NBS CIRCULAR 530

PRINTED CIRCUIT TECHNIQUES:
AN ADHESIVE TAPE-RESISTOR SYSTEM

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Printed Circuit Techniques:
An Adhesive Tape-Resistor System

By B. L. Davis

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Foreword

The work covered in this Circular is part of a program supported by the Bureau of Aeronautics, Department of the Navy, and conducted by the National Bureau of Standards. The program is directed toward the development of new techniques and new materials applicable in the fabrication of improved airborne military electronic equipment.

The nature of this developmental project and the need for specific information on the part of industry have led to the mention of specific proprietary products and of manufacturers. This report would have little meaning without mention of specific proprietary products, reflecting in some measure the empirical nature of the study. The mention of proprietary products does not mean, however, that the Bureau conducted an exhaustive survey of such products: the objective was to achieve those developmental results which the Bureau of Aeronautics desired as quickly as possible; nor does it mean that the Bureau, in fact, endorses these products: the products are mentioned only because certain results were achieved which industry may wish to duplicate, and which, it is possible, may be difficult to duplicate without knowledge of particular materials. Similarly, the list of manufacturers is supplied as a convenience to industry, for the sources of supply of some materials are not well known, as the Bureau has discovered in the extensive correspondence following publication of developments of this kind.

The fact that the Bureau has mentioned either products or manufacturers shall not constitute a basis for the use of the name of the Bureau, this report or any portions thereof, in advertising, sales promotion, or public relations activity. Here the policy of the Bureau is explicit: neither its name nor its materials, including publications, shall be used in any way to suggest, directly or indirectly, the Bureau's endorsement of any proprietary product, process, or material.

The adhesive tape resistor was originally developed for use in a printed circuit i–f strip for the VHF band (Contract NAer 00686, January 1950). The potentialities of adhesive tape resistors, particularly in high-temperature applications, led to the more thorough study of fabrication and operational characteristics which is reported here. This activity is part of the program of the Bureau's Electronic Division, J. G. Reid, Jr., Chief, and was conducted under the general cognizance of P. J. Selgin, Chief of the division's Engineering Electronics Section. The project, initially begun by P. V. Horton (then a member of the Bureau's staff), was carried out by F. A. Deeken, Harold Horiuchi, R. D. Rhodes, C. C. Tharpe, and R. G. Whistler under the immediate direction of B. L. Davis.

A. V. Astin, *Acting Director.*

Contents

AN ADHESIVE TAPE-RESISTOR SYSTEM

by B. L. Davis

A carbon-resin film-type resistor in tape form which is self-adhesive and suitable for use in printed circuitry has been developed. The range covered is 10 ohms to 10 megohms. The use of asbestos paper tape and silicone resin binder results in a resistor capable of operation up to 200° C. The size of the resistor is fixed, 0.130 by 0.300 inch. Resistance values are varied by changing the resin-to-carbon ratio and by changing carbons. The curing temperature is high, 300° C for several hours. Consequently the tape is applicable at present only to glass or ceramic base materials. Satisfactory operation is considered to be less than ±6-percent change during 500 hours under 1/4-watt load at the stated ambient temperatures. Other electrical characteristics are similar to those of commercial carbon-resin film-type resistors.

1. INTRODUCTION

This circular presents a complete description of the development of the National Bureau of Standards Tape-Resistor System. In section 2, detailed information is given on the production of the tape-resistor including equipment and materials needed. Data for each of the carbons studied are also presented as Appendices A and B. Section 3 gives a complete description of the ovens, switching equipment and recorder for making load-life tests. Section 4 makes recommendation for further study, and a Source of Supply list for all uncommon materials and equipment used is presented in Appendix C.

1.1 Objectives

For several years the Department of the Navy, Bureau of Aeronautics, has sponsored a program of printed-circuit evaluation and development at the National Bureau of Standards. Improved techniques for printing electronic circuits and subassemblies for airborne use are the purpose of the program. In the course of this work it became evident that a great deterrent to the development of printed circuitry has been the difficulty of controlling resistance values. The production of individual resistors to close tolerance is difficult, and the reduced probability of producing a number of resistors on the same base to reasonable tolerances greatly affects the yield of acceptable assemblies. It appeared evident that a self-adhesive tape-resistor would be a real step forward, if one could be developed with satisfactory characteristics. Developmental work, leading to the NBS tape-resistor, was therefore undertaken.

During the work on a miniaturized printed-circuit i-f amplifier, it was realized that temperatures would be encountered greatly in excess of the breakdown temperatures of conventional carbon-composition and carbon-film resistors heretofore used in the printed-circuit industry. These resistors are formulated with a phenolic or melamine base binder, which decomposes at about 120° C, thereby setting a limit of safe operating temperature. On the other hand, this i-f amplifier, operating in ambient temperatures of about 85° C, will reach about 200° C within the case. It was recognized that as a minimum goal, the following requirements would have to be met: (1) stability at a temperature of 200° C, (2) ready application and cure, and (3) reasonable degree of reproducibility.

Stability for long periods at 200° C, is a formidable requirement, for this temperature is considerably in excess of the decomposition temperatures of practically all presently known binders and film-forming materials. Fortunately, in the work on the i-f amplifier, electrical characteristics, such as low voltage and temperature coefficients and low noise, could be compromised. Also, only a few definite values of resistance in a rather narrow range of values were required.

Under Interdepartmental Government Orders NAer 01015 and 01147, the National Bureau of Standards was authorized to further develop this tape-resistor to cover a resistance range of 10 ohms to 10 megohms, based on a resistor size of 1/8-inch width and 1/2-inch length, including end connections. Specification JAN-R-11 established general performance requirements. In addition the units were to be capable of 1/4-watt dissipation at 200° C ambient. Storage of the tapes for reasonably extended periods of time in an uncured or semicured state was another requirement.

1.2 Summary Description

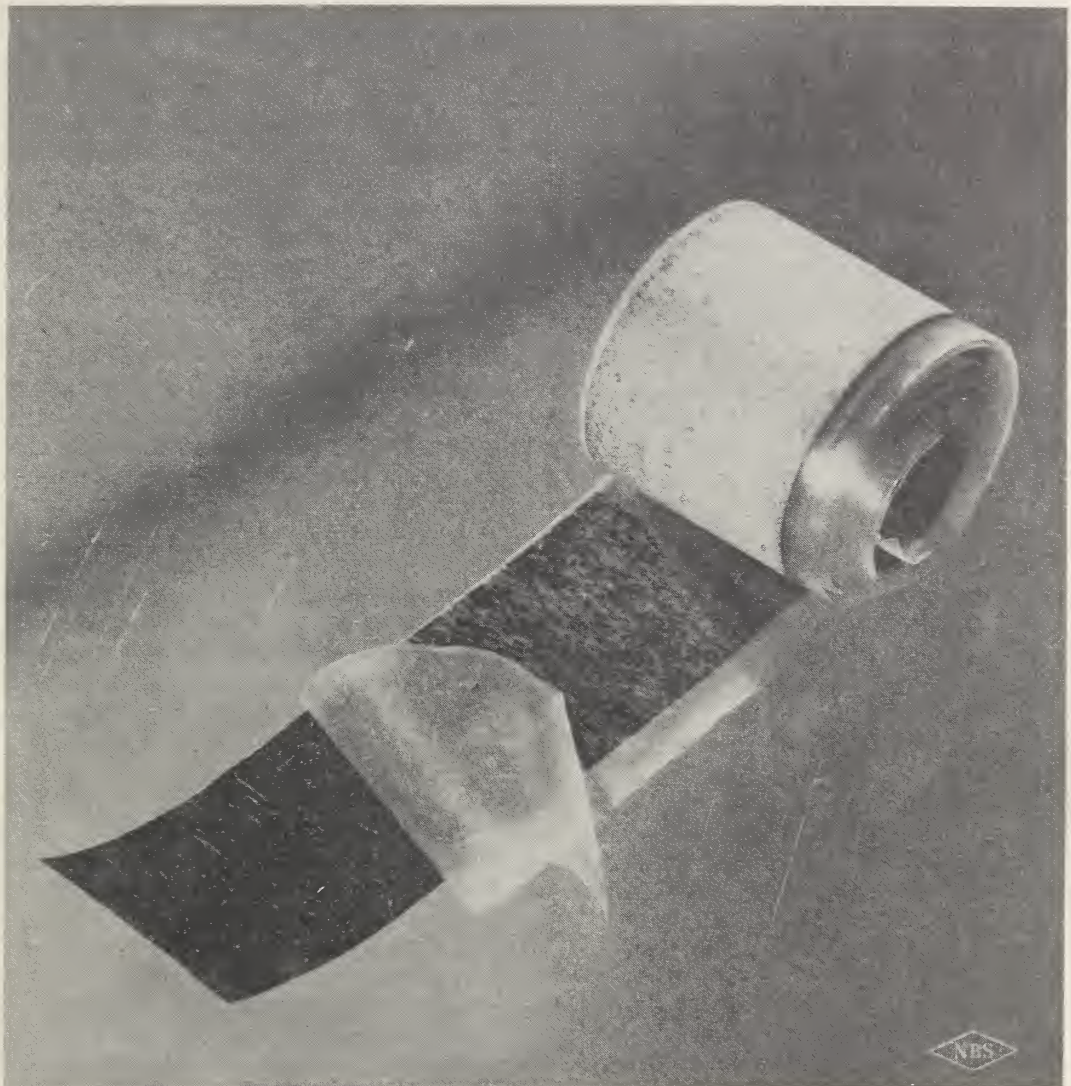
The NBS tape-resistor is of the carbon-film type. A roll of the tape, before slitting, is shown in figure 1-1. It is made by coating a flexible heat-resistant tape base with a resistance-paint formulation. The preferred base material is an asbestos-paper tape known as Quinterra. The tape-resistor carries its own pressure-sensitive adhesive, making contact to printed electrodes when lightly pressed in place and subsequently cured.

The advantages of these resistors are several: (1) They may be pretested, and may therefore be considered a compromise between the manufacture of resistors as a separate component and existing methods of printing resistors. (2) The resistors are adhesive, the resistor film on the uncured tape being sufficiently tacky to adhere of itself, making an intermediate adhesive layer or extraneous electrical connective materials unnecessary. (3) The resistors are not cured until they are in place in the circuitry, at which time they are all cured simultaneously. (4) The resistance film is protected from abrasion and electric shorts by the layer of heat-resistant tape, which is on top in the finished resistor.

The manufacture of the resistor tape presents no serious problems. The asbestos tape, in the form of an endless belt, is carried past a spray gun by a suitable mechanism, and the film is applied slowly in a large number of passes. This is important for uniformity.

The major consideration in this work has been operation at high temperatures. A silicone resin is therefore used. The formulations are exceedingly simple, consisting only of carbon black or graphite, silicone resin, and solvent.

It was decided to establish a fixed size of the resistor, 0.130 by 0.300 inch. Values of resistors are varied by changing the ratio by weight of resin to carbon, and by changing carbons. The solids content of the formulation is kept constant, so that all values of resistors sprayed have substantially the same solids content in the film.



UNCURED RESISTOR TAPE WITH PROTECTIVE PLASTIC COVERING
FIG. 1-1

The curing temperature is high, 300° C, and curing takes several hours. Consequently, the tape is applicable at present only to glass or ceramic base materials. Enough work has been done with lower curing resins, such as the Melmacs, to indicate that they will make suitable tapes for use at conventional temperatures and with cure temperatures low enough to use on the newer heat-resistant plastic materials.

Graphites are used for some resistance values, carbon blacks for others. Graphite gives resistors unusual stability at an ambient temperature of 200° C. Unfortunately, the range is limited. Thus, graphite formulations are used to make resistors from 100 ohms to about 5, 000 ohms. For low values, 5 to 100 ohms, a layer of material containing silver, followed by a layer of graphite or carbon black, is deposited by spraying. Carbon blacks are used for formulations from 5, 000 ohms to 10 megohms. Only a few of the carbon blacks tried are satisfactory for long operations at 200° C. For some values, a completely satisfactory carbon black has not yet been found. In these ranges, however, tapes have been made that will give satisfactory performance at a slightly lower temperature.

A change of less than ±6 percent after 500 hours of operation under 1/4-watt load at the stated ambient temperature is considered satisfactory. In other respects, the criterion for satisfactory performance is the same as for commercial carbon-resin film-type resistors.

2. TAPE-RESISTOR PRODUCTION

Carbon-resin film-type resistors on cylindrical or tubular glass or ceramic base materials have been very extensively used in the electronic industry for a great many years. In the printed-circuit field, too, carbon-resin film-type resistors have been widely used, deposited by screening, spraying, hand-painting, and so forth. Because of the numerous advantages of the carbon-resin resistor, it seemed advisable to retain this general type as part of the tape-resistor process.

Fundamentally, carbon-resin film-type resistors are composed of carbon particles, acting as a conducting medium, encased in an insulator binder. The binder serves the threefold purpose of (1) holding the carbon particles in a definite spatial relationship (thus aiding in the fixing of the resistance value), (2) acting as an adhesive (providing the means of attaching the conductive coating to the base material), and (3) giving some protection against abrasion, humidity, etc., although an outer protective covering is usually needed.

Satisfactory operation at 200° C was a primary goal of the tape-resistor project. The resin binder used in commercial carbon-resin film-type resistors of both the piece component and the printed varieties is a melamine or phenolic compound. The decomposition temperature of these resins is in the neighborhood of 120° C, which limits the safe operating temperature of resistors made with these binders. The two major problems, therefore, were (1) finding a suitable resin binder capable of withstanding ambient temperatures up to 200°C, and (2) developing resistor formulations with satisfactory characteristics at these high temperatures.

In producing the finished NBS tape-resistor, a resistive formulation of carbon black (or graphite), resin, and solvent is first sprayed on a tape or ribbon of appropriate material formed into a closed loop. After drying, the sprayed tape is slit to the proper width. The tape is applied to the circuit, consisting of a ceramic plate or "chassis", by pressing over fired silver electrodes on the printed-circuit chassis and cutting to length. The entire chassis is then cured in an oven to polymerize the resin.

2.1 Heat-Resistant Tape

It is important for the success of the project that all materials used in the resistor formulation be commercially available. The Quinterra asbestos-paper tape, manufactured as an electrical insulator, is used as the base material for the NBS tape-resistor. This heat-resistant, inorganic-base Quinterra paper is available in various widths, thicknesses, and grades. Grade 5C Quinterra has been used throughout most of the NBS tape resistor work. Quinterra is manufactured with a binder of polyvinyl acetate and a clay filler. Attempts to use grade 1 Quinterra, which has no organic binder, have been unsuccessful. For convenience in handling, a width of 1.25 inches and a thickness of 0.006 inch are preferred. The asbestos fiber used is a very short-staple fiber (ample reserves) mined in the United States and Canada.

Good control of resistance values requires that the properties of the asbestos-base paper be uniform. According to the manufacturer, the Quinterra composition can be controlled to within 3 to 5 percent, depending on thickness. Moisture content is approximately 2 percent, under standard atmospheric conditions.

A silicone treated Quinterra, grade 3N, is now on the market. The material is impregnated with Dow-Corning No. 801 silicone resin and has approximately the same weight and thickness tolerances as grade 5C, the preferred base at present. Indications are that grade 3N Quinterra will also be useful for the production of tape-resistors.

Among the difficulties encountered in this study is the lack of any definitive information regarding the absorption of carbon into the asbestos-base tape. Grade 3N tape (silicone impregnated), when treated with the same carbon composition, has produced tapes of higher resistance than the grade 5C Quinterra. The explanation is believed to be that the silicone resin in the resistor formulation cannot penetrate as deeply into the pores of the impregnated tape.

2.2 Carbons

Of the profuse accumulation of data available on the subject, only those are included that can contribute to an understanding of the scope and purpose of the project. For example, only representative carbons have been chosen to portray group properties in the main body of the report: Additional information is included in Appendix A.

A table showing some of the properties of NBS tape-resistors is included at the close of this section (table 2-1) More complete information concerning electrical characteristics of the various carbons will be found in Appendix A. A tabulation of resistance values obtainable from various carbon formulations is available in Apendix B.

Both graphites and carbon blacks were selected for experimentation in order to achieve as wide a resistance range as possible. The carbon blacks were of the furnace and channel black varieties. Some twenty-one carbon blacks and twelve graphites were tried for use in the NBS Tape-Resistor System with varying success. It has been difficult to classify the various carbons as to their resistive qualities. However, the graphites tend to produce resistors with good all-around electrical properties when used in the low-resistance range, and in a fairly low-weight ratio of resin to carbon, whereas the carbon blacks are better suited to the higher values. This does not mean that upon load-life testing all the carbons remain within the limits specified by the study.

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Physically, carbon blacks are amorphous, with no crystalline structure. Graphite, on the other hand, consists of distinct crystals of regular shapes. Graphite particles are larger than those of the carbon blacks. Those used in this study range from 2 microns to about 15 to 20 microns. Carbon blacks are of two types, classified as furnace blacks and channel blacks, according to the method of production. Furnace-black particles are of the order of 50 to 150 millimicrons. Channel-black particles are the smallest, about 15 to 35 millimicrones. Generally, channel blacks are in the shape of spherical particles, whereas the furnace blacks are rod-like under the electron microscope. Graphite is harder than either of the carbon blacks. The correlation, if any, between the physical and the electrical characteristics of the carbons has not yet been established.

Figure 2-1 shows, in general terms, the load-life characteristics of the four different classes of carbons used in the manufacture of NBS tape resistors. Separate curves are shown for natural and artificial graphite for channel black and for what seem to be two classes of furnace blacks. These curves are intended to show group characteristics rather than individual idiosyncrasies, which will be described in a later section.

a. GRAPHITES. Natural graphites of the Joseph Dixon Crucible Co. and artificial graphites from the Acheson Colloids Corporation have been used in resistor formulations. Graphite resistors have proved to be most successful for values below 5,000 ohms. Above this value, they tend to be objectionably noisy.

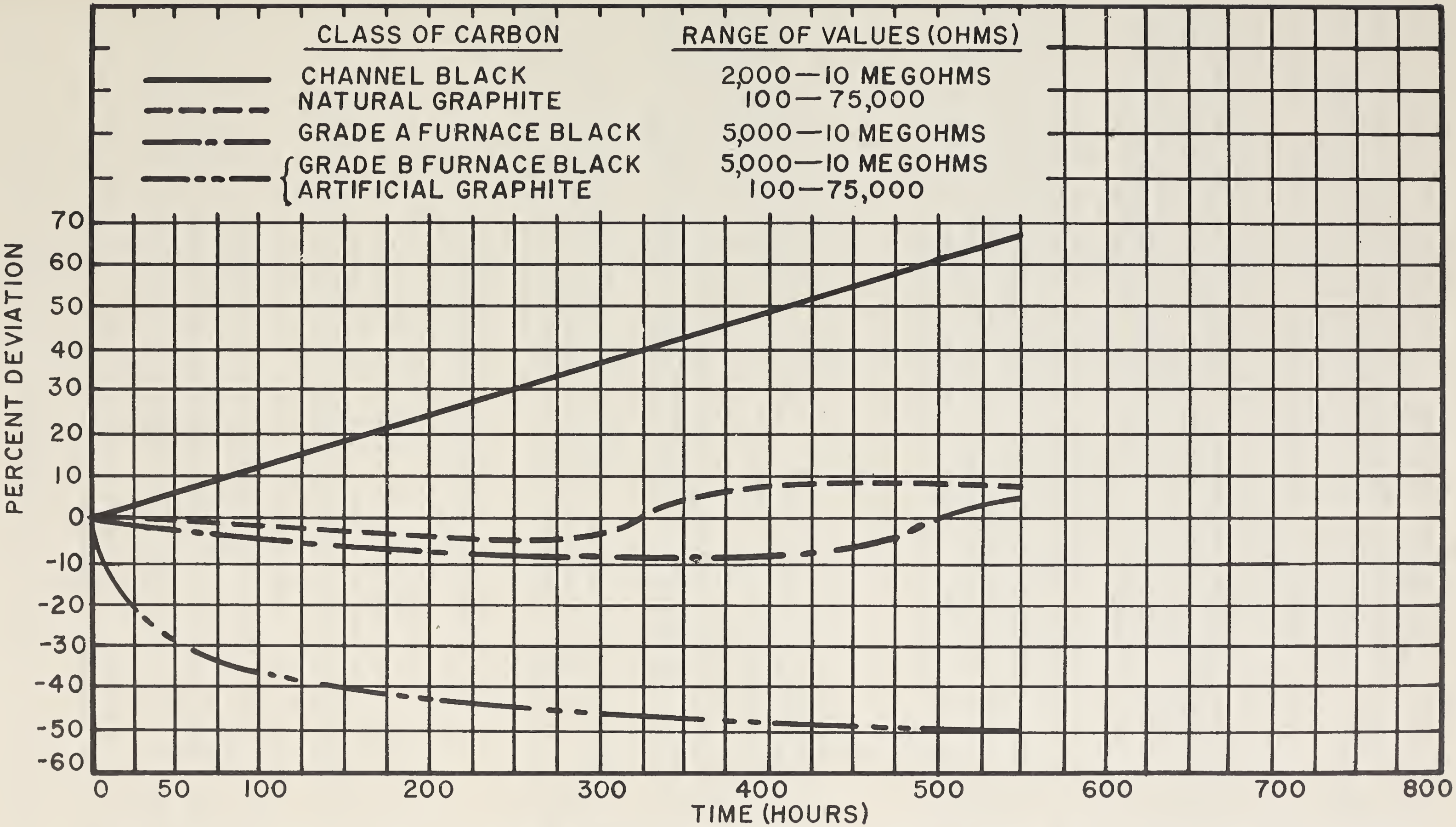
The performance of natural graphite differs somewhat from that of artificial graphite. Artificial graphites investigated include dispersions in mineral spirits and aromatic solvents, with an alkyd resin to improve the consistence of the mixture. Such mixtures are available commercially under the DAG trade mark. Their resistive properties are similar to those of a group of furnace blacks described below. The natural graphites, depending upon the carbon-to-resin ratio, have yielded NBS tape resistors ranging from 100 to 72,000 ohms. In load-life tests, these resistors show a remarkable stability over long periods of time at ambient temperatures up to 200° C.

b. CARBON BLACKS. In general, carbon blacks have not proved as stable as the graphites at temperatures as high as 200° C. When the ambient temperature is lowered somewhat, to say 150° to 180° C, their performance improves markedly, and they are well qualified for service in this temperature range. Even at these lower temperatures they are a distinct improvement from a temperature standpoint upon the resistors in use today.

Carbon blacks are available in a multitude of grades and types. In this study it was found that properties of the carbon blacks fall into two groups corresponding to the two categories, channel blacks and furnace blacks. The furnace blacks, furthermore, seem to be of two types electrically, for convenience called furnace blacks A and B. Twelve channel blacks and nine furnace blacks were tested and rated according to their behavior under load-life tests.

c. CHANNEL BLACKS. A channel black is a carbon black produced by impingement or contact of fan-shaped natural gas flames on a channel surface.[1] Extensive use for

[1] I. Drogin, Devçlopment and Status of Carbon Blacks, United Carbon Co., Inc., Charlestown, W. Va. (1945).



GENERALIZED LOAD—LIFE CHARACTERISTICS AT 200° C OF VARIOUS CLASSES OF CARBONS USED IN THE NBS TAPE RESISTOR SYSTEM (SEE P. 9)

FIG. 2-1

this material is found in the manufacture of rubber. As a high-temperature resistive coating, channel blacks are unsatisfactory because of failure during load-life tests at 200° C, although at temperatures below 200° C the load-life qualities show a decided improvement. Typically, in load-life tests at 200° C, channel black resistors increase rapidly in resistance; after 500 hours the resistance is far in excess of the desired value (fig. 2-1). For 200° C operation, therefore, channel blacks were abandoned in favor of the more suitable furnace blacks.

d. FURNACE BLACKS. A carbon black produced by the partial combustion or thermal decomposition of natural gas or other hydrocarbons in a furnace is known as a furnace black.[2] The furnace blacks studied at NBS fall into two classes in accordance to their resistive properties. Four blacks having excellent resistive characteristics comprise group A. Those with poorer characteristics are designated group B.

Furnace blacks A remain within the maximum deviation limits throughout the entire 500-hour load-life test period and have produced eminently successful resistors in the 6,000 to 500,000-ohm range. On the other hand, furnace blacks B and artificial graphite resistors show a sharp, continuous decrease in resistance value at 200° C ambient (fig. 2-1). At lower temperatures, however, resistance values do not fall off as rapidly, and resistors adequate at 150° C have been produced from the B blacks.

2.3 Resins

Silicone resins have proved highly satisfactory in NBS tape resistor work. The silicone resin finally adopted for the NBS resistor is Dow-Corning Corp. DC996. Other silicone resins investigated include the DC804 and DC2103. DC804 was discarded because its load-life characteristics were poor. The resistance to elevated temperatures of tapes using DC804 was much less than for tapes using DC996. DC2103 silicone was also rejected, because it fails in time, finally developing a crazed surface. DC803 and General Electric Co. No. 9982 and 9989-1 were also tried, with even less success.

Tape resistors made from formulations using DC996 have curing temperatures of approximately 300° C. As curing is done after the resistors have been positioned in the circuit, the NBS tape resistor using this resin is, at present, applicable only to glass or ceramic base materials.

2.4 Resistance Paint Formulations

The formulations found to be successful are exceedingly simple, consisting only of graphite or carbon black, resin and solvent. The carbon blacks are calcined before use. Two methods of calcining carbons have been used. There seems to be a little choice in the behavior of carbons calcined by these two methods. The second method is more convenient.

In the first method, a thermocouple tube, 2-5/8-inch outside diameter, 2-1/4-inch inside diameter, and 24 inches long was used. The tube was filled to within 6 inches of the top, a plug of Pyrex glass wool was inserted, and the tube was then placed into an electrically heated tube furnace. The tube was connected by means of suitable tubing and stopcocks to a Megavac pump and evacuated. The furnace was heated to 900° C (1650°F) with the tube continuously under vacuum, held at this temperature for 1 hour, then allowed to cool to room temperature in vacuum.

[2] See note, Page 6.

In the second method, a graphite crucible was filled with carbon black, and a graphite cover was placed over the crucible. The crucible was placed in a muffle furnace and heated to about 1,100° C (2,000° F), held there for four hours, then allowed to cool. The muffle furnace can not be opened during the heating period as oxygen will ignite the crucible and contents.

Formulations are made up by using definite ratios of resin to carbon black. The carbon content of the formulations is kept, in general, between 10 to 50 percent of the total solids content. Leaner mixtures have poorer electrical characteristics. Solvent is added to make the ratio of solvent to total solids 2 to 1; the total solids content of the formulations is kept constant. All values of resistor tapes sprayed have therefore substantially the same solids content in the film.

Curves in which resistance value is plotted against resin-to-carbon ratio have been constructed for some of the carbons used (fig. 2-2). From these curves, the ratio of resin to carbon necessary to prepare the formulation required for a tape of a particular value may readily be determined. Several of the family curves overlap in resistance value. This permits some choice in selecting the carbon to give the optimum electrical properties desired.

The following formulations are typical:

1. 500-ohm formulation 4 G-09 (fig. 2-2B).

   Dixon graphite 200-09 . . . . 20 g.
   DC996 resin . . . . 160 g.
   Toluene . . . . 120 g.
   Solids present: 20 g of carbon and 80 g of resin. Total 100 g.
   Solvent present: 80 g of resin and 120 g added. Total 200 g.

2. 100,000 ohm formulation 9 S (fig. 2-2D).

   Statex A . . . . 10 g.
   DC 996 resin . . . . 180 g.
   Toluene . . . . 110 g.
   Solids present: 10 g of carbon and 90 g of resin. Total 100 g.
   Solvent present: 90 g of resin and 100 g of added. Total 200 g.

2.5 Milling Procedure

The formulations are mixed and milled in a glass or ceramic jar of suitable capacity. All ingredients- carbon, silicone resin, and solvent are added together with porcelain balls. The jar is then placed on a ball mill rolling at 80 rpm for at least 72 hours. There is some evidence that even 72 hours may not be sufficient to produce a thoroughly uniform mixture; in one series of experiments (fig. 2-3) using a Halo carbon black formation, results indicated that the tape resistance did not level off until the duration of the milling process had been extended to about 300 hours. The ball milling equipment used is shown in figure 2-4.

2.6 Coating Methods

A number of possible methods of coating the asbestos paper tape were tried in an

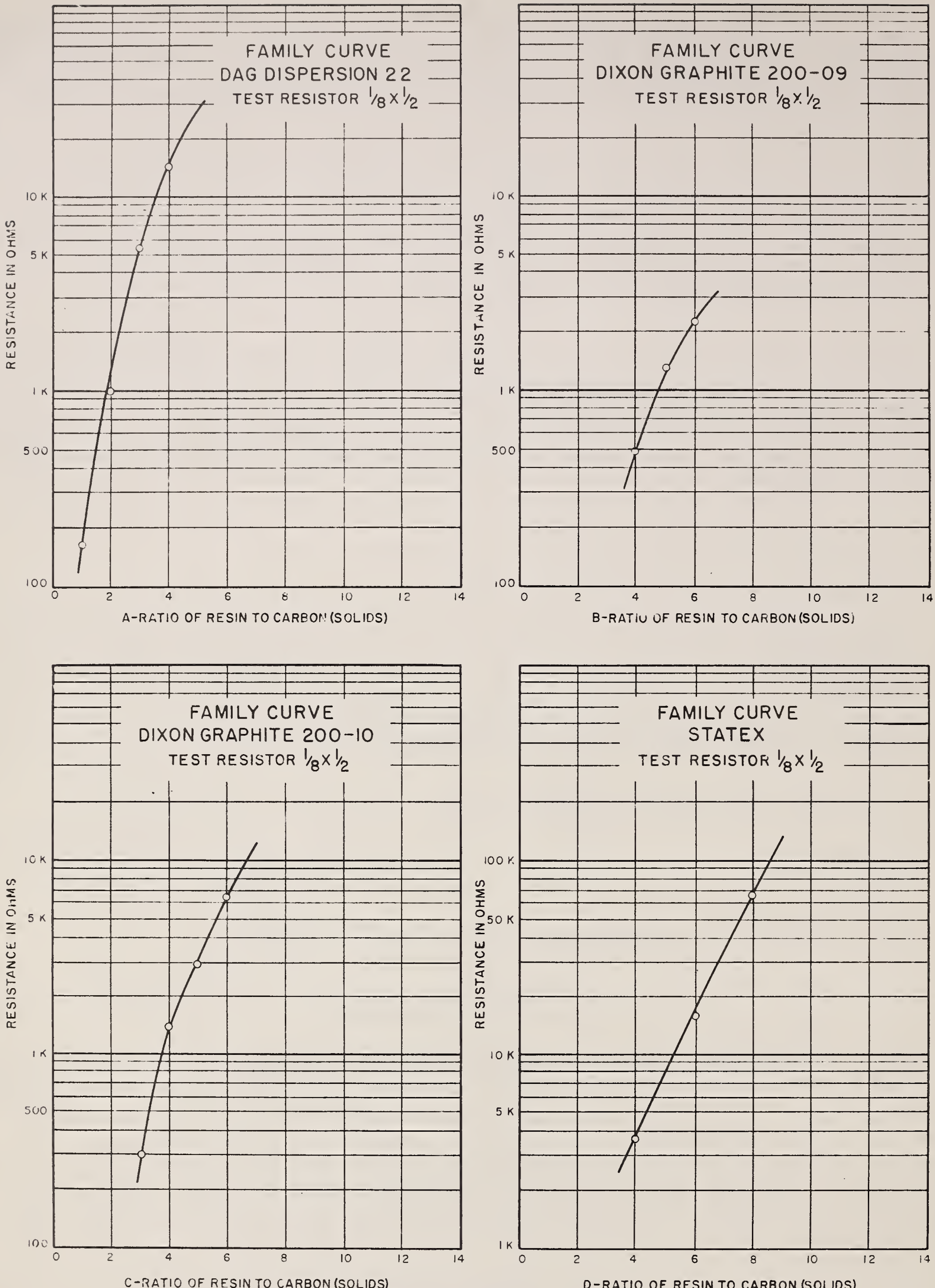
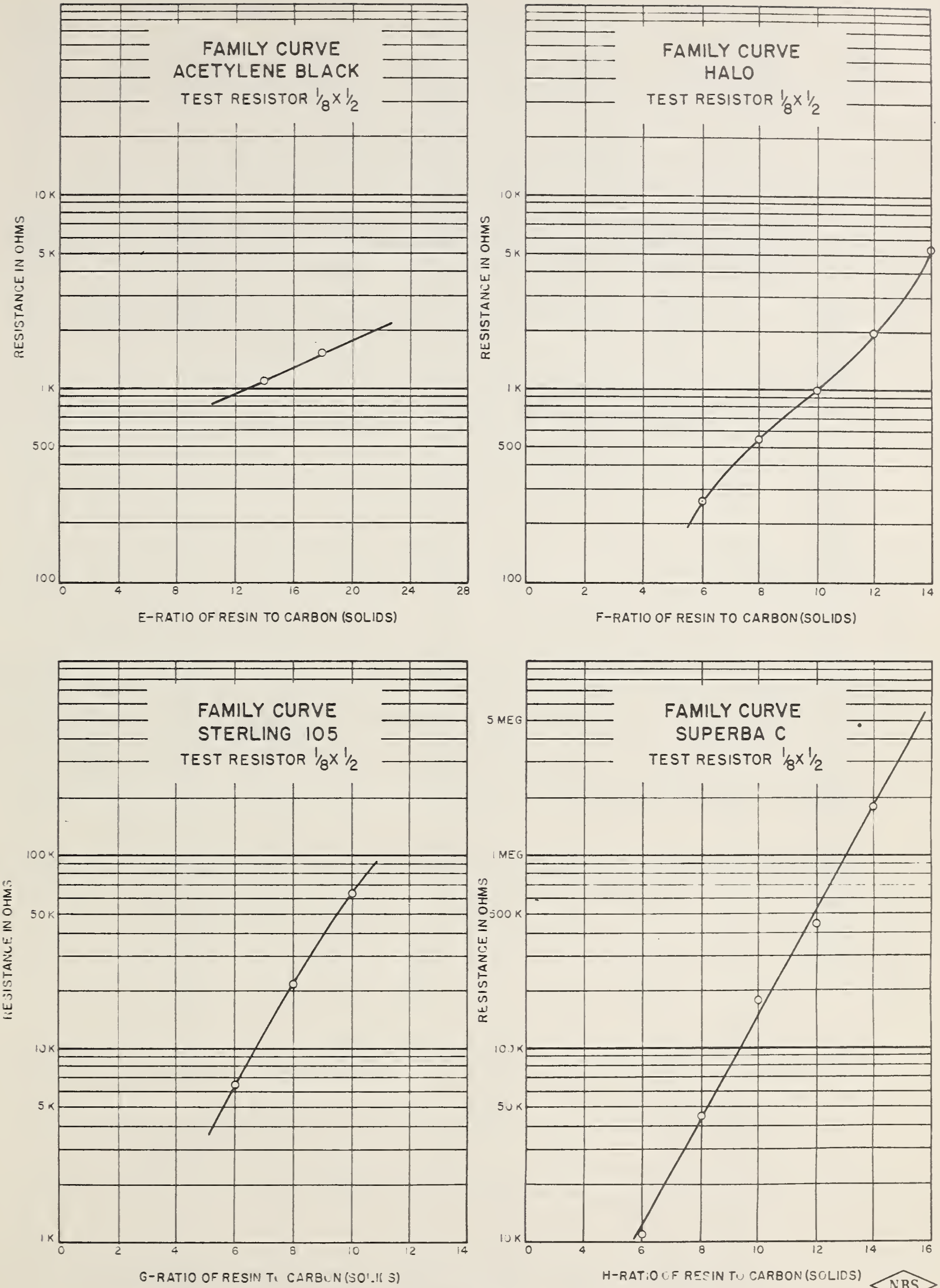

FAMILY CURVE
DAG DISPERSION 22
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
10 K
5 K
1 K
500
100
0 2 4 6 8 10 12 14
A-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
DIXON GRAPHITE 200-09
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
10 K
5 K
1 K
500
100
0 2 4 6 8 10 12 14
B-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
DIXON GRAPHITE 200-10
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
10 K
5 K
1 K
500
100
0 2 4 6 8 10 12 14
C-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
STATEX
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
100 K
50 K
10 K
5 K
1 K
0 2 4 6 8 10 12 14
D-RATIO OF RESIN TO CARBON (SOLIDS)

FIG. 2-2



FAMILY CURVE
ACETYLENE BLACK
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
10 K
5 K
1 K
500
100
0 4 8 12 16 20 24 28
E-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
HALO
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
10 K
5 K
1 K
500
100
0 2 4 6 8 10 12 14
F-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
STERLING 105
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
100 K
50 K
10 K
5 K
1 K
0 2 4 6 8 10 12 14
G-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
SUPERBA C
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
5 MEG
1 MEG
500 K
100 K
50 K
10 K
0 4 6 8 10 12 14 16
H-RATIO OF RESIN TO CARBON (SOLIDS)
NBS

