MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 00089 7318

LIBRARY
Michigan State
University

This is to certify that the

thesis entitled

THE DESIGN OF AN INDUSTRIAL SHIPPING CONTAINER: A PRACTICAL APPROACH

presented by

Terry Michele Ciccaglione

has been accepted towards fulfillment
of the requirements for

B.S. degree in Packaging

Jack R. Giacin

Jack R. Giacin, Ph.D.

Major professor

Date November 15, 1985

O-7639

MSU is an Affirmative Action/Equal Opportunity Institution

MSU
LIBRARIES

RETURNING MATERIALS:
Place in book drop to remove this checkout from your record. FINES will be charged if book is returned after the date stamped below.

APR 1 6

NOV 0 2

MAR 0 1

THE DESIGN OF AN INDUSTRIAL SHIPPING CONTAINER: A PRACTICAL APPROACH

By

Terry Michele Ciccaglione

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

School of Packaging

1985

ABSTRACT

THE DESIGN OF AN INDUSTIAL SHIPPING
CONTAINER: A PRACTICAL APPROACH

By

Terry Michele Ciccaglione

Utilizing the example of designing a packaging system for a circuit board used in an International Business Machine's mainframe computer, a logical design sequence was established for industrial shipping container design.

DEDICATION

This thesis is dedicated to my wife, my parents and my mother, Elizabeth, whose spirit will live forever.

The a

thes

and

and

lear

vibr

desi

tests

years

on th

Brews

Proje

the t

ACKNOWLEDGEMENTS

The author would like to thank the following:

Dr. Jack Giacin for his guidance in writing the thesis, allowing me to delve into his areas of expertise, and keeping the lines of communication open between myself and Michigan State.

Dr. Julian Lee and George Nikolsky for helping me learn and understand more about the theory of shock and vibration.

Dr. Joe Kuszai for turning me on to the world of design and being a friend.

Bob Drake who helped perform the shock and vibration tests on the packaged product.

Hank Stingel (my engineering mentor for the last few years), Eric Straus and Tim Bender for their collaboration on the design of the subject packaging system.

The current management team, George Franke and Tom Brewster, for alotting me time at work to complete this project.

John Zachos for his help with the artwork used in the thesis.

TABLE OF CONTENTS

MAI

ESTI

CLOS

RECO

APPE

APPE

APPE

REFE

Tab

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

LIST OF TABLES

LIST OF FIGURES

14

15

16

17

18

19

20.

21.

22.

23.

24.

25.

26.

27

28

29

30

31

32,

int
des
pro
its
env
eng

INTRODUCTION

The design of a packaging system, although partially intuitive, is best accomplished by following a logical design sequence. Although the primary focus is on the product itself, it is the relationship of this product with its package and of the packaged product with its external environment that is the crucial focus of the packaging engineer.

LOGICAL DESIGN SEQUENCE

1. Understanding the product
2. Examine the external environment
3. Packaging system style and material review
4. Prototype construction
5. Experimental/Data Compilation
6. Engineering Analysis of Data and Redesign
7. Implementation
8. Maintaining quality assurance at the Vendor
9. Establish a refurbishing program (if the system is reuseable)

PHYS

in

Its

wei

at

REL

sen

for

SHO

eng

and

to

cir

sho

1)

VIB

dir

vib

whi

boa

tes

tes

UNDERSTANDING THE PRODUCT

PHYSICAL/PRODUCTION CHARACTERISTICS

In this study the product was a circuit board used in an International Business Machines mainframe computer. Its external dimensions were 700 mm x 610 mm X 25 mm with a weight of 28.58 kg. The board was produced totally in-house at a rate of 20 boards/day and a cost of $50,000/board.

RELATIVE HUMIDITY FRAGILITY

The product, composed of electrical circuits, is sensistive to relative humidity above 50 % (M.S. HTOO, 1980) for any length of time while in it's package.

SHOCK FRAGILITY

Shock fragility testing, conducted by product engineering, was performed on the circuit board in the x, y and z axes. In each axis the mode of damage was considered to be relative movement of the power buss attached to the circuit board. To illustrate the product's fragility to shock in the x,y and z axes, a damage boundary curve (Figure 1) has been constructed using product engineering test data.

VIBRATION CHARACTERISTICS

The natural frequency (Fc) of the board in the z direction is 90 Hz. This was determined by a sinusoidal vibration sweep from 5-500 Hz @ 0.5 G input to the product which was fixtured to a vibration platten. To establish the board's fragility to vibration, if any, a sinusoidal dwell test was performed on the board by product engineering. The test was run at 90 Hz @ 0.4 G input for 30 minutes. The G

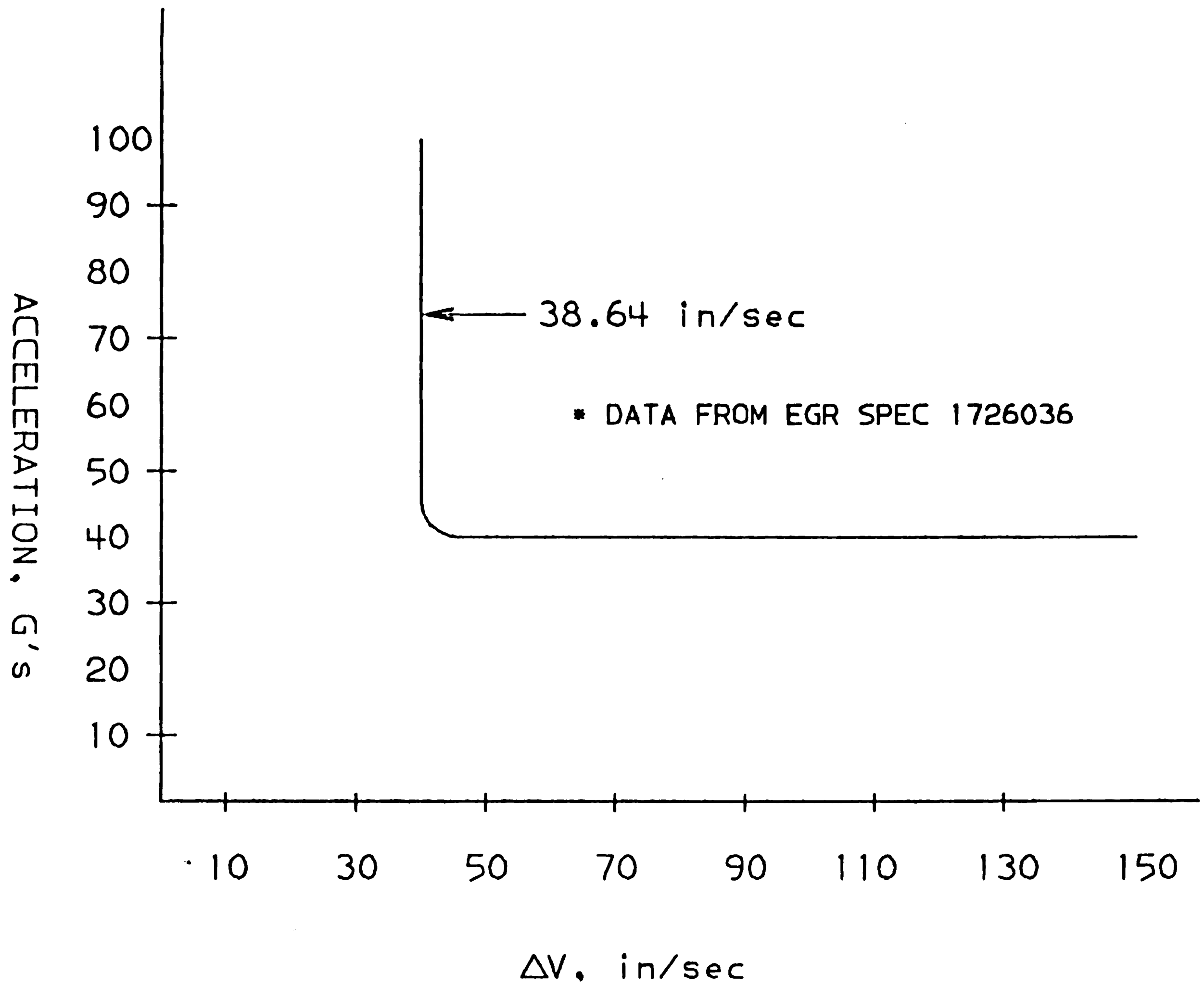


FIGURE 1. DAMAGE BOUNDARY CURVE FOR THE BOARD ASM (X,Y and Z AXES)*

V
d
r
d
d
ir
fr
pa
Te

y
low
vib
to
in

frag
thes
test
ELECT

elect
stati
packag

response values, from accelerometers placed on the board, varied from 7.7 G's to 13.7 G's. No mechanical or electrical damage was observed by product engineering due to the above responses. Even though there was no observable damage during this dwell test, over an extended period of time in distribution, the product could possibly see damage due to input vibration in this axis. Therefore, the natural frequency of the product in the z axis was considered in the packaging system's design (see section on Vibration Testing).

The natural frequencies of the product in the x and y direction were so high and the resulting displacement so low that these two axes weren't considered fragile to input vibration. Therefore, information on the board's response to vibration in the x and y axes was not considered crucial in the packaging system's design.

Although no information existed on the board's fragility to random vibration, as a follow up study to this thesis, both the product and the packaged product should be tested using random vibration.

ELECTROSTATIC DISCHARGE

The product was not considered to be susceptible to electrostatic discharge damage. Therefore, no conductive, static dissipative or anti-stat materials were used in the packaging system's design.

CORROSION

The product's susceptiblity to corrosion, because of corrosive volatiles, was a major concern in the system's design. Plastics containing halogen groups, such as polyvinylchloride, were therefore not considered. In addition, paper based products were not considered in the system's design. This was due to the possibilty of outgassing of sulphur, which is used to pulp the paper during manufacture. Any plastics that were used in the design were tested for organic and inorganic volatiles using the hot jar method with analysis by a gas chromatograph/mass spectrometer (A.S.T.M F-151, 1972).

EXAMINING THE EXTERNAL ENVIRONMENT

The packaging system was designed to package the circuit board from the end of the manufacturing line (E.O.L.) for distribution to either new systems being built or to a customer location (as a spare part). To better understand this, a flow chart of the packaged part's movement through the distribution environment was constructed and presented in Figure 2.

```
                                  |---► new systems build
                                  |       (via truck)
E.O.L.--► in-house stocking--►|
                                  |
                                  |---► customer accounts
                                         (via truck/air)
```

Figure 2. Flow Chart of the Circuit Board's Distribution

In-house, the package was designed to be moved by itself, either palletized (then moved by fork lift or pallet jack) or in a specialized cart (holding a maximum of five cases). Outside the production environment, the system's predominant mode of distribution was by truck. However, the packaging system was also designed to withstand handling via air and rail distribution.

Storage duration of the circuit boards, in the packaging system, in-house was about one month. In the field (off site storage locations) the average storage duration was about two years. Both in-house and in the field storage conditions varied from controlled environments (temperature and relative humidity) to uncontrolled environments. The above information established a target of two years for the shelf life of the product in the packaging system.

PACKAGING SYSTEM STYLE AND MATERIAL REVIEW

The initial design of the packaging system was segmented into two parts. The design of the outer case and the design of the internal cushioning/holding system.

Two methods of manufacturing the outer case were explored. The first was rotary molding and the second was vacuum forming. Both methods could give production volumes needed to keep up with product production. In addition, a wide range of high impact materials could be used with the above manufacturing methods. The benefit of rotary molding was that part tolerances could be closely held and scrap would be kept to a minimum. Unfortunately, the cost of the mold (about $25,000 for a rotary mold versus $5,000 for a vacuum form mold) and debuging the processing of the part in the mold would be greater in rotary molding versus vacuum forming. Based on these considerations and because of the time constraints placed on the design group, it was decided to develop the vacuum formed method for production of the outer case.

OUTER CASE DESIGN

The design requirements established for the outer case are as follows:

1. Case separates into two equal halves
2. Ergonomically designed handles in the bottom tray
3. Casters (two fixed and two swivel)
4. View ports (used to view part number information of the product)
5. Stackable
6. Paperwork holder (for packaging instructions)
7. Magnetic card holder (for inventory control)
8. Information labels
9. Aluminum valence (structural integrity/hermetic seal)
10. Security catches
11. Shock bumps
12. High impact plastic for outer case
13. Pressure relief valve
14. Serial number for each case
15. Shipability at extreme temperatures ($-40^{\circ}C$ to $60^{\circ}C$)

Since the packaging system was to be used by customer engineers in the field, the first feature of the outer case was to have it made up of two equal and separable halves. A schematic design of the proposed packaging system is presented in Figure 3.

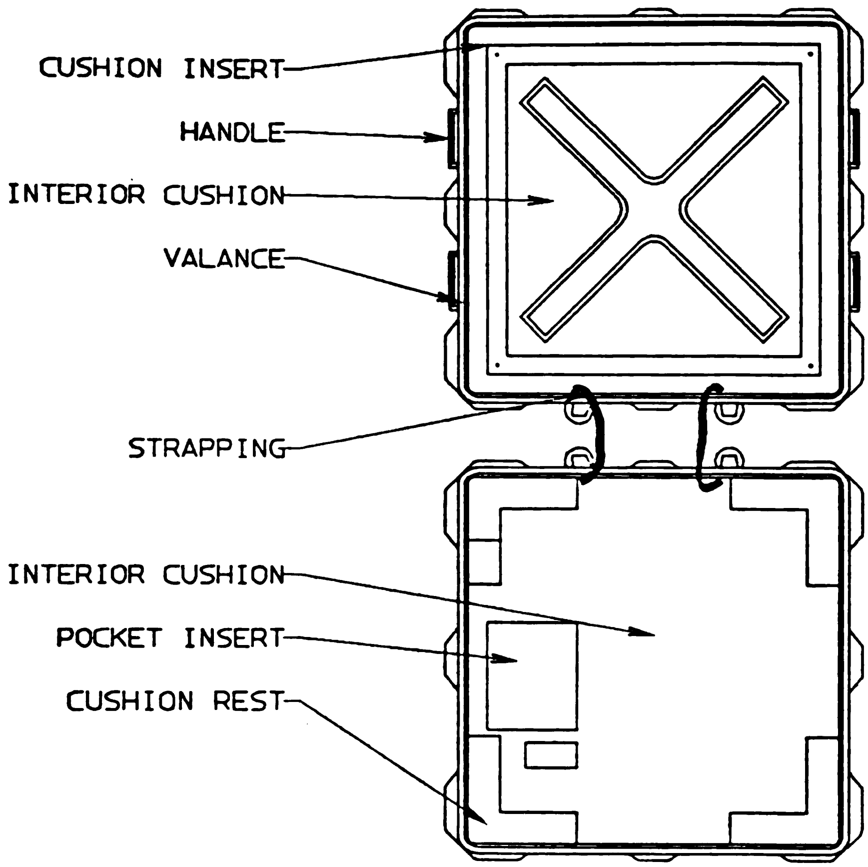


Figure 3. Top View of the Packaging System for the I.B.M. Circuit Board.

The rationale for this design was that in the field, when a board is replaced, the old board could be placed in the top half of the shipping case, then the new board could be placed into the frame. In essence, the case acts as a tool for the customer engineer. Another reason for having the case separable was the packaging operation at the end of the manufacturing line. This operation involved placing the finished board into the tray portion of the case. Having the case separate into two equal halves made handling less cumbersome. Also, if the board and the tray needed to be lifted, the product/package system would still be below safe lifting limits (27.22 kgs/person) for a manual lift.

The retractable handles (one handle/hand) were placed in the tray portion of the case. They were designed to lock in the horizontal position only if the case/tray is lifted in the correct orientation. This feature safely protects the person handling the case from pinching their fingers as well as preventing the product from being picked up in the wrong orientation and dropped (see Figure 4).

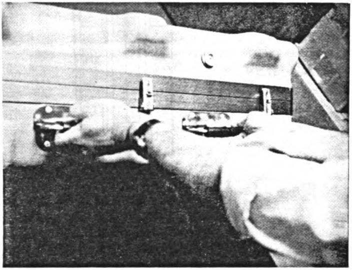


Figure 4. Retractable Handles in the Bottom Tray of the Outer Case

In addition to the locking feature of the handle, a large grip was used (20 mm diameter) to ease hand strain of a person handling the case for an extended amount of time (E. Grandjean, 1981). A .0003" thick zinc chromate finish was used on the cold rolled steel handle to protect it from oxidation.

To aid in moving the upright case, a set of four casters were added. To provide control of the case when it was being pushed, two of the casters were fixed and two were swivel. An illustration of the caster assembly is shown in Figure 5.

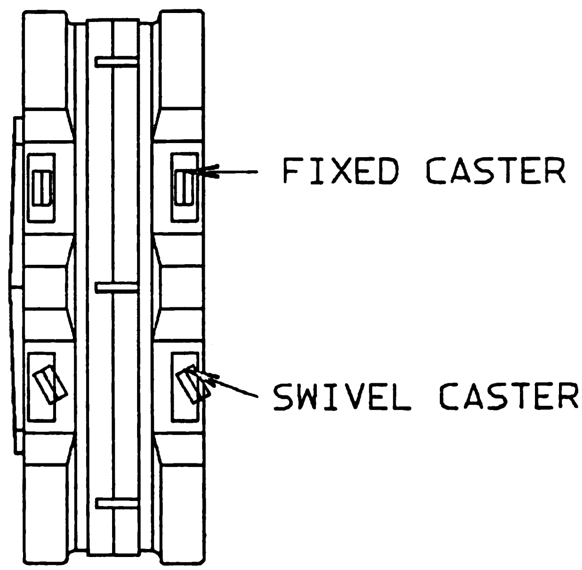


Figure 5. View of the Caster Arrangement on the Packaging System

In designing the shipping case, shock bumps were formed directly in the case, thus allowing an operator to grab and move the case. This configuration of casters and gripping bumps provided a packaging system that could be wheeled around in-house or into a customer's office with greater ease.

View ports were also needed for board shipments that required a customs inspection. Because of this there are two ports per case. One to view through, the other to shine a flashlight through to illuminate the information being viewed. The view ports incorporated into the design of the shipp

Figure
System

cover
additio
.15 " p
seal in

shippin
had a 9
9.53 mm
minimum
sharper
greater
the load.

T
informati

shipping case are represented schematically in Figure 6.

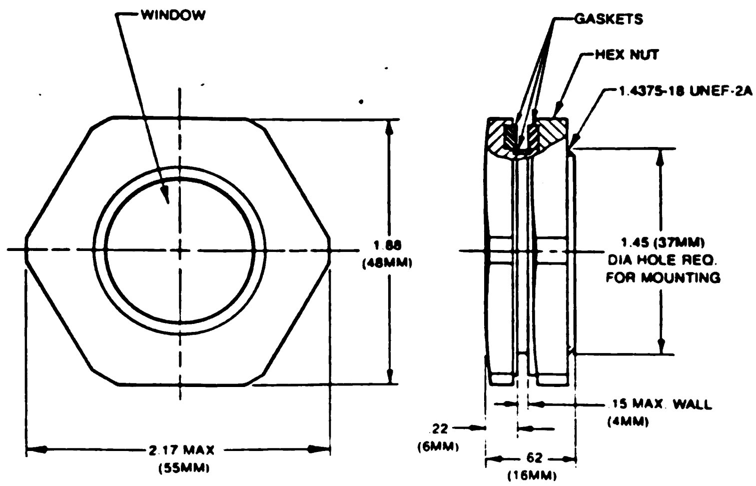


Figure 6. Schematic of the View Ports used in the Packaging System

Both ports are located in a recessed area in the cover of the case which protects them from damage. In addition to this the construction of the view port, using a .15 " polycarbonate lens with gaskets, helps maintain the seal integrity of the case.

Stackability was another design feature of the outer shipping case. For the prototype design, the tray portion had a 9.53 mm deep concave stacking "X" while the cover had 9.53 mm high convex stacking "X". Radii were kept to a minimum on these X's. The reason for this is that the sharper the breaks and the deeper the stacking feature, the greater the amount of shear force that is needed to topple the load.

The paperwork holder was designed to hold information printed on 8.5" x 11.0 " paper. Like the view ports, the paperwork holder nests inside a recessed area to protect it from being damaged in transit. The envelope, made from polyvinylchloride, has a clear face. This aids in reading any information contained in the pouch. The backing of the holder is a heavier gauge polyvinylchloride laced with fiberglass filaments. It is white and opaque. The paperwork holder can be removed from the case and be used as a shop traveler. Paperwork kept in the pouch is held in by a flap with two snaps.

At the end of the manufacturing line each board is identified not only by human readable alpha-numeric data but also magnetically encoded data. Thus, an exterior magnetic card holder is needed. The card itself is approximately 125 mm x 80 mm with a 10 mm wide magnetic stripe on one face of the card.

The magnetic card holder, which is permanently attached to the case, is placed on the side of the case as shown in Figure 7.

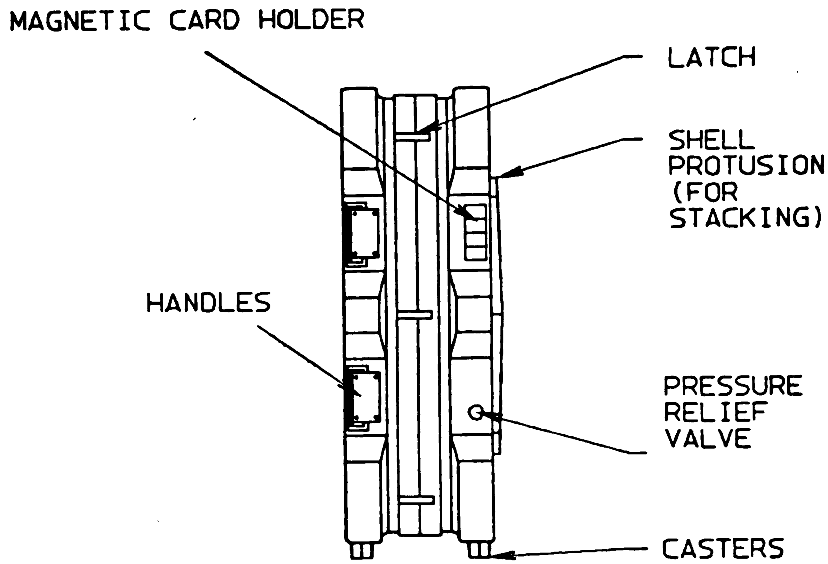


Figure 7. End View of the Case

One interesting feature of the magnetic card holder design is that the card holder must have a cut out portion where the magnetic stripe is in order for the magnetic wand to be able to read the information contained on the stripe. Based on discussions with personnel who design the wands, the maximum thickness a wand could read through is about 2.5 mils.

In most cases warning or direction labels, placed on a packaging system, are ignored. This is fairly evident by looking at how incoming product is treated on a receiving dock. However, in this example the combination of the physical configuration of the packaging system, as in caster or handle location, and the graphic design of the labels should lend to proper handling of the shipping container.

In general, when designing information labels there should be only a few major ideas to be conveyed to the person handling the packaging system. For example, things such as the weight of the packaged product, its fragilty to moisture or shock and the correct orientation to ship or open the packaging system. Since the package was to be shipped world-wide, international handling symbols (Figure 8) such as the style established in the I.B.M. design guide were used.

