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PRODUCIBILITY
OF
POTTING COMPOUNDS

Report Number GD/A-BRW64-[illegible]
1 March 1964

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FOREWORD

This report has been prepared for the National Aeronautics and Space Administration (NASA), Lewis Research Center (LeRC), Cleveland, Ohio, by General Dynamics/Astronautics (GD/A) under the requirements outlined in Contract NAS3-3232.

This study was generated because variations in ambient temperatures were resulting in unpredictable potting compound cures and had created production line stoppages in the GD/A factory.

SUMMARY

This study was conducted in the GD/A factory. Experiments were performed to document the effect of various temperature variations and relative humidities upon commercially available potting compounds. Three polyurethane compounds; Coast Proseal 777, Products Research PR-1538, Chem Seal CS-3501, and one polysulfide, Churchill 3C-737 were used to conduct the experiments.

Three environmental cures were selected. These cures represented local summer and winter weather conditions in the San Diego area, and the manufacturers' recommended ambient environment. The specimens were periodically checked to determine the effect of time upon the potting compounds.

Cure environments indicated the highest over-all ratings were in the 90 degree fahrenheit 10 percent relative humidity cures. The lowest over-all ratings were in the 55 degree fahrenheit 90 percent relative humidity cures. Also indicated was the longer the cure time the higher various characteristics rated.

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SECTION I

INTRODUCTION

1.1 GENERAL

A study to determine the affects of various ambient temperatures on the cure times of potting compounds was conducted by General Dynamics/ Astronautics. The study was undertaken because variations in ambient temperatures had resulted in unpredictable cures and assembly line stoppages in the GD/A factory.

The study consisted of a series of experiments which were conducted in a GD/A shop area. Because the experiments were concerned with the shop productibility of potting compounds, the specimens were fabricated and potted in the shop. Therefore the normal controls adhered to in a laboratory were absent except for controlling the environments for the potting compounds and for the measuring instruments utilized. This experiment evaluated four potting compounds:

a. Coast Proseal 777 (polyurethane)
b. Products Research PR-1538 (polyurethane)
c. Chem Seal CS-3501 (polyurethane)
d. Churchill 3C-737 (polysulfide)

The Coast Proseal 777 compound is presently used in the factory. The other three (two polyurethanes and one polysulfide) were chosen because of their commercial availability and to provide a method for comparison.

1.2 EXPERIMENTS CONDUCTED

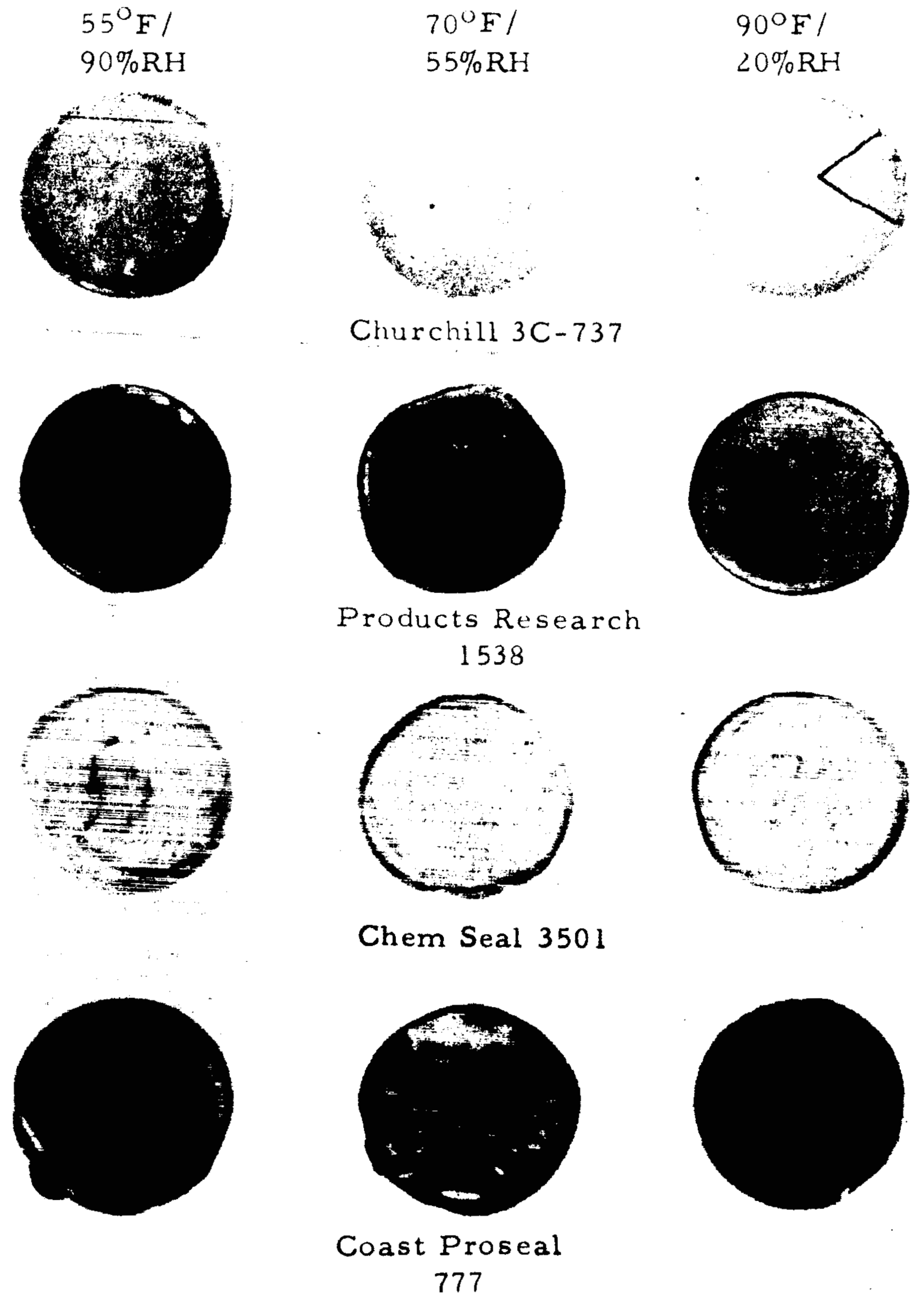
The experiments to which the four potting compounds were subjected are listed in the following paragraphs.

1.2.1 ENVIRONMENTAL. Flat specimens and potted compounds were cured in three different controlled environments. See Figure 1-1.

a. Low temperature and high humidity (55°F/90%RH)
b. Ambient temperature (70°F/55%RH)
c. High temperature and low humidity (90°F/20%RH)

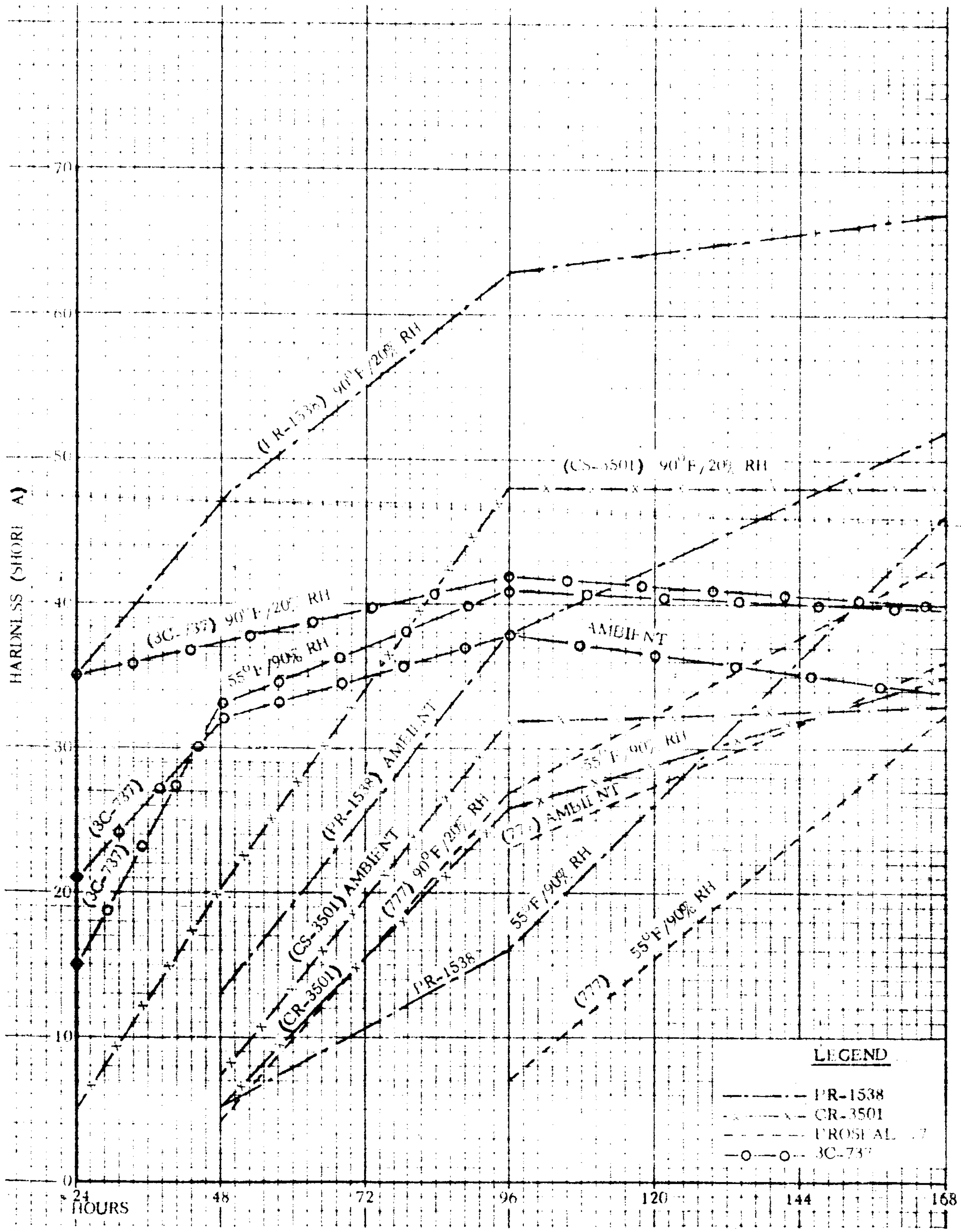
The element of time was checked by removing the potted connectors from the controlled environments at the end of 24-, 48-, and 96 hours for testing; the connectors were then bisected for a visual examination. The hardness or degree of cure of the flat specimens was measured at the end of 24-, 48-, 96-, and 168 hours.

