NATIONAL BUREAU OF STANDARDS REPORT

4283

CHARACTERIZATION OF METAL-INSULATOR LAMINATES

by

D. S. Hoynes

Progress Report
to
Navy Bureau of Ships
Period of January 1955 through December 1955

NBS

U. S. DEPARTMENT OF COMMERCE
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D. S. Hoynes

Engineering Electronics Section
Electricity and Electronics Division

Progress Report
to
Navy Bureau of Ships
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

FOREWORD

This report covers work done under a program sponsored by the Bureau of Ships, Department of the Navy. The program is under the administration of the Electricity and Electronics Division and the technical supervision of the Engineering Electronics Section. The project was established for the purpose of determining physical and electrical properties suitable for the evaluation of metal-insulator laminates for use in printed circuit applications. A series of tests have been devised which may serve in part as the basis for a specification on printed circuit laminates.

This report, covering the period of January 1955 through December 1955, is a continuation of the work described in National Bureau of Standards Progress Report No. 3392, "Characterization of Metal-Insulator Laminates," dated June 30, 1954.

Gustave Shapiro, Acting Chief
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CHARACTERIZATION OF METAL-INSULATOR LAMINATES

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INTRODUCTION

This report deals with tests conducted on the current-carrying capacity of etched copper conductors, resistance measurements on samples having a variety of protective coatings, and dielectric properties of a number of metal-clad laminates at various temperatures. For background information on the preparation of test samples for resistance measurements, the reader is referred to National Bureau of Standards Report No. 3392, "Characterization of Metal-Insulator Laminates," dated June 30, 1954.

A chart showing the relationship between temperature rise, conductor width, cross-sectional area, and copper thickness has been included as a design aid for determining conductor sizes in printed circuit application utilizing etched conductors.

1. CURRENT-CARRYING CAPACITY

The current-carrying capacity, or the ability of an etched or printed conductor to carry an adequate current safely for a particular application, is considered to be an important property especially now that printed circuit techniques are gaining widespread acceptance for military and industrial applications. It is generally recognized that the average "printed" conductor is capable of carrying more current than is usually encountered in an electronic design application. There are a sufficient number of applications, however, where it is necessary to know with some degree of certainty whether a particular conductor can fulfill its requirements. Because information of this type has not been generally available, it was deemed sufficiently important to investigate not only the current-carrying capacity of etched-type conductors bonded to different base materials, but also their general behavior patterns under different conditions of use.

1.1 Resistivity Values

Initial measurements, made principally with thermocouples, showed a general behavior pattern of temperature-rise for a given current flow with respect to the cross-sectional area of the copper. The accuracy of the thermocouple method, however, is generally limited by the

accuracy of the conductors' dimensional measurements, which are somewhat difficult to ascertain even with precision instruments.

It was found more expedient to derive the cross-sectional area from the resistivity of the copper and the temperature-rise as computed by using the temperature coefficient of resistivity and values of resistance obtained by the IR drop method.

In order to arrive at a reasonable value of resistivity for the copper, oven measurements were made on eight samples of laminates over a temperature range of 25.6°C to 125.2°C and the temperature coefficient of resistivity established by*:

$$\alpha_{t_1} = \frac{R_{t_2} - R_{t_1}}{R_{t_1} \; (t_2 - t_1)}$$

and adjusted to a desired temperature by:

$$\alpha_t = \frac{1}{\frac{1}{\alpha_{t_1}} + (t - t_1)}$$

Values of α at 25.6°C for the eight samples varied from .00380 to .00387, as shown in Table I (p. 4), with an average value of .003844. When adjusted, the average values

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*National Bureau of Standards Circular No. 31

TABLE I

VALUES OF α FOR VARIOUS COPPER-CLAD LAMINATES BASED ON RESISTANCE MEASUREMENTS

MATERIAL AND CU. THICKNESS	TEMP. °C	I	I.R. DROP	R (OHMS)	$\alpha_{25.6}$
4-10 Epoxy .0027"	25.6 125.2	.100 .100	.004033 .005573	.04033 .05573	.00383
2-7 XXXP .0027"	25.6 125.2	.100 .100	.001651 .002288	.01651 .02288	.00387
5-26 N-1 .00135"	25.6 125.2	.100 .100	.005227 .007238	.05227 .07238	.00386
6-16 G-5 .00135"	25.6 125.2	.100 .100	.004346 .006010	.04346 .06010	.00384
2-7 XXXP .00135"	25.6 125.2	.100 .100	.003370 .004663	.03370 .04663	.00385
5-7 XXXP .00135"	25.6 125.2	.100 .100	.004057 .005608	.04057 .05608	.00384
4-7 XXXP .00135"	25.6 125.2	.100 .100	.003465 .004797	.03465 .04797	.00386
5-7 XXXP .0027"	25.6 125.2	.100 .100	.002175 .002999	.02175 .02999	.00380

for α are .00385 at 25°C, and .00393 at 20°C, which values correspond to those given in the tables (NBS Circular No. 31) for 100% conductivity copper which at 20°C has a volume resistivity equal to 1.7241 ohm-cm. From the value of α at 20°C, and the established volume resistivity at the same temperature, the volume resistivity at any temperature may be calculated by:

$$\rho t = \rho t_1 \ (1 + \alpha t_1 \ [t - t_1])$$

This results in an average resistivity value of 1.76×10^{-6} ohm-cm.at 25°C for the eight samples of copper, a value somewhat higher than that normally associated with electrolytic copper. Actual comparisons were made of cross sections of a number of conductors. In the comparisons, a combination of precise optical and physical measurements were made, an average being used of five points of measurement in thickness and width per conductor sample. The results of this method showed good agreement with computed cross sections derived from the IR drop method and may be seen in Table II, (p. 6). The results of these measurements indicate, however, that the effective resistivity of this copper is slightly higher than the value of resistivity obtained from α alone. This is probably due to a combination of several factors as follows:

a. Slight irregularities in the conductor pattern

TABLE II

CROSS-SECTIONAL AREAS AND RESISTIVITY VALUES FOR VARIOUS ETCHED COPPER CONDUCTORS

MATERIAL	AVERAGE THICKNESS (inches)	AVERAGE WIDTH (inches)	AVERAGE CROSS-SEC.* (sq. mils.)	RES. 25°C (ohms)	ρ 25* ($x10^{-6}$)	COMPUTED CROSS-SEC.** (sq. mils.)
2-7 A	.00221	.2030	448.6	.00456	1.73	466
2-7 B	.00232	.1243	288.4	.07330	1.79	290
4-7 A	.00120	.2035	244.2	.00848	1.75	251
4-7 B	.00125	.1245	155.6	.01368	1.80	155
4-7 C	.00123	.0599	73.7	.02936	1.83	72
5-10 A	.00135	.1993	269.1	.00795	1.81	267
5-10 B	.00132	.1245	164.3	.01385	1.79	165
5-10 D	.00135	.0378	37.5	.05778	1.83	37
5-10 E	.00137	.0120	16.4	.13230	1.84	16
5-7 C	.00045	.0598	26.9	.08151	1.86	26
5-7 D	.00042	.0307	12.9	.16330	1.78	13
5-7 E	.00042	.0145	6.1	.35680	1.84	6

*Based on dimensional measurements

**Based on resistance measurements and $\rho = 1.80 \times 10^{-6}$ ohm-cm.

caused by the etching procedure.

b. Somewhat lower than normal density of the copper due to manufacturing procedures for thin foils.

c. Variations in the copper due to depressions, pinholes, and variable thickness.

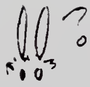
The average resistivity value for the 12 samples, as shown in Table II (p. 6), is 1.80 x 10^{-6} ohm-cm at 25°C, and for the purpose of this report, this value has been used in all computations for determining the cross-sectional areas of conductors under test. Temperature rises in the conductors (except for the purpose of checks where thermocouples were used) were computed using the α_{25} value of .00385 as described earlier (pp. 3-4), and may be obtained by:

$$\Delta T = \frac{R_2 - R_1}{\alpha R_1}$$

where R_1 = Resistance of the conductor at the low temperature.

R_2 = Resistance of the conductor at the elevated temperature.

1.2 Temperature Rise Measurements



In order to obtain a general behavior pattern for conductors of the etched type as regards current-carrying capacity, a large number of measurements were made on different lengths of conductors on a variety of materials and under different conditions of use, as shown in Table III (p. 8). The results of these measurements are shown in the current vs. cross section curves in Figs. 1-7 (pp. 9-15).

TABLE III

Length of conductor ?

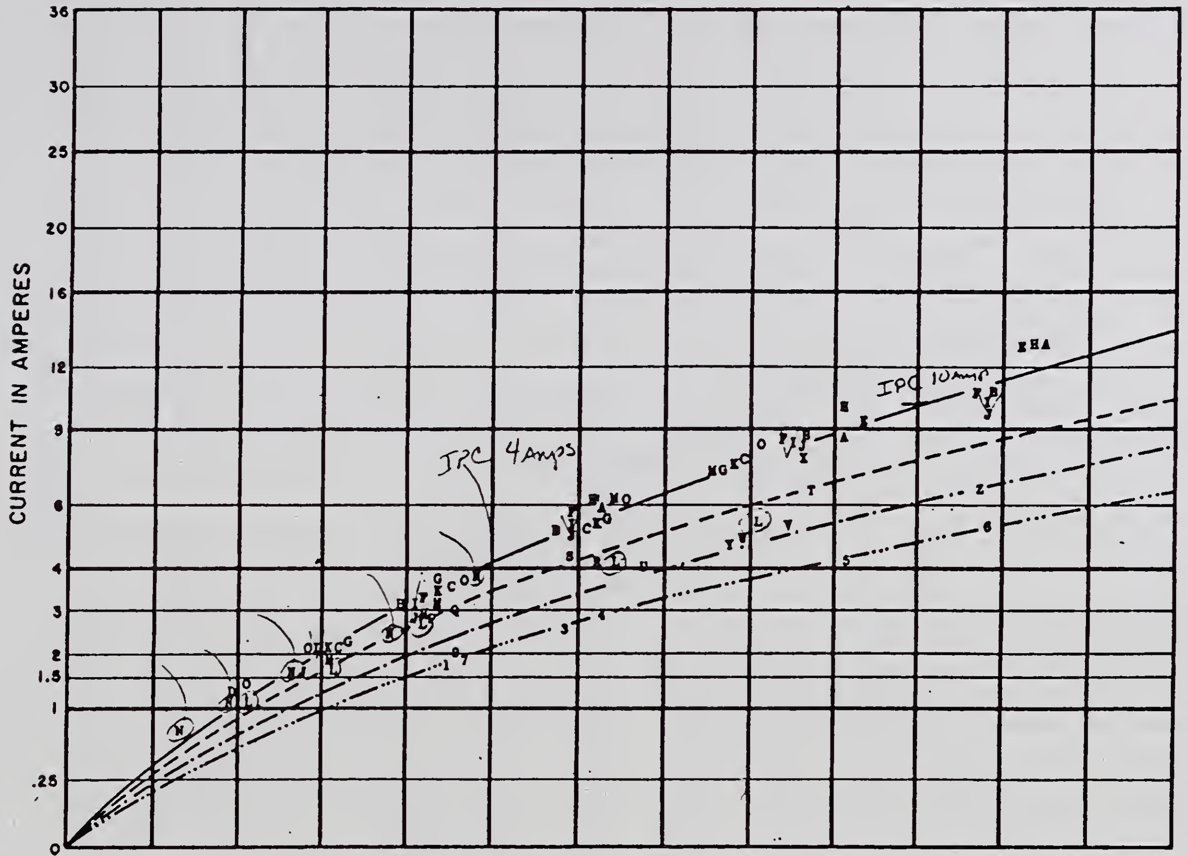
MATERIALS, PROCESSING, AND CONDITIONS USED IN DETERMINING THE TEMPERATURE RISES OF VARIOUS ETCHED CONDUCTORS (SEE FIGURES 1-7)

CODE	MATERIAL AND CORE THICKNESS (IN)	COPPER THICKNESS (IN)*	ADDITIONAL PROCESSING	TEST TEMP °C	TEST METHOD**
A	5-7 XXXP 1/16	.0027KK	None	50	IR & TC
B	2-7 XXXP 1/16	.004K	None	50	IR & TC
C	4-7 XXXP 1/16	.00135K	None	50	IR
D	4-10 Epoxy 1/16	.00135K	None	50	IR & TC
E	5-7 XXXP 1/16	.0027K	None	60	IR & TC
F	2-7 XXXP 1/16	.0027K	None	60	IR
G	4-7 XXXP 1/16	.00135KK	None	60	IR
H	5-7 XXXP 1/16	.0027KK	None	25	IR
I	2-7 XXXP 1/16	.004K	None	25	IR & TC
J	5-10 Epoxy 1/8	.0027K	None	25	IR
K	4-7 XXXP 1/16	.00135KK	None	25	IR
L	5-10 Epoxy 1/32	.00135K	None	25	IR
M	4-10 Epoxy 1/16	.00135K	None	25	TC
N	2-7 XXXP 1/16	.00067K	None	25	IR
O	5-10 Epoxy 1/32	.00135KK	None	25	IR
P	4-10 Epoxy 1/16	.00135K	Coated with .005" Epoxy Resin	25	IR
Q	2-7 XXXP 1/16	.00135K	Coated with .002" Insulating Varnish	25	IR
R	5-7 XXXP 1/16	.0027K	Coated with .001" Silicone Spray	25	IR
S	4-7 XXXP 1/16	.00135K	Coated with .003" Insulating Varnish	25	IR
T	2-7 XXXP 1/16	.0027K	Coated with .006" Silicone Resin	25	IR
U	2-7 XXXP 1/16	.00135K	Dip Soldered 10 sec. 250°C	25	IR
V	2-7 XXXP 1/16	.0027K	Dip Soldered 10 sec. 250°C	25	IR
W	10-7 XXXP 1/16	.00135K	Dip Soldered 10 sec. 250°C	25	IR
X	5-10 Epoxy 1/8	.0027K	Dip Sold. and Coated with .005" Epoxy Res.	25	IR & TC
Y	4-7 XXXP 1/16	.00135K	Dip Soldered 10 sec. 250°C	25	IR
Z	2-7 XXXP 1/16	.0027K	Dip Soldered 10 sec. 250°C	25	TC
1	5-7 XXXP	.00135	Core Removed Conductor in Free Air	25	IR
2	6-16 G-5	.00135	Core Removed Conductor in Free Air	25	IR
3	2-7 XXXP	.00135	Core Removed Conductor in Free Air	25	IR
4	5-7 XXXP	.0027	Core Removed Conductor in Free Air	25	IR
5	2-7 XXXP	.0027	Core Removed Conductor in Free Air	25	IR
6	2-7 XXXP	.0027	Core Removed Conductor in Free Air	25	IR
7	4-10 Epoxy	.00135	Core Removed Conductor in Free Air	25	IR

*K denotes single-clad, and KK denotes double clad material.
**IR = IR Drop Measurement, TC = Thermocouple Measurement.

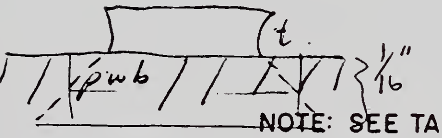
FIG. I

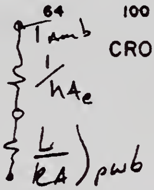
CURRENT VS. CROSS SECTION
FOR 10° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS



CROSS SECTION IN SQ. MILS

A_e = exposed area



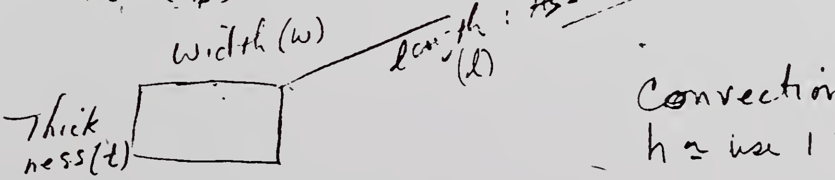


NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

Conduction:

$t \times W$ = Cross-sectional area

$2(W*l) + 2(t*l)$ = perimeter area (A_p)



$$G = \frac{kA}{L_1} \quad ⚠$$

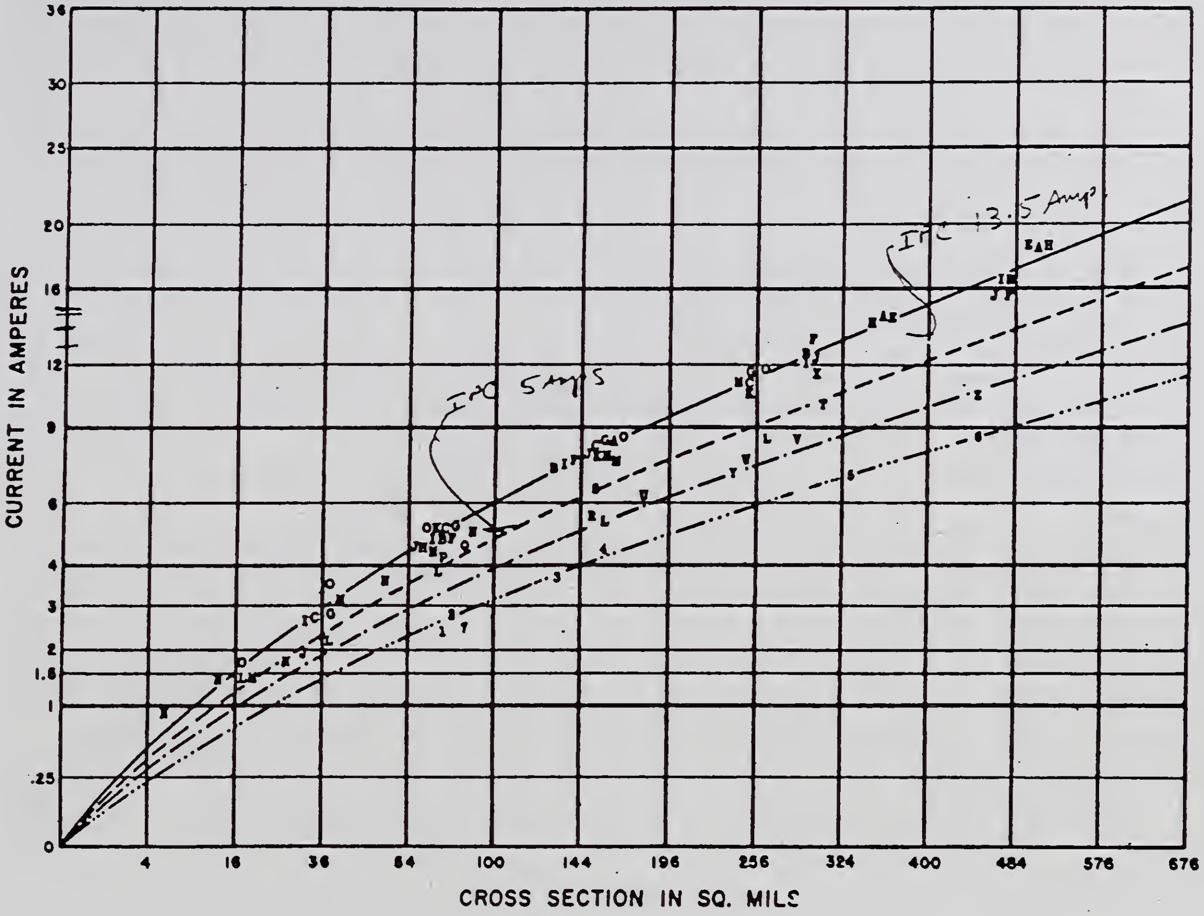
$$= \frac{k(A_p)}{L_1}$$

Convection:

$h \simeq$ use 1 BTU/hr Ft² °

⚠ L_1 = conduction length ≡ Thickness of sample board (Assume sides are exposed to air

FIG. 2



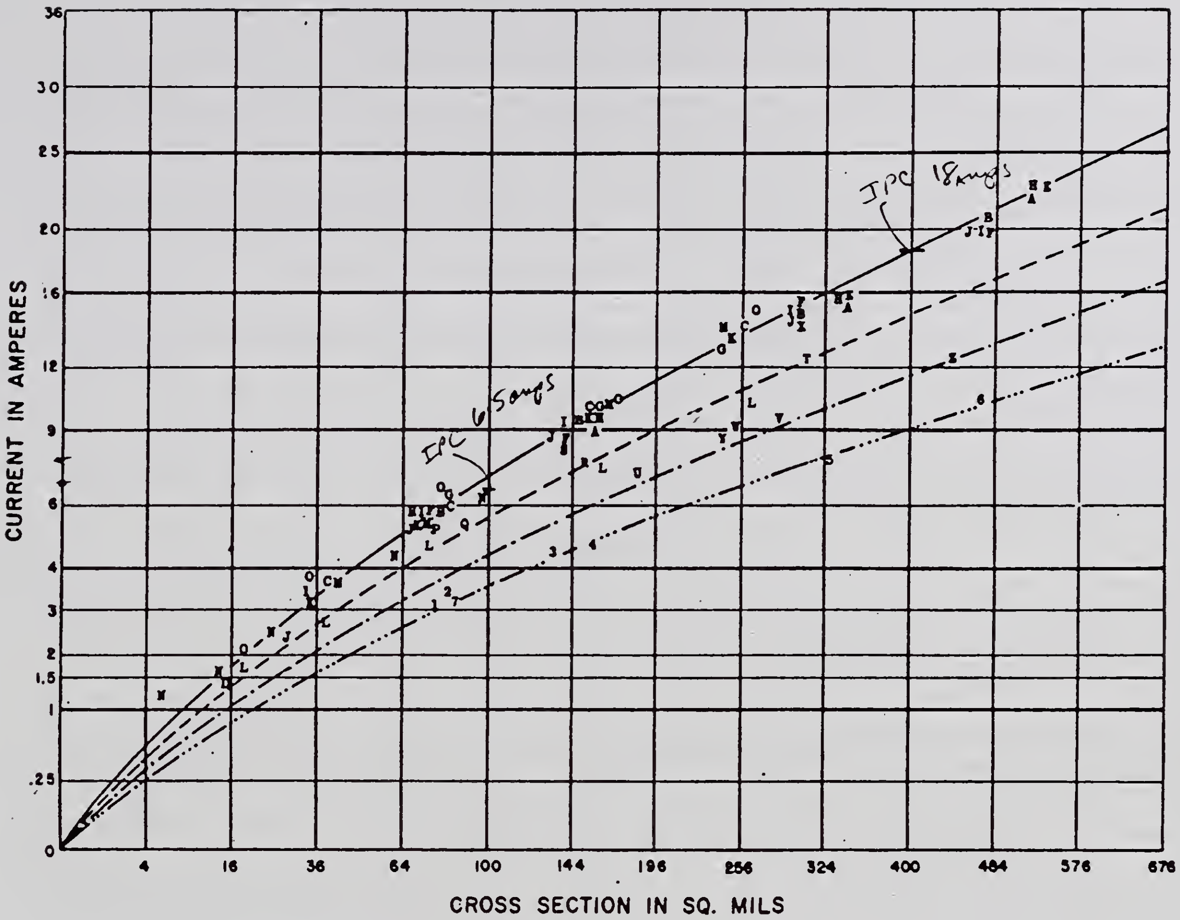
CURRENT VS. CROSS SECTION
FOR 20° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS

± 3°C

NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

FIG. 3

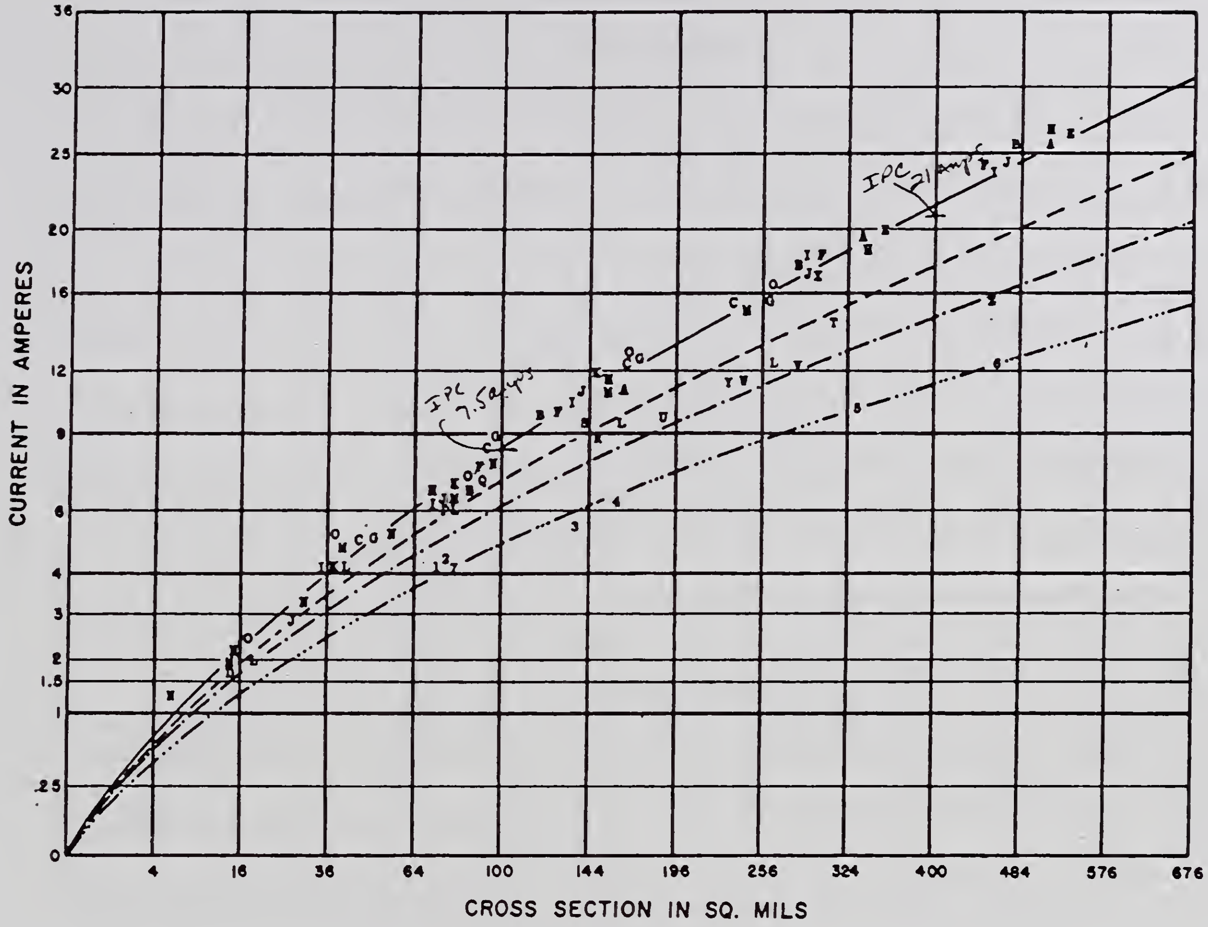
CURRENT VS. CROSS SECTION
FOR 30° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS



NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

FIG. 4

CURRENT VS. CROSS SECTION
FOR 45 °C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS

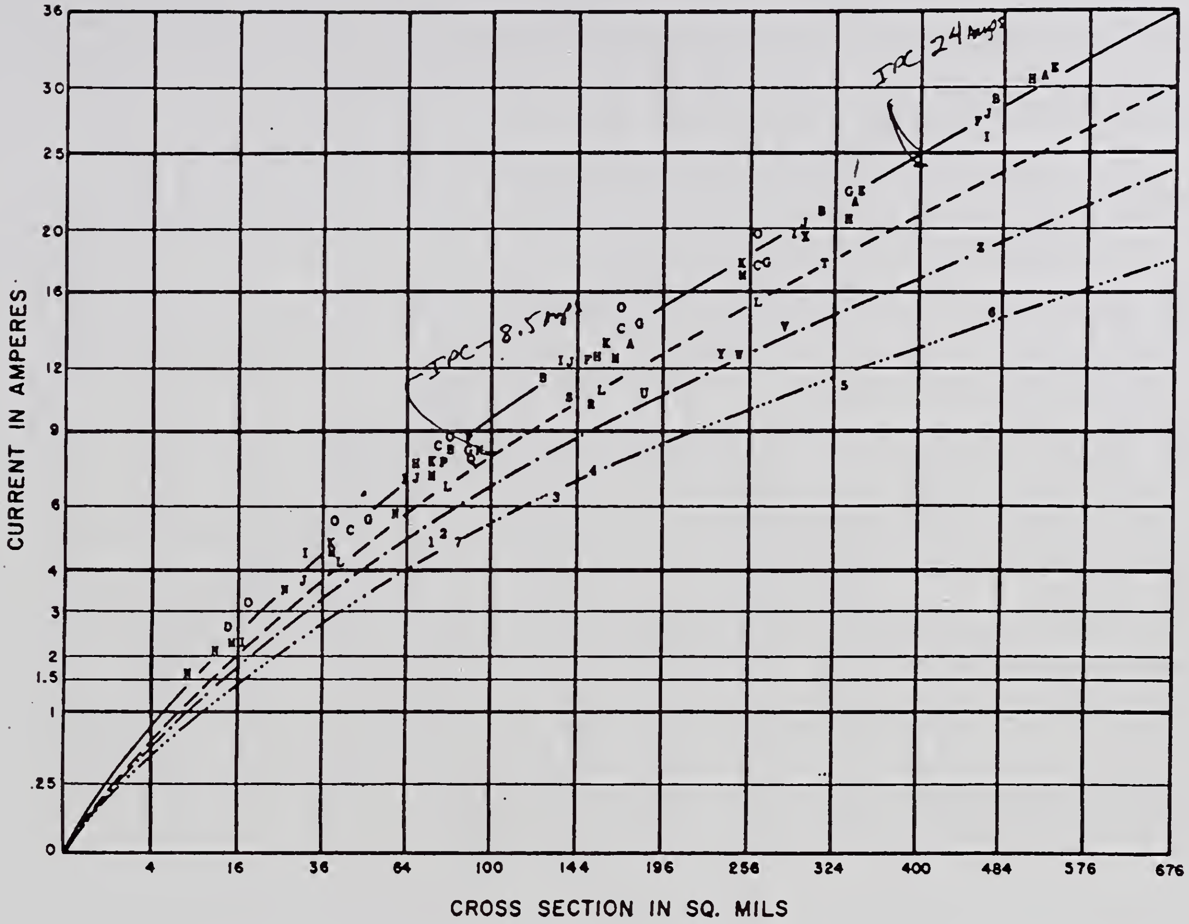


NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

4

FIG. 5

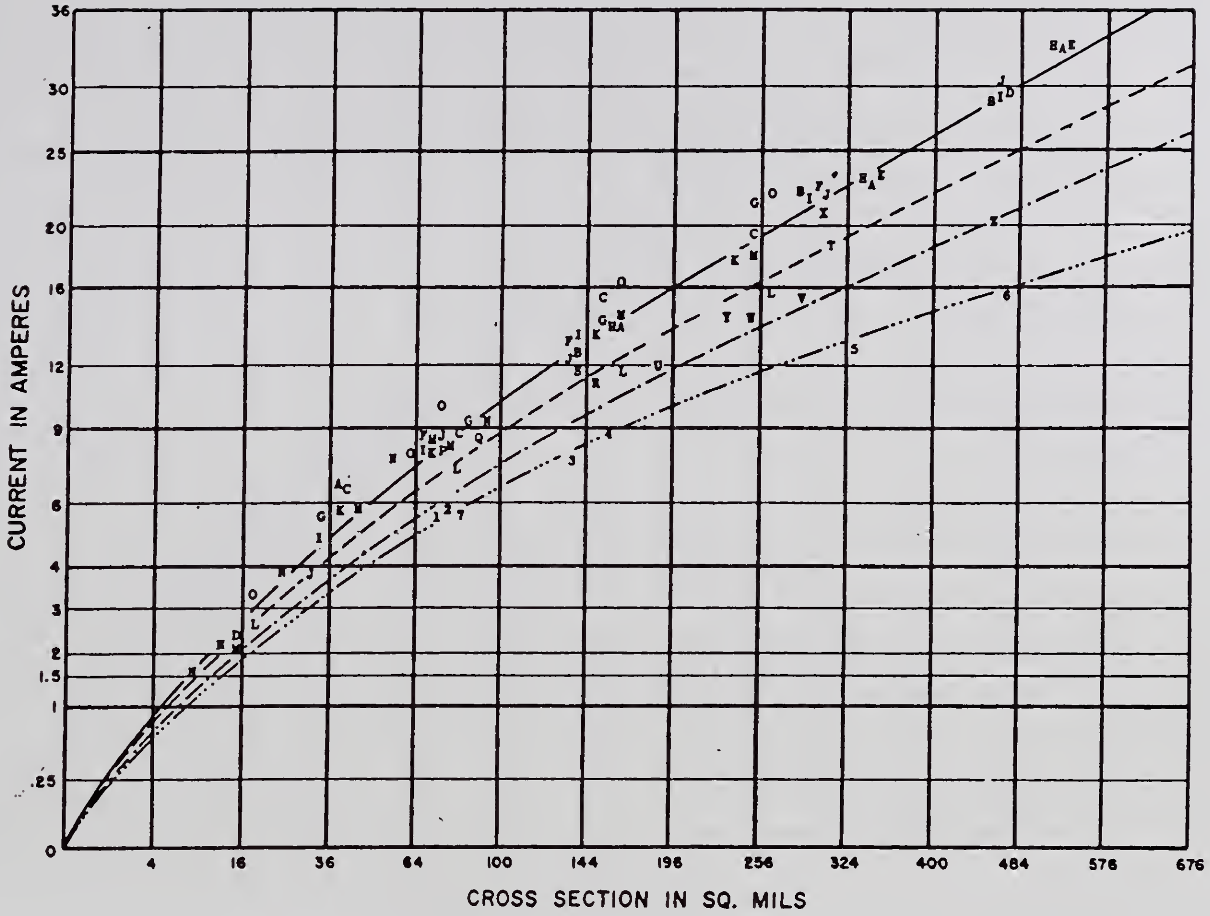
CURRENT VS. CROSS SECTION
FOR 60° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS



NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

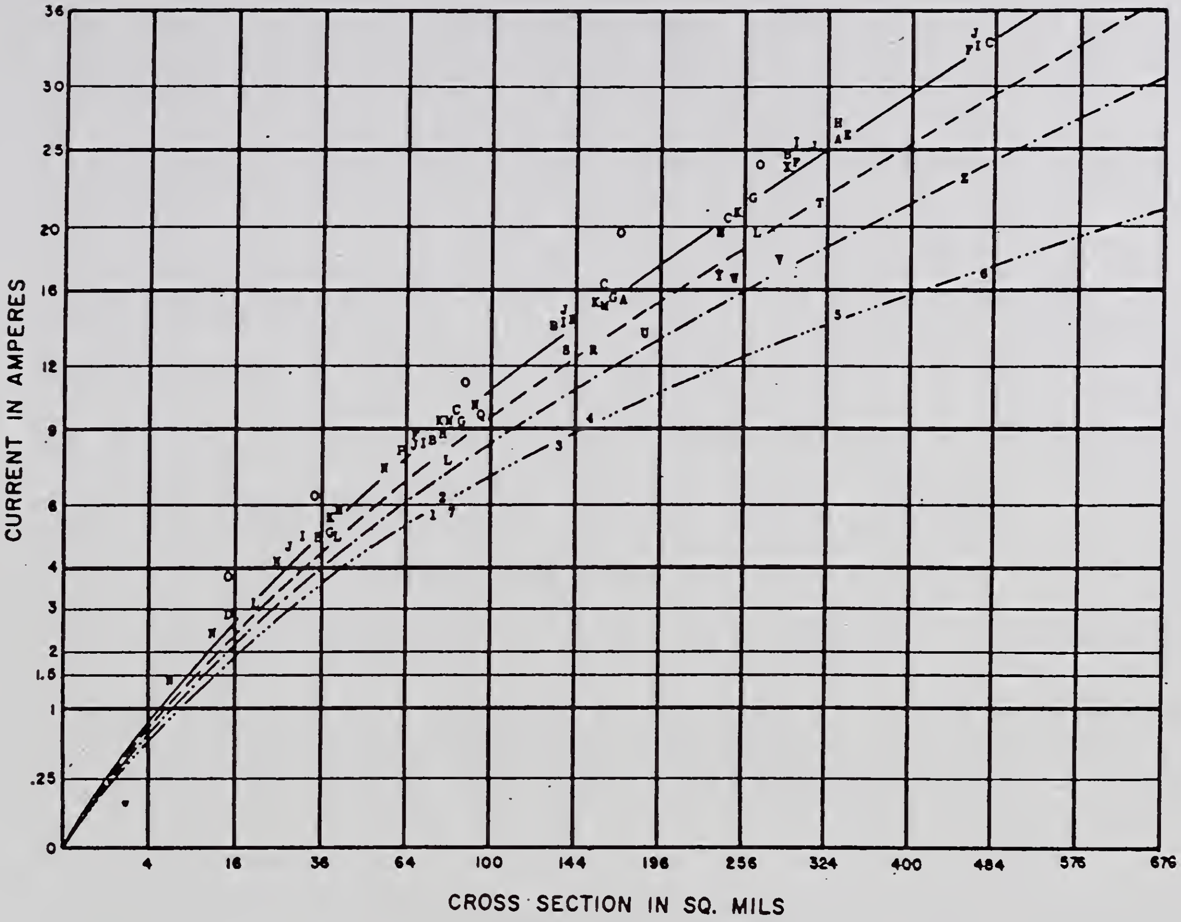
FIG. 6

CURRENT VS. CROSS SECTION
FOR 75° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS



NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

FIG. 7



CURRENT VS. CROSS SECTION
FOR 100° C. TEMP. RISE
OF ETCHED COPPER CONDUCTORS

NOTE: SEE TABLE III, PAGE-8 FOR IDENTIFICATION OF SYMBOLS RELATING TO TESTING METHOD, TEST CONDITIONS, MATERIALS AND PROCESSING

The points on the curves, which are presented as symbols, and which from Table III may be identified as to the conditions of test, show the current required to raise each conductor a given temperature above ambient as established from individual temperature-current interpolation curves for each conductor. The individual interpolation curves were obtained by making IR drop measurements at several different current levels for each of the conductors and plotting the calculated temperature rise for each particular current level. These interpolation curves were then used as a means of finding the currents required to cause the specific temperature rises, as shown in Figures 1 through 7. This method was used because of the obvious difficulties that would have ensued if an attempt had been made to elevate each conductor to a predetermined temperature rise by varying the current.

All measurements were made with calibrated instruments accurate to within 1/2 of 1 percent, or better. The temperature rise measurements were made with sufficient time

allowed for the samples to reach equilibrium, and current values for establishing reference resistances and cross-sectional areas were kept at the lowest practicable level for the particular conductor under test. As an additional check, all samples were measured with current flow in each direction, and the average of the two measurements for each current level was used in determining the interpolation curves on which Figures 1 through 7 are based. With allowances for variations in resistivity and measurement procedures, the points as presented in the current vs. cross section curves of Figures 1 through 7 are considered to be within ±3°C.

In each of the figures (1-7) the solid line represents an average for those samples in which there was no processing other than the forming of the conductor pattern by the usual photo-etching technique. The adjacent line represents an approximate level for those samples additionally processed with protective coatings, as identified in Table III (p. 8). The next line shows an approximation for those samples which were dip-soldered. The lowest line indicates the average levels for various conductors which had been completely removed or stripped from their core materials and tested in free air.

The recurrence of the same identifying symbol at several points in the figures (1-7) indicates that measurements were

made on more than one conductor and at the cross section indicated by the location of the symbol and under the conditions listed in Table III.

From the curves (Figures 1-7), it may easily be seen that the cross-sectional area of a conductor is a dominant factor in its ability to carry a given current for a particular temperature rise, especially for the usual copper thicknesses of .00135 (1 oz.) and .0027 inch (2 oz.). Heavier coppers (.004 in.), as might be expected, appear capable of carrying somewhat less current, and thinner coppers (.00067 in.) somewhat higher current for a given cross-sectional area. A factor appearing to be of secondary importance is the manufacture or type of core material. A specimen with thinner core material of about 1/32 inch thickness (L) showed a noticeable reduction in current-carrying capacity as compared with heavier cores. The same type of material showed a higher current-carrying capacity when a solid copper backing (O) was used. For the usual core thickness of 1/16 inch (or higher), only small difference could be noticed between those panels having a copper backing (indicated by KK in Table III), and those without, (indicated by K). Variations in ambient temperature are also shown to have little effect on the temperature rise above ambient due to a given current.

Significant reduction in current-carrying capacity of

about 15 to 20% was noted for those samples in which coatings were used, indicating a reduced ability of the samples to dissipate the heat generated in the copper conductor.

Additional reductions in current-carrying capacity in varying degrees up to about 30% were noted in most dip-soldered samples. A comparison of a number of conductor samples showing resistances and temperature rises at various current levels before and after dip-soldering is given in Table IV (p. 20). From this table it will be noted that in most instances the resistance of the particular conductor was actually lowered by dip-soldering. This should be considered reasonable since the addition of the solder layer would be expected to add something to the conductance of the whole, as well as to the total cross-sectional area of the conductor.

Separate oven measurements were made to determine the values for α of the dip-soldered conductors, which values are shown in the last column in Table IV (p. 20). It will be noted that the temperature coefficient of resistivity has been lowered from the .00385 value for the average copper conductor, as determined earlier (page 3), to an average value of about .00310 for the dip-soldered samples. This indicates the possibility of an alloying effect between the copper and the solder coating, or at the least, a higher value of resistivity for the combination conductor. For obvious reasons, however, no attempt has been made to determine the degree of

TABLE IV

COMPARISON OF CONDUCTORS BEFORE AND AFTER DIP-SOLDERING

MATERIAL AND CROSS-SEC. AREA	TEMP. °C	BEFORE DIP-SOLDERING			AFTER DIP-SOLDERING			
		I	RESISTANCE	I^2R	I	RESISTANCE	I^2R	α_{25}*
4-7 XXXP	25	.5	.009222		.5	.009233		
230	98	18	.011814	5.8	15	.011440	2.6	.00327
2-7 XXXP	25	.5	.011332		.5	.010813		
188	70	13	.013295	2.2	10	.012345	1.2	.00315
10-7 XXXP	25	.5	.008982		.5	.008808		
237	55	13	.010019	1.7	10	.009632	0.9	.00312
2-7 XXXP	25	.5	.007158		.5	.006824		
297	92	21	.009004	3.9	15	.008253	1.8	.00312
4-7 XXXP	25	.5	.013112		.5	.011689		
162	98	14	.016797	3.2	12	.014283	2.1	.00304
5-10 EPOXY	25	.5	.006920		.5	.006744		
307	58	16	.007799	1.9	15	.007400	1.6	.00292

*Based on resistance measurements at 25° and 104.5°C

each of these possibilities, particularly since the primary cause of the reduced current-carrying capacity of a dip-soldered conductor appears to be the result of a partial loss of bond or a change in the heat transfer characteristics of the adhesive interface between the copper and the core material.

From the tabulations in Table IV, it will be noted in each case that for the dip-soldered conductors less power was actually required to cause a given rise in their temperature than was required for the unsoldered conductors. In addition, the variations that occurred were over a considerable range, as indicated on the curves of Figures 1-7, and were generally of a greater magnitude than were the coated samples. For these reasons, it seems evident that the variations were due to a reduction of heat transfer into the panel, particularly since it is unlikely that a change in the conductor's radiating ability due to a metal solder coating could have as much effect on the sample as that shown or exceed the effect noted for the coated samples. This supposition is strengthened in the instance of the epoxy base sample (identified by the symbol X), in which, it may be noted, deviation from the normal curve was small as compared with other dip-soldered samples, thereby indicating that the dip-soldering process had less effect on the bond of this material than on the XXXP samples. This is particularly evident inasmuch as the sample in question had a .005 inch epoxy resin coating, which under

normal conditions would have caused an even greater reduction in current-carrying capacity than that recorded. If the coating had not been present, the sample would in all likelihood have been capable of carrying more current in the dip-soldered condition since the resistance of the sample was actually lowered.

The results of measurements on a number of samples of conductors which had been physically stripped from the core material may be noted from the curves (Figures 1-7). Cross section measurements are based on measurements made after stripping, and temperature rises are based on IR measurements and a temperature coefficient of resistivity of .00385. From the curves it may be seen that none of the other conductors approached the reduced current values for a given temperature rise regardless of the type of processing. It would seem safe, therefore, to assume that even with the poorest bond available, a conductor would never exceed the temperature rise above that indicated for the stripped conductors, except perhaps under very restricted conditions.

With time permitting, additional measurements will be made on a greater variety of materials in order to determine with more certainty whether the effects noted extend to most laminates or whether they are restricted to just a few materials under certain conditions of processing. The materials under test, it will be noted, were all dip-soldered under the

same time-temperature conditions of 10 seconds at 250°C, which in some applications might be considered excessive. If further work on this subject is felt to be warranted, the possibility of developing a test in which the temperature rise of a given conductor may be used as a function of the "quality" or effectiveness of a bond should not be overlooked.

1.3 Design Guide and Chart

Although the preceding work cannot be considered complete, the information on hand is considered adequate for providing the tentative design guide and chart presented on pages 25 and 26. This design chart shows the basic relationship of current vs. temperature rise for various cross sections of copper for average usage.

The chart may also be used for the determination of temperature rises for other than single conductor applications, such as parallel conductors and coils. Tests on a limited number of samples show that the temperature rise of closely spaced parallel conductors (such as filament lines) may be estimated by using an equivalent cross section and current condition based on the summation of the cross sections and currents involved, and interpolating directly from the chart. The estimated temperature rise thus obtained will be somewhat on the high side, since it has been obtained by assuming the least favorable condition possible, i.e., a condition where the conductors are so close together that they may be considered

as a single conductor carrying the sum total of the currents. For practical purposes, however, this estimate is considered adequate for most applications, and the addition of a correction factor to provide adjustments dependent on the spacing between conductors would be of little value.

In the case of coils, estimates become somewhat more difficult owing to possible variations in conductor sizes, configurations, panel areas, and heat transfer from one part of the coil to another. Thermocouple measurements on a number of coils ranging in size from 0.350 inch to 1.5 inch diameter showed that safe estimates in temperature rise of the hottest portions may be made from the chart (Figure 8, p. 26) by utilization of equivalent cross sections and currents based on a factor of 2n, where n is equal to the number of turns in the coil. Here again, while the temperature rise estimates are generally on the high side, it is felt that little would be gained by introduction of correction factors of a complicated nature. This is considered particularly true in view of the inherent difficulties in obtaining accurate cross-sectional estimates from measurements due to variations in copper thickness, undercutting during etching,variations in the pattern, etc.

An additional chart (Figure 9, p. 27), showing resistance per linear inch vs. cross-sectional area of etched copper conductors, has been included for convenience in the estimation of conductor sizes in applications where the IR drop in a given conductor would be the limiting factor in the conductor's use rather than its temperature rise.

DESIGN GUIDE

The design chart on the following page (Fig. 8) has been prepared as an aid in estimating temperature rises (above ambient) vs. current for various cross-sectional areas of etched copper conductors. It is intended for use primarily with XXXP and Epoxy-glass materials* of 1/16 to 1/8" thickness and copper thickness of .00135" (1 oz), and .0027" (2 oz). It is assumed that normal design conditions prevail where the conductor surface area is relatively small compared to the adjacent free panel area. The curves as presented include a nominal 10% derating (on a current basis) to allow for normal variations in etching techniques, copper thickness, and conductor width estimates.

Additional derating** of 15% (current-wise) is suggested under the following conditions:

1. If the panel is to be coated.
2. For panel thickness of 1/32 inch.
3. For conductor thickness of .004" (3 oz).

A derating of 30% is suggested for panels that are to be dip-soldered.

For general use the permissible temperature rise is defined as the difference between the maximum safe operating temperature of the laminate (assumed to be 105°C for XXXP and Epoxy base materials), and the maximum ambient temperature in the location where the panel will be used.

For single conductor applications the chart may now be used directly for determining conductor widths, conductor thickness, cross-sectional area and current-carrying capacity for various temperature rises.

For groups of similar parallel conductors, if closely spaced, the temperature rise may be found by using an equivalent cross-section and an equivalent current. The equivalent cross-section is equal to the sum of the cross-sections of the parallel conductors, and the equivalent current is the sum of the currents in the conductors.

For applications where etched coils are to be used, the maximum temperature rises may be obtained by using an equivalent cross-section equal to 2n times the cross-section of the conductor, and an equivalent current equal to 2n times the current in the coil, where n is equal to the number of turns.

A conversion chart (Fig. 9), showing resistance (per linear inch) vs. cross-section for etched conductors has been included for use in those applications where the IR drop in a conductor may be the primary consideration as opposed to temperature rise.

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*The measurements on which this chart has been based have been made on XXXP and Epoxy laminates. It may be assumed, however, that other types of laminates will behave in the same general manner providing they have equivalent bonds.

**The suggested derating of the permissible current is based on the assumption that maximum usage of the material is desired. For general design purposes, however, the user may find it more expedient to set the derating figure at a uniform 50% value in order to take care of all possible considerations, which according to data would even include complete delamination of the conductor from the panel.

FIG. 8

DESIGN CHART

(TENTATIVE)

FOR USE IN DETERMINING CURRENT CARRYING CAPACITY AND SIZES OF ETCHED COPPER CONDUCTORS FOR VARIOUS TEMPERATURE RISES ABOVE AMBIENT. (NOTE: SEE DESIGN GUIDE ON PRECEDING PAGE FOR USE OF THIS CHART).