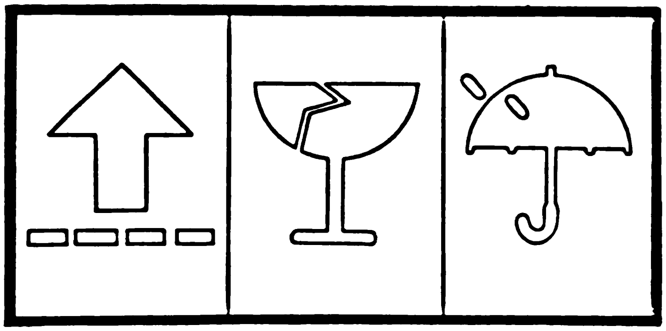


Figure 8. I.B.M. International Handling Symbol Designating This Side Up / Fragile / Moisture Sensitive

Color identification is also an option. Although the human eye is most susceptible to green (International Paper Co., 1981), because of socialization, other colors such as yellow for caution or red for danger were considered more appropriate in catching the attention of a person handling a package. In this particular packaging system the outer case was Pantone Blue 285, I.B.M.'s big blue image reinforced in it's packaging system design.

Using bold face type is another way to communicate a message. First, the message communicated is more legible but it also means PAY ATTENTION TO THIS. In essence increasing the density of the character, while maintaining resolution, increases the amount of electrical impulses to the brain which controls recognition of symbols.

One of the critical elements of the design was the requirement of the package to maintain a low humidity environment for the moisture sensitive product contained. This environment would be maintained by the barrier established by the outer case. Part of this barrier would be provided by the case material and more importantly by the case's closure. Both the vacuum formed and rotary molded style of case would have a closure system comprised of a bezel with a gasket that is held closed by catches. One of the advantages of the rotary molded case would be that the bezel could be molded as part of the case with a gasket and catches added to complete the seal. However, with the vacuum formed style, an aluminum valence had to be added to the tray and cover portions of the case. From the side view of the valence, as shown in Figure 9, it can be seen that the male portion of the valence is attached to the tray portion of the case while the o-ring gasket is in the female portion of the valence and is attached to the cover of the case.

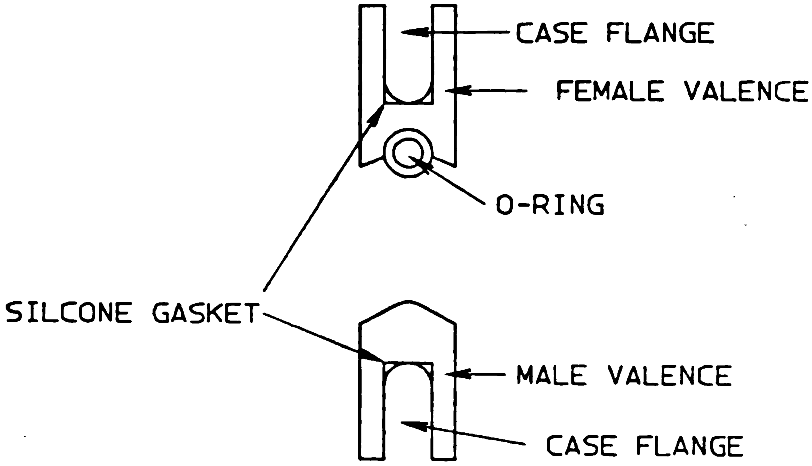


Figure 9. Cross Sectional View of the Outer Case Closure

The o-ring material is a 55 durometer silicone rubber that has a 2.5 mm wall thickness. The male valence locates into the o-ring creating the seal. The valences are sealed to the case using a silicone rubber gasket and crimped along the flange of the tray and cover. Although no other type of material was used in the o-ring, the wall thickness was increased from 1.5 mm to its present 2.5 mm and, as described in the experimental portion of this thesis, gave the seal needed to achieve the required shelf life.

Another function of a bezel or valence is its contribution to the structural strength of the outer case. This would stand to reason, since the torsional stiffness of the aluminum used in the valence is about 10 times greater than the sheet stock used in the vacuum formed case (Measurements Group, 1979). The valence also served as an anchor for the security catches used in the outer case.

In any closure system, and particularly in an industrial application, durabilty and repeatability are key requirements. The catches used in the outer case, three per side, complete the closure system in the case per Figure 10.

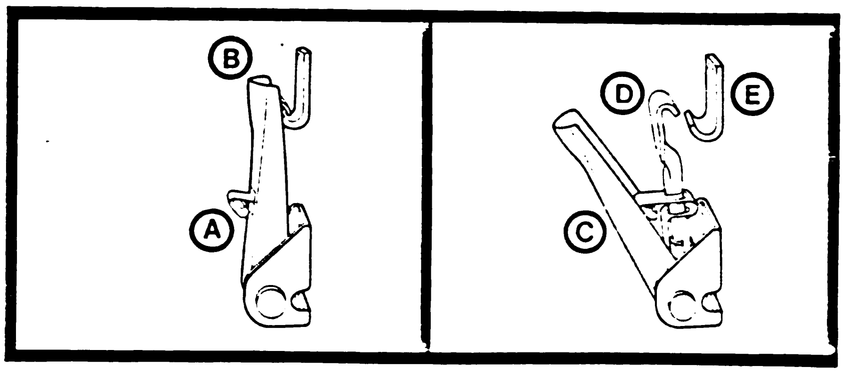


Figure 10. Locking Clip Catches used on the Outer Case

As shown, the catches have a single strike with a locking clip that keeps the latch from popping open. This locking clip is also used as the security portion of the catch.

In the packaging industry there are a number of ways to make a closure tamper evident. In this design review, the types of tamper evident closures examined were as follows:

1. Destructible tape
2. Destructible plastic lock
3. Closure label w/ removeable graphics
4. Wire with a lead seal

With options 1 and 3, once the tape or label is removed, the case would have to be cleaned, which would add to the rework cost. With option 4, a special crimp tool would have to be used when crimping the lead seal on the wire. The method we chose was a destructible lock, where the lock fits through the locking clip on the catch and, once closed, the only way to remove it would be to break the shackel of the lock (per Figure 11). Thus, the catches performed the service of closing the outer case and as a security seal.

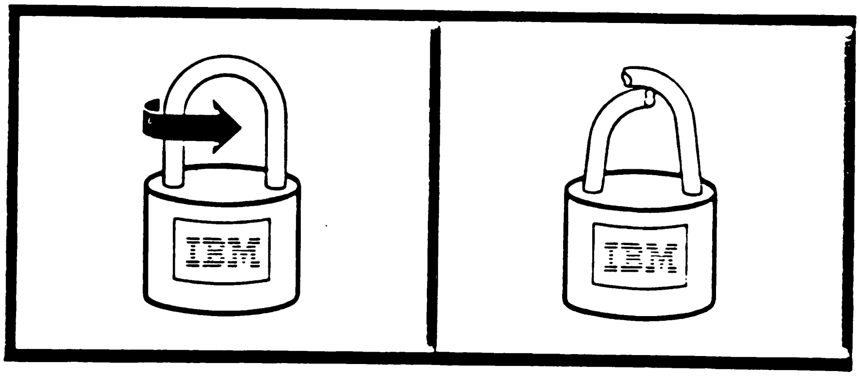


Figure 11. Breaking Mode of the Shackel on the Plastic Lock

Because of the products fragility to shock, shock attenuation bumps were added to the outer case. This is shown schematically in Figure 12.

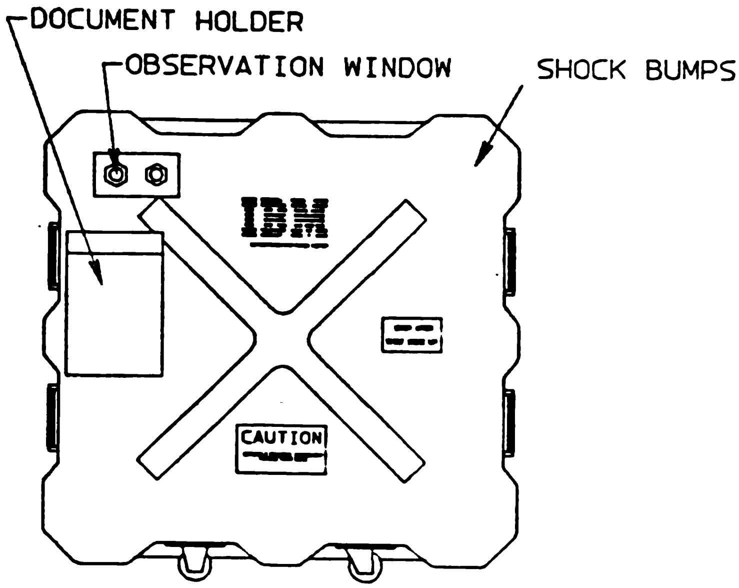


Figure 12. Shock Attenuation Bumps Located on the Outer Case

These shock bumps also added some structural rigidity to the case and provided an area to grasp and move the case. Actually, it was found that shock bumps, added to the corners of the case, decreased the amount of shock directly into the product.

In the material review for the packaging system, it was discovered that there are a limited number of polymers that can be used in the fabrication of an industrial shipping container. The general catagories are: homopolymers, copolymers and polymeric blends (summarized below).

HOMOPOLYMERS

High Density Polyethylene (H.D.P.E.)
Polypropylene
Polystyrene

COPOLYMERS

Acrylonitrile-Butadiene-Styrene (A.B.S)

POLYMERIC BLENDS

Polyethlene/Polypropylene*
Polypropylene/Ethylvinylacetate (E.V.A.)
Polypropylene/Butyl Rubber

* an 80/20 ratio should be used

The homopolymers, copolymers, and polymer blends listed above can be extruded into sheet stock for thermoforming or used as a resin for rotary molding.

In selecting a sheet stock for forming the outer case, only A.B.S. and high density polyethylene polymers were reviewed for the prototype build. A.B.S. was selected for its flexural strength and scuff resistance while high density polyethylene was selected for its impact resistance over a range of temperatures. The temperature range over which the shipping container was designed to function in was -40° C to 60° C . This range was used in shock testing and thermal cycle testing of the prototype shipping container designs.

As discussed in the shock test portion of the experimental section, A.B.S. cracked at a reduced temperature drop. Thus, the decision was made to use polyethylene for fabrication of the shipping container.

The need of a pressure relief valve in the shipping container is to prevent the case from deforming due to a rapid change in pressure from the interior of the case to the exterior of the case. This change in barometric pressure can occur due to changing weather conditions, an increase or decrease in temperature or an altitudinal change, as in a package being shipped in an unpressurized cargo hold. The spring valve can open in either a vacuum or pressure situation. The setting of the valve in this example was between +0.5 p.s.i. to -0.5 p.s.i., although other settings are available, these settings would give the least amount of stress to the outer case.

Studies have shown that the greatest amount of valve actuations occurs at desert station storage conditions, such as in Las Vegas, Nevada (Mustin, 1963). This would be logical, since the temperature fluctuates greatly in a desert condition.

Barometric pressure changes that would cause the pressure relief valve to actuate the most would occur in a monsoon station such as Bangkok, Thailand (Mustin, 1963).

Altitudinal changes can also effect the relief valve, depending upon the rate of ascent or descent of the cargo plane and the difference between initial and final altitudes. This is shown clearly in Figure 13.

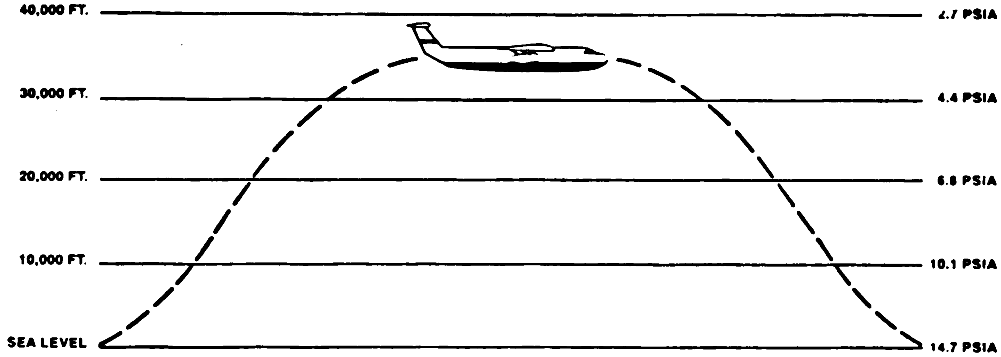


Figure 13. Altitudinal Effect on Pressure

Since the cases were designed to be reuseable, and required coding, each case was serialized by a vibro-etched serial number on both halves of the valence between the two sets of casters. This serializing of the cases made it easier to track them through recycling. Also, if any of the shipping cases were made with non-specification components, they could be collected and returned for credit to the case manufacturer. The serializing also helped keep the results of the source inspector organized.

INNER CASE DESIGN

The design requirements of the inner case consisted of the following components. A holding fixture, an inner cushioning medium (for the circuit board held in the fixture) and compartments to hold desiccant inside the case.

In the example outlined, the holding fixture (presented schematically in Figure 14) consists of a frame and four clamps made from 9.0 pounds per cubic foot (p.c.f.) expanded polyethylene foam.

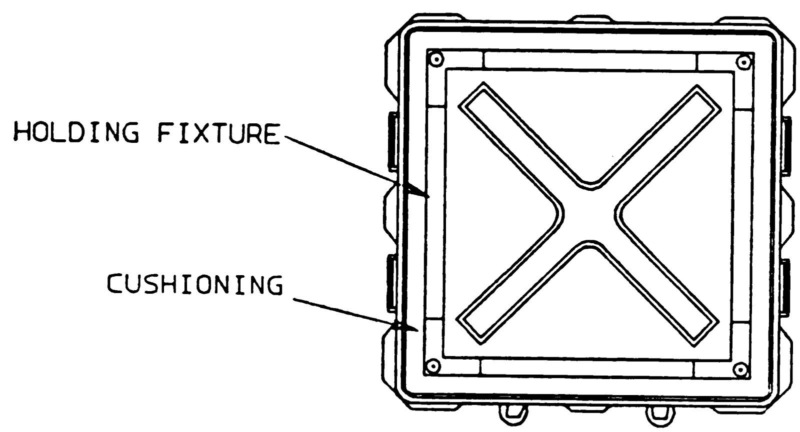


Figure 14. Inside View of the Bottom Tray of the Shipping Case

The clamps are held in place by shot pins that actuate by pressing the button on the top of the pin (see Figure 15).

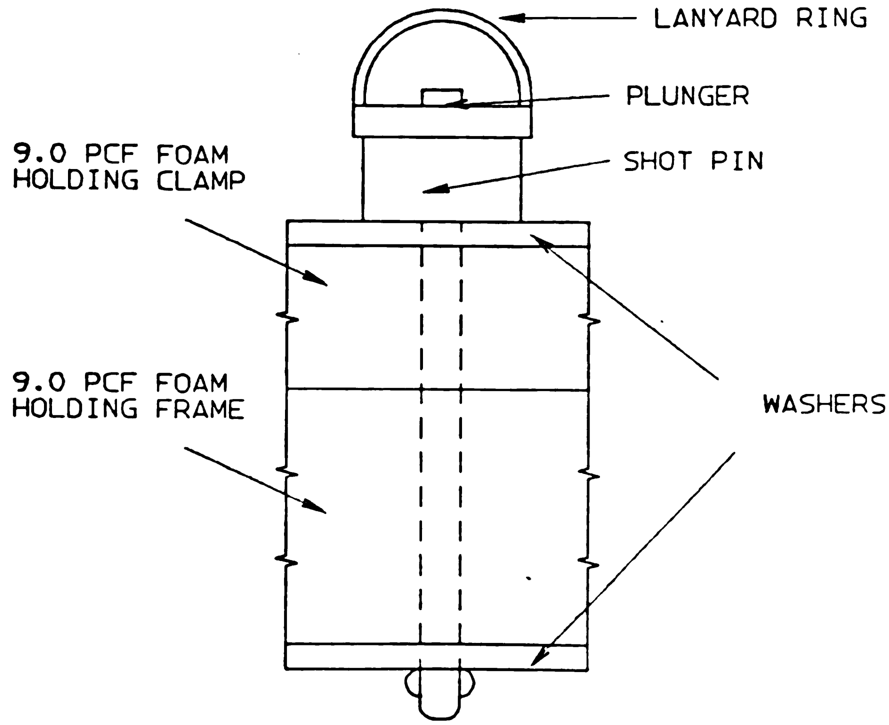


Figure 15. Cross Sectional View of the Clamp/Shot Pin Assembly

As shown, this rigid part is held and cushioned at each corner and supported around its perimeter by the inner holding fixture.

In this example the cushioning system used was a 2.2 p.c.f. expanded polyethylene foam. In the initial analysis both polyethylene foam and elastomeric shock mounts were considered as the cushioning system. The shock mounts were coupled with an aluminum cast holding fixture. As discussed in the experimental section, some of the shock response values, at room temperature, were close to or above the fragility of the product when these mounts were used.

As previously mentioned, the product is sensitive to humidity. Thus, a desiccant is required with the packaging system and consequently desiccant compartments were incorporated into the shipping container design. The bottom cushion housed four of these compartments. Each compartment held a 16 unit bag of desiccant (bag dimensions: 200 mm X 100 mm X 35 mm). This gave a capacity of 64 units total. If the packaging system requires desiccant, it is best to locate the desiccant compartments around the inside perimeter of the case (Figure 16). This gives the best coverage of dessicant to absorb any incoming moisture.

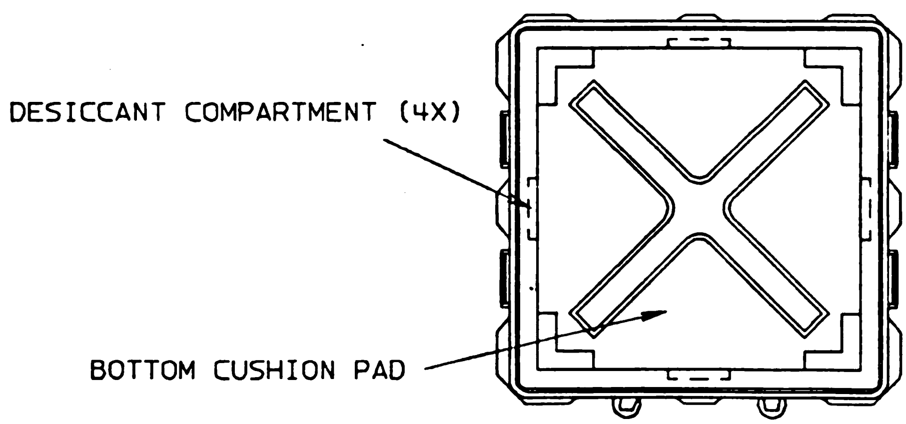


Figure 16. Bottom Cushion Pad with Desiccant Compartments

PROTOTYPE CONSTRUCTION

By looking at the specific design requirements that have been established, the packaging engineer can then proceed to this step. Usually when doing prototype testing it is most cost effective to test an "off the shelf" packaging system that is representative of what has been established in your design requirements. Besides being cost effective, the lead time for the initial concept is reduced dramatically. This allows the packaging engineer to see how adaptable the proposed packaging concept is to the product being packaged.

For this packaging system three different prototypes were tested. Two were vacuum formed cases with an inner cushion and holding fixture made from polyethylene foam. Of the two, one case used acrylonitrile-butadiene-styrene (A.B.S.) and the other high density polyethylene.

The third case consisted of a rotary molded (using polyethylene) outer case with an aluminum frame holding fixture and elastomeric shock mounts for cushioning.

EXPERIMENTAL/DATA COMPILATION

In the example cited, the initial screening was done by shock testing each of the three prototypes having non-functional boards packaged in them. The A.B.S. case cracked during shock tests that were carried out at low temperatures (-40^{o}C). From observation of the various shock tests performed on the prototype packaging systems, depressed temperature shock testing was the most severe.

The packaging system using the shock mounts gave shock values above the fragility of the product (see Data Set 1, Appendix A) during an edge drop.

Because of these results, not all of the subsequent tests were performed on each prototype.

With industrial shipping container design the experimental/data compilation phase should be separated into the following test catagories:

1. Shock
2. Sinusoidal vibration
3. Thermal cycle
4. Shelf life
5. Outgassing
6. Flamability*
7. Random vibration*

*these tests were not performed on this packaging system

SHOCK

In performing any valid shock testing you first must have an idea of the products fragility. The most valuable way of expressing that fragility is in terms of a damage boundary curve (see Figure 1, pg. 3). A conventional damage boundary curve is a graphical representation of a product's or product component's fragility, stated in terms of a critical acceleration and a critical velocity change.

The critical velocity change is indicative of the drop height to which the product protects itself and is the level of an uncushioned shock pulse (< 2 milliseconds) that the product can withstand before damage. This value is determined by a stepwise input of half-sine shock pulses, with increasing velocity change, into the product.

The critical acceleration is the maximum G level that the product will withstand before damage. This value is determined by a stepwise input of increasing G level square wave shock pulses (> 4 milliseconds), with constant velocity change, into the product. The value of the critical acceleration is used in conjunction with a cushioning curve to insure that the type, loading, thickness and density of the cushion will yield G levels less than the product's or component's critical accelertion.

In the packaging design process the equivalent drop height (h equiv), which is determined from the critical velocity change, is compared to the design or expected drop height (h exp), which depends on the product's mass and size. Table 1 is a representative specification of the expected drop heights and procedures that manual and non-manual packages are to be subjected to during shock testing.

Table 1. Test Procedure Guide for Manual and Non-Manual Packages I.B.M. Corporate Specification C-H 1-9711-005 (Appendix B)

Class	Mass (Packaged Product) kg Above-incl	Mass (Packaged Product) lb* Above-incl	Number of Shocks (Drops)	Typical Design Drop Height: Boxed with No Pallet mm	Boxed with No Pallet in*	Palletized mm	Palletized in*	Minimum Pack (No Box) mm	Minimum Pack (No Box) in*
Manual	0-10	0-23	8 (Para 4.1.2)	900	36	600	24		
	10-30	23-67	8 (Para 4.1.2)	750	30	450	18		
	30-40	67-89	8 (Para 4.1.2)	600	24	300	12		
	40-60	89-133	8 (Para 4.1.2)	450	18				
			5 (1 bottom)			450	18		
			(4 sides)			300	12		
			12 (2 bottom)					300	12
			(10 bottom)					100	4
Non-Manual	60-90	133-199	5 (1 bottom)	450	18	300	12		
			(4 sides)	300	12	200	8		
			12 (2 bottom)					250	10
			(10 bottom)					50	2
	90-120	199-265	12 (2 bottom)			250	10	200	8
			(10 bottom)			100	4	50	2
	120-240	265-530	12 (2 bottom)			200	8	150	6
			(10 bottom)			50	2	25	1
	240-450	530-993	12 (2 bottom)			150	6	100	4
			(10 bottom)			50	2	25	1
	450-Above	993-Above	12 (2 bottom)			100	4	75	3
			(10 bottom)			50	2	25	1

The equivalent drop height can be determined by the following formula.

$$V\ crit = (1 + e)\sqrt{2\ G\ h\ equiv} \qquad (1)$$

Where:

V crit = the critical velocity change of the product or component (in/sec)

e* = the coefficient of restitution (ex. 50% rebound = .5)

G = acceleration of gravity ($386.4\ in/sec^2$)

h equiv = the product's equivalent drop height (inches)

* The value for e, between 0 and 1, is specifically dependent on the shock pulse imparted to the product that established V crit. If the profile of this pulse is known

then e can be determined by taking the ratio of the rebound velocity ("last" half of the pulse) to the impact velocity ("first" half of the pulse).