1.2.2 MECHANICAL CHARACTERISTICS. The mechanical characteristics of the potting compounds were checked by obtaining viscometer, durometer, and pull-test measurements on the prepared specimens. These results were tabulated and graphs prepared. See Tables A-1, A-2, A-3, and Figures 1-2 through 1-5.



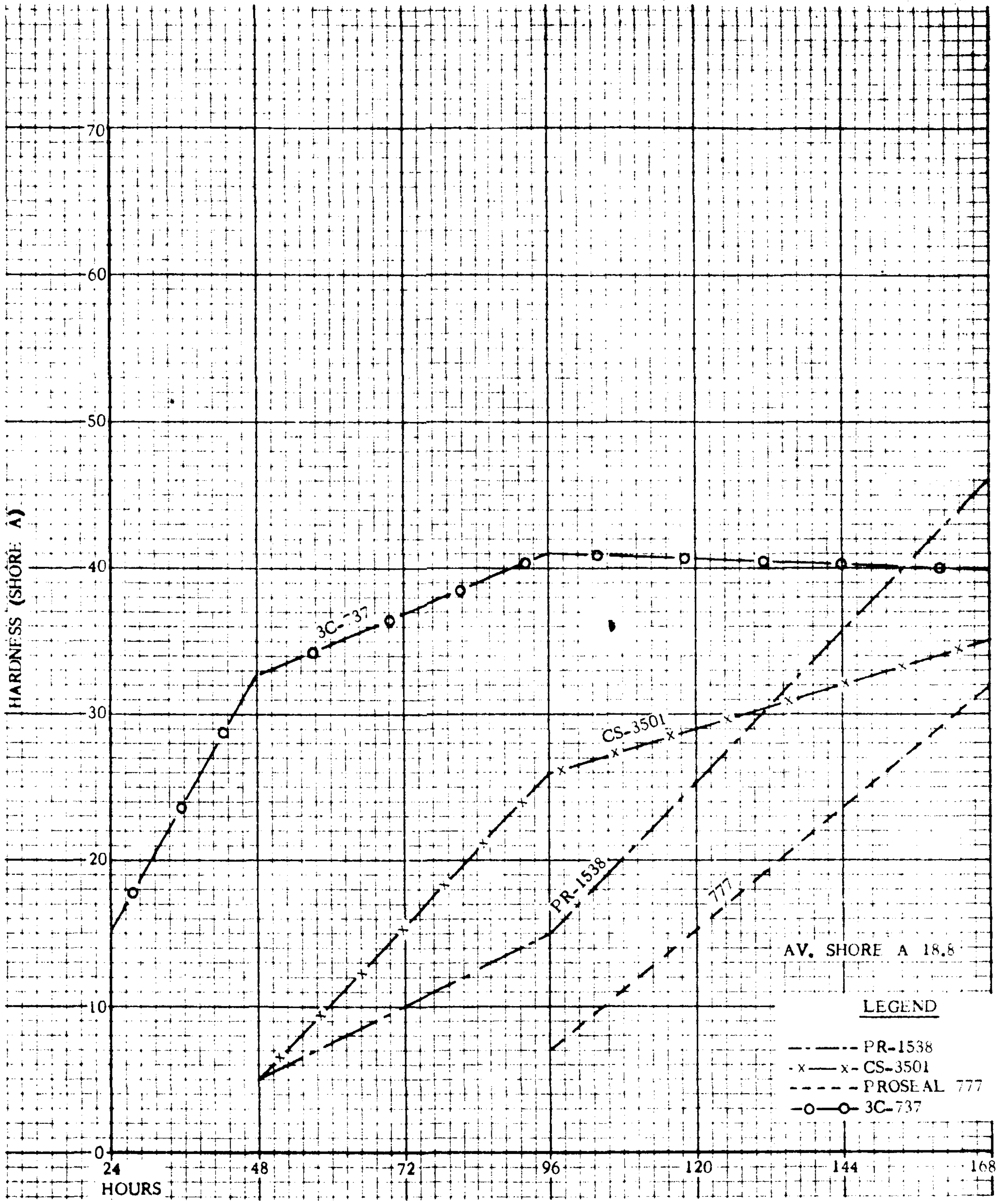
1Y01P

Figure 1-1. Potting Compounds



1Y02G

Figure 1-2. Hardness Vs Cure Time - Composite



1Y03G

Figure 1-3. Hardness Vs Cure Time - Low Temperature and High Humidity Cure Cycle (55°F/90%RH)

