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ENGINEERING REPORT

VACUUM TEST FACILITY REQUIREMENTS
ERDA BIPS GDS

76-311736

March 15, 1976

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
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ERDA BIPS GDS

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ENGINEERING REPORT
VACUUM TEST FACILITY REQUIREMENTS
ERDA BIPS GDS

1. INTRODUCTION

This report presents the results of a study undertaken to define the requirements for a reference vacuum test facility, as well as some operating procedures for the Phase I Brayton Isotope Power System (BIPS) Ground Demonstration System (GDS), ERDA Contract E(04-3)-1123.

The vacuum system is required to simulate the space environment in which the BIPS flight system will function. The BIPS GDS will require a high vacuum environment during performance and endurance testing to enable the multi-foil insulation to be effective and to protect GDS refractory alloys from contaminant attack.

Assuming that proper techniques of manufacturing, storage, application and final argon back-flushing and bake-out are used on the multi-foil insulation, adequate containment protection will be assured. The available test data indicate that the maximum pressure at which the multi-foil insulation is effective is on the order of 1×10^{-4} torr. Protection of the refractory materials requires that the partial pressures of oxidizing and reducing elements be limited to the number of exposures and time-dependent levels (yet to be defined) when the refractory materials are above 450°F (232°C).

2. SUMMARY

A reference vacuum facility was analyzed using an effective pumping speed of 2230 liters/sec for a vacuum chamber size of 8600 liters (the same size as the AIRPHX present medium vacuum chamber). Several candidate materials for the chamber were analyzed with and without the test article. The test article comprises the BIPS GDS and its support structure. Outgassing rates of unbaked and baked materials were estimated from data in the literature and used to determine approximate pumpdown times required to reach 10^{-6} torr. The calculated pumpdown times varied from 22 hours (for a cleaned, unbaked or baked stainless steel chamber or a baked aluminum or mild steel chamber) to 35 hours (for an uncleaned, unbaked stainless steel chamber or a cleaned, unbaked aluminum or mild steel chamber).

Based on the results of the reference system study and available test data from the literature, a list of system requirements was formulated:

- (a) Tentative allowable partial pressures of contaminant gases at the surface of the refractory metals (turbine plenum, ducts, HSA, etc.) are identified.
- (b) The allowable evacuation time is defined.
- (c) A GDS bakeout procedure is established.
- (d) The vacuum and roughing pump size ranges are defined.
- (e) Pump reliability, a protective shutdown system, an alarm system, and unattended operation are defined.

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- (f) Automatic startup and shutdown requirements are formulated.
- (g) The maximum allowable chamber leakage rate is defined.

3. REFERENCE VACUUM CHAMBER STUDY

A search through the literature (see Bibliography) revealed a great deal of theoretical analyses, but some data required for the theoretical equations was virtually non-existent. Therefore, some empirical relationships from existing data were devised to fill the gap. The basic procedure, terminology, etc., used to analyze a reference vacuum system are outlined in this section. It should be understood that all calculations in this section were made on an assumed reference system to aid in defining the BIPS GDS vacuum system requirements. The reference chamber is the same size as the existing chamber used for medium vacuum testing; the reference effective pump speed is based on two large turbomolecular pumps and associated ducting. As the results of the study point out, these sizes can be varied and the results extrapolated.

The various vacuum pressure ranges and the properties associated with them are given in the following table:

VACUUM PRESSURE RANGE		Nature of Flow	Remarks
Regime	Torr		
Rough	760 to 1	Laminar (Viscous)	Convection is pressure dependent
Medium	1 to 10^{-3}	Knudsen (Transitional)	Marked change of thermal conductivity of the gas
High	10^{-3} to 10^{-7}	Molecular	a. Flow pressure b. Molecules at surface > molecules in the chamber space c. More molecules strike surface than those that strike each other.
Ultra High	$<10^{-7}$	Molecular	a, b, and c above plus the need for metallic gaskets and other more expensive pieces of equipment and procedures (e.g., bakeout).

