

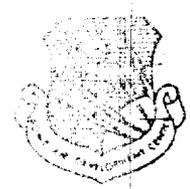
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Final Report



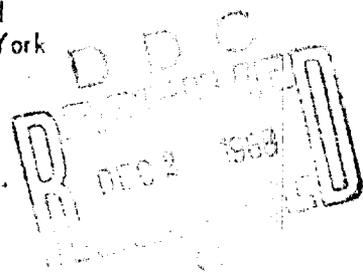
HELIUM TRACER GAS FINE LEAK TEST ANALYSIS

John P. Farrell
Edgar A. Doyle, Jr.

TECHNICAL REPORT NO. RADC-TR-68-392
November 1968

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York



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FOREWORD

The report context covers work performed under Project 5519, Task 551904, and includes a detailed analysis of the Helium Tracer Gas Fine Leak Test, as specified in MIL-STD-883, "Test Methods and Procedures for Microelectronics," Method 1014, Test Condition A. The report was prepared in response to numerous queries by both governmental agencies and the semiconductor industry concerning several aspects of subject hermetic Seal Test.

The authors wish to thank Mr. George W. Lync for his work in conducting the required computer analysis.

This technical report has been reviewed and is approved.

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ABSTRACT

The Helium Tracer Gas Fine Leak Test, as specified in MIL-STD- 883, Method 1014, Test Condition A, based on the "back-pressurization" technique for determining the hermeticity of microelectronic device packages is described. The sensitivity of Seal Test parameter variations to package leak rate measurement test results is analyzed in detail by a systematic variation of exposure pressure, exposure time and dwell time over the complete range of microelectronic package volumes. Analysis results verify the need for specifying standard seal test conditions, for defined package volumes, as required in MIL -STD-883, to insure that the specified level of package hermeticity will be achieved. Microelectronic device reliability as related to package volume leak rate (atm cc/sec) is discussed. Microcircuit failure modes and associated failure mechanisms dependent on package hermeticity are presented.

The primary intent of this technical report is to provide a supplemental documented guide to both microcircuit manufacturers and Air Force contractors engaged in screen testing and device procurement concerning the subject Seal Test contained in MIL-STD-883.

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LIST OF TERMS

- R - Measured Leak Rate of Tracer Gas in atm cc/sec or u-liters/sec.
- L - Standard or Reference Leak Rate in atm cc/sec or u-liters/sec.
- P_e - High Pressure Tracer Gas Exposure Pressure in Atmospheres (Gauge Pressure);
(psia = psig plus atmospheric pressure in psia).
- P_o - Atmospheric Pressure in Atmospheres.
- M - Molecular Weight of Tracer Gas in Grams.
- M_a - Molecular Weight of Air in Grams.
- t_1 - Time of High Pressure Tracer Gas Exposure (P_e) in Seconds.
- t_2 - Dwell Time Between Release of High Pressure and Leak Rate Measurement
(leak detector) in Seconds.
- V - Internal Package Volume in Cubic Centimeters (cc).
- η - Viscosity of Tracer Fluid in Poise.
- R - Universal Gas Constant in $\text{erg } ^\circ\text{E}^{-1} \text{ mol}^{-1}$
- k - Boltzman's Constant in $\text{erg } ^\circ\text{K}^{-1}$.
- T - Absolute Temperature in $^\circ\text{K}$.
- V_a - Average Molecular Velocity at 25°C in cm/sec.
- D - Cylindrical Tube Diameter in cm.
- l - Cylindrical Tube Length in cm.
- n - Molecular Density or Concentration in Molecules/cc.
- m - Mass of Molecule in Grams.
- L_o - Molecular Mean Free Path at a Specified Temperature and Pressure.
- N - Number of Molecules.
- dN/dt - Free Molecular Gas Flow Rate Through a Cylindrical Tube Cross-Section
(plane) in Terms of Molecules/sec.
- C - Constant Determined by Leakage Path Geometry.
- K - Constant Determined by Leakage Path Geometry and Absolute Temperature.
- P_1 - Internal Package Helium Partial Pressure in dynes/cm² After High Pressure
Exposure P_e for a Time Interval t_1 .
- P_2 - Internal Package Helium Partial Pressure in dynes/cm² at Time t_2 , the Period
of Package Exposure to Atmospheric Conditions.
- ppm - Parts per Million.
- %RH - Percent Relative Humidity.
- Å - Angstrom Units (10^{-4} cm).
- V_{CEO} - Collector to Emitter Voltage in Volts with the Base Open Circuited.
- I_{CEO} - Collector to Emitter Reverse Leakage Current in Microamperes (ua).

I. INTRODUCTION

During the preparation of MIL-STD-883, "Test Methods and Procedures for Microelectronics," numerous problems were cited concerning the hermetic seal fine leak test specification. An extensive literature survey revealed that little quantitative experimental effort has been conducted in this reliability area. The major problem areas consisted mainly of clarifying and standardizing the terminology and leak test parameters and procedures used in the specification and testing of hermetically sealed microelectronic device packages.

Several publications concerned with various aspects of hermeticity testing are referenced which provide technical background information delineating the basic test techniques and theoretical gas laws applicable to the helium fine leak hermeticity test. RADC-TR-67-52¹. "Analysis of Integrated Circuit Package Integrity Using Helium Leak Detection Techniques," contains a general description of several standard microcircuit packages and several gross and fine hermeticity tests including a detailed description of the helium leak rate measurement system and test procedures. The viscous, diffusional, and free-molecular steady state gas flow rate equation derivations and time dependence corrections required when an enclosed volume is imposed on the system are presented.

D. A. Howl and C. A. Mann, in the article, "The Back-Pressurizing Technique of Leak Testing,"² derived equations for free-molecular and viscous (laminar) gas flow rate through a leak. A Boeing report³ extended this work by using the Howl and Mann free-molecular flow equations to determine the minimum and maximum detectable leak size for several microelectronic packages at specified fine leak test parameters.

It is recognized that the detection sensitivity of the helium fine leak test system and the measured package leak rate is dependent on the actual leak test parameters, such as (1) the time duration and pressure of the high pressure helium exposure; (2) the dwell time at atmospheric conditions between high pressure exposure and package leak rate measurement; and (3) the internal volume of the package. Package volume considerations are extremely important in view of the numerous microcircuit package sizes currently used throughout the semiconductor industry.

The intent of this report is the discussion, analysis, and clarification of the Helium Tracer Gas Fine Leak Test, Method 1014, as specified in MIL-STD-883, which is analyzed in detail by selectively varying the test parameters for several package volumes illustrating the significant variations in test results.

II. MIL-STD-883, METHOD 1014, TEST PROCEDURE A, HELIUM TRACER GAS FINE LEAK TEST DESCRIPTION.

MIL-STD-883, Method 1014, Test Procedure A, specifies the reliability screen test procedure for determining microelectronic device package fine leak rates utilizing the "back pressurization" detection technique. The specified test procedure consists of placing the test package in a pressurized chamber containing the tracer gas (Helium) at a specified helium pressure and exposure time period. The resulting pressure or molecular concentration differential forces the inflow of tracer gas into the package through any existing leakage path. Depending on the actual test sequence, the packages may be

exposed to atmospheric conditions for a period prior to package leak rate measurement. During the dwell period, loss or outflow of helium gas from the package will occur due to the existing pressure differential. MIL-STD-883 specifies a maximum dwell time of 30 minutes. The package is subsequently placed in a vacuum chamber connected to a leak detector, a mass spectrometer tuned for Helium, for package leak rate measurement. During leak detection, the rate of flow measured is a function of the leakage path size or physical dimensions and the helium partial pressure within the package.

The following equation (1), which allows for the determination of leak size under specified conditions, has been developed. The derivation of this equation is contained in Appendix I. It is based on molecular flow, both in and out of the package, which is the best approximation for small leaks.

$$R = \frac{LP_e}{P_o} \left[\frac{M_a}{M} \right]^{1/2} \left\{ 1 - \exp \left[\frac{-Lt_1}{VP_o} \left(\frac{M_a}{M} \right)^{1/2} \right] \right\} \exp \left[\frac{-Lt_2}{VP_o} \left(\frac{M_a}{M} \right)^{1/2} \right]$$

This equation can be divided into three basic parts with the function of each defined as follows:

a. $\frac{LP_e}{P_o} \left(\frac{M_a}{M} \right)^{1/2}$ represents the measured leak rate R in atm cc/sec at t the summation of t_1 the exposure time and t_2 the dwell time, compared to a standard leak size L in atm cc/sec.

b. $1 - \exp \left[\frac{-Lt_1}{VP_o} \left(\frac{M_a}{M} \right)^{1/2} \right]$ represents the partial pressure of the tracer gas (He) within the package, due to molecular flow, after exposure to pressure P_E for time t_1

c. $\exp \left[\frac{-Lt_2}{VP_o} \left(\frac{M_a}{M} \right)^{1/2} \right]$ represents the partial pressure of the tracer gas (He) after the dwell period of t_2 , allowing for the molecular outflow of gas upon removal of the exposure pressure P_E and subjecting the package to an external pressure of one atmosphere.

