LEAK TESTING 6 MILLION IC's

By

Robert L. Stewart
Burroughs Corporation
Pasadena, California

George R. Neff
IsoVac Engineering Inc.
Glendale, California

Background

The test program was undertaken to evaluate the basic seal integrity of the ceramic package and to determine seal quality level supplied from normal production processes. It was felt that by conducting a test program involving a large quantity of devices that the manufacturers' process capability could be established and that the proper device user controls employed. For this reason, large quantities of dual in-line packages were investigated for hermetic seal by the Burroughs Corporation in Pasadena, California, to determine the actual average seal quality level received. The approach was to run a preliminary screening on approximately 100,000 14-lead dual in-line ceramic packages.

The first 100,000 devices evaluated were tested against a 10^{-4} to 10^{-6} standard cc/second leak rate specification in order to determine whether there was major cause for concern. The average fall-out for these devices, which was chosen from stock on a random basis, appears to be approximately 2.7% reject, greater than 10^{-6}. For this reason, a program was launched that would evaluate approximately six million devices on a 100% screening basis to a specification of 1 x 10^{-6} standard cc/second (air).

Introduction

With the usage of approximately 50,000 ceramic type dual in-line packages per day for manufacturing computer circuit boards, it was rather an alarming test to consider 100% screening on an indefinite basis. The cost had to be reduced and yet, if the test was not reliable, the results would be meaningless. Helium mass spectrometry was considered for this purpose and was eliminated based on technical concerns by Burroughs' quality engineering personnel. These concerns essentially stem from the fact that the devices themselves provide only a 0.02 cc internal void as a maximum. A leak rate of 10^{-7} standard cc/second (air) will permit evacuation of helium tracer gas from that cavity on an almost instantaneous basis. True, it is not totally removed during the evacuation and sensing steps in the mass spectrometer, but it is changing at a rate commensurate with leak size. Thus, the true percentage of helium within the device at the instant that it is read on the mass spectrometer is never known.

It is realized that a helium mass spectrometer go/no-go leak test is possible on such a device on an individual basis, or at a slow enough rate that there is no chance of missing devices that are losing their helium too rapidly. The radioisotope leak detection process was chosen as a faster screening system with more reliable results throughout the range of 10-4 to 10-6cc/second. The radioisotope process is normally applied over much greater ranges than this; however, the specification limits are in an extremely critical zone (10^{-5} to 10^{-6}), which has always been a gray area between standard bubble tests and fine leak tests.

Military Standard 750, method 1071, suggested the lower limit of the bubble tests to be 1 x 10^{-5} standard cc/second, and the suggested range of detectability for helium mass spectrometry is 1 x 10^{-6} to 5 x 10^{-8} for semiconductors. There is a very distinct questionable zone as a gray area between the two leak rate ranges, and thus, the radioisotope method was investigated and found to cover this gap. The controlling parameters of the leak test were Military Standard 883, method 1014, test condition "B," with minor modifications primarily influenced by Military Standard 750, method 1071. These limitations were 1) the Krypton-85 transfer back into the storage system should be accomplished within two minutes and 2) a maximum of one hour was permitted for counting the devices after removal from the activation system. An additional restriction was used during bulk testing--that was to allow no greater than 30 minutes counting time on the devices after they had been removed from activation. This was done in an effort to assure that the larger leak rate devices would not be missed in normal, uncontrolled mass testing.

The sample plan that was initially used for screening of the devices under Military Standard 19500 E, Appendix C, was an LTPD of seven with a sample size of 55 devices. Acceptance was on one and rejection was based on two or more parts. This sample plan had been scrutinized prior to the test program. One of the purposes of the program was to determine what a proper sample size should be in order to assure the desired level of reliability. A statistical study would have to be performed on the results of the total program; thus, six million devices were certainly adequate for an evaluation of proper sample size. These samples, which were run on each batch of devices, were then compared to the total number of rejects found on the lot when 100% tested. It is recognized that these would vary with different part types and part numbers. A total of approximately ten different part numbers were evaluated under this program, but all were of a basic ceramic 14 lead DIP configuration.

Material Control

The number of devices per individual identifiable production lot varied from as few as 100 devices to quantities of 40,000 or more. The majority of these batches, however, were quantities of 3,000 to 8,000. The lots of devices as received by Burroughs Corporation were controlled by assigning a lot number to each of the lots that would cover, in some cases, many different date codes and/or manufacturing control numbers. In some cases, they were sampled separately in order to determine if the mixture was homogeneous. Also, at the end of the testing of the entire lot of devices, the individual date codes or manufacturing numbers were collected, and a determination of which group caused the greatest number of failures was not representative of what would be encountered in some of the sub-lots or batches.

Traceability was maintained throughout the entire test program. An additional requirement for each of the devices tested was to maintain orientation. This had to be done so that the devices could then be fed directly through automatic electrical test equipment without rejection. This, complicated by lead bending during handling, required very careful control so that any problems that originated at the manufacturers could truly be identified after the leak test phase.