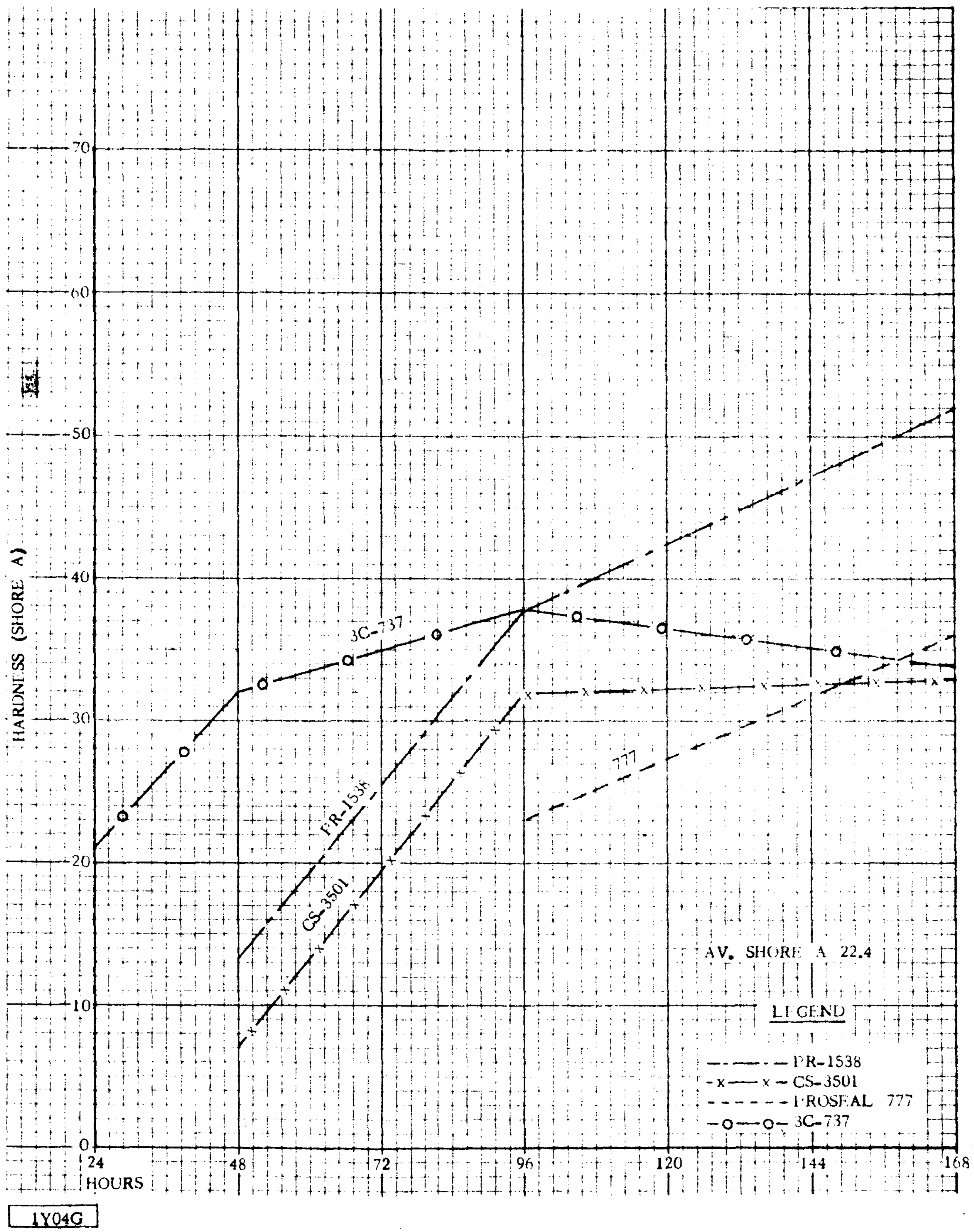


Figure 1-4. Hardness Vs Cure Time - Ambient Cure Cycle

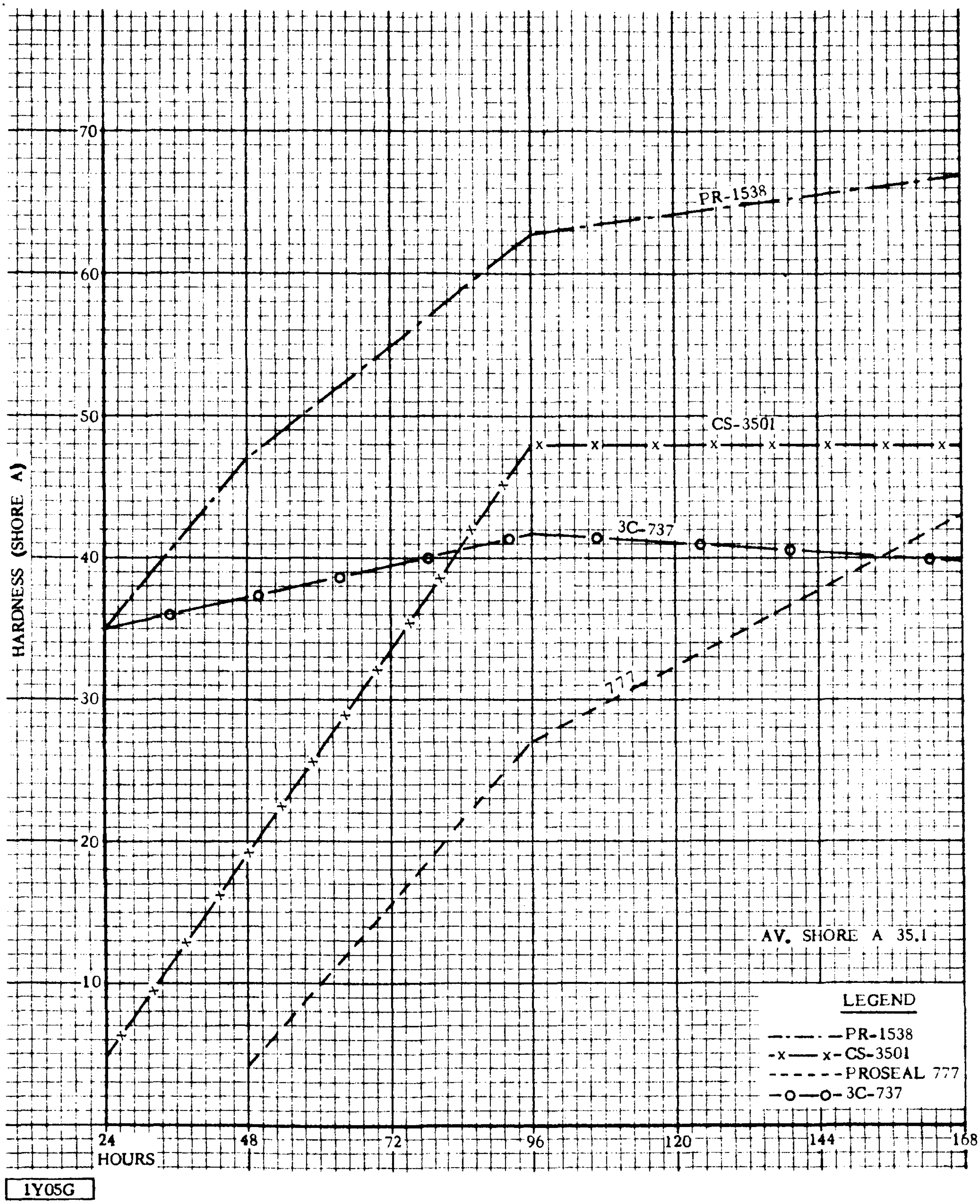


Figure 1-5. Hardness Vs Cure Time - High Temperature and Low Humidity Cure Cycle

1.2.3 ELECTRICAL CHARACTERISTICS. The electrical characteristics were measured on all connectors to determine the effects of the different curing environments and curing times on the insulation resistances. The results were tabulated and graphs prepared. See Tables A-4, A-5, A-6 and Figures 1-6 through 1-12.

1.2.4 PHYSICAL CHARACTERISTICS. The physical characteristics of the potted connectors were based upon visual observations of the bisected connectors. Various undesirable characteristics such as bubbles, voids, and lack of adhesion to wires, inserts, and shells were rated by an arbitrary grading system. This permitted the recording of relative changes in various cure environments and times, and also permitted the ranking of the four compounds. See Tables A-7 through A-10.

1.2.5 HEAT-CYCLE TESTING. A heat-cycle test was given to one-half of the specimens to determine the ability of the compounds to withstand high, sustained heats. The other half of the specimens were not heat-cycled and served as control specimens.

1.3 TEST OBJECTIVES

1.3.1 POTTING COMPOUND EVALUATION. The objective of the test was to evaluate some typical potting compounds for:

a. Mechanical characteristics such as adhesion and degree of hardness under various conditions of temperature, humidity, and time
b. Electrical characteristics of potted connectors under various conditions of temperature, humidity, and time
c. Physical characteristics of potted connectors under various conditions of temperature, humidity, and time.

1.3.2 ENVIRONMENTAL CURES SELECTED. Three environmental cures were selected. These cures represented the prevailing extremes of local summer and winter weather conditions in the San Diego area, and the manufacturers' recommended ambient environment. Specimens were checked at intervals to determine the effect of time.

1.4 CONCLUSIONS

1.4.1 CURE ENVIRONMENT RATINGS. When the three cure environments were rated for mechanical, electrical, and physical characteristics the highest over-all rating was found in the $90^{\circ}F/10\%RH$ cure. The lowest over-all rating was found in the $55^{\circ}F/90\%RH$ cure.

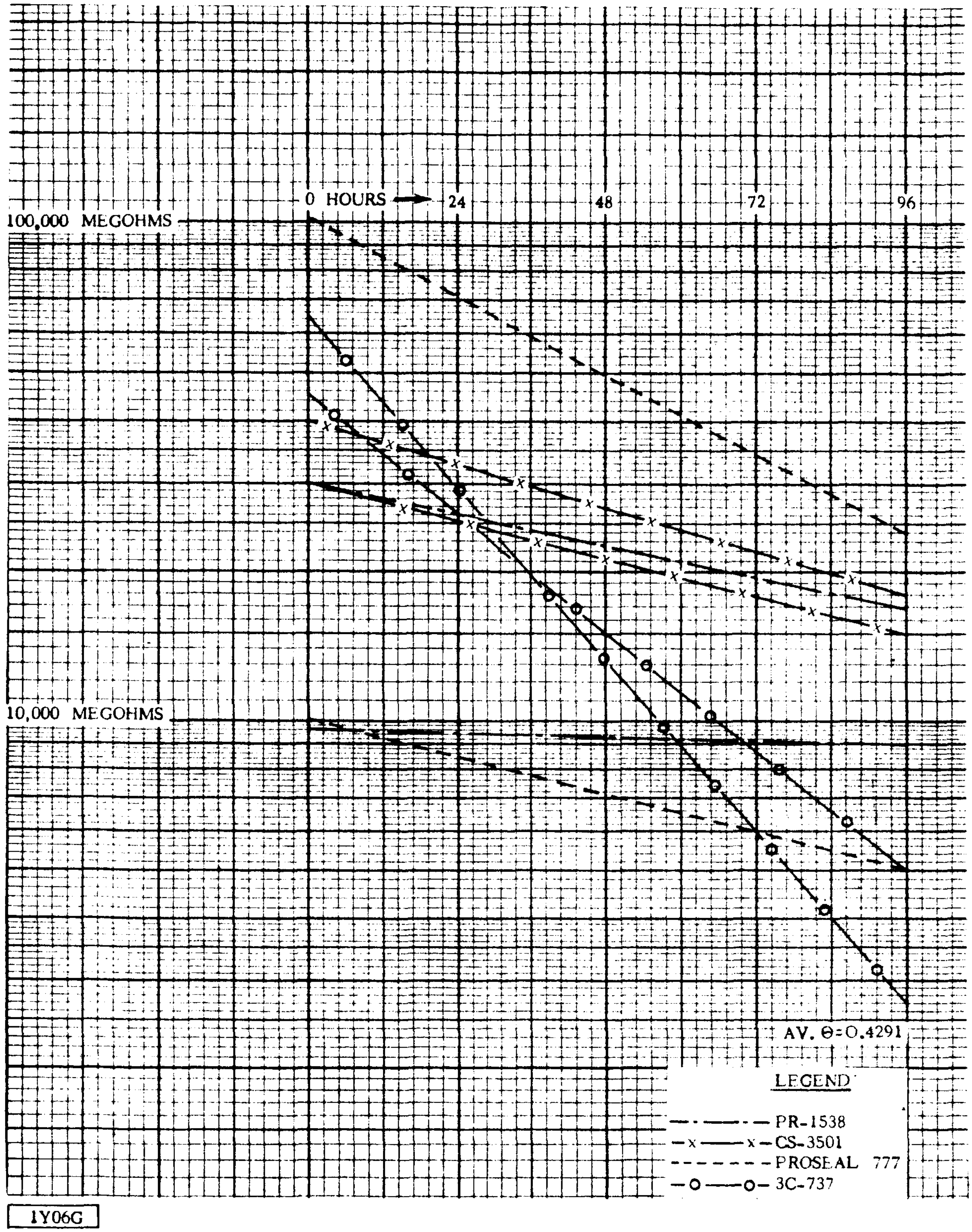


Figure 1-6. Ninety-Six Hour Insulation Resistance Measurements Grouped by Cure - Low Temperature and High Humidity (55°F/90%RH)

