REPORT NO.
NASA-CR-54092
WESTINGHOUSE
WAED 64.53E
OCTOBER 1964

ELECTRICAL CONDUCTORS AND ELECTRICAL INSULATION MATERIALS TOPICAL REPORT

RESEARCH AND DEVELOPMENT PROGRAM ON MAGNETIC, ELECTRICAL CONDUCTOR, ELECTRICAL INSULATION, AND BORE SEAL MATERIALS

by

P. E. Kueser et al

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS3-4162

Westinghouse Electric Corporation
AEROSPACE ELECTRICAL DIVISION
LIMA, OHIO

AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D. C.
Attn: AFSS-A

Report No. 64.53E
October 1964

RESEARCH AND DEVELOPMENT PROGRAM ON MAGNETIC, ELECTRICAL CONDUCTOR, ELECTRICAL INSULATION AND BORE SEAL MATERIALS

ELECTRICAL CONDUCTOR AND ELECTRICAL INSULATION MATERIALS TOPICAL REPORT

NAS3-4162

sponsored by

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-4162

Project Management
NASA-Lewis Research Center
Space Power Systems Division
R. A. Lindberg

Prepared by:

P.E. Kueser, et al
Manager, NASA Materials Study and Research Program

W. S. Neff
W.S. Neff
Sr. Project Engineer-
Electrical Insulation Materials

D. H. Lane
D.H. Lane
Project Engineer-
Electrical Conductor Materials

Approved by:

N.W. Bucci, Jr.
Manager, Engineering Systems Research and Development Department

Westinghouse Electric Corporation
Aerospace Electrical Division
Lima, Ohio

PREFACE

The work reported here was sponsored by the Space Power Systems Division of NASA Lewis Research Center under Contract NAS 3-4162. Mr. R. A. Lindberg of NASA has provided the Project Management for the program. His technical contributions are also gratefully acknowledged. Mr. T. A. Moss of NASA is also acknowledged for his support and interest and for his recognition of the importance of this work. The work was accomplished at the Westinghouse Aerospace Electrical Division, which was the prime contractor, and at the Westinghouse Research and Development Center, which was a subcontractor. The Eitel-McCullough Corporation also acted as a subcontractor conducting the ceramic-metal bore seal investigation.

In a project of this type, many skilled engineers and scientists are consulted. While the reporting of electric material technology is given in three Topical Reports entitled: Magnetic Materials; Electrical Conductor and Insulation Materials; and Bore Seal Materials; no attempt will be made to single out a person's specific contribution, since, in many cases, it was in several areas. Those who actively contributed during the total program are recognized below:

Westinghouse Aerospace Electrical Division	Westinghouse Research and Development Center	Eitel-McCullough Incorporated
H. E. Keneipp	J. J. Clark	R. C. McRae
P. E. Kueser	L. J. Ceschini	
D. H. Lane	W. P. Hughes	
W. S. Neff	Dr. D. W. Lewis	
Dr. D. M. Pavlovic	L. E. Moberly	
R. P. Shumate	J. Sefco	
J. W. Toth	R. N. Sampson	
	J. Valentich	
	E. H. VanAntwerp	
	C. H. Vondracek	

Those who acted as consultants, advisors, supervisors, or directly participated for a shorter period of time are recognized below:

Dr. A. C. Beiler
R. M. Frost
W. L. Grant
E. F. Hammond
H. B. Johnson
D. W. Sawitke
J. W. Cunningham
Dr. L. W. Frost
R. D. Olson
S. Rosecrans
M. S. Savitski
M. Spewock
Dr. G. W. Weiner
D. W. Grobecker
Dr. W. H. Kohl
Dr. L. Reed

Credit for handling the publication of these documents is given to R. J. Heine.

SUMMARY

This Topical Report accomplished under NASA contract NAS 3-4162 contains thermophysical, electrical, and mechanical property data on electrical conductor and electrical insulation materials of interest to advanced space electric power systems. It represents a thorough search of the recent literature on these subjects and a bibliographic record on these topics.

Tests were run under consistent guidelines to provide reliable design data for the selected materials in the instances where suitable data were not disclosed in the literature search phase. Over 1200 specimens were prepared and tested and 3500 test points evaluated at elevated temperature in appropriate atmosphere such as air, inert gas, or vacuum.

Thermophysical, mechanical, and thermal aging stability properties were established for the conductor materials. Thermophysical, mechanical, thermal aging and vacuum stability properties were established for electrical insulating materials in various forms. The forms included wire insulation, sheet material, molded insulation, encapsulation compounds, and interlaminar insulation.

Typical applications for electrical conductor and electrical insulation materials are discussed and various materials are suggested for these applications. The recommended maximum operating temperature is presented along with the material properties which may limit the application.

The electrical conductors selected for evaluation and their maximum recommended operating temperature are presented in the Summary Table on the following page.

Table of Electrical Conductor Materials Selected for Investigation

Material	Desirable Characteristics	Maximum Long-Time Use Temperature[a]	Non-Desirable Characteristics
Nickel-clad Oxygen-free Copper	1. Low cost 2. Stable to 900°F for long times 3. Easy to insulate and wind	to 900°F	1. Use limited to temperatures below 1000°F 2. Joining difficult
321 Stainless-Steel-Clad Fine Silver	1. Alkali metal resistant 2. High conductivity for clad conductor 3. Easy to insulate	to 1400°F	1. Somewhat difficult to make 2. Joining difficult
304 Stainless-Steel-Clad Zirconium Copper	1. Alkali metal resistant 2. Core resistant to grain growth to approximately 1200°F 3. Non-magnetic clad at all temperatures	to 1200°F	1. Somewhat difficult to make 2. Joining difficult
Bare Dispersion-Strengthened Copper (Cu-1%BeO)	1. Highest strength conductor 2. Highest conductivity conductor 3. Most stable conductor on aging	Greater than 1600°F	1. Not resistant to alkali metal 2. Difficult to form and insulate
TD Nickel	1. Exceptional high-temperature strength	Greater than 1600°F	1. Very high resistance 2. Difficult to insulate and wind
Inconel 600-Clad, Columbium-Barrier, Dispersion-Strengthened Copper	1. Alkali-metal resistant, high-strength conductor	to 1500°F	1. Difficult to insulate and wind 2. Somewhat difficult to make 3. Joining difficult
Inconel 600-Clad Fine Silver[b]	1. Alkali metal resistant 2. High conductivity for clad conductor 3. Easy to insulate and wind	to 1500°F	1. Somewhat difficult to make 2. Joining difficult

(a) Estimated capability for 10,000 hours based on 2,000 hour data.

(b) Inconel cladding was chosen for its improved oxidation resistance in comparison to nickel. Nickel-clad silver exhibits similar electrical and stability properties.

The electrical insulation material evaluated are grouped into three temperature ranges based upon operational lifetimes of greater than 10,000 hours.

1) -65° to 400°F Polyimide base materials which are well suited to long-term exposures to the environment of outer space. This class of materials may be used in the form of magnet-wire insulation, flexible sheet (both supported and unsupported), and rigid laminate. Diphenyl-oxide glass laminate also shows good stability through the -65° to 400°F range. At temperatures to 250°F, the epoxy-glass laminates are also stable. Rigid or molded parts made of filled polyester or epoxy resins may be used to 250°F while the polyimide molding resin (though somewhat more difficult to fabricate) is good to 500°F.

2) 400° to 1200°F This temperature range is above the practical operating limit of organic insulating materials. Magnet wire with ceramic-base insulation coatings satisfactory for 1000°F application were Anaconda CeramicEze (fused glass coating containing mixture of refractory oxides) and Westinghouse R2554B (refractory oxides and glass frit in an organic binder). Anaconda Anadur insulated wire (an E-glass fiber with refractory oxide and glass frit) proved to be the most durable and has an operating limit of about 1100° to 1200°F. Of the flexible inorganic sheet insulations, the mica-glass-silicone materials have the best working characteristics and a temperature capability of 1000°F in hard vacuum. Synthetic-mica paper (Minnesota Mining & Mfg. Co. Burnil CM-1) and silicate-fiber paper (Carborundum Company Fiberfrax) have satisfactory characteristics to 1200°F, but consideration in design and special care in handling must be used to obtain satisfactory performance. Boron-phosphate-bonded asbestos laminate may be used to 1600°F in a gas-filled system but only to 1200°F in a hard vacuum because of outgassing of the material. Inorganically-bonded mica laminate (General Electric Co. Mica Mat 78300) maintains adequate electrical and mechanical properties to 1100°F. Rigid insulation forms of 94 percent pure alumina perform well up to 1200°F. Alumina is generally rated as having very high stability at temperatures in excess of 1200°F, but the impurity content level of the 94 percent pure material prevents its application at high electrical stresses above 1200°F. The encapsulation compounds suitable for the temperature range 400° to 1200°F are Anaconda Anacap (refractory oxides and glass with cementatious bonding materials) and Sauereisen Cement Co., Sauereisen 8 (insulating cement of refractory materials) and Westinghouse W839 (zirconium and aluminum orthophosphate). Sauereisen 8 and W839 are limited to 1200°F operation and Anacap to approximately 900°F.

The interlaminar insulations incorporating glass, aluminum orthophosphate, or aluminum orthophosphate filled with either mica or Bentonite, used on the magnetic materials, perform well under all operating conditions to 1100°F.

3) 1200° to 1600°F Materials satisfactory for use in this temperature range are limited to the higher-purity alumina and beryllia bodies (99%). These bodies, molded and pressed and sometimes precision ground into shapes with proper attention to equipment design, may be used satisfactorily as electrical insulation. None of the ceramic-base wire coatings studied on this program were satisfactory for use in this temperature range. A promising plasma-jet-sprayed high-purity alumina wire insulation being developed on other contracts is described in Section II. B-1 of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

Section Page

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

Section Page

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

SECTION I

INTRODUCTION

This report presents the electrical, mechanical and thermo-physical properties on conductor and insulation materials suitable for application to advanced space electric power systems. It was conducted under NASA Contract NAS3-4162 for the Lewis Research Center and is one of three topical reports prepared on Magnetic Materials (WAED 64.52E), Electrical Conductor and Insulation Materials (WAED 64.53E), and Bore Seal Materials (WAED 64.54E).

Electric power systems for use in space require better performance and reliability than most terrestrial applications. The success in fabrication and design analysis of these space power systems is dependent on reliable material properties. Very little design information was available prior to this study. This became evident during a literature search which was made of the world's literature in an attempt to minimize the amount of testing to be conducted.

The scope of the literature search conducted on conductor and insulation materials is outlined in Appendix B where over 400 significant references are listed in a punched card format. Included is a keyword or descriptor and a code number which identifies the property information available in each reference. Reference numbers prefaced by LC, LI, RC or RI in the test are listed in Appendix B.

The information presented in this report is a composite of the literature search and the tests run on this program. The tests run on this program represent over half of the data presented and are referenced as NAS 3-4162. Other sources are also identified.

This Topical Report is divided into four discussion areas. The first (Section II) is a technical discussion which describes the applications of electrical materials to advanced space electric power systems. Also in Section II is a general discussion of the materials and the observations made during the test program. Section III defines the material descriptions, specimen configurations and test procedures followed during the program. Sections IV and V present the data on electrical conductors and insulators. These last sections do not contain a discussion so they can be used as a design manual.

They include a master index for all properties, and each material has a material summary which can be used as a guide in material selection. This summary was thought quite important since the data presented in tabular and graphic form for each material are quite extensive.

Appendix A defines the symbols used in this report and explains certain terms which might be misunderstood by the reader.

SECTION II

TECHNICAL DISCUSSION

A. APPLICATION OF MATERIALS TO ELECTRIC POWER SYSTEMS.

1. General Requirements.

The primary functional properties of conductor and insulating materials for high-temperature space power systems should approach, as far as possible, those same prime properties of materials used in equivalent functions in conventional power systems. For example, the electrical strength of a high-temperature stator conductor insulation coating should be no lower than typical organic enamel coatings such as polyimide or polyvinylformal. Secondary properties of the high-temperature conductor and insulating materials differ greatly from those related properties for the conventional devices. An example of a secondary property would be the capacity of polyimide or polyvinylformal enamels to be wound and inserted into stators by machine. No such goal is desired at present in the development of refractory conductor insulations. These property differences and the effect of high temperature on electrical, mechanical, and compatibility properties must be taken into account in component design.

These materials are not used in rotors except in the a-c motor and here conductor material is used without insulation. The latter rotor is designed to use a conductor material in such a manner that its stress limit is not exceeded. Insulation has been omitted from the rotor conductors because the interlaminar insulation serves to isolate the conductors and prevents appreciable leakage of current.

The problem of using conductor materials is fundamentally the same in all system components except that special winding techniques are required to protect the conductor where sharp bends are required as in the a-c stator windings of the generator.

Special techniques are also required in the application of insulating materials. Good high-temperature insulators are often very brittle, but there are many ways in which brittle materials can be used successfully.

Some conductor materials considered in this report have low physical strength at elevated temperature and must also be sealed against contamination vapors which may escape from the system. Insulation may also be affected by these vapors. For this reason, all system components are sealed as required to protect the conductors and insulating parts.

Other sections of this report discuss the application of materials to the design of system components. These designs are typical rather than specific. They do not represent the only way that each component can be designed, but rather the most likely at this state of development.

The component drawings which accompany this report illustrate the most likely manner in which the materials under consideration will be used. Part temperatures are based on (a) coolant temperature, (b) calculations from previous designs, and (c) test results from an experimental model. The purpose of these part temperatures is to indicate the probable temperature with respect to the coolant and to provide a base line against which material properties can be evaluated. Two coolant temperatures were chosen, 600°F and 1000°F, except for the solenoid where temperatures of 300°F and 1000°F were chosen for the entire component. This component design generates very little heat internally, and it could be mounted in a cooled container.

2. Specific Applications to Electric Apparatus

a. MOTOR

The a-c motor is a dynamic device consisting of a rotor and stator with their associated windings, bore seal, insulation, bearings and seals, a cooling system, and encapsulation as required.

The rotor must be able to withstand the thermal and mechanical stresses which will be encountered and must be mechanically stable so that it will retain its balance under all operating conditions. The rotor must also be capable of carrying magnetic flux at high temperature.

The coils of the stator are wound with magnet wire which is clad to meet the system high-temperature requirements.

Insulation is needed for the stator winding as a coating on the conductor and in rigid or flexible form as a ground insulation. Impregnants may be used to add rigidity and protection to the coil structure and to aid in heat transfer. Interlaminar insulation is required for the magnetic sheet materials.

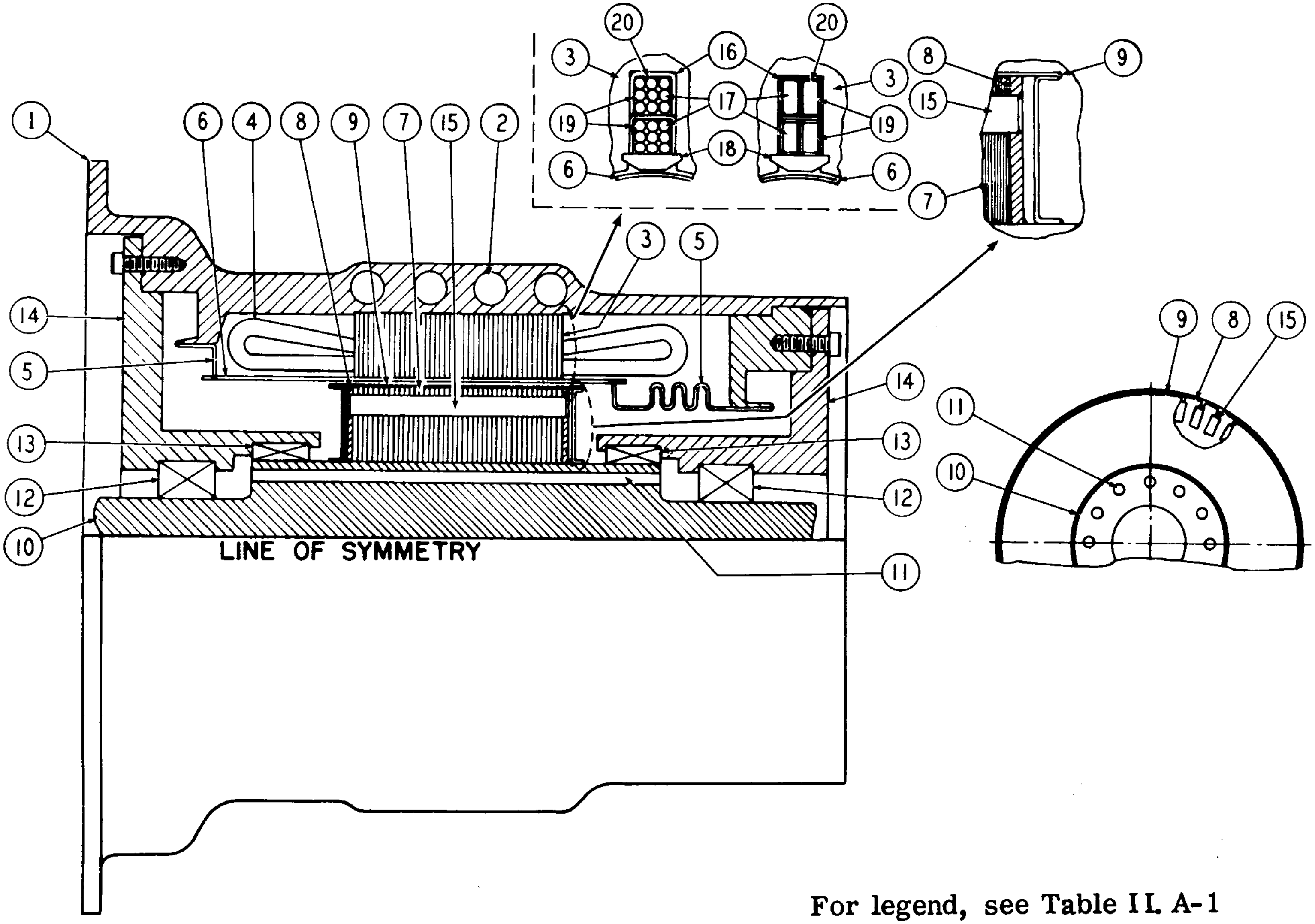
Rotor conductors are made of clad material, but insulation is not required either for the conductors in the slots or for the end ring because the electrical potential is low and the interlaminar insulation on the laminations will provide sufficient insulation.

Figure II.A-1 shows a typical design for a motor suitable for operation in a high-temperature, liquid metal system. Table II.A-1 is a list identifying the major parts and features in the motor.

The rotor laminations and conductors (Items 7 and 15) are protected from alkali metal vapors by a hermetically sealed sheet metal can (Item 9). The stator laminations and windings are similarly protected by a ceramic bore seal and associated end pieces, (Items 5 and 6), which form a chamber seal from alkali metal vapors. This chamber may be either hermetically sealed or open to the vacuum of space.

Heat generated in the motor is removed by using liquid metal as a coolant. Coolant flow passages (Items 2 and 11) are provided in the rotor shaft and stator housing. Bearings and seals are shown in the motor but are not covered in this discussion.

Figures II.A-2 and II.A-3 are sketches of the motor which emphasize the areas where conductor and insulating materials are used. Conductor applications shown are the stator winding (Item 4), rotor end ring (Item 8), rotor conductor (Item 15) and stator conductor and cladding (Items 17 and 19). Insulation applications include the conductor and slot insulation (Items 16, 18 and 20). Tables II.A-2 and II.A-3 are tabulations showing the suitability of the various conducting and insulating materials and material forms for this application.

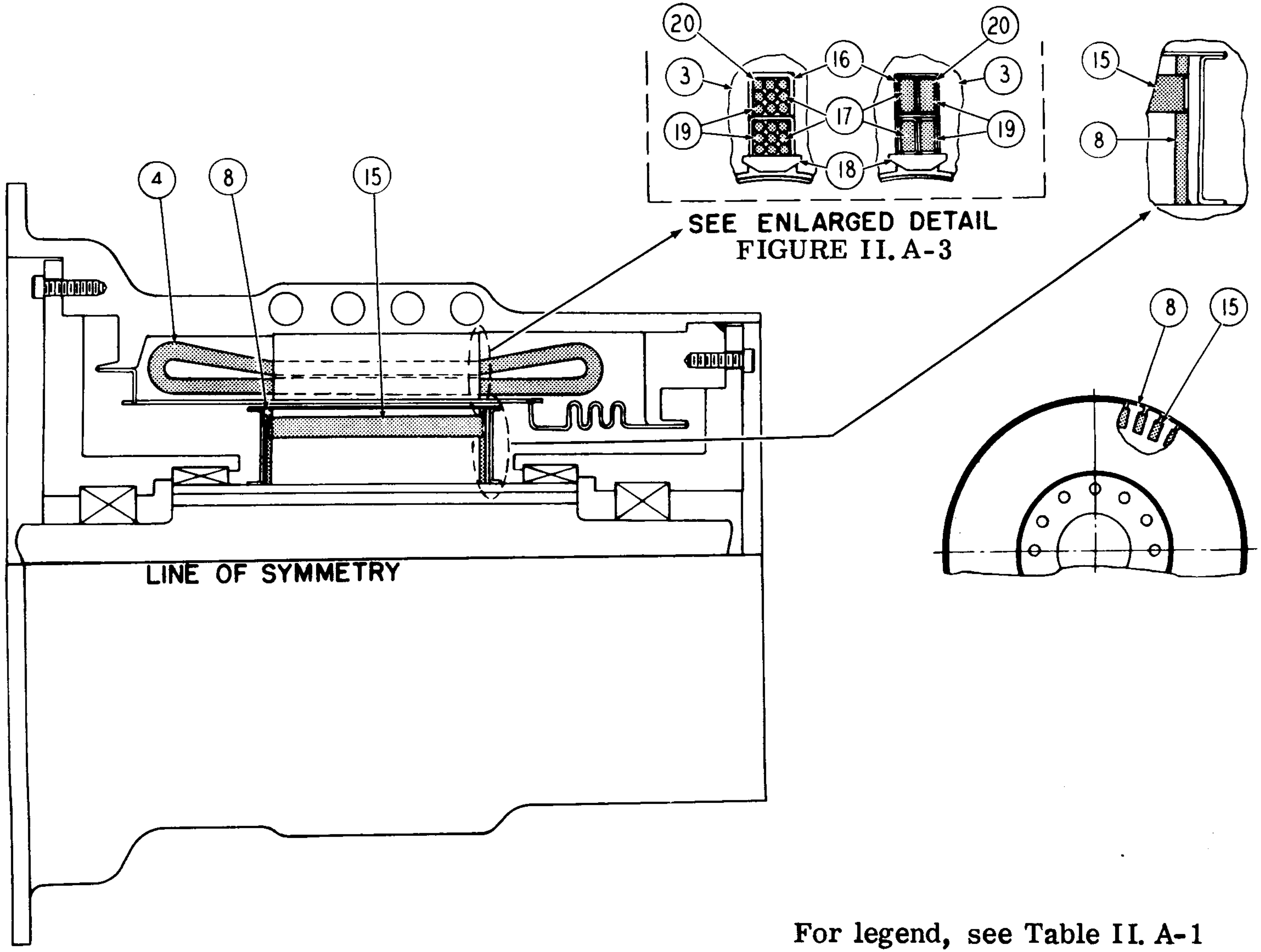


For legend, see Table II. A-1

FIGURE II.A-1. A-C Motor, General Assembly

TABLE II. A-1. Details of Motor Assembly

Item No.	Description
1	Frame - Motor
2	Passage - Coolant, Stator
3	Lamination - Stator
4	Winding - Stator
5	Bore Seal - End Piece, Metal
6	Bore Seal - Cylinder, Ceramic
7	Lamination - Rotor
8	End Ring - Rotor
9	Can - Rotor
10	Shaft - Rotor
11	Passage - Coolant, Rotor
12	Bearing - Shaft, Support
13	Seal - Shaft
14	Carrier - Bearing & Seal
15	Conductor - Rotor
16	Insulation - Slot, Stator Winding
17	Conductor - Stator
18	Retainer - Winding, Slot
19	Cladding - Conductor
20	Insulation - Conductor



For legend, see Table II. A-1

FIGURE II. A-2. A-C Motor, Conductor and Insulation Materials Usage

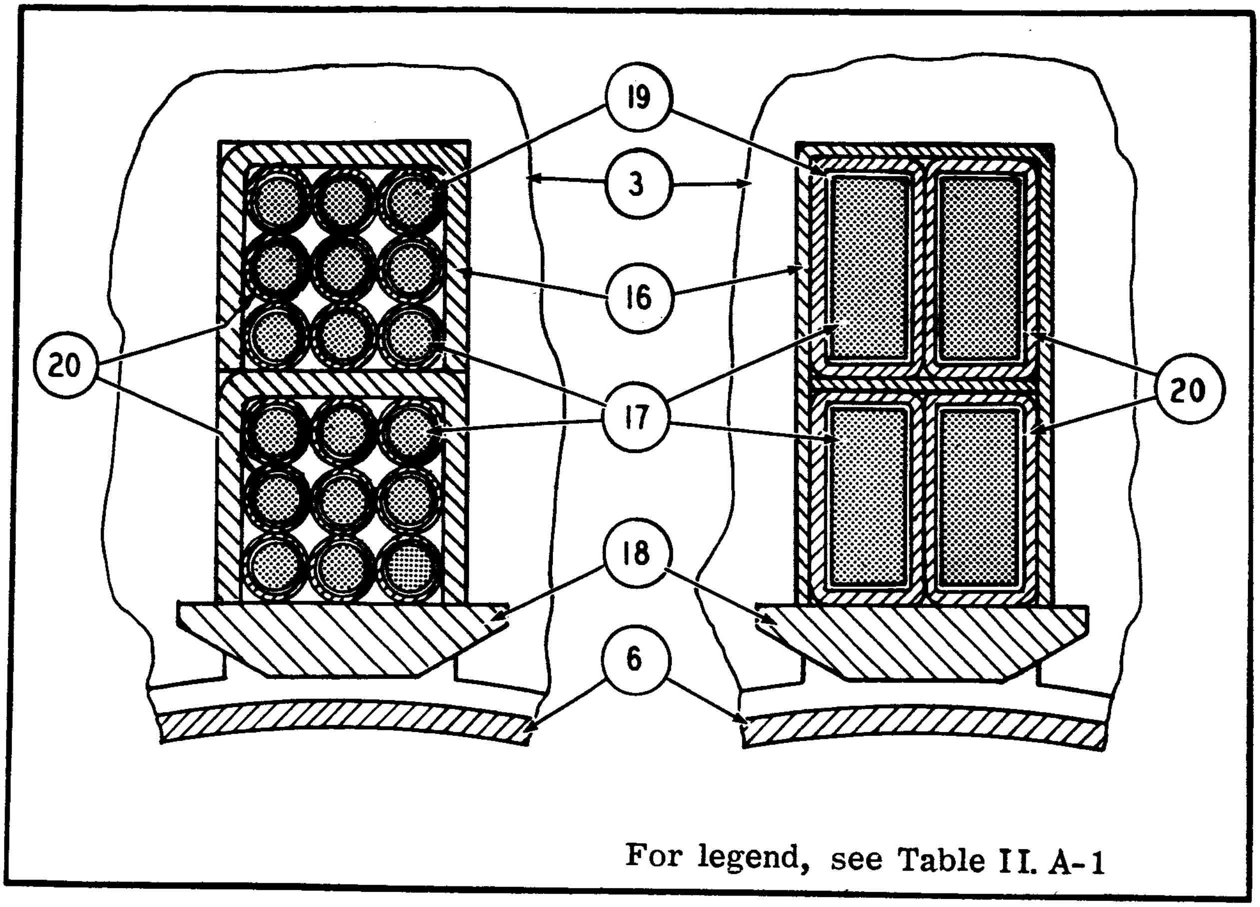


FIGURE II. A-3. A-C Motor, Stator Slot Detail, Conductor and Insulation Material Usage

TABLE II. A-2. Conductor Material Usage, A-C Motor

Location of Material Property Summary	Material	Temperature Limit - °F		Rotor Conductor		Rotor End Ring		Stator Conductor	
		Sealed	Open to Vacuum	(a) 1000	(b) 1400	(a) 950	(b) 1350	(a) 1000	(b) 1400
IV. A.	Nickel-Clad Copper	900	900	3	3	3	3	3	3
IV. B.	321SS-Clad Silver	1400	1400	1	3	1	3	1	1
IV. C.	304SS-Clad Zirconium Copper	1200	1200	1	3	1	3	1	3
IV. D.	DS Copper	>1600	1600(c)	1	1	1	1	1	1
IV. E.	TD Nickel (d)	>1600	>1600	2	2	2	2	2	2
IV. F.	Inconel-600-Clad DS Copper	1400	1400	1	1	1	1	1	1
IV. G.	Inconel-600-Clad Silver	1400	1400	1	1	1	1	1	1

(a) - Anticipated part temperature in °F with coolant temperature of 600°F
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F
(c) - Sublimation occurs
(d) - High resistivity, relative to copper or silver

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

TABLE II.A-3. Insulation-Inorganic[c] Material Usage, A-C Motor

Location of Material Property Summary	Material	Temperature Limit - °F		A-C Stator								Stator Stack Interlaminar Insulation		Rotor Stack Interlaminar Insulation	
		Sealed	Open to Vacuum	Conductor		Slot		Wedge		Encapsulation					
				(a) 1000	(b) 1400	(a) 950	(b) 1350	(a) 950	(b) 1350	(a) 1000	(b) 1400	(a) 900	(b) 1300	(a) 950	(b) 1350
V.A.	Magnet Wire Insulation														
	2. Anacote	1000	1000	1	3	--	--	--	--	--	--	--	--	--	--
	3. Anadur	1200	1200	1	3	--	--	--	--	--	--	--	--	--	--
	4. Ceramiceze	900	900	1	3	--	--	--	--	--	--	--	--	--	--
	5. R2554B	1000	1000	1	3	--	--	--	--	--	--	--	--	--	--
	High Purity Refractory Oxides[d]	>1600	>1600	1	1	--	--	--	--	--	--	--	--	--	--
V.C.	Flexible Sheet														
	3. Mica Glass, Silicone Bonded	1000	1000	--	--	1	3	--	--	--	--	--	--	--	--
	4. Synthetic Mica Paper	1200	1200	--	--	1	3	--	--	--	--	--	--	--	--
	5. Silicate Fiber Paper	1200	1200	--	--	1	3	--	--	--	--	--	--	--	--
V.D.	Rigid Insulation - Laminated														
	1. Asbestos BPO_4 - Bonded	1600	1200	--	--	2	3	1	1	--	--	--	--	--	--
	7. Mica Laminate	1200	1100	--	--	2	3	1	3	--	--	--	--	--	--
V.E.	Rigid Insulation - Molded or Pressed														
	1. Alumina 99.5%	>1600	>1600	--	--	1	1	1	1	--	--	--	--	--	--
	2. Alumina 99%	>1600	>1600	--	--	1	1	1	1	--	--	--	--	--	--
	3. Alumina 94%	1200	1200	--	--	1	3	1	3	--	--	--	--	--	--
	4. Alumina 0.25% MgO	>1600	>1600	--	--	1	1	1	1	--	--	--	--	--	--
	5. Beryllia 99.8%	>1600	>1600	--	--	1	1	1	1	--	--	--	--	--	--
V.F.	Encapsulation Compounds														
	1. Anacap	900	900	--	--	--	--	--	--	2	3	--	--	--	--
	3. Sauereisen 8	1200	1100	--	--	--	--	--	--	1	3	--	--	--	--
	6. W839	1200	1200	--	--	--	--	--	--	1	3	--	--	--	--
V.G.	Interlaminar Insulation														
	1. Aluminum Orthophosphate	1100	1100	--	--	--	--	--	--	--	--	1	3	1	3
	2. Aluminum Orthophosphate plus Mica and Bentonite	1100	1100	--	--	--	--	--	--	--	--	1	3	1	3
	3. Glass	1100	1100	--	--	--	--	--	--	--	--	1	3	1	3

(a) - Anticipated part temperature in °F with coolant temperature of 600°F
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F
(c) - Organic Materials not Suitable for Motor
(d) - In the early experimental stages of development

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

b. GENERATOR

The a-c generator is a dynamic device consisting of a rotor without windings, stator, a-c windings, d-c excitation coil, insulation, encapsulation as required, bore seal, bearings and seals and a cooling system.

The rotor is a solid magnetic material part which does not require any conducting or insulating materials.

The coils of the stator and exciter are wound with wire which is clad to meet the system high-temperature requirements.

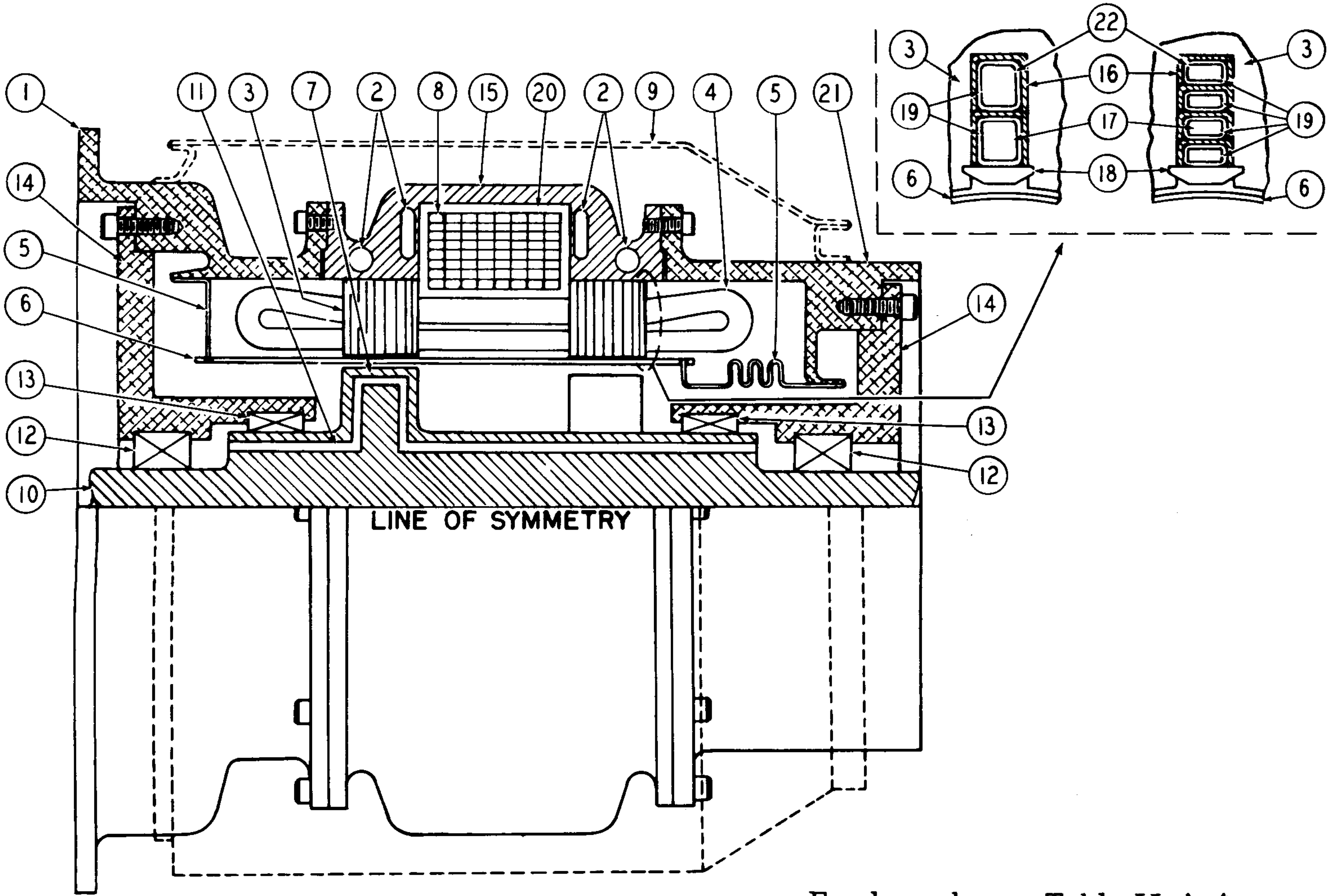
Insulation is required as a coating on the conductor and in sheet or molded form as a ground insulation. To add rigidity and protection to the coil structure of the winding, impregnating materials may be used. For added mechanical strength and to aid in heat transfer from the winding to the cooled frame, encapsulation materials may also be used.

Figure II.A-4 presents a typical design of a radial-gap inductor generator capable of operation in a high-temperature, liquid alkali-metal system. Table II.A-4 is a list identifying the major parts and features in the generator.

The rotor (Item 10) and rotor pole (Item 7) as shown are made from a solid, forged magnetic material which does not require any special protection against the corrosive effects of alkali vapors. The stator magnetic material consists of laminations (Item 3) having interlaminar insulation, and a cast magnetic frame (Item 15) to complete the magnetic circuit. The stator laminations and conductors are protected from alkali metal vapors by a ceramic bore seal and associated end pieces (Items 5 and 6) which form a chamber sealed from alkali metal vapors. This chamber may be either hermetically sealed or open to the vacuum of space.

Heat generated in the rotor, stator and windings is removed by using liquid metal as a coolant. Coolant flow passages (Items 2 and 11) are provided in the rotor and stator housings. Bearings and seals are indicated in the drawing but are not covered in this discussion.

Figure II.A-5 is another sketch of the generator which emphasizes the areas where conducting and insulating materials are used. Conductor applications shown are the stator winding (Item 4), and field coil (Item 8). Additional stator winding details are shown in the upper right hand corner. The conductor and cladding are shown as Items 17 and 19. Conductor insulation is shown as Item 22. The slot insulation and winding retainer are shown as Item 16 and 18 respectively. Figure II.A-6 is a drawing showing some of the details of the field coil. The clad conductor is shown as Items 1 and 2. Item 3 is the conductor insulation and Item 4 is ground insulation. Tables II.A-5 and II.A-6 are tabulations showing the suitability of the various conducting and insulating materials and material forms for this application.

