STERILIZABLE OPTICAL COUPLING MATERIAL

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Final Report

8 July 1964 to 8 March 1965

Jerry [illegible]

DOW CORNING CORPORATION
Research Department
Midland, Michigan

March 8, 1965

Contract No. 950767

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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I. Abstract

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An optical coupling material was developed and tested as per J.P.L. contract number SW 3257. The material finally developed would withstand the optical and environmental tests required. Dow Corning® XR6-3488 Resin and Curing Agent with one-hour catalyst, were recommended as the optical coupling material. A bonding agent, Dow Corning® 92003, was found to be helpful in securing the resin to the glass surfaces. A procedure was established for preparing the resin and assembling the fixture in which the optical coupling material will function. An accelerated test, conservatively projected, indicates the sample will lose less than 1.7 percent weight in 1400 days at 25°C and a pressure of one millimeter of mercury. The probability of the sample functioning in the specified environments for periods of several months are therefore concluded excellent.

II. Recommendations

Dow Corning® XR6-3488 Resin and Curing Agent with one-hour catalyst are recommended as the proposed optical coupling material. A bonding agent, Dow Corning® 92003, was found desirable in bonding the resin to the glass surfaces. A procedure for mixing, deaerating, casting and bonding the resin is recommended as outlined in Section VIII of this report.

III. Introduction

The material described under this contract is intended for use in future explorations to planets in our solar system. It will be used to couple light emitted by a scintillation crystal to a photomultiplier tube. The material must therefore have excellent light transmissibility, as described herein, and a refractive index within specified limits. Also, the materials must be capable of withstanding heat sterilization, gas sterilization, static acceleration, vibration, shock, elevated temperatures, and high vacuum for prolonged periods of time. These environmental conditions are fully described in Section IV of this report.

It is necessary that the optical coupling material does not undergo degradation at 145°C; this condition alone eliminates most classes of polymeric materials. Silicone polymers and rubbers are known for their thermal stability, and therefore are well suited for this type of application.

The over-all purpose of the work described in this report was to develop or find a material capable of meeting all the physical and environmental conditions set forth in the contract statement of work, SW-3257A.

IV. Fixture Design

The first effort under this contract was to design a test fixture. This fixture was expected to assimilate as near as feasible the mechanical and optical surroundings of the material to be evaluated. The final packaging of the scintillation crystal and photomultiplier tube, being concurrently developed under other contracts, was to have glass face plates. The coupling material developed was to provide optical coupling between the two glass face plates.

It was necessary that a fixture be designed to withstand, without change, the environmental conditions. A given sample specimen had to undergo the various environmental tests and be examined after each test. The examinations (see Section V of this report) required were light transmissibility, refractive index, and visual inspections.

Aluminum was chosen as the basic fixture material since it is both light weight and capable of withstanding the forces anticipated. In that optical and visual tests had to be nondestructively made, windows of glass were provided in the aluminum test blocks. The glass assimilated the face plates of the photomultiplier and the scintillation crystal. A space was provided between the two glass windows for the optical coupling material.

One of the big problems was to find a method of rigidly securing the glass to the aluminum blocks so the glass would not be broken during the high g shock tests. This problem was compounded because the technique used would also have to withstand the elevated temperature environments without chemical or mechanical change. Many epoxy resins were used as a bonding agent between the aluminum fixture and the glass plates. The first epoxies found which would successfully bond the materials together degraded at 145°C. Other epoxy resin systems would bond and had the necessary thermal stability, but had so great a thermal expansion coefficient that a small change in temperature would break the glass. The system found successful was Dow resin 331-E and Dow Corning catalyst SA 500.

Two Pyrex® glass plates 3/16 inches thick and one inch square were used as the windows in each test fixture. The final tests were conducted with Corning Glass Company 7052 glass plates in place of the Pyrex®. A total of ten fixtures were intially constructed. Figure one is a perspective drawing of a completed fixture. Figures two and three are detail drawings of the same fixture. The fixture was constructed so a sample 0.020 inches thick was sandwiched between the glass plates.

V. Sample Measurements

Each sample underwent a series of examinations after it was prepared in the test fixture. These same examinations were also conducted following each environmental test as shown on the test flow diagram, (figure 4). The small boxes labeled "T" of figure four represent the examinations as outlined below.

A. Refractive Index:

The test fixture was designed to allow a microscope objective lens to fit inside the aluminum frame. This was necessary to allow the microscope to be focused on the inside surfaces of the glass plates. A single fine line was scribed on the inside surface of the glass plates with a diamond-tipped scriber.

The refractive index of the optical coupling material was determined by measuring the distance between the two glass plates. To achieve this, each test fixture was assembled without the optical coupling material. The distance between the two scribed marks on the inside of the glass plates was measured with a traveling microscope. Next the fixtures were disassembled and then reassembled with the optical coupling material between the two glass plates. Again the distance between the two plates was measured. The refractive index is the ratio of the speed of light in air to the speed of light in the material in question. Therefore, the ratio of the observed optical distances between the glass plates both with and without the specimen is the refractive index.

$$\mu = \frac{d_1}{d_2}$$

μ = refractive index

d_1 = optical distance in air (actual)

d_2 = optical distance with sample (apparent)

Since the above test is nondestructive, it was used before and after each environmental test. See figures 16,17, & 18. This method was used only to observe changes as a result of the environmental condition. A second technique, the Beche line method, was used to make a more precise determination of the refractive index. Since this technique is a destructive test, it can be performed only once on a given sample. See figure 18.

B. Light Transmissibility:

A measurement of the samples ability to transmit light was made before and after each environmental test. A double-beam broadband visible light source instrument was used. This instrument, Lumetron Colormeter Model 402-E, was calibrated per the manufacturer's instructions before each measurement. A black anadized one quarter inch diameter aperture plate was used in the sample beam for all measurements. In that the sample was coupled between two glass plates, the light transmissibility of the plates and the sample were determined together. The values given in Figures 19,20 & 21 were obtained by this method.

The surface of the glass sheets was flat and polished as is typical of glass. This caused light to be reflected from the glass surfaces which in turn lowered the value of the actual light transmissibility as compared to the measured value. Even though this phenomena occurred, the over-all transmissibility was above the 90 percent specified.

A second method was used to determine the light transmissibility. This technique made use of the Cary Model 14 Spectrophotometer. With this device the light transmissibility of the optical coupling material alone was made. As was discussed above, some of the light was reflected from the sample surface. The light transmissibility vs wave length plot was determined so to show the effect of wave length, see figure 12. The sample tested via the latter technique had a thickness of .125 inches.

C. Visual Examination:

Each sample was carefully examined by the naked eye and then under the microscope. The first examination occurred immediately after the sample was placed in the test fixture, even before it cured. The position of the cured sample in the test fixture was noted with respect to the scribe marks on the glass plates. Sample movement, cracking, splitting, bubbling, and size were all carefully observed before and after each environmental test. See figures 13,14, & 15.

D. Stress-Strain

Figure 11 is the stress-strain curve of the material recommended. The sample was cut from a one-eighth inch sheet with an ASTM, D die and pulled in an Instron tensile machine.

VI. Environmental Tests

After the sample had been prepared and examined per Section III, the environmental tests were initiated. The over-all tests were conducted in the order shown in the test flow diagram, figure 4. Following is a description of the environmental tests:

A. Dry Heat Sterilization

The samples were placed in a four-liter glass flange-rimmed container. The glass container was sealed and evacuated to one millimeter of mercury. Dried nitrogen gas was flowed into the container and the pressure was returned to atmospheric pressure. Dried nitrogen gas was then flowed through the container at the rate of one liter per hour for the duration of the test.

