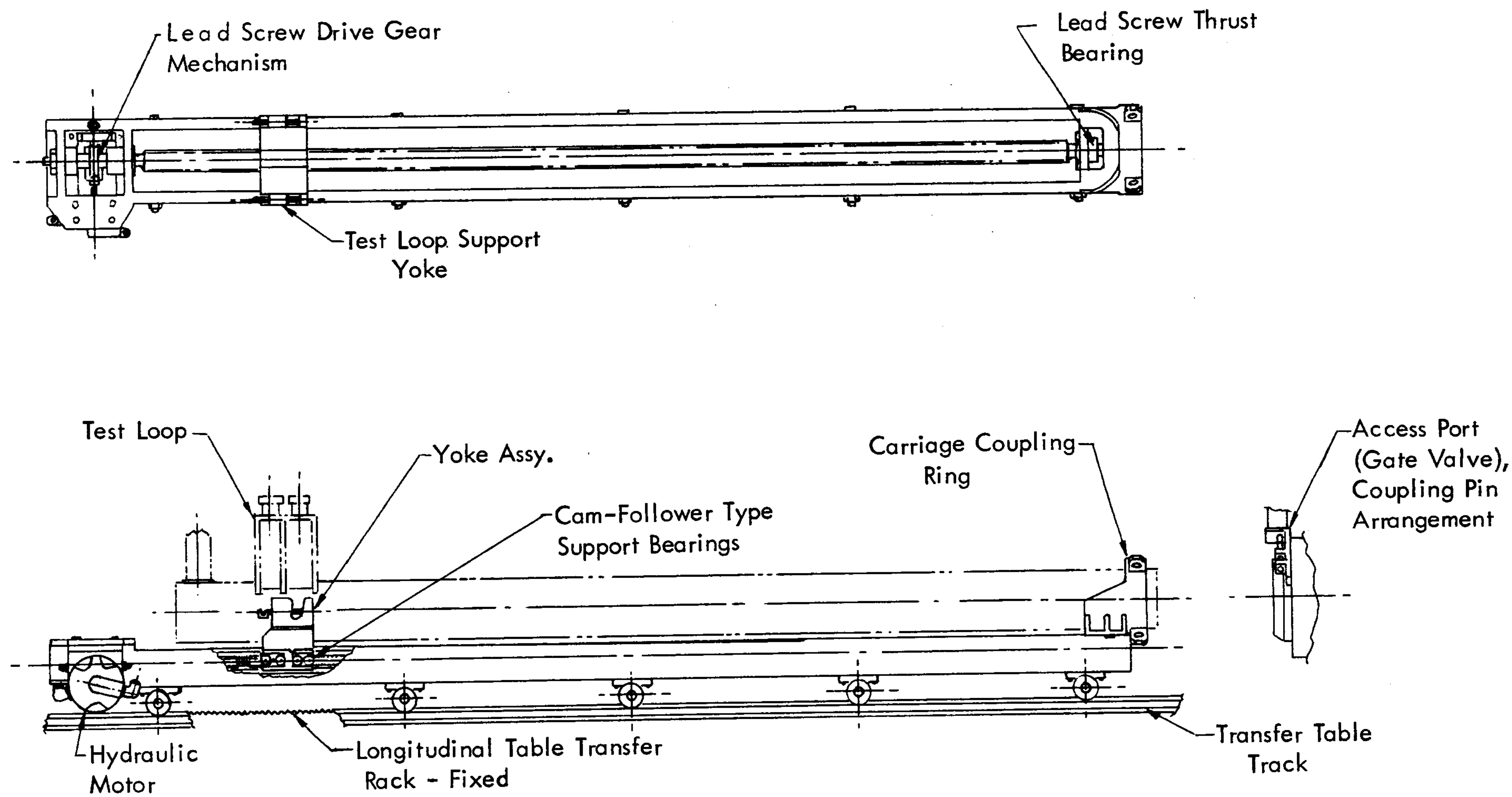


FIGURE 4.3 TEST LOOP CARRIAGE ASSEMBLY

had a short service life and high failure rate due to the inability of this rather brittle material to absorb localized over-loading through microscopic plastic flow. Subsequently, a 18 Ni (300) maraging type steel was substituted eliminating the high failure rate and consequently extended the operating life of the bearings. These bearings, however, are still subjected to the effects caused by foreign material in the quadrant water and by surface corrosive attack from quadrant water and must, therefore, be frequently inspected. The drive system which operates without normal lubrication is also subjected to similar effects and must be inspected frequently.

It is evident that only the carriage supporting the test loop that is in the test position is essential for performing the test. Considering this, provisions for removal and temporarily storing the loop on any carriage was made together with the establishment of procedure for removing the carriage even though the quadrant is filled.

This permits maintenance and inspection of the carriage assemblies, without disrupting the scheduled testing. It also permits the interchange of the carriage assembly if an unanticipated failure should occur in the carriage supporting the test loop to be used. This can be accomplished in a relatively short period of time, thus minimizing the possible loss of available reactor test time.

4.2.1 Test Loop Carriage Maintenance

Each of the carriage assemblies was removed from the quadrant for disassembly, inspection and overhaul during the maintenance program. The maintenance performed is shown on Table No. 8.

4.3 HYDRAULIC PANEL - GENERAL

The hydraulic panel contains the following pump systems:

12.0 GPM (1000 psig)	axial piston pump for the operation of the transfer system
2.46 GP Hr. (500 psig)	diaphragm type pump for maintaining a positive seal pressure
235 cc/hr. (1000 psig)	positive displacement type pump to operate test loop specimen loading actuator.

TABLE 8

TEST LOOP CARRIAGE MAINTENANCE PERFORMANCE

Carriages	001	002	003	004
Thrust Bearings	⊠	⊠	⊠	⊠
Cage Assemblies	△	△	△	△
Outer Race	⊕	⊕	⊕	⊕
Inner Race	⊕	⊕	⊕	⊕
Needle	⊠	⊠	⊠	⊠
Housings	△	△	△	△
Shafts	△	△	△	△
Worm Gear	⊕	⊕	⊕	⊕
Worm	⊠	⊠	⊕	⊕
Gear Alignment	✓	✓	✓	✓
Hydraulic Motor	◇	◇	◇	◇
Lead Screw	✓	✓	✓	✓

⊕ Replaced

⊠ Inspected

△ Zyglo Inspected

◇ Stall Tested

✓ Performed Inspection & Alignment

In addition to these pump systems, the de-ionized water reservoir and distribution manifolds with the remotely operated valves are also located in the panel.

4.3.1 Hydraulic Panel Maintenance

Initially the axial piston pump was overhauled, replacing the seals and inspecting pump components; subsequently, the positive displacement pump was disassembled, inspected, cleaned and reassembled. The manually operated three-way valves, incorporated in the system to provide tensile-compression capabilities were also disassembled, inspected and cleaned. This pump system was then reassembled and leak tested to assure the system integrity.

The diaphragm pump system was inspected and tested in-place with no evidence of leakage.

The manifold and distribution system was inspected and the following four way-two position spool valves were leaking abnormally and they were replaced by rebuilt valves. These valves have a history of repetitive failure due to body erosion and constant inspection and test is required to assure continuous adequate performance of the distribution system. Various valves considered suitable for this application have been investigated to determine their suitability and warranty of service, but the extent of system modification required to replace the present valves has dictated the refurbishment of present valves as an overall cost saving. The following list of valves are those that were replaced during this maintenance period.

SV-15	Hot Cave Couple Pin Actuator Valve
SV-21	North Table Rotational Drive Valve
SV-32	North Table Track 3 Clutch Actuator Valve
SV-33	South Table Track 1 Clutch Actuator Valve
SV-34	South Table Track 2 Clutch Actuator Valve
SV-35	South Table Track 3 Clutch Actuator Valve
SV-38	South Table No. 2 North Stop Actuator Valve
SV-41	South Table No. 3 South Stop Actuator Valve
SV-45	North Table No. 3 South Stop Actuator Valve
SV-47	North Table No. 1 East Stop Actuator Valve

4.3.2 Manipulator Repair

The two manipulators, incorporated in the hot cave installation, are used for the specimen change-over during a reactor test cycle. These units are normally removed from their mounting port holes in the hot cave for extensive maintenance to permit access for disassembly, inspection and repair. Special precautions were taken in the performance of this task to prevent the spreading of contamination. The floors of the work area were covered and the removal and disassembly operation was monitored by a member of the HSOO. The external surfaces were carefully cleaned and the manipulators were then disassembled. All tapes were carefully inspected as were the master and slave wrist assemblies. Gears were inspected for evidence of wear. Tape rollers were completely disassembled and inspected and faulty bearings were replaced.

The manipulators were then reassembled with appropriate lubrication and reinstalled into the hot cave ports.

5 RELIABILITY EVALUATION AND MAINTENANCE SCHEDULE

To establish the maintenance schedule, a typical test irradiation cycle was developed as shown in Figure 5.1 which indicates the operational time required for various systems used in the test facility. The fourteen hour irradiation time was an average test period used during the preceeding test program; however, this will vary relative to test requirements and the systems that operate throughout the irradiation phase of the cycle will vary accordingly. The precooling requirement, as indicated, is the mean time required during previous test cycles and it will not exist beyond the first test irradiation period unless the refrigerator is shut down and the system permitted to warm-up.

It is evident that the operating requirements for the refrigerator system are paramount in the performance of any low temperature test program. The emphasis of this maintenance requirement study is therefore centered around the refrigerator while still recognizing that the other facility equipment is essential.

5.1 RELIABILITY ANALYSIS

The reliability analysis as shown in Table 9, considers only the performance probability of the refrigerator engine assembly (Figure 5.2) and the determination of mean time between failure (MTBF) of individual engine components.

The compilation of this information as shown in Figure 5.3 and Tables 10, 11, 12, 13, 14 and 15, provides a suitable guide for a maintenance schedule. Some of the assumptions made in the data compilation are:

> "O" rings were replaced each time the engine was disassembled.
>
> The replacement of a piston rod, when inspection indicated failure was incipient, was considered as a piston rod failure.

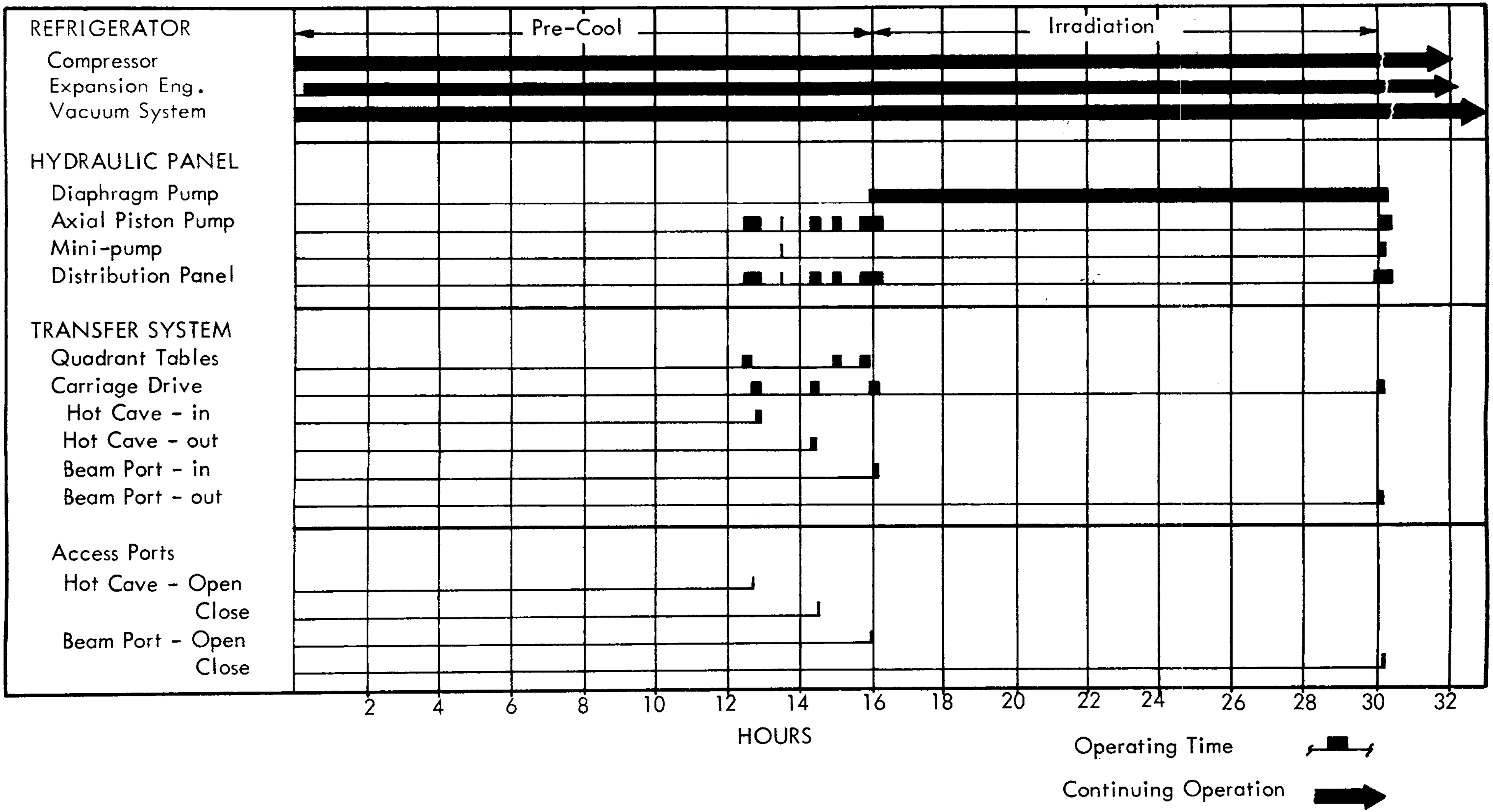


FIGURE 5.1 EQUIPMENT OPERATION TYPICAL IRRADIATION TEST CYCLE VS. HRS.

