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INITIAL PUMPDOWN AND LEAK CHECK OF THE AEROSPACE ENVIRONMENTAL CHAMBER (MARK I)

H. D. Moore and R. B. Williams
ARO, Inc.

August 1966

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AEROSPACE ENVIRONMENTAL FACILITY
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NOTICES

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FOREWORD

The work reported herein was done at the request of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65402234.

The results of the work described in this report were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The engineering preparation began in 1963, and the work was conducted from September 21 to October 26, 1965, under ARO Project No. SM9524. The Aerospace Environmental Chamber (Mark I) was constructed under Corps of Engineers contract DA-01-076-ENG.-5448 monitored by Lt. Col. F. N. Price, Air Force Project Officer. The manuscript was submitted for publication on July 1, 1966.

This technical report has been reviewed and is approved.

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ABSTRACT

This report describes the planning, procedures, and results of the first complete pumpdown and leak check of the Aerospace Environmental Chamber (Mark I). The objective of the pumpdown and leak check was to reduce the total leakage of the 106,000-ft^3 vacuum chamber to the low 10^{-3} std cc/sec range. The total leakage was reduced from 5000 std cc/sec to 2×10^{-3} std cc/sec in 26 normal work days, 50 hr of which was devoted to chamber operational leak detection. The procedures and techniques of vacuum system analysis and leak detection used in this operation are described, as are the modifications and additions to the chamber which were required to accomplish the project objective. The results of the operation proved the adequacy of the techniques used, and demonstrated the capability of reducing chamber leakage to much less than 2×10^{-3} std cc/sec.

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SECTION I
INTRODUCTION

The Aerospace Environmental Chamber (Mark I) is a 42-ft-diam, 82-ft-high space simulation chamber designed to test full-scale space vehicles and components (Fig. 1). Pressures in the 10^{-8} torr range will be maintained by forty-eight 32-in. oil diffusion pumps and by 70°K and 20°K cryogenic pumping systems. The space thermal heat sink will be simulated by a liquid-nitrogen (LN_2)-cooled chamber liner 35 ft in diameter by 65 ft high. Solar energy will be simulated with a bank of carbon-arc lamps and optics 10 ft wide by 32 ft high, and planet radiation will be simulated with an array of tungsten filament lamps.

The facility was designed for the U. S. Air Force under contract AF 40(600)-904 and constructed under contract DA-01-076-ENG-5448. Beneficial occupancy of the chamber was assumed by the Government on September 20, 1965, and by ARO, Inc., the operating contractor, on September 21, 1965. At the time of writing, the basic vacuum chamber and external support equipment are essentially complete. The internal cryogenic systems, the solar and albedo simulators, and the diffusion pumps will be installed as required to meet specific test objectives and as test schedules permit.

The basic vacuum chamber contains more than 14,000 ft^2 of surface area, approximately 5000 ft of weld joint separating the vacuum environment from atmosphere, and approximately 180 removable vacuum penetrations ranging in size from 2 in. to 20 ft in diameter. Each penetration contains either a metallic crush-type or a flexible elastomeric vacuum seal. These seals expose approximately 1000 linear feet of sealing surface between atmosphere and the vacuum environment. Addition of the solar simulator and internal cryogenic systems will add 44 vacuum penetrations, 40,000 ft^2 of cryogenic surface, and hundreds of cryogenic system weld joints in the vacuum environment. In this large complex system, the existence of a single leak the diameter of a human hair will prevent attainment of the 1×10^{-8} torr vacuum level for which the facility was designed.

A program was initiated, well in advance of assuming responsibility for operation of the facility, to develop techniques and procedures for vacuum system analysis and leak detection (Ref. 1) and to train operating personnel. The results, applicable to vacuum systems of any size or complexity, were then used to develop a complete, detailed leak detection program designed to put Mark I into operation and to assure the attainment of the desired space vacuum conditions with a minimum of time and expense.

The leak detection program was put into effect on the first day of chamber beneficial occupancy — September 21, 1965. Preparing the chamber for pumpdown required 17 days of one-shift operation. Reduction of the total chamber leak rate to 2×10^{-3} std cc/sec was accomplished 150 hr after initiation of chamber pumpdown.

After permanent repair of the leaks found, a second chamber pumpdown to verify the overall vacuum integrity of the chamber was accomplished in 26 hr.

SECTION II
THEORY OF LEAK DETECTION

2.1 VACUUM SYSTEM PERFORMANCE

In any vacuum chamber the lowest pressure which can be attained is a direct result of the balance between the total system pumping capacity and the system's total gas load.

The pumping system may consist of mechanical, diffusion, cryogenic, ion, sublimation, or sorption pumps, or any combination of these, each having a unique performance characteristic for different gases. The gas load which must be removed from the chamber may originate from several sources, such as:

a. Leakage directly from the atmosphere

b. Leakage from subsystems in the vacuum chamber (including the test article)

c. Leakage from trapped volumes in the vacuum chamber (virtual leaks)

d. Release of absorbed gases from surfaces in the vacuum chamber (outgassing)

e. Permeation of gases through elastomeric seals

The basic purpose of leak detection is to achieve a specific vacuum level in the test chamber by:

1. Determining the capacity of the pumping systems
2. Determining the magnitude of the gas load contributed by each source

3. Comparing the magnitude of the gas loads with the pumping capacity
4. Reducing chamber pressure by reducing the gas loads which exceed the pumping capacity at the desired vacuum level

The general relationship between gas load, pumping speed, and chamber pressure is:

$$P = \frac{Q}{S} \tag{1}$$

where

P = pressure in torr (mm Hg)

Q = gas load in torr-liters/sec

S = pumping speed in liters/sec

This equation may be applied to a mixture of gases, such as air, in terms of total pressure, total gas load, and total pumping speed; or it may be applied to individual components of the mixture in terms of the component partial pressure, gas load, and pumping speed.

2.2 PARTIAL PRESSURE ANALYSIS

2.2.1 General Considerations

Since one of the prime objects in leak detection is to identify the sources of the gas load, it is necessary to deal with individual components of the mixture. In this case, Eq. (1) can be expanded into the sum of the partial pressures of the mixture:

$$PP_1 = \frac{Q_1}{S_1},\ PP_2 = \frac{Q_2}{S_2},\ \ldots PP_n = \frac{Q_n}{S_n} \tag{2}$$

$$P_T = PP_1 + PP_2 + \cdots + PP_n \tag{3}$$

$$P_T = \frac{Q_1}{S_1} + \frac{Q_2}{S_2} + \cdots + \frac{Q_n}{S_n} \tag{4}$$

where

P_T = Total pressure of mixture

PP_1 = Partial pressure of gas no. 1

Q_1 = Magnitude of gas no. 1 load

S_1 = Pumping speed of system for gas no. 1

The magnitude of each component of the total gas load is determined by the use of Eq. (2) and a partial pressure analysis obtained with a mass spectrometer residual gas analyzer (section 2.2.2). The system pumping speed for each component is obtained from the pump manufacturer's data or by pump calibration. The origin of each component of the total gas load is determined by comparing the residual gas analysis with the known composition in each potential gas load source.

The necessity of determining the magnitude of the major gas load components prior to initiating any effort to search for individual leaks can be illustrated by considering a vacuum system in equilibrium under the following conditions:

$$P_T = PP_1 + PP_2 + PP_3 = 1 \times 10^{-4} \text{ torr}$$
$$PP_1 = 9 \times 10^{-5} \text{ torr because of inleakage of atmospheric air}$$
$$PP_2 = 5 \times 10^{-6} \text{ torr because of internal system leakage}$$
$$PP_3 = 5 \times 10^{-6} \text{ torr because of outgassing}$$

The obvious course, in this case, is to reduce the partial pressure of atmospheric air by searching for and eliminating significant air leaks. Elimination of all air leaks would, theoretically, reduce the total pressure to

$$P_T = 0 + 5 \times 10^{-6} + 5 \times 10^{-6} = 1 \times 10^{-5} \text{ torr}$$

If, without knowledge of the magnitudes of the gas loads, an attempt had been made to eliminate the internal system leakage, the total pressure could not have been reduced to less than $P_T = 9 \times 10^{-5} + 0 + 5 \times 10^{-6} = 9.5 \times 10^{-5}$ torr, which is an insignificant reduction in total pressure.

2.2.2 The Mass Spectrometer Residual Gas Analyzer

The mass spectrometer residual gas analyzer (RGA) provides a quantitative analysis of the mixture of gases in the vacuum chamber. The principles of operation of this instrument are described in Refs. 1 and 2 and are not discussed here. Rather, the methods and techniques of using the instrument for leak detection in an operating chamber are described.

a. Residual Gas Analysis at Chamber Pressures less than 10^{-5} Torr

The instrument can be attached to the vacuum chamber in one of two different ways, depending on the chamber pressure at which the instrument is to be used. The analyzer section of the instrument, i.e., the sensing element, cannot operate at pressures much greater than 10^{-5} torr. For those cases where it is known that the chamber pressure will reach this level, or below, before the RGA is needed, the sensing element can be installed inside the vacuum chamber for direct sampling of chamber gases (Fig. 2).

b. Residual Gas Analysis at Chamber Pressures greater than 10^{-5} Torr

For those cases where leakage problems prevent attainment of 10^{-5} torr chamber pressure, a mass spectrometer sampling system can be designed to provide a means of using the RGA for leak detection at chamber pressures from approximately 200 to 10^{-5} torr. A schematic of this system is shown in Fig. 3. As can be seen from the schematic, molecular leaks covering a wide range of sizes are installed between the chamber and the RGA. When it is desired to analyze the gas composition in the chamber at the higher pressures, one of the leaks is opened permitting gas to flow from the chamber into the RGA equipped with an independent vacuum pumping system. The appropriate leak is selected on the basis of the chamber pressure, the pumping speed of the RGA pumping system, and the sensing element pressure desired (less than 10^{-5} torr).

One disadvantage of the mass spectrometer sampling system is that the sensing element also analyzes the gases contributed by the outgassing and leakage in the piping connecting the RGA to the chamber. This effect can be compensated by analyzing the gas composition in the piping system before admitting gas from the chamber, then subtracting the results from chamber data.

2.2.3 Interpretation of the Residual Gas Analysis

Figure 4 is a typical residual gas analysis obtained during operation of a large space simulation chamber. The mass spectrometer RGA automatically scans through a range of atomic mass numbers (m/e) — the mass range being a function of the particular make and model of the instrument. The presence of a residual gas component is indicated by a parent mass peak at a position on the recording corresponding to the mass number of the component. For example, oxygen (O_2) has a molecular weight of 32 and, when singly ionized in the RGA, has a mass number of 32. The presence of oxygen as a residual gas component is, therefore, indicated by a parent peak at the mass 32 position. The magnitude of a peak is directly proportional to the partial pressure of the component creating that peak. An instrument sensitivity factor (i. e., torr/division of peak height), obtained by calibrating the instrument with gas samples of known composition, is used to determine component partial pressure.

Each gas creates a unique fragment pattern which includes the parent mass peak and a number of fragment mass peaks at different mass numbers. The fragment mass peaks result from isotopes, double ionization, and molecular dissociation. Two or more components, such as N_2 and CO, may have common parent mass peaks, and others may have a number of common fragment peaks. Accurate interpretation of the residual gas analysis of a combination of three or more components requires solution by a computer programmed with the known fragment patterns of all components present.

Efficient leak detection can be accomplished by visual inspection of the residual gas analysis. The gas loads which most often prevent attainment of a low chamber pressure are atmospheric air leakage, internal system leakage, and outgassing. Fortunately, each of these gas loads can be identified by its unique characteristic effect on the residual gas analysis.

2.2.3.1 Atmospheric Air

Oxygen is the only gas commonly found in space simulation chambers which produces a mass peak at the mass number 32 location. A mass peak at this location, therefore, indicates the presence of oxygen in the chamber. In those cases where no internal system contains oxygen, a mass 32 peak can be attributed to the oxygen content of atmospheric air leakage. Atmospheric air also creates a mass 28 peak, which is about five times the magnitude of the mass 32 peak, and fragment peaks at the mass 14 and mass 16 locations. The existence of mass 28, 14, and 16 peaks in addition to the mass 32 peak verifies the existence of atmospheric air; the existence of these peaks in the absence of a mass 32 peak indicates that atmospheric air is not a component.

a. Determining the Size of an Air Leak during Steady-State Operation

The approximate size of an air leak can be calculated using the residual gas analysis and the chamber pumping system throughput curve as in the following example:

The residual gas analysis shown in Fig. 5 was recorded while a measured air leak of 3.5×10^{-1} std cc/sec was being admitted into the chamber. The sensitivity factor of the RGA for air had been found by previous calibration to be approximately 6×10^{-8} torr of air per division of the mass 32 peak. The mass 32 peak of 51 divisions indicates an air partial pressure of (51 divisions) (6×10^{-8} torr of air/division) = 3×10^{-6} torr of air. Reference to the chamber pumping system throughput curve at this pressure showed a throughput of about 3.5 x 10^{-1} std cc/sec, which agrees with the actual value.

b. Determining the Size of an Air Leak by the Chamber Rate of Rise

Chamber pressure rate of rise is determined by isolating all pumps from the vacuum chamber and recording the increase in chamber pressure over a period of time. The gas load responsible for the pressure increase is calculated by:

$$Q = \left(\frac{\Delta P}{\Delta t}\right)\left(V\right) \tag{5}$$

where

ΔP = Pressure rise during the period Δt

Δt = Period of time

V = Volume of the system experiencing the pressure rise

Q = Gas Load

This relation can be used to calculate the total gas load when ΔP is in terms of total pressure, and can be used to calculate component gas loads when ΔP is in terms of partial pressure.