Rearranging equation 1 gives:

$$h\ equiv = \frac{V\ crit^2}{(1 + e)^2 \cdot 2 \cdot G} \qquad (2)$$

If h equiv > h exp all that is required of the packaging system is to provide a means of handling, storing and dispensing the product. If h equiv < h exp then, in addition to the above functions, the packaging system must provide cushioning to prevent the input of a damaging shock into the product that could occur at h exp.

By using the product's expected drop height and the critical acceleration, established in the damage boundary curve, the type and configuration of foam used in the packaging system can be determined. This is done by reviewing the cushioning curve* (see Figure 17) of the candidate materials at the expected drop height. Then establishing if the product packaged with this type of foam (at a specific p.s.i, thickness and density) would yield a value less than the product's critical acceleration, if dropped from this height.

* a cushioning curve is a graphical representation of a material's average deceleration, in G's, versus its static loading, in pounds/square inch. Each trace is specific for a given material thickness and density at a given h exp.

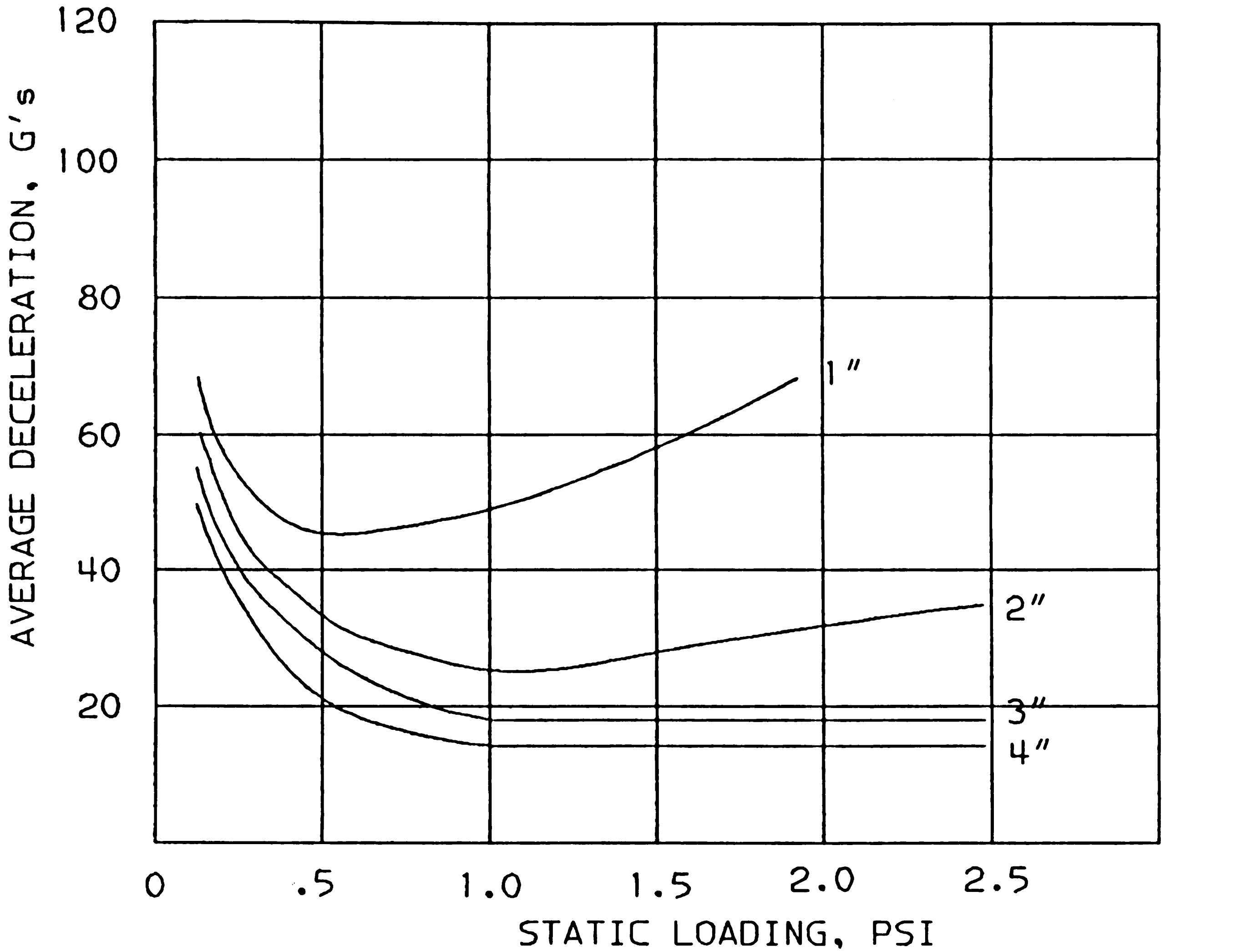


FIGURE 17. CUSHIONING CURVE FOR 2.2 p.c.f. EXPANDED POLYETHYLENE FOAM 2-5 IMPACT @ A 12" DROP (70°F)

For the example described, Figure 18 is the product's damage boundary curve in the x,y and z axes. From this graph, and knowing the physical characteristics of the product, it was initially determined that the packaging system would be in the catagory of a manually handled package with an expected drop height of 18 inches. When cushioned and dropped from that height the board itself should not experience a shock above 40 G's. To accomplish this, elastomeric shock mounts and polyethylene foam (cushioning curve listed in Figure 19) were used in the prototype build. Initial testing was carried out at room temperature with the results tabulated in Data Sets 1 and 2 (Appendix A).

While values for the polyethylene foam were good, an edge drop using the shock mounts exceeded the value established for critical acceleration of the product. Therefore, the shock mounts were deleted as a cushioning medium and the polyethylene foam was considered appropriate.

The board in the package would be shipped flat, z axis normal to the plane of the earth. The input of shock and vibration would be most direct to the product in this axis. Knowing this, the product's natural frequency, and having a damage boundary curve of the product, it was considered that the z axis was the most fragile axis of the product. Because of this the design group experimented with static loading and density of the polyethylene foam used for z axis cushioning to yield the best results for both shock and vibration protection of the product.

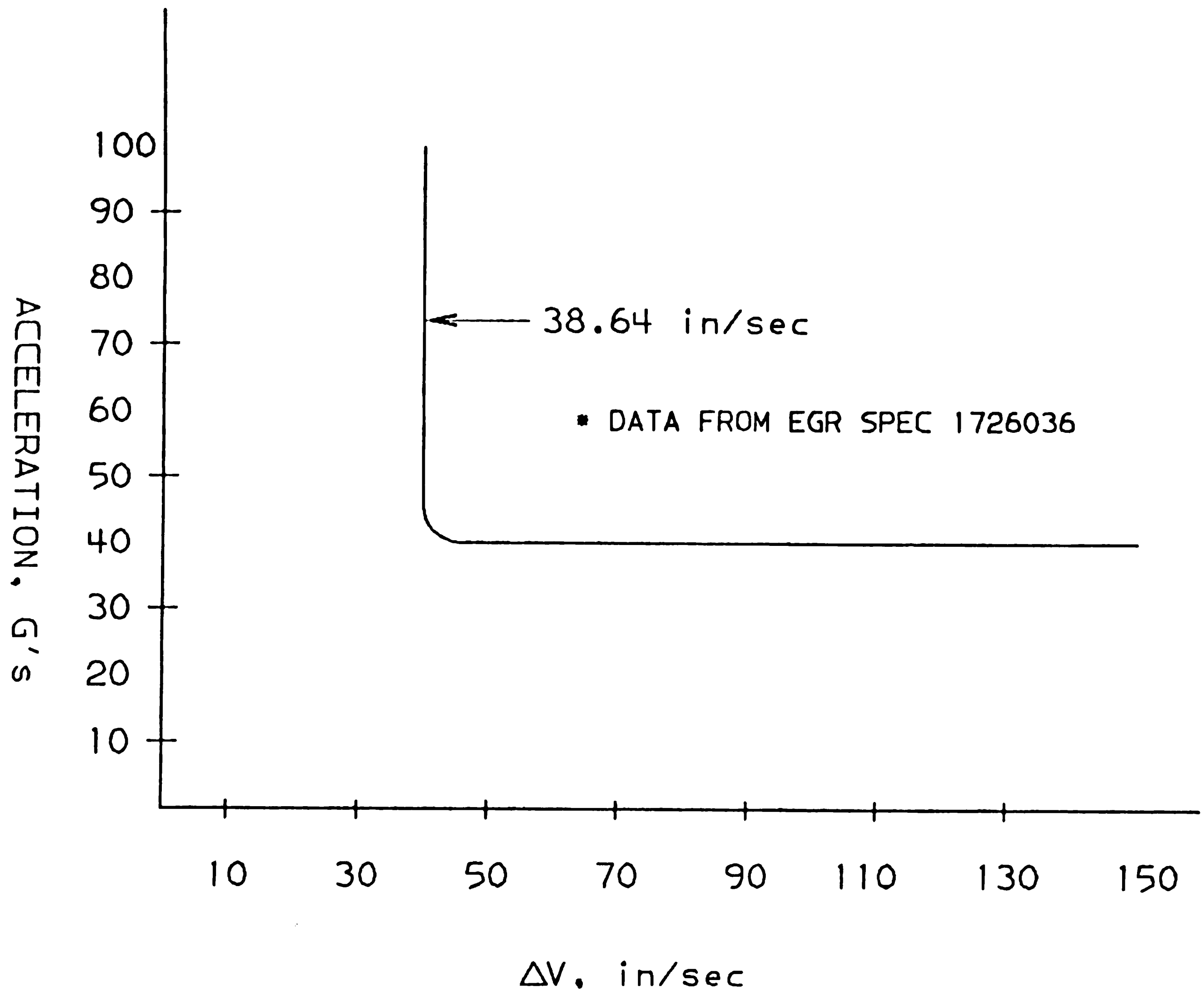


FIGURE 18. DAMAGE BOUNDARY CURVE FOR THE BOARD ASM (X,Y and Z AXES)*

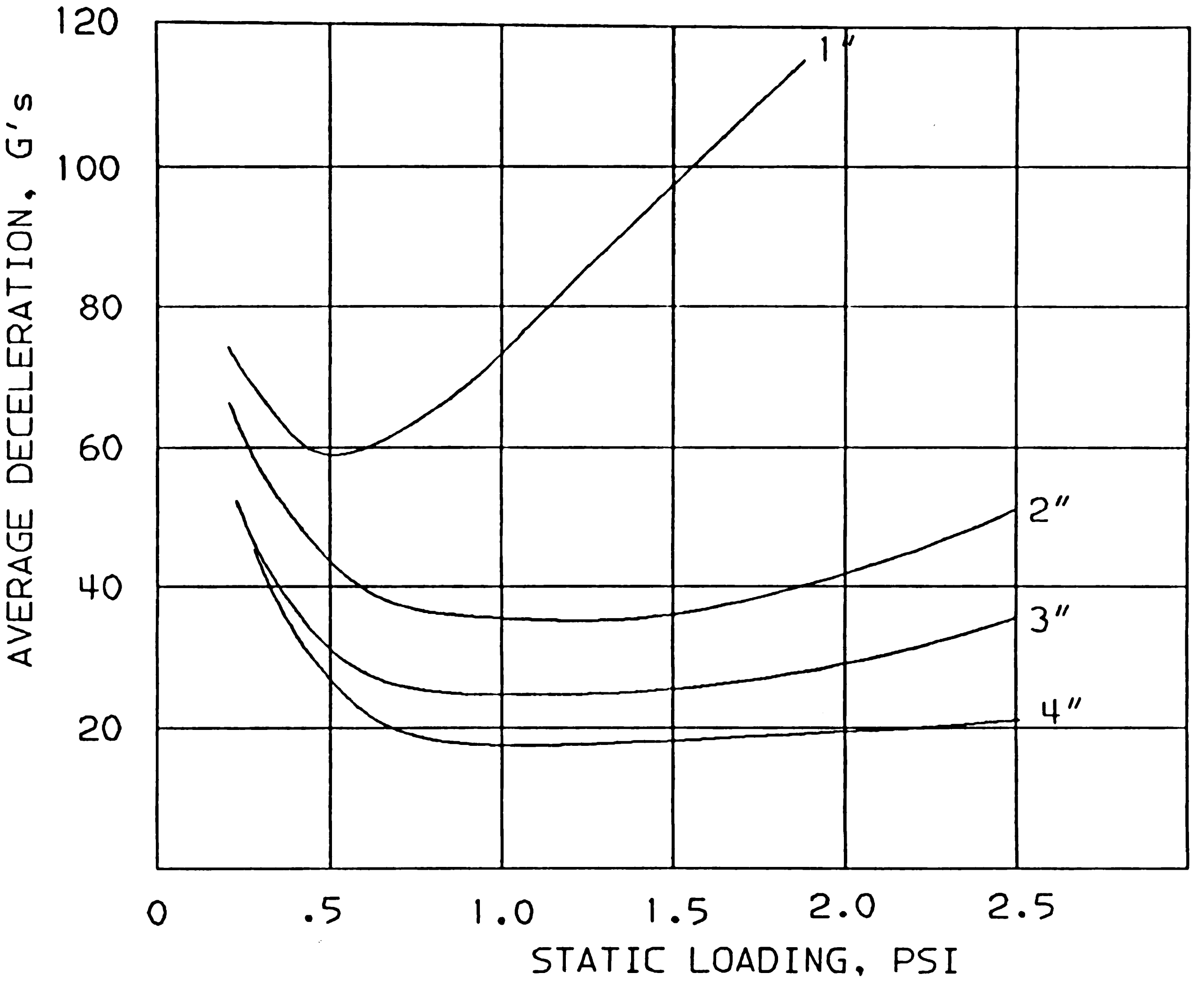


FIGURE 19. CUSHIONING CURVE FOR 2.2 p.c.f. EXPANDED POLYETHYLENE FOAM 2-5 IMPACT @ AN 18" DROP (70°F)

In these experiments the initial 0.74 p.s.i. loading was changed to 1.2 p.s.i. loading. The foam densities were changed from 2.2 p.c.f. to 4.0 p.c.f. and 6.0 p.c.f. @ 2.4 p.s.i., (Data Sets 3-10, Appendix A). The results of this study are summarized in Table 2.

It can be seen that by changing the density of the foam, from 2.2 to 4.0 p.c.f., and keeping the p.s.i. loading constant, the value of peak G's increases while the duration of the shock pulse diminishes. Also, the 6.0 p.c.f. foam gave the lowest velocity change value for bottom drops at room temperature. However, according to the cushioning curves for the 6.0 p.c.f. foam at lower temperatures, the theoretical values of the shock pulse would have exceeded the fragility limits of the circuit board (Dow Corp., 1981). Therefore, this density of foam wasn't used in the packaging design.

Table 2. Effect of Foam Density and P.S.I. Loading on Peak G's and Duration for Top and Bottom Drops

		Orientation	
Foam Density (lbs/cu. ft.)	Foam Loading (lbs/sq. in.)	Top Drop (G's/millisec.)	Bottom Drop (G`s/millisec.)
2.2	1.2	15/16	24/17
2.2	1.2	20/16	36/14
2.2	1.2	17/20	28/18
2.2	1.2	16/26	26/18
	Ave.	17/19.5	28.5/16.75
2.2	.74	16/25	20/21
2.2	.74	13/30	18/22
	Ave.	14.5/27.5	19/21.5
4.0	1.2	15/28	22/22
6.0	2.4	N/A	20/16

The effect of the wall thickness of the outer case on the shock attenuation characteristics of the shock bumps (Data Sets 11-13) was also examined. The most enlightening was a drop done on an edge of the case at the interface of the 2 and 6 planes of the case. This showed a slight increase of peak G's as the sheet stock's gauge increased (see Table 3).

Table 3. Effect of Sheet Stock Thickness on G's for a 2,6 Edge Drop

Sheet stock gauge (inches)	Sum of G's on 2,6 edge drop
0.312	24
0.375	26
0.400	27

At this point in time it had been established that the polyethylene foam worked well at ambient conditions. How the foam's shock absorbtion characteristics would change at depressed temperatures is presented in Figure 20.

An actual test was set up to place the product and package into a chamber at $-40^{o}C$ for 12 hours then continue the drop testing. The resulting data is compiled in Data Set 14 (Appendix A). As shown the values increased to the 30 G's range in the z direction, with durations decreasing, as opposed to testing conducted at ambient conditions. No shock tests were done at elevated temperatures since it was felt that the cushion would still be able to dampen a damaging shock pulse at $140^{o}F$ (see Figure 21). Also the availablity of a 140^{o} F test chamber was unknown [this temperature was specified as an upper limit, although inside box cars the temperature could reach an extreme of 152^{o} F (Guins, 1980)].

After completing each phase of the shock testing, values obtained were plotted on the original damage boundary curve. In Figure 22 shock values for bottom drops are plotted on the damage boundary curve. According to this figure, shock pulses imparted to the product, while polyethylene foam was used in the packaging system, wouldn't damage the product. This data, obtained from an accelerometer mounted in the center of the circuit board, is summarized in Table 4.

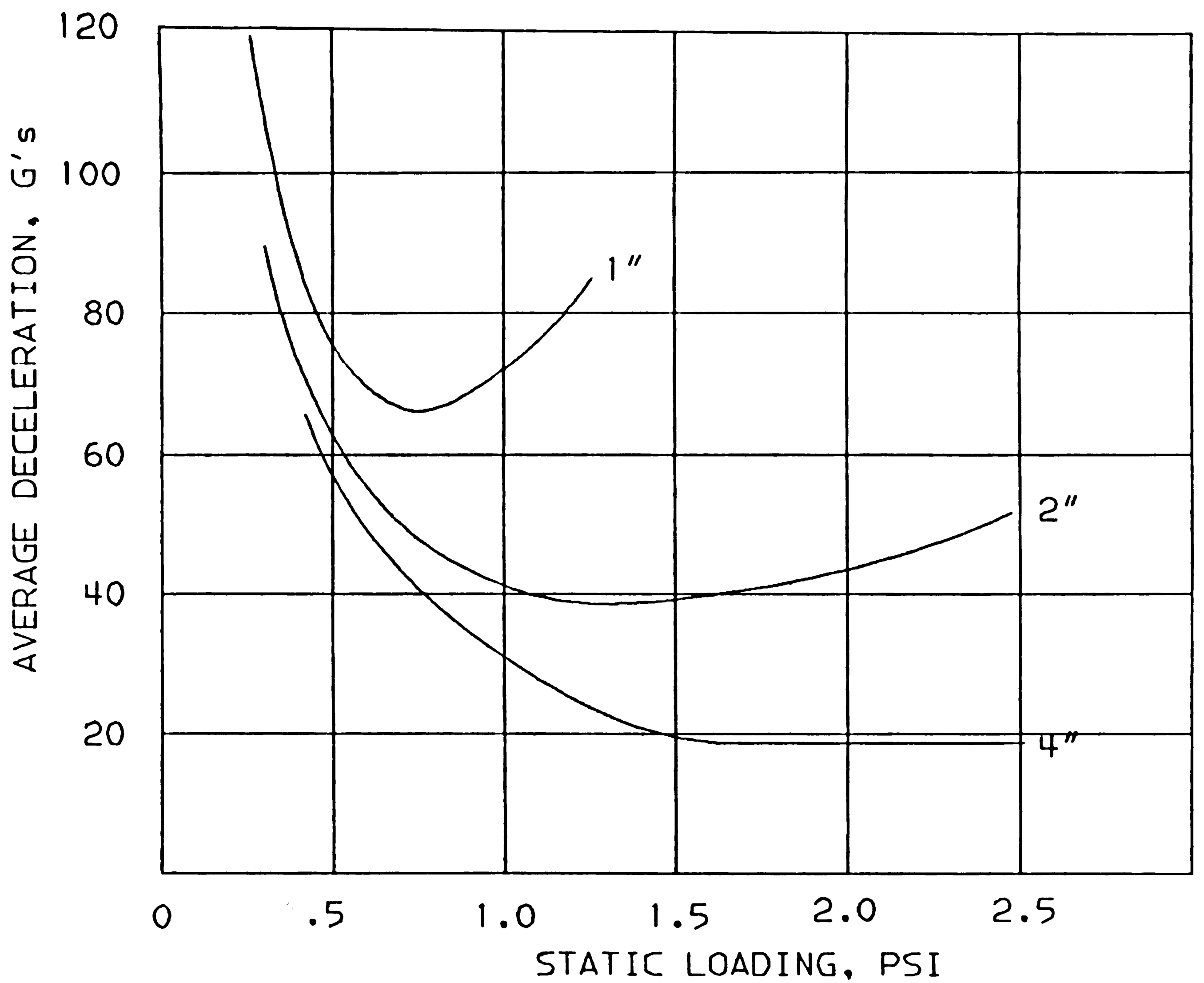


FIGURE 20. CUSHIONING CURVE FOR 2.2 p.c.f. EXPANDED POLYETHYLENE FOAM 2-5 IMPACT @ A 24" DROP (-40°F)

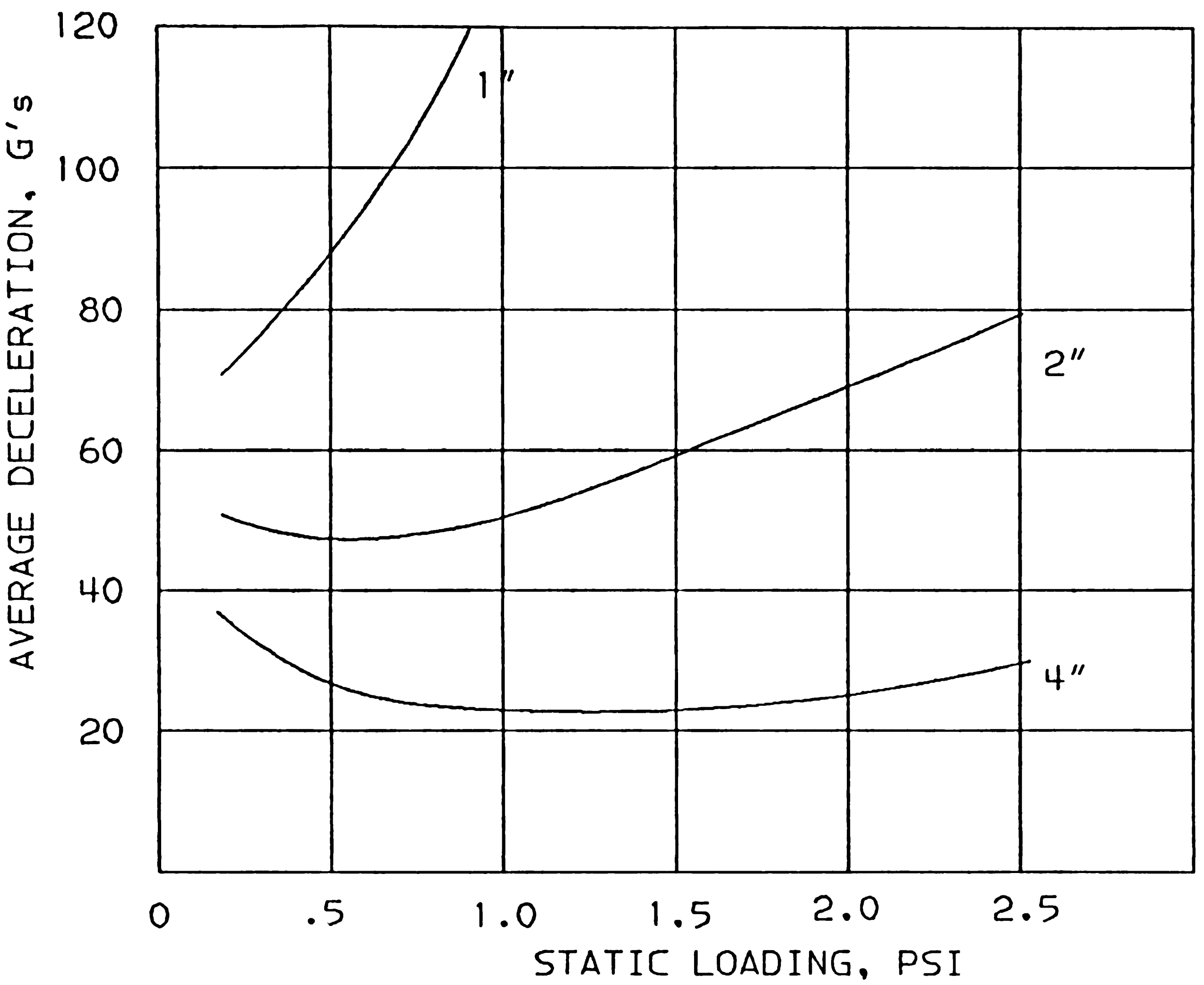


FIGURE 21. CUSHIONING CURVE FOR 2.2 p.c.f. EXPANDED POLYETHYLENE FOAM 2-5 IMPACT @ A 24" DROP (160°F)