FIG. 2-2

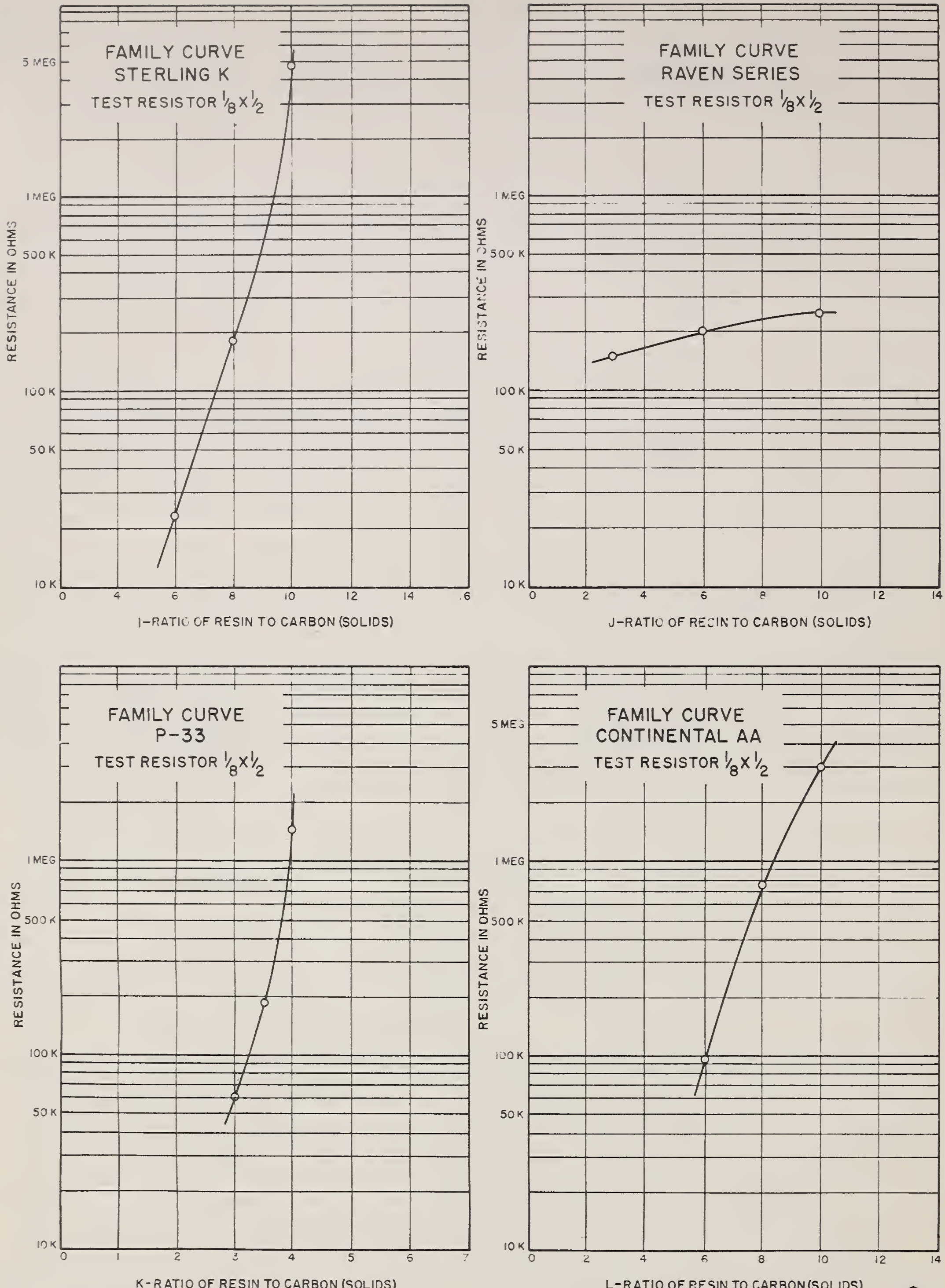
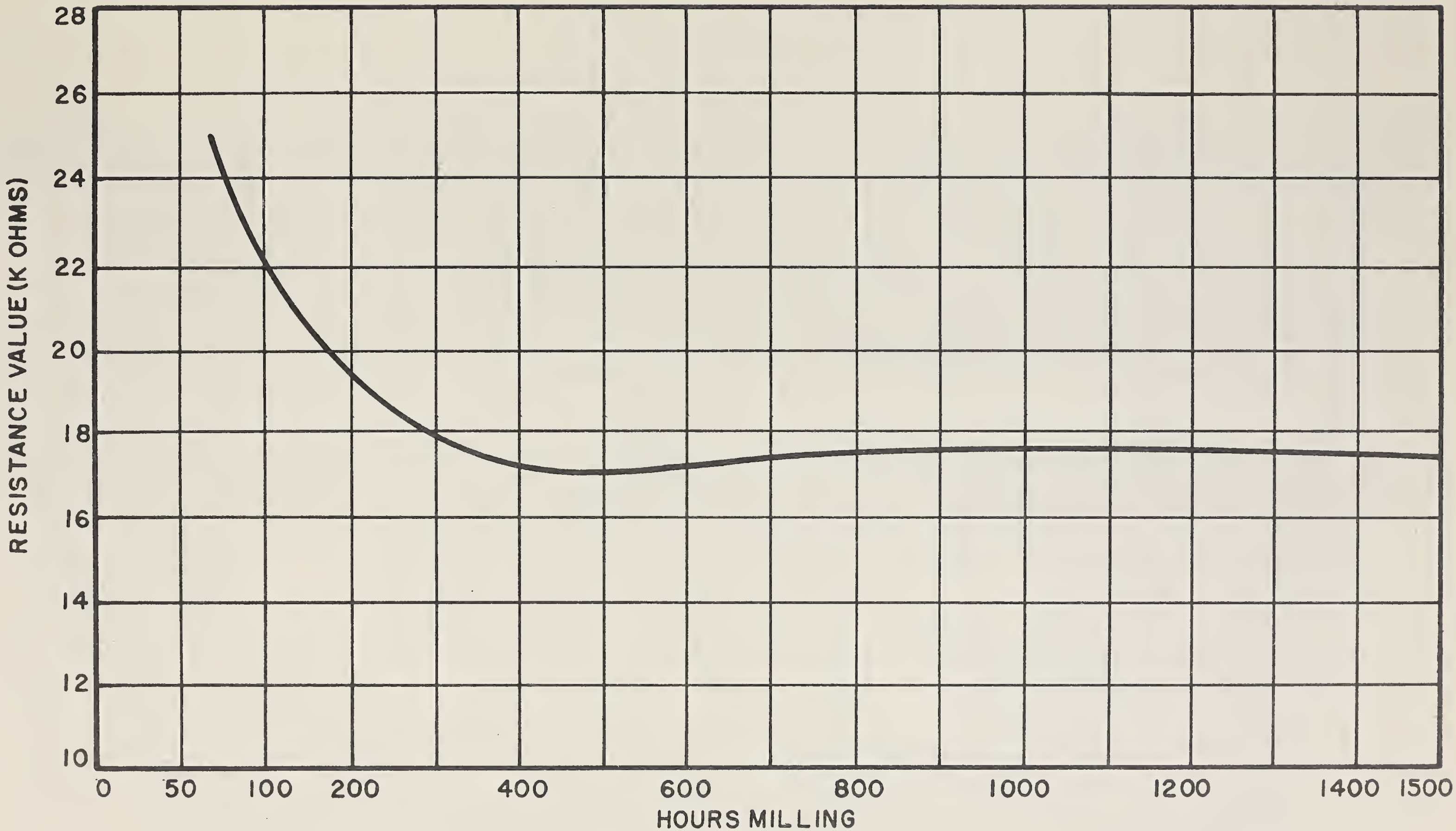

FAMILY CURVE
STERLING K
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
5 MEG
1 MEG
500 K
100 K
50 K
10 K
0 4 6 8 10 12 14 16
I-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
RAVEN SERIES
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
1 MEG
500 K
100 K
50 K
10 K
0 2 4 6 8 10 12 14
J-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
P-33
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
1 MEG
500 K
100 K
50 K
10 K
0 1 2 3 4 5 6 7
K-RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
CONTINENTAL AA
TEST RESISTOR 1/8 X 1/2
RESISTANCE IN OHMS
5 MEG
1 MEG
500 K
100 K
50 K
10 K
0 2 4 6 8 10 12 14
L-RATIO OF RESIN TO CARBON (SOLIDS)

FIG. 2-2



MILLING TIME VERSUS RESISTANCE VALUE

FIG. 2-3

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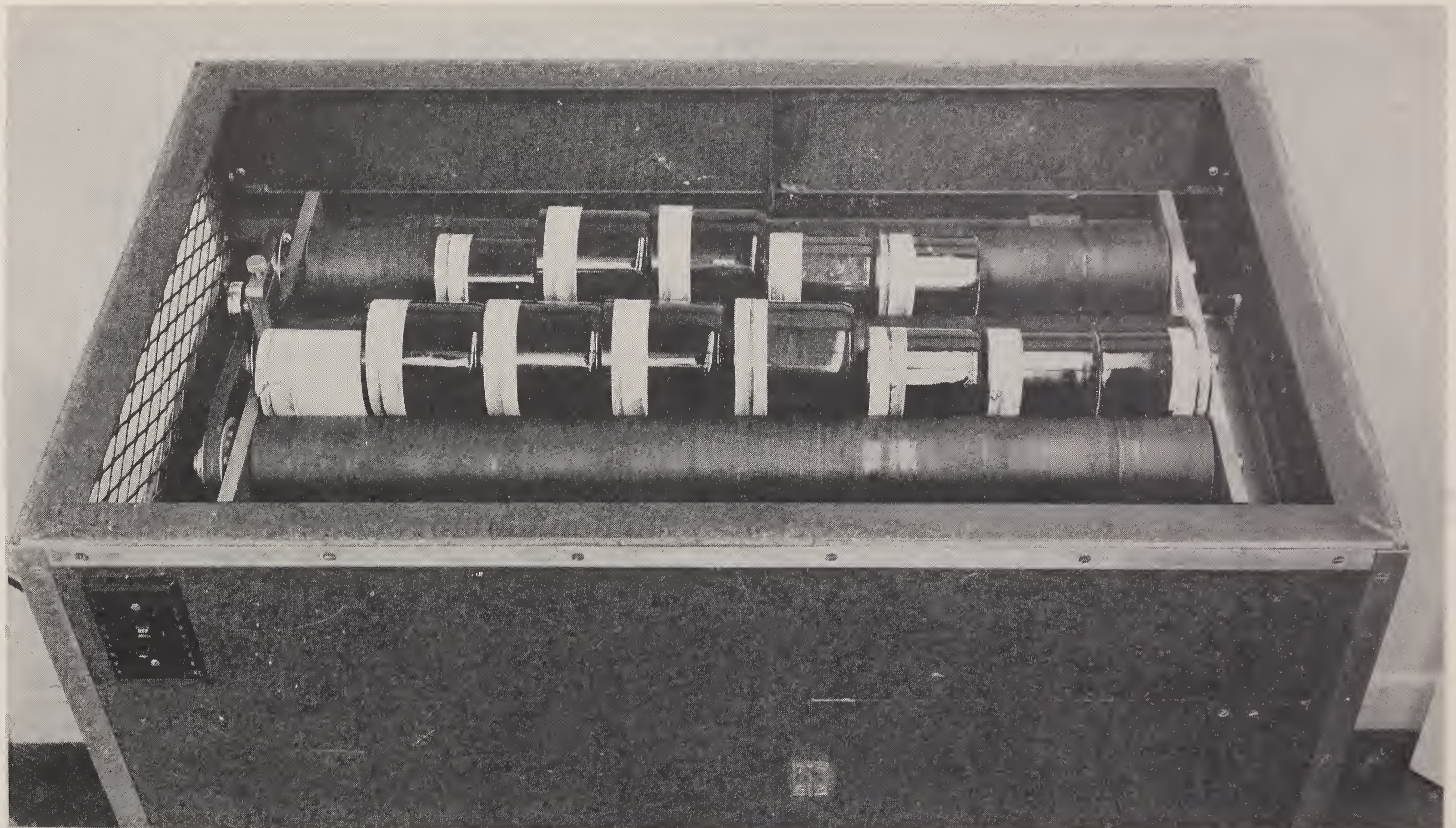


BALL MILLING EQUIPMENT FOR MIXING RESISTOR FORMULATIONS
FIG. 2-4

effort to produce a reproducible tape in fairly large quantities for test purposes. Two methods (adaptations from widely used industrial techniques) were considered most favorably prior to the adoption of the spray method. Others were under consideration when the success of the spray method cancelled any further search.

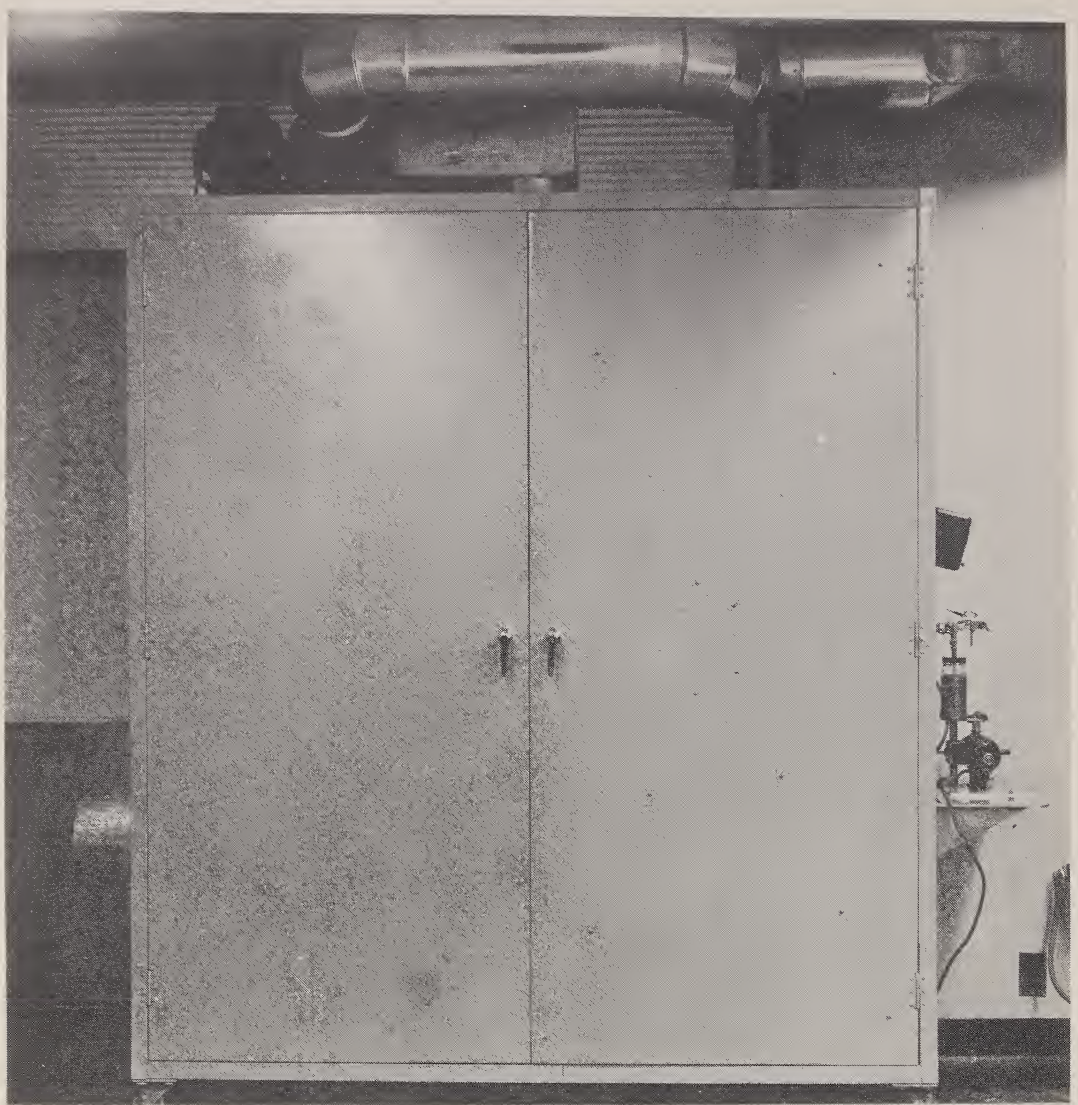
a. DOCTOR BLADE METHOD. Used extensively for laying down films, the doctor blade method was the first to be tried for coating the NBS tape resistor. The tape was placed between accurately spaced blocks so that the thickness of the film could be predetermined. A reservoir containing the resistor formulation was held above the tape, resting on the blocks. A blade, built into the reservoir, transferred the resistor paint to the tape as it was drawn under the blade. This method was abandoned because uniformity of thickness could not be attained. Moreover, the single thick coating took several days to dry before it could be placed in the circuit. During this period the resistor film would pick up dust and other contamination. Measured values of positioned resistors varied widely from design values. This nonconformity was due partly to the thickness of the one-coat film. Pressure variations used in applying the resistors seriously affected the resistance values.

b. ROLLER METHOD. Similar to the method used to moisten glued paper tape, the roller method consists of a flat wheel or roller which picks up resistor paint on its periphery from a reservoir and deposits it on the tape. As with the doctor blade method, large quantities of resistor tape could be produced. However, quality and not quantity was the goal of this project. Again, a thick resistive coating was laid down in one pass with the same unsatisfactory results. It became apparent that a better tape would be produced if the coating was applied in a large number of passes, with partial drying between passes. A multi-pass roller coating method could probably be worked out along these lines. Because of the great success of the spray method, however, both the doctor blade and the roller methods have been abandoned.

c. NBS SPRAY METHOD. The spray cabinet illustrated in figures 2-5, 2-6, and 2-7 has proved highly satisfactory for coating the NBS tape resistor. Although modifications in design are necessary for large-scale production, the simple arrangement shown has produced remarkably uniform resistor tapes. Essentially, it is a large cabinet in which the Quinterra tape, in the form of an endless belt supported on pulleys, is coated as it moves past a spray gun.

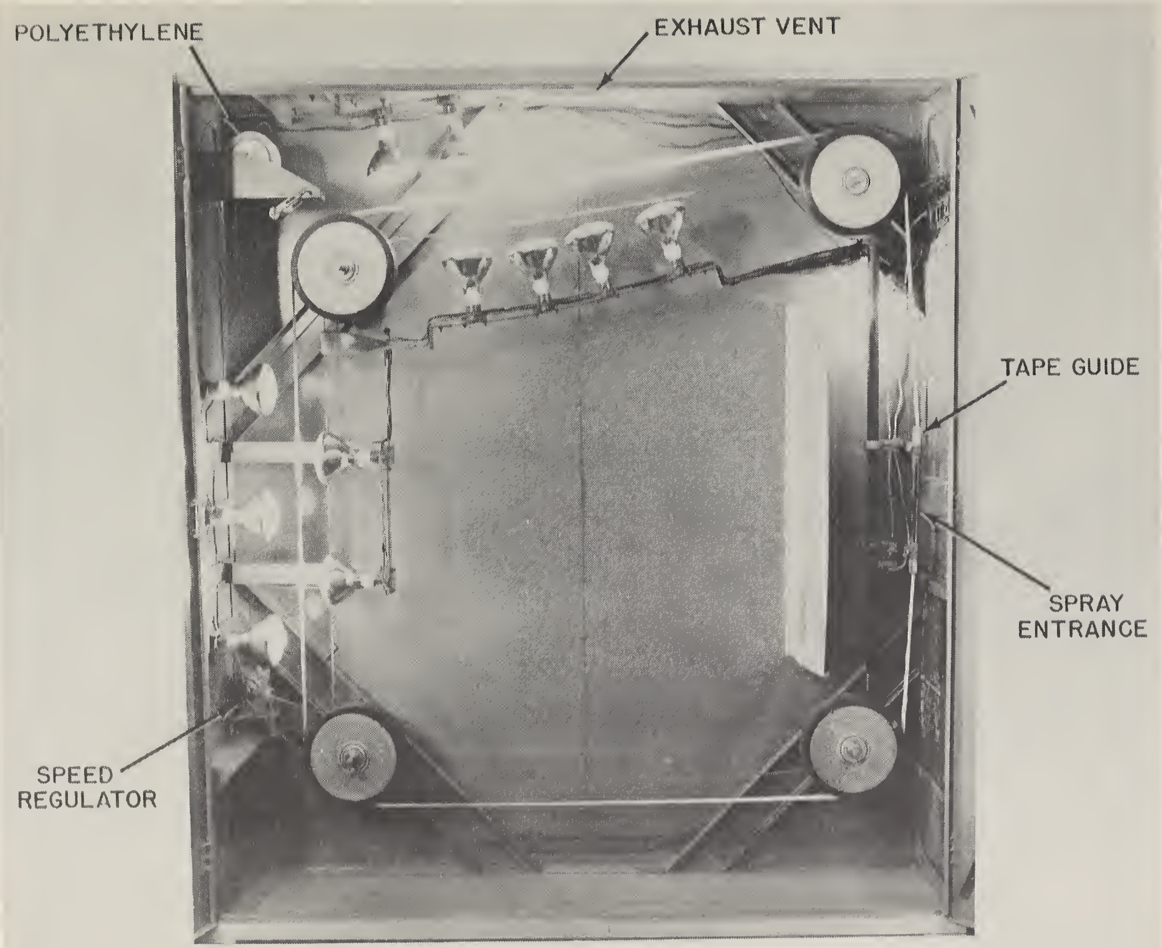
The spray cabinet, 6 feet square and 18 inches deep, is made of sheet steel. Two doors are provided to prevent the escape of solvent vapors. An exhaust-fan system is built into the top of the cabinet to remove the solvent vapors. Four rubber-coated pulleys (rubber-tired industrial wheels individually driven) are alined so that the asbestos tape rides smoothly without "walking". Power is transmitted to the pulleys by means of sprockets and ladder chains driven by a 1/4-hp motor. The pulley speed is regulated by a gear reducer and variable sheave type speed-changing mechanism. The cabinet accomodates about 19 feet of tape. The tape moves past the spray gun at a rate of about 38 feet per minute. Thirty passes are used to insure uniformity. Two and one-half ounces of formulation are sprayed during this period. This length of tape, which yields over 2,000 NBS resistors, was decided upon as a matter of convenience rather than from the standpoint of production. (This cabinet is merely a pilot setup; dimensions, capacity, and efficiency were determined in terms of demand and economy).

The asbestos tape, rough side up, is placed around the pulley system, pulled tight and the ends glued together with Duco cement. Scotch tape may be used to strengthen the

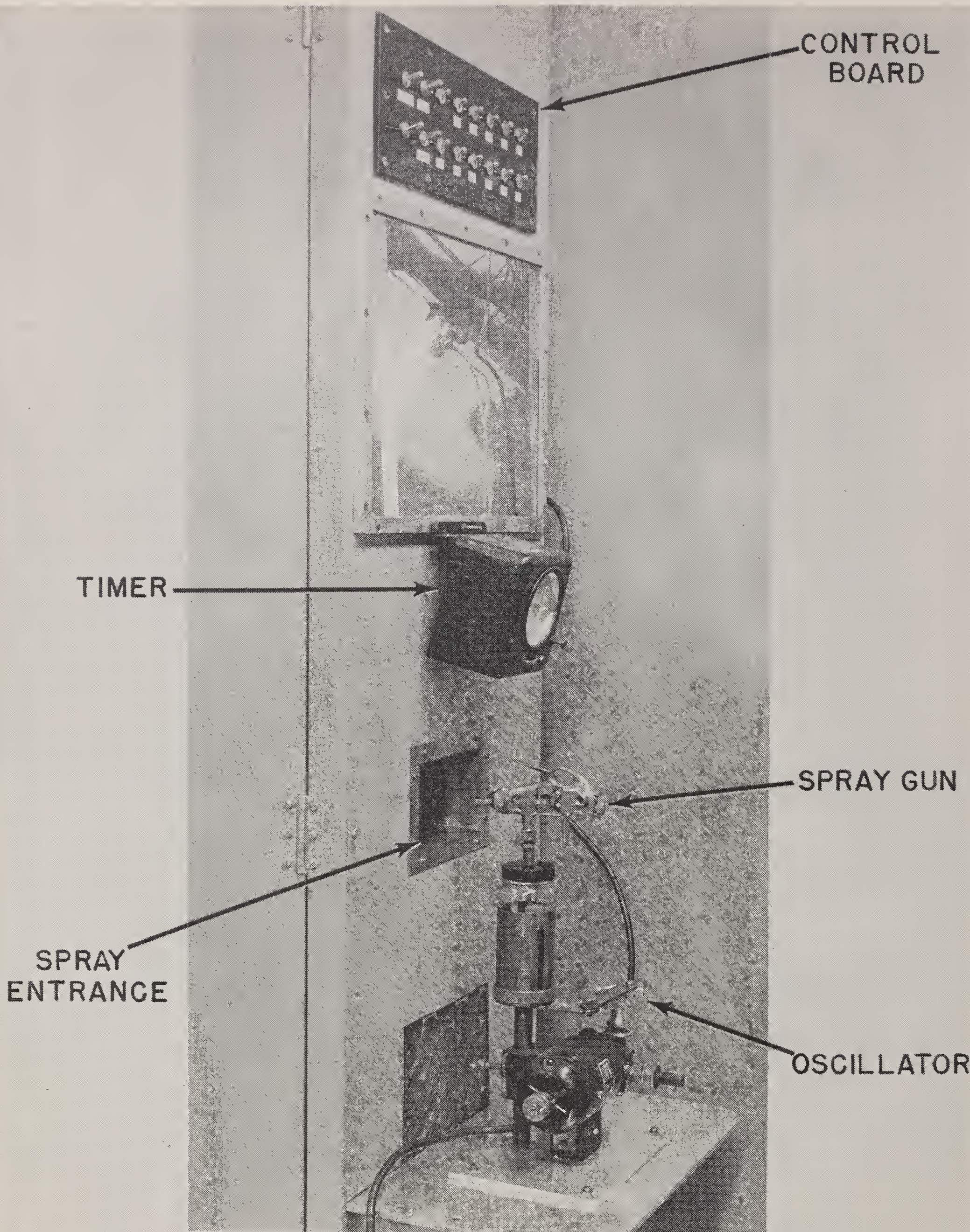


EXTERIOR VIEW OF SPRAY CABINET
SHOWING SPRAY GUN ARRANGEMENT AND EXHAUST SYSTEM

FIG. 2-5



INTERIOR VIEW OF SPRAY CABINET
ASBESTOS TAPE IN PLACE
FIG. 2-6



CLOSE-UP VIEW
SPRAY GUN ARRANGEMENT

FIG. 2-7

NBS

splice, if desired. The spliced section must be in line with the full length of tape to prevent "walking" off the pulleys. The tape passes within a few inches of 250-watt infrared heating lamps. When a high ratio of resin to carbon formulation is being sprayed, the lamps are turned on during the after spraying to hasten the removal of the solvent and dry the tape to the desired degree of adhesiveness. Care must be exercised to prevent the loss of tack. After drying, a thin film of polyethylene (0. 002 inch) is lightly pressed over the restor film on the tape as a protective coating for handling and storage. This is accomplished by means of the roller attachment shown in the upper left-hand. section of the spray cabinet.

The spray gun used is the vacuum-type Binks model 15 operating under about 20-psi pressure. The spray nozzle produces a fan spray. The spray gun is rapidly oscillated from side to side. This oscillation, together with the large number of passes and small quantity sprayed per pass, gives highly uniform resistor tapes. Figure 2-7 shows the control switches for the motors and heat lamps used in the equipment, the timer, and the spray gun with its oscillating mounting.

2.7 Slitting and Applying Tapes

There has been some interest among printed circuitry fabricators in reducing the number of formulations necessary to produce a complete range of resistance values by making dimensional changes of the resistor. This system has been called "Aspect Ratio". It is believed that this system, carried to the extent where it will materially reduce the number of formulations necessary for a range of resistor values (especially for circuitry where miniaturization is also a major consideration), introduces enough design and production difficulties to bar or severely limit its use. Instead, it has been found expedient to standardize the resistor dimensions to 0. 130 inch, ± 0. 020 inch in width and 0. 5 inch in length (0. 300-inch interelectrode distance). By means of a slitter described below, it is possible to adjust variations (of the order of 10 percent) in formulation or deposition of the resistor paint. This variation in width is then the only use of dimensional change to affect resistor value and is regarded as a temporary procedure until adequate controls have been developed to eliminate small variations. This limitation on resistor dimensions simplifies the design layout, makes the electrode silvering patterns more uniform, and gives better resistor characteristics. With the dimensions the same, wattage ratings of the resistors remain substantially constant regardless of value, and different contact resistance values due to different contact areas of silver and resistor are eliminated. In the NBS tape Resistor System, changes in resistor value are accomplished by varying the ratio of resin to carbon in the formulation and by changing carbons.

The resistor tape, as it comes from the spray cabinet, is 1-1/4 inches wide. This width has been selected only for convenience, and a wider or narrower tape could readily be made. Coated with the protective polyethylene film, the tape may be handled and stored in an uncured, or "green", condition. The tape is then cut by the slitting machine, described and illustrated in section 2. 6a. Five tapes are slit from the 1-1/4-inch starting material. These may be of the same width, or may vary in fixed steps of 0. 010 inch between the limits of 0. 110 inch and 0. 150 inch. Other spacers may be used, and other widths of tapes slit.

The resistor tape may be tested for value before the entire tape is slit: The slitter is set up (with the spacers varying in size from each other by 0. 010 inch) to cut a series of tapes, such as 0. 110, 0. 120, 0. 130, 0. 140, 0. 150 inch in width. A small piece of tape, six inches, is slit and the test plates are made up and cured. A test plate of steatite (fig. 2-8) measuring 1.3 inches by 1.75 inches by 0.1 inch, weighing about 10 grams (1/3 ounce) is used. This plate size was decided upon because it is fairly representative of the chassis used in current printed-circuit technology. As shown in the illustration, silver electrodes are first placed upon the test plate. A silk-screen process using a special silver-containing screening paint is used to print the electrodes on the test plate. The paint used is Du Pont's No. 4731. The printing is followed by drying under an infra-red lamp and firing in a furnace at approximately 750° C (1350° F). From the results obtained, the slitter is then set to the desired value using the appropriate spacers and the entire tape slit.

With the tape in this condition, it is ready to be transformed to a usable product. First, it is placed on spools to facilitate the laying down of the resistors in the circuit. The protective plastic layer is then removed and the resistor is pressed, face down, into the circuitry like a piece of adhesive tape, in intimate contact with the printed silvered electrodes, cut to length and cured in accordance with a predetermined schedule (section 2.7). At present, the resistor tape is applied to the circuit by hand, figure 2-9, but plans are in progress to develop a mechanism, analogous to a wire stapler, which will accept a roll of the resistor tape and permit its application where desired by pressing a knob or handle.

It must be emphasized again that (1) the resistors are not cured until they are in place in the circuitry; (2) they are adhesive; making an intermediate adhesive layer unnecessary; (3) the resistance film is protected from abrasion and electrical shorts by a covering of heat-resistant tape.

a. RESISTOR TAPE SLITTING MACHINE. All work has been directed toward making a tape resistor adaptable to commercial production. It is believed the NBS Resistor System meets this requirement, and the equipment is sufficiently simple to offer no production drawbacks. The tape slitter designed and built at NBS is a simple, accurate device for attaining and maintaining close tolerances on the dimensions of the resistor. It was necessary to make this slitter flexible with regard to choice of width. The length is readily controlled by the electrode spacing printed from a silk-screen pattern. The slitter, shown in figure 2-10, has proved its merit through continued service during this study.

The cutting head consists of 12 hardened steel disc cutters. The cutting edges of the upper and lower discs overlap slightly, giving a scisors action. The knife edge gives a minimum area of distortion as the tape is cut. The cutter discs are separated by steel spacers, surface ground to close tolerance. These spacers are varied in thickness in 0.010-inch steps to vary the width of tape slit, as desired. A sewing-machine motor, controlled by a resistor-type foot-pedal switch, drives the cutter head by a large pulley and appropriate gearing. This machine can cut to a high degree of accuracy, thereby minimizing the effect of variations in width.

b. RESISTOR DIE-CUTTING PRESS. An alternate method of cutting out resistors, once used in this program but abandoned because of the need for auxilliary equipment, utilized a punch and die. This method is well suited to mass-production methods because it can simultaneously cut the resistor to size and place it in the circuit. Both the length and width are determined in a single operation. The resistor tape is placed between the two cutting members, which are hardened and ground to size. The punch is brought down and the tape is cut. The top surface of the die is chromium plated to minimize adherence of the tape. This press is illustrated in figures 2-11 and 2-12.