NOTE: The term $L \left(\frac{M_a}{M} \right)^{1/2} / P_o$ appears in all three parts, since the leak is to be specified or referenced to standard conditions of one atmosphere of air on one side of the leak and a vacuum on the other.

III. ANALYSIS OF SEAL TEST PARAMETER VARIATIONS THAT ALTER THE DETECTABLE RANGE OF PACKAGE LEAK RATES

a. Detectable Package Leak Rate Range as a function of Hermetic Seal Test Parameters.

The examples, chosen to illustrate the usefulness of the aforementioned equation, to determine L the detectable leak range as Seal test parameters t_1 , t_2 and P_e are varied as outlined in Table I:

TABLE I

Example	P_e atm.	P_o atm.	t_1 seconds	t_2 seconds	M_a	M	R atm. cc/sec	V cc	Fig.
A	2	1	7200	7200	28.7	4	5×10^{-8}	.02	1
B	2	1	7200	<u>1800</u>	28.7	4	5×10^{-6}	.02	2
C	2	1	7200	<u>3600</u>	28.7	4	5×10^{-8}	.02	3
D	2	1	7200	<u>10800</u>	28.7	4	5×10^{-8}	.02	4
E	<u>4</u>	1	7200	7200	28.7	4	5×10^{-8}	.02	5
F	2	1	<u>3600</u>	7200	28.7	4	5×10^{-8}	.02	6
G	2	1	<u>14400</u>	7200	28.7	4	5×10^{-8}	.02	7

In all cases, test parameters were held constant except for those underlined in the preceding table.

Example A. This shall be considered the general case and used as a reference that can be compared with subsequent results to show the deviation in detectable leak range as test parameters are changed. The aforementioned equation was solved for various values of L to generate the curve illustrated in Figure 1. From this plot the minimum and maximum detectable leak size for R , the signal presented to the mass spectrometer, can be determined. For example, the horizontal line drawn within the curve of Figure 1, indicating an R of 5×10^{-8} atm cc/sec, defines the leak range detectable at this sensitivity. Projecting the points at which this line strikes the curve downward to the X axis, we find the smallest detectable leak to be 1×10^{-7} atm cc/sec while the largest detectable leak is approximately 7.5×10^{-5} atm cc/sec.

Example B. Figure 2 shows the change that occurs when t_2 is reduced to 1800 seconds. The detectable leak range has increased and extends from 1×10^{-7} atm cc/sec up to 4.5×10^{-5} atm cc/sec.

Example C. When t_2 is changed to 3600 seconds, half as large as the original dwell time, another change, as shown in Figure 3, occurs. The smallest detectable leak again is 1×10^{-7} atm cc/sec but the largest is now 1.5×10^{-5} atm cc/sec.

Example D. The dwell time is increased to 10,800 seconds. Again, the minimum detectable leak remained at 1×10^{-7} atm cc/sec, while the largest has decreased to 4×10^{-6} atm cc/sec as shown in Figure 4.

Example E. Figure 5 illustrates the variance as bomb pressure is increased to 4 atmospheres. In this case the detectable leak range has extended in both directions. The smallest detectable leak is now 7.5×10^{-8} atm cc/sec and the largest leak is 8.5×10^{-6} atm cc/sec. A decrease in bomb pressure will subsequently decrease the detectable leak range.

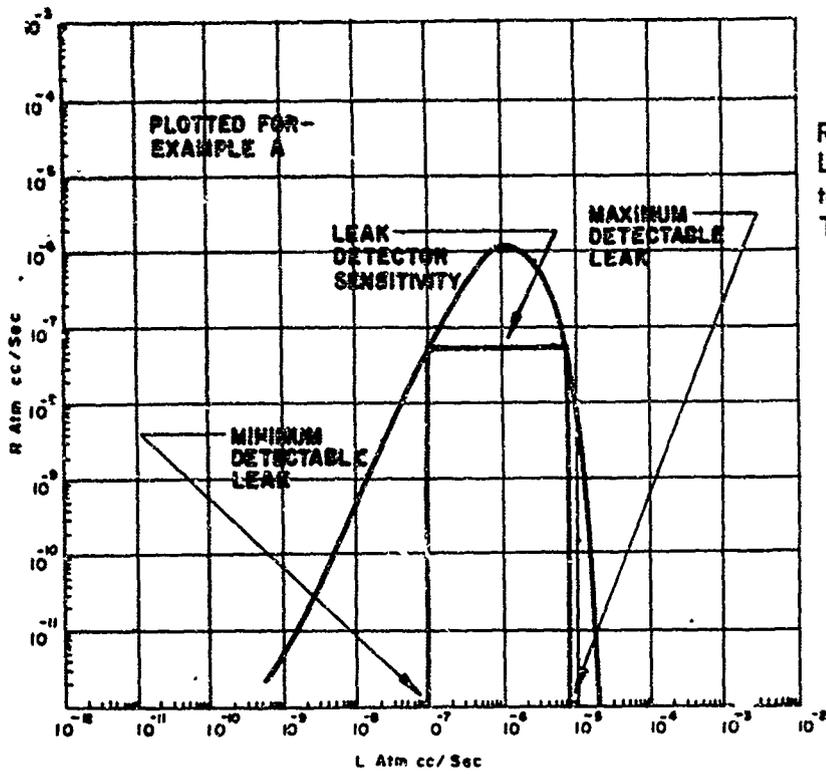
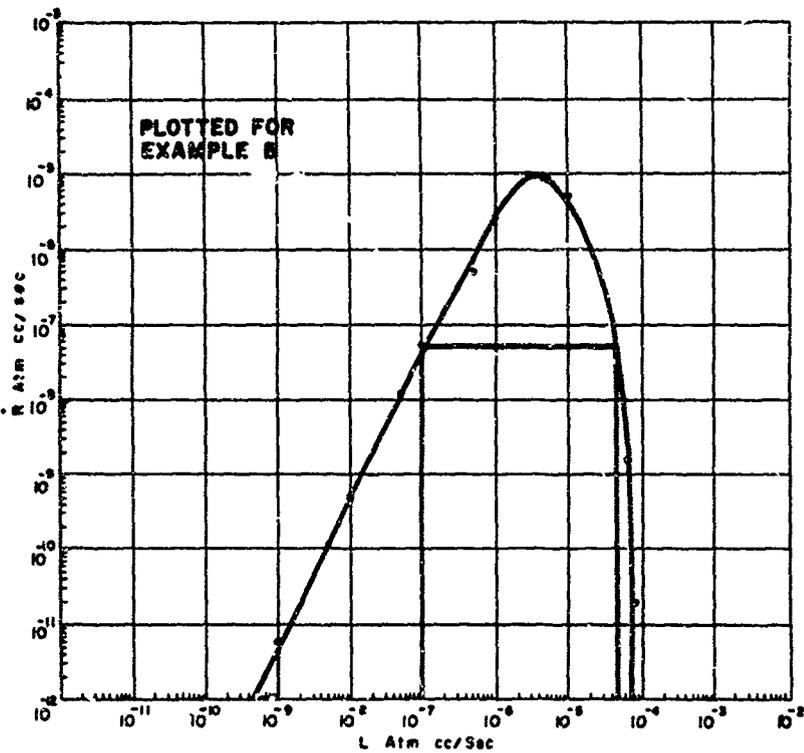


Figure 1
Relationship Between
Leak Rate Signal R
to Leak Size L For
The General Case.

Figure 2
Relationship Between
Leak Rate Signal R
to Leak Size L When
 t_2 The Dwell Time is
Reduced to 1800 Seconds.