An electric temperature-controlled oven was used to heat the container and samples to 145° ± 2°C. The temperature was checked with a mercury thermometer traceable to the National Bureau of Standards. The samples remained in this environment for 36 hours. At the end of that period the samples were allowed to stabilize at room conditions, i.e. about 21°C. The examinations as outlined in Section V were conducted. This entire heat sterilization process was performed three times on each sample.

B. Gas Sterilization

The samples were placed in the above described container and allowed to stabilize at 110° ± 4°F. The container was evacuated to less than one millimeter of mercury. A mixture of ethylene oxide and Freon 12 gas was flowed into the container, see figures 5 & 6. The gas mixture was composed of 12% ethylene oxide and 88% Freon 12 by weight as analyzed by gas-liquid chromatography techniques. Sufficient water was added to raise the relative humidity in the container to 60% ± 15%. These conditions were maintained for a period of 32 hours.

At the end of the test period the container was purged with dried nitrogen. The samples were removed from the

the container and allowed to stabilize at room conditions. The examinations of Section V were conducted.

C. Static Acceleration

The test fixtures complete with the optical coupling material included were accelerated to 190 g. A hydraulically operated centrifuge was used to test five samples at one time. The samples were accelerated for 20 minutes in both the plus and minus directions for each of the three orthogonal directions. This represented a total of six tests for each set of samples. The examinations of Section V were again conducted.

D. Vibration

The samples were vibrated sinusoidally along each axis at a sweep of one half octave per minute over the following frequency spectrum and g levels:

1. ± 0.5 inch constant displacement, 5-17 CPS
2. ± 5 g rms, 17-50 CPS
3. ± 15 g rms, 50-100 CPS
4. ± 35 g rms, 100-2000 CPS

Next the samples underwent wide-band noise vibration, 25 g rms, 15-2000 CPS, for nine minutes along each axis. Again the examinations of Section V were conducted.

E. Shock

Each of the following shock tests were performed five times in each direction along each of the three axes. (total of 90 tests):

1. ± 200 g terminal peak sawtooth, 0.5 milliseconds rise time.
2. ± 150 g terminal peak sawtooth, 5.0 milliseconds rise time.
3. ± 1000 g terminal peak sawtooth, 3.0 milliseconds rise time.

A test facility capable of performing the ± 1000 g, 3.0 milliseconds rise time sawtooth shock test was not located until the contract was partially completed. Therefore, for the first three sets of five samples of ± 1000 g, 3.0 milliseconds duration, half-sine shock test was substituted. The final two sets of five samples were tested per the 1000 g sawtooth shock as stated above. Figure 7 shows the shock wave formations.

The examinations of Section V were conducted following the completion of the above shock tests.

F. Elevated Temperatures

The optical coupling samples and test fixtures were placed in a four liter glass container. The temperature was elevated to 75° ± 2°C for twelve days. During this period a pressure of one millimeter of mercury was maintained in the container. After the sample stabilized at room conditions, the examination of Section V was conducted.

G. Depressed Temperature

For four days the samples were maintained at -10°C at a pressure of one millimeter of mercury. The samples were warmed to room conditions and the Section V examinations performed.

H. Life Test

A sheet one by three by one eighth inches thick was subjected to 10^{-6} millimeters pressure and 100°C for 92 hours. During that period the weight loss of the specimen was continuously recorded. A second test was performed on the specimen for 69 hours; this test was conducted at 25°C and at a pressure of 10^{-6} millimeters of mercury. From the derived data, extended life of the sample was determined as outlined in Section VII.

VII. Reliability Tests

Two methods for determining the reliability of the optical coupling material were used. In the one approach five samples, all alike, were given the complete set of environmental tests. All five samples met these conditions and were therefore shown to be totally reliable.

The second method used to evaluate the optical coupling material reliability involved an accelerated testing method. In this approach a sample of the coupling material one inch by three inches and 0.125 inches thick was continuously weighed in a high temperature and high vacuum environment. The high vacuum, i.e. less than 10^{-6} millimeters of mercury, was used to assimilate space conditions. The evelated temperature accelerates the rate sample deterioration. The data obtained is given in figures 8, 9, & 10. First the sample was subjected to 10^{-6} millimeters of pressure at room temperature for 69 hours. The total percent weight loss during that period was 0.38%. The rate of weight loss at the end of the test was less than .001% per hour. Another specimen of the same material was then continuously weighed for 92 hours at 10^{-6} millimeters and 100°C. Again it is seen from figure 10 that the weight change at the end of the test is very small, i.e. .002% per hour. It is also noted that the total percent weight loss under these conditions was 1.760%. A very conservative method for projecting the time it would take for the specimen to lose the same weight at 25°C as it did at 100°C is as follows:

$$T = \frac{A \times C}{B}$$

T = time in hours at 25°C for the sample to lose the same weight as it did at 100°C.
A = rate of weight loss at 100°C after one hour.
B = rate of weight loss at 25°C after 69 hours.
C = time in hours of 100°C equilibrium

$$T = \frac{\frac{.0169 \times 100}{4.5809} \times 91}{\frac{.0008 \times 100}{4.130 \times 19}}$$

T = 33,579 hours or 1400 days.

This means that a conservative estimate of the weight loss of the optical coupling material would be less than 1.7 percent in 1400 days at 25°C and 10^{-6} millimeters.

VIII. Sample Preparation

The method for preparing the samples for use in the test fixtures is the same as suggested for the final application. Care must be exercised in keeping the sample free from dirt since it is to be used for light transmission. Clean glassware was used in all cases and covers were carefully kept in place. Although only 0.15 grams of samples were needed to fill the test fixture, 10 grams were usually prepared each time. This was done for two reasons. First, it is difficult to thoroughly mix very small quantities. Second, if contaminations were unknowningly introduced into the mixing process, they would be in relatively small quantities.

Ten grams of the resin, XR6-3488, were poured from the original container into a 200 milliliter glass beaker, which was on a laboratory balance. One gram of the catalyst was added to the beaker and the two components were thoroughly mixed, using a glass rod as the stirrer. The mixture was stirred for five minutes. Next the sample was placed in a glass desiccator and pumped down to one millimeter of mercury for fifteen minutes of until the material was ready to be used. This removes all the air entrapped in the sample during the mixing process. The catalyzed resin was then ready to use. The catalyzed material does not cure immediately; the proposed material has a working time of one hour. It is noted, however, that it is not desireable to remove the mixture from the one millimeter pressure until everything is ready for its use.

The glass surfaces were primed with Dow Corning®92003 primer. This was accomplished by painting a thin film of the primer onto the glass surfaces with a small camels hair brush. The primer was allowed to air dry in a clean environment for thirty minutes before the catalyzed resin was added. A very useful technique for putting the resin between the two glass surfaces without entrapping air between the surfaces is as follows: Face both of the glass surfaces up. Pour or carefully drop the catalyzed resin onto one of the glass surfaces. The glass plate with the resin on it is then carefully lifted and turned over. Just enough time for the resin to start to flow into a droplet is allowed before the plate is lowered slowly onto the

the lower glass surface. The upper glass piece is then slowly pressed into position. The resin is then cured by letting it remain at room temperature for 24 hours. To fully cure the resin it is placed in a 50°C oven for eight hours.