The general process of a gas adhering to a solid is called sorption. When the solid gives up molecules, desorption (outgassing) takes place. Sorption theory comprises three basic processes:

- (a) Chemisorption - Gas molecules are held by a chemical bond with the base material. All but the noble gases are generally held to the base material by this process.
- (b) Adsorption - Gas molecules adhering to the surface of the base material by means of a physical sticking mechanism.
- (c) Absorption - Gas molecules that penetrate the surface cracks and interstices of the base material and those that are in solution with the base material.

The GDS ducting, shrouds, etc., will not allow the xenon-helium gas mixture (BIPS working fluid) to permeate through since noble gases will not permeate metals. However, helium (including the trace amount in air) is well known to be capable of permeating polymers and organic solids such as the vacuum chamber gaskets from the ambient air to the chamber interior. Helium is sometimes used in leak detection, but some types of vacuum pumps cannot pump helium across anything but a small pressure ratio. The argon gas used during the bakeout of the test article insulation to flush the contaminant gases out of the multi-foil insulation and dry the chamber and test article will not sorb into any metal, thereby precluding any outgassing problem with argon.

Duct Conductance at Medium and Higher Vacuums

The required effective pump speed, S_e , is a function of the pump speed, S , and the various conductances, F_i , of the intermediate ducting:

$$\frac{1}{S_e} = \frac{1}{S} + \sum_{i=1}^n \frac{1}{F_i} \quad (1)$$

or,

$$S = \frac{S_e F}{F - S_e} \quad (2)$$

For a tube, the conductance is found from Ref. 1, Pages 99 and 101:

$$F = \frac{CA v_a}{4} \times 10^{-3} \quad (3)$$

Where: v_a = Mean molecular vel = $14,551\sqrt{T/M}$ cm sec⁻¹

C = Configuration constant = $\frac{1 + 0.4 L/r}{1 + 0.95 L/r + 0.15(L/r)^2}$

$A = \pi r^2$, cm²

L = Duct length, cm

r = Duct radius, cm

T = Temperature, K

M = Molecular weight

F = Duct conductance, ℓ sec⁻¹

Basic Pumpdown Equations

The mass flow rate of gas when outgassing is the predominant pumping load (as in the high and ultra-high vacuum ranges); it is conventionally given as the product of the volumetric pump speed and the pressure:

$$Q_p = P S_e \quad (4)$$

Where: Q_p = Pump throughput, torr ℓ sec⁻¹

ℓ = Liter

torr = 1/760 standard atmosphere pressure

D = Chamber pressure, torr

S_e = Effective pumping speed, ℓ sec⁻¹

In its simplest terms, the throughput presented to the vacuum system by the outgassing of the chamber and test article (neglecting leakage and permeation from the outside) is:

$$Q_o = \sum_{i=1}^n K_i A_i \quad (5)$$

Where: Q_o = Outgassing throughput, torr ℓ sec⁻¹

K_i = Outgassing rate of i^{th} material, torr ℓ sec⁻¹,
cm⁻²

A_i = Area of i^{th} material, cm²

The solution of Equation (5) is the more difficult task because of the many variables involved, especially for bakeout conditions.

The basic equation for rough-out pumping or pumpdown of an inert gas from a chamber that has been completely outgassed and subsequently filled with argon is:

$$-\frac{dp}{dt} = \frac{S_e}{V} p$$

Integrating p between P_1 and P_2 torr and time from 0 to t sec, and changing the units of t to hours,

$$S_e = \frac{V}{3600 t} \ln \frac{P_1}{P_2} \quad (6)$$

or,

$$t = \frac{V}{3600 S_e} \ln \frac{P_1}{P_2} \quad (6a)$$

Where: V = Chamber volume, liters

Outgassing Data at Room Temperature

Figure 1 shows a sampling of data from various sources (all at unbaked conditions) with the lines drawn according to a least squares curve fit of the data points. Outgassing rates not only depend upon the material involved, but also on the surface roughness, the presence of oxides, and the presence of oil or other liquids. From Figure 1 it is seen that for stainless steel, a properly cleaned chamber will exhibit an outgassing rate approximately 0.01 that of an uncleaned chamber. Mild steel (plated or unplated) and aluminum exhibit

FIGURE 1

outgassing characteristics similar to uncleaned stainless steel. Nickel is worst of all. The data for nickel-plated mild steel is suspect since there were only two data points. The data is for infinitely thick materials; at 100 hours at room temperature, the data would be valid for materials approximately 1/8 inch thick and over.