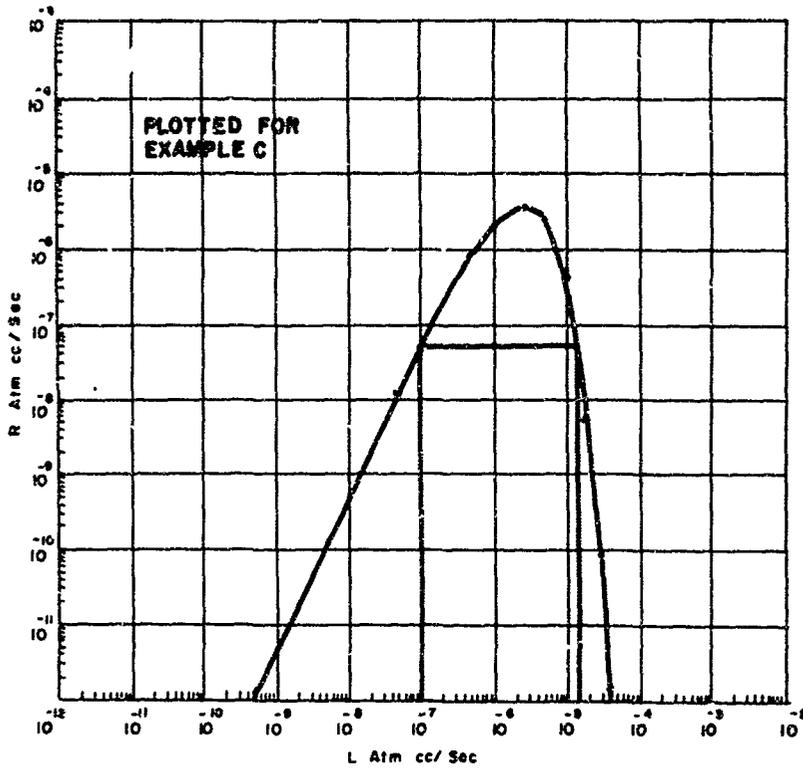
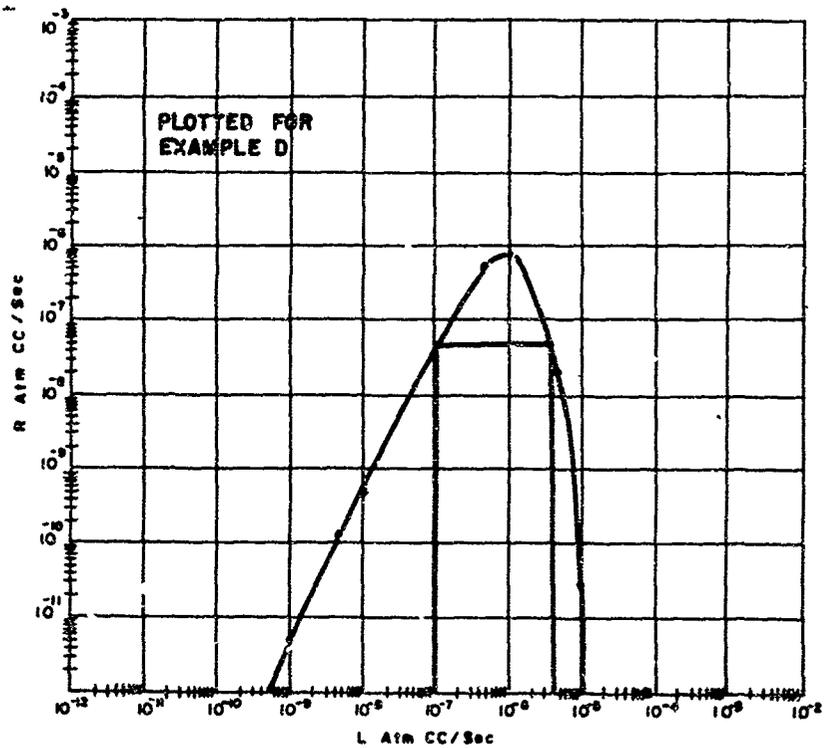


Figure 3
Relationship Between
Leak Rate Signal R to
Leak Size L When t_2 the
Dwell Time is Reduced
to 3600 Seconds.

Figure 4
Relationship Between
Leak Rate Signal R
to Leak Size L When
 t_2 the Dwell Time
is Increased to
10,800 Seconds.



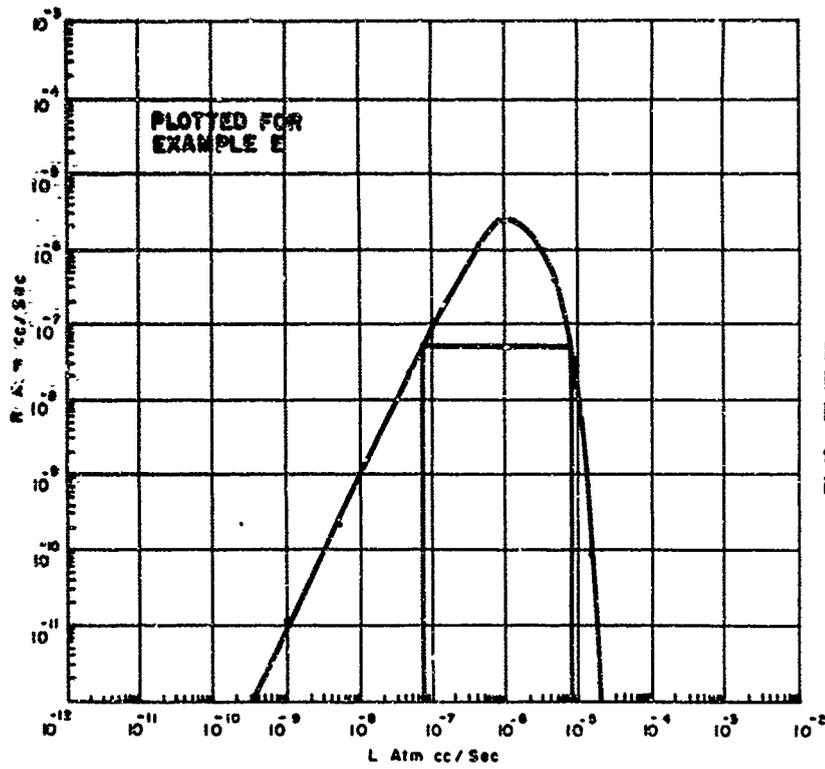


Figure 5
Relationship Between
Leak Rate Signal R to
Leak Size L When P_e
the Exposure Pressure
is Doubled

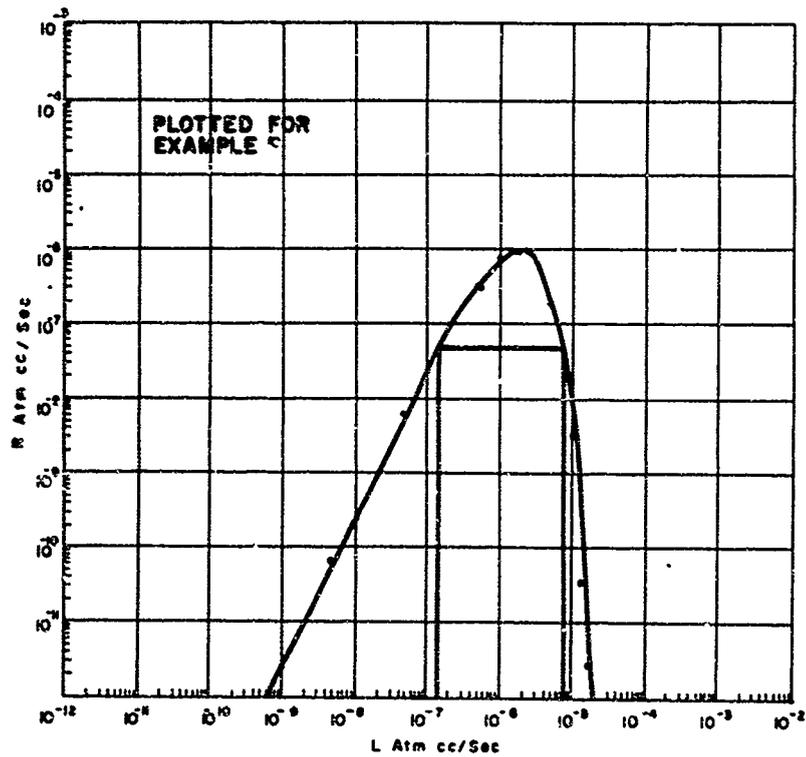


Figure 6
Relationship Between
Leak Rate Signal R to
Leak Size L When t_1
The Exposure Time is
halved

Example F. The remaining condition to be varied in this series was bomb time, which was decreased to 3600 seconds. This increased the smallest detectable leak to 1.5×10^{-7} atm cc/sec, while the maximum detectable leak remained the same as shown in Figure 6.

Example G. The bomb time was increased to 14400 sec which extends the leak range in both directions as shown in Figure 7.

In summary, table II shows how the test parameter changes vary the detectable leak size.

TABLE II

Variable	Increase Min	Decrease Min	Increase Max	Decrease Max
t_2 increase	X			X
t_2 decrease		X	X	
t_1 increase		X	X	
t_1 decrease	X			X
Bomb Pressure increase		X	X	
Bomb Pressure decrease	X			X

b. Detectable Package Leak Rate Range as a Function of Package Volume

This section has a twofold purpose; first, to determine how the detectable leak range changes as the package volumes varies and, secondly, it verifies the detectable leak range limits stated in the Seal Test, Method 1014 section of MIL-STD-883 for the listed range of package volumes. The test parameters used for this example are those specified in the aforementioned Seal Test, and are listed below:

- P_o - 1 atmosphere
- P_e - 5 atmosphere
- M_a - 28.7 grams
- M - 4 grams
- t_1 - 3600 seconds
- t_2 - 1800 seconds