Figure 6 is a recording of data taken during a rate of rise measurement in a 106,000-ft^3 chamber. The trace is a record of the mass 32 peak increase, and the superimposed values correspond to the total pressure in the chamber at the times noted.

The total gas load is calculated using Eq. (5) and the total pressure rate of rise as follows:

$$Q_{\text{Total}} = \left(\frac{\Delta P}{\Delta t}\right)\left(V\right) = \frac{(6.9 \times 10^{-6}\ \text{torr} - 2.9 \times 10^{-6}\ \text{torr})}{(29\ \text{min} - 3.4\ \text{min})}(106{,}000\ \text{ft}^3)$$

$$= \frac{4 \times 10^{-6}\ \text{torr}}{25.6\ \text{min}}(1.06 \times 10^5\ \text{ft}^3) = 1.66 \times 10^{-2}\ \frac{\text{torr-ft}^3}{\text{min}}$$

and, converting to std cc/sec,

$$Q_{\text{Total}} = \frac{1.66 \times 10^{-2}\ \text{torr-ft}^3}{\text{min}} \times \frac{\text{cc}}{3.53 \times 10^{-5}\ \text{ft}^3} \times \frac{\text{std}}{760\ \text{torr}} \times \frac{\text{min}}{60\ \text{sec}}$$

$$= 1.03 \times 10^{-2}\ \text{std cc/sec}$$

The atmospheric air leak rate is calculated using Eq. (5), the mass 32 peak rate of rise, and the mass 32 sensitivity factor.

$$Q_{Air} = \frac{(18.6 - 5.1 \text{ divisions})}{(30 \text{ min})} (1.06 \times 10^5 \text{ ft}^3)(6 \times 10^{-8} \text{ torr of air/div. of mass } 32)$$

$$= 2.86 \times 10^{-3} \frac{\text{torr-ft}^3}{\text{min}}$$

and, converting to std cc/sec,

$$Q_{Air} = 1.78 \times 10^{-3} \text{ std cc/sec}$$

2.2.3.2 Internal System Leakage

Complex space simulation chambers usually contain a number of internal systems, each a potential source of leakage. The RGA can be used to determine which, if any, of the systems are leaking and the approximate magnitude of the leak. A leaking internal system will create a parent mass peak and fragment pattern on the RGA scan corresponding to the mass number of the fluid in the system. The magnitude of a leak is determined by the same methods used for air leaks. When more than one system contains the same type of fluid identified by the RGA scan, the leaking system is identified by varying the internal systems pressures or injecting a tracer gas into each system in turn and noting the results on the RGA scan.

2.2.3.3 Outgassing

The outgassing gas load is one of the most difficult to identify. Both the magnitude and composition of this gas load are functions of materials present, temperature, previous history of the materials, and time under vacuum.

Probably the most distinguishing characteristic of outgassing is the large H_2O content from unbaked materials near room temperature. However, the H_2O content decreases with vacuum exposure time and with decreasing material temperature.

2.3 LEAK CHECKING

Leak checking is the act of locating a specific leak so that it can be eliminated. Many instruments and techniques are available for leak checking — the choice being dependent on factors such as the size and complexity of the vacuum chamber and the sensitivity desired (i. e., the magnitude of the smallest leak of interest).

A detailed discussion of leak checking techniques and instrumentation is contained in Ref. 1.

2.4 PERSONNEL TRAINING

Personnel training is an important part of any efficient operation, and leak detection is certainly no exception. Misinterpretation of data during leak detection of large complex systems can easily result in the unnecessary expenditure of days, or even weeks, of valuable test time. However, leak detection of very large systems has been found to be a very rapid process when performed by trained and experienced personnel.

SECTION III
DEVELOPING THE MARK I LEAK DETECTION PROGRAM

3.1 CHAMBER PERFORMANCE PREDICTIONS

Before any operation of Mark I was attempted, it was necessary to predict the various performance characteristics for the purpose of evaluating actual test results. The significant performance predictions required were: chamber vacuum pumping capacity, maximum acceptable total leak rate, total chamber outgassing rate, and chamber pumpdown rate.

a. Chamber Vacuum Pumping Capacity

Figure 7 shows the predicted pumping capacity of the major systems in Mark I. This figure was used to determine the maximum allowable leak rate and, during leak detection operations, to determine the total gas load present when the chamber pressure reached a steady-state condition with a specific pumping system in operation.

b. Maximum Acceptable Leak Rate

It was first decided that the chamber must be capable of maintaining a pressure of 1×10^{-8} torr with all cryogenic systems and diffusion pumps in operation. Figure 7 then showed that a maximum total gas load of 2×10^{-1} std cc/sec could be tolerated at this pressure. Approximately 1 percent of this total was allotted for chamber leakage. This, then, was the goal established for the leak detection program — to reduce the total chamber leakage to approximately 2×10^{-3} std cc/sec or less.

c. Chamber Outgassing Rate

Figure 8 shows the total chamber outgassing rate predicted on the basis of data contained in Refs. 3 and 4. The curve predicts an outgassing load on the order of 2×10^{-2} std cc/sec after a nominal pumping time of 100 hr. Results obtained during the subsequent leak detection effort showed the actual value to be about 2×10^{-1} std cc/sec, of which approximately 1.4×10^{-1} std cc/sec was water vapor.

d. Chamber Pumpdown Rate

Figure 9 shows the predicted and actual chamber pressure versus time during the pumpdown period. The predicted curve is a plot of the equation.

$$t = \frac{V}{S} \ln \frac{P_1}{P_2} \quad \text{(Ref. 5)}$$

where

t = Time

V = Chamber volume

S = Pumping speed at the chamber

P_1 = Initial pressure at $t = 0$

P_2 = Pressure at $t = t$

This equation neglects the effects of leakage and outgassing on the pumpdown rate. The deviation of the actual from the predicted curve can be explained as a difference between predicted and actual pumping speed and by the effects of leakage at the lower chamber pressures. The large deviation at the lower pressures was the first indication that a leakage problem existed. Subsequent leak detection and leak checking resulted in the location and elimination of a 20-std cc/sec air leak.

3.2 LEAK DETECTION PROGRAM

The basic leak detection program developed for Mark I is shown in flow chart form in Fig. 10. The values of chamber pressure, pumpdown rate (dP/dt) and leak rate shown were based on the unique performance characteristics of Mark I and, in general, are applicable to that chamber only. A number of details, such as when cryopumping of the water vapor in the chamber should be attempted, are omitted for the sake of clarity. This program was used for the actual leak detection effort and was adhered to with few exceptions.

SECTION IV
CHAMBER PUMPDOWNS PRIOR TO LEAK DETECTION OPERATIONS

Two chamber structural integrity pumpdowns were conducted by the construction contractor prior to Government acceptance of the chamber. The first of these pumpdowns was terminated at a pressure of 10 torr because of leakage in a vibration system bellows seal. The second pumpdown, conducted after replacing the bellows seal with a blind O-ring flange, produced a base pressure of 1.2 torr which verified the structural adequacy of the chamber.

Data from the second structural integrity pumpdown indicated a total chamber gas load of approximately 5000 std cc/sec.

SECTION V
PREPARING THE CHAMBER FOR PUMPDOWN AND LEAK DETECTION

Since it was known that the chamber gas load was approximately 5000 std cc/sec when beneficial occupancy was assumed by ARO, Inc., a program was initiated to eliminate all possible leaks prior to attempting a vacuum integrity pumpdown. At the same time, leak detection equipment and instrumentation was installed in the chamber.

5.1 ELIMINATION OF LEAKS PRIOR TO PUMPDOWN

5.1.1 Vacuum Penetrations

Several vacuum penetrations were removed from the chamber and inspected to determine the condition of the vacuum seals. Since the majority of the seals inspected were either damaged or improperly seated, all 180 penetrations were removed from the chamber. The condition of typical vacuum penetrations is shown in Figs. 11a through h. Each figure shows a leakage source which would have affected chamber performance and would have required detection and elimination during chamber operation.

The following is an outline of the program followed to ensure the vacuum integrity of all chamber vacuum penetrations:

a. Each penetration was assigned an identification number.

b. A written record was kept for each penetration which included the following:

1. Name of person removing penetration
2. Condition of penetration
3. Corrective action taken
4. Name of person re-installing penetration
5. Results of penetration leak check prior to pumpdown

c. All wire seals were temporarily replaced with elastomer O-ring seals by modifying the penetration plates.

d. Each penetration was carefully re-installed.

e. Each penetration was leak checked, using the leech technique where possible.

5.1.2 Vacuum Pumping System

The vacuum pumping system used for the vacuum integrity pumpdown consisted of two 850 cfm mechanical pumps, two 4000-cfm blowers, and one 32-in. oil diffusion pump with a 32-in. angle valve backed by a ring jet booster and an 80-cfm mechanical pump in series (see Fig. 12).

This external vacuum system was operated independently by closing the vacuum valves between the system and the chamber. A helium mass spectrometer leak detector was used to pinpoint leaks in the system until the ultimate pressure indicated an acceptable system leak rate.

5.2 INSTALLATION OF EQUIPMENT AND INSTRUMENTATION

The following instrumentation and equipment were installed prior to pumpdown and leak detection of the chamber.

a. A mass spectrometer sampling system, discussed in section 2.2.2.b, was installed (Fig. 13). This system was used very effectively to determine the source of significant gas loads and to distinguish between leakage and outgassing.

b. Six LN_2-cooled surfaces were installed to provide cryogenic pumping of 77°K condensables, particularly water vapor. The stainless steel coil panels, each approximately 2 by 4 ft, were assembled in two banks for a total of 96 ft^2 of LN_2-cooled surface. These banks were installed in the chamber on the floor grating and leak checked prior to the pumpdown (Fig. 14).

c. Chamber pressure instrumentation, consisting of two Alphatron® gages and two ion gages with spare filaments, was installed in the chamber. A recorder was connected to one Alphatron and one ion gage so that a record could be kept of the pressure versus time data. The other gages were installed as backup instruments.

d. A vacuum valve was installed in one penetration plate so that rotometers and standard leaks could be connected to the chamber as needed. From this valve, gas could be metered into the chamber for such purposes as leak detector calibrations, pumping system calibrations, and obtaining leak detector response time figures.

e. Vacuum valves were attached near the inlet of each 4000-cfm blower and near the inlet of each mechanical forepump. These valves were used for connecting the mass spectrometer leak detector to the vacuum system. When the chamber was being pumped by the 4000-cfm blowers, the leak detector was connected at the inlet to the blower; while the chamber was pumped by the diffusion pump, the leak detector was connected at the inlet to the mechanical forepump.

SECTION VI
PUMPDOWN AND LEAK DETECTION RESULTS

6.1 FIRST PUMPDOWN

The first pumpdown and leak detection operation was begun on October 14, 1965. The following describes the significant events which occurred during this operation.

Time from Start of Pumpdown hr-min	Chamber Pressure, torr	Remarks
0	760	Began pumpdown of chamber with two 850-cfm mechanical pumps.
2	150	Pressure-time curve began to deviate from predicted. Two 3/8-in. plugs in chamber found open and sealed.
3-20	50	Mass spectrometer sampling system opened to chamber.
6-12	5.5	Two 4000-cfm blowers turned on.
7	10^{-1}	Mass spectrometer analysis showed atmospheric leakage to be approximately 30 std cc/sec.

Time from Start of Pumpdown, hr-min	Chamber Pressure, torr	Remarks
8-40	1.8×10^{-2}	Began cooling cryogenic panels with LN_2.
9-22	1.3×10^{-2}	One operating 32-in. diffusion pump opened to chamber.
11-07	2.8×10^{-3}	Diffusion pump valve closed.
12	8×10^{-3}	All pumps valved off. Chamber secured for the night.
25	3.4×10^{-1}	Pumping resumed with two 4000-cfm blowers. Overnight rate of rise indicated a total gas load of approximately 27 std cc/sec.
26	2×10^{-2}	One 4000-cfm blower valved off from chamber
27	1.5×10^{-2}	Chamber pressure stabilized. Leak checking started with helium mass spectrometer leak detector to locate atmospheric leak of approximately 27 std cc/sec.
29	1.5×10^{-2}	Large air leak found in vibration can and sealed with vacuum putty.
30-40	7×10^{-3}	Chamber pressure stabilized. Total gas load approximately 12 std cc/sec as determined from throughput curve. Leak detector system sensitivity and response time calibrations run. Systematic rough leak check of main chamber started.
31-20	7×10^{-3}	Air leak of approximately 10 std cc/sec found in a viewport vacuum seal and eliminated with vacuum putty.
33	2×10^{-3}	All pumps valved off. Chamber secured for the weekend.
96	2.4×10^{-2}	Pumping resumed with two 4000-cfm blowers. Weekend rate of rise indicated a total gas load of approximately 1 std cc/sec.