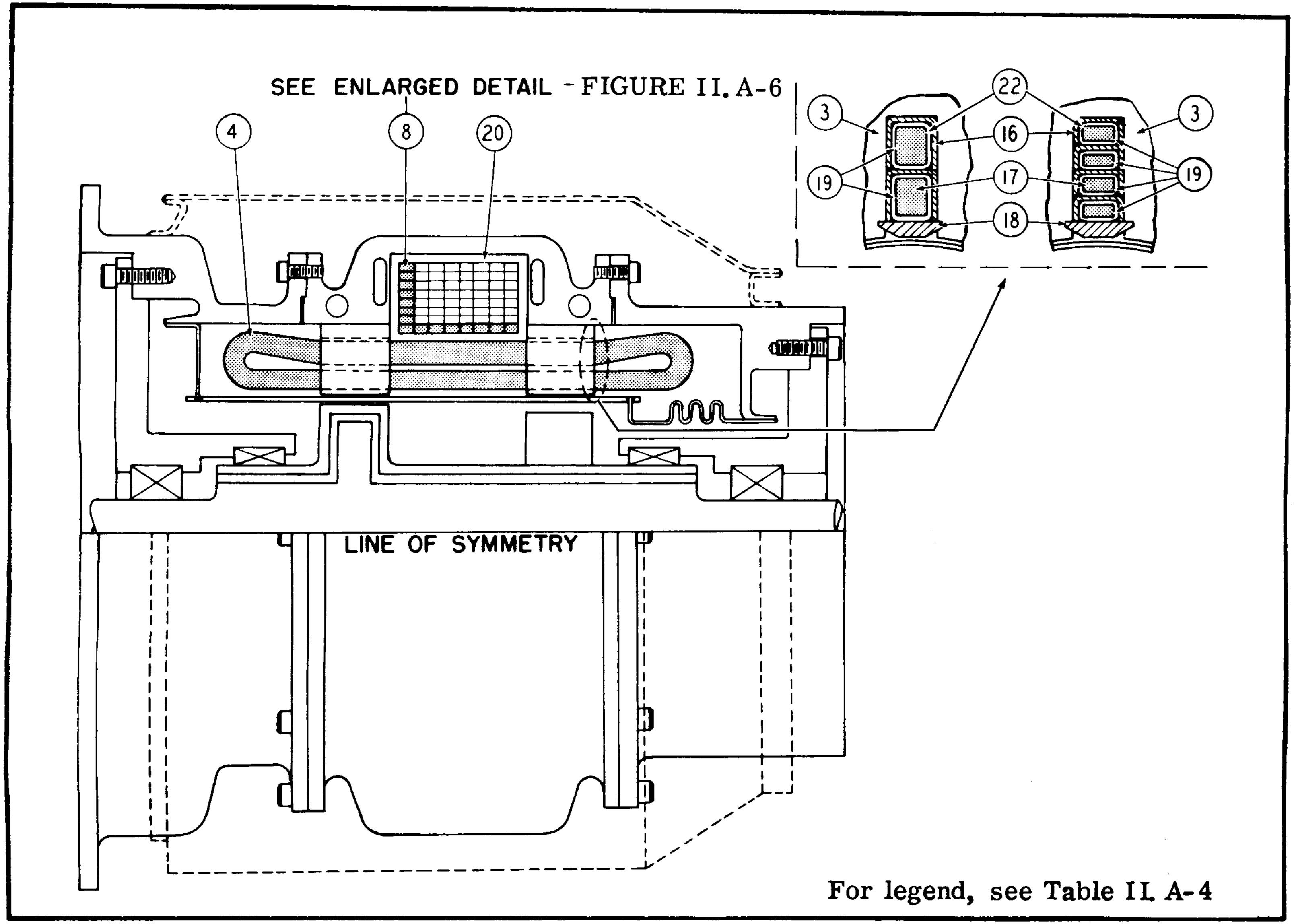


For legend, see Table II. A-4

FIGURE II. A-4. A-C Generator, General Assembly

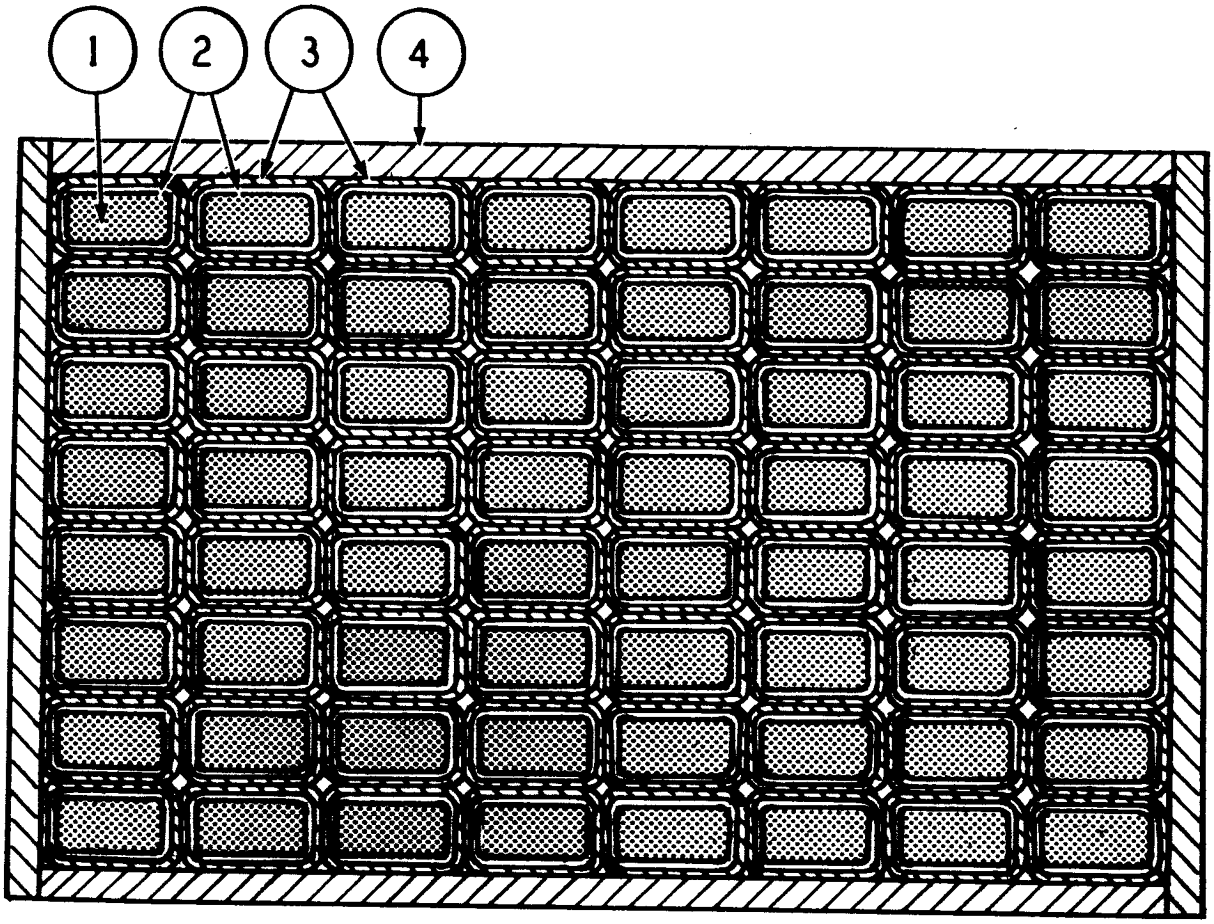
TABLE II.A-4. Details of Generator Assembly

Item No.	Description
1	Bracket
2	Passage - Coolant, Stator
3	Laminations - Stator, A-C
4	Winding - Stator, A-C
5	Bore Seal - End Piece, Metal
6	Bore Seal - Cylinder, Ceramic
7	Pole - Rotor
8	Coil - Field, D-C
9	Shield (Required only if inert gas cover is used)
10	Rotor
11	Passage - Coolant, Rotor
12	Bearing - Shaft, Rotor
13	Seal - Shaft
14	Carrier - Bearing and Seal
15	Frame - Magnetic
16	Insulation - Slot, Stator Winding
17	Conductor - Stator
18	Retainer - Winding, Slot
19	Cladding - Conductor
20	Insulation - Coil, D-C
21	Bracket
22	Insulation - Conductor, Stator



For legend, see Table II. A-4

FIGURE II. A-5. A-C Generator, Conductor and Insulation Material Usage



Item No.	Description
1	Conductor
2	Cladding - Conductor
3	Insulation - Conductor
4	Insulation - Ground

FIGURE II. A-6. A-C Generator, Excitation Coil Detail

TABLE II.A-5. Conductor Material Usage, A-C Generator

Location of Material Property Summary	Material	Temperature Limit - °F		A-C Winding Conductor		D-C Winding Conductor	
		Sealed	Open to Vacuum	(a) 1000	(b) 1400	(a) 1200	(b) 1600
IV.A.	Nickel-Clad Copper	900	900	3	3	3	3
IV.B.	321SS-Clad Silver	1400	1400	1	3	1	3
IV.C.	304SS-Clad Zirconium Copper	1200	1200	1	3	1	3
IV.D.	DS Copper	>1600	1600(c)	1	1	1	2
IV.E.	TD Nickel (d)	>1600	>1600	2	2	2	2
IV.F.	Inconel 600-Clad DS Copper	1400	1400	1	1	1	3
IV.G.	Inconel 600-Clad Silver	1400	1400	1	1	1	3

(a) - Anticipated part temperature in °F with coolant temperature of 600°F
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F
(c) - Sublimation occurs
(d) - High resistivity as compared to copper of silver

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

TABLE II. A-6. Insulation-Inorganic$^{(c)}$ Material Usage, A-C Generator

Location of Material Property Summary	Material	Temperature Limit - °F		A-C Winding										D-C Winding										Stator	
		Sealed	Open to Vacuum	Conductor		Conductor Insulation		Slot Insulation		Wedge		Encapsulation		Conductor		Conductor Insulation		Ground Insulation		Encapsulation		Interlaminar Insulation	
				(a) 1000	(b) 1400	(a) 1000	(b) 1400	(a) 950	(b) 1350	(a) 950	(b) 1350	(a) 1000	(b) 1400	(a) 1200	(b) 1600	(a) 1200	(b) 1600	(a) 1100	(b) 1500	(a) 1200	(b) 1600	(a) 900	(b) 1300
V.A.	Magnet Wire																						
	2. Anacote	1000	1000	--	--	1	3	--	--	--	--	--	--	--	--	3	3	--	--	--	--	--	--
	3. Anadur	1200	1200	--	--	1	3	--	--	--	--	--	--	--	--	1	3	--	--	--	--	--	--
	5. R2554B	1000	1000	--	--	1	3	--	--	--	--	--	--	--	--	3	3	--	--	--	--	--	--
	High Purity Refractory Oxides$^{(d)}$	>1600	>1600	--	--	1	1	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--
V.C.	Flexible Sheet																						
	3. Mica Glass, Silicone Bonded	1000	1000	--	--	--	--	1	3	--	--	--	--	--	--	--	--	3	3	--	--	--	--
	4. Synthetic Mica Paper	1200	1200	--	--	--	--	1	3	--	--	--	--	--	--	--	--	1	3	--	--	--	--
	5. Silicate Fiber Paper	1200	1200	--	--	--	--	1	3	--	--	--	--	--	--	--	--	1	3	--	--	--	--
V.D.	Rigid Sheet-Laminated																						
	1. Asbestos BPO$_4$ - Bonded	1600	1200	--	--	--	--	1	1	1	1	--	--	--	--	--	--	1	2	--	--	--	--
	7. Mica Laminate	1100	1100	--	--	--	--	1	3	1	3	--	--	--	--	--	--	1	3	--	--	--	--
V.E.	Rigid Insulation-Molded or Pressed																						
	1. Alumina 99.5%	>1600	>1600	--	--	--	--	1	1	1	1	--	--	--	--	--	--	1	1	--	--	--	--
	2. Alumina 99%	>1600	>1600	--	--	--	--	1	1	1	1	--	--	--	--	--	--	1	1	--	--	--	--
	3. Alumina 94%	1200	1200	--	--	--	--	1	3	1	3	--	--	--	--	--	--	1	3	--	--	--	--
	4. Alumina, 0.25% MgO	>1600	>1600	--	--	--	--	1	1	1	1	--	--	--	--	--	--	1	1	--	--	--	--
	5. Beryllia 99.8%	>1600	>1600	--	--	--	--	1	1	1	1	--	--	--	--	--	--	1	1	--	--	--	--
V.F.	Encapsulation Compounds																						
	1. Anacap	900	900	--	--	--	--	--	--	--	--	2	3	--	--	--	--	--	--	2	3	--	--
	3. Sauereisen 8	1200	1100	--	--	--	--	--	--	--	--	1	3	--	--	--	--	--	--	1	3	--	--
	6. W839	1200	1200	--	--	--	--	--	--	--	--	1	3	--	--	--	--	--	--	1	3	--	--
V.G.	Interlaminar Insulation																						
	1. Aluminum Orthophosphate	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	2. Aluminum Orthophosphate plus Mica and Bentonite	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	3. Glass	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3

(a) - Anticipated part temperature in °F with coolant temperature of 600°F.
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F.
(c) - Organic Materials not Suitable for Generator.
(d) - In the early experimental stages of development.

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

c. EXCITER-REGULATOR AND MAGAMP

The exciter-regulator is a static device which provides regulation and control for the electrical output of the a-c generator. In the present state of the art, the rectifier and diodes of the exciter-regulator are essentially low temperature devices. Because of their intimate relation to other parts, the exciter-regulator becomes a low temperature device which requires a coolant temperature of 120°F or less.

The usual exciter-regulator contains a power transformer to provide power for the field of the a-c generator. The power transformer occupies a substantial portion of the exciter-regulator package and also contributes significantly to the losses. Further, available materials permit building a transformer which can operate with a coolant temperature of 600°F to 1000°F. The power transformer has, therefore, been removed from the exciter-regulator package and is described later in this section.

Figure II.A-7 is an assembly drawing showing the components which make up an exciter-regulator, and Table II.A-7 is a list of the various components of the exciter-regulator.

Another component which must be intimately associated physically with the exciter-regulator but which can be made capable of high temperature operation is the magnetic amplifier (magamp).

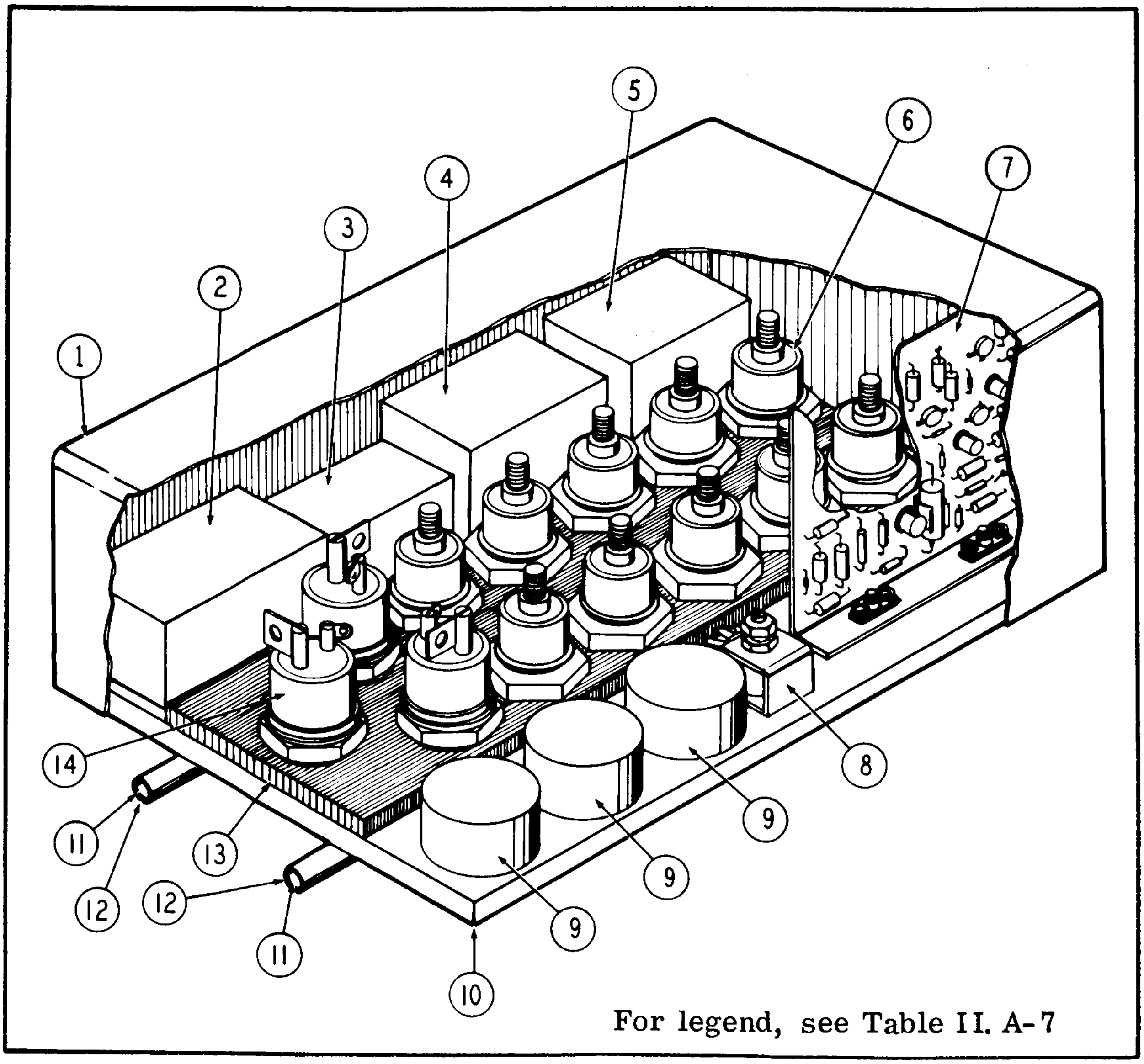
The magamp is a static device which consists of a magnetic toroid core, an insulating core box and damping fluid, insulated control and gate (output) windings, insulation between windings, an encapsulant or potting material, and a container. For high-temperature operation, cooling must be supplied by the mount which supports the entire assembly.

The magamp core must be made from a saturable magnetic material so an over-riding input signal can cause saturation and control the output signal. The core may be assembled from tape or from punched laminations and interlaminar insulation is required.

Insulation is required on the windings as a coating on the conductor between adjacent turns, as rigid insulation between adjacent windings, and as a molded box between the core and windings. Potting material is used to anchor the magamp in its container.

Figure II.A-8 is a drawing of a typical magnetic amplifier design and Table II.A-8 is a list of the various parts and features of the design. The construction shown is based on the use of magnetic tape for the core (Item 6). The core is installed in a core box (Item 2) with a suitable damping media (Item 3), and the control and gate windings are wrapped around the box.

Figures II.A-8 and II.A-9 are cross-section drawings showing how conducting and insulating materials are used. Figure II.A-8 indicates the insulating core box (Item 2), the interwinding insulation (Item 4), and the relation of the control and gate windings to the core. Figure II.A-9 is a drawing of the coil construction showing the clad conductor (Items 1 and 2) and the conductor insulation (Item 3). The entire assembly is potted in the container. Table II.A-9 is a tabulation of conducting and insulating materials and material forms showing their suitability for this application. Since it is possible that these devices may operate either in the vacuum of space or in a hermetically sealed chamber, the suitability of each material under both ambients is shown in Table II.A-9.

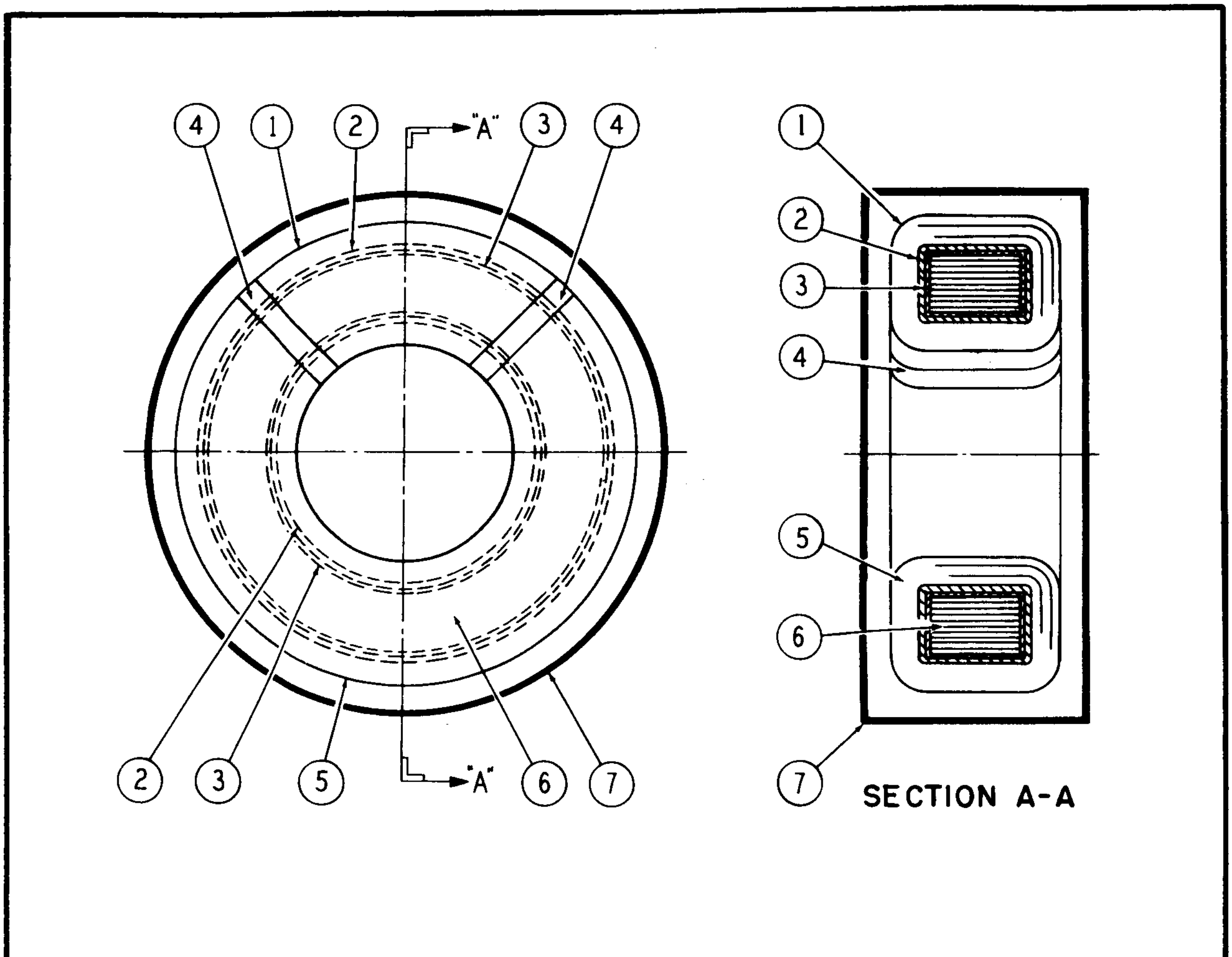


For legend, see Table II. A-7

FIGURE II. A-7. Exciter Regulator, General Assembly

TABLE II. A-7. Details of Exciter Regulator

Item No.	Description
1	Cover
2	Capacitor
3	Choke-Filter
4	Transformer-Supply, Magamp, Three Phase
5	Transformer-Sensing, Three Phase
6	Diodes (10)
7	Board-Circuit, Printed, Aluminum
8	Adjustment - Voltage
9	Magamp
10	Plate - Cold
11	Coolant
12	Tubes - Cooling
13	Insulator
14	Silicon Controlled Rectifiers (3)

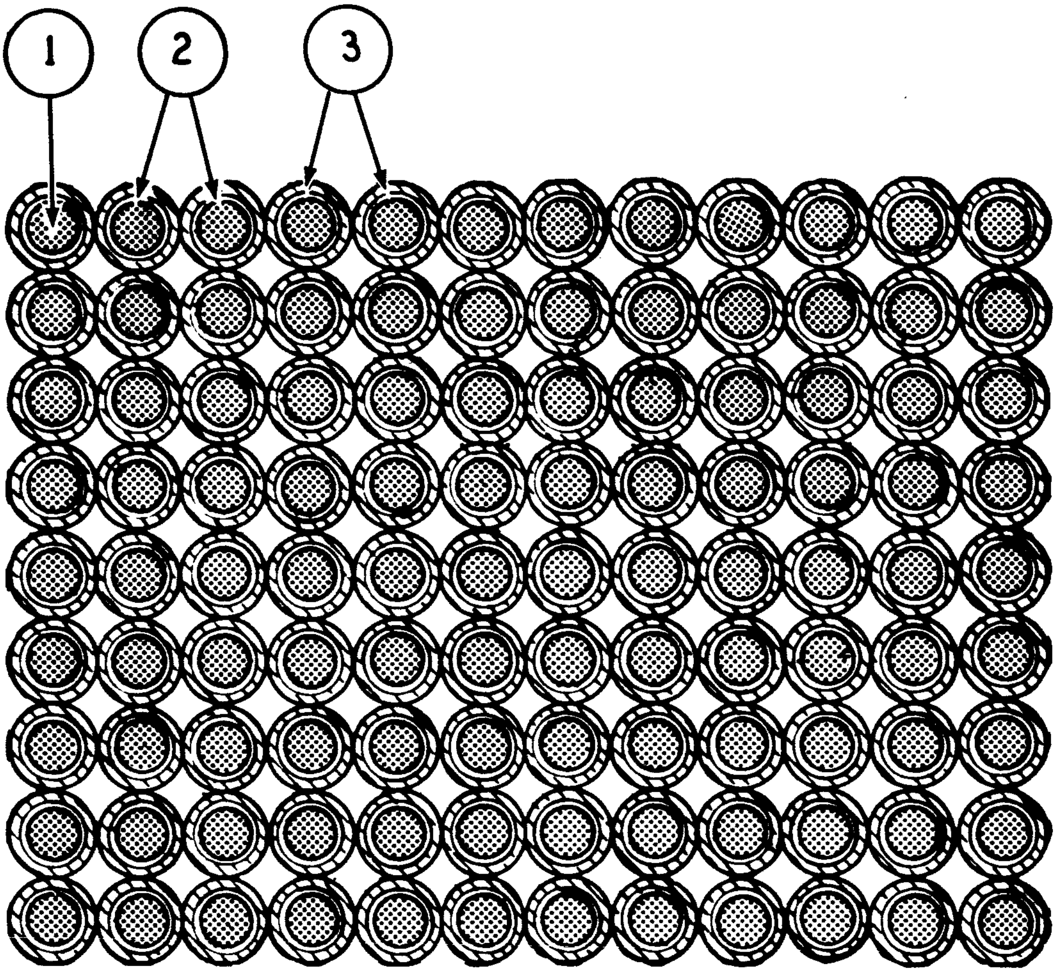


For legend, see Table II. A-8

FIGURE II. A-8. Magnetic Amplifier, Assembly and Cross-Section

TABLE II. A-8. Details of Magnetic Amplifier

Item No.	Description	Item No.	Description
1	Coil - Control	5	Coil - Gate
2	Box - Core	6	Core
3	Media - Damping	7	Container - Hermetic
4	Insulation - Interwinding		



Item No.	Description
1	Conductor
2	Cladding - Conductor
3	Insulation - Conductor

FIGURE II. A-9. Magamp, Control and Gate Coil Detail

TABLE II. A-9. Conductor and Insulation Usage, Magnetic Amplifier

Location of Material Property Summary	Material	Temperature Limit - °F		Core Box		Control and Gate Windings		Conductor Insulation		Insulation Interwinding		Encapsulation		Interlaminar Insulation	
		Sealed	Open to Vacuum	(a) 515	(b) 1300	(a) 475	(b) 1250	(a) 475	(b) 1250	(a) 475	(b) 1250	(a) 475	(b) 1250	(a) 565	(b) 1350
	Conductors														
IV. A.	Nickel-Clad Copper	900	900	--	--	1	3	--	--	--	--	--	--	--	--
IV. B.	321SS-Clad Silver	1400	1400	--	--	1	1	--	--	--	--	--	--	--	--
IV. C.	304SS-Clad Zirconium Copper	1200	1200	--	--	1	1	--	--	--	--	--	--	--	--
IV. D.	DS Copper	>1600	1600(c)	--	--	1	1	--	--	--	--	--	--	--	--
IV. E.	TD Nickel (d)	> 1600	>1600	--	--	1	1	--	--	--	--	--	--	--	--
IV. F.	Inconel-600-Clad DS Copper	1400	1400	--	--	1	1	--	--	--	--	--	--	--	--
IV. G.	Inconel-600-Clad Silver	1400	1400	--	--	1	1	--	--	--	--	--	--	--	--
V. A.	Magnet Wire Insulation, Inorganic														
	2. Anacote	1000	1000	--	--	--	--	1	3	--	--	--	--	--	--
	3. Anadur	1200	1200	--	--	--	--	1	3	--	--	--	--	--	--
	4. Ceramiceze	900	900	--	--	--	--	1	3	--	--	--	--	--	--
	5. R2554B	1000	1000	--	--	--	--	1	3	--	--	--	--	--	--
	High Purity Refractory Oxides (e)	> 1600	> 1600	--	--	--	--	1	1	--	--	--	--	--	--
V. C.	Flexible Sheet, Inorganic														
	3. Mica Glass, Silicone Bond	1000	1000	--	--	--	--	--	--	1	3	--	--	--	--
	4. Synthetic Mica Paper	1200	1200	--	--	--	--	--	--	1	3	--	--	--	--
	5. Silicate Fiber Paper	1200	1200	--	--	--	--	--	--	1	1	--	--	--	--
V. D.	Rigid Insulation Laminated, Organic														
	6. Polyimide	600	600	--	--	--	--	--	--	1	3	--	--	--	--
V. D	Rigid Insulation Laminated, Inorganic														
	1. Asbestos BPO4	1600	1200	1	1	--	--	--	--	1	1	--	--	--	--
	7. Mica Laminate	1100	1100	1	3	--	--	--	--	1	3	--	--	--	--
V. E.	Rigid Insulation, Molded or Pressed														
	4. Alumina 0. 25% MgO	> 1600	> 1600	1	1	--	--	--	--	1	1	--	--	--	--
V. F.	Encapsulation Compounds, Inorganic														
	1. Anacap	900	900	--	--	--	--	--	--	--	--	1	3	--	--
	3. Sauereisen 8	1200	1100	--	--	--	--	--	--	--	--	1	3	--	--
	6. W839	1200	1200	--	--	--	--	--	--	--	--	1	3	--	--
V. G.	Interlaminar Insulation, Inorganic														
	1. Aluminum Orthophosphate	1100	1100	--	--	--	--	--	--	--	--	--	--	1	3
	2. Aluminum Orthophosphate plus Mica and Bentonite	1100	1100	--	--	--	--	--	--	--	--	--	--	1	3
	3. Glass	1100	1100	--	--	--	--	--	--	--	--	--	--	1	3

(a) - Anticipated part temperature in °F with coolant temperature of 300°F
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F
(c) - Sublimation occurs
(d) - High resistivity
(e) - In the early experimental stages of development

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

d. SOLENOID

The solenoid is a d-c device which is always in one of two possible positions: actuated or not actuated. It consists of a magnetic plunger, actuator rod, close and trip coils and associated magnetic cores, permanent magnet, magnet-latch circuit, conductor and ground insulation, actuator return spring, suitable actuator rod stops, and a hermetically sealed container. Actuation and de-actuation are accomplished by very short time current applications and the solenoid is latched closed magnetically. Therefore, no internal cooling provisions are required. The solenoid could be mounted in a high temperature region by providing an external coolant supply to keep external heat from reaching the container.

The nature of the solenoid application is such that the magnetic materials are all solid rather than laminated. The magnetic circuits carry only d-c flux so magnetic losses are relatively unimportant. It is important that the magnetic circuits be able to carry a substantial amount of flux with low magnetizing forces.

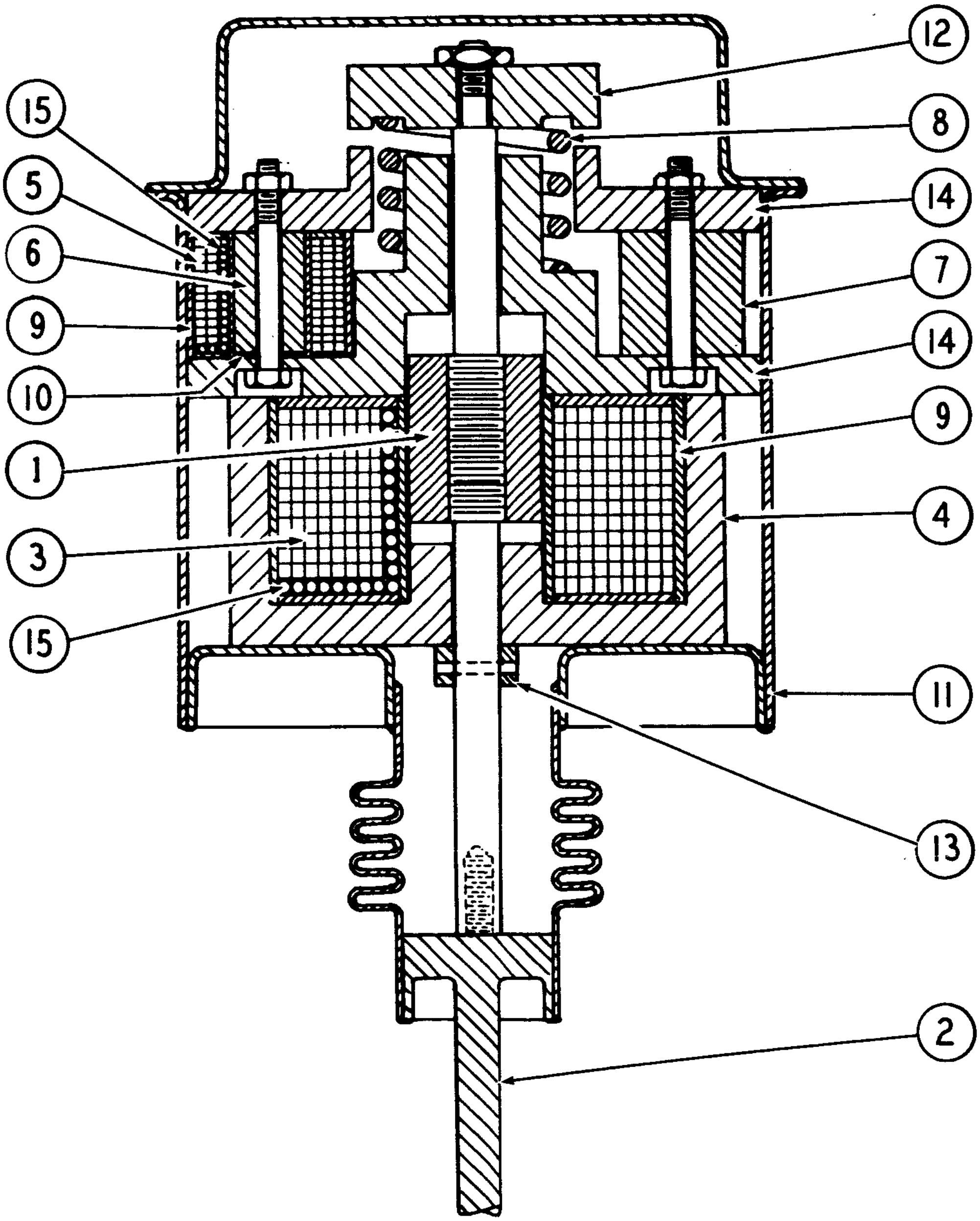
The coils of the close and trip windings are wound with magnet wire which is clad to meet high-temperature applications.

Insulation is required as a conductor coating and in sheet or molded form as ground insulation.

Figure II.A-10 is a drawing of a typical d-c solenoid capable of operation in a high-temperature, liquid alkali metal system. Table II.A-10 is a list identifying the major parts and features of the solenoid.

The magnetic plunger and actuator rod (Items 1 and 2) are pulled in a downward direction (as drawn) when current is passed through the close coil (Item 3). A magnetic latch plate (Item 12) serves as a stop and also completes a magnetic circuit with the permanent magnets (Item 7), which hold the actuator rod in the downward position when current through the close coil is stopped. The solenoid is de-actuated by energizing the trip coil, (Item 5) which diverts the permanent magnet flux from the latch plate and allows the spring to return the actuator rod to its original position.

Figure II. A-11 is a drawing showing the conducting and insulating materials used in the solenoid. Figure II.A-12 shows a typical solenoid coil construction. Items 1 and 2 show the round-wire clad conductor and Item 3 is the conductor insulation. Ground insulation is denoted by Item 4. Table II. A-11 is a tabulation showing the suitability of the various conducting and insulating materials and material forms for this application. Although this design shows a hermetically sealed application, the possibility of these materials being exposed to vacuum of space is recognized. The suitability of the materials in vacuum is also shown on Table II. A-11.