Outgassing with Bakeout

The effect of bakeout in decreasing the time required to evacuate a vacuum chamber is well known in practice, again with a considerable amount of theoretical and empirical equations available. Difficulty arises when a reliable and simple analytical procedure is sought to determine the effects of bakeout. This section outlines the method used.

Contrary to the empirical relationship of outgassing without bakeout, the theory leads us to a slope of the outgassing rate curve of $-1/2$ rather than approximately -1 (Ref. 6, page 303). The theory also uses equations with D , the diffusion coefficient defined as a function of temperature only. D is defined by:

$$D = D_0 e^{-\frac{\Delta E}{RT}} \quad (7)$$

where: $R = 1.987$ cal/gram mole °K

$T =$ temperature, °K

$D_0 =$ diffusion coefficient constant, cm^2/sec

$\Delta E =$ activation energy, cal/gram mole

The activation energy is defined as that energy required to release a specific sorbed gas from its solid shelter. It is generally conceded that D_0 varies from about 0.01 to 10 (Ref. 2, page 189), and ΔE for hydrogen from 10,000 to 20,000 (Ref. 5, page 299), but precise and reliable data is difficult, if not impossible, to find in the literature. Therefore, as much as possible, equations were selected which used only the ratio of the diffusion coefficient at bakeout to that at room temperature. The ratios were determined from outgassing data in the literature using the following relationship at the time of bakeout:

$$\frac{D_b}{D_a} = \frac{K_b}{K_a} \quad (8)$$

Where: Subscript a = ambient ($\approx 20^\circ\text{C}$)
Subscript b = bakeout temperature

Using a least squares curve fit from stainless steel outgassing curves, three pairs of ambient-bakeout outgassing rates versus temperatures (Ref. 8, pg 92) were used to determine the following empirical equation:

$$\left(\frac{K_b}{K_{a.s.s.}}\right) = 353 \left(\frac{T_b}{T_a}\right)^{0.92} \quad (9)$$

Where: T = temperature, $^\circ\text{K}$

No outgassing rates for bakeout of nickel were found, but two data points of diffusion coefficient with a corresponding temperature were found for hydrogen in nickel which gives:

$$D_{ni} = 8.73 \times 10^{-43} T^{13.36} \text{ cm}^2 \text{ sec}^{-1} \quad (10)$$

From which,

$$\left(\frac{D_b}{D_{a ni}}\right) = \left(\frac{T_b}{T_a}\right)^{13.36} \quad (11)$$

The diffusion coefficient for hydrogen in ferrous materials at 20°C was assumed to be $2.6 \times 10^{-9} \text{ cm}^2 \text{ sec}^{-1}$ and for nickel was assumed to be 1×10^{-9} (Ref. 4, pg 115). The theoretical outgassing rate during bakeout (after a theoretical instantaneous rise in K) for a thick material is given by (Ref. 5, pg 297):

$$K_b = \frac{(D_b/D_a) K_a}{[(D_b/D_a) (t - t_b) + t_b]^{1/2}} \quad (12)$$

where: t_b = time when bakeout heat is applied, hrs.

t = some arbitrary time

The time (t_d) at which the material has outgassed to the point where the outgassing rate begins to decay more rapidly toward zero is given by Ref. 5, Page 299:

$$t_d = \frac{\pi L_m^2}{16 \times 3600 D_b} + t_b [1 - 1/(D_b/D_a)] \quad (13)$$

where: D_b = diffusion coefficient at bakeout temperature, $\text{cm}^2 \text{sec}^{-1}$