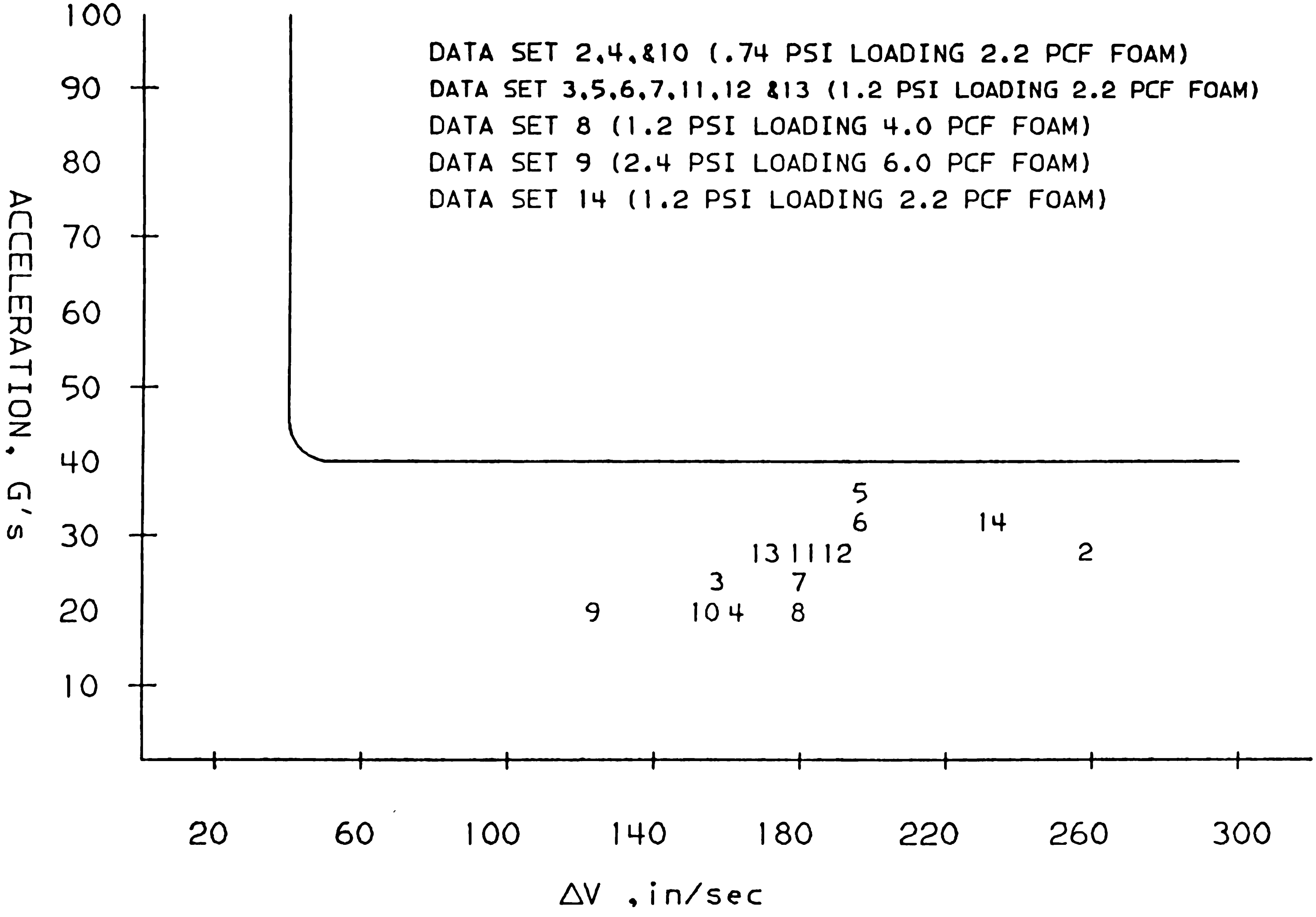


FIGURE 22. BOTTOM DROP VALUES GRAPHED ON THE DAMAGE BOUNDARY CURVE

Table 4. Bottom Drop Values from Data Sets 2-14

Data Set	Bottom drop ΔV (in/sec.)*	Peak G's (zero to peak)
2	259.6	28
3	157.7	24
4	162.2	20
5	194.7	36
6	194.8	28
7	180.8	26
8	187.0	22
9	123.7	20
10	153.0	18
11	183.9	28
12	183.9	28
13	173.1	28
14	231.4	30

*$\Delta V = 3.22 \times 10^{-2} \times$ G peak x T (duration in millisec.) x 12 in/ft

It must be pointed out that although the accuracy of the test equipment used to determine shock values, tabulated in Appendix A, was at best +/- 10 %. When measurements were compared with the circuit board's critical acceleration of 40 G's there was still a safe margin between the 40 G limit and the highest reading recorded during the shock testing. When various components were changed in the packaging system, such as the foam density or sheet stock gauge, the precision of the test equipment was good enough to discern relative differences in shock values for the samples tested.

SINUSOIDAL VIBRATION

As with the relationship of fragility to shock, knowing a product's fragility to vibration, if any, is critical information for the packaging engineer.

Specifically, you must have an understanding of all the components that are most likely to go into resonance and if that resonant situation will cause damage to the product. One of the common methods used to extract this information from the product is to do a vibration sweep on the product fixtured to a vibration platten. I.B.M. corporate specification C-H 1-9711-001 (Appendix B) calls for a sweep from 2-200 Hz @ 0.3 G input to determine the natural frequency/frequencies of the product or component. To determine the product/component's fragility to vibration a dwell test of 15 min @ 0.5 G input is run at each natural frequency. After the test, the product is inspected for damage. If there is no damage, the product/component is not considered to be susceptible to vibration damage. If there is damage, then the product/component is vibration sensitive and the packaging system must filter out any harmful vibrations from getting to the product. The circuit board had a similar test run on it (the dwell portion was 0.4 G input for 30 minutes) in the x, y and z axes. As previously mentioned, the information relating to the x and y axes of the product was not considered in the packaging design. Response values for the sample boards tested, in the z axis (normal to the board), ranged from 7.7 to 13.7 G's with the natural frequency (Fc) of the board being 90 Hz. No electrical or mechanical failures were observed by the test group during or after these dwell tests. Even with this information, the design group thought that over an extended amount of time the product might experience problems due to vibration input, in the z axis, inherent to the modes of distribution for the packaged product. The occurance of damage could come from the board flexing and causing solder joints to crack or the circuitry in the board to break.

Because the board was considered to be vibration sensitive, materials used in the packaging system and the packaged product were tested as such. Since the product's response to vibration was known, the response to vibration of the packaging system and the product in the system was next determined. For an initial look at how the cushioning of the system will respond, transmissibility (Q) curves are available to the packaging engineer (Mil Handbook 304-B, 1978). Realistically since the package is made up of more than just foam, a packaging engineer can't tell how the packaging system responds to vibration until the total system is tested in the lab. More importantly, it is necessary to determine how the packaged part responds to vibration inputed into the packaging system. This would be done in much the same way as determining the natural frequency of the product. The only difference is that the product would be in the packaging system fixtured to the vibration platten. The accelerometer would still be mounted on the product.

To this point, the natural frequency of the critical component and that of the packaged product have been considered, with the results of these values determined in laboratory testing. How then can this information be used when designing a packaging system?

Before this can be done, we should understand vibration amplification in a critical component due to an input forcing frequency.

To what extent an input G force is amplified (M) by an input forcing frequency (Ff) to a component's natural frequency (Fc) is best described by the following equation:

Assuming a linear spring with no damping:

$$M = 1/1-(Ff/Fc)^2 \qquad (3)$$

Table 5 is a tabular representation of the ratios and equations above.

Table 5. Various Values Derived from Equation 2

Ff	Fc	Ff/Fc	$(Ff/Fc)^2$	$1-(Ff/Fc)^2$	M
1	5	.2	.04	.96	1.04
3	5	.6	.36	.64	1.56
3.54	5	.707	.50	.50	2.00
4	5	.8	.64	.36	2.78
5	5	1.0	1.0	0	infinity
6	5	1.2	1.44	-.44	-2.27
7	5	1.4	1.96	-.96	-1.04
7.07	5	1.414	2.0	-1.0	-1.0
10	5	2.0	4.0	-3.0	-.333
15	5	3.0	9.0	-8.0	-.125
25	5	5.0	25.0	-24.0	-.042

Using information from Table 5 (Figure 23), where amplification (M) is plotted as a function of the ratio of the forcing frequency (Ff) to the natural frequency of the component (Fc), helps illustrate the three phases of a component being driven by an input vibration.

Namely: Coupling, Resonance and Attenuation. (Mindlin, 1946).

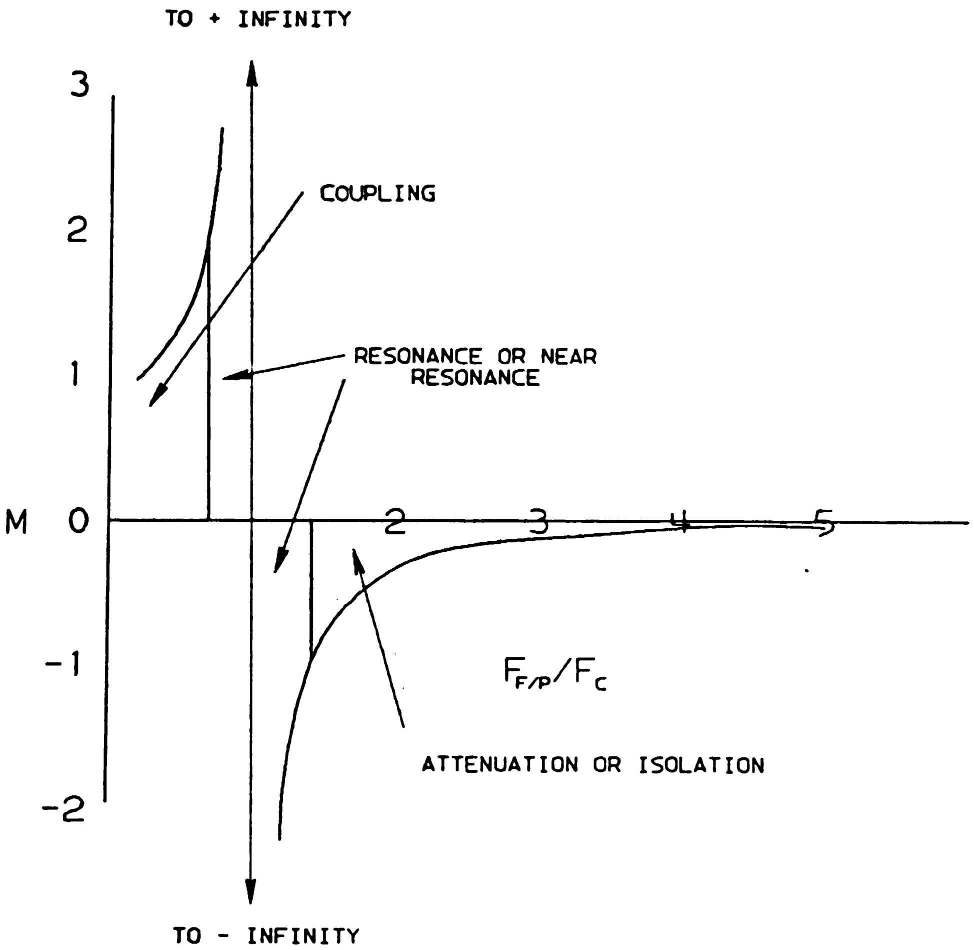


Figure 23. Amplifcation vs. Ff/Fc with Detail of Coupling, Resonance and Attenuation.

In equation 1 the ratio of Ff/Fc was used to determine M in an unpackaged product. With a packaged product the ratio becomes the natural frequency of the packaged product (Fp) to the natural frequency of the unpackaged critical component (Fc). However, the following description of coupling, resonance and attenuation continue to hold true.

Coupling: where the input G force amplification is up to 1:2 (input/response)

Resonance: where the input G force amplification is much greater than 1:2, and is the most dangerous situation for a packaged product sensitive to vibration.

Attenuation: where the input G force amplification is less than 1:1, and is the most favorable situation for a packaged product sensitive to vibration.

By using the ratio of Fp/Fc the component/product's phase in vibration can be determined.

Fp/Fc < or = .707 (Coupling)

Fp/Fc = .707 to 1.4 (Resonance)

Fp/Fc > or = 1.4 (Attenuation)

In the example cited the critical vibration mode was in the z axis. Fc was 90 Hz, and was determined by an accelerometer placed on the board's stiffner (Figure 24).

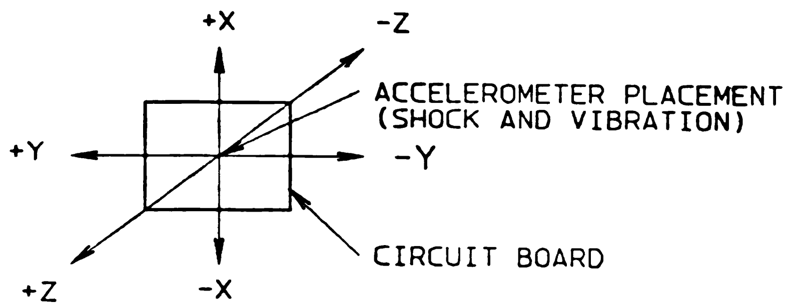


Figure 24. Accelerometer Placement on the Circuit Board for Shock and Vibration Testing

In the following testing to determine Fp, the accelerometer was mounted in the same location and orientation as in the determination of Fc.

Information in Data Sets 15,16,17 and 20 (Appendix A) show how the packaged part responded to vibration on each face of the package.* As stated above, the most critical axis was the z axis. Values from this axis are tabulated in Table 6.

* Packaged product vibration tests were carried out according to I.B.M. corporate specification C-H 1-9711-005 (Appendix B). Values listed in the data sets were obtained during initial resonance tests. Endurance tests were performed on the packaged product but the functionality of the product was not tested. Only the condition of the package and the product were noted after the test. Due to their cost no electrically functional boards were available for testing.

Table 6. Values from Vibration Sweeps done on the Bottom of the Case

Fp (Hz)	G Response (0 to Peak)	Q	Foam Loading (p.s.i.)	Foam Density (p.c.f.)
30	1.87	1.74	.74	2.2
28	1.95	3.9	.74	2.2
25	2.37	4.74	.74	2.2
17.5	1.7	3.4	1.2	2.2
20.5	1.4	2.8	1.2	4.0

By taking the ratio of Fp/Fc (Fp/Fc = 27.7/90 = .32) it can be seen that we are in the coupling portion of the amplification graph. Considering that the input G force is multiplied by a factor of 2 or less in coupling, for a long or short exposure of vibration, the design group felt that the packaged product was adequately protected from vibration damage in its latest configuration.

What could the packaging engineer do if Fp was too close to Fc and the product was vibration sensitive? Changing the product design is one option, not likely, but not out of the question. The other option is to change something in the packaging system's design. If cushioning is used in the packaging system this would be the likely thing to alter.

A few general relationships that relate to the packaging foam's response to sinusoidal vibration are listed below. All things being equal, by:

--increasing the density of the foam the natural frequency of the packaged product increases.

--increasing the thickness of the foam the natural frequency of the packaged product decreases.

--increasing the p.s.i. loading of the foam the natural frequency of the packaged product decreases.

Information listed in Table 6 shows how changing the p.s.i. loading and density of the foam changed Fp. The Fp decreased from an average of 27.7 Hz to 17.5 Hz as the p.s.i. loading went from 0.74 p.s.i. to 1.2 p.s.i. . Fp also increased from 17.5 Hz to 20.5 Hz as the density of the foam went from 2.2 p.c.f. to 4.0 p.c.f.. This helps prove the validity of the first and third rules listed above.

After reviewing the results of the shock testing and seeing how the prototype performed in vibration, it was decided to use a 2" thick, 2.2 p.c.f. polyethylene foam. The loading of the cushioning system would be 0.74 p.s.i. in the z axis.

THERMAL CYCLE

Thermal cycling or thermal shocking the packaging system helps isolate flaws in the system by checking the material/component's physical characteristics before and after the thermal test. It is also valuable in identifying stresses between the different materials used in the packaging system.

The procedure used to test the prototype package was the following: The board packaged in the prototype system was subjected to four thermal shock cycles. Each cycle of the test consisted of 3 +/- 1 hour @ -40°C +/- 2°C followed by 3 +/- 1 hour @ 60°C +/- 2°C. The relative humidity in the test chamber was uncontrolled and no effort was taken to minimize condensation. The rate at which the temperature increased or decreased was 100°C per 30 +/- 5 minutes. The four cycles were performed on consecutive days (chamber readout Figure 25).

Some of the observations from the test are as follows:

- Hardware using nickel-cadmium and zinc-chromate were used in these tested prototypes. The zinc chromate plated hardware withstood oxidation better that the nickel-cadmium components.

- The closed cell polyethylene foam shrank slightly but still cushioned the product from shock (data set 10, Appendix A).

- The pressure relief valve kept the case from deforming.

- Stresses built up between the metal and plastic components. This caused some of the rivets to become undone.*

* This is because the coefficient of thermal expansion for plastics is about 5 times greater than it is for metal (Measurements Group,1979).

-There were no problems as far as stress cracking of the vacuum formed or rotary molded case.

Based on these results, only a few changes were made to the case. All hardware was to be zinc-chromate plated and the material used for the rivets was changed from aluminum to steel.

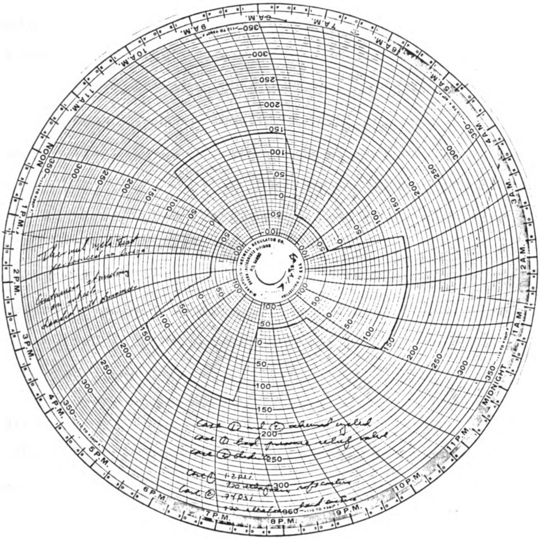


Figure 25. Chamber Readout for Thermal Cycle Testing done on the Circuit Board's Packaging System

SHELF LIFE

Shelf life is the amount of time that the packaging system must keep the product's fragility, to some external condition, from being exceeded and making the product unacceptable for customer use.

With electronic equipment, as in this example, one of the product's most sensitive fragilities is to moisture. This fragility is quantified as relative humidity.

The amount of time the product must remain on the shelf in an acceptable state is defined by a marketing or a field service organization (For this example it was two years). The difference between the length of time an unpackaged product would remain acceptable for use and what is required for the product's shelf life is compensated for by the packaging system.

Stated:

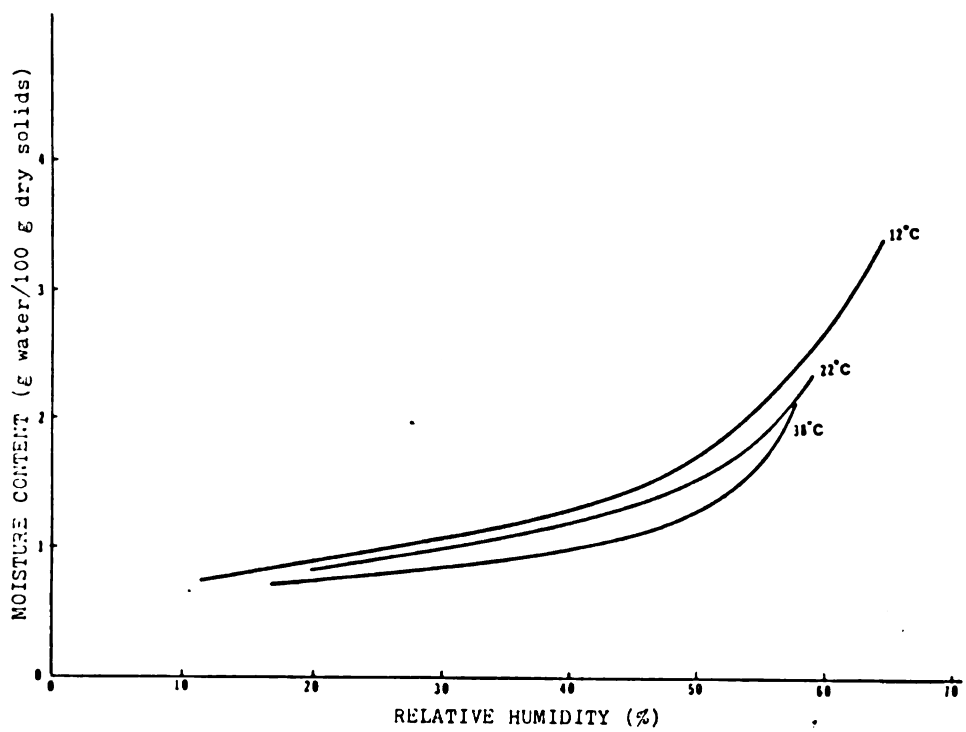
Shelf life (defined)= Shelf life (unpackaged product) + Shelf life (packaging system)

Each component of the right hand of the equation is also dependent on specific variables.

Shelf life (unpackaged product) = f(product's interaction w/moisture)

Shelf life (packaging system) = f(desiccant's, packaging material's and headspace interaction w/moisture)

Some products have little or no interaction with permeated water vapor, while others do. This interaction is either as a sorption reaction or a chemical reaction. The product's interaction with moisture in sorption is described in a graph called a moisture isotherm (Figure 26). This shows specifically how much moisture the product will adsorb at a given temperature and relative humidity. This, along with the rate of moisture sorption quantifies the value for Shelf life (unpackaged product).