Experimental Program

Theory of Leak Test.

The leak detection process used for this program was the Radiflo process. The theory of the Radiflo leak detection process utilizes the radioisotope krypton-85 and has been in use commercially for approximately twelve years. This process is one in which devices are bombed in what is called an activation tank for a specified time period in order to allow krypton-85 to penetrate the devices that have faulty hermetic seals.

There are many concerns in the use of radioisotopes that are unnecessary with krypton-85. It is without biological health hazard and is an extremely weak emitter of beta particles and gamma rays. It is totally inert chemically and, because it is an isotope, does not change its chemical properties.

Pressure bombing is performed in a gas handling system of cross sections similar to Fig. 1. The equation that is applicable to the Radiflo leak test is $T = \frac{R}{SKQ\bar{P}t}$, where T is soak time in hours, R is reject level (or count rate in counts per minute) at which devices will be considered to fail, S is specific activity or concentration of krypton gas in mixture with nitrogen (μc/atm.cc), K is counting efficiency or detection efficiency of 1 μc of krypton-85 in tested device (c/m/μc),

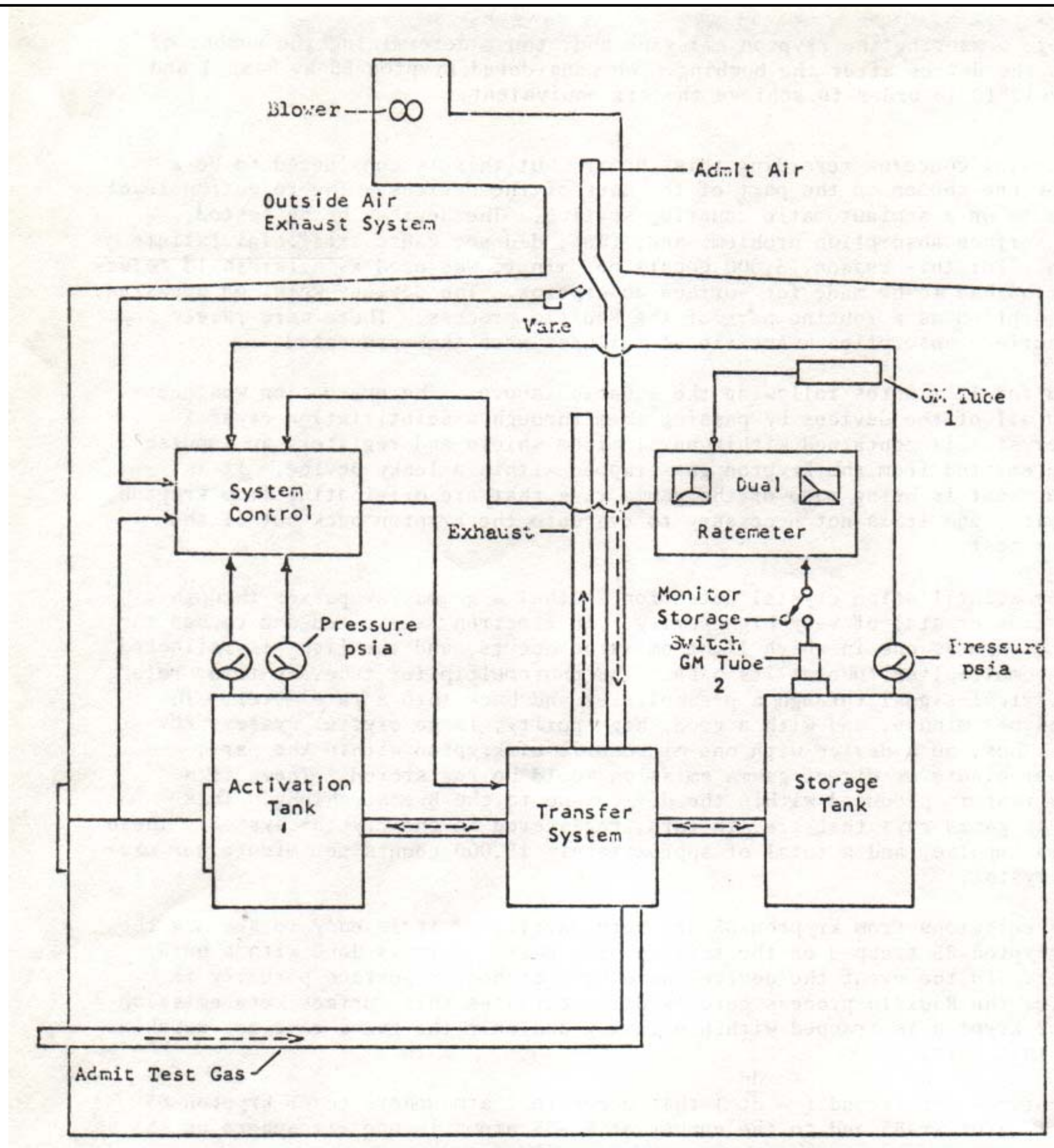

Fig. 1. Activation unit

Q is leak rate sensitivity in atmosphere cc/second (desired), P is Pe2 - Pie or the external pressure (in atm. abs. squared)-internal pressure (atm. abs. sq.), and t is conversion from seconds to hours (3.6×10^3).