IX. Formulations

The formulations of the materials tested are as follows:

Set #1 (preliminary evaluation set):

Sample	Formulation
A	SYLGARD® 182; 9:1 resin to catalyst
B	SYLGARD® 182; 9:1 resin to catalyst, plus 1% 1107 fluid
C	SYLGARD® 51 ; 8:1 resin to catalyst
D	SYLGARD® 51 ; 3:1 resin to catalyst
E	C2-0057 ; Dow Corning grease
F	Type K interlayer; unvulcanized

Set #2

Sample	Formulation
D	SYLGARD® 51; 8:1 resin to catalyst
E	SYLGARD® 51; 3:1 resin to catalyst
G	DOW CORNING® 200 polymer gum
H	SYLGARD® 182; 9:1 resin to catalyst
I	SYLGARD® 182; 15:1 resin to catalyst
J	SYLGARD® 182; 9:1 resin to catalyst plus, 1% DOW CORNING® 1107 Fluid

Set #3

Sample	Formulation
A,B	DOW CORNING® XR-6-3488 resin; 10:1 resin to catalyst, plus bonding agent 92003 on the glass surfaces
C,D	DOW CORNING® XR-6-3488 resin; 10:1 resin to catalyst
E	DOW CORNING® XR-6-3488 resin; 5:1 resin to catalyst

Set #4

Sample	Formulation
F,G	DOW CORNING® XR-6-3488 resin; 10:1 resin to catalyst, plus bonding agent 92003 on the glass surfaces
C,D	DOW CORNING® XR-6-3488 resin; 10:1 resin to catalyst.
E	DOW CORNING® XR-6-3488 resin; 5:1 resin to catalyst.

Set #5

Sample	Formulation
A,B,C, D,E	DOW CORNING® XR-6-3488 resin; 10:1 resin to catalyst, plus bonding agent 92003 on the glass surfaces.