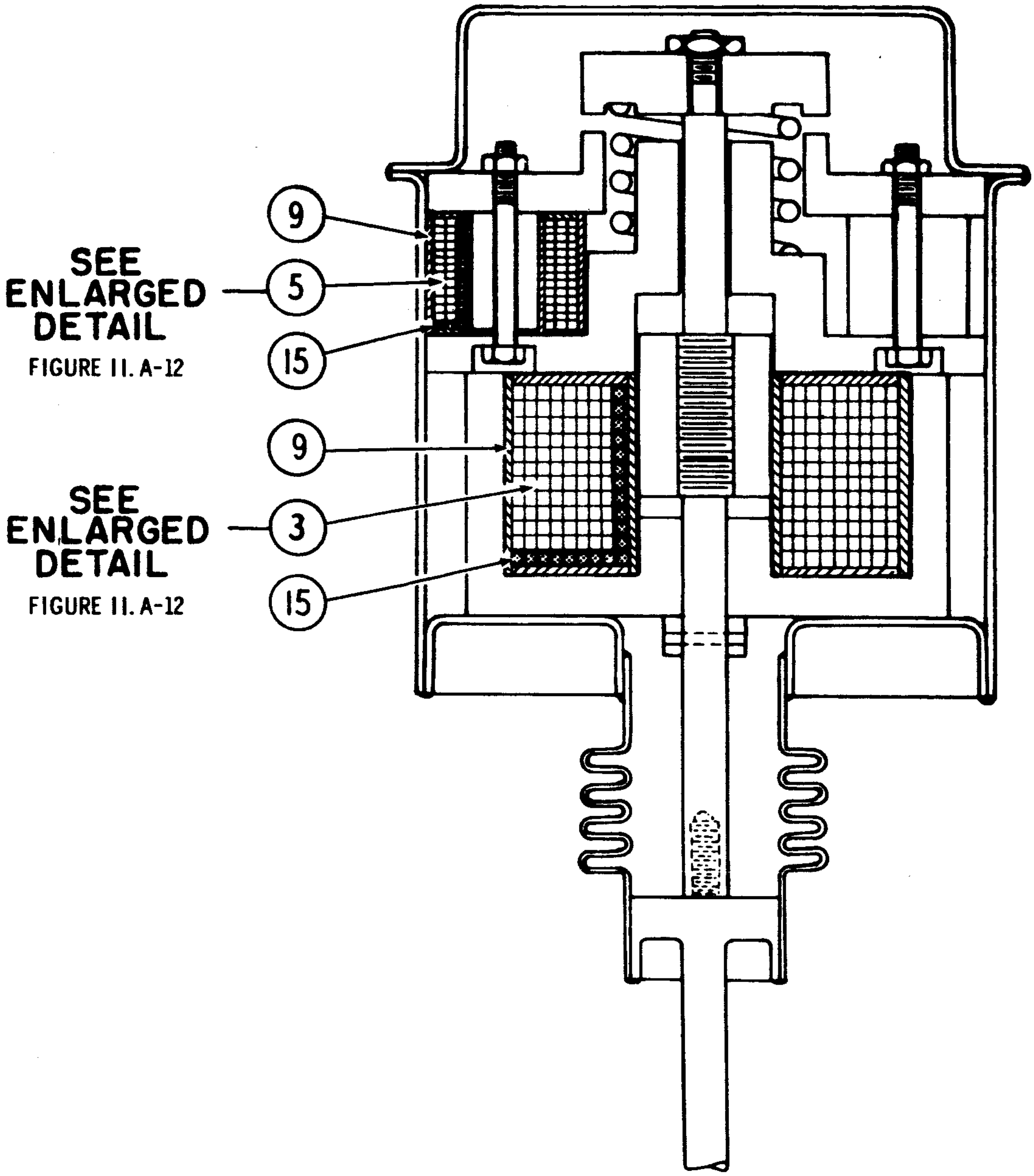


For legend, see Table II. A-10

FIGURE II.A-10. Solenoid, General Assembly

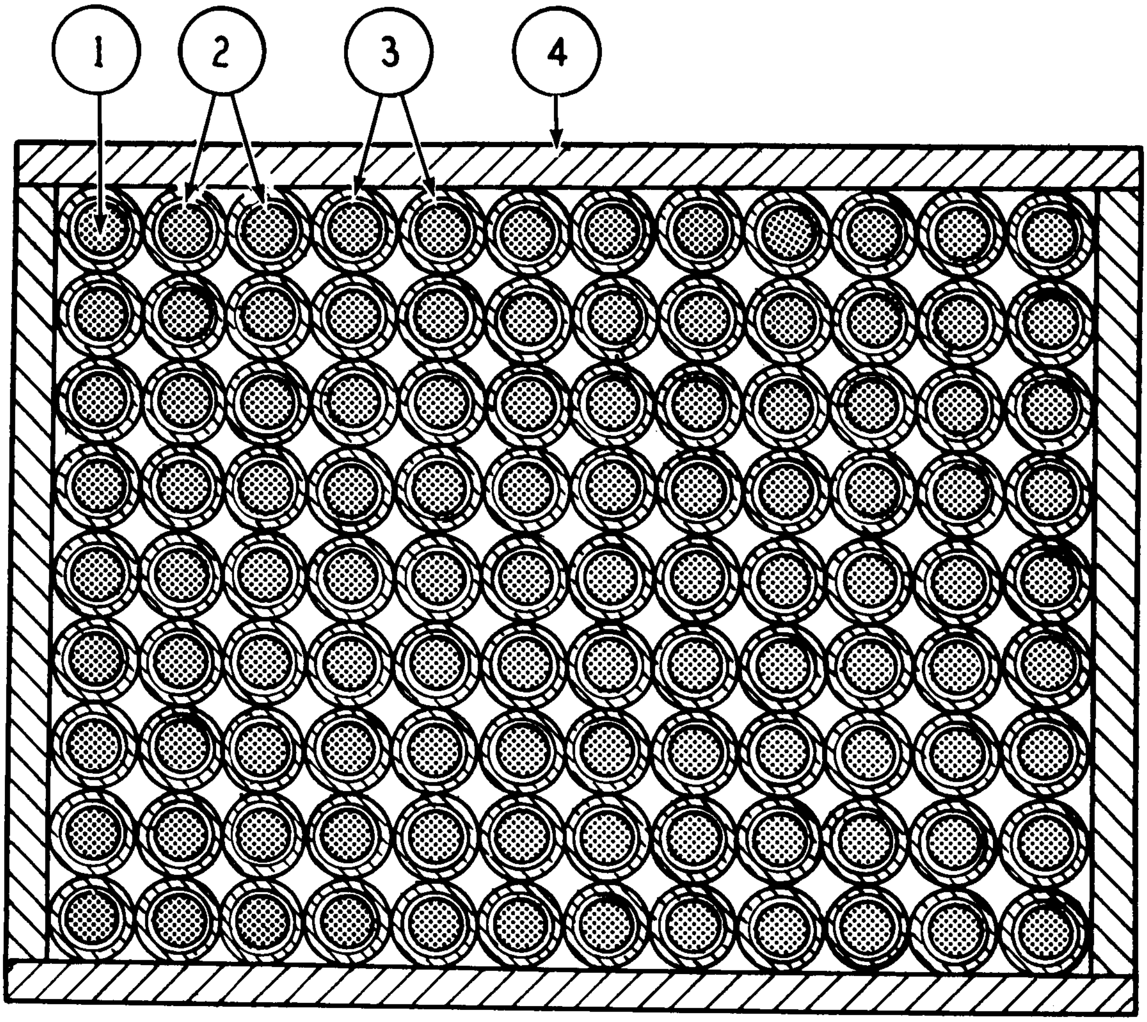
TABLE II.A-10. Details of Solenoid

Item No.	Description
1	Plunger - Actuator
2	Rod - Actuator
3	Core - Coil, Close
4	Core - Close
5	Coil - Trip (2)
6	Core - Coil, Trip
7	Magnet - Permanent (2)
8	Spring - Return
9	Insulation - Ground
10	Washer - Non Magnetic
11	Container - Sealed, Hermetic
12	Plate, Latch
13	Stop - Rod and Plunger
14	Core - Trip and Hold Circuit
15	Conductors



For legend, see Table II. A-10

FIGURE II. A-11. Solenoid, Assembly and Cross-Section



Item No.	Description
1	Conductor
2	Cladding - Conductor
3	Insulation - Conductor
4	Insulation - Ground

FIGURE II. A-12. Solenoid, Close and Trip Coil Detail

TABLE II. A-11. Conductor and Insulation Usage, D-C Solenoid

Location of Material Property Summary	Material	Temperature Limit - °F		Wire		Closing Coil Wire Insulation		Ground Insulation		Wire		Trip Coil Wire Insulation		Ground Insulation		Encapsulation	
		Sealed	Open to Vacuum	(a) 300	(b) 1000	(a) 300	(b) 1000	(a) 300	(b) 1000	(a) 300	(b) 1000	(a) 300	(b) 1000	(a) 300	(b) 1000	(a) 300	(b) 1000
	Magnet Wire																
IV.A.	Nickel-Clad Copper	900	900	1	3	--	--	--	--	1	3	--	--	--	--	--	--
IV.C.	304SS-Clad Zirconium Copper	1200	1200	1	1	--	--	--	--	1	1	--	--	--	--	--	--
V.A.	Magnet Wire Insulation, Organic																
	1. Polyimide	400	300	--	--	1	3	--	--	--	--	1	3	--	--	--	--
V.A.	Magnet Wire Insulation, Inorganic																
	2. Anacote	1000	1000	--	--	1	1	--	--	--	--	1	1	--	--	--	--
	3. Anadur	1200	1100	--	--	1	1	--	--	--	--	1	1	--	--	--	--
	4. Ceramiceze	900	900	--	--	1	3	--	--	--	--	1	3	--	--	--	--
	5. R2554B	1000	1000	--	--	1	1	--	--	--	--	1	1	--	--	--	--
V.C.	Flexible Sheet, Organic																
	1. Polyimide Film	400	300	--	--	--	--	1	3	--	--	--	--	1	3	--	--
	2. Polyimide Glass	400	300	--	--	--	--	1	3	--	--	--	--	1	3	--	--
V.C.	Flexible Sheet, Inorganic																
	3. Mica Glass, Silicone Bonded	1000	1000	--	--	--	--	1	1	--	--	--	--	1	1	--	--
	4. Synthetic Mica Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
	5. Silicate Fiber Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
V.F.	Encapsulation Compounds, Organic																
	4. Silicone Foam	300	300	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	5. Urethane Foam	300	200	--	--	--	--	--	--	--	--	--	--	--	--	2	3
V.F.	Encapsulation Compounds, Inorganic																
	1. Anacap	900	900	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	3. Sauereisen 8	1200	1100	--	--	--	--	--	--	--	--	--	--	--	--	1	1
	6. W839	1200	1200	--	--	--	--	--	--	--	--	--	--	--	--	1	1

(a) - Anticipated part temperature in °F with solenoid operating temperature of 300°F with no coolant.
(b) - Anticipated part temperature in °F with solenoid operating temperature of 1000°F with no coolant.

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

e. TRANSFORMER

The power transformer is a static device consisting of two or more coils of wire, a magnetic core, insulation, a cooling system, and means of holding the parts in place.

The coils of the transformer are wound with magnet wire. A clad material is used to meet the system temperature requirements.

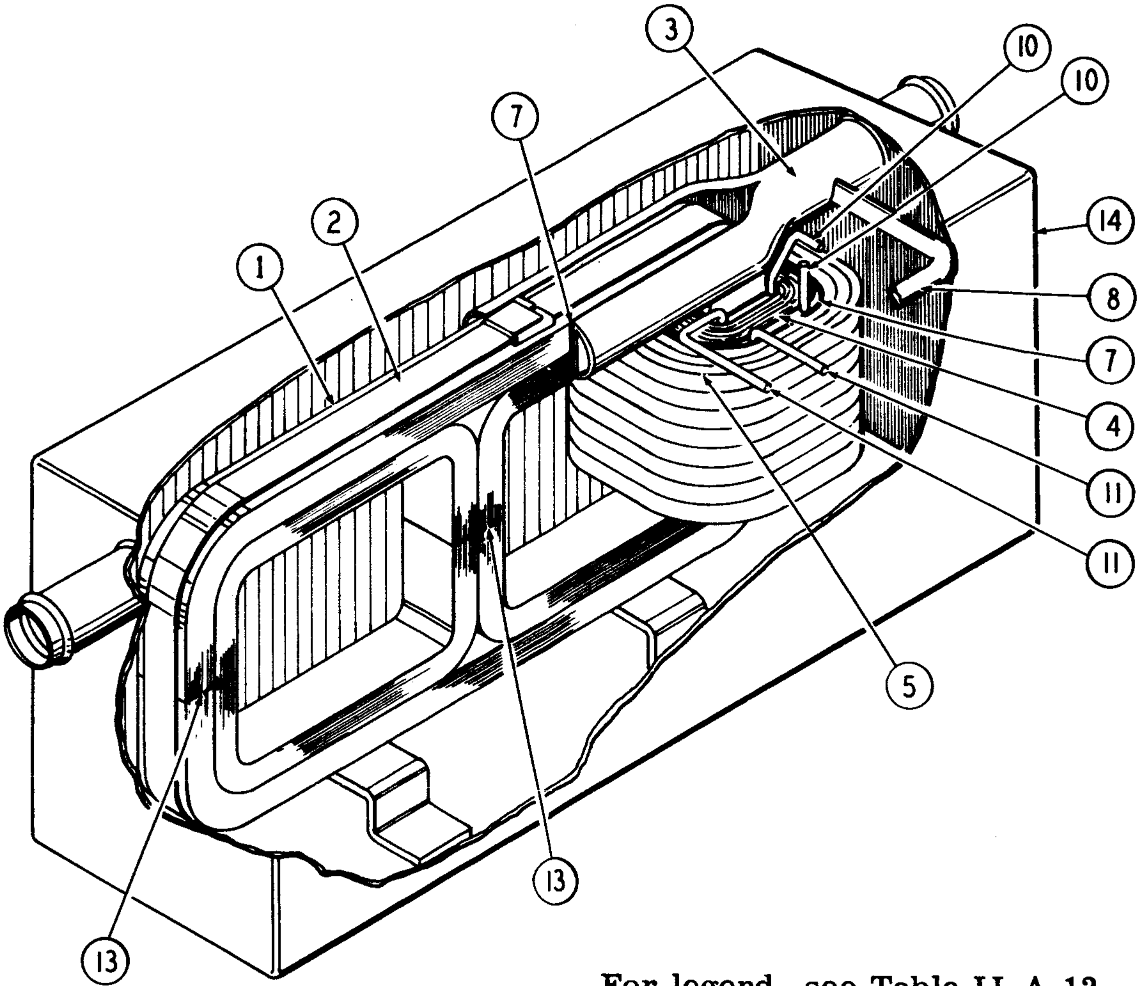
The transformer core may be assembled from tape or from punched laminations. Low losses and exciting volt-amperes per pound are very important in transformers. Therefore, special consideration must be given to these properties in the material.

Insulation is required as a coating on the conductor between adjacent turns, as sheet insulation between layers of coils, and as sheet or some other form between coils and core. Impregnants may be used to add rigidity and protection to the coil structure, and potting material may be used for mechanical strength and to aid in heat transfer. The core requires interlaminar insulation.

Figure II.A-13 is a drawing of a typical three-phase transformer design and Table II.A-12 presents details of the transformer design. The construction shown is based on the use of magnetic tape for the core (Item 1). Each leg is then encased by primary and secondary coils (Items 4 and 5) and coolant passages (Items 10 and 11). The core could be constructed of laminations rather than tape. The only major change required would be to relocate the core coolant passages (Item 3) so they draw heat from the edges of the laminations. In either case, manifolding (Items 8 and 9) will be required to tie together the coolant-in and coolant-out passages respectively in proper sequence.

Figure II.A -14 is a cross-section drawing showing the primary and secondary windings (Items 4, 5 and 6), insulation, magnetic core, and coolant passages. Figure II.A-15 is a cross-section of a typical primary or secondary coil showing the conductors, cladding and insulation on the conductor. (Items 1, 2 and 3 on the figure).

Table II.A-13 shows the suitability of conductor and insulating materials for application in the transformer in a hermetically sealed chamber or exposed to the vacuum of space.

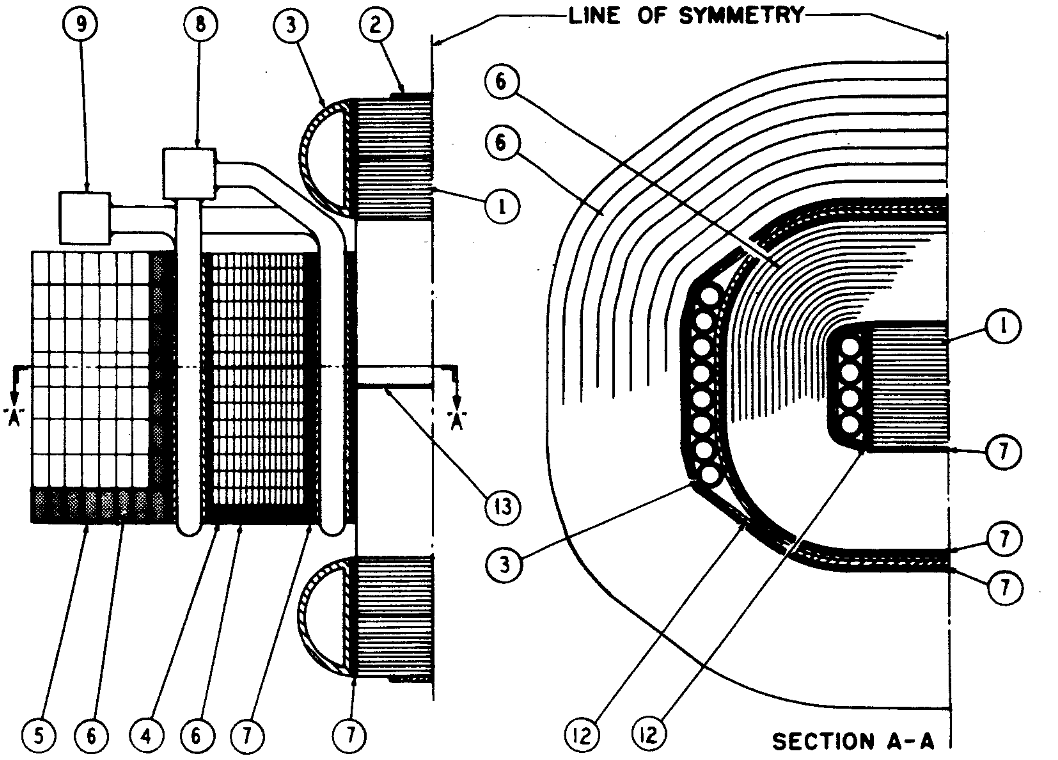


For legend, see Table II. A-12

FIGURE II. A-13. Transformer, General Assembly

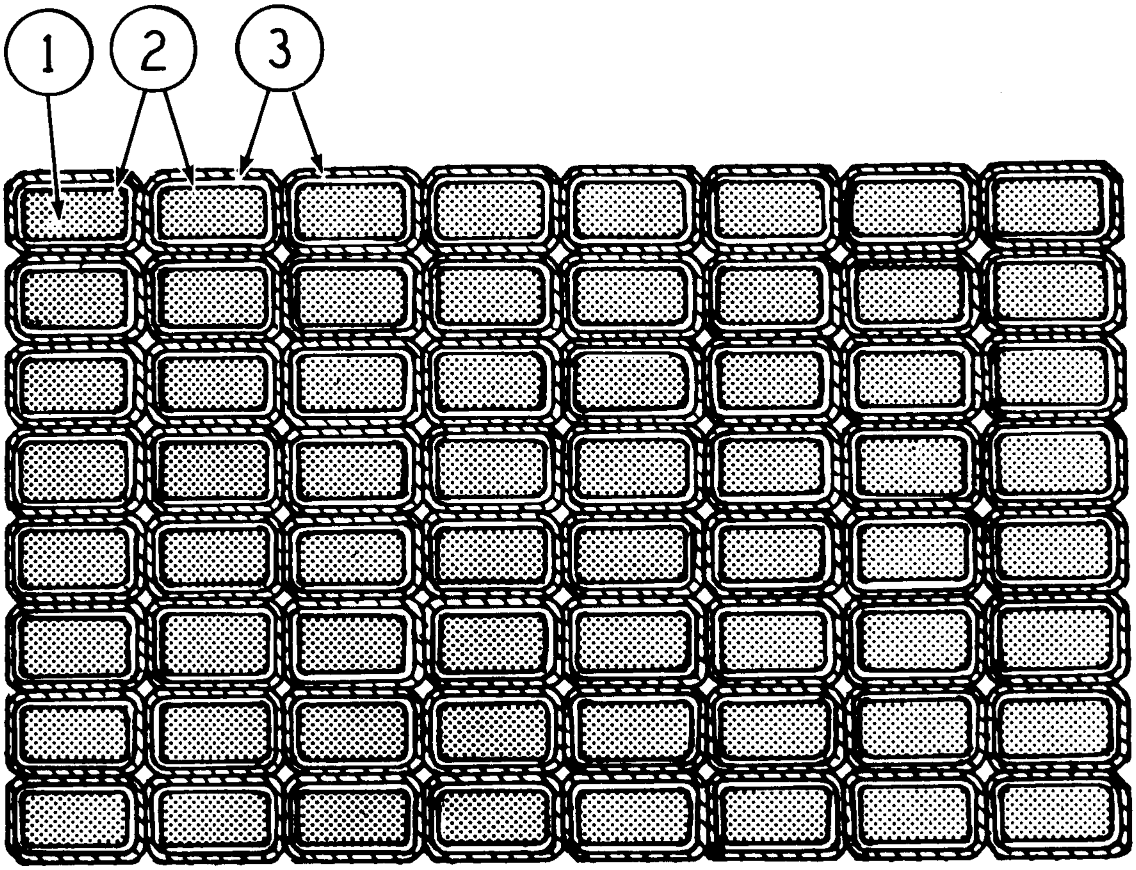
TABLE II.A-12. Details of Transformer

Item No.	Description
1	Magnetic Tape
2	Strap
3	Duct - Cooling, Core
4	Coil - Primary
5	Coil - Secondary
6	Conductor - Coil
7	Insulation - Ground
8	Manifold - Coolant, Inlet
9	Manifold - Coolant, Outlet
10	Tubes - Coolant, Inlet (manifolded)
11	Tubes - Coolant, Outlet (manifolded)
12	Plates - Heat Conduction
13	Parting Line - Core Leg
14	Housing - Hermetic



For legend, see Table II. A-12

FIGURE II. A-14. Transformer, Cross Section



Item No.	Description
1	Conductor
2	Cladding - Conductor
3	Insulation - Conductor

FIGURE II. A-15. Transformer, Coil Detail

TABLE II. A-13. Conductor and Insulation Usage, Transformer

Location of Material Property Summary	Material	Temperature Limit - °F		Coils												Core	
				Primary						Secondary							
				Conductor		Conductor Insulation		Ground Insulation		Conductor		Conductor Insulation		Ground Insulation		Interlaminar Insulation	
		Sealed	Open to Vacuum	(a) 900	(b) 1300	(a) 900	(b) 1300	(a) 800	(b) 1200	(a) 900	(b) 1300	(a) 900	(b) 1300	(a) 800	(b) 1200	(a) 750	(b) 1150
	Conductors																
IV.A.	Nickel-Clad Copper	900	900	2	3	--	--	--	--	2	3	--	--	--	--	--	--
IV.B.	321SS-Clad Silver	1400	1400	1	1	--	--	--	--	1	1	--	--	--	--	--	--
IV.C	304SS-Clad Zirconium Copper	1200	1200	1	3	--	--	--	--	1	3	--	--	--	--	--	--
IV.D.	DS Copper	>1600	1600$^{(c)}$	1	1	--	--	--	--	1	1	--	--	--	--	--	--
IV.E.	TD Nickel $^{(d)}$	>1600	>1600	2	2	--	--	--	--	2	2	--	--	--	--	--	--
IV.F.	Inconel 600-Clad DS Copper	1400	1400	1	1	--	--	--	--	1	1	--	--	--	--	--	--
IV.G.	Inconel 600-Clad Silver	1400	1400	1	1	--	--	--	--	1	1	--	--	--	--	--	--
	Insulation-Inorganic																
V.A.	Magnet Wire																
	2. Anacote	1000	1000	--	--	1	3	--	--	--	--	1	3	--	--	--	--
	3. Anadur	1200	1100	--	--	1	3	--	--	--	--	1	3	--	--	--	--
	4. Ceramiceze	900	900	--	--	1	3	--	--	--	--	1	3	--	--	--	--
	5. R2554B	1000	1000	--	--	1	3	--	--	--	--	1	3	--	--	--	--
	High Purity Refractory Oxides $^{(e)}$	>1600	>1600	--	--	1	1	--	--	--	--	1	1	--	--	--	--
V.C.	Flexible Sheet																
	3. Mica Glass Silicone Bond	1000	1000	--	--	--	--	1	3	--	--	--	--	1	3	--	--
	4. Synthetic Mica Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
	5. Silicate Fiber Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
V.D.	Rigid Sheet-Laminated																
	1. Asbestos BPO_4 - Bonded	>1600	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
	7. Mica Laminate	1100	1100	--	--	--	--	1	3	--	--	--	--	1	3	--	--
V.E.	Rigid Insulation-Molded or Pressed																
	1. Alumina 99.5%	>1600	>1600	--	--	--	--	1	1	--	--	--	--	1	1	--	--
	4. Alumina 0.25% MgO	>1600	>1600	--	--	--	--	1	1	--	--	--	--	1	1	--	--
V.F.	Encapsulation Compounds																
	1. Anacap	900	900	--	--	--	--	1	3	--	--	--	--	1	3	--	--
	3. Sauereisen 8	1200	1100	--	--	--	--	1	2	--	--	--	--	1	2	--	--
	6. W839	1200	1200	--	--	--	--	1	1	--	--	--	--	1	1	--	--
V.G.	Interlaminar Insulation																
	1. Aluminum Orthophosphate	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	2. Aluminum Orthophosphate plus Mica and Bentonite	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	1	3
	3. Glass	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	1	3

(a) - Anticipated part temperature in °F with coolant temperature of 600°F
(b) - Anticipated part temperature in °F with coolant temperature of 1000°F
(c) - Sublimation occurs
(d) - High resistivity
(e) - In the early stages of application to electrical conductor insulation

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

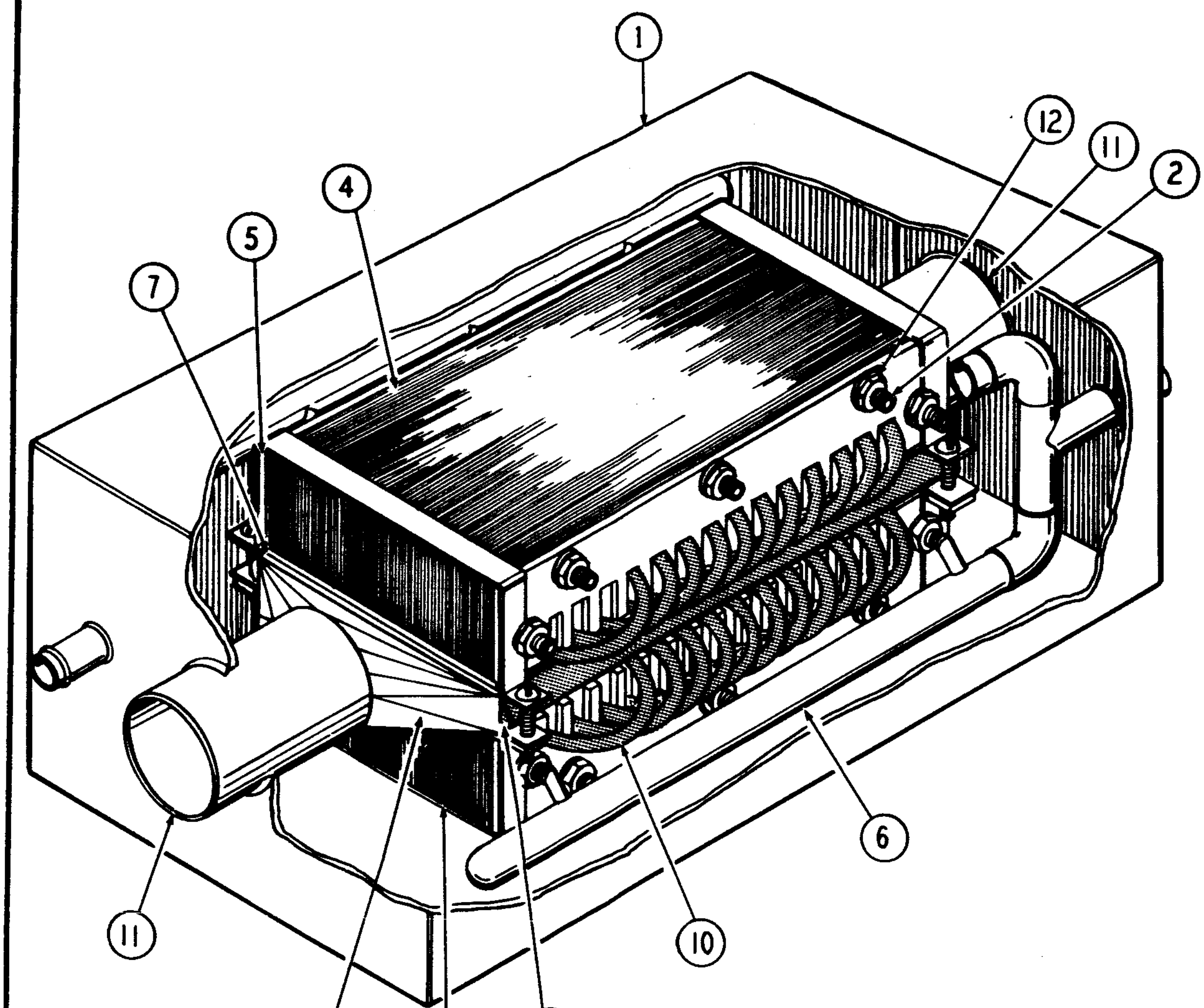
f. ELECTROMAGNETIC PUMP

The electromagnetic pump described in this report is a static device consisting of two magnetic core sections, a series of insulated coils in each section, a cooling system, a duct to carry the liquid metal, and insulation between the liquid metal duct and the magnetic core.

Figure II.A-16 is a drawing of a typical linear-type electromagnetic pump design. Table II.A-14 presents details of this pump. The function normally fulfilled by the rotor in a motor is handled by the liquid metal as it is pumped through the duct.

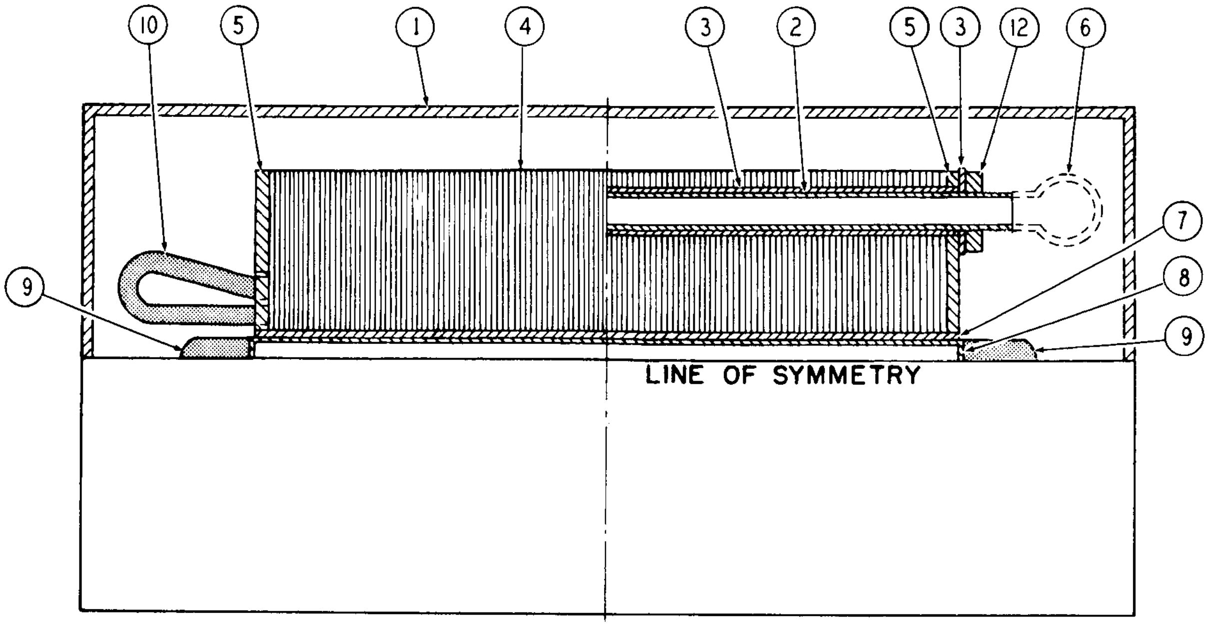
The pump is of sandwich type construction with an insulating sheet (Item 7) between the pumping duct (Item 8) and each stator (Item 4). Heat generated in the laminations and windings is carried away by a coolant which flows through passages at the outer periphery of each stator. The cooling passage tubes also serve to hold the assembly together. The stator requires interlaminar insulation.

Figures II.A-17 and II.A-18 are cross-section drawings showing the ways in which conducting and insulating materials are used. Conductor applications shown are the end conductor on the pumping duct (Item 9) and the winding conductor and cladding (Items 16 and 13). Insulation applications include the coolant tube insulation (Item 3), duct-stator insulation (Item 7) and the conductor and slot insulation (Items 17 and 14). Table II.A-15 is a tabulation showing the suitability of the various conducting and insulating materials and material forms for this application. The table shows material suitability whether the device is to be in a hermetically sealed chamber, or in the vacuum of space.