L_m = material thickness, cm

The outgassing rate after t_d is given by Ref. 4, Page 108:

$$K_d = K_o/t_\alpha \quad (14)$$

where: K_d = outgassing rate during decay after bakeout, $\text{torr} \ell \text{sec}^{-1} \text{cm}^{-2}$

$$K_o = (K_d \text{ at } t = t_d) (t_\alpha \text{ at } t = t_d)$$

$$t_\alpha = t^{1/2} - (t_d^{1/2}/2) 1 - e^{-\frac{t}{2 t_d}} \quad (15)$$

Once the curves of K versus time have been established, combining Equations 4 and 5 gives:

$$P = \frac{\sum_{i=1}^n K_i A_i}{S_e} \quad (16)$$

Calculations of Outgassing Rates

As previously mentioned, the outgassing rates for the unbaked conditions are given on Figure 1. For the heated or baked condition, the rates involve the calculation procedure previously outlined. The calculated data for the nickel foil insulation at 400°F is given in Figure 2 and for a stainless steel chamber at 200°F and cooled is given in Figure 3. Figures 2, 3, 4 and 5 should be self-explanatory as they were constructed with the aid of Equations 8 through 15. In all cases, the time starts at one hour, the presumption being that a medium vacuum will be reached somewhere between 15 minutes and several hours. Also, the minimum time for virtually all outgassing data is one hour.

Pressure Calculations

The pressures were calculated using Equation 15, the K values from Figures 1 through 5, and plotted on Figures 6 and 7 for the reference chamber size of 83 inches inside diameter and 101 inches long. From 1 to approximately 16 hours there is no difference in the pressure between the several configurations used in the calculations. This is due to the large nickel foil area compared to the aluminum structure area and chamber area. The nickel outgassing rate drops off dramatically due to its thinness, and after 16 hours, the effects of chamber and aluminum structure are seen.

Following the example of the cooldown effect on Figure 6, assume that a pressure of 2×10^{-8} torr is desired and that the stainless steel chamber is being baked at 200°F (93°C). When the chamber pressure reaches 1.55×10^{-7} torr at 101 hours, the heat is cut off and the pressure drops to 2×10^{-8} torr. The pressure does not continue on down the slope of the cooled vacuum chamber, however, but remains constant for a considerable period of time. Note that if the chamber were not baked and cooled at all, the same final pressure (2×10^{-8} torr)

EXTIMATED NICKEL OUTGASSING RATE
BIPS GDS FOIL INSULATION

FIGURE 2

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ESTIMATED STAINLESS STEEL OUTGASSING RATE
(CLEANED ONLY)

FIGURE 3

ESTIMATED ALUMINUM OUTGASSING RATE
BIPS GDS STRUCTURE

FIGURE 4

ESTIMATED MILD STEEL OUTGASSING RATE
BIPS GDS VACUUM CHAMBER

FIGURE 5

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ESTIMATED PERFORMANCE
BIPS GDS VACUUM TEST FACILITY

FIGURE 6

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ESTIMATED PERFORMANCE
BIPS GDS VACUUM TEST FACILITY
BAKED MILD STEEL VACUUM CHAMBER

FIGURE 7

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would be reached in 114 hours. This small difference is due to the effect of the aluminum structure not having been baked and cooled. Since 1×10^{-6} torr is our stated goal, there appears to be no advantage at all in baking the chamber. In fact, no advantage is evident down to 1×10^{-7} torr. The above discussion presumes that the chamber has been thoroughly degreased. The outgassing of the aluminum structure is predominant after about 40 hours, causing the pressure curves to be straight lines on the log-log plot.

The aluminum vacuum chamber data is also approximately correct for uncleaned stainless steel and mild steel (plated or cleaned), all without a bakeout procedure. Figure 7 shows the results of a mild steel vacuum chamber analysis using a 200°F bakeout procedure. Included is the aluminum structure, baked and unbaked (200°F). Note that in this case, there is very little to be gained from baking the aluminum structure.