X. Figures

Figure 1
Test Fixture
Prespective Drawing

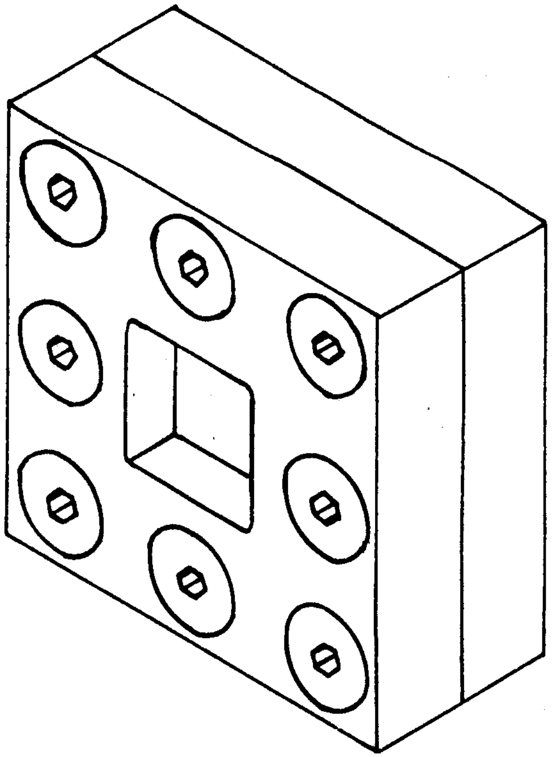


Figure 1

Figure 2
Test Fixture
Detail Drawing

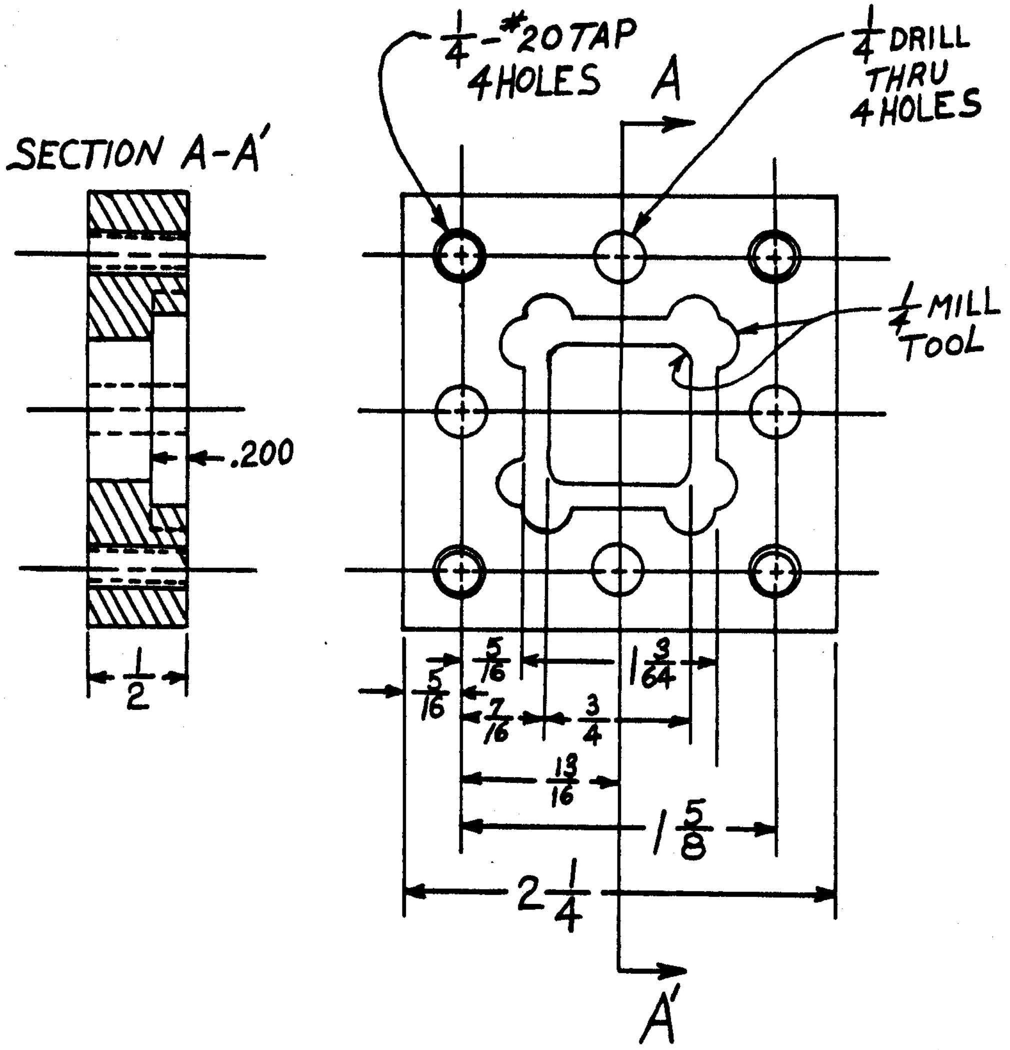


Figure 3
Test Fixture
Detail Drawing

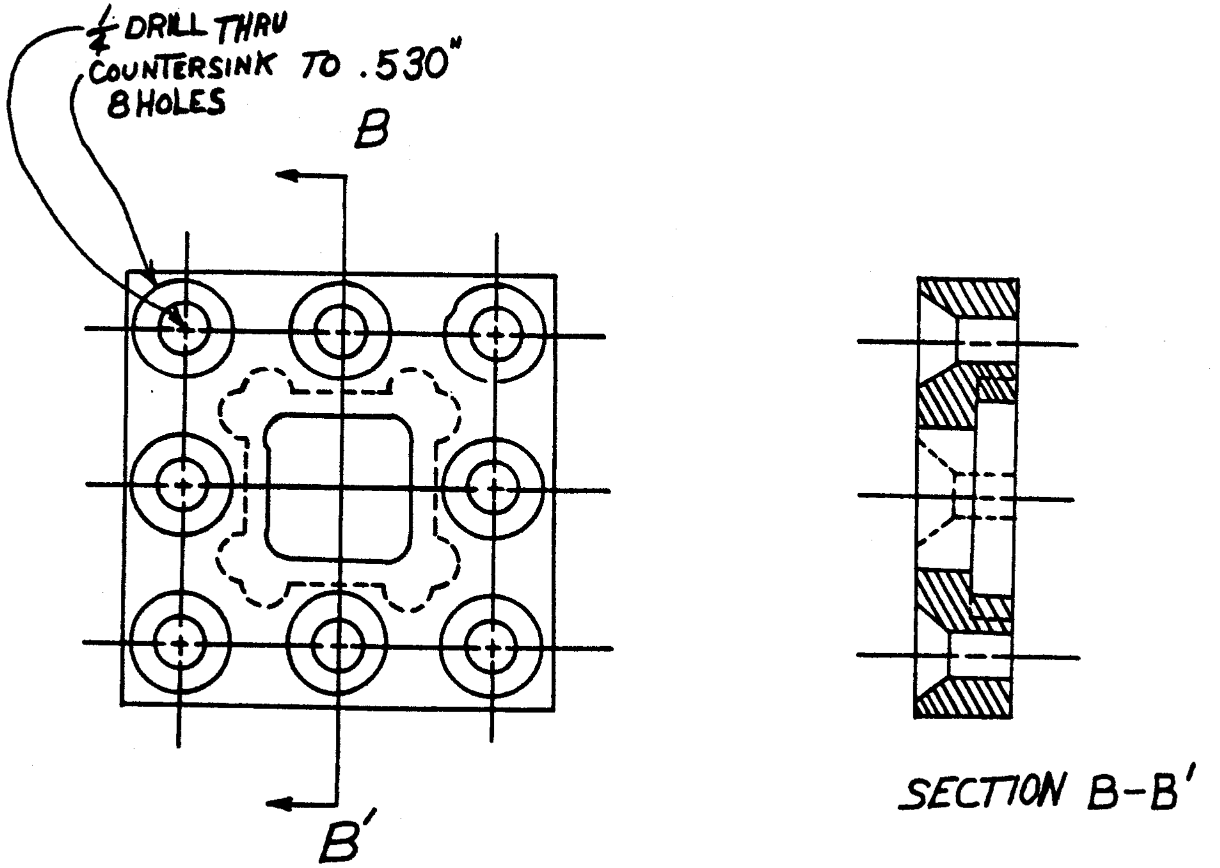
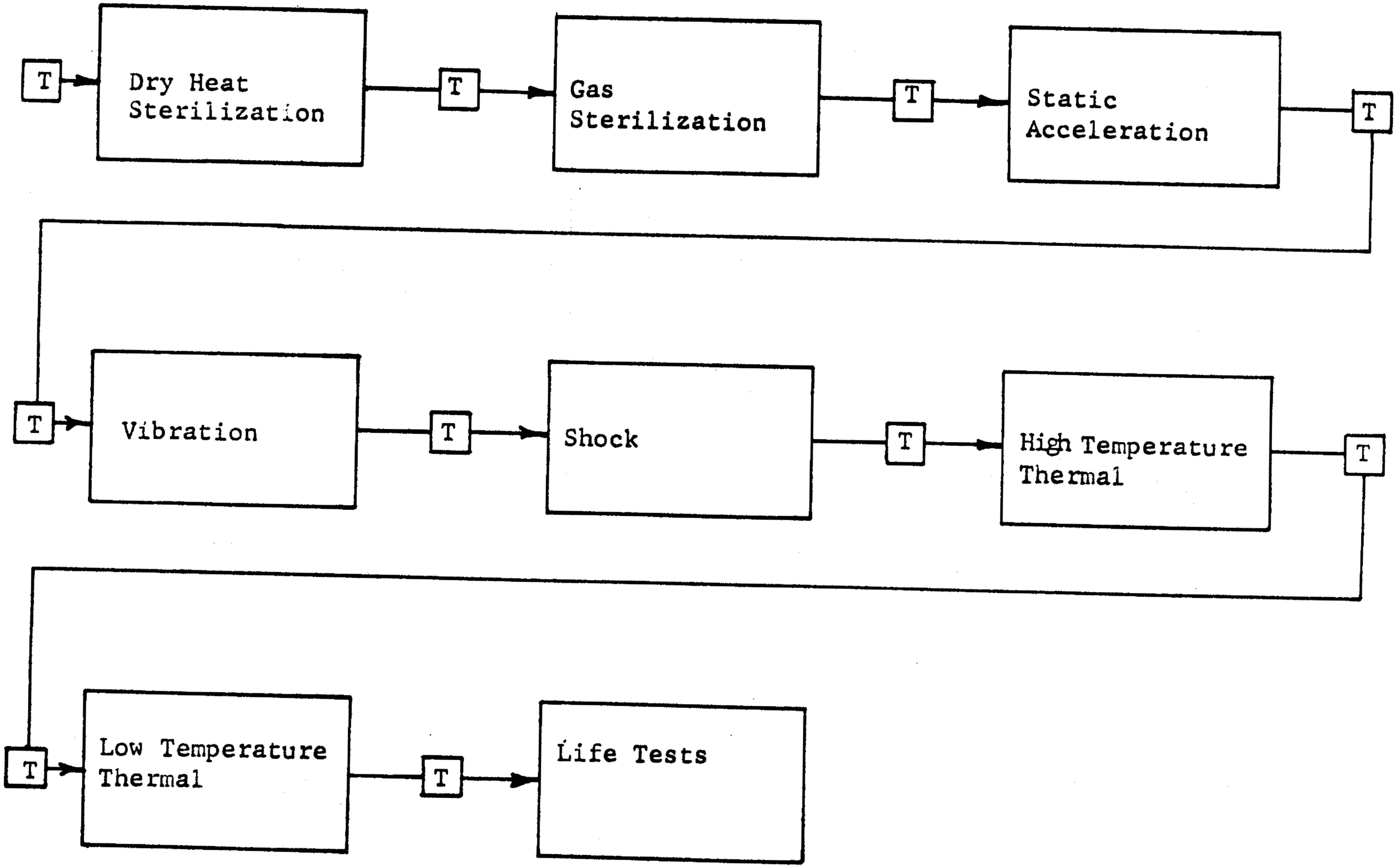


Figure 4
Test Flow Diagram



T = light transmissibility, refractive index measurements and visual examinations.