Time from Start of Pumpdown, hr-min	Chamber Pressure, torr	Remarks
98-40	1.1×10^{-3}	One operating 32-in. diffusion pump opened to chamber. Two 4000-cfm blowers valved off from chamber.
100-40	2.3×10^{-5}	Began cooling cryogenic panels with LN_2.
102	1.3×10^{-5}	Chamber pressure stabilized.
102-30	1.3×10^{-5}	LN_2 supply to cryogenic panels stopped. Rough leak checking of chamber with helium leak detector resumed. One air leak of approximately 1×10^{-1} std cc/sec found in a pipe plug and eliminated. Residual gas analysis indicated a total atmospheric air leakage of approximately 2×10^{-1} std cc/sec. Leak detector system sensitivity and response time calibrations were run with the following results: 30-sec response time and 1×10^{-6} std cc/sec per division of leak detector reading.
111	2.7×10^{-5}	Operations discontinued overnight. One 32-in. diffusion pump left operating on chamber.
120	1.5×10^{-5}	Operations resumed. Detailed leak check of chamber begun.
121-30	1.4×10^{-5}	An air leak of 2×10^{-1} std cc/sec found in a diffusion pump elbow weld and sealed with vacuum putty.
123	9×10^{-6}	Began cooling cryogenic panels with LN_2.
127	3×10^{-6}	Chamber pressure stabilized.
128	3×10^{-6}	LN_2 flow to cryogenic panels stopped. Detailed leak check of chamber completed. Operations discontinued overnight. One 32-in. diffusion pump left operating on chamber.
144-30	9×10^{-6}	Operations resumed. Began cooling cryogenic panels with LN_2.

Time from Start of Pumpdown, hr-min	Chamber Pressure, torr	Remarks
150	2.3×10^{-6}	Chamber pressure stabilized. Total atmospheric air leakage was determined to be 2×10^{-3} std cc/sec by partial pressure analysis. Diffusion pump throughput calibration tests run.
151	---	Operations completed. Chamber returned to atmospheric pressure.

Final Results

a. Lowest pressure achieved in 106,000-ft^3 chamber — 2.3×10^{-6} torr (with one 32-in. diffusion pump and 96 ft^2 of LN_2-cooled surface)

b. Final gas loads (approximate):
   1. Total Gas Load — 2×10^{-1} std cc/sec
   2. Water Vapor — 1.4×10^{-1} std cc/sec
   3. Atmospheric Air Leak Rate — 2×10^{-3} std cc/sec

6.2 SECOND PUMPDOWN

After completion of the first pumpdown and leak check, the leaks found in the two welds and viewport were repaired, and a mass spectrometer sensing element was installed inside the chamber. A second pumpdown was begun on October 25, 1965, to determine the total chamber leak rate after repair of the leaks. The following describes the significant events which occurred during this operation:

Time from Start of Pumpdown, hr-min	Chamber Pressure, torr	Remarks
0	760	Began pumpdown of chamber with two 850-cfm mechanical pumps.
5-40	7.8	Two 4000-cfm blowers turned on.
7	4×10^{-2}	Pressure-time curve began to deviate from predicted. Total gas load approximately 30 std cc/sec.

Time from Start of Pumpdown, hr-min	Chamber Pressure, torr	Remarks
8-50	9×10^{-3}	Chamber pressure stabilized. External vacuum system 84-in. butterfly valve found to be leaking approximately 30 std cc/sec. Blowers valved off and the chamber secured for the night.
18-40	2×10^{-2}	Pumping resumed with one ring jet booster pump and one 32-in. diffusion pump.
20-30	9×10^{-5}	Chamber pressure stabilized. Began cooling cryogenic panels with LN_2. Residual gas analysis identified major portion of gas load as atmospheric air leakage.
21-30	8×10^{-5}	Check with He leak detector showed the vibration can weld, which had been repaired, to be leaking approximately 1 std cc/sec. Leak sealed with vacuum putty.
24	2.2×10^{-6}	Chamber pressure stabilized. Partial pressure analysis indicated an atmospheric air leak rate of 2×10^{-3} std cc/sec.
24-30	2.2×10^{-6}	The mass spectrometer RGA was calibrated.
26	2.2×10^{-6}	All pumps valved off. LN_2 flow to cryogenic panels stopped.
		During the next 24 hr the chamber pressure rate of rise was recorded, and an oxygen partial pressure rate of rise was recorded. The chamber was then returned to atmospheric pressure.

Final Results

a. Lowest pressure achieved in the 106,000-ft^3 chamber — 2.2×10^{-6} torr (with one 32-in. diffusion pump and 96 ft^2 of LN_2-cooled surface)

b. Final gas loads (approximate):
   1. Total Gas Load — 2 x 10^{-1} std cc/sec
   2. Atmospheric Air Leak Rate — 2 x 10^{-3} std cc/sec

SECTION VII
CONCLUDING REMARKS

The goal of the operation to reduce the total chamber leakage to approximately 2 x 10^{-3} std cc/sec was achieved with 50 hr of chamber operational leak detection. The entire pumpdown and leak check of Mark I, including the necessary chamber preparation and modification, was accomplished in 26 normal work days.

The results of the operation proved the soundness of the planned leak detection program and the adequacy of the techniques used for vacuum system analysis and leak detection. Moreover, the capability of reducing the chamber leakage to much less than 2 x 10^{-3} std cc/sec was demonstrated.

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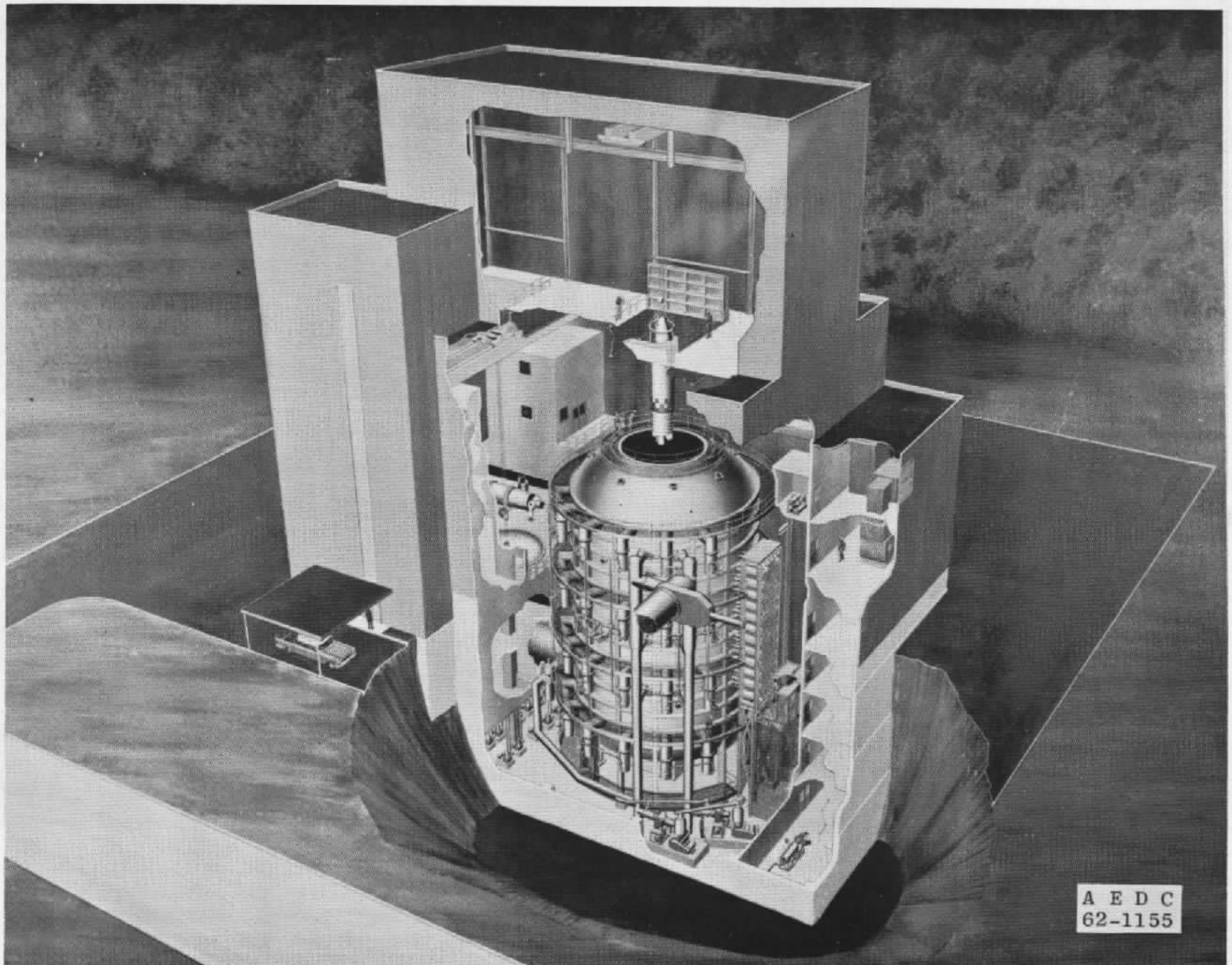


Fig. 1 Aerospace Environmental Chamber (Mark I)