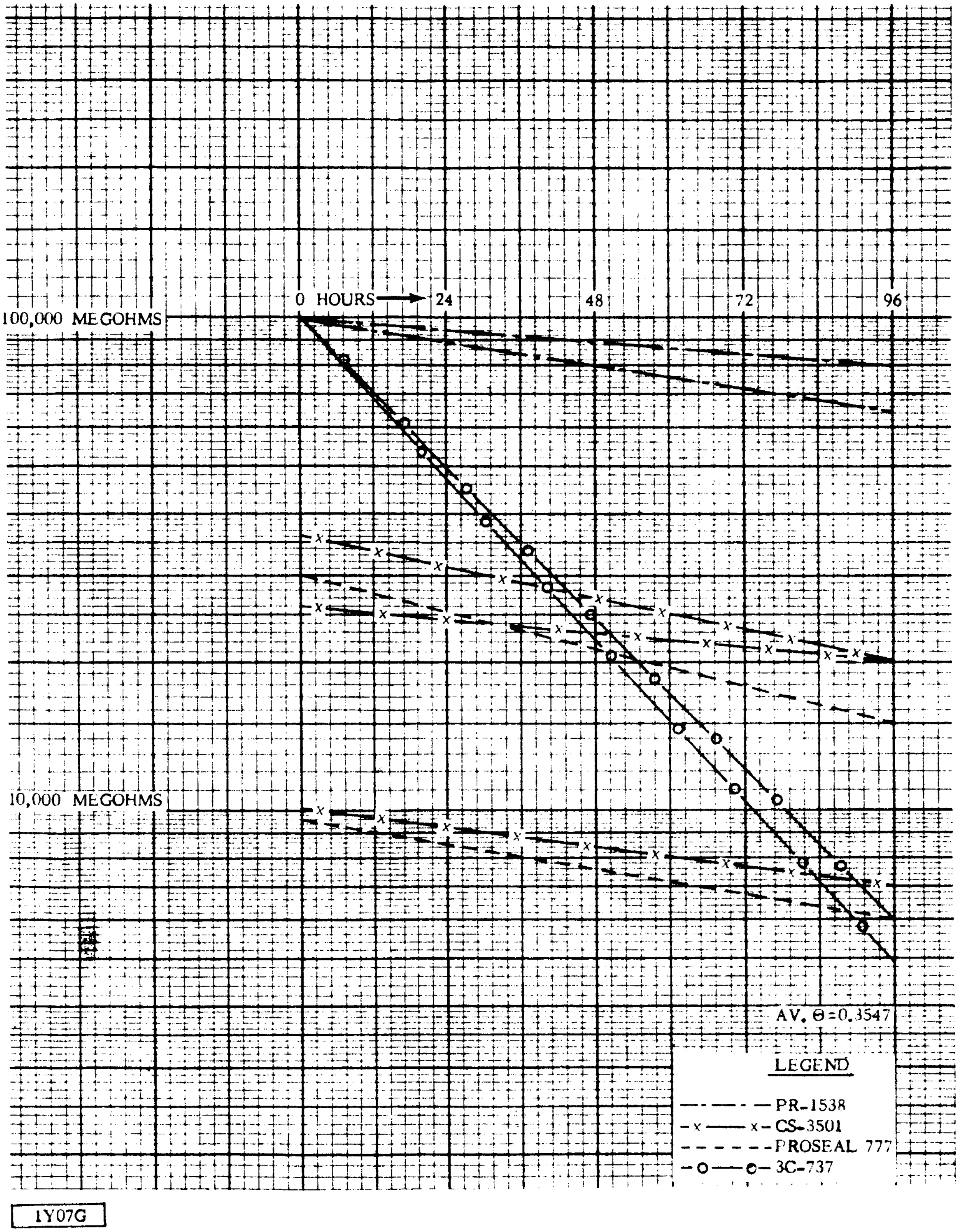
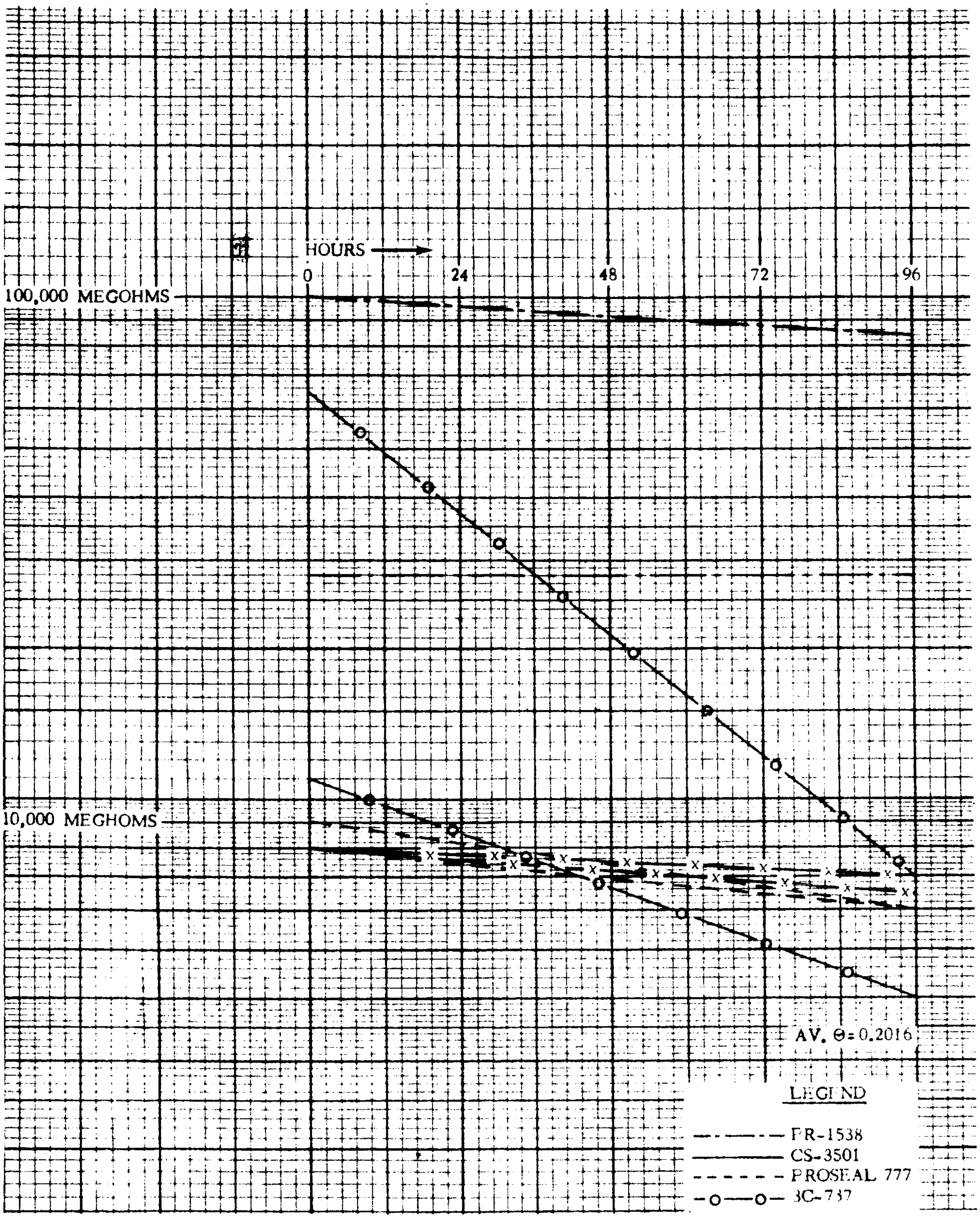


Figure 1-7. Ninety-Six Hour Insulation Resistance Grouped by Cure Cycle-Ambient Cure ($72^{O}F/55\%RH$)



1Y08G

Figure 1-8. Ninety-Six Hour Insulation Resistance Measurements Grouped by Cure Cycle-High Temperature and Low Humidity (90°F/20%RH)

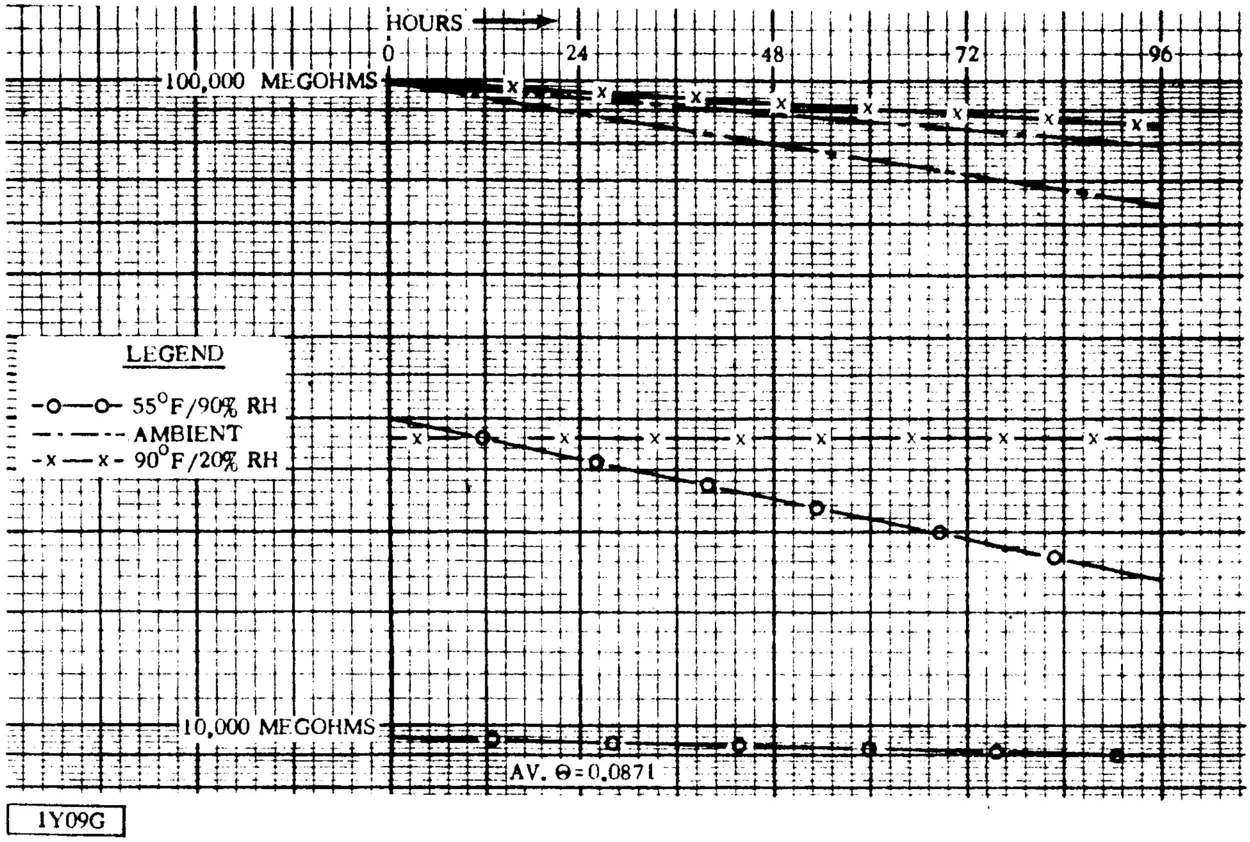


Figure 1-9. Ninety-Six Hour Insulation Resistance Measurements - Products Research PR-1538