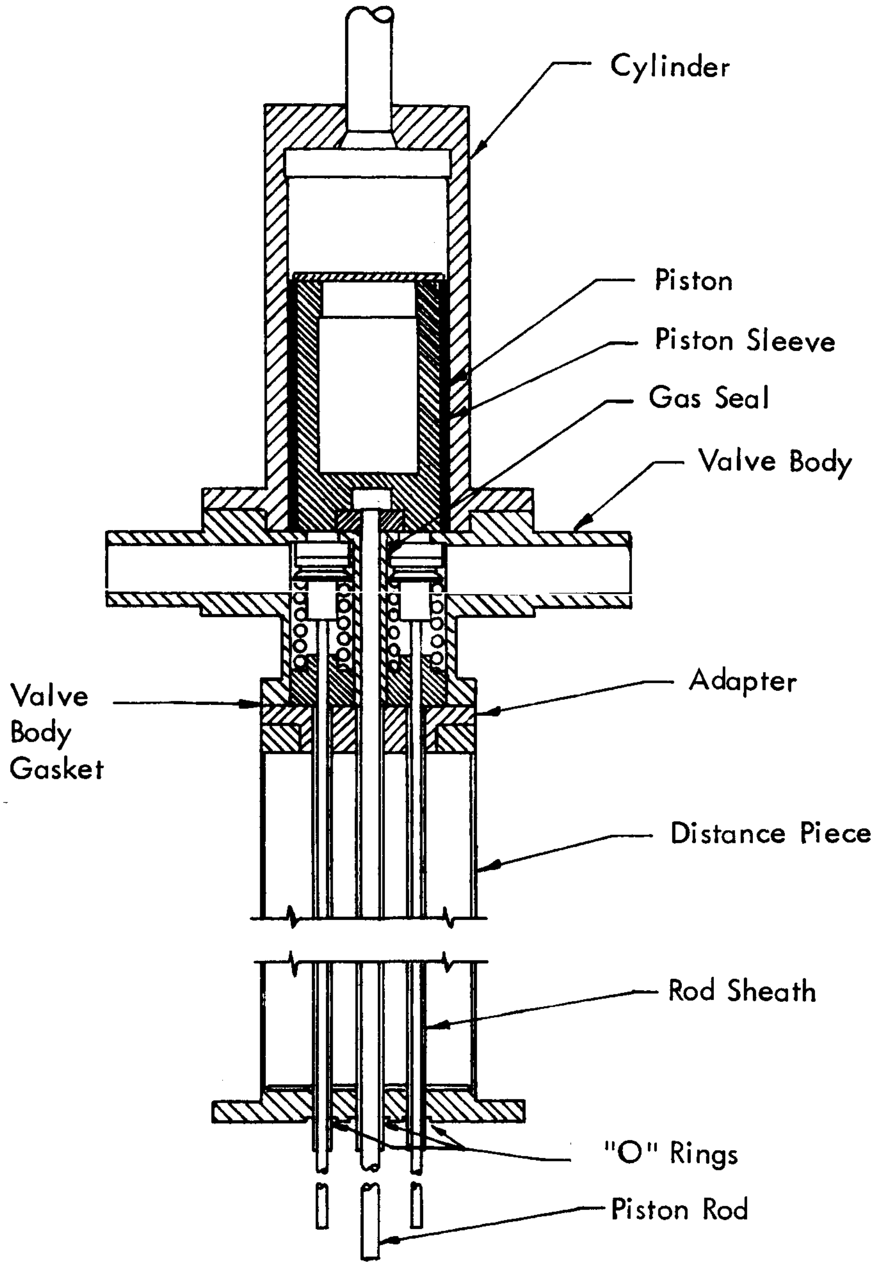


FIGURE 5.2 EXPANSION ENGINE

TABLE 9

SUMMARY - EXPANSION ENGINE COMPONENT FAILURE HISTORY

	MTBF (Hrs)
"O" Rings	399.7
Valve Body Gaskets	428.5
Piston Rod	1622.8
Inlet Valve	2061.0
Gas Seal - Piston	2156.1
Piston Sleeve	1716.4
Cylinder*	2719.0
Exhaust Valve	2918.1
Items with only one failure time recorded:	
Sheath Assembly	4163.0
Distance Piece	4163.0

* This component was replaced when the piston and leather sheath were replaced with a piston using a plastic sheath

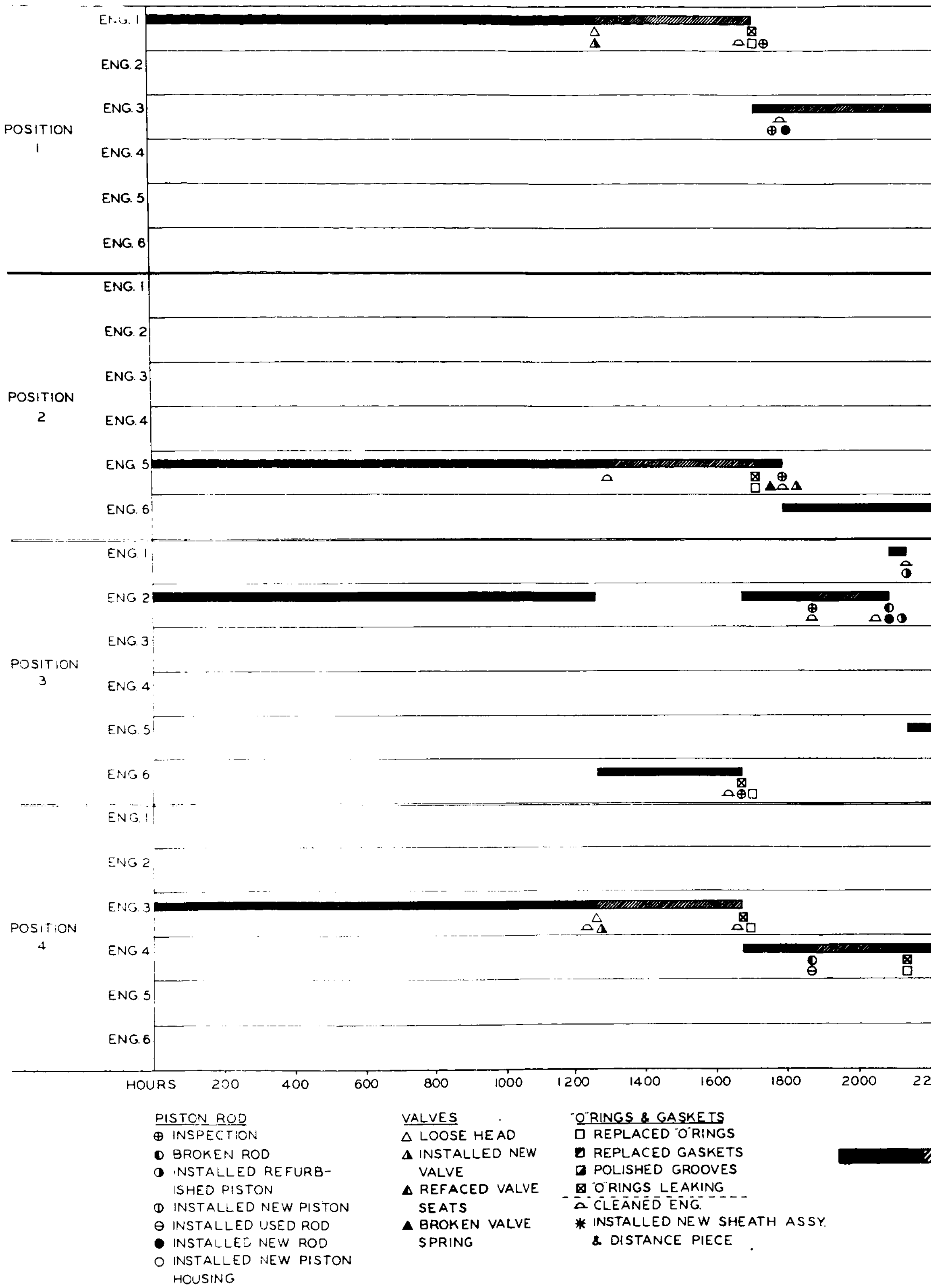
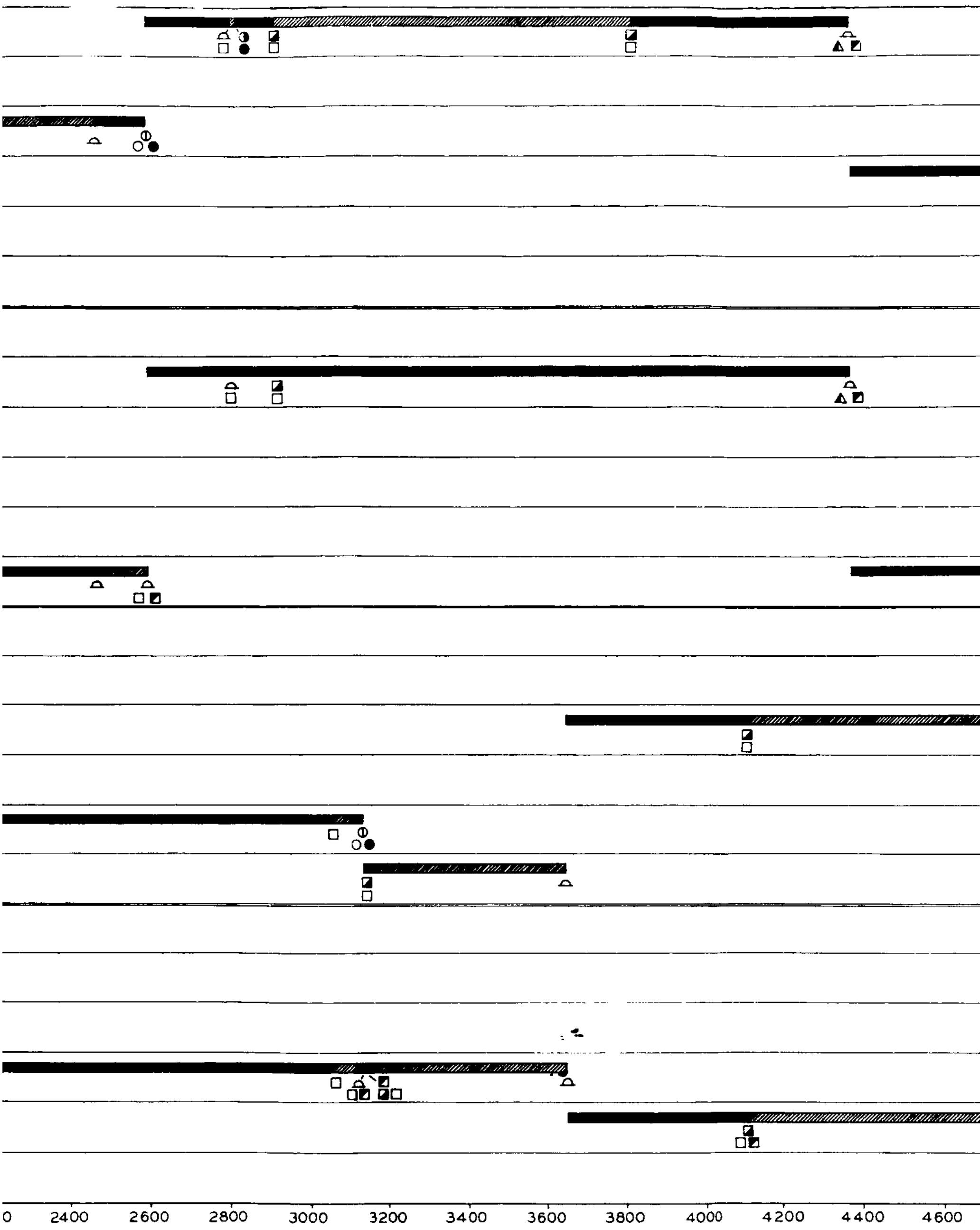