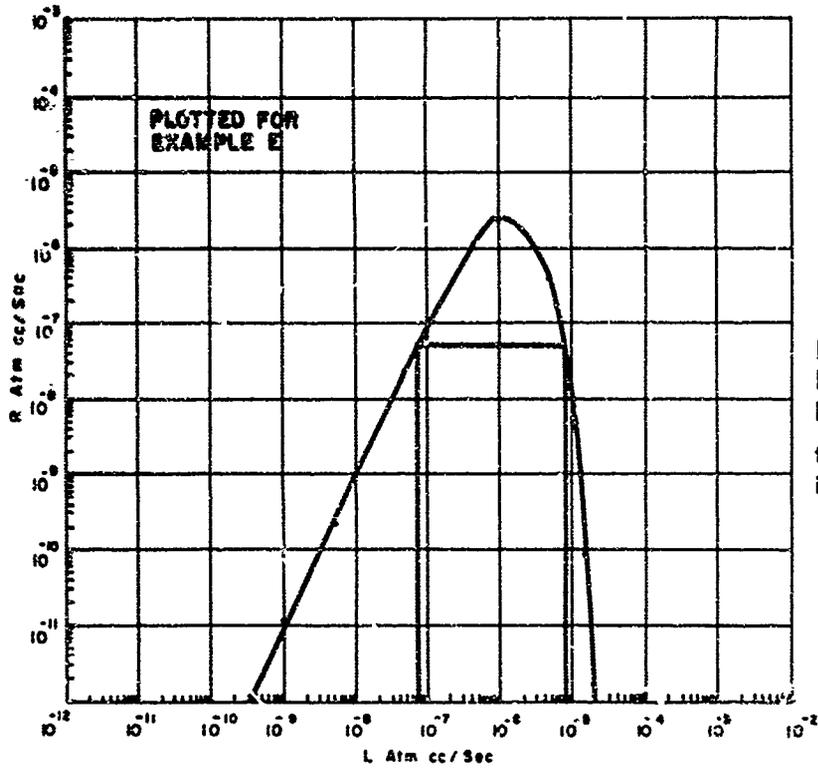


Figure 5
Relationship Between
Leak Rate Signal R to
Leak Size L When P_e
the Exposure Pressure
is Doubled

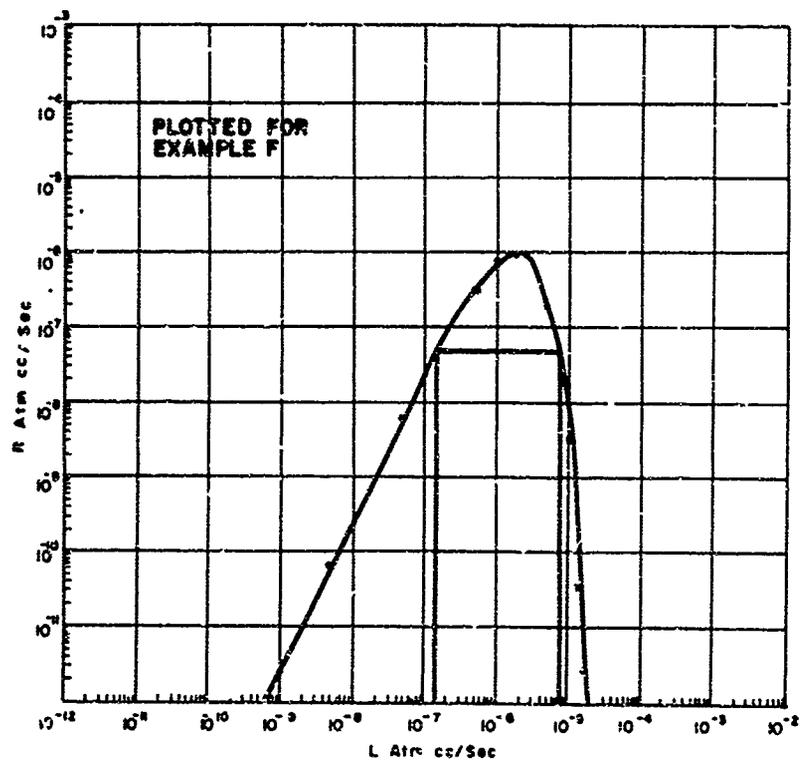


Figure 6
Relationship Between
Leak Rate Signal R to
Leak Size L When t_1
The Exposure Time is
Halved

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t_1 increase		X	X	
t_1 decrease	X			X
Bomb Pressure increase		X	X	
Bomb Pressure decrease	X			X

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- P_0 - 1 atmosphere
- P_e - 5 atmosphere
- M_a - 28.7 grams
- M - 4 grams
- t_1 - 3600 seconds
- t_2 - 1800 seconds

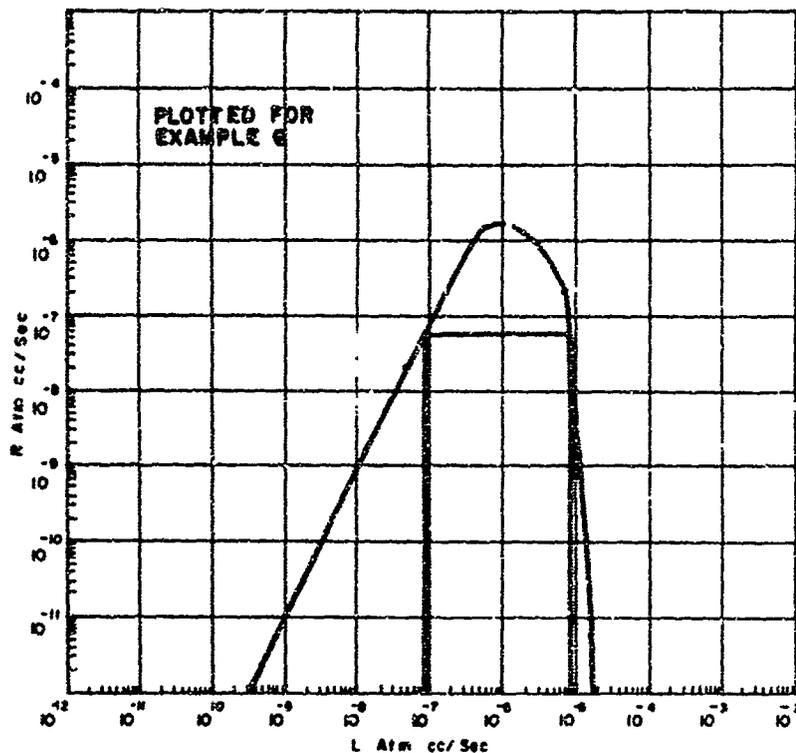


Figure 7. Relationship Between Leak Rate Signal R to Leak Size L When t_1 The Exposure Time is Doubled

The various package volumes used are as follows: 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1.0, 5.0, 10.0 cc.

Figure 8 is a composite showing the curves that resulted from analyzing the various volumes. These curves shall be used as described in the previous section to determine detectable leak rate ranges for various volumes when MIL-STD-883 test conditions are used.

The expected change in the detectable leak rate, with increasing package volume namely an increase in the minimum and maximum detectable leak rate, is apparent.

Also, in using the aforementioned curves, if a particular volume is not graphically illustrated, interpolation can be used, rather than generating a curve for that particular case.

All calculations were obtained through use of the RADC On Line Laboratory Computer, using basic language. The results were verified by comparison with the Fortran results obtained by North Electric. A sample of the basic program used is shown in Appendix II.