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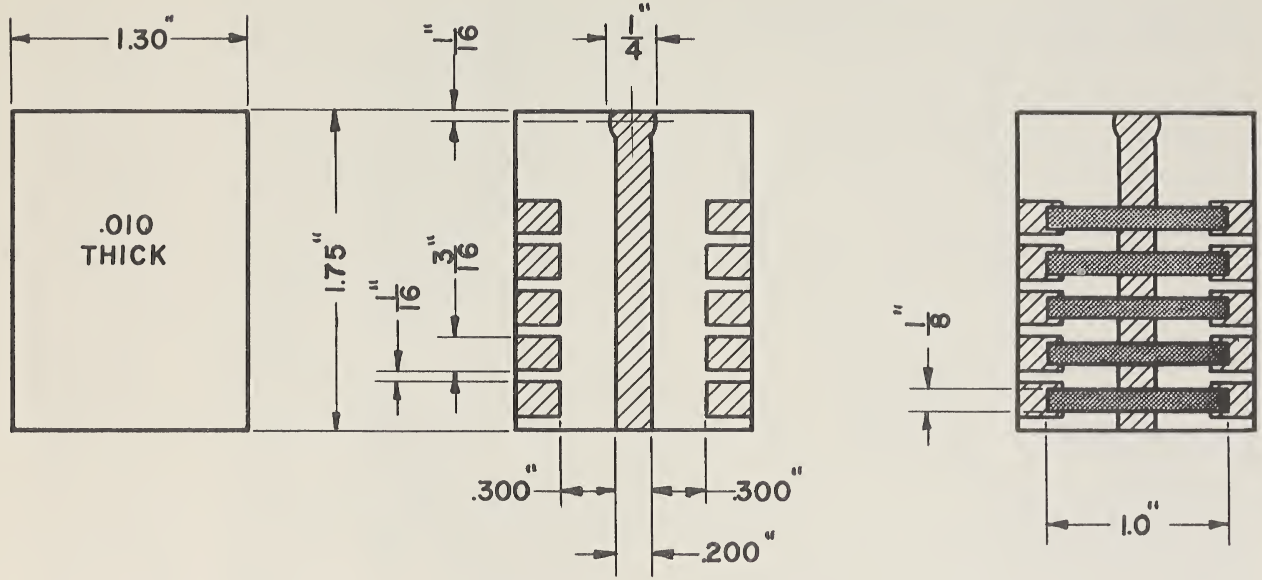


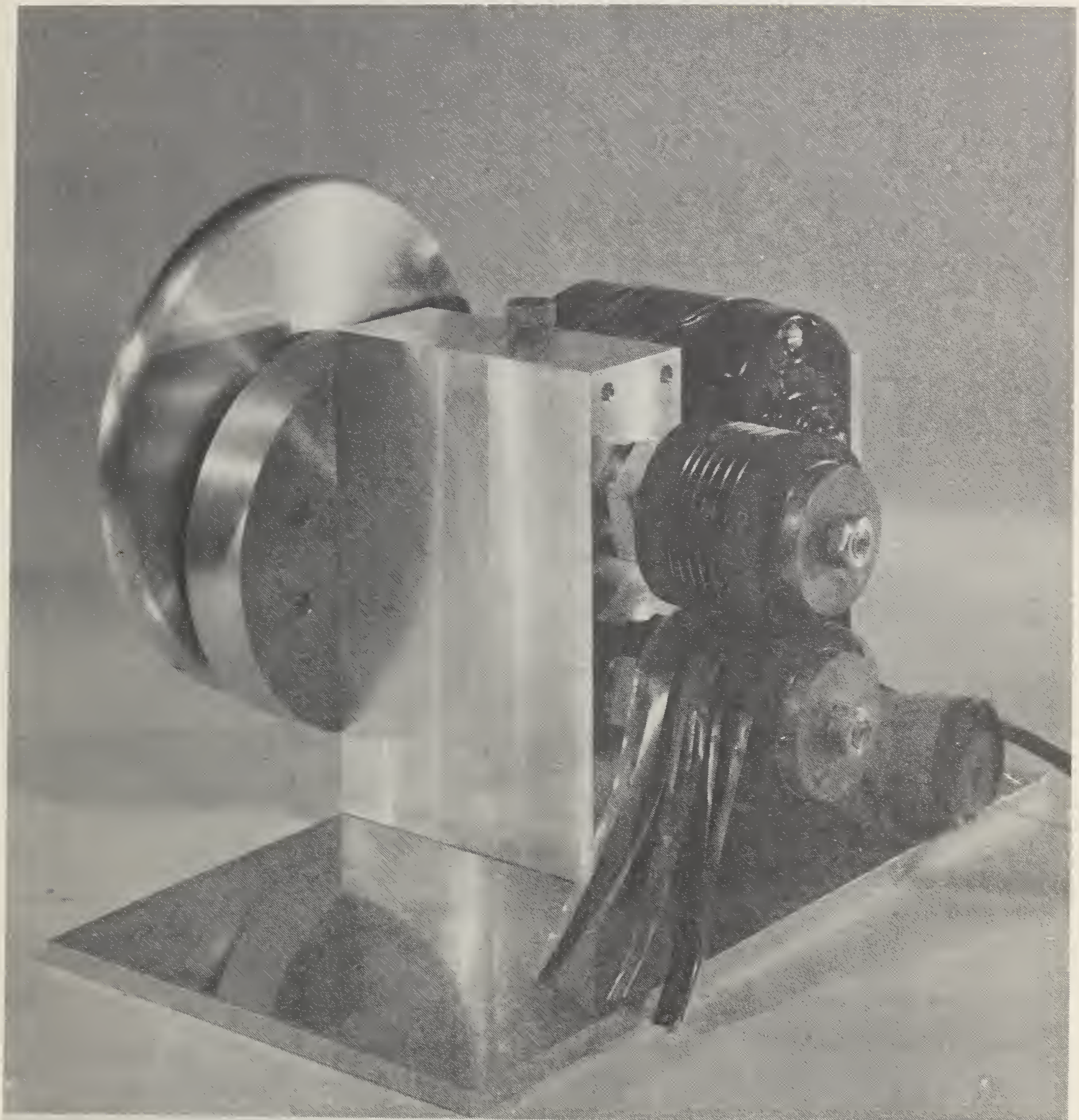
RESISTOR TEST PLATE

TEST PLATE IMPRINTED
WITH CONDUCTIVE SILVER TERMINALS

COMPLETED RESISTOR
TEST PLATE

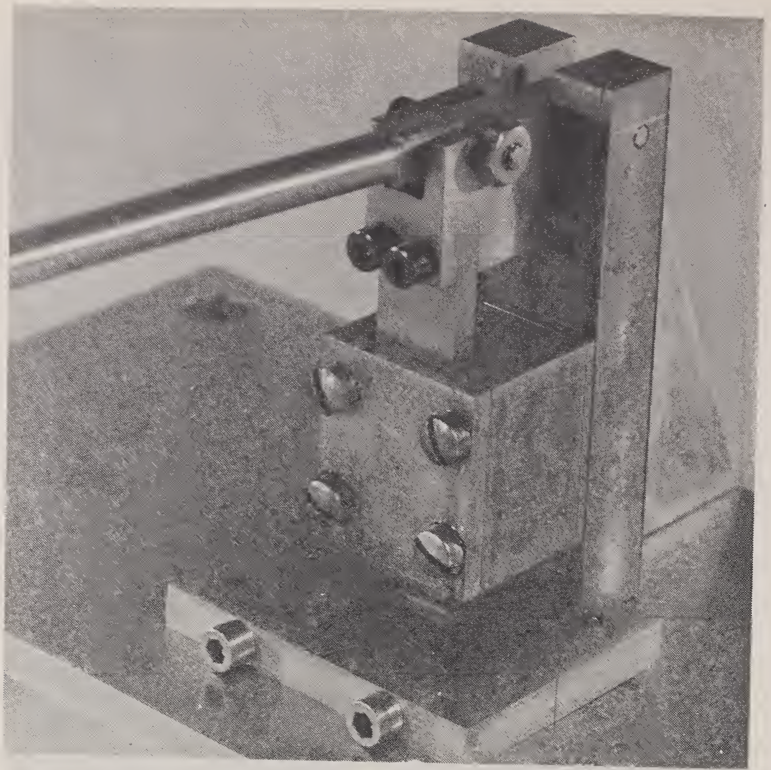
FIG. 2-8

PLACING THE NBS TAPE RESISTOR IN CIRCUIT
FIG. 2-9

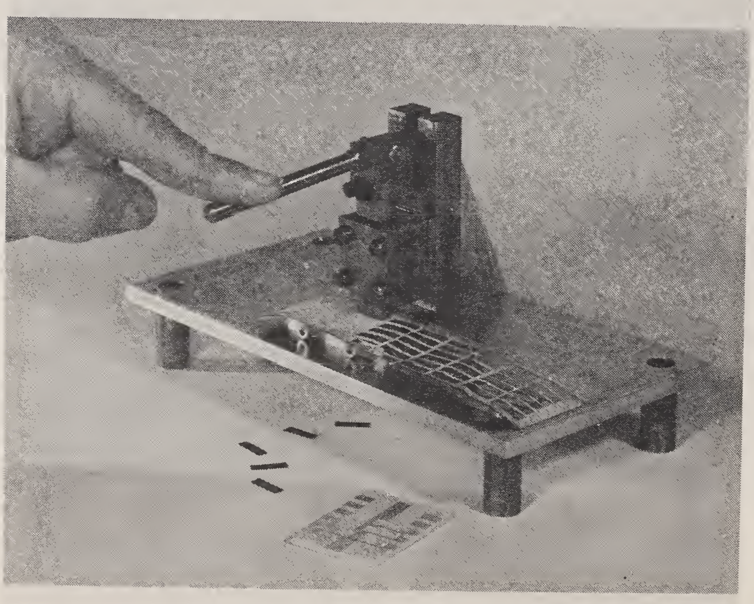


EQUIPMENT FOR SLITTING RESISTOR TAPE
GUARD AND FEED GUIDES REMOVED TO SHOW CUTTING HEAD

FIG. 2-10



CLOSE-UP OF RESISTOR DIE-CUTTING PRESS
FIG. 2-11



DIE-CUTTING PRESS IN OPERATION
FIG. 2-12

NBS

2.8 Curing of Resistors

After the resistor has been placed in the circuit, it must be cured to fix its resistance value. The curing process consists of placing the entire circuit, contained on the ceramic plate, in an oven and heating for a prescribed period of time at a predetermined temperature. The determination of the optimum temperature and time cycle has been the object of much experimentation. It is of the utmost importance to cure the resistors at the proper temperature and for the correct length of time. All carbons do not react identically in curing: each carbon requires a different temperature and time cycle to reach an optimum stable value. This has necessitated the adoption of a compromise cure schedule, for the design of printed-circuits usually requires several resistors of different values on the same base. Usually these resistors are of divergent values and use different carbon formulations. Since the optimum cures may differ, a compromise cure must be used.

a. ESTABLISHMENT OF CURE TIME AND TEMPERATURE. To justify the choice of the time and temperature of the cure chosen, a detailed account of the accumulated data obtained from testing about 6,000 resistors will be presented.

The graphs shown in figures 2-13 to 2-17 illustrate the reactions of individual carbons to different curing procedures and their subsequent behavior in load-life tests. It can readily be seen that no single cure is satisfactory for all. Artificial graphites, composed of the various Dags, react best to load-life tests when cured for 4 hours at 300° C or even 350° C. The natural or Dixon graphites are most stable when they have been cured for 4 hours at 300° C. The furnace blacks, represented by the Statex and Sterling carbons, behave best when cured for either four hours at 300° C or 3 hours at 250° C. In the case of these furnace blacks and the graphites, the data indicate that an additional cure of twenty-four hours at 200° C will further stabilize the carbons under load-life. The initial drop in value, as depicted, will be eliminated, and any further change in resistance value will fall within the acceptable limits imposed as a requirement for satisfactory operation. On the other hand, there is evidence to show that even at temperatures as low as 250° C, the optimum cure temperature of the channel blacks has been exceeded (fig. 2-17). The minimum curing schedule attempted was 250° C for 1 hour. This has proved to be in excess of that required for all the channel blacks tested. In every case the data show that a lower temperature cure will be necessary. At the present, this fact has necessitated the abandonment of many of the channel blacks as resistor material.[3]

On the basis of the material at hand, the compromise cure schedule adopted consists of a 4 hour treatment at 300° C, followed in some cases by 24 hours at 200° C. Experimentation in the direction of establishing an alternate schedule, so as to include all carbons, is continuing. A cycling procedure- rapid heating and cooling between fixed temperature limits, appears promising.

b. THE CURING FURNACE. A muffle-type furnace with good temperature control is used to cure the resistor samples (fig. 2-18). Owing to the poor thermal distribution in a furnace of this type, a liner of 1/4-inch aluminum is placed around the furnace chamber to give more uniform temperature. Shelving, of 1/4-inch aluminum, is fitted into the

[3] For the purpose of illustration, a typical channel black, Halo, has been chosen. The remaining graphs dealing with the effect of cure schedules upon load-life characteristics are presented in Apendix A.

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING ARTIFICIAL GRAPHITE

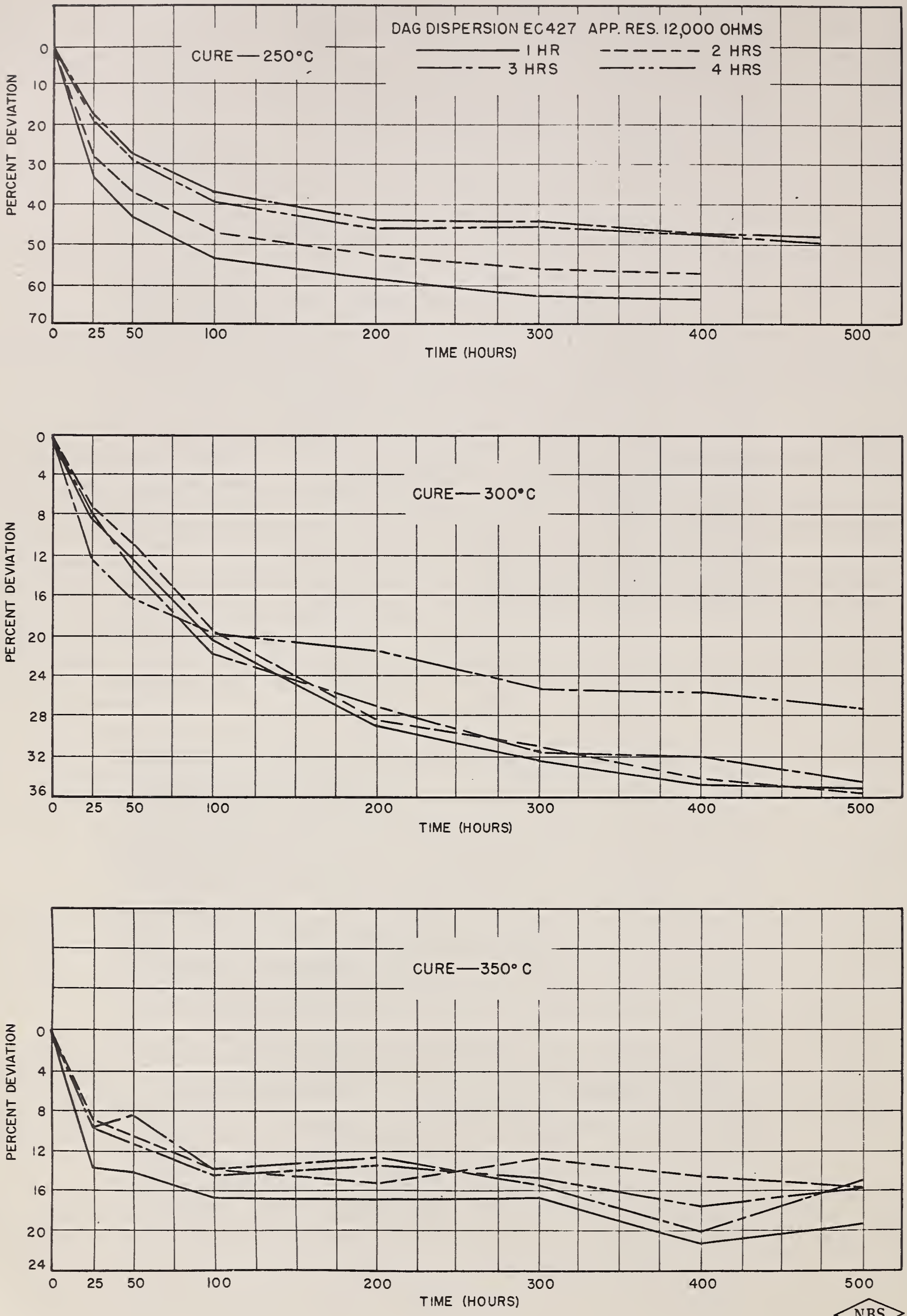


FIG. 2-13

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING NATURAL GRAPHITE

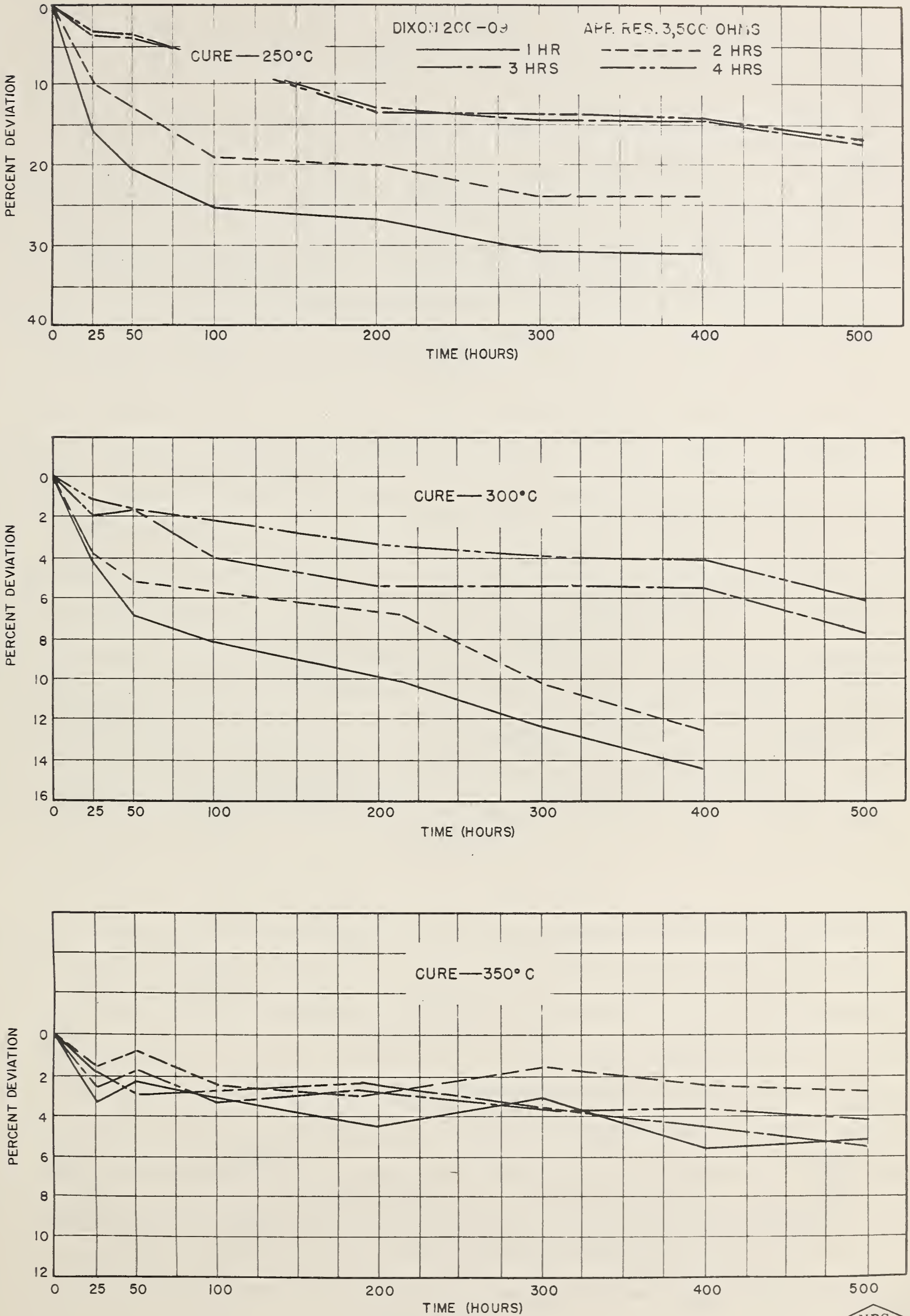


FIG. 2-14

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING FURNACE BLACK

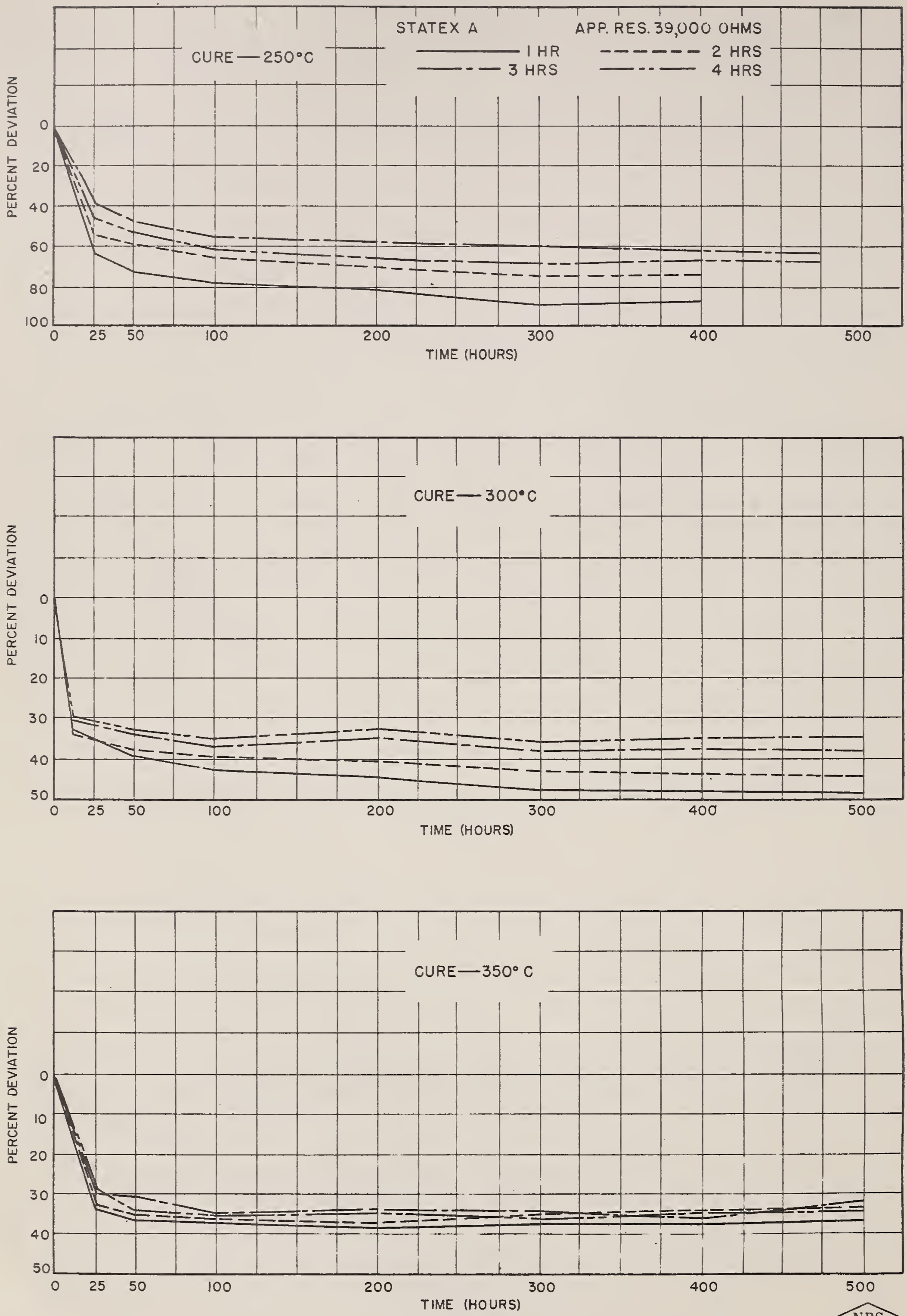


FIG. 2-15

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING FURNACE BLACK

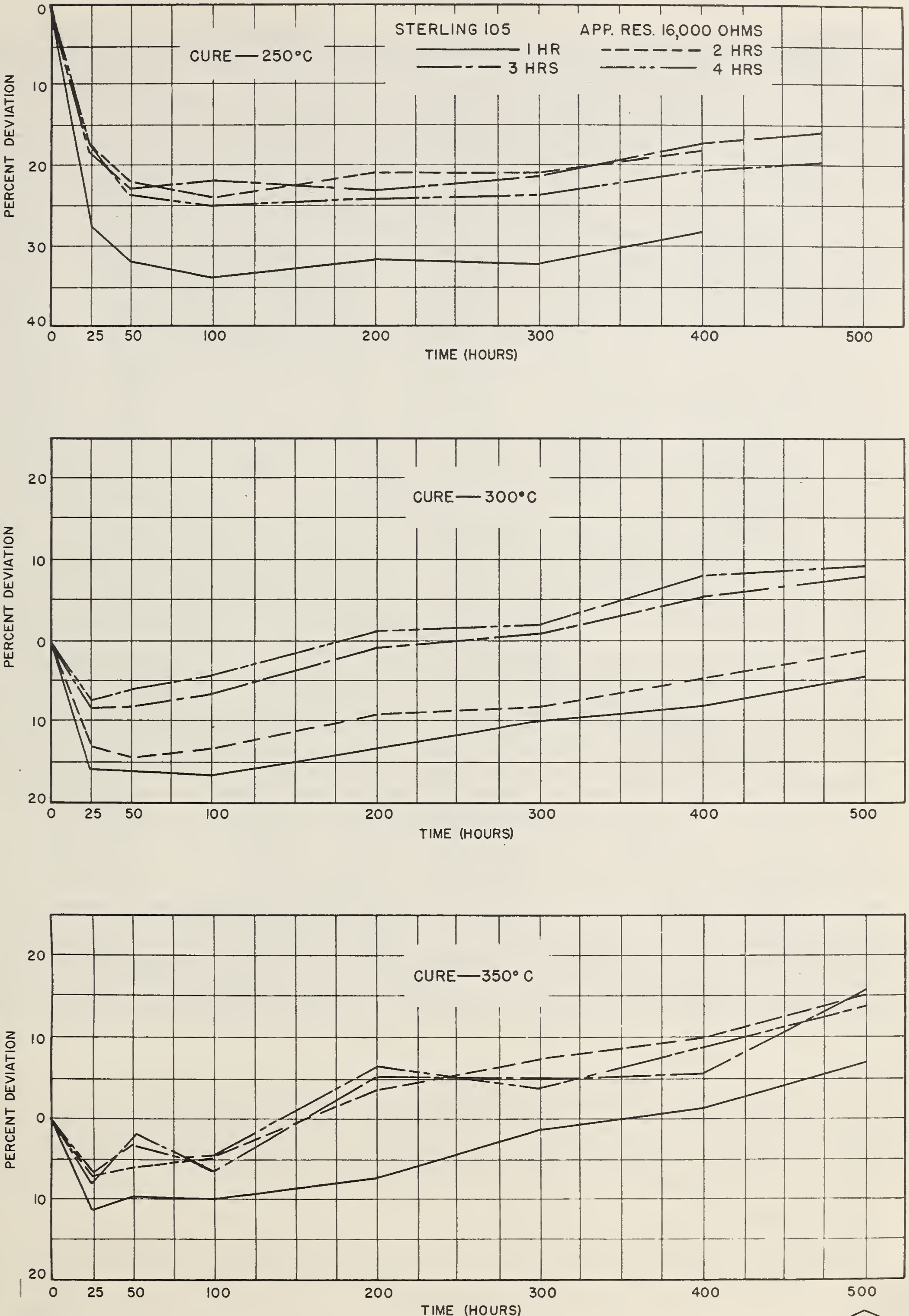


FIG. 2-16

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EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

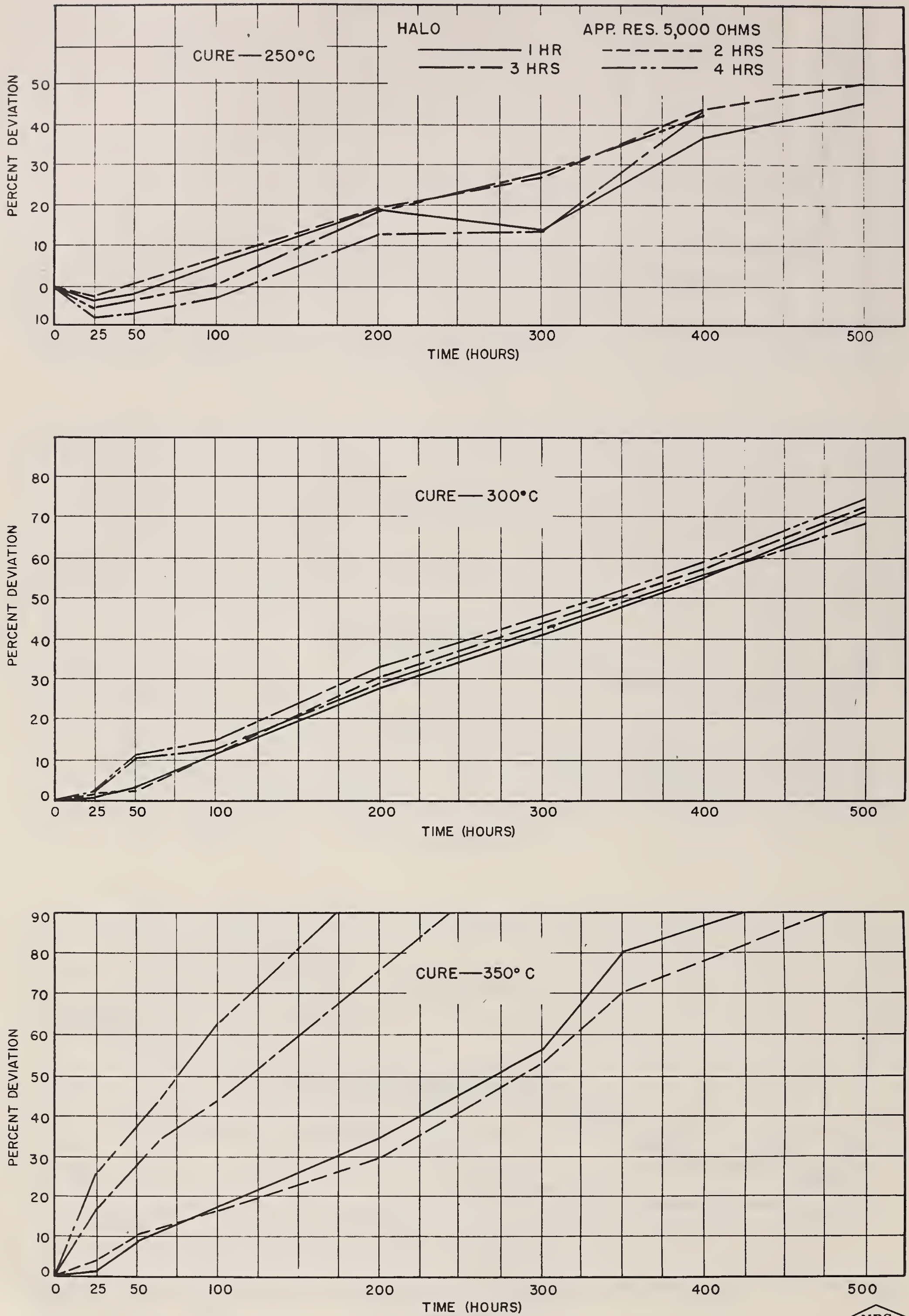
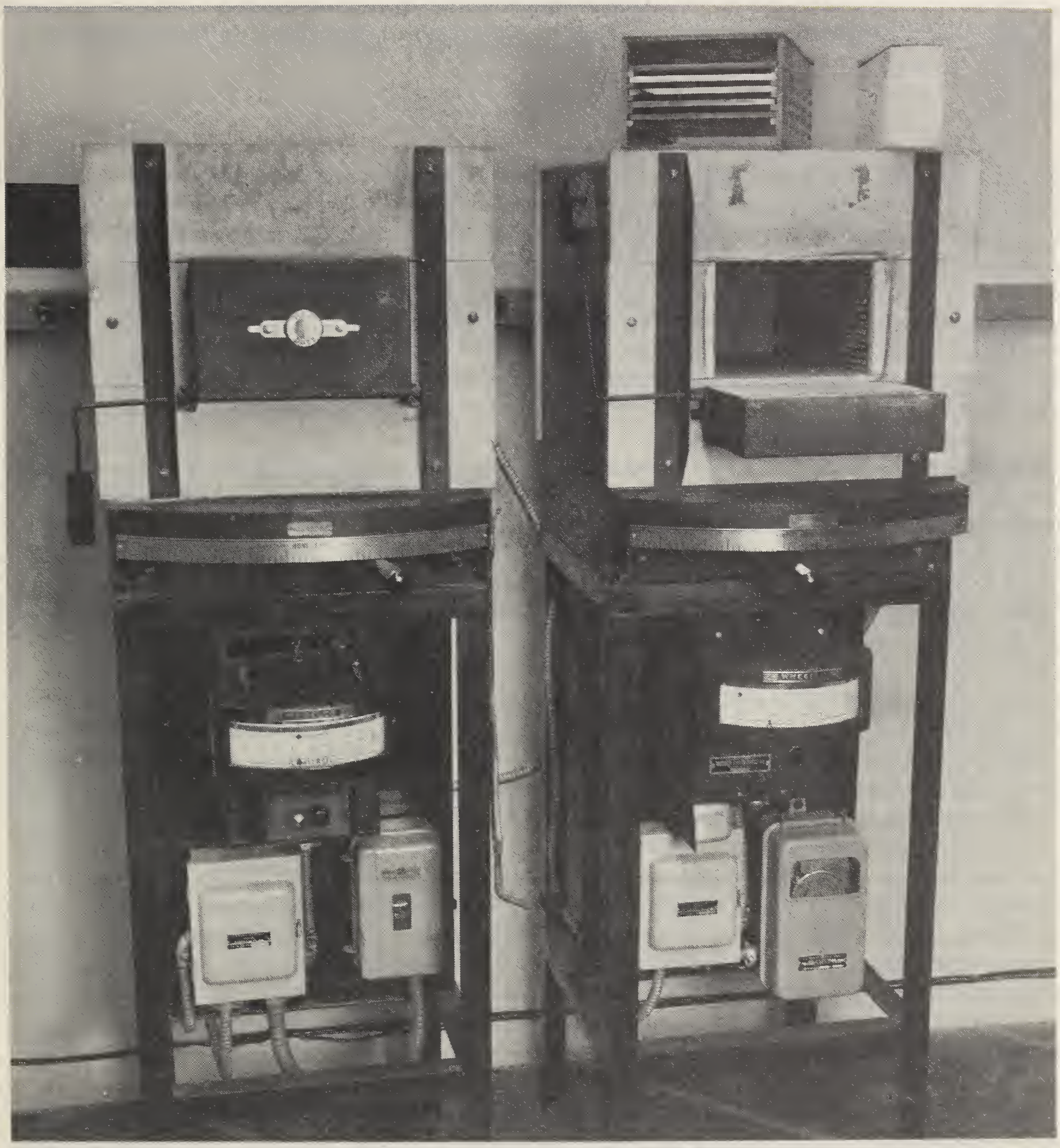


FIG. 2-17



MUFFLE FURNACES FOR CURING RESISTORS
ALUMINUM LINER AND ADDITIONAL INSULATION REMOVED

NBS

FIG. 2-18

chamber to provide increased space. In the usual laboratory-type muffle furnace, at 300° C the temperatures in various parts of the furnace differ by as much as ±15° C from the value indicated by the temperature controlling thermocouple. The insulation provided in the furnace construction was augmented by additional insulation at the front of the furnace. The aluminum liner and increased insulation have reduced the temperature variations to less than ±2° C.

2.9 Low-Valued Resistors

The importance of a low-valued carbon-resin film-type resistor warrants a separate discussion. The range of values from 10 to 100 ohms has always presented difficulties, even in conventional commercial film-type resistors. One manufacturer uses wire exclusively for low-value resistors. Results obtained using the NBS Tape Resistor System have shown promise in obtaining values in the range below 100 ohms. All methods experimented with are characterized by the inclusion of metallic material in the resistor formulations. This is accomplished in two ways. Either the metal is included as an integral part of the carbon-resin-solvent mixture or it is sprayed separately so that two distinct formulations are required.

In the former method, silver, aluminum, stainless steel and carbonyl iron were added to resistor formulations. When silver is used, the amount added is so critical that acceptable resistors can not be made. If too little silver is added, it has no effect on the resistance, and values above 100 ohms result; if the critical value is exceeded, the effect of the carbon is negligible with the result that values below one ohm are obtained. The other metals produced resistors whose values were too high (in excess of 150 ohms). It was therefore necessary to adopt the second spraying procedure.

Previous research had established that spraying a mixture consisting only of silver and resin produced an extremely low valued resistor. The new method consisted of shunting the regular carbon resistor with a layer of silver. Better results are obtained if the silver is placed first upon the tape, followed by the layer of carbon. Resistance values are determined primarily by the thickness of the silver film.

While no definite procedure has been adopted as yet, the general spraying process is as follows: The tape is placed in the spray cabinet in the conventional manner. From one to thirty passes of silver are deposited depending on the resistance value desired. The spray formulation is composed of 2 parts silver powder (DuPont V-9), 3 parts silicone resin (DC996), and a suitable solvent and (solvent content equals twice solid content). Constant agitation of the formulation, during spraying, is required because of the rapid settling of the silver from the mixture. After the silver has been sprayed and dried, the carbon is deposited upon the silver base and the tape is processed in the manner previously described. It is usual to spray a low ratio formulation (1 to 1 or a 2 to 1 ratio) of a natural or artificial graphite. When used alone, this carbon formulation produces tapes having values ranging between 80 and 150 ohms.

The resistors were cured under standard conditions - 4 hours at 300° C. Values have been obtained, using this process, ranging from 100 to 0.5 ohms. Under load-life, these resistors remained well within the ±6-percent change limit. The metallic inclusion in these tape resistors adversely effects the temperature coefficient values, however, and much is still to be desired in this respect.

The accuracy achieved in higher value resistors (100 to 500,000 ohms) is not as yet attainable. It is believed that continued research along the lines described above will produce suitable low-valued resistors.

Table 2.1 Some properties of NBS Tape Resistors

Commercial name	Particle size	Highest ratio [a]	Resistance for high ratio [b]	Lowest ratio [a]	Resistance for low ratio [b]	Temp. coefi-cient [c]
Artificial Graphites						
Dag Dispersion 22	(d)	6	770K	1	100	F (f)
Dag Dispersion 47	(d)	5	91K	---	---	F (f)
Dag Dispersion 2412	(d)	5	43K	(e)	---	F (f)
Dag Dispersion 2475	(d)	5	86K	(e)	---	F (f)
Dag Dispersion EC-427	(d)	5	30K	2	780	F (f)
Dag Ultra-Fine	(d)	5	5K	---	---	(g)
Natural Graphites						
Dixon 200-08	10μ	5	1100	(e)	---	(g)
Dixon 200-09	5μ	10	72K	1	110	F
Dixon 200-10	2.5μ	6	6600	3	370	E
Dixon 200-10F	2.5μ	5	6300	---	---	(g)
Dixon 200-18	5μ	5	29K	(e)	---	(g)
Dixon 200-19	2.5μ	5	22K	(e)	---	(g)
Channel Blacks						
Continental AA	30 to 35 mμ	10	2.9Meg	4	6.4K	F
Dixie 5	16mμ	8	42K	(e)	---	F
Excelsior Black	21mμ	8	4K	(e)	---	F
Halo Black	20mμ	28	1.2Meg	6	1.2K	F
Kosmobile Hm	28mμ	8	680K	(e)	---	F
Kosmobile S	20-25mμ	8	240K	(e)	---	F
Kosmobile 77	30mμ	8	260K	(e)	---	F
Raven 15	28mμ	10	470K	6	200K	E
Spheron C	29mμ	8	40K	(e)	---	F
Spheron N	18mμ	8	13K	(e)	---	E
Superba	18mμ	6	18K	(e)	---	F
Voltex	16mμ	8	67K	(e)	---	F
Furnace Blacks A						
Statex A	50mμ	10	300K	4	5K	E
Statex "B" Beads	43mμ	8	25K	-	---	F
Sterling 99	39mμ	8	80K	-	---	E
Sterling 105	32mμ	14	140K	6	10K	E
Furnace Blacks B						
Acetylene Black	43mμ	18	1.6K	14	1.2K	(g)
Continex HMF	50-60mμ	8	685K	(e)	---	(g)
Continex SRF	70-90mμ	8	600K	(e)	---	(g)
P-33	150-200mμ	4	1.3Meg	3	63K	(g)
Sterling K	43mμ	14	185K	6	16K	E

(a) Ratio is silicone resin to carbon. A 5 to 1 ratio is 5 parts of silicone to 1 part of carbon by weight. (b) Resistance in ohms. (c) Jan-R-11 Specification ratings for maximum allowable percent change with temperature. Based on percent change per degree Centigrade from 25° C to 200° C; for actual values, consult Apendix A. (d) Particle size varies. (e) No other ratio has been made because of unsatisfactory results. (f) Based on data obtained after sample was subjected to load-life test for 500 hours. These carbons stabilize only after long periods of time at high temperatures. (g) No data are available. (E) Characteristic E in Jan-R-11 Specification. See section 3.1. (F) Characteristic F in Jan-R-11 Specification. See section 3.1

3. SPECIFICATIONS AND TEST METHODS

NBS tape resistors made from a wide variety of coating formulations have been given extensive load-life tests. In these tests the resistors were run at the design temperature of 200° C for 500 hours under 1/4-watt load, and resistance versus time was plotted. Those that proved unsatisfactory at 200° C were tested again at lower temperatures.