Calculated moisture sorption isotherms at 12°, 22° and 38°C

Figure 26. Example Isotherm of a Moisture Sensitive Product

The term Shelf life (packaging system) is derived from: (i) the type* and amount of desiccant used; (ii) the type of materials used such as the foam used to cushion the product or the barrier material used to make up the case/closure seal; and (iii) how much headspace volume (which should be kept to a minimum) there is for the permeated moisture vapor to occupy.

* Three of the most widely used desiccants (Cullen, 1975) in shipping containers are...

1. Molecular sieve
2. Montmorlinite (clay activated)
3. Silica Gel

Molecular sieve is the most aggressive in sorbing water. For example, it takes 350^{o}C in a vacuum of 10 mm Hg (D.W. Breck, 1964) to drive water off of molecular sieve, where as clay desiccant can be reactivated by placing the bag into a chamber @ 250^{o}F for 16 hours (Culligan Corp., 1979). However, the cost for molecular sieve is much greater than either of the other two desiccants.

Cost per one time performance would be best with silica gel but it could not be dried out and reused. In a recyclable packaging system, such as the example described, the clay desiccant, because of its ease of reactivation and cost per use, was the desiccant of choice.

In determining the amount of desiccant needed for commercially shipped packaging systems, there are some basic formulas available to the packaging engineer.

For example, for water and vapor-proof sealed flexible barriers and fiber cans (Culligan Corp., 1979) the amount of activated clay desiccant needed is:

Units of desiccant= 1.6 x surface area in square feet

Units of desiccant= 17 x surface area in square meters

For rigid metal containers* :

Units of desiccant= K x V   (Culligan Corp.,1979)

Where:

V = volume of container

K = 0.161, volume in gallons

K = 0.0007,volume in cubic inches

K = 1.2, volume in cubic feet

K = 0.42, volume in liters

K = 42.3, volume in cubic meters

* according to MIL-P-116 a rule of thumb is 1.2 units of desiccant per cubic foot of the sealed rigid container (Mustin, 1963).

If dunnage is used in the interior packaging it could absorb water and consequently desorb water onto the product causing damage. Because of this extra desiccant is needed.

Units of desiccant to offset dunnage = X x D

D = dunnage weight in ounces

X = .5 for wood

X = .37 for bound fibers

X = .125 for glass fibers

X = .032 for open cell foam or rubber

The above sets of equation gives the packaging engineer a first approximation at determining how much desiccant is needed in the packaging system to obtain the desired Shelf life (packaging system).

However, to obtain the value of Shelf life (packaging system) field testing, accelerated testing or simulation modeling could be used on the prototype packaging system. Based on the results of these tests the amount of desiccant, barrier material, closure method etc. could be evaluated and reengineered if necessary.

For this practical example, field testing was out of the question because of time limitations. For a good reference on this topic the reader is refered to "Water Gain Behavior of Outdoor Closed Structures" by Gordon S. Mustin (1963). Rather, an accelerated test on the prototype packaging system was conducted. From these tests a mathematical model has been derived that, by using the sum of the variables in Shelf life (packaging system), predicts the value for Shelf life (packaging system).

ACCELERATED TESTING

Accelerated testing was conducted with two cases of the following design:

- .375 High Density Polyethlene outer case
- 32 Units of Montmorlinite clay desiccant (1 gram = 1 unit) contained in a cloth bag
- Aluminum bezel on outer case with 2.5 mm O-ring seal
- Closed cell polyethylene foam cushioning
- Pressure relief valve +/- 0.5 p.s.i actuation
- Wooden models were used in place of the real product

The cases were exposed to (nominally) 90 % R.H. and 100° F. This temperature and humidity setting represents some of the severest conditions an unprotected shipping container would need to withstand in the field (Mustin, 1963).

Temperature and humidity measurements of the case interior were recorded using a custom made instrument pack (Figure 27). This pack was coupled magnetically through the container walls with a remote readout device to record temperature and humidity data (Appendix C). The instrument readings showed an initial decrease in humidity inside the containers to a very low level (< 6%) where it remained until the completion of the tests. Initially these tests were intended to be a 90 day exposure. The time was extended to approximately 120 days when the instrument batteries failed.

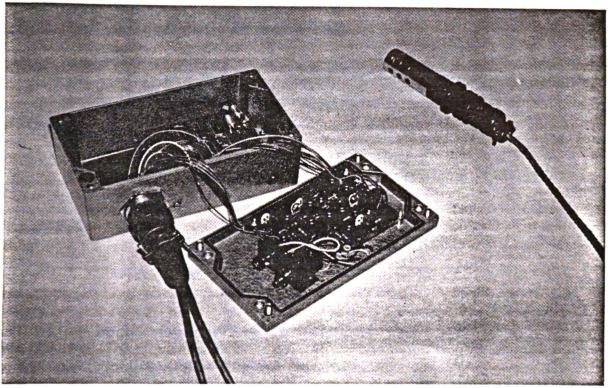


Figure 27. Signal Conditioning Electronics Mounted in a Hermetic Enclosure (Cover Open)

To confirm the humidity readings of the instrumentation, each case had 32 units of dried desiccant placed in it. Each bag was weighed before and after the test (Table 7).

Table 7. Weight Gain of Desiccant

Package #	Initial Weight (grams)	Final Weight (grams)	Change in Weight (grams)
Case A			
1	550	566	+16
2	543	564	+21
Case B			
3	544	563	+19
4	543	560	+17

Each "package" is 16 units of desiccant and so the average weight increase is:

Case A: Adsorbed Moisture = 16 + 21 / 32 = 1.2 grams/unit

Case B: Adsorbed Moisture = 19 + 22 / 32 = 1.1 grams/unit

From these values, and the moisture isotherm for the desiccant (see Figure 28), it appeared that the relative humdity inside the packaging system, for the time tested (i.e. 120 days), remained at or below 5%*. This agreed well with the internal relative humidity values recorded by the instrumental method.

* even though this is for desiccant at 25^{o}C the amount of moisture desiccant can adsorb at 38^{o}C is about the same (Union Carbide, 1979).

Considering how much moisture was absorbed in 120 days at these test conditions, how long would it take to

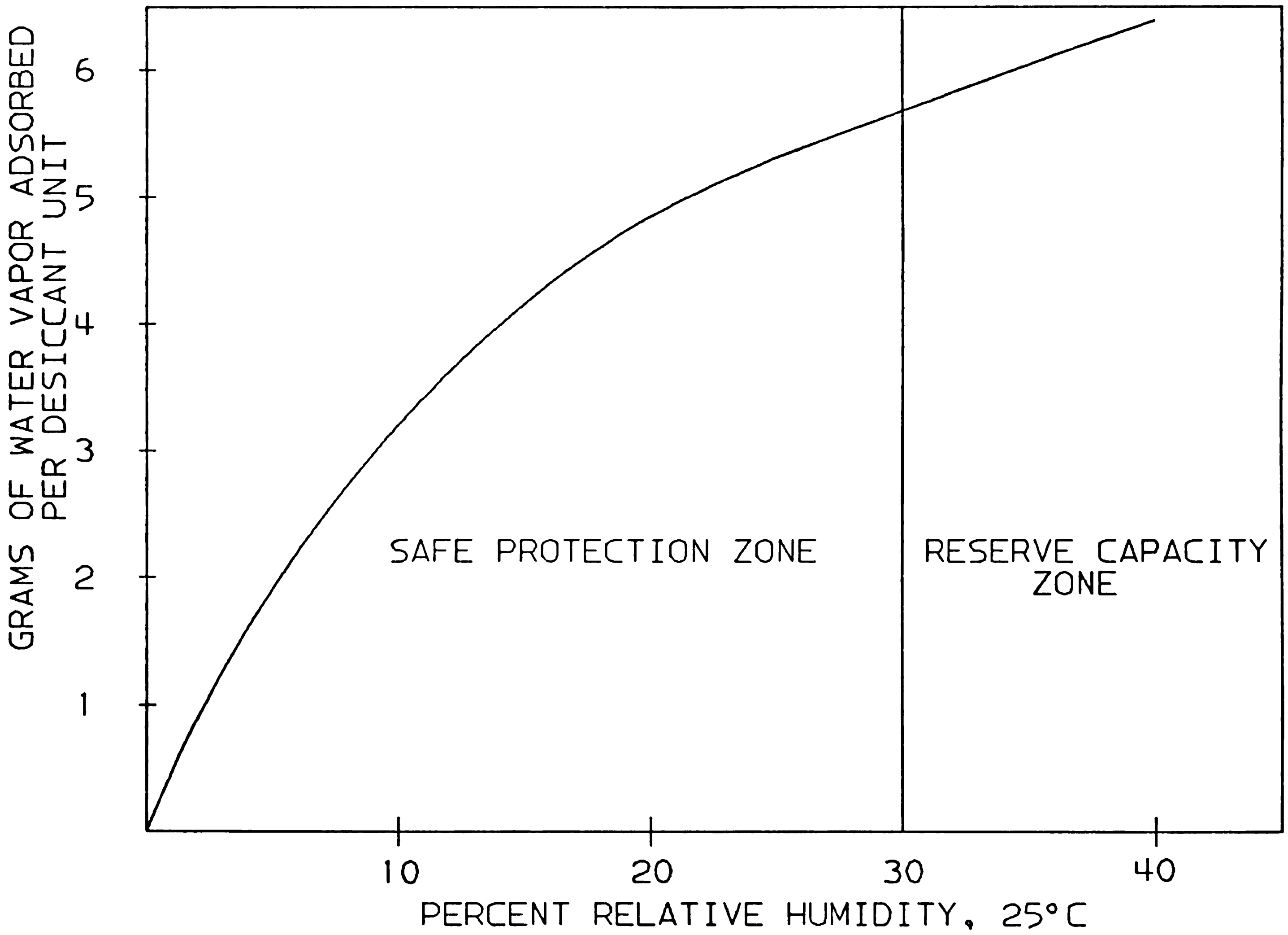


FIGURE 28. MOISTURE ISOTHERM FOR CULLIGAN'S ACTIVATED CLAY DESICCANT

bring the level of relative humidity inside the case over the safe range (30 % R. H.) referred to in Figure 28 ?

According to the desiccant`s moisture isotherm, when the grams of water vapor adsorbed per unit exceeds 5.4, the relative humidity > 30 %. Therefore, if: (i) A linear relationship for moisture absorbed by the desiccant; (ii) A constant driving force is set up between the partial pressure of moisture internal to the package vs. the partial pressure of moisture external to the package, is assumed. Then a direct ratio could be used to solve the above problem.

$$\frac{5.4 \text{ grams/unit}}{1.15 \text{ grams/unit}} = \frac{X \text{ days}}{120 \text{ days}}$$

X days = 563.5 days

or 1.54 years

Since the product/package's Shelf life (defined) was two years and Shelf life (unpackaged product) = 0, each board was packed with 64 units of desiccant, making Shelf life (packaging system) = 3.08 years. This would satisfy Shelf life (defined) of 2 years at these high temperature and humidity conditions.

It must be pointed out that the value for Shelf life (packaging system) is probably a low estimate. This is because, as time goes on, the desiccant absorbs moisture resulting in a continual increase of the relative humidity internal to the package. This is illustrated by the desiccant's moisture isotherm. This increasing internal relative humidity would decreases the driving force (the difference between the relative humidity outside the package to inside the package) of moisture through the package. This change of driving force would decrease the transmission rate of moisture into the package and consequently increase the value of Shelf life (packaging system) in a non-linear manner.

To give us a more accurate answer, unlike the direct ratio comparison above, the following mathematical model was derived to quantify the value of Shelf life (packaging system). This value could be determined by using readily accessible information about the packaging system and the environment to which it would be subjected.

MATHEMATICAL MODEL

In deriving this model, the following assumptions were made:

- Temperature and humidity, exterior to the packaging system, are held constant.
- There is no interaction of moisture with the product.
- Moisture interaction with the foam is low (Dow Corporation, 1981).
- Permeability coefficient ($\bar{P}_p$) is of the packaging system.
- Moisture is adsorbed by the desiccant per its moisture isotherm, with the driving force of the partial pressure gradient between the interior and exterior of the package decreasing non-linearly until the desiccant is saturated.

- Once the desiccant is saturated, assuming that the package's internal relative humidity (R.H. int) is less than the relative humidity external to the package (R.H. ext), transmission of moisture into the headspace halts when R.H.int equals R.H. ext. This also occurs in a non-linear fashion.

- The headspace is not a modified, N_2, atmosphere.

As previously mentioned:

Shelf life (packaging system) = f (desiccant's, packaging material's and headspace interaction with water vapor)

In a packaging system with a desiccant, the contribution of the desiccant to Shelf life (packaging system) ends when the desiccant is saturated.

To predict the moisture change in the desiccant, interior to the packaging system, and consequently the time it will take to saturate the desiccant, accurate knowledge of the water vapor transmission of the packaging system and the water sorption characteristics of the desiccant are required. The water vapor transmission of a packaging system is described by Fick's First Law and Henry's Law (Karel, 1975):

$$\frac{dQ}{dt} = \frac{\bar{P}}{\rho} \cdot S\ max \cdot (Ae - Ai) \qquad (4)$$

Where: Q = quantity of water permeated through the package (g)

Ai = moisture activity internal to the package

Ae = water activity external to the package

$\bar{P}_p$ = permeability constant of the package

$$\frac{g \cdot H_2O}{day \cdot mm\ Hg \cdot package}$$

t = time (days)

S max = saturated vapor pressure of water at the temperature of test (mm Hg)

By combining the permeability of the package and the moisture sorption characteristic of the desiccant, a moisture change simulation model can be derived, as follows:

$$\frac{dQ}{dt} = \bar{P}_p \cdot S\ max \cdot (Ae - Ai) \qquad (5)$$

Since

$$dm = \frac{dQ}{W} \qquad (6)$$

and the activity of water can be described as the internal or external relative humidity.

$$Ae = \frac{RH\ ext}{100} \quad \text{and} \quad Ai = \frac{RH\ int}{100} \qquad (7)$$

Therefore:

$$\frac{W \cdot dm}{dt} = \bar{P}_{\rho} \cdot \frac{S\ max}{100} \cdot (RH\ ext - RH\ int) \tag{8}$$

$$dt = \frac{W \cdot dm}{\bar{P}_{\rho} \cdot \frac{S\ max}{100} \cdot (RH\ ext - RH\ int)} \tag{9}$$

$$\int_0^t dt = \frac{100 \cdot W}{P \cdot S\ max} \cdot \int_{M0}^{Mt} \frac{dm}{(RH\ ext - RH\ int)} \tag{10}$$

Where dm is the instantaneous moisture content change, W is the dry weight of the desiccant, M0 is the initial moisture content of the desiccant, Mt is the moisture content of the desiccant at time t. Relative humidity, internal to the package, can be expressed as a function of moisture content of the desiccant using a polynomial model of the following form:

$$RH\ int = A + Bm + Cm^2 + Dm^3 + \cdots \tag{11}$$

Combining equations 10 and 11 yields:

$$t = \frac{100 \cdot W}{\bar{P}_{\rho} \cdot S\ max} \cdot \int_{M0}^{Mt} \frac{dm}{[RH\ ext - (A + Bm + Cm^2 + Dm^3)]} \tag{12}$$

By using this model, the relationship between t and Mt can be used to calculate the time required to saturate the desiccant in the packaging system. By having Mt equal to the value for the desiccant being saturated the exact amount of time of Shelf life (desiccant) can be determined.

Once the desiccant is saturated, the external environment seeks to achieve equilibrium with the internal environment. Thus starting with $\bar{P}_\rho$:

$$\bar{P}_\rho = \frac{\text{grams}}{\text{day} \cdot \text{mm Hg} \cdot \text{package}} = \frac{\text{grams}}{t \cdot P \cdot \text{package}} \qquad (13)$$

$$\text{grams} = \bar{P}_\rho \cdot \text{package} \cdot (P\ \text{ext} - P\ \text{int}) \cdot t \qquad (14)$$

Stating the ideal gas law : $p \cdot V = n \cdot R \cdot T$ (15)

$$n = \frac{P \cdot V}{R \cdot T} \qquad (16)$$

Converting moles of water to grams :

$$\text{grams} = 18\ \text{grams/mole} \cdot n \qquad (17)$$

Therefore: $$\text{grams} = \frac{18 \cdot P\ \text{int} \cdot V\ \text{int}}{R \cdot T} \qquad (18)$$

Where:

P ext is the vapor pressure of moisture external to the package (mm Hg)

P int is the vapor pressure of moisture internal to the package (mm Hg)

V int is the headspace volume of the package (liters),

R is the ideal gas constant ($\frac{1 \cdot \text{mm Hg}}{K^{o} \cdot \text{mole}}$)

T is the temperature (K^{o})

Combining equation 18 and 13 yields:

$$\frac{18 \cdot P\ int \cdot V\ int}{R \cdot T} = \bar{P}_p \cdot package \cdot (P\ ext - P\ int) \cdot t \qquad (19)$$

$$P\ int = \frac{R \cdot T \cdot \bar{P}_p \cdot package}{18 \cdot V\ int} \cdot (P\ ext - P\ int) \cdot t \qquad (20)$$

$$C_1 = \frac{R \cdot T \cdot P \cdot package}{18 \cdot V\ int} \qquad (21)$$

$$P\ int = C_1 \cdot (P\ ext - P\ int) \cdot t \qquad (22)$$

$$\frac{P\ int}{(P\ ext - P\ int)} = C_1 \cdot t \qquad (23)$$

Setting the limits for the right side of the equation from the internal vapor pressure at time 0 [P int (t=0)] to the internal vapor pressure at time t [P int (t=t)] and setting the limits of the left side of the equation from t = 0 to t = t. Then integrating yields:

$$\int_{P\ int\ (t=0)}^{P\ int\ (t=t)} \frac{d\ P\ int}{(P\ ext - P\ int)} = \int_{t=0}^{t=t} C_1\ dt \qquad (24)$$

Evaluating the integral

$$\Big|_{P\ int\ (t=0)}^{P\ int\ (t=t)} \ln\ (P\ ext - P\ int) = \Big|_{t=0}^{t=t} C_1 \cdot t = C_1 \cdot t \qquad (25)$$

$$\ln\,[P\,ext(t)-P\,int(t)] - \ln\,[P\,ext(0)-P\,int(0)] = C_1 \cdot t \qquad (26)$$

$$\ln x - \ln a = \ln x/a \qquad (27)$$

$$\text{Therefore : } \ln \frac{[P\,ext\,(t) - P\,int\,(t)]}{[P\,ext\,(0) - P\,int\,(0)]} = C_1 \cdot t \qquad (28)$$

$$C_2 = 1/C_1 = \frac{18 \cdot V\,int}{R \cdot T \cdot \bar{P}_p \cdot package} \qquad (29)$$

Combining equation 28 and 29 yields

$$t = C_2 \cdot \ln \frac{[P\,ext\,(t) - P\,int\,(t)]}{[P\,ext\,(0) - P\,int\,(0)]} \qquad (30)$$

$$R\,H\,ext = \frac{P\,ext}{S\,max} \cdot 100 \qquad (31)$$

$$R\,H\,int = \frac{P\,int}{S\,max} \cdot 100 \qquad (32)$$

Where S max is the water vapor saturation pressure at a specific temperature.

Using equations 31 and 32 in equation 30 gives us

$$t = C_2 \cdot \ln \frac{[R\,H\,ext\,(t) - R\,H\,int\,(t)]}{[R\,H\,ext\,(0) - R\,H\,int\,(0)]} \qquad (33)$$

Substituting in equation 29 gives:

$$t = \frac{18 \cdot V\,int}{R \cdot T \cdot \bar{P}_p \cdot package} \cdot \ln \frac{[R\,H\,ext\,(t) - R\,H\,int\,(t)]}{[R\,H\,ext\,(0) - R\,H\,int\,(0)]} \qquad (34)$$

Using the critical R.H. for the product, for R.H. int (t=t) in the previous equation would tell us how long it would take the headspace of the packaging system to reach the critical relative humidity. Having R.H. int (t=t) equal to the relative humidity that the packaging system is stored in will tell how long it will take for the R. H. inside the package to equilibrate with the external relative humidity. R H ext (t=0) would equal the external relative humidity for any situation. R H int (t=0) would equal the internal relative humidity when the desiccant is saturated. With this example this value would be 30 %. Therefore, the above equation describes f(headspace) for a product with a specific R.H. critical or when R.H. int = R.H. ext.

The contribution of f (material's) shows that the previous equations consider $\bar{P}_p$ of the material used in the packaging system and that the foam's contribution to moisture adsorbtion is low.

Combining equations 12 and 34 gives an equation that can be used to quantify the value of Shelf life (packaging system) based on the level of relative humidity within the package's internal environment.

$$t = \frac{100 \cdot W}{\bar{P}_p \, S \, max} \cdot \int_{M0}^{Mt} \frac{dm}{[RH\,ext - (A + Bm + Cm^2 + Dm^3)]}$$

$$+ \frac{18 \cdot V\,int}{R \cdot T \cdot \bar{P}_p \cdot package} \cdot \ln \frac{[R\,H\,ext\,(t) - R\,H\,int\,(t)]}{[R\,H\,ext\,(0) - R\,H\,int\,(0)]} \qquad (35)$$

The only changes to the preceding equation, for a packaging system whose $\bar{P}_p$ does not vary over a temperature range, would be the different parameters established from the external conditions in which the packaging system was placed. For those systems where $\bar{P}_p$ varies over a temperature range, the addtional information needed is the $\bar{P}_p$ values at each temperature of test. The $\bar{P}_p$ values could be easily established by doing permeability testing of the system at the temperatures of interest. By using this method, the time to establish the shelf life is only limited to the time it takes to quantify $\bar{P}_p$ rather than performing a time consuming field test or an over stressful accelerated shelf life test.

How valid this model is, has not been checked with an actual experimental verification, but that is a topic for further investigation.

OUTGASSING

The outgassing of corrosive volatiles is also a concern to the packaging engineer, especially if the product involves any electrical circuitry. This fragility comes from the minuteness of the circuit (some circuits are as fine as 10 Å in diameter) or involves contact points that are later to be connected to conduct electricity. The corrosive volatile could corrode a fine circuit and create a short circuit or it could oxidize a contact point in a component creating a resistive short. Outgassing of non-corrosive volatiles could coat the contact point on an assembly and hamper its solderability or its ability to conduct electricity as in low voltage/current applications, i.e. "signal contacts" (Jordamo, 1985).

The two catgories for outgassed monomers (Bayer, 1981) are:

(i) Hydrocarbons/Halogenated Hydrocarbons

-Vinylchloride monomer
-Vinylidenechloride monomer
-Vinylidenefloride monomer
-Vinylfloride monomer
-Butyl compounds such as
Butylated Hydroxytoluene (B.H.T.)

(ii) Inorganics

-Cyanide from Polyacrylonitrile
-Chlorine, Iodine, Bromine; from halogenated polymers
-Sulphur from corrugated
-Nitrogens from Polyurethanes
-Phosphorous Oxides.