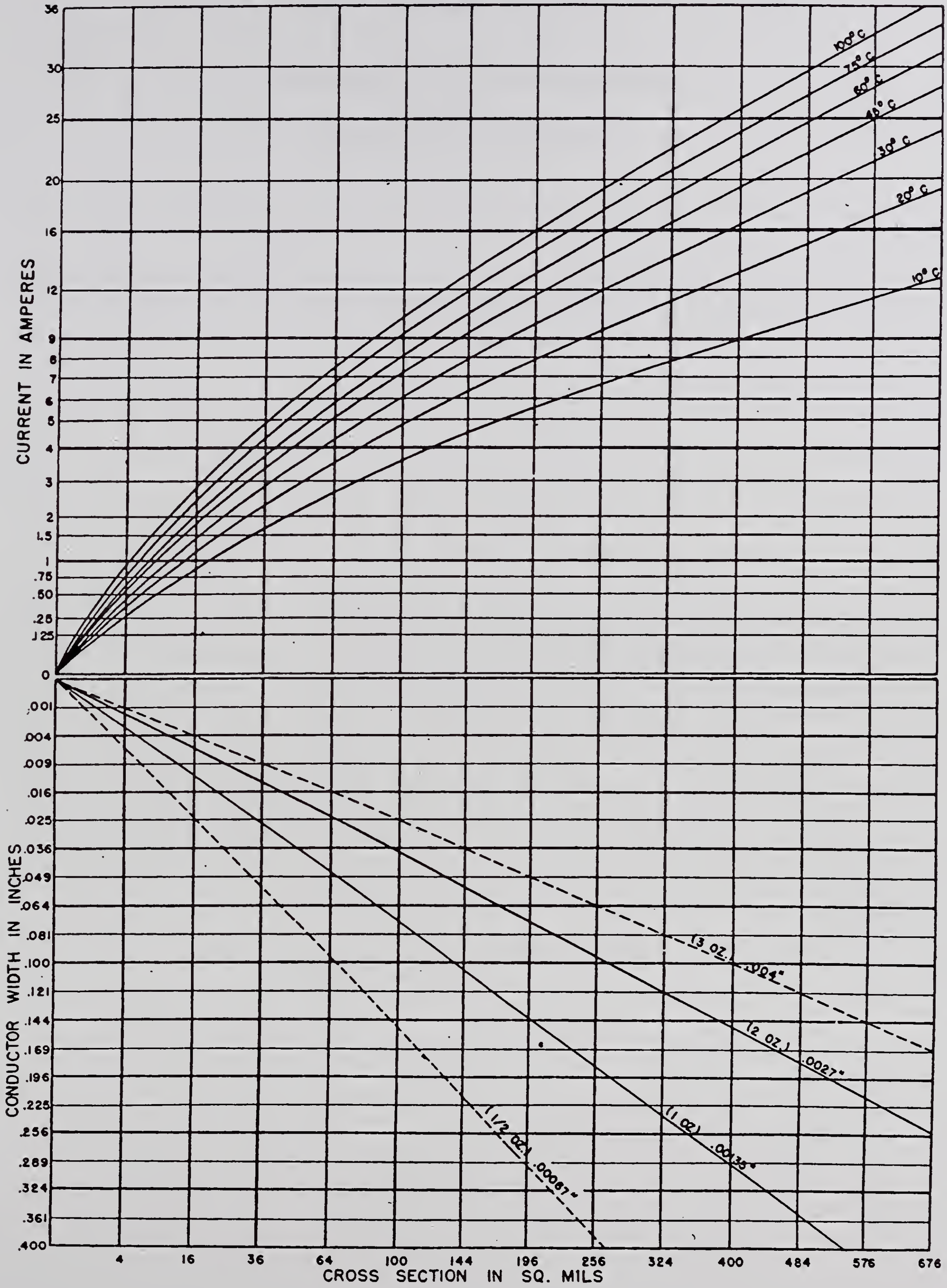
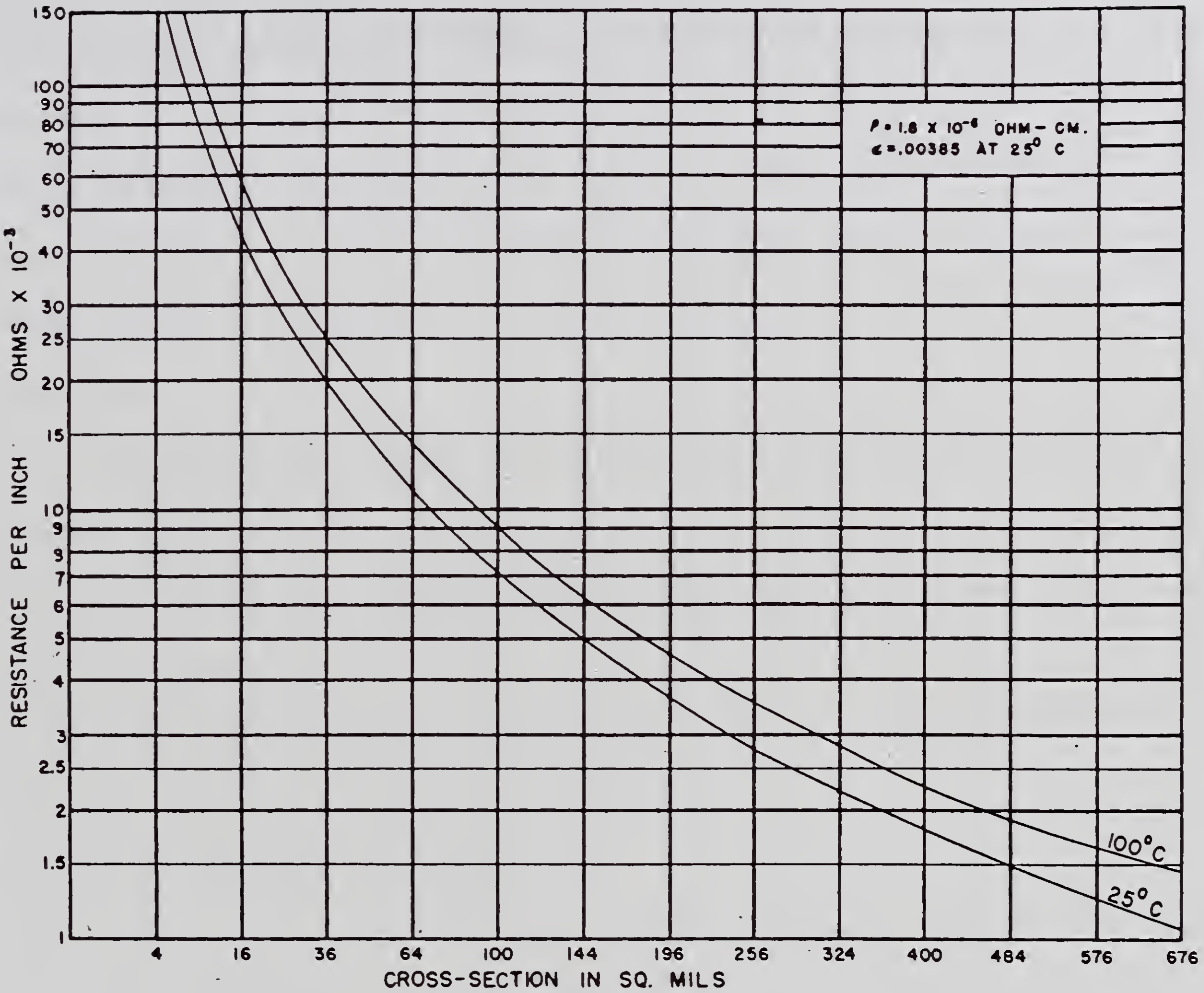


FIG. 9

CONVERSION CHART

RESISTANCE VS CROSS SECTION

FOR
ETCHED COPPER CONDUCTORS



2. ELECTRICAL RESISTANCE - COATED SAMPLES

As a continuation of measurements described earlier in National Bureau of Standards Report No. 3392, new groups of test samples were subjected to a temperature of 70°C and 95% R.H. for a period of 2000 hours in order to determine the effects of various protective coatings on the electrical resistance characteristics of metal-clad laminates. Seven groups of XXXP laminates and one of the epoxy glass-mat type were included in this test. Also, other materials, a nylon (N-1) laminate and a styrene co-polymer (both without coatings), were included to determine their basic behavior patterns.

The coatings used and their approximate thicknesses are listed below.

1. Modified epoxy .005", Mfr. No. 1.(Designated as Epoxy No. 1.)
2. Epoxy resin, .005", Mfr. No. 2. (Designated as Epoxy No. 2.)
3. Microwax, .004".
4. Insulating varnish, .003". (Clear, air drying type.)
5. Silicone resin, .006".
6. Silicone fluid (125 CS), 1-1/2% solution CCl_4.

The same procedure as that outlined in the earlier report was used to prepare the test samples, all of which were of the three-terminal circular type having gap widths of 1 and 2 mm.

2.1 Surface Resistivity

Surface resistivity is given in megohms per "square" and is computed on the basis of:

$$\rho_s = \frac{P}{g} R_s$$

where R_s = surface resistance as measured

g = distance between electrodes

P = effective perimeter of the guarded electrode.

The curves of Figures 13 to 61 (pp. 40 to 88) show the surface resistivity of the materials tested and have been arranged to show their relationship to the uncoated samples included as controls. The curves for the controls for a particular group have been repeated in each set of curves for the coated samples (Figures 13-59, pp. 40-86) so that comparisons may more easily be made.

Bar graphs, Figures 10, 11, and 12 (pp. 37-39), show the extremes in surface resistivity recorded for the samples and their various coatings during the 2000 hour test. It will be easily seen from these graphs that the variation in resistivity for the coated samples is generally much higher than for the control samples.

From the corresponding curves (Figures 13 to 61, pp. 40 to 88), it may be seen that the variation between dip-soldered samples and nondip-soldered samples is relatively low. Although no set pattern has been established that could not be ascribed to normal variations in

the samples, a slight trend toward higher resistivities may be detected for the dip-soldered samples on an over-all basis. This agrees substantially with previous results, and may possibly be due to a slight loss of bond between the copper and the core material. For purposes of resistivity measurements, however, it can only be concluded that dip-soldering has no substantial effect on the surface resistivity of these materials.

A review of the present surface resistivity measurements and those reported previously shows excellent agreement on an over-all basis, with an average surface resistivity of 10^3 megohms or higher for most of the XXXP control samples. Although different lots of materials were used in the present tests than in the earlier ones, a comparison of the test results shows substantial agreement for the individual manufacturers.

The results of the test on the epoxy-glass base laminate (5-10) were somewhat lower than had been expected for materials of this type (Figures 54 to 59, pp. 81 to 86). Although the resistivity was relatively high (10^4 megohms per square) at the initial portion of the test, the value dropped rather rapidly for the first 1000 hours to an average value of about 3 x 10^2 megohms per square, which is somewhat lower than the average for XXXP materials under the same test conditions. The probable reason for this lower average was the

formation of corrosion along the edges of the electrodes of the test pattern. The formation of corrosion, in all likelihood, was also the reason for the relatively high number of complete electrical breakdowns in this group. Although these particular samples are the only ones which have thus far exhibited the formation of corrosion along the electrode edges in any of the tests conducted in this laboratory, it cannot be assumed, on the basis of a single test, that this is characteristic of the material, particularly since the material in question is of relatively early vintage. Other samples have been obtained from several sources and additional tests will be made, time permitting. It was interesting to note that none of the coatings used on this material entirely prevented the formation of corrosion. Substantial reduction of corrosion formation was observed, however, on the coated samples.

Of the additional samples included in the test, the N-1 type (Figure 60, p. 87) was characterized by exceptional uniformity throughout the entire test period. The styrene co-polymer base material (Figure 61, p. 88) was, on the other hand, characterized by erratic behavior, which made readings difficult to obtain.

In a comparison of the curves for the coated samples with those for the controls, little or no improvement is to be

seen in most instances for the six coating materials. Considerable variation in the resultant surface resistance over and above that recorded for the control samples was the rule rather than the exception. Additional variations may be noted in the behavior of a particular coating material on different core materials, with the exception of the coating material described as Epoxy #1, which had a uniformly adverse effect on all of the samples on which it was used.

Epoxy #1

From the low values recorded for each group of samples, it can only be concluded that this particular coating material has a resistivity as low as, or lower than, that of the materials under test.

Epoxy #2

The second coating material (Epoxy #2) had, in general, very little over-all effect on those samples on which it was used. The exception to this was the 4-7 XXXP group (Figure 25, p. 52), which exhibited a relatively high resistivity in the control samples.

Microwax

Samples coated with microwax showed a slight but fairly consistent trend toward higher resistivity over the non-coated or control samples. In only one case, again in group 4-7 (Figure 26, p. 53), was the resultant resistivity lower than

that of the control samples, and then only after approximately 1000 hours of exposure. Significant improvement may be noted in the 10-7 group (Figure 50, p.77), indicating that these particular samples were somewhat sensitive to surface moisture. In the 5-10 epoxy group (Figure 57, p. 84), little or no improvement can be seen up to the point where failure occurred. This is probably a reflection of the low resistivity of the group caused by the formation of corrosion on the edges of the electrodes.

Insulating Varnish

In those samples coated with insulating varnish little over-all change is noticeable, most of the results running approximately at par with the control samples. Some improvement is again seen in the 10-7 group (Figure 51, p. 78), and somewhat lower resistivity is noticeable in the 4-7 group (Figure 27, p. 54).

Silicone Resin

The silicone resin coatings also exhibited no apparent improvement on an over-all basis. The initial improvement noticed in most cases can be attributed to the particular curing procedure (150 hours at 100°C) used before testing. After reaching a point of equilibrium (at approximately 1000 hours) these coatings behaved in a manner similar to the Epoxy #2 and the insulating varnish coatings, with little or no improvement to be seen.

Silicone Fluid Coatings

In this group of samples an initial improvement was noticed, which in all likelihood was also caused by the curing procedure used before testing. Silicone fluid, of the type generally used for imparting moisture resistance, was applied by immersing the samples for five minutes in a 1-1/2% solution of the fluid in CCl_4, and subsequently curing them for 150 hours at 100°C. The resultant thin-film type of coating, after reaching equilibrium at about 1000 hours, also had little effect on the surface resistivity of the samples, with perhaps two exceptions. These are the 6-7 group, (Figure 35, p. 62), in which the resistivity was increased by approximately 2 decades, and the 4-7 group (Figure 29, p. 56), upon which the coating had the least adverse effect of the various coatings tried. Although this type of coating could not be expected to give the samples physical protection against surface contamination, the results are of sufficient interest to merit further investigation with other fluids of the same type and perhaps in combination with other coating materials.

2.2 Volume Resistivity

Volume resistivity is given in megohm-cm and is computed as follows:

$$\rho_v = \frac{A}{t} R_V$$

where A = effective area of the guarded electrode

t = average thickness of the specimen

R_V = volume resistance as measured.

The effects of the coating materials on the volume resistivity of the samples were generally so slight that no advantage could be gained by presentation of the results separately for each of the coated materials. Therefore, curves for only uncoated samples included as controls are presented, Figures 62 to 71 (pp. 89 to 98).

2.3 General Observations

1. None of the coatings tested had a marked uniform beneficial effect on the surface resistivity of the samples under test.

2. From the group to group variations observed, it would appear that some improvement in resistivity might be obtained if a particular coating is selected for a particular base material. Although a coating might show an improvement in one material, it should not be assumed, however, that the improvement would necessarily extend to other materials, even of the same type or grade.

3. A coating material may be used with advantage on printed-circuit panels for the purpose of physically protecting the surfaces against corrosion, contamination during

handling, accumulation of dust, etc. In areas where low leakage is required, however, it would seem advantageous to rely primarily on a base material with a high basic resistivity and a compatible coating, at least until such time as a coating material has been developed that may be relied upon to offer substantial improvement on a broad basis, i.e., on a variety of base material types or at least on a wide selection of materials in a given class.

(Text recommences on p. 99)

FIG. 10

SURFACE RESISTIVITY* OF
VARIOUS TYPES OF METAL-CLAD
LAMINATES USING DIFFERENT PROTECTIVE COATINGS

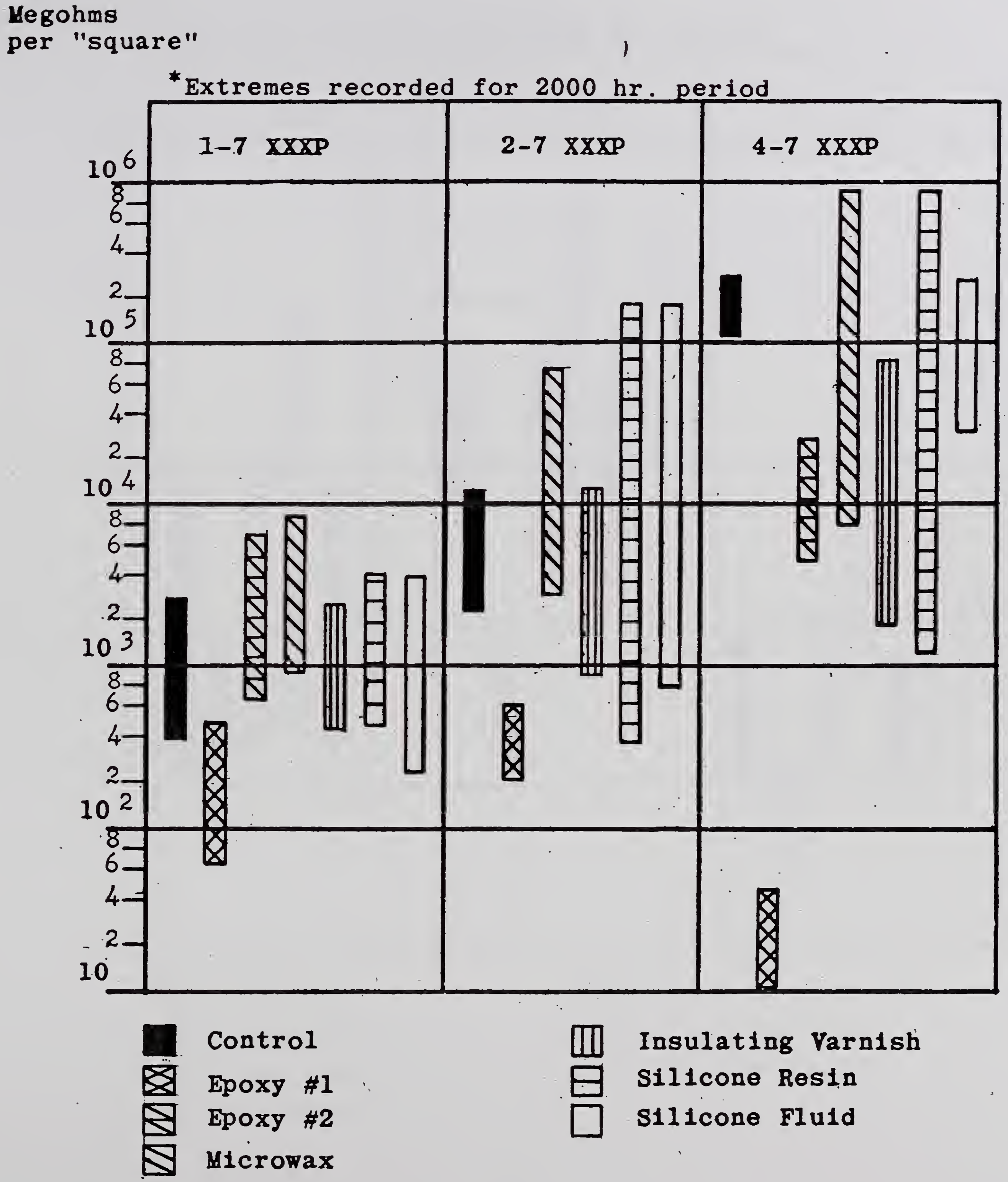
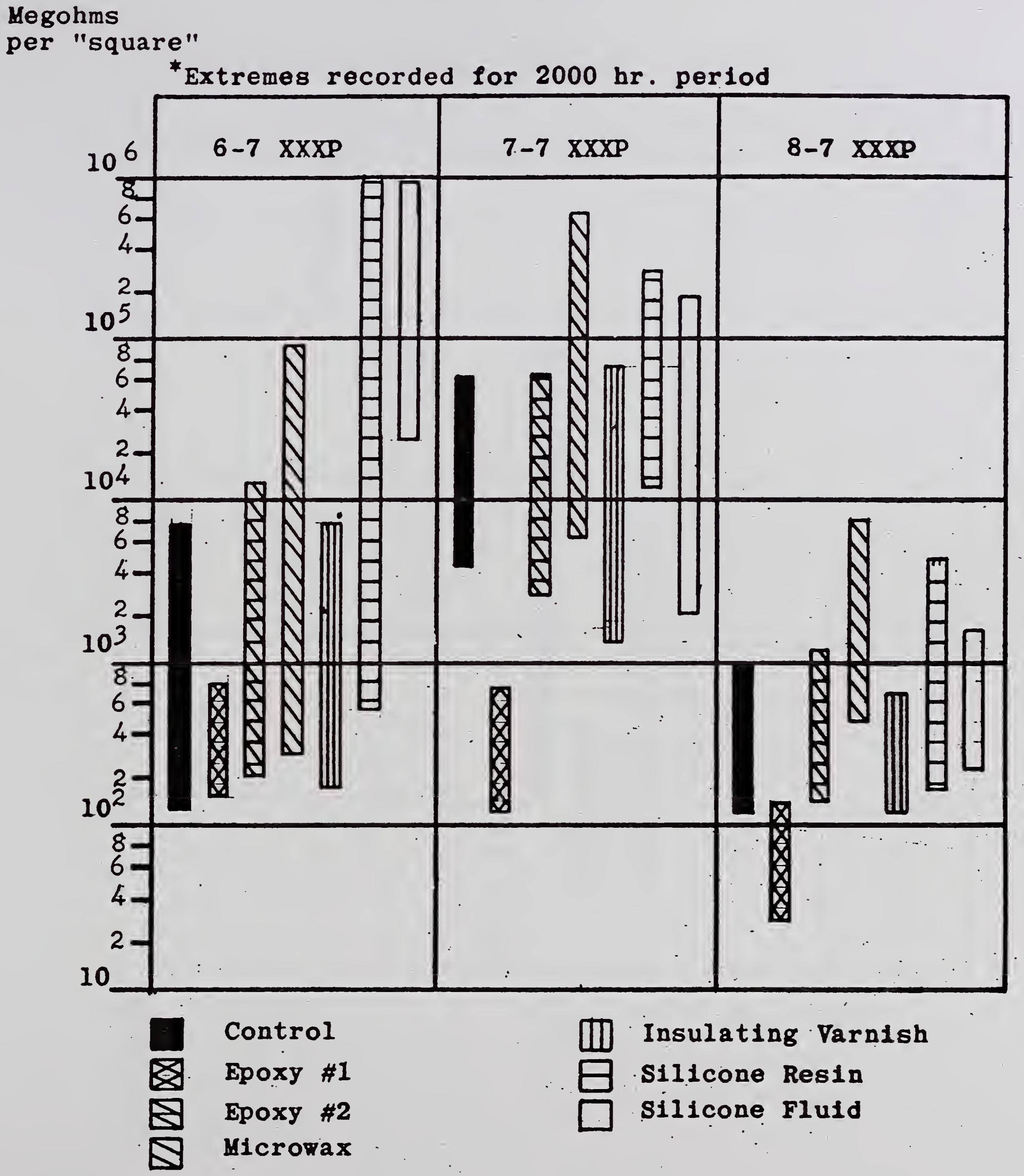


FIG. 11

SURFACE RESISTIVITY* OF VARIOUS TYPES OF METAL-CLAD LAMINATES USING DIFFERENT PROTECTIVE COATINGS



*Extremes recorded for 2000 hr. period

FIG. 12

SURFACE RESISTIVITY* OF
VARIOUS TYPES OF METAL-CLAD
LAMINATES USING DIFFERENT PROTECTIVE COATINGS

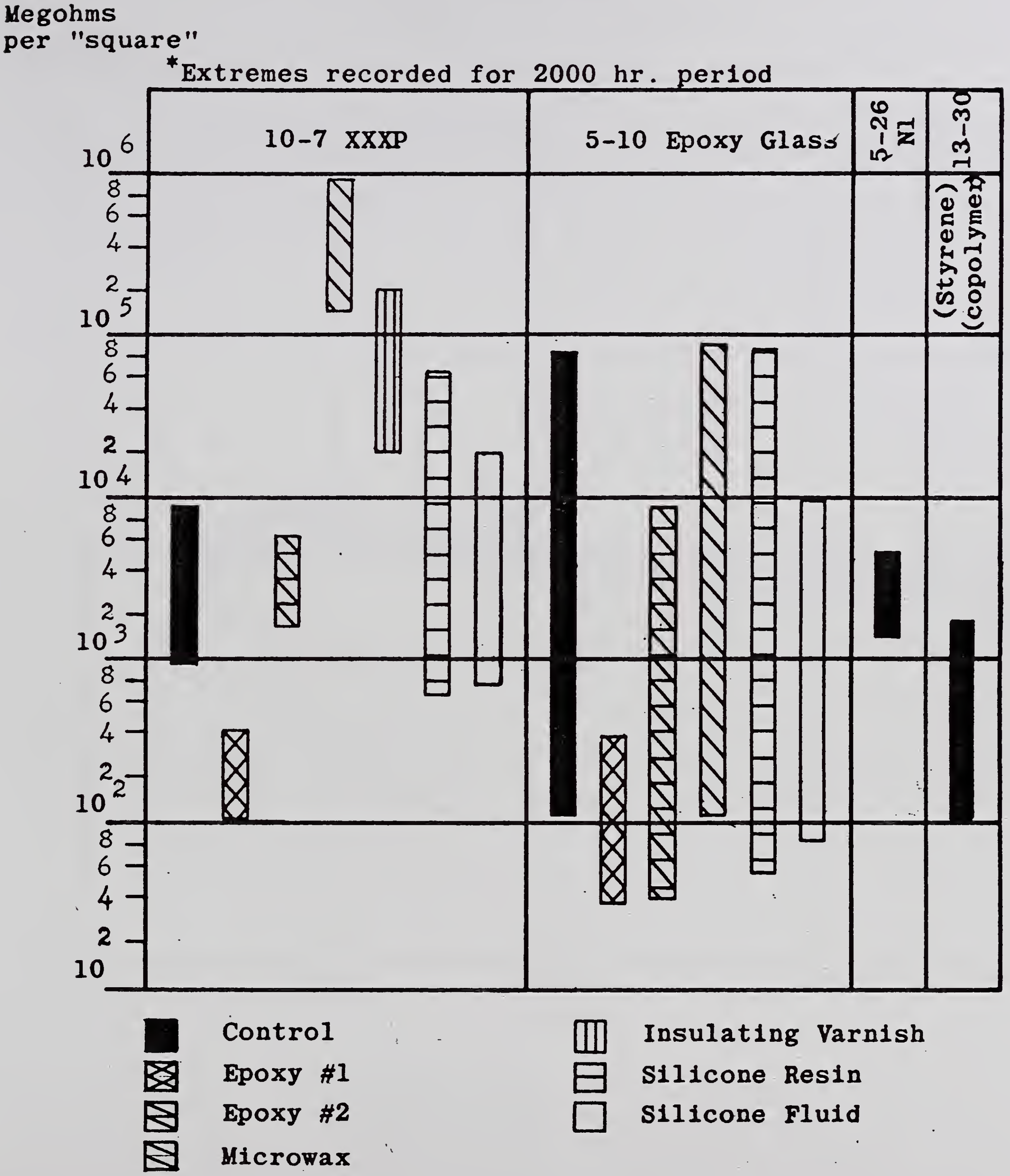
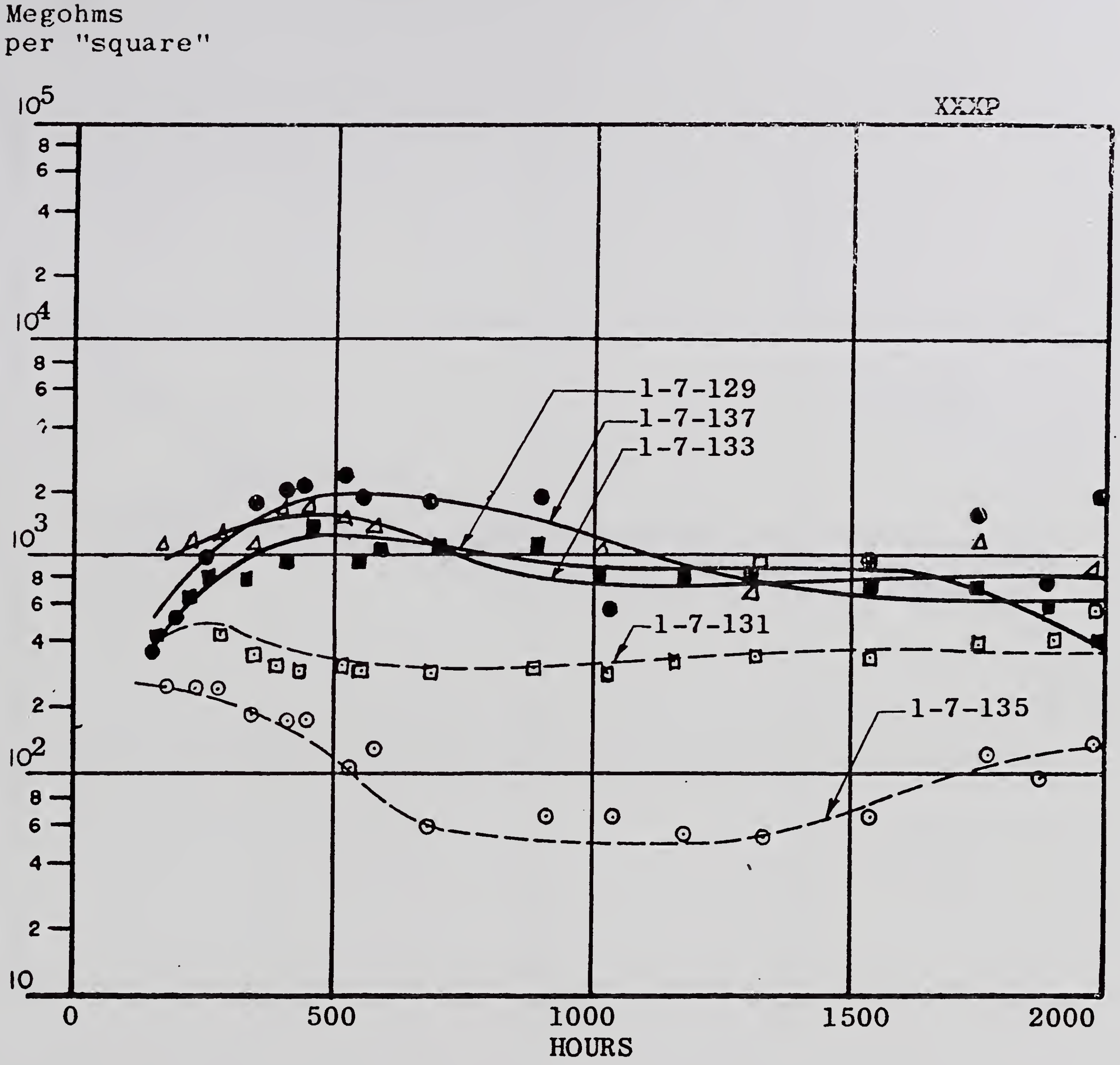


FIG. 13

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

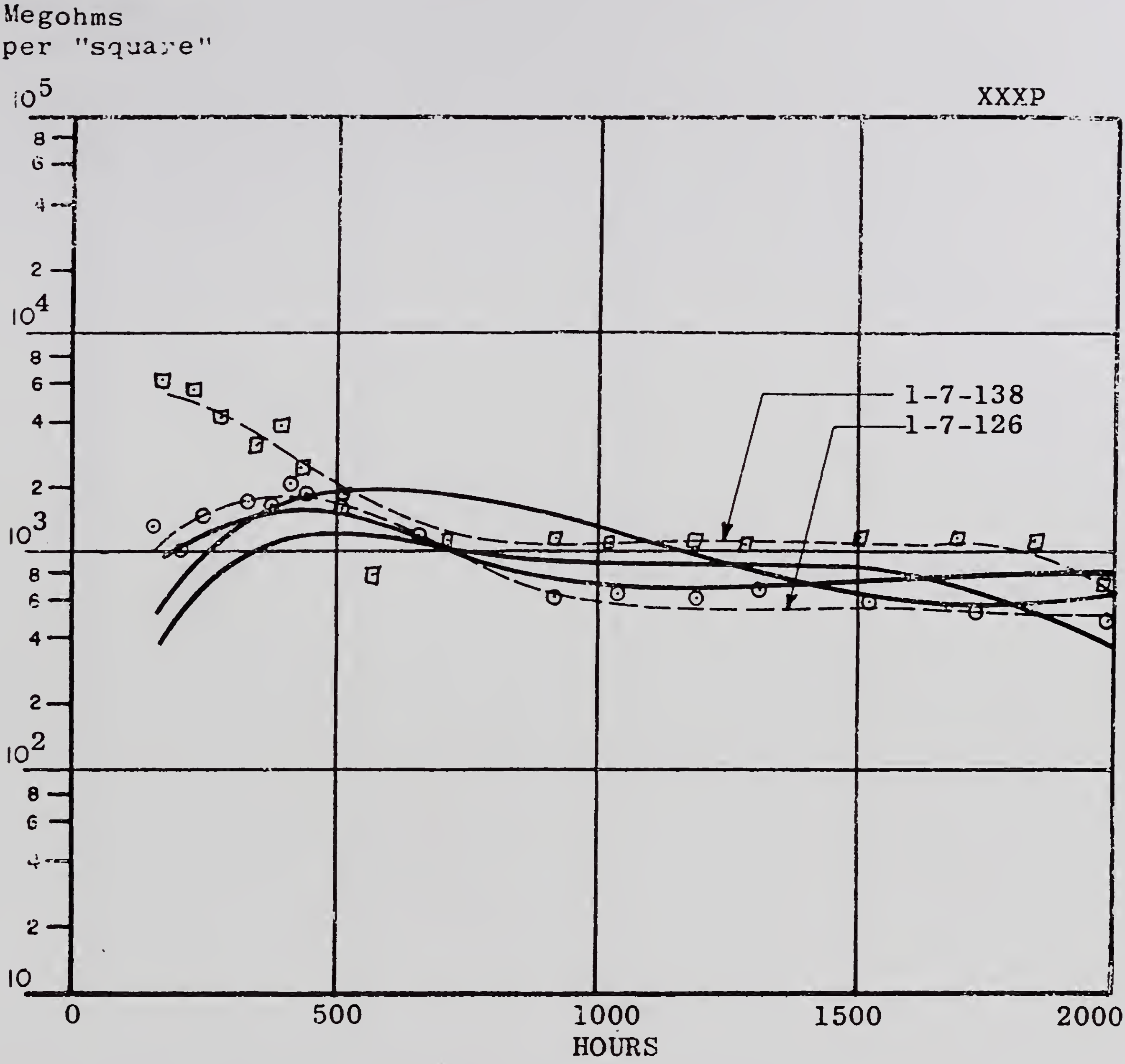


1-7-129 Control (Dip soldered)
1-7-137 Control (Dip soldered)
1-7-133 Control (No preconditioning)
1-7-135 Coating: Epoxy #1
1-7-131 Coating: Epoxy #1 (Dip soldered)

FIG. 14

SURFACE RESISTIVITY VS TIME

70°C 95% R. H.

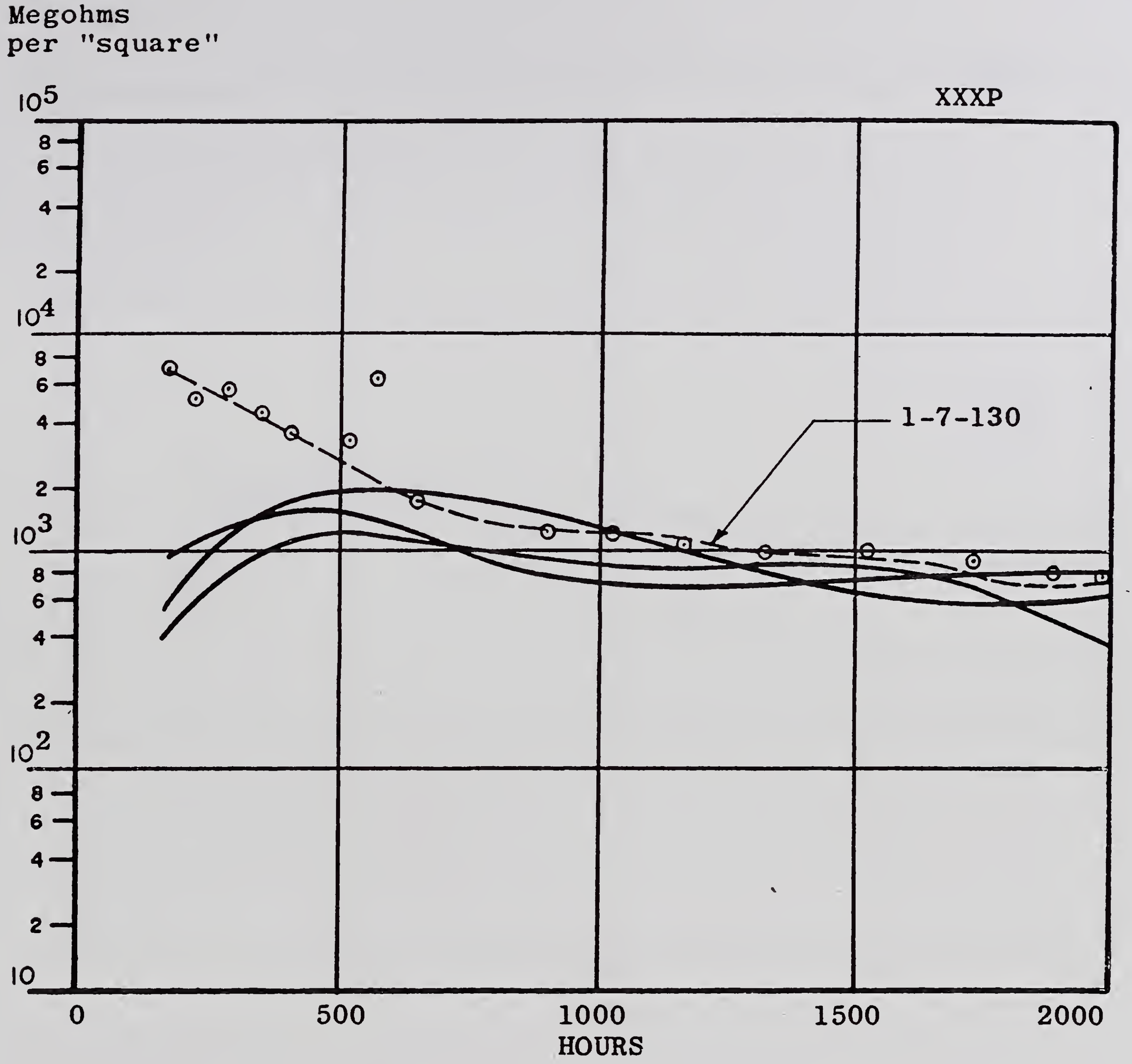


1-7-138 Coating: Epoxy #2 (Dip soldered)
1-7-126 Coating: Epoxy #2

FIG. 15

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

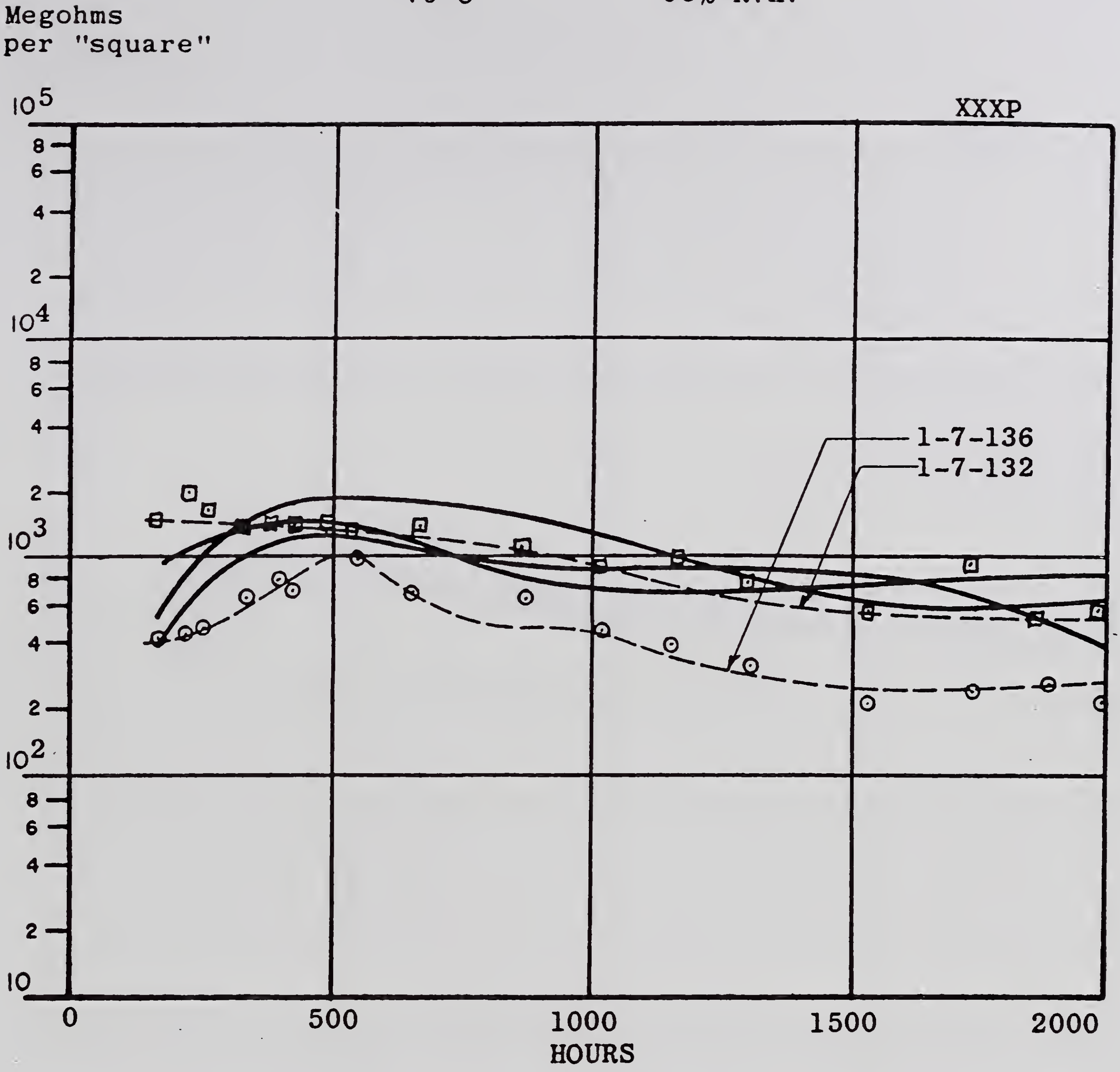


1-7-130 Coating: Microwax

FIG. 16

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

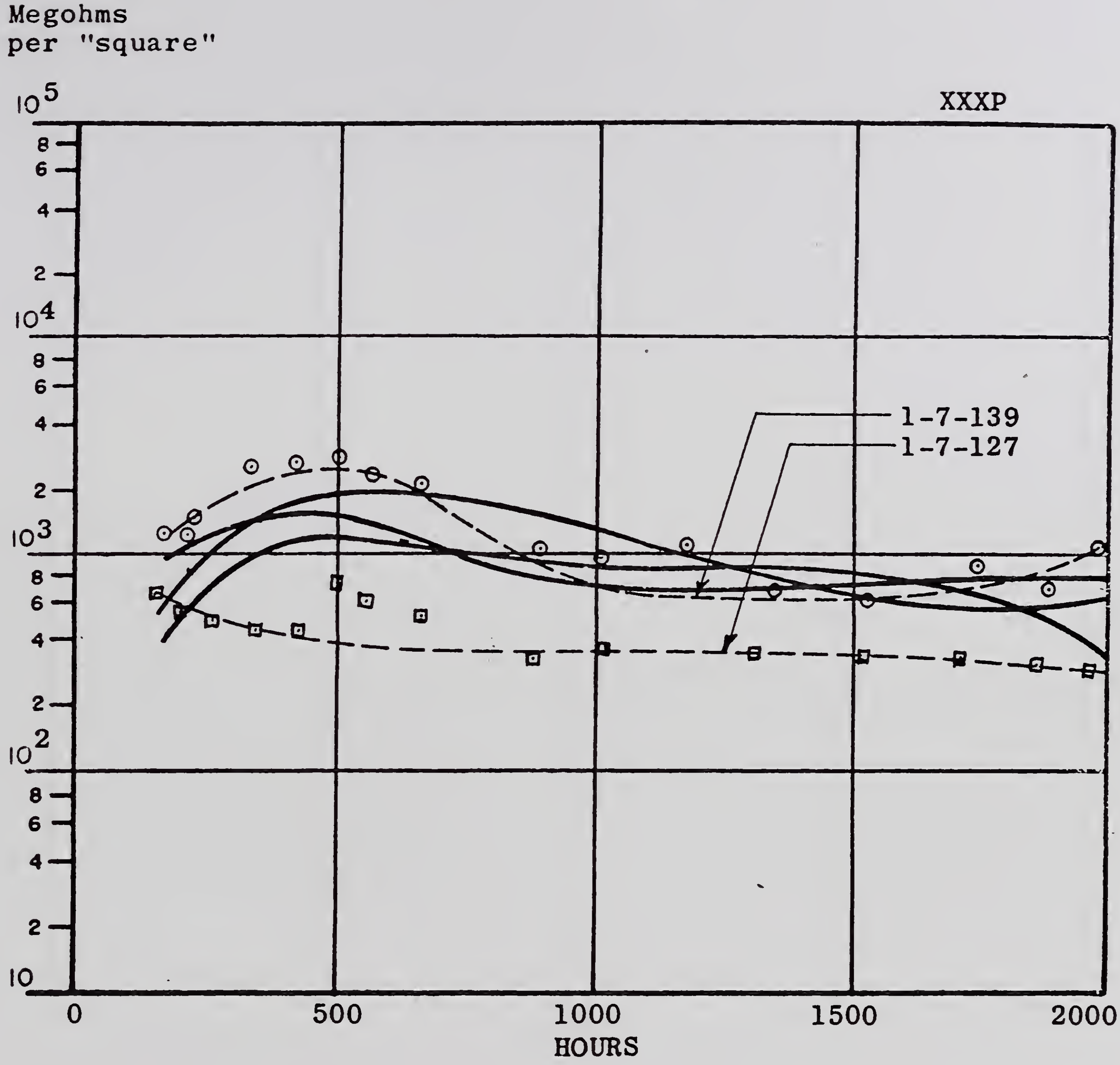


1-7-136 Coating: Insulating varnish (Dip soldered)
1-7-132 Coating: Insulating varnish

FIG. 17

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

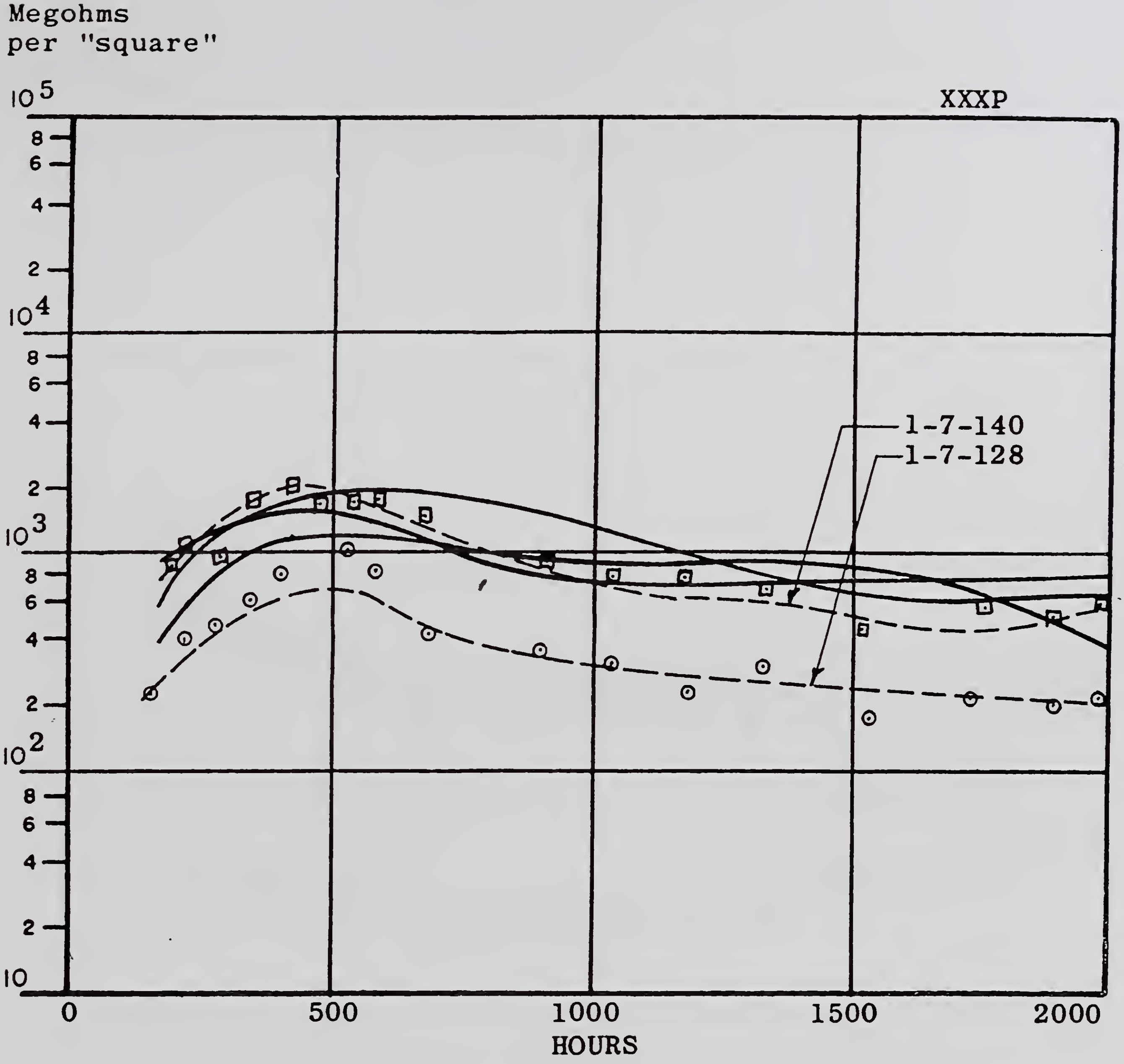


1-7-139 Coating: Silicone resin
1-7-127 Coating: Silicone resin (Dip soldered)