3.1 Specifications

The performance requirements set forth below were formulated to serve as goals for the development of the NBS tape resistor. These specifications conform closely to the JAN-R-11 specifications in most respects, except that operation at 200°C under 1/4-watt load is required.

RESISTANCE-TEMPERATURE CHARACTERISTICS. The change in resistance at any temperature, referred to an ambient temperature of 25°C, shall not exceed the limits given below:

Nominal resistance Ohms	Maximum allowable change %/°C	
	Characteristic E	Characteristic F
1,000 and below	.125	.062
Above 1,000 to 10,000	.150	.075
Above 10,000 to 100,000	.188	.094
Above 100,000 to 1,000,000	.250	.125
Above 1,000,000 to 10,000,000	.450	.225

These values are for the temperature range above room temperature, to 200°C. Only a limited amount of work has been done on temperature coefficient checking below room temperature. In every case, the NBS tape resistor has acceptable temperature coefficients well within the JAN-R-11 requirements. Seventy-two percent of the resistors tested qualified for F characteristic, and all of the remaining resistors are within requirements for the E characteristic.

VOLTAGE COEFFICIENT. The voltage coefficient shall not exceed 0.035 percent per volt. This requirement is applicable only to resistors of 1,000 ohms or more. Enough data have not been accumulated to present a complete evaluation of the NBS tape resistor. In the higher values, not all formulations developed thus far are acceptable under JAN-R-11 specifications.

EXPOSURE TO HUMIDITY. Resistors shall be capable of withstanding exposure to an atmosphere of 40° C with a relative humidity of 95 percent for 250 hours without a change of value in excess of 10 percent of the initial value. There has been no indication that moisture effects the operation of the NBS tape resistor in any manner. Immersion in boiling salt water has no appreciable effect on the resistance value.

NOISE. The root-mean-square value of actual noise generated in a resistor shall not exceed 3.0 rms microvolts per volt. This is applicable to resistors of 1,000 ohms or more. Noise tests are in progress; it is not possible at this time to attempt a complete evaluation. In the higher values, not all formulations developed thus far have noise characteristics entirely acceptable under JAN-R-11 specifications.

LOAD-LIFE. Following a measurement of resistance, rated continuous working voltage from a direct-current supply shall be applied intermittently 1-1/2 hours on and 1/2 hour off for a total of 500 hours at an ambient temperature of 200° C. Resistance measurements shall be made at the end of the 1/2 hour off period after 50, 200, and 500 hours have elapsed. The resistance change between the initial resistance measurement and each of the succeeding measurements shall not exceed a change of ±6 percent. This requirement has received the greatest attention, and the accumulated data are presented in section 2, Appendix A, and in figures A-1 through A-18.

SHORT-TIME OVERLOAD. Resistors shall be capable of withstanding a direct-current voltage equivalent to 2.5 times rated continuous working voltage for 5 seconds without change in resistance in excess of 5 percent. No conclusive tests have been performed, but it is believed that the NBS resistor can meet this requirement.

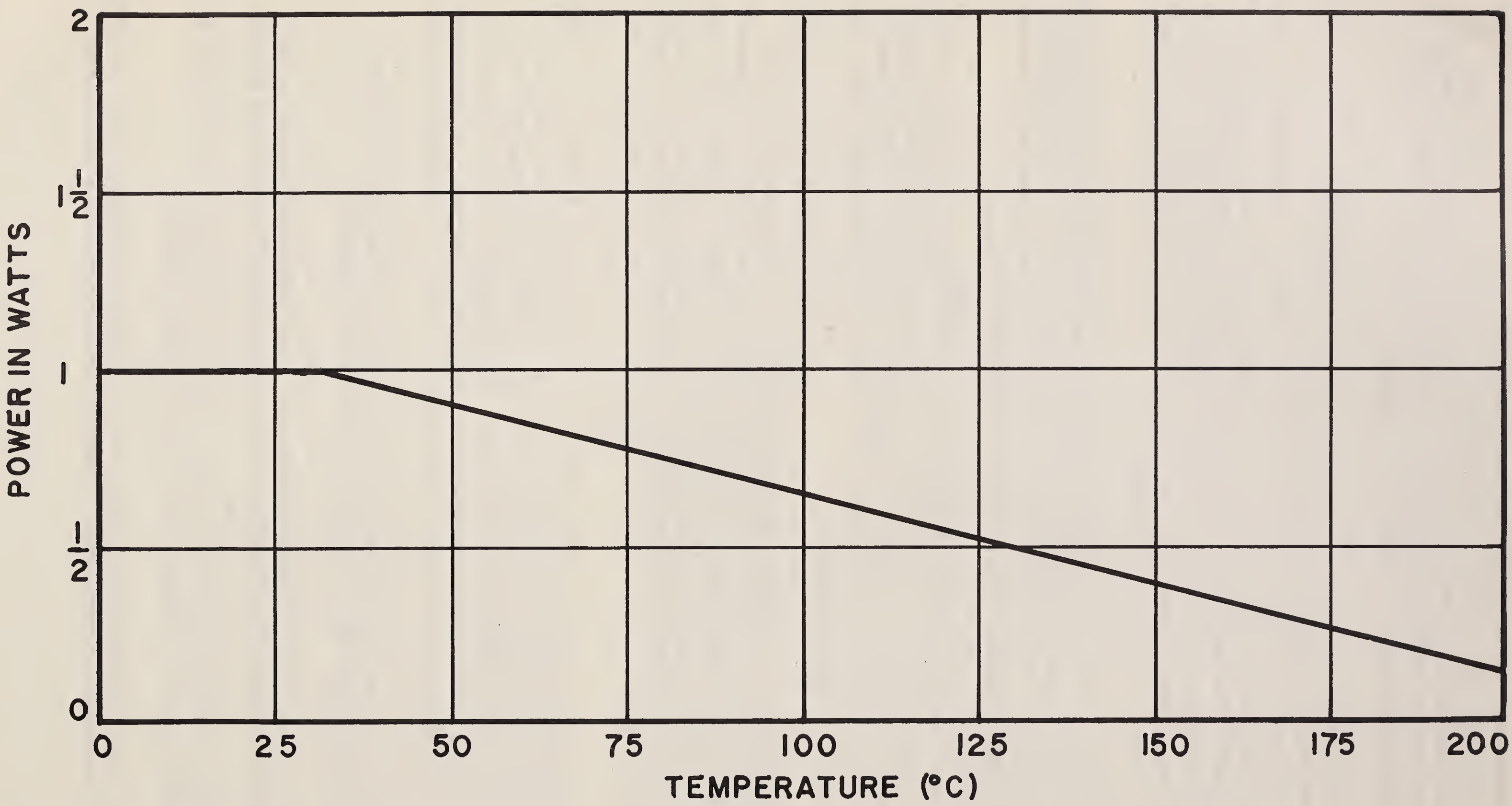
SHELF-LIFE. Resistance value must not change more than 2.5 percent of the initial value after storage for 6 months at 20° to 30° C and a relative humidity of 45 to 55 percent. The number of shelf-life tests conducted is relatively small, but if a resistor possesses good load-life characteristics (500 hours at 200° C under 1/4-watt load), it is assumed its shelf-life will also be acceptable.

TEMPERATURE DERATING. To indicate possible extension of the use of the NBS Tape Resistor System under conditions other than high temperature operation, figure 3-1 is presented. It is believed that under reasonable thermal conditions of use, this curve probably represents a fair performance evaluation of these resistors. The mounting of the chassis plate should be such as to allow dissipation of heat from other heat producing elements of the assembly.

It has been found that the heat caused by high electrical loads is more destructive than high ambient heat. An NBS tape resistor should not be operated even in low ambient temperatures under such a high electrical load as to cause the surface temperature to exceed approximately 185° C. Yet with loads of 1/4-watt, the resistor may be operated in 200° C ambients for several hundred hours without seriously affecting it. At room temperatures, and under 2-watt loads, the surface temperature of the resistors were about 120° C. At 100° C and 1-1/2-watt load, the surface temperature of the resistors was 150° C. As these temperatures are considerably below what is considered critical (185° C) it is believed that the curve given in figure 3-1 is conservative.

It must be borne in mind that the NBS tape resistor is of the carbon-resin film-type and is therefore subject to the same limitations in electrical characteristics as conventional resistors of this type. In the higher values, not all formulations developed thus far have noise and voltage coefficient characteristics entirely acceptable under JAN-R-11 specification. Continuing work, it is hoped, will improve this condition.

While the prime requirement imposed upon this study by the Navy Department, Bureau of Aeronautics, is high-temperature operation, there have been other requirements



TEMPERATURE DERATING CURVE FOR NBS RESISTORS

FIG. 3-1

which have become a fundamental part of this study. These include (1) the extension of the resistance range to the entire range from 10 ohms to 10 megohms, (2) the attainment of a high degree of reproducibility of resistance value from tape to tape, (3) the simplification of the preparation and application of the resistor formulation so as to achieve rapid production of the resistor tapes, (4) the use of readily available starting materials, and (5) the formulation of a working theory to explain the operation of the tape resistor so as to meet better the previous requirements. The NBS tape resistor has exceeded some requirements, has not fulfilled some, and has yet to be tested with respect to the remaining requirements.

3.2 Load-Life Test Equipment

To test the NBS tape resistors for high-temperature load-life, a system was devised to provide means for (1) maintaining a desired ambient temperature, (2) applying the voltage necessary to dissipate 1/4-watt, and (3) measuring and recording the resistance values of the individual resistors throughout the test period. The large number of resistors tested necessitated that all test equipment be automatic. A block drawing of the load-life test equipment is shown in figure 3-2.

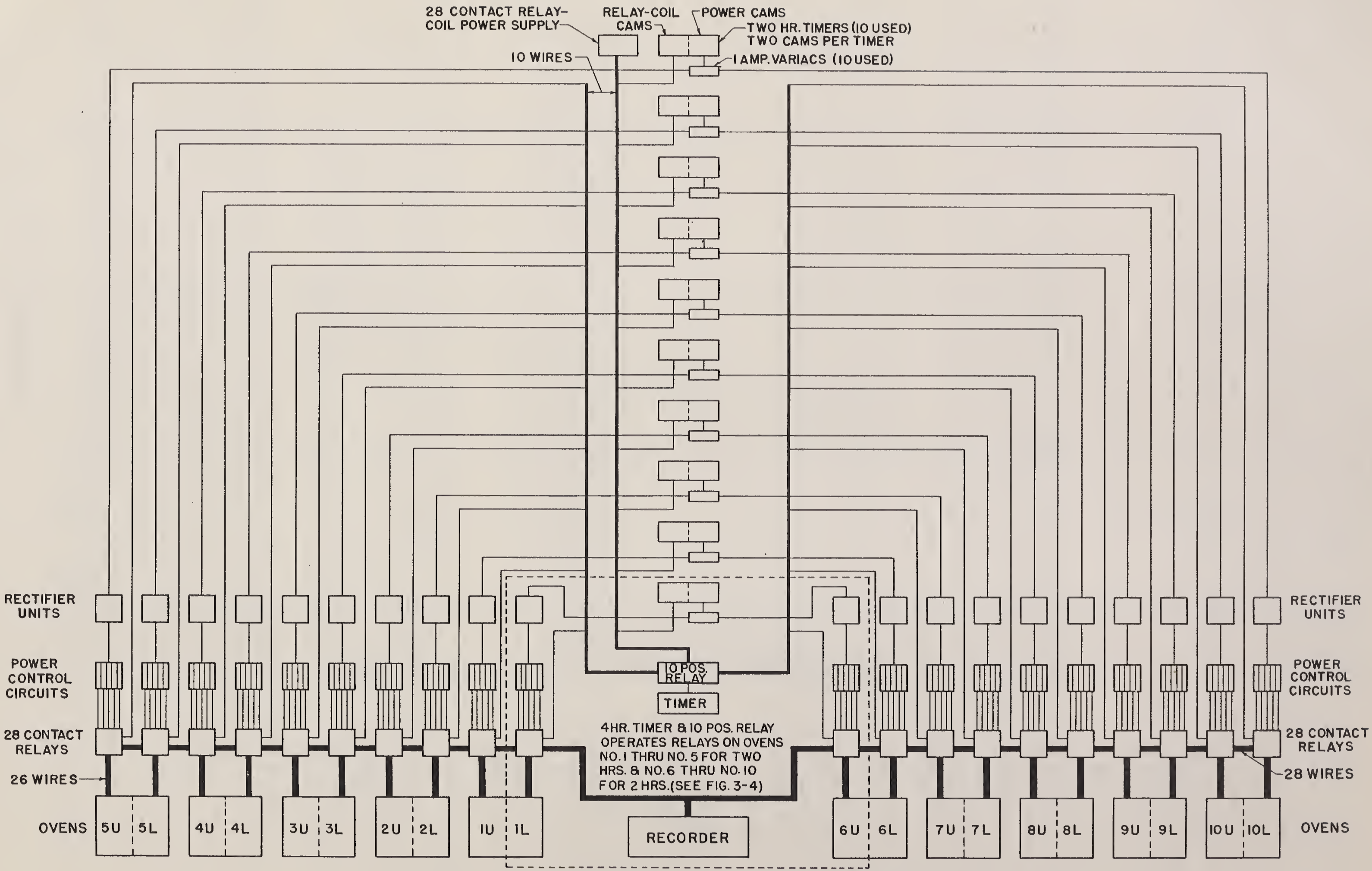
a. RESISTOR CIRCUIT. The resistors under test are connected to 28-contact dual-circuited relays by means of trays equipped with especially designed binding posts and plug arrangements (see section 3.2, g). The relays, each controlling 25 resistors, provide a means of switching to the test circuit or to the recording circuit. An over-all view of this switch gear is shown in figure 3-3. The details of the electric wiring of the resistor circuit are illustrated in figure 3-4.

As used below, TEST CYCLE means the 2-hour period of 1-1/2 hours "on" and 1/2 hour "off". The RECORDING CYCLE is the 12-minute interval of recorder operation.

b. TEST CIRCUITS. When the 28-contact dual-circuited relays are in the TEST CYCLE position, the 25 resistors controlled by each relay are connected to a single power source and its voltage control circuit (section 3.2i). All relays are normally in the TEST CYCLE position; only one relay at a time switches to the RECORDING CYCLE position. Two-hour timers are used to switch the power supply on for 1-1/2 hours and off for 1/2 hour (fig. 3-4).

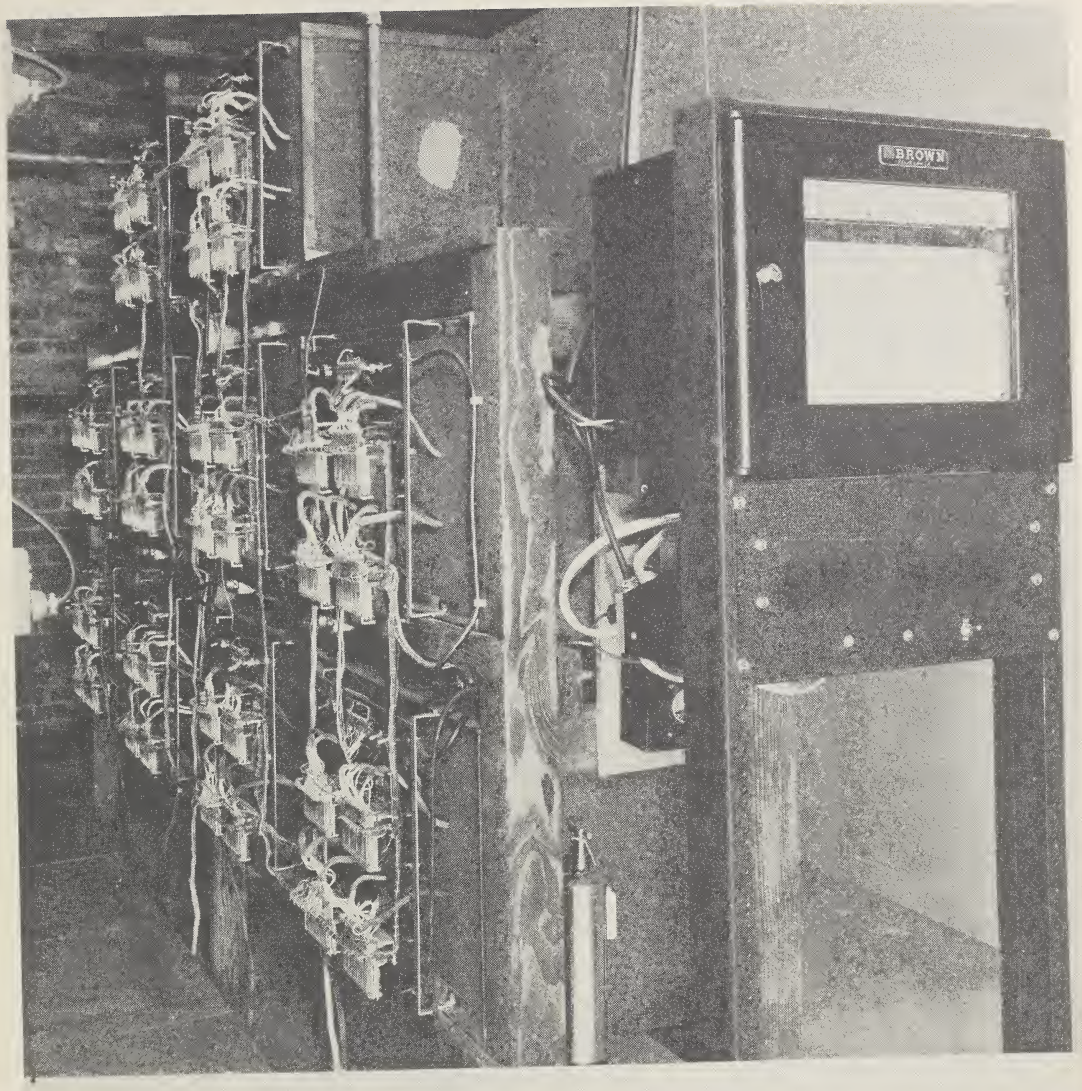
c. RECORDER CIRCUIT. The recording circuits of all relays and the input to the recorder are connected in parallel. Hence, as the relays are switched, one at a time, to the RECORDING CYCLE position, the resistors are connected to the recorder in groups of 25. A 25-position stepping switch inside the recorder feeds the resistors to the recorder one at a time. When one of the relays goes into the RECORDING CYCLE position, a signal is transmitted to the recorder and its operation begins (fig. 3-4).

d. RECORDER-TIME CYCLE. The total recorder time cycle is of four-hour duration since the maximum capacity of the equipment is 500 resistors and 12 minutes are necessary for the recording of 25 resistors. The two-hour timers controlling the test cycle have an additional cam and switch arrangement which is used to regulate the RECORDING CYCLE. Each of these cams and switches control two relays which are so synchronized that the switches are closed, one at a time, for the 12-minute RECORDING CYCLE. An additional four-hour timer controlling a 10-contact dual-circuited relay selects one or the other of the two relays controlled by the 2-hour timers; thus, the total recorder-time cycle is 4 hours (fig. 3-5).

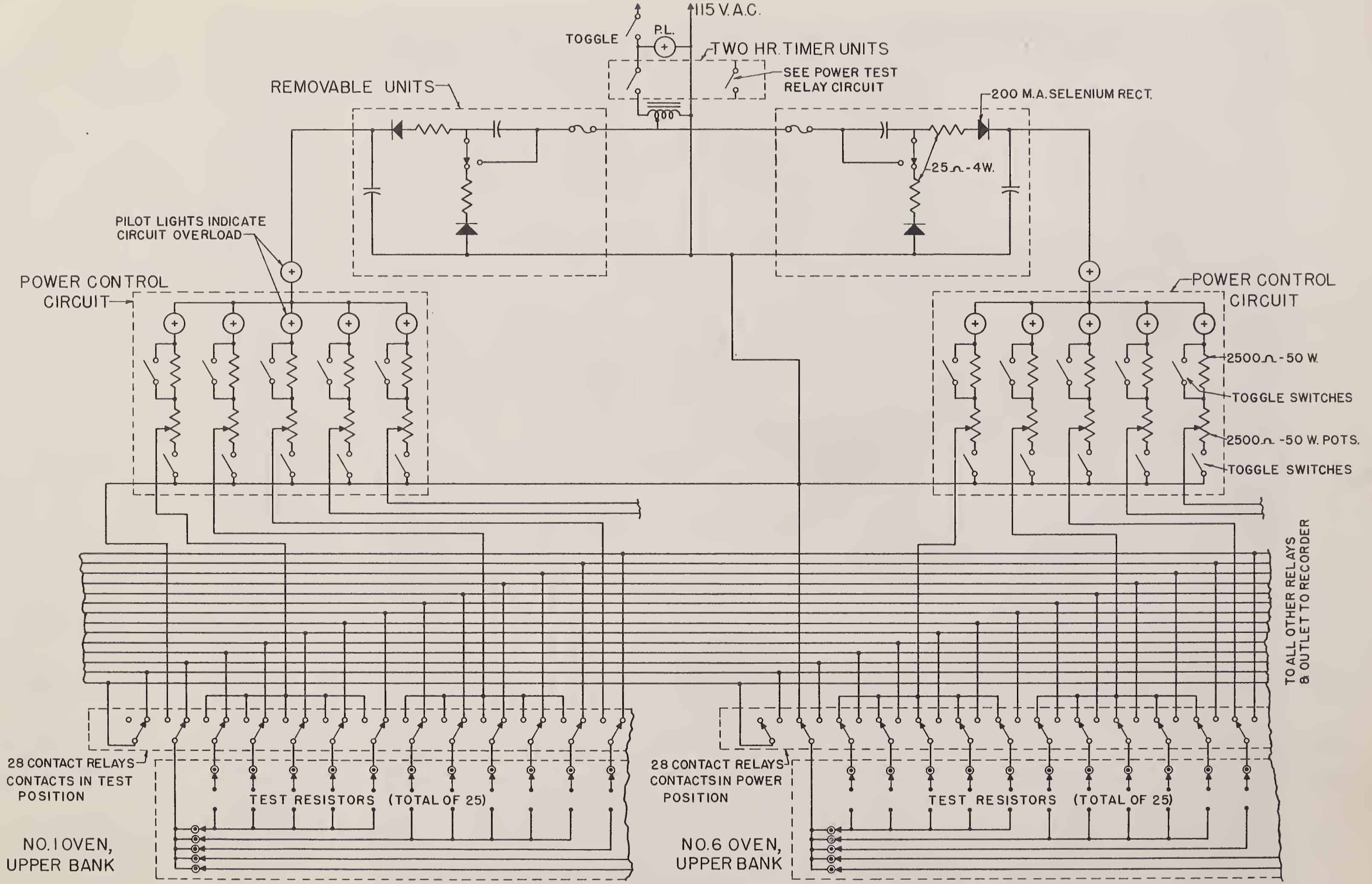


BLOCK DIAGRAM OF LOAD-LIFE TEST EQUIPMENT

FIG. 3-2

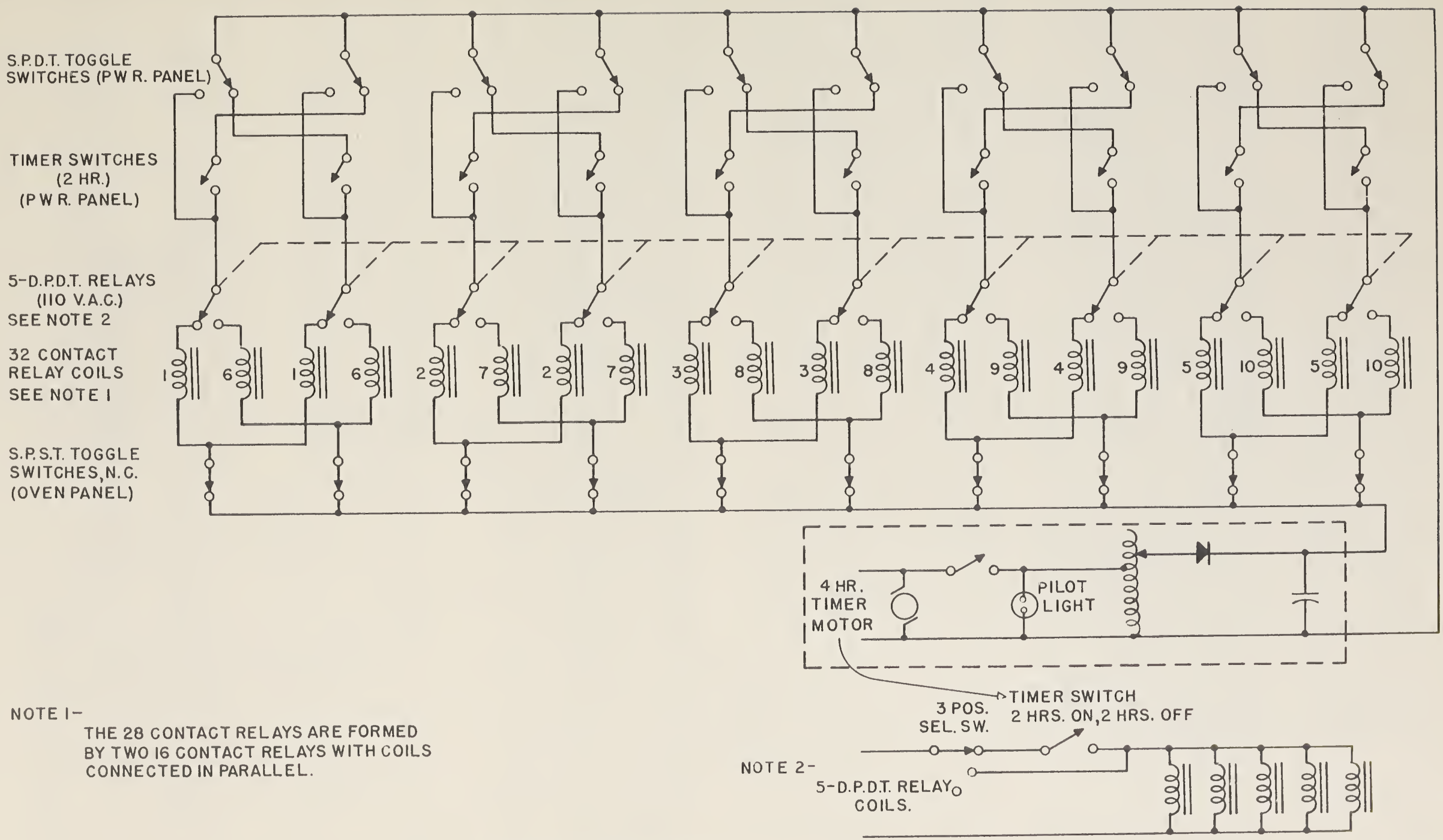


EQUIPMENT FOR THE RESISTOR, TEST AND RECORDER CIRCUITS
FIG. 3-3



SCHEMATIC DIAGRAM OF RESISTOR, TEST AND RECORDER CIRCUITS

FIG. 3-4



TEST-RECORD RELAY
COIL CIRCUIT

FIG. 3-5

e. RECORDER OPERATION. The recording unit records resistance values and individually identifies resistors ranging from 10 ohms to 10 megohms in groups of 25 within a 12-minute period. In order to obtain a linear recording cycle for measuring resistance values within this range, an 8-position Brown Multipoint recorder with a modified measuring circuit was used. The order of presentation of the resistors to the recorder may be completely random between the indicated limits.

The basic measuring circuit (fig. 3-6) is a resistance bridge with Amplifier A connected across the bridge to detect any bridge unbalance. The output of the amplifier is fed into a motor which drives the slidewire resistor R_s in the proper direction to rebalance the bridge. Attached to the slidewire is a scale graduated into 100 linear divisions. Six ratio arms are used to cover the complete resistance range. All six of the ratio arms are scanned automatically by switch S_1, in the recorder, for each unknown resistance measured. If the resistor being recorded does not fall within the range controlled by a given ratio arm, the reoorder prints off scale; hence, for each resistor measured, only one recording will appear on the scale.

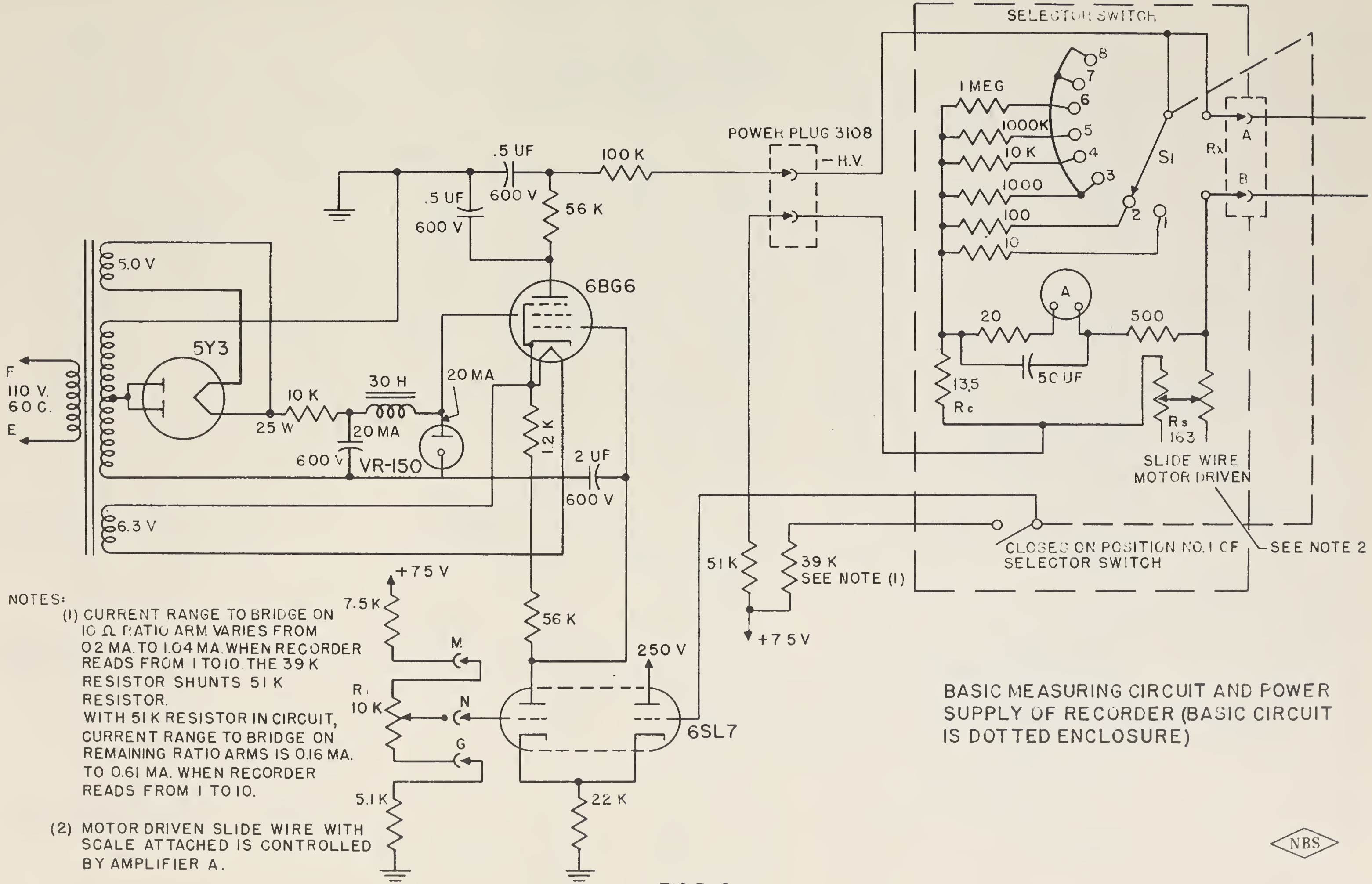
Records are produced by a print-wheel which places a plus sign and an accompanying number, consecutively from 1 to 8 The plus sign fixes a point on the scale which, when interpreted, yields a number consisting of three significant figures, the third of which is interpolated. The numbers from 1 to 6, which accompany the plus sign, indicate the ratio arm used and, hence, the range in which the resistor falls. Numbers 7 and 8 are used for resistor identification purposes discussed later. The calibration of the ratio arms is such that the product of the three significant figures and 10 raised to the power of the accompanying number yields the actual value of the resistor recorded. For example, if the recorder prints +4 at position 7. 63 of the chart, the unknown resistance is 7. 63 by 10^4 or 76, 300 ohms.

Some means of identifying the individual resistors within the group of 25 measured by the recorder was necessary. This was accomplished electrically, by automatically switching fixed ±1 percent wire-wound resistors into the recorder when it prints numbers 7 and 8. These fixed resistors are governed by a three deck 25-point stepper switch. This same switch is also used to feed the resistors within the group of 25 to the recorder one at a time. The values of the fixed resistors are such that the recorder in printing numbers 7 and 8 establishes a binary numbering system which serves to identify the resistors being measured. These resistors also serve to give a continuous calibration to the recorder.

In this numbering system, number seven is used to denote the ten's digit and number 8 the unit's digit. Thus, it is possible to record a maximum of 99 units, but only 25 are necessary. As an example, if number 7 is printed at 2 and number 8 at 3 on the chart, the 23 resistor has been recorded. Similarly, if number 7 is printed at 0 and 8 at 5, the 5th resistor has been recorded. Because of the arrangement of the print-wheel, the resistor is measured prior to its identification.

The circuit used to feed resistors into the measuring circuit of the recorder consists of a 3-deck, 25-point stepper relay along with a power supply and several switches to energize the stepper relay in a planned program to scan the unknown resistor bank.

The bank of 25 resistors to be measured is connected with one common lead. The common lead is connected to the resistance bridge through contacts on relays RE_1 and RE_2 (fig. 3-7). The other leads of the resistance bank are connected to the 26 resistance deck of the stepper relay.



NOTES:

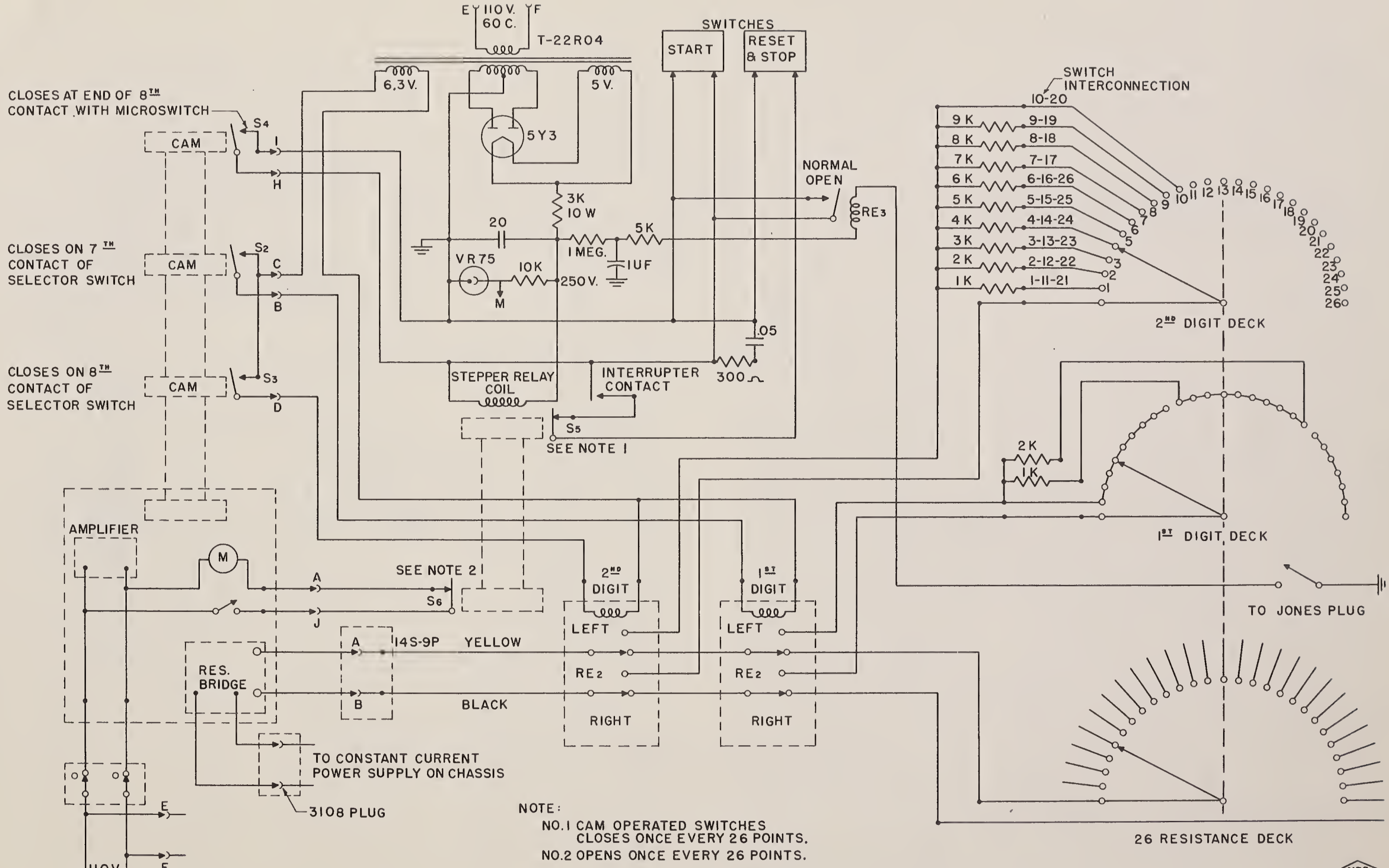
(1) CURRENT RANGE TO BRIDGE ON 10 Ω RATIO ARM VARIES FROM 0.2 MA. TO 1.04 MA. WHEN RECORDER READS FROM 1 TO 10. THE 39 K RESISTOR SHUNTS 51 K RESISTOR.
WITH 51 K RESISTOR IN CIRCUIT, CURRENT RANGE TO BRIDGE ON REMAINING RATIO ARMS IS 0.16 MA. TO 0.61 MA. WHEN RECORDER READS FROM 1 TO 10.