The specific activity of the Radiflo system used was approximately 250 uc/atmospheric cc of gas. This was a concentration of krypton-85 mixed with nitrogen gas in the system. The total system pressure operates at approximately 185 pounds maximum, and the bombing of the devices was accomplished at 90 pounds in the activation tank. Q in the testing program was set up as the leak rate in standard cc/second (air). For a 1×10^{-6} s.c.s. leak rate requirement of air, a 5.85×10^{-7} S.C.S. of krypton-85 was used. Leak rate values of 5×10^{-7} s.c.s. and smaller are in the molecular flow region. However, it is recognized that this is not a distinct point, but rather a range transition between viscous and molecular flow. Thus, using molecular flow theory, the flow rate varies inversely as the square root of molecular weight, and the flow rate of air is equivalent to 1.712 times the flow rate of krypton-85 gas.

In this program, we were measuring the krypton emission and, thus, determining the number of krypton-85 molecules within the device after the bombing. We considered krypton-85 as base 1 and converted by multiplying by 1.712 in order to achieve the air equivalent.

There are many controversial concerns regarding this theory, but this is considered to be a conservative approach and the one chosen on the part of the user of the devices. The rejection level (R) was 3,000 counts per minute on a semiautomatic counting station. The devices being tested, although ceramic, showed no surface absorption problems and, thus, did not cause artificial failure due to krypton-85 absorption. For this reason, 3,000 counts per minute was used as a threshold rejection level, and no compensation had to be made for surface absorption. The devices were, on occasion, measured for surface gas absorption as a routine part of the Radiflo process. There were rarely any devices that displayed any surface absorption. Artificial failures were thus prevented.

The devices were bombed for 12 minutes following the equation above. The evaluation was accomplished within 30 minutes on all of the devices by passing them through a scintillation crystal system. The scintillation crystal is contained within an aluminum shield and registers an impulse from the gamma rays that are emitted from the krypton gas trapped within a leaky device. It is important to note that measurement is being made of the gamma rays that are originating from krypton gas remaining within the device, and it is not necessary to evacuate the krypton back out of the device as is done in a helium test.

The actual theory of the scintillation crystal detection is that a gamma ray passes through a thallium activated sodium iodide crystal of very high purity. An electron is excited and caused to change orbit. This orbital change is one in which light emission occurs, and the light is reflected through the crystal to a photomultiplier tube at its base. The photomultiplier tube, in turn, relays the light impulse as an electrical signal through a preamplifier and back into a rate meter. The readout is normally in counts per minute, and with a good, high purity, large crystal system, 80% efficiency can be achieved. Thus, on a device with one microcurie of krypton within the part, approximately 8,000 counts per minute of direct gamma emission would be registered. There is a secondary emission, however, that is produced within the device due to the Bremstrahlung. This causes a secondary emission as gamma rays that are, in turn, registered in the crystal system. These complement the original gamma impulse, and a total of approximately 15,000 counts per minute per microcurie is measured by the crystal.

In as much as 99+% of the emissions from krypton-85 are beta particles, it is easy to see how the Radiflo process can detect krypton-85 trapped on the surface of a part. This is done with a beta detector or a surface counter. In the event the devices have been etched or surface porosity is extremely high in the ceramic, the Radiflo process quickly differentiates this surface beta emission from a leaky device where the krypton is trapped within a cavity and only the gamma rays are capable of penetrating the walls of that part.

The number of disintegrations per second ($-\frac{dn}{dt}$) that occur in 1 atmosphere cc of krypton-85 is related to the half life ($T^{1/2}$) of Kr-85 and to the number of Kr-85 atoms in one atmosphere cc (N)

$$-\frac{\frac{dn}{dt}}{N} = \left(\frac{0.693}{T^{1/2}}\right)$$

where $T^{1/2}$ = 10.5 years = 3.3×10^8 seconds.

<u>Assume</u>: A sample with 110 Kc/m = 1833 c/second with an 80% crystal counting efficiency = 1467 c/s; only 57% of the Gamma rays detected are directly from Kr-85 disintegration. Thus, 1467 x .57 = 836.2 c/s. Only 0.46% of the disintegrations of Kr-85 produce a gamma ray. Thus, 836.2 ÷ 0.0046 = 181,780 disintegrations/second. One microcurie of Kr-85 produces 3.7×10^4 disintegrations/second. Therefore, $18.178 \times 10^4 \div 3.7 \times 10^4$ = 4.9 microcuries of Kr-85.