Gas Chromatography/Mass Spectrometry (GC/MS) and thermogravimetric (T/G) analytical techniques are most common in testing for the above volatiles. These were the methods used in testing the different components used in the prototype packaging systems (Table 8):

Table 8. List of Materials that were Tested for Corrosive Outgassed Organic/Inorganic Volatiles

Material	Test method
Clay Desiccant	GC/MS
Ethafoam (blue pigment)	"
Outer case H.D.P.E	"
Aluminium bezel	"
Silicone Rubber Tubing (o-ring seal)	"
Ethafoam (white)	"
Hot Melt Adhesive (to adhere cushion to case)	T/G

The GC/MS tests were carried out by placing samples of the above materials in separate nitrogen purged flasks and heated to 103 +/- 5^{o}C for twelve hours. The evolved gases were analysed for organics by the GC/MS method. The units of measure for any eluted media was parts per billion weight/volume.

Thermogravemetric (T/G) tests were carried out by heating the sample at a constant rate to 190^{o}C, then measuring weight loss to initial weight of the product as a function of time.

No volatile hydrocarbons or halogenated hydrocarbons were measured above the 1 ppb detection limit.

No volatile inorganics such as Cyanide, Chlorine, Iodine, Bromine, Sulphur, Nitrogen or Phosphorus Oxide were measured above the 1 ppb detection limit.

From these results, the design group felt that there was no risk due to outgassed volatiles. Thus, the prototype had passed this engineering criteria.

FLAMMABILITY

Although flammability may be of little concern to the product itself, from a safety and a materials point of view it is important. In fact it may even be important from an insurance coverage point of view. The following table provides an understanding of the combustability of standard plastic packaging materials (Table 9) (Packaging 427, 1979).

Table 9. Combustabilty of Plastic Packaging Materials

Material	Supports Combustion
Cellophane	Yes
Polystyrene	Yes
Polyethylene	Yes
Polyvinylchloride	No
Polypropylene	Yes
Mylar (Polyester)	Yes (not readily)
Cellulose Acetate	Burns slowly
Nylon	Yes (poorly)
Saran	Yes
Corrugated (untreated)	Yes
Polyurethane	Yes (toxic fumes)

A common test method used in determining how well plastic materials support cumbustion is Underwriters Laboratories Standard for Safety 94, Test for Flammability of Plastic Materials for Parts in Devices and Appliances.

In this test method there are four different categories:

- Structural Plastics (94 V-X)*
- Structural Plastics (94 5-V) (Enclosure Applications)
- " Acoustic" Foams (94 H-X)
- Printed Circuit Cards/Boards (94 V-X)

* some ratings of flame retardency (best to worst) : V-0 , V-1 , V-2 or HB.

There is no specific test procedure for testing packaging materials, although sections 94 V-X and 94 H-X are the tests used. In 94 V-X samples are held vertically and the rate of flame propagation measured in inches/minute. For 94 H-X samples are held horizontally with flame propagation also measured in inches/minute.

In the packaging system under study, most of the components were polyethylene and metal. The metal components and the heavy gauge polyethylene were fairly safe materials to use from a flammability point of view. Even though the polyethylene foam, used to cushion the product, would support cumbustion, it is enclosed in the outer case and not readily accessible from an exterior flame.

RANDOM VIBRATION

Random vibration testing is another test method available to the design engineer. In this example it was not used since there was no data available on the product's fragility to random vibration. Also, it was assumed that the primary resonance at 90 Hz was the most crucial vibration exposure. A brief discussion on the differences of sinusoidal and random vibration testing would be beneficial to a packaging engineer.

The basic differences between the source of discrete sinusoidal and broadband random vibration is listed in Table 10 (Kerr, 1982).

Table 10. Comparison of Random and Sinusoidal Vibration

Discrete Sinusoidal Vibration	Broadband Random Vibration
- Cyclic and periodic	- Nonrepetitive and aperiodic
- Usually constant and nonvarying peak amplitude levels	- Continuously and randomly varying peak amplitide levels
- Energy at only one frequency	- Energy at many frequencies

Tests have shown that the vibration present in transportation environments is broadband and mostly random in nature (Figure 29). This means that packaged products are exposed to many different frequencies simultaneously during shipment, and the multitude of frequencies present are randomly varying in amplitude.

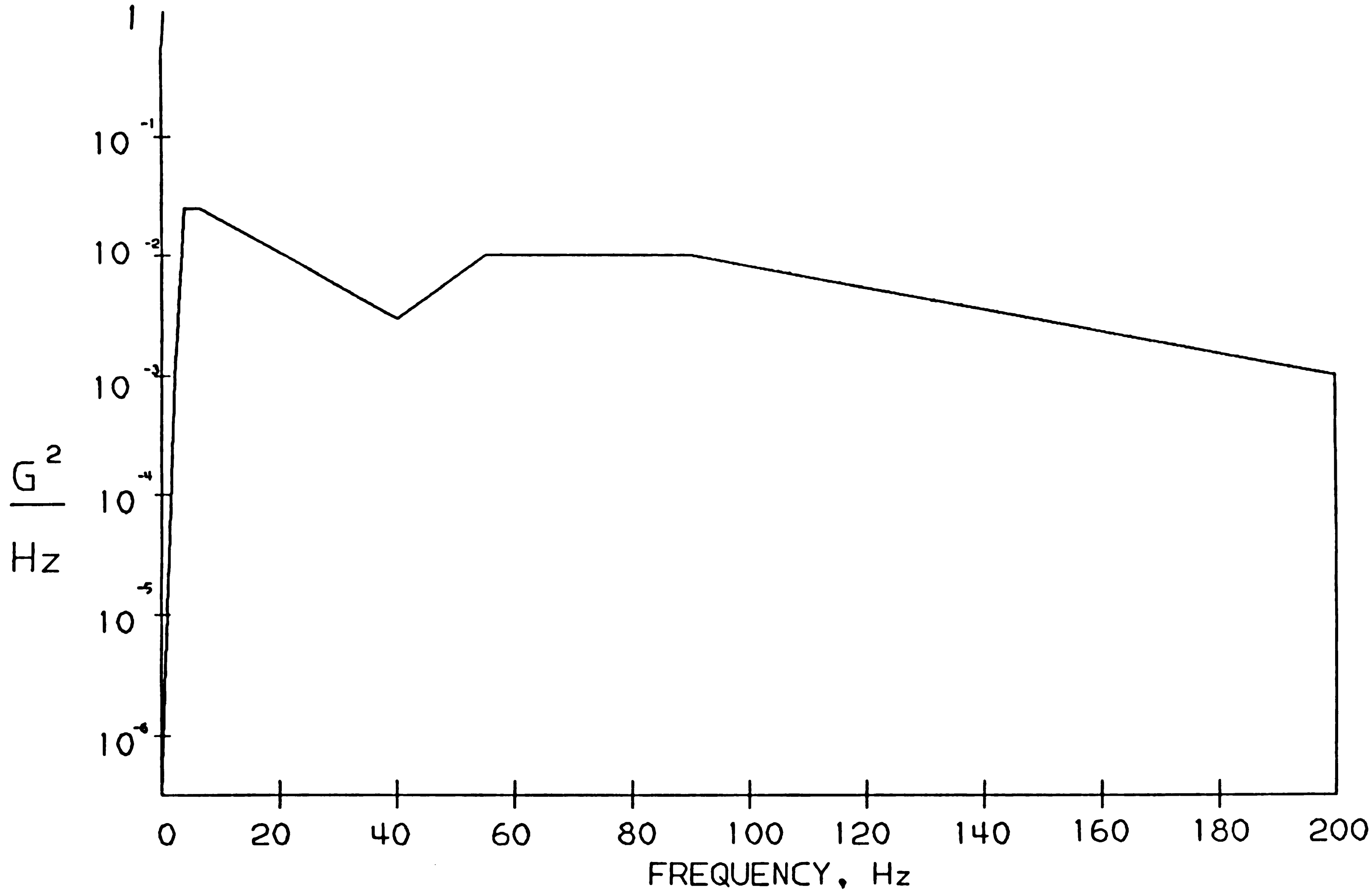


FIGURE 29. CORPORATE COMPOSITE POWER SPECTRAL DENSITY ENVELOPE
(RMS LEVEL = 1.037 G's)

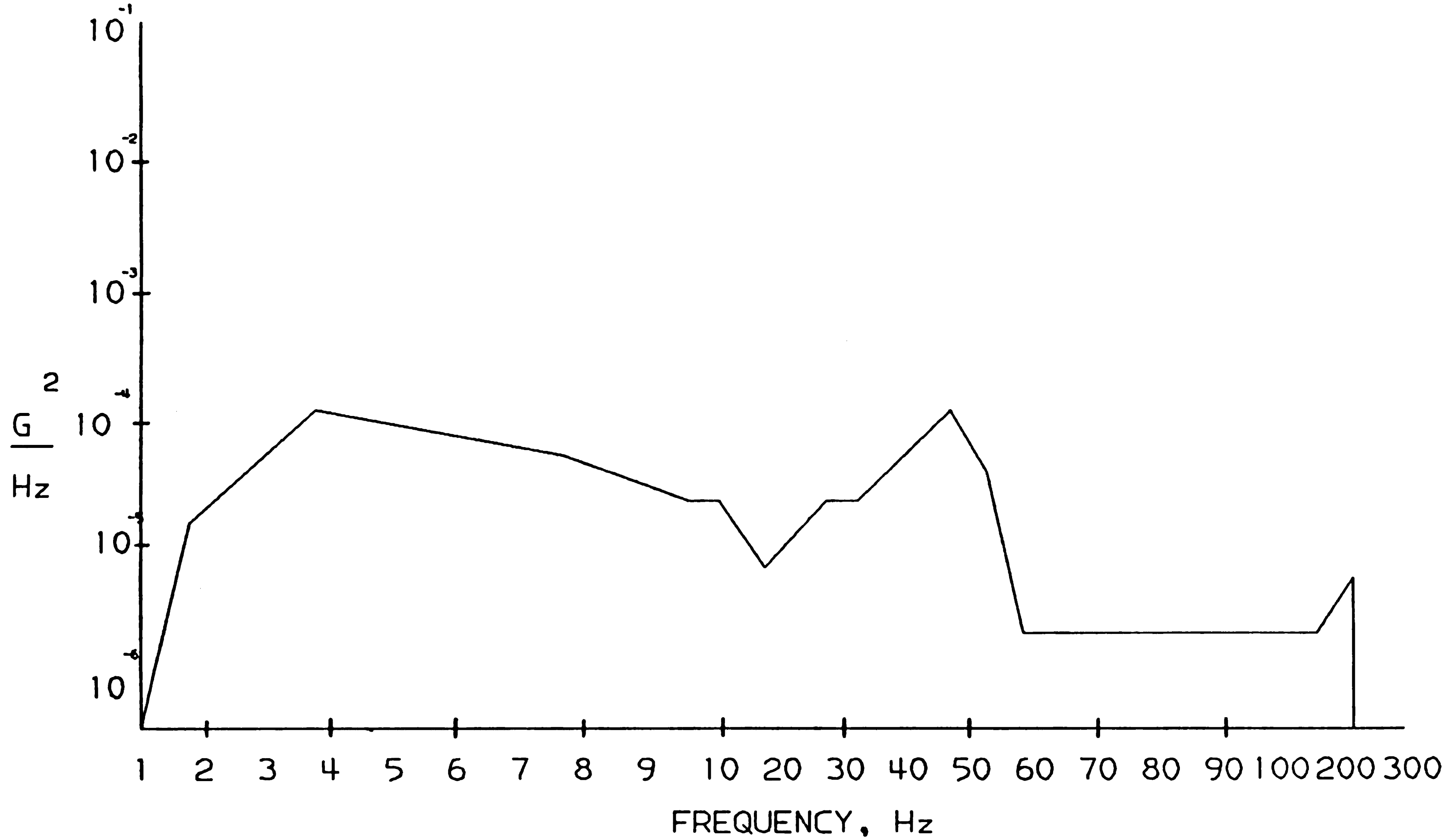


FIGURE 30. TRUCK SPECTRUM POWER SPECTRAL DENSITY ENVELOPE (AIR-RIDE AND COMMON CARRIER)

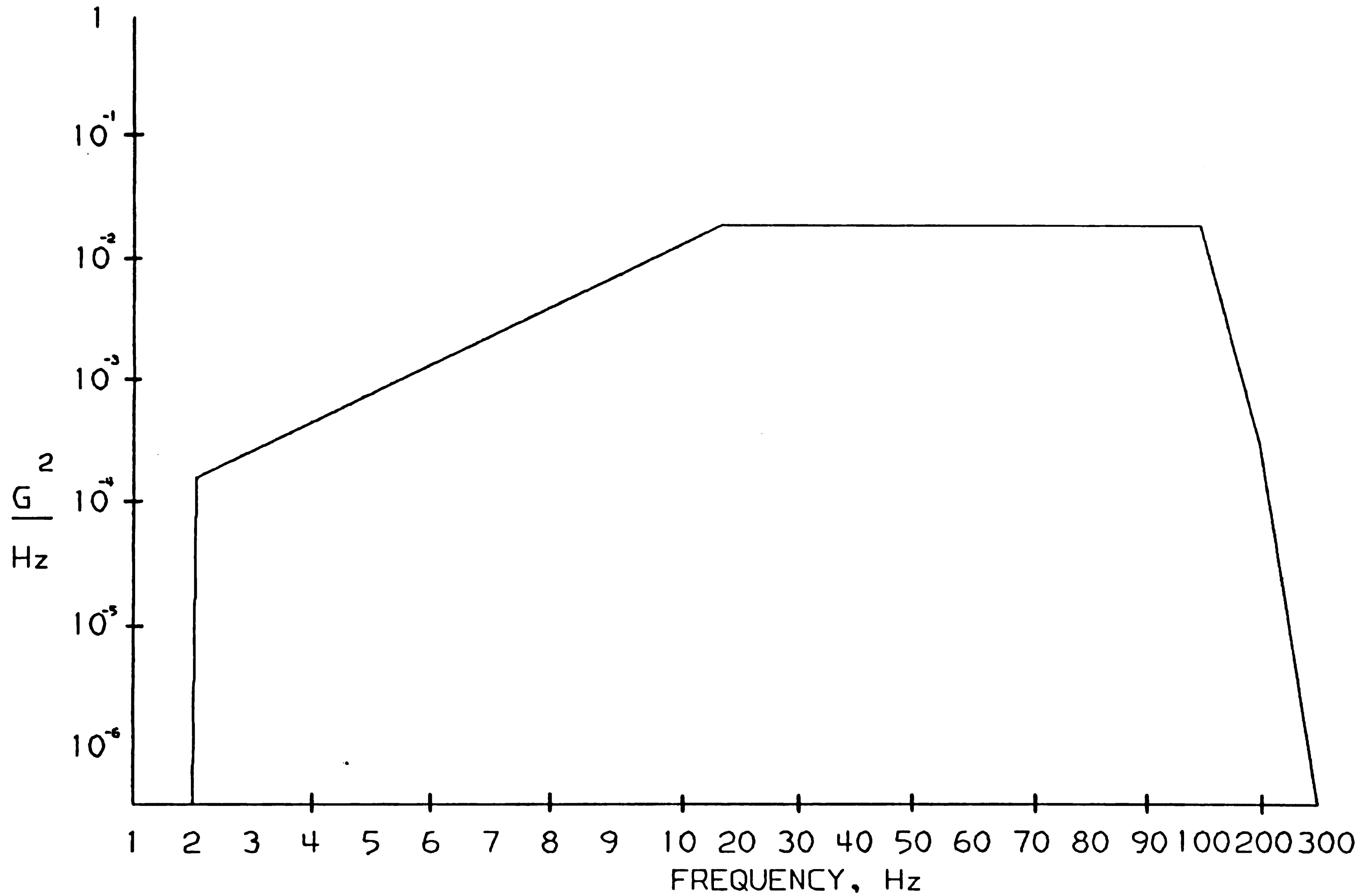


FIGURE 31. AIR SPECTRUM POWER SPECTRAL DENSITY ENVELOPE

Random vibration profiles vary from distribution mode to distribution mode. This is represented graphically, in terms of G^2/Hz (power spectral density) vs frequency, for truck and air (Figures 30 and 31).

Random vibration testing is particularly advantageous when trying to identify problems with:

- simutaneous resonances
- nonlinear system resonances

Because of the nature of sine testing, for vibration problems using resonance dwell and search, some interaction between critical frequencies could escape the test and not be identified. These critical frequencies could cause problems later on if they aren't identified and the packaging system designed to filter out these harmful components of vibration. Random vibration, with its broadband input, could excite these critical frequencies in unison which would notify the engineer that indeed there is a set of frequencies that should be considered in the packaging system's design.

Another type of vibration problem that is difficult to reveal with sine vibration testing is with nonlinear system resonances. A linear system's response is proportional to the input excitation regardless of the stimulus type. A nonlinear system's response is not proportional to the input and is dependant on the type of input or stimulus.

Most mechanical systems are linear. However, some products could respond to vibration in a nonlinear manner. For these products, there is difficulty in producing responses in the product using sine vibration. For such a case random vibration should be used.

The best test method would be to use both sinusoidal and random vibration in evaluating the product's and packaged product's responses to vibration.

ENGINEERING ANALYSIS OF DATA/REDESIGN

This step, along with the previous steps, should be considered the basis of the engineering loop that eventually yields the final implemented design. In each part of the experimental portion of the design sequence, changes on the initial prototype were made to give the best design. This method of engineering is less time consuming than constantly building new prototypes, going through the full experimental sequence, compiling/analysing data and then going into redesign.

Once the final design is reached, implementation into the manufacturing process can begin.

IMPLEMENTATION

Implementing a design can be the severest test of both the packaging system, and the packaging engineer. This comes from the scrutiny placed on both the system and the engineer. The way to alleviate some of the contention in implementation is to allow the various organizations to which the design is provided, to participate in user review meetings. Allow them to have some input into the design but reserve the right to make the final judgement.

With the example presented, the organizations with which one had to interface were: quality engineering, field engineering, manufacturing engineering, manufacturing, product engineering, industrial safety and industrial engineering. Input from the groups were solicited by both formal and informal meetings during the fifth and sixth steps of the design sequence. Once the design was finalized, follow-up meetings were held and participants were asked to sign-off on a document of understanding, documenting concurence with package engineering that the design was indeed ready to be implemented.

Earlier, a flow chart of the product was detailed (see Figure 2, pg. 5). This is key in determining where you want the package to be implemented.

For illustration:

```
                                                  |--►   build
                                                  |    (via truck)
   end of                                         |
manufacturing  -►in house stocking -►             |
    line                                          |
                                                  |-► distribution
                                                        centers
                                                  (via truck and air)
```

Figure 32. Flow Chart of the Circuit Board's Distribution

The easiest way to implement the design would be to have all new product placed into the new packaging system as it comes off the manufacturing line. If the packaging system that has been designed is far superior to what is currently being used , as was in this example, then a blanket implementation should be used. This means all product throughout the flow (E.O.L. to customer accounts) should be retrofitted into the new design.

In order for this to be accomplished, a complete packaging specification is required, as well as a vendor who is able to keep up with the quantities needed to "fill up the pipeline".

A complete specification was one that the organizations, mentioned earlier, could use when interfacing with this new packaging system. As previously discussed, it was known that the vacuum formed case would not create a gap between packaging systems available and boards produced.

With the above items satisfied, there is one other requirement that the design engineer must complete. That is to assure that the cases produced are to the specifications that were established during the engineering phase of the design sequence. This leads to the next section of the design sequence, that of maintaining quality assurance at the vendor.

MAINTAINING QUALITY ASSURANCE AT THE VENDOR

In the production of the packaging system, maintaining quality is best accomplished by having the systems produced conforming to engineering specifications established by the packaging engineer. These specifications are in the form of assembly and part prints from which completeness of the package can be determined. Information on items such as dimensional, functional or cosmetic specifications, established for the implemented packaging system, should be available on these prints.

In order to assure that the specifications established are being conformed to by the vendor, an inspection procedure should be carried out either by an in-house receiving inspection or at the vendor site. It is best to do inspections at the vendor site because of the immediate feedback that could be generated to the vendor if indeed a problem did crop up.

Table 11 lists some of the elements that are needed for a complete inspection procedure.

Table 11. Elements of an Inspection Procedure

1. Inspection sequence
2. Defect classification
   (in conjunction with a sampling plan)
3. Written evaluation of inspection

The inspection sequence helps organize the lot evaluation. In the example described, a pressure test was one of items in the sequence. This was performed after the outer case's dimensions were checked, since the pressure test deformed the outer case. After this pressure test, the inner case was checked for its dimensional and assembled correctness.

Defect classification defines both the defect and its severity. The three defect levels used with this example were critical, major and minor defects. An example of a critical defect is the packaging system's inability to pass the pressure test. This would indicate a loss of seal integrity and the potential transmission of water vapor to the product. An example of a major defect is when the casters didn't roll and swivel as they were suppose to. An example of a minor defect is when the paperwork holder was improperly placed on the outer case.

Not every case produced could be checked for defects in the critical, major and minor categories. Therefore, a sampling plan was used to inspect the production lots of cases that were to be used by I.B.M. Poughkeepsie.

A sampling plan allows the inspector to get a measurement of the lot's conformance to specifications by examining only a small percentage of cases in the lot. The amount sampled is determined by the Acceptable Quality Level (A.Q.L.) established by a quality organization. One of the most common sampling plans used is Military Standard 105-D.

Depending on whether the lot is rejected or passed, a writen report should be required. This report gives the engineer a method of locating specific lots of cases if there were any problems in the manufacturing of the packaging systems. For example, if after a period of time a certain lot starts to fail for one reason or another, the cases from that lot could easily be recalled.

Establishing specifications and inspecting cases produced to these specifications will help maintain the level of quality needed to insure the packaging systems received are acceptable and will function as designed.

ESTABLISH A REFURBISHING PROGRAM

It is not always a good idea to design your packaging system to be reuseable. For obvious reasons a reuseable design is generaly more costly. If it is felt that the package is a throw-away item, then it is safe to design the package as a one-way package. In the electronics industry, when a part is sent out, invariably the part returned from the field uses the same package as that which held the replacement unit. Many times one-way packaging has been used to return parts from the field and many times this has resulted in the damage of valuable product, due to the reuse of this packaging.

One of the biggest causes of damage, is that of foam in place being reused to return a part. Usually the customer engineer damages the foam so severely, when removing the part from the package, that it is of little use in protecting the part on its return trip to the plant.

For the example cited, because of the cost of the part and of the packaging system, a refurbishing/return program was established. Two types of programs were considered: that of 100% of the cases to be sent to a refurbishing operation or to have each area do a brief inspection and send any cases that needed to be repaired to a refurbishing vendor. The latter was selected, since this would take the least amount of cases out of use and keep the float* levels at an economical level.

* Float is defined as the amount of cases that are not avalable in which to store new product, as with cases in stock with product in them or those at the refurbishing vendor.

The refurbishing vendor need not be the same as the new-build vendor. However, This would help in procuring parts needed for refurbishing the returned cases. Both the new-build and the refurbish vendor should work to the same quality level and be inspected using the same inspection criteria. In our example, the refurbishing vendor was the same as the new-build vendor. This helped keep the price of the refurbishing operation down and again allowed parts to get to the refurbishing operation in a timely manner.

CLOSE

To date, approximately 4000 of these packaging systems have been purchased since its introduction into the I.B.M. Poughkeepsie manufacturing process in January, 1983. Due to the configuration of the circuit boards in the new computer systems changing slightly, the inner cushioning in the newer packaging systems has changed. However, the outer case can still be used for these new computer system's circuit boards. In fact, until the circuit packaging of the board changes, these shipping/handling containers will be an integral part of the movement of this product in-house and in the field.