(2) MOTOR DRIVEN SLIDE WIRE WITH SCALE ATTACHED IS CONTROLLED BY AMPLIFIER A.

BASIC MEASURING CIRCUIT AND POWER SUPPLY OF RECORDER (BASIC CIRCUIT IS DOTTED ENCLOSURE)

FIG. 3-6

NBS



RECORDER SCANNING CIRCUIT

FIG. 3-7

To start an operation with the stepper relay switch in the normal (N) position, the start switch (fig. 3-7) is closed, momentarily energizing the stepper relay coil and advancing the stepper switch to position one (1). For automatic operation the recorder is started by closing switch S_7. This switch is closed when any of the 28-contact dual-circuited relays (described in section 3.2a) is in the recorder position. This throws the first resistor to be measured into the bridge circuit of the recorder. The first resistor remains in the bridge circuit while switch S_1 (fig. 3-6) scans the six ratio arms and the value of its resistance is recorded.

In order to identify which unknown resistor was measured, the first digit and second digit decks of the stepper relay and position 7 and 8 of switch S_1 are used in the following manner: Switches S_2, S_3 and S_4 (fig. 3-7) are mechanically coupled to S_1 so that when S_1 advances to position 7, S_2 closes. This energizes relay RE_1 which disconnects the first unknown resistor from the bridge and connects, in its place, the first resistor in the first digit deck of the stepper relay. Since this resistor is zero ohms, the bridge is balanced at zero and the recorder prints +7. Switch S_1 then advances to position 8. This opens switch S_2 and closes switch S_3 which energizes relay RE_2. This connects the 1,000-ohm resistor of the second deck of the stepper relay into the bridge circuit. Since the 1,000-ohm ratio arm is in the circuit when S_1 is in position 7 and 8, the recorder will balance and print +8 on line one of the chart. Since +7 was printed on zero and +8 printed on line 1 on the chart, the unknown resistor measured was the first resistor in the bank of 25.

Immediately after the recorder prints, in position 8, S_3 opens and S_4 closes momentarily. Switch S_4 energizes the stepper relay coil and advances the stepper switch to the second unknown resistor. This procedure is repeated for the 25 unknown resistors. When the stepper relay advances to the 26th position, switches S_5 and S_6 are opened. Switch S_6 cuts off the power to the recorder motor; this completes the operation cycle for the first bank of 25 unknown resistors.

After the first bank of resistors has been measured, the second bank of 25 resistors is automatically connected to the stepper relay through circuitry shown in figure 3-4. The external time circuit closes switch S_7 energizing relay RE_3, which advances the stepper relay to position 1 and the duty cycle is repeated.

The reset or stop switch was installed to provide a manual means of stopping or resetting a bank of resistors as desired. Switch S_5 is provided so the stepper relay will reset to the normal position each time the reset switch is closed.

The power supply of the recorder is illustrated in figure 3-6. For the bridge circuit to have constant sensitivity regardless of the value of the unknown resistance measured, a constant current must flow through the slidewire resistor, R_s. Using a constant current supply to the bridge, the current through R_s would obviously decrease as R_s increases. To obtain a constant current through R_s as the slider on R_s is moved upscale, potentiometer R_1 in the power supply was mechanically coupled to the slider on R_s so that the total current delivered to the bridge was increased proportionately to the distance the slider moved upscale. The power supply is designed as a constant current source with respect to load impedance: the total current supplied to the bridge is independent of ratio arms and the unknown resistance, when the bridge is balanced. The total current to the bridge varies only as the slider on R_s is driven up or down scale.

f. CERAMIC TEST PLATES. The ceramic test plate used in the load-life tests is shown in figure 3-8. It is similar to that described in section 2.7 except for a slightly different silver pattern. The NBS resistors are placed on the ceramic plate in a single vertical row. The resistors are selected for the load-life test so that each test tray contains resistors of approximately the same value for more uniform loading. Five test plates are placed in the test tray in a single row connected in parallel.

g. TEST TRAYS. The plates are held firmly in the test tray (fig. 3-9) by means of binding posts screwed to a silicone impregnated asbestos-cement base. Electrical contact is made by means of a set screw passing through the binding post which holds the test plate securely. All electrical connections are brazed at the joints with silver solder to assure low electrical resistance, strong connections, and ability to withstand 200° C ambients.

Because extremely high resistance measurements are encountered in some of the tests, a completely insulated test rack is necessary. It was found after much experimentation that silicone impregnated Transite yielded the best insulation at a low cost.

Transite, available from the Johns-Manville Company, when used as furnished proved unsatisfactory because of high leakage. If the Transite is dried in an oven for two hours, however, the entrained water (1 to 2 percent) is removed, and there is a marked improvment in its insulating properties. To preserve the Transite in this condition, it is further treated by dipping in silicone resin and redrying in the oven at 200° C. The final product has proved satisfactory in every case during the test period.

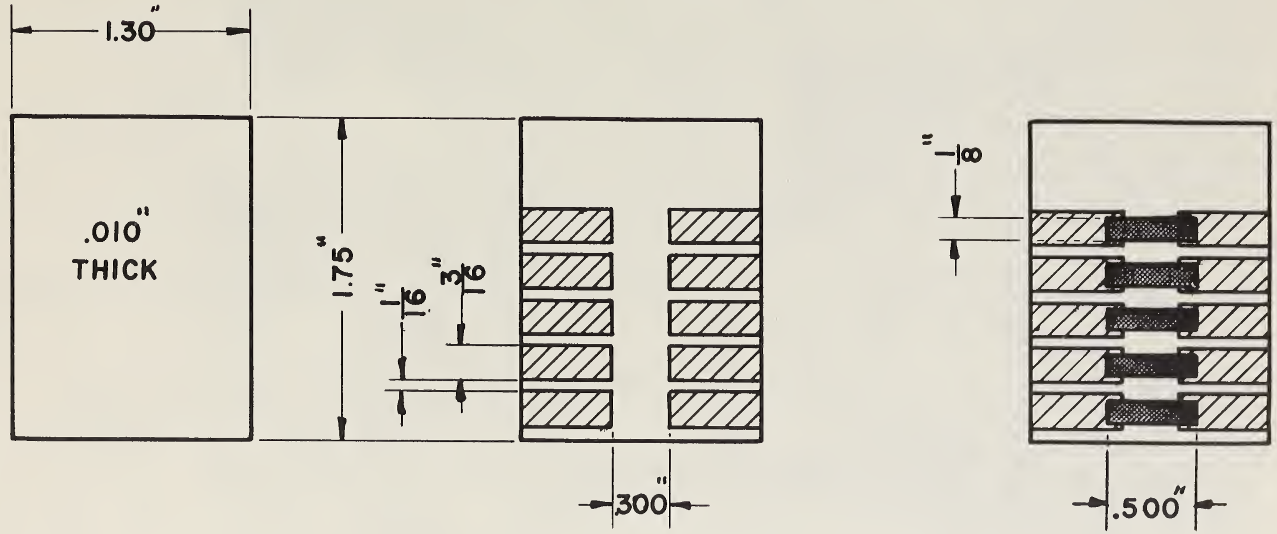
Care is needed in applying the silicone coating to the Transite or the coating will not be satisfactory. The solvent must be removed evenly throughout the thickness of the coating. If the silicone treated Transite is placed in the oven at high temperature, a hard surface coating is formed which is later ruptured when the entrapped solvent is volatilized. To prevent this, it has been found necessary to heat at low temperatures for one hour and then slowly increase the temperature to 200° C.

The test tray is connected electrically to the power supply and the recorder by means of a plug assembly which fits into sockets in the rear wall of the oven chamber (figs. 3-9 and 3-10). Plug type sockets facilitate connection and repair. The plugs used are of the banana type and are designed so that they may be removed without disturbing the electrical circuitry.

The temperature of the oven and the prolonged exposure of the metal parts necessitate the plating of all mechanical joints to prevent rapid deterioration. A flash coating of rhodium over silver produces a lasting and satisfactory finish. This coating also reduces the resistance of the binding post and the set screws. Silver wire is used on the tray. All electrical joints are brazed using a high temperature solder (600-700° C) to assure continued service under the test conditions.

h. OVEN CONSTRUCTION. The ovens are especially designed for conducting the load-life tests as specified in JAN-R-11. Ten ovens were constructed with a capacity for testing 500 NBS resistors simultaneously (fig. 3-10).

The oven chamber measures 20 inches wide, 8-1/2 inches deep, and 10 inches in height. A horizontal shelf divides the oven chamber into an upper and lower compartment. The chamber proper and the shelf are constructed of 1/4-inch aluminum plate, valuable for

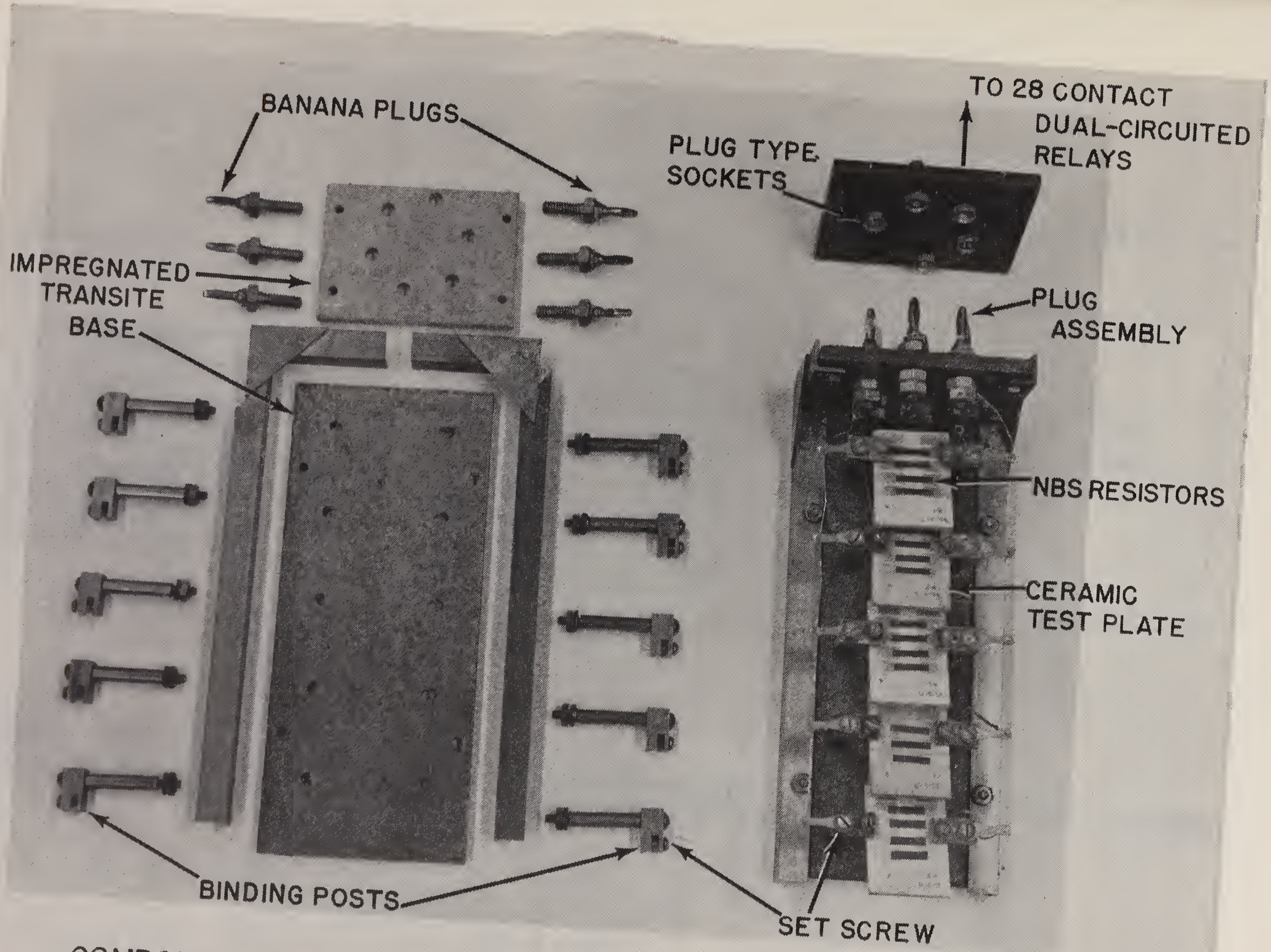


RESISTOR TEST PLATE

TEST PLATE IMPRINTED WITH CONDUCTIVE SILVER TERMINALS

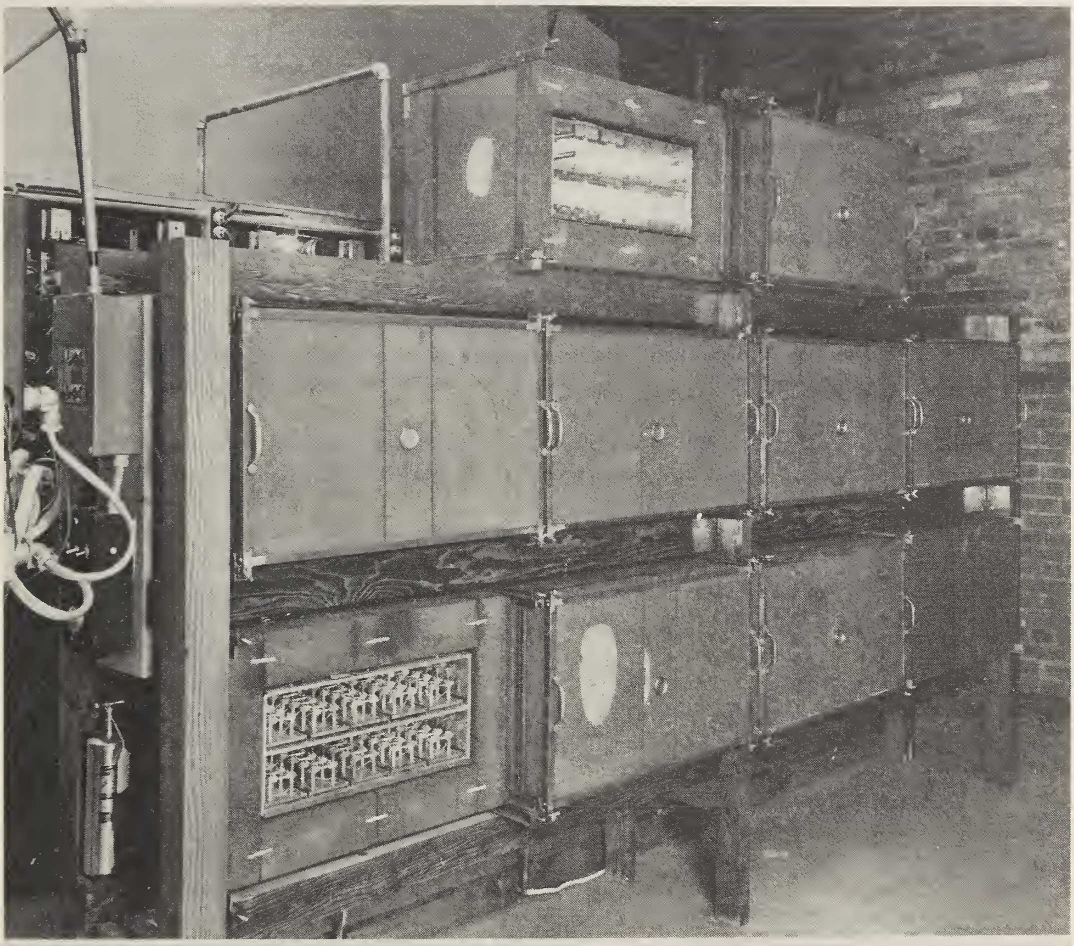
COMPLETED RESISTOR TEST PLATE

FIG. 3-8



COMPONENTS OF RESISTOR TEST TRAY AND ASSEMBLED TEST TRAY
RESISTORS IN PLACE

FIG. 3–9



RESISTOR LOAD-LIFE TESTING OVENS
FIG. 3-10

NBS

its conductive and radiative properties. The sides of the oven chamber are machined and fastened by self-tapping screws to insure good heat conductivity. An aluminum door (not shown) is pressed against the front of the chamber.

The shelves have grooves to hold five test trays which slide into and out of the ovens. The trays are held stationary by the banana plugs which are secured into sockets in the rear wall of the oven chamber. These plugs provide the electrical connections between the control-board and the test rack.

The oven chamber is encased in 4-inch thick Foamglass insulation which is held rigid by the steel frame of the oven. The sections of Foamglass are joined and sealed by Transite wedges and commercial furnace cement.

The oven is heated by three 50-foot sections of No. 26 asbestos-insulated Nichrome wire. These heating elements are wound around the oven chamber so that all sides except the front and back have heat evenly applied. This arrangement has proved quite satisfactory. The temperature within the chamber is controlled by Fenwal Thermo-switch, which gives a maximum variation over a full heat cycle of less than $\pm 1^{\circ}$ C (fig. 3-11).

A thermometer is inserted at the center of the door by pressing a steel rod through the insulation and placing the tube of the thermometer through the resulting aperature. A hole drilled at the center of the aluminum door permits entry into the chamber proper.

Tests conducted in different parts of the oven chamber to determine the temperature gradient show conclusively that the maximum thermal distribution does not exceed $\pm 2^{\circ}$C.

i. RESISTOR LOADING POWER SUPPLY. In testing, it is desired to limit the NBS resistors to 1/4-watt at the ambient test temperature. Because of the wide range in resistors values tested and the attempt to conform to the JAN-R-11 requirements, an intricate power supply set-up is used. This system is illustrated in figures 3-12 and 3-13.

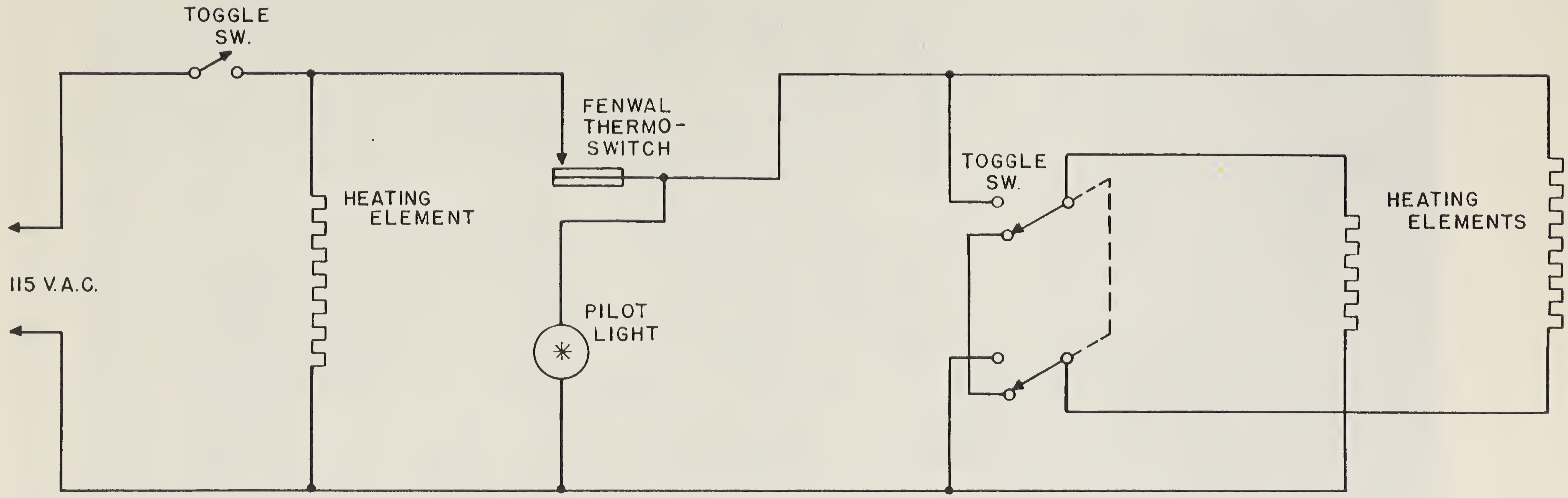
The power supply is taken from a 117 VAC line and is routed through Variacs where its value is changed to one slightly above the calculated value to give resistors a 1/4-watt dissipation. There are 10 Variacs in the power supply system. To be sure a voltage of about 300 v with no load and 250 v with load, there is provision for two manually switched rectifiers. Each power supply unit contains two 200 ma selenium rectifiers which may be connected as a simple half-wave or as a voltage doubler. The Variac controls the supply voltage from zero volts to above line voltage. The two rectifiers can, therefore produce voltages from 0 to about 300 v. As the diagram illustrates, the current passes through a bank of five voltage control circuits consisting of one 2500-ohms, 50-watt fixed resistor and one 2500-ohms, 50-watt potentiometer; these may be switched into and out of the circuit. The current then passes through the 28-contact dual-circuited relay to one tray of five resistors placed in the oven chamber. An 80 mf output condenser filters the rectified current.

3.3 Summary of Test Procedure

1. The resistors are placed in the cold oven.

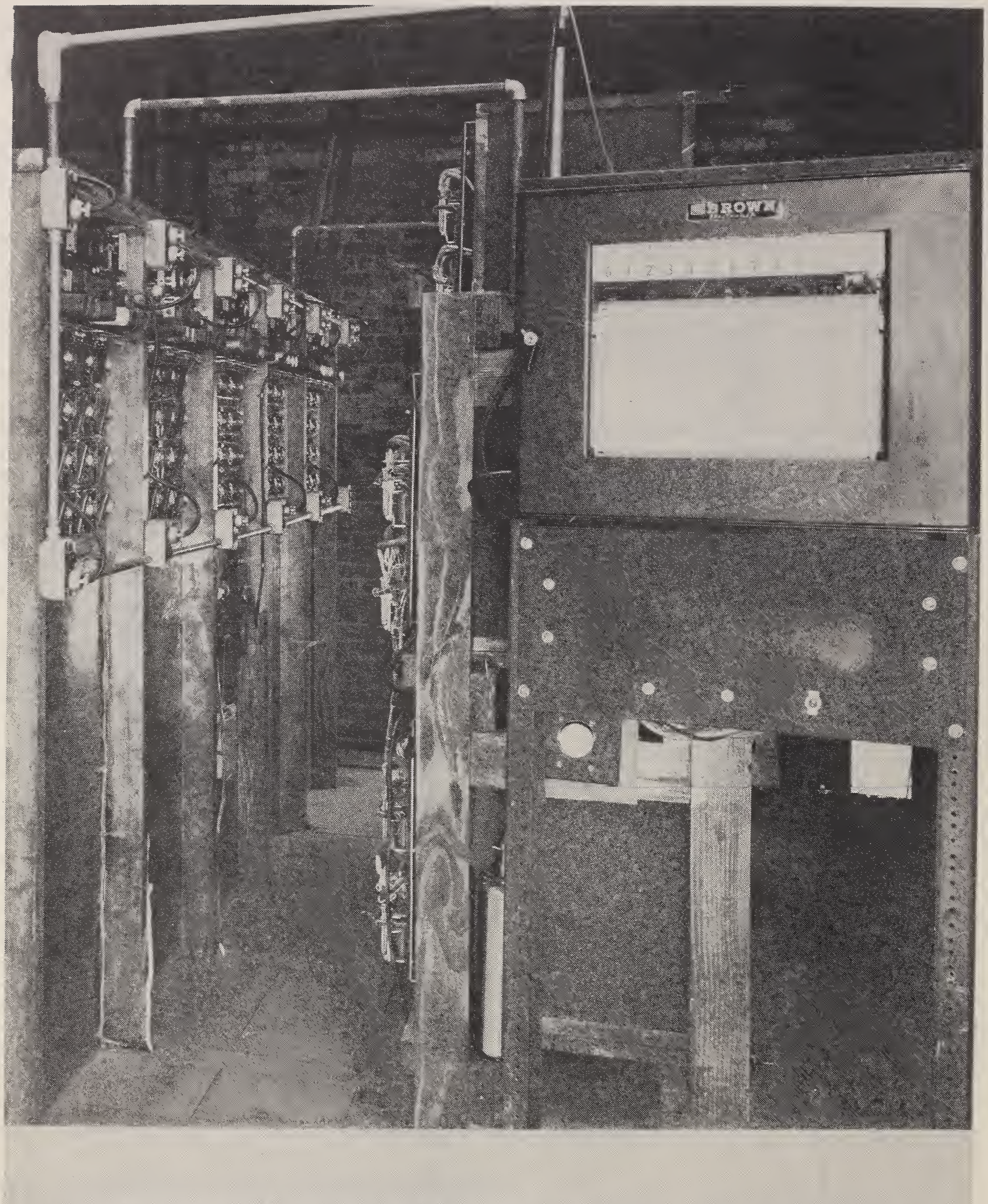
2. A test of the resistance is conducted.

3. The oven is sealed and the chamber heated to the desired ambient temperature.



OVEN HEATING ELEMENT
SCHEMATIC DIAGRAM

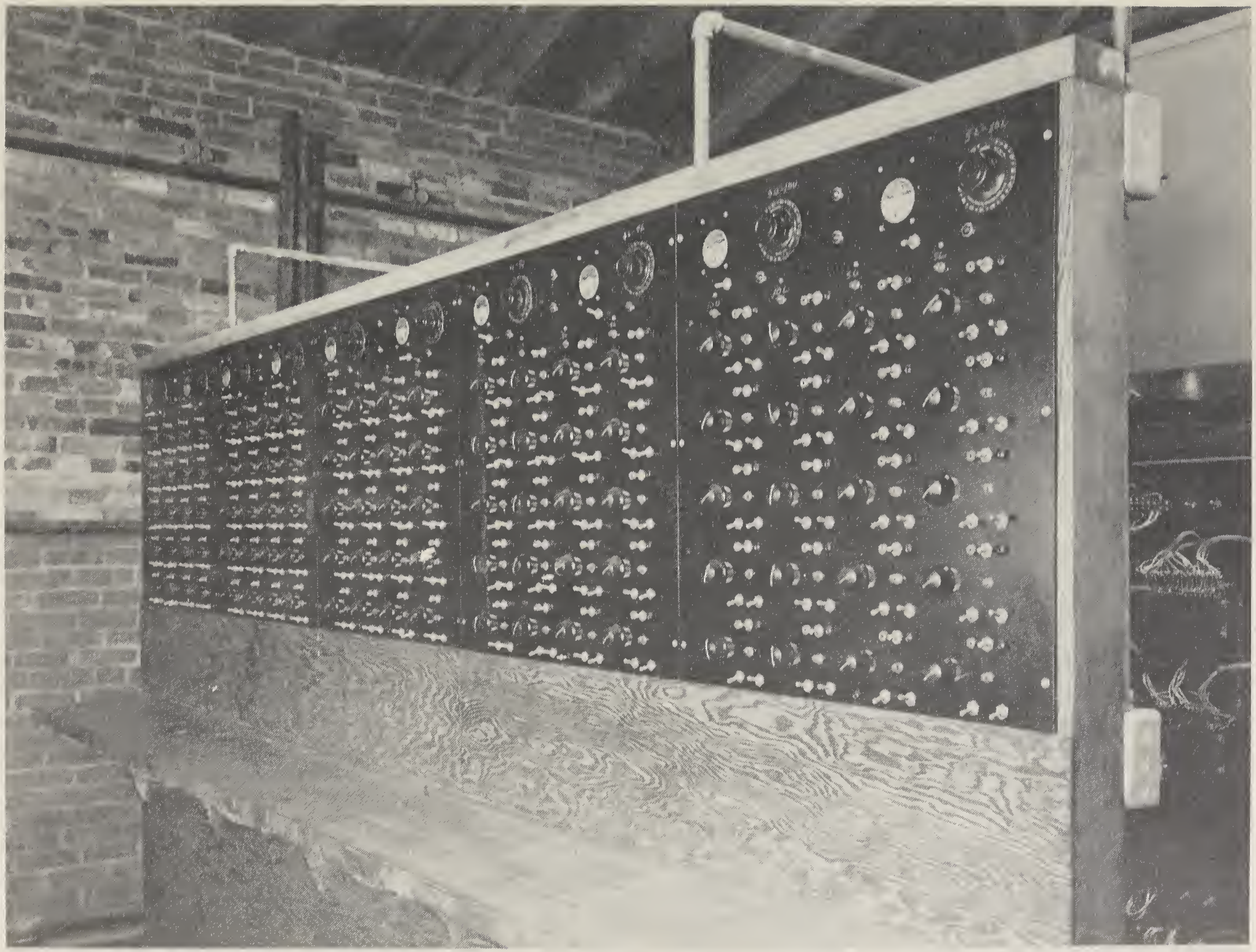
FIG. 3-11



RESISTOR LOADING POWER EQUIPMENT AND RECORDER

FIG. 3-12

NBS



TEST CONTROL PANEL
FIG. 3-13

4. The resistance is again measured at the test temperature; from these data, the temperature coefficient is computed.

5. The proper voltage to dissipate 1/4-watt is applied, and the value set by means of the Variac and the variable resistors.

6. Resistance readings are taken at approximately 25, 50, 100 and every 100 hours thereafter until 500 hours are reached or the ± 6 percent change limit is exceeded.

4. FURTHER DEVELOPMENT OF THE NBS TAPE-RESISTOR-SYSTEM

It is felt at this time that the development of this resistor system has reached a stage favorable for commercial exploitation. In the range of values from 100 ohms to about 0.5 to 1.megohm, formulations are now available which will meet JAN-R-11 specifications with the added advantage that they will operate under 1/4-watt loads at 200° C. Additional work is necessary, however, more firmly to establish formulations and procedures for making resistors in the 10 to 100 ohm range. For high value resistors (1 to 10 megohms) it is also necessary to find carbons which will yield resistors possessing improved electrical properties. For this purpose, every available furnace black should be studied.

Silicone resin has one serious disadvantage. Even after curing, it is attacked by solvents and by solder fluxes. It is necessary, therefore, to exercise care in soldering so that flux is kept from the resistors to avoid changing their value. It is possible that some of the newer silicone-alkyd resins or the ethoxyline resins such as the Epons and the Araldites might produce binders less subject to chemical attack by solvents and fluxes while giving satisfactory high temperature operation.

There is a great interest today in the use of copper-clad plastic materials as printed circuit bases. Here the conductive patterns are formed by etching away the unwanted copper after masking the desired pattern using screen printed or photographic resists. At present, the only possible material which will withstand the cure temperature for the silicone resin binder is copper-clad teflon-glass laminate. This material is not yet commercially available; in the experiments conducted, limited success has been achieved in curing resistors on this base plate.

The success attained in preliminary experiments using the Melmac resins as binders warrants more work developing a resistor system which will cure at lower temperatures, and be applicable to copper-clad plastic base materials. Admittedly, this will give resistors usable only at lower temperatures, but the resistors should be at least as good as the base materials. It should be possible, also, to use some channel blacks at these lower temperatures and obtain resistors having better electrical characteristics.

Work along the lines indicated above has been initiated and will continue in the NBS laboratories.

5. APPENDICES

A: Carbons

To best utilize the information presented in section 2, a description of the results obtained from using the various carbons in making the NBS tape resistor, with as much pertinent information as has been determined up to this time, is presented in this Appendix.

Natural Graphites

DIXON 200-08. A 5 to 1 ratio produced an 1,100-ohm resistor showing fair load-life qualities at 200° C. Noise and voltage coefficients are unknown.

DIXON 200-09, Thoroughly tested up to 72,000 ohms at 200° C; above 5,000 ohms, poor noise characteristics. Highest ratio of resin to carbon made was 10 to 1, lowest 1 to 1. The low ratio has a value of 110 ohms, but proves unsatisfactory because of lack of tack. Very stable under the load-life tests. Temperature coefficient is +0.052%/°C at 3,000 ohms (figs. 2-14, A-1, A-2).

DIXON 200-10. Tapes produced having a resin to carbon ratio of 6 to 1 through 3 to 1. The resulting resistance values were 6,600 ohms to 400 ohms. The lower ratios have good tack. Stable under load-life tests. The temperature coefficient is +0.086%/°C at 3,000 ohms (fig. A-19).

DIXON 200-10F. Only one tape was made and results obtained were inconclusive. The testing of this carbon is in progress.

DIXON 200-18; DIXON 200-19. In the process of being tested. The load-life properties are good. The 5 to 1 ratio has produced tapes of 25,000 ohms.

Artificial Graphites

DAG DISPERSION 22. This is the best artificial graphite available. Can be used in 6 to 1 through 1 to 1 ratios. The 1 to 1 ratio has excellent tack. The load-life is good except for an initial drop of 20 percent. Values of 770,000 ohms to 100 ohms have been produced. The temperature coefficient is poor; after the resistor cools, it does not return to its original value. Requires a cycling cure to be acceptable. At the present time, a high valued tape is being attempted using a silicone impregnated Quinterra (fig. A-20).

DAG DISPERSIONS 47; 2412; 2475. Inconclusive data are available for an estimate (figs. A-21, A-22, A-23).

DAG DISPERSION EC-427. Makes an excellent 30,000-ohm resistor. The load-life over the resistance range is good. The initial drop is only 2 to 3%. Made in ratios of 5 to 1 through 2 to 1 having resistances of 30,000 ohms and 800 ohms, respectfully. Temperature coefficient is -0.010%/°C at 12,000 ohms (fig. 2-13).

DAG ULTRA-FINE GRAPHITE. Very stable load-life with a low initial drop. Noise and voltage coefficients are unknown. A 5 to 1 ratio yields a resistance value of 5,000 ohms (fig. A-3).

CONTINENTAL A A. The load-life qualities at 150° C are excellent; at the 200° C ambient they are poor. Values in the megohms can be obtained but without precision. The same tape can produce values from 2 to 4 megohms. In ratios below 5 to 1, the tapes have no tack. The tapes lose all tack after storage at 35° C for 2 months. Temperature coefficient is -0.057%/°C at 1.8 megohms (figs. A-4, A-5, A-6, A-24).

DIXIE 5. A characteristic channel black; abandoned because of poor load-life at 200° C (fig. A-25).

EXCELSIOR BLACK. At 200° C, load-life characteristics were acceptable, but better performance is attained at lower temperatures. Temperature coefficient is good. Loss of tack after 2 months is noted (figs. A-11, A-12).

HALO BLACK. The most promising channel black used. The range of ratios and resistance values is very wide. A 26 to 1 ratio yields a 1,000,000-ohm resistor and a 6 to 1 ratio a 1,200-ohm resistor. The resistors fail at 200° C, but are acceptable at 150° C. The temperature coefficient is -0.023%/°C at 450,000 ohms. The noise and voltage coefficients are all good. Its shelf-life is excellent. An attempt is being made to stabilize its load-life at 200°C because of its range in resistor values. Additional fillers, e.g., glass beads, talc, etc., have proved unsuccessful. A mixture of Halo and graphite was made in an attempt to produce a stable resistor, but this has failed. Different silicones on various grades of Quinterra tape have also failed to produce a resistor capable of withstanding 200°C. All the accumulated data indicate a 150°C resistor, but further attempts to increase the safe operating temperature limit are continuing (figs. 2-17, A-7, A-8, A-9, A-10).

KOSMOBILE Hm; S; 77. Abandoned because of characteristic channel black load-life properties (figs. A-26, A-27, A-28).

RAVEN 15, Poor load-life qualities. Can be produced in high ratios and resistance values to 1,000 megohms. An attempt is being made to produce high valued tapes stable at lower temperatures. Temperature coefficient is -0.125%/°C at 270,000 ohms (fig. A-29).

SPHERON C; N. Abandoned because of poor load-life qualities (figs. A-30, A-31).

SUPERBA. Abandoned (fig. A-32).

VOLTEX. Abandoned (fig. A-33).

Furnace Blacks A

STATEX A. The most versatile of all the furnace blacks. Good for middle range of 300,000 ohms to 5,000 ohms in ratios from 10 to 1 through 4 to 1. Load-life at 200°C is good after a sharp initial drop. The additional cure for 24 hours at 200°C does much to eliminate this drop in value. Noise characteristics are acceptable in lower valued resistors. Temperature coefficient is +0.096%/°C at 25,000 ohms (figs. A-15, A-34).

STATEX "B" BEADS. An excellent resistor material capable of operation at 200°C ambient. There is a slight initial drop and then a slow increase in the resistance value as the load-life progresses. An 8 to 1 ratio produces a 25,000-ohm resistor. The temperature coefficient is +0.080%/°C at 25,000 ohms (figs. A-15, A-34).

STERLING 99. Fine load-life at 200°C. An 8 to 1 ratio produces an 80,000-ohm resistor. Noise and voltage coefficient are unknown. Excellent tack. Temperature coeficient is +0.114%/°C at 35,000 ohms (figs. A-16, A-35).