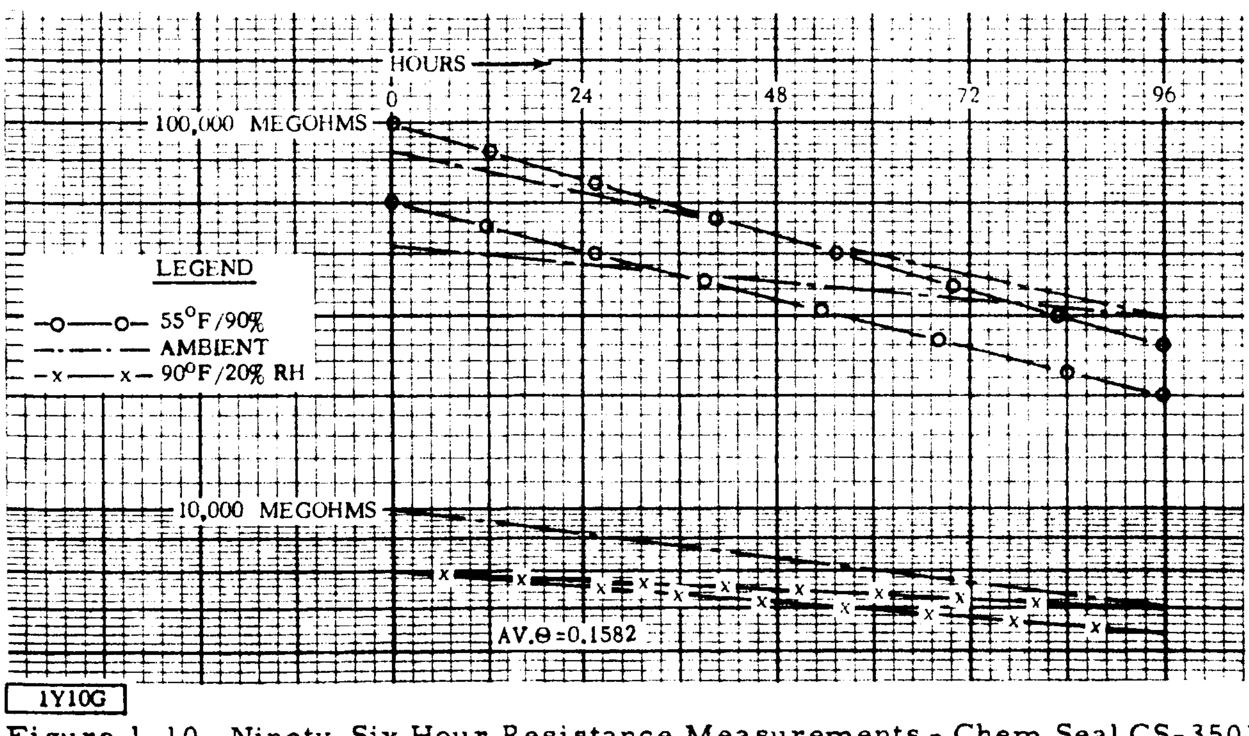
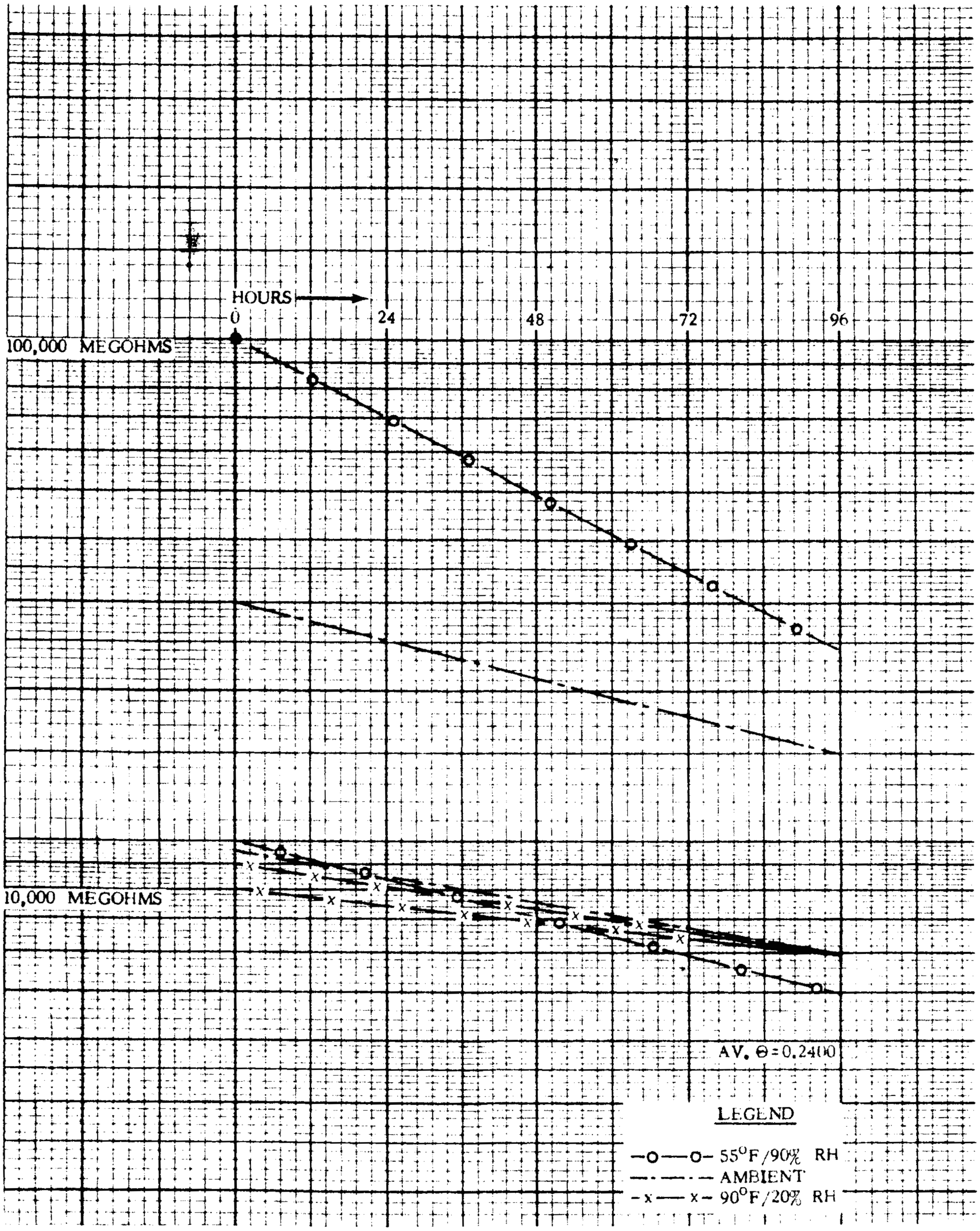


Figure 1-10. Ninety-Six Hour Resistance Measurements - Chem Seal CS-3501



1YIIG

Figure 1-11. Ninety-Six Hour Insulation Resistance Measurements - Coast Proseal 777

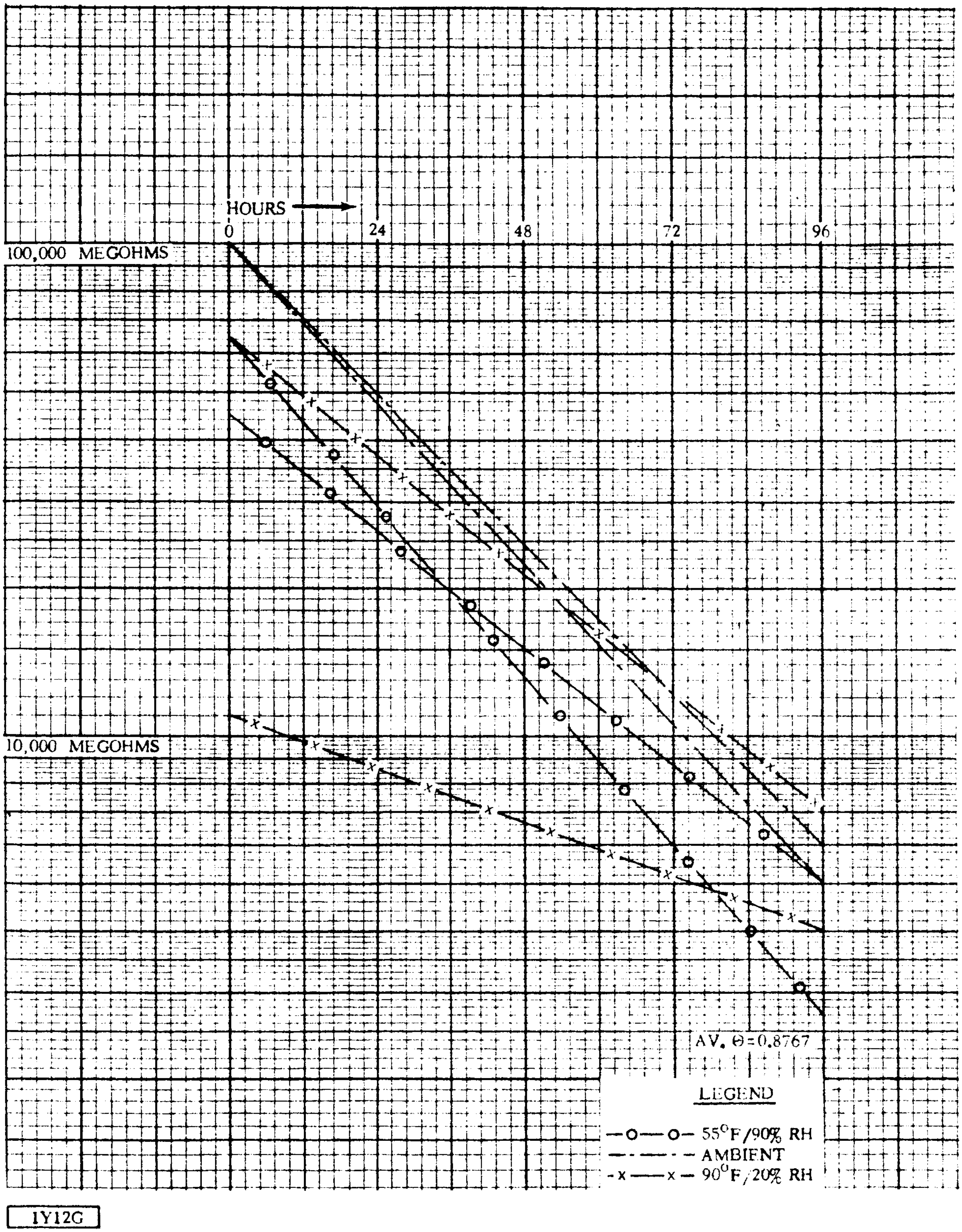


Figure 1-12. Ninety-Six Hour Insulation Resistance Measurements - Churchill 3C-737

1.4.2 CURE TIME CHARACTERISTICS. The longer the cure time the higher were the various characteristics rated. Twenty-four and forty-eight hour samples were electrically unstable and no trends could be found. Shore A hardness of 30 is considered minimum for handling connectors; only two samples in the 90°F cure (PR-1538 and 3C-737) had reached this level in 24 hours. In 48 hours all three of the Churchill 3C-737 samples had exceeded this level but none of the other polyurethanes had. The findings did not verify the vendors' claims of ambient cures within 24 hours. The longer cure times indicated the best characteristics in the 90°F cure and the poorest in the 55°F cure. The polyurethanes tended to stabilize with time and in direct relationship to the cure cycle (i.e., the higher the temperature cure, the higher the hardness readings). The polysulfide compound was fully stable by 96 hours with little relationship to the other conditions of cure.

1.4.3 MECHANICAL CHARACTERISTICS. Viscosity and peel strength measurements were of little value for this study because there was little correlation between these measurements and the results of the other tests.

1.4.4 ELECTRICAL CHARACTERISTICS. The application of potting compounds to connectors lowered the insulation resistance as measured between pins-to-case, and pin-to-pin; the pin-to-case measurement dropping the most (54 percent). The 90°F cure cycle showed the least IR loss and the 55°F cure cycle indicated the most.

Considering cure time the 96-hour cure was the most consistent with all of the specimens showing some IR loss. The 24- and 48-hour specimens showed little consistency. In the 24-hour period specimens, 44 percent of the connectors showed loss, 56 percent showed gain. In the 48-hour specimens 85 percent of the connectors showed loss and 15 percent showed gain. This indicates that the length of time in the cure cycle is important for IR stability.