RECOMMENDATIONS

1. Use the equations developed in the mathematical model of shelf life determination to establish some theoretical values. Compare these values to values obtained from similar packaging systems exposed to various temperature and humidity conditions.

2. Establish a realistic method for determining the flammability of packaging materials.

3. Determine how a packaging system acts as a filter when subjected to random vibration.

4. Compare accelerated shelf life values to ambient condition shelf life values and determine if there is any correlation.

APPENDIX A

SHOCK AND VIBRATION DATA SETS

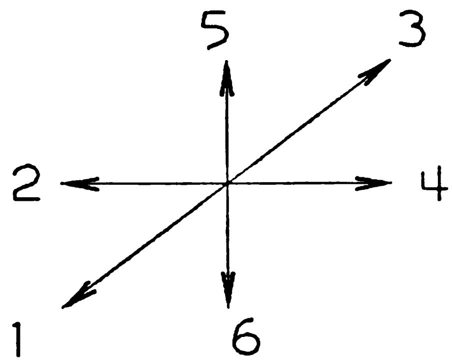
SHOCK EQUIPMENT USED

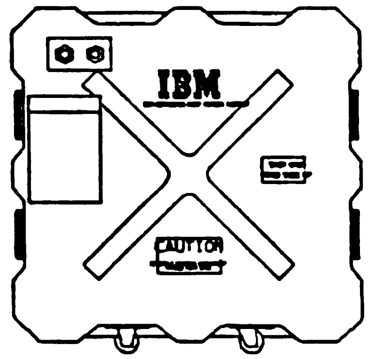
- Endevco 2228 triaxial acclerometer
- Lansmont Model 100/225 shock table
- Kisler charge amplifiers
- Textronix 613 storage oscilloscope

VIBRATION EQUIPMENT USED

- Lansmont Model 6000-15 electro hydraulic vibration table
- Endevco 2228 triaxial acclerometer
- Kisler charge amplifiers
- Textronix 613 storage oscilloscope

SHOCK DATA SET SHEET
DROP HEIGHT 18″





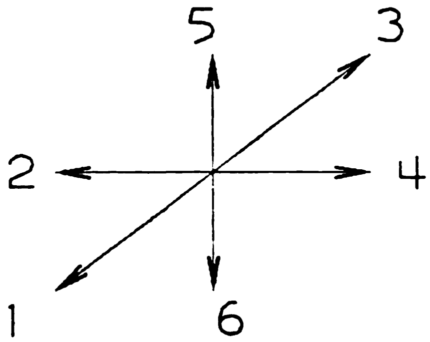
DATA SET 1 (ROTARY MOLDED CASE W/ELASTOMERIC SHOCK MOUNTS)

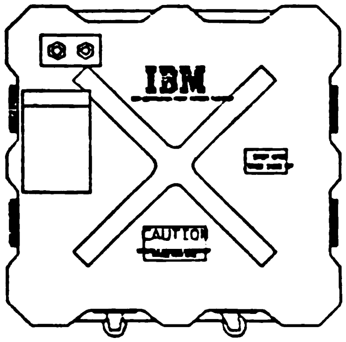
Type of drop	Side #	X	Y	Z (G's)
ON CASTERS	6	20	0	0
TOP	1	0	3	30
BOTTOM	3	0	0	36
RIGHT SIDE	4		27	
LEFT SIDE	2	3	32	4
LEFT SIDE	2		29	
OPP CASTERS	5	19.5	2	0
CORNER	2-6-1	23	24	7
EDGE	2-6	9.5	29	0
EDGE	2-1	51		

DATA SET 2 (2.2 pcf foam loaded to .74 psi in the z-axis)
TEMP 70° F

Type of drop	Side #	X	Y	Z (G's/ms)	
CORNER	2-6-1	20/3	22/25	14/25	
EDGE	3-4	12/25	22/10	16/25	sum of g's 32.8
BOTTOM	3	-	-	28/24	ΔV=259.6
TOP	1	-	-	22/21	″
ON CASTERS	6	19/23	-	-	
OPP CASTERS	5	17/24	-	-	
LEFT SIDE	2	-	20/24	-	
RIGHT SIDE	4	-	21/26	-	

SHOCK DATA SET SHEET
DROP HEIGHT 18"





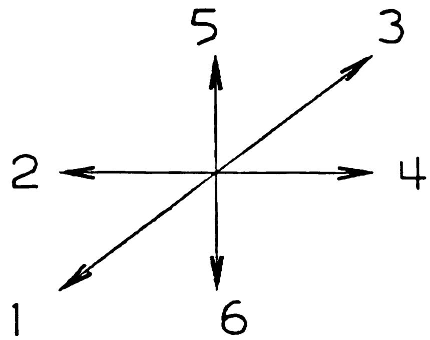
DATA SET 3 (2.2 pcf foam loaded to 1.2 psi in the z axis)
TEMP 70° F

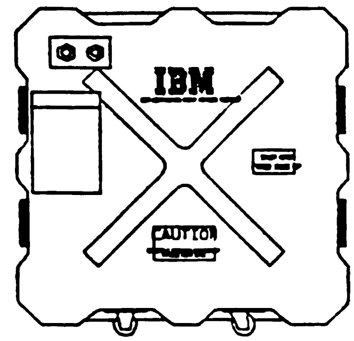
Type of drop	Side #	X	Y	Z (G's/ms)	
EDGE	2-6	14/18	18/19	12/3	sum of g's 22.8
LEFT SIDE	2	-	17/22	12/3	
RIGHT SIDE	4	-	14/20	7/2	
CASTERS	6	14/22	-	5/3	
OPP CASTERS	5	17/21	-	12/4	
BOTTOM	3	-	-	24/17	ΔV =157.7
TOP	1	-	-	15/16	

DATA SET 4 (2.2 pcf foam loaded to .74 psi in the z axis)
TEMP 70° F

Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	3	3/4	-	12/16	
EDGE	2-6	16/22	17/20	8/3	sum of g's 23.3
LEFT SIDE	2	-	13/20	12/3	
RIGHT SIDE	4	-	12/2	12/4	
CASTERS	6	18/25	4/11	4/3	
OPP CASTERS	5	12/22	-	8/3	
BOTTOM	3	-	-	20/21	ΔV =162.2
TOP	1	-	-	16/15	

SHOCK DATA SET SHEET
DROP HEIGHT 18"





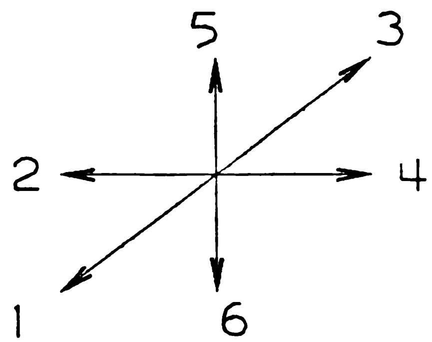
DATA SET 5 (2.2 pcf foam loaded to 1.2 psi in the z axis)
TEMP 70° F

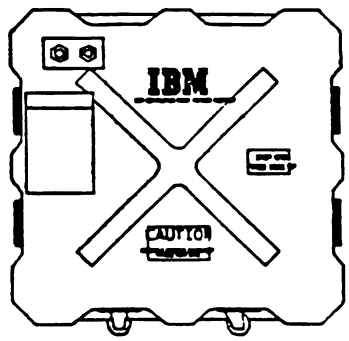
Type of drop	Side #	X	Y	Z (G's/ms)	
EDGE	2-6	16/19	17/23	8/3	sum of g's 23.3
LEFT SIDE	2	-	16/21	9/3	
RIGHT SIDE	4	-	15/20	12/3	
CASTERS	6	17/22	-	9/6	
OPP CASTERS	5	16/22	-	10/4	
BOTTOM	3	-	-	36/14	ΔV= 194.7
TOP	1	-	-	20/16	
TIP	1	-	-	16/12	

DATA SET 6 (2.2 pcf foam loaded to 1.2 psi in the z axis)
TEMP 70° F

Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	1	3/12	-	15/24	
EDGE	6-4	10/14	15/14	16/4	sum of g's 18.0
RIGHT SIDE	4	-	15/19	10/4	
LEFT SIDE	2	-	19/20	10/4	
CASTERS	6	14/22	-	10/4	
OPP CASTERS	5	15/22	-	10/4	
BOTTOM	3	-	-	28/18	ΔV= 194.8
TOP	1	-	-	17/20	

SHOCK DATA SET SHEET
DROP HEIGHT 18"





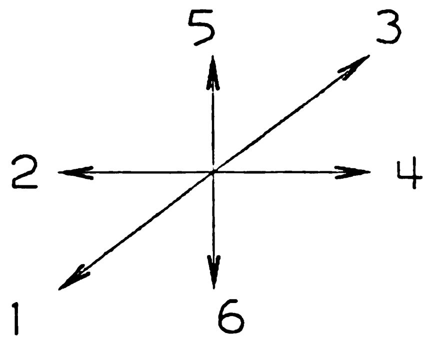
DATA SET 7 (2.2 pcf foam loaded to 1.2 psi in the z axis)
TEMP 70° F

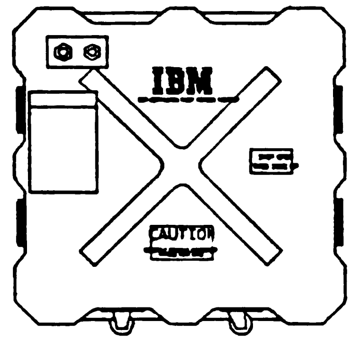
Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	3	-	-	12/18	
TIP	1	-	-	10/22	
EDGE	6-2	10/16	18/21	10/10	sum of g's 20.6
LEFT SIDE	2	-	17/21	12/4	
RIGHT SIDE	4	-	17/22	10/4	
CASTERS	6	17/16	4/7	10/4	
OPP CASTERS	5	17/21	-	11/5	
BOTTOM	3	-	-	26/18	ΔV = 180.8
TOP	1	-	-	16/26	

DATA SET 8 (4.0 pcf foam loaded to 1.2 psi in the z axis)
TEMP 70° F

Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	3	-	-	17/22	
TIP	1	-	-	15/24	
TIP	1	-	4/10	10/29	
TIP	3	-	-	20/20	
EDGE	2-6	12/15	20/20	10/4	sum of g's 23.3
LEFT SIDE	2	-	20/19	10/3	
RIGHT SIDE	4	-	19/18	10/4	
CASTERS	6	17/22	4/14	10/4	
OPP CASTERS	5	18/22	-	10/5	
BOTTOM	3	-	-	22/22	ΔV = 187.0
TOP	1	-	-	15/28	

SHOCK DATA SET SHEET
DROP HEIGHT 18″





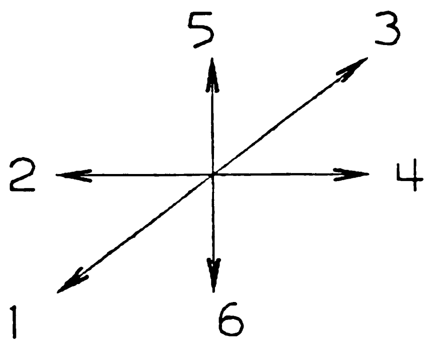
DATA SET 9 (6.0 pcf foam loaded to 2.4 psi in the z axis)
TEMP 70° F

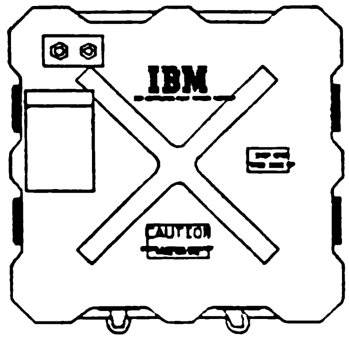
Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	3	-	-	17/26	
EDGE	6-2	13/15	20/18	10/4	sum of g's 23.8
LEFT SIDE	2	-	21/18	12/5	
CASTERS	6	20/18	3/13	8/3	
BOTTOM	3	-	-	30/16	ΔV = 123.7

DATA SET 10 (2.2 pcf foam loaded to .74 psi in the z axis)
TEMP 70° F

Type of drop	Side #	X	Y	Z (G's/ms)	
TIP	3	-	-	20/22	
EDGE	6-2	12/17	19/23	8/4	sum of g's 22.4
LEFT SIDE	2	-	19/24	10/4	
RIGHT SIDE	4	-	16/20	12/4	
CASTERS	6	20/23	-	14/4	
OPP CASTERS	5	12/22	-	10/5	
BOTTOM	3	-	-	18/22	ΔV = 153.0
TOP	1	-	-	13/30	

SHOCK DATA SET SHEET
DROP HEIGHT 18"





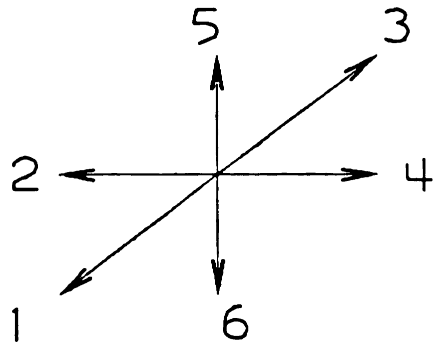
DATA SET 11 (STARTING SHEET THICKNESS .375")
TEMP 70° F

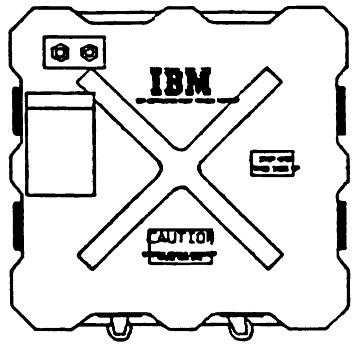
Type of drop	Side #	Y	X	Z (G's/ms)	
LEFT SIDE	2	19/20	-	12/3	
CASTERS	6	-	28/20	16/3	
OPP CASTERS	5	-	17/19	12/3	
RIGHT SIDE	4	22/22	-	12/2	
EDGE	4-6	17/18	19/17	-	sum of g's 25.5
EDGE	2-6	16/17	20/16	-	" 25.6
BOTTOM	3	-	-	28/17	ΔV = 183.9
TOP	1	-	-	21/20	
TIP	3	-	-	16/14	

DATA SET 12 (STARTING SHEET THICKNESS .312")
TEMP 70° F

Type of drop	Side #	Y	X	Z (G's/ms)	
TIP	3	-	-	12/8	
CASTERS	6	-	18/20	-	
RIGHT SIDE	4	18/21	-	12/2	
OPP CASTERS	5	-	18/19	12/2	
LEFT SIDE	2	17/18	-	-	
TOP	1	-	-	17/20	
BOTTOM	3	-	-	28/17	ΔV = 183.9
EDGE	6-2	16/15	18/16	-	sum of g's 24.1
EDGE	4-5	17/16	16/17	-	" 23.3

SHOCK DATA SET SHEET
DROP HEIGHT 18"





DATA SET 13 (STARTING SHEET THICKNESS .400 ")
TEMP 70° F

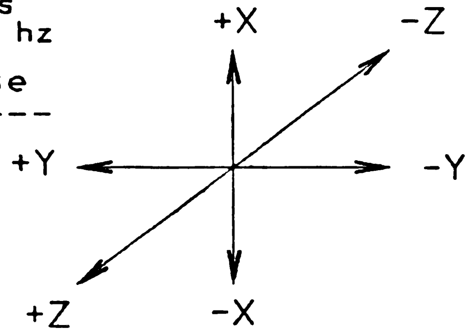
Type of drop	Side #	Y	X	Z (G's/ms)	
TIP	3	-	-	16/17	
EDGE	6-2	18/16	19/16	-	sum of g's 26.2
EDGE	5-2	16/16	16/15	-	" 22.6
CASTERS	6	-	24/16	12/2	
RIGHT SIDE	4	21/20	-	12/2	
OPP CASTERS	5	-	18/20	12/2	
LEFT SIDE	2	18/20	-	-	
TOP	1	-	-	17/21	
BOTTOM	3	-	-	28/16	ΔV = 173.1

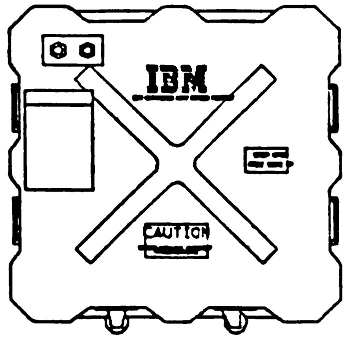
DATA SET 14 (2.2 pcf foam top pad .74 psi bottom pad 1.2 psi)
TEMP -40° F

Type of drop	Side #	X	Y	Z (G's/ms)	
BOTTOM	3	-	-	31/19	
CASTERS	6	19/22	-	-	
CASTERS	6	21/22	-	-	
CORNER	1-4-6	25/20	24/19	16/12	
BOTTOM	3	-	-	30/20	Δ V= 232
TOP	1	-	-	50/20	

VIBRATION DATA SET SHEET
Fc=90 hz (z axis)
input=.5 g's
sweep 2-200 hz

$$Q=\frac{\text{g response}}{\text{g input}}$$





DATA SET 15

AXIS	SIDE	Fc (hz)	g response	Q	psi loading
-Z	3	25	2.37	4.74	.74
-X	6	16.5	1.55	3.10	
+Y	2	24	1.38	2.76	

DATA SET 16

AXIS	SIDE	Fc (hz)	g response	Q	psi loading
+X	6	17	1.39	2.78	
-Z	3	30	1.87	1.74	.74

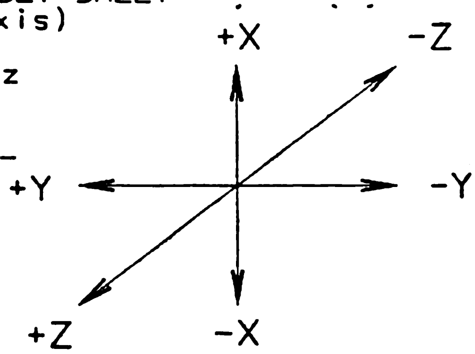
DATA SET 17

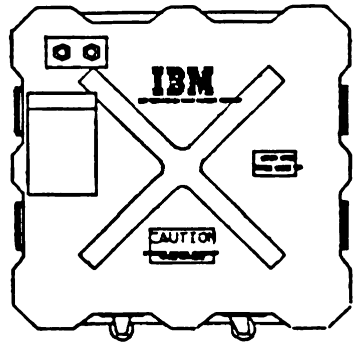
	AXIS	SIDE	Fc (hz)	g response	Q	psi loading
	-X	6	18	1.24	2.48	
(1)	-Z	3	17.5	1.70	3.40	1.2
(2)	-Z	3	20.5	1.4	2.8	1.2
(3)	-X	6	19.5	1.83	3.66	
(4)	-X	6	14	1.62	3.24	

(1) 2.2 PSI CLOSED CELL POLYETHYLENE FOAM
(2) 4.0 PSI CLOSED CELL POLYETHYLENE FOAM
(3) HARD RUBBER CASTERS
(4) SOFT RUBBER CASTERS

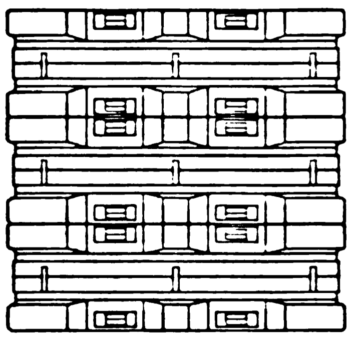
VIBRATION DATA SET SHEET
Fc=90 hz (z axis)
input=.5 g's
sweep 2-200 hz

$$Q = \frac{\text{g response}}{\text{g input}}$$





DATA SET 18



3 HIGH STACK OF CASES
RESTRAINED TO THE VIBRATION PLATTEN USING NYLON WEB BELTS
ACCELEROMETER MOUNTED IN THE Z AXIS
ON A BOARD IN THE TOP CASE.

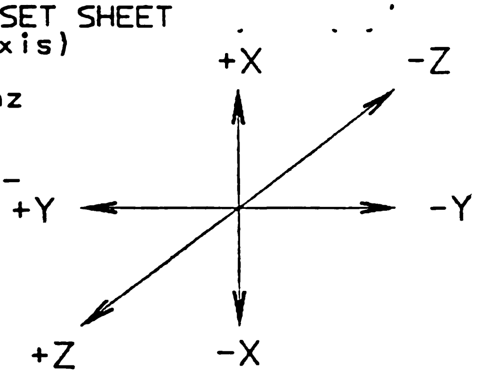
Fc = 10 hz g response = 2.2 Q= 4.4

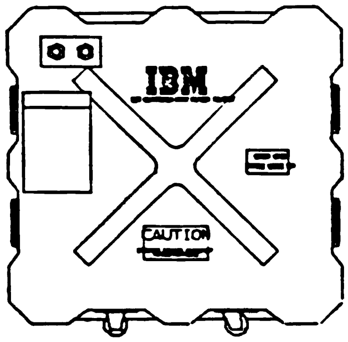
DATA SET 19 (ROTARY MOLDED CASE W/ ELASTOMERIC SHOCK MOUNTS)

AXIS	SIDE	Fc (hz)	g response	Q	psi loading
-Z	3	11.1	2.0	4.0	
-X	6	11.0	2.0	4.0	
+X	5	14.0	2.5	5.0	
+Z	1	10.0	1.9	3.8	
-Y	4	16.0	1.1	2.2	
+Y	2	17.5	1.05	2.1	

VIBRATION DATA SET SHEET
Fc=90 hz (z axis)
input=.5 g's
sweep 2-200 hz

$$Q = \frac{\text{g response}}{\text{g input}}$$





DATA SET 20

	AXIS	SIDE	Fc (hz)	g response	Q	psi loading
(1)	-X	6	21	2.2	4.4	
(1)	-Z	3	28	2.3	4.6	.74
(1)	-Y	4	24	2.2	4.4	
(2)	-X	6	24	1.73	3.46	
(2)	-Z	3	28	1.95	3.9	.74
(2)	+X	5	30	1.4	2.8	
(2)	-Y	4	31	2.4	4.8	
(3)	-X	6	34			
(3)	-Z	3	27			.74
(3)	-Y	4	26	1.8	3.6	
(3)	+Y	2	25	2.0	4.0	
(3)	+Z	1	28	2.4	4.8	.74
(3)	+X	5	29	1.8	3.6	

(1) OUTER CASE FORMED FROM .312" SHEET STOCK
(2) OUTER CASE FORMED FROM .375" SHEET STOCK
(3) OUTER CASE FORMED FROM .400" SHEET STOCK

APPENDIX B

IBM Corporate Specification

C-H 1-9711-005
1979-04

Packaged Product Tests

Test Levels and Procedure

Applicability: All Operating Units — *Manual: None*

Introduction

1. Scope

1.1 Abstract
This specification covers package test levels and procedures for IBM products to be shipped to national or international locations by all modes of transport (ocean, rail, truck, air).

1.2 Objective
The packaging design should protect the product in transit to support satisfactory installation. The objective of this specification is to provide a basis of appropriate package tests to meet this need.

1.3 Application
This document applies to IBM-manufactured products (machines, common subassemblies and individually packaged components) that are to be shipped to any worldwide location.

1.4 Effective Date
This specification shall become effective on date of publication.

Note: All products and packages completing Phase I design prior to the effective date of this specification are exempt from the requirements of this specification.