STERLING 105. Same as Sterling 99 except the 10 to 1 ratio yields a 60,000-ohm resistor and the 6 to 1 ratio a 9,500-ohm resistor. The temperature coefficient is +0.096% /°C at 15,000 ohms. (Figs. 2-16, A-17, A-18).

ACETYLENE BLACK. Resistance range is very limited. An 18 to 1 ratio yields a 1,500-ohm resistor and the 14 to 1 ratio a 1,200-ohm resistor. Below a 14 to 1 ratio tack is very poor. Load-life at 200°C is good.

CONTINEX HMF; SRF. Abandoned because of poor load-life.

P-33 A tape with a definite resistance cannot be produced with any fair degree of accuracy because a 3 to 1 ratio gives a 90,000-ohm resistor and a 4 to 1 ratio a 3-megohm resistor. The initial drop in value during load-life at 200° C is very sharp. The load-life qualities are acceptable up to 170° C. The noise characteristics are very poor.

STERLING K. The testing of this carbon is in progress.

* * *

As an extension of the presentation of the data on individual carbons, figures A-1 through A-18 are included. This grouping of curves illustrates the effect of the load-life tests upon resistors cured for four hours at 300° C. The furnace blacks were further cured for 24 hours at 200°C. These curves furthermore portray the effect of temperature ambients upon load-life qualities. In the case of Continental AA, Excelsior Black and Halo, it is readily seen that as the temperature ambient is decreased, the load-life characteristics improve. In addition, an attempt is made to show the effect of increased resistance value upon the deviation under load-life. It has been found, generally, that as the weight ratio of resin to carbon is increased the percent deviation under load-life also increases; whereas, in the case of the furnace blacks, the transition from a negative to a positive value is shifted further to the right on the time scale.

All of the carbons shown in this series of plots are highly acceptable for use at the proper ambients and have produced successful resistors. These graphs and the chart found in Appendix B have been included as a guide for producing resistor formulations.

Following this series of graphs are the remaining curves showing the effect of various cure schedules upon the load-life characteristics, figures A-19 through A-35. These curves were discussed in section 2.8a, and inclusion of the major portion of these graphs was delayed until this time to preserve the continuity of the report.