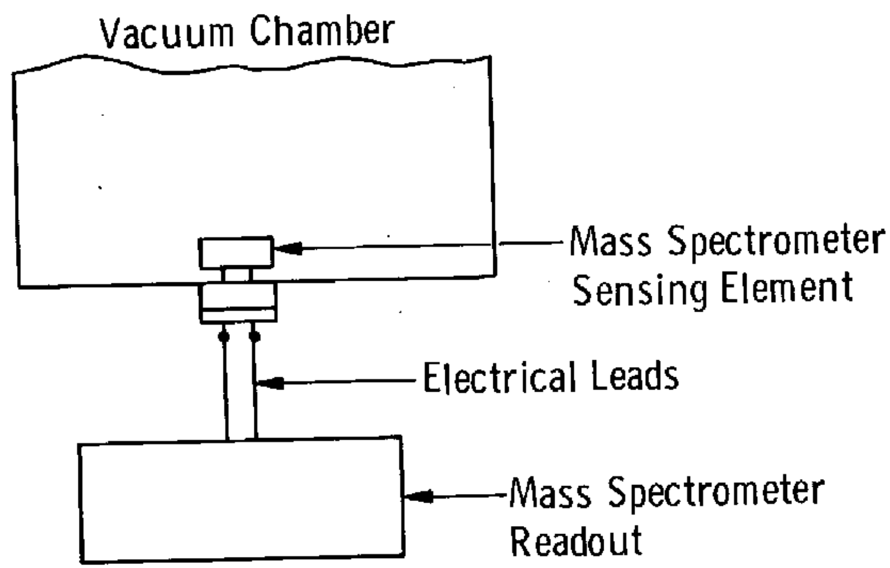


Fig. 2 Mass Spectrometer with Sensing Element inside the Vacuum Chamber

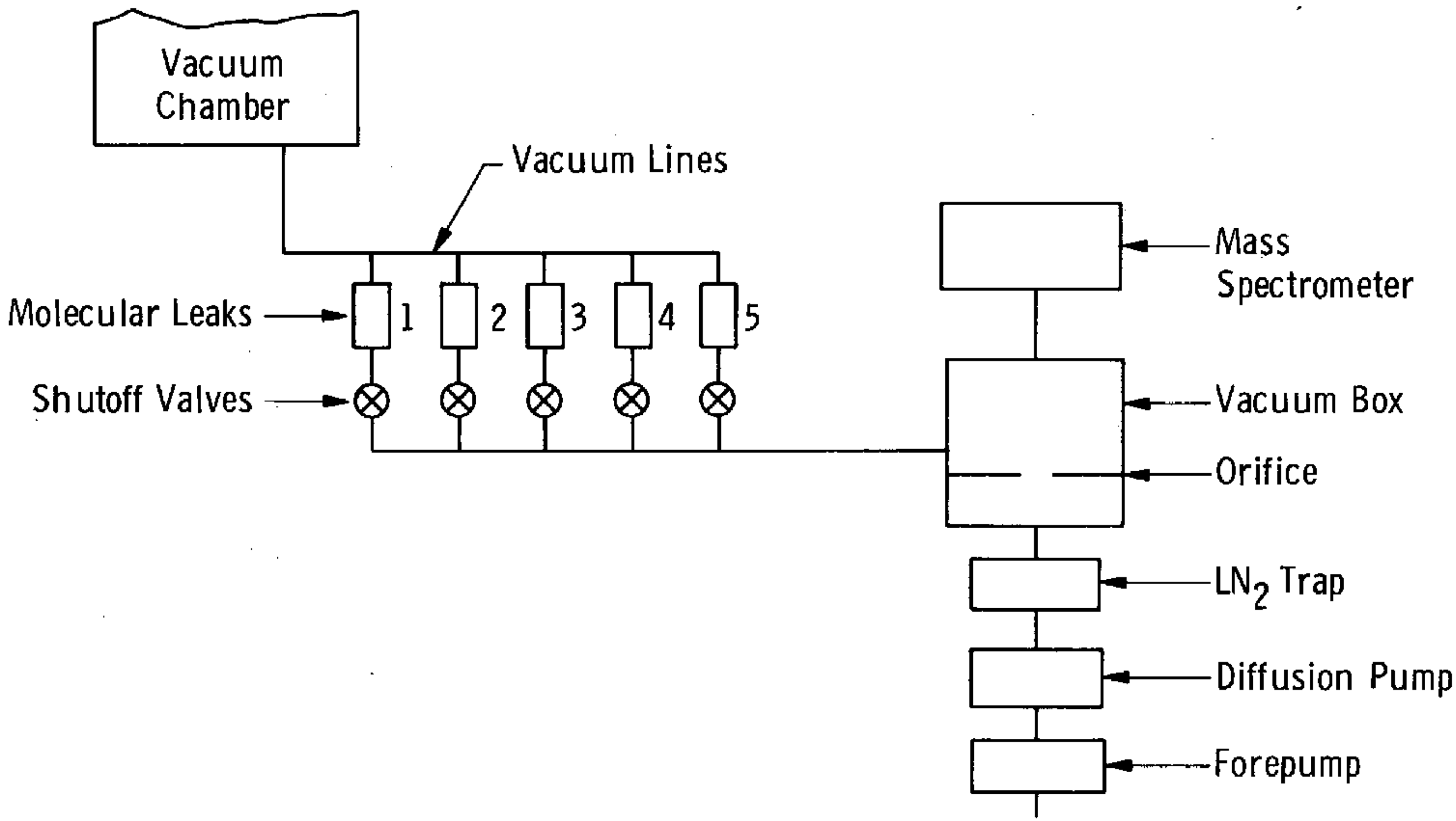


Fig. 3 Mass Spectrometer Sampling System

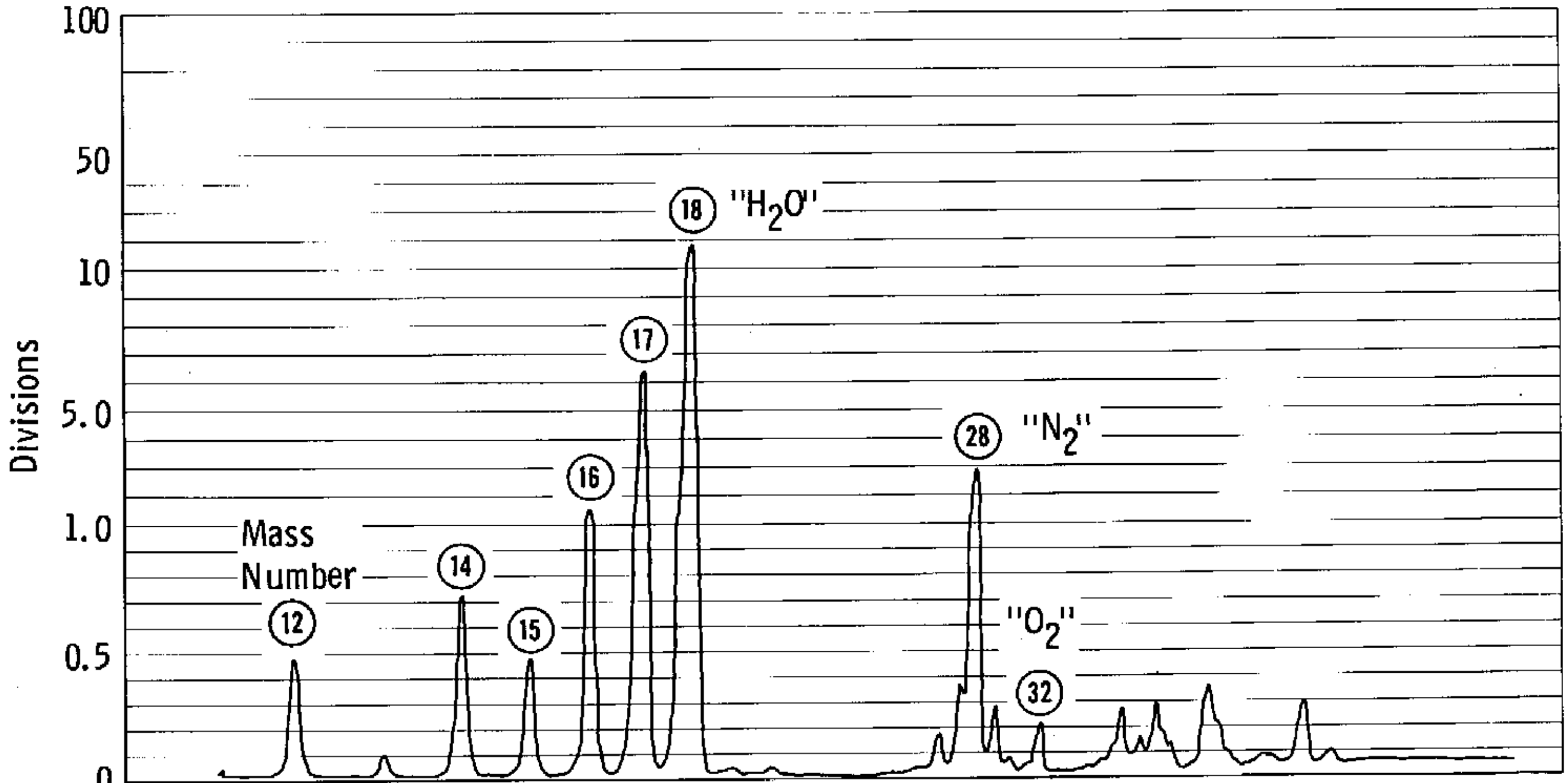


Fig. 4 Typical Residual Gas Analysis of Large Space Chamber showing Predominant Outgassing