FIG. 18

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

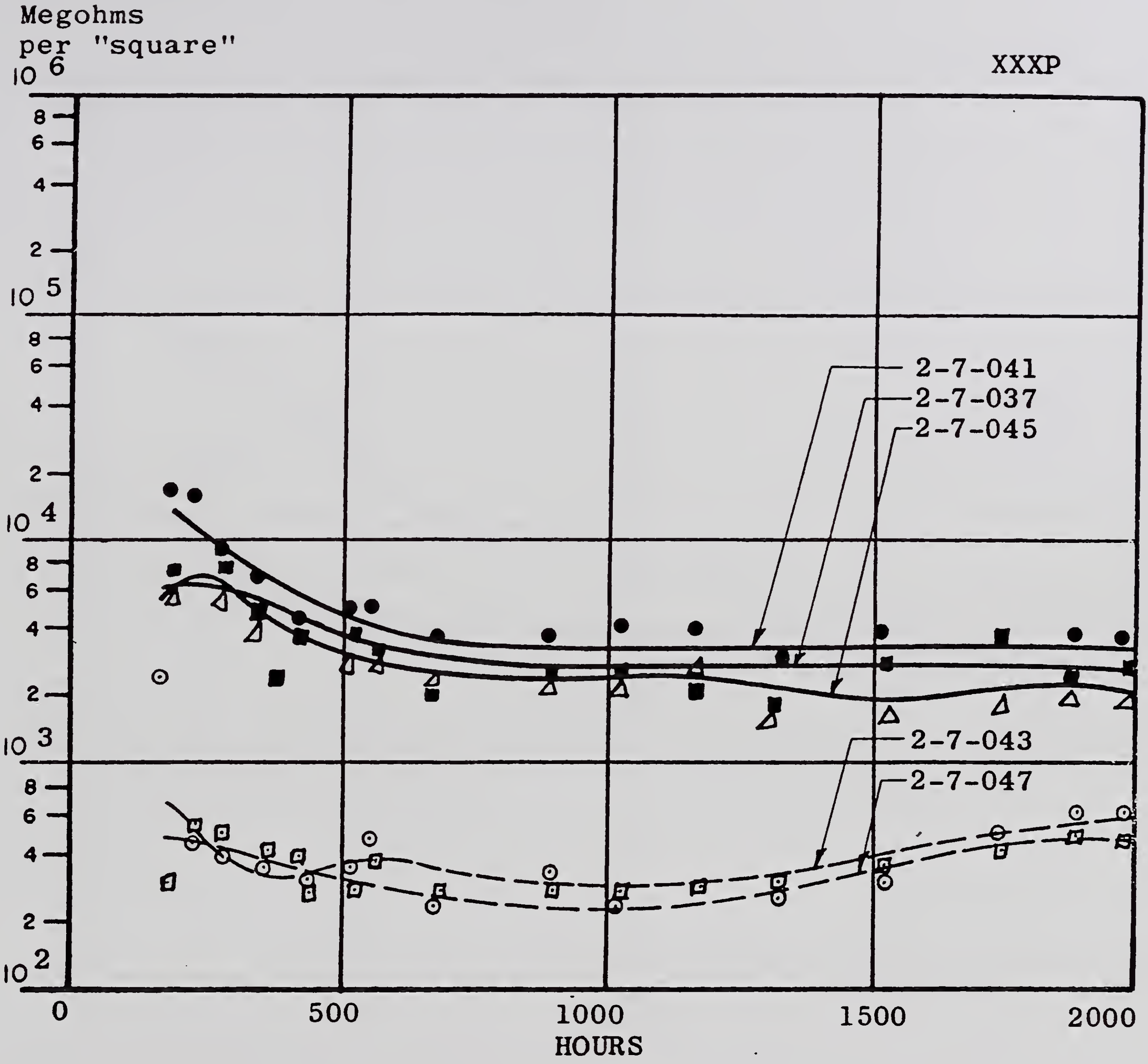


1-7-128 Coating: Silicone fluid
1-7-140 Coating: Silicone fluid (Dip soldered)

FIG. 19

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

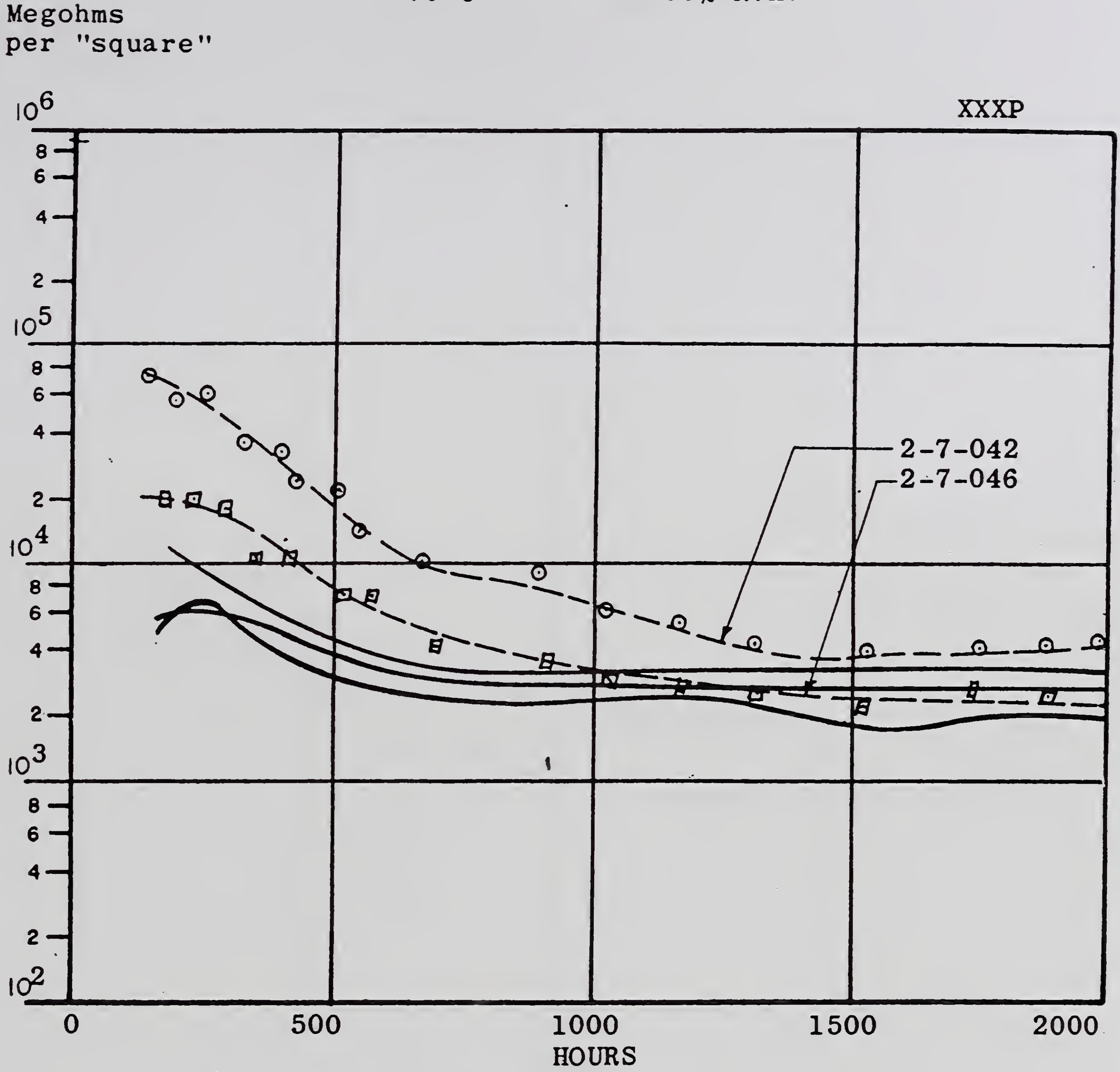


2-7-041 Control (No preconditioning)
2-7-037 Control (Dip soldered)
2-7-045 Control (Dip soldered)
2-7-043 Coating: Epoxy #1
2-7-047 Coating: Epoxy #1 (Dip soldered)

FIG. 20

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

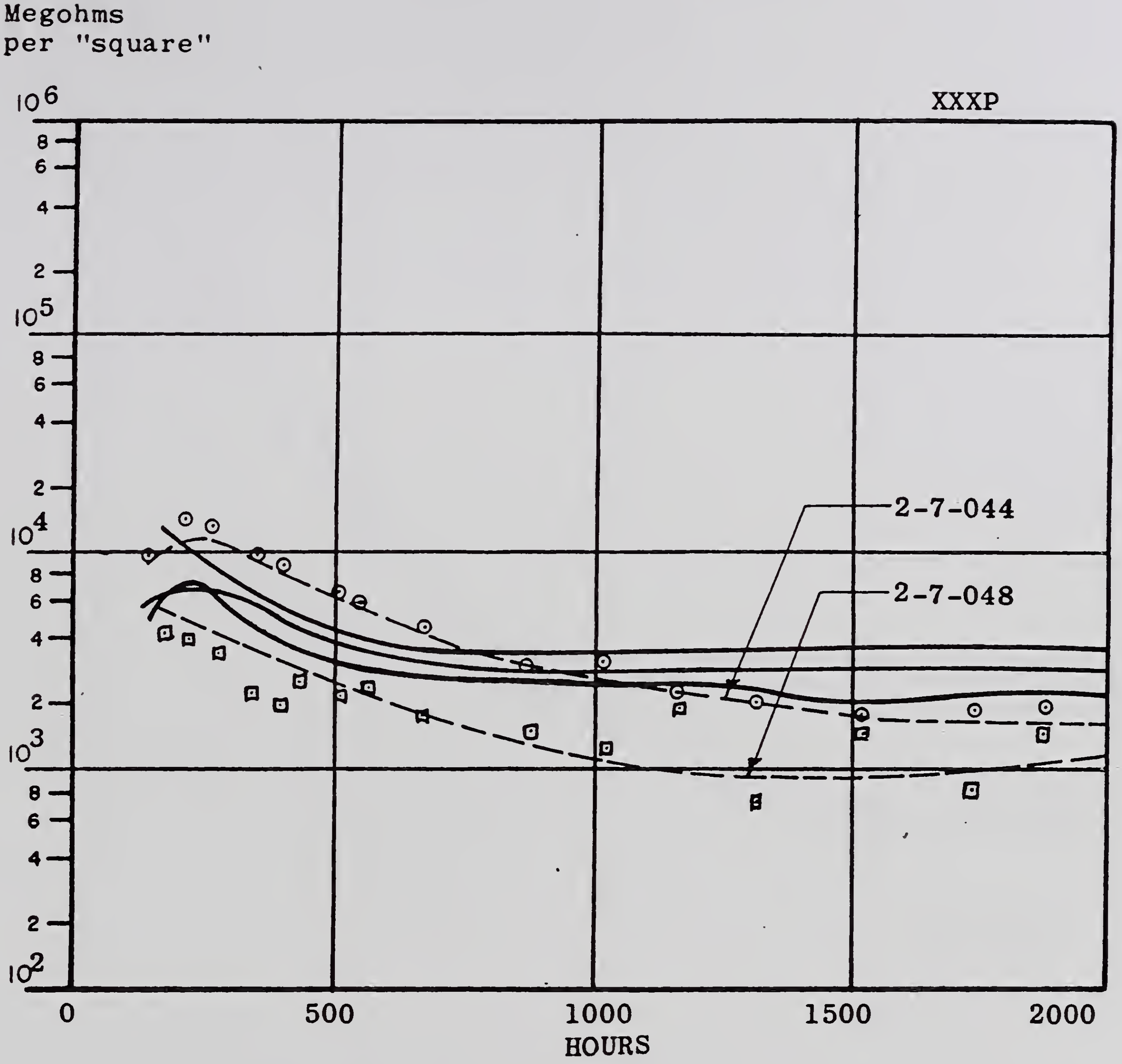


2-7-042 Coating: Microwax (Dip soldered)
2-7-046 Coating: Microwax

FIG. 21

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

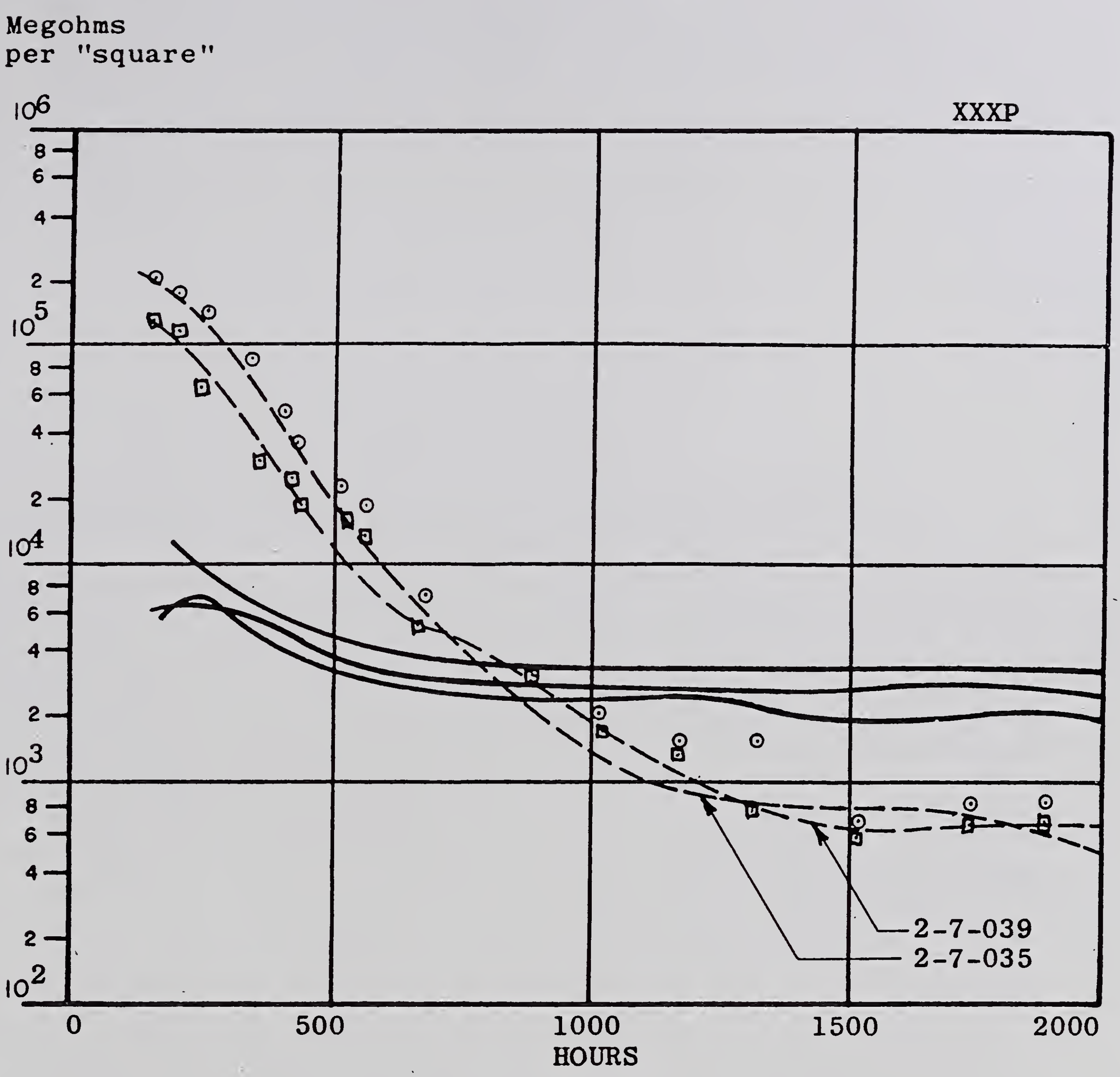


2-7-044 Coating: Insulating varnish (Dip soldered)
2-7-048 Coating: Insulating varnish (Dip soldered)

FIG. 22

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

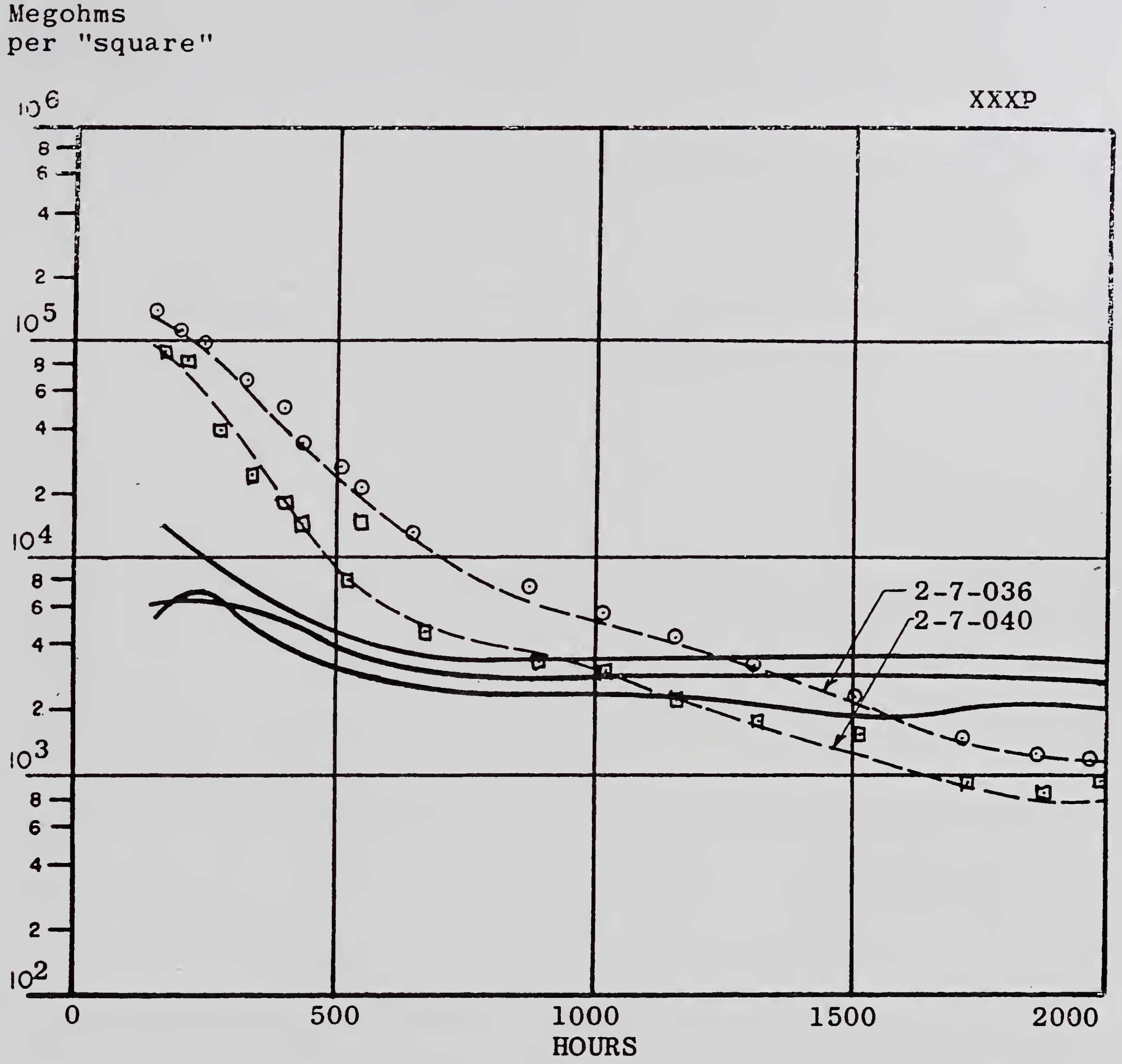


2-7-039 Coating: Silicone resin
2-7-035 Coating: Silicone resin (Dip soldered)

FIG. 23

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

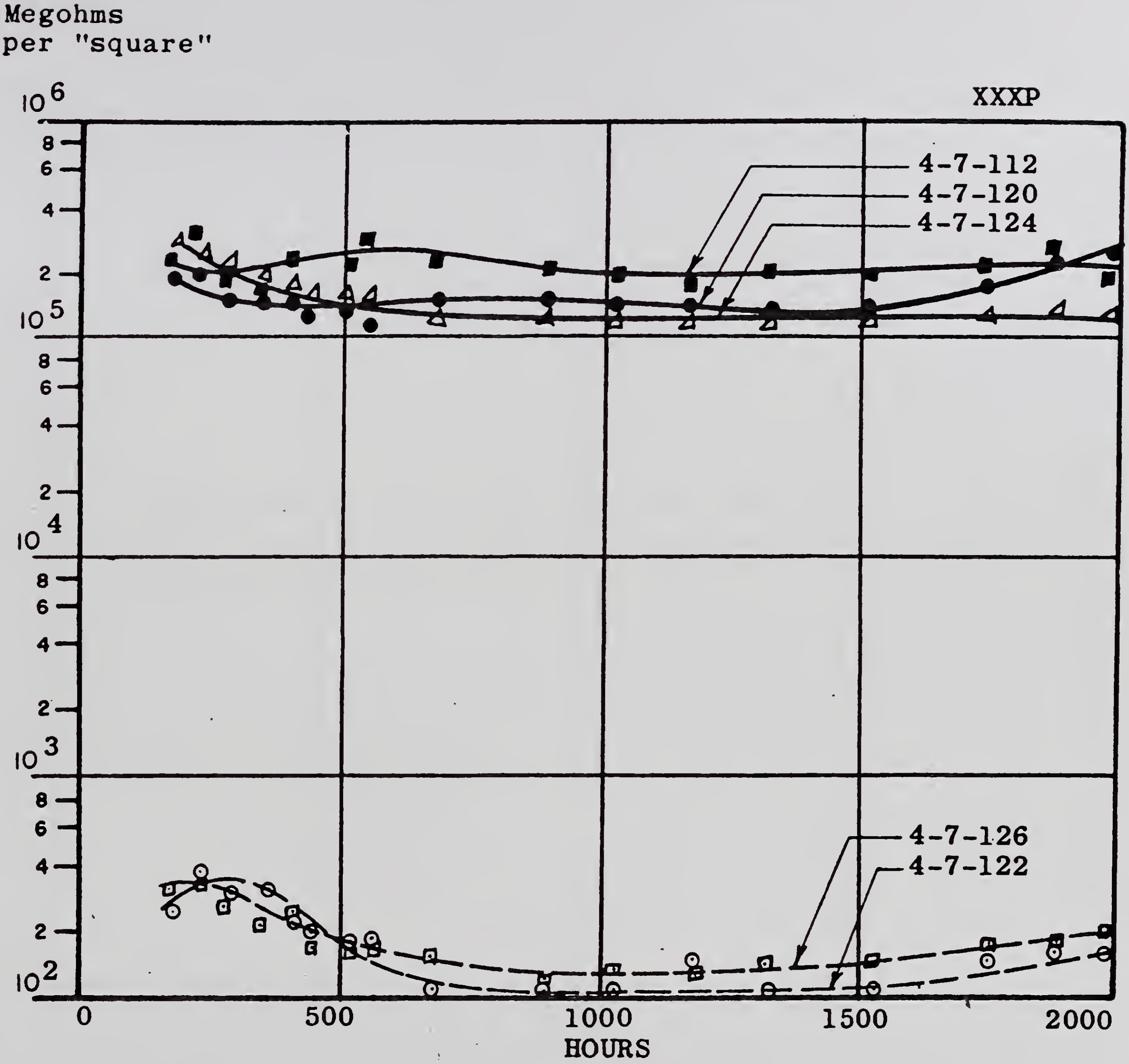


2-7-036 Coating: Silicone fluid
2-7-040 Coating: Silicone fluid (Dip soldered)

FIG. 24

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

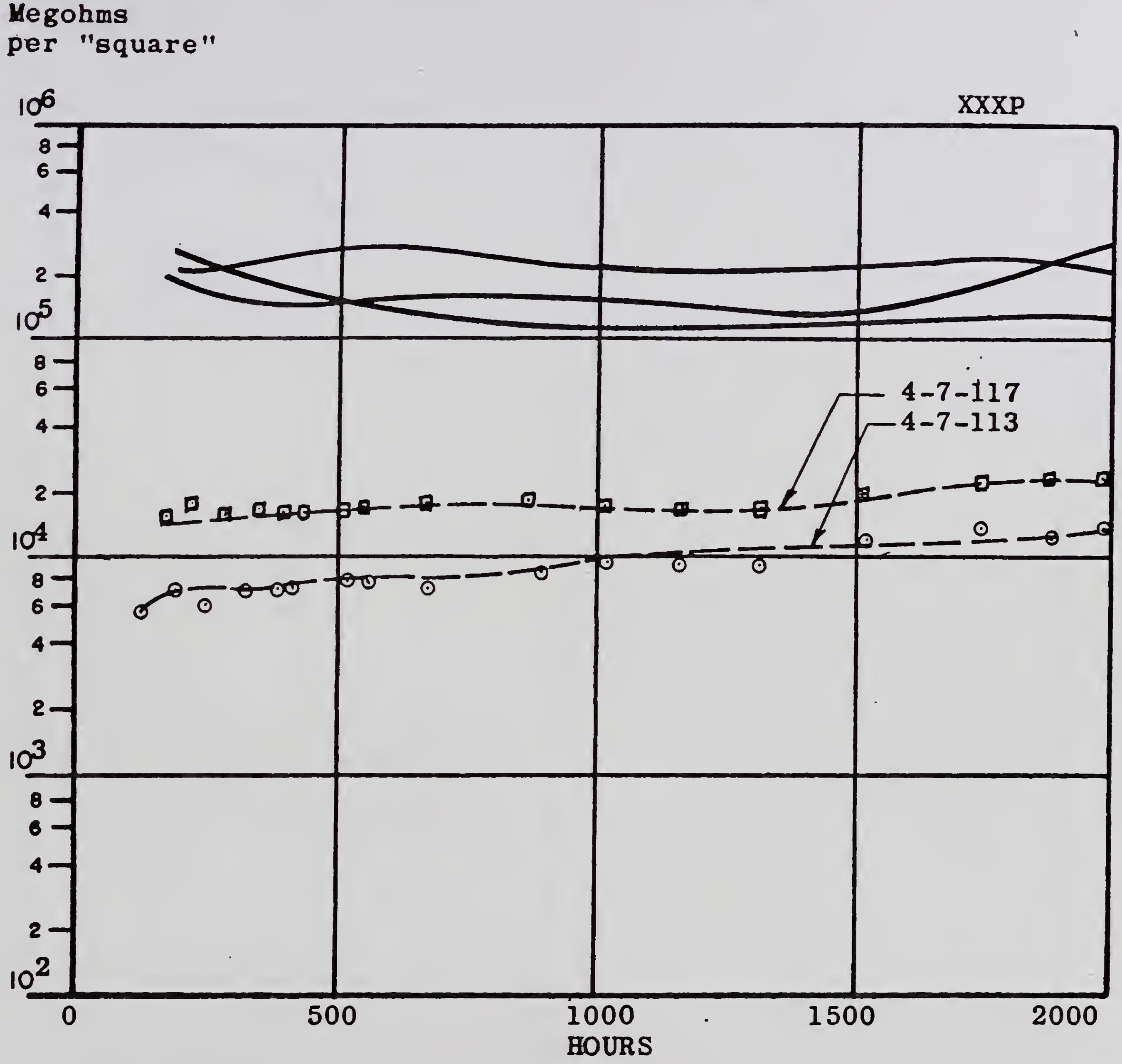


4-7-112 Control (Dip soldered)
4-7-122 Coating: Epoxy #1
4-7-126 Coating: Epoxy #1 (Dip soldered)
4-7-120 Control (No preconditioning)
4-7-124 Control (Dip soldered)

FIG. 25

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

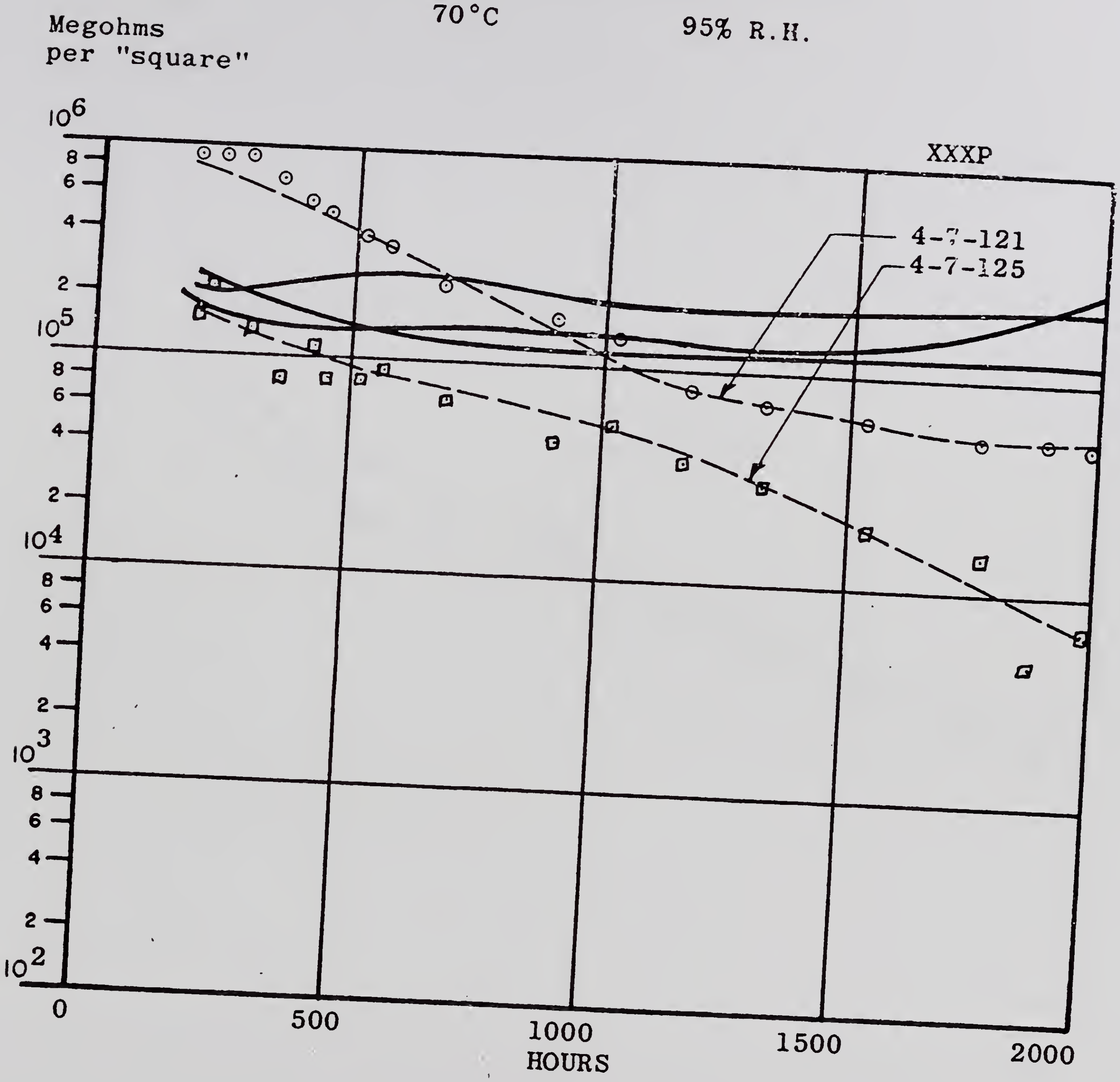


4-7-117 Coating: Epoxy #2
4-7-113 Coating: Epoxy #2 (Dip soldered)

FIG. 26

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

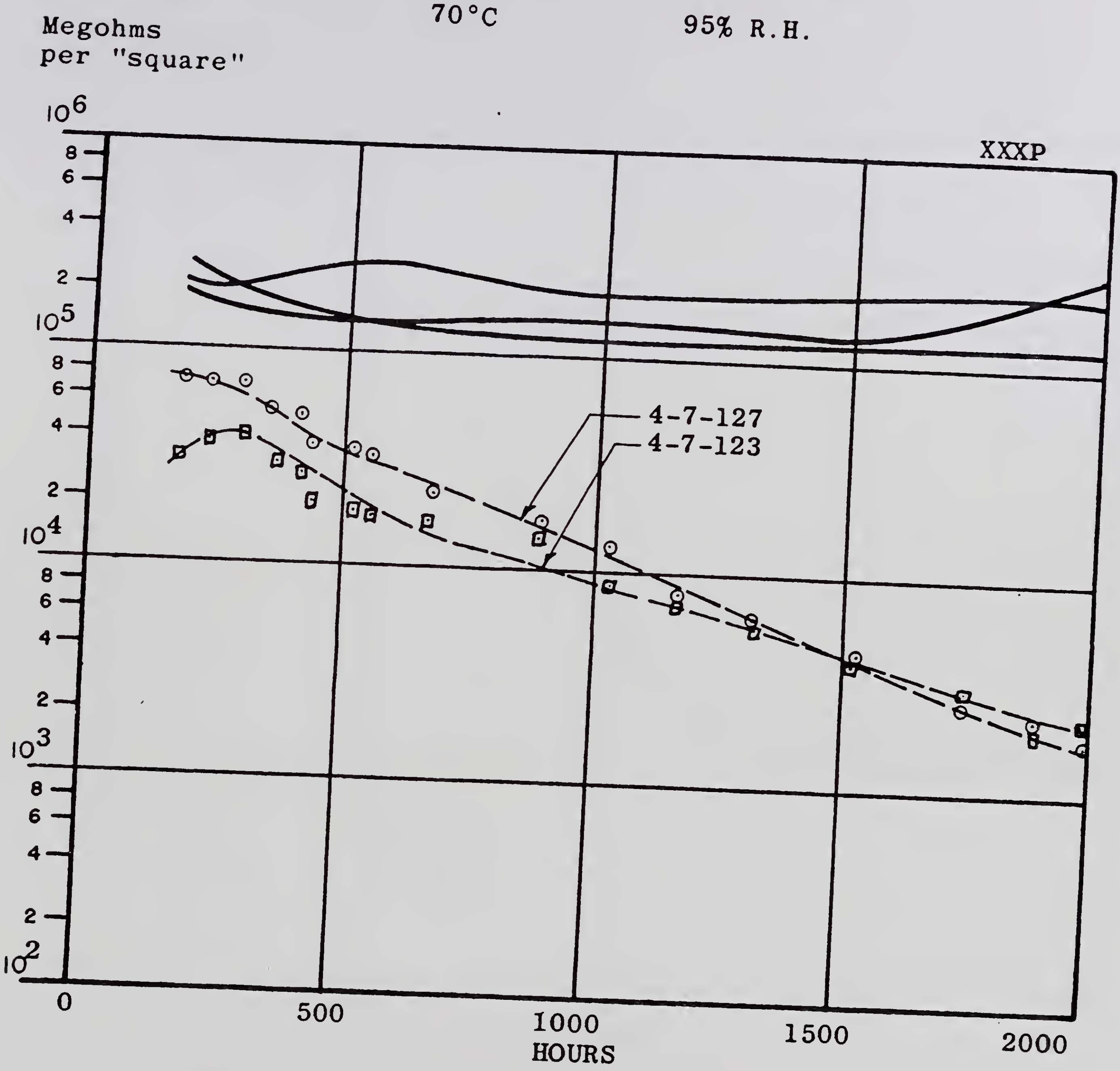


4-7-121 Coating: Microwax (Dip soldered)
4-7-125 Coating: Microwax

FIG. 27

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

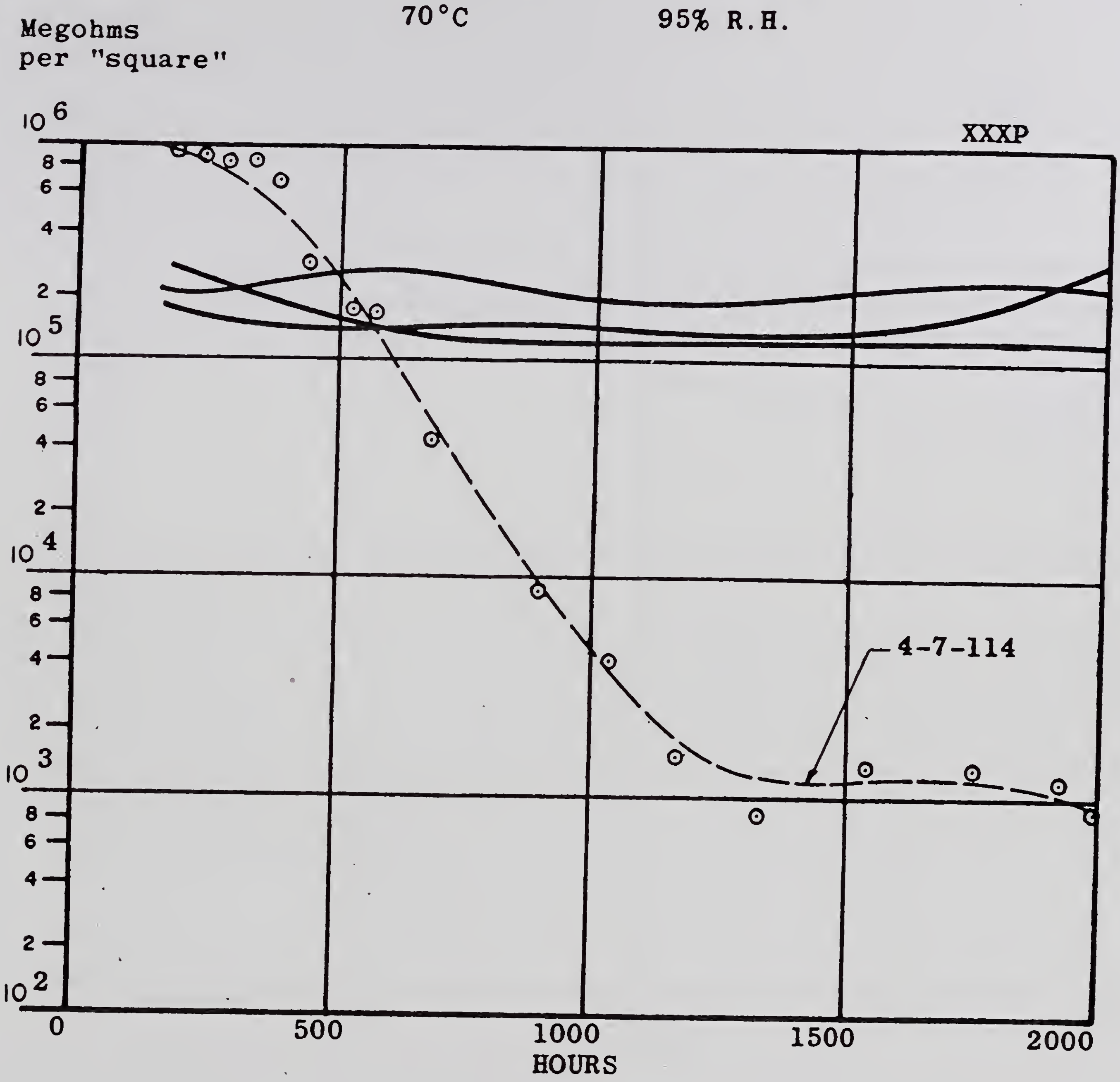


4-7-127 Coating: Insulating varnish (Dip soldered)
4-7-123 Coating: Insulating varnish

FIG. 28

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

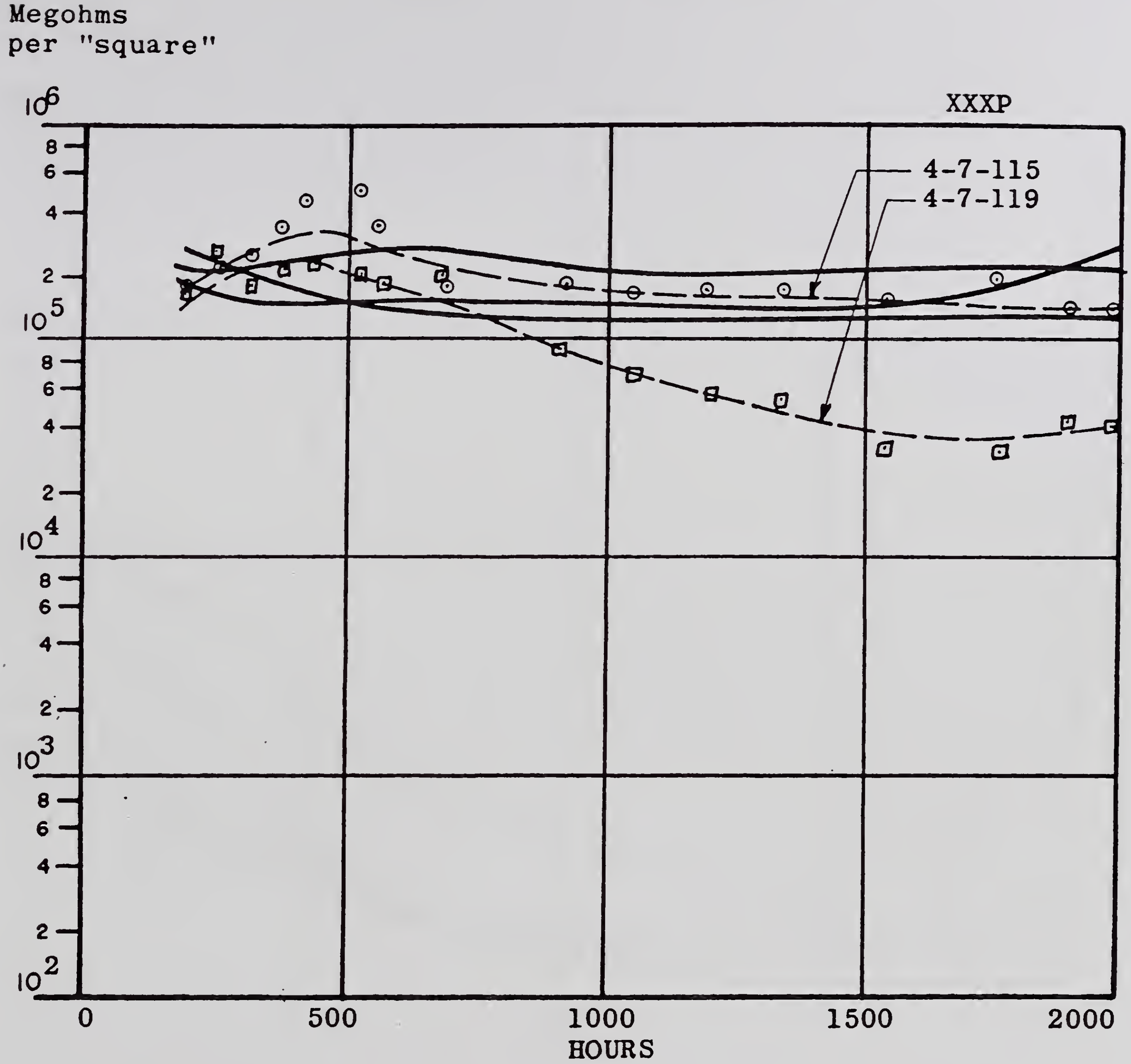


4-7-114 Coating: Silicone resin

FIG. 29

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

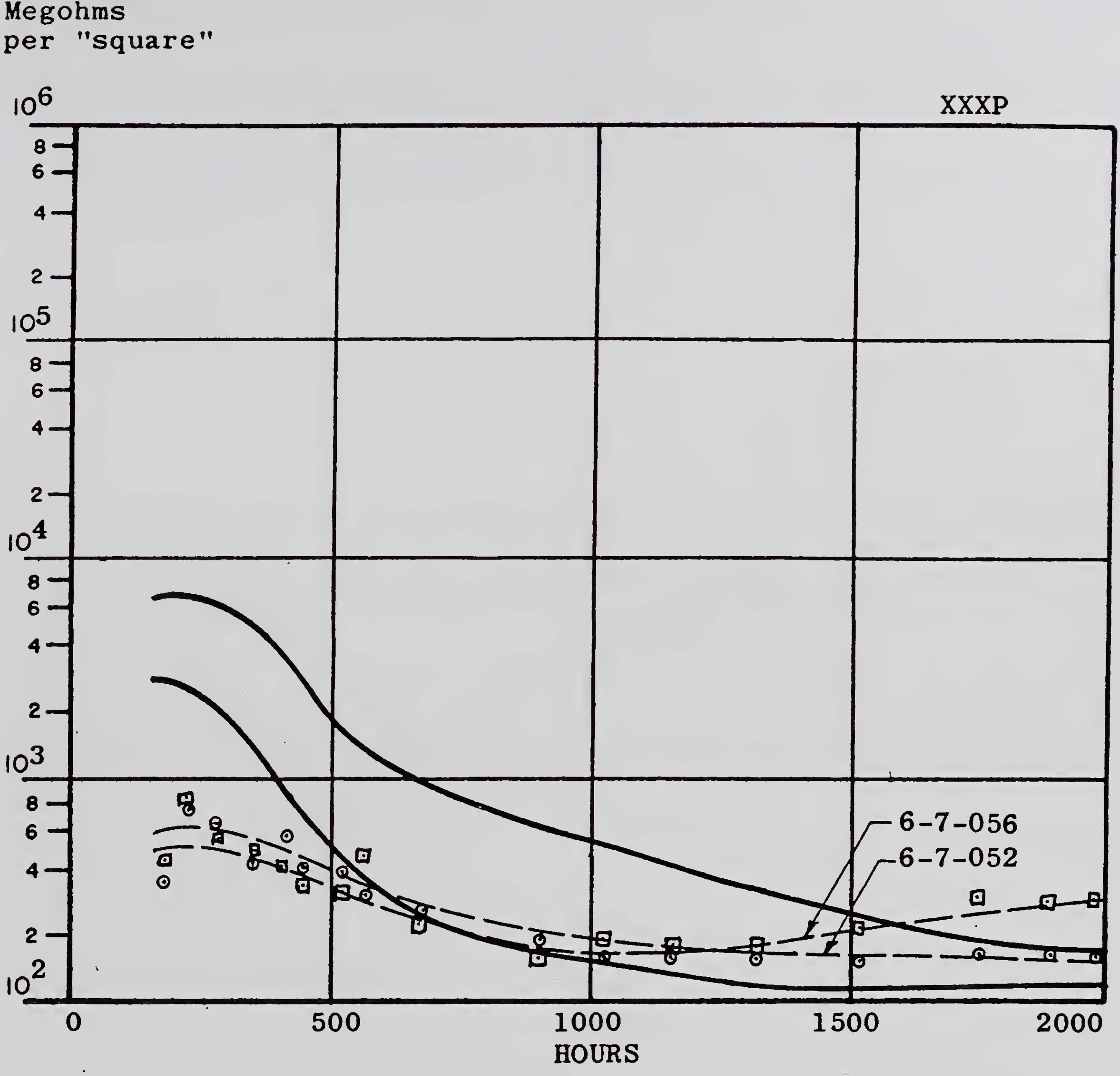


4-7-115 Coating: Silicone fluid (Dip soldered)
4-7-119 Coating: Silicone fluid

FIG. 30

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

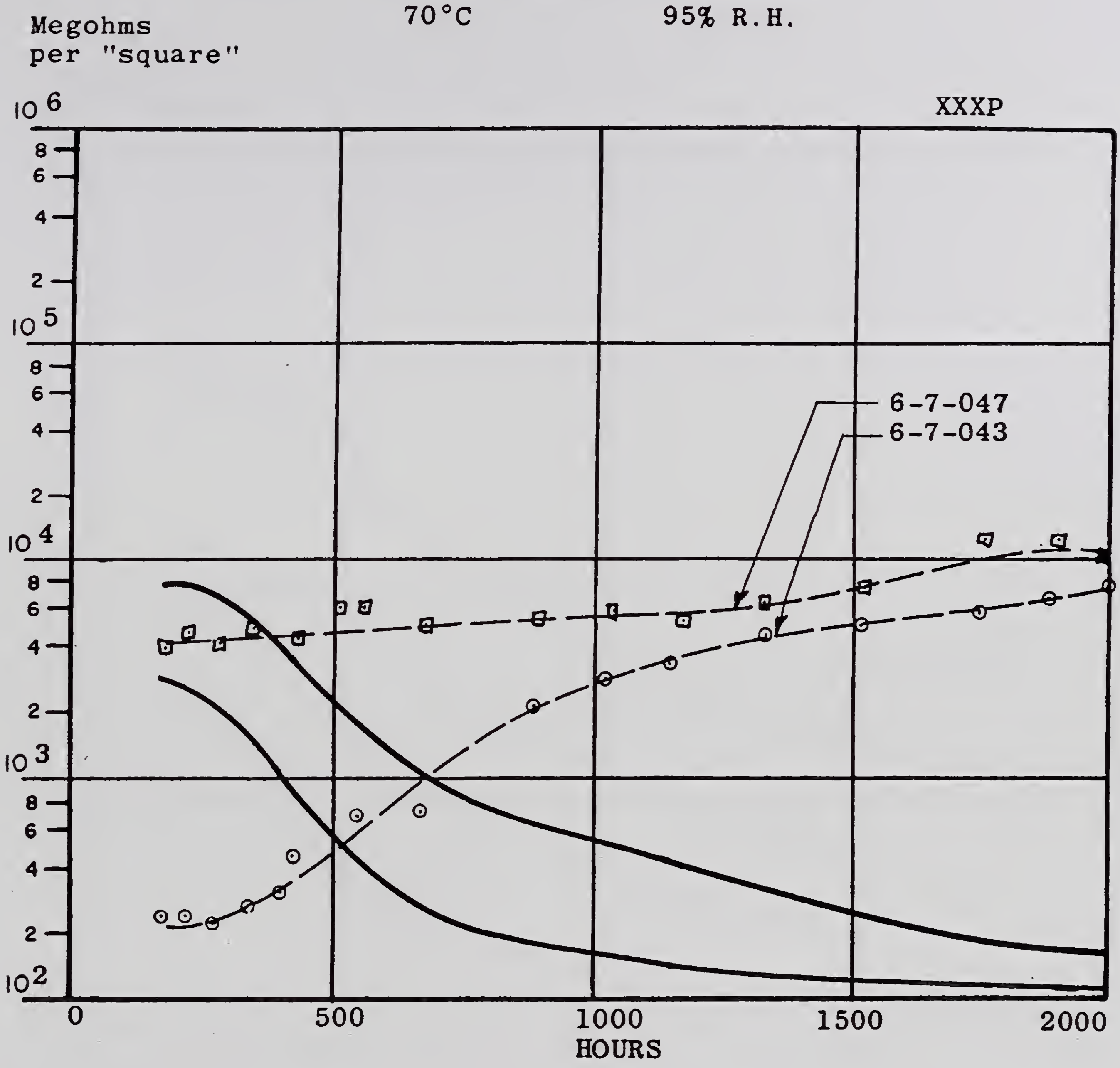


6-7-056 Coating: Epoxy #1
6-7-052 Coating: Epoxy #1 (Dip soldered)

FIG. 31

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

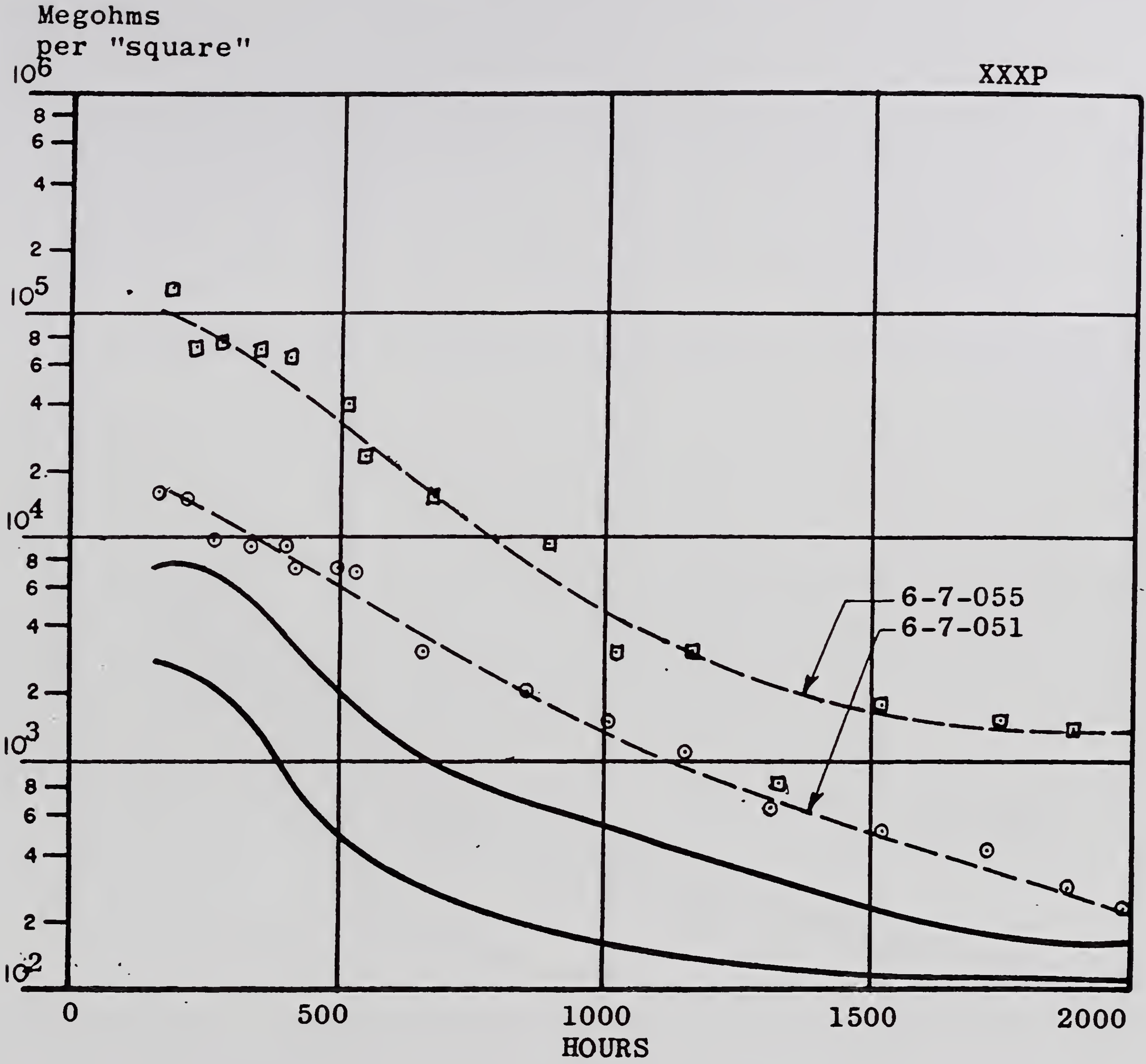


6-7-047 Coating: Epoxy #2
6-7-043 Coating: Epoxy #2 (Dip soldered)