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

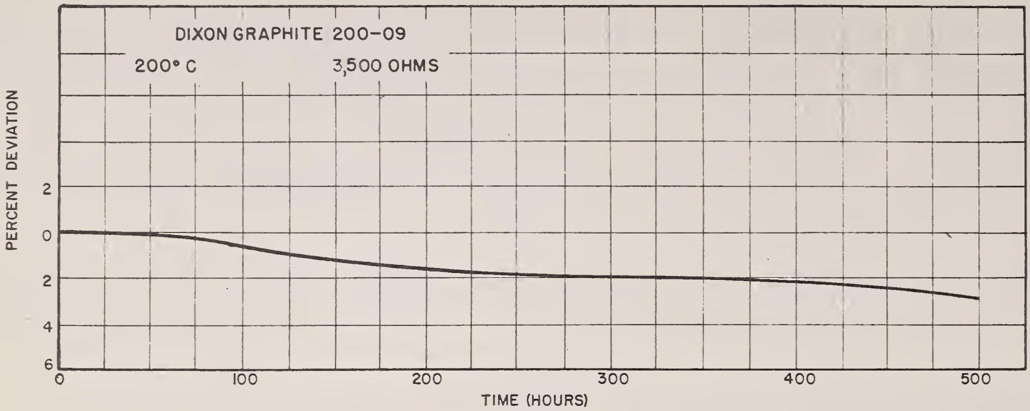


FIG. A-1

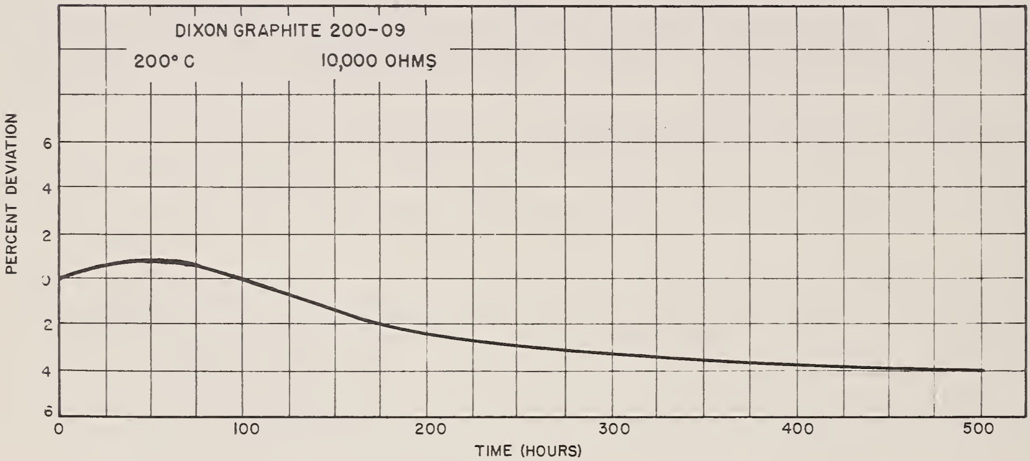


FIG. A-2

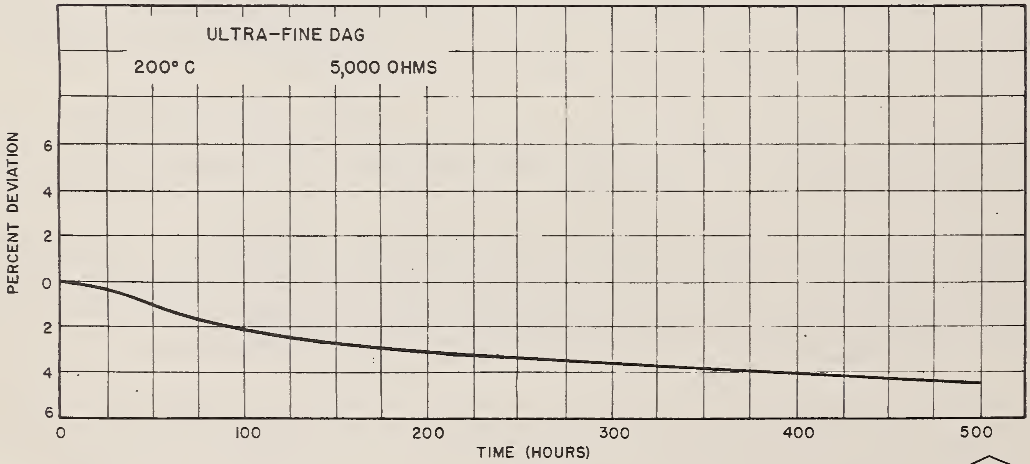


FIG. A-3

NBS

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

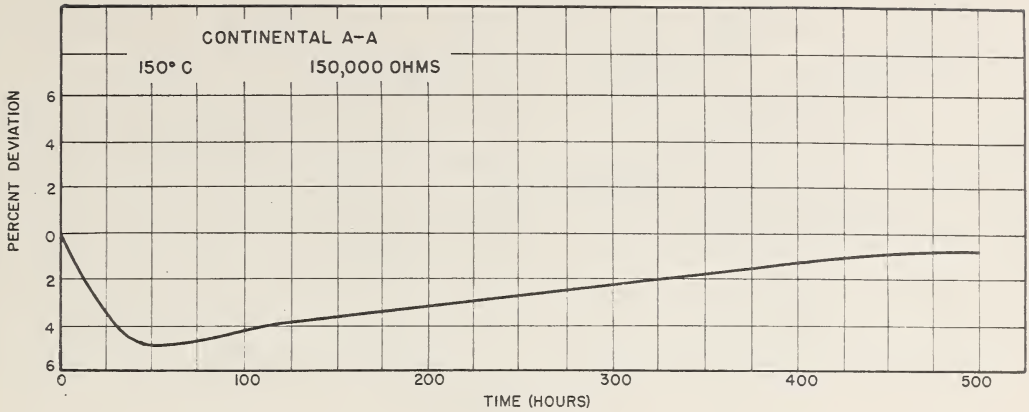


FIG. A-4

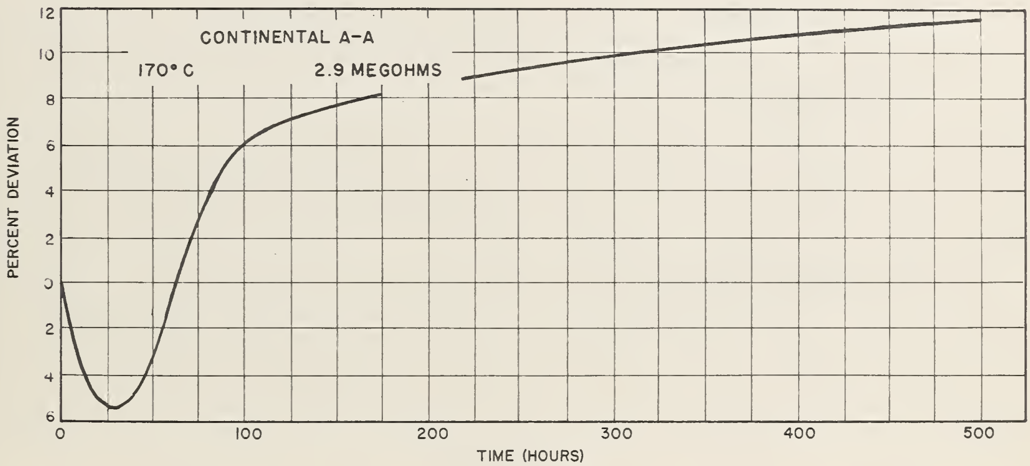


FIG. A-5

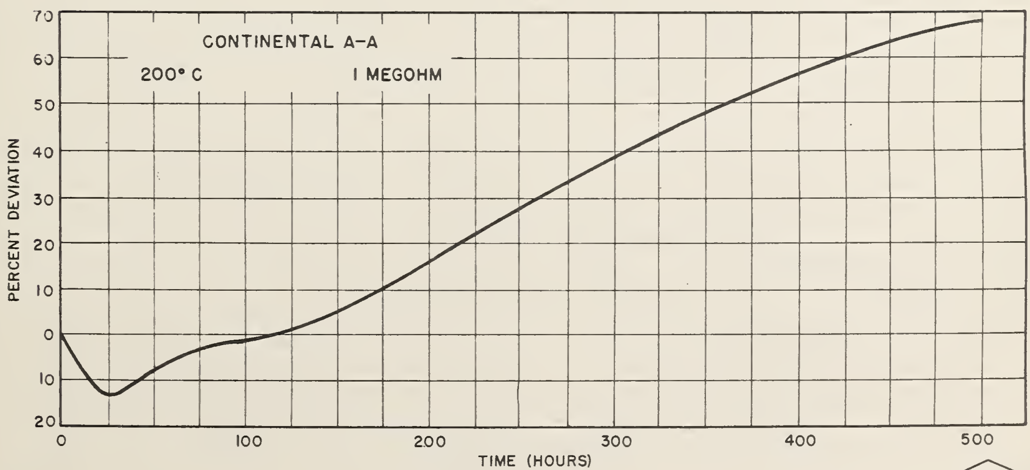


FIG. A-6

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

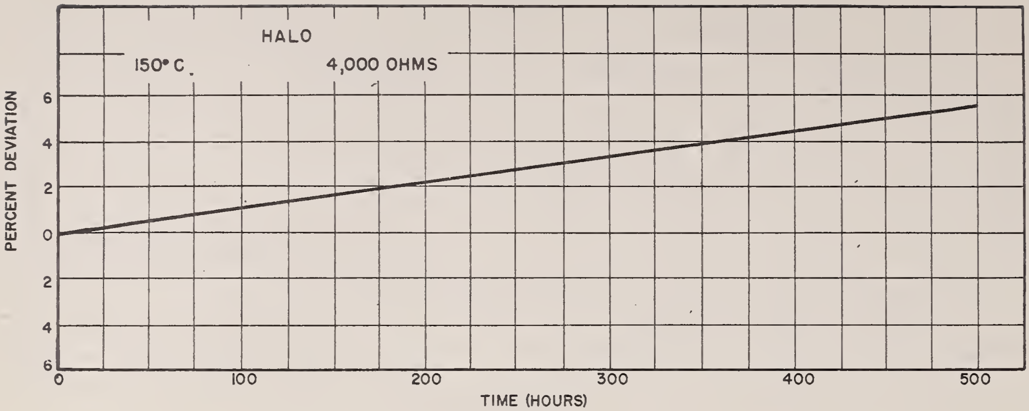


FIG. A-7

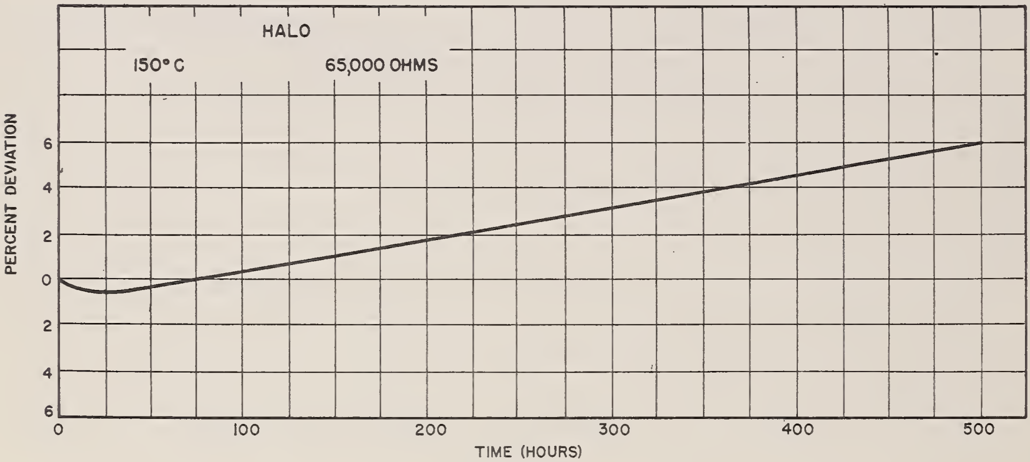


FIG. A-8

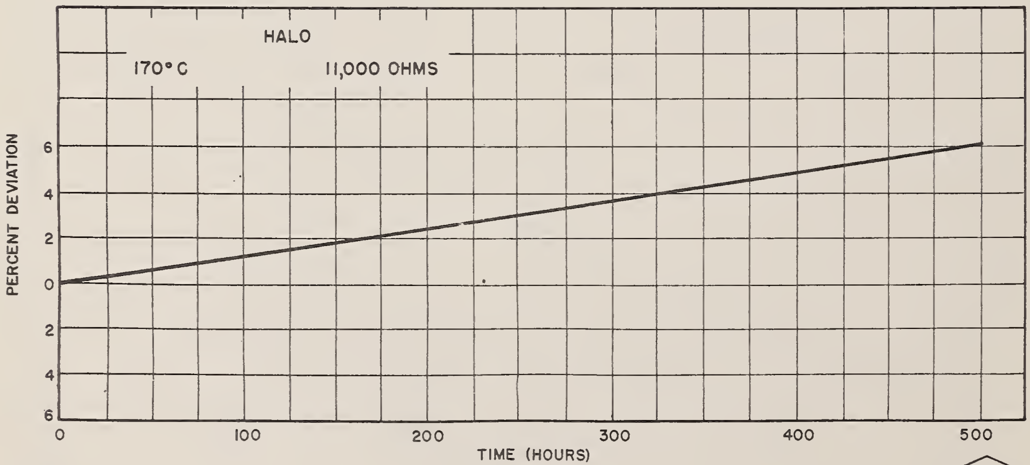


FIG. A-9

NBS

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

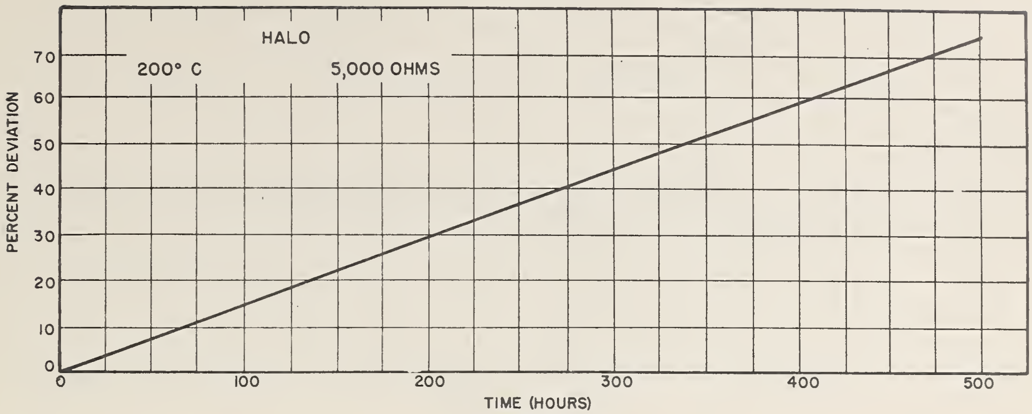


FIG. A-10

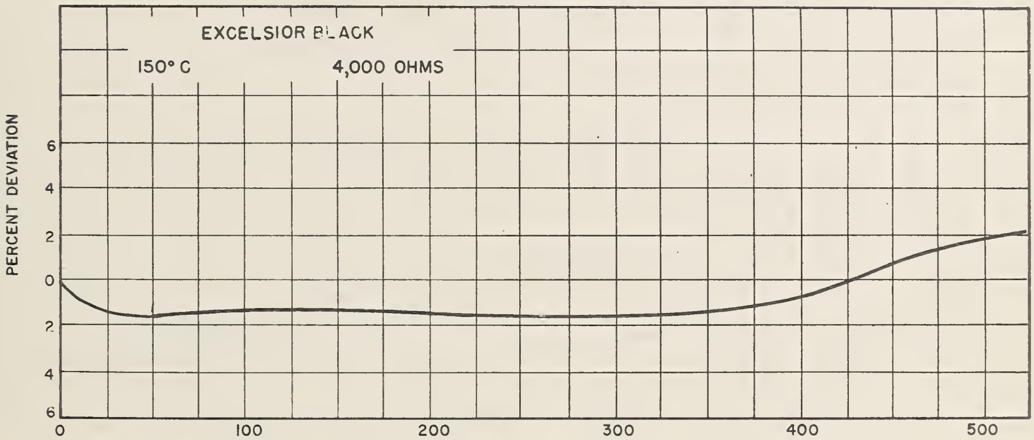


FIG. A-11

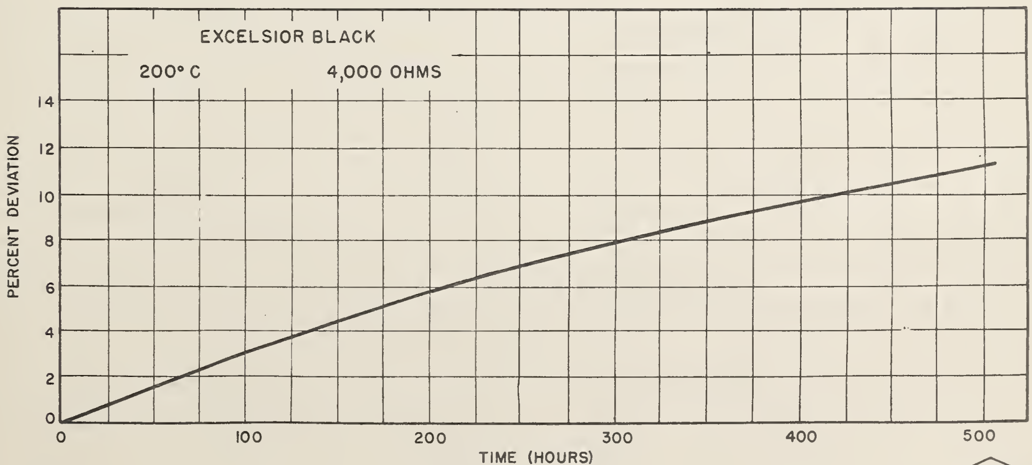


FIG. A-12

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

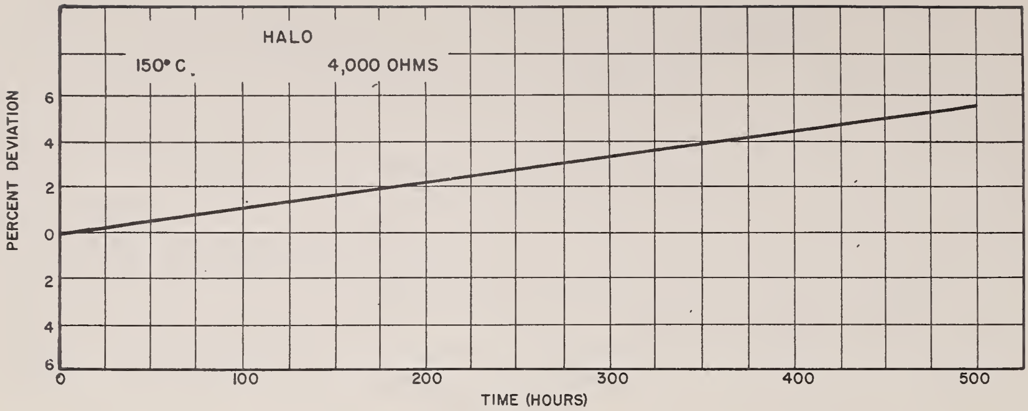


FIG. A-7

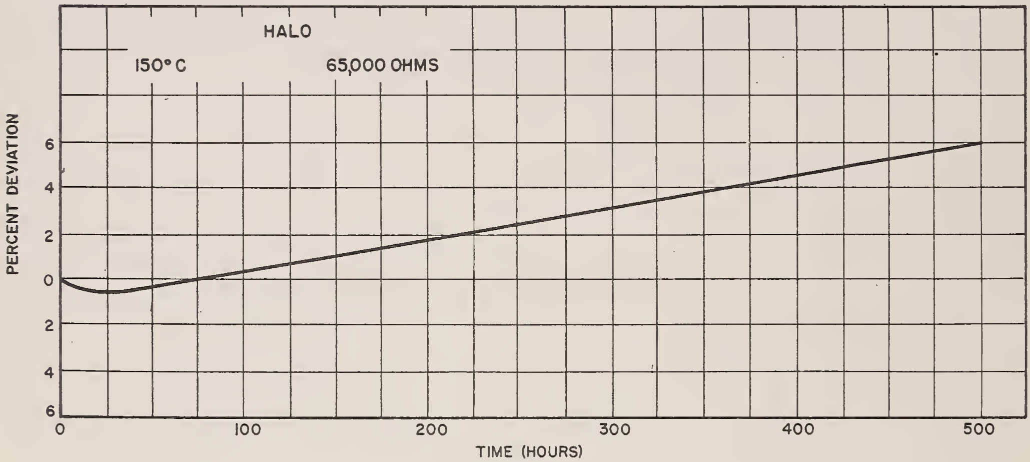


FIG. A-8

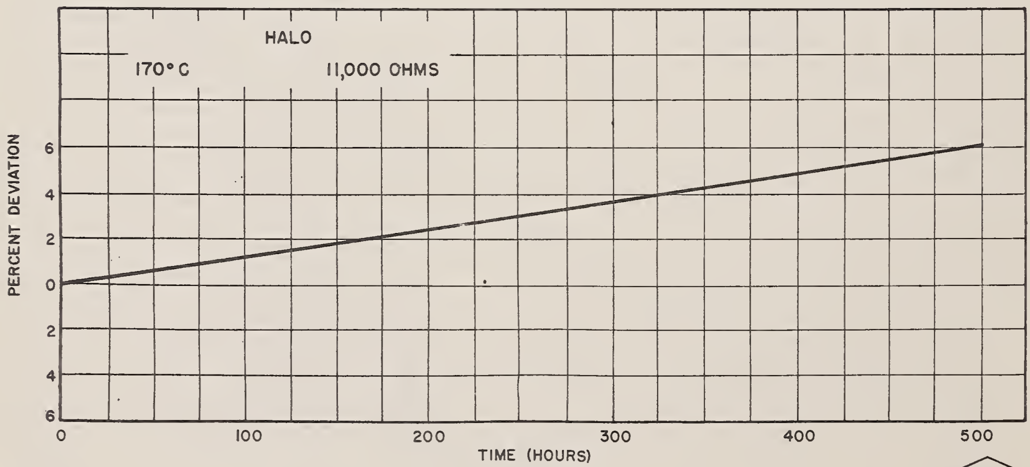


FIG. A-9

NBS

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

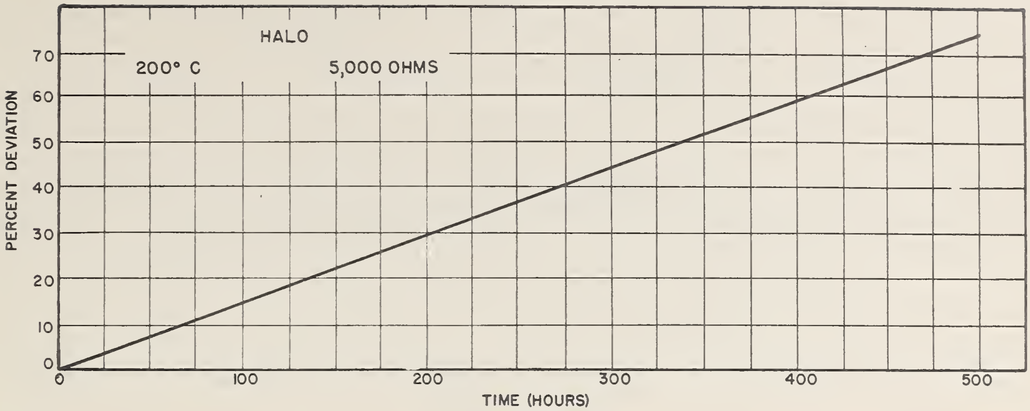


FIG. A-10

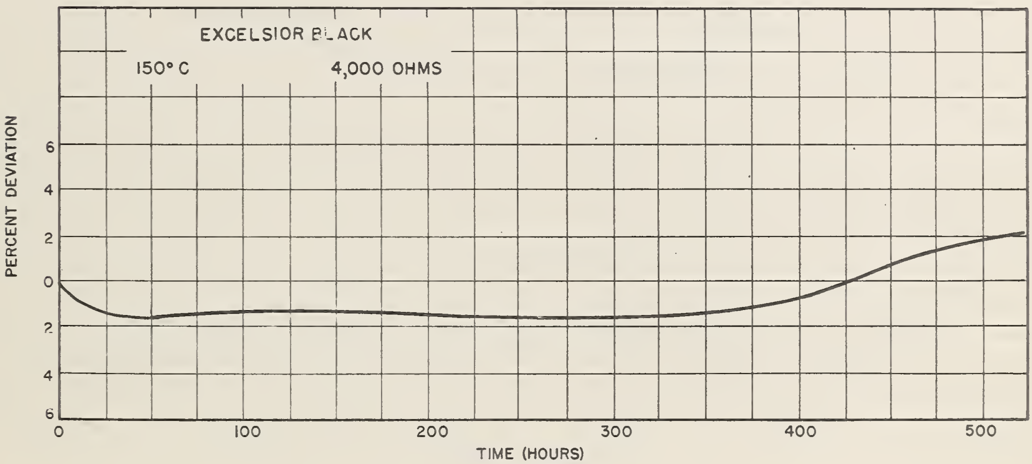


FIG. A-11

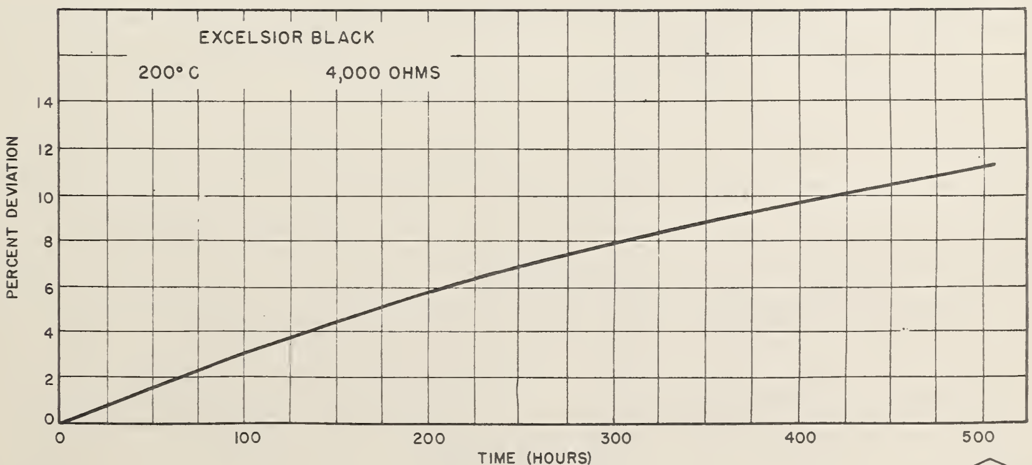


FIG. A-12

NBS

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

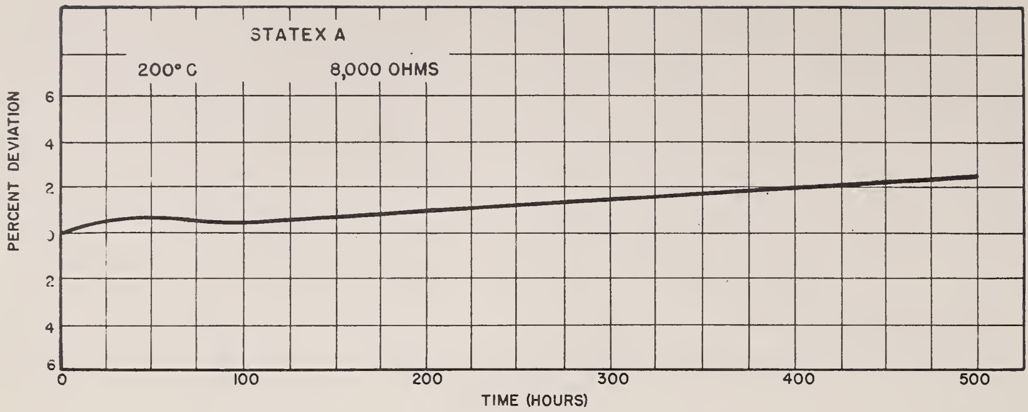


FIG. A-13

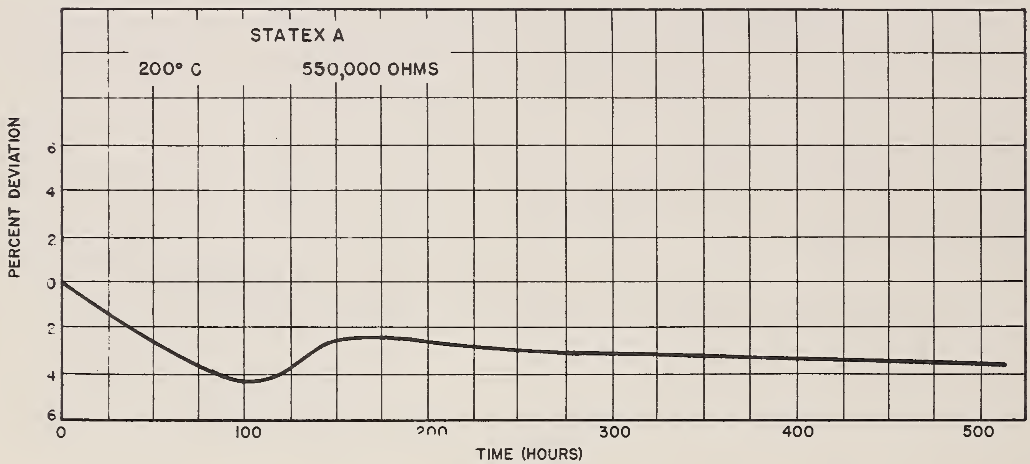


FIG. A-14

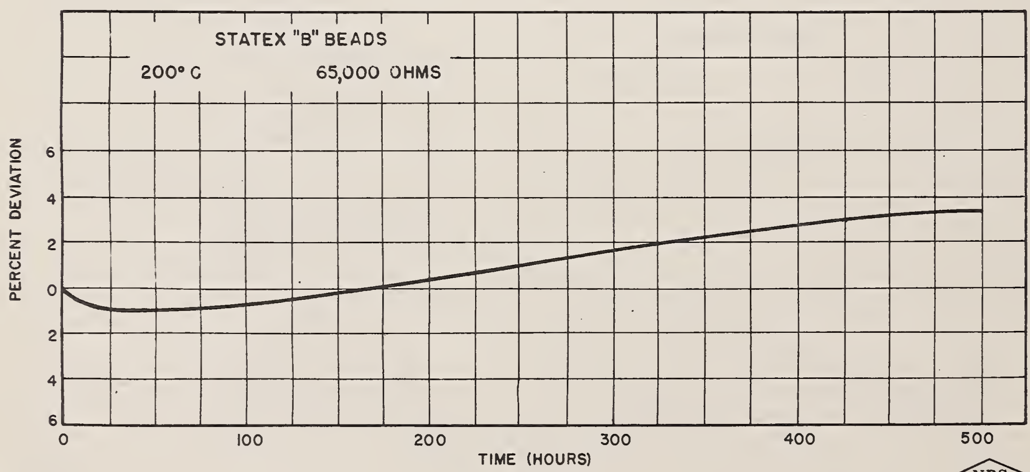


FIG. A-15

NBS

LOAD-LIFE CURVES
$\frac{1}{4}$ WATT

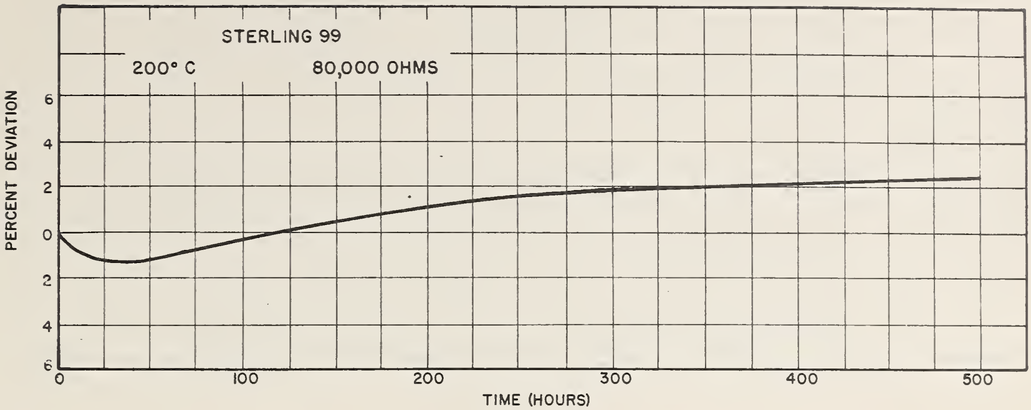


FIG. A-16

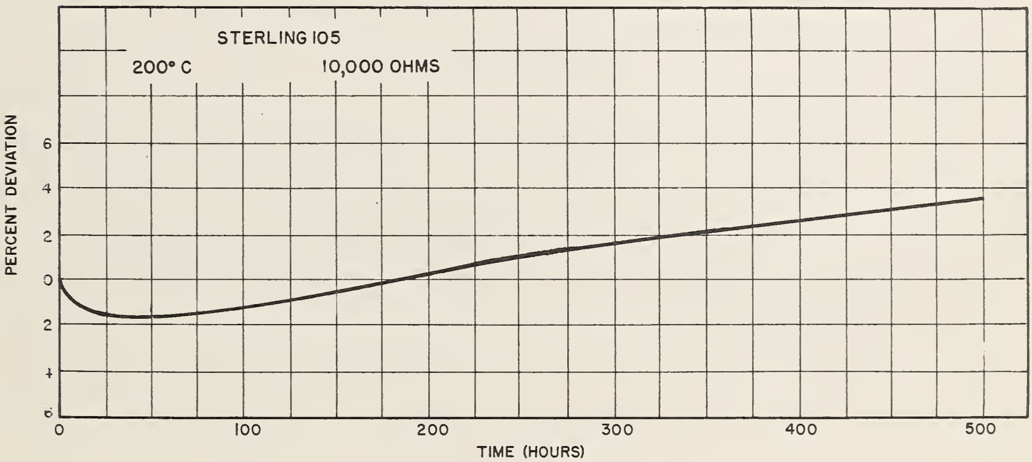


FIG. A-17

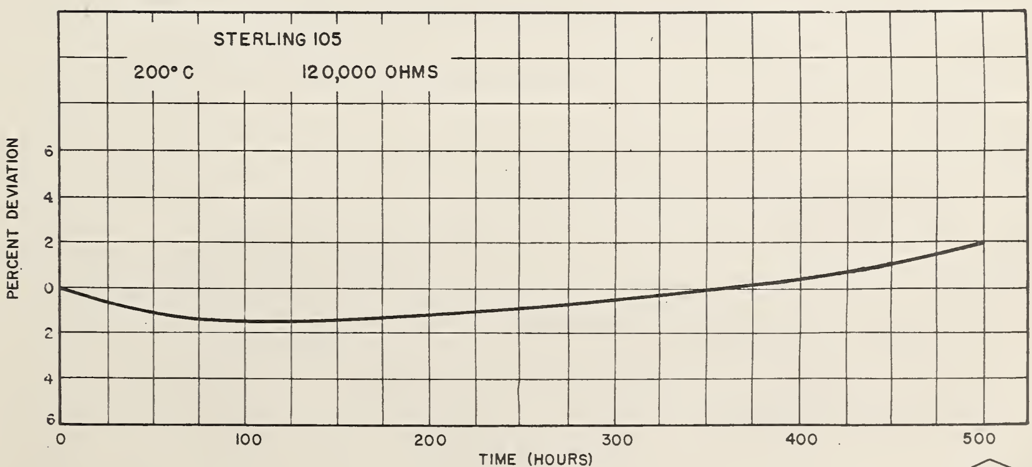


FIG. A-18

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING NATURAL GRAPHITE

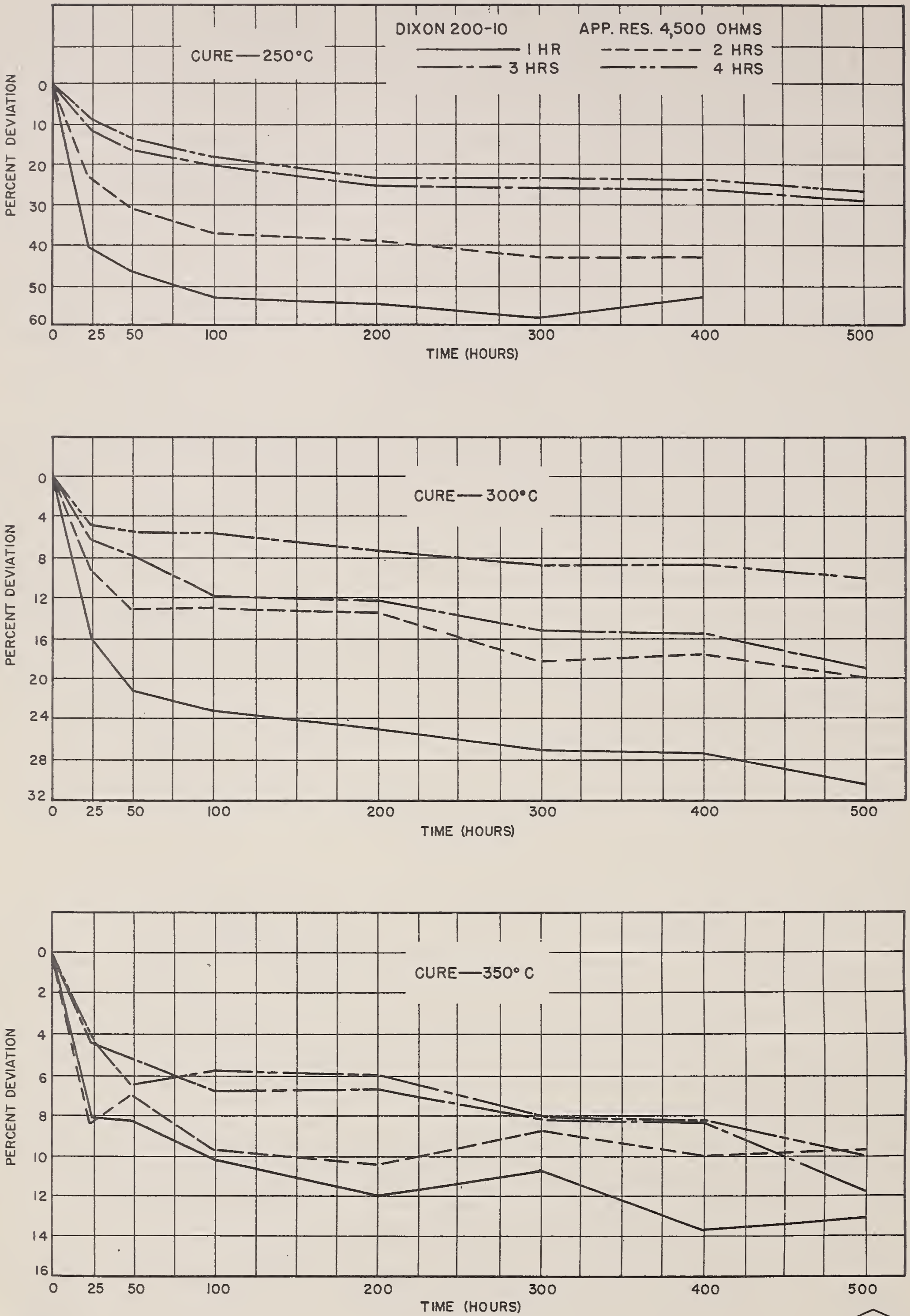


FIG. A-19

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING ARTIFICIAL GRAPHITE

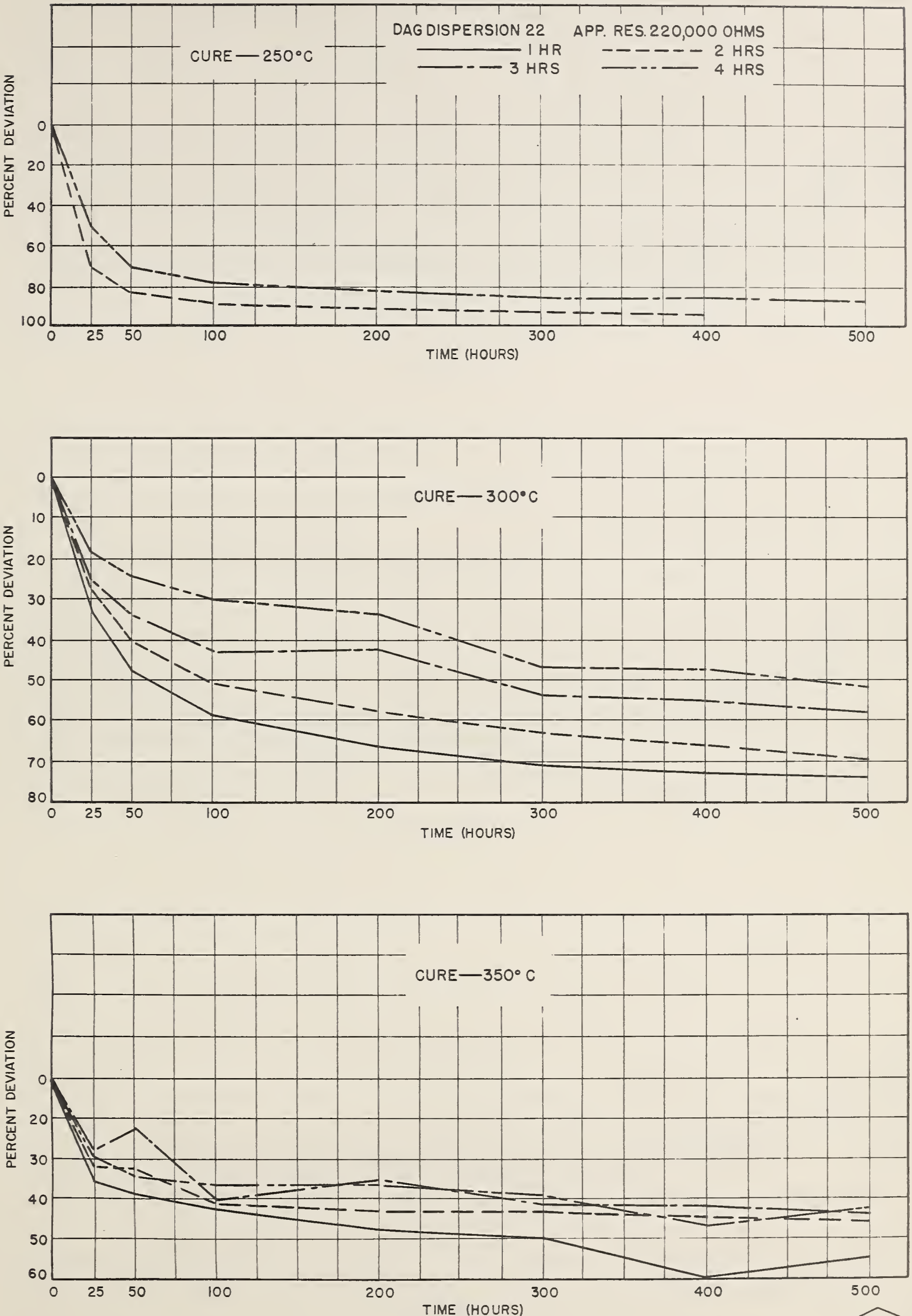


FIG. A-20

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING ARTIFICIAL GRAPHITE

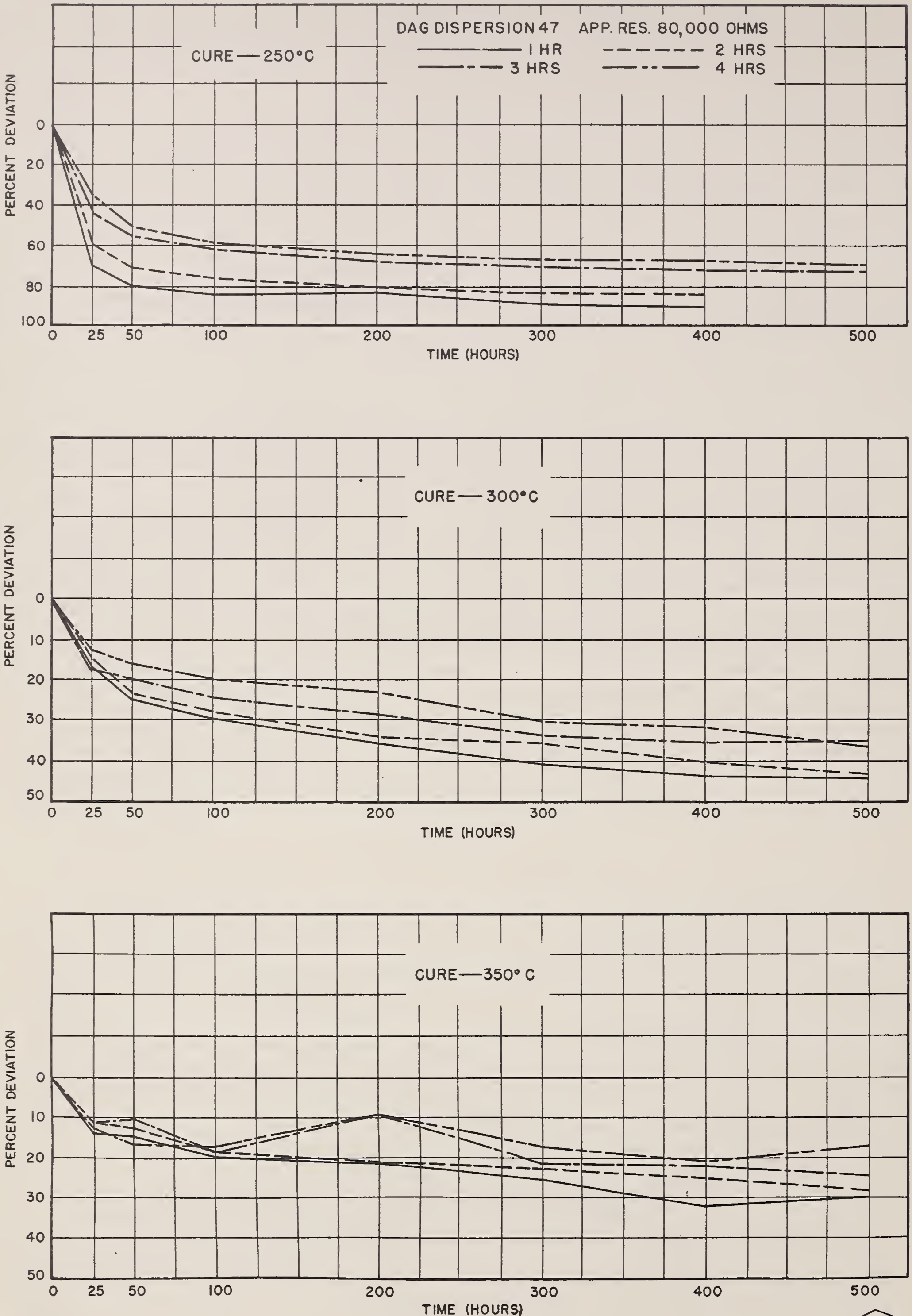


FIG. A-21

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING ARTIFICIAL GRAPHITE

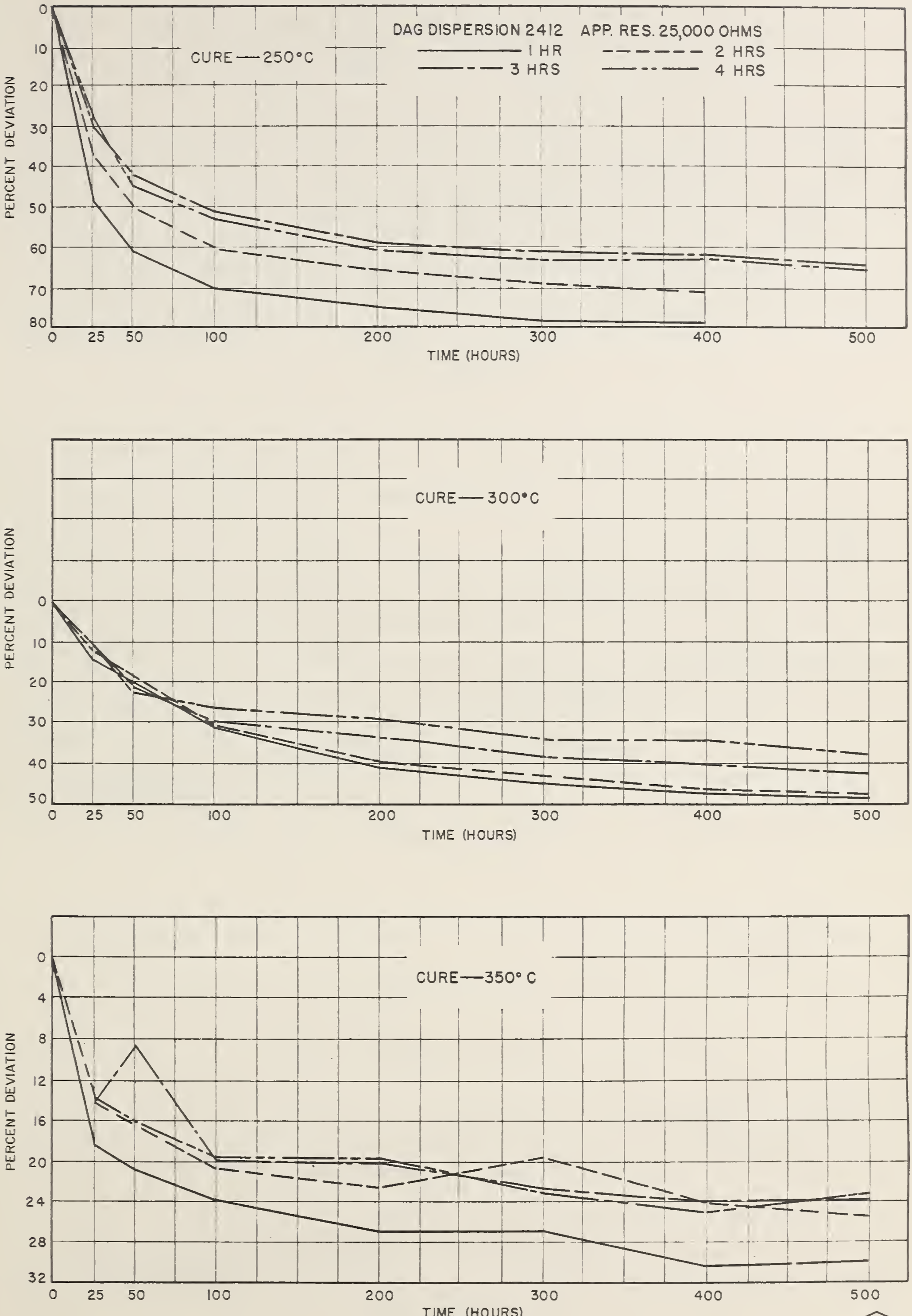


FIG. A-22

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING ARTIFICIAL GRAPHITE

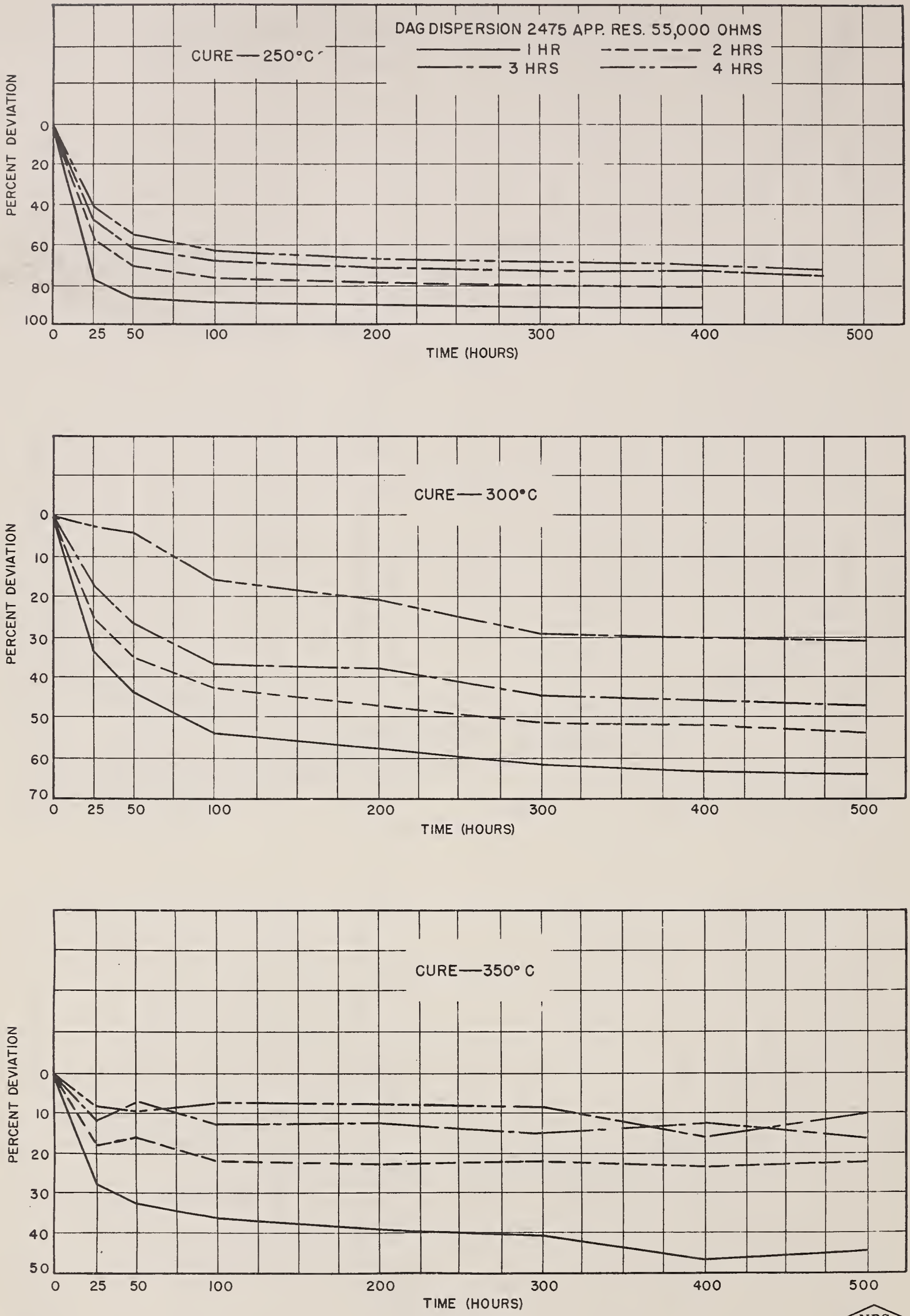


FIG. A-23

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

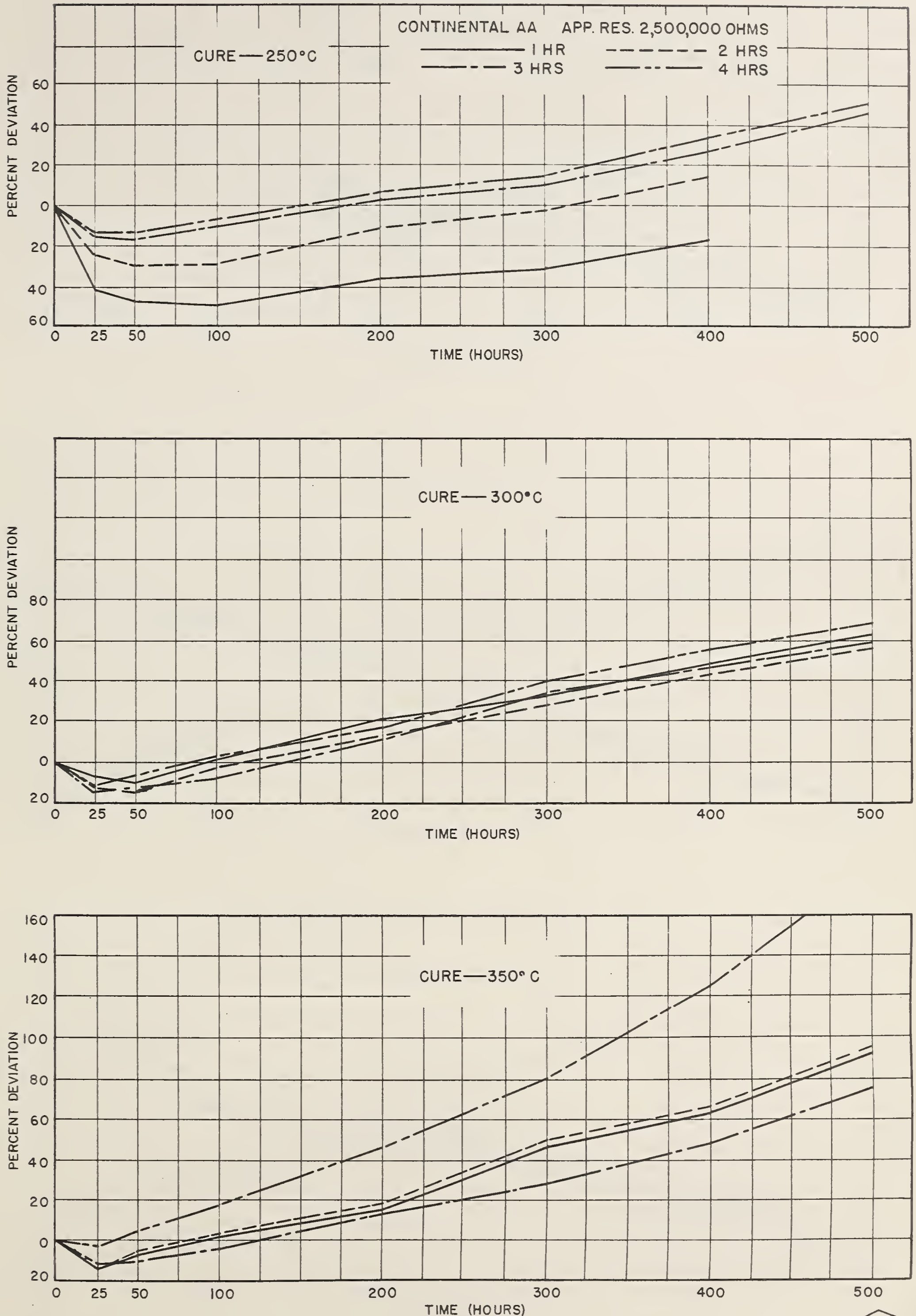


FIG. A-24

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

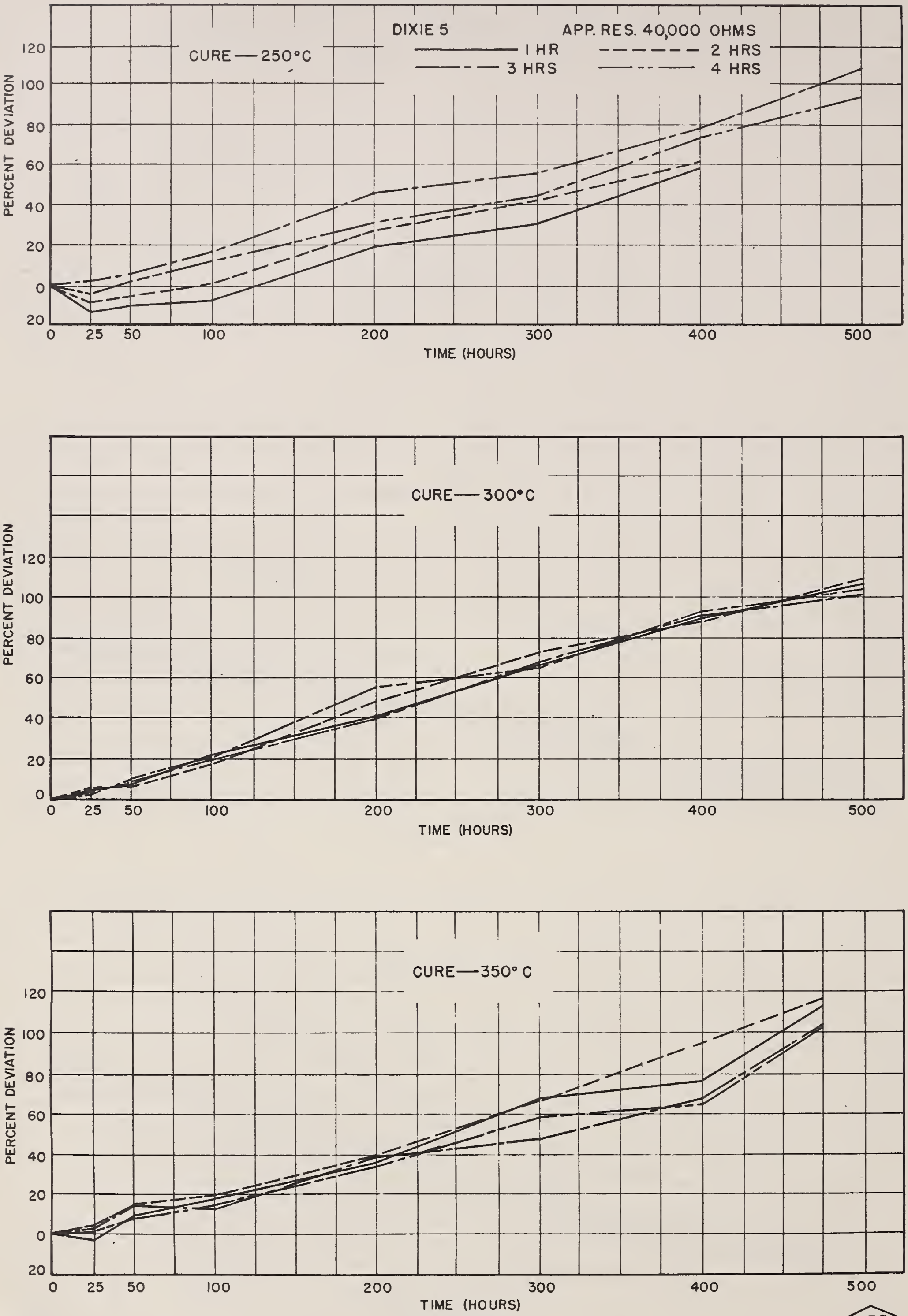


FIG. A-25

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

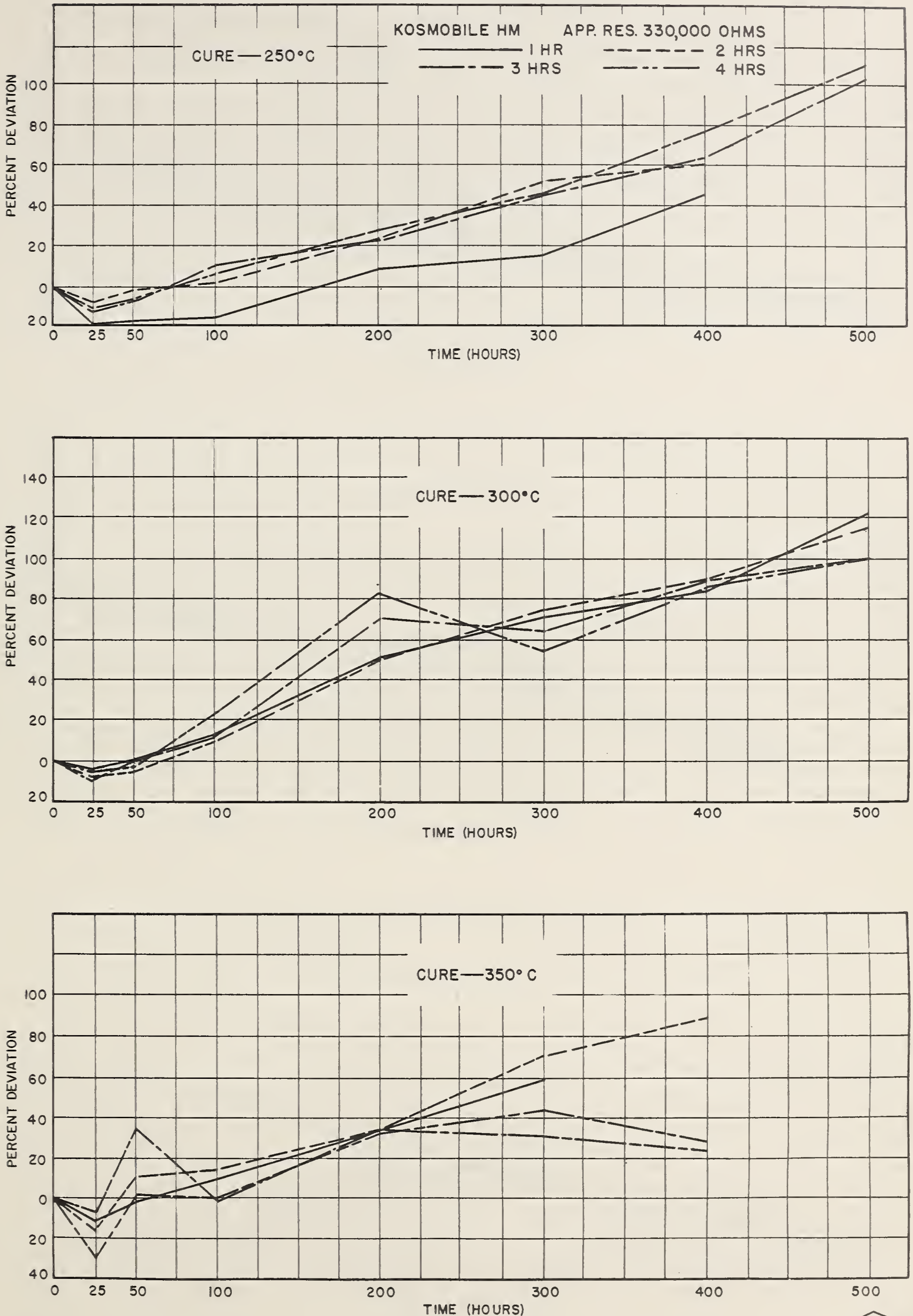


FIG. A-26

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

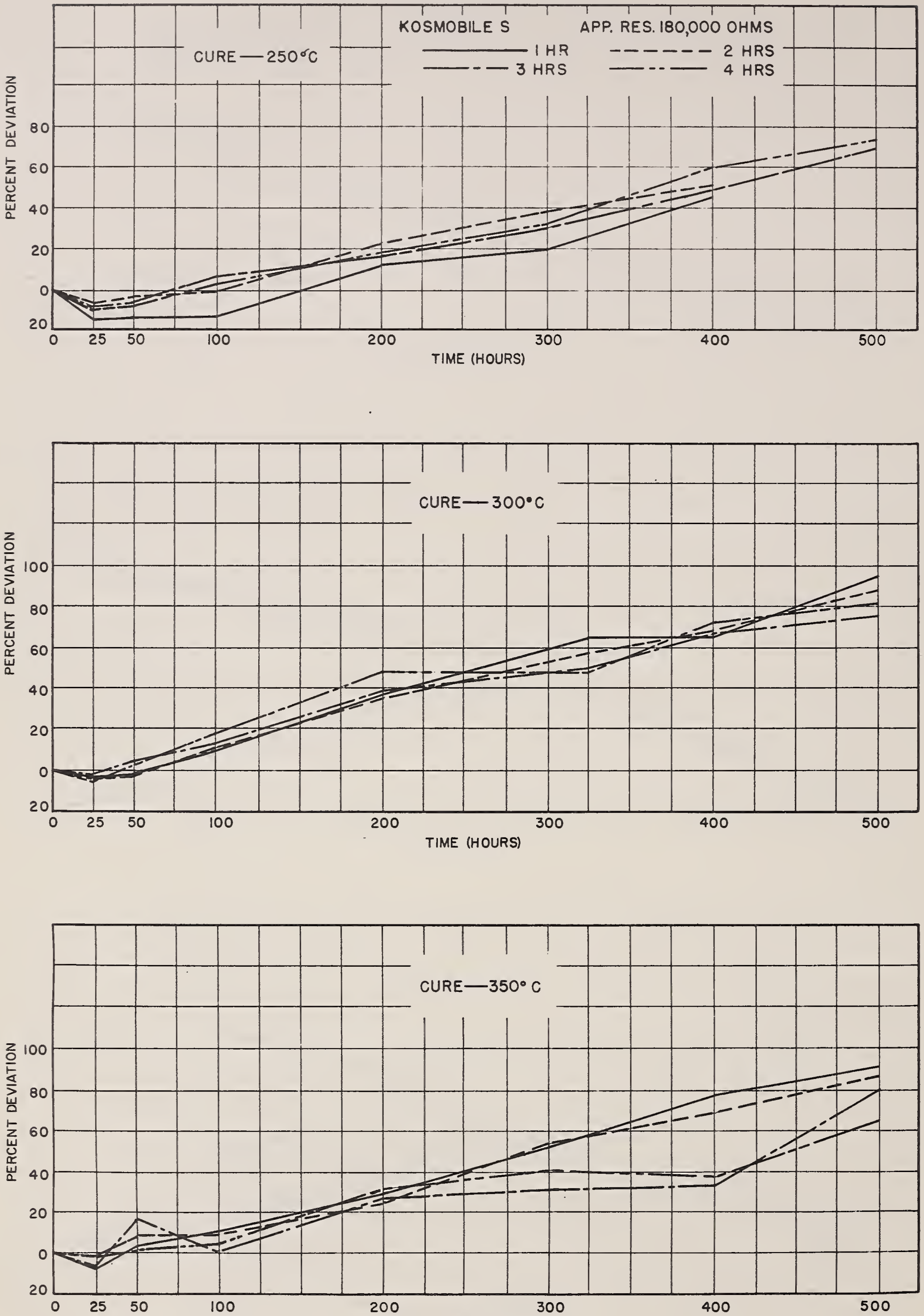
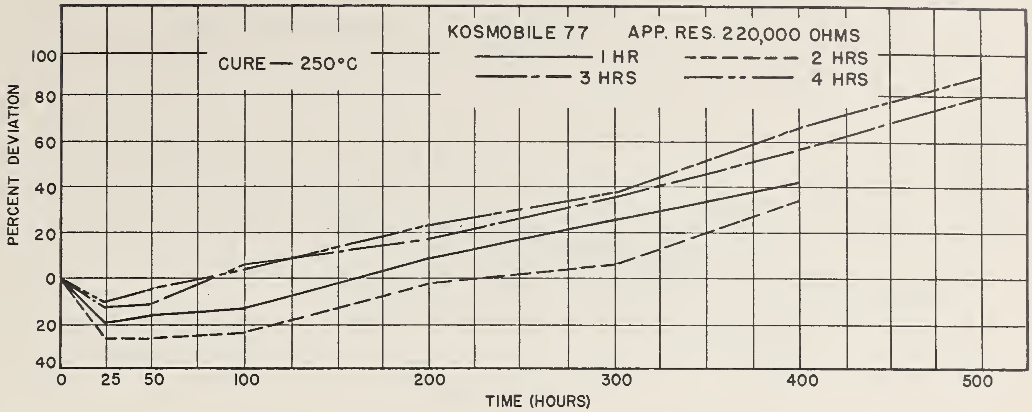
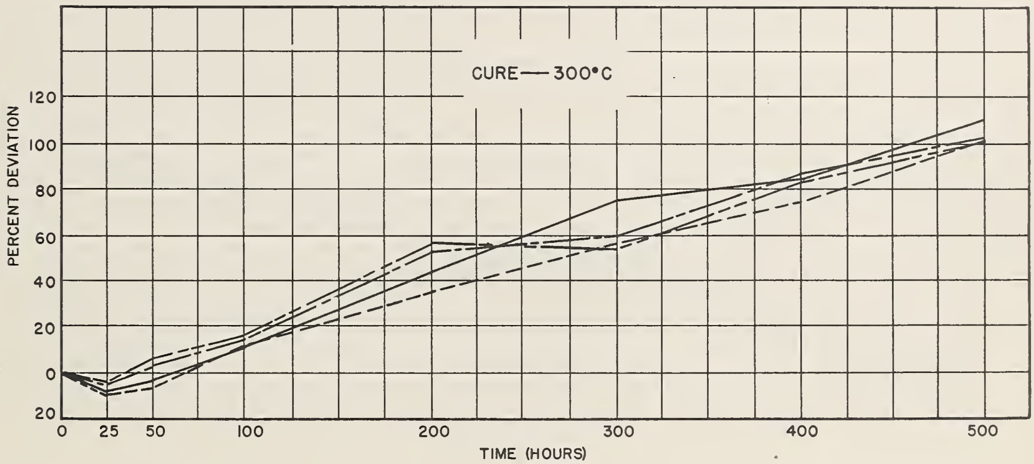