Using the above equation, $N = \frac{1.817 \times 10^5 \text{ dis/sec.} \times (3.3 \times 10^8 \text{ sec})}{0.693} = 8.7 \times 10^{13}$ molecules of Kr-85 within the device. The volume of the cavity is f 0.02 cc = 0.02 atm cc = 4.92×10^{17} molecules.

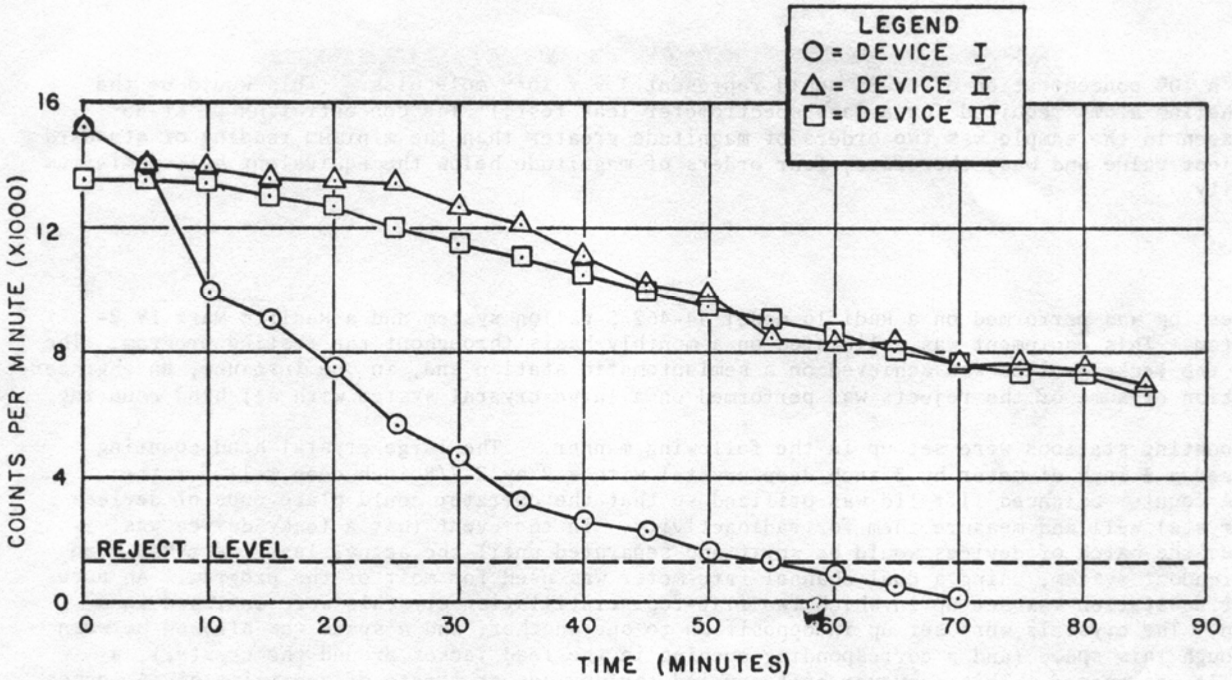

Fig. 2. Radiation decay versus time for DIPS after gross leak test.