FIG. 32

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

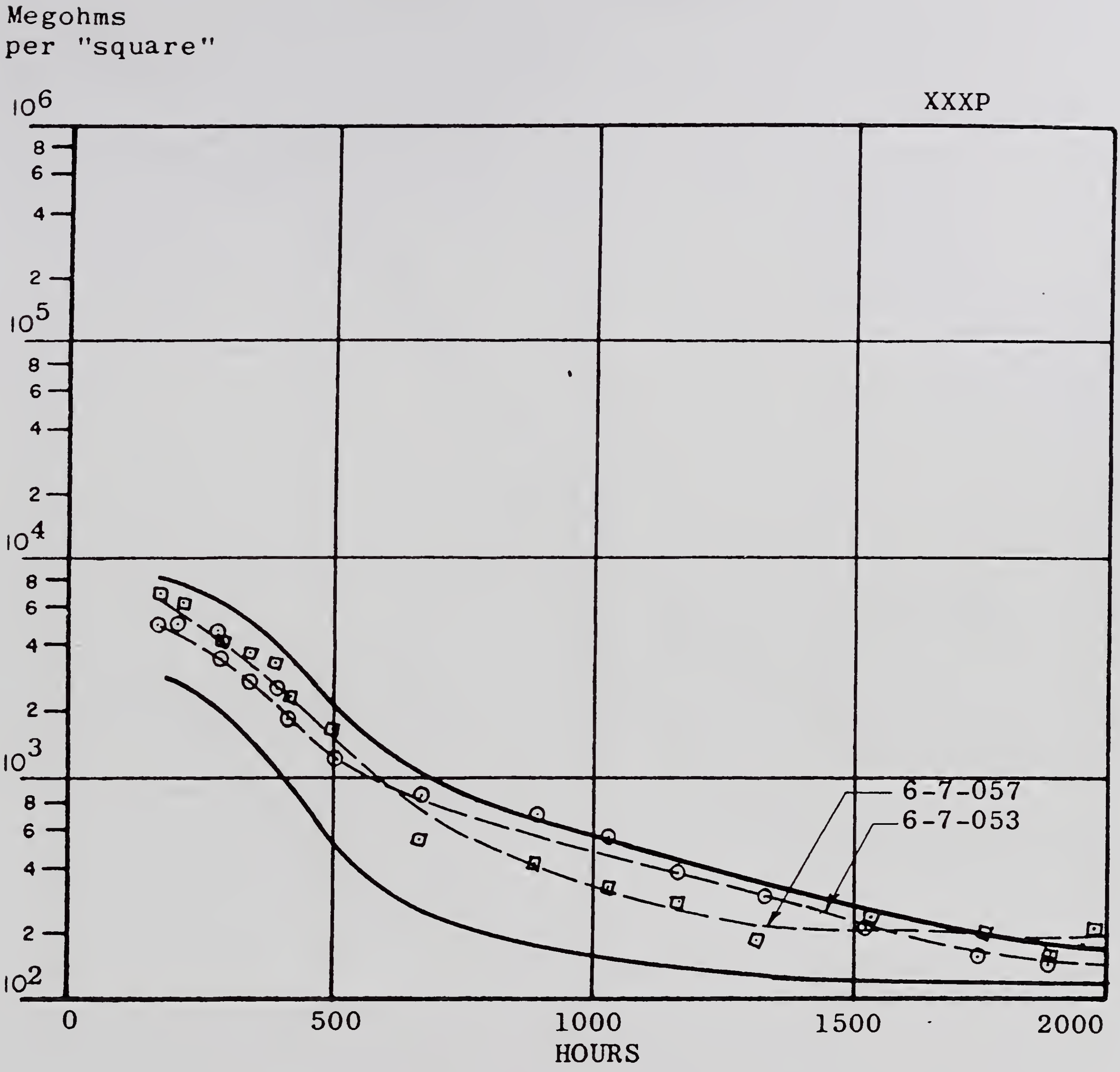


6-7-055 Coating: Microwax (Dip soldered)
6-7-051 Coating: Microwax

FIG. 33

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

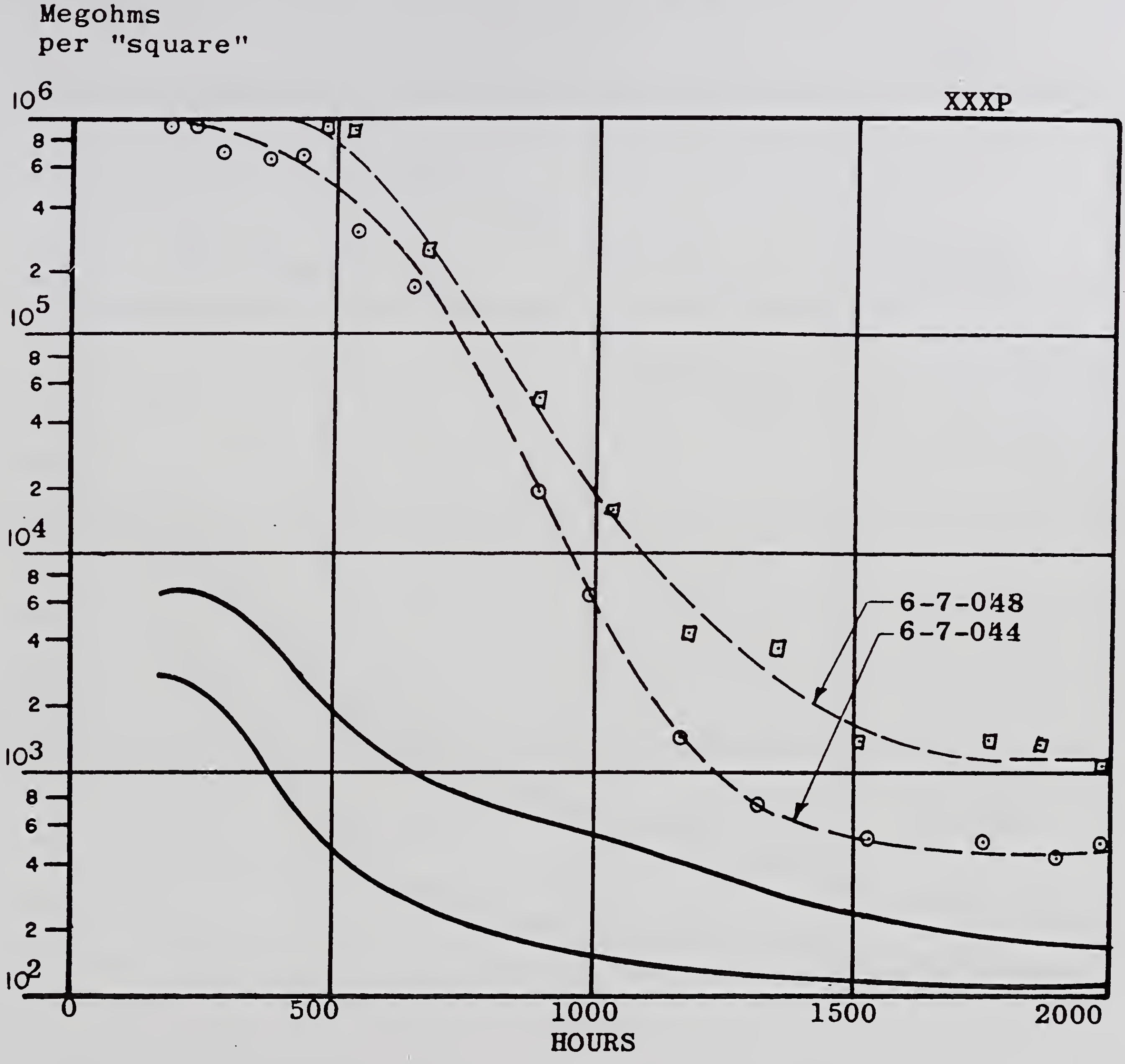


6-7-057 Coating: Insulating varnish (Dip soldered)
6-7-053 Coating: Insulating varnish

FIG. 34

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

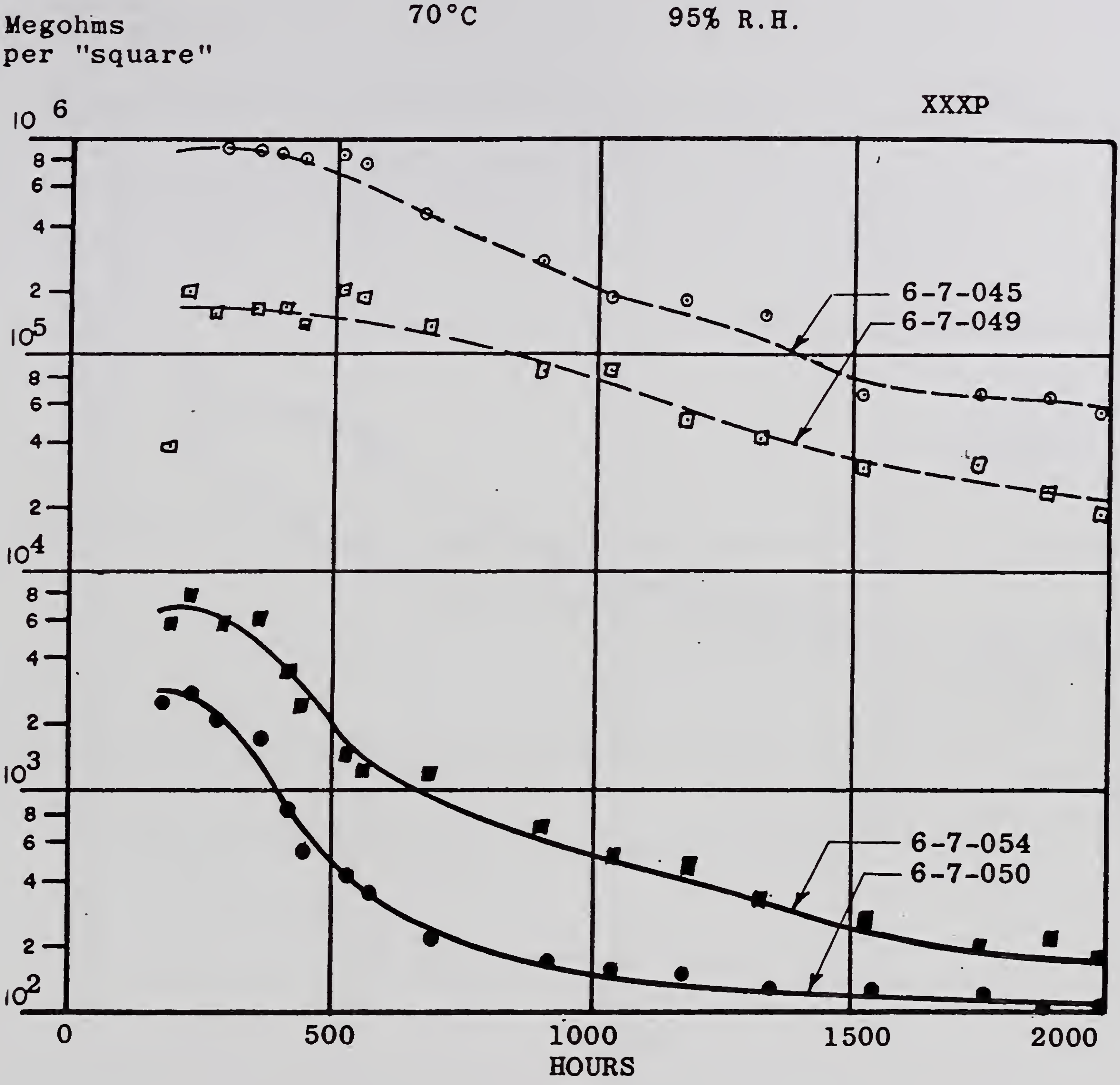


6-7-048 Coating: Silicone resin (Dip soldered)
6-7-044 Coating: Silicone resin

FIG. 35

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

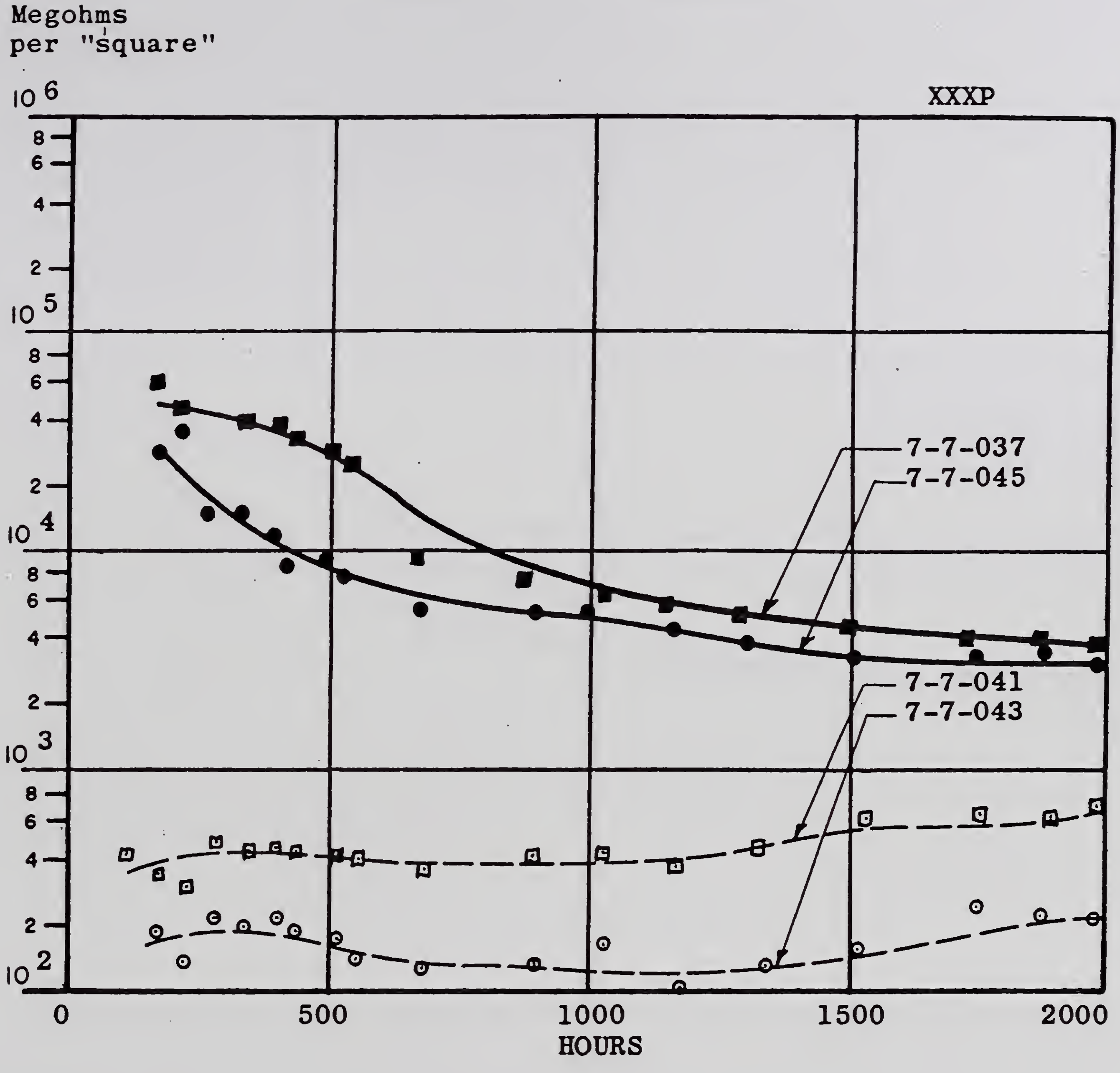


6-7-045 Coating: Silicone fluid (Dip soldered)
6-7-049 Coating: Silicone fluid
6-7-050 Control (Dip soldered)
6-7-054 Control (No preconditioning)

FIG. 36

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

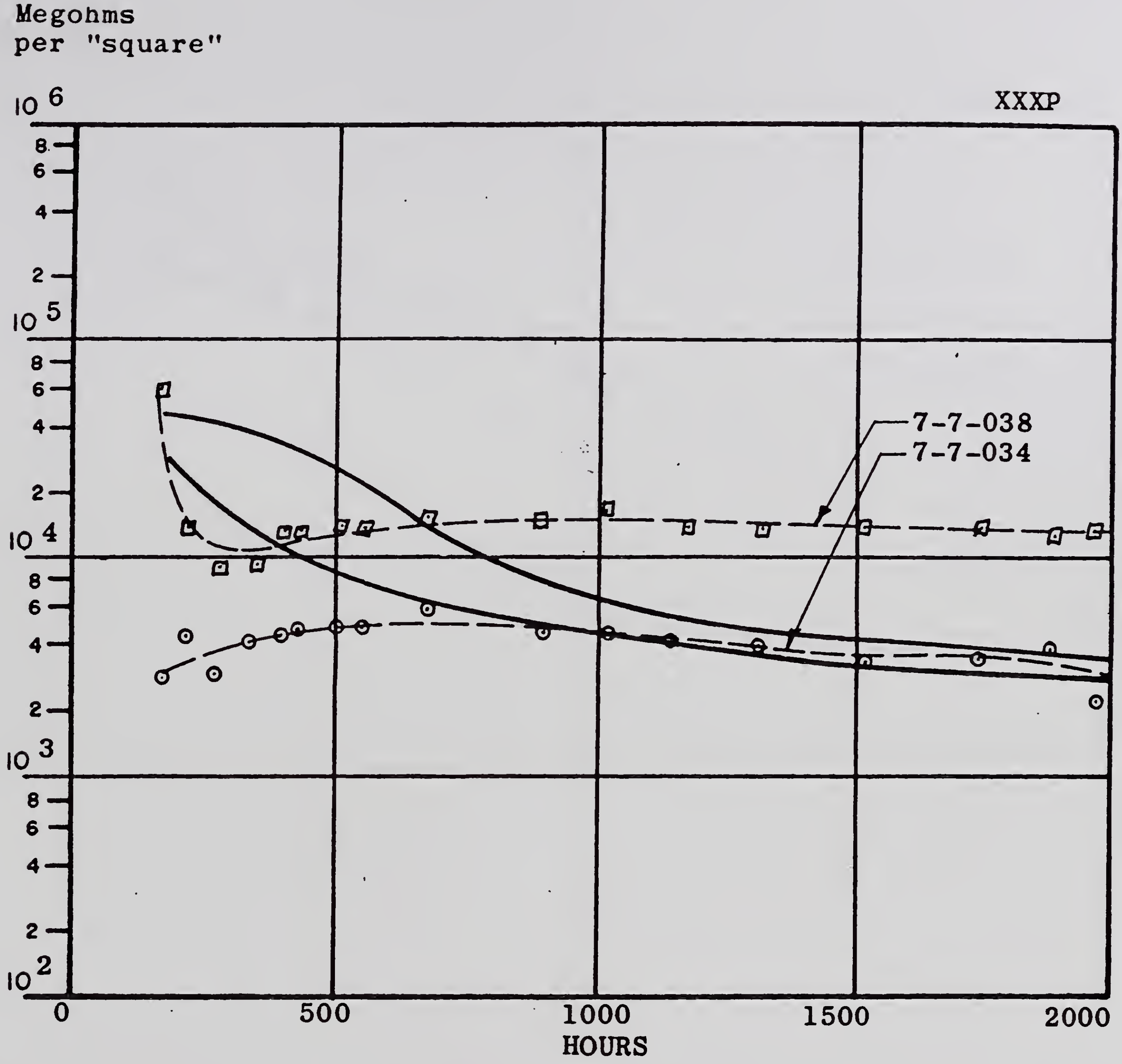


7-7-041 Coating: Epoxy #1 (Dip soldered)
7-7-043 Coating: Epoxy #1
7-7-037 Control (Dip soldered)
7-7-045 Control (No preconditioning)

FIG. 37

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

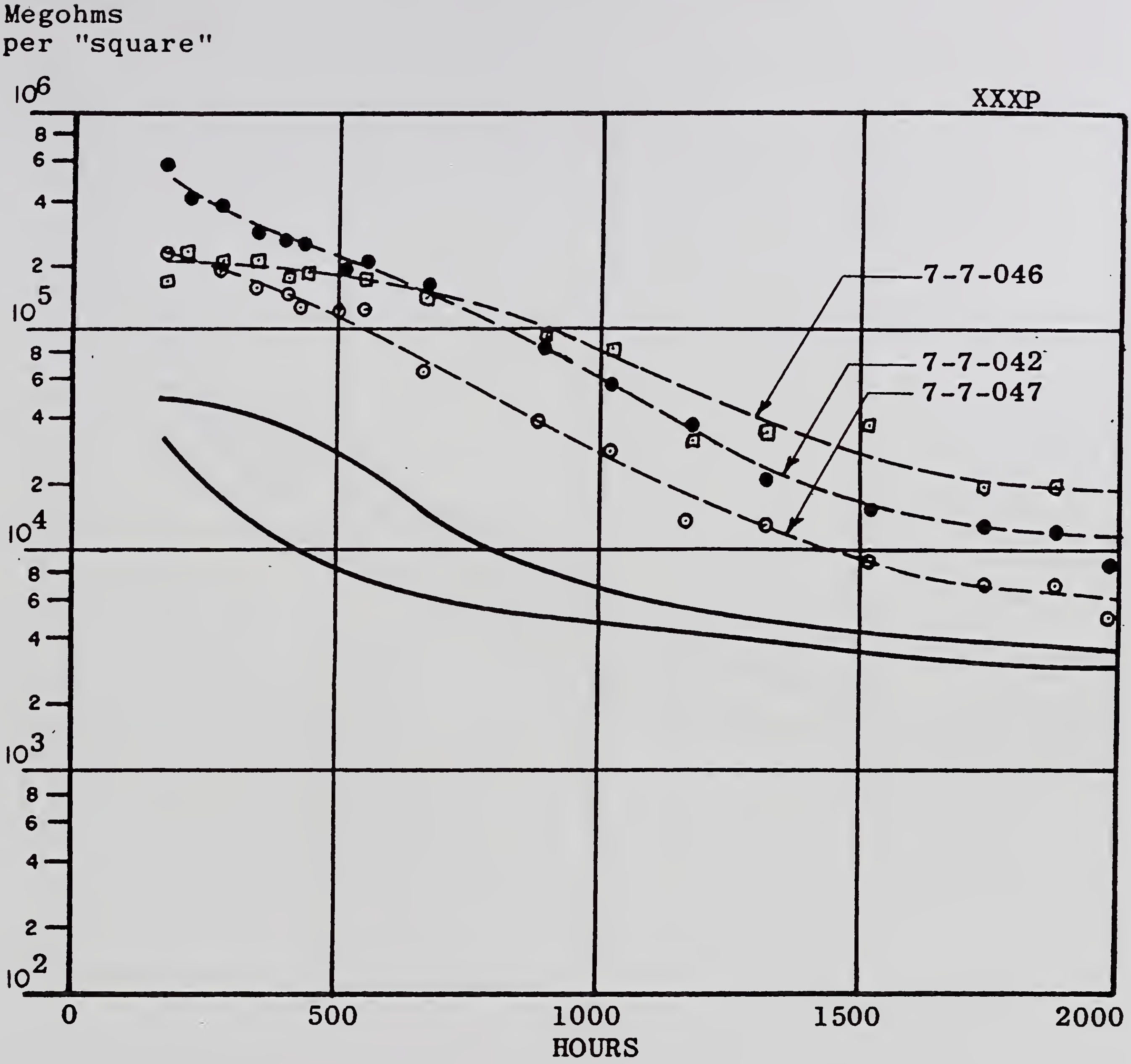


7-7-038 Epoxy #2
7-7-034 Epoxy #2 (Dip soldered)

FIG. 38

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

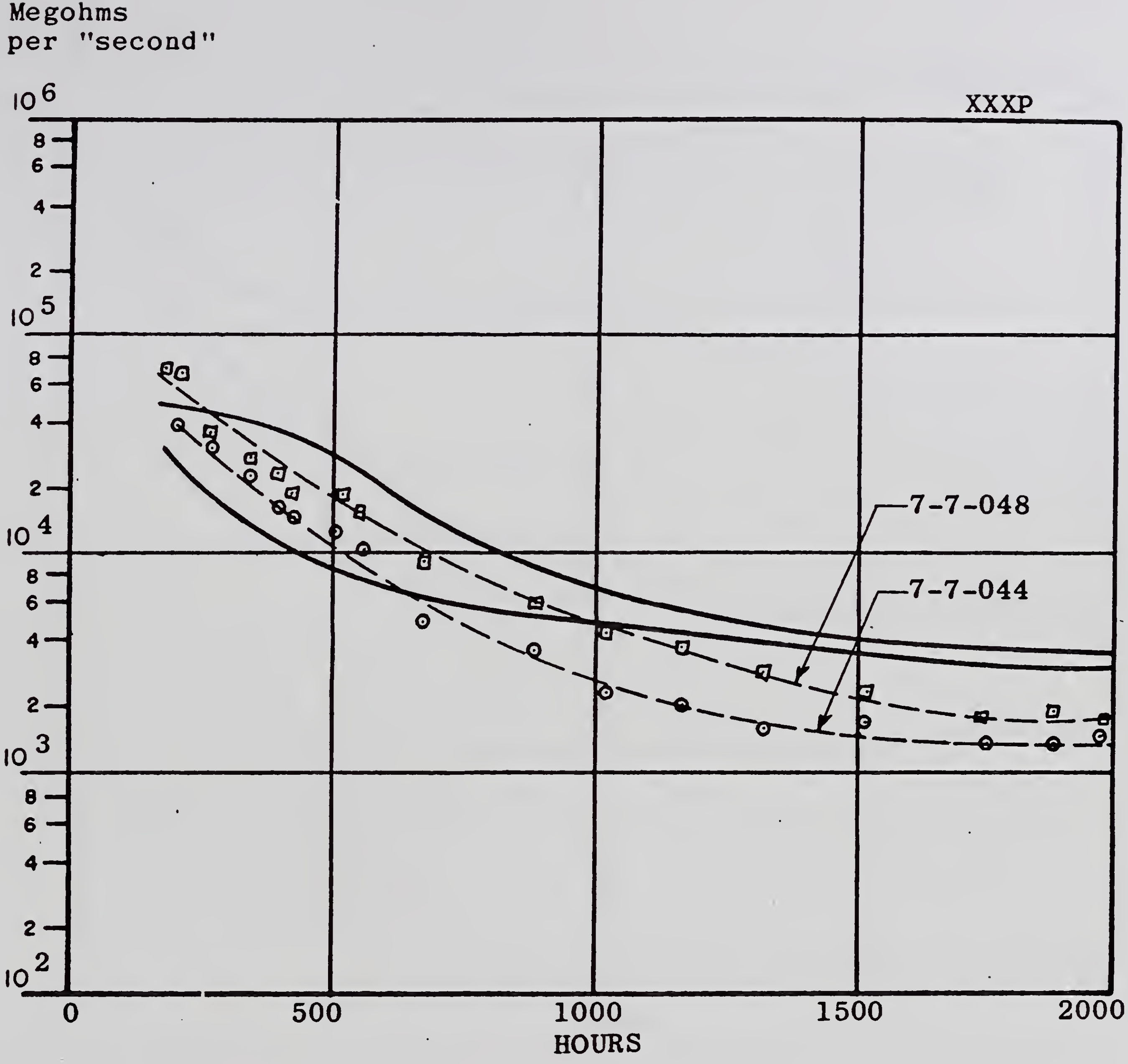


7-7-047 Coating: Microwax (Dip soldered)
7-7-046 Coating: Microwax
7-7-042 Coating: Microwax (Dip soldered)

FIG. 39

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

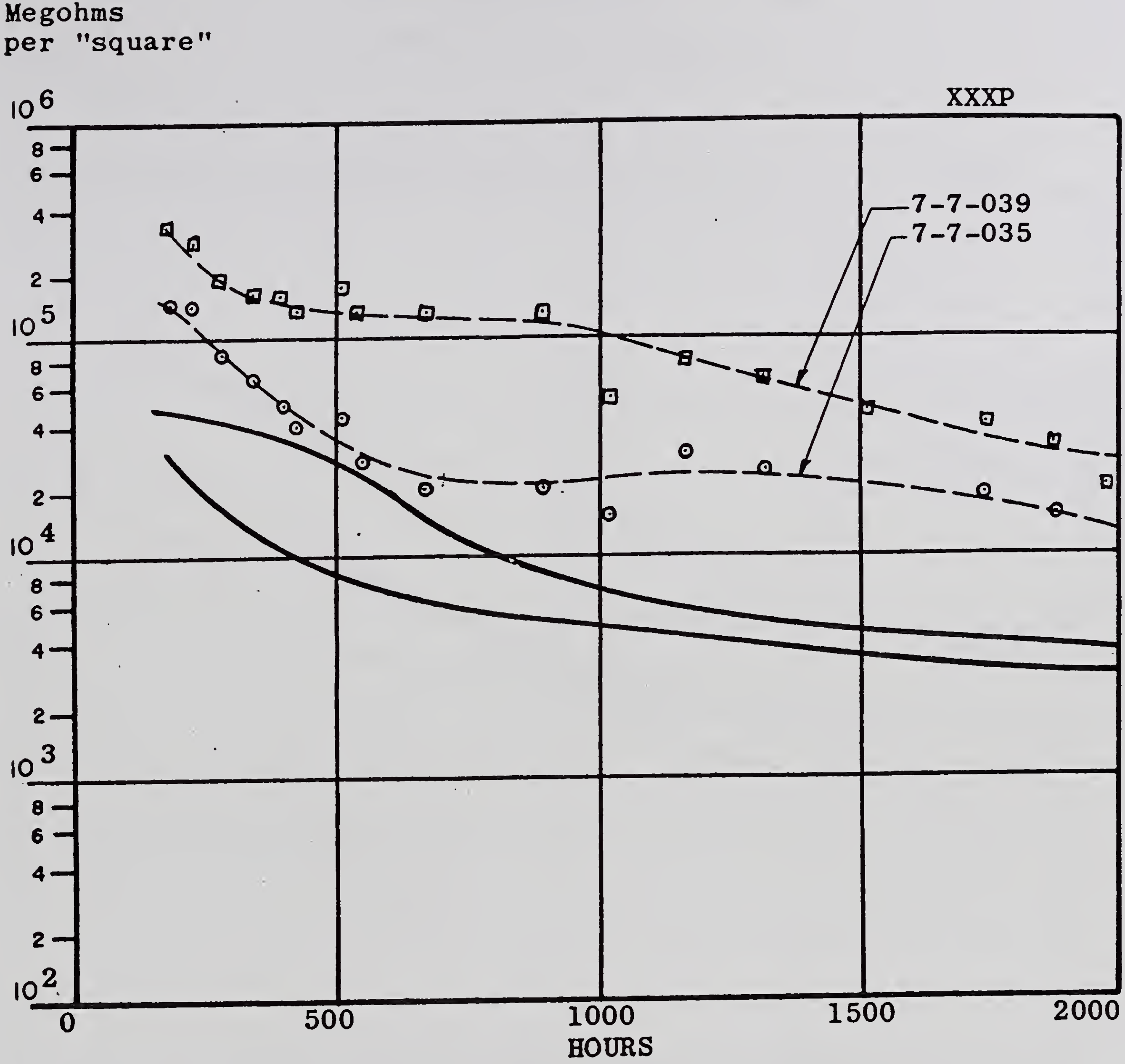


7-7-044 Coating: Insulating varnish (Dip soldered)
7-7-048 Coating: Insulating varnish

FIG. 40

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

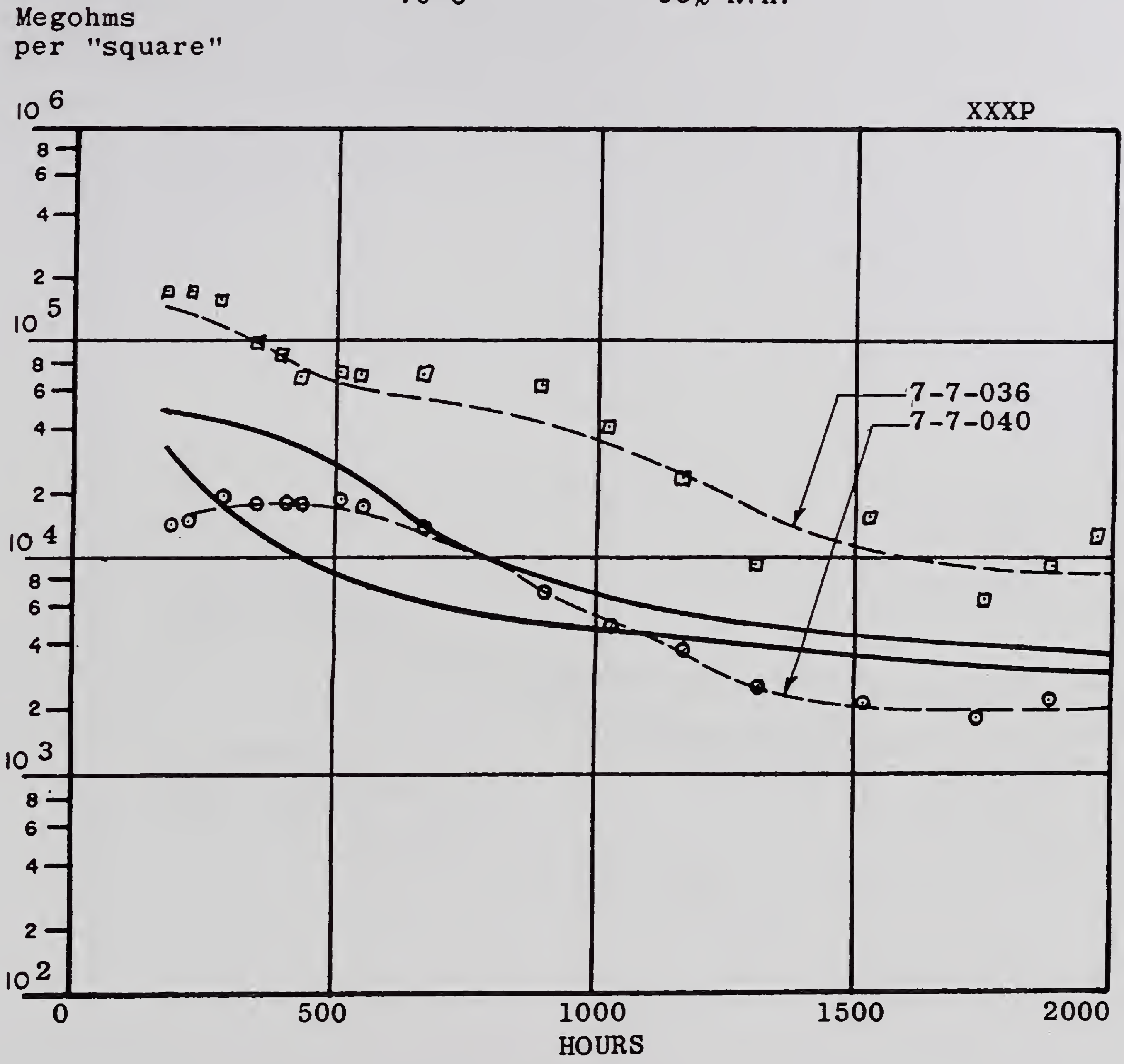


7-7-035 Coating: Silicone resin
7-7-039 Coating: Silicone resin (Dip Soldered)

FIG. 41

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

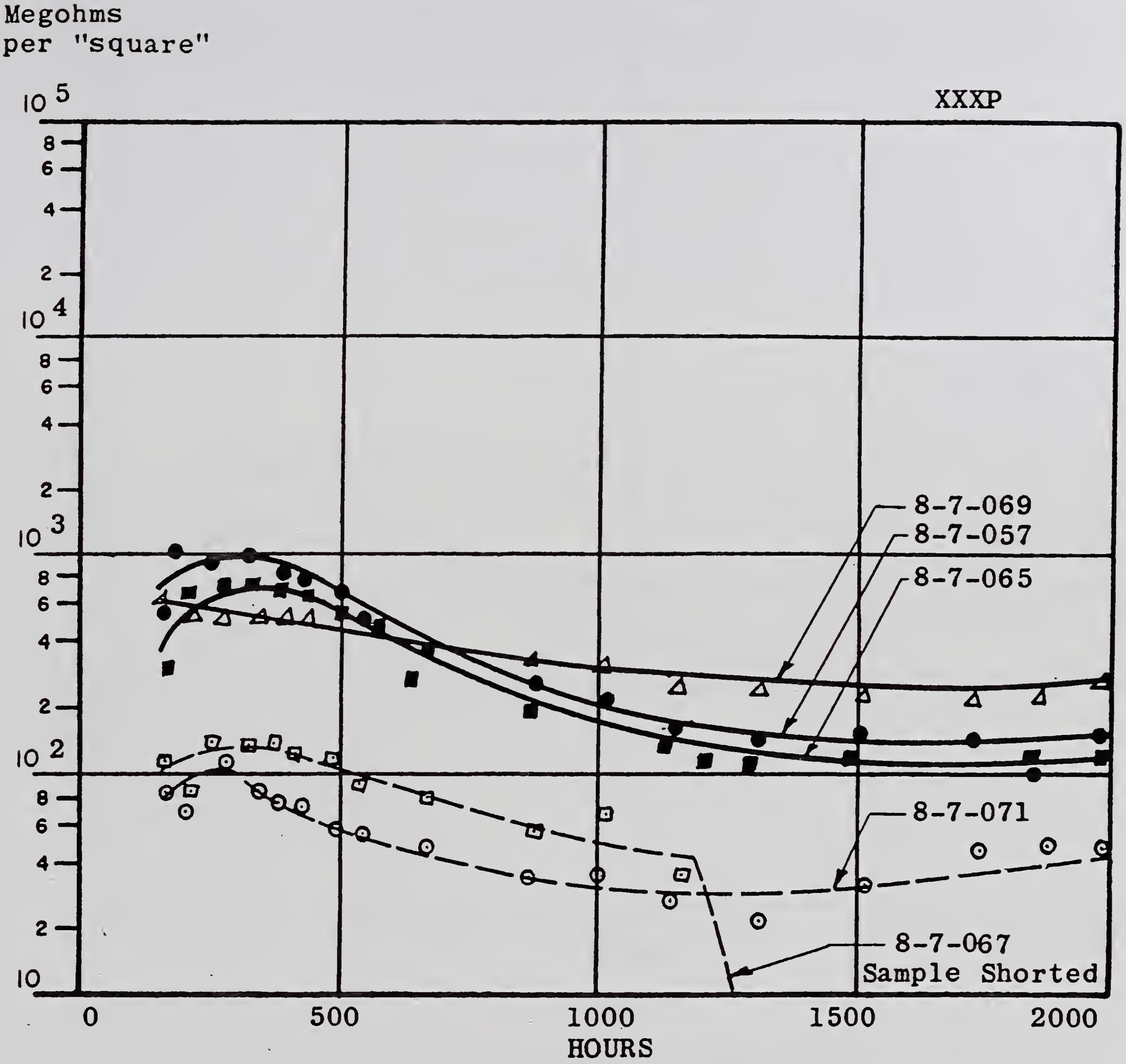


7-7-036 Coating: Silicone fluid (Dip soldered)
7-7-040 Coating: Silicone fluid

FIG. 42

SURFACE RESISTIVITY VS TIME

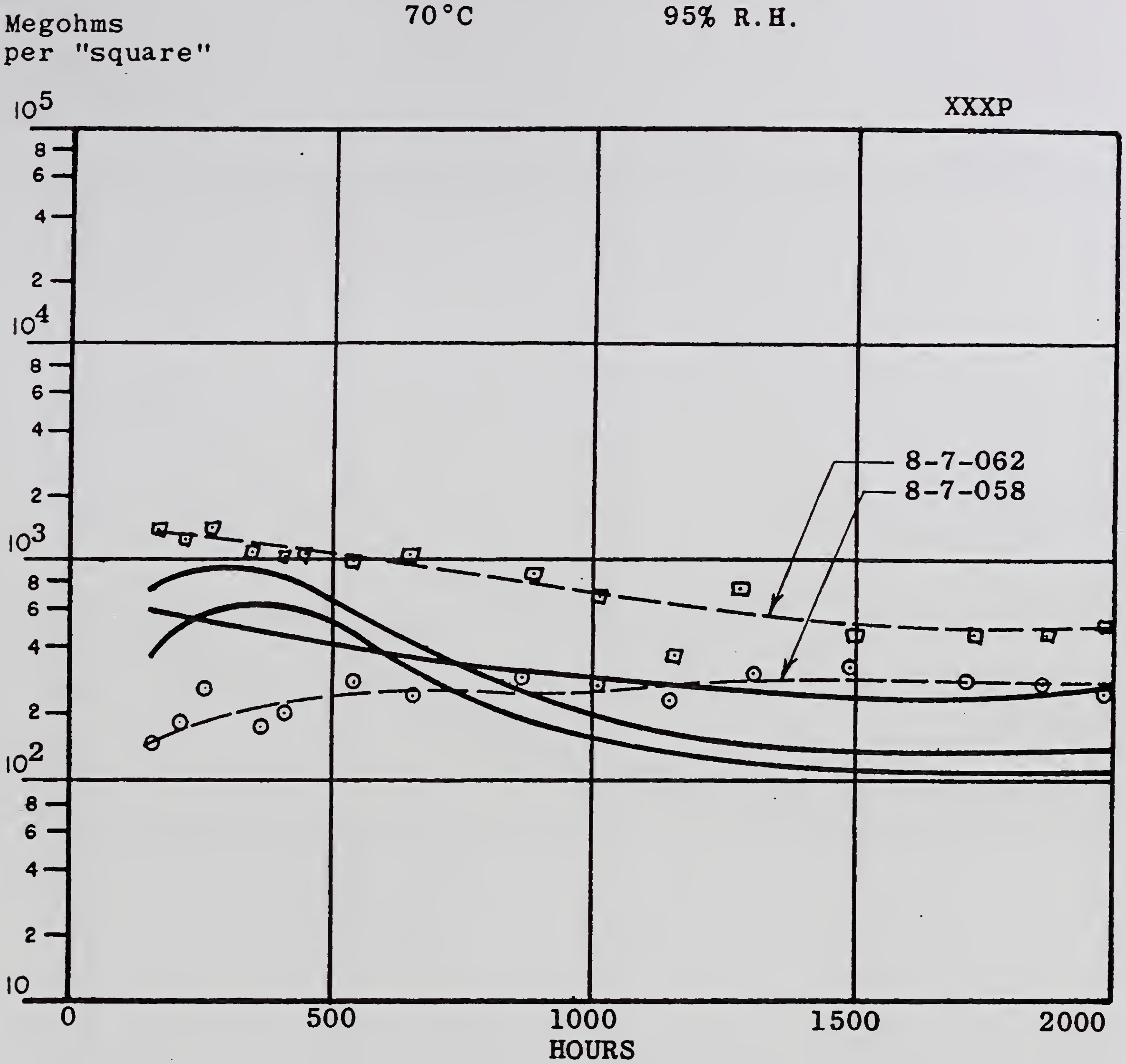
70°C 95% R.H.