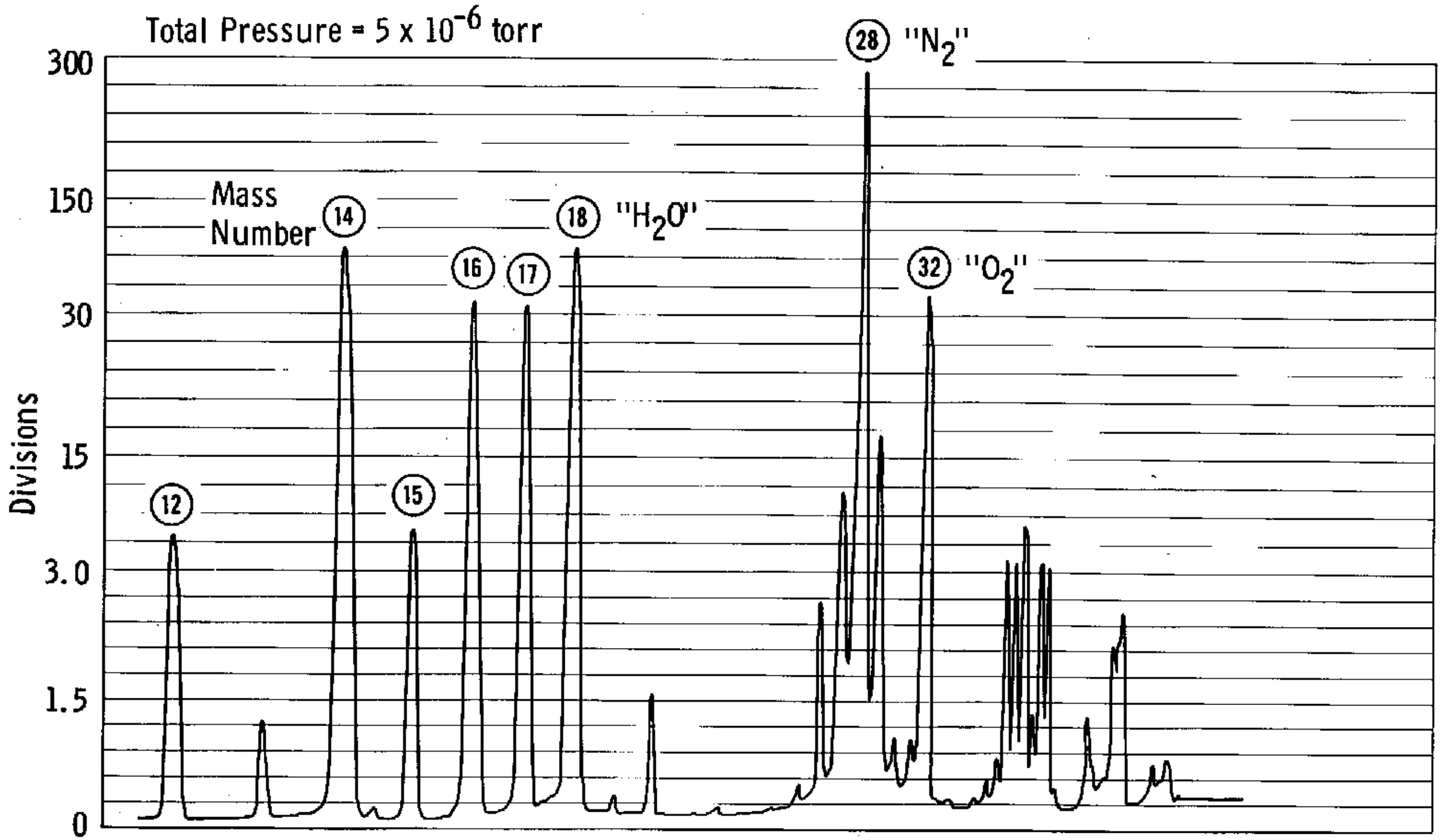


Fig. 5 Residual Gas Analysis showing Air Leak

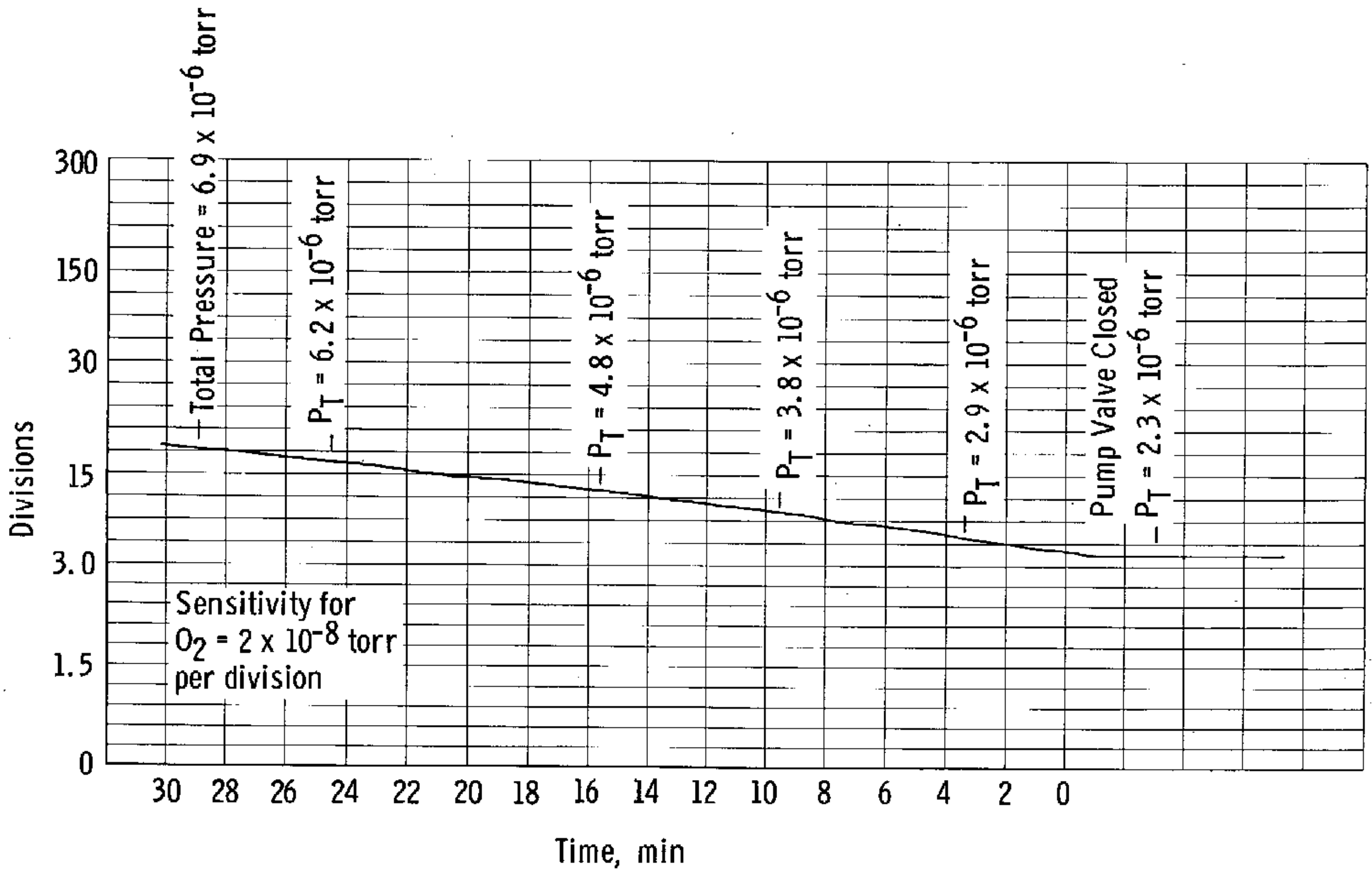


Fig. 6 Chamber Oxygen Partial Pressure Rate of Rise

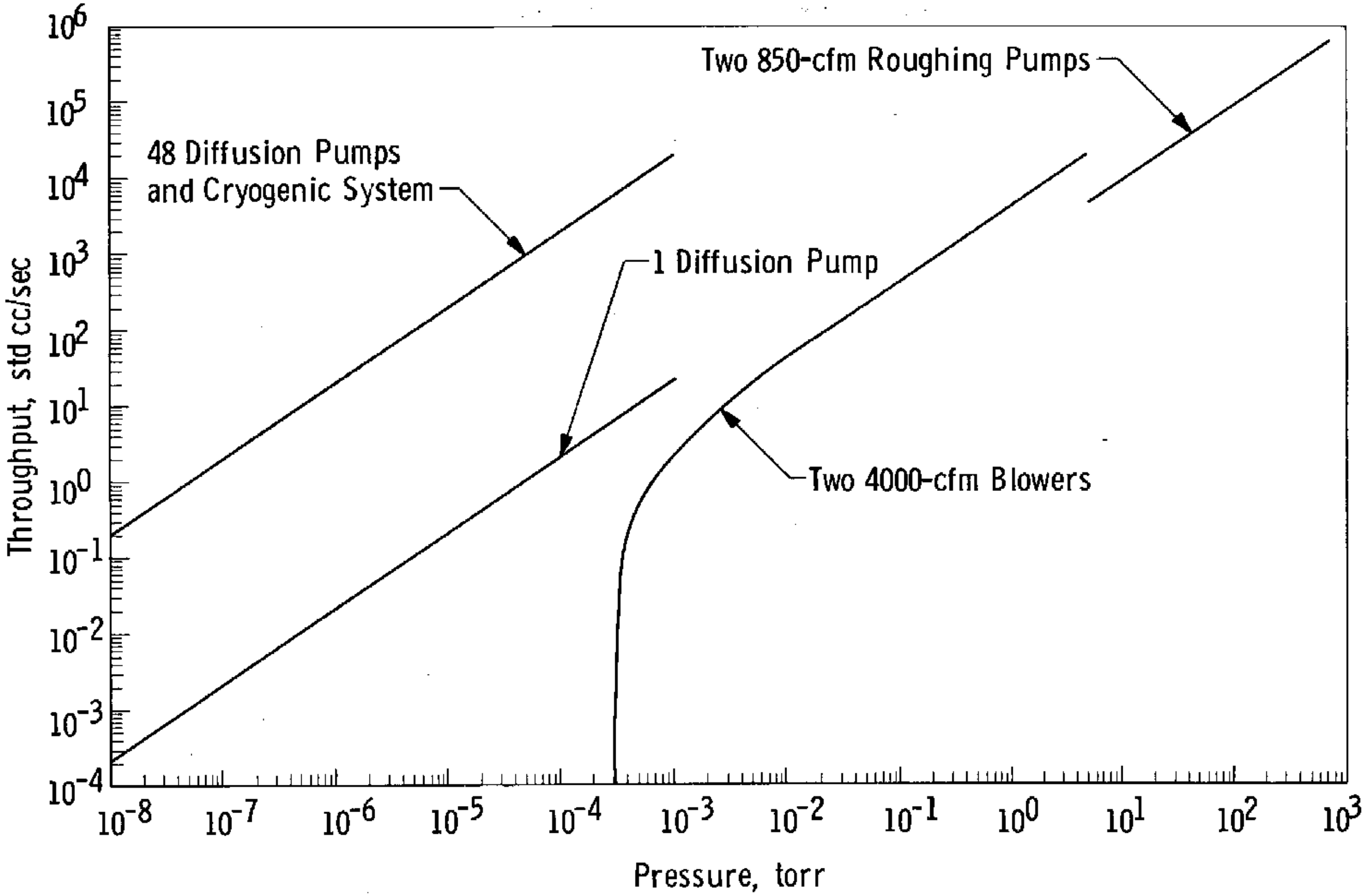


Fig. 7 Predicted Throughput Curve for Pumping System

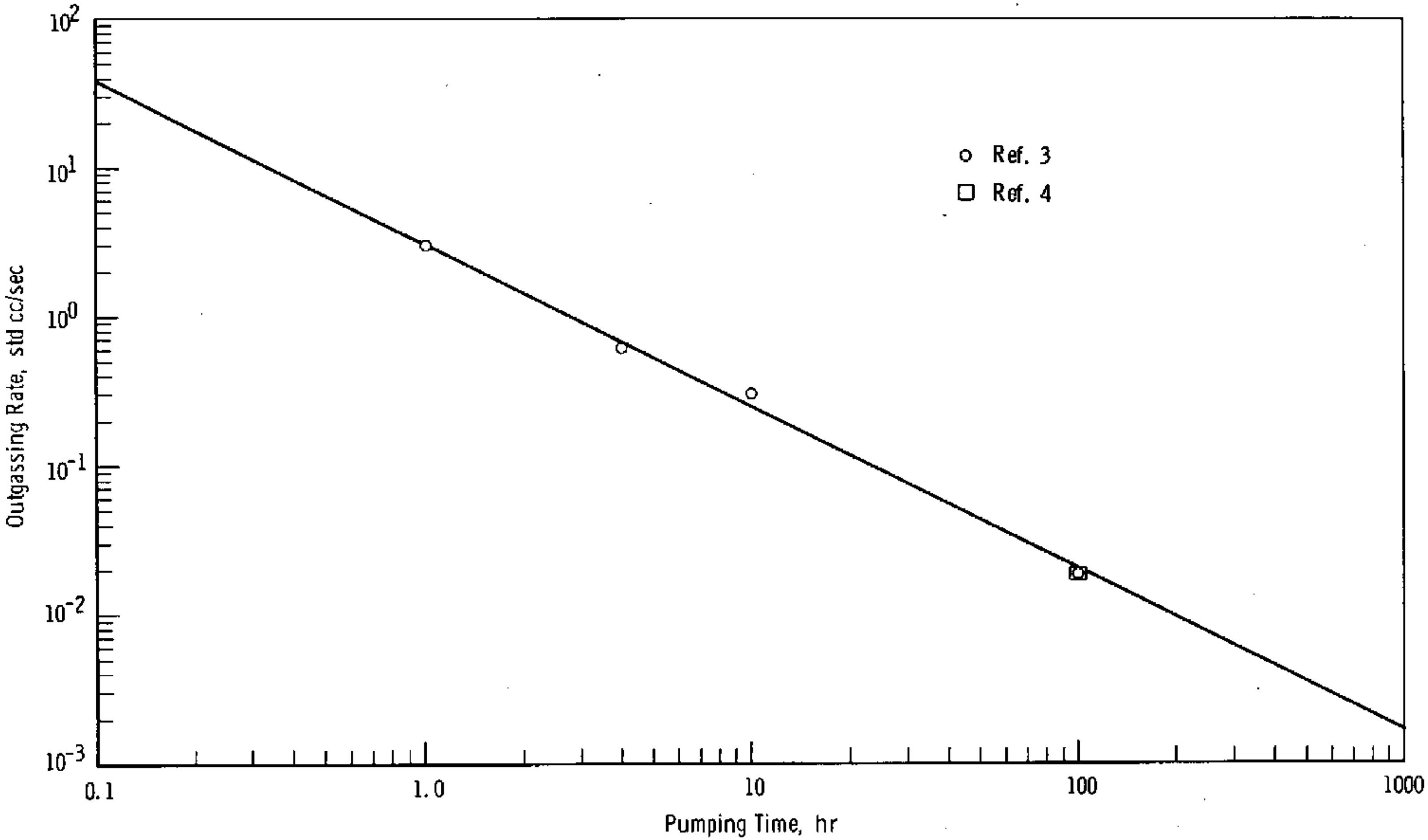


Fig. 8 Predicted Outgassing Rate for Chamber Wall