POSITION 1
POSITION 2
POSITION 3
POSITION 4
ENG. 1
ENG. 2
ENG. 3
ENG. 4
ENG. 5
ENG. 6
HOURS 200 400 600 800 1000 1200 1400 1600 1800 2000
PISTON ROD
INSPECTION
BROKEN ROD
INSTALLED REFURB-ISHED PISTON
INSTALLED NEW PISTON
INSTALLED USED ROD
INSTALLED NEW ROD
INSTALLED NEW PISTON HOUSING
VALVES
LOOSE HEAD
INSTALLED NEW VALVE
REFACED VALVE SEATS
BROKEN VALVE SPRING
O RINGS & GASKETS
REPLACED O RINGS
REPLACED GASKETS
POLISHED GROOVES
O RINGS LEAKING
CLEANED ENG.
INSTALLED NEW SHEATH ASSY. & DISTANCE PIECE

FIGURE 5.3



Periods of engine operation, between maintenance, in a position is presented graphically by the change in bar gradation.

ENGINE PERFORMANCE HISTORY VS. HRS. OF OPERATING TIME

2

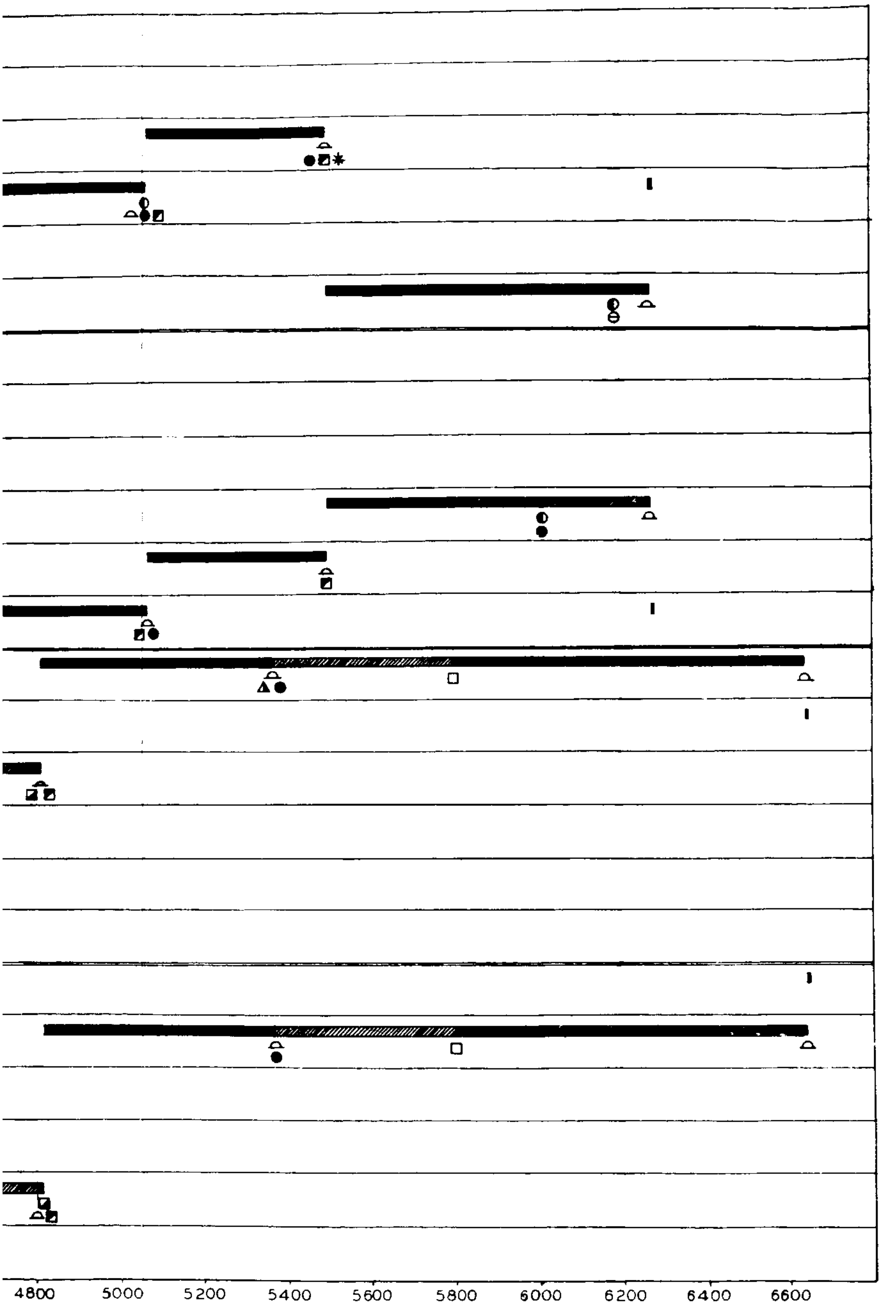

4800
5000
5200
5400
5600
5800
6000
6200
6400
6600

TABLE 10

FAILURE HISTORY EXPANSION ENGINE NO. 1

Cumulative Operating Time - Hrs.	
0.0	
1270.8	Inlet valve failure
1711.5	"O" ring failure
1760.5	Piston sleeve replacement
1976.0	"O" ring failure
1988.0	Piston rod failure
2075.0	"O" ring failure
2974.0	"O" ring failure
3526.5	Valve faces worn, gas seal replaced
4086.0*	Valve faces worn (re-faced valves) & piston rod failure (incipient)
4512.5	"O" ring failure
5354.0	Inspection, cleaning and re-assembly
5363.5	Time at end of Contract NASw-114

Time of Component Failures

Exhaust Valve	Inlet Valve	"O" Rings	Piston Sleeve	Piston Rod	Gas Seal
3526.5	1270.8	440.7	1760.5	1988.0	3526.5
	2255.7	215.5		2098.0	
		87.0			
		899.0			
		426.5			

"O" rings replaced each time engine removed

* Original failure considered only

TABLE 11

FAILURE HISTORY EXPANSION ENGINE NO. 2

Cumulative Operating Time-Hrs.	
0.0	
1262.8	Engine removed and cleaned
1460.8	Engine cleaned, piston rod ultrasonically inspected (Okay)
1672.3	Piston rod failure - Piston sleeve replaced
1887.8	"O" ring failure
1986.8	"O" ring and valve body gasket failure
2885.8	"O" ring failure
3438.3	Valve failure, gas seal replaced
3997.8	Piston rod failure
4424.3	"O" ring failure
5265.8	Inspection, cleaning and re-assembly
5275.3	Time at end of Contract NASw-114

Time of Component Failure

Exhaust Valve	Inlet Valve	"O" Rings	Piston Sleeve	Piston Rod	Gas Seal	Body Gasket
3438.3	3438.3	215.5	1672.3	1672.3	3438.3	314.5
		99.0		2325.5		
		899.0				
		426.5				

"O" rings replaced each time engine removed

TABLE 12

FAILURE HISTORY EXPANSION ENGINE NO. 3

Cumulative Operating Time - Hrs.	
0.0	
1262.8	Valve failure - inlet
1674.5	"O" ring failure
1752.5	Piston rod inspection (failure incipient)
2433.0	Cleaned engine
2561.0	Piston and rod failure
3034.5	"O" ring failure
3734.0	"O" ring failure, gas seal replaced
4163.0	Piston rod failure, gas seal replaced, sheath assy. and distance piece
4163.0	Time at end of Contract NASw-114

Time of Component Failure

Inlet Valve	"O" Rings	Piston Rod	Piston	Gas Seal	Distance Piece	Sheath Assy.
1262.8	411.7	1752.5	2561.0	3734.0	4163.0	4163.0
	473.5	808.5		429.0		
	699.5	1602.0				

"O" rings replaced each time engine removed

TABLE 13

FAILURE HISTORY EXPANSION ENGINE NO. 4

Cumulative Operating Time-Hrs.	
0.0	
198.0	Piston rod failure
458.5	"O" ring failure
1388.0	"O" ring failure
1459.5	"O" ring failure, gas seal replaced
1468.0	"O" ring failure
1967.5	Removed for cleaning
2664.5	Piston rod failure, gas seal replaced
3178.5	Piston rod failure
3447.0	Removed for inspection - re-installed
3456.5	Time at end of Contract NASw-114

Time of Component Failures		
Piston Rod	"O" Rings	Gas Seal
198.0	260.5	1459.5
2466.5	929.5	1205.0
514.0	71.5	
	8.5	

"O" rings replaced each time engine removed

TABLE 14

FAILURE HISTORY EXPANSION ENGINE NO. 5

Cumulative Operating Time-Hrs.	
0.0	
1270.8	Cleaned engine
1711.5	"O" ring failure
1789.5	Exhaust valve failure-Piston rod ultrasonically inspected (Okay)
2719.0*	Piston failure, cylinder replaced, piston rod failure (incipient)
3261.5	"O" ring and valve body gasket failure
3960.5	"O" ring failure, gas seal replaced
4389.5	Gas seal replaced
4389.5	Time at end of Contract NASw-114

Time of Component Failures

Exhaust Valve	"O" Rings	Piston	Cylinder	Piston Rod	Gas Seal	Body Gasket
1789.5	440.7	2719.0	2719.0	2719.0	3960.5	542.5
	542.5				429.0	
	699.0					

"O" rings replaced each time engine removed

* Cylinder replaced due to change from leather piston sheath to plastic sheath.

TABLE 15

FAILURE HISTORY EXPANSION ENGINE NO. 6

Cumulative Operating Time-Hrs.	
0.0	
411.7	"O" ring failure-Piston rod ultrasonically inspected (Okay)
1092.2	Cleaned engine
1220.2	"O" ring failure, gas seal replaced
1228.2	"O" ring failure
1731.2	Cleaned engine
2428.2	Piston rod failure, gas seal replaced
2951.7	Piston rod failure
3119.2	Piston rod failure*
3119.2	Time at end of Contract NASw-114

Time of Component Failure		
"O" Rings	Gas Seal	Piston Rod
411.7	1220.2	2428.2
128.0	1208.0	523.5
8.0		

"O" rings replaced each time engine removed

* Used rod not used in determination of $\overline{\text{MTBF}}$

- Gas seal failure was considered as a component failure where it could as easily have been the result of misalignment during assembly.
- Where only one failure has been experienced during the total operating period to date, the failure was not included in the data tabulation.

Recognizing the analysis is only as valid as the assumptions it is believed that results will reflect relative failure rates for various engine components which will permit the determination of probable engine operational reliability for various operating times.

The ability to express reliability quantitatively is a prerequisite to the ability to exert control over this important parameter. The definition of reliability which makes it amenable to a numerical expression is:

> Reliability - The probability of a device performing its purpose for the period of time intended under the operating conditions specified.

As a probability, the reliability of a device takes on values from zero, which is equivalent to never operating without failure to 1, which is the equivalent of always operating without failure.

Statistical reliability data collected to date suggests an important form of reliability equation which is:

$$R(t) = e^{\frac{-t}{M}} \qquad (1)$$

where M is the mean time between failures (MBTF) in hours. When the mean time between failures "M" in hours, is known then from the above formula, the reliability of the device can be determined for any operating time (t).