Figure 5
Sterilization Equipment

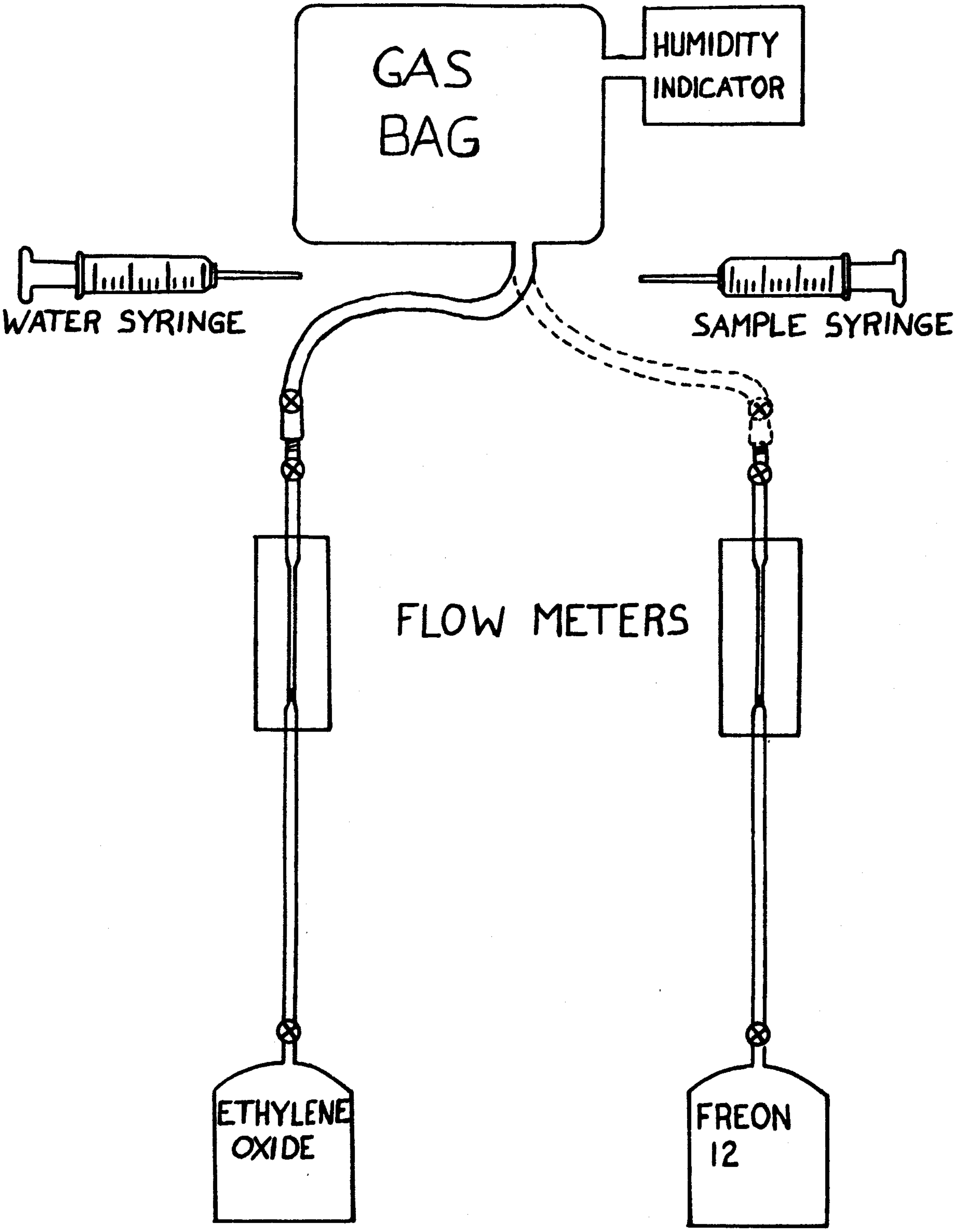


Figure 6
Sterilization Equipment

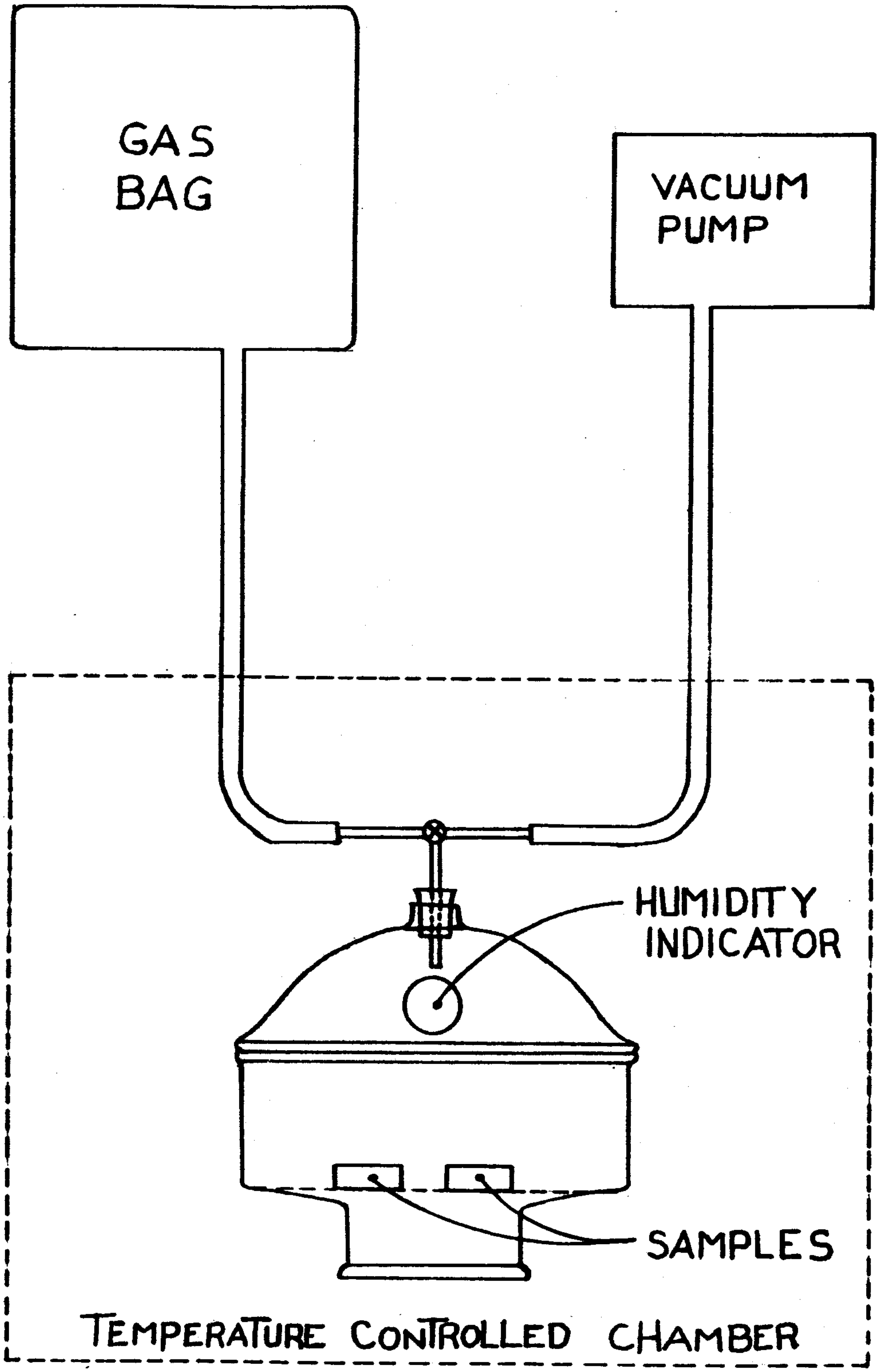
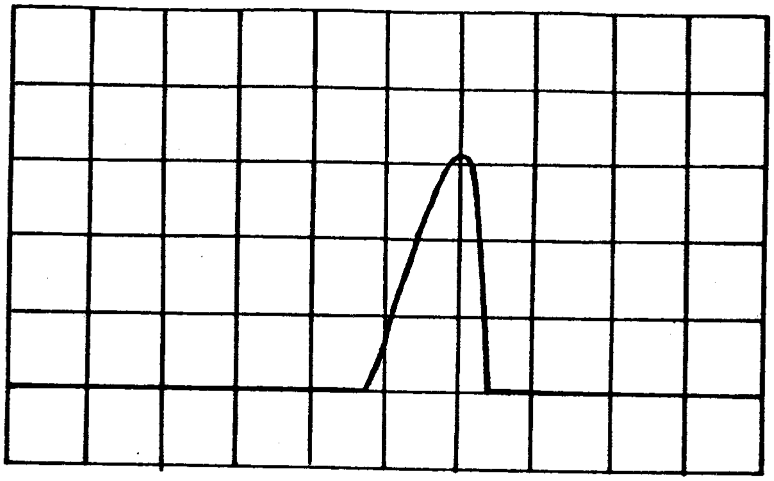
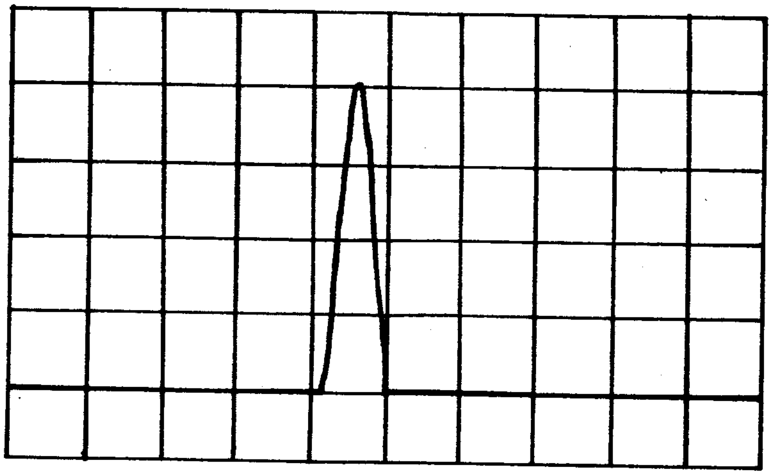