8-7-065 Control (Dip soldered)
8-7-057 Control (Dip soldered)
8-7-069 Control (No preconditioning)
8-7-071 Coating: Epoxy #1
8-7-067 Coating: Epoxy #1 (Dip soldered)

FIG. 43

SURFACE RESISTIVITY VS TIME

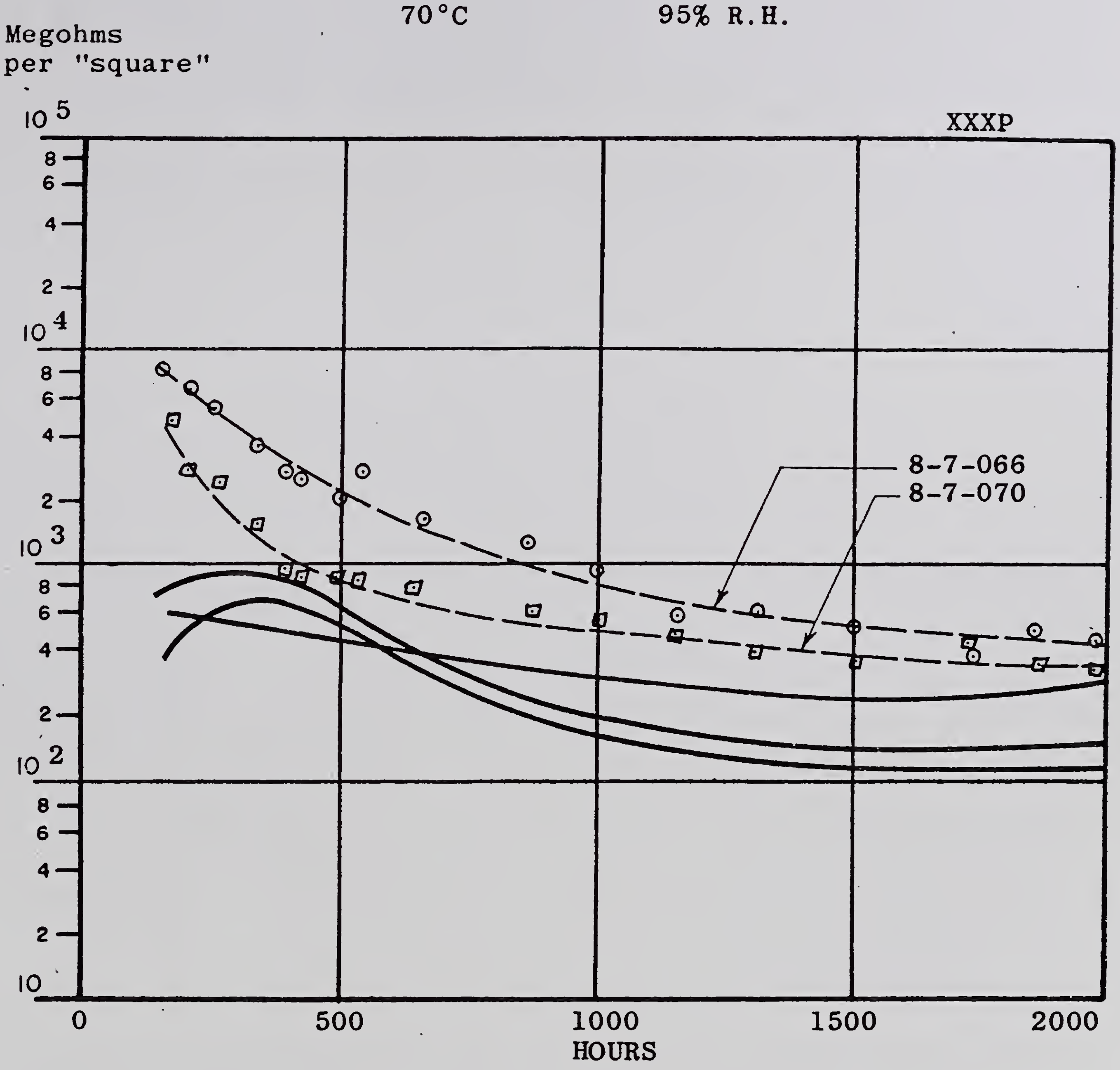


8-7-062 Coating: Epoxy #2
8-7-058 Coating: Epoxy #2 (Dip soldered)

FIG. 44

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

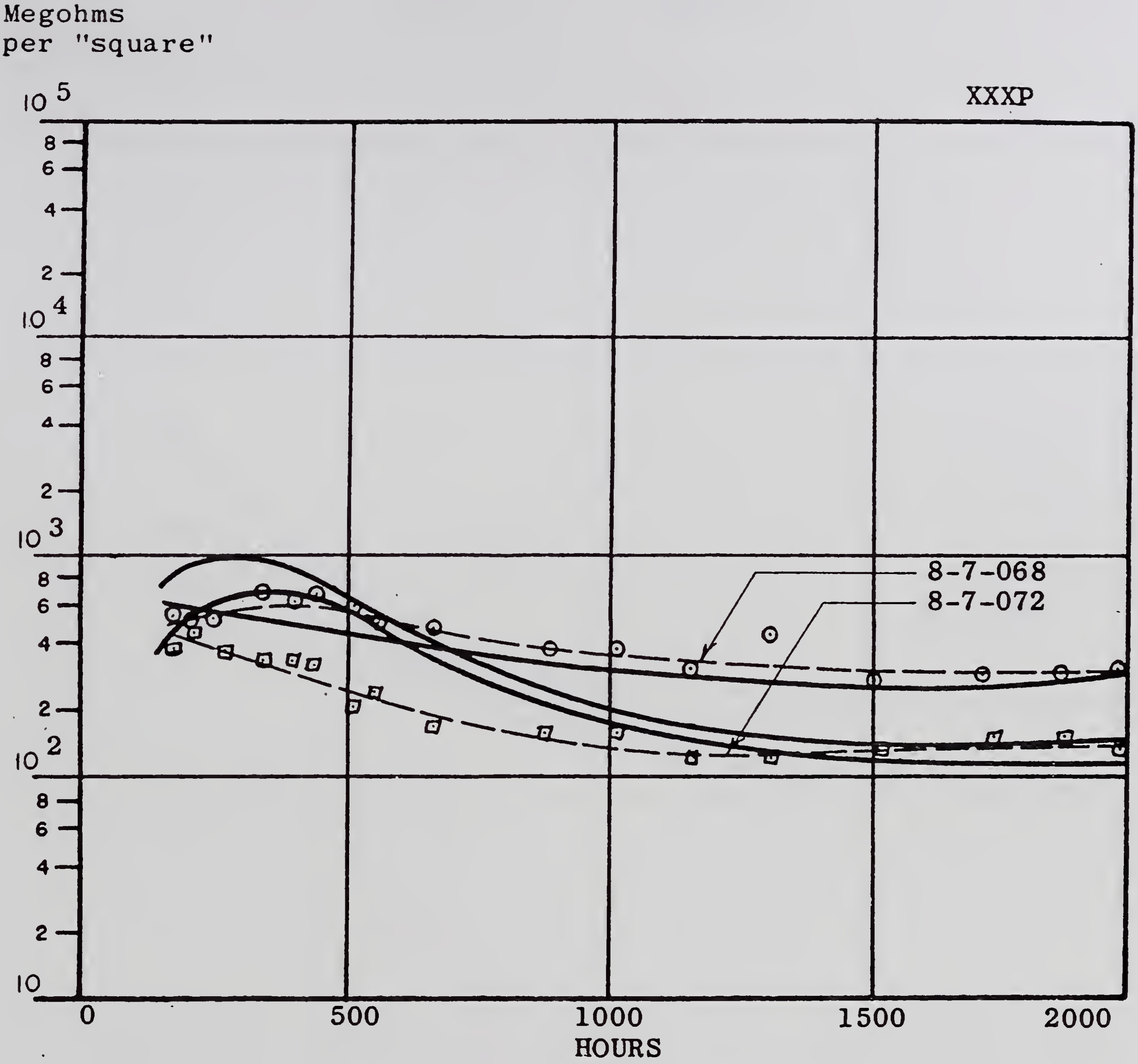


8-7-066 Coating: Microwax
8-7-070 Coating: Microwax (Dip soldered)

FIG. 45

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

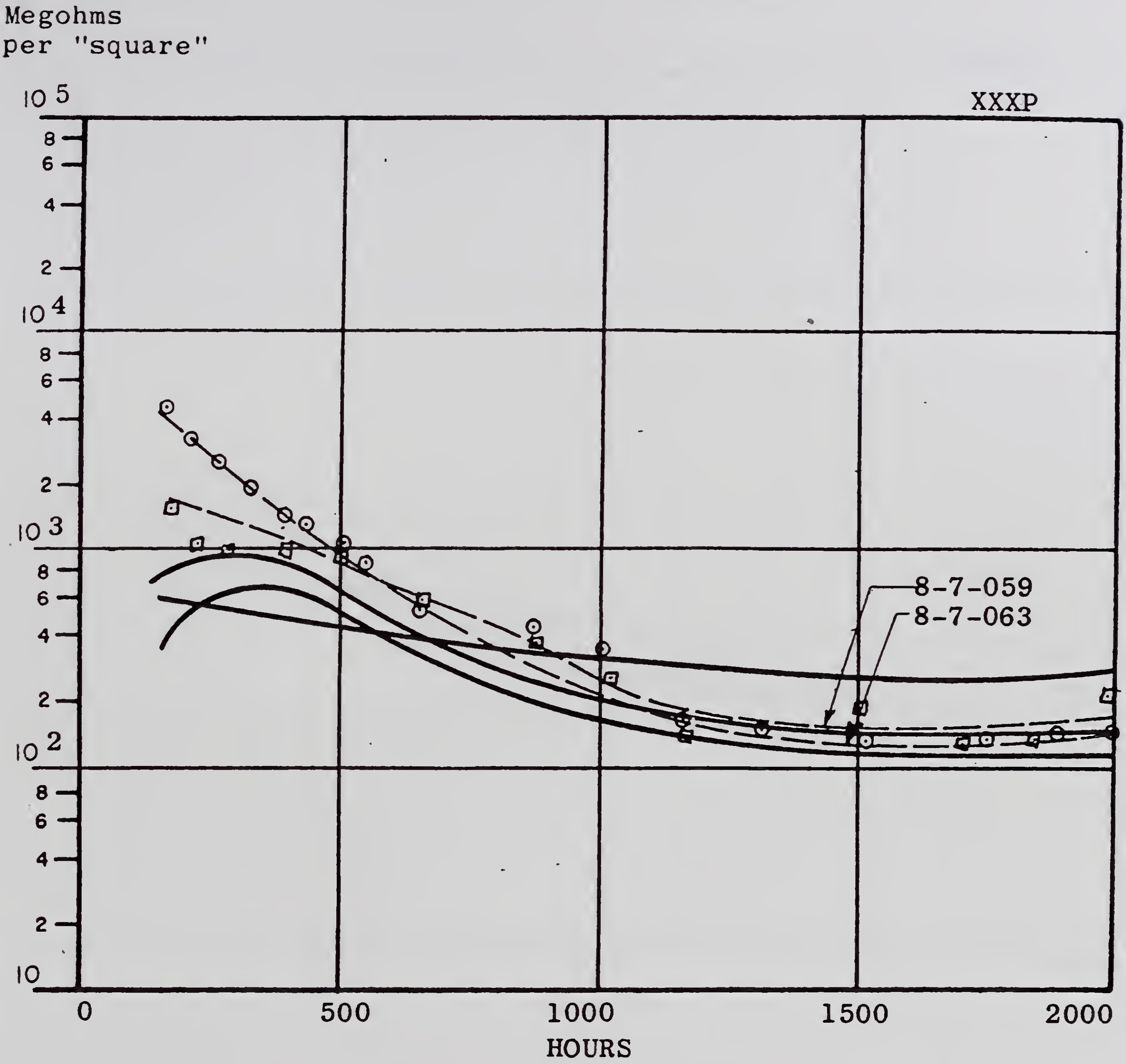


8-7-072 Coating: Insulating varnish (Dip soldered)
8-7-068 Coating: Insulating varnish

FIG. 46

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

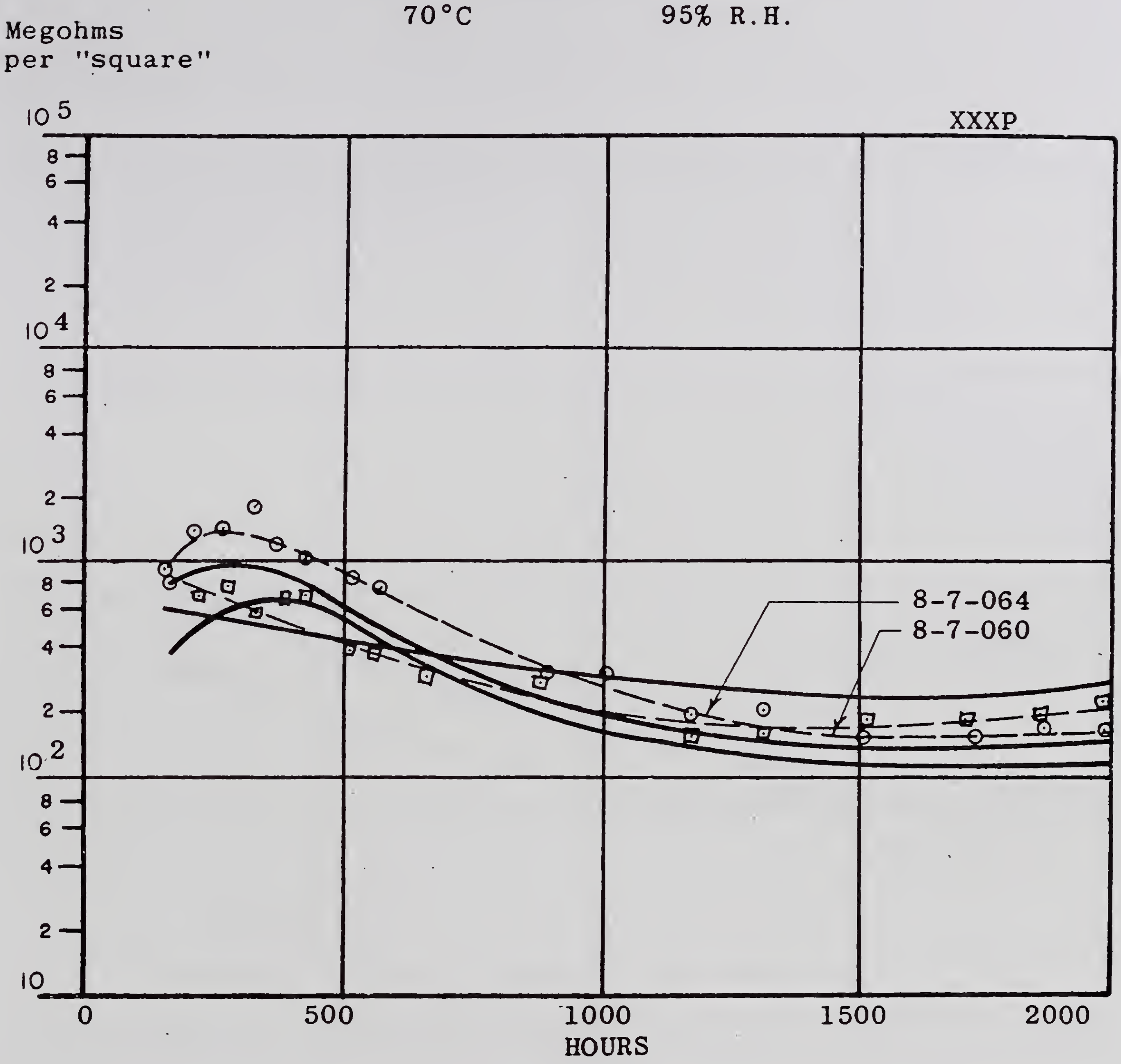


8-7-059 Coating: Silicone resin
8-7-063 Coating: Silicone resin (Dip soldered)

FIG.47

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

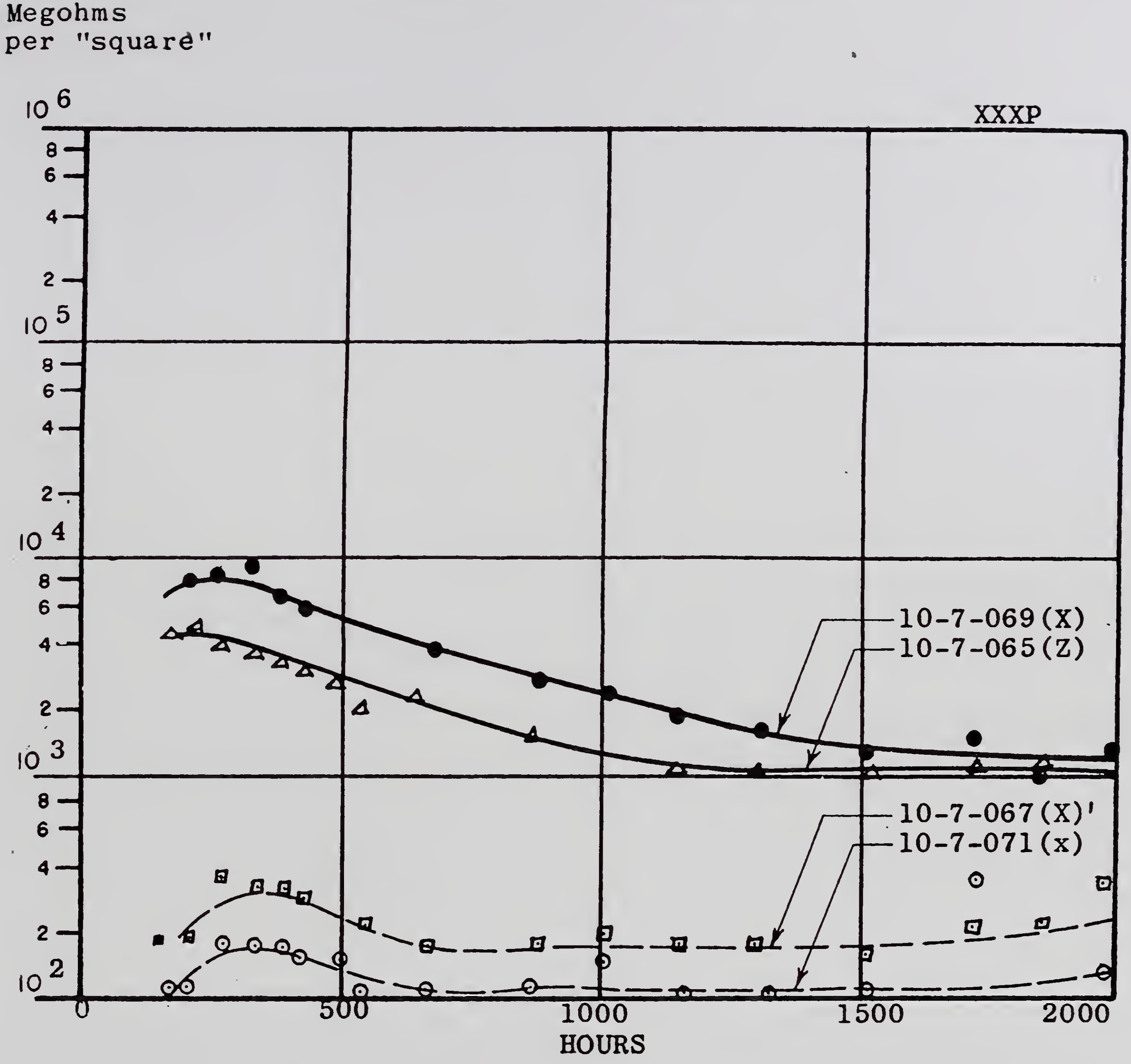


8-7-064 Coating: Silicone fluid
8-7-060 Coating: Silicone fluid (Dip soldered)

FIG. 48

SURFACE RESISTIVITY VS TIME

70°C 95% R. H.

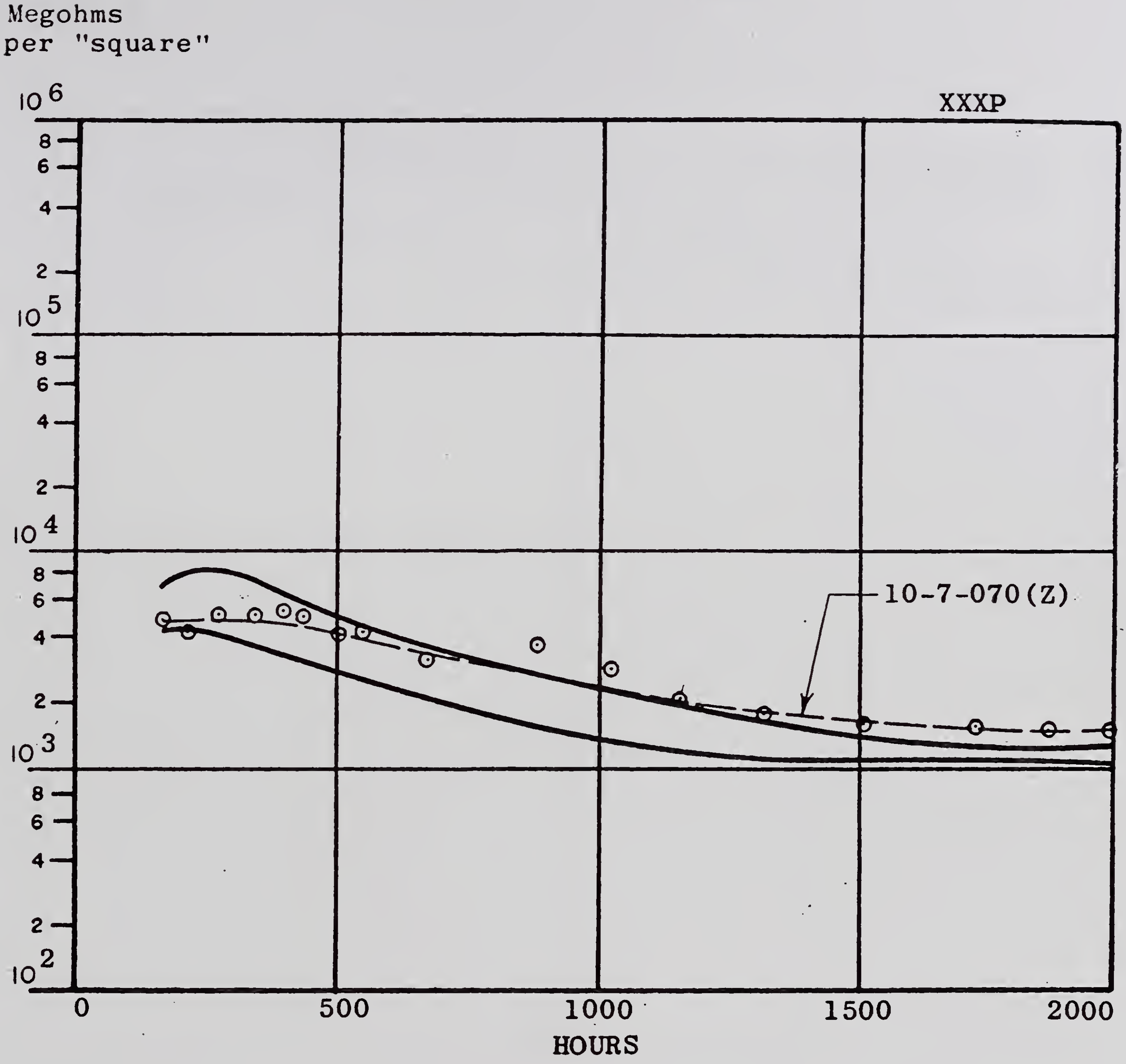


10-7-071(X) Coating: Epoxy #1
10-7-067(X) Coating: Epoxy #1 (Dip soldered)
10-7-069(X) Control (No preconditioning)
10-7-065(Z) Control (No preconditioning)

FIG. 49

SURFACE RESISTIVITY VS TIME

70°C 95% R. H.

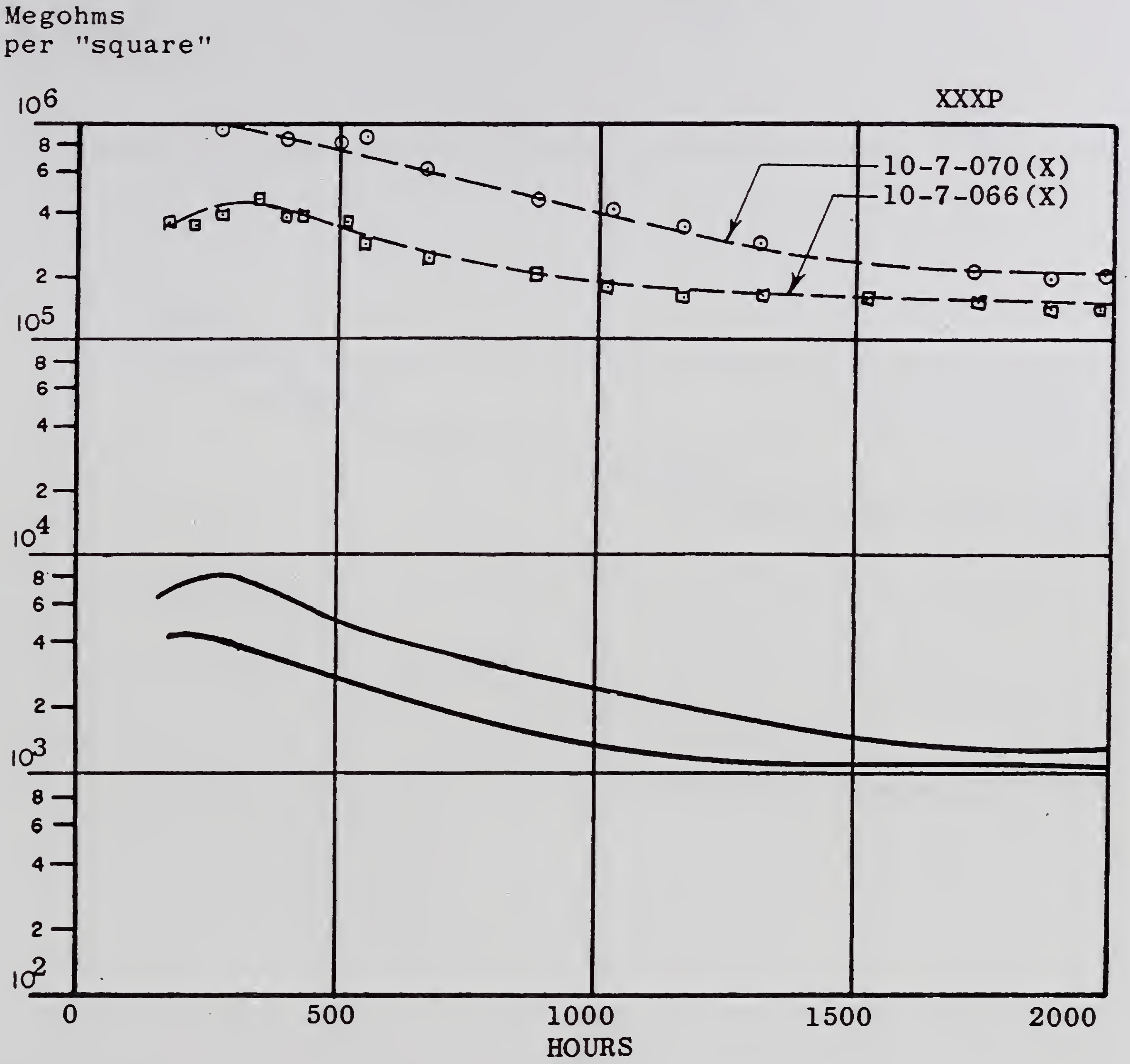


10-7-070(Z) Coating: Epoxy #2

FIG. 50

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

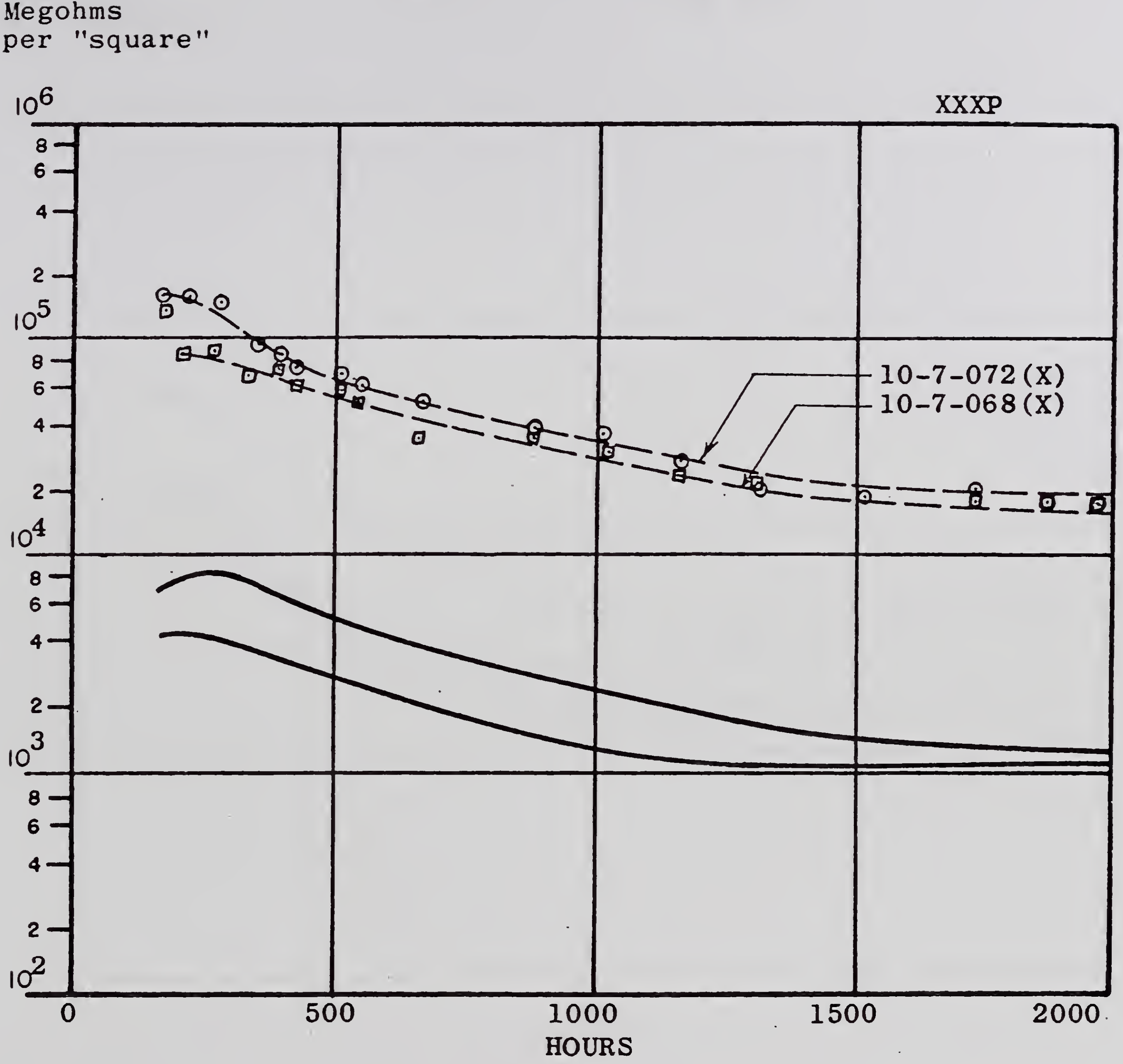


10-7-070(X) Coating: Microwax (Dip soldered)
10-7-066(X) Coating: Microwax (Dip soldered)

FIG. 51

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

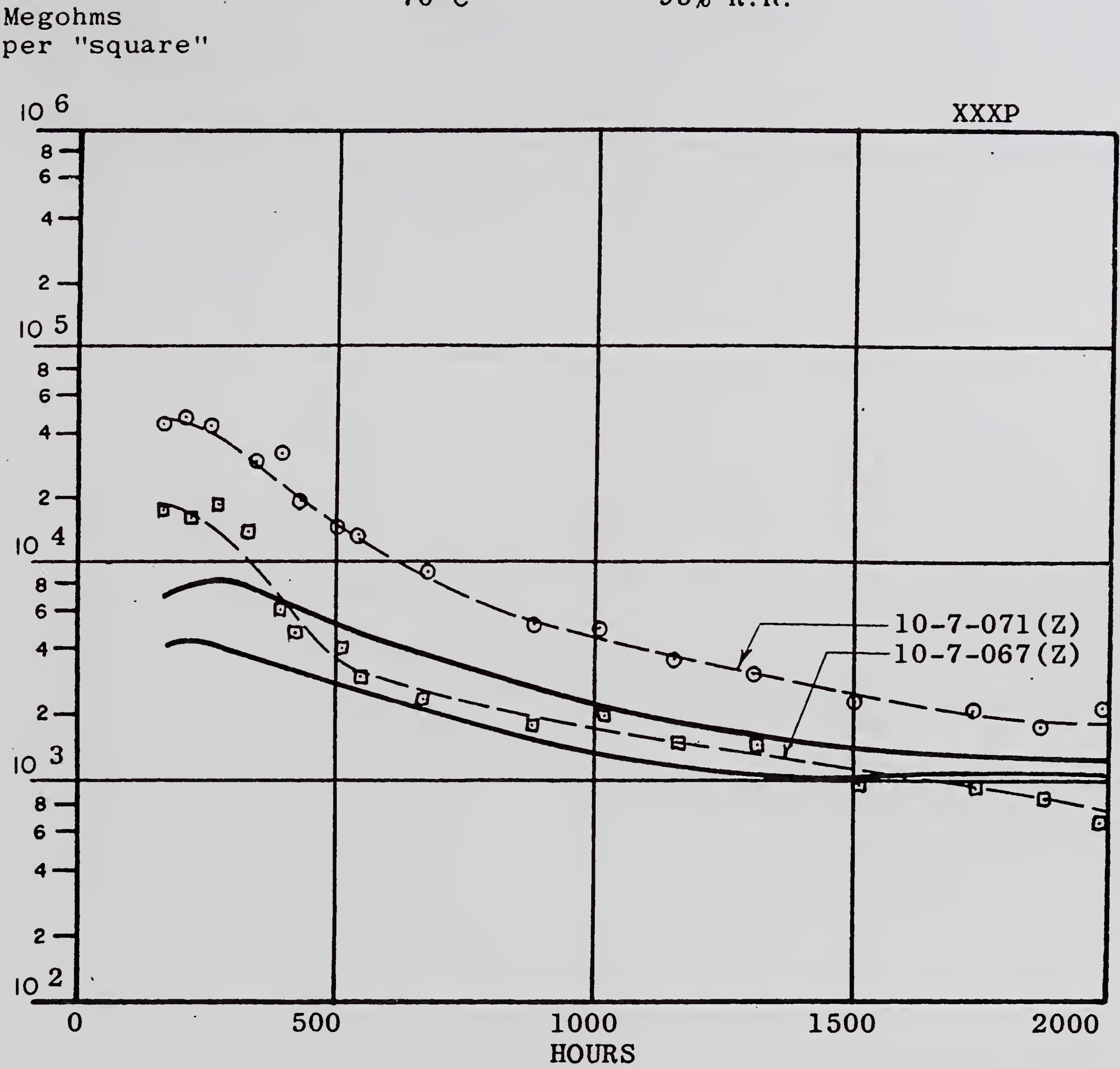


10-7-072(X) Coating: Insulating varnish (Dip soldered)
10-7-068(X) Coating: Insulating varnish

FIG. 52

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

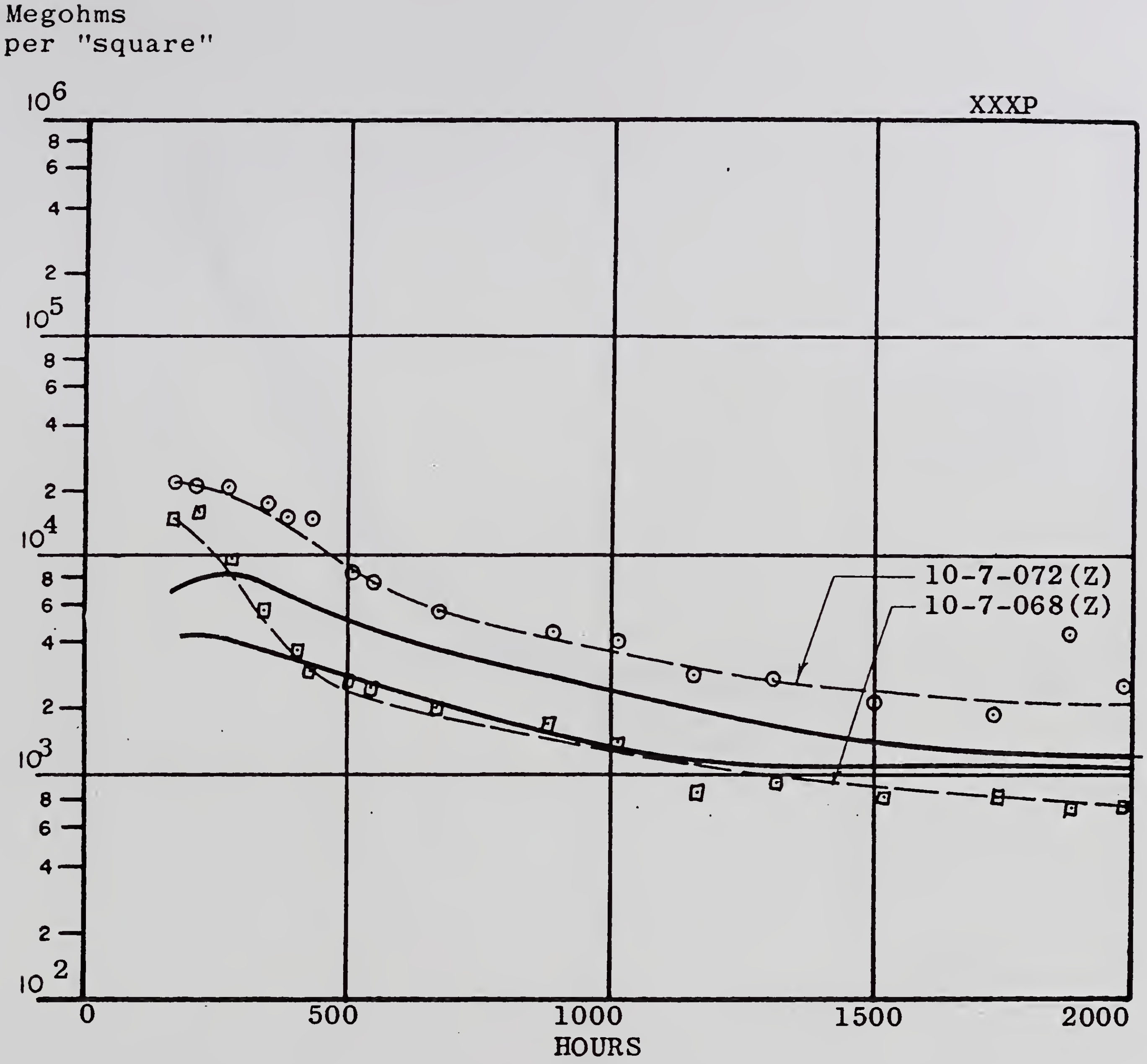


10-7-071(Z) Coating: Silicone resin (Dip soldered)
10-7-067(Z) Coating: Silicone resin

FIG. 53

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

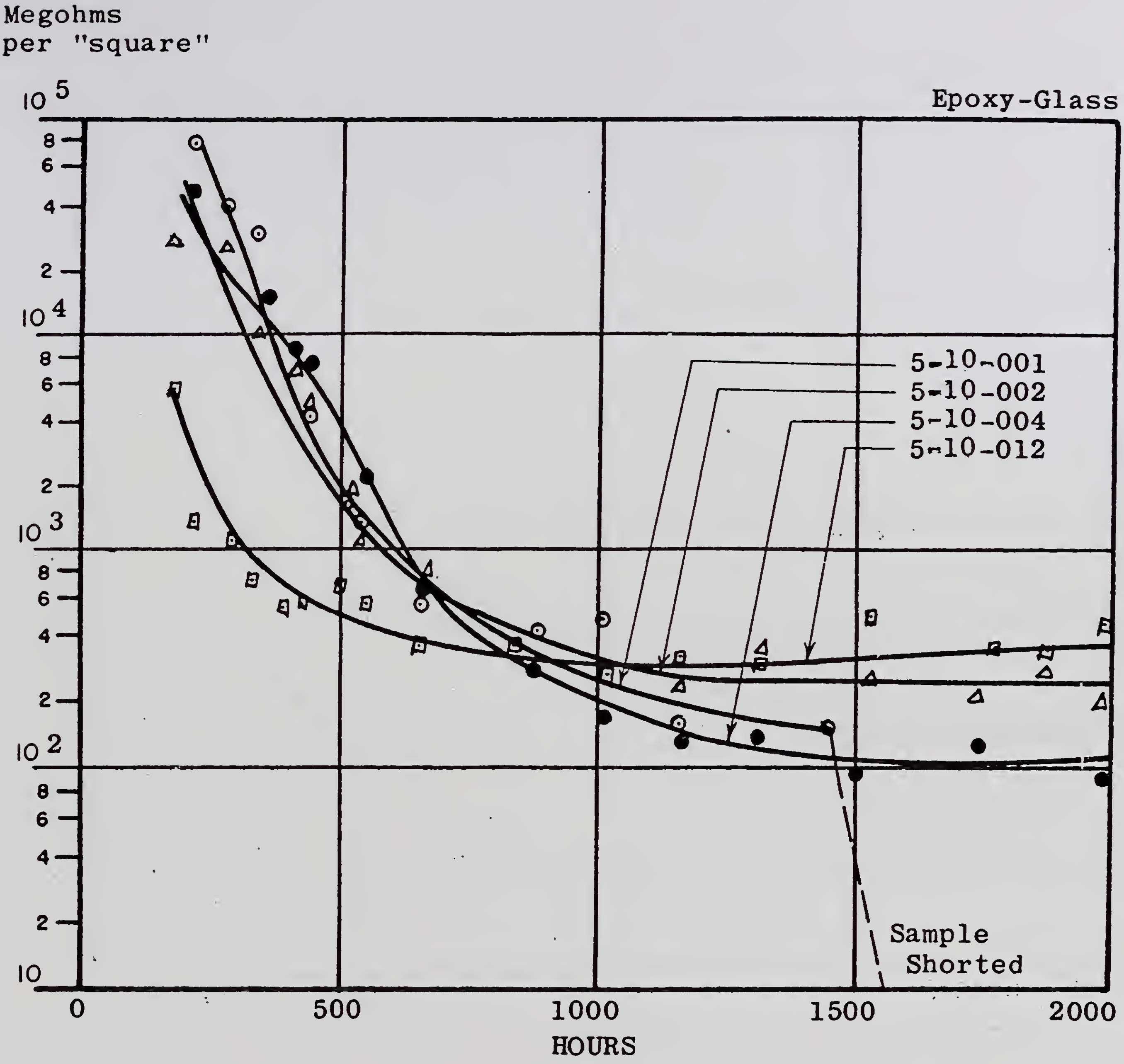


10-7-072(Z) Coating: Silicone fluid
10-7-068(Z) Coating: Silicone fluid

FIG. 54

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

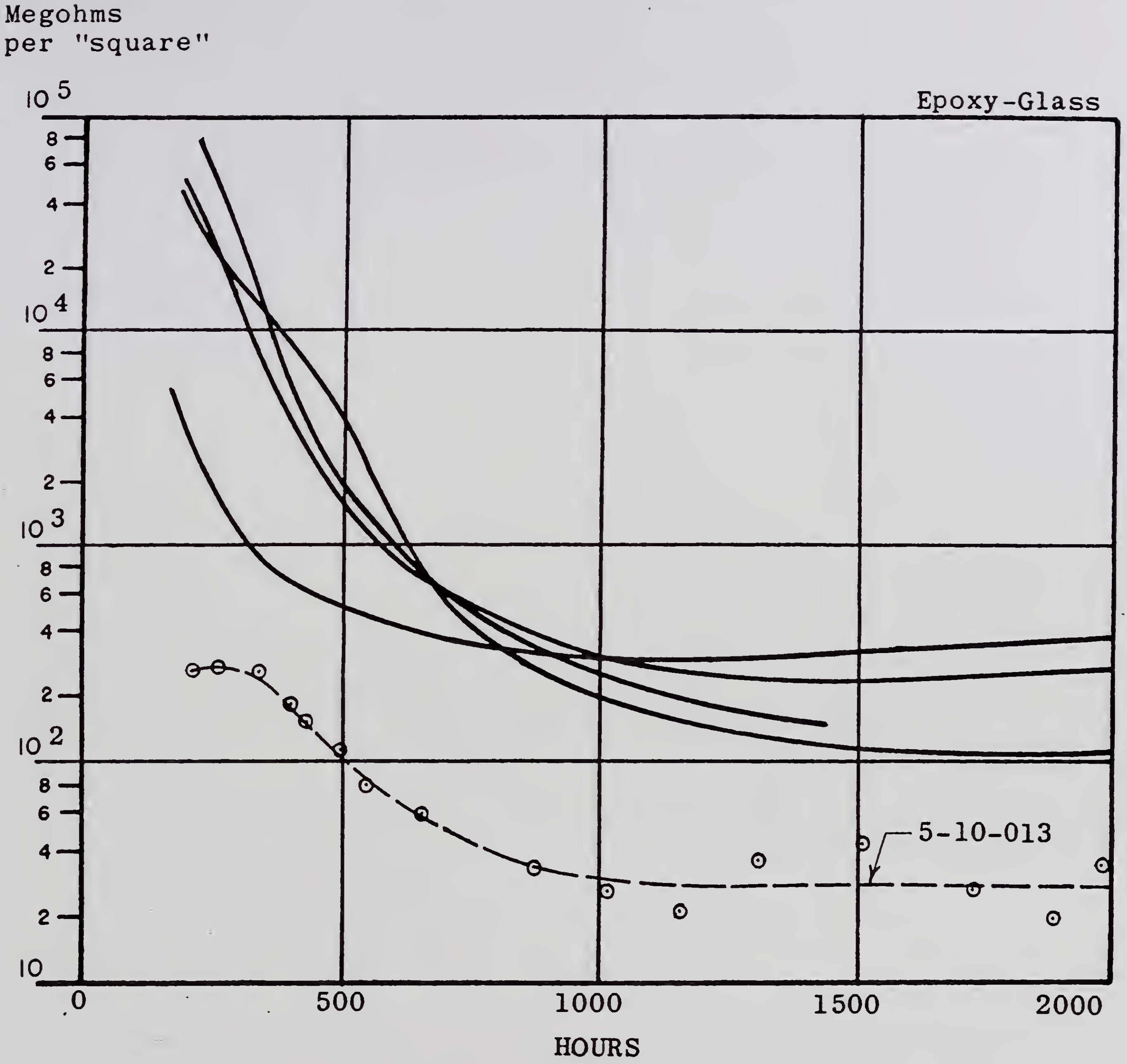


5-10-001 Control (Dip soldered)
5-10-002 Control (Dip soldered)
5-10-004 Control (No preconditioning)
5-10-012 Control (No preconditioning)

FIG. 55

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

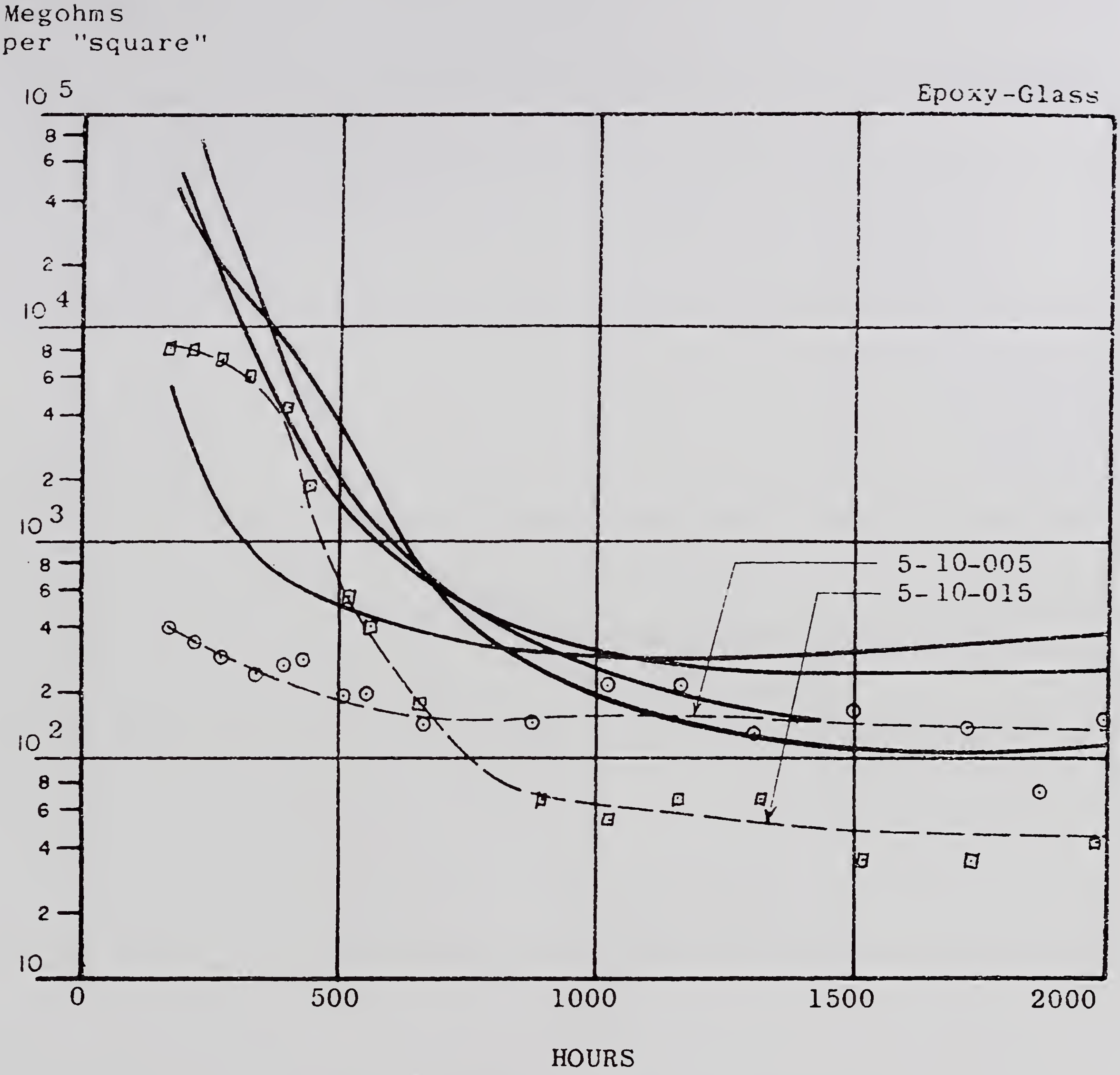


5-10-013 Coating: Epoxy #1 (Dip soldered)

FIG. 56

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

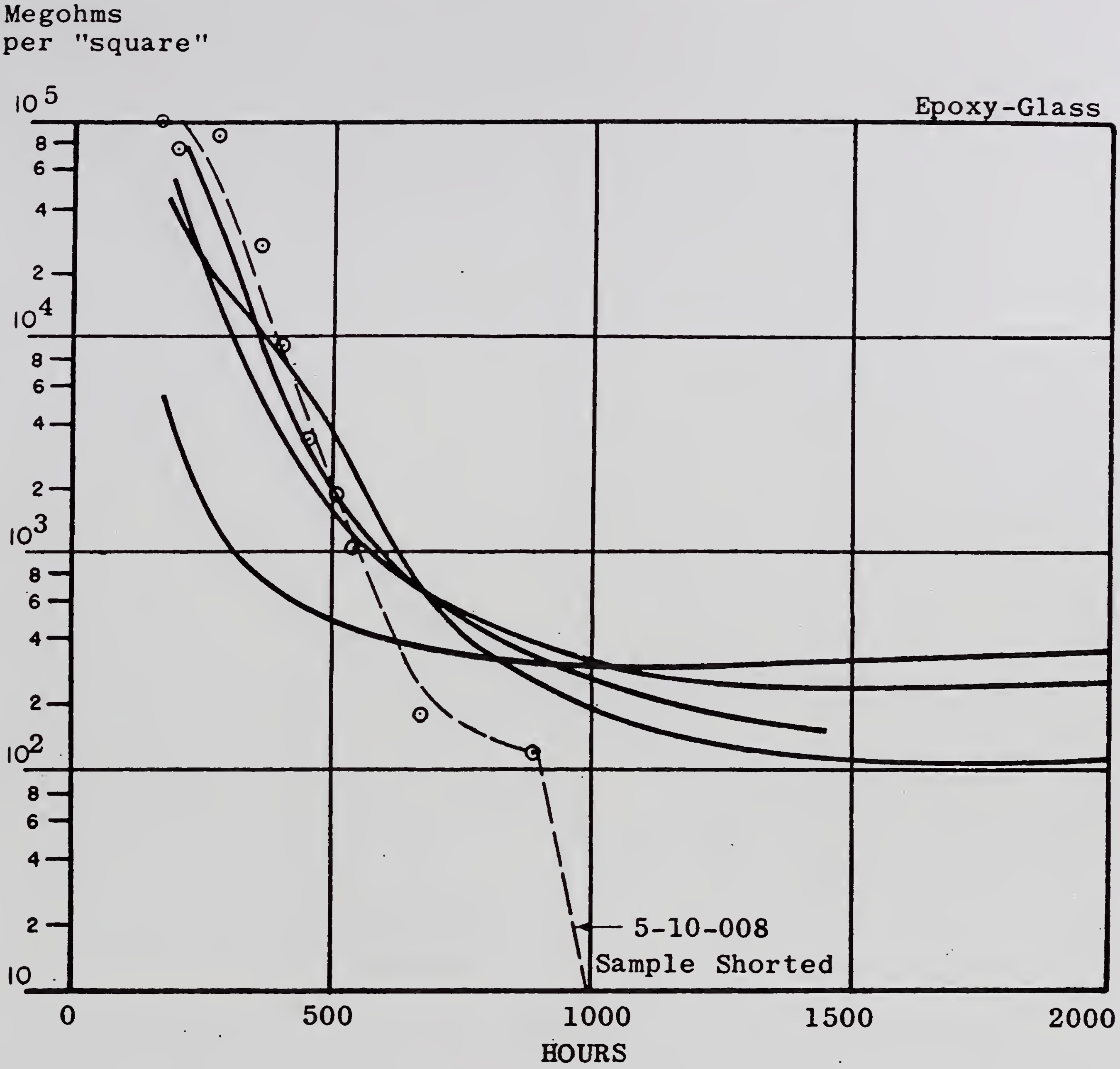


5-10-005 Coating: Epoxy #2 (Dip soldered)
5-10-015 Coating: Epoxy #2

FIG. 57

SURFACE RESISTIVITY VS TIME

@ 70°C 95% R.H.

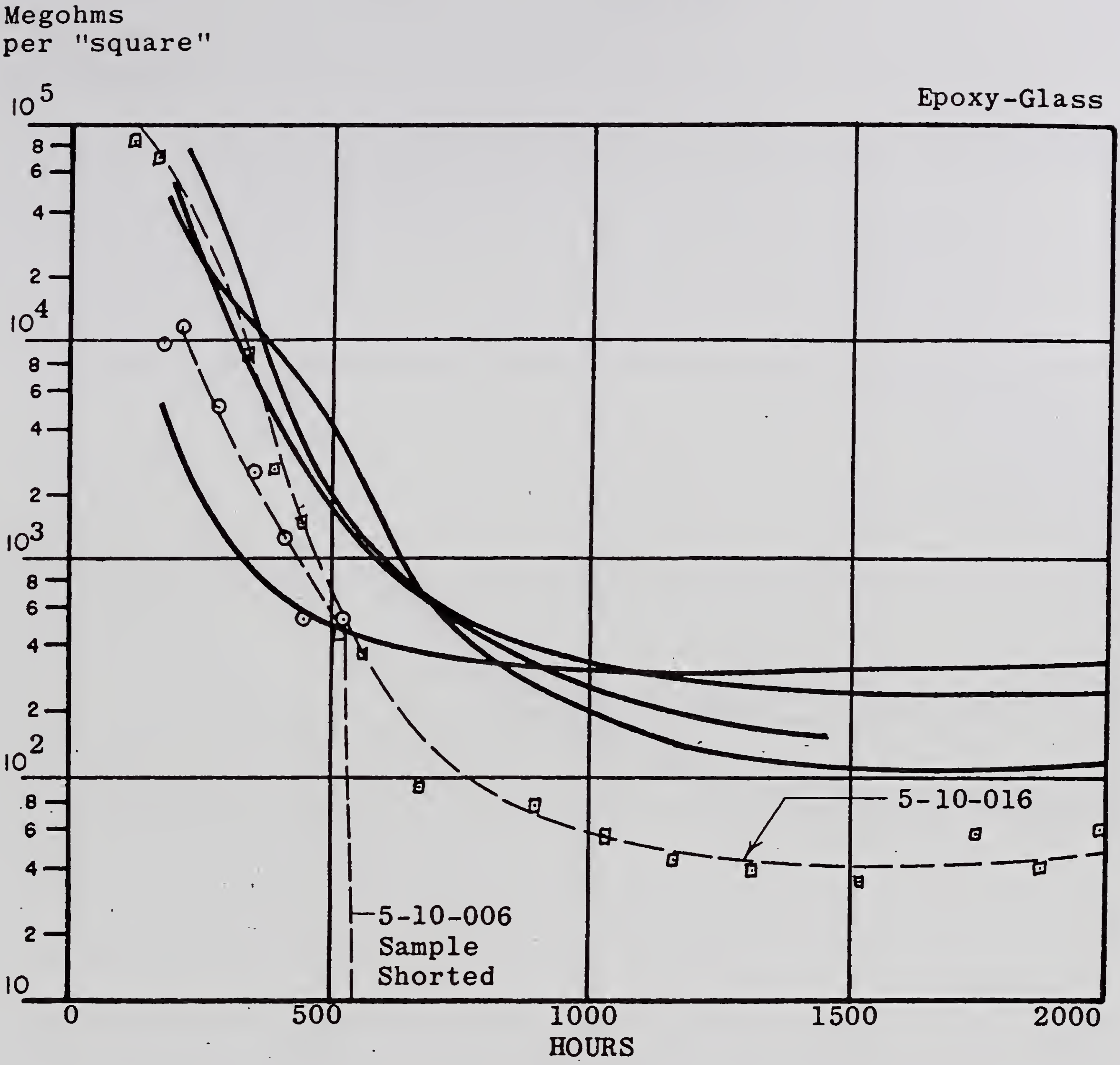


5-10-008 Coating: Microwax

FIG. 58

SURFACE RESISTIVITY VS TIME

70°C 95% R. H.