The failure rate " λ " of an equipment is the number of failures which occur during any cycle of operation, λ is the reciprocal of M or:

$$\lambda = \frac{1}{M} \qquad (2)$$

Using λ equation, 1 can be written:

$$R(t) = e^{\frac{-t}{M}} = e^{-\lambda t}$$

To determine the reliability with components in series the theory of joint probabilities applies to the equipment where components are functionally in series. The resulting reliability of a series combination of " n " components is the product of the components individual reliabilities.

$$R_{total} = R_1 \cdot R_2 \cdot R_3 \cdot \ldots \cdot R_n$$

Each of the reliabilities R_1, R_2 and R_3, etc., is characterized by mean time between failure M_1, M_2, M_3, etc., or by the hourly failure rates λ_1, λ_2, λ_3, etc., and therefore:

$$R_{total} = e^{-\lambda_1 t} \cdot e^{-\lambda_2 t} \cdot e^{-\lambda_3 t} = e^{-(\lambda_1 + \lambda_2 + \lambda_3 + \ldots)t} = e^{-\lambda_s t}$$

It is apparent that the failure rates λ_s of the system is the sum of the failure rates of the components:

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 + \cdots \lambda_n$$

To calculate the reliability of a series combination of components, we simply add up their failure rates to obtain λ_s and the reliability of such a combination is then:

$$R_s = e^{-\lambda_s t}$$

5.1.1 Results on Expansion Engines

Engine component failure (λ_i) rates are as follows:

"O" Rings	$\frac{1}{399.7}$	=	2.502×10^{-3}
Valve Body Gasket	$\frac{1}{428.5}$	=	2.334×10^{-3}
Piston Rod	$\frac{1}{1622.8}$	=	6.162×10^{-4}
Inlet Valve	$\frac{1}{2056.9}$	=	4.862×10^{-4}
Gas Seal	$\frac{1}{2061.0}$	=	4.852×10^{-4}
Piston Sleeve	$\frac{1}{1716.4}$	=	5.826×10^{-4}
Cylinder	$\frac{1}{2719.0}$	=	3.678×10^{-4}
Exhaust Valve	$\frac{1}{2918.1}$	=	3.427×10^{-4}

To determine the reliability of an engine assembly, the components listed above act in series; therefore:

$$R_s = e^{-\lambda_s t} \quad \text{where } \lambda_s = 77.147 \times 10^{-4}$$

for 560 hours $\quad R_s = e^{-.00771\,(560)} = e^{-4.32} = .013$

for 280 hours $\quad R_s = e^{-.00771\,(280)} = e^{-2.16} = .116$

for 140 hours $R_s = e^{-.00771\,(140)} = e^{-1.08} = .340$

for 70 hours $R_s = e^{-.00771\,(70)} = e^{-.54} = .583$

By increasing the MTBF of the "O" rings to ≈ 1000 hours through improved maintenance techniques and careful testing of the valve body gasket prior to engine installation thus eliminating this failure, the reliability would be enhanced as follows:

for 560 hours $R_s = e^{-.00388\,(560)} = e^{-2.17} = .114$

for 280 hours $R_s = e^{-.00388\,(280)} = e^{-1.09} = .336$

for 140 hours $R_s = e^{-.00388\,(140)} = e^{-.543} = .581$

for 70 hours $R_s = e^{-.00388\,(70)} = e^{-.272} = .762$

The increase in MBTF for the "O" rings appears reasonable in view of the steadily increasing operational time evident in the recorded performance history. Also, the elimination of the gasket failure has been evident as the result of more intensive and long term leak testing of the engines.

It is also believed that the gas seal failure will be eliminated through careful inspection procedures and required replacement when a piston rod failure occurs.

Recognizing that other items included in the records maintained by LNP do not include the system operating time accrued prior to installation at the reactor facility the actual failure rates would decrease if this time were known and could be included in the determination of the failure rates.

5.1.2 Maintenance Schedule Expansion Engines

The maintenance schedule for the expansion engines shown in Figure 5.4 uses the reliability analysis as a criteria in establishing inspection and replacement requirements versus operating time.

5.1.3 Maintenance Schedule Test Facility Items

Other test facility items which must be periodically inspected and replaced are the components in the hydraulic panel, the transfer system and the test loops. No specific operational time history has been maintained on which a reliability analysis can be performed, but the number of times the equipment has been used to insert and withdraw the test loops from the beam port thimble or hot cave port was maintained. This information was used in compiling the maintenance schedule shown in Figure 5.5.

Components and their respective failure rates have been used in the study, knowing comparable components have operated without failure to date. This may appear to invalidate the absolute reliability values, but to establish a reasonable maintenance schedule the relative values should be useful.

A cycle as shown in Figure 5.5, includes the complete test operation of placing the specimen in the test loop cryostat, withdrawal from the hot cave, table positioning for insertion of the test loop into the beam port, withdrawal from the beam port and insertion of the test loop into the hot cave.

The performance of any maintenance on the test facility items listed in Figure 5.5 must coincide with draining of the quadrant. Therefore, the operational cycles between maintenance must be considered nominal and the performance of maintenance will be scheduled to coincide with other activities which normally require the draining of the quadrant. Cycles of operation are maintained in test performance logs but specific maintenance logs for this equipment have not been established or used. Information to determine the maintenance schedule was obtained by relating test cycles to maintenance performed, as recorded in the project logs.

The schedule, as developed, is predicated on best jusgment and is not intended as a rigid or absolute requirement necessitating an unscheduled quadrant draining or in any other way interfering with reactor operation.

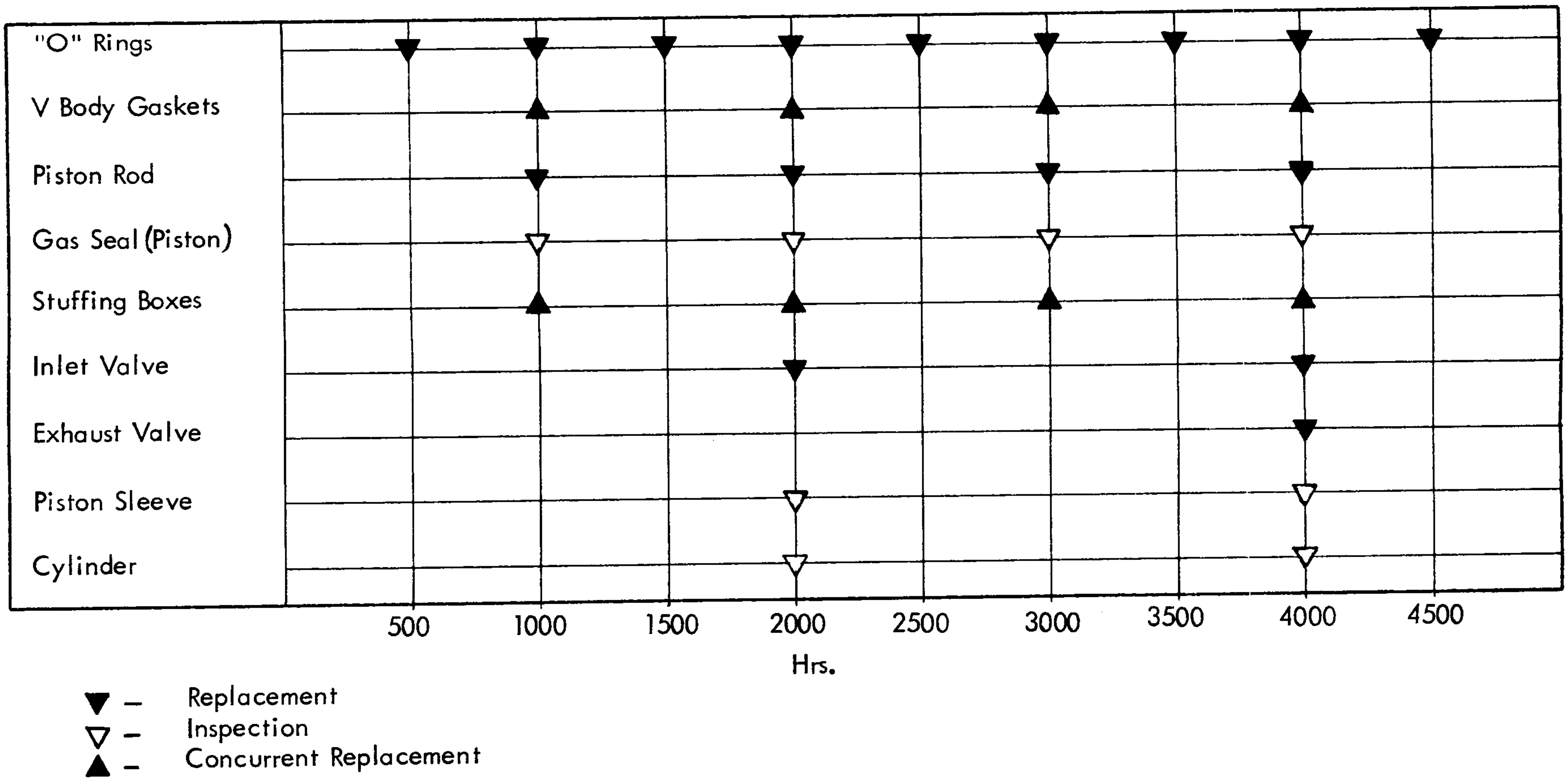


FIGURE 5.4 EXPANSION ENGINE MAINTENANCE SCHEDULE

	0	5	10	15	20	25	30	35	40	45	50
TEST LOOP											
Instrumentation											
Calibration Load Transducer											▼
Electrical Integrity			▽		▽		▽		▽		▽
Extensometer	▼▼▼▼▼	......	......	......	......	......	......	......	......	......	......
Mechanical Integrity			▽		▽		▽		▽		▽
Pressure Integrity											
Refrigerator System-Helium											▽
Static Sumergence-Water											▽
Coolant System-Water											▽
Load Actuator Mechanism											
Dynamic Characteristics			▽ f		▽ f		▽ f		▽ f		⧩
Hydraulic Units (Mini Pump)			▽ f		▽ f		▽ f		▽ f		⧩
CARRIAGES											
Drive System			▽		▽		▼		▽		▽
Hydraulic Motor							⧩				
Drive Gearing			▽		▽		⧩		▽		▽
Drive Bearings			▽		▽		▽		▽		▽
Yoke Support Bearings			⧩		⧩		▼		⧩		⧩
Limit Switches			▽		▽		▽		▽		▽
TRANSFER TABLES											
Carriage Drive (Longitudinal)											
Hydraulic Units											▽
Stop System - Fixed											▽
Stop System - Hydraulic											⧩
Clutch Mechanism											⧩
Rack & Pinion Drive											▽
Limit Switches			▽		▽		▽		▽		▽
Transverse Drive											
Hydraulic Units											▽
Bearing Assemblies											▽
Stop System - Fixed											▽
Stop System - Hydraulic											▽
Limit Switches			▽		▽		▽		▽		▽
Rotational Drive (North Table)											
Stop System - Fixed							▽				
Limit Switches			▽		▽		▽		▽		▽
BEAM PORT AND HOT CAVE ACCESS VALVES											
Carriage Coupling Assembly											⧩
Seal Integrity											⧩
Primary Water Isolation System						▽					▽
Cycles	0	5	10	15	20	25	30	35	40	45	50

▽ Inspection & Adjustment if Required

⧩ Disassembly and Inspection

▼ Replacement Overhaul

f Fatigue Equipment

Note: The definition of a cycle and the limitation of application of this schedule is stated on page 102. Ten (10) tests ≈ 1 reactor cycle.

FIGURE 5.5 TEST FACILITY EQUIPMENT MAINTENANCE SCHEDULE

Careful management and surveillance of schedules is necessary to effect positive maintenance action without interfering with reactor operating schedules.

The frequency of limit switch inspection, implies that they will be inspected each time the quadrant is drained and the number of cycles indicated on Figure 5.5 is the best estimate of the operational interval between the quadrant draining events.