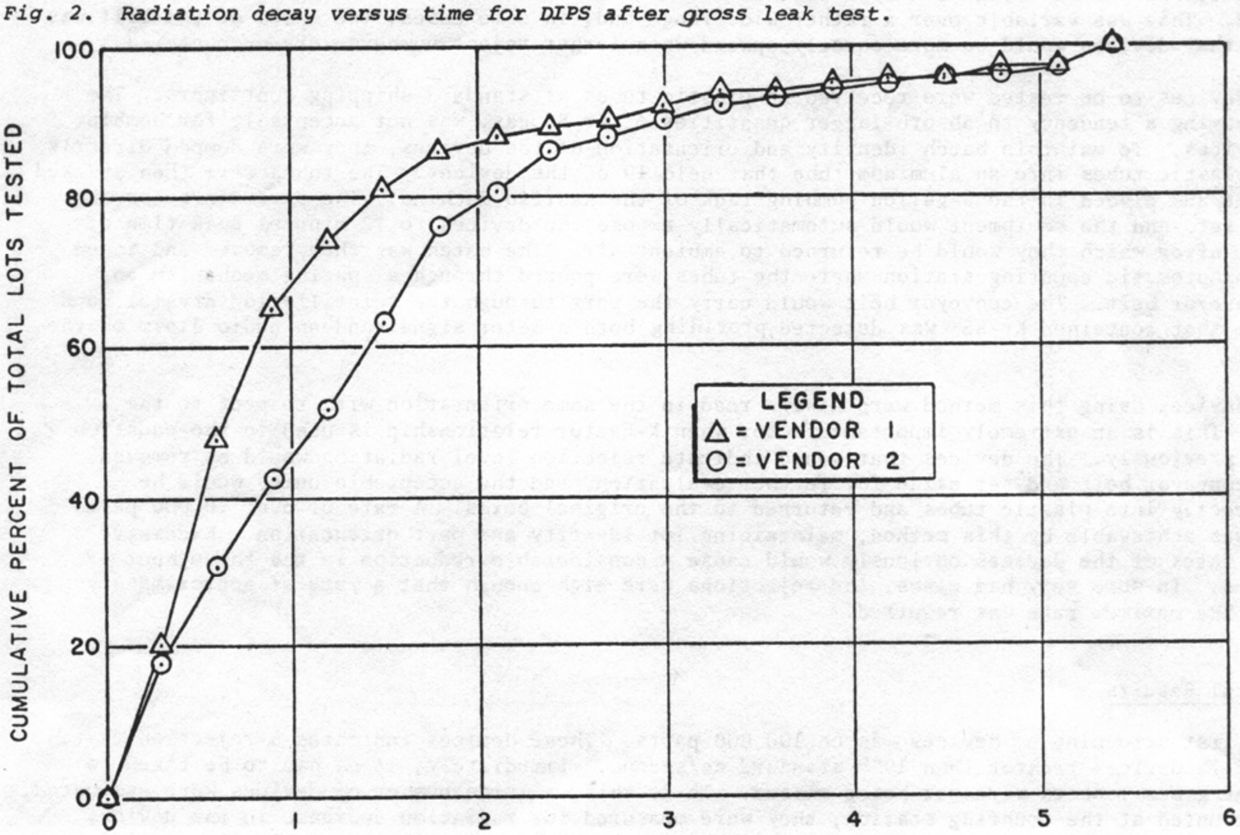

Fig. 3. Cumulative percent of lots exhibiting lot percent defective less than or equal to the indicated percent.

Therefore, a 10% concentration of Kr-85 would represent 4.9×10^{16} molecules. (This would be the number of helium atoms required for a mass spectrometer leak test.) The concentration of Kr-85 molecules seen in the sample was two orders of magnitude greater than the minimum reading or standard Radiflo reject value and was, therefore, four orders of magnitude below the equivalent helium minimum detectability.

Equipment

The testing was performed on a Radiflo model 44-462 5-gallon system and a Radiflo Mark IV 2-gallon system. This equipment was calibrated on a monthly basis throughout the testing program. The readout of the leaky devices was achieved on a semiautomatic station and, in one instance, an engineering evaluation of some of the rejects was performed on a large crystal system with all hand counting.

The counting stations were set up in the following manner. The large crystal hand counting stations used a 3 inch diameter by 3 inch deep crystal with a 2 by 2-7/8 inch deep well for the devices. A counter-balanced lift lid was utilized so that the operator could place cups of devices into the crystal well and measure them for radioactivity. In the event that a leaky device was encountered, the batch of devices would be split and separated until the actual leaky part had been found. A readout system, using a dual-channel rate meter was used for most of the program. An automatic counting station was set up in which two flat-top scintillation crystals were enclosed in a lead column. The crystals were set up in opposition to one another, and a space was allowed between them. Through this space (and a corresponding opening in the lead jacket around the crystal), a conveyor belt was passed. This conveyor belt carried the devices at a rate of approximately 4 inches per second. This was variable over a rather wide range and, in some cases, the speed of the belt was varied so that devices would be more equally spaced when larger reject numbers were encountered.

The devices to be tested were received in plastic tubes as standard shipping containers. The plastic, having a tendency to absorb larger quantities of Kr-85 gas, was not acceptable for bombing of the devices. To maintain batch identity and orientation of the devices, they were dumped directly from the plastic tubes into an aluminum tube that held 19 of the devices. The tubes were then stacked in a basket and placed in the 5-gallon bombing tank of the Radiflo machine. The parameters for the test were set, and the equipment would automatically expose the devices to 12 minutes soak time of KR-85 gas, after which they would be returned to ambient air. The batch was then removed and taken to the semiautomatic counting station where the tubes were poured through a spacing mechanism and onto a conveyor belt. The conveyor belt would carry the part through the scintillation crystal, and any device that contained Kr-85 was detected,providing both a meter signal and an audio alarm on the rate meter.

The devices using this method were always read in the same orientation with respect to the crystals. This is an extremely important factor when K-Factor relationship is used in the equation mentioned previously. The devices that would indicate rejection level radiation would be removed from the conveyor belt and set aside for further evaluation, and the acceptable units would be placed directly into plastic tubes and returned to the original boxes. A rate of over 10,000 parts per hour was achievable by this method, maintaining lot identity and part orientation. Excessive rejection rates of the devices obviously would cause a considerable reduction in the throughput of the devices. In some very bad cases, the rejections were high enough that a rate of approximately one-third the maximum rate was required.