For legend, see Table II. A-14

FIGURE II. A-16. Electromagnetic Pump, General Assembly

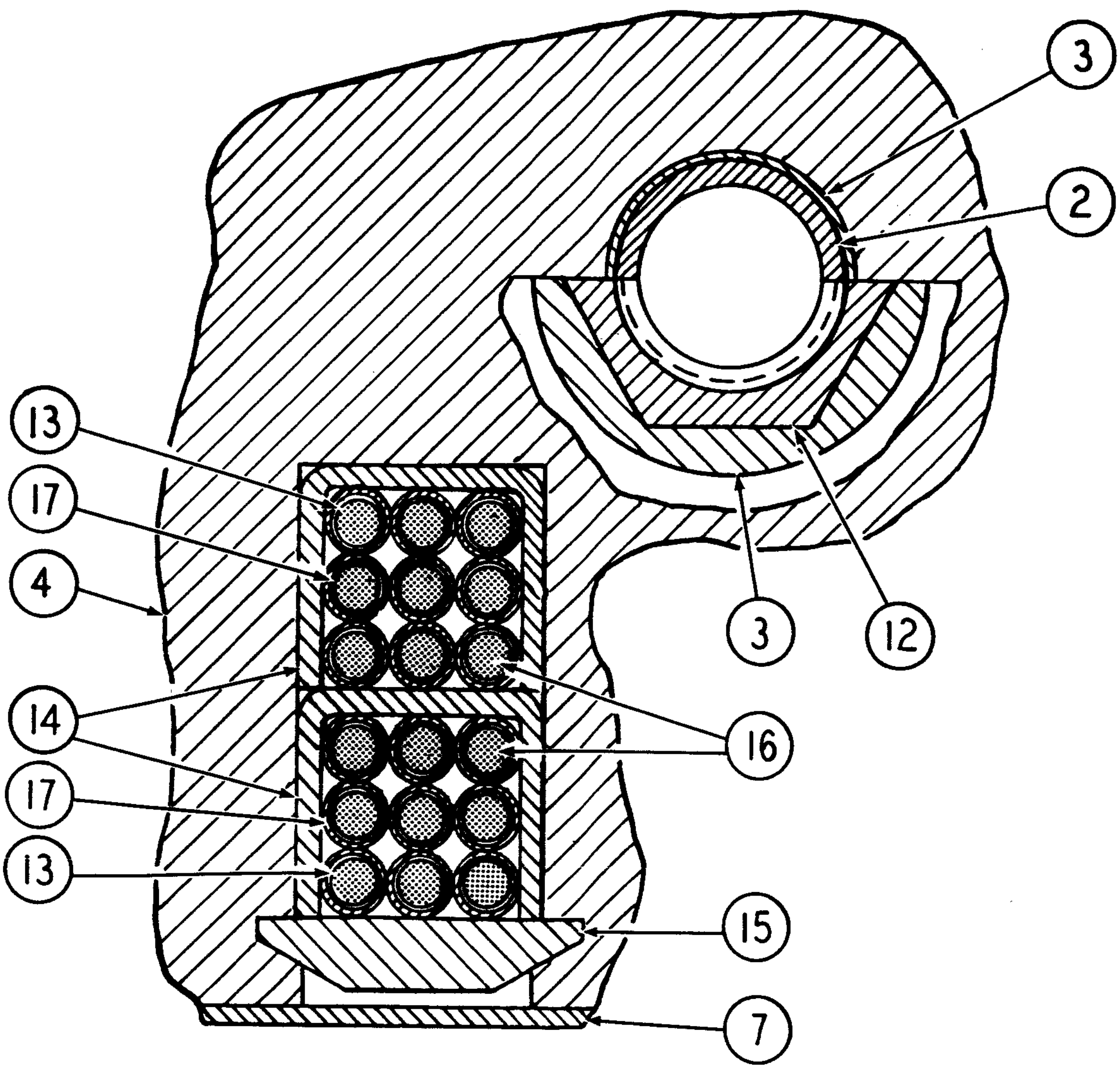


For legend, see Table II. A-14

FIGURE II. A-17. Electromagnetic Pump, Cross Section

TABLE II. A-14. Details of Electromagnetic Pump

Item No.	Description	Item No.	Description
1	Pump Enclosure	10	Winding - Stator
2	Thru-bolt-Coolant Tube (Combined)	11	Inlet, Outlet Passage-Duct, Pumping
3	Insulation - Thru-bolt	12	Nut - Thru-bolt
4	Laminations - Stator	13	Cladding - Conductor
5	End Lamination - Stator	14	Insulation - Slot, Stator Winding
6	Manifold - Fluid, Cooling		
7	Sheet - Insulation	15	Retainer - Stator, Winding, Insulation
8	Duct - Pumping, Fluid Metal	16	Conductor
9	End Conductor - Duct, Pumping	17	Insulation - Conductor



For legend, see Table II. A-14

FIGURE II. A-18. Electromagnetic Pump, Stator Slot and Coolant Tube Detail

TABLE II. A-15. Conductor and Insulation Usage, Electromagnetic Pump

Location of Material Property Summary	Material	Temperature Limit - °F		Conductors				Insulation														Interlaminar Insulation	
		Sealed	Open to Vacuum	Stator Winding		Duct End Conductor		Duct Sheet		Stator Conductor		Stator Slot		Slot Wedge		Cooling Tube		Washer					
				(a) 1000	(b) 1150	(a) 1200	(b) 1200	(a) 1200	(b) 1200	(a) 1000	(b) 1150	(a) 950	(b) 1100	(a) 950	(b) 1100	(a) 650	(b) 1050	(a) 650	(b) 1050	(a) 900	(b) 1100		
	Conductors																						
IV. B.	321SS-Clad Silver	1400	1400	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
IV. C.	304SS-Clad Zirconium Copper	1200	1200	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
IV. D.	DS Copper	>1600	1600(c)	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
IV. E.	TD Nickel (d)	>1600	>1600	2	2	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
IV. F.	Inconel 600-Clad DS Copper	1400	1400	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
IV. G.	Inconel 600-Clad Silver	1400	1400	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	Insulation-Inorganic																						
V. A.	Magnet Wire																						
	2. Anacote	1000	1000	--	--	--	--	--	--	1	3	--	--	--	--	--	--	--	--	--	--		
	3. Anadur	1200	1100	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--		
	5. R2554B	1000	1000	--	--	--	--	--	--	1	3	--	--	--	--	--	--	--	--	--	--		
	High Purity Refractory Oxides (e)	>1600	>1600	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--		
V. C.	Flexible Sheet																						
	4. Synthetic Mica Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--		
	5. Silicate Fiber Paper	1200	1200	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--		
V. D.	Rigid Sheet-Laminated																						
	1. Asbestos BPO_4 - Bonded	>1600	1200	--	--	--	--	1	1	--	--	--	--	--	--	--	--	1	1	--	--		
	7. Mica Laminate	1100	1100	--	--	--	--	3	3	--	--	--	--	--	--	--	--	1	1	--	--		
V. E.	Rigid Insulation-Molded or Pressed																						
	1. Alumina 99.5%	>1600	>1600	--	--	--	--	--	--	--	--	1	1	1	1	1	1	1	1	--	--		
	2. Alumina 99%	>1600	>1600	--	--	--	--	--	--	--	--	1	1	1	1	1	1	1	1	--	--		
	3. Alumina 94%	1200	1200	--	--	--	--	--	--	--	--	1	1	1	1	1	1	1	1	--	--		
	4. Alumina 0.25% MgO	>1600	>1600	--	--	--	--	--	--	--	--	1	1	1	1	1	1	1	1	--	--		
	5. Beryllia 99.8%	>1600	>1600	--	--	--	--	--	--	--	--	1	1	1	1	1	1	1	1	--	--		
V. F.	Encapsulation Compounds																						
	3. Sauereisen 8	1200	1100	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--		
	6. W839	1200	1200	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--		
V. G.	Interlaminar Insulation																						
	1. Aluminum Orthophosphate	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1		
	2. Aluminum Orthophosphate plus Mica and Bentonite	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1		
	3. Glass	1100	1100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1		

(a) - Anticipated part temperature in °F while pumping liquid metal at 1200°F with coolant temperature of 600°F
(b) - Anticipated part temperature in °F while pumping liquid metal at 1200°F with coolant temperature of 1000°F
(c) - Sublimation occurs
(d) - High resistivity
(e) - In the early stages of application to electrical conductor insulation

Legend:
1 Satisfactory
2 Marginal
3 Unsatisfactory because of temperature

B. DISCUSSION OF MATERIAL PROPERTIES

1. General Discussion of Conductor and Insulation Properties

a. ELECTRICAL CONDUCTORS

In space power systems, elevated-temperature conductors will be used over a wide range of applications and under different environmental conditions. In some applications, the conductors may be required to withstand elevated-temperature operation for a relatively short time, but most space electrical power system applications require conductors having a long life (10,000 hours minimum) at elevated temperature. The environmental conditions under which electrical conductors are likely to be used vary widely and include air, vacuum, inert gas, and alkali metal environments. Ideally, it would be desirable that a conductor for high-temperature use (500°F-1600°F) have the following characteristics:

1) Low electrical resistivity.
2) A low, with respect to temperature, coefficient of electrical resistivity.
3) Good resistance to oxidation and alkali-metal corrosion so that an exposure of at least 10,000 hours does not increase electrical resistivity or impair mechanical integrity.
4) Acceptable mechanical properties over the temperature range of 72°-1600°F such that the conductor may be easily bent into coils yet be able to retain its physical shape in operation.
5) possess a magnetic permeability approaching 1.00.
6) possess a low vapor pressure (for vacuum applications)
7) Easily joined to itself and other conductors.

At the start of NAS3-4162, it was realized that no one material could possibly meet all the above criteria for high-temperature conductor. It was also apparent that the more stringent the operating conditions, the higher the cost and the more difficult it would become to make, insulate, and form the conductor coil. For this reason, different and progressively more complex conductors were selected for evaluation. These conductors are tabulated in Table II. B-1. The maximum operating temperatures for long-time operation (10,000 hours) and both desirable and non-desirable characteristics are also listed.

Probably the two most important characteristics measured are the resistivity of the conductors at temperature and the conductors 10,000 hour temperature-atmosphere stability. A summary plot of resistivity versus temperature for all seven conductors studied on this program are shown in Figure II.B-1. While the resistivity data as a function of temperature are important to the designer, these data are only useful as long as the change in resistivity with time at temperature is small. The stability test data shown in Figures II.B-2 through II.B-5 illustrate this point. Note that all of the tested conductors were stable at temperatures to 1000°F, yet only the dispersion-strengthened copper was stable at 1600°F over the entire 2000 hour argon test time. The bare DS copper is oxidation resistant at temperatures to 1000°F in free air. This marked degree of oxidation resistance is surprising in view of the materials low alloy content. No scaling or oxygen penetration has been observed during long time creep testing at 1000°F by the manufacturer of the alloy. Pure copper on the other hand scales rapidly and eventually disintegrates at 1000°F in air. Protection for the DS copper may be achieved by cladding the material with an alloy, such as Inconel, and an integral diffusion barrier such as columbium. This protection is achieved at the expense of lowering maximum operating temperature of the conductor, since some reaction between the Inconel and columbium was observed in the 1600°F stability tests which caused an increase in the resistivity of the wire. If elevated temperature strength is not desired, and if the hot spot temperature does not exceed the individual conductors limiting temperature, one of the lesser conductor combinations may be given consideration. For instance, nickel-clad copper provides low resistivity, modest cost, fabrication ease, alkali metal resistance and good performance to at least 900°-950°F and is generally easy to form.

Inconel 600-clad silver, stainless-steel-clad silver, and stainless steel-clad zirconium copper all appear to promise dependable operation for extended times at temperatures to 1200°-1500°F. Recent Westinghouse published data on stability for 5000 hours at 1500°F support the use of at least Inconel 600-clad silver and Inconel 600-clad columbium barrier, dispersion-strengthened copper to 1500°F. These new data are plotted in the summary presentation of Figure II.B-5. At the end of 5000 hours, the 72°F resistivity of both wire composites had increased less than eight percent. TD nickel is suggested for operation only under conditions of extremely high stress and temperature where low electrical resistivity is of little importance.

The two stainless-steel-clad materials offer the desirable characteristics of a completely non-magnetic sheath over cores which are not susceptible to grain-growth problems. Three of these conductors represented entirely new technology. The two austenitic-stainless-clad materials and the dispersion-strengthened copper have never been reported before. The balance of the materials, with the exception of TD nickel and nickel-clad copper, were available, but only in experimental quantities. Each of the new conductors tested on NAS3-4162 was procured at modest cost and is now available in development quantities.

These conductors will withstand approximately 10^{17} fast neutrons/cm^2 total dose. Higher neutron exposures will begin to cause the internal resistance of the wire to increase due to the damaging effect of the fast neutrons upon the crystal lattice of the conductor.

If the conductor is maintained at a relatively high temperature, such as from 1200 to 1600°F, some of the radiation damage becomes gradually annealed. At these temperatures, the conductors would withstand about 10^{18} fast neutrons/cm^2. The absorption of gamma particles , by the conductor, will increase the amount of heat deposited within the conductor. The heating rate from this source is relatively small compared to the heat generated by the passage of a large current through the conductor.

b. ELECTRICAL INSULATIONS

The primary function of electrical insulation is to isolate current carrying materials from each other or from their supporting environment. Satisfactory performance of this function places two inter-related demands upon the material. These demands are that the material have high electrical resistance and sufficient mechanical strength to remain in proper configuration. The values of these general properties will be dictated by the form in which the insultion is to be used and the environment to which the assembly will be subjected.

Electrical insulation for space power systems is used in numerous forms which present a wide variety of mechanical and physical properties. These forms include wire coverings, slot liners, phase separators, rigid structural members, interlaminar coatings, and sealing , impregnating and encapsulating compositions. These groups of insulating materials have several vital requirements in common as follows:

1) Stability under electrical, thermal and mechanical stress.

2) Compatibility with other materials with which it may be in contact.
3) Ability to be applied in the desired configuration without detriment to its properties.

This study included two temperature ranges: -65 to 1000°F and 500 to 1600°F. Organic materials may be selected which will operate in space applications over a portion of the lower temperatures up to 500°F. Organic and refractory electrical insulation materials were examined for weight loss performance when heated in vacuum of approximately 1 x 10^{-6} torr pressure. Weight loss rates were determined which will be an initial guide in the selection of materials for particular applications. Final selection of a suitable material should be preceded by vacuum testing of sample configurations comparable to the intended application. The outgassed products should be examined by means of a residual gas analyzer for identification of their nature and source. The following discussions of properties are classified by material function and form.

1) Magnet wire

Four important properties are required of a conductor insulation intended for wound apparatus. They are:

a) High insulation strength.
b) Abrasion resistant and flexible.
c) Low space factor.
d) Physical and chemical compatibility with the conductor.

Operation over the entire lower temperature range of this program is too severe for organic polymers. The selection of organic wire coatings is narrowed to the polyimide because it offers maximum heat stability. This resin, used as a wire enamel, fulfills all four of the above basic requirements for a conductor insulation. It is a thermosetting polymer which resists, to an outstanding degree, chemical, physical, thermal, and radiation damage. Its stability, after proper processing, would permit its satisfactory use in either hermetically sealed or open-to-space apparatus. Its upper temperature limit for ten to twenty thousand hour life under these conditions is greatly dependent upon winding configuration, voltage stresses, and impregnating resin selection. In combination with an impregnating varnish composed of polyimide resin, such as Dupont ML varnish, polyimide enameled wire would perform satisfactorily at temperature up to 400°F (sealed) or 300°F (vacuum).

The high temperature range, up to 1600°F makes the four wire insulation requirements more difficult to satisfy. In practice, compromises between the four factors must be made even to attain some successful performance at temperatures as low as 1200°F.

Work on alkali metal resistant conductors for operation at 1600°F on Contracts AF33(657)10701 and AF33(615)1360 have revealed that plasma-arc-sprayed, high-purity alumina shows great potential. However, two of the four performance factors were necessarily affected. They were flexibility and low space factors. In the state of ceramic technology today, flexibility is not known in a 1600°F insulating coating of adequate electrical strength for a motor or generator. Examination of Figure II. B-6 will reveal the electrical capabilities at varied temperatures of four leading candidates for high-heat resistant windings. All four magnet wires require a compatible encapsulating or filling compound to restrain motion and prevent mechanical damage during operation. The test program disclosed that the most durable magnet wire of the group was Anadur (a) which was also the heaviest in thickness. The insulation layer of Anadur is composed of served E-grade glass fibers, fusible glass frit, and refractory oxide powders retained on the conductor during winding by a resin binder. Subsequent firing of the wound apparatus fuses the glass frit which is then a rigid binder. Anadur will perform well at temperatures up to 1100-1200°F. Ceramic-Eze (b) has the lowest space factor and rather good durability. Ceramic-Eze is a fused glass coating which contains a mixture of refractory oxides. None of the insulations have yet been applied successfully to wire of rectangular cross-section. This wire configuration is very important to efficient high-temperature generator and motor design.

2) Lead Wire

Two lead wire designs were examined in this program. They were Micatemp (c) and Continental type AA (d) wire. Micatemp insulation is wrapped mica tape covered with E-glass braid coated with a silicone resin. Continental type AA lead wire consists of E-glass reinforced mica tape wrapping overlaid

(a) Anaconda Wire and Cable Company
(b) Phelps-Dodge Copper Products Corp.
(c) Rockbestos Wire and Cable Company
(d) Continental Wire Corp., York, Pa.

with asbestos braid. Both insulation constructions were applied over nickel-plated stranded copper wire and are relatively flexible before and after firing. However, whether the post-fired condition of the flexible lead wires can be considered adequate, depends upon the amount of flexing and vibration it will be subjected to in the design. Repeated flexing and/or abrasion as that caused by vibration easily fractures individual fibers and platelets of insulation. This gradually degrades the insulation strength. If possible, reliance upon flexible refractory wire wrappings should be avoided. If unavoidable, then some consideration should be given to encasing the entire wire and insulation with a flexible heat-resistant metallic sheath. Figure II. B-7 shows a comparison of the total electric strengths versus temperature for Micatemp and Continental Type AA. Since Micatemp has a much thinner wall than the Continental wire, it would be more convenient where space demands are critical. Electric strength requirements, however, might dictate selection of a heavier insulation thickness. Vacuum weight loss of Micatemp is approximately one-third of the other wire. Insulation resistance of Micatemp is also better because of the mica platelets.

3) Sheet Insulation - Flexible

Flexible sheet electrical insulation is a useful and important form when applied in the winding of motors, generators, transformers, and other components of power systems. The advantages of sheet insulation include ease of handling and its ability to conform to somewhat irregular slot or winding shapes. The barrier to thermal transfer can often be a disadvantage; however, filling with a compatible resin or other insulating compound will overcome most of the thermal drop. Two organic sheet insulations were examined. The organic component of both forms was the polyimide resin known as ML (e). The first form was unsupported film identified as H-Film (e) and the second was resin-treated glass fabric marketed as Pyre-ML (e). A modified, more flexible grade of Pyre-ML was introduced during the term of this evaluation program by the manufacturer and was partially tested and compared with the original grade. Both supported and unsupported forms have good resistance to cut-through but

---

(e) E. I. DuPont de Nemours and Company, Inc.

the glass-based composite is generally more reliable for long life applications. The glass fabric is a handicap in designs requiring extreme creases and bends during manufacturing and, in such applications, the resin film would be best.

The use of the term "flexible", when referring to inorganic sheet insulations, must be qualified. Most flexible inorganic sheet insulations are flexible only because discrete refractory fibers or particles are held together by means of an organic binder. This binder is driven off or destroyed during preliminary firing of the apparatus or component. After exposure to the firing temperature, the resulting form of the sheet insulation is not easily handled and will be damaged if flexed. The insulation must, therefore, be undisturbed in locations where electrical strength is required. Porosity of inorganic sheet insulation is increased by firing process and makes the insulation more receptive to filling or impregnating with an encapsulation compound.

The three inorganic flexible sheet insulations evaluated were Minnesota Mining and Manufacturing's synthetic mica paper (Burnil CM-1; 0.010 inch thick), Westinghouse's silicone bonded micaglass (128-50-1; 0.0045 inch thick), and Carborundum's Fiberfrax (0.020 inch thick) paper. The thicknesses of the specimens are not equal but they are at the minimum practical application thicknesses for flexible, high-temperature-resistant sheet insulations of these compositions. Despite this variable, the silicone-bonded mica glass gave the highest total electric strength at elevated temperatures, as shown in Figure II.B-8. This high-electrical strength is attributed to the layer of mica platelets. Fiberfrax is low at all temperatures. The thermal conductivity of Burnil CM-1 is best of the three materials at elevated temperatures, as shown in Figure II.B-9. Vacuum weight loss determinations reported in Section V.C.3 indicate that some degradation does occur between 1200 and 1600°F. Additional insulation life tests at several intermediate temperatures would be required to determine the maximum usable temperature more accurately.

4) Rigid Insulation, Laminated

Laminated rigid insulation is an important form of electrical insulation. Structural components often need to be electrically nonconductive but space or assembly method requirements prevent the use of insulating washers, tubes, standoffs, or other forms of spacers. In such cases, insulating resin structures reinforced with suitable fibers offer major assistance to the designer. Two classes of laminated materials were examined in this program. The organic-resin laminates were:

a) Diphenyl oxide-glass
b) Epoxy-glass
c) Phenolic-glass
d) Polybenzimidazole-glass
e) Polyimide-glass

The inorganic compositions were boron-phosphate bonded asbestos and inorganically bonded mica. All of the materials were studied as flat sheets; however, most of them may be fabricated in simple shapes during the laminating process.

After the literature survey and early test stages were complete, several of these materials were withdrawn for the following reasons. The phenolic laminate was withdrawn from further testing because its properties useful to space electric power systems were represented by other materials in the study and because a large amount of information was available already on that class of composites. In addition, the poor arc resistance of the phenolic laminate limits application of the material. Polybenzimidazole-glass laminate was withdrawn because of high cost and poor long-term performance at 600°F. Recent work by the producer of polybenzimidazole-glass has been directed at the solution of this problem, but data was not available in time for inclusion in this report.

Polyimide-glass laminate displayed the highest order of thermal stability followed by the diphenyl oxide-glass laminate. Both of these composites have low-weight loss in vacuum and retain good electrical and physical properties up to 500°F. Epoxy-glass laminate is affected much more severely at 500°F. Both mechanical and dielectric properties decreased greatly at temperatures over 400°F. Organic laminates, when thermally cycled, do not return exactly to their original dimensions.

The two refractory-laminated insulations are bonded with inorganic materials. The asbestos laminate is useful at temperatures up to 1200°F. Its vacuum weight loss when heated is about 5 percent, which will be excessive for many proposed designs. The vacuum weight loss of the mica laminate is much lower and will probably be suitable for space power devices. The electrical performance of the mica composite is better than the asbestos laminate and indicates that in a proper design, this material could be used up to 1600°F. The thermal conductivity of the mica material is lower than the asbestos. This is attributed to the plate-like laminar mica structure which also causes the superior electric performance.

5) Rigid Insulation, Molded or Pressed

Molded or pressed electrical insulations are used in many locations as described in Section II.A. of this report. Spacers, terminal boards, wedges and slot liners are typical of these applications. Materials in both organic and inorganic classes were examined in this program. The organic compositions included an epoxy-glass premix, a polyester-glass premix and an unfilled polyimide resin. The inorganic materials were beryllia 99.8%, alumina grades 99.5%, 99%, 94%, and 99.8%-0.25% MgO.

Organic molding materials are generally composed of a resin, a hardener, fibrous reinforcements, mineral fillers and supplemental additions, such as lubricants, pigments and dyes. It is difficult to obtain molding materials with the thermal stability of the laminates because of these supplemental additives. Silicone compositions are excellent in thermal stability, but in space applications and where sliding or mating electrical contacts are in use, the thermal decomposition products, which are mainly silica, introduce excessive wear and necessitate the use of alternate materials. The most thermally stable organic material examined in this program was the polyimide molding resin produced by DuPont and identified as SP resin. Unfortunately, the molding characteristics of the polyimide preclude compression and transfer molding operations in the conventional sense. SP resin can be obtained only in bar stock and blocks from which the necessary parts must be machined. The electrical properties of SP are satisfactory at 500°F and there is very little reduction in mechanical properties at temperature. This resin has displayed low-weight loss when heated in vacuum as reported in Sections V. C. 1 and 2. The other two organic molding compounds, polyester and epoxy, perform very much alike and are limited to long-life applications at temperatures of about 250°F.

The four alumina and one beryllia bodies have many uses in applications for space power apparatus. By consideration of the following discussion and the Material Properties Summaries contained in Section V. E. of this report, the designer will find that purity level and product history are significant factors in performance of the parts. For example, 94% alumina is generally satisfactory for a slot wedge, since electrical stresses are very low in that application. However, 99% purity or higher will probably be required when this primary electrical insulation is needed at 1400°F. Another case is that of beryllia. The curves of thermal conductivity versus temperature at three purity levels are presented in Figure V. E. 5-2, showing the desirability for high purity when high-heat transfer is required.

Nominal values of the mechanical properties of commercially available high-temperature inorganic insulation are presented in Section V. E. 1, 2, 3, 4, and 5. Generally, they have excellent temperature tolerance. These data reflect standard values. Strength of polycrystalline oxides are affected by grain size, porosity, surface conditions, environment and loading conditions. It is, therefore, as important to know the thermal history of a ceramic which is selected for critical applications as to know the purity.

The moduli of elasticity presented in Figures V. E. 1-4, V. E. 2-7, V. E. 3-4, V. E. 4-7 and V. E. 5-7, reflect the findings of a number of investigators, including Wachtman (LI 282), Swartz (LI 283), Coble (LI 208) and Kovalev (LI 294). It was noted that there is a gradual, nearly linear decrease in elastic modulus and flexural strength in polycrystalline alumina to about 1800°F. At higher temperatures, a sharp, non-linear drop was observed. This drop has been attributed to grain boundary slip. Therefore, factors which promote slip will accentuate this drop in strength. For instance, presence or formation of a glassy phase will induce slip.

The effect of grain size on the mechanical properties of beryllia and alumina were reported in LI 296, LI 290, and LI 50. The elastic modulus of polycrystalline alumina is essentially independent of grain size to 2500°F. However, as shown in Figure V.E.4-5, the flexural strength of fine-grain alumina (1 to 15 microns) is substantially greater than for alumina of larger grain size. This holds true over the entire temperature range being considered (LI 290).

Although thermal expansion is relatively unaffected by varying porosity, the porosity (or relative density) of polycrystalline oxides must be stipulated and maintained in order that consistent mechanical properties of the insulation be realized. Coble and Kingery (LI 208) showed a sharp decrease in the modulus and strength of polycrystalline alumina with increased porosity.

Electrical properties of alumina and beryllia oxides are more sensitive to impurities than are the mechanical properties. In general, the dielectric constant of aluminum oxide rises exponentially with temperatures at low frequencies (e.g., 1000 cps). At higher frequencies, it rises gradually at a shallow slope as temperature increases. Of the cationic impurities, magnesium causes the greatest rise in dielectric constant, followed by silicon, titanium, calcium, chromium, and iron. Silica has by far the greatest detrimental effect on dielectric losses. Power factor rises by a factor of ten or more with addition of 0.1 percent silica to alumina. The effect of magnesium or titanium are much less marked followed by calcium, iron and chromium. As the frequency increases into the microwave region, the influence of low concentrations of impurities diminishes.(IRI 35, LI 189, LI 193, LI 295).

6) Encapsulation Compounds.

Encapsulation compounds are needed in many electrical equipment designs to reduce relative motion between windings and supplementary insulation pieces and to aid in removal of heat from the coils. Many organic insulation systems may safely use an impregnating varnish, but there are no equivalent materials for inorganic systems. Impregnation of windings with glass have been performed with moderate success in small devices but problems of thermal expansion mismatch and low electric strength of glass at high temperature are serious limitations.

Three organic and three inorganic compounds were examined in this program. The organic materials were a filled epoxy compound, silicone foam, and urethane foam. The epoxy composition is hard and is sensitive to thermal shock. If rapid temperature cycling can be avoided, it is probable that this material could be used up to 400°F. The amount of weight loss in vacuum will probably limit the material to 350°F operation in some devices. Epoxy compounds may be produced in a more flexible composition, but only at the expense of decreased thermal stability and strength and increased thermal expansion.

The silicone foam is more thermally stable than the urethane and may be used at 400 to 450°F. The silicone composition may be used where electrical contact surfaces are not exposed to degradation products of the resin.

The urethane foam appears to be suitable for use up to 400°F. However, as a result of transfer of production and marketing rights for this material to another manufacturer, who reported slight modification in composition (see Section V. F. 4), the out-gassing tendencies and high temperature electrical properties would require re-testing.

The three inorganic encapsulation compounds evaluated were Sauereisen Cement Company's No. 8, Westinghouse's W839 and Anacap of Anaconda Wire and Cable Co. In comparing the electrical properties of these compounds, it was interesting to note the similarity between W839 and Sauereisen No. 8 even though they are of different compositions. An example of this similarity is shown in the volume resistivity curve of Figure II. B-10. In all cases, the Anacap is inferior in electrical properties to the other two compounds. The thermal expansion value of Anacap is almost double the thermal expansion value of the other two compounds. These data are shown in Figure II.B-11 and indicate that Anacap is more compatible with most metals of interest than the other two materials. The compressive strength of W839 is higher than that of the other compounds, as illustrated in Figure II. B-12. Pot life of these three compounds varied from 10 minutes for Anacap, 50 minutes for No. 8, to greater than 72 hours for W839. The desirability of a short or long pot life depends on the application. All of the encapsulation compounds displayed low-weight loss values in vacuum. However, because all three are porous and have large surface areas, out-gassing of an assembled device is required prior to operation of an encapsulated device.

One thousand hour aging tests were performed at 1112°F, and 1292°F on the refractory compounds. Sauereisen, (Figure V. F. 3-5) and W839 (Figure V. F. 6-5) were relatively stable. Anacap (Figure V. F. 1-3) was better electrically after the aging period at 1292°F than it was after the 1112°F exposure. The color remained dark green throughout the 1112°F exposure, but faded to a light green color during the 1292°F aging. The silver electrodes were attacked and became bonded to the compound during the 1112°F test, but this did not occur in the 1292°F exposure. Metallic components with increased compatibility are recommended for all three compounds. The other two compounds had no visual appearance changes throughout the stability testing at all temperatures.

7) Interlaminar Insulations

The function of interlaminar insulation is to provide electrical resistance between magnetic laminations to reduce core losses. The insulation must be extremely thin to keep the stacking factor of the core to a maximum. The stacking factor should be above 90 percent for satisfactory utilization of space. The material should have sufficient adhesion to permit assembly of low loss magnetic cores. The insulation may also serve to bond the laminations to each other.

Three forms of interlaminar insulation were tested. The materials were aluminum orthophosphate, aluminum orthophosphate plus mica plus bentonite (MAB), and M 305 glass. M 305 glass is a modified borosilicate composition developed by Westinghouse Research and Development Center. Aluminum orthophosphate coating produces the highest stacking factor and glass, the lowest. All three coatings appear to be suitable for 1100°F in line with the discussion and conclusions presented in Section II. B. 3. g. None of the materials were satisfactory after exposure to 1400°F. Figures V. G. 1 through V. G. 6 present the performance comparisons of these materials in contact with CUBEX magnetic alloy.

TABLE II. B-1. Electrical Conductor Materials Selected for Investigation

Material	Desirable Characteristics	Maximum Long-Time Use Temperature (a)	Non-Desirable Characteristics
Bare Dispersion-Strengthened Copper	1. Highest strength conductor 2. Highest conductivity conductor 3. Most stable conductor on aging	Greater than 1600°F	1. Not resistant to alkali metal 2. Difficult to form and insulate 3. Not oxidation resistant above 1000°F (c)
304 Stainless-Steel-Clad Zirconium Copper	1. Core resistant to grain growth to approximately 1200°F 2. Oxidation and limited alkali metal resistant 3. Non-magnetic clad at all temperatures.	to 1200°-1300°F	1. Somewhat difficult to make
Nickel-clad Oxygen-free Copper	1. Stable to 900°F for long times 2. Easy to insulate and wind 3. Oxidation and limited alkali metal resistant	to 900°F maximum hot spot temperature	1. Use limited to temperatures below 900°F
Inconel 600-Clad, Columbium-Barrier, Dispersion-Strengthened Copper	1. Very high strength conductor 2. Oxidation and alkali metal resistant	to 1400°F	1. Difficult to insulate and wind 2. Somewhat difficult to make
Inconel 600-Clad Fine Silver (b)	1. Oxidation and alkali metal resistant 2. High conductivity for clad conductor	to 1400°F	1. Somewhat difficult to make 2. Relatively difficult to insulate and wind
321 Stainless-Steel-Clad Fine Silver	1. Oxidation and limited alkali metal resistant 2. High conductivity for clad conductor	to 1400°F	1. Somewhat difficult to make 2. Relatively difficult to insulate
TD Nickel	1. Exceptional high temperature 2. Oxidation and limited alkali metal resistance	Greater than 1600°F	1. Very high resistance 2. Difficult to insulate and wind

(a) Estimated capability for 10,000 hours based on approximately 2,000 hour data (see Section IV for individual conductors).

(b) Inconel cladding was chosen for its improved oxidation resistance in comparison to nickel. Nickel-clad silver exhibits similar electrical and stability properties. (See RC5 and RC47 for additional discussion.)

(c) A thin tightly adherent oxide was observed to form on this alloy during long time creep testing in air at 1000°F.

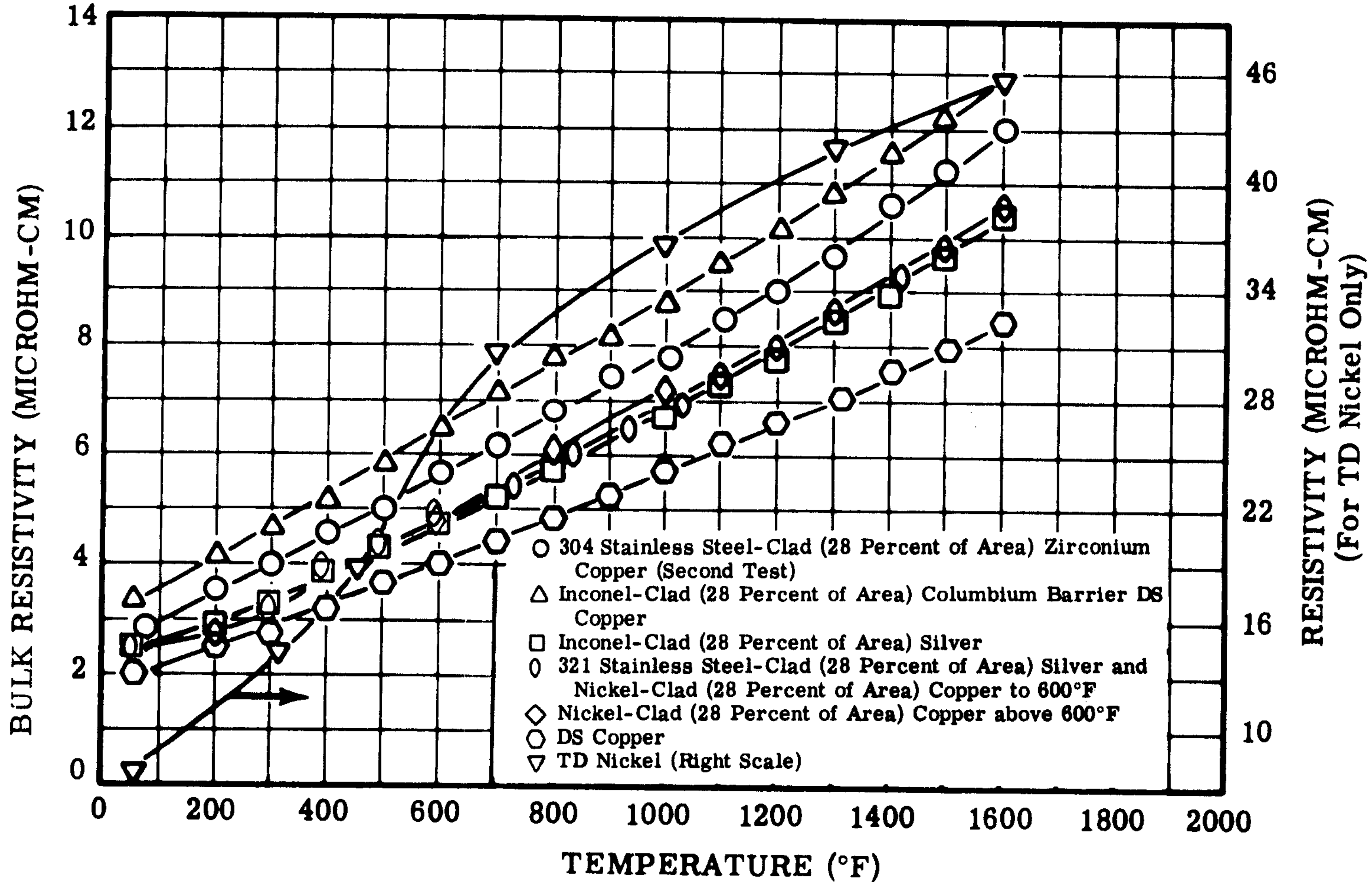


FIGURE II. B-1. Electrical Resistivity Versus Temperature of Conductors in Vacuum. All Cladding is 28% of Conductor Area Except Dispersion-Strengthened Copper Which is Columbium-Clad (8%) Inconel-Clad (28%).