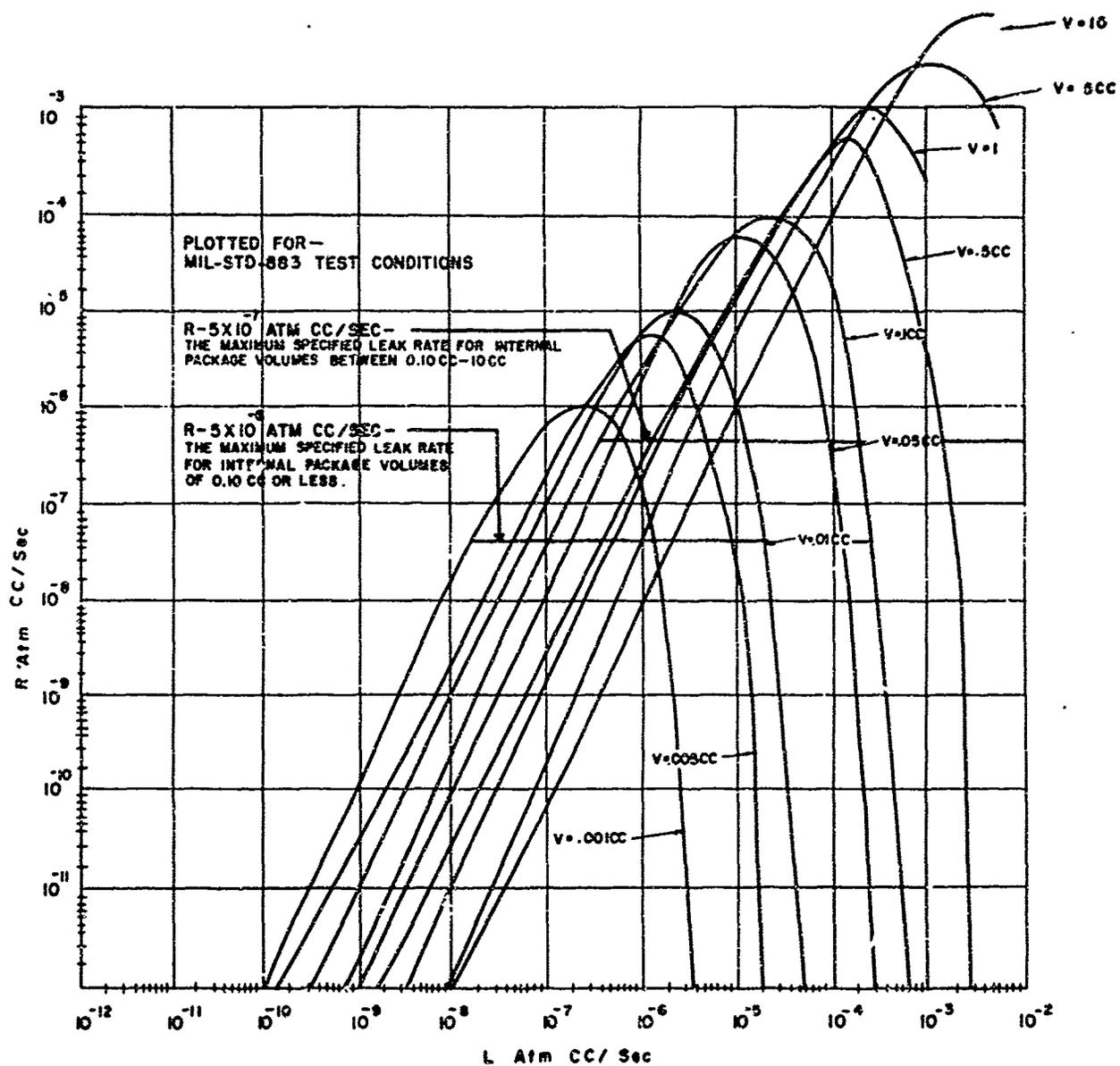


Figure 8. Relationships Between Leak Rate Signal R to Leak Rate Size L for Various Package Volumes.

IV. ANALYSIS OF DISCRETE HELIUM LEAK TEST PROCEDURES

The preceding analysis used the general molecular leak rate equation where a measured leak rate R referenced to a standard leak rate was calculated, imposing actual leak test specifications as contained in MIL-STD-883. This section analyzes the tracer gas flow during each individual leak test procedure in sequence using Equations 5, 8, and 9 of Appendix I.

It should be emphasized here that this analysis defines the leakage path geometry to be a cylindrical tube of diameter D and length ℓ . These terms are contained in the constant K (D^3/ℓ ratio) of Equation 12 in Appendix I. Analyzing each test procedure separately using the applicable equation lends more physical meaning to, and facilitates interpretation of fine leak test data. Test specifications taken directly from MIL-STD-883 and RADC-TR-67-52 are considered.

Figures 9, 10, and 11 illustrate (1) the internal helium partial pressure after high pressure helium exposure for time t_1 ; (2) the internal helium partial pressure after atmospheric exposure for dwell time t_2 ; and (3) the measured package leak rate R as a function of representative package volumes and D^3/ℓ ratios. The range of D^3/ℓ ratios (10^{-7} to 10^{-14}) applicable was determined by extreme case analysis. The lower limit (10^{-14}) is obtained using the smallest hole diameter where the free-molecular flow rate exceeds diffusional flow through the bulk package material and the largest leakage path length based on package dimensions. The upper limit (10^{-7}) reflects the largest hole diameter where the free-molecular flow laws are valid and the shortest path length again based on package dimensions.

Referring to Figure 9, the internal helium partial pressure P_1 after exposure time t_1 can be determined for any specified package where the volume (V) and minimum seal length (ℓ) are known over the range of hole diameters within the D^3/ℓ ratio limits.

Figure 10 allows the subsequent determination of the internal helium partial pressure P_2 resulting from helium loss during package exposure to atmospheric conditions for a dwell time t_2 .

Finally, Figure 11 gives the measured leak rate R for the specified package over the allowable hole diameters at time $t_1 + t_2$. Experimentally, the measured magnitude of R will be less than the R value obtained using Figure 11 by a factor determined by the time, t_v , required for the leak detector system to attain the specified mass spectrometer operating vacuum pressure.

In addition, at a specified leak detector sensitivity (μ -liters/sec), when the package volume V and minimum seal length ℓ are known, the detectable range of package equivalent hole diameters D can be determined graphically.

A typical example illustrating the use of Figures 9, 10, and 11 is in order. Assuming (1) a TO-84 flat package where $V \approx 10^{-2}$ cc and $\ell \approx 0.05$ cm; (2) a 10^{-10} D^3/ℓ ratio corresponding to an equivalent hole diameter of 1.72×10^{-4} cm (1.72 micron); and (3) MIL-STD-883 test conditions, P_1 , P_2 , and R are 3×10^6 dynes/cm², 2×10^6 dynes/cm², and 4×10^{-3} μ -liters/sec, as indicated in Figures 9A, 10A, and 11A, respectively. Obviously, the leak detector sensitivity required is $\geq 4 \times 10^{-3}$ μ -liters/sec.

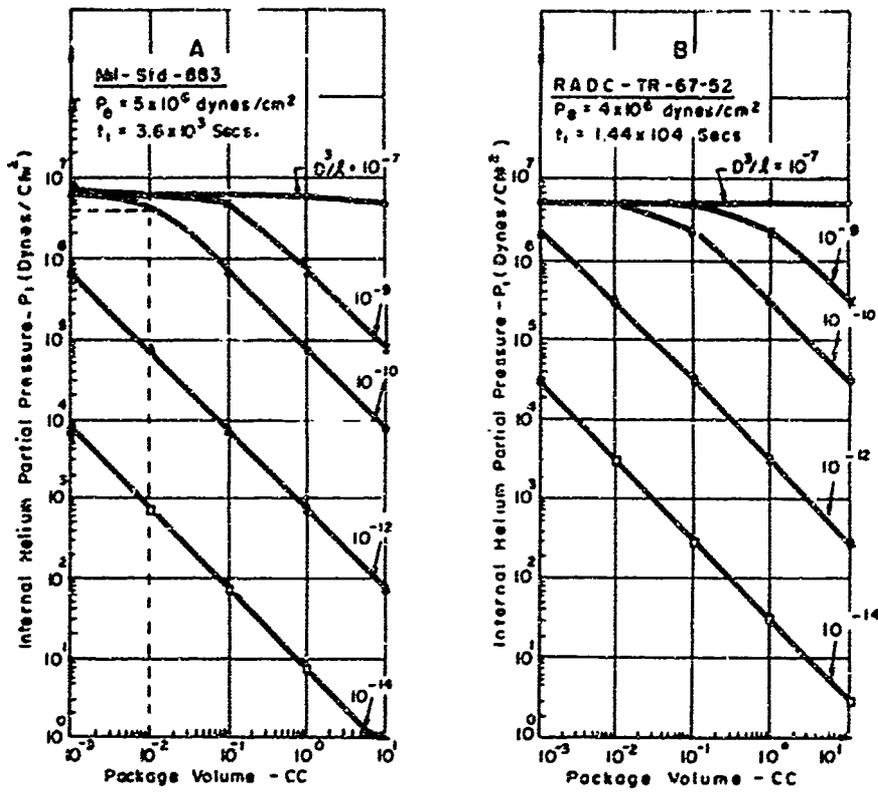


Figure 9
Helium Partial Pressure P_1 After Helium Pressure Exposure Time t_1 as a Function of Leak Test Parameters and Several V and D^3/l Ratios