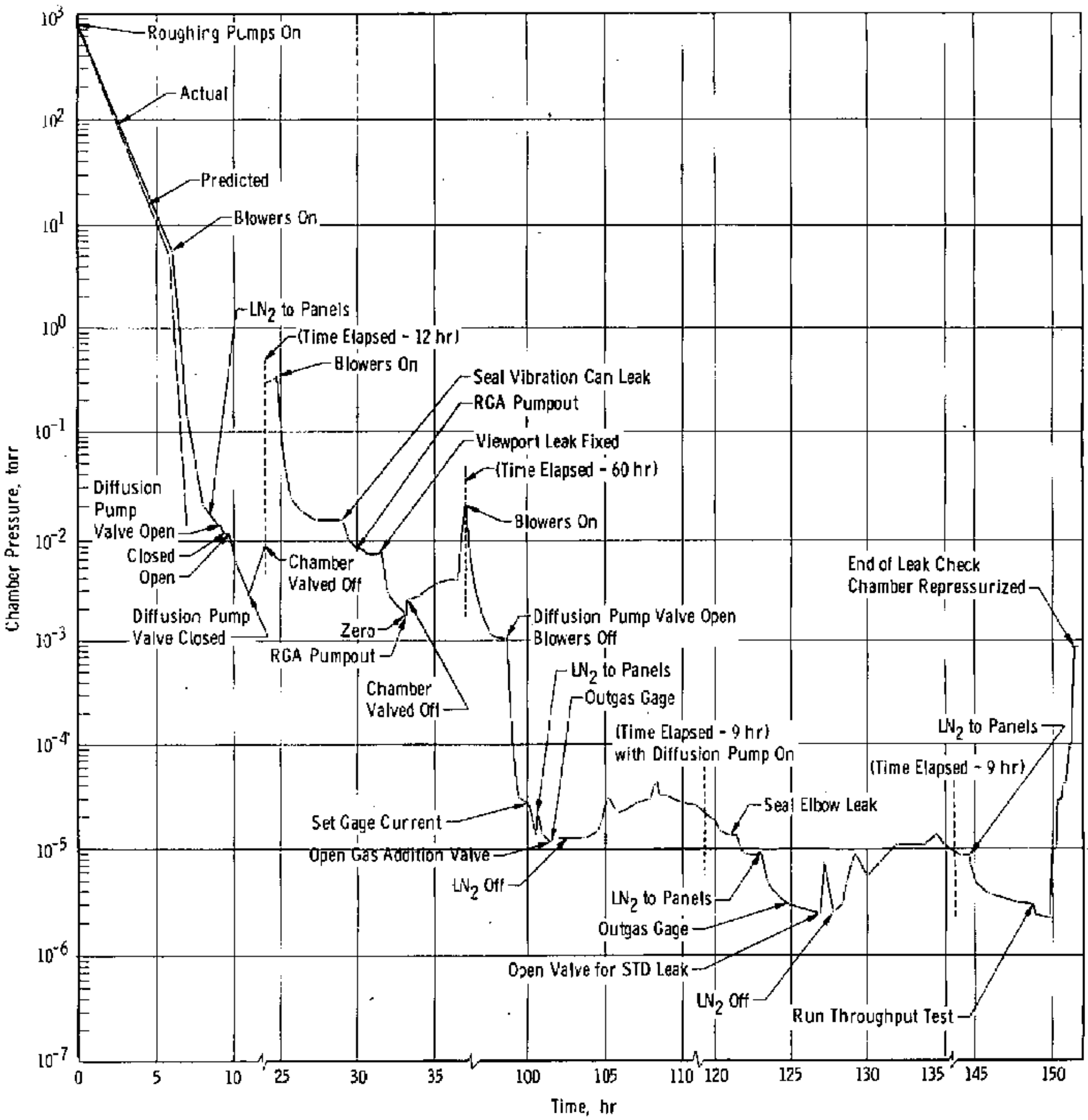


Fig. 9 Pressure versus Time for Bare Chamber Leak Check

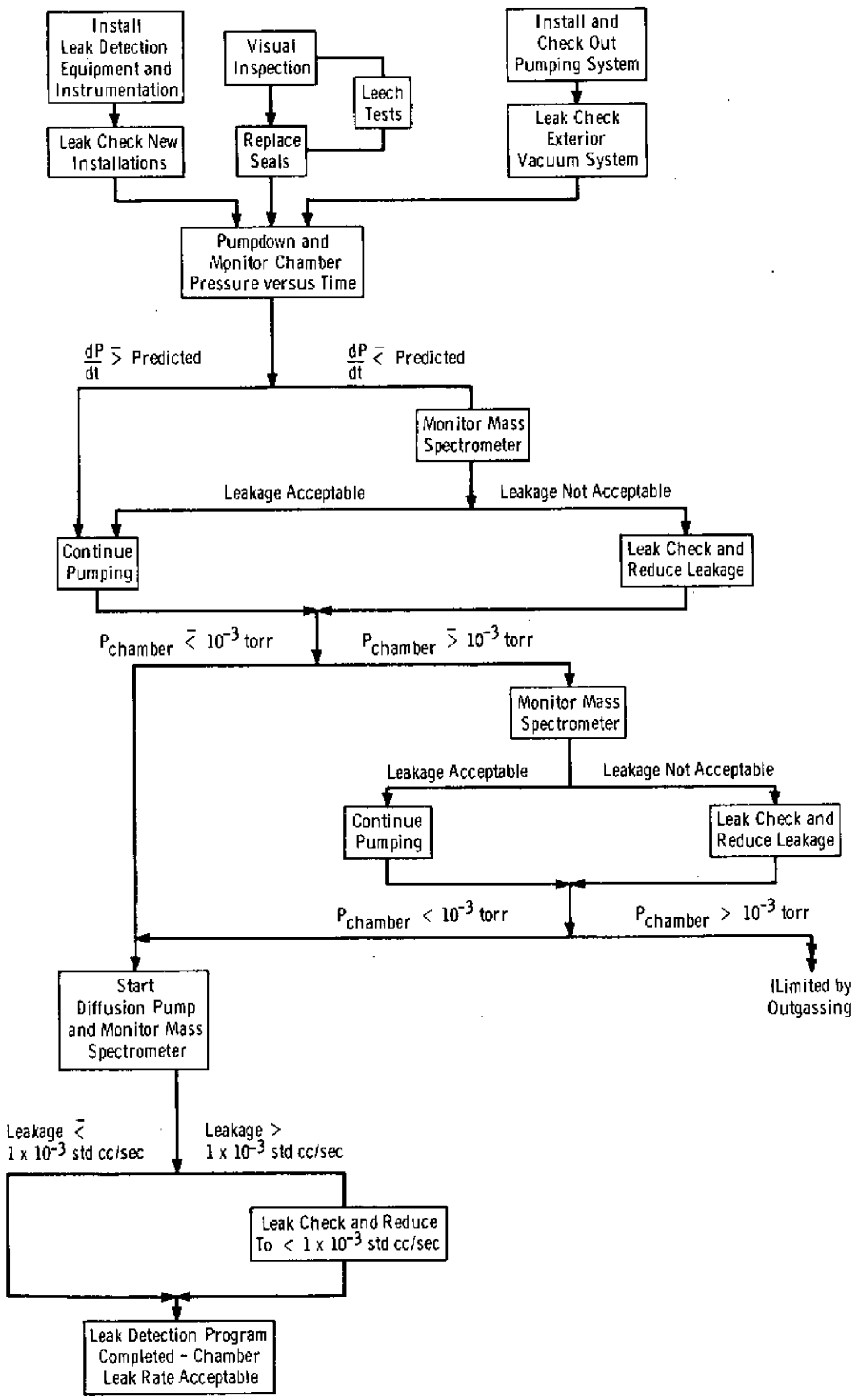
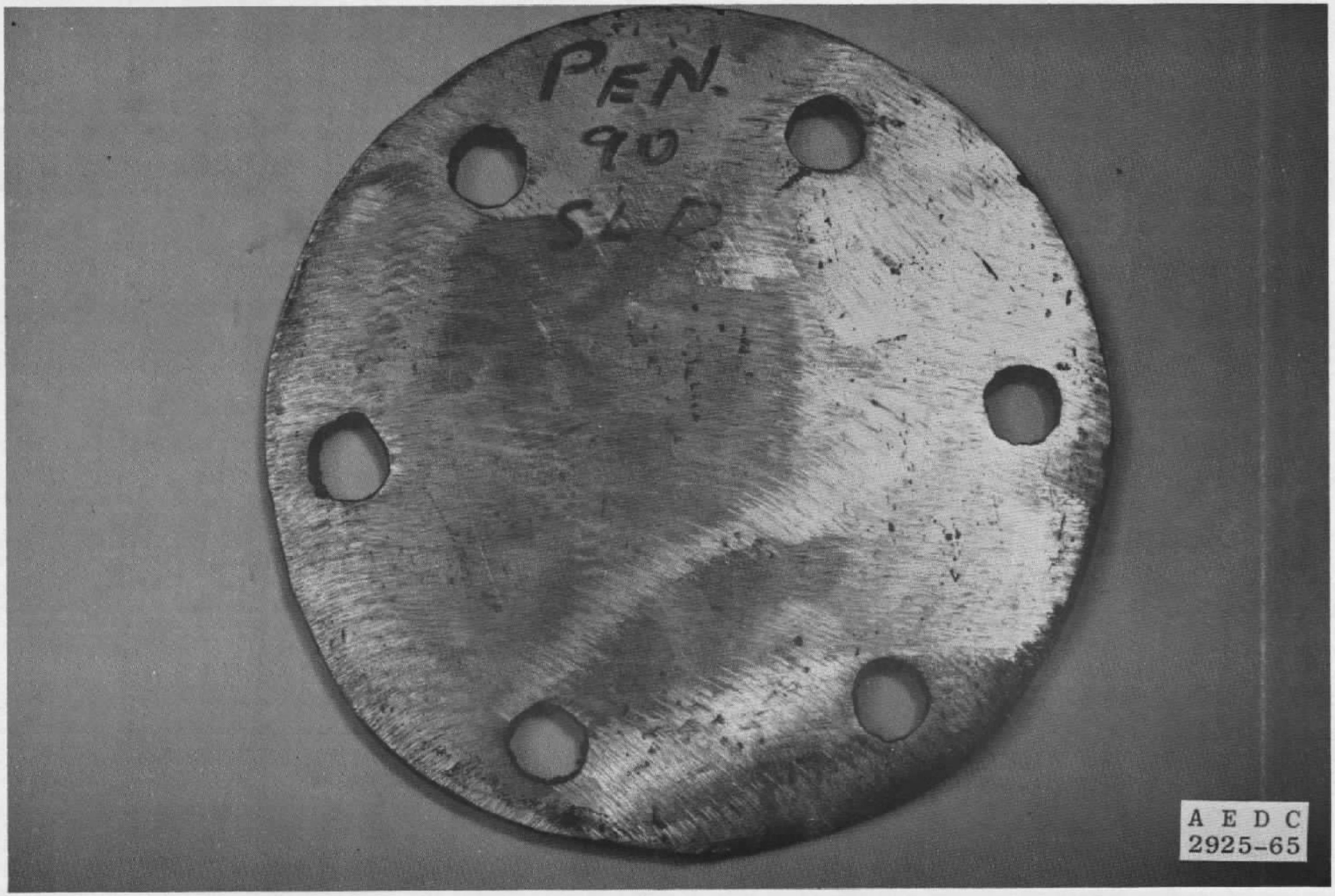
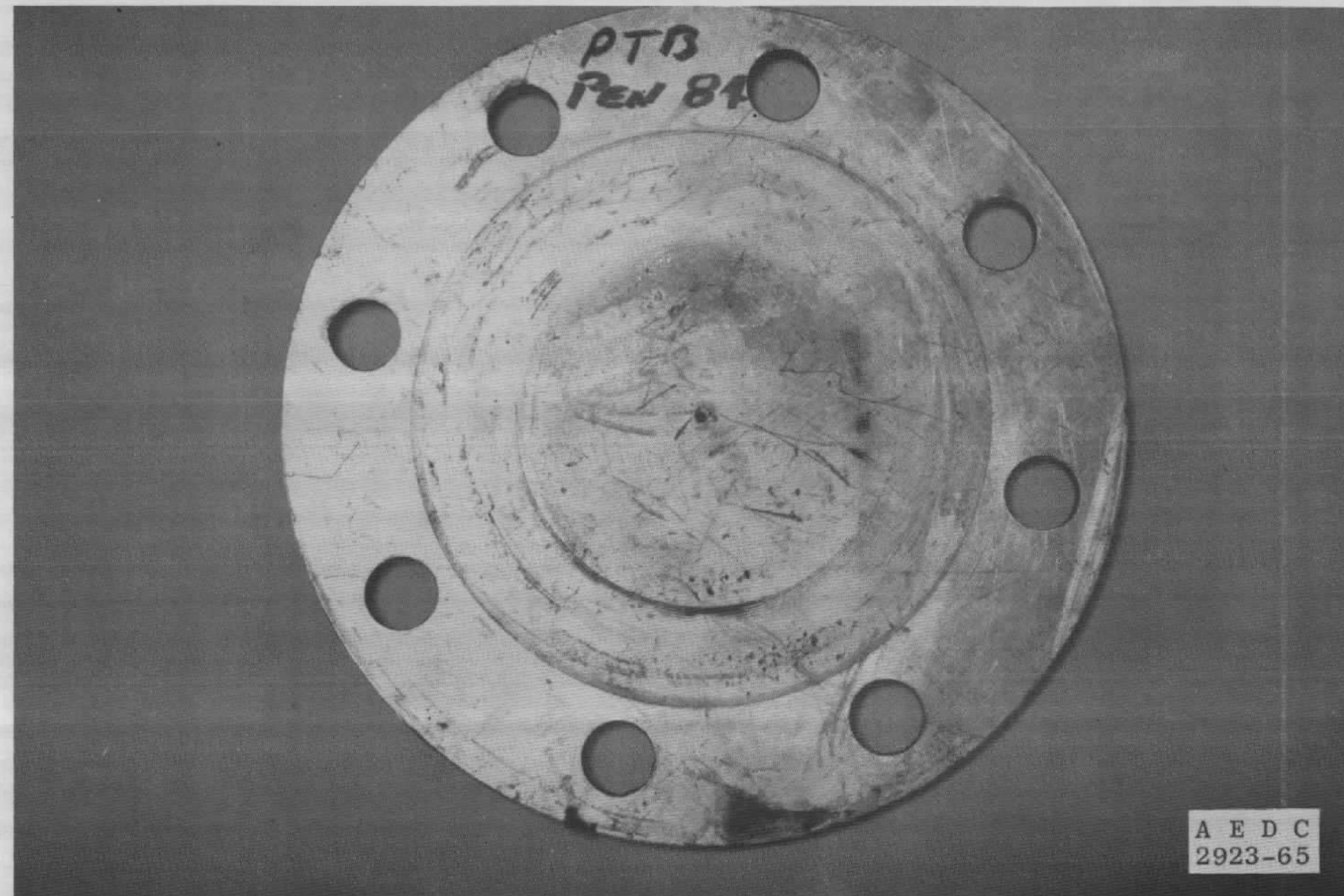


Fig. 10 Leak Detection Program Flow Chart



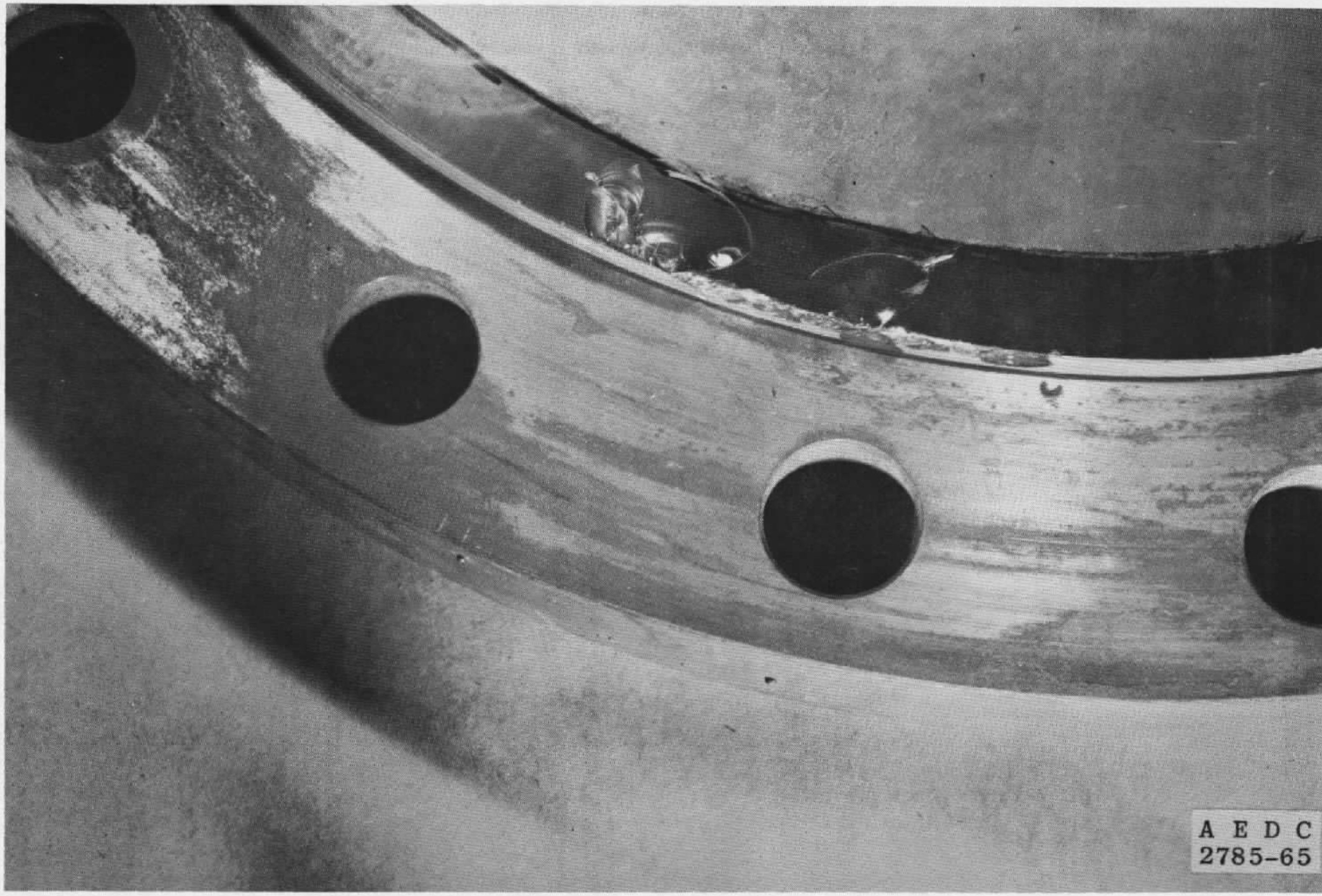
a. Temporary Vacuum Flange for "O" Ring Seal