Figure II. B-1. Electrical Resistivity - Conductors

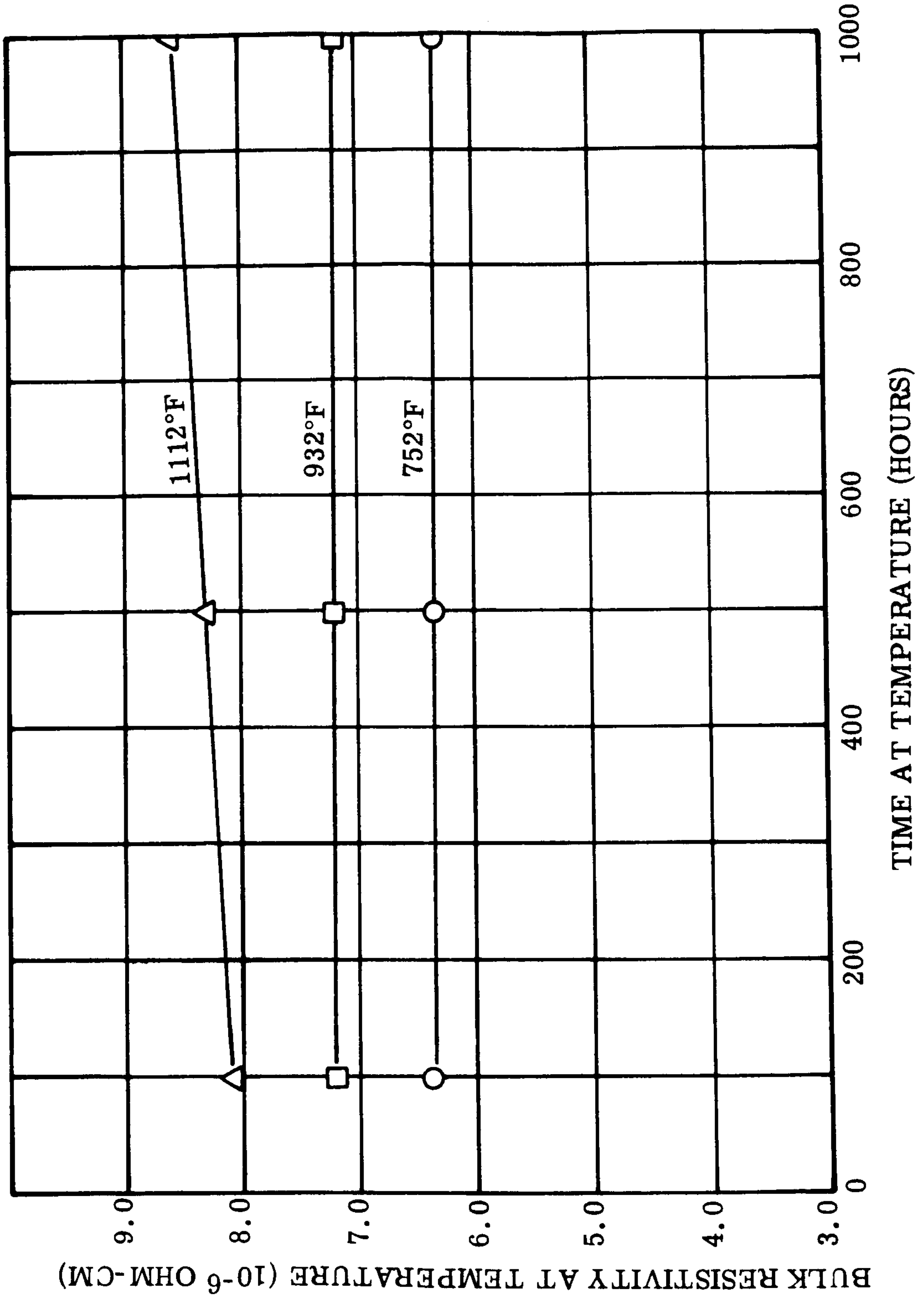


FIGURE II. B-2. Effect of Time at Temperature on the Resistivity of Nickel-Clad (28 Percent of Area) Oxygen-Free Copper. Measurements Made at Temperature. Air Test. See Table IV. A-1. (Reference: RC5 and RC47)

Figure II. B-2. Electrical Resistivity Stability - Ni Clad Oxygen-Free Copper

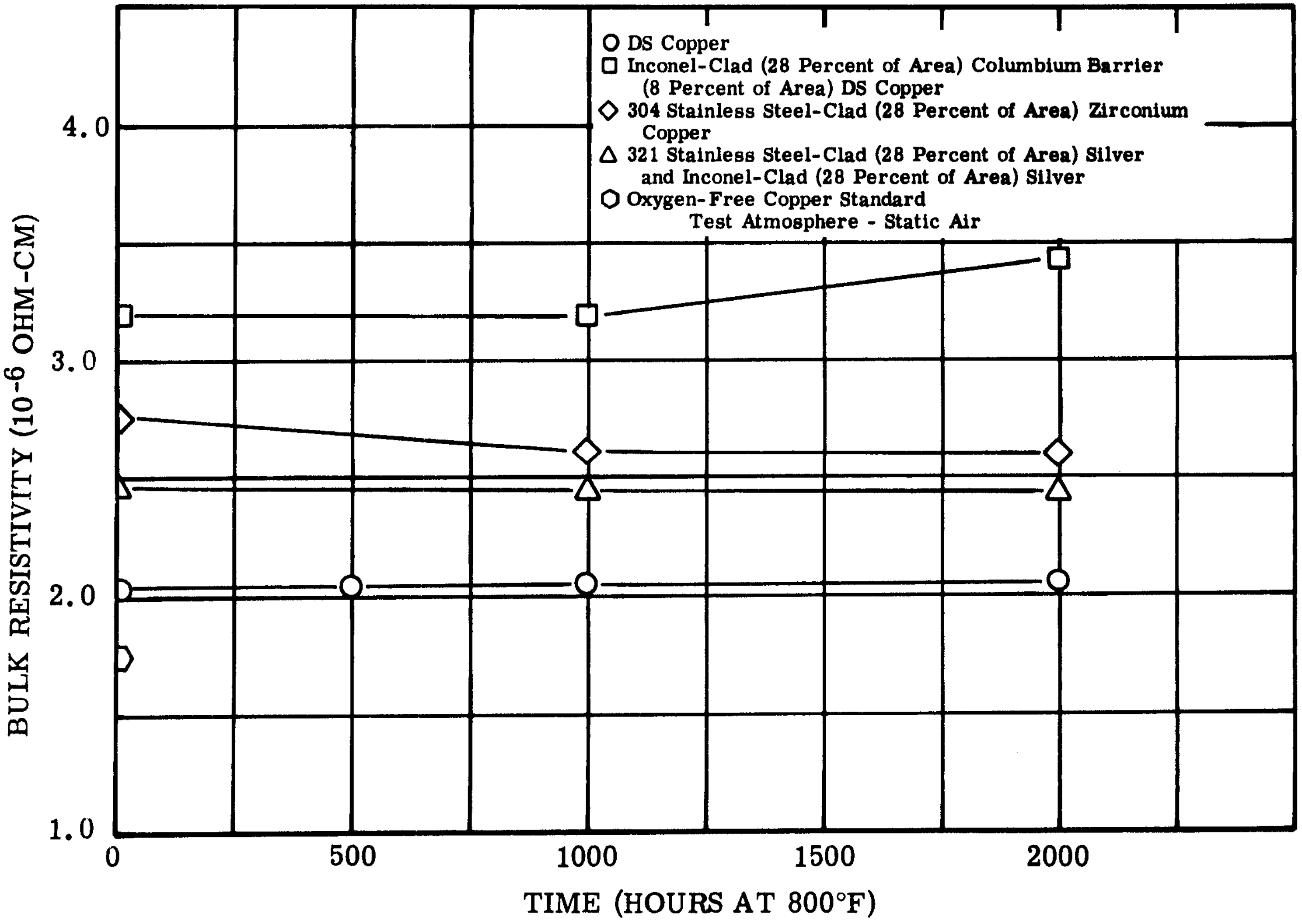


FIGURE II. B-3. Effect of Time at 800°F on the 72°F Resistivity of Four Different Conductor Materials. See Tables IV. B-2, IV. C-5, IV. D-3, IV. F-2, and IV. G-2. (Reference: NAS 3-4162)

Figure II. B-3. 800°F Stability - Conductors

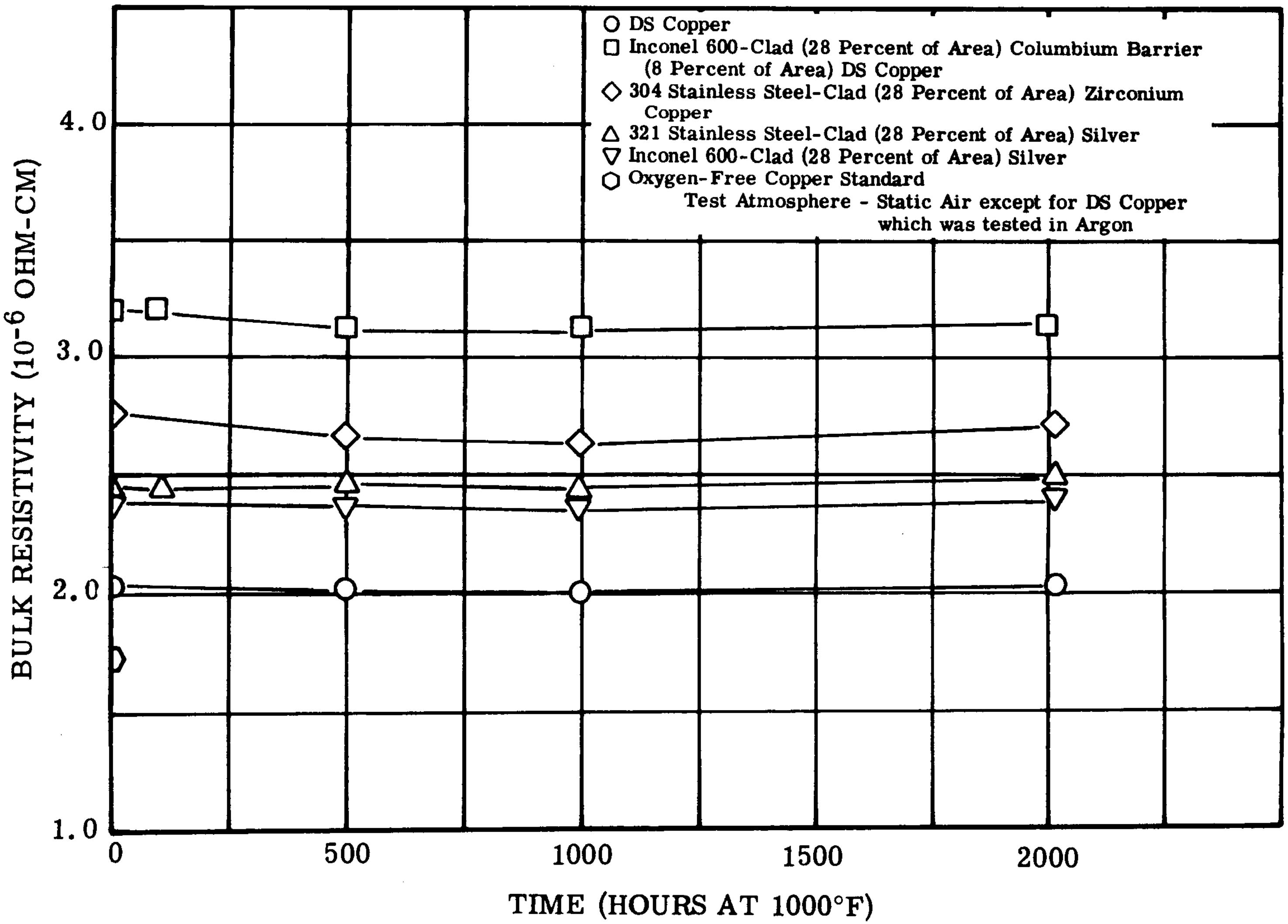


FIGURE II.B-4. Effect of Time at 1000°F on the 72°F Resistivity of Five Different Conductor Materials. See Tables IV.B-2, IV.C-5, IV.D-3, IV.F-2, and IV.G-2. (Reference: NAS 3-4162)

Figure II.B-4. 1000°F Stability - Conductors

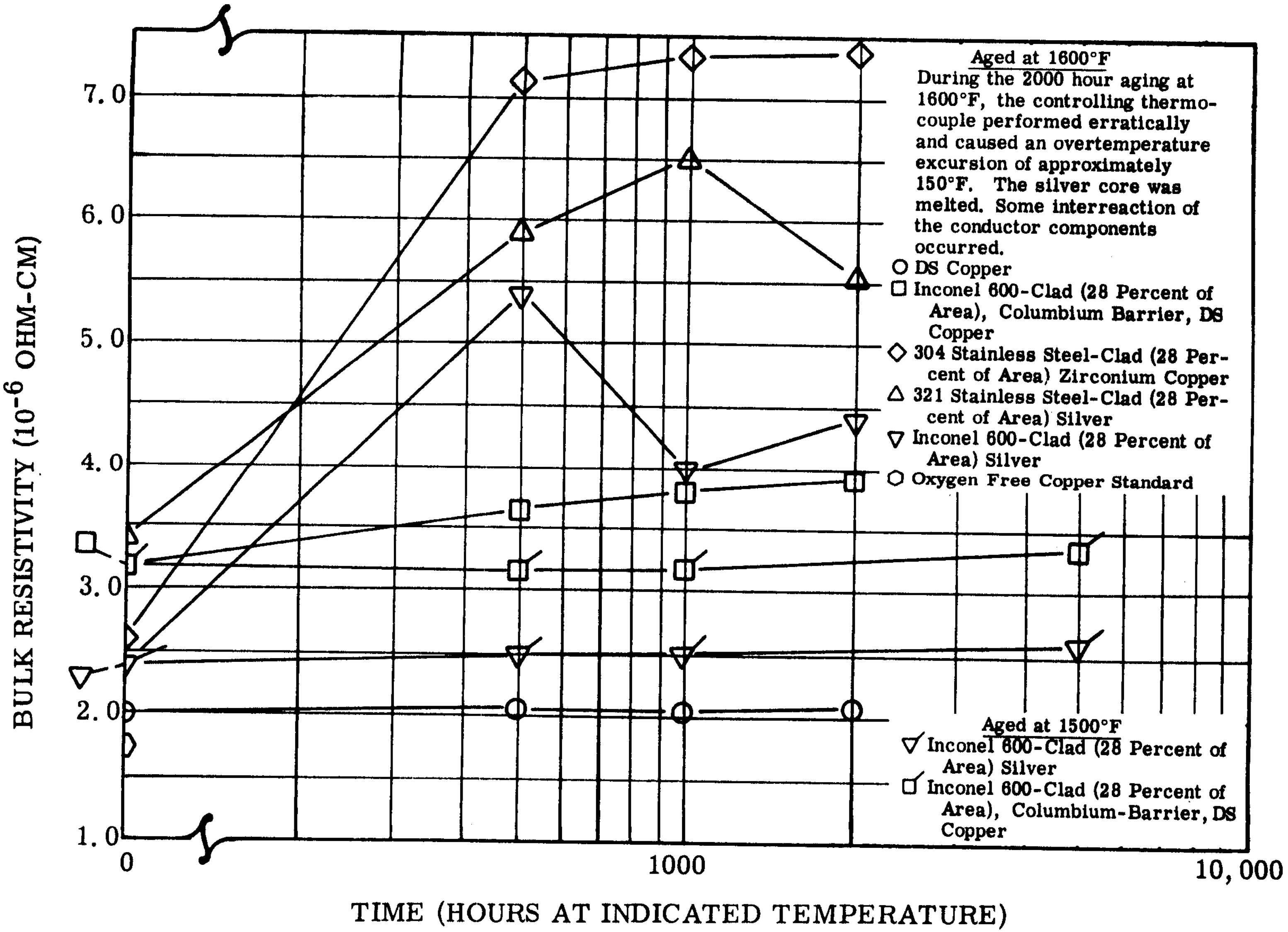


FIGURE II. B-5. Effect of Time at Elevated Temperatures on the 72°F Resistivity of Five Different Conductor Materials. See Data Tables IV. B-2, IV. C-5, IV. D-3, IV. F-2, and IV. G-2. (Reference: NAS3-4162 and Westinghouse)

Figure II. B-5. 1600°F Stability - Conductors

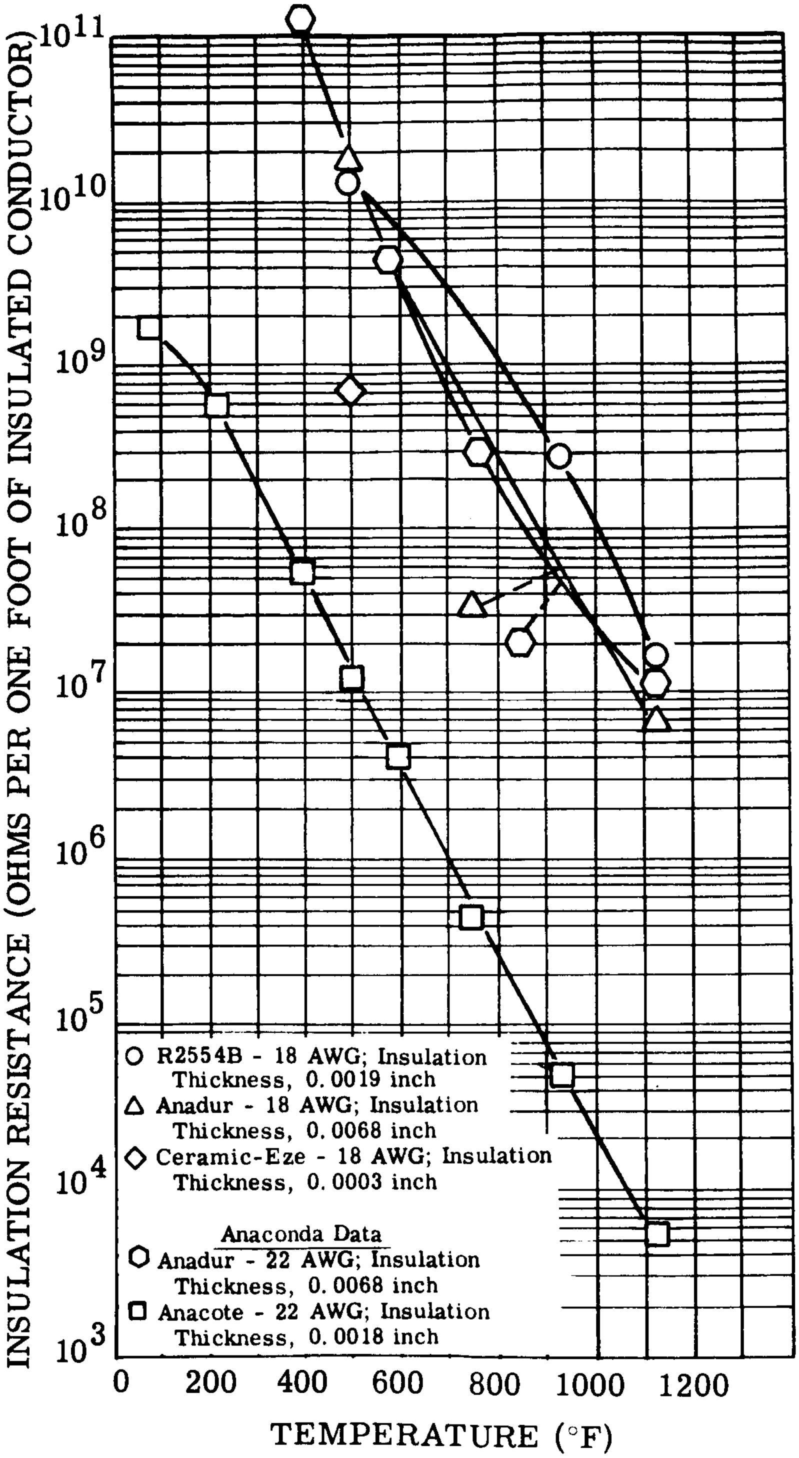


FIGURE II. B-6. Insulation Resistance of Inorganic Magnet Wire. (D-C Resistance Measured from Wire to Tubular Electrode Surrounding Wire Insulation.) (Reference: NAS 3-4162)

Figure II. B-6. Insulation Resistance - Magnet Wire - Inorganic

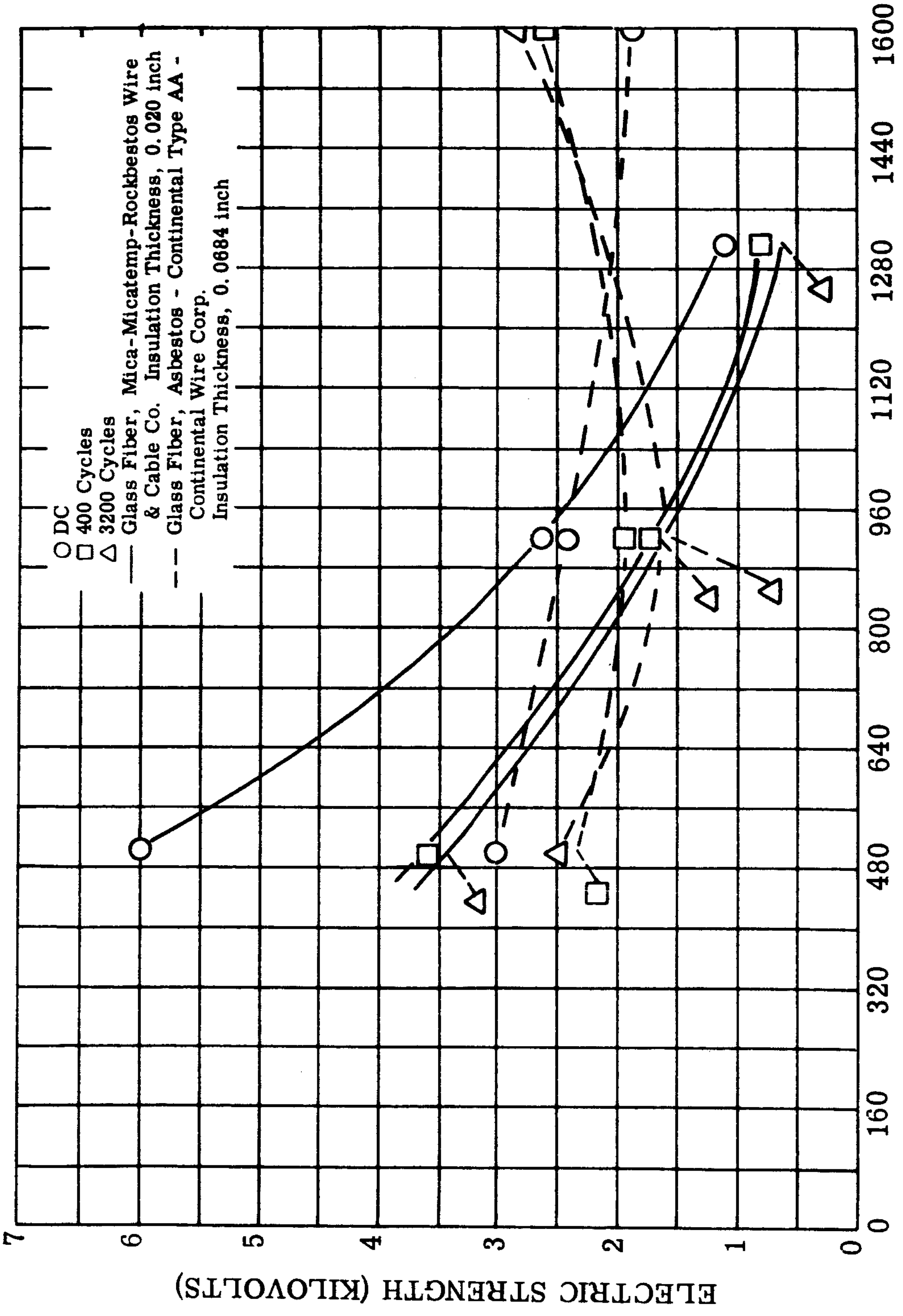


FIGURE II. B-7. Electric Strength of Inorganic Insulated Lead Wire in Air. (Reference: NAS 3-4162)

Figure II. B-7. Electric Strength - Lead Wire - Inorganic Insulated

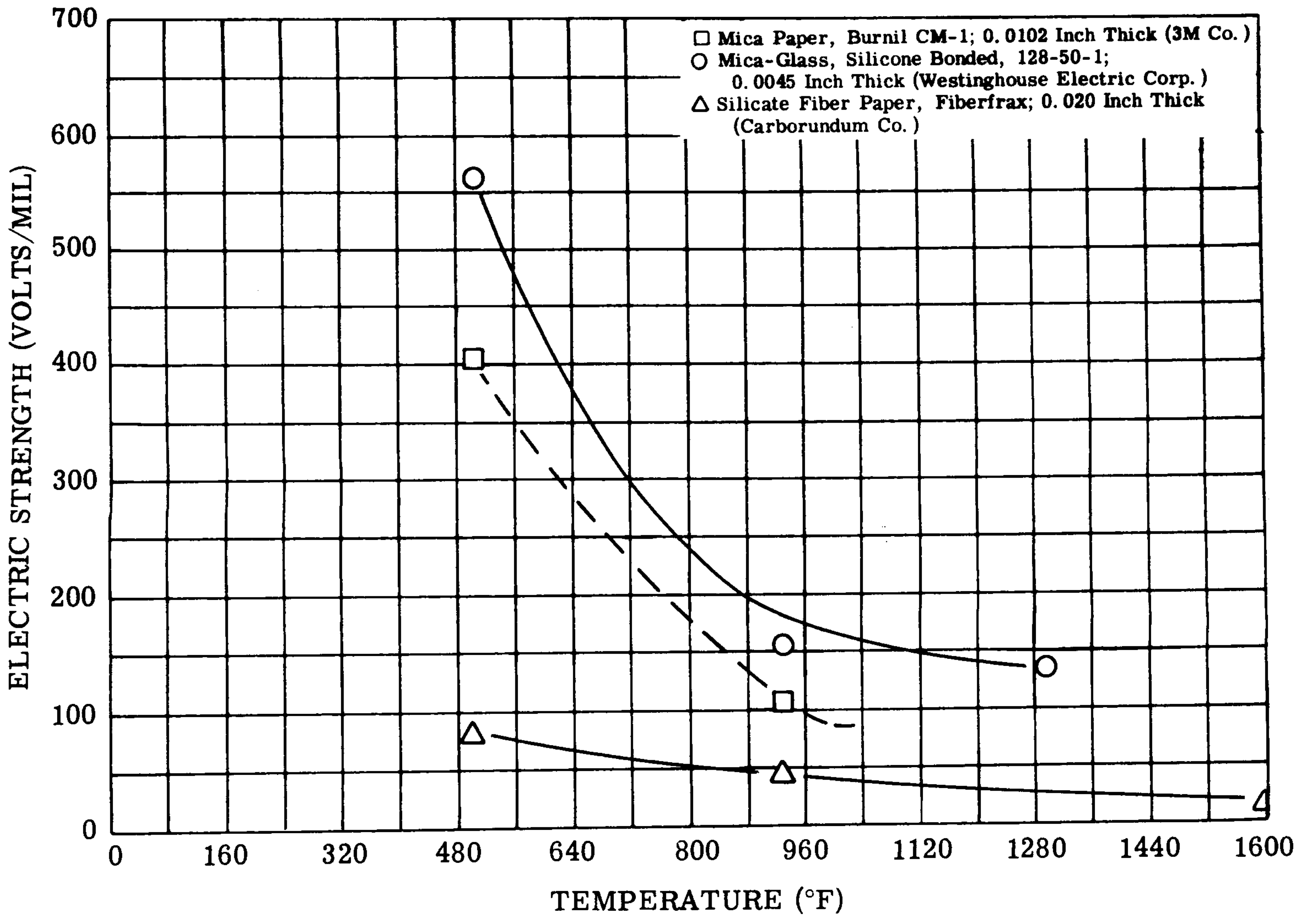


FIGURE II. B-8. D-C Electric Strength of Inorganic Flexible Sheet Insulation in Air.
(Reference: NAS 3-4162)

Figure II. B-8. Electric Strength - Inorganic Flexible Sheet Insulation

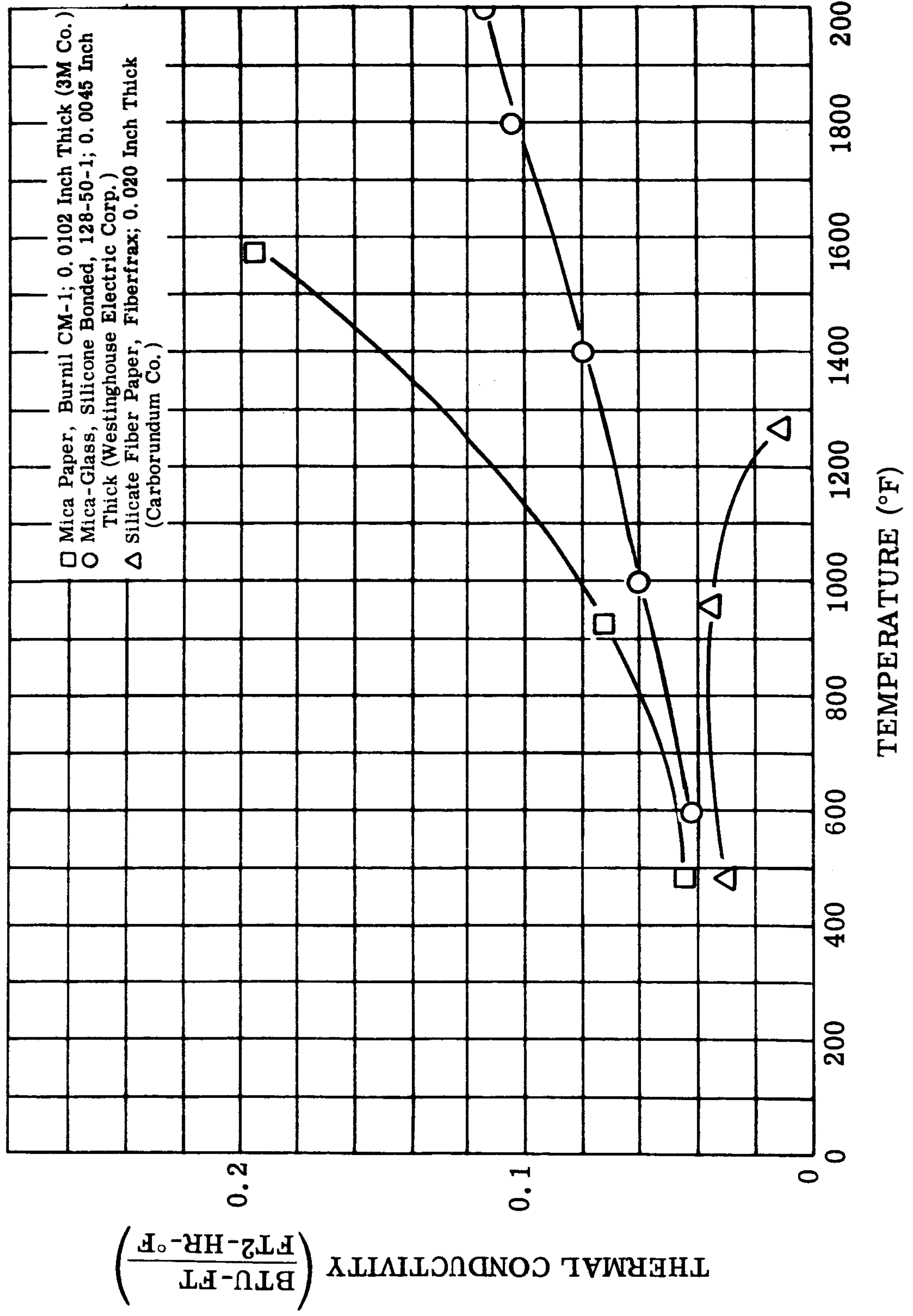


FIGURE II. B-9. Thermal Conductivity of Inorganic Flexible Sheet Insulations. (Reference: NAS 3-4162)

Figure II. B-9. Thermal Conductivity - Inorganic Flexible Sheet Insulation

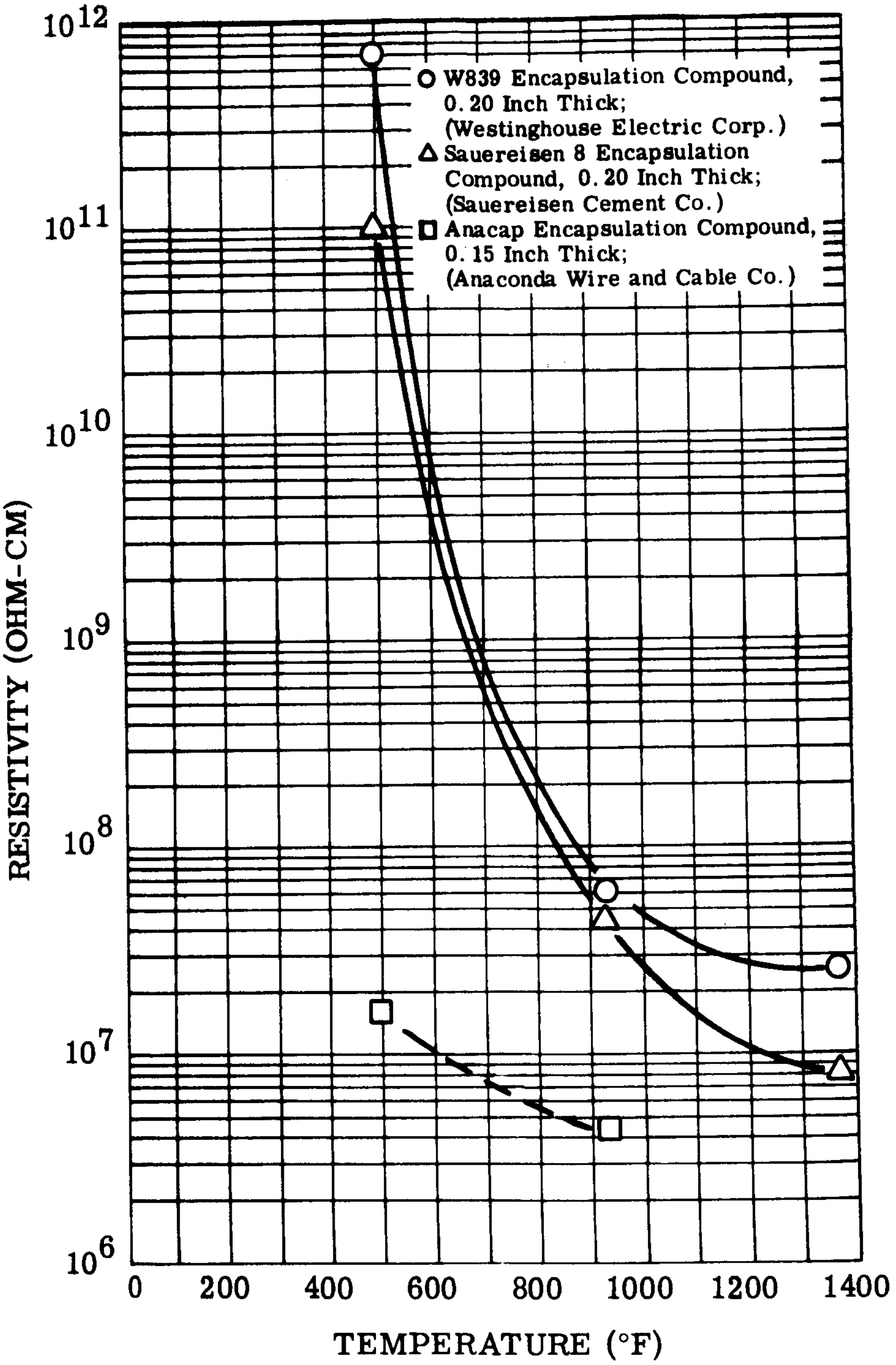


FIGURE II. B-10. D-C Volume Resistivity of Inorganic Encapsulation Compound in Air. (Reference: NAS 3-4162)

Figure II. B-10. Volume Resistivity - Inorganic Encapsulating Compound

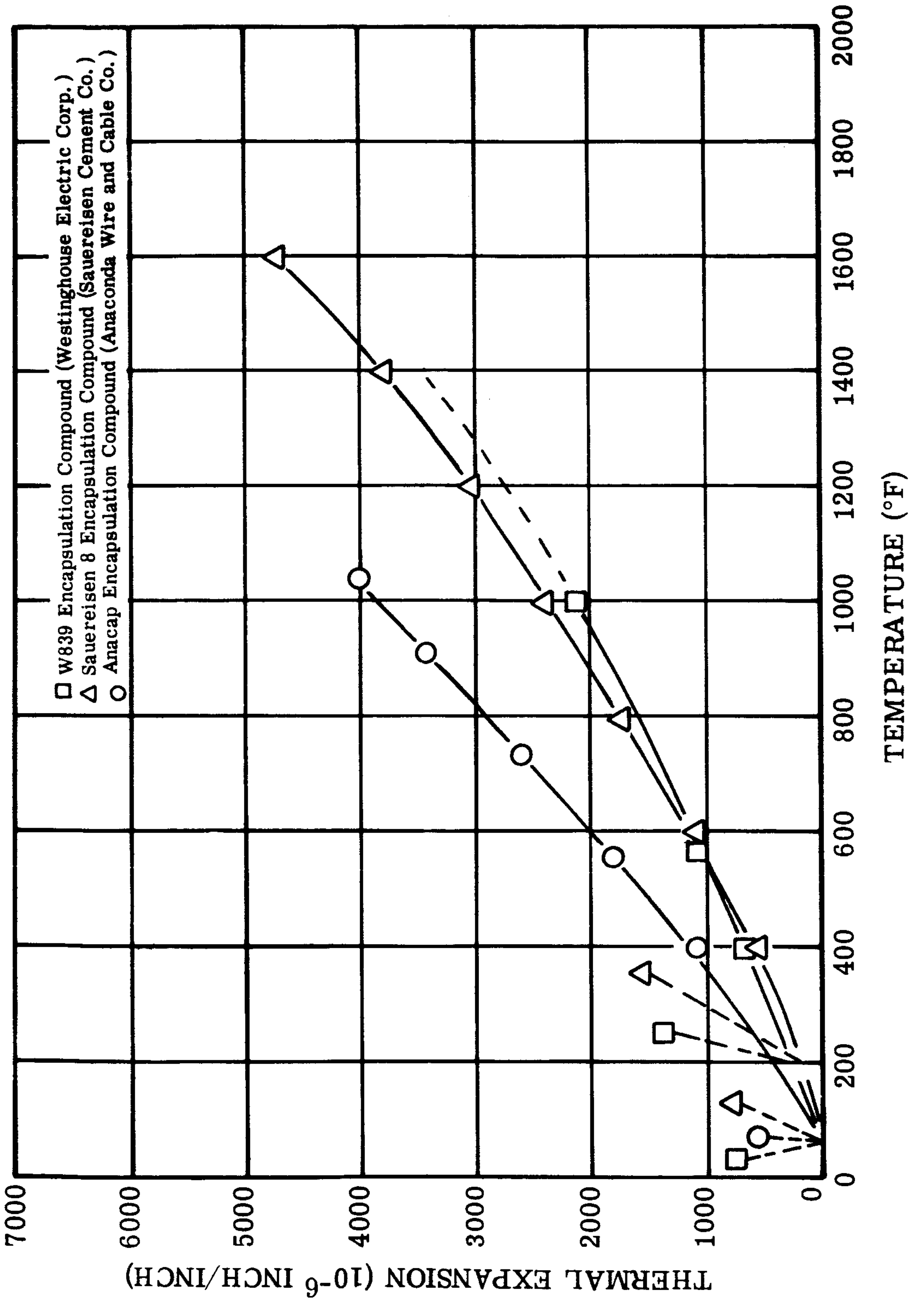


FIGURE II.B-11. Thermal Expansion - Inorganic Encapsulation Compounds. (Reference: NAS 3-4162)

Figure II. B-11. Thermal Expansion - Inorganic Encapsulating Compounds

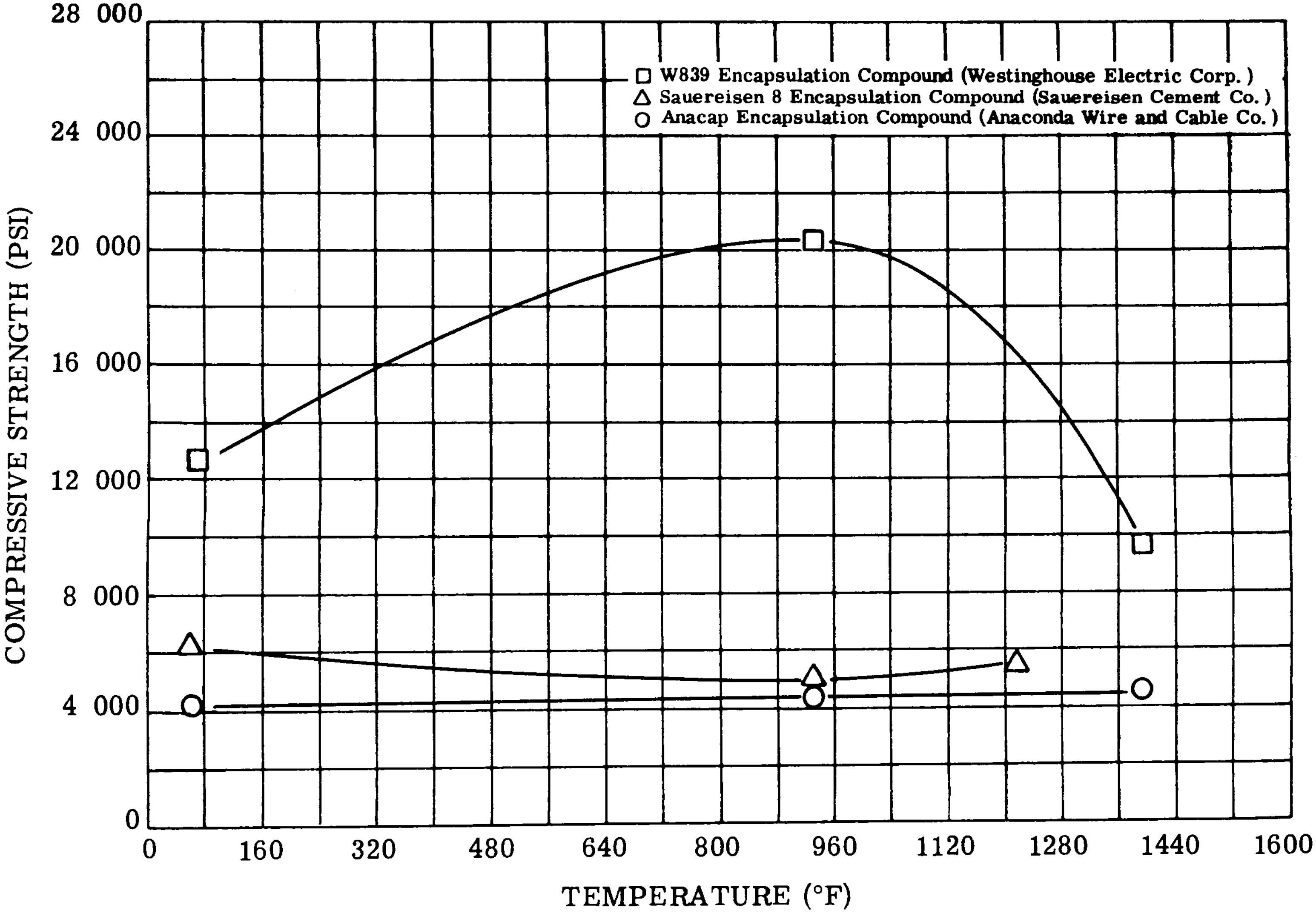


FIGURE II. B-12. Compressive Strength of Inorganic Encapsulation Compounds in Air. (Reference: NAS 3-4162)

Figure II. B-12. Compressive Strength - Encapsulant - Inorganic

2. Detail Discussion of Electrical Conductors

a. NICKEL-CLAD COPPER CONDUCTOR

This conductor consists of 'Oxygen-Free High-Conductivity' Brand Copper clad with type 'A' Nickel (99.4 percent Ni plus Co). This cladding is approximately 28 percent of the conductor area. A material properties summary for this material is located in Section IV.A.