1.4.5 PHYSICAL CHARACTERISTICS. Adhesion of potting compounds to electrical wires, shells, and inserts of the connectors tended to be better in the 55°F cure. However, adhesion to wires, shell, and insert all decreased with time. Roughness and voids decreased with cure time and the 90°F cure.

1.4.6 COMPARISON OF COMPOUNDS. Products Research PR-1538 (a polyurethane) consistently outrated all other compounds in all characteristics measured, except in adhesion to shell or insert.

Chem Seal CS-3501 (a polyurethane) rated consistently below PR-1538, but above all other compounds tested. CS-3501 had an affinity for moisture in the air and indicated bubbles in the 55°F/90%RH cure because of the formation of carbon dioxide. The transparency of the compound permitted an easier inspection and was a distinct advantage in rating the connectors.

Coast Proseal 777 (a polyurethane) rated the lowest of all of the polyurethanes in all characteristics measured, except adhesion to wire and insert. The durometer readings indicated Coast Proseal 777 to be unsuitable for ambient and low temperature cures. No durometer reading could be made for 24 hours, and a reading of 4 in the 90°F cure was obtained at 48 hours.

Churchill 3C-737 (a polysulfide) rated the lowest of all the compounds in every category tested. The curing environment had little effect on the compound. Heat cycling caused a physical degradation of the compound, but did not radically change its electrical characteristics. Electrical degradation was ten times that of PR-1538. The compound had certain merits for shop producibility. It was the only compound tested that did not require a priming operation. Special storage facilities for handling the compound are not necessary. Curing was rapid and was not greatly affected by the various cure cycles. However, it should be used only where IR loss will not adversely affect the circuit loads and design parameters.

1.5 SHOP PRODUCIBILITY EVALUATION

1.5.1 POTTING COMPOUNDS. From a shop producibility standpoint the various ambient cures of polyurethane potting compounds leave much to be desired and can be considered unsatisfactory for consistent production output. After 24 hours only Products Research PR-1538 was above a Shore A Hardness of 30 in the 90°F cure cycle. From a sealing standpoint Coast Proseal 777 was slightly superior to Products Research PR-1538 in adhesion to wires, and slightly superior to Chem Seal CS-3501 in adhesion to insert. Coast Proseal 777 was the poorest of all compounds in adhesion to connector shell. The opaque nature of Coast Proseal 777 made the evaluation of voids almost impossible.

1.5.2 ADDITIONAL TESTING AND RESEARCH. For a more complete evaluation of the effect of ambient cures, tests should be conducted in environments of 55°F and 20 percent RH (low temperature - low humidity) and 90°F and 90 percent RH (high temperature - high humidity). This would test the relationship between temperature and humidity.

Also, research should be done on the relationship between viscosity measurement, the slump and flow characteristics, and the wetting power of sealing compounds. A low viscosity reading is usally regarded as a necessary characteristic of a sealing compound to seal connectors with dense wire bundles. This series of experiments indicated that low viscosity may not be a necessary requirement. The compound having the highest viscosity (PR-1538) also had the highest flow characteristics and wetting power.

1.5.3 HEAT CYCLING. The effect of heat cycling was difficult to evaluate. The IR measurements taken during the test showed a significant average decrease in the order of 1 to 2×10^3. The lowest reading obtained was 2.9 megohms (Coast Proseal 777 cured for 24 hours at 55°F/90%RH, and the highest reading was 150 megohms (PR-1538 cured for 24 hours at 70°F). When the compounds are ranked according to the average IR reading during the heat cycle, the compounds ranked as follows:

a. Churchill 3C-737, 20 megohms
b. Products Research PR-1538, 17 megohms
c. Chem Seal CS-3501, 15.6 megohms
d. Coast Proseal 777, 9.3 megohms.

The side effect of the heat cycle seemed to puff the Churchill 3C-737 and to cure the Coast Proseal 777. Upon cooling the connectors recovered nearly all of the IR loss. The type of cure had little effect on the IR loss. In view of the low IR measurements during the heat cycle, some thought should be given by electrical designers to the application of potting compounds to connectors in zones where high temperatures will be experienced.

SECTION II

TEST MATERIALS AND TEST PROCEDURE

2.1 TEST MATERIALS

2.1.1 POTTING COMPOUNDS. The three polyurethane potting compounds used in this study were vendor-supplied. The specimens were premixed and frozen in six-ounce tubes. Because of the interest generated in polysulfide compounds, the commercially available Churchill 3C-737 was added to the study. This compound was procured from the supplier in two-ounce tubes.

2.1.2 ELECTRICAL CONNECTORS. Typical production electrical connectors were used. These were Bendix GP3206E-20-16P.

2.1.3 ELECTRICAL WIRING. The wiring used was 20 gauge MIL-W-5086A, Type II, Nylon coated.

2.1.4 PEEL SPECIMENS. The peel specimens were made of standard aluminum sheet stock, 4 inches wide, 12 inches long, and 0.035 inch thick. Stainless steel mesh was used as the pull material.

2.2 TEST PROCEDURE

2.2.1 PREPARATION OF SPECIMENS. The electrical connectors had two foot lengths of wire soldered to the outside row of pins. The assembly work was completed by GD/A personnel in the factory. The connectors were cleaned by standard shop procedures and then sent to a GD/A laboratory for numbering and identification. Installation resistance measurements were made on all connectors. The readings were recorded in engineering laboratory notebooks. The connectors were then returned to the electrical shop area and prepared for potting.

The connectors and peel test items were primed as follows: 17 connectors and one peel test item were primed with Products Research PR-611 18 connectors and one peel test item were primed with Chem Seal 9920-S, 17 connectors and one peel test item were primed with Coast Proseal 777P, and 17 connectors and one peel test item were left unprimed for Churchill 3C-737.

The polyurethane potting compounds had been received from the vendors in 6 ounces tubes, the compound being premixed, frozen, and packaged in dry ice. Upon arrival at the factory the specimens were stored at -30°F for approximately ten days in the electrical shop area. The compounds were thawed under controlled conditions as required by the manufacturers' recommendation in the GD/A Materials Research Plastic Laboratory.

After viscometer measurements were taken, the compounds were transported to the electrical shop area and were then injected into the connectors, using standard manufacturing procedures. Seventeen connectors each were sealed with Products Research PR-1538, Churchill 3C-737, and Coast Proseal 777 while eighteen connectors were sealed with Chem Seal CS-3501. At the same time four flat specimens were prepared by injecting each compound into flat disks (1/2 inch high by 2 inch diam.) for durometer readings; and peel specimens were fabricated. During this time there had been intermittent light rains, the inside temperature averaged 58°F and the relative humidity ranged from 70 to 75 percent.

2.2.2 CURING CYCLES. All electrical connectors and test specimens were transported to the GD/A Reliability Laboratory where the specimens were placed in controlled environments as follows:

a. Five connectors and one flat specimen of each compound in a humidity chamber set at 55°F/90%RH
b. Six connectors and one flat apecimen for each compound in a humidity chamber set at 90°F/20%RH
c. Six connector and one flat specimen for each compound were left outside the humidity chambers in an air conditioned area of the laboratory which was set for an ambient atmosphere of 70° to 75°F and 55%RH.

Four peel specimens were left in the ambient atmosphere for ten days.

2.2.3 CURE TIMES. The flat specimens were removed from the various controlled environments at intervals of 24-, 48-, 96-, and 168 hours. Each was checked for hardness and then returned to the environments. The instrument used to measure hardness was a Shore A durometer.

At the end of 24-, 48-, and 96 hours, two connectors were removed from the various environments and insulation resistance readings were taken. One of each pair of connectors was subjected to a heat cycle for 30 minutes at 300°F. At the end of the 30 minutes an IR measurement was recorded. After the connector had cooled to ambient temperature the IR measurement was again recorded. The connectors that were not heat-cycled were used to serve as controls.

At the end of each time period those connectors taken from the environments (and after the 300°F heat cycle) were bisected. Visual observations were made and the results were recorded.

2.2.4 INSULATION RESISTANCE MEASUREMENTS. All connectors had their insulation resistance (IR) measured from pin-to-pin and from pin-to-case. Since the average pin-to-case readings were lower in all cases, only those readings were used for tabulation and comparison purposes. All IR measurements were made with an Industrial Instrument Megohmeter, Model L-7, S/N 11965. The connectors that were heat-cycled were placed in a Delta Oven, Model 1060, Serial Number 1127.

2.2.5 TABULATION OF RESULTS. Since many variables were present, empiric evaluation methods were used. By this method numerical values could be assigned, and were used to compare cure environment to cure time, compound to cure environment, and compound to compound.

The 96-hour IR readings were plotted on 60-division, 3-cycle, semilog paper. The tangent of the slope was calculated to give comparative value. These values were used as an index of IR degeneration.

The smoothness of the surface and the absence of voids were noted as fulfilling the requirement of the specification on sealing compounds. Simple percentages were assigned to arrive at an evaluation.

For an evaluation of general adhesion, and adhesion to wires, shell and insert, the amount and degree of adhesion is rated in Table 2-1. Also refer to Tables A-7 through A-10.

TABLE 2-1. ADHESION EVALUATIONS

Numerical Value	Standard	Definition
1	Poor	Little or no adhesion
2	Fair	50% to 70% separation
3	Average	Some separation allowed (30% to 50%)
4	Good	Little Separation (10% to 30%)
5	Excellent	No Separation (0%)

SECTION III

SUMMARY

3.1 MECHANICAL CHARACTERISTICS

3.1.1 VISCOSITY. After thawing or mixing, the viscosity of each of the compounds with a RVF-7 Brookfield Viscometer with a Number 6 spindle. The viscosity ranged from Products Research PR-1538 (2,340 centipoise) to Coast Proseal 777 (360 centipoise). Reference Table A-1. When the viscosity measurements were compared with the findings of voids in the connectors, Products Research PR-1538 had the highest viscosity and the least number of voids of the polyurethanes while Coast Proseal 777 had the lowest viscosity and the highest number of voids. It can only be concluded that there is little direct relationship between low viscosity and lack of voids.