Experimental Results

The first screening of devices was on 100,000 parts. These devices indicated a rejection that averaged 2.7% devices greater than 10-6 standard cc/second. Immediately, steps had to be taken to assure that gross leakers were not being missed. To do this, a large number of devices were evaluated,

and when counted at the counting station, they were measured for radiation decrease in the devices and plotted as a function of time. Some of these results are shown in Fig. 2. It is interesting to note that the plot of the three devices (which were selected from a large number of rejects) shows two devices that are of molecular flow type leakage and one device of viscous flow. These particular plots were chosen in order to display the fact that a gross leak device will increase in internal pressure during bombing as an exponential function. It will also return to ambient in the same manner. The molecular flow or smaller leak rate device follows a theory of pressure change directly as a function of time and a linear plot is thus obtained. These are good examples of this type of behavior.

Interestingly enough, the viscous flow leak rate device was demonstrated to be a bubble type leaker. This device in the gross leak rate range could be seen to bubble when immersed in hot water immediately'after bombing. A safe limit was thereby determined of 55 minutes during which time the devices could be read out after removal from the Radiflo machine. To add safety to the test, a maximum of 30 minutes was normally allowed. Many other devices were broken in half through the chip cavity. This was done after the devices were read. They were immediately returned to the crystal cavity, and evidence of krypton loss was a demonstration of krypton trapping within the cavity itself. Prior to this type of fracturing, the devices were viewed through a small window in a lead plate that covered a scintillation crystal. Through scanning of the body of the DIP, it was demonstrated that the krypton gas was trapped within the cavity zone and not peripherally in the glass itself. A matter of one or two seconds is all that is required for the Kr-85 to be totally lost from within the cavity, if it were there initially. This is a constant concern, since it has been demonstrated that cavities in the glass base can cause rejections that are not true cavity leakers.

A review of Fig. 3 shows the lot quality on a cumulative basis when comparing the major manufacturers of the dual in-line packages tested. It is interesting to note that there is strong similarity between the manufacturers until approximately 20% of all devices evaluated is reached. From this