1) Electrical Resistivity

The electrical resistivity and available stability data are summarized in Table IV.A-1 and plotted in Figure IV.A-1. These data are taken from the literature and show the material to be stable to about 1000°F. At 1112°F the resistivity increases at a significant rate. The stability data for this conductor were taken at temperature and are plotted in Figure II. B-2.

2) Thermal Expansion

The thermal expansion of nickel-clad copper wire (28 percent nickel-clad area) is linear over the temperature range 72°-1000°F, as shown in Figure IV.A-2. Total expansion over this range is 0.009 inch/inch.

3) Tensile Properties

The short-time elevated temperature tensile properties of nickel-clad copper wire are tabulated in Table IV.A-2 and are plotted in Figure IV.A-3 and IV.A-4. The 72°F, 0.2 percent offset yield strength of nickel-clad copper is only 25 percent of the ultimate tensile strength. Yield strength, however, is not affected as is the ultimate strength by the increasing test temperature, such that at 1000°F the 0.2 percent offset yield strength is over 50 percent of the ultimate strength. The plots of reduction of area and elongation, as shown in Figure IV.A-4, show the usual intermediate temperature ductility minimum. (1)

---

(1) Reid, B. J. and Greenwood, J. N. "Intergranular Cavitation in Stressed Copper Nickel Alloys". AIME Transactions, Vol. 212, No. 4, August 1958 pp. 503-507.

b. 321 STAINLESS-STEEL-CLAD SILVER CONDUCTOR

This conductor consists of fine silver (99.9% Ag)(2) clad with Aerospace quality type 321 stainless steel. This clad is approximately 28 percent of the conductor area. A material properties summary for this material is located in Section IV. B.

1) Electrical Resistivity

Electrical resistivity measurements were made on this wire during heating to and cooling from 1600°F. These data are tabulated in Table IV. B-1 and plotted in Figure IV. B-1. Figure II. B-1 compares the electrical resistivity of the various conductors tested under NAS3-4162. The resistivity of stainless-steel-clad silver is nearly linear and low to 1600°F.

Electrical resistivity measurements at room temperature of aged conductor wires are tabulated in Table IV. B-2 and plotted in Figures II. B-3 through II. B-5. The resistivity of the stainless-steel-clad silver was not affected by stability testing in air up to 2022 hours at 1000°F. This wire should be capable of operation at temperatures up to 1400°F in any atmosphere. Metallographic examination of the 1600°F aging samples revealed extensive evidence of melting, as shown by the irregular surface of the clad and the shrinkage shown in Figure II. B-13. The lower resistance of the 2000 hour sample shown in Figure II. B-5 is further evidence of an over-temperature furnace condition which caused melting on the 1000 hour conductors. The 1000 hour and 2000 hour specimens were in different furnaces. This suggests that for design purposes, the application temperature should be less than 85 percent of the melting point. Though negative, these aging data were included in this report to emphasize what may happen when operated close to the melting temperature of one of its constituants. The 1600°F test condition represented 93 percent of the absolute melting temperature.

2) Thermal Expansion

The thermal expansion of stainless-steel-clad silver conductor wires is shown in Figure IV. B-2. Expansion is linear over the temperature range 72 to 1200°F. Above 1200°F, the expansion rate decreases slightly.

---

(2) Concise Chemical and Technical Dictionary, Chemical Publishing Co., Brooklyn, N.Y. 1949.

3) Tensile Properties

The ultimate tensile strength of 321 stainless-steel-clad silver is substantially reduced with increasing temperature, while the yield strength is much less affected up to 1000°F, as shown in Figure IV.B-3. The tabulated tensile test results for temperatures to 1600°F are shown in Table IV.B-3.

The reduction of area and elongation data, plotted in Figure IV.B-4, show typical intermediate temperature ductility minimum.

c. 304 STAINLESS-STEEL-CLAD ZIRCONIUM COPPER CONDUCTOR

This conductor consists of 0.15 percent zirconium copper clad with Aerospace quality type 304 stainless steel. The clad is approximately 28 percent of the conductor area. A material properties summary for this material is located in Section IV.C.

1) Electrical Resistivity

The electrical resistivity data of 304 stainless-steel-clad zirconium copper from 72° to 1600°F are tabulated in Tables IV.C-1 through IV.C-4. Measurements were made during both heating to and cooling from 1600°F, respectively. The initial test data, shown in Figure IV.C-1, showed a discontinuity in the plot of electrical resistivity at approximately 900°F. This discontinuity is attributed to the precipitation of the zirconium from solid solution. A second test, using the same specimen resulted in a smooth curve, (as shown in Figure IV.C-2.) indicating the zirconium-copper core was in an overaged equilibrium condition as a result of heating during the first test. One resistivity specimen aged noticeably during test, as shown in Table IV.C-4. The 200°F resistivity on the heating cycle was about the same as the 150°F resistivity measured on cooling.

The 72°F electrical resistivity data taken on the aged stability test conductor specimens are listed in Table IV.C-5 and plotted in Figures II.B-3 through II.B-5. Stainless-steel-clad zirconium copper should probably not be considered for temperatures above 1200°-1300°F.

2) Thermal Expansion

The rate of expansion for stainless-steel-clad zirconium copper increases slightly during heating to 1600°F, as shown in Figure IV. C-3. The hysteresis which occurred on cooling is slight.

3) Tensile Properties

Table IV. C-6 lists the short-time, elevated-temperature tensile properties of 304 stainless-steel-clad zirconium copper conductor at temperatures to 1600°F. The ultimate tensile strength is sharply reduced at elevated temperature. However, the yield strength remains relatively constant up to 1000°F, as shown in Figure IV. C-4. The tensile ductility (Figure IV. C-5) shows the same ductility minimum observed in other conductors.

d. CUBE (f) DISPERSION-STRENGTHENED COPPER (Cu-1 volume percent-BeO) CONDUCTOR

This conductor consists of copper containing approximately 1 volume percent beryllium oxide. A material properties summary for this material is located in Section IV. D.

1) Electrical Resistivity

The electrical resistivity of cube dispersion-strengthened copper alloy to 1600°F is tabulated in Table IV. D-1 and IV. D-2. A plot of these data is shown in Figure IV. D-1. The resistivity measurements were made during both heating to and cooling from 1600°F. The two electric current carrying and two measuring lead wires were resistance welded to the specimen to assure a good connection; however, the leads separated from the specimen at about 1550°F terminating the first test. To overcome this problem for the second test, small holes (0. 020 inch diameter) were drilled through the 0. 040 inch diameter wire at the ends, the 0. 020 inch chromel lead wires inserted, and the holes peened closed.

Cube has the lowest electrical resistivity of any conductor tested. Furthermore, Cube is completely unaffected by

---

(f) Copy-righted name of Handy and Harman's dispersion-strengthened copper.

stability testing at 1000°F for 2022 hours and 1600°F for 2000 hours in argon or at 800°F in air for times up to 2000 hours. The room temperature electrical resistivity measurements of Cube wire after stability testing are tabulated in Table IV. D-3 and are plotted as a function of time in Figures II. B-3 through II. B-5.

2) Thermal Conductivity

The thermal conductivity of Cube dispersion-strengthened copper is shown in Figure IV. D-2. It shows a slight decrease in thermal conductivity with increased temperature.

3) Thermal Expansion

The thermal expansion of Cube is linear to 1300°F, as shown in Figure IV. D-3. Above 1300°F, there is a slight decrease in expansion rate on both the heating and cooling curves.

4) Tensile Properties

All Cube tensile test data are tabulated in Table IV. D-4 and plotted in Figures IV. D-4 through IV. D-7. Table IV. D-5 lists the basic data on Cube dispersion-strengthened copper as supplied by Handy and Harman. Figure IV. D-4 compares data obtained on NAS3-4162 with the data published by Handy and Harman.(g) These data are a measure of the accuracy of the published information and the apparent uniformity of the semi-commercial product.

The yield strength of Cube dispersion-strengthened copper is not materially reduced at temperatures up to 800°F, Figure IV. D-5. However, the ultimate strength decreases at a steady rate over the temperature range of 72° to 1600°F. The yield strength decreases at approximately the same rate as the ultimate above 800°F. The ductility of Cube decreases rapidly and approaches zero at 1600°F, Figure IV. D-6. Figure IV. D-7 shows that heating above 1300°F results in a stress relief anneal which causes a decrease in the room temperature tensile properties of Cube.

(g) Handy and Harman product literature (formerly called CuFo) January 1964.

5) Creep Properties

Creep test data for Cube are presented in Table IV.D-6. Figures IV.D-8, IV.D-9, and IV.D-10 are creep strain-time plots of the creep data at constant stress. A stress rupture comparison of Cube dispersion-strengthened copper and beryllium Copper No. 10 is shown in Figure IV.D-11. Until the introduction of Cube, Beryllium Copper No. 10 was the best commercially available, elevated-temperature, copper base alloy.

e. TD NICKEL CONDUCTOR

This material is a composite of nickel and two volume percent thoria. The thoria is added as a secondphase for dispersion-strengthening. A material properties summary for TD Nickel wire is located in Section IV. E.

1) Electrical Resistivity

The electrical resistivity of TD Nickel is tabulated in Table IV. E-1, and plotted in Figure IV. E-1. The data for TD Nickel resistivity showed an inflection point at approximately 600°F. This change in $\frac{d\rho}{dt}$ at about 700°F may be associated with the transition from the ferromagnetic condition to the non-magnetic state. Additional room-temperature electrical resistivity measurements of conductor wire during stability testing are tabulated in Table IV. E-2. TD Nickel was unaffected by aging at temperature to 1600°F.

2) Thermal Conductivity

The thermal conductivity of TD Nickel is plotted in Figure IV.E-2. These data were taken at temperatures to 1600°F.

3) Thermal Expansion

Thermal expansion data for TD Nickel was unavailable from its manufacturer. In use, however, the alloy has been observed to exhibit values which are 10 percent below those measured on 99.94 percent pure nickel, Figure IV. E-3.

4) Tensile Properties

The published tensile properties for TD Nickel are plotted in Figure IV. E-4. The 0.2 percent offset yield strength and ultimate tensile strength coincide at temperatures above 1550°F. These data are similar to those obtained on Cube alloy discussed in Section II. B. 2. d.

5) Creep Properties

A Larson-Miller plot of the stresses required to produce 0.1, 0.2 percent creep strain and rupture in TD Nickel are shown in Figure IV. E-5. These data are taken from the literature and represent the current state of development for DuPont's dispersion-strengthened nickel.

f. INCONEL 600-CLAD, COLUMBIUM-BARRIER, DISPERSION-STRENGTHENED COPPER CONDUCTOR

This conductor consists of dispersion-strengthened copper ("Cube") clad with Inconel 600 and a columbium diffusion barrier layer. The Inconel clad approximates 28 percent of the conductor area and the columbium, eight percent. A material properties summary for this material is located in Section IV. F.

1) Electrical Resistivity

The electrical resistivity of Inconel 600-clad, columbium barrier dispersion-strengthened copper is tabulated in Table IV. F-1 and is plotted in Figure IV. F-1. The 72°F electrical resistivity data for the stability tested conductor wires are listed in Table IV. F-2 and plotted in Figures II. B-3 through II. B-5. This conductor is recommended for use to 1400°F. The presence of silver slivers on the surface of the Cube rod could have caused the degradation observed on aging at 1600°F. No change in resistivity was observed on stability testing at 1000°F for 2022 hours. Metallographic examination of the 1600°F. samples revealed evidence of some kind of reaction which occurred between the Inconel and the columbium, as shown in Figure II. B-14. It is not known if this layer was responsible for the increased resistivity of the aged sample; however, the nickel-columbium phase diagram calls for the inter-metallic compound columbium nickelide (Ni_3Cb) which could have formed at 1600°F during aging.

2) Thermal Expansion

The thermal expansion curves for annealed Inconel 600-clad, columbium-barrier, dispersion-strengthened copper are shown in Figure IV. F-2 and are similar to the curves obtained for bare dispersion-strengthened copper.

3) Thermal Conductivity

The thermal conductivity of this material is shown in Figure IV. F-3. These data are constant from 600°F to 1472°F after attaining a value of 92.5 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-}^\circ\text{F}}$.

4) Tensile Properties

The tensile properties of Inconel 600-clad, columbium-barrier dispersion-strengthened copper are tabulated in Table IV. F-3, and plotted in Figures IV. F-4 through IV. F-5. As the test temperature increases from 72°F to 1225°F, the ultimate tensile strength decreases and converges with the 0.2 percent offset yield strength. The ductility of this material plotted in Figure IV. F-5, decreased to a constant value at temperatures above 1000°F.

g. INCONEL 600-CLAD FINE SILVER CONDUCTOR

This conductor consists of fine silver(3) (99.9% Ag) clad with Inconel 600 alloy. The Inconel clad area is approximately 28 percent of the conductors cross section. A material properties summary for this material is located in Section IV.G.

1) Electrical Resistivity

Tabulated resistivity measurements for Inconel 600-clad silver are shown in Table IV.G-1 and plotted in Figure IV.G-1. Next to Cube, this conductor has the lowest electrical resistivity of any material tested on NAS3-4162.

---

(3) Concise Chemical and Technical Dictionary, Chemical Publishing Company, Brooklyn, New York, 1947.

The high-conductivity silver core was unaffected by the alloying elements of the Inconel 600 cladding as measured after 2022 hours of stability testing at 1000°F. Data obtained from the literature (RC5), are shown in Figure IV. G-2 and show Inconel 600-clad silver capable of withstanding 1000 hours at 850°C (1562°F). Considering the data obtained on NAS3-4162 this conductor is recommended for service to 1400°-1500°F. Stability test data obtained on NAS3-4162 are presented in Table IV. G-2 and are plotted in Figures II. B-1 through II. B-5. Metallographic examination of the 1600°F aging specimens exposed evidence that some kind of reaction occurred between the Inconel and the silver as shown in Figures II. B-14 and 15. The phase diagrams of nickel-iron and chromium with silver do not explain the reaction zone. The lower resistivity of the 2000 hour specimens would definitely indicate the 500 and 1000 hour samples were over temperatured. The 2000 hour specimens were in a different furnace than the 500 and 1000 hour samples. After test, it was observed that the 500 and 1000 hour control thermocouples had deteriorated considerably. These samples may have been 150°F above the desired aging temperature. This suggests that any application should be at least 200°F below the melting point of silver (1760°F) to insure satisfactory operation.

2) Thermal Expansion

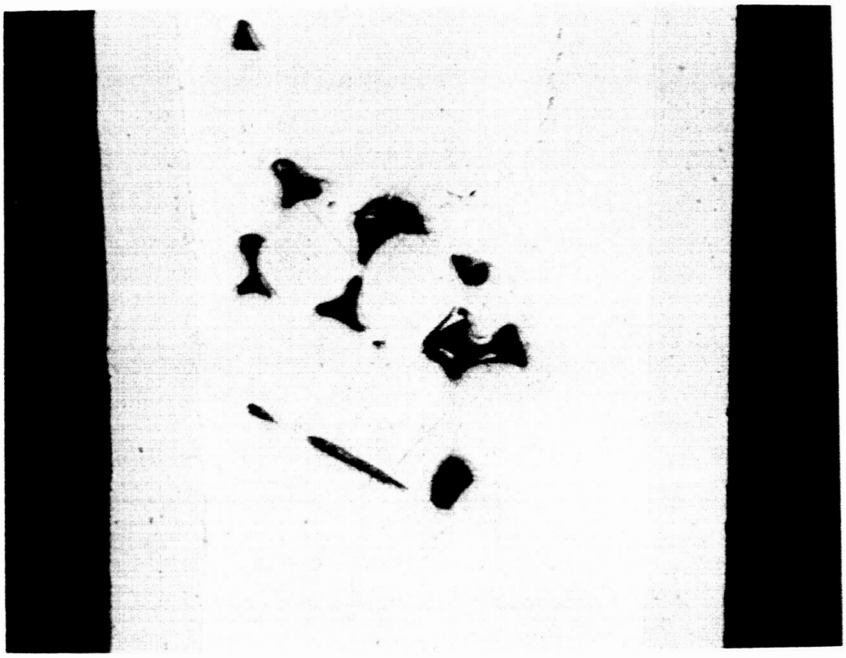
The thermal expansion of Inconel 600-clad silver is nearly linear over the temperature range 75°-1600°F. Data points taken on both heating and cooling fell nearly on the same line. These data are plotted in Figure IV. G-3.

3) Thermal Conductivity

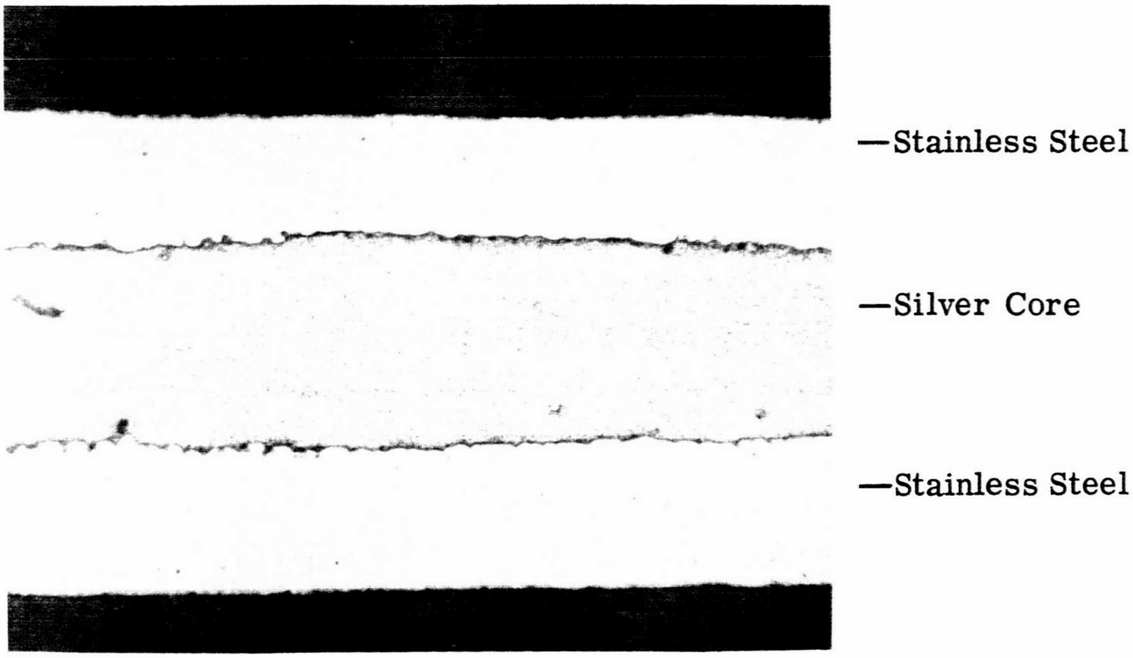
The thermal conductivity of Inconel 600-clad silver, as shown by Figure IV. G-4, decreases slightly with increasing temperature to about 1282°F.

4) Tensile Properties

Tabulated tensile test results for Inconel 600-clad silver are shown in Table I V. G-3 and plotted in Figures I V. G-5 and I V. G-6. The ultimate and yield strengths decrease with increasing temperature. Tensile ductilities, while generally good, are slightly erratic and are probably the result of slight variations in processing.

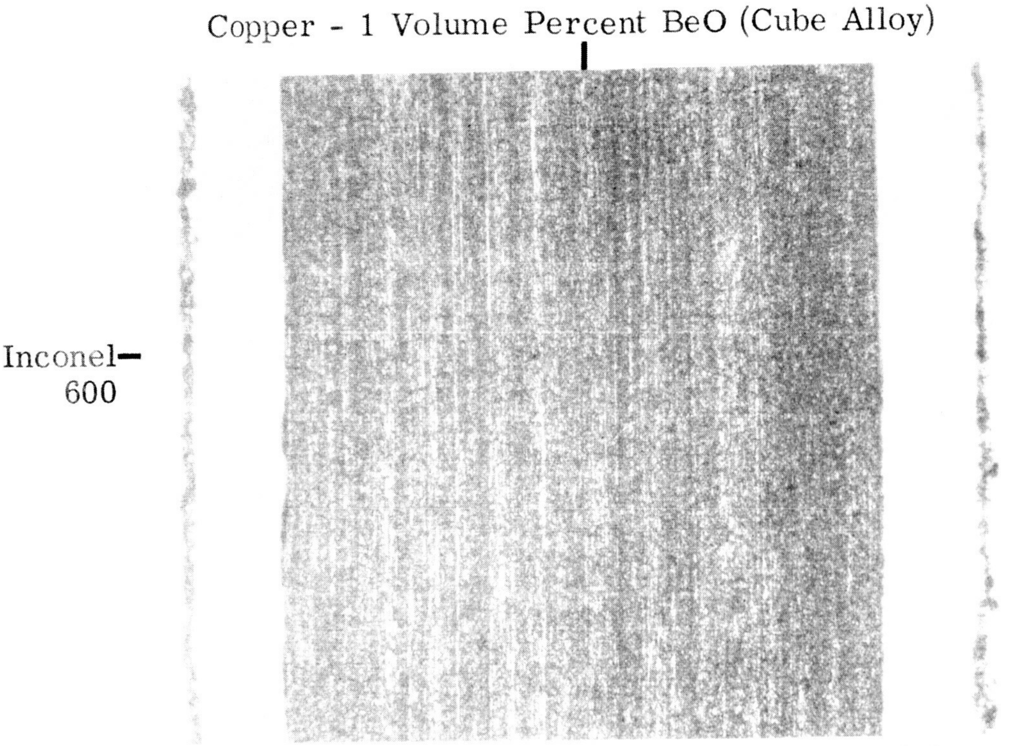


Unetched 100X

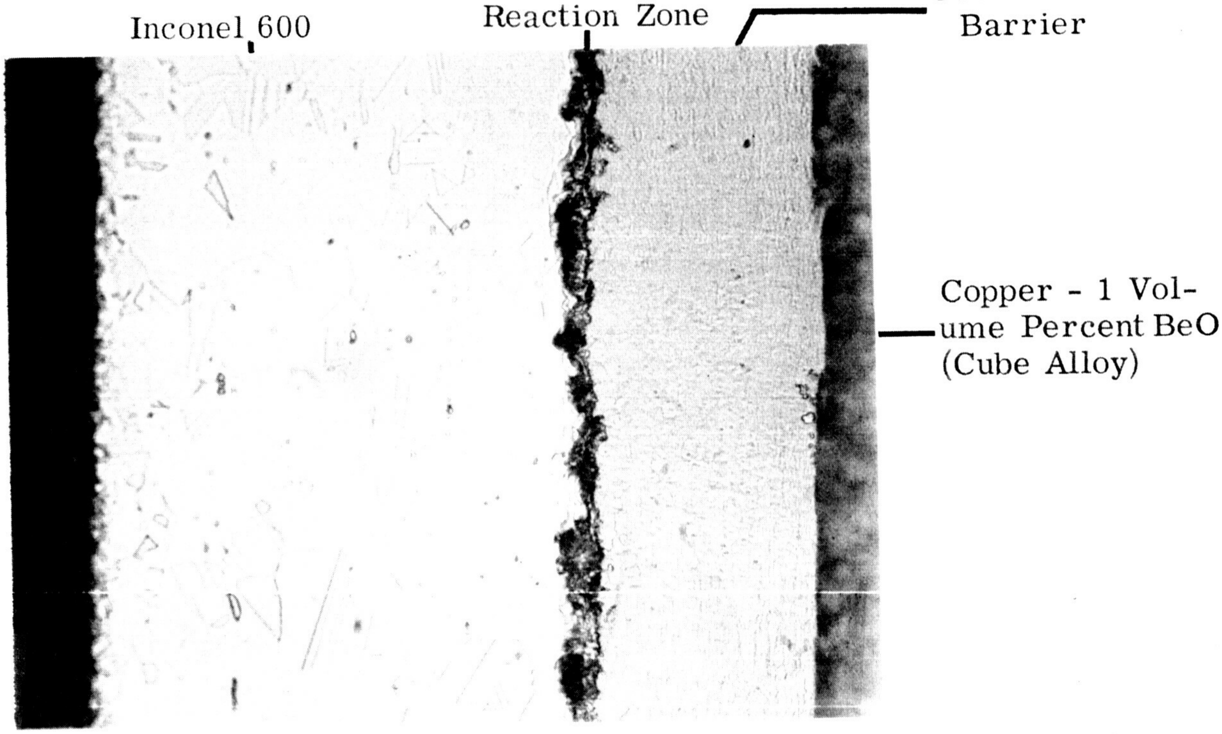


Unetched 100X

FIGURE II. B-13. Type 321 Stainless Steel-Clad Silver Wire Showing Evidence of Melting During Agings at 1600°F. Upper Micrograph Shows Shrinkage. Lower Micrograph Shows Dissolution of Clad Material.

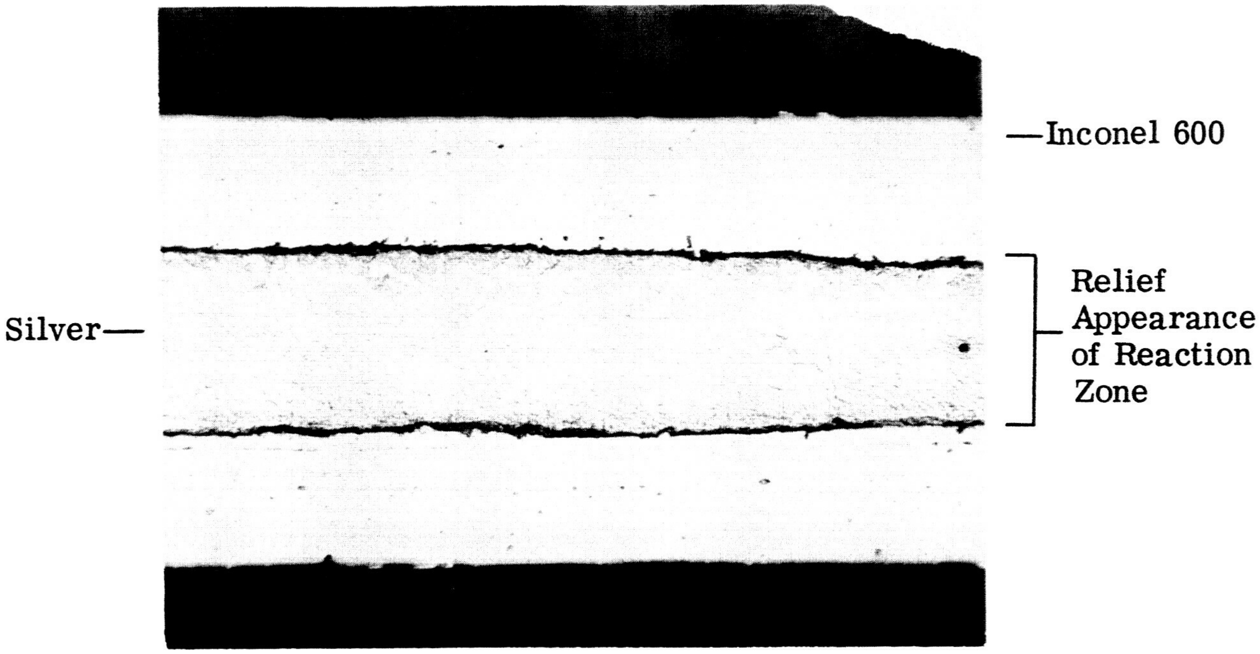


Unetched 200X

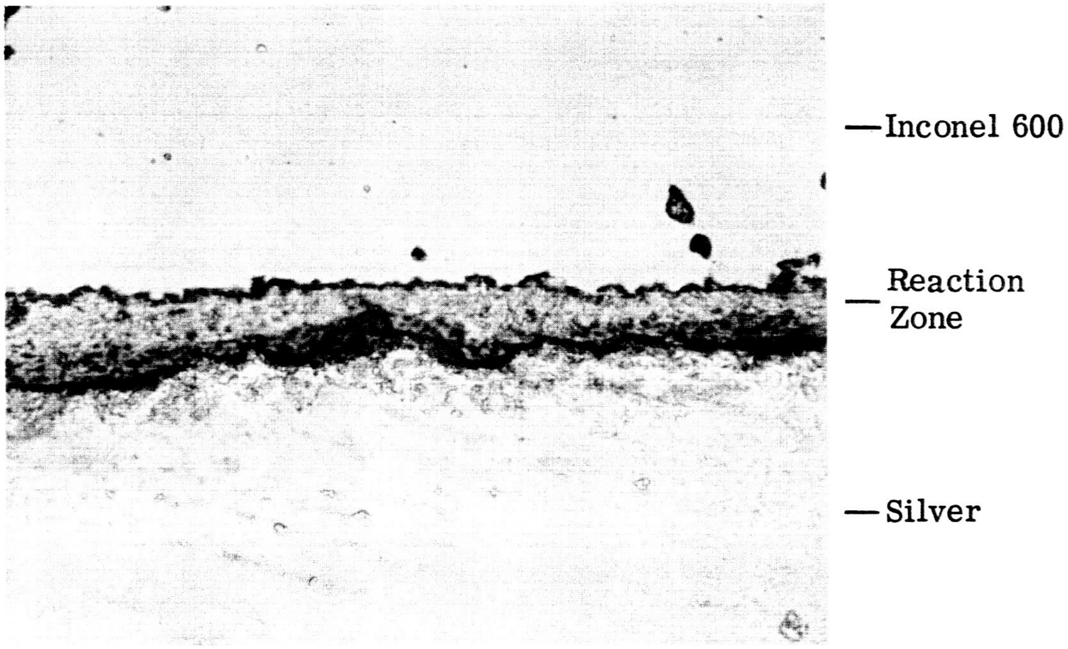


Unetched 500X

FIGURE II. B-14. Micrograph Showing Suspected Inconel 600-Columbium Reaction Zone in 1600°F Aging Specimen Using Dispersion-Strengthened Copper Core Material.



Unetched 100X



Unetched 500X

FIGURE II. B-15. Micrographs Showing the Reaction Zone in 1600°F Aging Specimen Which Occurred Between the Inconel Clad and the Fine Silver Core.

3. Detail Discussion of Electrical Insulation Materials

The following section presents discussion of the seven major forms of electrical insulation materials included in this study. Significant test results and comparisons within groups are analyzed and referenced.

a. MAGNET WIRE INSULATION

One non-refractory insulated wire was examined. It was the organic polyimide resin, Dupont ML, on electrolytic tough pitch copper. The test data summarized in Section V. A-1, indicates a superior combination of thermal stability, high electrical and mechanical strength, and environmental compatibility properties. The lower electrical strength of polyimide enamel at 3200 cycles per second may be a limitation for some designs. Early production lots of ML with high-weight loss, caused sporadic electrical problems until the condition was discovered and related to electrical properties. Nearly all wire coaters now control this factor by tests for either weight loss, dissipation factor, or both. Typical recommended values are two percent maximum weight loss at 465°F and a dissipation factor at 77°F and 100 cps of 0. 80. Thermal life tests indicate that polyimide enamel is suitable for over 20, 000 hour life at 400°F. The very low weight loss, 0. 06 percent, determined at 482°F and 10^{-5} torr for a 24 hour test period, is a strong indication of this resin's suitability for long term space operation in vacuum.

The refractory-insulated magnet wires which were examined in this program are listed below together with their property summary section numbers.

Section V.A.2 Anacote (Anaconda Wire and Cable Company)
Section V.A.3 Anadur (Anaconda Wire and Cable Company)
Section V.A.4 Ceramic-Eze (Phelps-Dodge Copper Products Co.)
Section V.A.5 R2554B (Westinghouse Electric Corporation)

Three approaches to the wire insulation problem are represented in this group. Anacote and R2554B are organic-resin enamels filled with a mixture of glass frit and refractory oxides. Anadur is a combination of served fiber glass, fusible glass frit, and refractory oxides and sealed with an organic resin binder as a winding aid. Ceramic-Eze is a fused coating composed of refractory oxides in a glass enamel and overcoated with an organic polymer layer.

The resin components of Anacote and R2554B improve the handling characteristics and are driven off by firing after winding. The glass frit is then fused by further firing for approximately 15 minutes at 1250°F to 1300°F. Both of these magnet wires are highly dependent upon proper selection of a well-matched encapsulation material. Compatibility tests of this type were not within the scope of this program. It was noted that Anacote was difficult to wind when handled below 100°F. Cut-through testing also indicated that pressure concentrations on the unfired conductor was a potential source of difficulty.

Magnet wire, R2554B, is suitable for operation up to approximately 1000°F with an encapsulation compound. Low-voltage applications are possible at temperatures up to 1200°F as revealed by examination of electrical properties presented in Section V. A. 5. The use of supplemental electrical phase separation is necessary in the 1000 to 1200°F range of operation and recommended for lower temperatures as well.

Anadur magnet wire, as reported in Section V. A. 3 is the most durable and most heat resistant insulated wire examined in this program. The glass fibers resist cut-through and abrasion damage much better than do the filled, organic-enamel coated conductors. The additional insulation thickness offers superior total electric strength. Test results indicate that, in proper configuration, Anadur would offer long life possibilities at 1200°F in inert gas or vacuum. Operational life in air at 1200°F would be dependent upon the oxidation resistance of the electrical conductor material.

Ceramic-Eze magnet wire is a fused glass coating containing refractory oxides. It is a dense, thin film with good winding characteristics. As reported in Section V. A. 4 and Figure V. A. 4-2, its total electric strength decreases sharply as the temperature approaches 1100°F. Adhesion tests resulted in crazing of the film but it is important to note that no spalling of the coating was observed.

b. LEAD WIRE

1) Glass Fiber - Asbestos

The lead wire whose properties are reported in Section V. B. 1 bears an insulation covering suitable for operation at 1100°F. Insulation life testing at 1292 and 1600°F was discontinued because of early failure of the nickel-clad copper conductor. It has been hoped that the conductor, while degrading because of diffusion of cladding, would maintain sufficient integrity to permit insulation tests; however, all test specimens developed open circuits within 200 hours because of cladding. A more stable conductor should be used with this insulation if operating temperatures over 1000°F are anticipated. The abrasion resistance of the unfired lead wire is good for a material intended for operation at temperatures in excess of 800°F.

2) Glass Fiber - Mica

This lead wire, whose properties are reported in Section V. B. 2, is suitable for long time operation at 1100°F. A tendency for embrittlement of the glass fiber when operated over 932°F is a deficiency which should be considered.

c. SHEET INSULATION

1) Polyimide Film

The flexible polyimide film known as H-Film is a durable easily handled material. It is suitable as electrical insulation for more than 10,000 hours at 400°F in air. It has good radiation resistance and outstanding chemical resistance. As reported in Section V.C.1, good electric strength values are maintained up to 500°F. While it is assumed designers of electric machines will not intentionally permit abrasive motion of components to occur, it has been encountered. This film has exceptional resistance to abrasive damage and cut-through and maintains much of its original electric strength.

2) Polyimide Glass

The summary presented in Section V.C.2 describes two grades of polyimide resin treated glass which have been used in aerospace generators. The resin components in both materials are the same but the glass pre-treatments are different. Grade 6508 used burned-off glass fabric which permits deep penetration of resin solution. Polymerization then produces a dense structure. Grade 6518 used a glass fabric treated with a heat-resistant resin which prevents complete penetration of the polyimide. After curing of the polyimide, the glass fibers are able to move slightly without breaking of the resin bonds. The abrasion test data in the summary demonstrates the increased durability of more flexible material (Grade 6518). Elmendorf tear strength tests offer further confirmation as follows:

Grade	Tear Strength
6508	1900 x 1650 (grams-wrap x filler)
6518	2600 x 2000 (grams-wrap x filler)

The value presented for 6518 is a minimum established by the manufacturer for quality control purposes.

Insulation life tests were performed only on the 6508 grade because the more flexible material was not available in time to be included. Examination of the electric properties indicates that the newer grade will perform in a superior manner in the temperature range of 400 to 500°F when installed in wound apparatus. The compatibility properties are outstanding for an organic insulating material. These materials would be suitable for operation at 400°F for more than 10,000 hours.