3.1.2 HARDNESS. The measurements of the flat specimens indicated clear trends concerning the effects of the various environments on hardness. The average readings for all compounds for 168 hours showed a Shore A hardness of 12.5 for the 55°F/90%RH cure, a hardness reading of 22.5 for the 70°F/55%RH cure, and a hardness reading of 35.0 for the 90°F/20%RH cure. Translated into shop producibility, to reach a Shore A hardness of 30, a cure of 52 hours at 90°F will be required; but at 55°F/90%RH, a cure of 132 hours (five and one-half days) will be required to obtain the same hardness. Refer to Table A-3 and Figures 1-2 through 1-5. Time was also a significant factor. A cure of 24 hours gave an average Shore A reading of 9.4, 48 hours gave an average reading of 17.0, 96 hours gave an average reading of 33.3, and 168 hours gave an average reading of 42.2. It is worth noting that within the first 24 hours, readings could be obtained only on Churchill 3C-737 in all three cure environments; and on Products Research PR-1538 in the 90°F cure only. Compounds rated by their individual over-all hardness averages appear in Table 3-1.

TABLE 3-1. POTTING COMPOUND INDIVIDUAL OVER-ALL HARDNESS AVERAGES

Potting Compound		Average Hardness (Shore A)
Churchill	3C-737	34.0
Products Research	PR-1538	31.7
Chem Seal	CS-3501	26.5
Coast Proseal	777	16.0

For individual compounds Churchill 3C-737, the polysulfide had cured to a Shore A hardness reading of 15 at 24 hours, in all three cure environments.

By 48 hours the curing had almost stopped at a reading of 30 and tended to level off within a narrow range for all three specimens.

The most sensitive compound to the various cure environments was Products Research PR-1538. It was the only polyurethane to reach a hardness reading of 35 within the first 24 hours of the 90°F cure. It also reached a reading of 67 at the end of 168 hours, the highest reading in the test.

Chem Seal CS-3501 was a softer and more transparent polyurethane than the Products Research PR-1538, and showed more of an affinity for moisture which resulted in the formation of bubbles in the 55°F/90%RH cure. The material had finished curing in the 90°F cure environment by 96 hours. Coast Proseal 777 did not give a reading at any temperature-cure cycle until 48 hours, and then only in the 90°F cure. The other Coast Proseal 777 specimens were still tacky. This observation was verified by examination of the bisected connectors. The material also showed an affinity for moisture in the 55°F cure since bubbles were present in nearly all of the low temperature-high humidity specimens.

3.1.3 PEEL STRENGTH. The peel specimens revealed little of value. The specimens were poorly prepared and the results varied widely. Refer to Table A-2.

3.2 ELECTRICAL CHARACTERISTICS

3.2.1 RESISTANCE READINGS. The 24- and 48-hour insulation resistance readings were widely scattered and showed little consistency. These were discarded as being of little value. This could indicate that the potting compounds did not stabilize during short cure periods. Refer to Tables A-4 and A-5.

The 96-hour IR readings showed consistent trends that could be plotted and used to establish comparisons. The tangent of the angle was calculated for each specimen and the relative IR loss was based on a scale of 0.0 to 1.0. Refer to Figures 1-6 through 1-8. When grouped by temperature cure the values were as follows:

a. 90°F/20%RH Average θ = 0.2016
b. 70°F/50%RH Average θ = 0.3547
c. 55°F/90%RH Average θ = 0.4291

When grouped by compounds (Refer to Figures 1-9 through 1-12) the values were as follows:

a. Products Research PR-1538 Average 0 = 0.0871
b. Chem Seal CS-3501 Average 0 = 0.1582

c. Coast Proseal 777 Average θ = 0.2400
d. Churchill 3C-737 Average θ = 0.8767

3.2.2 HEAT CYCLE READINGS. The heat-cycle readings indicated extreme IR loss during the heat to an average reading of 9 to 20 megohms. After cooling a recheck showed that all connectors recovered to within 10 percent of the original reading, except Churchill 3C-737 which exceeded the original readings in every case. All of the Churchill 3C-737 specimens indicated puffing. Refer to Tables A-4, A-5 and A-6.

3.3 PHYSICAL CHARACTERISTICS

3.3.1 CURE ENVIRONMENTS. Physical characteristics such as adhesion rated highest (2.97) in the 55°F cure cycle based on over-all averages. They rated lowest (2.78) in the 90°F cure cycle. Adhesion to wires and inserts increased slightly in the 90°F cure cycle but adhesion to shell decreased. Refer to Table A-7. Physical characteristics such as smoothness and lack of voids rated highest (65 percent) in the 90°F Cure. Refer to Table A-7. See Table 3-2 for the compounds' physical characteristics as they are ranked by cure environments. Also refer to Table A-9.

TABLE 3-2. COMPOUND CURE ENVIRONMENT RANKING

Compound		Smoothness	Voids (%)	Adhesion Average Rating
Product Research	PR-1538	83%	0%	3.23
Chem Seal	CS-3501	61%	41%	2.73
Coast Proseal	777	42%	45%	2.80
Churchill	3C-737	47%	97%	2.40

3.3.2 CURE TIMES. Physical characteristics showed a peculiar pattern with time. Bubbles, voids, and rough surfaces decreased as cure time increased. The average rating of all adhesion characteristics decreased as time increased. See Table 3-3 for physical characteristics ranked by cure times. Also refer to Table A-10.

TABLE 3-3. COMPOUND CURE TIME RANKING

Compound		Smoothness	Voids (%)	Adhesion Average Rating
Product Research	PR-1538	93%	0%	3.30
Chem Seal	CS-3501	63%	40%	3.03
Coast Proseal	777	40%	29%	2.86
Churchill	3C-737	43%	53%	2.49

APPENDIX A

TABLES A-1 THROUGH A-10

TABLE A-1. VISCOSITY MEASUREMENTS OF POTTING COMPOUNDS

Compound	Reading
Coast Proseal 777 (Thawed in H_20 at 37°C for 30 min)	34,000, 35,000, 40,000 Average 36,000 cp (centipoise)
Chem Seal CS-3501 (Thawed in air 30 min & H_20 at 35°C for 22 min)	128,000, 141,000 Off scale cp Average 134,000 cp
Products Research PR-153B (Thawed in 130°F over 30 min)	188,000, 280,000 Off scale cp Average 234,000 cp
Churchill 3C-737	175,000, 175,000 Off scale cp Average 175,000 cp
Equipment: Number 6 spindle in RVF-7 Brookfield Viscometer	

TABLE A-2. PEEL STRENGTH MEASUREMENTS

Compound	Peel Strength		
	Right	Center	Left
Chem Seal CS-3501	10 lbs	20 lbs	7 lbs
Products Research PR-1538	25 lbs	17 lbs	2 lbs
Coast Proseal	17 lbs	10 lbs	20 lbs
Churchill 3C-737	25 lbs	34 lbs	16 lbs
Parts peeled at cross head travel of 2 inches per minute and 180° angle of peel			

TABLE A-3. HARDNESS VS CURE TIME

Time	Cure Cycle 55°F	Cure Cycle Ambient	Cure Cycle 90°F
24 Hour Readings			
Chem Seal CS-3501	NR	NR	5
Products Research PR-1538	NR	NR	35
Coast Proseal 777	NR	NR	NR
Churchill 3C-737	15	21	35
24 Hour Shore A Average = 9.25			
48 Hour Readings			
Chem Seal CS-3501	5	7	20
Products Research PR-1538	5	13	47
Coast Proseal 777	NR	NR	4
Churchill 3C-737	33	32	37
48 Hour Shore A Average = 16.9			
96 Hour Readings			
Chem Seal CS-3501	26	32	48
Products Research PR-1538	15	38	63
Coast Proseal 777	7*	23	27
Churchill 3C-737	41	38	42
96 Hour Shore A Average = 33.3			
168 Hour Readings			
Chem Seal CS-3501	35	33	48
Products Research PR-1538	46	52	67
Coast Proseal 777	32	36	43
Churchill 3C-737	40	34	40
168 Hour Shore A Average = 42.2			

55°F Shore A Average = 9.3
Ambient Shore A Average = 22.5
90°F Shore A Average = 35.0

*(15 on skin)
NR - No reading
Equipment used: Shore A Durometer

TABLE A-4. INSULATION RESISTANCE MEASUREMENTS OF TWENTY-FOUR HOUR CURE TIME TEST SPECIMENS

Cure Cycle	No.	Before Potting		24 Hours		*30′-300°F		Amb. after Heat	
		Pin to Pin	Pins to Case	Pins	Case	Pins	Case	Pins	Case
PRODUCTS RESEARCH -PR1538									
55°	8	80	30	20	70				
55°	58	100	100	14	100	100-150	34	50-100	22
72°	68	100	100	45	12	550	180	100	45
72°	3	24	9	8-14	22	24-38	8.5	20	8.5
90°	69	100	100	100	100	80-100	23	80-100	24
CHEM SEAL CS-3501									
55°	47	28	8	100	100				
55°	54	100	34	100	100	42-57	13	55-80	17
72°	48	33	11	4-8	17	55-70	18	28-34	8.5
72°	57	100	100	20-30	5.5	600-800	150	100	40
90°	28	20	8.5	2.2-5	1	20-30	8	21-30	7.5
PROSEAL 777									
55°	26	85	24	14	35				
55°	16	26	10	100	100	9-12	2.9	13	5
72°	38	100	25	10-20	4.5				
72°	37	38	12	4-5	1.8	31-38	10	13-16	5
90°	34	100	32	100	100	34-46	12	28-40	9
CHURCHILL 3C-737									
55°	1	100	40	100	100				
55°	13	22-40	10	20	20	11-20	4.2	14-30	6.5
72°	20	10°	65	3.6-5.5	1				
72°	22	100	80	3.6-6	1.2	110-114	30	32-50	8.5
90	11	28	10	100	100	12-20	4.5	20-28	7

*Note: (1) All figures are in thousound megohms, except 30′-300°F cycle. These figures are in megohms.