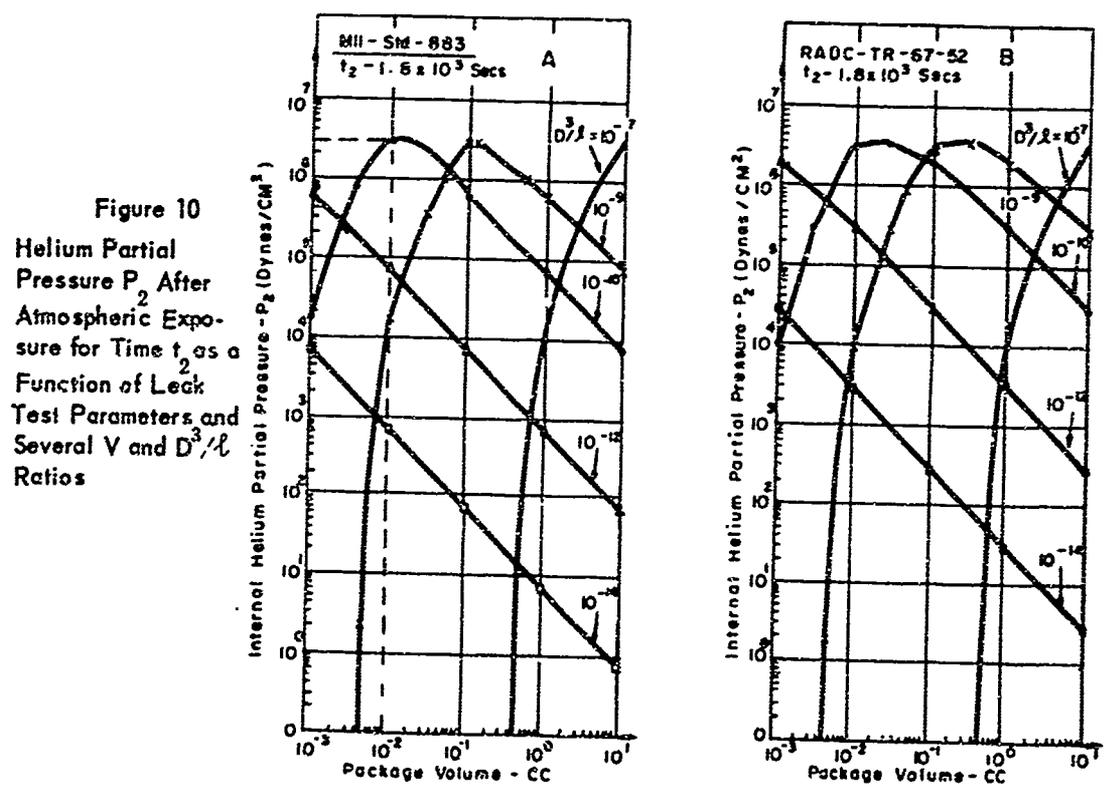


Figure 10
Helium Partial Pressure P_2 After Atmospheric Exposure for Time t_2 as a Function of Leak Test Parameters and Several V and D^3/l Ratios

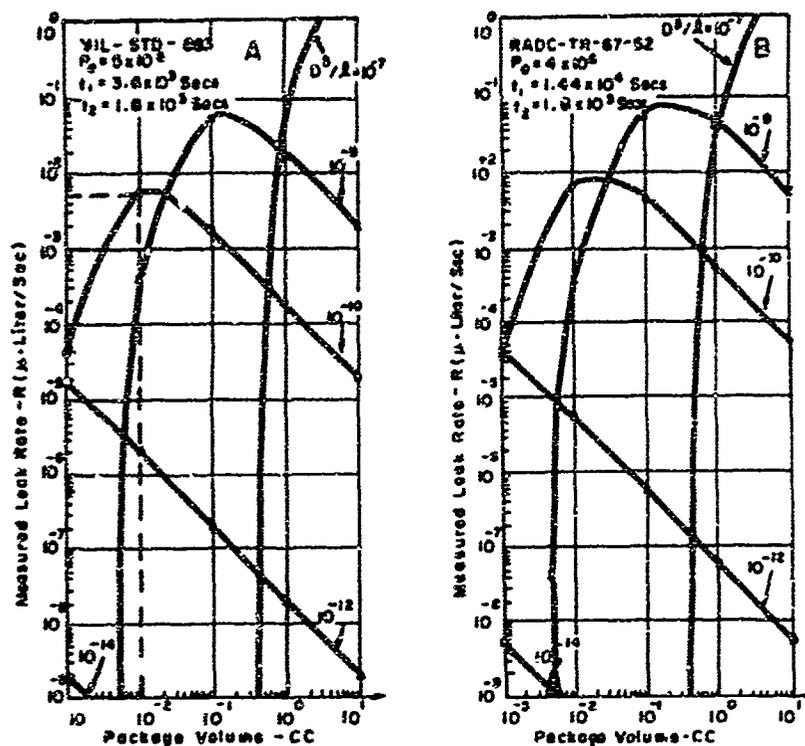


Figure 11. Measured Leak Rate R as a Function of Leak Test Parameters, Internal Package Volume V , and Various Leak Dimension D^3/l Ratios.

V. MICROELECTRONIC DEVICE RELIABILITY RELATED TO PACKAGE LEAK RATE

The penetration of water vapor and/or ionic contaminants into the package can result in (1) electrolytic corrosion of metallization and bonding wires, and (2) formation of surface inversion layers or channels causing microcircuit failure. The failure modes observed are changes in metal continuity and excessive device reverse leakage currents, respectively. The rate at which external contaminants penetrate a package under use conditions is determined by the package leakage path characteristics. A measured package volume leak rate (R -atm cc/sec) indicates only an equivalent leak (hole) diameter. The actual leakage path may be a singular hole or a large series of smaller holes resulting in a measured leak rate R . From the microcircuit reliability standpoint, under identical operating conditions, a singular hole increases the probability of microcircuit failure within a specified time period when compared to a large number of smaller holes. Thus, a measured package leak rate R indicates only the degree of package hermeticity rather than microcircuit reliability, which depends on a number of additional device structure considerations including metal system, passivation, etc.

(a) External Ambient Moisture Penetration Rate by Diffusion

Under normal microcircuit operating conditions, the device is exposed to existing external ambients, typically atmospheric pressure at ambient temperature and percent relative humidity (%RH). Assuming a package leakage path exists, the laws of diffusion predict a change in internal package ambient with time to equalize internal and external ambients molecular concentrations.

In general, 200 ppm water vapor package content is sufficient to generate micro-circuit electrical parameter instability. The range of ppm of water vapor resulting in unstable device parameters is obviously dependent on the several factors previously stated.

Neilson and Weisberg⁵ derived an expression based on diffusional gas flow laws for determining the time required for a specified ppm of water vapor to penetrate a package assuming a leakage path diameter and the initial internal package ambient and existing external environment.

$$t = \frac{12 \ell N_{H_2O}}{\pi D^2 L v_a (n_{ext} - n_{int})}$$

where $N_{H_2O} = \frac{P_t V}{kT} \times \text{ppm } H_2O$

$$n_{ext} = \frac{P_{H_2O}}{kT} \text{ at } \%RH \text{ at } 300^\circ K$$

Consider a TO-84 flat package backfilled with dry N_2 gas at atmospheric pressure and a 50% RH external ambient at 27°C.

$$V = 10^{-2} \text{ cc}$$

$$\ell = 0.050 \text{ cm}$$

$$L = 450 \text{ \AA} = 4.5 \times 10^{-6} \text{ cm}$$

$$v_a = 5.8 \times 10^4 \text{ cm/sec}$$

D = leakage path singular hole diameter in cm.

$$n_{int} = 0$$

$$N_{H_2O} = \frac{P_t V}{kT} \times \text{ppm } H_2O = 4.83 \times 10^{13} H_2O \text{ molecules}$$

$$n_{ext} = \frac{P_{H_2O}}{kT} \text{ at } 50\% RH \text{ at } 300^\circ K = 4.3 \times 10^{17} \text{ molecules/cc}$$

The time required to attain a level of 200 ppm water vapor content within the micro-circuit TO-84 package is computed by:

$$t = \frac{12 \ell N_{H_2O}}{\pi D^2 L v_a (n_{ext} - n_{int})} = \frac{8.25 \times 10^{-5}}{D^2} \text{ sec}$$

For $D = 10^{-4}$, 5×10^{-5} , and 10^{-5} cm, $t = 2.28$, 9.2 , and 228 hours, respectively.

It is apparent that in the case where a singular leakage path exists the time to attain the 200 ppm internal package water vapor level under the above specified conditions is relatively short term and thus represents a potential microcircuit reliability risk.

(b) Microcircuit Failures Resulting From Moisture Penetration

Figure 12 (B-C) illustrates two common types of failure modes experienced as a result of moisture penetration, (B) metal continuity and/or corrosion, and (C) semiconductor surface effects. Figure 12A shows strip chart recordings prior to and after mechanical fracturing of a TO-84 flat package. Trace (1) indicates a hermetic package. Trace (2) indicates a gross leak by inspection of the detected Helium decay with time. However, it should be noted that the measured package leak rate using the Helium Fine Leak Seal Test was within MIL-STD-883 specifications. This experimental evidence points out the requirement for performing both a fine and a gross leak test.

The microcircuit (DTL - Dual NAND Gate) was subjected to a Moisture Resistance test at 85°C and 95% RH and subsequently failed at the 24 hour test point. Gross leak testing after stress revealed the existence of a package gross leak.

The observed failure modes were crystal growths projecting from the Mo layer under the Au causing a resistive path between adjacent metal intraconnects and an output transistor base channel resulting in a reverse collector-emitter leakage current of $100 \mu\text{a}$. The failure mechanism generating the observed failure modes was moisture penetration into the package.

VI. CONCLUSIONS

The analysis contained herein provides the theoretical basis for the Seal Test, Method 1014, Test Procedure A, as specified in MIL-STD-883.

Detailed analysis of the Seal Test package leak rate equation in Sections III and IV verifies the validity in specifying two discrete maximum volume leak rate magnitudes corresponding to the defined package volume ranges under the specified Seal Test parameters, and provides a sound understanding of the basic physical laws underlying the tracer gas Seal Test technique.

The deleterious effect of package moisture penetration on microcircuit reliability based on integrated circuit field failure analysis justifies the subject reliability screen test requirement.