3) Mica - Glass - Silicone - Resin Bonded

The summary in Section V.C.3 reports the properties collected on the silicone-resin-bonded glass and mica-sheet insulation. Insulation life data indicate that use of this combination should be limited to below 1000°F. Mechanical properties, particularly cut-through performance, demonstrates the inherent difficulties in applying these forms of insulation. Compatible encapsulation compounds, which restrain internal shifting of components, are necessary for maximum equipment life expectancy. When the insulation is in place and fired with a compatible encapsulant, it proves to be durable and well bonded. The degree of winding difficulty will dictate the selection of sheet insulation based on a trade-off of handling properties versus fired-in-place characteristics.

4) Synthetic Mica Paper

Synthetic mica paper, known as Burnil CM-1 and described in Section V.C.4, is thermally stable to 1600°F. However, high-temperature electrical properties limit its application to about 1200°F. If winding operations impose more than very low stresses on the material then operation should be limited to 1000°F since the material is weak. The high degree of abrasion resistance noted in the summary is exceptional for inorganic flexible materials.

5) Silicate Fiber Paper

Silicate fiber paper, although generally used as a thermal insulation, has fair electrical properties up to 1300°F as reported in Section V.C.5. Although reported to be thermally stable to 2300°F, it would not be a satisfactory primary electrical insulation above 1300°F because of basic changes in the material. The extremely low tensile strength of this material is reported in the material properties section and would need careful handling in any application.

d. RIGID INSULATION

1) Laminated Asbestos - Boron - Phosphate Bonded

This asbestos laminate, 92M, showed some improvement in insulation resistance with time at 932°F as reported in Section V.D.1. This is attributed to gradual loss of water from the asbestos which would tend to improve electrical performance. Essentially all of the water in chrysotile asbestos is lost after heating at 1112°F for 1000 hours and no appreciable change in insulation resistance was expected or found at this temperature. This is a mechanically strong material and with proper design is useful as an insulating structural member. Its weight-loss characteristics indicate the need for proper vacuum de-gassing prior to operation in hard vacuum.

2) Laminated Diphenyl Oxide - Glass

This laminate is a stable laminate for high-temperature exposure. Electrical properties as reported in Section V. D. 2 are excellent. The dielectric constant is uninfluenced by temperature at both 400 and 3200 cycles per second up to 482°F. The volume resistivity does not decrease rapidly and electric strength is maintained. The power factor increases somewhat with temperature, 2.2 percent at room temperature to 6.98 percent at 482°F (400 cycles) but this change is small and not critical to aerospace generator design. As shown in Figure V.D.2-8, the flexural strength at 350°F is about 15 percent lower than at room temperature and, while aging at 500°F reduces its strength, the reduction is not drastic and the laminates are still sound. The long-life thermal capability of the diphenyl oxide laminate is 450°F and temperatures of 550°F can be experienced satisfactorily for short times.

3) Laminated Epoxy - Glass

The dielectric constant of H-2497 epoxy-glass laminate increases slightly with temperature from about five to seven at 400 cycles and the power factor also increases as reported in Section V.D.3. At 400 cycles and 482°F, the power factor is 42 percent while at the same temperature and 3200 cycles it is 12.0percent. Volume resistivity decreases in typical fashion with increasing temperature. The electric strength, however, was only mildly influenced by temperature as shown in Figure V.D.3-6. The thermal expansion curve indicates that some additional curing was experienced up to 350°F. This material had a high-impact strength. The decrease in flexural strength with temperature was moderate. The material is capable of long operational life at 300°F.

4) Laminated Phenolic - Glass

Some properties of the phenolic-glass laminate, 91-LD, are reported in Section V.D.4. The very poor arc resistance properties of this laminate as reported in Section V.D.4, are strong indication that it should not be used as a primary electrical insulation. Phenolic laminations are used largely as structural members. The porosity of the laminates reduces the useful critical electric properties. For example, the electric strength of the 91-LD is 350 volts per mil at room temperature. The porosity is also shown by a water absorption of 1/2 percent. Mechanical properties are maintained at temperatures up to 500°F. The maximum temperature capability for long life of this laminate is considered to be 400°F with excursions to 450°F. The laminate should be considered primarily for structural purposes.

5) Laminated Polybenzimidazole - Glass

Some properties of polybenzimidazole - glass laminate, Imidite 1850, are reported in Section V.D.5. The dielectric constant decreases only slightly with temperature up to 600°F. Over this same range, the dissipation factor increases slightly. The flexural properties of Imidite were measured, which revealed that the laminate degrades rapidly at 600°F having little strength left after 250 hours at temperature. It would appear that the maximum temperature for Imidite is about 450°F.

6) Laminated Polyimide - Glass

This polyimide - glass is the most thermally stable organic laminated material studied in this project. The properties are reported in Section V.D.6. The electrical properties, interpolated at 200 and 250°F, are similar to diphenyloxide glass except the resistivities which are higher at all temperatures and frequencies. The dielectric constant is very stable. The tendency for a small decrease indicates some additional curing is taking place. In like fashion, the power factor is little influenced by increasing temperature. For example, at 400 cycles, the power factor increased from 0.168 percent at room temperature to only 1.5 percent at 482°F. Electric strength (d-c) shows a small decrease with temperature and at 400 and 3200 cycles there is virtually no change up to 482°F.

The physical properties of this material are equally good. Examination of the thermal expansion curve indicates that some additional curing of the specimen took place while the specimen was heated to 600°F. The samples were tested for physical properties at higher temperature (600°F) than any of the other laminates. It can be noted at 600°F, once the original decrease in flexural strength from room temperature values has occurred, little further aging change occurs up to 1500 hours.

This material can be used for structural and electrical insulation purposes at 600°F.

7) Laminated - Mica

The mica laminate, GE78300, has a slightly better insulation resistance than 92M at 1112°F as reported in Section V.D.7. This material even at 1600°F shows good insulation resistance. The wide variation in the insulation resistance data at 1600°F is attributed to the deterioration and distortion of the electrodes during the aging. The furnace was shut down after the 800 hour tests and the electrodes removed and examined. Aging was continued but the necessity of new electrodes was evident.

New gold foil electrodes were put in place for determination of the 1000 hour values. The thousand hour values are considered to be more accurate than the intermediate figures. Vacuum weight loss data show that operation at 932°F should be satisfactory. Operation at 1100°F may prove satisfactory but will require additional confirmatory tests.

e. RIGID INSULATION - MOLDED OR PRESSED

1) Alumina, 99.5 Percent

Material properties on 99.5 percent alumina are summarized in Section V.E.1. It should be noted that the only properties reported for this and the other grades of alumina and beryllia are those for which the composition and density were known.

Based on the similarity of the reported electrical properties of 99 percent and 99.5 percent alumina bodies, the use of this alumina grade can be recommended for reliable electrical insulation at temperatures up to 1600°F. The best electrical and mechanical properties are obtained from hot pressed shapes, but plasma sprayed material can also be effectively used in many configurations. As described in Section II. B.1.b, thermophysical, electrical, and mechanical properties are dependent upon contaminants and thermal history of the fired body. The higher-purity aluminas, 99 percent and 99.5 percent are recommended for use especially in the 1200 to 1600°F range. This purity level (99.5 percent) has the best chemical resistance to the alkali metals of the alumina grades included in this report, and under this exposure should be limited to a maximum of 1000°F.

2) Alumina, 99 Percent

The material properties of 99 percent alumina are summarized in Section V.D.2. Examination of the properties indicate that this grade of alumina as well as the 99.5 percent body could be best utilized in the 1200 to 1600°F temperature range, and where good mechanical strength is needed. Detailed discussion of effects of purity and density upon material properties are presented in Section II. B.1.b.

3) Alumina, 94 Percent

Material properties presented in Section V.E.3, show that this grade of alumina is best used as an electrical ceramic at temperatures up to 1200°F. Both mechanical and electrical properties begin to drop in value in the 1200°F region because of the relatively large proportion of a glassy phase. Alumina, 94 percent purity, is convenient for many applications where a dense, easily metallized body is needed. Examples of these applications for 1000°F and below are slot wedges, terminals, bushings, feedthroughs, and printed circuit boards. A comparison of the effects of purity levels is presented in Section II. B. 1. b of this report.

4) Alumina, 99.8 Percent, 0.25 MgO

The materials properties of this magnesium oxide modified alumina are reported in Section V.E.4. This body, known as Lucalox, has been used in contact with alkali metals and also as insulating supports in electronic tubes. It is expected to be satisfactory as a primary electrical insulation at elevated temperatures including 1600°F. Use with alkali metal systems reduces its capability to the 1000-1200°F range.

5) Beryllia, 99.8 Percent

As reported in Section V.E.5, the material properties show that beryllia can be used as an electrical insulation at all temperatures (up to 1600°F) considered in this study. The chemical resistance of the beryllia grade, including that to alkali metals, is outstanding. The mechanical strength is less than that of the high-purity, high-density alumina, but care in component design can often compensate for the lower value. One of the most useful properties of high-purity beryllia is the very high thermal conductivity values. It should be noted that lower-purity beryllia compositions do not possess this exceptional characteristic.

6) Epoxy Premix

Material properties of the glass fiber-filled epoxy molding are summarized in Section V.E.6. The physical properties were measured at 300°F. At this temperature the flexural and compressive properties were severly reduced. Aging at 300°F for 1000 hours did not substantially change the flexural strength from its initially low 200°F value.

The high impact strength (30 foot pounds per inch notch) makes the material attractive for applications demanding a tough material at moderate temperatures.

Complete tests were not performed on this compound because of limitations in testing time of this program and the need for selection of those materials best suited to space electric power generation. Tests of organic resin based compositions were generally reduced because related design studies had indicated the need for more thermally stable materials.

7) Polyester Premix

The materials data for the glass-filled polyester molding compound are presented in Section V.E.7. The electrical properties determined in this program indicate that the compound is suitable for long-term use at temperatures up to 300°F and frequencies up to 400 cps. Operation at frequencies up to 3200 cps, depending upon design configurations, may be limited to as low as 250°F.

The electrical properties shown in the summary Section V.E.7 and Figures V.E.7-3 through V.E.7-8 indicate that a second order transition of the resin structure occurs in the temperature range of about 280 to 325°F. Short-time operation of several hundred hours at 400 cps and below may be suitable at 400°F if voltage stresses are moderate.

Substantial reductions were noted in flexural strength modulus, and compressive strength at 300°F. Very small additional strength increases occurred as a result of aging up to 1000 hours. These changes are attributed to the gradual loss of short polymer molecular structures by cross-linking and oxidation.

8) Polyimide

The properties which are reported in Section V.E.8, were collected from correspondence and publications of the manufacturer. Because of the completeness of the manufacturer's evaluation and the close correlation of test results of other polyimide forms evaluated on this program, it was decided that no further tests would be conducted. The material is the most thermally stable organic molding material considered on NAS3-4162. There is little change in dielectric constant with increasing temperature. Volume resistivity is high as may be noted in data reported for the same basic resin in Section V.C.1. The mechanical properties show it to be a high-strength organic with definite structural application potential. The electric strength of one mil thick material was recently reported by the manufacturer to be dependent on temperature in the following manner.

Temperature (°F)	Electric Strength (kilovolts)
100	6.9
200	6.4
300	5.9
400	5.4
500	4.8

The resin exhibits very good chemical resistance and is well suited for insulation of oil-cooled generators and other devices.

f. ENCAPSULATION COMPOUNDS

1) Anacap

Materials data is reported for the compound Anacap, in Section V. F. 1. Because of high shrinkage, sample preparation was very difficult. Excessive cracking on repeated attemps to fabricate thermal conductivity specimens resulted in abandoning the determination. The handling characteristics of Anacap indicate that it is most suitable as a coating composition. The electrical properties which were determined suggested that the maximum operating temperature under electrical stress be limited to approximately 900 to 1000° F.

Vacuum weight loss study indicates that the material may be suitable with preliminary out-gassing for operation in hard vacuum at temperatures up to 1200° F. This conclusion assumes adequate design considerations be given to mechanical and electrical properties of the compound.

2) Epoxy

Materials data on this compound is presented in Section V. F. 2. This material is highly filled with a mineral filler and is thus very rigid. Polymerization shrinkage of 1. 7 percent by volume was recorded. The material failed on the first cycle when subjected to the hex washer test of 3M over the temperature range of 75° F to 300° F and back to 75° F. Flexible epoxies would be expected to pass at least three such cycles.

The electrical properties demonstrated the typical epoxy reaction to elevated temperatures. However, because of the anhydride hardener and large proportion of mineral filler, the electrical properties do not show seriously detrimental changes until about 400° F. The vacuum weight loss is typical for an organic material. If vacuum performance of this compound would be an important factor in a particular design, then the operating temperature would be restricted to less than 300° F.

3) Sauereisen 8

Materials properties for the refractory compound, Sauereisen 8, are reported in Section V.F.3. The electrical properties indicate that this compound could be used satisfactorily at temperatures up to 1400°F. The mechanical properties are not as high as the other two compounds on this program but its relative ease of application is an advantage. The coefficient of thermal expansion offers a fairly good degree of compatibility with many proposed winding configurations. Vacuum weight-loss tests at 932°F and 1382°F indicate that vacuum pre-treatment of insulated assemblies would be required for satisfactory operation. With pre-treatment, it is anticipated that this material could be used in temperatures as high as 1100 to 1200°F.

4) Silicone Foam

The material properties for silicone foam, XR5017, are summarized in Section V.F.4. This encapsulating compound is little influenced by temperatures up to 500°F.

Dielectric constant decreased with temperature and the same is true of electric strength and volume resistivity.

The weight loss of the foam in vacuum was high at 400°F. The high weight-loss value is partially explained by the large surface area (not determined) of the very porous foam. The reported weight loss value is based on apparent surface area. This foam could be used up to 500°F if out-gassing is not a detriment to the function of the device. If the out-gassing products are harmful to a device operating in vacuum, then this foam should be limited to 300°F and then only with caution.

5) Urethane Foam

The materials properties are presented in Section V.F.5. The exact material for which this data applies was withdrawn from the market late in the program. A composition has been announced which is reported by the succeeding manufacturer to be essentially the same as this material.

No further evaluation was performed because of the timing of this substitution. The dielectric constant remains steady up to 400°F and the compressive strength is reduced only 17 percent at 500°F. It would appear that this foam could be used up to 400°F for low frequency operation.

6) W839

The material properties for W839 compound are found in Section V. F. 6. The electrical properties reported show that this material may be used at temperatures up to 1200°F. The thermal expansion data reported in the Figure V. F. 6-2 shows a volumetric change on heating this material from 1000°F to 1400°F. This indicates that the material should be heated above the operating temperature of the device prior to use if uniform reversible expansion is necessary.

The high physical strength of this compound makes it desirable for applications where improved mechanical strength is required. The pot life of this compound is more than twenty-four hours and is a significant advantage if application is over an extended period of time, as in complex windings. Vacuum weight-loss values indicate that some space applications will require a vacuum-bake pre-treatment of this compound. If out-gassing is a problem of a particular device, then this compound, as other similar porous compounds, may well require a limitation of about 1000°F.

g. INTERLAMINAR INSULATION

Three interlaminar insulation coatings were examined in the program. The coatings were aluminum orthophosphate (h) (Alkophos), mica aluminum orthosphosphate bentonite (i) (MAB), and M305 glass (i) and were applied to 0.012 inch thick Cubex magnetic alloy. The samples were prepared as described below.

(h) Monsanto Chemical Company
(i) Westinghouse Electric Corporation

1) Sample Preparation

a) Aluminum Orthophosphate (Alkophos)

Two coats of Alkophos were placed on 120 pieces measuring 6 x 6 inches of 12 mil Cubex magnetic alloy. Coatings were applied to the pieces by conventional rubber roll applicators and cured at approximately 400°C. The coating thickness was 0.11 to 0.15 mils per side total. The insulation solution consisted of 600 milliliters Alkophos C, 600 milliliters H_2O, and 1/2 percent wetting agent.

b) Aluminum Orthophosphate Plus Mica Plus Bentonite (MAB)

The procedure for coating with MAB was identical with the above except that the coating thickness ranged from 0.16 to 0.20 mils per side total. The insulation solution was composed of 1200 milliliters H_2O, 300 milliliters Alkophos, 50 grams of KWK Volclay bentonite (j), and 200 grams of minus 300 mesh mica.

c) M305 Glass

The glass coatings consisted of a modified borosilicate glass identified as M305. Before coating, the panels were degreased, lightly etched, and nickel flashed (approximately 0.05 gram/ft^2).

The Cubex alloy pieces were coated by dipping into a slip which consisted of a mixture of the finely ground frit and an alcohol vehicle. The dried and unfired coated pieces were then inserted into a preheated furnace at 1800°F and held for about 25 seconds. Thickness of the coating was approximately 0.5 mils per side.

(j) American Colloid Company

2) Aging Program

Multiple specimens were aged in nitrogen for time periods up to 1000 hours and temperatures up to 1400°F. Aging was conducted in an annealing furnace with the nitrogen supply maintained at 99.99 percent purity, -46°F dew point, and gas flow of 100 cubic feet per hour. Table II. B-2. presents the specimen history of the three coating systems.

3) Insulation Test Methods

Two methods of measuring insulation resistance were used in this evaluation. The first was based on 100 square centimeter test area. The second method used a two inch diameter electrode.

The first type of interlaminar resistance tests were made by placing two pieces back-to-back between two 100 cm^2 electrodes at 150 psi. Resistance in ohms was measured across the 100 cm^2 area by connecting each lead of a conventional ohmmeter to a bared corner of the top and bottom laminations. Temperature of the pieces was increased from room temperature to 1100°F by an auto-transformer controlled 500 watt heater enclosed in the upper and lower electrodes. These also contained two thermocouples for reading temperature. Edges of the test panels were insulated from each other by placing glass tape over the burrs and between the laminations outside the test heads. Resistance readings were taken at 100°F intervals to 1100°F. Extracted data are presented in Table II. B-3. In testing the various specimens, initial test temperature was not always 77°F because excessive time would be required to lower electrode temperature to this value from 1100°F of the preceding test. In most cases, the magnitude of the insulation value was sufficiently high at 200°F to warrant starting at this higher temperature.

TABLE II.B-2. Outline of Interlaminar Insulation Coating Aging Program

Aging Treatment	Number of Specimens Aluminum Orthophosphate (a)	Number of Specimens Aluminum Orthophosphate Plus Mica Plus Bentonite (a)	Number of Specimens M305 Glass (a)
As Coated	5	5	2
Aged 100 hr at 800°F, N_2	5	5	2
Aged 6 hr at 1100°F, N_2	5	5	2
Aged 24 hr at 1100°F, N_2	5	5	2
Aged 96 hr at 1100°F, N_2	5	5	2
Aged 1000 hr at 1100°F, N_2	3	3	2
Aged 1/2 hr at 1400°F, N_2	5	5	2
Aged 1 hr at 1400°F, N_2	5	5	None
Aged 2 hr at 1400°F, N_2	5	5	None
Aged 4 hr at 1400°F, N_2	5	5	None
Aged 8 hr at 1400°F, N_2	5	5	2
Aged 24 hr at 1400°F, N_2	5	5	None
Aged 96 hr at 1400°F, N_2	5	5	2
Aged 1000 hr at 1400°F, Argon	3	3	2

(a) - All coatings were applied to stress-relief-annealed Cubex magnetic alloy, 0.012 inch thick.

(Reference: NAS 3-4162 and recent unpublished Westinghouse Data)

TABLE II. B-3. Summary of Insulation Resistance of Interlaminar Insulations at 100°F and 1100°F Before and After 100 hours Aging at 800°F, 1100°F, and 1400°F in Nitrogen

Condition	Coating					
	Aluminum Orthophosphate (Thickness; 0.13 mil/side) Test Temperature		Aluminum Orthophosphate Plus Mica Plus Bentonite (Thickness; 0.18 mil/side) Test Temperature		Glass (Thickness; 0.5 mil/side) Test Temperature	
	100°F	1100°F	100°F	1100°F	100°F	1100°F
As Coated	> 10^9	4 x 10^3	> 10^9	1.3 x 10^4	> 10^9	1 x 10^4
Aged 100 Hours at 800°F	> 10^9	3 x 10^3	> 10^9	1 x 10^4	> 10^9	1 x 10^4
Aged 96 Hours at 1100°F	3 x 10^8	2 x 10^4	6 x 10^7	5 x 10^3	4 x 10^6	1.3 x 10^4
Aged 96 Hours at 1400°F	2.6 x 10^4	1 x 10^2	5 x 10^6	3 x 10^2	1.2 x 10^4	2 x 10^2

(a) Coatings were aged and tested on CUBEX magnetic alloy panels, 0.012 inch thick, 6 x 6 inches square. The values are arithmetic averages and the units are ohm-cm^2 per lamination. The aging atmosphere was nitrogen.

NOTE: Data extracted from Tables V.G-1 and V.G-2.

The second type of insulation resistance test was adopted because the remaining specimens available for thousand hour aging and other tests were cut into pieces measuring 4 x 4 inches from the original 6 x 6 inch panels. The method consisted of applying on the test surface an unheated electrode with a flat face measuring two inches in diameter (20.3 sq. cm.) with a nineteen pound total force. The total insulation resistance of a single insulation layer was measured between the Cubex alloy and the electrode using a RCA Voltohmist voltmeter. Total resistance was measured at room temperature on unaged 4 x 4 inch samples of each of the three types of insulated panels. The samples were then aged 1000 hours in two groups in an argon atmosphere. The inert gas purity is described in Section III.C.1.g. One group was aged at 1100°F and the second was aged at 1400°F. After the exposure period was completed, total insulation resistance was again determined.

Magnetic tests were performed on Cubex magnetic alloy, 0.012 inches thick, to determine the degree of compatibility between the alloy and aluminum orthophosphate based interlaminar insulations. Two insulations were used. They were aluminum orthosphosphate alone and MAB. MAB is a composition containing mica, aluminum orthophosphate, and bentonite and is described in detail in Section II.B.3.g.1) b). Comparative magnetic tests were made on Epstein strips after varying aging periods at 800°F, 1100°F, and 1400°F. These specimens were prepared in the same manner as the test panels.

Table V.G-5. reports the results of aging of the Epstein strips. One thousand hour results are reported for MAB aging in the Magnetics Topical Report, page 219, prepared under NAS3-4162 (WAED 64.52E).

4) Conclusions

General conclusions drawn from these tests are based on data presented in Table II.B-3 and the interlaminar insulation summary, Section V.G.

a) Interlaminar resistance of all coatings decreases exponentially with test temperature regardless of the amount of deterioration produced by the aging treatments.

b) There is large performance variability within a coating system as well as from coating to coating and condition to condition.

c) None of the three coatings age significantly at 800°F.

d) There is some deterioration of MAB and M305 glass on aging at 1100°F but electrical insulation resistance values at room temperatures are still high in both cases after 96 hours. The thousand hour exposure at 1100°F indicated adequate stability of Alkophos.

MAB displayed definite reduction of insulation resistance to the level of unmodified Alkophos.

The glass degraded at 1100°F to a lesser degree than the Alkophos-based coatings and remained in a satisfactory condition.

e) All coatings degraded as a result of the aging at 1400°F. The MAB insulation coating performed the best of the three. M305 glass was severely damaged by both short term and thousand hour aging.

f) No loss of weight was detected when the specimens were aged for 24 hours at 1112°F in a vacuum of 10^{-6} torr.

g) Based on core loss measurements, MAB and aluminum orthophosphate do not produce deterioration in Cubex when aged in nitrogen at 800 or 1100°F but may in fact impede deterioration.

h) After aging at 1400°F, deterioration of Cubex core loss properties produced by MAB and aluminum orthophosphate is more than that of uncoated specimens.

5) Discussion

Evaluation of an interlaminar coating on steel generally requires that a large number of tests be made on the coating because of large variation in interlaminar resistance. It is not uncommon to obtain values on some coatings which have a spread of 10^2 to 10^8 ohm-cm^2 per lamination. In such cases, a large number of determinations are performed to give a representative distribution of the subject insulation. Reasons for variations are many. Directly, it is caused by variation in coating thickness and/or discontinuities. Indirectly, these can be caused by variations in metal surface, coating solution and coating mechanics.

Precautions were taken to minimize variability in coating the pieces for this investigation. However, it is known that there are differences in thickness and continuity; therefore, the variability obtained, even within a given coating condition, was not unexpected. For this reason, it was considered justifiable to average the test results.

Although efforts were taken in applying the coatings to obtain approximately same coating thicknesses on the three insulations, coating thicknesses on the average were significantly different: 0.5 mils/side for glass, 0.11 to 0.15 for aluminum orthophosphate and 0.16 to 0.20 for aluminum orthophosphate plus mica plus bentonite (MAB).

The interlaminar insulation values obtained on the five specimens (only two for glass) representing each aging-time condition were averaged for each test temperature. Further, all tests (as many as 25 per coating) were averaged in those cases where resistance values after aging at a given temperature were inconsistent with aging time, i.e., where resistances were obviously independent of aging duration. Their averages were then plotted on five-cycle semilogarithmic paper as a function of test temperature with aging temperature as the other parameter. However, in the case of aging at 1400°F, there is a marked difference in results on aging for 96 hours as compared to 1/2 and 8 hours aging. Therefore, the data representing 96 hours at 1400°F were plotted twice, once for comparison with other aging temperatures and once for comparison with the aging durations. In all cases, a minimum curve is shown in Figures V. G-1 through V. G-4. This represents the lowest values obtained on each of the coatings in their most degraded states (generally after aging 96 hours at 1400°F).

The results reported in Tables V. G-3 and V. G-4 describe drastic reductions of insulation resistance values. Since eddy current potential encountered in the generator designs described in Section II. A. 2 is very low, it is believed that the low resistance levels would be adequate. A benefit is derived in that the insulation operates undisturbed in the stacked core while these specimens were aged, handled and tested as separate pieces.

On aging at 1400°F, there were some visible physical deteriorations in glass and aluminum orthophosphate plus mica plus bentonite (MAB) coatings. Fusion occurred on some glass-insulated laminations, which resulted in peeling when separated. However, on testing these pieces, the least damaged surfaces were placed under test using the 100 cm^2 electrode. The thousand hour specimens were not in contact during the aging and thus did not fuse together. Some lifting of the glass coating occurred during the time period at 1400°F, indicating an oxide substrate formation. This substrate may have been formed by an inter-reaction due to incompatibility or by undetected oxygen contamination of the test chamber. The latter is probably correct.

Weight-loss determinations during vacuum-heat aging of these three insulation coatings revealed no detectable change in the materials as reported in Table V. G-9.

SECTION III

MATERIALS DESCRIPTIONS, SPECIMEN PREPARATION AND TEST SPECIFICATIONS

A. MATERIALS DESCRIPTIONS

1. Conductors

All the conductor materials for NAS 3-4162 were made into 10 and 18 AWG wire by Sylvania Electric Products, Incorporated, Parts Division, Warren, Pennsylvania. Three of the conductors tested; stainless-steel clad silver, stainless-steel clad zirconium copper and dispersion-strengthened copper, were made for the first time on this program. Unless otherwise specified, the clad areas of the conductors described in paragraphs a through g is 28 percent of the cross-sectional area of the conductor.

a. NICKEL-CLAD COPPER

Sylvania markets nickel-clad copper under the Product Specification Kulgrid 28. The 28 indicates that 28 percent of the conductor area is nickel. Raw materials for this conductor are Inco A nickel (99.4 percent nickel plus cobalt) and American Metal Climax Oxygen-Free, High-Conductivity brand copper.

b. TYPE 321 STAINLESS-STEEL-CLAD SILVER

The silver core of this conductor was lithium-deoxidized, fine silver obtained by Sylvania from Handy and Harman. J. Bishop and Company supplied the quality 321 stainless steel tubing to meet all requirements of AMS5770. This material was somewhat difficult to manufacture because of the high rate of work hardening of the stainless-steel clad. The use of a greater-than-normal number of anneals allowed the successful drawing of both wire gages. Table III. A-1 lists the as-drawn and annealed mechanical properties of the conductors tested on this program, including the 321 stainless-steel clad silver.

c. TYPE 304 STAINLESS-STEEL-CLAD ZIRCONIUM COPPER

The zirconium-copper core material for this conductor was supplied by Chase Brass and Copper Company and contained 0.17 percent zirconium in oxygen-free high-conductivity copper. J. Bishop and Company supplied the quality 304 stainless-steel tubing. The drawing problems associated with this material were similar to those encountered during drawing of the stainless-steel-clad silver. It had been hoped that the switch from type 321 to type 304 stainless steel would simplify the drawing operation and reduce the number of intermediate anneals. No improvement in drawability was experienced. The basic mechanical properties of both wire sizes are listed in Table III. A-1.

d. DISPERSION-STRENGTHENED COPPER (CUBE)

Cube, originally called Cufo, was described by the developer and manufacturer, Handy and Harman, Incorporated, as a beryllia, dispersion-strengthened copper. Redraw rod (0.375 inch diameter) was supplied without charge for this program and was subsequently drawn by Sylvania without serious difficulty to 0.1006 and 0.0401 inch diameter wires. The redraw rod had some silver imbedded in the surface which was ground out by hand between several of the initial passes through the drawing dies. Surface silver in the Cube rod was the result of incomplete cleaning of the extrusion containers and dies between runs of different materials. Such a condition can cause flaking. The condition has since been eliminated by Handy and Harman by running clean-up billets of copper through the press. The as-drawn and annealed mechanical properties of Cube are shown in Table III. A-1.

As with any dispersion-strengthened material, it was desirable to know the average particle size, interparticle spacing, and chemistry of the dispersion. To do this, electron microscope and qualitative electron diffraction studies of the structure and extracted particles were made, the results of which can be summarized as follows:

1) The average particle of the dispersed phase size was 0.4 micron.
2) The dispersed phase interparticle spacing was 1.8 microns.
3) Beryllium nitride was the "most likely" identification of the particles followed by beryllium oxide (beryllia), free beryllium and copper beryllide (β', ordered body centered cubic CsCl structure type B2). It is likely that all of the above were present to some degree in the microstructure.
4) Some of the extracted particles of dispersed phase were single crystals as indicated by the Laue electron diffraction patterns obtained. Ring type diffraction patterns were indicative of good extraction techniques wherein a large number of dispersed phase particles were extracted. Ring patterns are indicative of a polycrystalline type of structure.
5) Cube alloy is defined by its manufacturer as copper + 1 volume percent beryllia.

A series of longitudinal and transverse light and electron micrographs are included in Figures III. A-1 through III. A-5. While an exact interpretation of the micrographs would require an extensive discussion, it has been concluded that the unusual 16,500X electron microstructures reflect mechanical history rather than actual grain structure. Studies of the structure at higher magnification did not reveal details beyond those observed at 16,500X. No copper oxide was observed in the microstructures when viewed under polarized light.

e. TD NICKEL

No difficulties were experienced in drawing the TD nickel, 2 volume percent thoria dispersion-strengthened wires. The material processed easily down to 0.101 and 0.405 inch diameter wires with frequent intermediate anneals.

f. INCONEL 600-CLAD, COLUMBIUM-BARRIER, DISPERSION-STRENGTHENED COPPER (CUBE)

The Cube dispersion-strengthened copper for this conductor was also clad by the tube-bar method using the columbium thin wall tubing (a) and Inconel 600 alloy (b). The wall thickness of the tubes was calculated so that the finished conductor area would be approximately eight percent columbium and 29 percent Inconel 600. Sylvania reported that the material processed better than anticipated considering the defects in the dispersion-strengthened copper rod. It was not possible to remove the defects during drawing as it had been in the case of the bare dispersion-strengthened copper rod. It was the opinion that the clad thickness on all conductors could be reduced to improve the electrical properties. The properties measured by the manufacturer are presented in Table III. A-1.

A micrograph of the Inconel 600-clad columbium-clad material is shown in Figure III. A-6. The thickness of both clad layers is quite uniform. The irregularity between the Inconel and columbium is a relief effect caused by the different material removal rates during polishing.

g. INCONEL 600-CLAD, FINE SILVER

The high-quality, lithium-deoxidized, fine silver (99.9 percent Ag) and Inconel 600 tube were obtained from Handy and Harman. The composite material worked nicely and, according to Sylvania, should be obtainable in volume should the need arise. Earlier difficulties with Inconel 600-clad silver encountered by Sylvania have now been overcome. Material properties supplied with the wire are tabulated in Figure III. A-1.

(a) Kawecki Chemical Company
(b) International Nickel Company

TABLE III. A-1. Preliminary Tensile Data for Special Conductors at 72°F as Supplied by Sylvania Electric Products, Inc., Warren, Pa.

Material	As Drawn[(a)]		Annealed[(a)]			
	Ultimate Tensile Strength (Psi)	Elongation (Percent)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Tensile Strength (Psi)	Elongation (Percent)	Wire Size (Inch)
Unclad Cube Dispersion-Strengthened Copper[(b)]	95,000 91,000	7.0 1.5	67,500 69,000	79,000 79,000	12.0 8.0	0.1006 0.0401
304 Stainless-Steel-Clad Zirconium Copper (28 Percent Clad Area)	- -	- -	27,800 19,000	55,500 50,000	45.0 30.0	0.101 0.0403
321 Stainless-Steel-Clad Fine Silver (28 Percent Clad Area)	75,000 90,000	4.0 2.0	17,700 25,900	45,000 49,700	41.0 33.0	0.1015 0.0405
Inconel 600-Clad Columbium-Barrier Dispersion-Strengthened Copper (37 Percent Total Clad Area)	108,000 -	1.5-2.0 -	61,750 72,700	74,500 77,000	16-18 22-24	0.101 0.040
Inconel 600-Clad Fine Silver (28 Percent Clad Area)	88,000 -	1.0-1.5 -	19,300 26,200	46,400 47,200	26-28 20.0	0.101 0.040

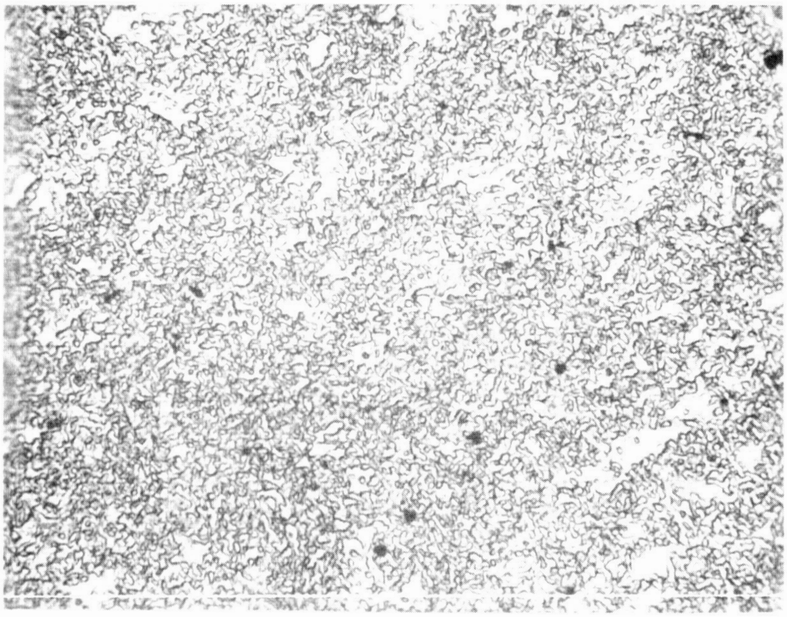
(a) Drawing conditions and annealing cycles not available except on Cube Alloy.
(b) Hydrogen anneal 1300°F, 1.5 hours.

Strain Rate: 0.005 in/in/min to yield; 0.05 in/in/min to failure.

(Reference: NAS3-4162)

NH_4OH - H_2O_2 Etch 1000X

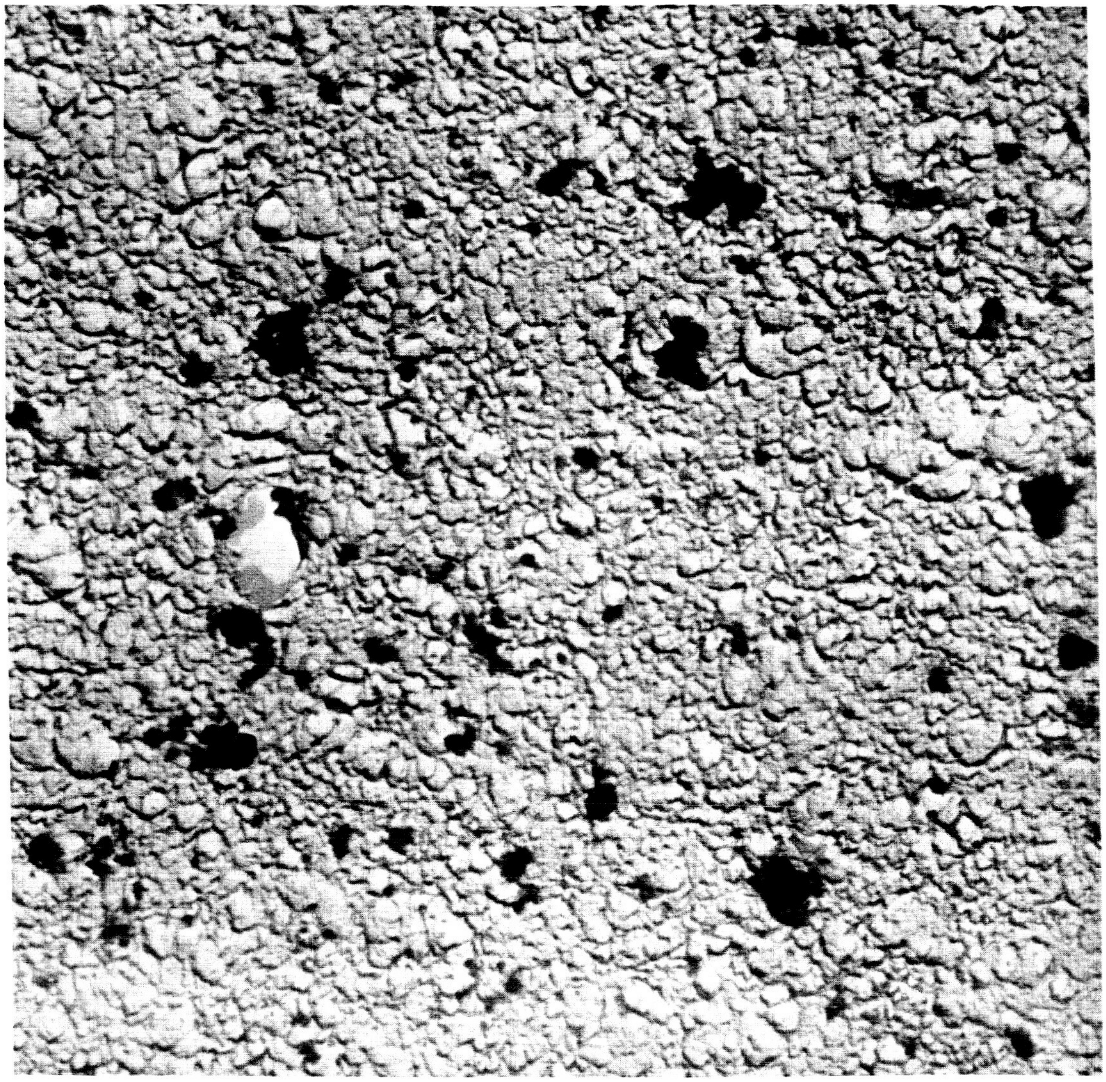
LONGITUDINAL



NH_4OH - H_2O_2 Etch 1000X

TRANSVERSE

FIGURE III.A-1. Light Micrographs of Dispersion-Strengthened Copper (Copper - 1 volume percent Beryllia).