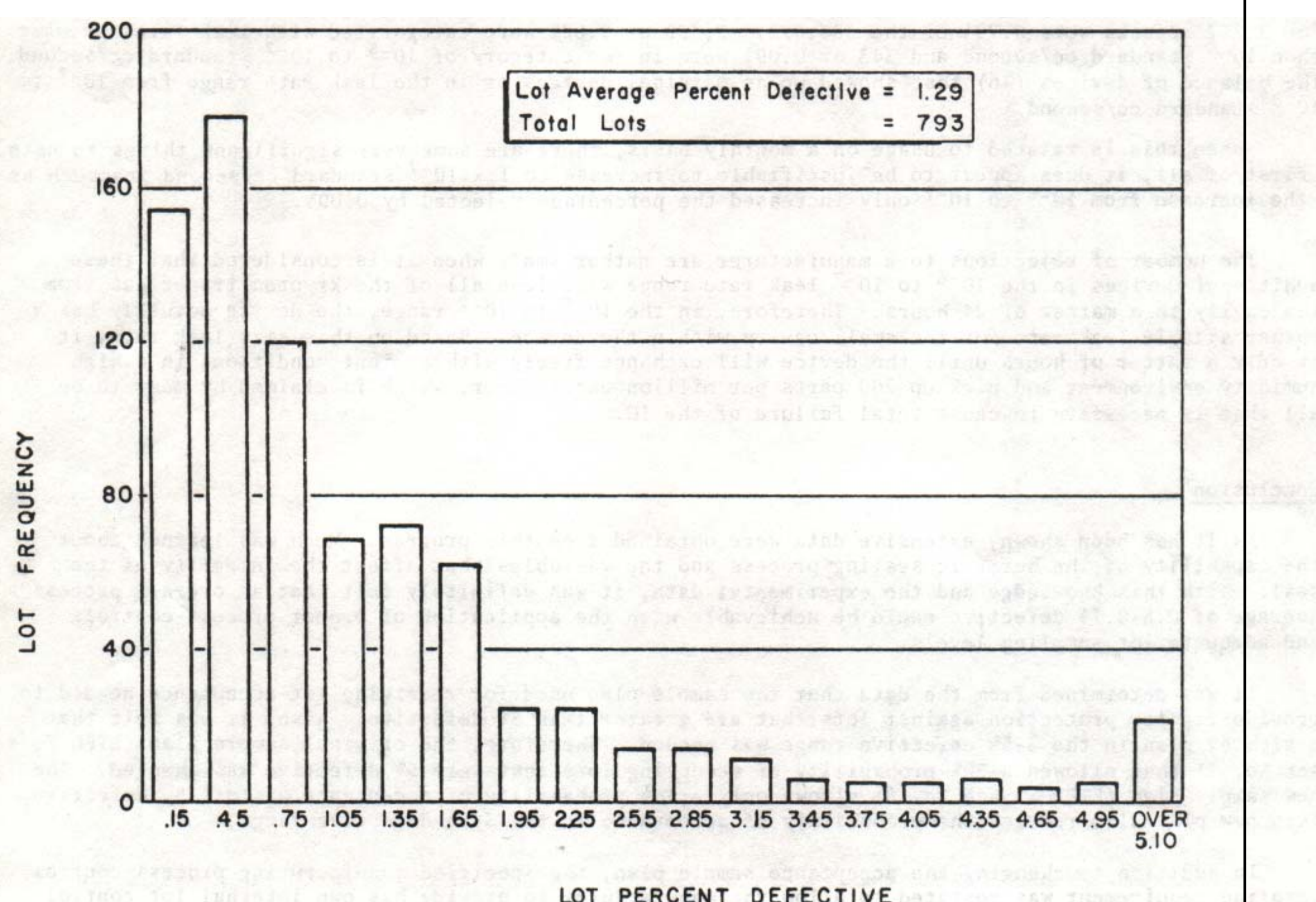

Fig. 4. Histogram of lot percent defective.

point until approximately 85% of all devices evaluated, there is a very definite difference that proved to be variations in the respective sealing process variables, such as sealing furnace temperature and belt speed, glass tape purity and ceramic porosity.

Figure 4 shows the histogram of the lot percent defective when plotting the lot frequency versus the lot percent defective for the same devices with the total of 793 lots being evaluated. Whereas the average lot percent defective is 1.29%, it should be noted that this average is weighted due to 20 plus lots that were over 5.1% defective, one as high as 18%. This weighting effect is evident in the lot average percent defective, due to the fact that more than 50% of the lots were less than 0.75% defective, and more than 85% of the lots were less than 1.95% defective.

Figure 5 shows the plot of the average percent defective for two vendors on a calendar basis throughout the program. It is important to note that the extreme deviation that occurs with the manufacturers was due to process and material variability, respectively, and that without proper control, these deviations can occur on an instantaneous basis.

In addition to evaluating the IC seal process capability, the difference in percent rejection at two different seal leak rate levels was also evaluated. The rejects from screening 380,073 devices at 10^{-6} totaled 2,727. These 2,727 devices were then categorized under an engineering screening program to establish how many of the devices were greater than 10^{-6} and how many of the devices fell into the category from 10^{-6} to 10^{-7} standard cc/second (air). The objective here was to determine whether it was appropriate and justifiable to tighten the leak rate specification from 1×10^{-6} to 1×10^{-7}. The 2,727 rejects were 0.72% of the 380,073. 2,338 or 0.62% were categorized with leak rates greater than 10^{-6} standard cc/second and 343 or 0.09% were in the category of 10^{-6} to 10^{-7} standard cc/second. The balance of devices (46) that showed up as marginal devices or in the leak rate range from 10^{-7} to 10^{-8} standard cc/second.

When this is related to usage on a monthly basis, there are some very significant things to note. First of all, it does appear to be justifiable to increase to 1×10^{-7} standard cc/second inasmuch as the increase from 10^{-6} to 10^{-7} only increased the percentage rejected by 0.09%.

The number of rejections to a manufacturer are rather small when it is considered that these additional devices in the 10^{-6} to 10^{-7} leak rate range will lose all of the krypton tracer gas from the cavity in a matter of 24 hours. Therefore, in the 10^{-6} to 10^{-7} range, the device actually has a rather sizable leak rate for the small cavity within the device. Based on this size leak rate, it is only a matter of hours until the device will exchange freely with ambient conditions in a high humidity environment and pick up 200 parts per million water vapor, which is claimed by many to be all that is necessary to cause total failure of the IC.

Conclusion

As it has been shown, extensive data were obtained from this program. Much was learned about the capability of the hermetic sealing process and the variables that affect the integrity of the seal. With this knowledge and the experimental data, it was definitely felt that an overall process average of O.5-0.7% defective could be achievable with the application of proper process controls and adequate lot sampling levels.

It was determined from the data that the sample plan used for receiving lot acceptance needed to provide tighter protection against lots that are greater than 5% defective. Also, it was felt that a tighter plan in the 3-5% defective range was needed. Therefore, the original sample plan (LTPD 7, acc No. 1) that allowed a 30% probability of accepting lots that were 5% defective was changed. The new sample plan (LTPD 5, acc No. 8) allows only a 10% probability of acceptance of lots 5% defective. This new plan also reduces the probability of acceptance in the 3-5% defective range.