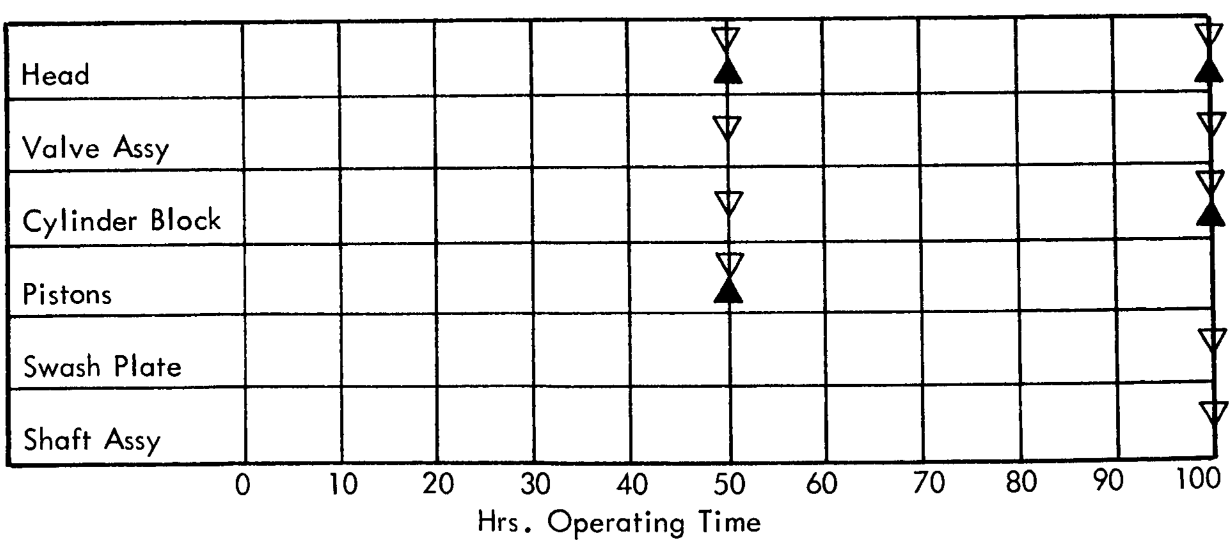
As stated previously in Section 4, the transfer system contains sufficient versatility to permit operation by the selection of numerous alternatives. Therefore, maintenance may be withheld to assure compatibility with reactor operation, without jeopardizing either reactor or test schedules.

The 12 gpm axial piston pump requires periodic maintenance also. This unit has been provided with an operating time meter which indicates cumulative operating hours. Previous maintenance history indicates that seal wear-out has occurred at about 70 hour intervals. In an effort to preclude this type of wear-out failure the schedule has been developed and is shown in Figure 5.6.

FIGURE 5.6

12.0 GPM 1000 psi

AXIAL PISTON PUMP MAINTENANCE SCHEDULE



▽ Disassembly & Inspection

▲ Seal Replacement

6 REMOVAL OF PRESENT BEAM PORT SHIELD

Preparation for the removal of the beam port shield included disconnecting the hydraulic lines and electrical leads associated with the operation of the beam port access gate valve.

NASA subsequently removed the valve and the shield assembly. The shield was transported to the hot cell area by NASA personnel and the valve was placed in temporary storage by Lockheed personnel.

7 INSTALLATION OF THE BEAM PORT SHIELD

This effort has been delayed pending delivery of the NASA designed shield assembly.

8 UPDATING OF MANUALS

The Experiment Design Manual and Hazards Analysis and the Experiment Operations Manual which provide required information to the Plum Brook Reactor Facility about the performance of tests by Lockheed to determine the radiation effects on materials at cryogenic temperatures were updated.

The information relating to the reactor beam port gamma shield has been deleted.

The manuals now represent the current status, having been updated. They have been published and distributed in loose leaf binder form.

APPENDIX "A"

CALIBRATION DATA FOR PLATINUM RESISTANCE THERMOMETER PROBES

Certificate of Calibration and Testing

Part Name **Temperature Sensor** REC Model No. **152T21F**

Customer Part No. **N/A** Customer P. O. No. **PL375-13**

REC Serial No. **391 Repaired** Customer Serial No. **N/A**

Loop #3 Inlet

All applicable tests required by **REC Dwg. 152T Revision J** were successfully conducted utilizing equipment whose calibration is directly traceable to the National Bureau of Standards. All materials used in the manufacture of this unit are in strict accordance with the applicable specification requirements. Applicable test data is on file subject to examination. Specific calibration and test data are attached or recorded on the reverse side of this form.

6 May 1965
Date of Certification

[signature]
Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

REC

ROSEMOUNT **ENGINEERING** COMPANY

4900 WEST 78th STREET

MINNEAPOLIS, MINNESOTA 55424

REC Form No 115923 Rev.

MODEL 152 T21F
SERIAL 391
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.94400
7.5708	.16431
139.0455	37.73950

FSC IS 7.8676413000
DRM IS -.0198800000

TEMP. R	RESISTANCE
5.00	.16431
10.00	.16431
15.00	.16431
20.00	.24065
25.00	.34442
30.00	.53370
35.00	.83971
40.00	1.29311
45.00	1.91690
50.00	2.72354
55.00	3.71858
60.00	4.89999
65.00	6.26077
70.00	7.78575
75.00	9.45789
80.00	11.26131
85.00	13.17941
90.00	15.19692
95.00	17.29805
100.00	19.46857
105.00	21.69655
110.00	23.97368
115.00	26.29095
120.00	28.63901
125.00	31.00883
130.00	33.39437
135.00	35.79195
140.00	38.19987
145.00	40.61637
150.00	43.03964
155.00	45.46683
160.00	47.89635
165.00	50.32185
170.00	52.74275
175.00	55.15856
180.00	57.56942

MODEL 152 T21F
SERIAL 391
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.94400
7.5708	.16431
139.0455	37.73950

FSC IS 7.8676413000
DRM IS -.0198800000

TEMP. R	RESISTANCE
185.00	59.97532
190.00	62.37643
195.00	64.77283
200.00	67.16458
205.00	69.55179
210.00	71.93451
215.00	74.31282
220.00	76.68687
225.00	79.05657
230.00	81.42219
235.00	83.78372
240.00	86.14126
245.00	88.49481
250.00	90.84456
255.00	93.19047
260.00	95.53269
265.00	97.87123
270.00	100.20622
275.00	102.53766
280.00	104.86568
285.00	107.19027
290.00	109.51156
295.00	111.82956
300.00	114.14436
305.00	116.45606
310.00	118.76461
315.00	121.07019
320.00	123.37274
325.00	125.67233
330.00	127.96916
335.00	130.26308
340.00	132.55427
345.00	134.84272
350.00	137.12850
355.00	139.41166

MODEL 152 T21F
SERIAL 391
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.94400
7.5708	.16431
139.0455	37.73950

FSC IS 7.8676413000
DRM IS -.0198800000

TEMP. R	RESISTANCE
360.00	141.69226
365.00	143.97031
370.00	146.24587
375.00	148.51897
380.00	150.78967
385.00	153.05797
390.00	155.32396
395.00	157.58764
400.00	159.84906
405.00	162.10828
410.00	164.36527
415.00	166.62010
420.00	168.87282
425.00	171.12345
430.00	173.37199
435.00	175.61848
440.00	177.86295
445.00	180.10539
450.00	182.34587
455.00	184.58440
460.00	186.82107
465.00	189.05573
470.00	191.28855
475.00	193.51949
480.00	195.74853
485.00	197.97577
490.00	200.20116
495.00	202.42467
500.00	204.64644
505.00	206.86636
510.00	209.08449
515.00	211.30076
520.00	213.51524
525.00	215.72789
530.00	217.93878
535.00	220.14776
540.00	222.35499

MODEL 152 T21F
SERIAL 391
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.94400
7.5708	.16431
139.0455	37.73950

FSC IS 7.8676413000
DRM IS -.0198800000

TEMP. R	RESISTANCE
25.00	.34442
26.00	.37434
27.00	.40798
28.00	.44559
29.00	.48740
30.00	.53370
31.00	.58462
32.00	.64020
33.00	.70112
34.00	.76755
35.00	.83971
36.00	.91780
37.00	1.00200
38.00	1.09250
39.00	1.18947
40.00	1.29311
41.00	1.40358
42.00	1.52103
43.00	1.64565
44.00	1.77757
45.00	1.91690
46.00	2.06305
47.00	2.21682
48.00	2.37817
49.00	2.54707
50.00	2.72354

Certificate of Calibration and Testing

Part Name **Temperature Sensor** REC Model No. **152T21F**

Customer Part No. **N/A** Customer P. O. No. **PL375-13**

REC Serial No. **392 Repaired** Customer Serial No. **N/A**

Loop #3 Return

All applicable tests required by **REC Dwg. 152T Revision** were successfully conducted utilizing equipment whose calibration is directly traceable to the National Bureau of Standards. All materials used in the manufacture of this unit are in strict accordance with the applicable specification requirements. Applicable test data is on file subject to examination. Specific calibration and test data are attached or recorded on the reverse side of this form.

6 May 1965
Date of Certification

Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

REC

ROSEMOUNT ENGINEERING COMPANY
4900 WEST 78th STREET
MINNEAPOLIS, MINNESOTA 55424

REC Form No 115923 Rev.:

MODEL 152 T21F
SERIAL 392
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.48570
7.5708	.16580
139.0813	37.72450

FSC IS 7.8496242000
DRM IS .0324900000

TEMP. R	RESISTANCE
5.00	.16580
10.00	.16580
15.00	.16580
20.00	.24157
25.00	.34575
30.00	.53495
35.00	.84262
40.00	1.29782
45.00	1.92304
50.00	2.73176
55.00	3.72815
60.00	4.91105
65.00	6.27222
70.00	7.79725
75.00	9.46917
80.00	11.27122
85.00	13.18779
90.00	15.20308
95.00	17.30153
100.00	19.46899
105.00	21.69360
110.00	23.96704
115.00	26.28039
120.00	28.62440
125.00	30.98979
130.00	33.37081
135.00	35.76401
140.00	38.16657
145.00	40.57788
150.00	42.99597
155.00	45.41778
160.00	47.84192
165.00	50.26264
170.00	52.67860
175.00	55.08944
180.00	57.49520

MODEL 152 T21F
SERIAL 392
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.48570
7.5708	.16580
139.0813	37.72450

FSC IS 7.849624200 0
DRM IS .0324900000

TEMP. R	RESISTANCE
185.00	59.89599
190.00	62.29192
195.00	64.68305
200.00	67.06949
205.00	69.45125
210.00	71.82853
215.00	74.20133
220.00	76.56978
225.00	78.93400
230.00	81.29393
235.00	83.64974
240.00	86.00150
245.00	88.34932
250.00	90.69315
255.00	93.03321
260.00	95.36950
265.00	97.70211
270.00	100.03108
275.00	102.35651
280.00	104.67841
285.00	106.99693
290.00	109.31208
295.00	111.62395
300.00	113.93258
305.00	116.23802
310.00	118.54036
315.00	120.83962
320.00	123.13590
325.00	125.42929
330.00	127.71968
335.00	130.00734
340.00	132.29212
345.00	134.57423
350.00	136.85363
355.00	139.13041

MODEL 152 T21F
SERIAL 392
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.48570
7.5708	.16580
139.0813	37.72450

FSC IS 7.8496242000
DRM IS .0324900000

TEMP. R	RESISTANCE
360.00	141.40456
365.00	143.67617
370.00	145.94529
375.00	148.21197
380.00	150.47619
385.00	152.73805
390.00	154.99756
395.00	157.25477
400.00	159.50973
405.00	161.76242
410.00	164.01295
415.00	166.26131
420.00	168.50753
425.00	170.75163
430.00	172.99364
435.00	175.23364
440.00	177.47161
445.00	179.70760
450.00	181.94161
455.00	184.17364
460.00	186.40373
465.00	188.63197
470.00	190.85829
475.00	193.08273
480.00	195.30532
485.00	197.52606
490.00	199.74499
495.00	201.96209
500.00	204.17737
505.00	206.39086
510.00	208.60252
515.00	210.81239
520.00	213.02042
525.00	215.22668
530.00	217.43105
535.00	219.63370
540.00	221.83452

MODEL 152 T21F
SERIAL 392
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.48570
7.5708	.16580
139.0813	37.72450

FSC IS 7.8496242000
DRM IS .0324900000

TEMP. R	RESISTANCE
25.00	.34575
26.00	.37566
27.00	.40927
28.00	.44683
29.00	.48866
30.00	.53495
31.00	.58598
32.00	.64196
33.00	.70324
34.00	.77006
35.00	.84262
36.00	.92107
37.00	1.00564
38.00	1.09651
39.00	1.19383
40.00	1.29782
41.00	1.40860
42.00	1.52635
43.00	1.65124
44.00	1.78343
45.00	1.92304
46.00	2.06974
47.00	2.22396
48.00	2.38571
49.00	2.55498
50.00	2.73176

Certificate of Calibration and Testing

REC Model No. 152T21F Serial No. 467

Customers Part No. None Customers P. O. No. GM21788

Part Name Open Wire Sensor, Temperature, Platinum Resistance Type

Loop #1 Return

All applicable tests required by REC Dwg. 152-84 Revision E were successfully conducted, and records of these tests are on file subject to examination. Specific Calibration and test data are recorded on the reverse side of this form.