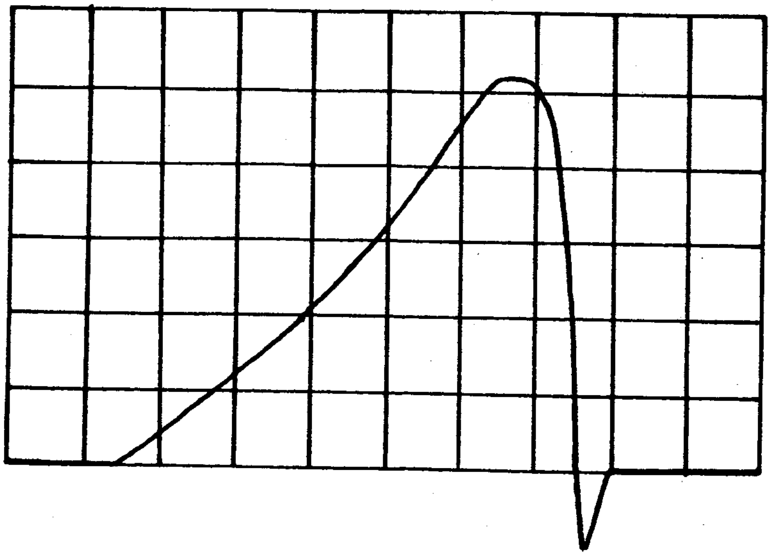
Figure 7
Shock Traces



150 g, 5 ms.
vertical = 50 g/cm
horizontal = 5ms/cm



200 g, .5 ms
vertical = 50 g/cm.
horizontal = 1 ms/cm



1000 g, 3 ms
vertical = 179 g/cm
horizontal = .5 ms/cm

Figure 8
Life Test Data

Hour	Environment	Weight	Weight Change	Total Weight Change	% Δ Weight
0	Air				
0	Vac.	4.1300	.0000	.0000	0.000
1/2	Vac.	4.1276	.0024	.0024	0.058
1	Vac.	4.1269	.0007	.0031	0.075
2	Vac.	4.1259	.0010	.0041	0.099
3	Vac.	4.1249	.0010	.0051	0.123
4	Vac.	4.1242	.0007	.0058	0.140
5	Vac.	4.1236	.0006	.0064	0.154
6	Vac.	4.1230	.0006	.0070	0.169
8	Vac.	4.1222	.0008	.0078	0.189
10	Vac.	4.1214	.0008	.0086	0.208
12	Vac.	4.1208	.0006	.0092	0.223
14	Vac.	4.1203	.0005	.0097	0.235
16	Vac.	4.1198	.0005	.0102	0.247
18	Vac.	4.1190	.0008	.0110	0.266
20	Vac.	4.1187	.0003	.0113	0.274
22	Vac.	4.1185	.0002	.0115	0.278
24	Vac.	4.1181	.0004	.0119	0.288
50	Vac.	4.1151	.0030	.0149	0.361
60	Vac.	4.1146	.0005	.0154	0.373
69	Vac.	4.1143	.0003	.0157	0.380
	Air			.0159	0.385

XR-6-3488 and curing agent with one hour catalyst
Temperature 100°C
Vacuum $<10^{-6}$ mm

Figure 9

XR-6-3488 and curing agent with one hour catalyst
Temperature 100°C.
Vacuum $< 10^{-6}$ mm.

Life Test Data

Hours	Environment	Weight	Weight Change	Total Weight Change	% Δ Weight
0	Air	4.5754			
0	Vac.	4.5809	0.0000	0.0000	0.000
1	Vac.	4.5640	0.0169	0.0169	0.394
2	Vac.	4.5540	0.0100	0.0269	0.626
3	Vac.	4.5477	0.0063	0.0332	0.757
4	Vac.	4.5430	0.0047	0.0379	0.883
5	Vac.	4.5390	0.0040	0.0419	0.976
6	Vac.	4.5360	0.0030	0.0449	1.046
8	Vac.	4.5315	0.0045	0.0494	1.150
10	Vac.	4.5282	0.0033	0.0527	1.228
12	Vac.	4.5257	0.0025	0.0552	1.285
15	Vac.	4.5228	0.0029	0.0581	1.351
20	Vac.	4.5190	0.0038	0.0619	1.442
30	Vac.	4.5150	0.0040	0.0659	1.535
40	Vac.	4.5121	0.0029	0.0688	1.603
50	Vac.	4.5103	0.0018	0.0706	1.644
60	Vac.	4.5090	0.0013	0.0719	1.675
72	Vac.	4.5074	0.0016	0.0735	1.713
80	Vac.	4.5064	0.0010	0.0745	1.735
91	Vac.	4.5054	0.0010	0.0755	1.760
92	Air	4.5022	0.0732	0.0732	1.705