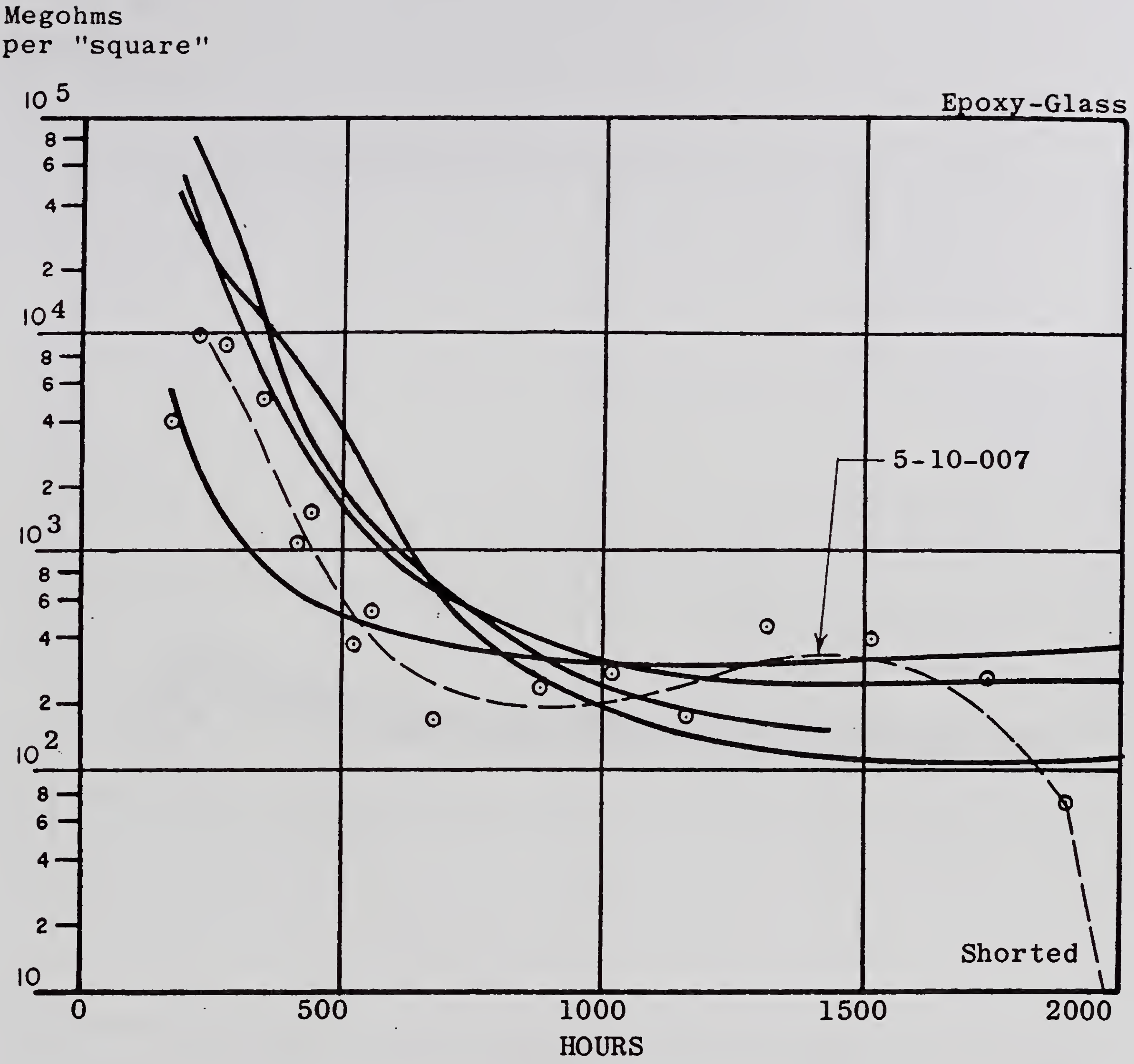


5-10-006 Coating: Silicone resin (Dip soldered)
5-10-016 Coating: Silicone resin

FIG. 59

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

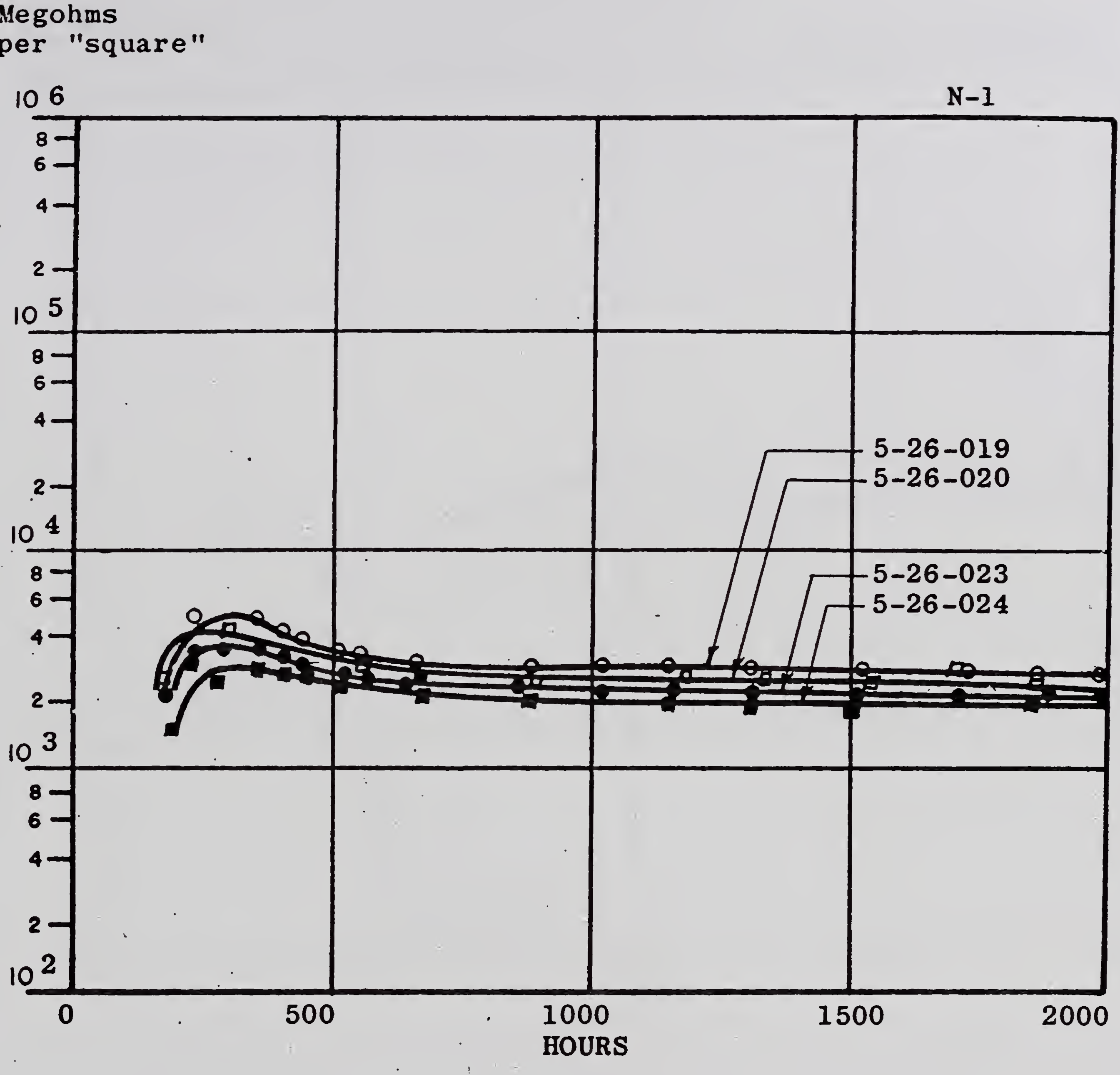


5-10-007 Coating: Silicone fluid

FIG. 60

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

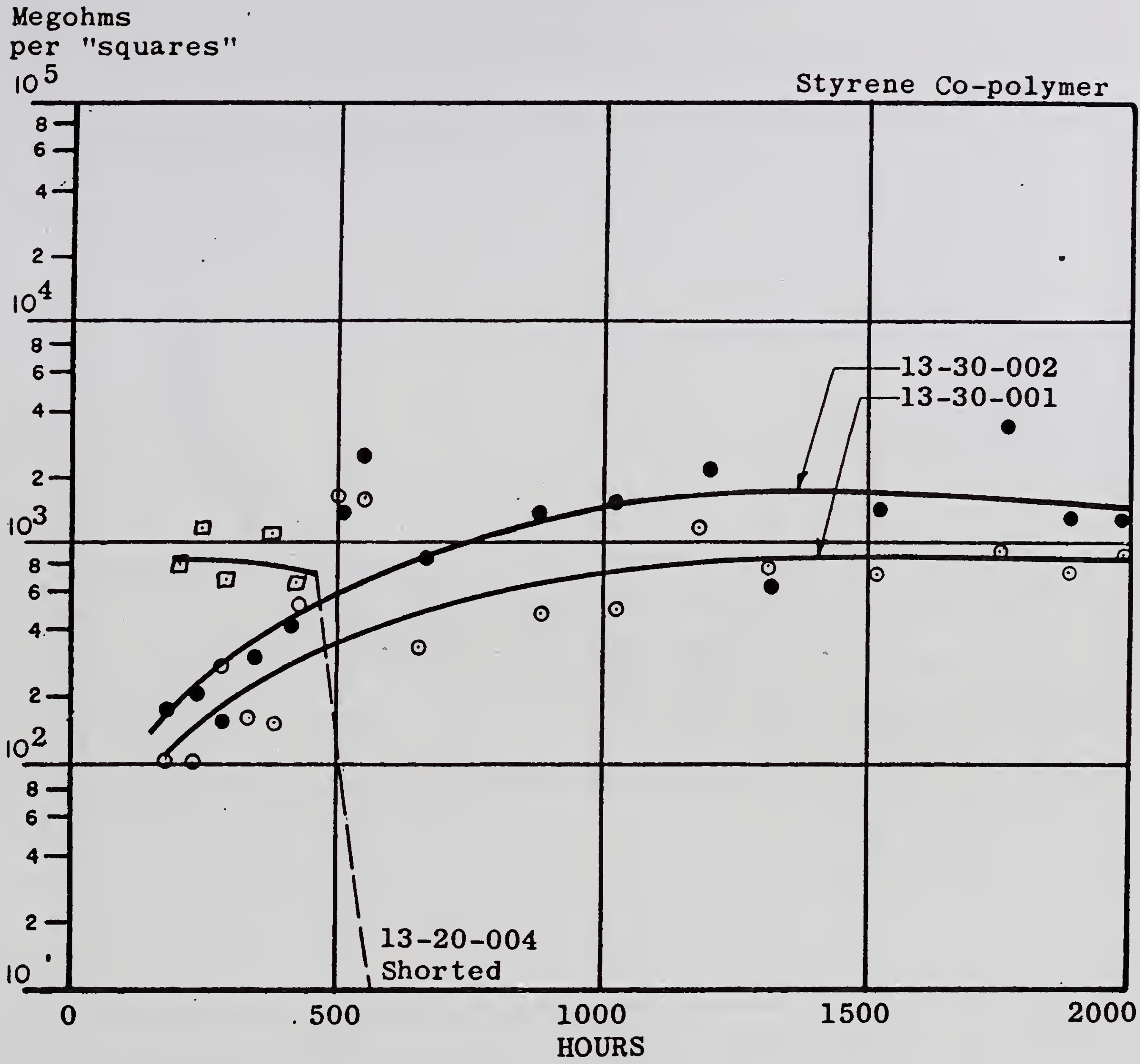


5-26-019 Control (No preconditioning)
5-26-020 Control (No preconditioning)
5-26-023 Control (No preconditioning)
5-26-024 Control (No preconditioning)

FIG. 61

SURFACE RESISTIVITY VS TIME

70°C 95% R.H.

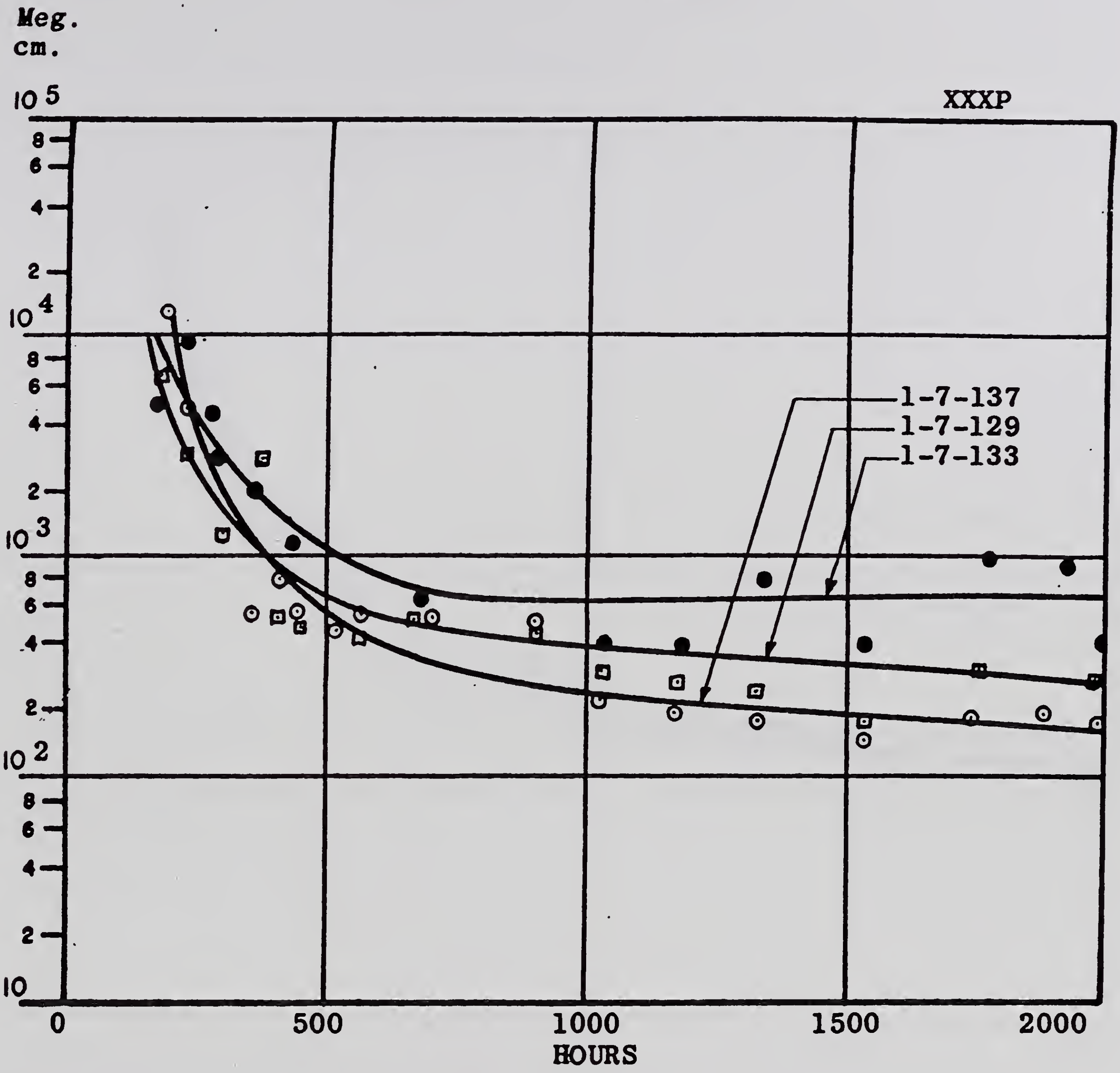


13-30-001 Control (Dip soldered)
13-30-002 Control (Dip soldered)
13-30-004 Control

FIG. 62

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

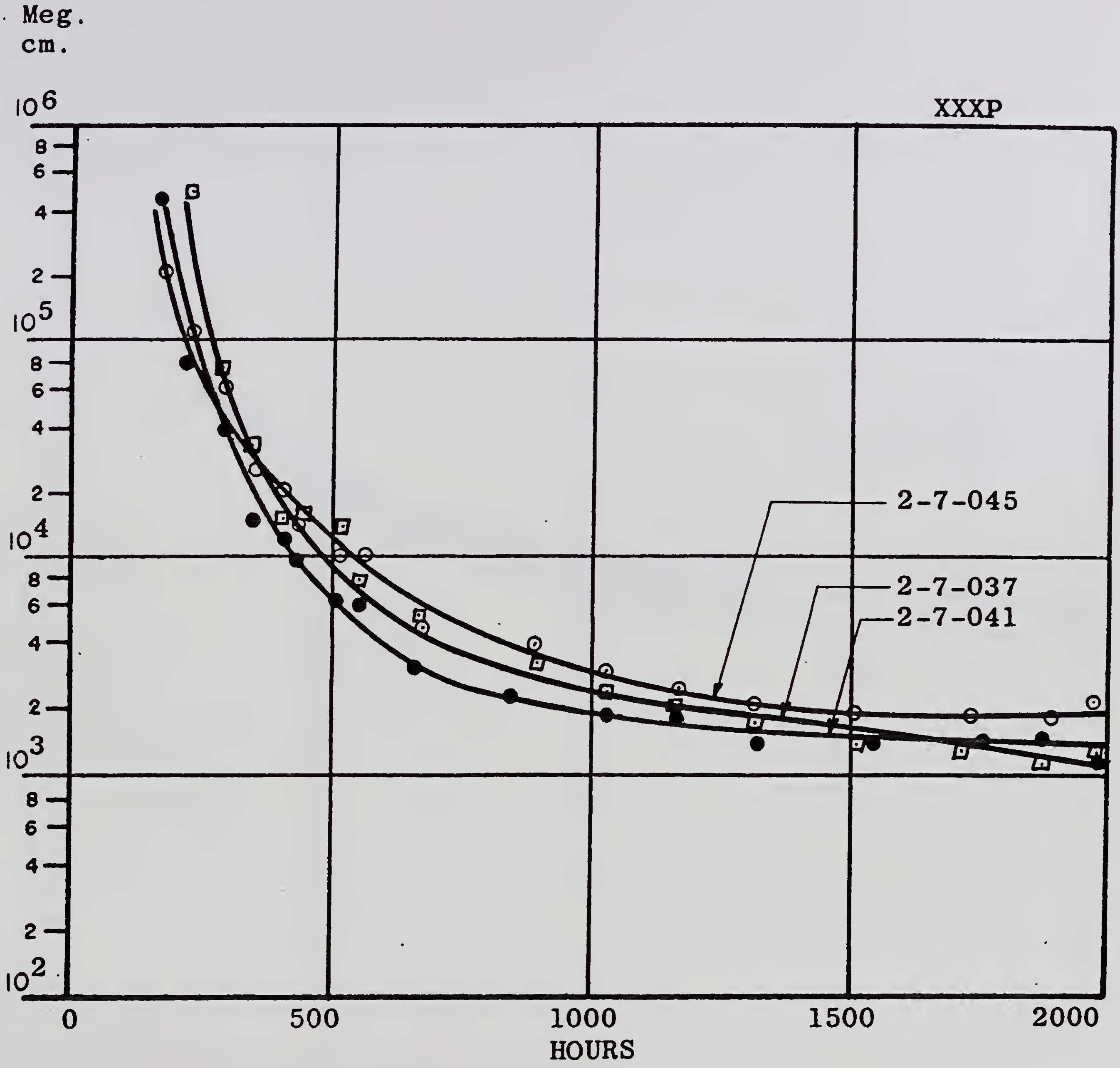


1-7-133 Control (No preconditioning)
1-7-129 Control (Dip soldered)
1-7-137 Control (Dip soldered)

FIG. 63

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

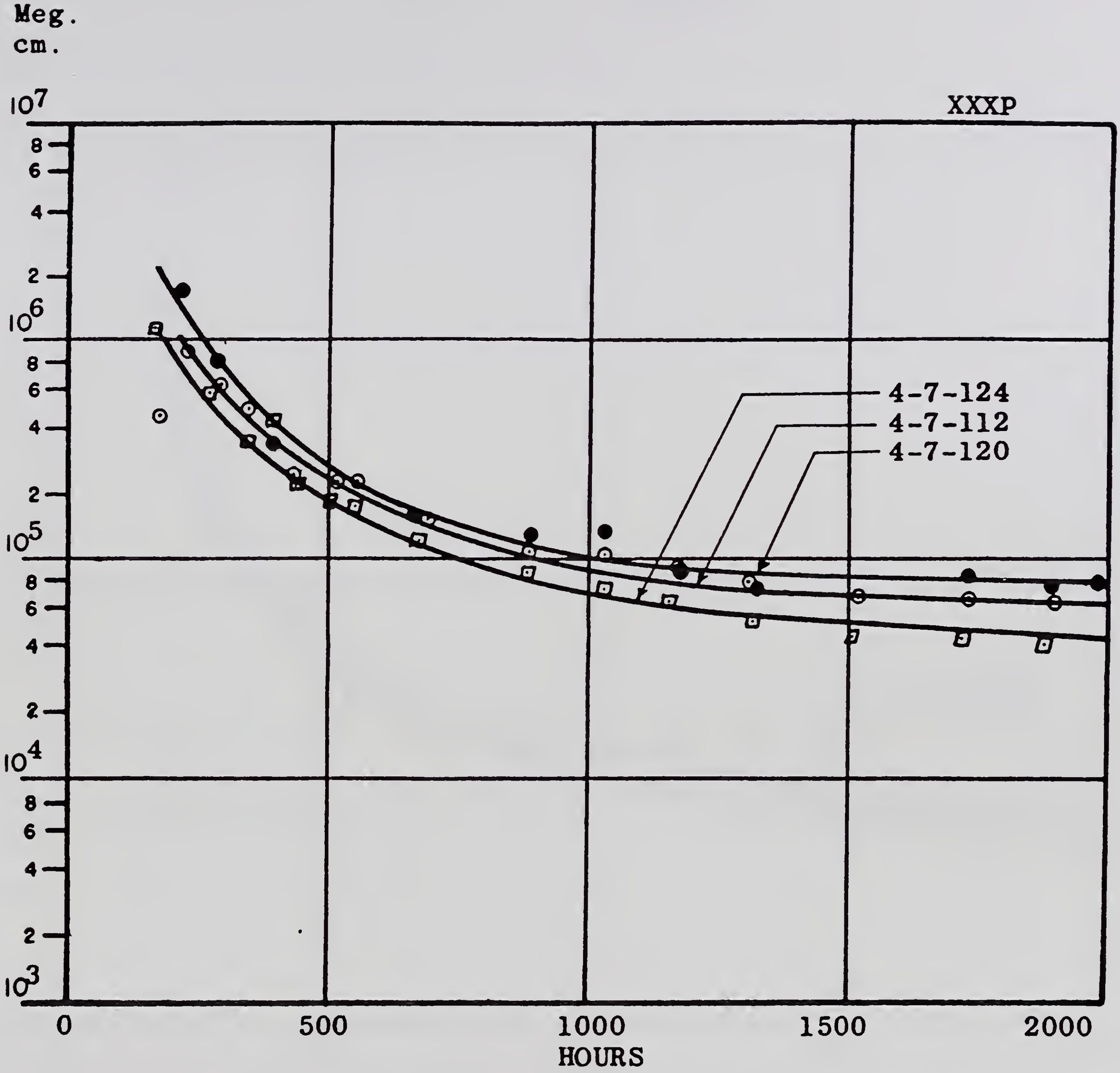


2-7-045 Control (Dip soldered)
2-7-037 Control (Dip soldered)
2-7-041 Control (No preconditioning)

FIG. 64

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

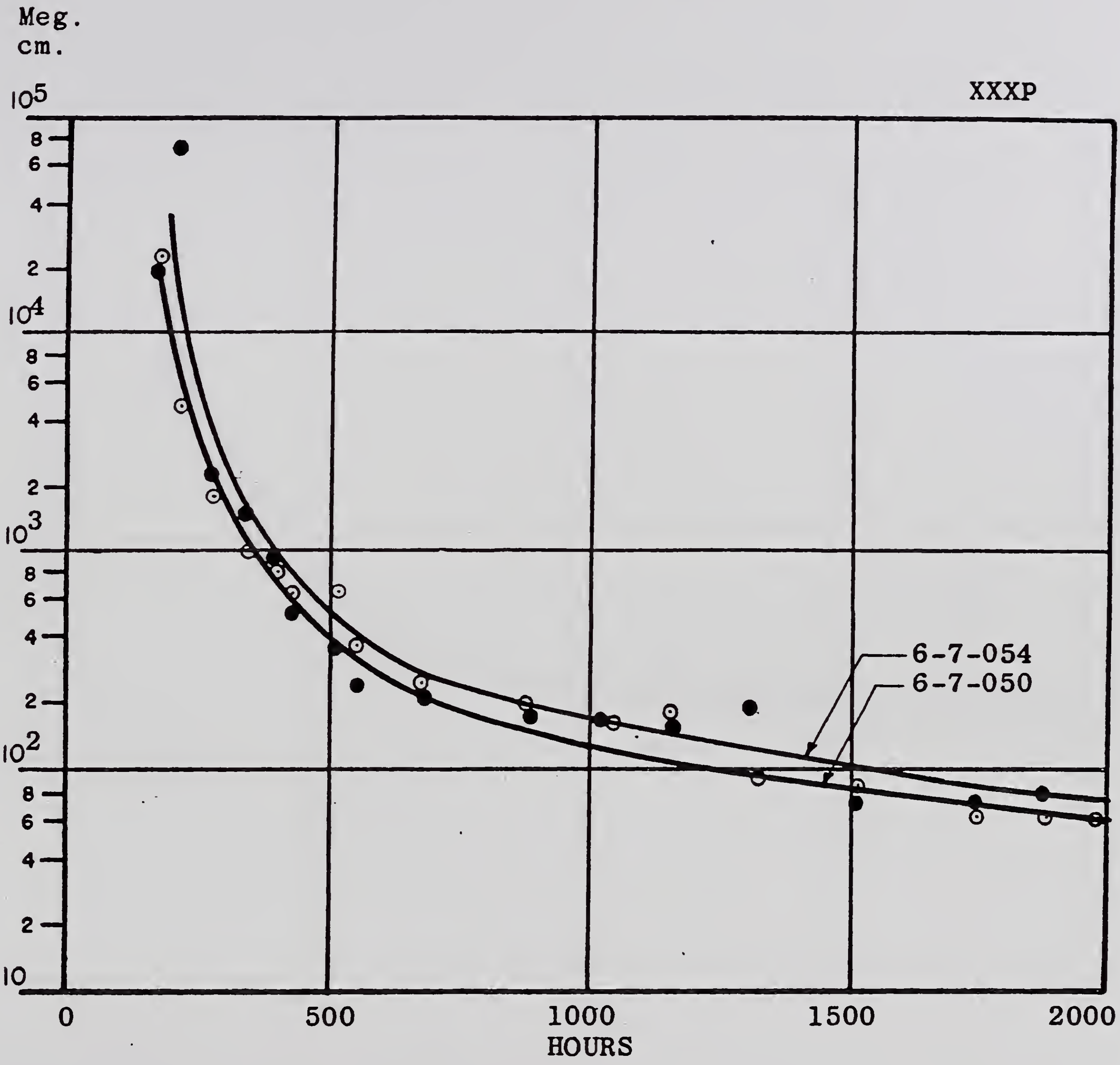


4-7-120 Control (No preconditioning)
4-7-112 Control (Dip soldered)
4-7-124 Control (Dip soldered)

FIG. 65

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

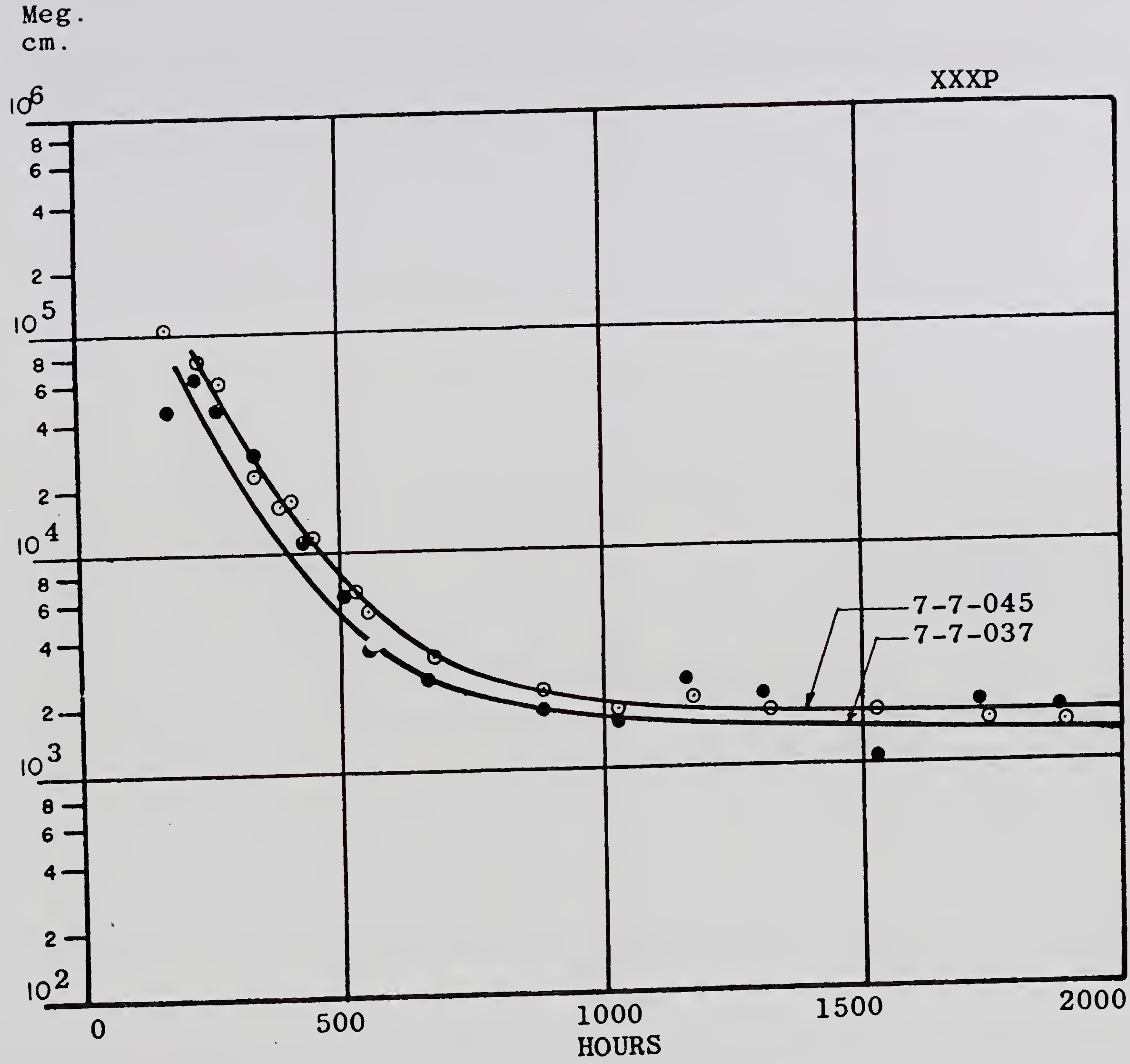


6-7-054 Control (No preconditioning)
6-7-050 Control (Dip soldered)

FIG. 66

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

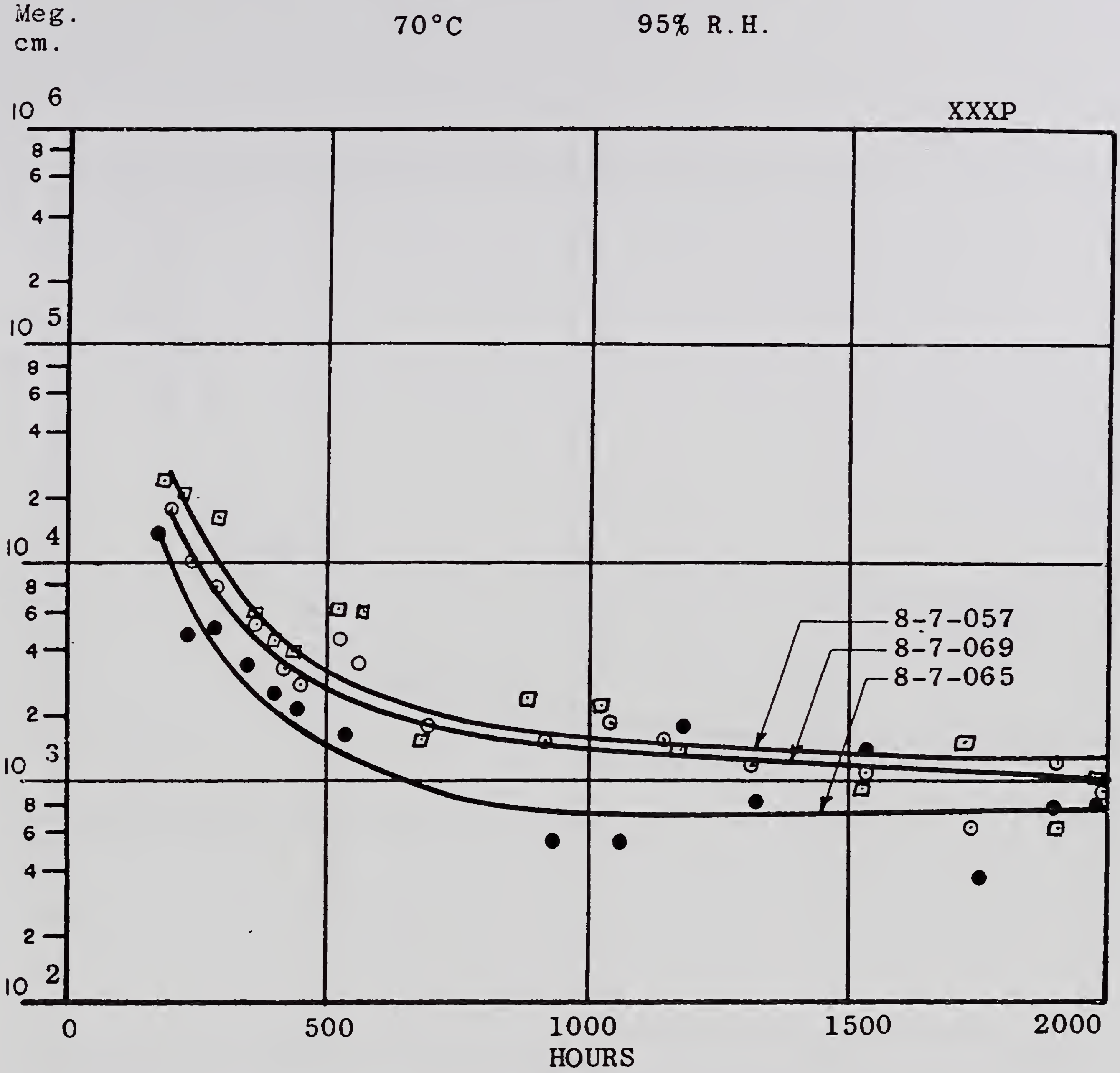


7-7-037 Control (Dip soldered)
7-7-045 Control (No preconditioning)

FIG. 67

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

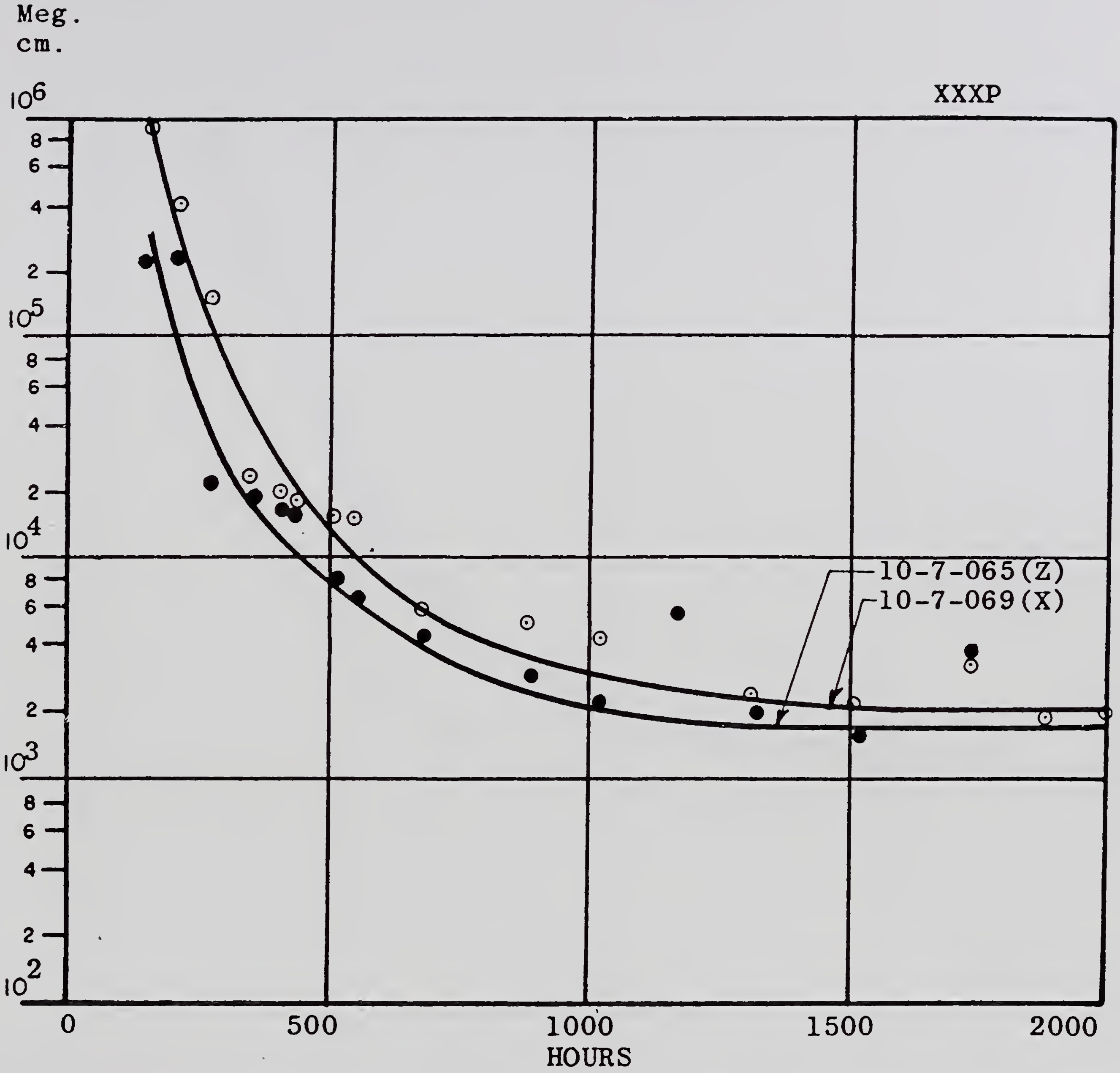


8-7-057 Control (Dip soldered)
8-7-069 Control (No preconditioning)
8-7-065 Control (Dip soldered)

FIG. 68

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.

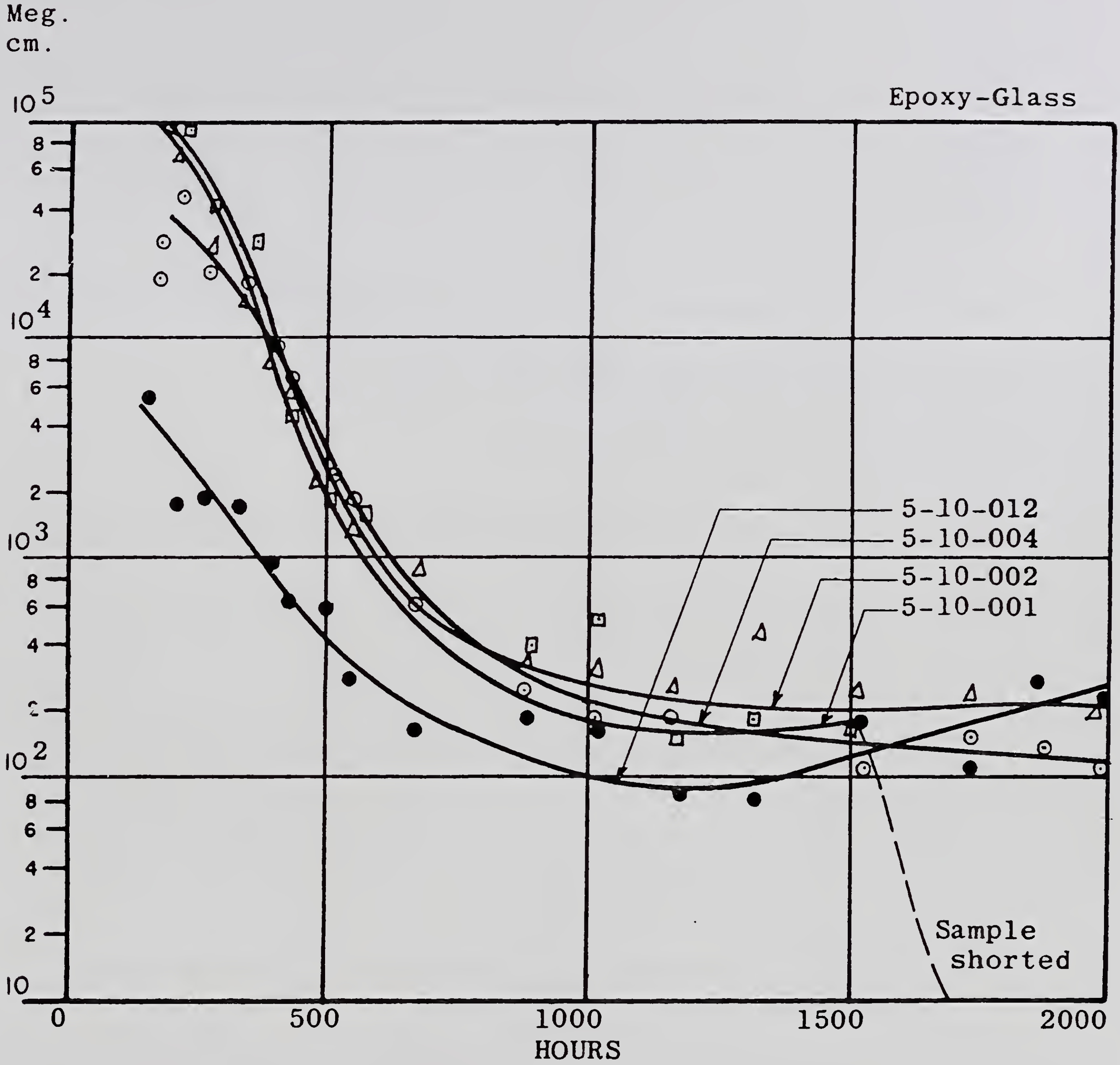


10-7-065(Z) Control (Dip soldered)
10-7-069(X) Control (No preconditioning)

FIG. 69

VOLUME RESISTIVITY VS TIME

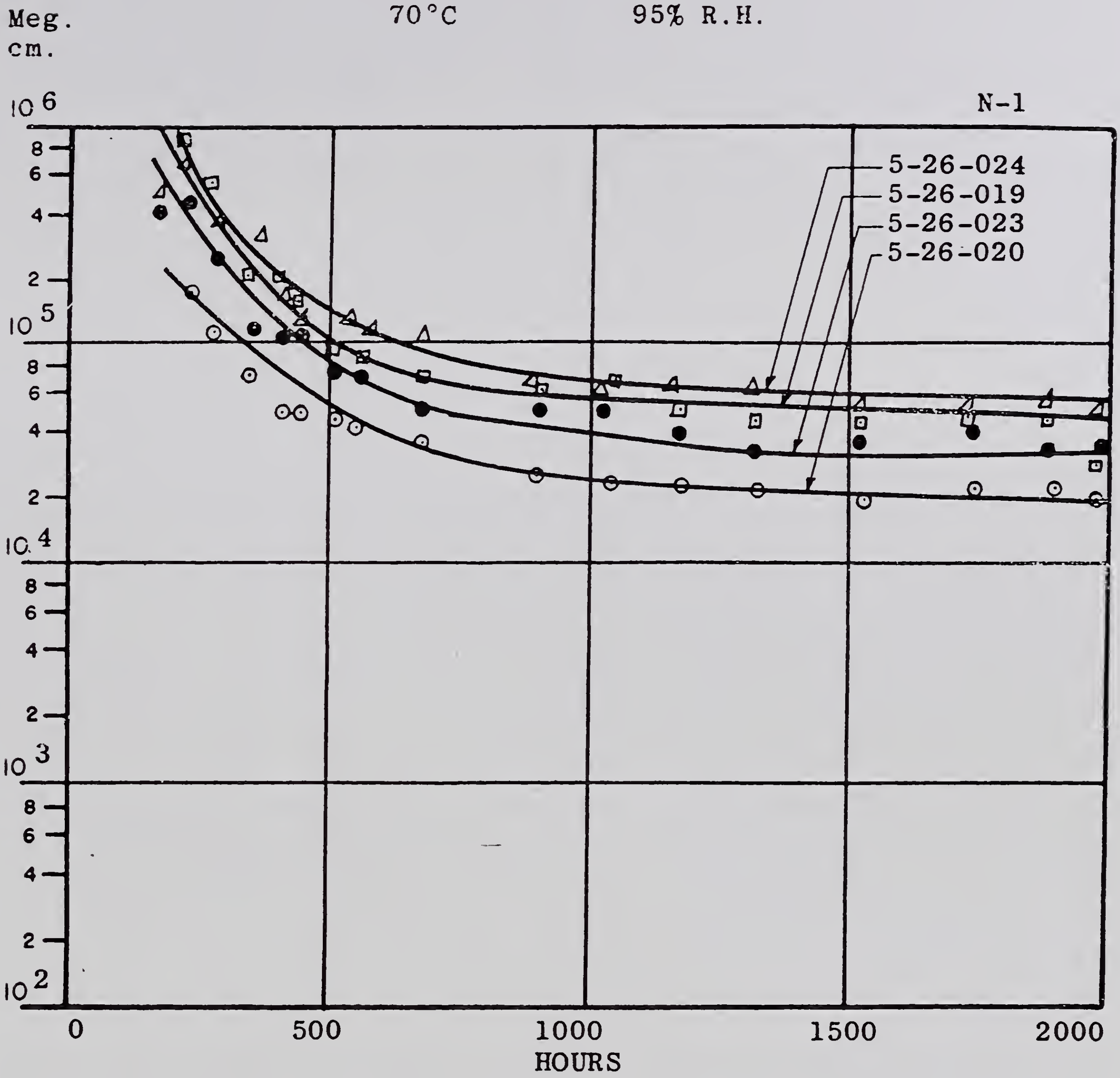
70°C 95% R.H.



5-10-001 Control
5-10-002 Control
5-10-004 Control
5-10-012 Control

FIG. 70

VOLUME RESISTIVITY VS TIME

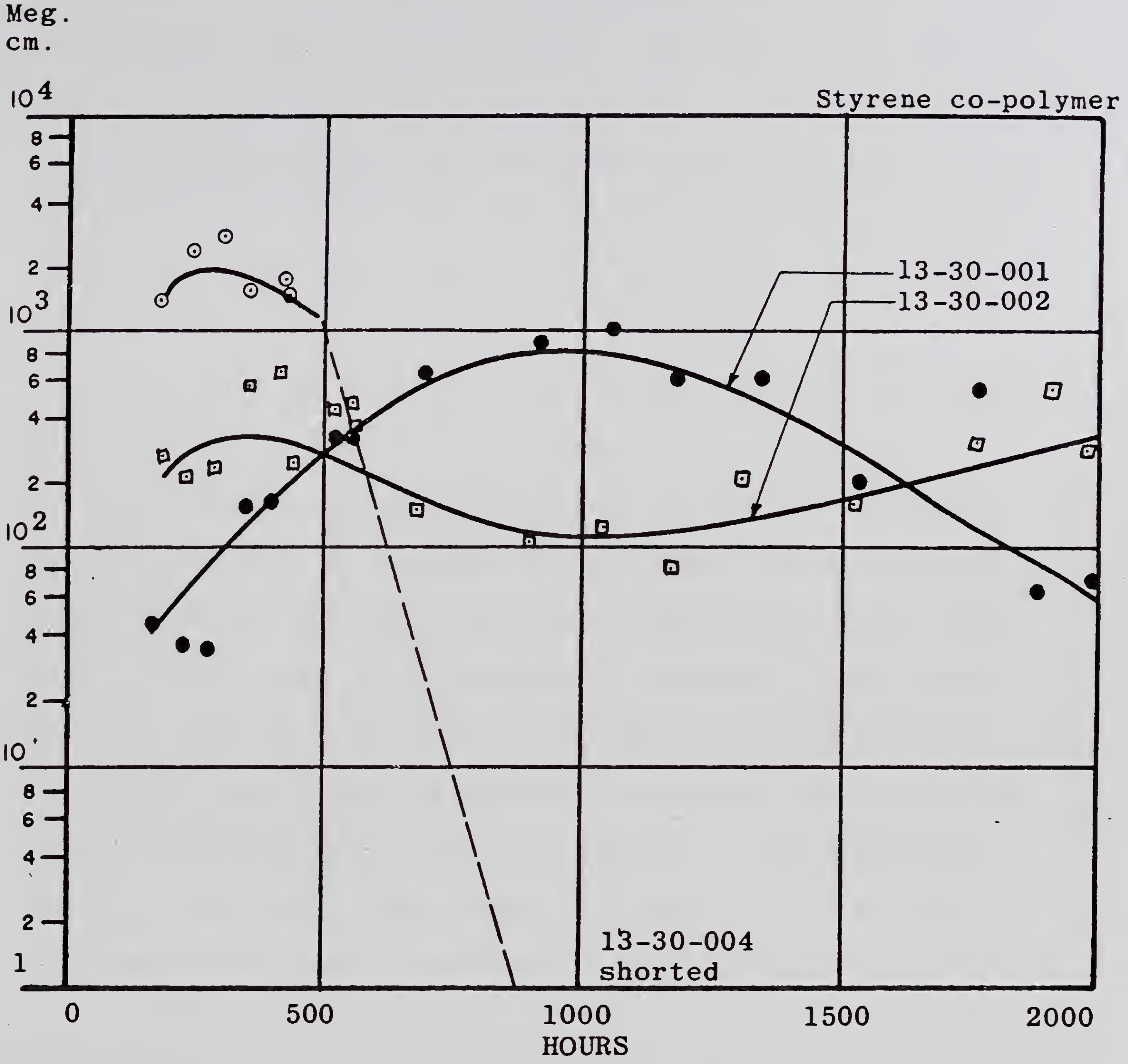


5-26-024 Control (No preconditioning)
5-26-019 Control (No preconditioning)
5-26-023 Control (No preconditioning)
5-26-020 Control (No preconditioning)

FIG. 71

VOLUME RESISTIVITY VS TIME

70°C 95% R.H.