Vacuum Chamber Study Results

Testing of the BIPS GDS can begin when 10^{-6} torr chamber pressure is reached. Presuming there are no leaks in the chamber and that at least one vacuum pump is operating, the pressure will decrease further. This pressure decrease is a function of time, the chamber material, and the cleanliness of the chamber walls.

At 10^{-6} torr, the calculated vacuum chamber pumpdown times from Figures 5 and 6 (all with the test article installed) are as follows--all vacuum chambers are assumed to be cleaned unless otherwise stated:

<u>Vacuum Chamber Material</u>	<u>Chamber Baked or Unbaked</u>	<u>Structure Baked or Unbaked</u>	<u>Hours to 10^{-6} torr</u>	<u>Pressure at 100 Hours, torr</u>
Stainless	Baked	Unbaked	22	2.19×10^{-8}
Stainless	Unbaked	Unbaked	22	2.55×10^{-8}
Uncleaned Stainless	Unbaked	Unbaked	35	4.4×10^{-7}
Aluminum	Unbaked	Unbaked	35	4.4×10^{-7}
Mild Steel	Unbaked	Unbaked	35	4.4×10^{-7}
Mild Steel	Baked	Unbaked	22	1.22×10^{-7}
Mild Steel	Baked	Baked	22	1.13×10^{-7}

It should be recognized that the chamber pressure is inversely proportional to the pumping speed. Therefore, if the pumping speed is halved (as in the situation when one of two pumps is inoperative), the chamber pressure will be double that shown on Figures 5 and 6. Where the slope of the pressure curve is steep, there will be less effect on the pumping time than at portions of the curve where the slope is flatter.

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The effect of increasing the chamber size may be estimated by recalling from the previous text those portions of the pressure curves (Figures 6 and 7) that are governed mainly by the chamber outgassing. In these cases, the pressure is proportional to the chamber area increase or decrease.

From the above table, it is apparent that there is no advantage to baking (or warming) a stainless steel vacuum chamber (except to lessen the need for pumping during a power outage). Also, for a mild steel chamber, the reduction of time for 10^{-6} torr from 35 to 22 hours for unbaked and baked, respectively, may not be worth the extra cost and effort of bakeout. Also, it must be recognized that the complexities introduced in adapting the existing mild steel chamber will probably eliminate it from further consideration.

4.0 GDS VACUUM SYSTEM REQUIREMENTS

In general, the GDS Vacuum System includes those items required to provide the necessary atmosphere for the GDS performance and 1000-hour endurance tests for an expected maximum of 3000 hours of operation. The vacuum system requirements for the GDS as established by material limitations and operational and performance objectives are as follows:

4.1 Pressure and Composition of Chamber Atmosphere

The maximum chamber pressure is a function of two parameters:

(1) the maximum pressure allowable within the layers of the multi-foil, and (2) the quantity of chemically active gases (also called contaminants) allowable at the surface of the high temperature (1600°F+) refractory metals in the BIPS. From existing multi-foil data, when the pressure within the multi-foil increases above approximately 10^{-4} torr, its effectiveness decreases rapidly. Also, operation at high temperatures causes any available contaminant gas (whether sorbed into the metal or in the volume between the foil layers) to chemically react with the refractory base metal and foils (C-103 for the base metal), forming a harmful oxide. To a lesser extent, this also occurs with other candidate foil materials (e.g., nickel and molybdenum).

In order to ensure that the pressure of 10^{-4} is not exceeded within the multi-foil, a maximum chamber pressure of 10^{-6} torr is recommended. This places the chamber pressure within the high vacuum range which means that the chamber-pump combination will probably be capable of an ultimate pressure of 10^{-7} torr or less. Nevertheless, 10^{-6} torr will be used as the preliminary pressure goal, and the pressure at which operation of the GDS may begin.

To keep gas contamination down to a tolerable level, the vacuum chamber will be pumped down and back-filled with argon while the BIPS

is heated to approximately 400°F (204°C) in accordance with the procedure of Section 4.3. The bakeout will drive off most of the sorbed contaminants and the argon back-fill and chamber re-evacuation will flush most of these contaminants out.