Figure 10

XR 6348B & CURING AGENT WITH ONE HOUR CATALYST*

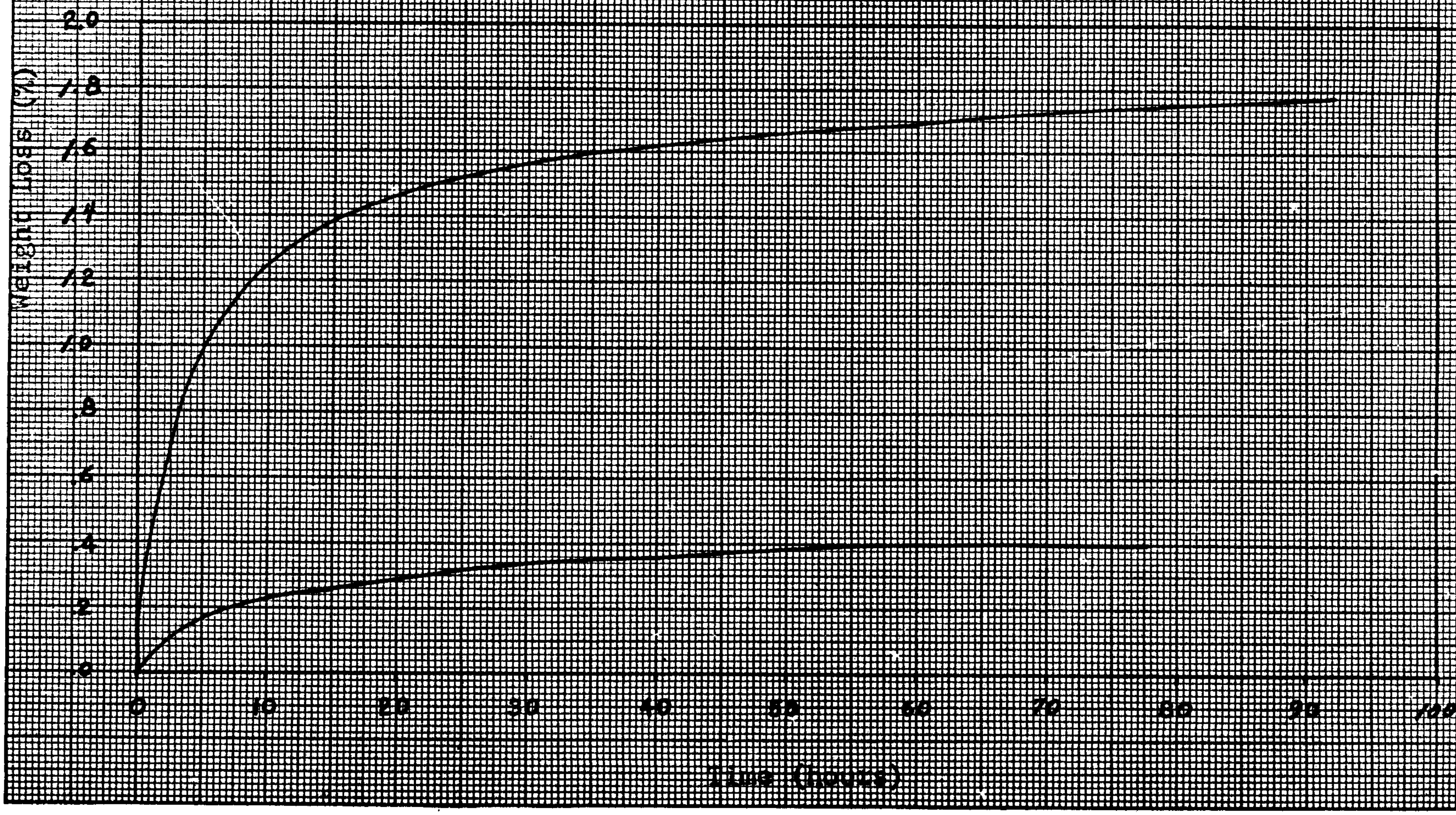


Figure 10

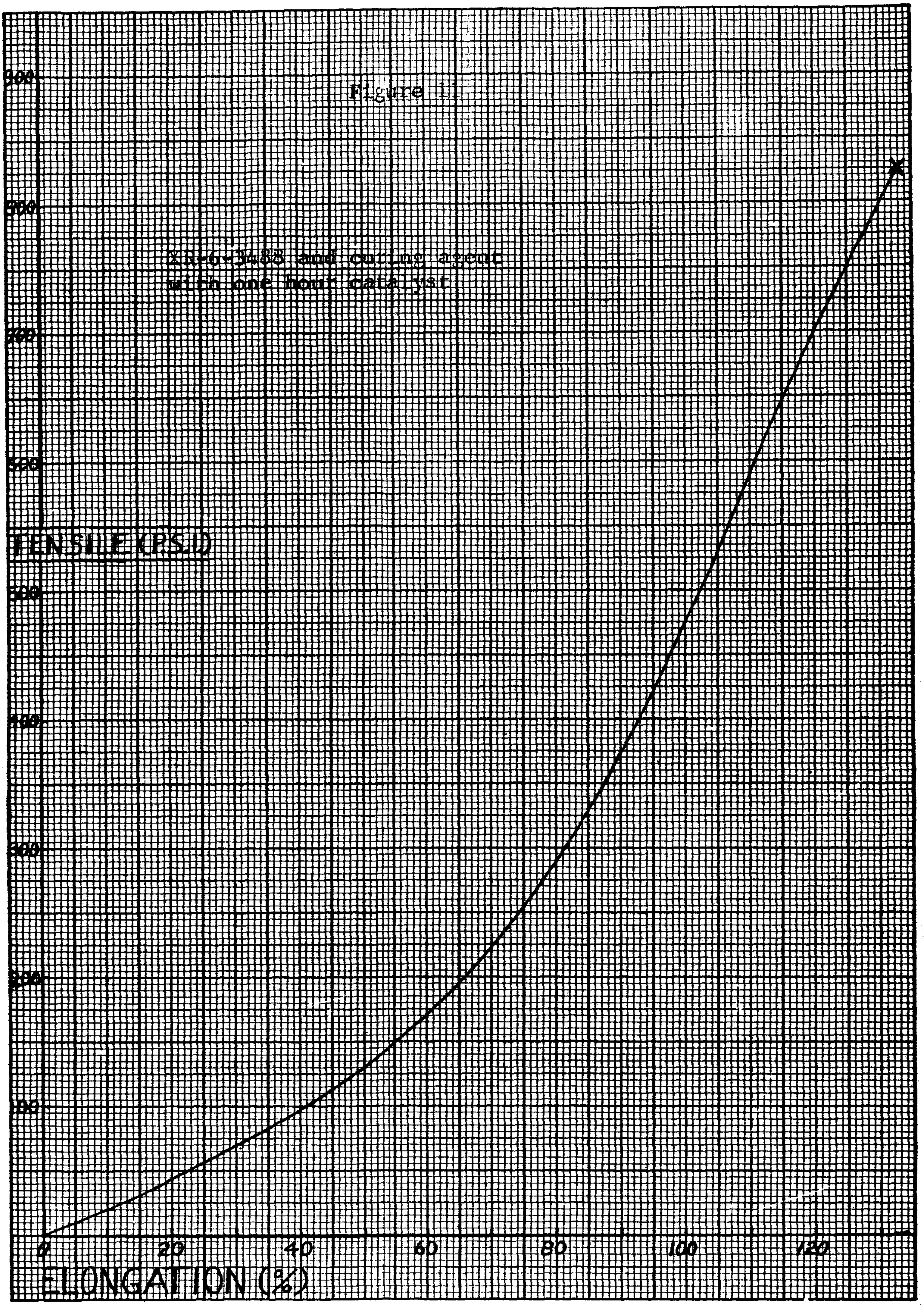


Figure 11

XR-6-3488 and curing agent
with one hour catalyst

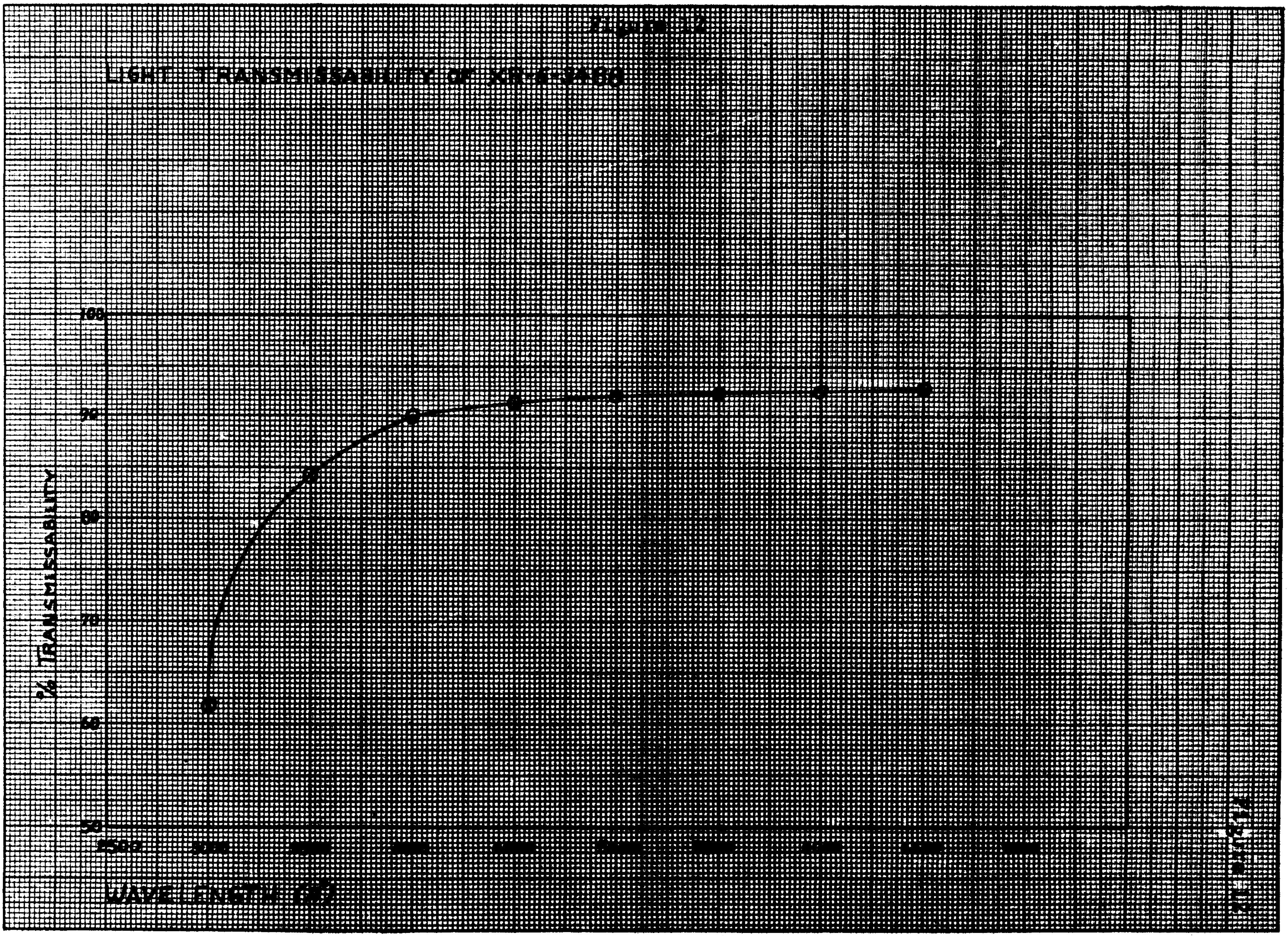


Figure 12

LIGHT TRANSMISSABILITY OF XR-6-3468

Figure 13

TEST DATA SHEET

Measurement: Visual

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
1	A	OK	→	→	→	→	→	→	→	40% Split
1	B	OK	→	→	→	→	→	→	→	→
1	C	OK	→	→	→	→	→	→	→	→
1	D	OK	→	→	→	→	→	→	→	cracked
1	D	OK	→	→	Flowed					
1	F	OK	40% Split							
2	D	OK	→	→	→	→	→	→	→	30% Split
2	E	OK	→	→	→	→	→	→	→	→
2	G	OK	→	→	→	→	→	→	→	50% Split
2	H	OK	→	→	→	→	→	→	→	→
2	I	OK	cracked							
2	J	OK	→	→	Flowed					

Figure 13

Figure 14

TEST DATA SHEET

Measurement: Visual

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
3	A	OK	—	—	—	—	→	glass broke		
3	B	OK	—	—	—	—	→	glass broke		
3	C	OK	—	—	—	—	→	glass broke		
3	D	OK	—	—	—	—	—	→		
3	E	OK	—	—	—	—	→	glass broke		
4	F	OK	—	—	—	—	—	—	—	→
4	G	OK	—	—	—	—	—	—	—	→
4	H	OK	—	—	—	—	—	—	—	→
4	I	OK	—	—	—	—	—	—	—	→
4	J	OK	—	—	—	—	—	—	—	→

Figure 15

TEST DATA SHEET

Measurement: Visual

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
5	A	OK	→	→	→	→	→	→	→	→
5	B	OK	→	→	→	→	→	→	→	→
5	C	OK	→	→	→	→	→	→	→	→
5	D	OK	→	→	→	→	→	→	→	→
5	E	OK	→	→	→	→	→	→	→	→

Figure 16

TEST DATA SHEET

Measurement: Refractive Index

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
1	A	1.42	1.42	1.41	1.42	1.42	1.41	1.41	1.41	
1	B	1.43	1.42	1.42	1.43	1.42	1.43	1.42	1.42	1.43
1	C	1.42	1.42	1.41	1.42	1.41	1.41	1.41	1.41	1.41
1	D	1.41	1.42	1.42	1.42	1.41	1.42	1.42	1.41	
1	E	1.43	1.42	1.43						
1	F	1.42								
2	D	1.43	1.43	1.43	1.43	1.42	1.43	1.43	1.43	
2	E	1.43	1.42	1.43	1.43	1.42	1.42	1.42	1.43	1.42
2	G	1.41	1.42	1.41	1.42	1.42	1.42	1.41	1.41	
2	H	1.42	1.42	1.42	1.41	1.41	1.42	1.43	1.42	1.42
2	I	1.41								
2	J	1.41	1.42	1.42						

Figure 17

TEST DATA SHEET

Measurement: Refractive Index

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