TABLE A-5. INSULATION RESISTANCE MEASUREMENTS OF FORTY-EIGHT HOUR CURE TIME TEST SPECIMENS

Cure Cycle	No.	Before Potting		48 Hours		*30'-300°F		Ambient after Heat	
		Pin to Pin	Pins to Case	Pin to Pin	Pins to Case	Pin to Pin	Pins to Case	Pin to Pin	Pins to Case
PRODUCTS RESEARCH PR-1530									
55°	53	100	45	36-100	22	38-65	14	65-100	26
55°	56	22	8.5	15-30	7				
72°	7	100	40	100	32	23-32	8.5	100	30
72°	49	22-34	8	7-27	5				
90°	9	28-45	11	100	80				
90°	55	15-26	5.5	100	38	11-17	4.2	14-24	5
CHEM SEAL CS-3501									
55°	50	20-30	8	7.5-18	4.5	13-25	7	15-27	6
55°	52.	24-36	8	15-22	5				
72°	40	20-34	7.5	17-28	6.5				
72°	43	18-32	7	14-24	6.5	23-28	7	15-28	6
90°	15	100	55	34-85	20				
90°	27	100	34	60-70	17	36-42	11	55-80	16
PROSEAL 777									
55°	25	90	30	30-40	12	30-40	11	22-30	8.5
55°	61	100	100	34-50	14				
72°	30	75	25	28-38	12	43-60	15	21-30	8
72°	36	100	34	40-65	17				
90°	39	100	24	30-40	10	30-36	10	20-25	7.3
90°	45	26-32	8.5	15	6				

TABLE A-5. INSULATION RESISTANCE MEASUREMENTS OF FORTY-EIGHT HOUR CURE TIME SPECIMENS (CONTINUED)

Cure Cycle	No.	Before Potting		48 Hours		*30'-300°F		Ambient after Heat	
		Pin to Pin	Pins to Case	Pin to Pin	Pins to Case	Pin to Pin	Pins to Case	Pin to Pin	Pins to Case
				CHURCHILL 3C-737					
55°	59	100	100	13-26	4	130-160	43	40-60	11
55°	60	100	100	22-30	5.5				
72°	17	100	4.5	13-20	4				
72°	19	100	55	16-22	4.5	48-68	12	28-50	8.5
90°	12	75-95	30	22-26	7				
90°	4	100	65	22-28	5.5	53-68	14	70-90	20

* Notes: (1) All figures are in thousand megohms, except 30'-300°F cycle. These figures are in megohms.

TABLE A-6. INSULATION RESISTANCE MEASUREMENTS OF NINETY-SIX HOUR CURE TIME TEST SPECIMENS

Cure Cycle	No.	Before Potting		96 Hours		*30′-300°F		Ambient after Heat	
		Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell
				PRODUCTS RESEARCH PR-1538					
55°	5	100	30	28-80	17	10-15	3.4	50-70	24
55°	10	26-36	9.5	15-38	9				
72°	63	100	100	100	80	130-170	55	100	70
72°	64	100	100	100	65				
90°	14	75	28	75-100	28	18-30	6.5	60-100	24
90°	62	100	100	100	85				
				CHEM SEAL CS-3501					
55°	29	100	40	60-90	18	37-48	12	55-95	21
55°	42	100	30	40-85	15				
72°	41	30-44	10	19-32	7	20-28	7	24-34	8
72°	44	100	36	65-100	20				
72°	46	100	26	60-100	20				
90°	23	25	8	19-23	6.5	8	24-28	18-26	6
90°	51	20-38	8	18-30	7				
				PROSEAL 777					
55°	33	25-40	10	12-18	5	16-22	6.5	11-16	4.5
55°	67	100	100	85-100	24				
72°	31	100	30	40-50	15				
72°	32	20-40	9.5	15-22	6	22-30	8	14-20	5.5
90°	24	20-25	8	15-24	6				
90°	35	20-36	9	14-22	6	20-30	8.5	13-20	5.5

TABLE A-6. INSULATION RESISTANCE MEASUREMENTS OF NINETY-SIX HOUR CURE TIME TEST SPECIMENS (CONTINUED)

Cure Cycle	No.	Before Potting		96 Hours		*30′ - 300°F		Ambient after Heat	
		Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell	Pin to Pin	Pins to Shell
CHURCHILL 3C-737									
55°	6	100	65	11-22	2.7				
55°	18	100	45	17-22	5	50-60	15	55-70	17
72°	65	100	100	18-30	6	120-190	38	23-37	6.5
72°	66	100	100	16-22	5				
90°	2	100	65	20-30	7				
90°	21	32-40	11	13-15	4	12-17	3.8	17-24	5.6

*Notes: (1) All figures are in thousands of megohms except the 30′-300°F. These figures are in megohms.

TABLE A-7. VISUAL GRADING OF POTTING COMPOUNDS - GROUPED BY CURE ENVIRONMENTS

Compound	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
$55^oF/90\%RH$						
Product Research (6 Spec.)	50%	3.5	4.0	2.8	17%	3.43
Chem Seal (6 Spec.)	50%	3.8	3.3	2.3	67%	3.13
Proseal (6 Spec.)	33%	3.7	1.8	2.8	67%	2.77
Churchill (6 Spec.)	50%	3.0	2.3	2.3	83%	2.53
Average	46%	3.5	2.85	2.55	59%	2.97
Ambient						
Product Research (6 Spec.)	100%	3.8	4.0	1.7	0	3.17
Chem Seal (7 Spec.)	72%	3.4	3.5	1.7	57%	2.87
Proseal (6 Spec.)	33%	4.0	0.6	3.7	67%	2.77
Churchill (6 Spec.)	50%	2.5	2.5	2.0	100%	2.33
Average	64%	3.6	2.65	2.3	56%	2.79

TABLE A-7. VISUAL GRADING OF POTTING COMPOUNDS - GROUPED BY CURE ENVIRONMENTS (CONTINUED)

90°F/20%RH						
Compound	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
Product Research (5 Spec.)	100%	3.4	3.1	2.8	0	3.1
Proseal (5 Spec.)	60%	4.0	1.0	3.6	0	2.86
Chem Seal (5 Spec.)	60%	2.8	2.8	2.8	0	2.8
Churchill (5 Spec.)	40%	3.0	1.8	2.2	100%	2.33
Average	65%	3.8	2.18	2.85	25%	2.91

Note: Table VII based on findings published in Appendix A of Reliability Laboratory Test Report RDL-576

TABLE A-8. VISUAL GRADING OF POTTING COMPOUNDS - GROUPED BY CURE TIMES

Compound	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
24 Hours						
Products Research (5 Spec.)	80%	3.2	3.8	3.2	20%	3.40
Chem Seal (5 Spec.)	20%	3.4	3.7	3.0	60%	3.37
Churchill (5 Spec.)	40%	3.0	3.0	3.4	60%	3.13
Proseal (5 Spec.)	20%	4.0	1.6	3.8	20%	3.11
Average	40%	3.4	3.03	3.37	40%	3.25
48 Hours						
Products Research (6 Spec.)	100%	3.6	3.8	2.7	0	3.4
Chem Seal (6 Spec.)	83%	3.3	3.5	1.8	33%	2.87
Proseal (6 Spec.)	50%	3.83	1.0	3.67	3.3%	2.83
Churchill (6 Spec.)	50%	3.17	2.33	1.83	50%	2.44
Average	70.7%	3.68	2.66	2.50	29%	3.14

TABLE A-8. VISUAL GRADING OF POTTING COMPOUNDS - GROUPED BY CURE TIME (CONTINUED)

Compound	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
96 Hours						
Products Research (6 Spec.)	100%	4.0	3.9	1.5	0	3.1
Chem Seal (7 Spec.)	86%	3.4	3.0	2.0	28.6%	2.8
Proseal (6 Spec.)	50%	3.83	1.5	2.67	33%	2.67
Churchill (6 Spec.)	50%	2.33	1.83	1.5	50%	1.89
Average	71.5%	3.39	2.56	1.92	28%	2.62

Note: Table A-8 based on findings published in Appendix C of Reliability Laboratory Test Report RDL-576.

TABLE A-9. VISUAL GRADING OF CURE ENVIRONMENTS - GROUPED BY POTTING COMPOUNDS

	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
Products Research						
55°F/90%RH	50%	3.5	4.0	2.8	0	3.43
(6 Spec.)	(Note: Heat-cycled items degraded most.)					
Ambient	100%	3.8	4.0	1.7	0	3.17
(7 Spec.)						
90°F/20%RH	100	3.4	3.1	2.8	0	3.10
(5 Spec.)						
Average	83%	3.6	3.7	2.4	0%	3.23
Chem Seal						
55°F/90%RH	50%	3.8	3.3	2.3	67	3.13
Ambient	72%	3.4	3.5	1.7	57%	2.89
90°F/20%RH	60%	2.8	2.8	2.8	0	2.80
Average	60%	3.3	3.5	2.3	41%	2.94
Proseal						
55°F/90%RH	33%	3.7	1.8	2.8	67%	2.77
Ambient	33%	4.0	0.6	3.7	67%	2.77
90°F/20%RH	60%	4.0	1.0	3.6	0	2.87
Average	42%	3.9	1.1	3.4	45%	2.80
Churchill						
55°F/90%RH	50%	3.0	2.3	2.3	83%	2.53
Ambient	50%	2.5	2.5	2.0	100%	2.33
90°F/20%RH	40%	3.0	1.8	2.2	100%	2.33
Average	47%	2.8	2.2	2.17	94%	2.40

Note: Table A-9 based on findings published in Appendix B of Reliability Laboratory Test Report RDL-576.

TABLE A-10. VISUAL GRADING OF CURE TIMES - GROUPED BY POTTING COMPOUNDS

Compound	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
Products Research						
24 Hours (5 Spec.)	80%	3.2	3.8	3.2	0	3.4
48 Hours (6 Spec.)	100%	3.6	3.8	2.7	0	3.4
96 Hours (6 Spec.)	100%	4.0	3.9	1.5	0	3.1
Average	93%	3.6	3.8	2.5	0	3.30
Chem Seal						
24 Hours (5 Spec.)	20%	3.4	3.7	3.0	60%	3.4
48 Hours (6 Spec.)	83%	3.3	3.5	1.8	33%	2.9
96 Hours (7 Spec.)	86%	3.4	3.0	2.0	28.6%	2.8
Average	63%	3.4	3.4	2.3	40%	3.03
Proseal						
24 Hours (5 Spec.)	20%	4.0	1.6	3.8	20%	3.11
48 Hours (6 Spec.)	50%	3.83	1.0	3.67	33%	2.8
96 Hours (6 Spec.)	50%	3.83	1.5	2.67	3.3%	2.67
Average	40%	3.89	1.37	3.25	29%	2.86

TABLE A-10. VISUAL GRADING OF CURE TIMES - GROUPED BY POTTING COMPOUNDS (CONTINUED)

Churchill	Smoothness	Wire	Adhesion Shell	Insert	Voids & Bubbles	Average
24 Hours (5 Spec.)	40%	3.0	3.0	3.4	60%	3.13
48 Hours (6 Spec.)	50%	3.17	2.33	1.83	50%	2.44
96 Hours (6 Spec.)	50%	2.33	1.83	1.5	50%	1.89
Average	43%	2.83	2.39	2.24	53%	2.49

Note: Table A-10 based on findings published in Appendix B of Reliability Laboratory Test Report RDL-576.