In order to appraise the effect of bakeout beyond a simple comparison of pumpdown times, it is useful to consider the partial pressures and percent composition of the chamber atmosphere. To estimate these, typical distributions of partial pressures were adjusted for the estimated effect of the argon back-filling and ratioed to give a total pressure of 10^{-6} torr. The percent of composition was then determined by weighting the partial pressures with the atomic weight of the constituents. The result of this estimate is shown on Table 1. The gaseous contaminants of prime concern are H_2O , CO_2 , N_2 , CO , and O_2 . Methane (CH_4) and hydrogen (H_2) would probably not be present after first or second bakeout and are therefore not considered to be a contaminant problem. The argon will not sorb since it is a noble gas.

Referring to Table 1, the unbaked chamber shows the presence of considerably more contaminants than the baked chamber. This is because outgassing is still taking place in the unbaked chamber, but in the baked chamber, most of the gaseous contaminants have been driven off. In order to estimate the partial pressures allowable at the base metal, the estimated total pressure of 10^{-4} torr at the base metal may be used to define a tentative schedule of allowable partial pressures for the contaminants:

TABLE 2

<u>Contaminant</u>	<u>Allowable Partial Pressure, Torr</u>
H_2O	1.9×10^{-7}
CO_2	1.9×10^{-7}
N_2	3.1×10^{-8}
CO	3.8×10^{-6}
O_2	0.0

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TABLE 1
ESTIMATED PARTIAL PRESSURES AND COMPOSITION AT 1×10^{-6} TORR

CONSTITUENT	ATOMIC WT.	UNBAKED CHAMBER		BAKED CHAMBER	
		PARTIAL PR. TORR	PERCENT COMPOSITION	PARTIAL PR. TORR	PERCENT COMPOSITION
H ₂ O	18	7.1×10^{-7}	54.2	1.9×10^{-9}	0.3
CO ₂	44	1.4×10^{-7}	26.4	1.9×10^{-9}	0.7
N ₂	28	5.4×10^{-8}	6.4	3.1×10^{-10}	0.1
CO	28	3.4×10^{-8}	4.1	3.8×10^{-8}	9.2
O ₂	32	1.1×10^{-8}	1.4	0.0	0.0
CH ₄	16	4.3×10^{-9}	0.3	4.4×10^{-9}	0.6
A	39.948	4.3×10^{-8}	7.2	2.2×10^{-7}	76.6
H ₂	2	<u>0.0</u>	<u>0.0</u>	<u>7.3×10^{-7}</u>	<u>12.5</u>
Totals		1.0×10^{-6}	100.0	1.0×10^{-6}	100.0

These allowable contaminant partial pressure levels are probably conservative in view of the long-term testing at high temperatures at which the contaminant will chemically combine with Cb C-103. Accelerated contamination tests are planned which should verify the usage of the above tentative partial pressure limit schedule.

4.2 Evacuation Time

The chamber evacuation time should be within reason. A maximum of two days is acceptable, but one day or less is desirable.

4.3 Test Article Insulation Bakeout

The foil insulation should be clean, dry, and argon-filled upon arrival at the test facility. However, to ensure a contaminant-free duct working gas loop, the test article will be baked out at 400°F (204°C) (maximum temperature compatible with the alternator windings and the turbine, ducts, heat source and insulation materials in air), according to the following procedure.

- 4.3.1 Heat the test article with the working fluid using electrical power to motor the turboalternator compressor (used as a starter motor) to provide flow and the electrical heat source (radio-isotope simulator) to provide heat. The working fluid gas temperature is to be maintained at 400°F as the roughing pump brings the chamber pressure down to 10^{-2} to 10^{-3} torr.
- 4.3.2 Hold the pressure range of 10^{-2} to 10^{-3} torr for two hours to thoroughly heat the insulation. (Conductivity at this pressure is such that the temperature of the outer foils will approach that of the inner foils.)
- 4.3.3 Backfill the chamber with argon to 10 - 100 torr pressure.