3 November 1961	
Date of Certification	Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

ROSEMOUNT ENGINEERING COMPANY
4900 WEST 78TH STREET
MINNEAPOLIS 24, MINNESOTA

3+133507'200138'-0000000'
2+173528''-0000000'
3+173529''-0000000'
6+013509'1000041'84'2575'-0000000''

Model 152 T 21 F
Serial 467
Date 11-3-61

'32.00°F = 200.138

TEMP	(R)	R (element)
	7.56	.1338
	20.00	.2094
	25.00	.3130
	30.00	.5019
	31.00	.5532
	32.00	.6088
	33.00	.6699
	34.00	.7363
	35.00	.8085
	36.00	.8867
	37.00	.9711
	38.00	1.0615
	39.00	1.1586
	40.00	1.2622
	41.00	1.3725
	42.00	1.4902
	43.00	1.6147
	44.00	1.7466
	45.00	1.8852
	46.00	2.0317
	47.00	2.1855
	48.00	2.3466
	49.00	2.5155
	50.00	2.6918

(Copy)

TEMP (R)	R (element)
55.00	3.6855
60.00	4.8652
65.00	6.2231
70.00	7.7451
75.00	9.4130
80.00	11.2114
85.00	13.1240
90.00	15.1352
95.00	17.2300
100.00	19.3935
120.00	28.5321
140.00	38.0585
160.00	47.7187
180.00	57.3555
200.00	66.9145
220.00	76.3999
240.00	85.8169
260.00	95.1709
280.00	104.4658
300.00	113.7065
320.00	122.8964
340.00	132.0395
360.00	141.1391
380.00	150.1977
400.00	159.2187
420.00	168.2041
440.00	177.1558
460.00	186.0751
480.00	194.9643
500.00	203.8242
520.00	212.6553
540.00	221.4570

(Copy)

Certificate of Calibration and Testing

Part Name **Temperature Sensor** REC Model No. **152T21F**

Customer Part No. **N/A** Customer P. O. No. **PL375-13**

REC Serial No. **468 Repaired** Customer Serial No. **N/A**

Loop #1 Inlet

All applicable tests required by **REC Dwg. 152T Revision J** were successfully conducted utilizing equipment whose calibration is directly traceable to the National Bureau of Standards. All materials used in the manufacture of this unit are in strict accordance with the applicable specification requirements. Applicable test data is on file subject to examination. Specific calibration and test data are attached or recorded on the reverse side of this form.

6 May 1965
Date of Certification

Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

ROSEMOUNT ENGINEERING COMPANY
4900 WEST 78th STREET
MINNEAPOLIS, MINNESOTA 55424

REC Form No 115923 Rev

MODEL 152 T21F
SERIAL 468
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.51370
7.5708	.15400
139.1122	37.72450

FSC IS 7.8511838000
DRM IS .0219400000

TEMP. R	RESISTANCE
5.00	.15400
10.00	.15400
15.00	.15400
20.00	.22986
25.00	.33393
30.00	.52310
35.00	.83036
40.00	1.28507
45.00	1.90984
50.00	2.71793
55.00	3.71378
60.00	4.89607
65.00	6.25680
70.00	7.78143
75.00	9.45296
80.00	11.25480
85.00	13.17117
90.00	15.18639
95.00	17.28482
100.00	19.45232
105.00	21.67702
110.00	23.95061
115.00	26.26415
120.00	28.60835
125.00	30.97401
130.00	33.35531
135.00	35.74875
140.00	38.15177
145.00	40.56349
150.00	42.98198
155.00	45.40423
160.00	47.82882
165.00	50.24987
170.00	52.66618
175.00	55.07740
180.00	57.48354

MODEL 152 T21F
SERIAL 468
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.51370
7.5708	.15400
139.1122	37.72450

FSC IS 7.8511838000
DRM IS .0219400000

TEMP. R	RESISTANCE
185.00	59.88473
190.00	62.28108
195.00	64.67263
200.00	67.05951
205.00	69.44174
210.00	71.81950
215.00	74.19279
220.00	76.56173
225.00	78.92643
230.00	81.28689
235.00	83.64322
240.00	85.99553
245.00	88.34388
250.00	90.68829
255.00	93.02891
260.00	95.36578
265.00	97.69897
270.00	100.02854
275.00	102.35457
280.00	104.67708
285.00	106.99622
290.00	109.31199
295.00	111.62449
300.00	113.93375
305.00	116.23984
310.00	118.54283
315.00	120.84275
320.00	123.13969
325.00	125.43372
330.00	127.72481
335.00	130.01312
340.00	132.29860
345.00	134.58138
350.00	136.86146
355.00	139.13893

MODEL 152 T21F
SERIAL 468
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.51370
7.5708	.15400
139.1122	37.72450

FSC IS 7.8511838000
DRM IS .0219400000

TEMP. R	RESISTANCE
360.00	141.41377
365.00	143.68609
370.00	145.95590
375.00	148.22328
380.00	150.48820
385.00	152.75077
390.00	155.01098
395.00	157.26890
400.00	159.52458
405.00	161.77799
410.00	164.02922
415.00	166.27829
420.00	168.52522
425.00	170.77005
430.00	173.01279
435.00	175.25350
440.00	177.49219
445.00	179.72889
450.00	181.96361
455.00	184.19637
460.00	186.42719
465.00	188.65614
470.00	190.88317
475.00	193.10833
480.00	195.33164
485.00	197.55312
490.00	199.77275
495.00	201.99056
500.00	204.20657
505.00	206.42076
510.00	208.63316
515.00	210.84374
520.00	213.05247
525.00	215.25944
530.00	217.46454
535.00	219.66788
540.00	221.86941

MODEL 152 T21F
SERIAL 468
DATE 5 4 65

ACTUAL CALIBRATION POINTS

TEMP. R	RESISTANCE
491.6700	200.51370
7.5708	.15400
139.1122	37.72450

FSC IS 7.8511838000
DRM IS .0219400000

TEMP. R	RESISTANCE
25.00	.33393
26.00	.36384
27.00	.39744
28.00	.43501
29.00	.47682
30.00	.52310
31.00	.57410
32.00	.62997
33.00	.69116
34.00	.75789
35.00	.83036
36.00	.90872
37.00	.99319
38.00	1.08396
39.00	1.18119
40.00	1.28507
41.00	1.39575
42.00	1.51342
43.00	1.63823
44.00	1.77032
45.00	1.90984
46.00	2.05638
47.00	2.21048
48.00	2.37211
49.00	2.54126
50.00	2.71793

Certificate of Calibration and Testing

REC Model No. 152T21F Serial No. 476

Customers Part No. None Customers P.O. No. GM22208

Part Name Open Wire Sensor, Temperature, Platinum Resistance Type
Loop #2 Return

All applicable tests required by REC Drwg. 152-84 "E" & REC Bulletin 5603, Style F were successfully conducted, and records of these tests are on file subject to examination. Specific Calibration and test data are recorded on the reverse side of this form.

25 January 1962
Date of Certification

Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

ROSEMOUNT ENGINEERING COMPANY
4900 WEST 78TH STREET
MINNEAPOLIS 24, MINNESOTA

3+133507'200376'-0000000'
2+173528' '-0000000'
3+173529' '-0000000'
6+013509'1000014'164'2575'-0000000''

Model 152 T 21 F
Serial 476
Date 1-25-62

TEMP	(R)	R (element)
	7.56*	.1391
	20.00	.2153
	25.00	.3188
	30.00	.5078
	31.00	.5590
	32.00	.6152
	33.00	.6762
	34.00	.7431
	35.00	.8154
	36.00	.8940
	37.00	.9790
	38.00	1.0698
	39.00	1.1669
	40.00	1.2709
	41.00	1.3813
	42.00	1.4995
	43.00	1.6240
	44.00	1.7563
	45.00	1.8955
	46.00	2.0424
	47.00	2.1962
	48.00	2.3583
	49.00	2.5273
	50.00	2.7040
	55.00	3.7002

* Actual Calibration Points

(Copy)

TEMP (R)	R (element)
60.00 *	4.8828
65.00	6.2431
70.00	7.7680
75.00	9.4394
80.00	11.2402
85.00	13.1557
90.00	15.1704
95.00	17.2680
100.00	19.4345
120.00	28.5859
140.00	38.1240
160.00	47.7953
180.00	57.4443
200.00	67.0146
220.00	76.5112
240.00	85.9390
260.00	95.3032
280.00	104.6079
300.00	113.8583
320.00	123.0580
340.00	132.2104
360.00	141.3188
380.00	150.3867
400.00	159.4165
420.00	168.4106
440.00	177.3711
460.00	186.2998
480.00	195.1972
500.00	204.0659
520.00	212.9052
540.00	221.7157

* Actual Calibration Points

(Copy)

Certificate of Calibration and Testing

REC Model No. 152T21F Serial No. 477

Customers Part No. None Customers P.O. No. GM22208

Part Name Open Wire Sensor, Temperature, Platinum Resistance Type

Loop #2 Inlet

All applicable tests required by REC Drwg. 152-84 "E" & REC Bulletin 5603, Style F

were successfully conducted, and records of these tests are on file subject to examination. Specific Calibration and test data are recorded on the reverse side of this form.

25 January 1962
Date of Certification

[signature]
Quality Control Representative

ROSEMOUNT ENGINEERING COMPANY is a leader in its field of precision temperature transducers and other instruments. Please contact us if you have any questions about the performance, application, or testing methods for this instrument.

ROSEMOUNT ENGINEERING COMPANY
4900 WEST 78TH STREET
MINNEAPOLIS 24, MINNESOTA

3+133507'200286'-0000000'
2+173528''-0000000'
3+173529''-0000000'
6+013509'1000026'144'2575'-0000000''

Model 152 T 21 F
Serial 477
Date 1-25-62

TEMP (R)	R (element)
7.56*	.1367
20.00	.2129
25.00	.3163
30.00	.5053
31.00	.5561
32.00	.6123
33.00	.6738
34.00	.7402
35.00	.8124
36.00	.8910
37.00	.9755
38.00	1.0663
39.00	1.1635
40.00	1.2676
41.00	1.3778
42.00	1.4956
43.00	1.6205
44.00	1.7524
45.00*	1.8916
46.00	2.0381
47.00	2.1924
48.00	2.3540
49.00	2.5229
50.00	2.6997
55.00	3.6948
60.00	4.8764

*Actual Calibration Points (Copy)

TEMP (R)	R (element)
65.00	6.2363
70.00	7.7597
75.00	9.4301
80.00	11.2304
85.00	13.1450
90.00	15.1582
95.00	17.2548
100.00	19.4204
120.00	28.5669
140.00	38.1010
160.00	47.7680
180.00	57.4125
200.00	66.9790
220.00	76.4711
240.00	85.8945
260.00	95.2549
280.00	104.5561
300.00	113.8027
320.00	122.9985
340.00	132.1469
360.00	141.2519
380.00	150.3163
400.00	159.3427
420.00	168.3334
440.00	177.2900
460.00	186.2153
480.00	195.1093
500.00	203.9746
520.00	212.8105
540.00	221.6171

(Copy)

APPENDIX "B"

NATIONAL BUREAU OF STANDARDS REPORT OF CALIBRATION - MOREHOUSE

PROVING RING No. 2485

FORM NBS-443
(REV. 4-11-63)

LRR:JVD:mac

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

Lab No. 6.4/180117
Project No. 06629
Trans letter 3-2-64
Order No. 22216-G

NATIONAL BUREAU OF STANDARDS

REPORT OF CALIBRATION

MOREHOUSE PROVING RING NO. 2485
submitted by
Morehouse Instrument Company
York, Pennsylvania

Proving ring No. 2485, capacity 5,000 lb compression and tension, was submitted by the Morehouse Instrument Company for recalibration. This ring had been calibrated previously under Lab No. 6.4/175628, April 29, 1963.