Fig. 11 Photographs showing Condition of Penetrations



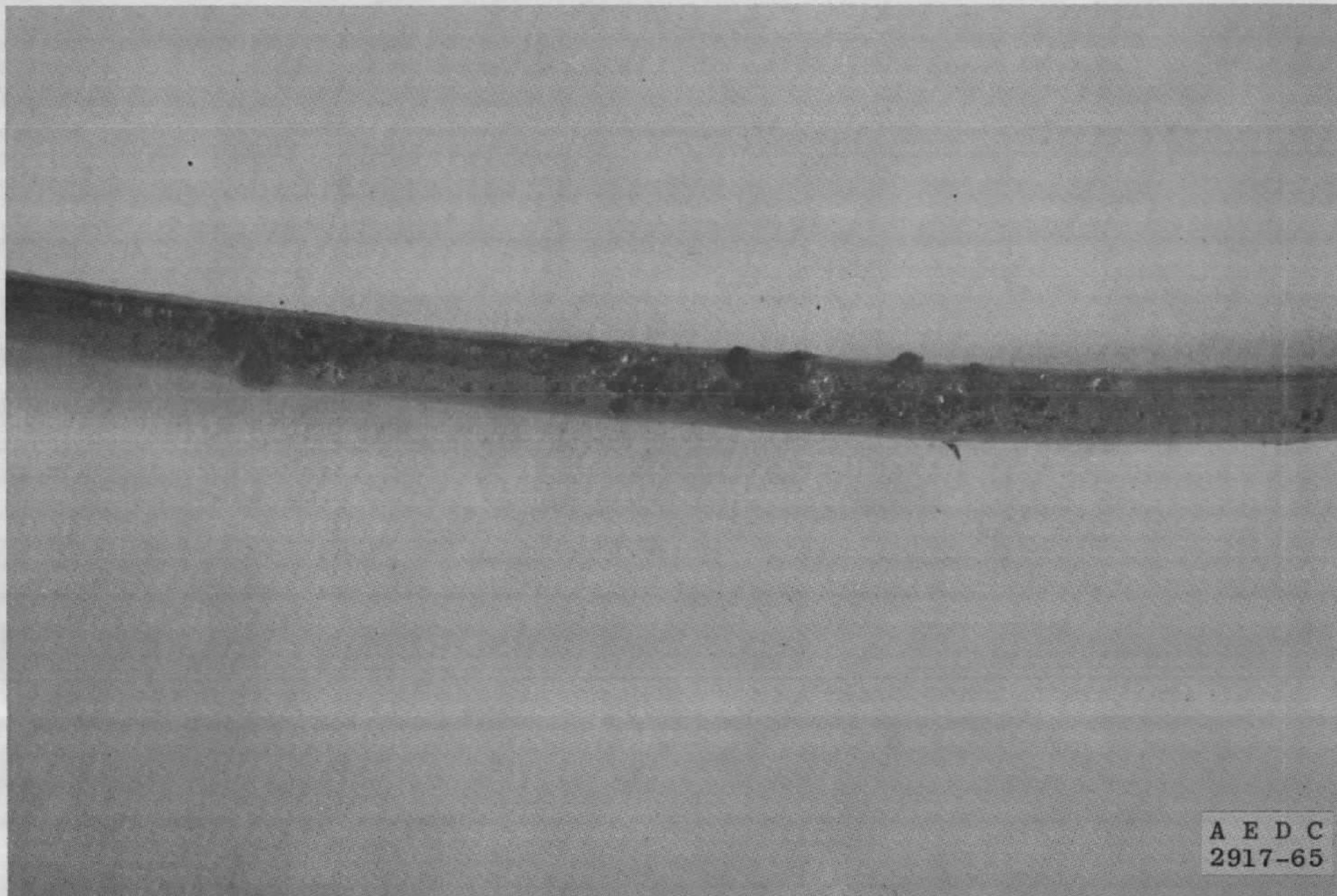
b. Permanent Vacuum Flange for Flat Gasket Seal

Fig. 11 Continued



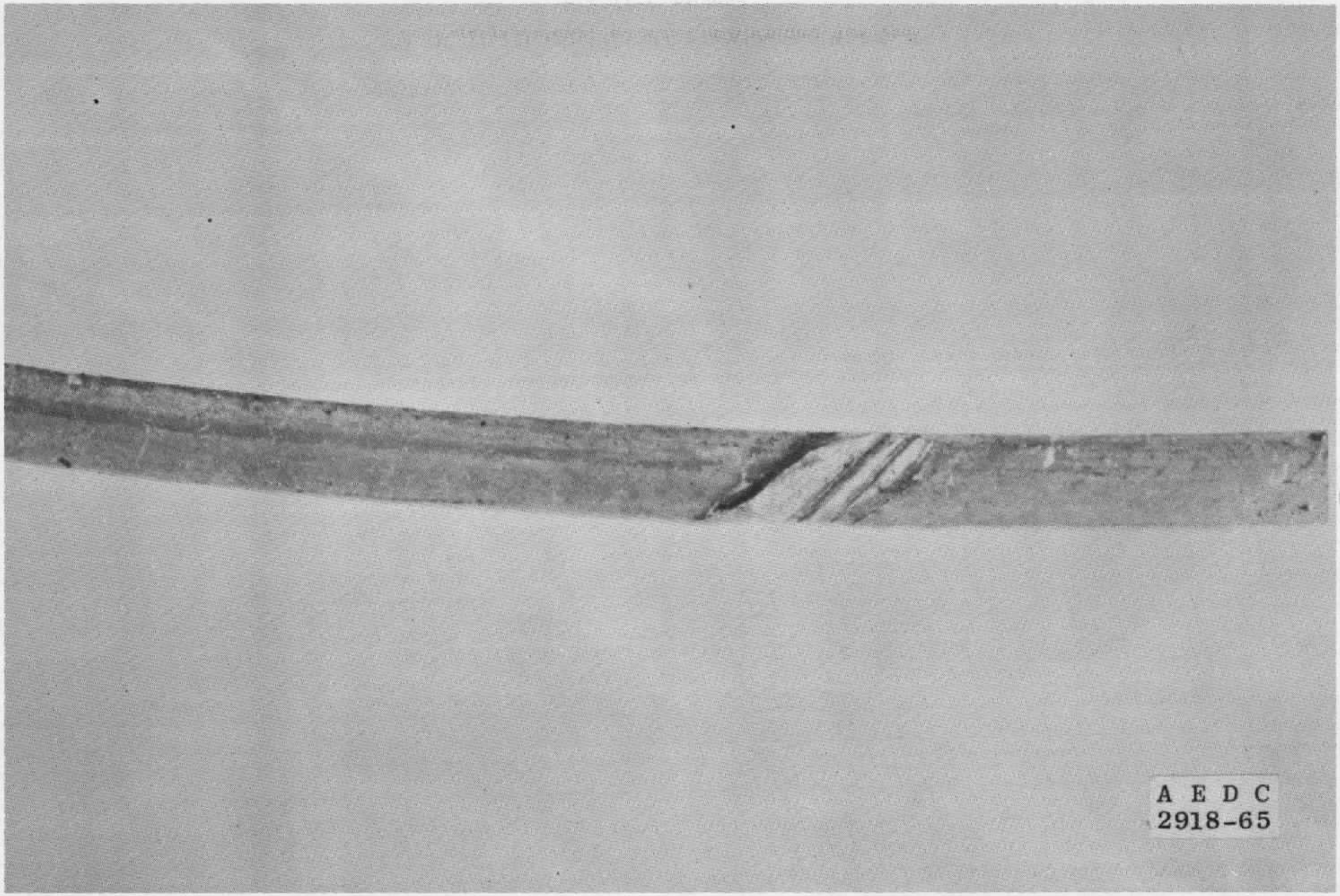
c. Quartz Window Sealing Surface Chipped

Fig. 11 Continued



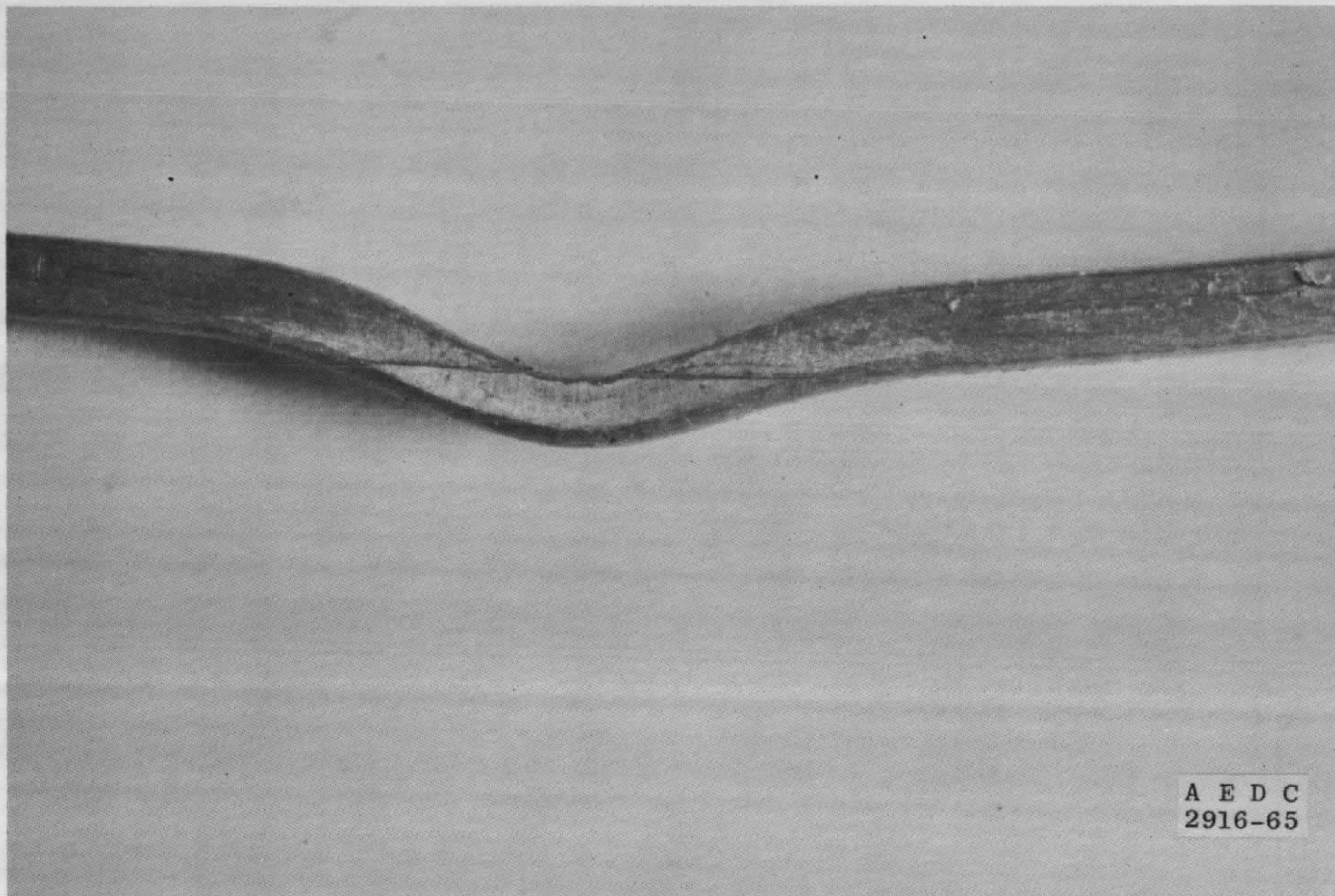
d. Foreign Material Imbedded in Aluminum Wire Seal