FIG. A-27

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK





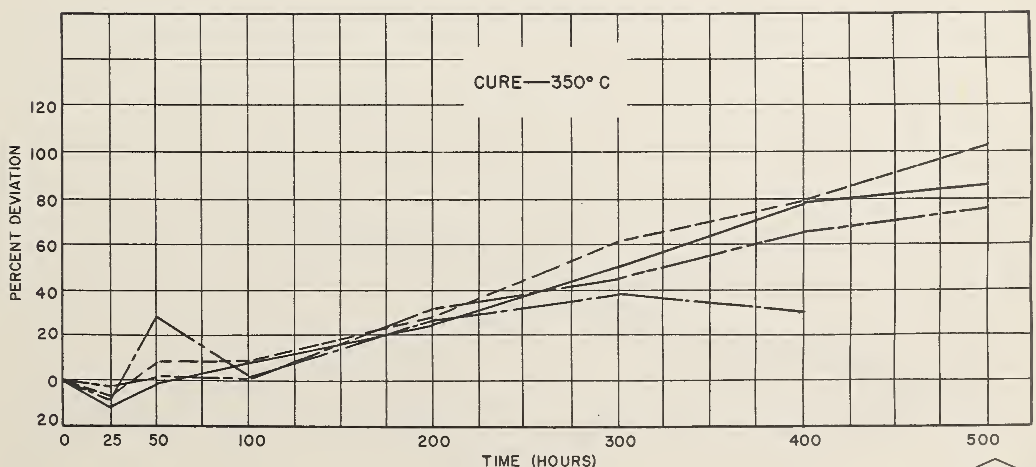


FIG. A-28

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

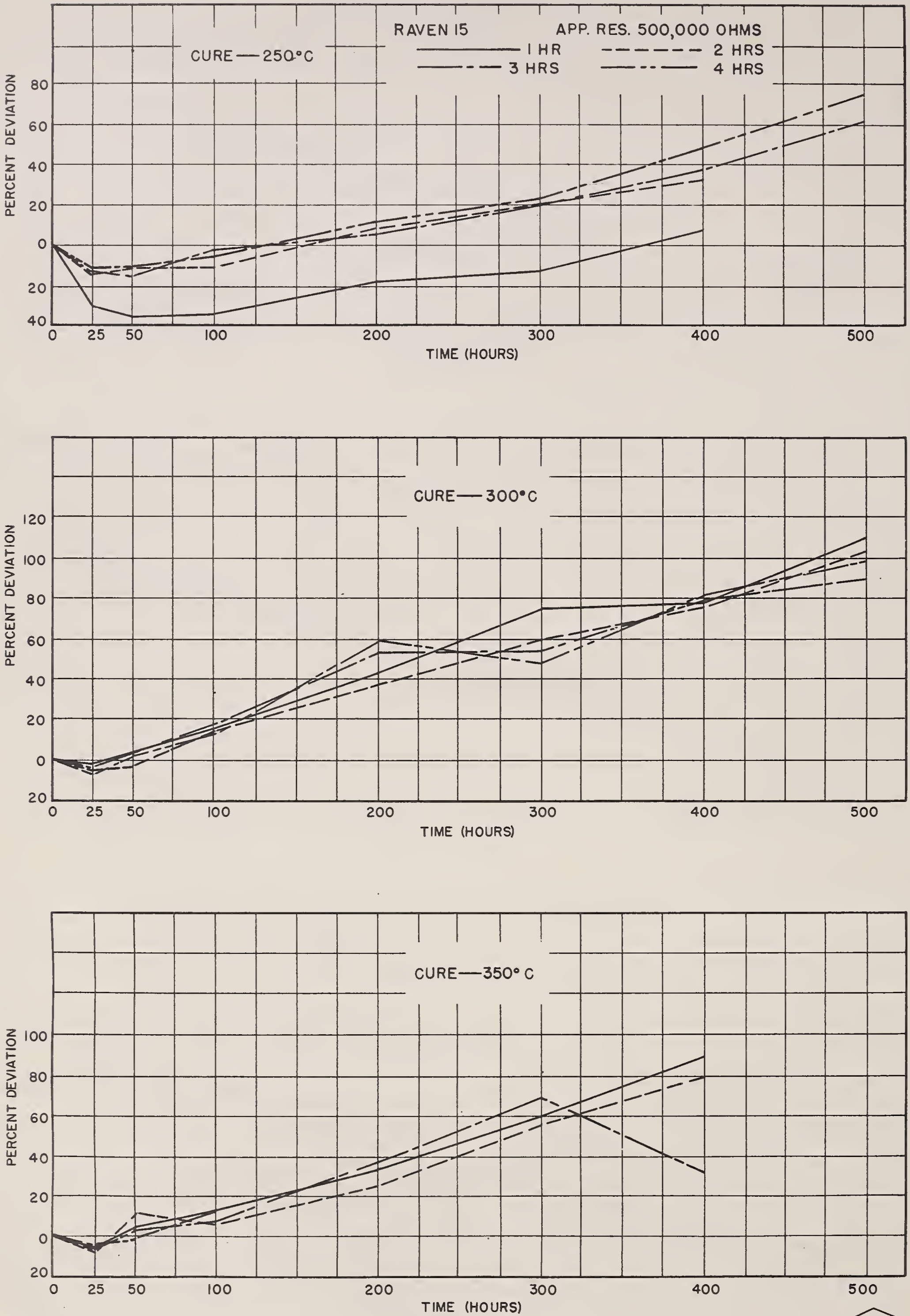


FIG. A-29

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

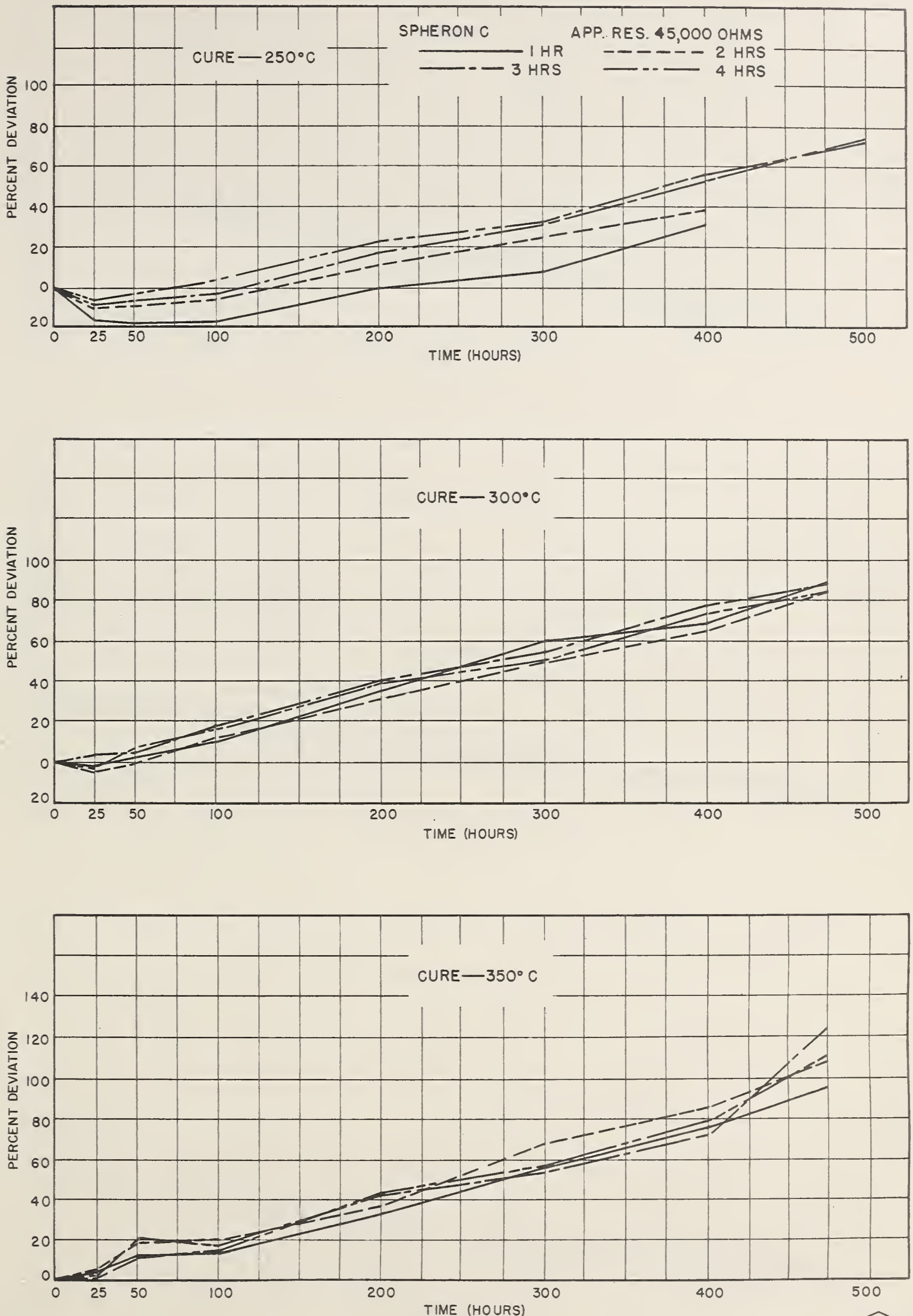


FIG. A-30

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK

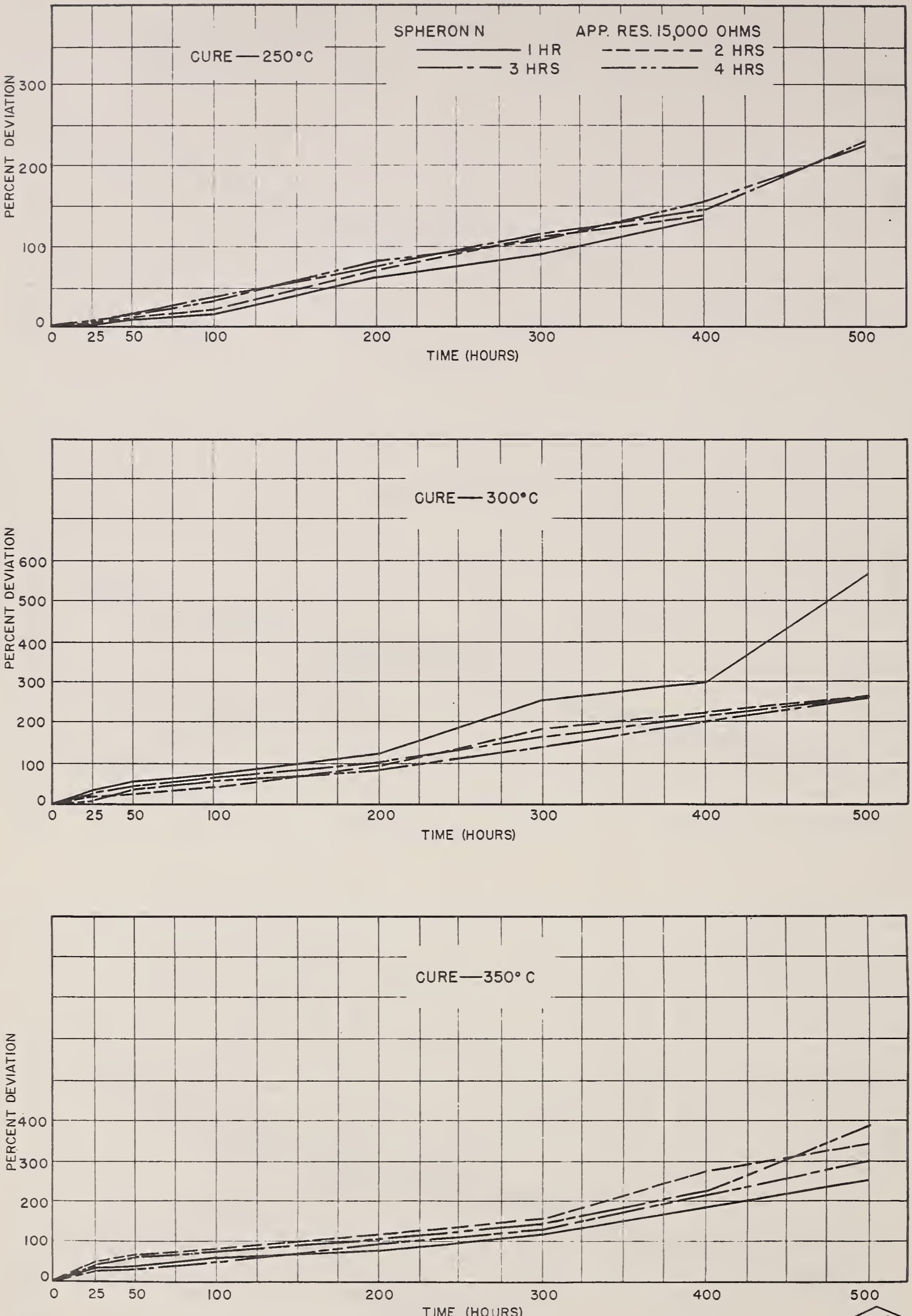
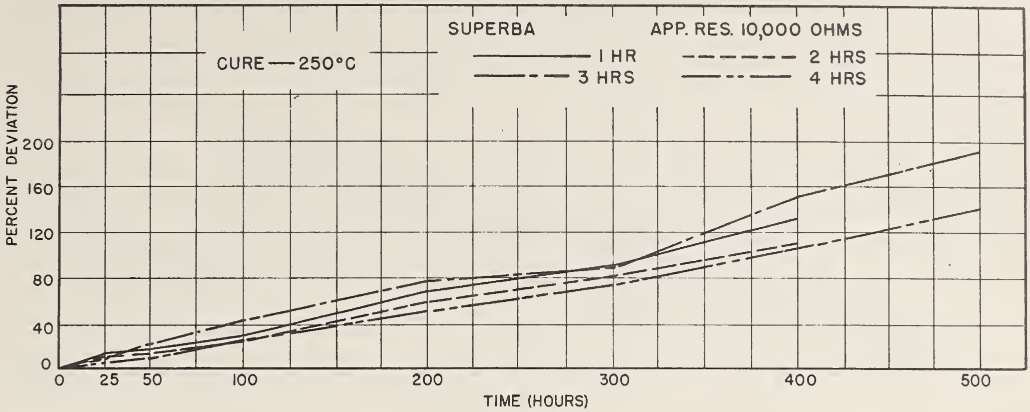
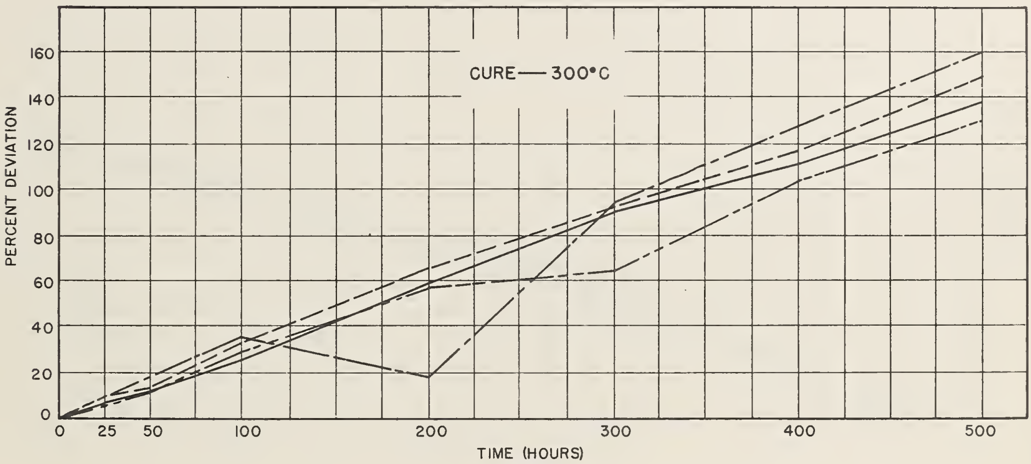


FIG. A-31

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK





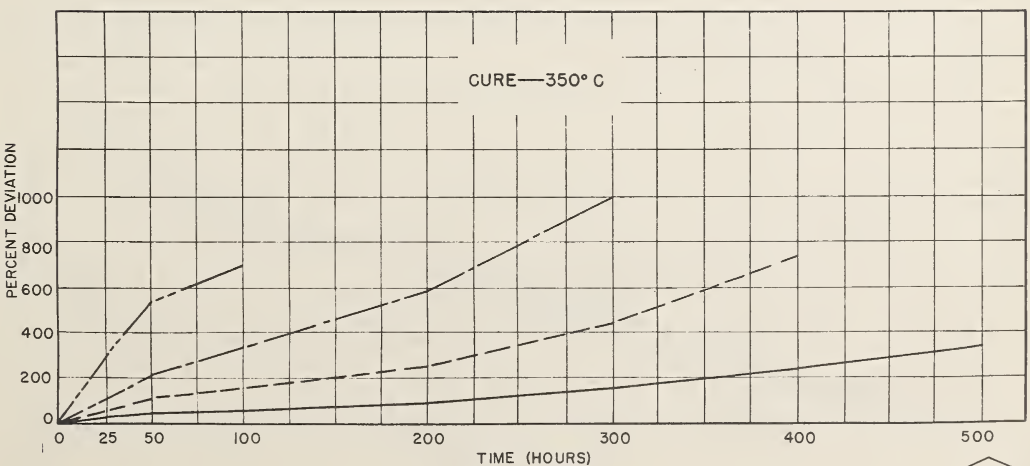
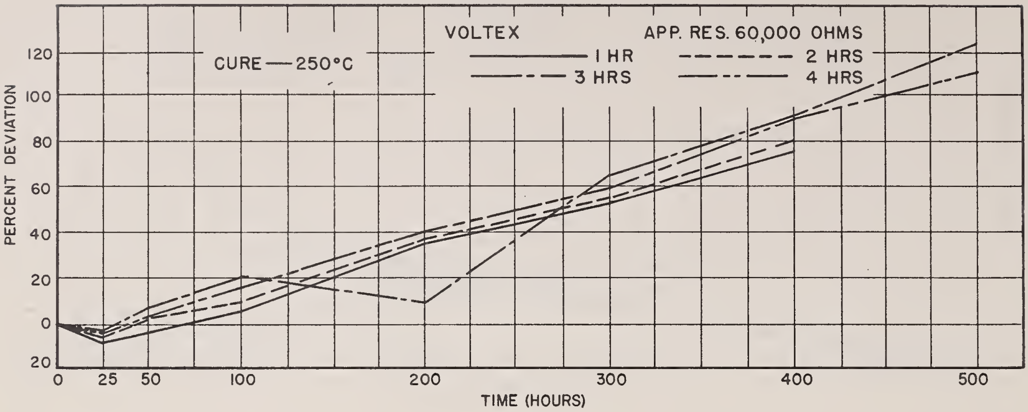
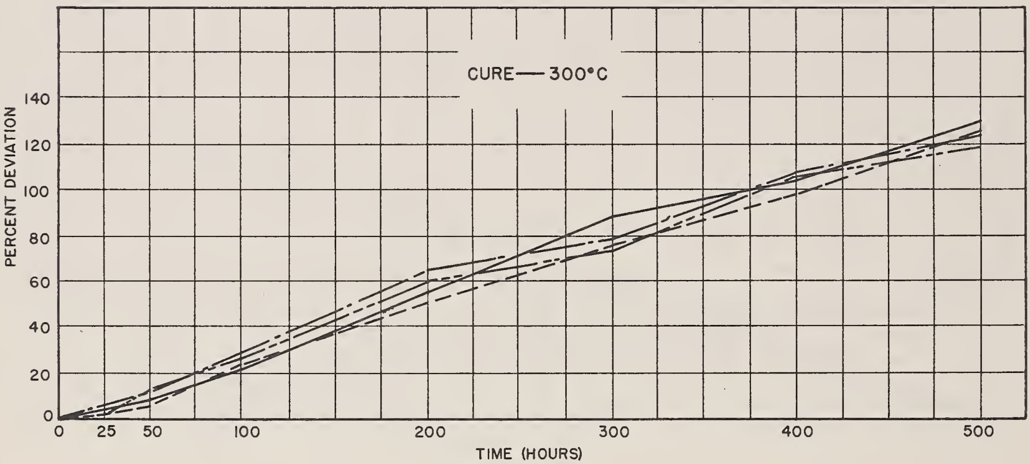


FIG. A-32

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING CHANNEL BLACK





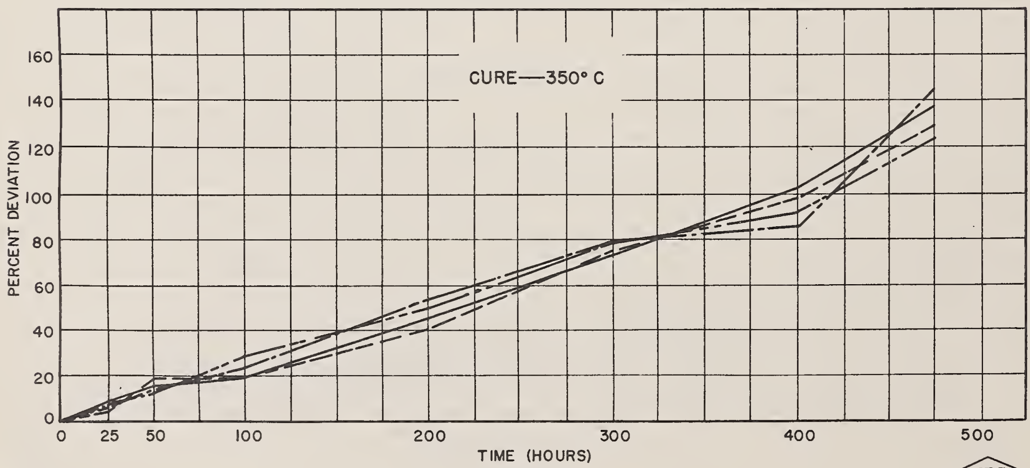


FIG. A-33

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING FURNACE BLACK

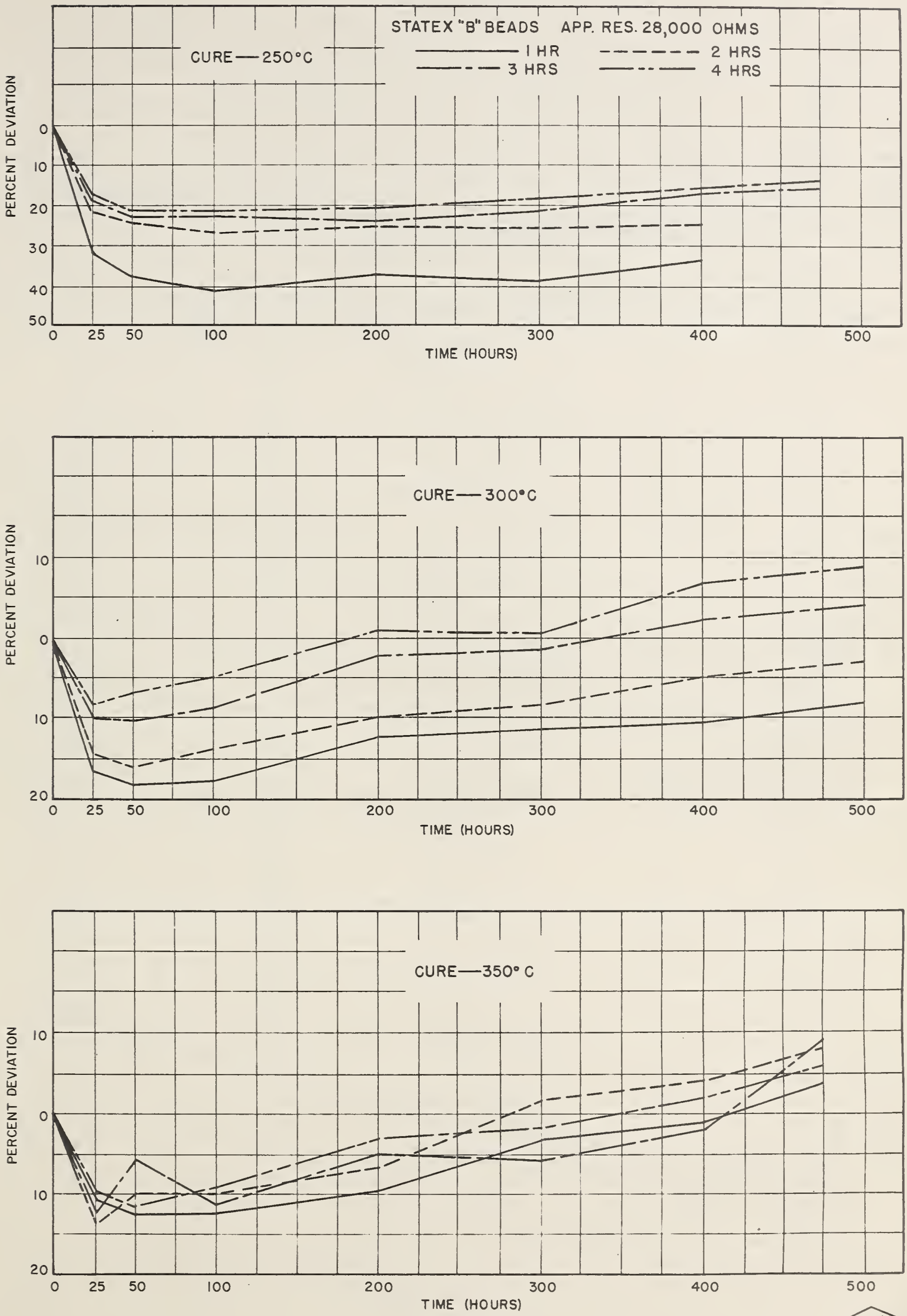


FIG. A-34

NBS

EFFECT OF CURE ON LOAD-LIFE CHARACTERISTICS FOR FORMULATIONS CONTAINING FURNACE BLACK

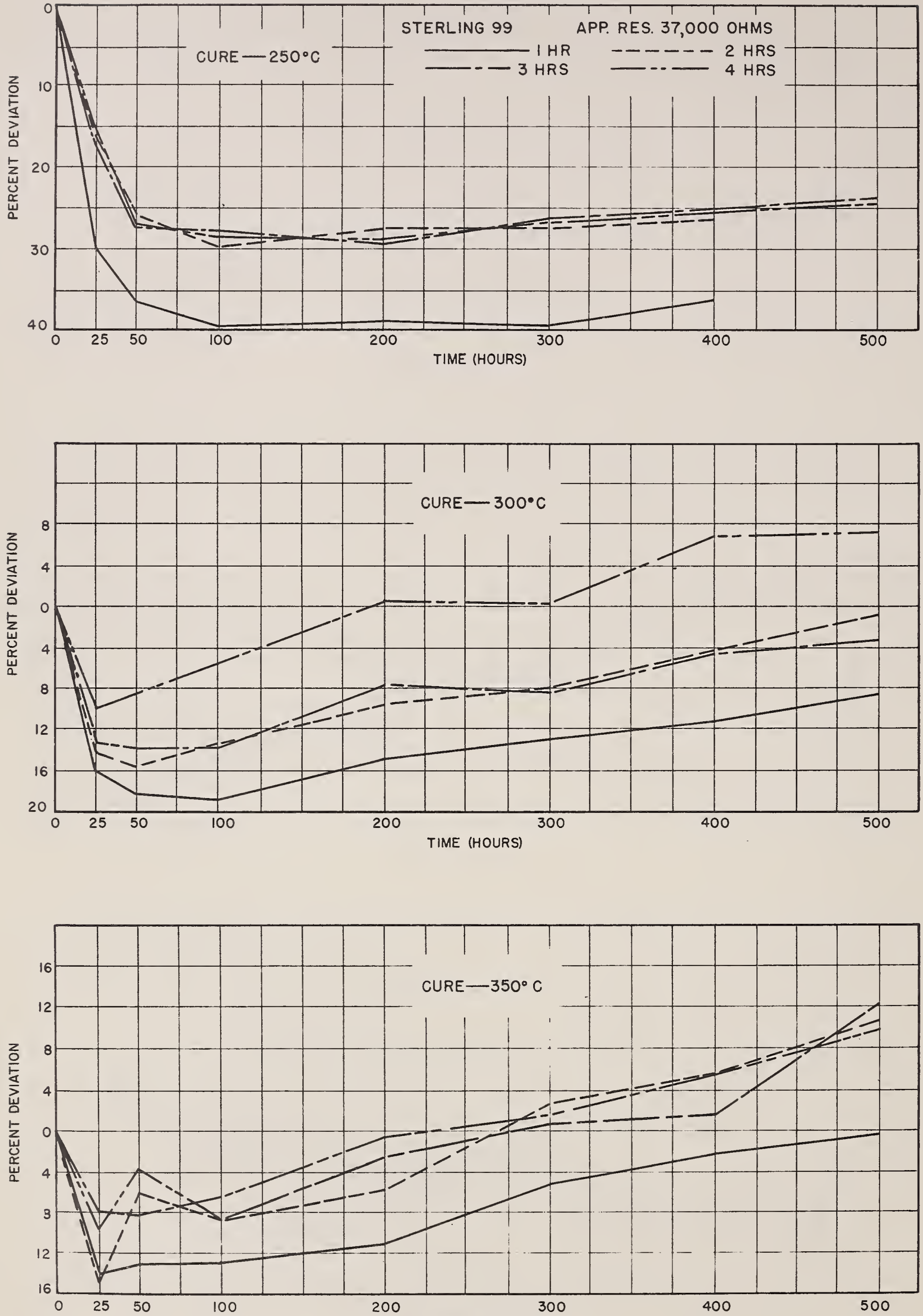


FIG. A-35

NBS

B: Resistance Values

A table of resistance values obtainable from the different carbon formulations experimented with is included below. If this table is to be used in producing resistor tapes, a number of qualifying statements are necessary. The formulations given have produced resistors having satisfactory electrical properties at the stated ambient temperatures. This listing includes only the more successful carbon formulations.

The tapes have been prepared according to the procedure given in section 2. The base used, in all cases, was the grade 5C Quinterra tape. All resistors mentioned were cured on steatite test plates for 4 hours at 300°C, followed in the case of the furnace blacks by 24 hours at 200°C. The resin was the Dow-Corning DC996 silicone. Solvent (butyl cellosolve, benzene, toluene, etc.) was added to make the ratio of solvent to solids 2 to 1.

Resistance value (Ohms)	Temperature ambient °C	Preferred carbon	Ratio by weight of silicone to carbon
100	200	Dag 22	1 to 1
200	200	Dixon 200-09	2.5 to 1
300	200	Dixon 200-09	3 to 1
500	200	Dixon 200-09	4 to 1
800	200	Dag EC-427	2 to 1
1,000	200	Dag 22	2 to 1
1,500	200	Dixon 200-09	5 to 1
2,000	200	Dixon 200-09	6 to 1
4,000	150	Excelsior Black	8 to 1
5,000	200	Statex A	4 to 1
5,000	150	Halo Black	8 to 1
6,000	200	Dixon 200-10F	5 to 1
7,000	150	Halo Black	9 to 1
10,000	200	Statex A	5 to 1
15,000	200	Sterling K	6 to 1
20,000	200	Statex A	6 to 1
30,000	200	Dag EC-427	5 to 1
35,000	200	Statex A	7 to 1
50,000	200	Statex A	7.5 to 1
60,000	150	Halo Black	14 to 1
70,000	200	Statex A	8 to 1
100,000	200	Statex A	8.5 to 1
130,000	150	Halo Black	15 to 1
140,000	200	Sterling 105	14 to 1
200,000	200	Statex A	9.5 to 1
300,000	150	Halo Black	22 to 1
500,000	150	Continental AA	7.5 to 1
800,000	150	Continental AA	8 to 1
1,000,000	150	Halo Black	26 to 1
2,000,000	150	Continental AA	9 to 1
3,000,000	150	Continental AA	10 to 1

C: Sources of Supply of Materials and Equipment

To serve the interests of those concerned with this study and because the manufacture of the NBS tape resistor is essentially a chemical process while its use is primarily electrical, a list of suppliers of the more uncommon items used in this project is herewith presented. It must be understood that inclusion of a manufacturer or his product does not, in any way, constitute an endorsement by the National Bureau of Standards. The list is by no means all inclusive since a complete survey of the available sources was not attempted.

Acetylene Black: Shawinigan Chemicals Limited, Shawinigan Falls, Quebec

Artificial Graphites: Acheson Colloids Corp., Port Huron, Michigan

Asbestos Paper Tape: Johns-Manville Sales Corp., New York, New York

Butyl Cellosolve: Carbide and Carbon Chemicals Corp., New York, New York

Carbons: See Graphites; Channel Blacks; Furnace Blacks

Ceramic Test Plates: American Lava Corp., Chattanooga, Tennessee
General Ceramics and Steatite Corp., Keasbey, New Jersey
Stupakoff Ceramic and Manufacturing Corp., Latrobe, Pennsylvania

Channel Black Carbons: See Continental AA; Dixie 5; Excelsior Black; Halo Black; Kosmobile HM, S, 77; Raven 15; Spheron N, C; Superba; Voltex

Continental AA: Witco Chemical Co., New York, New York

Continex HMF, SRF: Witco Chemical Co., New York, New York

Dag 22, 47, 2412, 2475, EC-427, Ultra-fine: Acheson Colloids Corp., Port Huron, Michigan

DC 996 Resin: Dow Corning Corp., Midland, Michigan

Dixie 5: United Carbon Co., Charlestown, West Virginia

Dixon Graphites 200-08, 200-09, 200-10, 200-10F, 200-18, 200-19:
Joseph Dixon Crucible Co., Jersey City, New Jersey

Excelsior Black: Binney and Smith Co., New York, New York

Foamglass, Oven Insulation: Pittsburgh Corning Co., Port Allegany, Pennsylvania

Furnace Blacks: See Acetylene Black; Continex HMF, SRF; P-33; Statex A, B beads; Sterling K, 99, 105

Graphite, Artificial: Dag 22, 47, 2412, 2475, EC-427, Ultra-fine
Acheson Colloids Corp., Port Huron, Michigan

Graphite, Natural: Dixon 200-08, 200-09, 200-10, 200-10F, 200-18, 200-19
Joseph Dixon Crucible Co., Jersey City, New Jersey

Halo Black: Binney and Smith Co., New York, New York

Heat Lamps, Infra-Red: Westinghouse Electric Corp., Pittsburgh, Pennsylvania
General Electric Co., Schenectady, New York

Industrial Wheels, Rubber Coated: Aerol Co., Los Angeles, California

Kosmobile HM, S, 77: United Carbon Co., Charlestown, West Virginia

Melamine Resin: American Cyanamid Corp., New York, New York

Muffle Furnace: Hevi-Duty Electric Co., Milwaukee, Wisconsin
Hoskins Manufacturing Co., Detroit, Michigan

Nichrome Wire, Asbestos insulated: General Electric Co., Philadelphia, Pennsylvania
Driver-Harris Co., Harrison, New Jersey
Hoskins Manufacturing Co., Detroit, Michigan

Oven Insulation, Foamglass: Pittsburgh Corning Co., Port Allegany, Pennsylvania

Poleythelene Tape: Plax Corp., Hartford, Connecticut

P-33: Thermatomic Carbon Co., Sterlington, Louisiana

Quinterra: Johns-Manville Sales Corp., New York, New York

Raven 15: Binney and Smith Co., New York, New York

Recorder, 8-position, Multipoint: Minneapolis-Honeywell Regulator Co., Brown Instrument Division, Philadelphia, Pennsylvania

Silicone Resin: Dow-Corning Corp., Midland, Michigan
General Electric Co., Chemical Department, Waterford, New York

Silk-Screens: B. F. Drakenfield and Co., Inc., New York, New York
Graining Equipment Co., Nashville, Tennessee
O. Hommel, Pittsburgh, Pennsylvania

Silver Paint: E. I. du Pont de Nemours Co., Wilmington, Delaware

Spheron N, C: Godfrey L. Cabot Inc., Boston, Massachusetts

Spray Gun: Binks Manufacturing Co., Chicago, Illinois

Statex A, B beads: Binney and Smith Co., New York, New York

Steatite Test Plates: American Lava Corp., Chattanooga, Tennessee
General Ceramics and Steatite Corp., Keasbey, New Jersey
Stupakoff Ceramic and Manufacturing Co., Latrobe, Pennsylvania

Sterling K, 99, 105: Godfrey L. Cabot, Inc., Boston, Massachusetts

Superba: Binney and Smith Co., New York, New York

Transite: Johns-Manville Sales Corp., New York, New York

Voltex: United Carbon Co., Charlestown, West Virginia

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As the principal agency of the Federal Government for fundamental research in physics, chemistry, mathematics, and engineering, the National Bureau of Standards conducts projects in fifteen fields: electricity, optics and metrology, heat and power, atomic and radiation physics, chemistry, mechanics, organic and fibrous materials, metallurgy, mineral products, building technology, applied mathematics, electronics, ordnance development, radio propagation, and missile development. The Bureau has custody of the national standards of measurement and conducts research leading to the improvement of scientific and engineering standards and of techniques and methods of measurement. Testing methods and instruments are developed; physical constants and properties of materials are determined; and technical processes are investigated.

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