The ring was recalibrated in accordance with Section III, paragraphs a, b, and c of the Appendix to Circular 454 of the National Bureau of Standards.

The ring was recalibrated by dead weights. The errors of the applied loads did not exceed 0.02 percent.

Values of the computed loads as a function of deflection for 70° F are given in the calibration tables. For a temperature other than 70° F, the deflection of the ring should be corrected by the formula given in Section IV, paragraph 6 of the Appendix to Circular 454 of the National Bureau of Standards. The temperature coefficient, K, for this ring is -0.00015 as supplied by the Morehouse Instrument Company.

The standard deviation of a deflection at a given calibration load is 0.04 division in compression and 0.04 division in tension with 7 degrees of freedom and was computed from fitting the calibration data to a second degree equation in load by the method of least squares. The standard deviation includes departures from the calibration curve due to the characteristics and condition of this particular proving ring at the time of calibration. Based on the standard deviation, the standard error of a tabled load value for each given deflection is calculated to be less than 0.3 lb in compression and 0.4 lb in tension.

This ring complies with the requirements of Section III of the Appendix to Circular 454 of the National Bureau of Standards. An excerpt from the Appendix is enclosed.

For the Director,
L. K. Irwin
L. K. Irwin, Chief
Engineering Mechanics Section
Division of Mechanics

Washington, D. C.

APR 24 1964

An Excerpt from the Appendix of
CIRCULAR OF THE NATIONAL BUREAU OF STANDARDS C454

(Issued August 14, 1946)

I. DEFINITIONS

1. Proving Ring

A proving ring is an elastic ring, suitable for calibrating a testing machine, in which the deflection of the ring when loaded along a diameter is measured by means of a micrometer screw and a vibrating reed mounted diametrically in the ring.

2. Reading

A reading is the value indicated by the micrometer dial when it has been adjusted to contact the vibrating reed.

3. Deflection

The deflection of the ring for any load is the difference between the reading for that load and the reading for no load.

4. Calibration factor

The calibration factor for a given deflection is the ratio of the corresponding load to the deflection.

II. COMPLETE CALIBRATION

1. Marking

The maker's name, the capacity load, and the serial number of the ring shall be legibly marked upon some part of the instrument.

2. Micrometer Dial

(a) The dial of the micrometer shall be of the uniformly graduated type. When successive graduation lines on the dial are set to one fixed index line, the positions of successive graduation lines nearly diametrically opposite referred to another fixed index shall differ from each other by not more than 1/20 of the smallest division of the dial.

(b) The smallest division of the dial shall be not less than 0.05 inch and not more than 0.10 inch.

(c) The width of any graduation line on the dial shall not exceed one-tenth of the average distance between adjacent graduation lines.

(d) The width of any index line shall be not less than 0.75 and not more than 1.25 times the average width of the graduation lines on the dial.

3. Overload

The ring shall be overloaded repeatedly to a load of not less than 9 percent nor more than 10 percent in excees of the capacity load. The difference between the no-load reading after the first overload and the no-load reading after any subsequent overload shall not exceed one-tenth of one percent of the deflection of the ring under capacity load.

4. Stiffness

Under the capacity load the ring shall deflect not less than 0.040 inch.

5. Constancy

(a) Range 1/10 to 2/10-Capacity Load.—The observed deflection of the ring, for an applied load of not less than one-tenth nor more than two-tenths of the capacity load, shall differ from the average of at least three successive observations for the same applied load by not more than one-half of one percent of the deflection for the applied load.

(b) Range 2/10 to Capacity Load.—The observed deflection of the ring, for any applied load not less than two-tenths nor more than the capacity load, shall differ from the average of at least three successive observations for the same applied load by not more than one-tenth of one percent of the deflection for the capacity load.

(c) Disassembling.—The difference between the deflections of the ring, observed before and after the deflection-measuring apparatus is removed and then replaced, shall be not greater than the maxima specified in paragraphs II-5(a) and II-5(b) of this specification, under the loads there specified.

(d) Bearing Blocks.—A compression proving ring shall be loaded through plane, concave, and convex bearing blocks. The deflections of the proving ring for the minimum load and for the maximum load applied by dead weights during the calibration shall be determined when the load is applied to the lower boss of the ring through concave and convex bearing blocks. The difference between the average deflections observed using the concave bearing block and the average deflections observed using a plane bearing block for the same loads shall not exceed the maxima specified in paragraphs II-5(a) and II-5(b) of this specification. The differences between the average deflections observed using the convex bearing block and the average deflections observed using a plane bearing block for the same loads shall not exceed the maxima specified in paragraphs II-5(a) and II-5(b) of this specification. The concave and convex bearing blocks shall comply with the following requirements:

(1) They shall be steel.
(2) The Brinell numbers shall be not less than 400 and not more than 600.
(3) The radii of curvature of the spherical surfaces shall be not less than 9 feet and not more than 10 feet.

III. RECALIBRATION

1. Constancy

(a) Range 1/10 to 2/10-Capacity Load.—The observed deflection of the ring, for an applied load of not less than one-tenth nor more than two-tenths of the capacity load, shall differ from the average of at least three successive observations for the same applied load by not more than one-half of one percent of the deflection for the applied load.

(b) Range 2/10 to Capacity Load.—The observed deflection of the ring, for any applied load not less than two-tenths nor more than the capacity load, shall differ from the average of at least three successive observations for the same applied load by not more than one-tenth of one percent of the deflection for the capacity load.

(c) Comparison with Last Calibration.—The observed deflections of the ring during recalibration shall differ from the deflections observed at the time of the last calibration by not more than the maxima specified in paragraphs III-1(a) and III-1(b) of this specification, under the loads there specified.

(d) Alternative Procedure.—If the ring fails to comply with the requirements of paragraph III-1(c) of this specification, the deflection-measuring apparatus shall be removed and then replaced. The difference between the deflections observed before and after this is done shall be not greater than the maxima specified in paragraphs III-1(a) and III-1(b) of this specification, under the loads there specified.

IV. METHOD OF CALIBRATION

1. Complete calibration

The proving ring shall be calibrated in accordance with the requirements given in section II, Complete Calibration:

(a) If the ring has not been calibrated by the National Bureau of Standards since the revision of this specification on April 4, 1934.

(b) If the ring was not certified when last calibrated by the National Bureau of Standards.

(c) If the ring has been repaired or modified since its last calibration by the National Bureau of Standards.

2. Recalibration

Except as provided in paragraphs IV-1(a), IV-1(b), and IV-1(c), Complete Calibration, a ring shall be recalibrated in accordance with the requirements given in section III, Recalibration.

3. Loads not exceeding 110,000 lb

For loads not exceeding 110,000 lb the proving ring shall be calibrated by applying dead weights known to within 0.02 percent.

4. Loads exceeding 110,000 lb

For loads exceeding 110,000 lb the applied load shall be known to within 0.1 percent.

5. Loading procedure

The proving ring shall be calibrated under increasing loads, Compression loads, except as provided in paragraph II-5(d), shall be applied to the lower boss of the ring through a plane, hardened-steel bearing block and to the upper boss either through a ball or a soft-steel block. Tensile loads shall be applied to the ring through the pulling rods provided with the ring.

6. Temperature correction

To compensate for temperature changes which occur during calibration, the deflections of the proving ring shall be corrected for temperature using the formula

$$d_{70} = d_t[1 + K (t - 70)],$$

where

d_{70} = deflection of ring at a temperature of 70° Fahrenheit

d_t = deflection of ring at a temperature of t degrees Fahrenheit

K = temperature coefficient

t = temperature, degrees Fahrenheit, during test.

The coefficient K depends upon the chemical composition of the steel of which the ring is made and its head treatment. For steels having a total alloying content not exceeding five percent, the value K = - 0.00015 per degree Fahrenheit is sufficiently accurate. For some other steels, values of K have been found ranging from - 0.00011 to - 0.00024. When the proving ring is submitted for calibration, the value of K shall be furnished this Bureau by the person submitting the ring or by the manufacturer of the ring.

USCOMM-NBS-DC

OMNITAB COMPUTED LOAD TABLE IN LB FOR 70 DEGREES F 2485

MOREHOUSE PROVING RING NO. 2485 CAPACITY 5,000 LB TENSION

6.4/180117 NATIONAL BUREAU OF STANDARDS APRIL 9, 1964

DEFLECTION DIV	0	1	2	3	4	5	6	7	8	9	DEFLECTION DIV
50.			490.4	499.9	509.3	518.7	528.2	537.6	547.1	556.5	50.
60.	566.0	575.4	584.9	594.3	603.8	613.2	622.7	632.1	641.6	651.0	60.
70.	660.5	670.0	679.4	688.9	698.3	707.8	717.3	726.7	736.2	745.7	70.
80.	755.1	764.6	774.1	783.5	793.0	802.5	811.9	821.4	830.9	840.4	80.
90.	849.8	859.3	868.8	878.3	887.7	897.2	906.7	916.2	925.7	935.2	90.
100.	944.6	954.1	963.6	973.1	982.6	992.1	1001.6	1011.1	1020.6	1030.1	100.
110.	1039.5	1049.0	1058.5	1068.0	1077.5	1087.0	1096.5	1106.0	1115.5	1125.0	110.
120.	1134.5	1144.1	1153.6	1163.1	1172.6	1182.1	1191.6	1201.1	1210.6	1220.1	120.
130.	1229.6	1239.2	1248.7	1258.2	1267.7	1277.2	1286.7	1296.3	1305.8	1315.3	130.
140.	1324.8	1334.4	1343.9	1353.4	1362.9	1372.5	1382.0	1391.5	1401.1	1410.6	140.
150.	1420.1	1429.7	1439.2	1448.7	1458.3	1467.8	1477.3	1486.9	1496.4	1506.0	150.
160.	1515.5	1525.1	1534.6	1544.2	1553.7	1563.2	1572.8	1582.3	1591.9	1601.4	160.
170.	1611.0	1620.6	1630.1	1639.7	1649.2	1658.8	1668.3	1677.9	1687.5	1697.0	170.
180.	1706.6	1716.1	1725.7	1735.3	1744.8	1754.4	1764.0	1773.5	1783.1	1792.7	180.
190.	1802.3	1811.8	1821.4	1831.0	1840.6	1850.1	1859.7	1869.3	1878.9	1888.5	190.
200.	1898.0	1907.6	1917.2	1926.8	1936.4	1946.0	1955.6	1965.1	1974.7	1984.3	200.
210.	1993.9	2003.5	2013.1	2022.7	2032.3	2041.9	2051.5	2061.1	2070.7	2080.3	210.
220.	2089.9	2099.5	2109.1	2118.7	2128.3	2137.9	2147.5	2157.1	2166.7	2176.4	220.
230.	2186.0	2195.6	2205.2	2214.8	2224.4	2234.0	2243.7	2253.3	2262.9	2272.5	230.
240.	2282.1	2291.8	2301.4	2311.0	2320.6	2330.3	2339.9	2349.5	2359.2	2368.8	240.
250.	2378.4	2388.1	2397.7	2407.3	2417.0	2426.6	2436.2	2445.9	2455.5	2465.2	250.
260.	2474.8	2484.4	2494.1	2503.7	2513.4	2523.0	2532.7	2542.3	2552.0	2561.6	260.
270.	2571.3	2580.9	2590.6	2600.2	2609.9	2619.5	2629.2	2638.9	2648.5	2658.2	270.
280.	2667.8	2677.5	2687.2	2696.8	2706.5	2716.2	2725.8	2735.5	2745.2	2754.9	280.
290.	2764.5	2774.2	2783.9	2793.6	2803.2	2812.9	2822.6	2832.3	2841.9	2851.6	290.
300.	2861.3	2871.0	2880.7	2890.4	2900.0	2909.7	2919.4	2929.1	2938.8	2948.5	300.
310.	2958.2	2967.9	2977.6	2987.3	2997.0	3006.7	3016.4	3026.1	3035.8	3045.5	310.
320.	3055.2	3064.9	3074.6	3084.3	3094.0	3103.7	3113.4	3123.1	3132.8	3142.5	320.
330.	3152.3	3162.0	3171.7	3181.4	3191.1	3200.8	3210.6	3220.3	3230.0	3239.7	330.
340.	3249.4	3259.2	3268.9	3278.6	3288.3	3298.1	3307.8	3317.5	3327.3	3337.0	340.
350.	3346.7	3356.5	3366.2	3375.9	3385.7	3395.4	3405.2	3414.9	3424.6	3434.4	350.
360.	3444.1	3453.9	3463.6	3473.4	3483.1	3492.9	3502.6	3512.4	3522.1	3531.9	360.
370.	3541.6	3551.4	3561.1	3570.9	3580.7	3590.4	3600.2	3609.9	3619.7	3629.5	370.
380.	3639.2	3649.0	3658.8	3668.5	3678.3	3688.1	3697.8	3707.6	3717.4	3727.2	380.
390.	3736.9	3746.7	3756.5	3766.3	3776.0	3785.8	3795.6	3805.4	3815.2	3825.0	390.
400.	3834.7	3844.5	3854.3	3864.1	3873.9	3883.7	3893.5	3903.3	3913.1	3922.9	400.
410.	3932.7	3942.5	3952.3	3962.1	3971.9	3981.7	3991.5	4001.3	4011.1	4020.9	410.
420.	4030.7	4040.5	4050.3	4060.1	4069.9	4079.7	4089.5	4099.4	4109.2	4119.0	420.
430.	4128.8	4138.6	4148.5	4158.3	4168.1	4177.9	4187.7	4197.6	4207.4	4217.2	430.
440.	4227.0	4236.9	4246.7	4256.5	4266.4	4276.2	4286.0	4295.9	4305.7	4315.5	440.
450.	4325.4	4335.2	4345.1	4354.9	4364.8	4374.6	4384.4	4394.3	4404.1	4414.0	450.
460.	4423.8	4433.7	4443.5	4453.4	4463.2	4473.1	4482.9	4492.8	4502.7	4512.5	460.
470.	4522.4	4532.2	4542.1	4552.0	4561.8	4571.7	4581.6	4591.4	4601.3	4611.2	470.
480.	4621.0	4630.9	4640.8	4650.7	4660.5	4670.4	4680.3	4690.2	4700.1	4709.9	480.
490.	4719.8	4729.7	4739.6	4749.5	4759.4	4769.2	4779.1	4789.0	4798.9	4808.8	490.
500.	4818.7	4828.6	4838.5	4848.4	4858.3	4868.2	4878.1	4888.0	4897.9	4907.8	500.
510.	4917.7	4927.6	4937.5	4947.4	4957.3	4967.2	4977.1	4987.0	4996.9	5006.9	510.