13-30-001 Control (Dip soldered)
13-30-002 Control (Dip soldered)
13-30-004 Control

3. DIELECTRIC PROPERTIES

Measurements have been made on the dielectric properties of a group of 16 metal-clad laminates. These include core materials of the following types: XXP, XXX, XXXP, Epoxy-Glass, G-5, G-7, Teflon-Glass, and N-1. Individual families of curves for each of the materials tested are presented in Figures 72 through 87 (pp. 106 to 121), and give dissipation factor and dielectric constant at various temperatures and frequencies. Measurements were made using a two-terminal conjugate Shering bridge system* with a two inch micrometer-type uniform-field electrode holder.

This system allows the use of a disk-shaped sample which may easily be prepared by machining the metal-clad laminate to the desired diameter. Because the electrodes extend to the edge of the sample, a special pattern such as would be used in a three-terminal system is not required, and the etching procedure is thereby eliminated as a possible source of variation in the test results. The measurement error in utilizing this system is considered to be about 1% or less for dielectric constant. For dissipation factor the

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*A. H. Scott, Paul Ehrlich, and J. F. Richardson, "Measurement of Dielectric Properties at Temperatures up to 500C," Symposium on Temperature Stability of Electrical Insulating Materials, Special Technical Bulletin No. 161; (American Society for Testing Materials, 1954).

error is considered to be within .0001 or 5%, whichever is greater, at the lower frequencies, and .0015 or 5%, whichever is greater, at 10^7 cycles. All of the samples used in this test were prepared from double-clad laminates having a nominal 1/16" core thickness.

Because of difficulties often encountered in making adequate electrical contact between the copper electrodes of the samples and the electrode holder, particularly at the higher temperatures, all samples in the present group were silver plated. The samples, which measured 2 inches in diameter, were machined from the central portions of 4 inch panels after the panels were electro-plated in order to eliminate the possibility of errors due to the absorption of the plating solution along the panel edges.

The present group of samples were tested principally at the three temperatures of -30°C, 23°C, and 100°C. Additional measurements were made at 150° and 200°C on those materials in which it was felt that higher temperature operation might be feasible.

Additional processing, such as aging at various temperatures and temperature shock, has not been included in the present group of measurements, but will be dealt with at a future date if exploratory tests indicate sufficient variation. Also, it will be necessary to make additional

measurements on a greater range of samples before sufficient information is acquired to provide averages for the various groups or classes of materials. Measurements will be made on new materials as they are acquired and the frequency range extended beyond 10^7 cycles when new equipment becomes available.

3.1 Dissipation Factor

A review of the curves for the phenolic base laminates, Figures 72 through 80 (pp. 106 to 114), shows that the dissipation factor was quite consistent in behavior at the various temperature levels. At 10^6 cycles the average dissipation factor at -30°C was .044 for the XXP material, .046 for the XXX, and .037 for the XXXP. At 23°C (room temperature) the average dissipation factor was .040, .040, and .031 respectively for the XXP, XXX, AND XXXP materials. At the 100°C temperature level the average dissipation factor was .030 for the XXP material, .021 for the XXX, and .029 for the XXXP. With the exception of an increase in the dissipation factor in the 8-7 material (Fig. 79, p. 113), from a value of .035 at 23°C and 10^6 cycles to a value of .046 at 100°C, all of the phenolic base materials showed a general reduction in the dissipation factor with an increase in temperature.

Considerable variation in magnitude may be observed in dissipation factor for the entire phenolic group at the lower frequencies, particularly at the 100°C temperature level. A clear characterization is not evident for each of the types of material tested, and further data will be necessary to complete this task.

Two samples of the epoxy-glass mat type were tested and also showed a variation in characteristics, as may be seen in Figures 81 and 82 (pp. 115 and 116). The dissipation factor at 10^6 cycles was about .02 or less, at all of the test temperatures, except for the 5-10 material (Fig. 82) in which there was a sharp rise to .06 at 150°C. At temperatures of 100° or less, however, these samples showed some advantage over those of the phenolic group.

Considerable differences may also be seen in the curves for the two G-5 samples tested, Figures 83 and 84 (pp. 117 and 118). In the 8-16 sample (Fig. 83), the dissipation factor was influenced to an extreme degree by the test temperature. At 100°C the dissipation factor was so high as to make impractical a determination with the existing equipment, and consequently it has not been recorded. The 10-16 sample (Fig. 84) showed characteristics similar to those of the phenolics with respect to temperature but had a dissipation factor of less than .02 at 10^6 cycles, which compares well with the Epoxy samples tested.

The dielectric properties of one sample of G-7 material are shown in Figure 85 (p. 119). Dissipation at 10^6 cycles was .02 or less at temperatures up to 100°C but was influenced to a marked degree at the lower frequencies.

The Teflon sample (4-19) had the lowest dissipation of any of those tested in the group, as may be seen in Figure 86, (p. 120). Variations may be noticed at the various temperature levels but are relatively slight considering the temperature range. At -30°C very little change is noticeable in the dissipation factor at the various frequencies, indicating a characteristic somewhat different from that shown at the higher temperatures.

The N-1 material, as shown in Figure 87 (p. 121), showed good stability at the lower temperatures with a dissipation factor of less than .02. At the higher temperature of 100°C, the dissipation factor increased considerably over the entire frequency range.

3.2 Dielectric Constant

From the curves showing the dielectric constant of the materials tested, Figures 72 to 87 (pp. 106 to 121), it will be noted that most of the materials behaved in the same general manner with respect to temperature, the higher values being associated with the higher temperatures. The notable exception to this was for the Teflon material (Fig. 86, p. 120) in which the opposite trend may be seen.

In the phenolic group the dielectric constant tended to be somewhat lower for the XXXP materials than for the XXP and XXX materials. At 10^6 cycles an over-all average for the XXXP materials tested would be about 4, while for the XXX and XXP materials the dielectric constant would have an average of about 5.

The epoxy-base samples tested, Figures 81 and 82 (pp. 115 and 116), both had dielectric constants at 10^6 cycles ranging between 5 and 6 at temperatures below 100°C. Above this temperature both samples showed increases to a value above 6, with the sharpest rise recorded for the 5-10 material (Fig. 82, p. 116).

The G-5 materials showed considerable differences in dielectric constant, as may be seen in Figures 83 and 84 (pp. 117 and 118), particularly at the lower frequencies where the 8-16 material rose to above 14 at 10^2 cycles and 23°C. At 10^6 cycles both materials showed dielectric constants above 6.

The G-7 material showed good uniformity in dielectric constant, Figure 85 (p. 119), at a temperature of 100°C and below, with an average of about 7.5 at 10^6 cycles. A sharp rise may be seen for the 150° level.

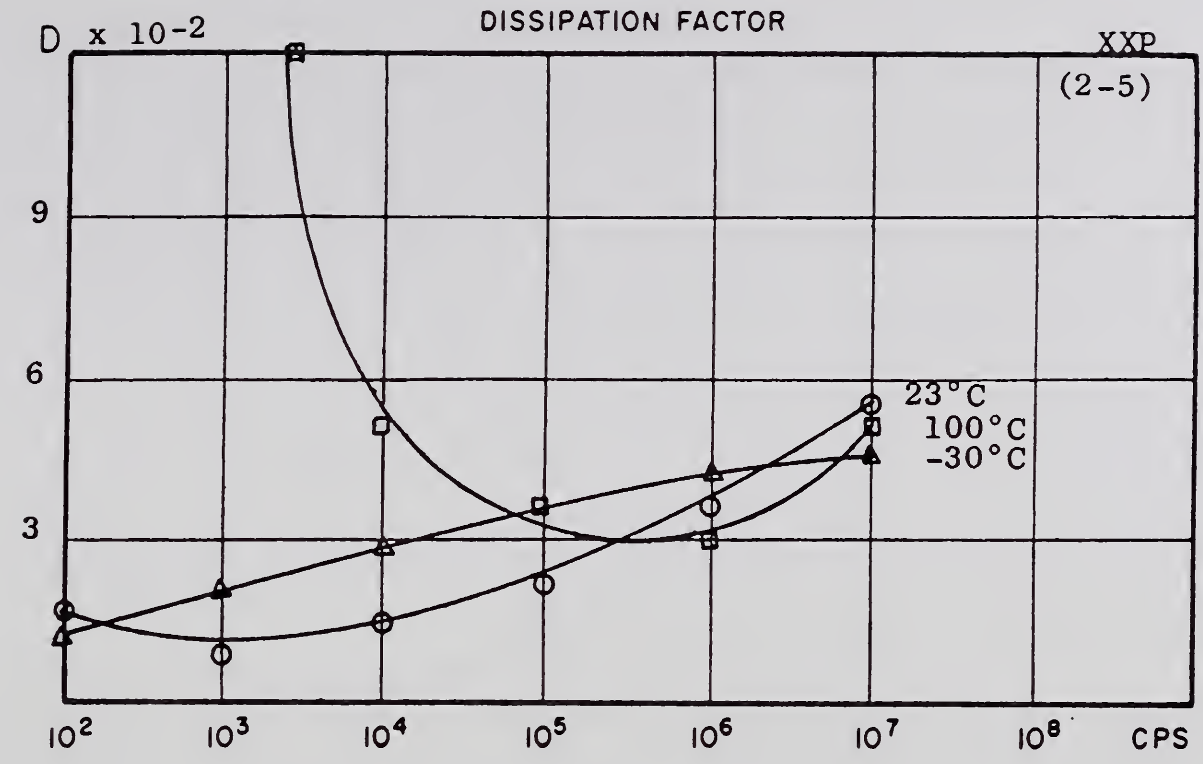
The Teflon material, Figure 86 (p. 120), showed excellent uniformity in dielectric constant for all conditions except for the -30°C level where a sharp rise may be noted.

The N-1 material, Figure 87 (p. 121), showed good uniformity in dielectric constant at the two lower temperatures, but a sharp rise at 100°C.

As outlined previously, additional measurements will be made and reported on as new materials are acquired.

FIG. 72

DIELECTRIC PROPERTIES



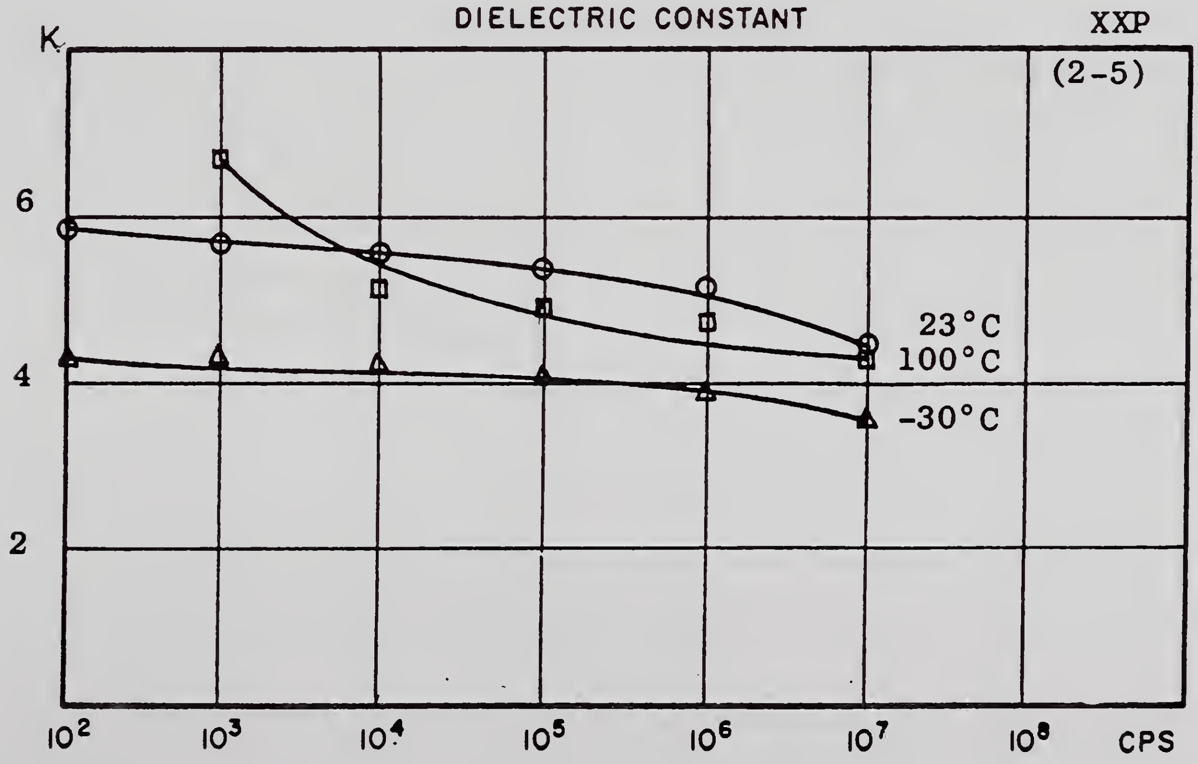
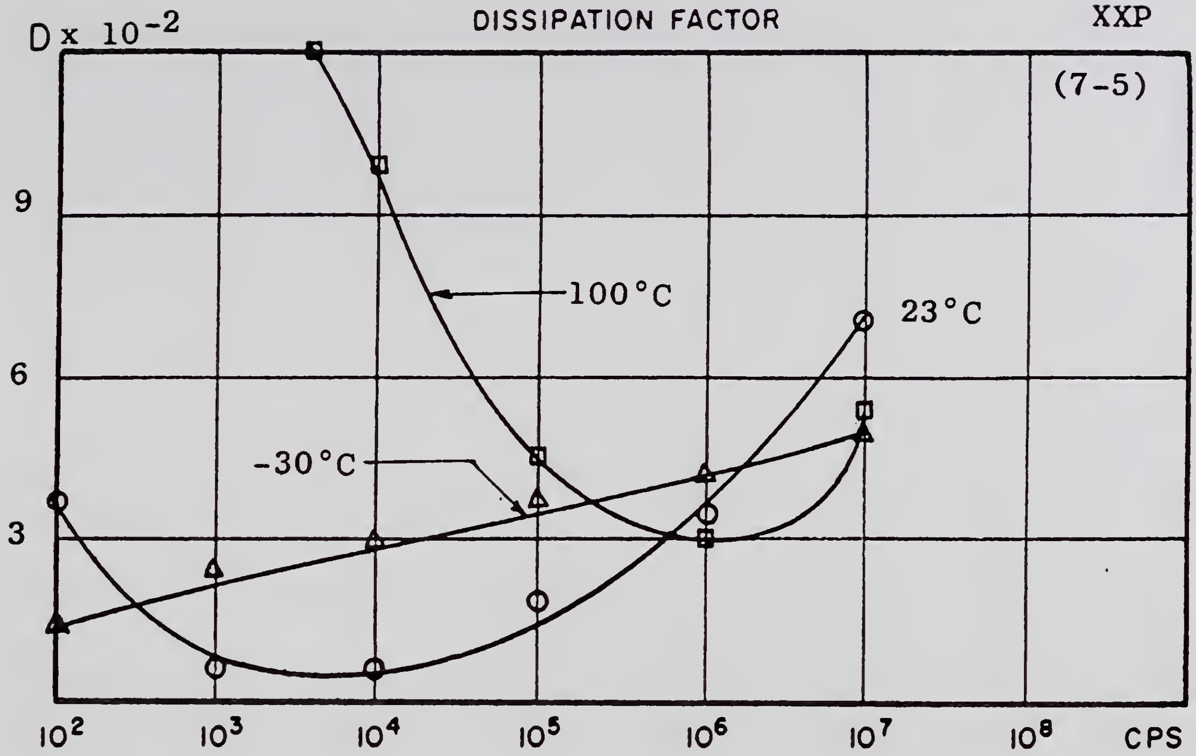


FIG. 73

DIELECTRIC PROPERTIES



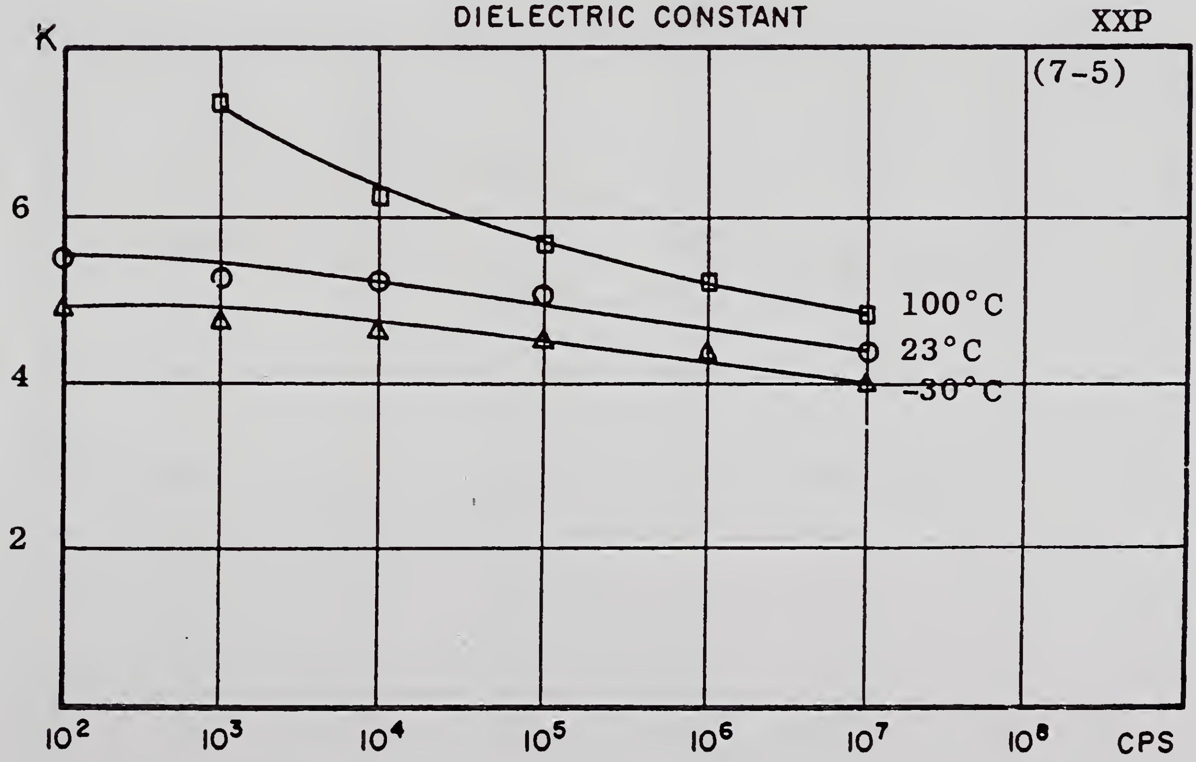
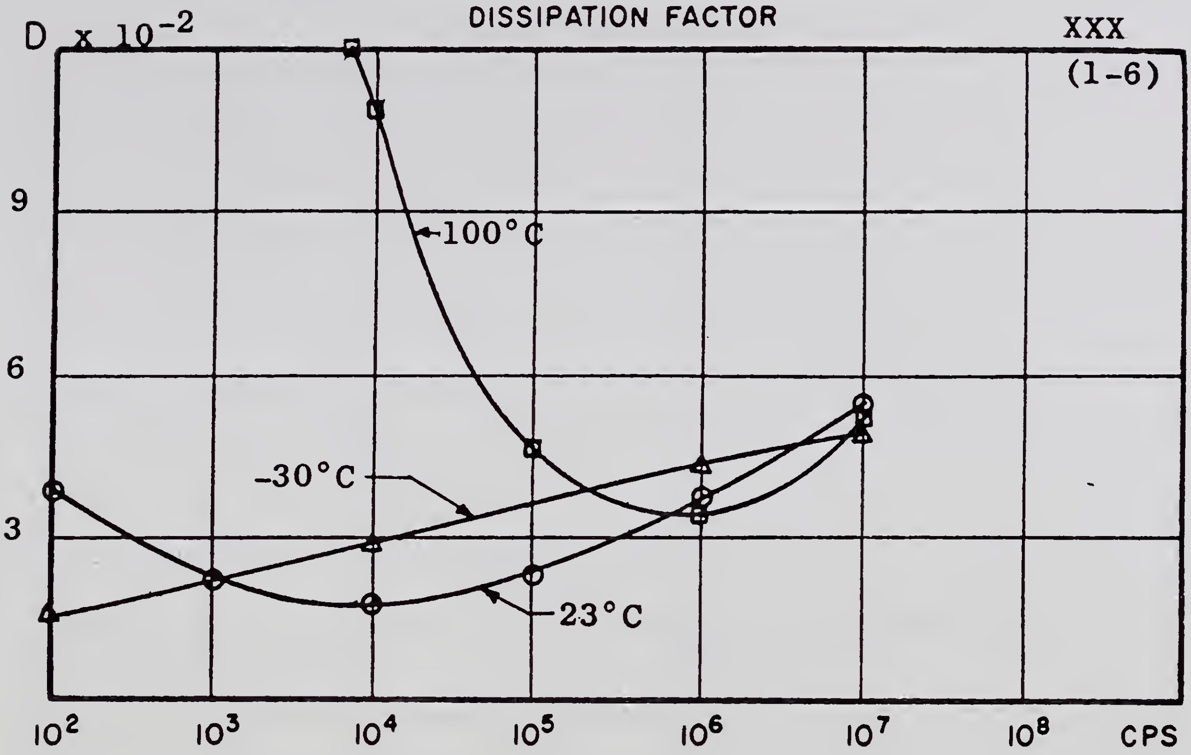


FIG. 74

DIELECTRIC PROPERTIES



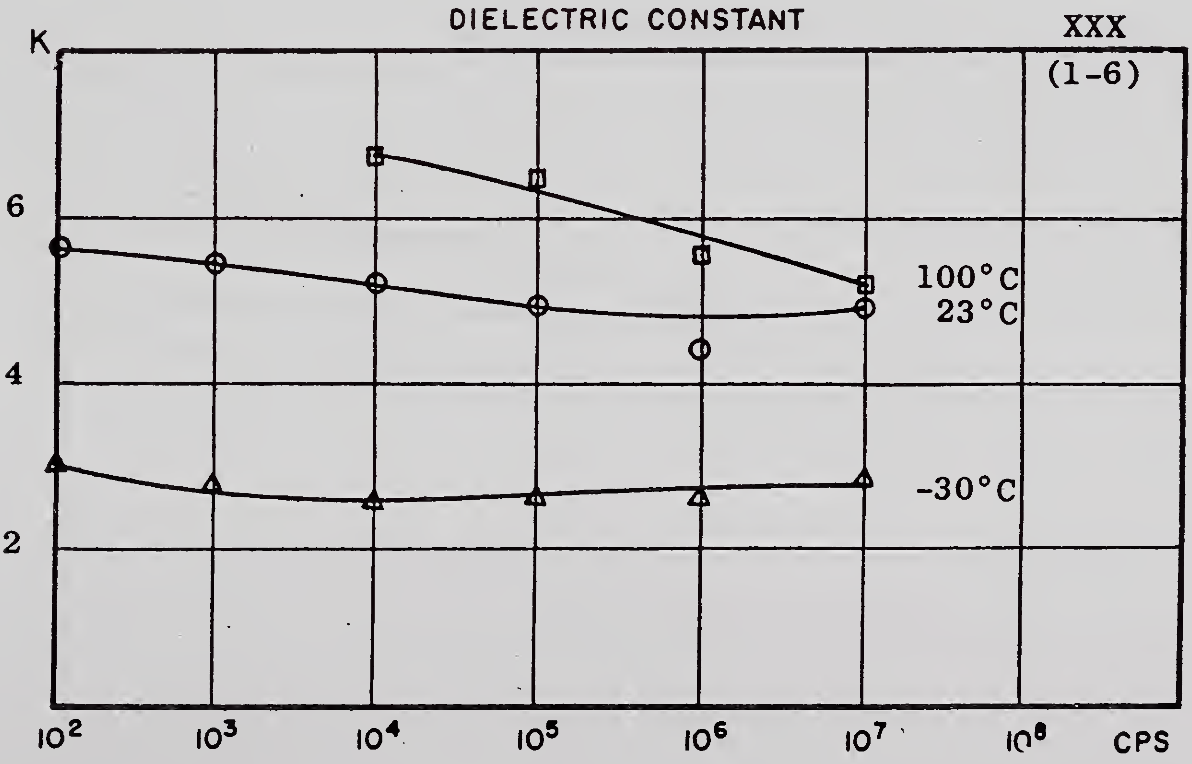
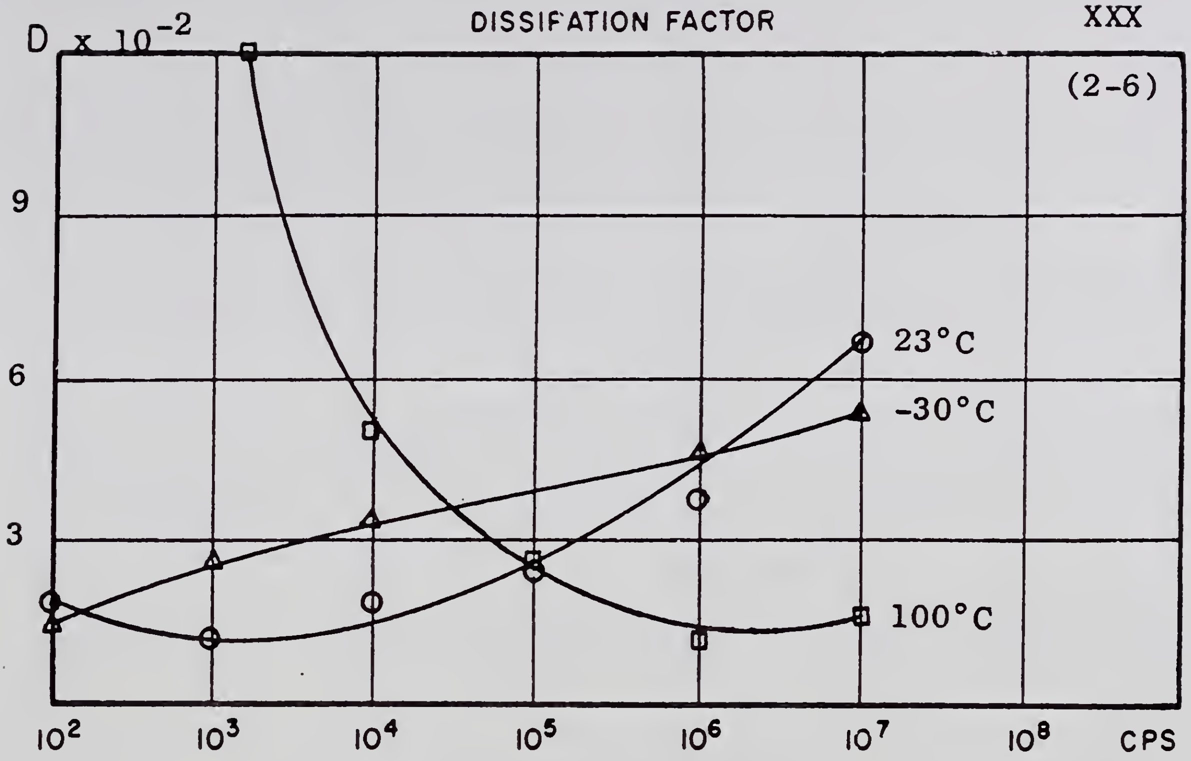


FIG. 75

DIELECTRIC PROPERTIES



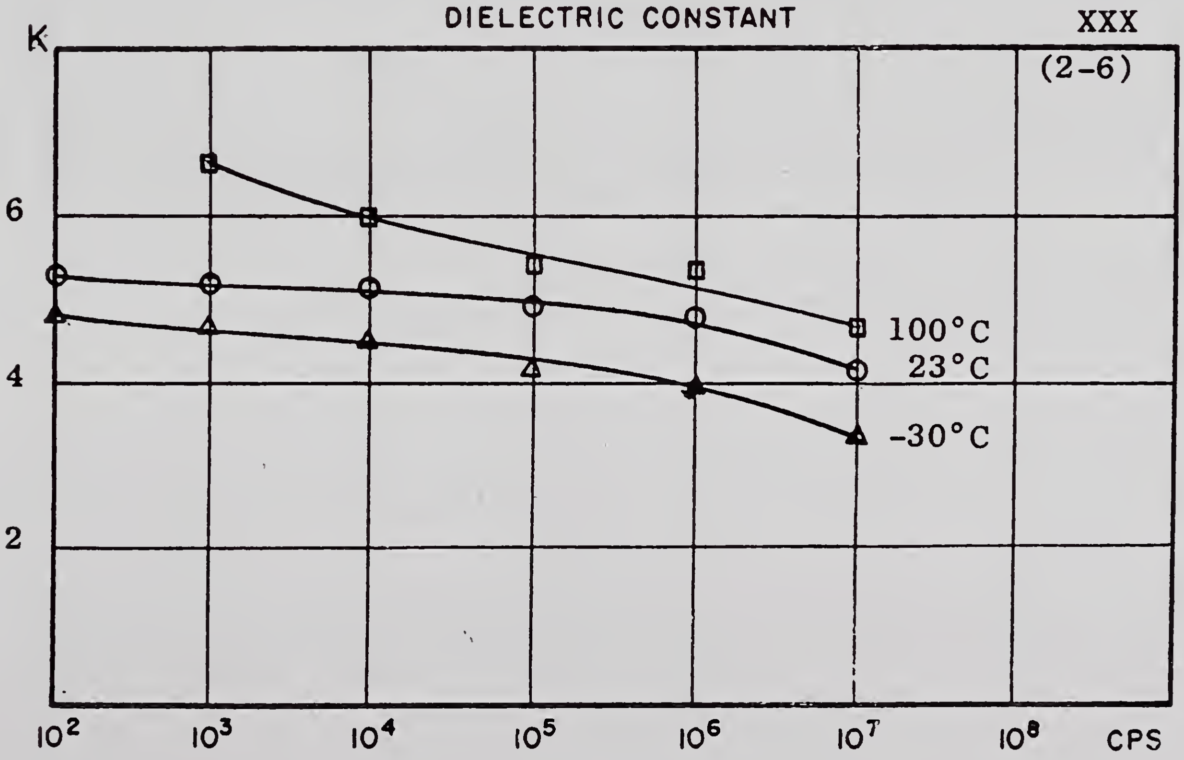
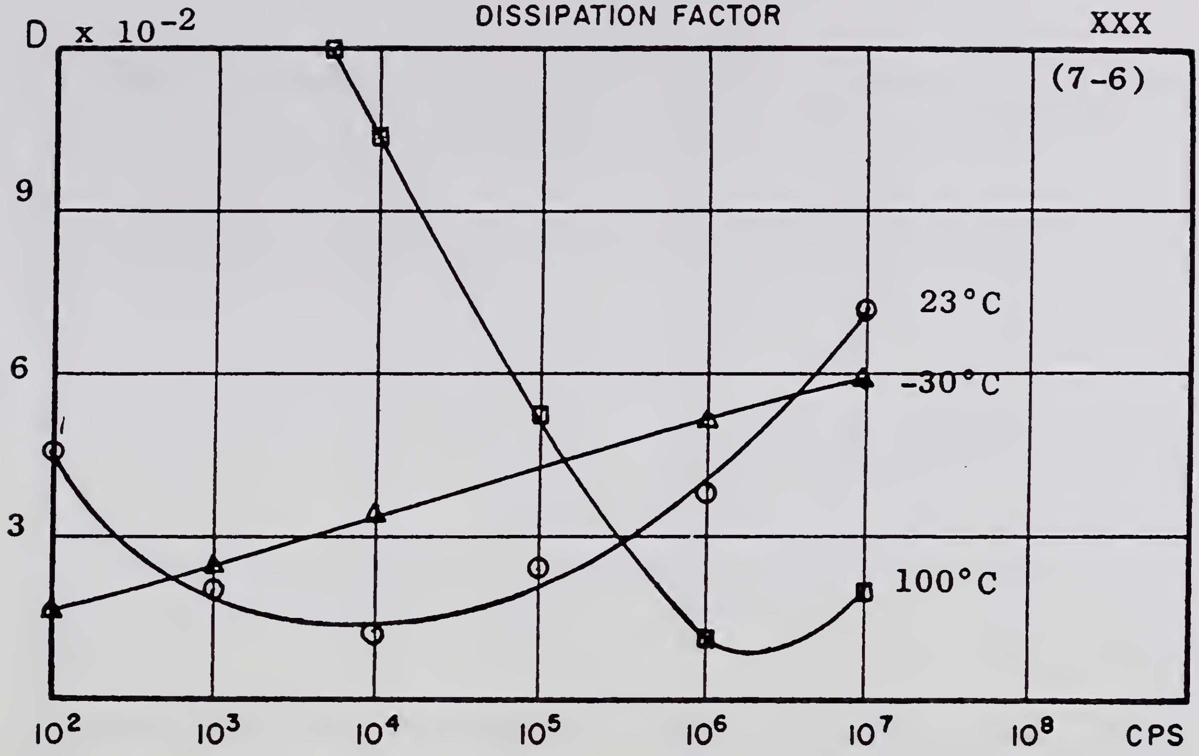


FIG. 76

DIELECTRIC PROPERTIES



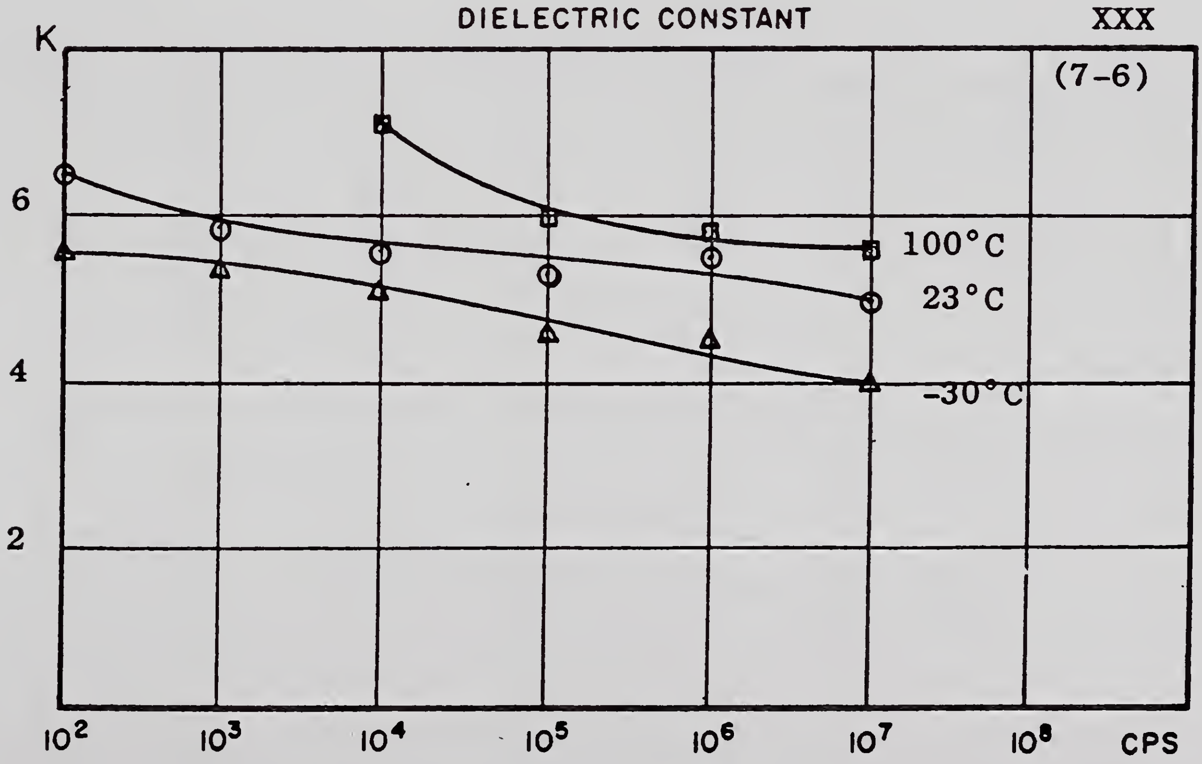
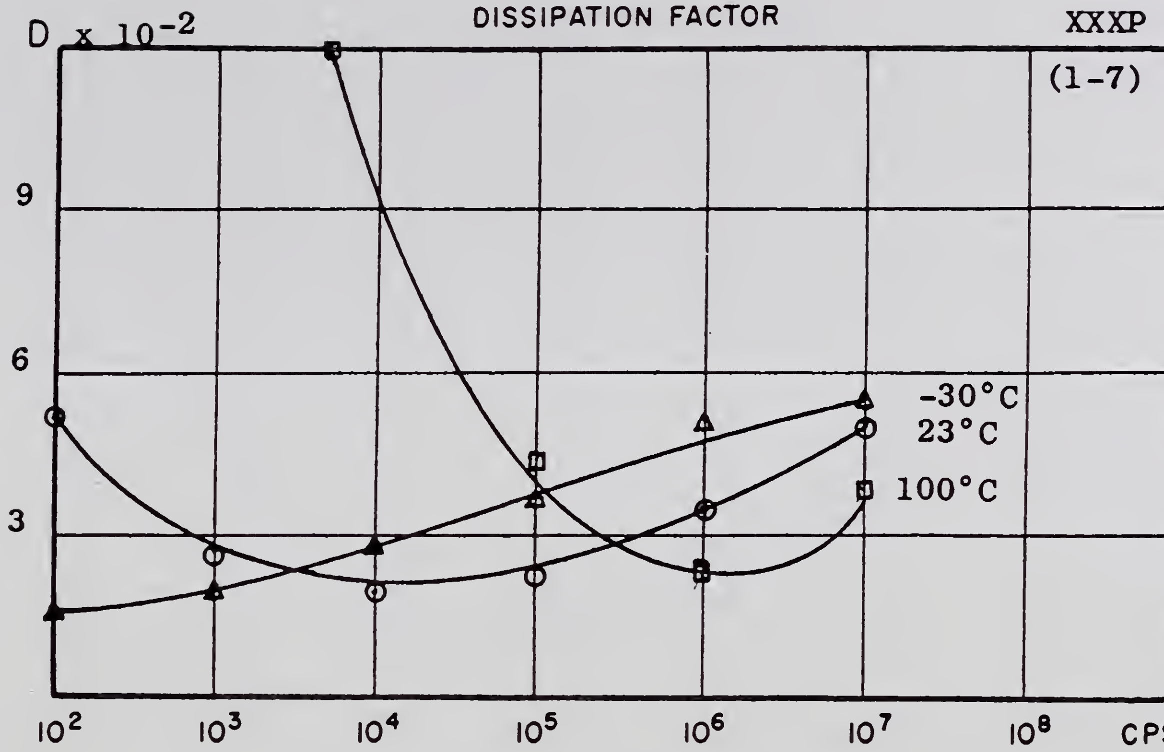


FIG. 77

DIELECTRIC PROPERTIES


DISSIPATION FACTOR

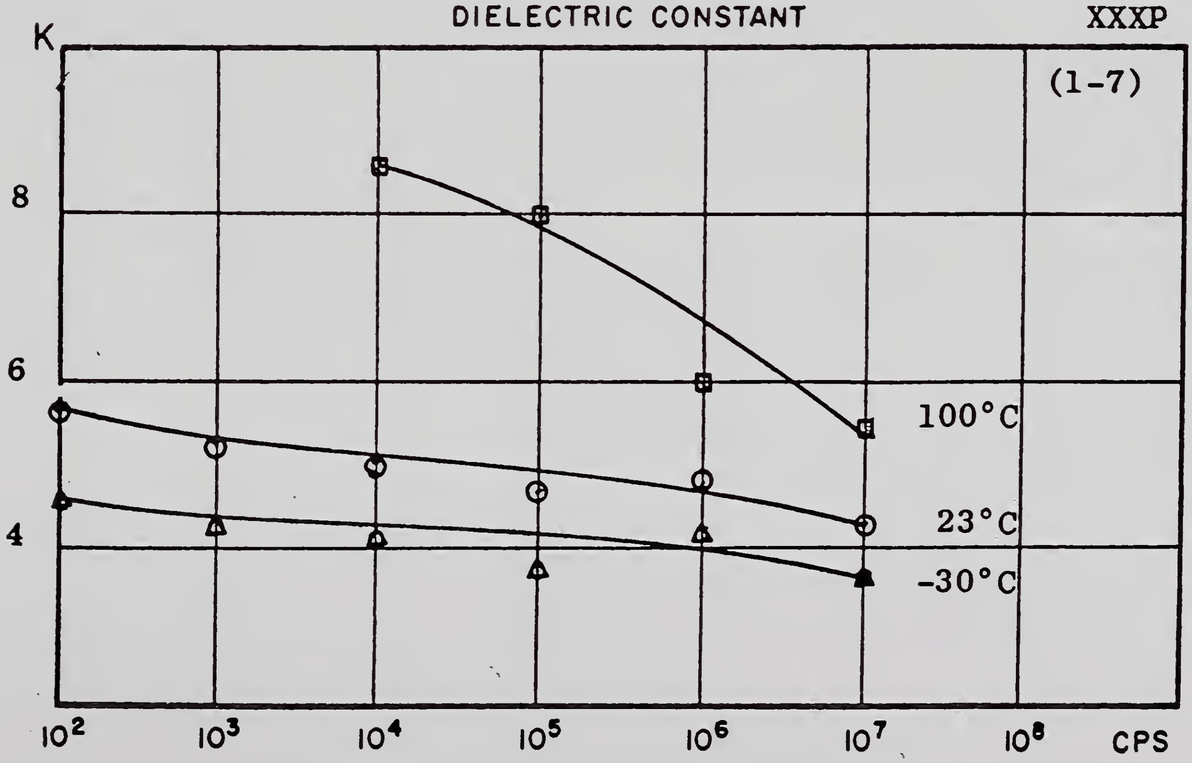
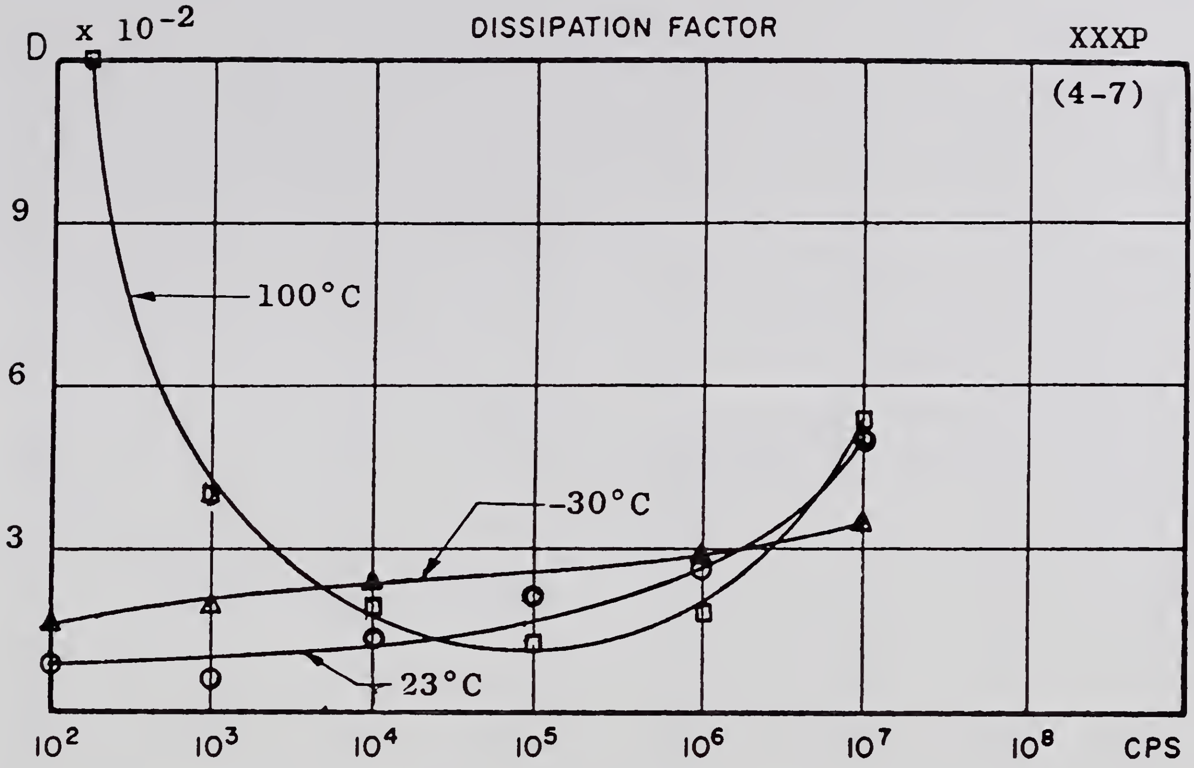

DIELECTRIC CONSTANT

FIG. 78

DIELECTRIC PROPERTIES



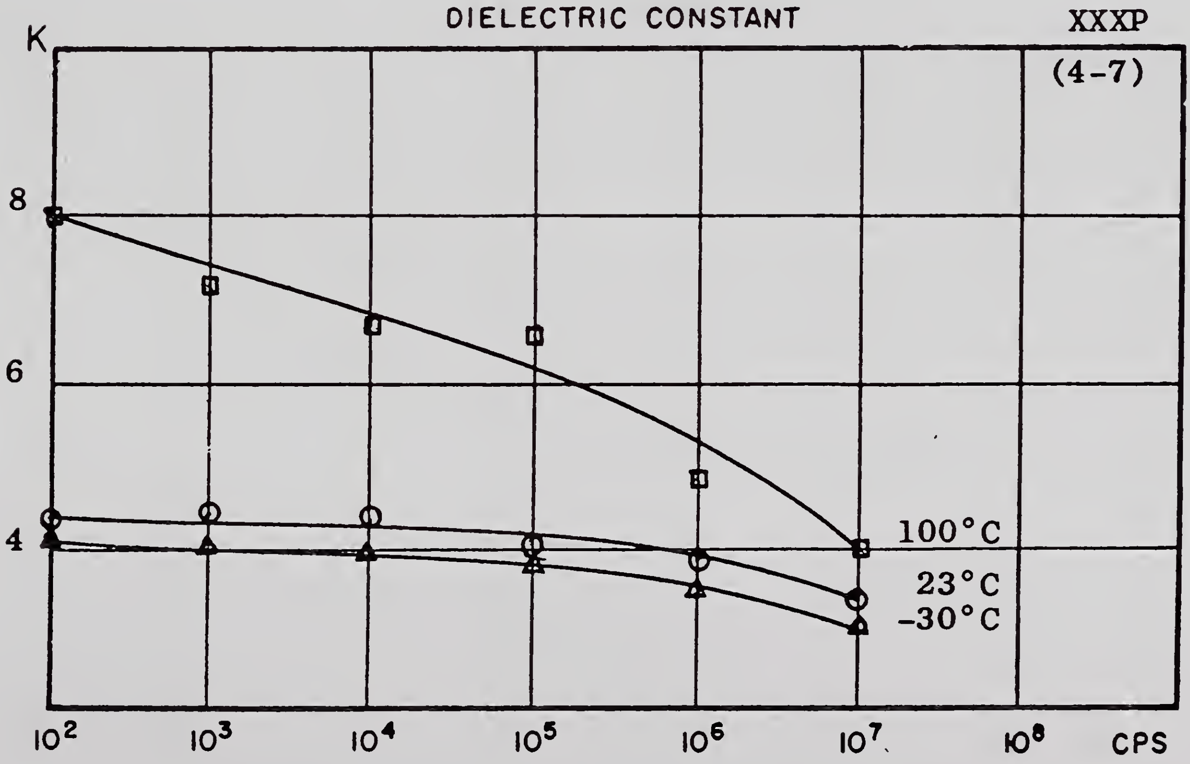
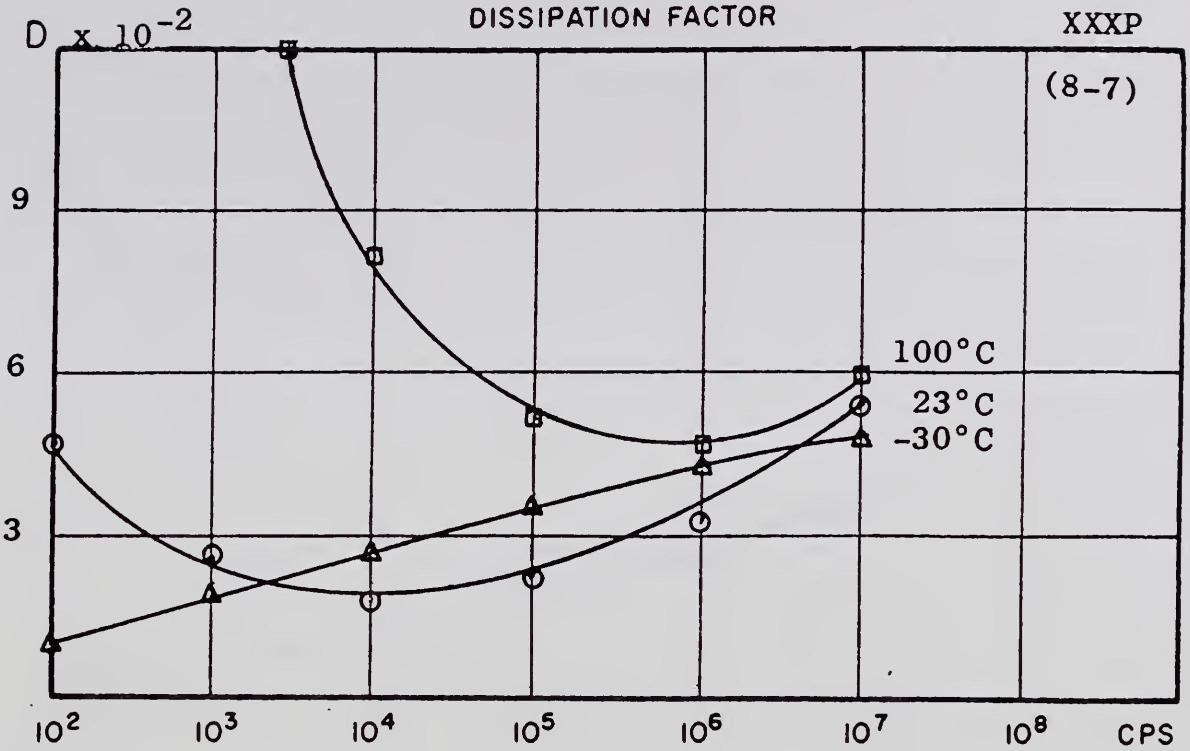