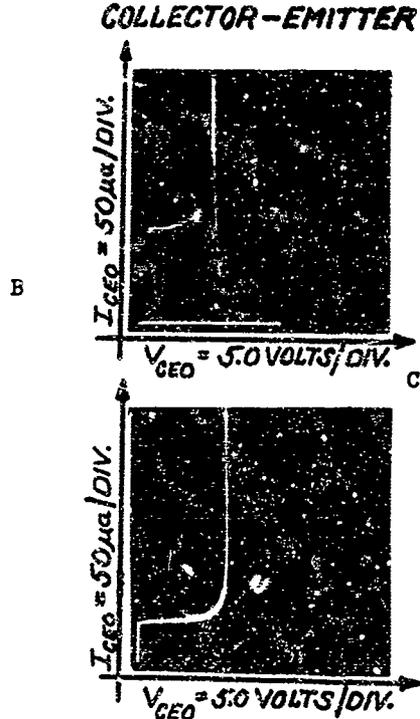
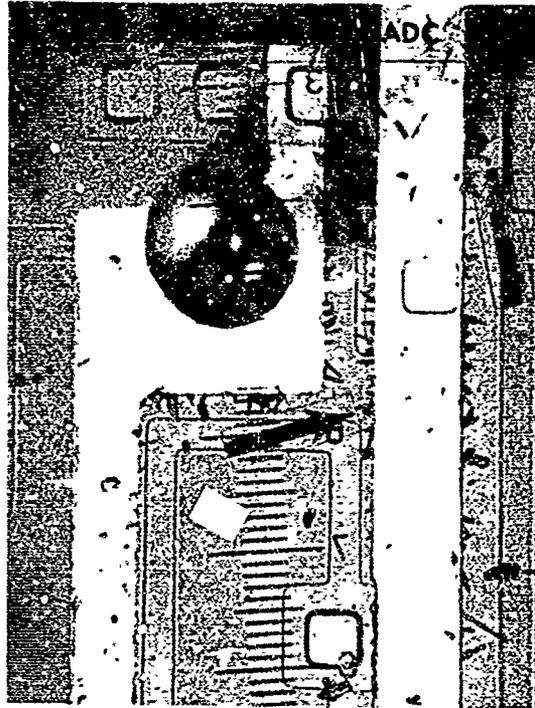
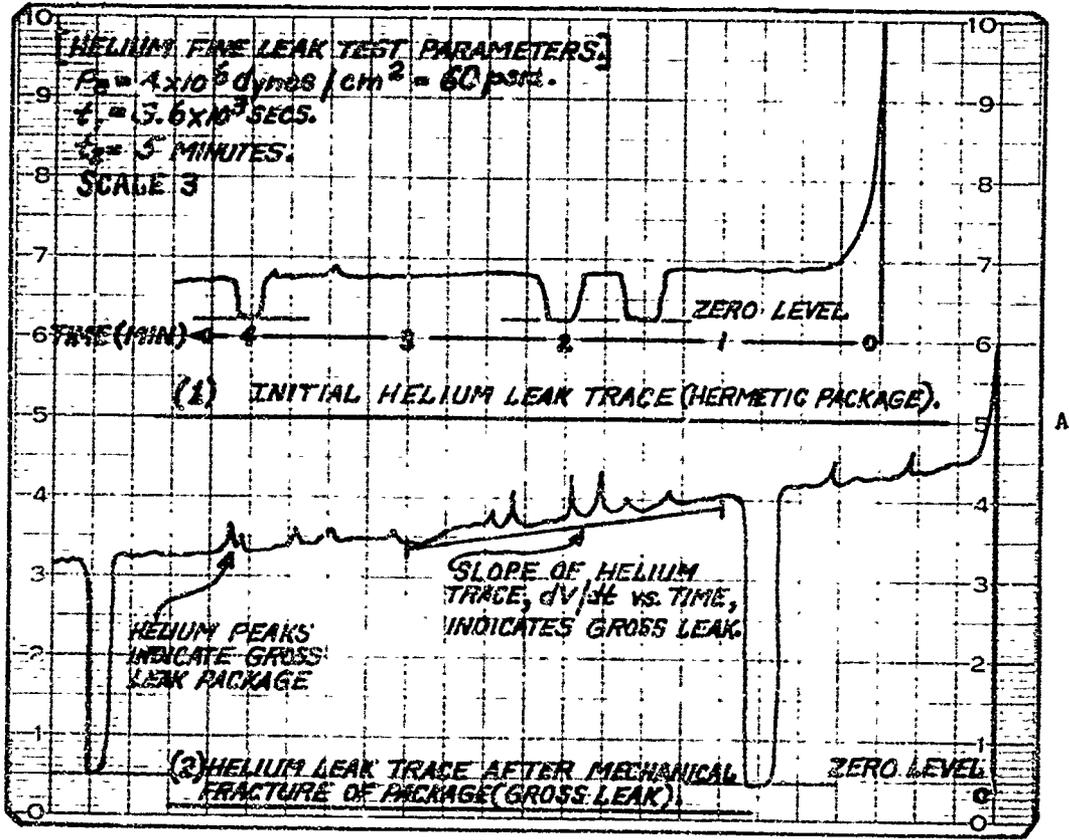


Figure 12. Integrated Circuit Failures Resulting From Moisture Penetration
 A - Hermetic Seal Test Results, B - Crystal Growth (Mo-Au Metal System) and,
 C - Excessive Transistor C-E Reverse Leakage Current.

APPENDIX I

DERIVATION OF EQUATION RELATING A MEASURED TRACER GAS VOLUME FLOW RATE (R) REFERENCED TO A STANDARD AIR LEAK RATE (L) AS A FUNCTION OF HERMETIC PACKAGE DIMENSIONS AND HELIUM FINE LEAK HERMETICITY TEST PARAMETERS.

The derivation and analysis of the viscous, diffusional, and free-molecular steady state molecular and volume gas flow rate equations and a detailed description of the standard helium leak rate measurement system including test procedures are given in the context of RADC-TR-67-52, "Analysis of Integrated Circuit Package Integrity Using Helium Leak Detection Techniques."⁽¹⁾

The gas flow derivation in this appendix was developed by Howl and Mann⁽²⁾ and includes the essential gas flow rate time dependence as related to the actual hermeticity test procedures where free-molecular inflow and outflow of the helium tracer gas is assumed. The justification for this general assumption is twofold. First, it is probable that several leakage paths exist in a non-hermetic package rather than a singular leakage path and, secondly, it is highly improbable that any existing leakage path exhibits a uniform cross-section or is unidirectional over its length.

Consider the Helium Fine Leak Test. During the helium pressure bomb test procedure the package under test is placed within a pressure chamber at a specified pressure for a given time interval. The partial pressure of helium within the package after time t_1 is a function of the bomb pressure or exposure pressure P_e , the initial internal package pressure P_c , and the geometrical properties of the existing leakage paths. Using the ideal gas equation and the free-molecular flow rate equation⁽¹⁾, the internal package helium partial pressure after time t_1 can be determined. The following derivation assumes a cylindrical leakage path of diameter D and length ℓ .

$$P_c V = nRT \quad \therefore V (dP_c/dt) = kT(dN/dt) \quad (1)$$

$$dN/dt = \pi v_a D^3 (n_e - n_c) / 12 \ell \quad \text{where: } D < L, D \ll \ell, (L/n)(dn/dx) \ll 1 \quad (2)$$

Direct substitution for dN/dt (Equation (2)) into Equation (1) yields:

$$V (dP_c/dt) = \pi v_a D^3 kT (n_e - n_c) / 12 \ell$$

$$\text{Since: } v_a = \sqrt{8kT/\pi m} = \sqrt{8RT/\pi M} \quad \text{and, } n_e - n_c = (P_e - P_c)/kT \quad \text{then:}$$

$$V (dP_c/dt) = (\sqrt{2\pi R/6}) (D^3/\ell) (T/M)^{1/2} (P_e - P_c) \quad (3)$$

$$\text{Letting } C = (\sqrt{2\pi R/6}) (D^3/\ell) \quad \text{and } K = (\sqrt{2\pi R/6}) (D^3/\ell) (T)^{1/2}$$

Equation (3) can then be rewritten as follows:

$$dP_c/dt = (C/V) (T/M)^{1/2} (P_e - P_c) = K(P_e - P_c)/V(M)^{1/2} \quad (4)$$

Equation (4) is a first order differential equation with variables separable. Separation of variables and integration yields:

$$\int_0^{P_1} dP_c / (P_e - P_c) = (K/V(M)^{1/2}) \int_0^{t_1} dt$$

Integration over the defined limits yields:

$$P_1 = P_e [1 - \exp (-Kt_1 / V(M)^{1/2})] \quad (5)$$

Equation (5) gives the internal package helium partial pressure P_1 at time t_1 during the high pressure helium bomb test procedure.