3	A	1.41	1.41	1.41	1.42	1.41	1.41			
3	B	1.42	1.43	1.42	1.43	1.43	1.42			
3	C	1.41	1.42	1.42	1.43	1.42	1.43			
3	D	1.42	1.42	1.42	1.42	1.41	1.41	1.42		
3	E	1.41	1.42	1.42	1.41	1.41	1.42			
4	F	1.41	1.41	1.42	1.41	1.41	1.41	1.42	1.41	1.42
4	G	1.43	1.43	1.42	1.41	1.42	1.42	1.41	1.43	1.43
4	H	1.42	1.42	1.42	1.42	1.41	1.41	1.42	1.42	1.41
4	I	1.43	1.42	1.42	1.43	1.43	1.42	1.43	1.43	1.43
4	J	1.42	1.42	1.41	1.42	1.41	1.42	1.41	1.42	1.41

Figure 18

TEST DATA SHEET

Measurement: Refractive Index

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
5	A	1.42	1.42	1.42	1.43	1.43	1.43	1.42	1.42	1.43
5	B	1.41	1.42	1.42	1.41	1.41	1.41	1.41	1.41	1.42
5	C	1.43	1.43	1.43	1.43	1.43	1.42	1.42	1.43	1.43
5	D	1.41	1.42	1.42	1.42	1.41	1.42	1.42	1.42	1.42
5	E	1.42	1.43	1.43	1.43	1.43	1.43	1.43	1.42	1.42

Beche line refractive index for XR-6-3488
was 1.422 ± .002

Figure 19

TEST DATA SHEET

Measurement: Light Transmissibility (%)

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
1	A	95%	94	95	95	94	95	95	94	
1	B	94	93	94	94	95	93	94	94	94
1	C	96	97	97	96	96	97	96	96	97
1	D	97	97	98	97	97	96	96	97	
1	E	93	92	93						
1	F	92								
2	D	95	95	96	95	95	95	96	95	
2	E	97	97	97	96	96	97	96	96	97
2	G	94	93	93	94	93	94	93	93	
2	H	98								
2	J	97	97	97						

Figure 19

Figure 20

TEST DATA SHEET

Measurement: Light Transmissibility (%)

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
3	A	94%	94	92	93	92	92			
3	B	97	95	95	95	96	96			
3	C	93	92	93	92	92	92			
3	D	97	97	96	96	97	96	97		
3	E	96	96	96	97	97	96			
4	F	94	93	94	94	94	93	94	93	93
4	G	93	92	92	94	94	92	93	94	94
4	H	94	94	95	95	95	94	95	94	95
4	I	92	94	94	92	92	93	92	93	93
4	J	95	96	94	95	95	96	96	95	95

Figure 21

TEST DATA SHEET

Measurement: Light Transmissibility (%)

Set No.	Sample	Initial	Heat 1,2,3	Gas Ster.	Static Accel.	Sine Vib.	Wide-Band	Shock	Hi-temp Vac.	Lo-temp Vac.
5	A	92%	93	93	92	93	93	93	93	93
5	B	95	96	96	95	96	96	96	95	95
5	C	93	94	94	93	93	94	93	94	94
5	D	94	93	94	92	93	93	94	92	92
5	E	93	92	94	93	93	92	92	92	93