FIG. 79

DIELECTRIC PROPERTIES



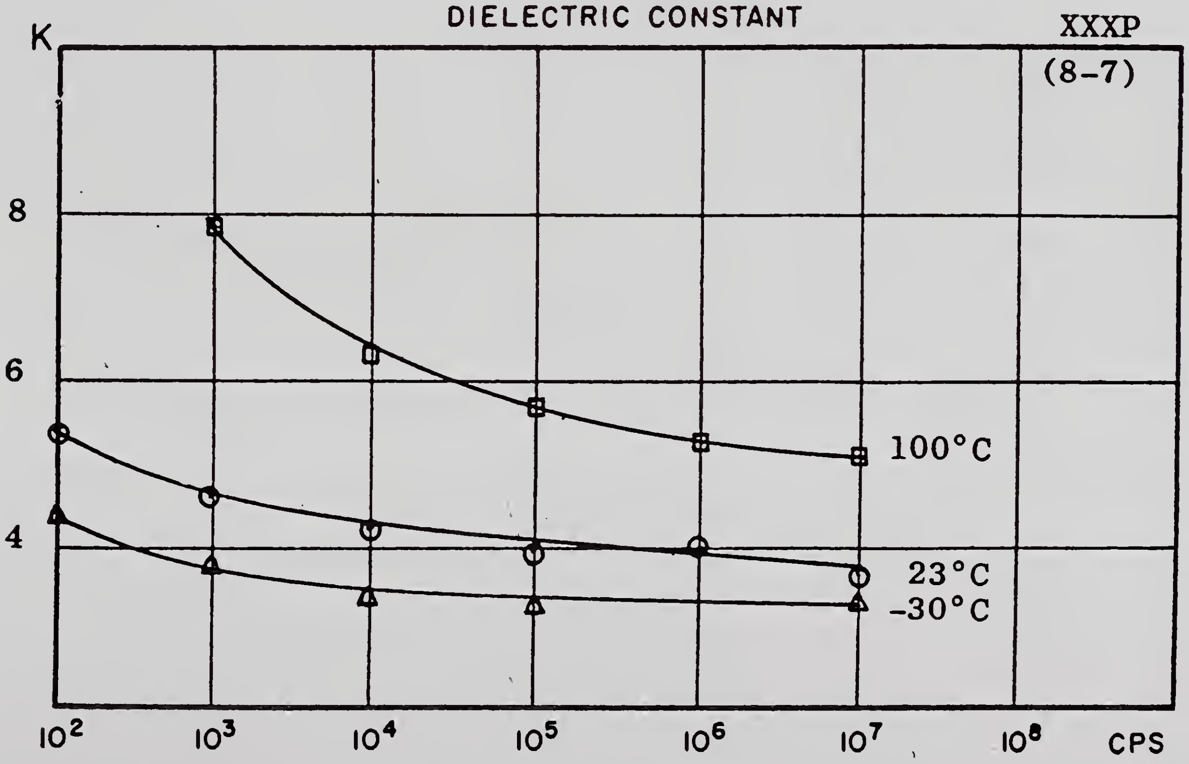
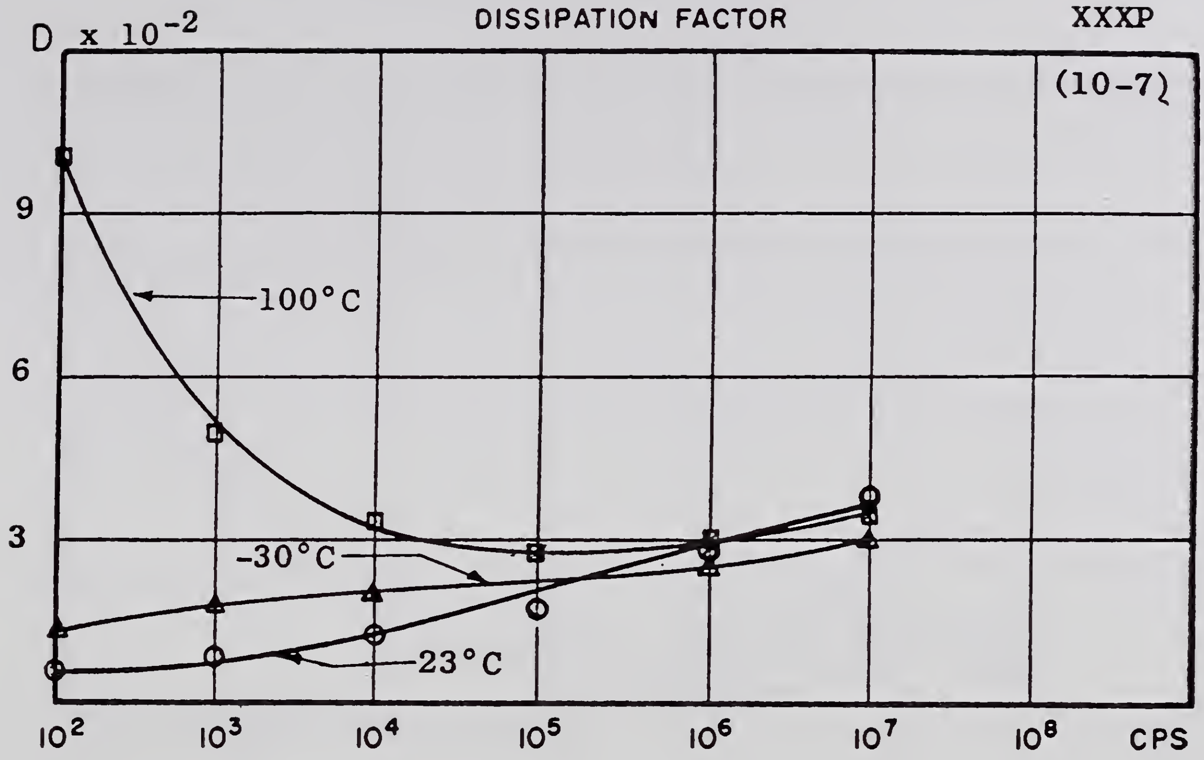


FIG. 80

DIELECTRIC PROPERTIES



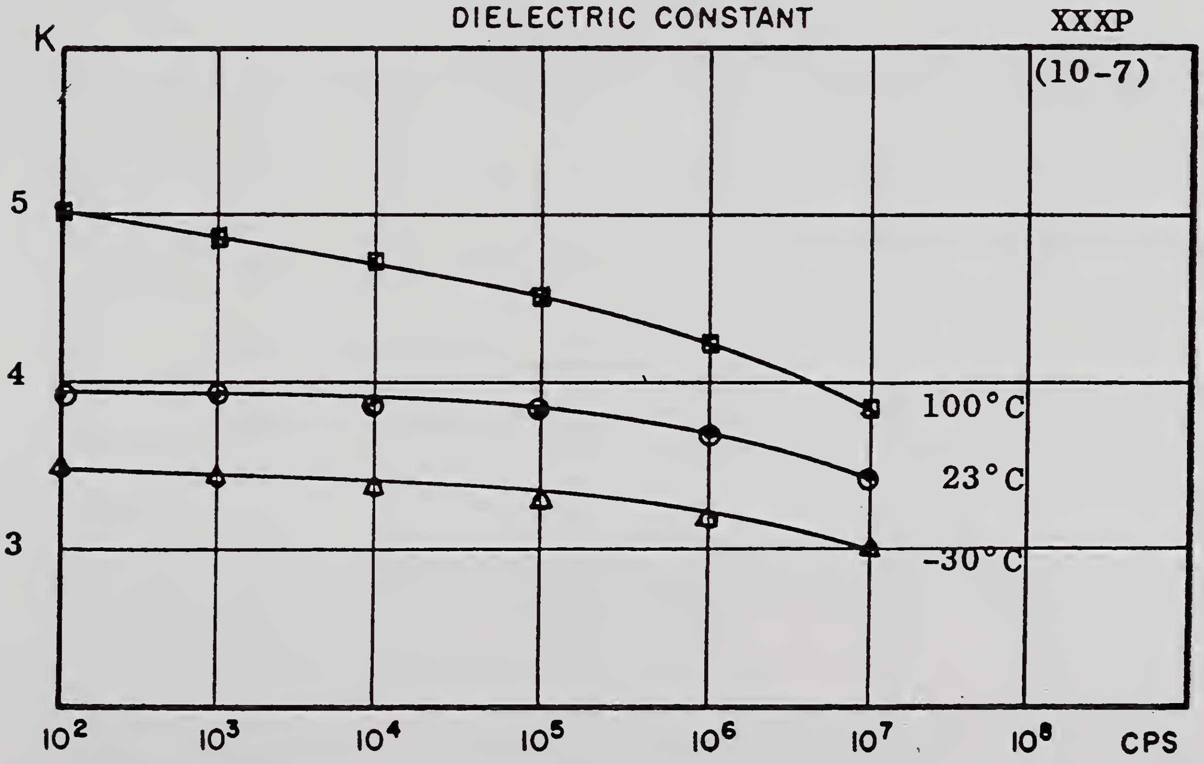
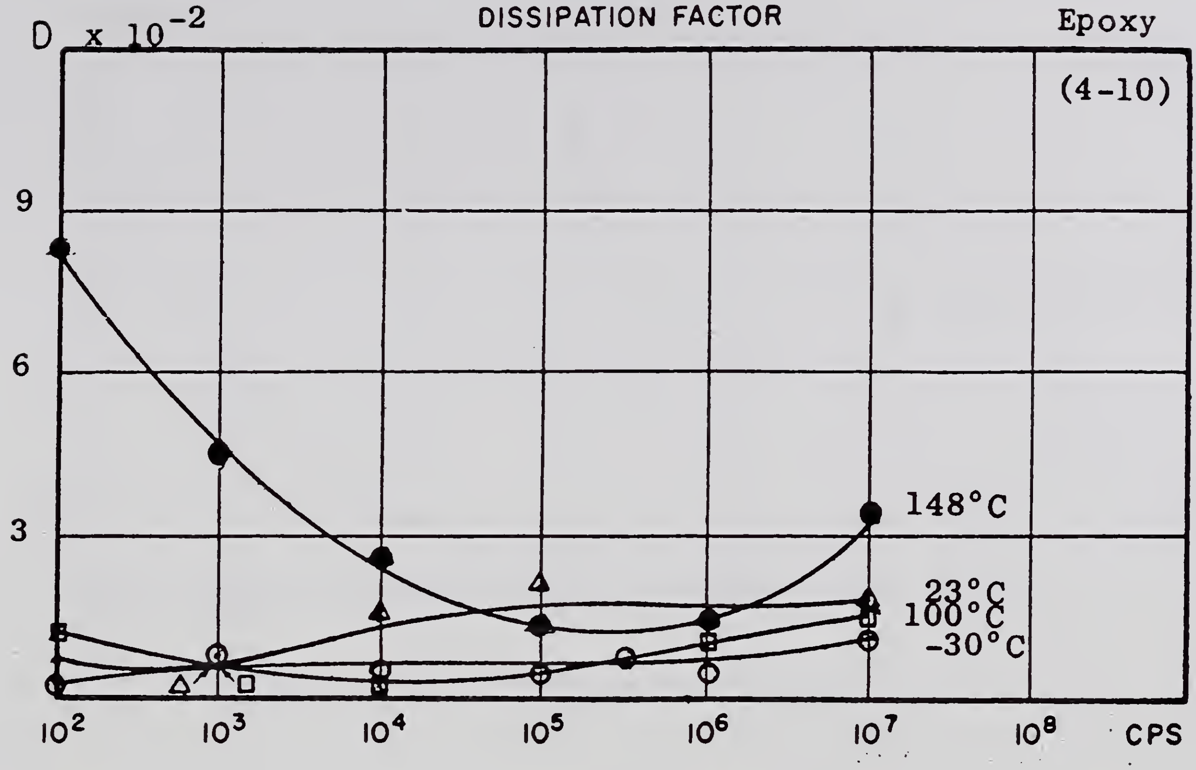


FIG. 81

DIELECTRIC PROPERTIES


DISSIPATION FACTOR

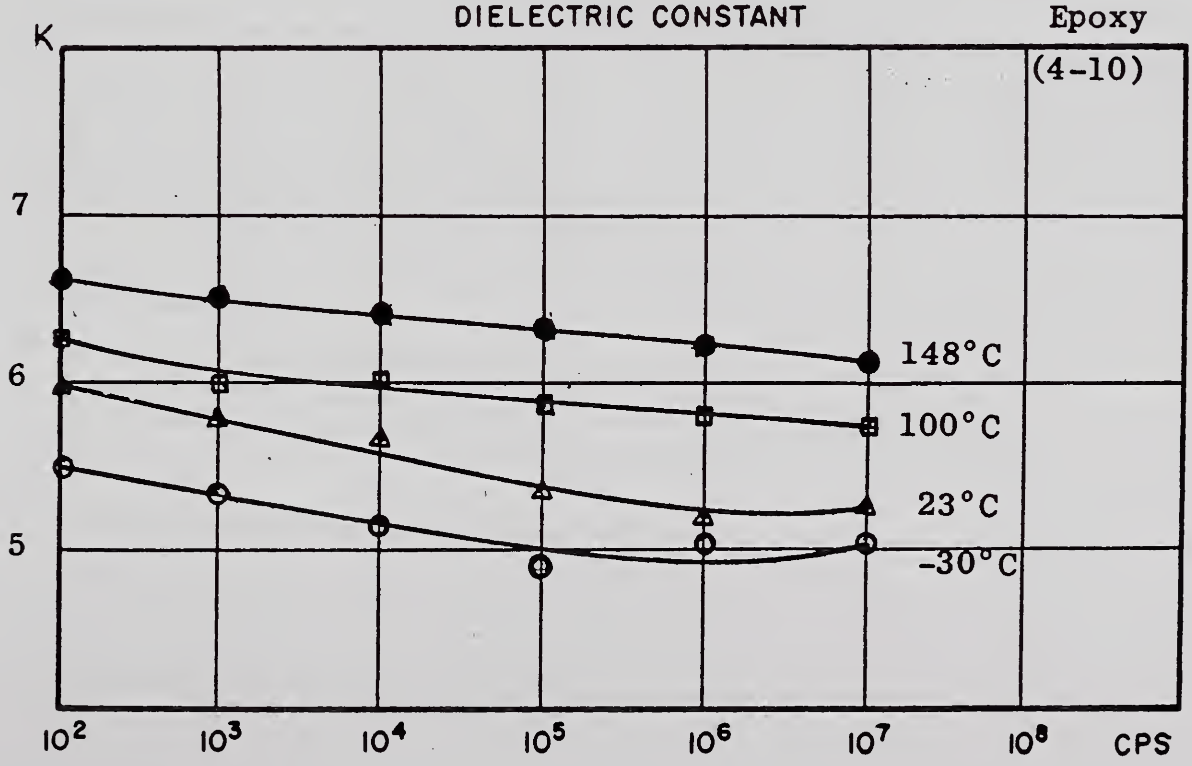
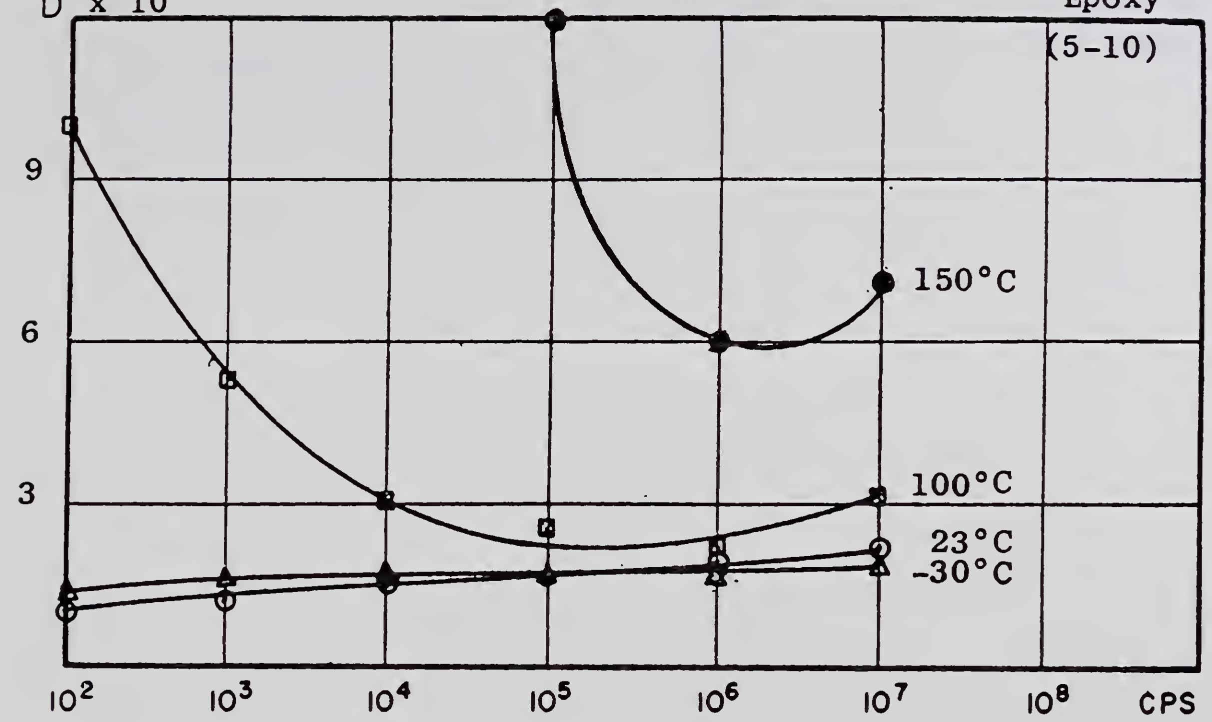

DIELECTRIC CONSTANT

FIG. 82

DIELECTRIC PROPERTIES

DISSIPATION FACTOR



DIELECTRIC CONSTANT

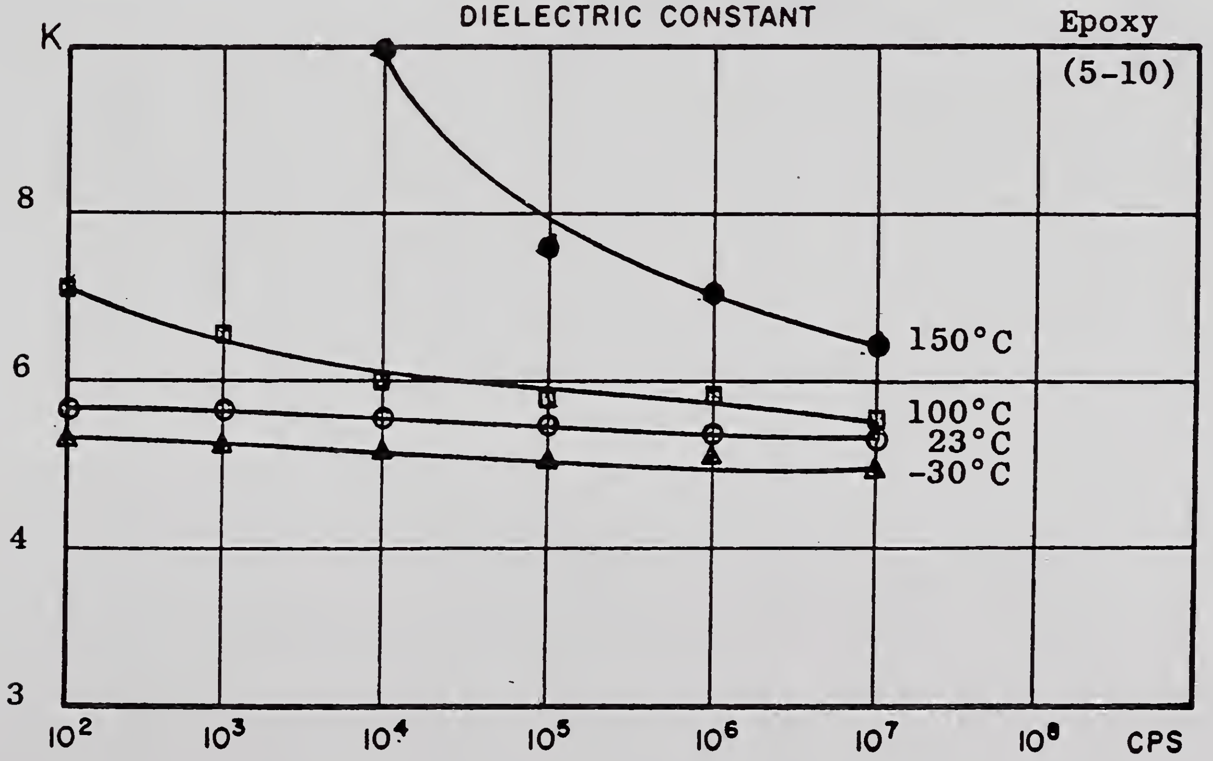
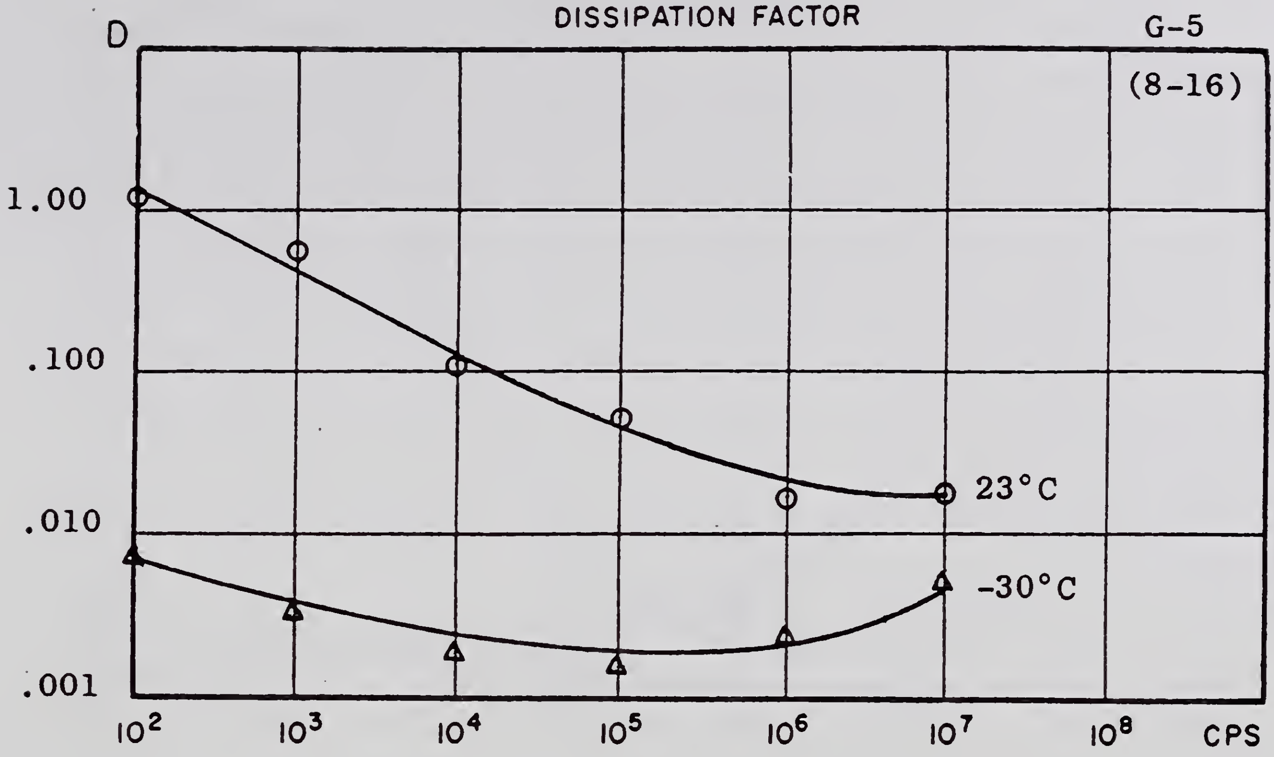


FIG. 83

DIELECTRIC PROPERTIES



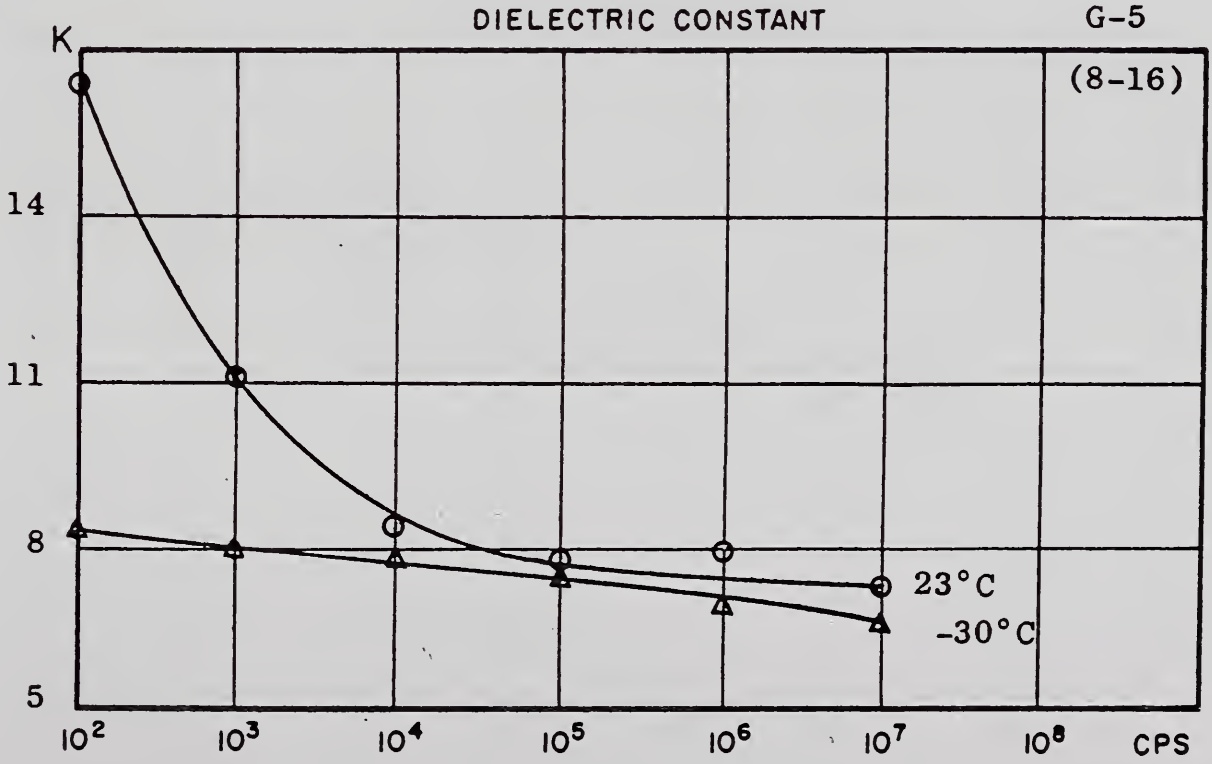
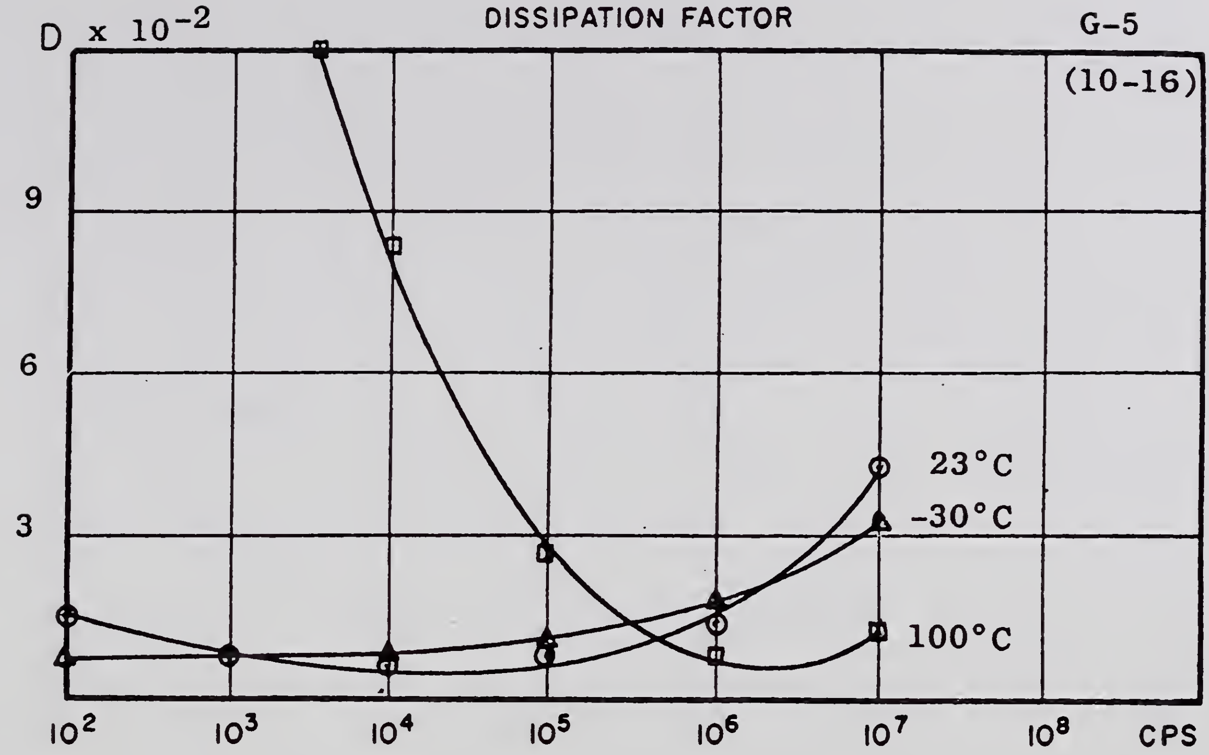


FIG. 84

DIELECTRIC PROPERTIES



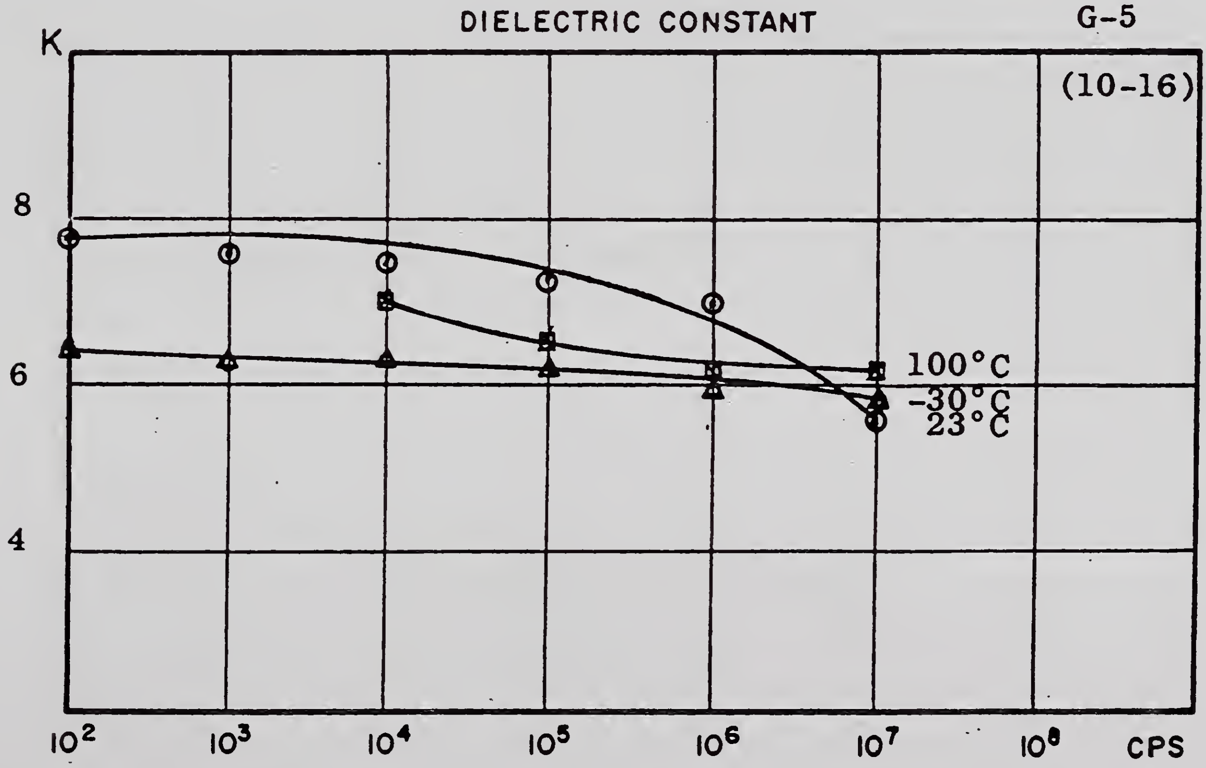
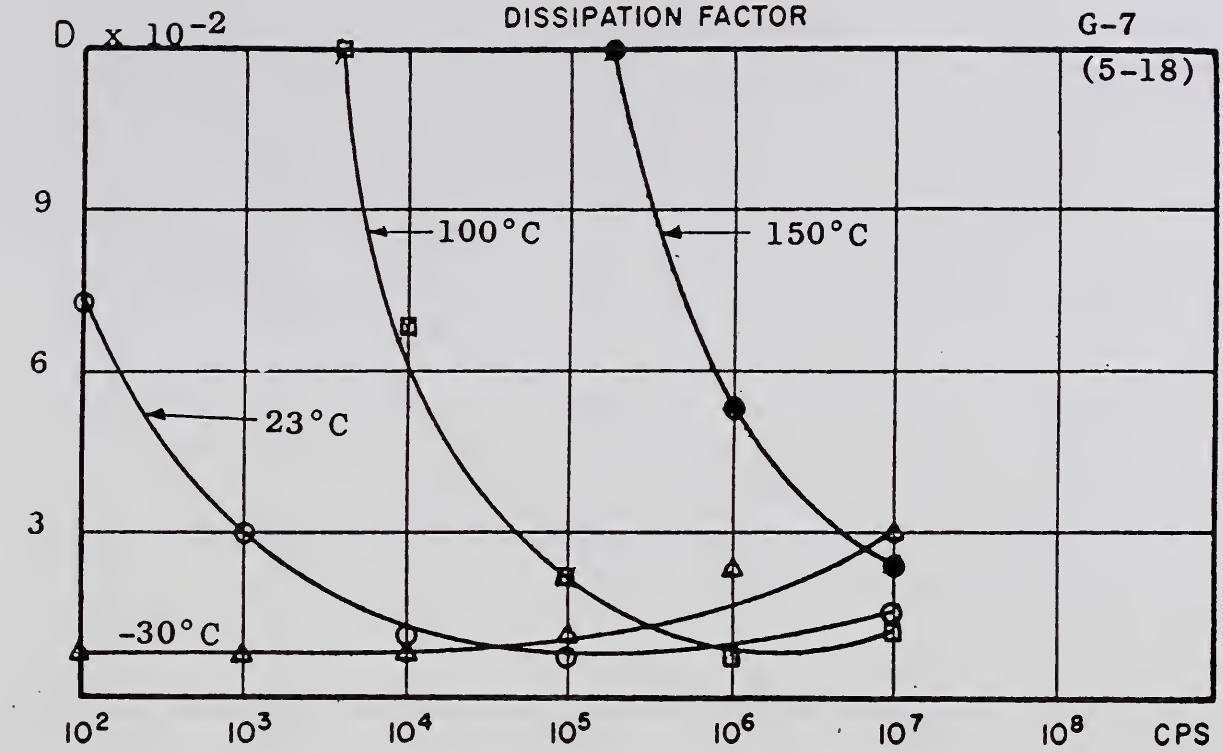


FIG. 85

DIELECTRIC PROPERTIES



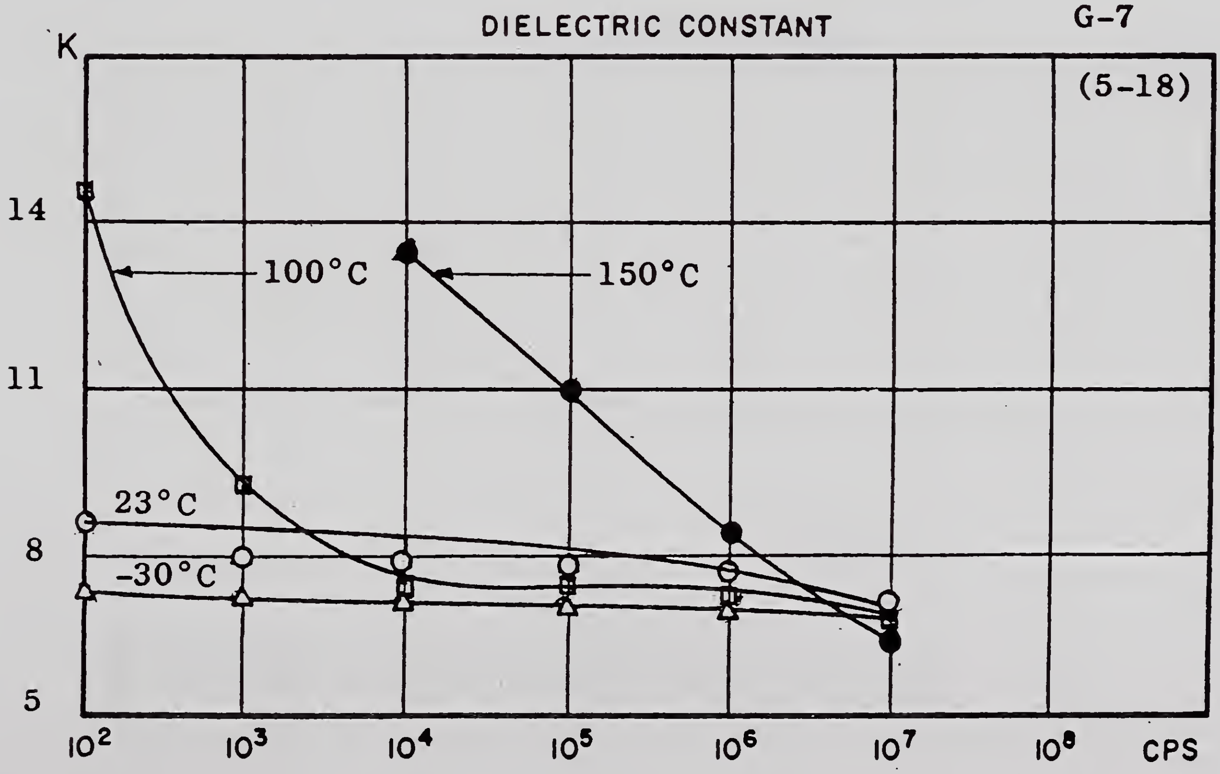
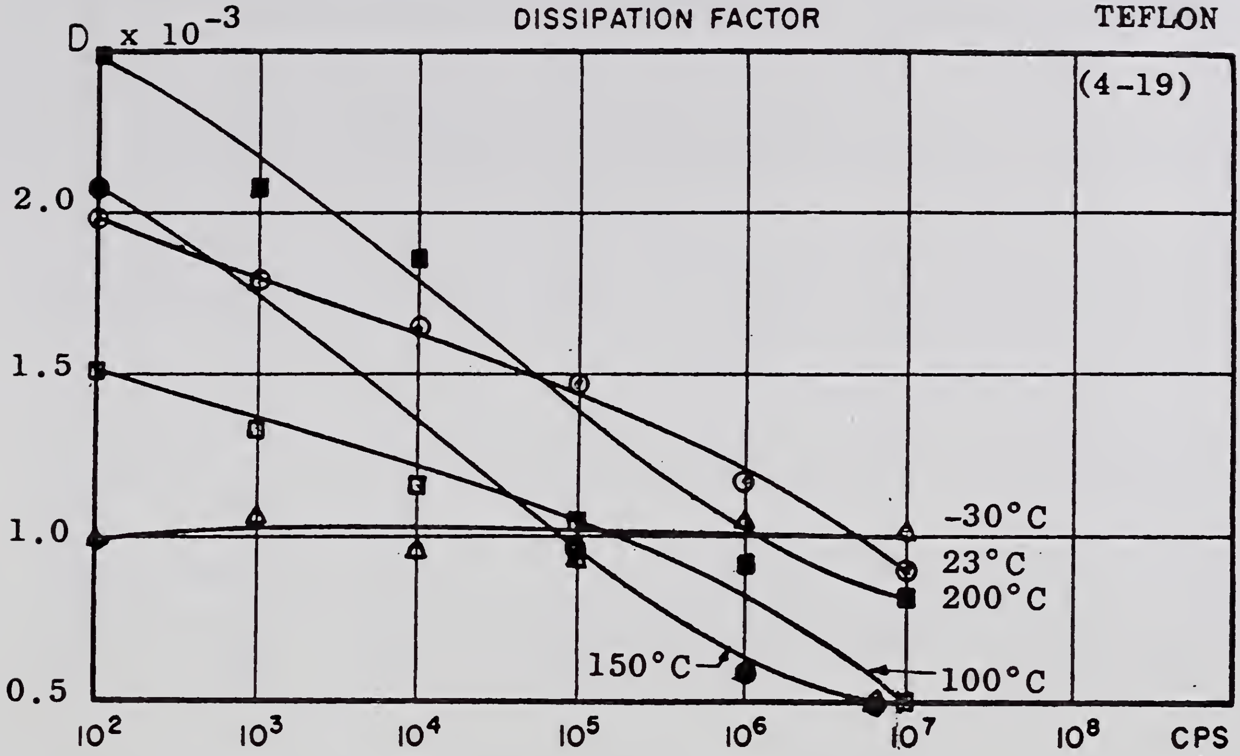


FIG. 86

DIELECTRIC PROPERTIES



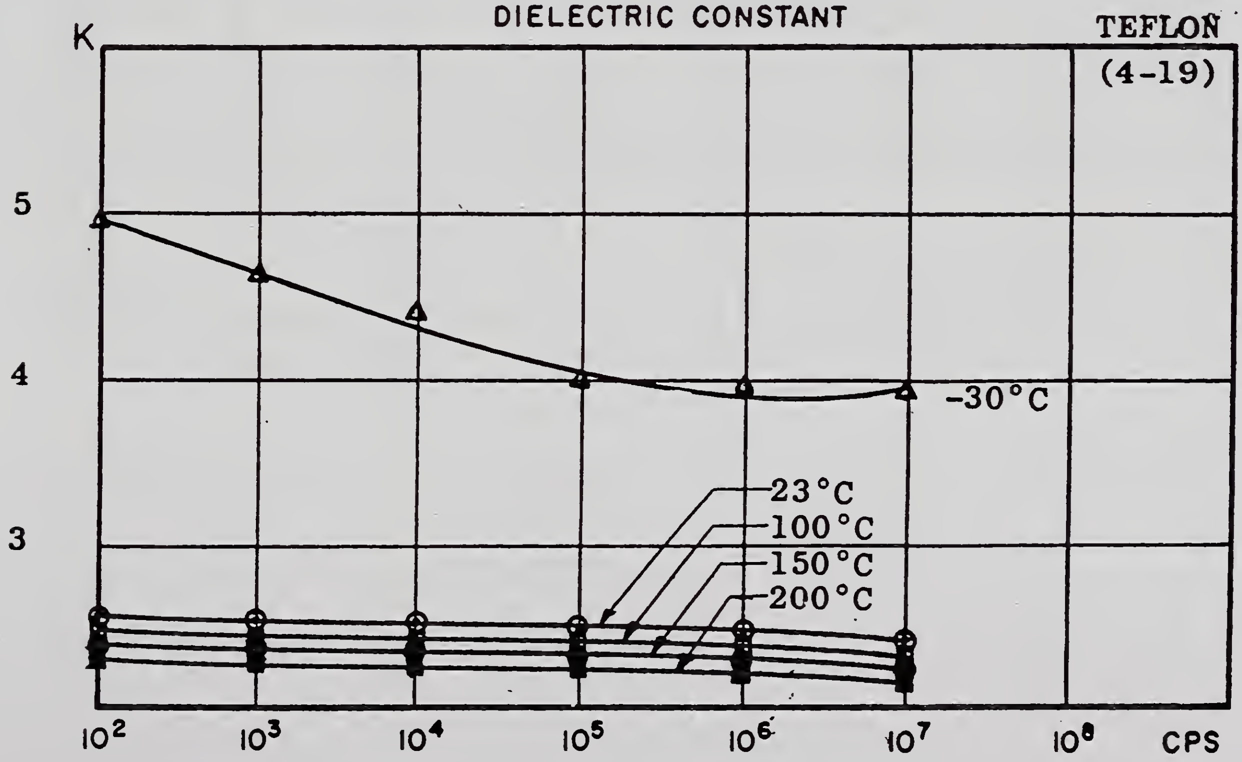
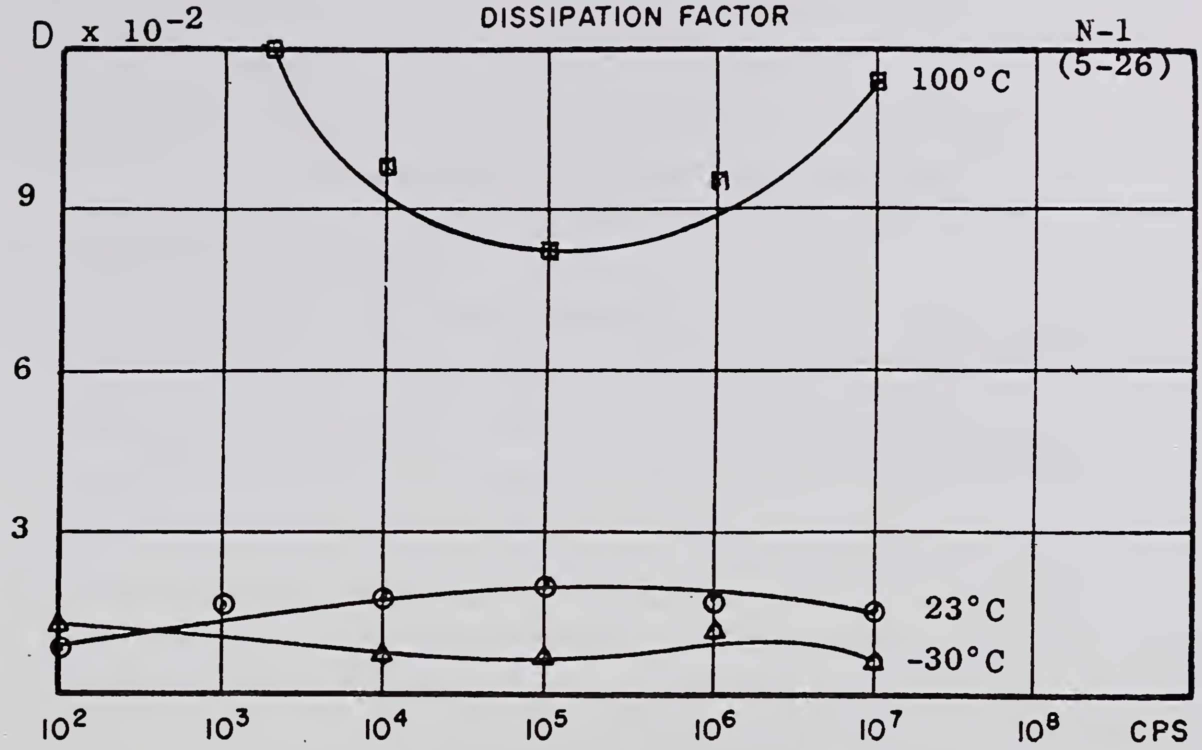


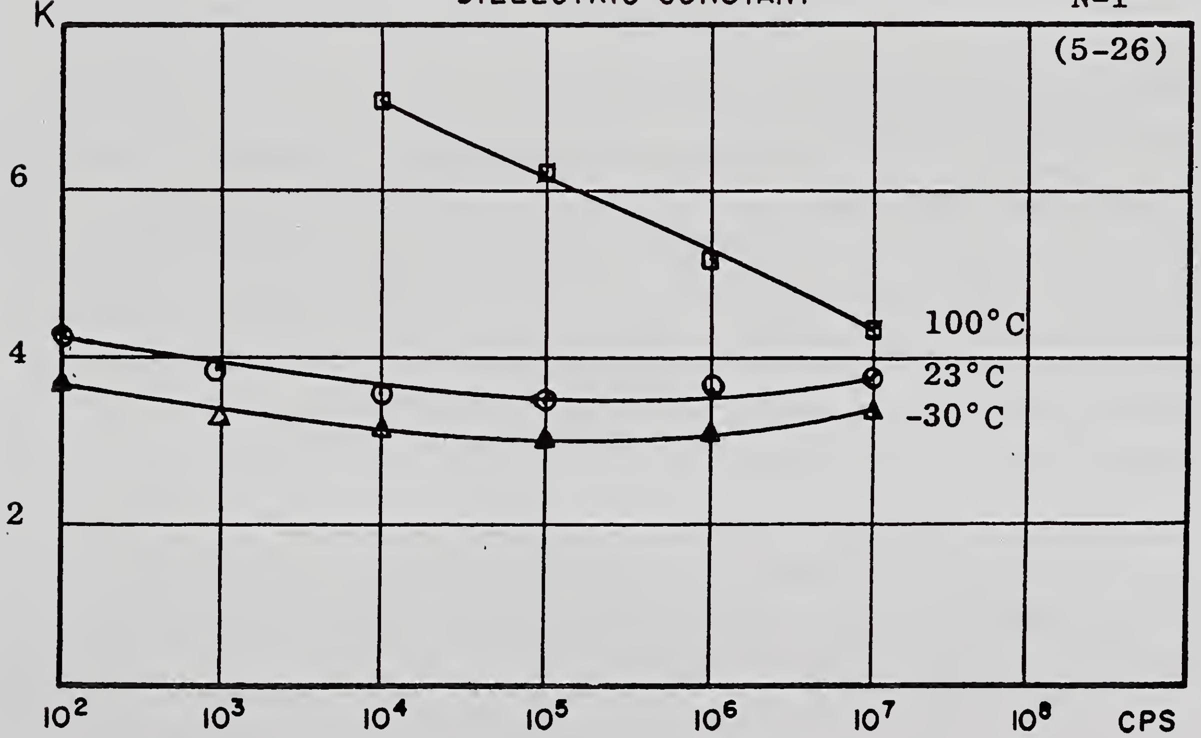
FIG. 87

DIELECTRIC PROPERTIES

DISSIPATION FACTOR



DIELECTRIC CONSTANT



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U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
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THE NATIONAL BUREAU OF STANDARDS

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Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

●Office of Basic Instrumentation

●Office of Weights and Measures.

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