The package under test is then removed from the high pressure chamber and exposed to atmospheric conditions for a time interval t_2 between back-pressurization and the leak rate measurement with subsequent helium loss. Again, using the ideal gas and free-molecular flow rate equations, the equation for helium gas outflow is derived as follows:

$$V (dP_c / dt) = (-kT) (dN/dt) \quad (1)$$

$$dN/dt = \pi v_a D^3 (n_c) / 12 \ell \quad \text{where: } D < L, D \ll \ell, (L/a) (dn/dx) \ll 1 \quad (6)$$

Direct substitution for dN/dt (Equation (6)) into Equation (1) yields:

$$V(dP_c/dt) = (-kT) (\pi v_a D^3 n_c) / 12 \ell = (\pi v_a D^3 P_c) / 12 \ell$$

Substituting the previous expression for v_a the resulting differential equation in terms of the defined constant K gives:

$$dP_c/dt = -K(P_c)/V(M)^{1/2} \quad (7)$$

Equation (7) is also a first order differential equation with variables separable. Separation of variables and integration yields:

$$\int_{P_1}^{P_2} dP_c / P_c = (-K/V(M)^{1/2}) \int_0^{t_2} dt$$

Integration over the defined limits yields:

$$P_2 = P_1 [\exp (-Kt_2 / V(M)^{1/2})] \quad (8)$$

Equation (8) gives the internal package helium partial pressure P_2 at time t_2 (Period of package exposure to atmospheric conditions).

The final leak test procedure consists of placing the package under test into the helium leak detector vacuum chamber. The continued outflow of tracer gas (helium) is detected by a mass spectrometer tuned for helium. The output detector signal is proportional to

the leak rate of helium out of the package through the leakage path. The measured leak rate of helium is expressed by the equation.

$$R = (K/(M)^{1/2}) P_2 \quad (9)$$

Defining a standard leak rate L as the gas flow through a leak under conditions of one atmosphere of air on the high pressure tube end and a vacuum on the opposite tube end, then:

$$L = (K/(M_a)^{1/2}) P_0 \quad \text{where } P_0 \text{ is atmospheric pressure} \quad (10)$$

The measured helium leak rate in terms of or referenced to the standard air leak rate is obtained by algebraically solving for the R/L ratio, thus:

$$R = L(P_2/P_0) (M_a/M)^{1/2} \quad (11)$$

Direct substitution for P_2 (Equation (8), into Equation (11) using Equations (5) and (8) yields:

$$R = L(M_a/M)^{1/2} (P_e/P_0) [1 - \exp(-Kt_1/V(M)^{1/2})] [\exp(-Kt_2/V(M)^{1/2})] \quad (12)$$

Substitution for K , in terms of L , P_0 , and $(M_a)^{1/2}$ using Equation (10), into Equation (12) gives:

$$R = L(M_a/M)^{1/2} (P_e/P_0) [1 - \exp(-Lt_1/VP_0) (M_a/M)^{1/2}] [\exp(-(Lt_2/VP_0)(M_a/M)^{1/2})]$$

The final equation expresses a measured helium leak rate (R -atm cc/sec) referenced to a standard air leak rate (L -atm cc/sec) as a function of hermetic package dimensions and helium fine leak hermeticity test parameters.

APPENDIX II

BASIC COMPUTER PROGRAMS FOR DETERMINING LEAK RATES USING THE HELIUM TRACER GAS FINE LEAK TEST

PARAMETERS

R = Leak rate of tracer gas through the leak

L = Leak size

P = P_e = Pressure of exposure

P1 = P_o = Atmospheric pressure

M1 = M_a = Molecular weight of air

M = Molecular weight of tracer gas

T1 = t_1 = Time of exposure to P_e (P)

T2 = t_2 = Dwell time - Time between release of pressure and leak detection

V = Internal volume of package

LEAK RATE R = $\text{SQR}(M1/M) * L * (P/P1) * (1 - \text{Exp}(-L * T1 * \text{SQR}(M1/M) / (V * P1))) * \text{EXP}(-L * T2 * \text{SQR}(M1/M) / (V * P1))$

COMPUTER PROGRAM FOR R AS A FUNCTION OF L AND V

Reference program SEALLV

COMPUTER PROGRAM FOR R AS A FUNCTION OF L

Reference program SEAL L

SEALLV

13:44

04/26/68

```
100 PRINT " R A FUNCTION OF L AND V"
110 PRINT
120 REM N = NUMBER OF VALUES THAT V WILL ASSUM
130 REM M2 = NUMBER OF VALUES THAT L WILL ASSUM
140 REM AT LINE 390 IN THE FOLLOWING SEQUENCE;
150 REM N, M2, T1, T2, M1, M, P, P1, V1, V2, . . . , VN, L1, L2, . . . , LM
160 READ N, M2, T1, T2, M1, M, P, P1
170 DIM V(100), L(100)
180 MAT READ V(N), L(M2)
210 FOR I = 1 TO N
220 LET V = V(I)
230 LET K = 1
240 PRINT "V="; V
245 PRINT
250 LET L = L(K)
260 LET R = SQR(M1/M)*L*P/P1
270 LET R = R - R * EXP (-L*T1*SQR(M1/M)/V*P1)
280 LET R = R * EXP (-L*T2*SQR(M1/M)/(V*P1))
290 PRINT "L="; L, "R="; R
300 IF K = M2 THEN 325
310 LET K = K + 1
320 GO TO 250
325 PRINT
326 PRINT
330 PRINT "T1="; T1; "T2="; T2; "M1="; M1; "M="; M; "PE="; P
340 PRINT "PO="; P1
350 PRINT
360 PRINT
370 PRINT
380 NEXT I
390 DATA 9, 16, 3600, 1800, 28.7, 4, 5, 1
400 DATA .001, .005, .01, .05, .1, .5, 1, 5, 10
410 DATA 5E-3, 1E-3, 5E-4, 1E-4, 5E-5, 1E-5, 5E-6, 1E-6, 5E-7, 1E-7, 5E-8, 1E-8
420 DATA 5E-9, 1E-9, 5E-10, 1E-10
430 END
```

READY

RUN

SEALLV

13:46

04/26/68

SEAL L

14:17

04/26/68

```
100 PRINT "R A FUNCTION OF L"
110 PRINT
120 REM N = THE NUMBER OF VALUES THAT L WILL ASSUM
130 REM THE DATA IS ENTERED IN THIS PROGRAM AS DATA STATEMENTS
150 REM AT LINE 270 IN THEN FOLLOWING SEQUENCE;
155 REM, N, T1, T2, M1, M, P, P1, V, L1, L2, . . . , LN
160 READ N, T1, T2, M1, M, P, P1, V
170 DIM L(100)
180 MAT READ L(N)
190 FOR I = 1 TO N
195 LET L = L(I)
200 LET R = SQR(M1/M)*L*P/P1
210 LET R = R - R * EXP(-I.*T1*SQR(M1/M)/(V*P1))
220 LET R = R * EXP(-L*T2*SQR(M1/M)/(V*P1))
230 PRINT "L="; L, "R="; R
240 NEXT I
245 PRINT
246 PRINT
250 PRINT "T1="; T1; "T2="; "M1="; M1; "M="; M; "PE="; P
260 PRINT "PO="; P1, "V="; V
270 DATA 16, 3600, 1800, 28,7, 4, 5, 1, .001
280 DATA 5E-3, 1E-3, 5E-4, 1E-4, 5E-5, 1E-5, 5E-6, 1E-6, 5E-7, 1E-7, 5E-8, 1E-8
290 DATA 5E-9, 1E-9, 5E-10, 1E-10
300 END
```

READY

RUN

SEAL L

14:19

04/26/68

R A FUNCTION OF L

L = 0.005	R = 0
L = 0.001	R = 0
L = 0.0005	R = 0
L = 0.0001	R = 0
L = 0.00005	R = 0
L = 0.00001	R = 1.53925 E-25
L = 0.000005	R = 2.27021 E-15
L = 0.000001	R = 1.07869 E-7
L = 5. E-7	R = 5.96156 E-7
L = 1. E-7	R = 5.11683 E-7
L = 5. E-8	R = 2.01297 E-7

R A FUNCTION OF L (Cont'd)

L = 1.	E-8	R = 1.17323	E-8
L = 5.	E-9	R = 3.07707	E-9
L = 1.	E-9	R = 1.27911	E-10
L = 5	E-10	R = 3.21322	E-11
L = 1.	E-10	R = 1.29026	E-12

T1 = 3600 T2 = 1800 MA = 28.7 M = 4 PE = 5
FO = 1 V = 0.001

TIME: .16 SECS.

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13. ABSTRACT The Helium Tracer Gas Fine Leak Seal Test, as specified in MIL-STD-883, Method 1014, Test Condition A, based on the "back-pressurization" technique for determining the hermeticity of microelectronic device packages, is described. The sensitivity of Seal Test parameter variations to package leak rate measurement test results is analyzed in detail by a systematic variation of exposure pressure, exposure time and dwell time over the complete range of microelectronic package volumes. Analysis results verify the need for specifying standard seal test conditions, for defined package volumes, as required in MIL-STD-883, to insure that the specified level of package hermeticity will be achieved. Microelectronic device reliability as related to package volume leak rate (atm cc/sec) is discussed. Microcircuit failure modes and associated failure mechanisms dependent on package hermeticity are presented. The primary intent of this technical report is to provide a supplemental documented guide to both microcircuit manufacturers and Air Force contractors engaged in screen testing and device procurement concerning the subject Seal Test contained in MIL-STD-883.			

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