In addition to changing the acceptance sample plan, the specified manufacturing process control sampling requirement was restated to allow the manufacturer to provide his own internal lot control at his option, as long as his lots passed the users' receiving acceptance sample plan. This was done to allow the manufacturer to have the internal freedom he needs to control his sealing process at the level that he knows can be achieved, for he knows his process best.

A further result of this extensive program and the resultant data was the decision to tighten the limit for allowable leak rate. The leak rate was changed from 1×10^{-6} atmospheric cc/second (air) to 1×10^{-7}. This was done for two reasons 1) to get below the gray area, much in dispute, where the transition between viscous and molecular flow occurs and 2) to reduce the size leak rate allowable, thereby reducing the IC failure rate. This change was not felt to be of economic handicap to the vendors, since the experimental data did not show a significant yield loss at the tighter limit.

The final conclusion derived from this program was that a follow-on program should be initiated to study the process and use environments effects on IC's of known but varying seal leak rates. It is felt that this study would provide the data required to establish more meaningful leak rate limits related to IC failures for devices processed and used in various configurations and end uses.

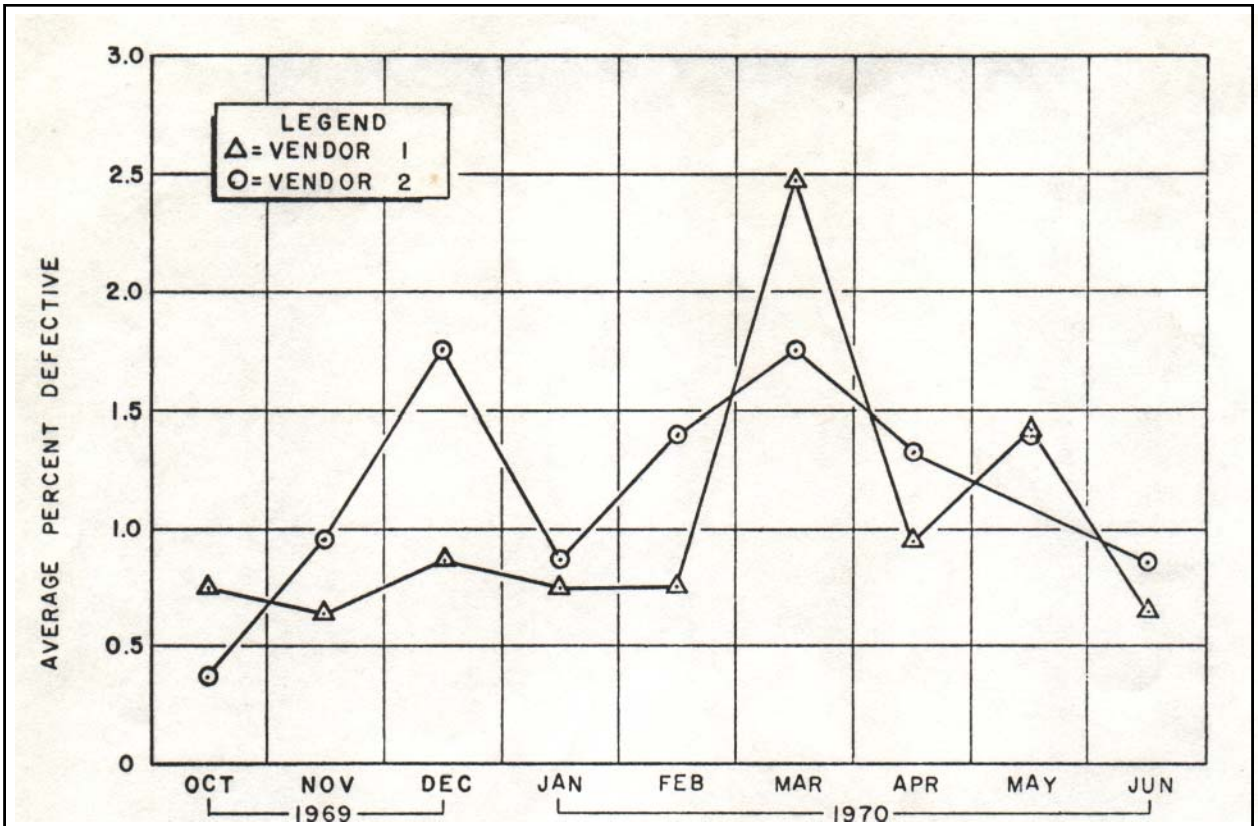

Fig. 5. Lot quality by month

Robert L. Stewart is Manager of the Quality Engineering Department at Burroughs Corp., Medium Systems Plant. He is responsible for the quality engineering activities involved in the production of the B-3500 computer system.

George R. Neff is Technical Director of IsoVac Engineering Inc., which he founded two years ago. The company manufactures Radiflo leak detection equipment and provides leak test service and engineering facilities.
WORLD MARKETING Weatherman Enterprises 1297 Logan St. Costa Mesa, Calif. 92626 714-557-8922