Fig. 11 Continued



e. Cut Across Aluminum Wire Seal

Fig. 11 Continued

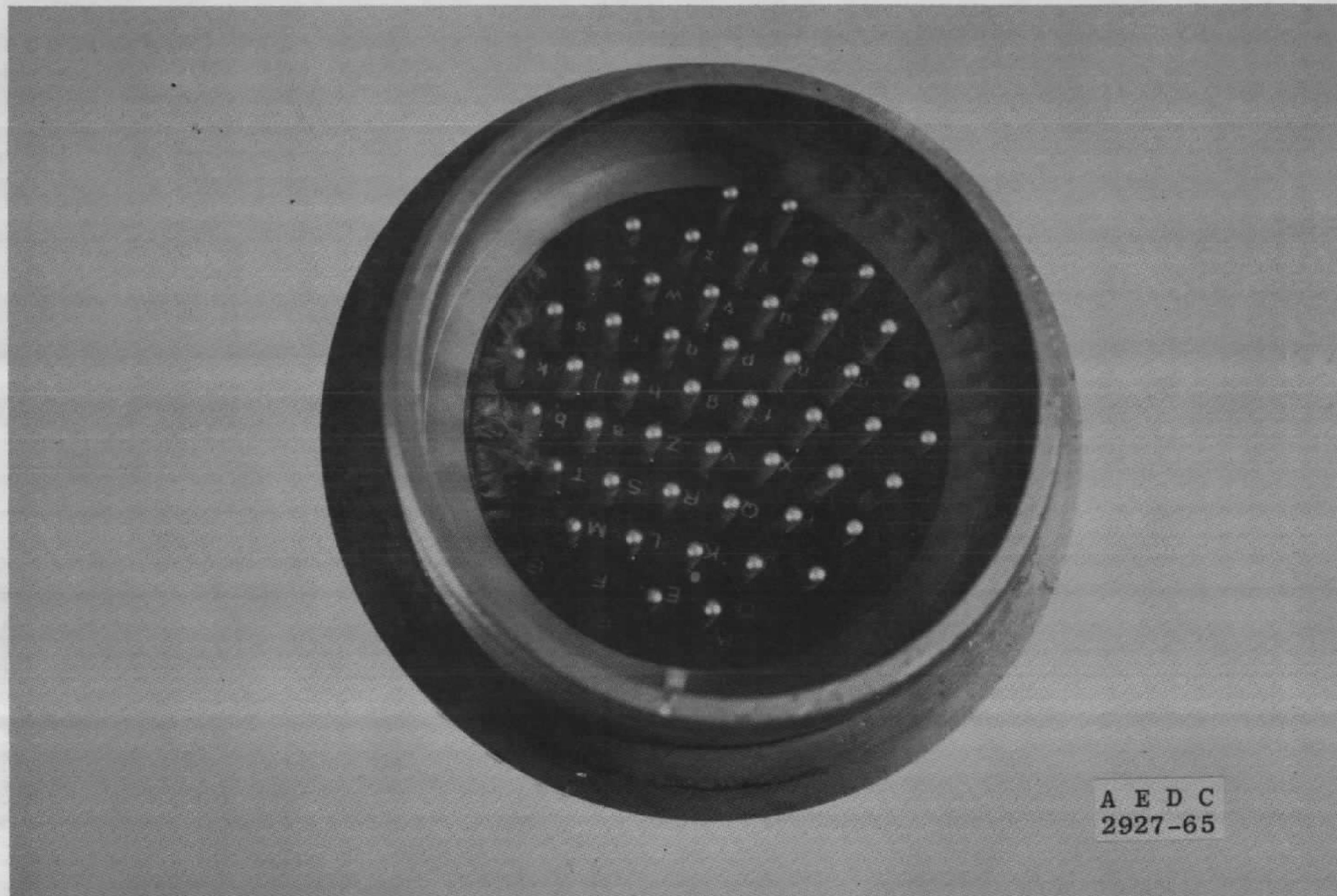


f. Distortion and Incomplete Seating of Aluminum Wire Seal

Fig. 11 Continued

g. Improper O-Ring Joint

Fig. 11 Continued



h. Chipped Ceramic in Electrical Feedthrough

Fig. 11 Concluded

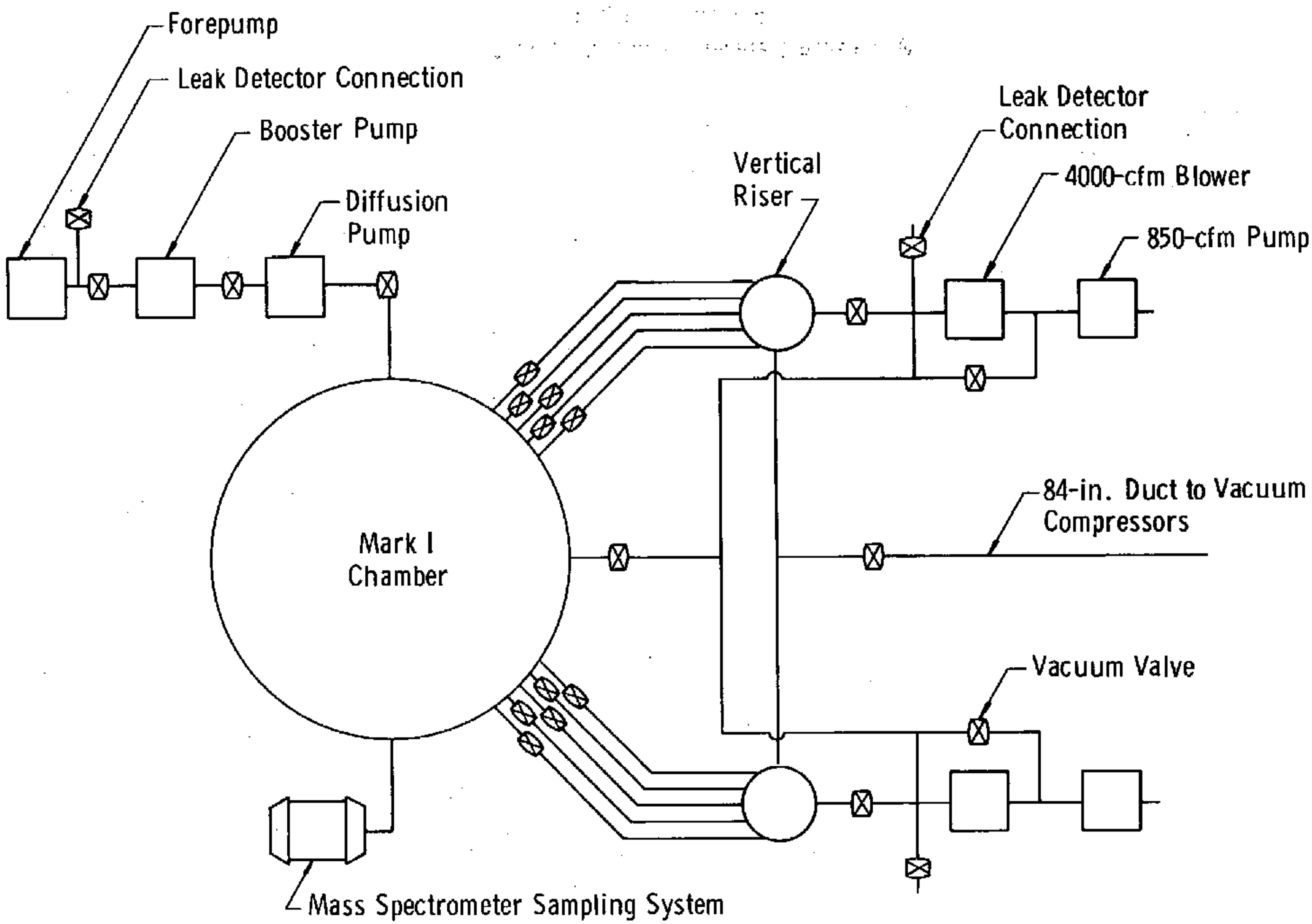


Fig. 12 Mark I Pumping System Schematic

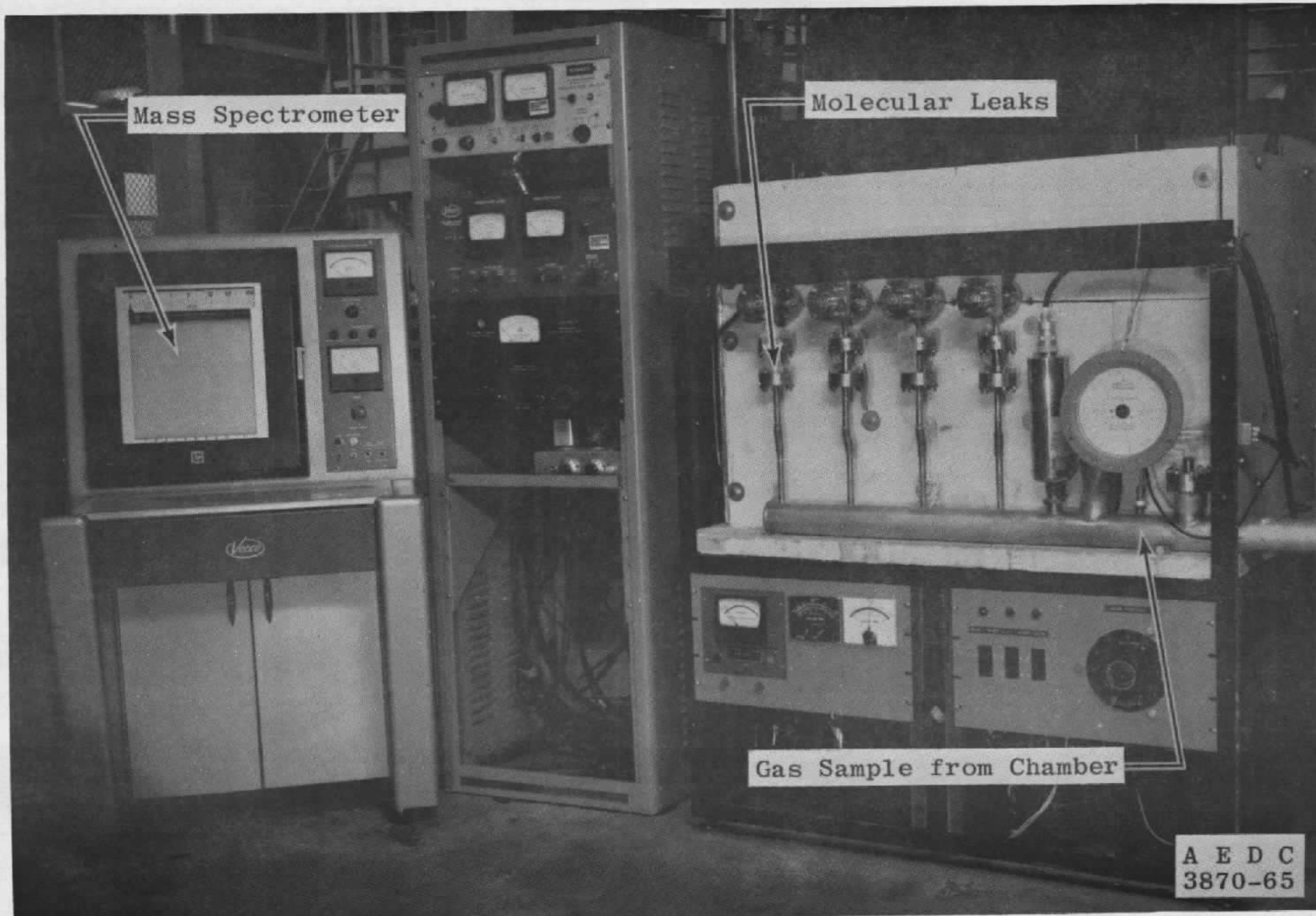


Fig. 13 View of Mass Spectrometer Sampling System

Fig. 14 View of Temporary LN_2 Panels inside Chamber

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13. ABSTRACT

This report describes the planning, procedures, and results of the first complete pumpdown and leak check of the Aerospace Environmental Chamber (Mark I). The objective of the pumpdown and leak check was to reduce the total leakage of the 106,000-ft^3 vacuum chamber to the low 10^{-3} std cc/sec range. The total leakage was reduced from 5000 std cc/sec to 2×10^{-3} std cc/sec in 26 normal work days, 50 hr of which was devoted to chamber operational leak detection. The procedures and techniques of vacuum system analysis and leak detection used in this operation are described, as are the modifications and additions to the chamber which were required to accomplish the project objective. The results of the operation proved the adequacy of the techniques used, and demonstrated the capability of reducing chamber leakage to much less than 2×10^{-3} std cc/sec. (U)

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