2. Document Administration

2.1 Originating Area and Responsibility
This document was originated by the Standards Project Authority (SPA) for SIRS #142 (Distribution Engineering). The responsible Standards department is GSD, Rochester, MN (Location Code 980).

2.2 Authorization
This standard was approved by the Division Standards Authorities of all affected operating units on 1979-02.

2.3 Deviation
Any deviation from the requirements of this specification requires written approval from the local Distribution/Packaging Engineering and Product Engineering functions. Contact your local Standards department.

Note I: The SPA for SIRS #142 shall be notified of all requests for deviation.

2.4 Exemption
When the requirements of this specification conflict with special customer contractual requirements, the latter shall take precedence and shall be exempt from the deviation requirements stated in Paragraph 2.3.

3. Related Documents

3.1 References
C-S 1-3600-002 Product Fragility and Packaging Tests
C-H 1-9711-001 Product Fragility–Vibration
C-H 1-9711-004 Product Fragility–Shock
C-S 1-3705-001 Machine Mobility, Stability, Size and Weight Requirements

Requirements

4. Conditions for Testing

The major test sequence should be: vibration testing, shock testing, other tests.

4.1 Orientation of the Test Specimen

4.1.1 Face Identification. For orientation of specimen (manual and nonmanual packages) the faces are identified as shown in Figure 1.

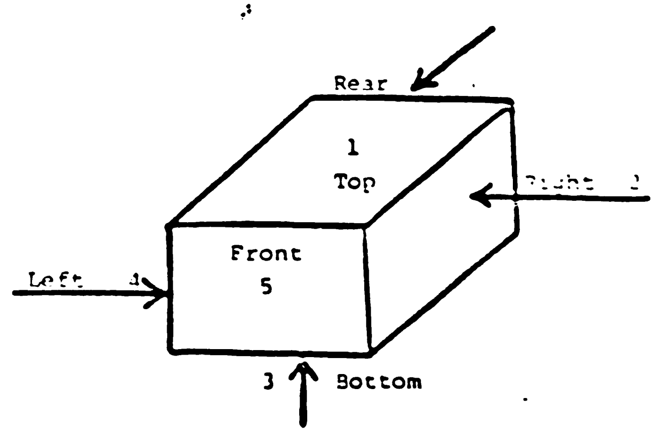


FIGURE 1 FACE IDENTIFICATION OF PACKAGED PRODUCT

Packaged Product Tests

Test Levels and Procedure

4.1.2 Shock Test Sequence (for manual packages only) The packaged product shall (see Paragraph 4.1.1 for face identification of package) be dropped in sequence as follows:

Drop No.

1 Corner drop in most critical component or product direction (e.g., corner formed by faces 5-3-2).

2 An edge drop in the most critical machine direction (e.g., formed by faces 5-2).

3 A flat drop on the left or right face of the package.

4 A flat drop on the opposite face of the package.

5 A flat drop on the front or rear of the package.

6 A flat drop opposite from drop 5.

7 A flat drop on the bottom (face no. 3).

8 A flat drop on the top (face no. 1).

Note II: Critical product direction is the most fragile direction.

Note III: The center of gravity must be directly above the npact point or line in drops 1 and 2.

4.1.3 Vibration Test Sequence. Manually handled packages shall be vibrated in the three mutually perpendicular axes if handling and transport in these orientations might occur. For nonmanually handled packages it is normally adequate to test in the vertical axis only.

4.2 Temperature and Humidity

Temperature and humidity conditions present shall be recorded prior to shock and vibration testing.

4.3 Characteristics of Test Equipment

4.3.1 Vibration. The apparatus shall consist of a vibration machine with a table having a horizontal surface of sufficient strength and rigidity that the applied vibrations are essentially uniform over the entire test surface. The table shall be supported by a mechanism capable of producing a sinusoidal vibration in the vertical direction at controlled accelerations and/or displacements over a controlled continuously variable range of frequencies.

Suitable fixtures shall be provided to prevent the test specimen(s) from losing contact with the table.

4.3.2 Shock. The packaged product shall be subjected to shock pulses with a duration of 3 ms or less and sufficient acceleration amplitude to produce the velocity change equivalent to the drop heights in Table 1.

Instrumentation may also be desirable for monitoring the response of the test specimen.

If a shock machine is used, suitable fixtures or belts shall be provided to prevent the test specimen from losing contact with the table.

If a programmable shock machine is not available, appropriate rigging, lift devices, quick release hooks, and instrumentation should be used to generate equivalent shock velocity changes using freefall or rotational end drops.

4.4 Evaluation Prior to Testing

4.4.1 Product. The product shall be inspected and functionally tested by knowledgeable test personnel in accordance with the relevant specifications and testing procedures.

4.4.2 Package. After the product has been visually inspected and functionally tested, it shall be prepared for shipment in accordance with the proposed releases (package design releases).

4.5 Evaluation After Testing

4.5.1 Package. The package shall be considered to have satisfactorily passed the test if the package affords sufficient protection to the product per Paragraph 4.5.2.

4.5.2 Product. The packaged product shall be evaluated to determine if it is free from physical damage and performs its intended function. (It is recommended that an agreed-to manufacturing final test be used.)

Appropriate personnel shall inspect and functionally test the product in accordance with the relevant product specifications. It is optional, but recommended, to visually inspect and functionally test after each major sequence of test procedure.

4.5.3 Safety. The structural components of the package should not be destroyed or altered so that any protruding and/or exposed sharp edges, splintered or fractured materials or fastening devices, etc., of the package creates hazardous and unsafe conditions for further handling or storage of the package.

Packaged Product Tests

Test Levels and Procedure

5. Packaged Product Tests

5.1 Vibration Test (required)

5.1.1 Procedure. The total test time for each axis tested should be 60 minutes (±10%) for nonmanual packages and 30 minutes (±10%) for manual packages.

Place the packaged test specimen in its normal shipping orientation on the vibration table (see Section 4.1.3).

For measurement of the major responses of the product, it may be necessary to attach vibration transducers to the product (inside the package).

Generally there are two distinct stages in the test:

1. Initial Resonance Test
2. Endurance Test

5.1.2 Initial Resonance Test. Adjust the vibration test apparatus to product a constant acceleration amplitude of 3 m/s² ($0.3g_n$) (zero to peak) over the frequencies of 2-200-2 Hz at 0.4 decades ±10% per minute recording all resonant responses. (Recording should preferably be done by X-Y recorders and accelerometers.)

Vibration amplitude may be decreased below this full value or increased over this full value if, thereby, more precise determination of the resonance characteristics can be obtained.

5.1.3 Endurance Test.

5.1.3.1 Dwell Test. Vibration is applied at the resonance frequencies determined in the initial resonance test at which failure or other undesirable effect is likely to occur. Acceleration amplitude of 5 m/s² ($0.51g_n$) (zero to peak) is applied at each frequency (Note IV). The total dwell time at each resonant point shall be 15 minutes (±10%). If resonance testing and dwell testing are not sufficient to meet the per axis time requirements of Paragraph 5.1.1, sweep testing should be done for the remainder of the test time.

5.1.4 Sweep Test. (Can be substituted for 5.1.3.1 in case of no major resonances.)

The frequency shall be continuously varied over the full frequency range of 2-200 Hz, with a constant acceleration of 5 m/s² ($0.51g_n$) (zero to peak) (Note IV) and a sweep rate of one octave/min. (0.3 decades ±10%/min.).

Note IV: The shock and vibration levels in this specification cover shipment of products by many modes of transport throughout the world. If unique marketing requirements (e.g., customer setup) or environmental data concerning drop heights, numbers of drops, vibration leve for specific modes of transport, etc., is available, th should be used to determine any deviation from this spec fication. A deviation requires Product Engineering an Packaging Engineering approval and the rationale must b documented in the test report.

5.2 Shock Test (required)

5.2.1 Typical Packaged Product Performance. Using the appropriate category (reference definitions in Paragraphs 7.1 and 7.2) and gross mass (weight) of the packaged product, select the design drop-height(s) and number of drop from Table 1 (Note IV).

If a shock machine is used, this design drop height is then an indication for the setting of the shock machine table drop height. The actual table drop height for any given simulated drop is dependent on the amount of rebound o. the shock table.

5.2.2 Test Procedure—Manual Handling. For manual packaged products, shock tests should be conducted according to Paragraph 5.2.1. The orientation and test sequence should be according to Paragraph 4.1.

5.2.3 Test Procedure—Nonmanual Handling. For nonmanual packaged products, shock tests should be conducted according to Paragraph 5.2.1. Tests should be done in the vertical direction and/or in those directions in which shock during handling and transport might occur.

5.3 Dynamic Stacking Test (required)

For all packaged products with a height below 1.2 m and with a flat top face (not for minimum packaged products).

5.3.1 Apparatus. (see Paragraph 4.3.1)

5.3.2 Procedure. If packed products or palletized loads can be stacked one on top of another during shipment, a stacked resonance dwell should be performed for 30 minutes ±10% at the critical resonant frequency (point at which top package reaches its maximum displacement) with constant input acceleration amplitude of 5 m/s² ($0.51g_n$) (zero to peak). The number of packages or palletized loads in the stack should be consistent with anticipated stack heights during shipment. A stacking fixture or restraint should be used to prevent the stacked load from moving laterally on the vibration table.

Packaged Product Tests

Test Levels and Procedure

Class	Mass (Packaged Product) kg Above-incl	lb* Above-incl	Number of Shocks (Drops)	Typical Design Drop Height: Boxed with No Pallet mm	in*	Palletized mm	in*	Minimum Pack (No Box) mm	in*
Manual	0-10	0-23	8 (Para 4.1.2)	900	36	600	24		
	10-30	23-67	8 (Para 4.1.2)	750	30	450	18		
	30-40	67-89	8 (Para 4.1.2)	600	24	300	12		
	40-60	89-133	8 (Para 4.1.2)	450	18				
			5 (1 bottom)			450	18		
			(4 sides)			300	12		
			12 (2 bottom)					300	12
			(10 bottom)					100	4
Non-Manual	60-90	133-199	5 (1 bottom)	450	18	300	12		
			(4 sides)	300	12	200	8		
			12 (2 bottom)					250	10
			(10 bottom)					50	2
	90-120	199-265	12 (2 bottom)			250	10	200	8
			(10 bottom)			100	4	50	2
	120-240	265-530	12 (2 bottom)			200	8	150	6
			(10 bottom)			50	2	25	1
	240-450	530-993	12 (2 bottom)			150	6	100	4
			(10 bottom)			50	2	25	1
	450-Above	993-Above	12 (2 bottom)			100	4	75	3
			(10 bottom)			50	2	25	1

*Pound and inch values are conservatively equivalent to but not exactly equal to metric values.

TABLE 1--Test Procedure Guide

5.4 Additional Tests (optional at the discretion of the Package/Distribution Engineer with Product Engineering approval)

If knowledge of the environment is available to such an extent that the packaging engineer is able to pinpoint a specific exposure somewhere along the distribution chain then additional tests should be done to cover these exposures.

5.4.1 Incline/Impact Test. Intended for packaged products which may receive horizontal shock inputs which cannot be simulated in a vertical shock test.

5.4.1.1 Apparatus. The recommended test apparatus shall consist of two-rail steel track inclined 10° ±1° from the horizontal plane, a freely rolling dolly or carriage, a suitable means of retracting and releasing the dolly and a rigid programmable barrier perpendicular to the plane of the track. If test apparatus is not available, then controlled horizontal impacts into a rigid barrier may be used.

5.4.1.2 Test Procedure. The packaged product shall be placed on the dolly with a face of the package coincident with the face of the barrier. The dolly shall be retracted a sufficient distance and released to give a maximum velocity change measured on the dolly per Table 2. Repeat this procedure for each vertical face.

Palletized	Minimum-Pack
1 m/s (39 in/sec)	0.5 m/s (20 in/sec)

Table 2 Incline/Impact Test

Packaged Product Tests

Test Levels and Procedure

5.4.2 Belt Compression (required for minimum packed products)

5.4.2.1 **Apparatus.** Two horizontal logistic rails securely fastened to a base structure for rigidity and having an adjustable belt with tension spring indicator or load cell. The lower rail is to be 450 ±10 mm from the floor and the remaining rail to be 850 ±10 mm from the floor. Vertical rails with minimum spacing of 500 ±10 mm between rails may also be used.

5.4.2.2 **Test Procedure.** Position the packaged unit against the horizontal rails. Attach belt(s) to the rails within 250 mm ±10 from the product so that pressure is placed on the corners of the product. Tighten each belt to 1.2 kN (270 lbf).

The locations where the belt(s) touches the product may not be permanently deformed nor may the covers, doors, hinges or other frame parts shift or slide under the belt tension.

5.4.3 **Humidity and Temperature Test.** (Method per 8.15)

5.4.4 **Rain Test.** (Method per 8.13)

5.4.5 Other Tests (mobility/stability, handling, etc.)

Not all possible test situations are covered in this document. Other tests are required when applicable unusual product design or local environment dictates (reference C-S 1-3705-001).

6. Reporting

6.1 Product/Package

- Dimensions of package and material specifications
- Description or photo of package
- Net and gross mass of packaged product
- Number of packages tested
- Package test sequence
- Package test procedure
- Description or identification of the product including serial number of the unit(s) tested
- Type and extent of damage to the product and the package and any observations which may be of value in correctly interpreting the results

6.2 Test Setup

- Relative humidity and temperature (if applicable)
- Pertinent information regarding any unusual environmental condition expected during shipping and handling
- Photo or description of fixtures used

6.3 Test Results and Recommendations

- Recommendations to improve the design of the package or the product. (Consider economic trade-offs between product and package design.)
- With package shock testing, the pulse duration, velocity change and peak acceleration level transmitted by the package (shock mounts, pallet, casters, etc.) should be recorded
- On vibration tests, resonance points and transmissibility factors should be recorded along with location of measurement points

Supplementary Information

7. Definitions

7.1 Manual Packaged Product

A package that because of its size and mass is likely to be picked up manually and has a maximum mass of 60 kg (133 lb.).

7.2 Nonmanual Packaged Product

A package or palletized load that is, because of its size and mass, not likely to be picked up manually but moved on its own casters or handled by lift trucks, hoists, dollies, skids, or other mechanical aids, or that has a mass of more than 60 kg (133 lb.).

7.3 Packaged Product

All loads, packages or products in the state of being transported through the distribution network.

7.4 Minimum Packed Product

A product packaged in such a way that it is capable of being shipped without an external shipping container or pallet but in special trailers or containers with protective pads and tie-down provisions. Exterior packaging is normally limited to items such as taped covers, polyethylene bags and special protection for exposed or protruding components.

Packaged Product Tests

Test Levels and Procedure

7.5 Acceleration of Gravity g
Acceleration produced by the force of gravity at the surface of the earth. The international standard value is $g_n = 9.806\ 65\ m/s^2$.

Other accelerations were frequently expressed in multiples of g_n but written as G.

7.6 Resonance
The point at which the natural frequency of an element is equal to the excitation frequency and produces the peak amplification of the input amplitude.

7.7 Design Drop Height
The handling drop height chosen for shipping container design based on consideration of range of drop heights, frequency of occurrence and economic factors.

8. Bibliography

8.1 Mil-STD-810C (March 1975) Environmental test methods.

8.2 CCDE shippability practice 08-01-00 (October 1975) SPA for SIRS #142.

8.3 Report PB 202-728. A survey of test methods currently used for simulating the transportation environment. Phase II Alan N. Henzi. General American Transport Corporation, April 1971.

8.4 Technical Report No. 23. Michigan State University School of Packaging. Control of damage and loss in distribution. A critical analysis of vibration measurements of the transportation environment. Janece Rae Hansch, 1975.

8.5 A survey of the transportation shock and vibration input to cargo. F. E. Ostrem. General American Research Div./General American Transport Corp. Niles, IL.

8.6 Acquisition of drop height data during package handling operations. Franklin D. Barca (75.108AMEL) US Army Natick Dev. Center. Natick. MA 01760.

8.7 NASA George C. Marshall. Space flight center final report NAS 8-11451, 1967.

- Transportation and handling shock and vibration design and criteria manual. MR 1262

8.8 Shock environment of packages in transit symposium papers SEE 1971.

8.9 A survey of environmental conditions incident to the transportation of materials. Fred E. Ostrem. October 1971. PB 204.442-GTE.

8.10 CES 1-9700-000 Product environment limitations. Temperature, humidity, and altitude.

8.11 ASTM D-775-73 Drop test for shipping containers.

8.12 ASTM D-880-73 Incline impact test for shipping containers.

8.13 ASTM D-951-73 Water resistance of containers by spray method.

8.14 ASTM D-999-73 Vibration test for shipping containers.

8.15 ASTM D-1251-68 (1973) Water vapor permeability of packages by cycle method.

8.16 ASTM D-1683-73 Testing large shipping cases and crates.

8.17 ASTM D-2956-71 Controlled shock input tests for shipping containers.

8.18 ASTM D-3331-74 Assessment of mechanical shock fragility using package cushioning materials.

8.19 ASTM D-3332-74 Mechanical shock fragility of products using shock machines.

APPENDIX C

WRIGHT MALTA
CORPORATION

DAY	CONTAINER "A" % RH	CONTAINER "A" TEMP (F)	CONTAINER "B" % RH	CONTAINER "B" TEMP (F)	TEST CHAMBER % RH	TEST CHAMBER TEMP (F)
1	14	75	15	71	35	72
2	4	102	3	101	87	103
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	4	97	3	98	88	100
7	-	-	-	-	-	-
8	4	103	3	102	89	102
9	4	103	3	101	90	101
10	4	103	3	102	91	100
11	-	-	-	-	-	-
12	-	-	-	-	-	-
13	-	-	-	-	-	-
14	4	104	3	102	88	102
15	4	102	2	101	91	101
16	4	102	3	101	90	100
17	4	102	2	102	87	103
18	-	-	-	-	-	-
19	-	-	-	-	-	-
20	4	101	2	100	92	98
21	4	102	2	102	90	99
22	4	101	2	100	89	101
23	5	102	2	102	91	100
24	-	-	-	-	-	-
25	-	-	-	-	-	-
26	-	-	-	-	-	-
27	4	102	2	100	92	99
28	5	104	2	101	91	100
29	-	-	-	-	-	-
30	5	102	2	101	89	101
31	4	104	2	101	91	99
32	-	-	-	-	-	-
33	-	-	-	-	-	-
34	4	101	2	101	90	99
35	4	100	2	99	92	100
36	5	102	2	100	88	102
37	4	102	2	100	91	101
38	-	-	-	-	-	-
39	-	-	-	-	-	-
40	-	-	-	-	-	-

WRIGHT MALTA
CORPORATION

DAY	CONTAINER "A" % RH	CONTAINER "A" TEMP (F)	CONTAINER "B" % RH	CONTAINER "B" TEMP (F)	TEST CHAMBER % RH	TEST CHAMBER TEMP (F)
41	-	-	-	-	-	-
42	4	102	2	99	90	102
43	5	101	2	100	91	100
44	-	-	-	-	-	-
45	4	100	3	101	90	100
46	-	-	-	-	-	-
47	-	-	-	-	-	-
48	5	101	3	100	91	101
49	5	102	2	100	91	100
50	5	101	2	100	90	100
51	-	-	-	-	-	-
52	-	-	-	-	-	-
53	-	-	-	-	-	-
54	4	100	2	100	90	101
55	4	101	2	100	91	100
56	4	100	2	100	89	100
57	4	102	3	101	89	101
58	5	100	2	99	92	100
59	-	-	-	-	-	-
60	-	-	-	-	-	-
61	5	101	3	100	91	100
62	5	102	3	101	89	101
63	5	102	2	99	92	100
64	5	101	3	100	90	100
65	5	101	3	100	91	101
66	-	-	-	-	-	-
67	-	-	-	-	-	-
68	5	102	2	102	87	103
69	5	101	2	101	89	101
70	5	101	2	100	90	100
71	4	98	3	99	89	101
72	4	100	2	99	89	100
73	-	-	-	-	-	-
74	-	-	-	-	-	-
75	5	101	2	99	91	100
76	4	101	2	100	90	101
77	4	102	2	99	88	102
78	5	102	3	99	89	100
79	5	100	2	101	90	101
80	-	-	-	-	-	-

LIST OF REFERENCES

REFERENCES

AMERICAN SOCIETY FOR TESTING AND MATERIALS., Test Method for: Residual Solvents in Flexible Barrier Material, F-151. Philadelphia: A.S.T.M., [1975].

BAYER, Dr. S. "Deleterious Volatiles for the Clark Board Assembly." Memo to E. Straus. Poughkeepsie: I.B.M., [1981] (Typewritten.)

BRECK, D.W., "Crystalline Molecular Sieves." Journal of Chemical Education. 48 (December 1964): 678-689.

[BRUNO, M. H.], International Paper Company Pocket Pal: A Graphic Arts Production Handbook. 12th ed. New York: International Paper Company, [1979].

CALLAWAY, R., Clark Board Assembly Engineering Specification Number 1726036. Poughkeepsie: I.B.M., [1981].

CULLEN, J. S., "The Right Desiccant: Your Weapon Against Moisture's Ravages." Package Engineering, February, 1975, pp. 46-50.

CULLIGAN CORPORATION., Humi-Sorb Activated Clay Desiccant for Protection Against Humidity Damage in Packaging. Northbrook: Culligan Corporation, [1980].

DOW CHEMICAL CORPORATION., Designing Packages to Survive Shipping and Handling with Ethafoam Brand Foam. Midland: Dow Chemical Corporation, [1980].

GRANDJEAN, E., Fitting the Task to the Man: An Ergonomic Approach. 3rd ed. London: Taylor and Francis Ltd., [1980].

GUINS, S. G., Notes on Package Design. 3rd ed. East Lansing: School of Packaging, [1979].

HTOO, M. S., T.C.M. Board Environmental Control Engineering Specification Number 878202. Poughkeepsie: I.B.M., [1981].

JORDAMO, G., "Flammability and Outgassing of Plastics." Presentation given to Package Engineering. Poughkeepsie, N.Y., [1985]. (Photocopy.)

KAREL, M., Phvsical Principal of Food Preservation. New York: Marcel Decker, [1975].

KERR, M. T., "Random Vibration for Package Testing," A Paper Presented at the Annual Meeting of the Corporate Vibration Personnel. Poughkeepsie, N.Y.: n.p., [1982].

MEASUREMENTS GROUP., Physical Constants of Common Engineering Materials. Raleigh: Measurements Group, [1979].

MINDLIN. R. D., Dynamics of Package Cushioning. New York: Bell Telephone Laboratories, [1946].

MUSTIN, G. S., Water Gain Behavior of Outdoor Closed Structures. Alexandria: American Scientific Corporation, [1963].

SCHOOL OF PACKAGING., Packaging 427, Packaging Materials and Svstems Lab Manual. East Lansing: School of Packaging, [1979].

UNION CARBIDE CORPORATION., Molecular Sieves. Tarrytown: Union Carbide Corporation, [1980].

U. S. DEPARTMENT OF DEFENSE., Package Cushioning Design: Mil Handbook 304-B. Washington: Government Printing Office, [1978].

U. S. DEPARTMENT OF DEFENSE., Sampling Procedures and Tables for Inspection by Attributes: Mil Standard 105-D. Washington: Government Printing Office, [1963].

MICHIGAN STATE UNIV. LIBRARIES
31293000897318