4.3.4 Pump down to 10^{-2} to 10^{-3} torr and hold until the partial pressures of H_2O , O_2 , N_2 and CO are at or below those for baked-out conditions in Table 2.

4.3.5 Continue with normal evacuation down to 10^{-6} torr.

4.4 Vacuum Pump Size

Desired total effective pump speed range is from 50 to 200 l/s for argon and from 1000 to 4000 l/s for all other gases. High reliability for long periods of operation is required (~3000 hours maximum for Phase I testing), which may require that two pumps be installed (each pumping half the load).

4.5 Roughing Pump

Desired effective pump speed range is from 40 to 80 l/sec for air or argon from atmospheric pressure to 10^{-3} torr. If the roughing pump is used as a forepump, it must be capable of handling at least five times the throughput of the high vacuum pump.

4.6 Pump Reliability and Protective Shutdown System

A simple and reliable pump system is a mandatory requirement. Oil, air or other contaminant backflow cannot be tolerated. If pumps are proposed that have any of these possible traits, there must be an adequate isolation protection and alarm system proposed as well. All components that may be required to protect the test article or the vacuum system must go to the emergency position when power is removed (fail safe). Examples of the need for automatic system isolation are:

4.6.1 Cooling or cryogenic supply (if used) is inadequate.

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- 4.6.2 Vacuum chamber pressure rises to 10^{-4} torr after reaching 10^{-6} torr.

For those pumps requiring protective valves, the valves must actuate with sufficient speed to prevent contaminants (oil, water, air) from backstreaming if any vacuum pump fails. Valve redundancy may be required in case one valve does not seal properly.

Sufficient chamber gas composition data recordings must be available to aid in determining the cause of the leak or pump failure. Panel switch(es) must be provided to enable automatic operation to take place as well as manual control over the chamber pressure and automatic control for the mode of operation described in Paragraph 2.3.2.

4.7 Alarm System

Failures or imminent failures that threaten the proper functioning of the system must be detected by an alarm system. Examples of the need for alarm actuation are:

- 4.7.1 All shutdown causes.
- 4.7.2 Cooling or cryogenic supply approaching a state of inadequacy.
- 4.7.3 System pressure rises to 5×10^{-6} torr after reaching 1×10^{-6} torr.

4.8 Unattended Operation

Operation must be automatic from startup to normal operation to automatic shutdown and shall provide monitoring, protection and alarm system actuation.

4.9 Automatic Shutdown and Startup After a Power Outage

Effect of Bake-Out

Using the maximum allowable leakage rate stated in 4.10 and a chamber volume of 8600 liters, the calculated time for the chamber pressure (ignoring outgassing) to rise from 1×10^{-6} to 1×10^{-5} torr is 2.75×10^{10} hours. Therefore, depending on the degree that the chamber and test article have been outgassed, the time for the pressure to rise from 1×10^{-6} to 1×10^{-5} torr could vary from a few seconds to many hours. To ensure a low outgassing rate which will aid in holding a usable pressure ($<1 \times 10^{-5}$ torr) during a power outage, the chamber and the entire test article should be baked.

System Considerations

Power interruptions require that backstreaming of oil or the atmosphere is prevented. It is preferred that the system be fail safe (not requiring energy to shut down), but a battery-operated shutdown system would be acceptable. Upon the availability of power after a power outage, the vacuum system shall start up and operate automatically.

Consideration should be given to operation of a low-power-consumption vacuum pump from battery power during a power outage to ensure a pressure of less than 1×10^{-5} torr. To aid in sizing the standby power system, assume a power outage of 0.5 hour duration.

4.10 Maximum Allowable Leakage Rate

The total maximum allowable leakage rate from all causes and for any combination of gas constituents must not exceed 2×10^{-10} standard cc/sec.

4.11 Gasket Vent

As a minimum, a double gasket shall be used at the mating flanges of the chamber that is vented to its own small roughing vacuum pump.

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