TABLE B 1 a

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-1
RECORDER DEFLECTION 140 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6			0		
500	127.1	49.5		37.0	37.0	
700	148.5	70.9	669.1	52.9	52.9	12.65
900	169.2	91.6	865.0	68.8	68.8	12.57
1100	190.2	112.6	1064.2	84.6	84.6	12.58
1300	210.2	132.6	1254.4	100.0	100.0	12.54
1500	232.5	154.9	1466.9	116.9	116.9	12.55
0	77.6					
500	127.6	50.0		37.4	37.4	
700	148.3	70.7	667.3	53.1	53.1	12.57
900	168.7	91.1	860.3	68.5	68.5	12.56
1100	190.2	112.6	1064.2	84.5	84.5	12.59
1300	210.1	132.5	1253.5	99.9	99.9	12.55
1500	231.3	153.7	1455.4	116.0	116.0	12.55
1300	208.6	131.0	1239.2	99.0	99.0	12.52
1100	188.3	110.7	1046.3	83.5	83.5	12.53
900	168.0	90.4	853.6	68.3	68.3	12.50
700	147.4	69.8	658.6	52.9	52.9	12.45
500	125.9	48.3		36.5	36.5	
0	77.6					

TABLE B 1 b

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-1
RECORDER DEFLECTION 280 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6					
500	127.1	49.5		18.5	37.0	
1000	180.8	103.2	975.0	38.8	77.6	12.56
1500	231.1	153.5	1453.5	57.8	115.6	12.57
2000	282.6	205.0	1946.0	77.3	154.6	12.59
2500	333.6	256.0	2436.2	96.9	193.8	12.57
3000	384.0	306.4	2923.3	115.9	231.8	12.61
0	77.6					
0	75.6					
500	127.0	49.3		19.0	38.0	
1000	180.7	103.2	975.0	39.2	78.4	12.44
1500	233.3	155.8	1475.4	59.3	118.6	12.44
2000	283.1	205.6	1951.8	78.2	156.4	12.48
2500	333.8	256.3	2439.1	97.0	194.0	12.57
3000	385.0	307.5	2934.0	116.5	233.0	12.59
0	77.5					

TABLE B 1 c

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-1
RECORDER DEFLECTION 560 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6					
1000	182.4	104.8	990.2	20.0	80.0	12.38
1500	233.5	155.9	1476.4	29.8	119.2	12.30
2000	285.2	207.6	1970.9	39.8	159.2	12.38
2500	336.3	258.7	2462.3	49.4	197.6	12.46
3000	386.8	309.2	2950.4	59.1	236.4	12.48
3500	438.0	360.4	3448.0	68.8	275.2	12.53
4000	487.8	410.2	3934.7	79.0	316.0	12.45
4500	537.5	459.5	4422.8	88.3	353.2	12.52
5000	588.4	510.8	4925.6	98.0	392.0	12.57
0	77.6					
1000	180.9	103.3	976.0	19.6	78.4	12.45
1500	231.8	154.2	1460.2	29.3	117.2	12.46
2000	283.9	206.3	1958.5	39.3	157.2	12.46
2500	335.6	258.0	2455.5	49.1	196.4	12.50
3000	384.8	307.2	2931.0	58.8	235.2	12.46
3500	437.5	359.9	3443.1	68.8	275.2	12.51
4000	488.0	410.4	3936.6	78.8	315.2	12.49
4500	538.2	460.6	4429.7	88.2	352.8	12.56
5000	588.0	510.4	4921.7	97.9	391.6	12.57
0	77.6					

TABLE B 2 a

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-2
RECORDER DEFLECTION 140 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6					
500	127.1	49.5		46.6	46.6	
700	147.8	70.2	662.4	66.5	66.5	9.96
900	169.6	92.0	868.8	87.4	87.4	9.94
1100	189.3	111.7	1055.8	106.3	106.3	9.93
1300	209.6	132.0	1248.7	126.0	126.0	9.91
1400	220.2	142.6	1349.6	136.1	136.1	9.92
0	77.6					
0	77.6					
500	126.8	49.2		46.3	46.3	
700	147.5	69.9	659.6	66.1	66.1	9.98
900	168.6	91.0	859.3	86.4	86.4	9.95
1100	189.1	111.5	1053.8	106.1	106.1	9.93
1400	220.7	143.1	1354.4	136.7	136.7	9.91
1100	187.9	110.3	1042.4	105.1	105.1	9.92
900	166.7	89.1	841.3	85.2	85.2	9.87
700	145.6	68.0	641.6	64.9	64.9	9.89
500	125.2	47.6		45.5	45.5	
0	77.6					

TABLE B 2 b

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-2
RECORDER DEFLECTION 280 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6					
500	127.4	49.8				
1000	180.6	103.0	973.1	49.0	98.0	9.93
1500	231.4	153.8	1452.5	73.5	147.0	9.88
2000	282.8	205.2	1947.9	98.6	197.2	9.88
2500	334.4	256.8	2444.0	123.6	247.2	9.89
0	77.6					
0	77.6					
500	127.3	49.7				
1000	180.4	102.8	971.2	48.9	97.8	9.93
1500	231.5	153.9	1457.3	73.5	147.0	9.91
2000	283.3	205.7	1952.7	98.7	197.4	9.89
2500	334.7	257.1	2446.9	123.8	247.6	9.88
0	77.6					

TABLE B 2 c

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-2
RECORDER DEFLECTION 560 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.6					
1000	179.5	101.9	962.7	24.3	97.2	9.90
1500	230.5	152.9	1447.8	36.8	147.2	9.84
2000	283.1	205.5	1950.8	49.6	198.4	9.83
2500	333.2	255.6	2432.4	61.8	247.2	9.84
3000	383.4	305.8	2917.5	74.0	296.0	9.86
3500	435.6	358.0	3424.6	86.9	347.6	9.85
4000	486.2	408.6	3919.0	99.7	398.8	9.83
4500	536.3	458.7	4411.0	111.9	447.6	9.85
5000	586.4	508.8	4905.8	124.4	497.6	9.86
0	77.6					
1000	180.8	103.2	975.0	24.9	99.6	9.79
1500	231.0	153.4	1452.5	37.3	149.2	9.74
2000	283.7	206.1	1956.6	49.9	199.6	9.80
2500	334.4	256.8	2444.0	62.6	250.4	9.76
3000	384.3	306.7	2926.2	74.8	299.2	9.78
3500	436.4	358.8	3432.4	87.5	350.0	9.81
4000	487.0	409.4	3926.8	99.9	399.6	9.83
4500	537.0	459.4	4417.9	112.1	448.4	9.85
5000	586.8	509.2	4909.8	124.4	497.6	9.87
0	77.6					

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. M-3
RECORDER DEFLECTION 560 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.7					
600	139.6	61.9	584.0	13.8	55.2	10.58
1000	185.0	107.3	1014.0	23.7	94.8	10.70
1500	237.8	160.1	1516.5	35.3	141.2	10.74
2000	291.4	213.7	2029.4	47.2	188.8	10.75
2500	333.6	255.9	2435.2	56.7	226.8	10.74
3000	392.3	314.6	3002.8	69.8	279.2	10.76
3500	447.0	369.3	3534.8	82.0	328.0	10.78
4000	494.8	417.1	4002.3	92.7	370.8	10.79
4500	545.2	467.5	4497.8	103.9	415.6	10.82
5000	595.9	518.2	4998.9	115.3	461.2	10.84
0	77.7					
600	142.7	65.0	613.2	14.6	58.4	10.50
1000	184.0	106.3	1004.5	23.7	94.8	10.60
1500	237.1	159.4	1509.8	35.3	141.2	10.69
2000	288.7	211.0	2003.5	46.7	186.8	10.73
2500	334.9	257.2	2447.8	57.0	228.0	10.74
3000	392.4	314.7	3003.8	69.9	279.6	10.74
3500	449.0	371.3	3554.3	82.7	330.8	10.74
4000	492.5	414.8	3979.7	92.4	369.2	10.78
4500	544.7	467.0	4492.8	104.0	416.0	10.80
5000	596.2	518.5	5004.9	115.5	462.0	10.83

TABLE B 4

CALIBRATION DATA LOAD SENSING DYNAMOMETER
SER. NO. 177
RECORDER DEFLECTION 560 MV FULL SCALE

INSTRON	DEFLECTION DIV.	ACTUAL DIV.	LOAD lbs.	CHART DIV.	MV	lb/MV
0	77.5					
600	139.8	62.3	587.7	15.0	60.0	9.80
1000	179.6	102.1	964.6	24.4	97.6	9.88
1500	234.4	156.9	1485.9	37.6	150.4	9.88
2000	289.6	212.1	2014.1	50.8	203.2	9.91
2500	338.1	260.6	2480.6	62.7	250.8	9.89
3000	390.8	313.3	2990.2	75.3	301.2	9.93
3500	443.2	365.7	3499.7	87.9	351.6	9.95
4000	493.3	415.8	3989.5	99.8	399.2	9.99
4500	542.9	465.4	4477.0	111.9	447.6	10.00
5000	591.0	513.5	4952.4	123.0	492.0	10.07
0	77.5					
600	141.3	63.8	601.9	15.3	61.2	9.83
1000	182.3	104.8	990.2	25.0	100.0	9.90
1500	237.5	160.0	1515.5	38.3	153.2	9.89
2000	285.7	208.2	1976.6	49.9	199.6	9.90
2500	339.1	261.6	2490.2	62.8	251.2	9.91
3000	393.2	315.7	3013.5	75.8	303.2	9.94
3500	444.2	366.7	3509.5	87.9	351.6	9.98
4000	489.7	412.2	3954.3	99.0	396.0	9.99
4500	544.6	467.1	4493.8	112.1	448.4	10.02
5000	589.4	511.9	4936.5	122.8	491.2	10.05

APPENDIX C

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