2-191-64-4 As Polished 16, 500X

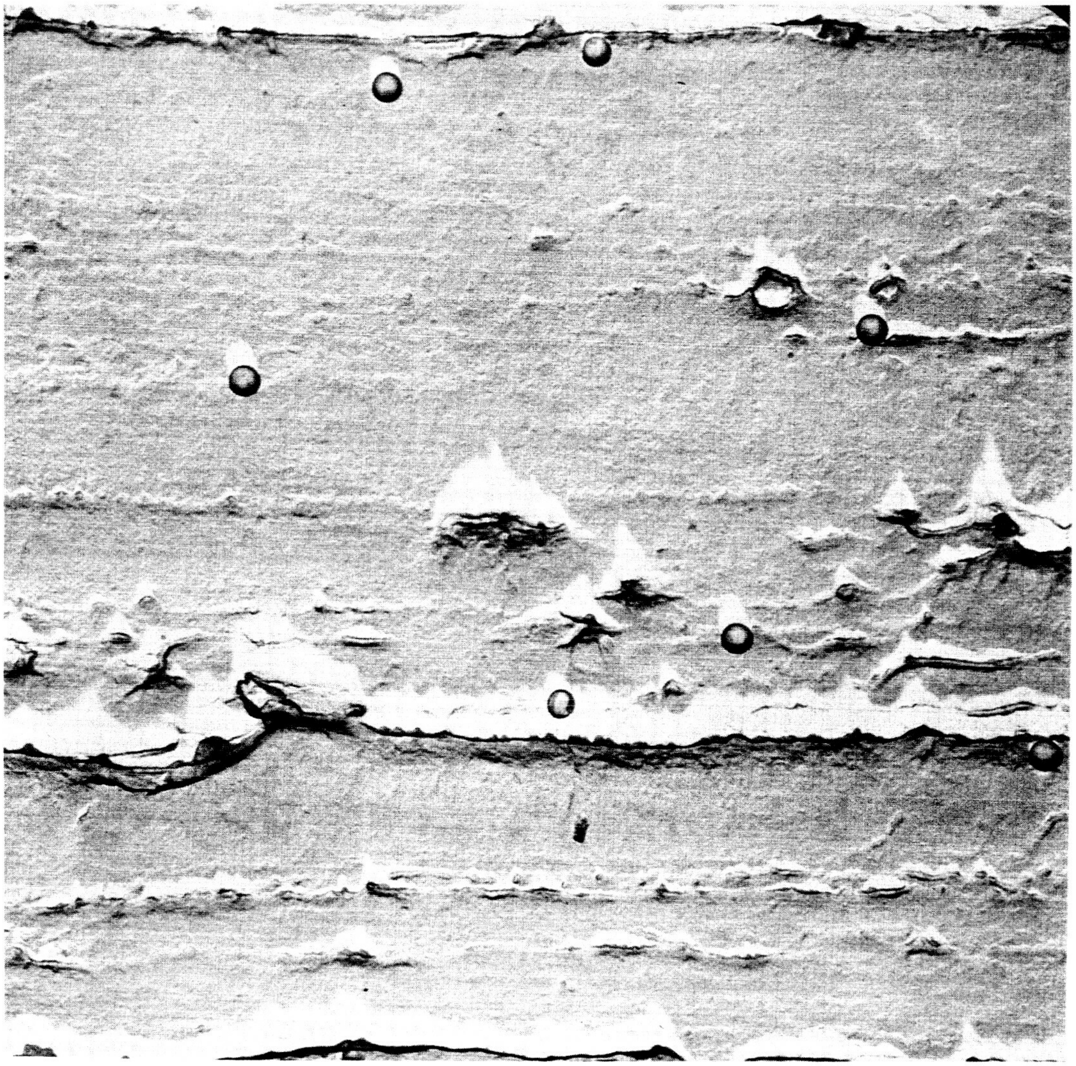
Two Stage Carbon Replica. Sample shows structure revealed by light etch which occurred during final polishing with Linde B Alumina and 10 percent $Fe(NO_3)_3$ solution on longitudinal section.

FIGURE III. A-2. Electron Micrograph of As Drawn Dispersion-Strengthened Copper (Copper - 1 volume percent beryllia).

2-194-64-3 Alcoholic Ferric Chloride Etch 16,500X

Two Stage Carbon Replica. Transverse Section

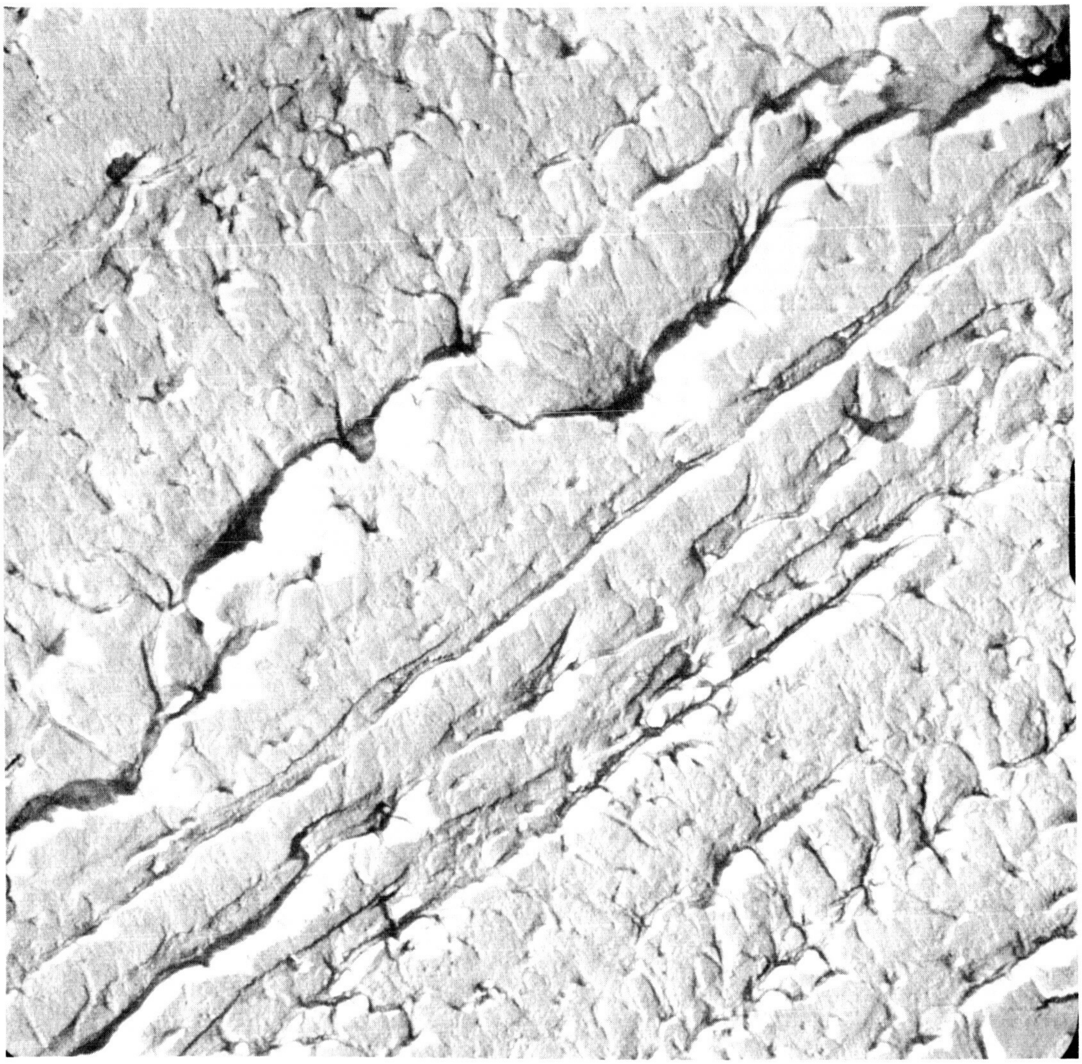
FIGURE III.A-3. Electron Micrograph of As Drawn Dispersion-Strengthened Copper (Copper - 1 volume percent beryllia).



2-195-64-3 Alcoholic Ferric Chloride Etch 16,500X

Two Stage Carbon Replica. Small Polystyrene spheres 0.260 micron diameter. Longitudinal Section.

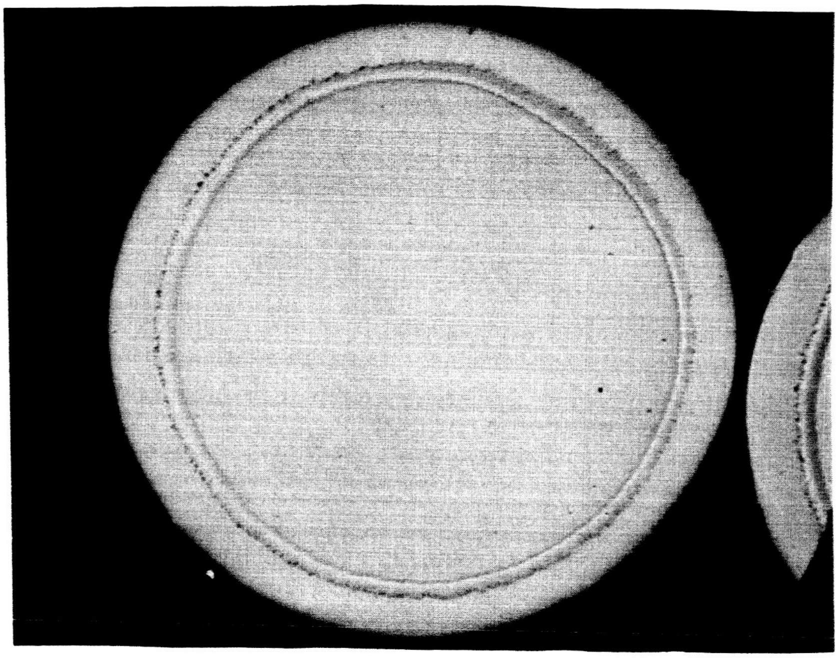
FIGURE III.A-4. Electron Micrograph of As Drawn Dispersion-Strengthened Copper (Copper - 1 volume percent beryllia).



2-196-64-5   Alcoholic Ferric Chloride Etch   16,500X

Two Stage Carbon Replica. Longitudinal Section

FIGURE III.A-5. Electron Micrograph of As Drawn Dispersion-Strengthened Copper (Copper - 1 volume percent beryllia).



Unetched 85X

Typical as drawn 0.040 inch diameter wire section illustrating relative thicknesses of outer and inner sheaths and core. These proportions remain constant during drawing.

FIGURE III.A-6. Micrograph of Inconel 600-Clad (28 Percent of Area) Columbium Barrier (8 Percent of Area) Dispersion-Strengthened Copper (Copper - 1 volume percent beryllia). (Reference: NAS 3-4162)

2. Insulation Materials

Most materials were acquired from the open market. However, some forms and compositions were available only from development programs and, in some cases, made specially for this test effort. Some material properties are represented by data from the literature. In the following summation, sample identifications and histories are presented wherever possible.

MATERIAL FORM

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
a.	Magnet Wire		
1)	Polyimide	ML	Polyimide enamel (DuPont ML) is an organic resin related to the nylon family. It is best described as an aromatic polyimide resin based on pyromellitic dianhydride. The conductor used in this program was electrolytic tough pitch copper with minimum conductivity of 100 percent of International Annealed Copper Standard (No. 18 AWG) and was manufactured by the Phelps Dodge Copper Products Corporation as the lot marked Feb. 25, 1964, Code 4 Bc, Spec 31211.
2)	Anacote	Anacote	Anacote is a resin-bonded mixture of glass frit and refractory oxides applied to either clad or plated conductors. The conductor used in this program was 28 percent nickel-clad copper of 0.0403 inch diameter (No. 18 AWG) and was manufactured by the Anaconda Wire and Cable Company.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
3)	Anadur	Anadur	The insulation is composed of E-grade fiber glass, fusible glass frit, and refractory oxide powders retained on the conductor during winding by a resin binder. Subsequent firing for at least 15 minutes at 1250°F in air of the wound apparatus fuses the glass frit to serve as a rigid binder. The conductor used in this program was 28 percent nickel-clad copper of 0.0403 inch diameter. (No. 18 AWG) and was manufactured by the Anaconda Wire and Cable Company.
4)	Ceramic-Eze	Ceramic-Eze	Ceramic-Eze is a fused glass coating which contains a mixture of refractory oxides. The coating is very thin, approximately 0.0003 inch per side, and is overcoated with an organic resin layer to improve windability prior to firing. The conductor used in this program was 28 percent nickel-clad copper of 0.201 inch diameter (No. 18 AWG) and was manufactured by the Phelps Dodge Copper Products Corporation.
5)	R2554B	R2554B	The composition of R2554B includes refractory oxides and glass frit bound to a plated or clad conductor by a polyester resin vehicle. The resin is destroyed during early stages of firing and leaves no carbonaceous residue.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
5)	R2554B (Cont)		The composition of the glass frit is such that fusion is achieved in final firing at 1250°F. The conductor used in this program was 28 percent nickel clad copper of 0.0403 inch diameter (No. 18 AWG) and was manufactured by the Westinghouse Electric Corporation, Copper Wire Department.
b.	Lead Wire		
1)	Glass-Fiber, Asbestos	Continental Type AA	The insulation of Continental AA lead wire consists of E-glass-reinforced mica type wrapping overlaid with asbestos braid. The asbestos braid is treated with a silicone resin to afford moisture resistance and flexibility during handling prior to exposure at temperatures above approximately 800°F. The conductor used in this program consisted of seven strands of 0.016 inch diameter nickel-plated copper with approximately 0.0002 inch of nickel plating per strand, asbestos braided (No. 18 AWG) and was manufactured by the Continental Wire Corporation, York, Pa.
2)	Glass-Fiber, Mica	Micatemp	Micatemp lead wire is made from stranded nickel-clad copper wire. The initial electrical insulation is a reinforced muscovite mica tape. The outer insulation is an E-glass braid coated with a heat-resistant finish of silicone resin.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
2)	Glass-Fiber, Mica (Cont)		Other protected copper conductors have been used by the producer. The conductor used in this program consisted of nineteen strands of 0.0114 inch diameter nickel-plated copper with approximately 0.0002 inch of nickel plating per strand (No. 18 AWG). It was manufactured by the Rockbestos Wire and Cable Company and marked as lot R22-5-304.
c.	Sheet Insulation-Flexible		
1)	Polyimide Film	H-Film	H-Film is a polyimide resin formed by the reaction of a dianhydride with a diamine. It is unsupported by any filler. The material used on this program was 0.002 inch thick. H-Film (now known as Kapton) is manufactured by the E. I. DuPont de Nemours & Company.
2)	Polyimide Glass	Pyre-ML 6508 Pyre-ML 6518	Pyre-ML is composed of E-glass fiber cloth treated with multiple applications of the polyimide resin (ML). In grade 6508, the fibers are well wetted by the resin during impregnation and curing producing a dense sheet material. The fibers in grade 6518 are not completely penetrated and wetted during the resin treatment. This latter modified material is a more flexible product. When 6518 is creased, fewer glass fibers are

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
2)	Polyimide Glass (Cont)		broken than in 6508. This reduced breakage is beneficial to quality of wound apparatus. The material used on this program was 0.010 inch thick, "semi-flexible" Pyre-ML grade 6508 and 0.010 inch thick "flexible" Pyre-ML grade 6518. Both were manufactured by the E. I. DuPont de Nemours & Company.
3)	Mica-glass, silicone-resin Bonded	128-50-1	This material is composed of phlogopite mica paper, 181 E-glass cloth and a silicone varnish, Dow Corning DC 997. The thickness is nominally 0.004 inch. The paper is identified as 2.8 mil integrated mica paper and is produced by MacAllen Company. The material used on this program was 0.0045 inch thick. The insulation, 128-50-1, is manufactured by the Westinghouse Electric Corp., Research Development Center.
4)	Mica Paper	Burnil CM-1	Burnil paper, CM-1, is composed of synthetic-mica platelets of lithium magnesium silicate, XMg_2 Li Si_4 O_{10} F_2 (where $X = Li$ or Na). The paper contains about 4.5 percent water which is eliminated at 230°F but is rapidly picked up from the air at room temperature. A very small amount of organic sizing material is present on the paper. The material used on this program was 0.010 inch thick. Burnil, CM-1, is manufactured by the Minnesota Mining & Manufacturing Company.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
5)	Silicate-fiber	Fiberfrax	Fiberfrax paper is composed of an alumina silicate fiber. The composition is : Al_2O_3, 51 percent; SiO_2, 47 percent; B_2O_3, 0.6 percent; Na_2O, 0.6 percent; and MgO, CaO, Fe_2O_3 totaling 0.5 percent. The average fiber diameter is 2.5 microns. The fiber melts or sinters at 2500°F. After long exposure above 2000°F, the amorphous glassy structure changes to a crystalline structure. One type has a 5 percent organic binder for added strength. The Fiberfrax examined in this program was approximately 0.020 inch thick and contained no binder. The material is manufactured by the Carborundum Company.
d.	Rigid Insulation-Laminated		
1)	Asbestos-boron-Phosphate Bonded	92M	The laminate is composed of long fiber chrysotile asbestos paper impregnated and laminated with boron phosphate solution as a binder. The composition of chrysotile asbestos is $2\,MgO \cdot 2\,SiO_2 \cdot 2H_2O$ and is applied in this laminate as a paper identified as RPD40 by the producer, Raybestos-Manhattan. The inorganic binder is prepared as water solution of ammonia pentaborate and diammonium phosphate which results in 28 percent available boron phosphate.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
1)	Asbestos-boron-Phosphate Bonded (Cont)		The material used for this program was 0.110 inch and 0.5 inch thick 92M and was manufactured by the Westinghouse Electric Corp., Research & Development Center, Pittsburgh, Pa.
2)	Diphenyl-Oxide Glass	DORYL H17511	Doryl H 17511 is a polymer of diphenyl oxide coated on style 181-A1100 E-glass cloth. The material used on this program was 0.12 inch and 1 inch thick and was manufactured by the Westinghouse Electric Corporation, Micarta Division.
3)	Epoxy-Glass	Micarta H2497	This material is an organic anhydride cured epoxy resin, coated on Style 181, Volan A treated glass cloth. It is cured at 320°F and 200 psi for 20 minutes. The material used on this program was 0.078 inch and 1 inch thick. It was manufactured by the Westinghouse Electric Corporation, Micarta Division.
4)	Phenolic-Glass	Poly-Preg 91LD	The phenolic bonding resin is formed by the condensation reaction of phenol and formaldehyde. The resin is impregnated on Style 181-A1100 E-glass cloth. The laminates are molded under contact pressure at 250°F for 2 minutes and then at 500 psi and 275°F for 20 minutes. The laminate should be post-cured in air for improved properties. The post-cure schedule depends upon the laminate thickness.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
4)	Phenolic-Glass (Cont)		The material used for this program was Poly-Preg 91LD manufactured by US Polymeric Chemicals Inc.
5)	Polybenzimidazole-Glass	Imidite 1850	This laminate is made with a 9 ounce satin weave E-glass cloth. The resin content is 40 ± 5 percent. The laminates are cured at 250°F and 200 psi contact pressure, followed by 700°F and 200 psi for 3 hours. The laminates are post-cured in nitrogen according to the following schedule: 24 hours at 600°F 24 hours at 650°F 24 hours at 700°F 24 hours at 750°F 8 hours at 800°F The material used for this program was Imidite 1850 manufactured by Narmco, a division of Whittaker Corporation.
6)	Polyimide-Glass	I-8	Polyimide I-8 is the reaction product of m-phenylene diamine and 3, 3', 4, 4'-benzophenonetetracarboxylic dianhydride. The polymer was impregnated into E-glass cloth (style 181-A1100) and laminates were pressed for 30 minutes at 716°F and 200 psi. The resin content in the laminates were 36 percent and thickness was 0. 125 inch. The material used for this program was manufactured by the Westinghouse Electric Corp., Micarta Division.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
7)	Mica	Mica Mat 78300	Mica Mat 78300 is a rigid mica plate bonded with an inorganic material. The laminate meets NEMA grade 9-P. The material used for this program was 0.012 inch thick Mica Mat 78300 manufactured by the General Electric Co., Insulating Materials Department.
e.	Rigid Insulation - Molded or pressed		
1)	Alumina 99.5 percent	AD995	99.5% Al_2O_3 0.2 - 0.3% SiO_2 0.0 - 0.2% MgO 0.0 - 0.2% Cr_2O_3 0.0 - 0.02% Fe_2O_3 Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer. The material used on this program was AD995 manufactured by the Coors Porcelain Co.
2)	Alumina 99 percent	AD99	99% Al_2O_3 0.1 - 0.5% SiO_2 0.3 - 1% CaO 0.0 - 0.2% MgO Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer. The material used on this program was AD99 manufactured by the Coors Porcelain Company.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
3)	Alumina 94 percent	AD94	94% Al_2O_3 0.5 - 4% SiO_2 1.0 - 3% CaO 0.2 - 1% MgO Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer. The material used on this program was AD94 manufactured by the Coors Porcelain Company.
4)	Alumina 99.8 percent, 0.25 MgO	Lucalox	99.8% Al_2O_3 0.15 - 0.25% MgO 0.002 - 0.04% CaO 0.05% SiO_2 The material used on this program was Lucalox manufactured by the General Electric Company.
5)	Beryllia 99.8 percent	Thermalox 998	99.8% BeO 150 PPM Al 100 PPM Fe 100 PPM Si 80 PPM Ca 1000 PPM MgO Approximate upper limits Other elements: Ag, Cu, Cr, Mn, Mo, Na, Ni, Zn, each less than 30 ppm; B, Cd, Co, K, Li, Pb, each less than 10 ppm. The material used on this program was Thermalox 998 manufactured by the Brush Beryllium Company.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
6)	Epoxy Premix	Scotchply 1100	This material is epoxy-based and is 37 percent by weight resin and the balance is 1/2 inch long E-glass fibers. The compound should be preheated to 200°F for 4 minutes and molded by compression or transfer for 20 minutes at 330°F (1/8 inch section). The material used on this program was Scotchply 1100 manufactured by the Minnesota Mining & Manufacturing Company.
7)	Polyester Premix	Plaskon 751	Plaskon 751 is a E-glass fiber and mineral-filled, polyester molding compound. It has a bulk factor greater than 1 and is molded in matched metal dies at 300°F and 1000 psi for 5 minutes (1/8 inch section). The material used on this program was manufactured by the Allied Chemical Company, Plastic Division.
8)	Polyimide	Vespel SP-1	The material is an aromatic polyimide, the reaction product of pyromellitic dianhydride and a diamine. The material reported on in this summary was not filled but filled moldings are available. The material used on this program was Vespel SP-1 manufactured by the E. I. DuPont de Nemours Company, Plastics Department.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
f.	Compounds, Encapsulation		
1)	Anacap	Anacap	The composition is described by the manufacturer as a combination of several refractory oxides and glass and cementatious bonding materials. The material is manufactured by the Anaconda Wire & Cable Corp.
2)	Epoxy	Hysol C9-4186	The resin is filled with 65 percent mineral filler and the hardener is an anhydride. The viscosity of the resin is 200,000 centipoise at 77°F and the epoxy equivalent is 618. Twenty-nine parts by weight of hardener are added to one hundred parts of resin. The recommended cure is 2 hours at 260°F followed by 2 hours at 300°F and 2 hours at 390°F. The material used on this program was Hysol C9-4186 hardened with H5-3537 and was manufactured by the Hysol Corporation.
3)	Sauereisen 8	Sauereisen 8	The compound is composed of magnesium oxide, zirconium silicate and magnesium ammonium phosphate. To apply, sufficient water is added to achieve desired working consistency. The material used on this program was manufactured by the Sauereisen Cement Co.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
4)	Silicone Foam	XR5017	XR5017 is a two part silicone rubber foam activated by mixing 100 parts by weight of the silicone rubber base to 4 parts of the activator. The foam can be poured immediately and cures in 24 hours at room temperature or in 1/2 hour at 250°F. The material used on this program was XR5017 and was manufactured by Minnesota Minning and Manufacturing Company, Electrical Products Division.
5)	Urethane Foam	Carthane 1008	This foam is a two part system containing an isocynate resin based on polymethylene polyphenylisocyanate (PAPI) and a polyester resin. The foaming action is caused by the evolution of water occurring as a result of the polyester-isocyanate condensation reaction. The reaction is self-induced and requires no baking. This product was withdrawn from the market during this test program by the Carwin Corporation, the original manufacturer. The formulation with improvements in purity of ingredients is now produced by Flexible Products Company as Flexipol 9020/8122-2 foam.
6)	W839	W839	This material is composed of seven parts by weight of zirconium silicate and three parts by weight of aluminum orthophosphate. For application purposes, water may be added. W839 used on this program was manufactured by the Westinghouse Electric Corp., Research & Development Center.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
g.	Interlaminar Insulation		
1)	Aluminum Orthophosphate	Alkophos C	Aluminum Orthophosphate insulation is a solution consisting of 600 milliliters of aluminum orthophosphate (Alkophos C), 600 milliliters of distilled or demineralized water, and 1/2 percent wetting agent. After application, the coating is dried and then cured at approximately 750°F. The resulting coating thicknesses on this program was 0.11 to 0.15 mil per side. The alkophos solution was purchased from the Monsanto Chemical Company.
2)	Aluminum Orthophosphate plus mica and bentonite	MAB	MAB insulation is a filled aluminum orthophosphate solution consisting of 300 Milliliters of aluminum orthophosphate, 1200 mililiters of distilled or demineralized water, 50 grams of bentonite (grade KWK Volclay, obtained from American Colloid Company), and 200 grams of -300 mesh phlogopite mica. After application the coating is dried and then cured at approximately 750°F. Thickness of the coating was approximately 0.16 to 0.20 mil per side. The material was compounded and applied by the Westinghouse Electric Corp., Research and Development Center.

	MATERIAL	TRADE NAME	SPECIMEN DESCRIPTION
3)	Glass	M305	M305 glass interlaminar insulation is a modified borosilicate composition. After cleaning and degreasing the specimens are lightly etched and given a nickel flash of approximately 0.05 gram per square foot of nickel. The specimens are dipped into a slip (suspension) consisting of finely ground glass frit (minus 400 mesh) and an alcohol vehicle. The dried and unfired coated pieces are then put into a furnace that has been preheated at 1800°F and held there for about 25 seconds. Thickness of the fused glass coating is approximately 0.5 to 0.8 mils per side. M305 is a developmental boro-silicate glass from the Westinghouse Electric Corp, Research and Development Center.

B. SPECIMEN PREPARATION AND CONFIGURATION

1. Conductors

Wire specimens were prepared by shearing to proper length. When end parallelism was desired on bundled specimens, the samples were chucked and ground to size. A tabulation of the specimen configuration on drawings is given in Table III. B-1. Drawings of the test specimens are shown in Figures III. B-1 through III. B-3.

TABLE III. B-1. Summary of Specimen Configurations and Test Methods - Electrical Conductor Materials

Material	Type of Test	Specimen Figure Number[(a)]	Test Specification or Method
Bare DS Copper	Creep	III. B-1	ASTM E139
Bare DS Copper	Tensile	III. B-1	ASTM E21
Bare DS Copper	Electrical Resistivity	III. B-1	ASTM B193
Bare DS Copper	Thermal Expansion	III. B-2	ASTM B95
Bare DS Copper	Thermal Conductivity	III. B-3	Comparison Bar
Nickel-Clad Copper	Tensile	III. B-1	ASTM E21
Nickel-Clad Copper	Thermal Expansion	III. B-2	ASTM B95
S. S. -Clad Zirconium Copper	Tensile	III. B-1	ASTM E21
S. S. -Clad Zirconium Copper	Thermal Expansion	III. B-2	ASTM B95
S. S. -Clad Zirconium Copper	Electrical Resistivity	III. B-1	ASTM B193
Inconel-Clad DS Copper	Tensile	III. B-1	ASTM E21
Inconel-Clad DS Copper	Electrical Resistivity	III. B-1	ASTM B193
Inconel-Clad DS Copper	Thermal Expansion	III. B-2	ASTM B95
Inconel-Clad DS Copper	Thermal Conductivity	III. B-3	Comparison Bar
S. S. -Clad Silver	Tensile	III. B-1	ASTM E21
S. S. -Clad Silver	Electrical Resistivity	III. B-1	ASTM B193
S. S. -Clad Silver	Thermal Expansion	III. B-2	ASTM B95
Inconel-Clad Silver	Tensile	III. B-1	ASTM E21
Inconel-Clad Silver	Thermal Conductivity	III. B-3	Comparison Bar
Inconel-Clad Silver	Thermal Expansion	III. B-2	ASTM B95
Inconel-Clad Silver	Electrical Resistivity	III. B-1	ASTM B193
Inconel-Clad DS Cb Cu Wire	Electrical Resistivity	III. B-1	ASTM B193
TD Nickel	Electrical Resistivity	III. B-1	ASTM B193

(a) All dimensions on the figures are in inches unless otherwise specified.
NOTE: Stability tests were conducted with electrical resistivity specimens as above.

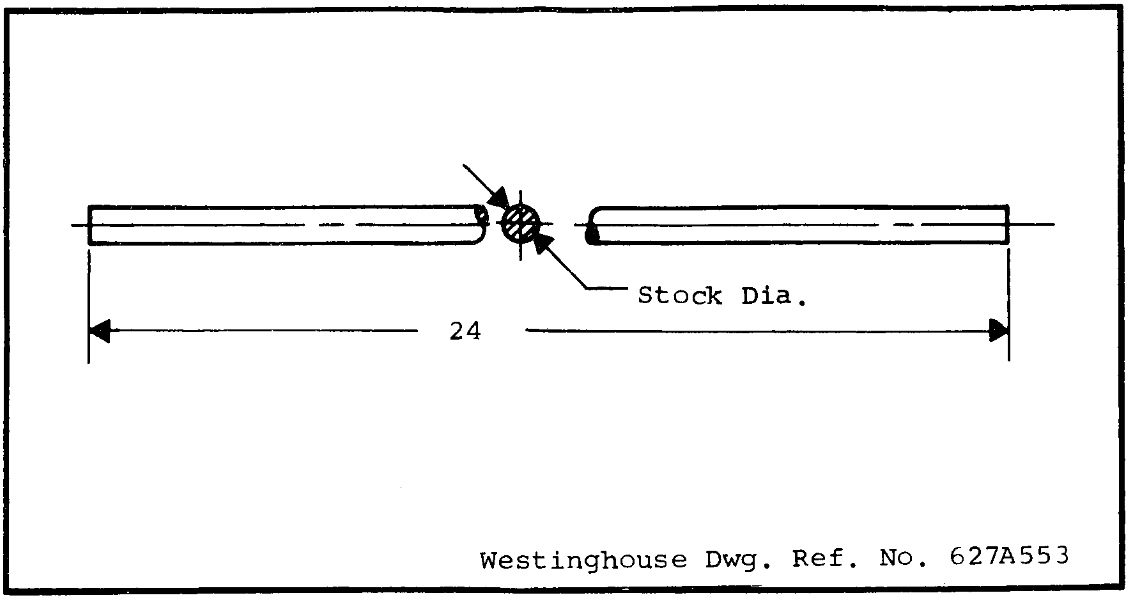


FIGURE III. B-1. Combination Tensile, Creep, and Resistivity Specimen for Conductors

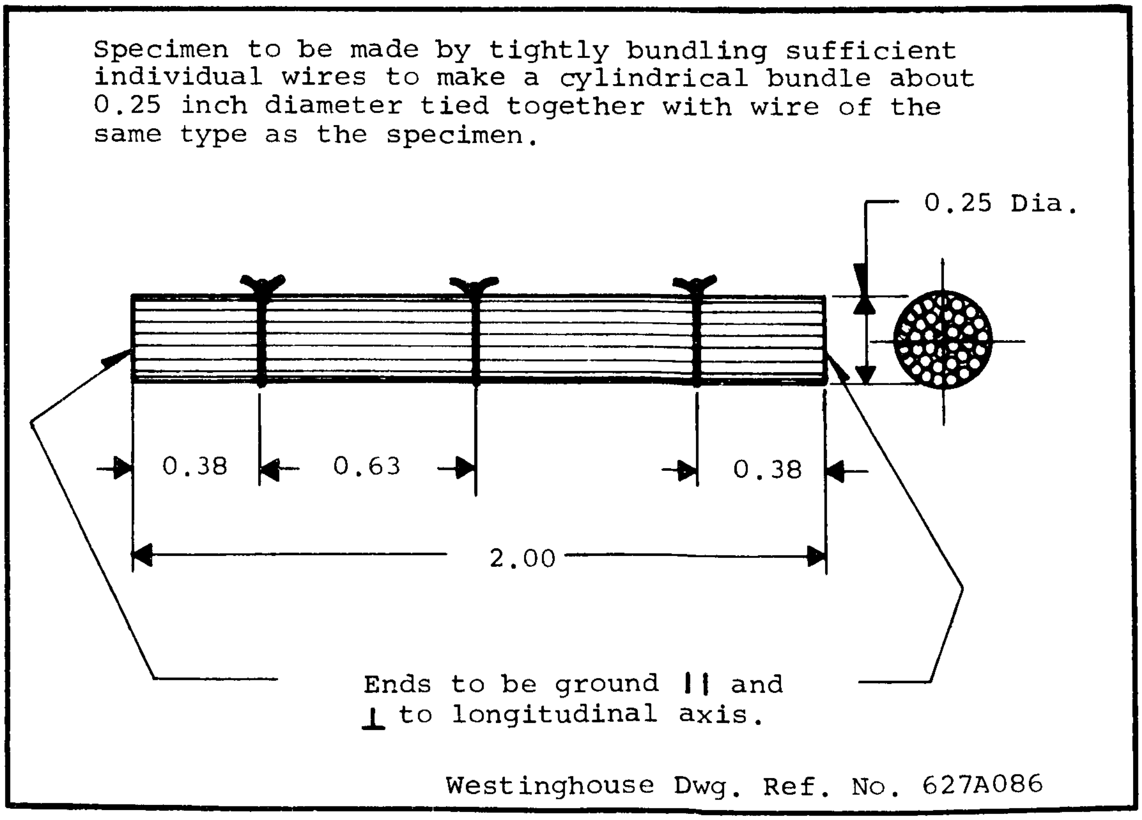
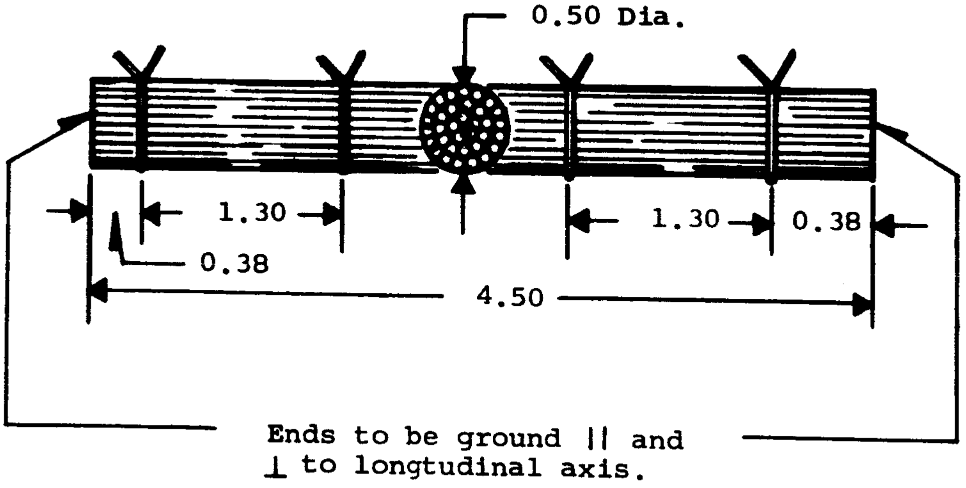


FIGURE III. B-2. Thermal Expansion Specimen - Wire Only

Specimen to be made by tightly bundling sufficient individual wires to make a cylindrical bundle 0.50 inch diameter tied together with wire of the same type as the specimen.



Ends to be ground || and ⊥ to longtudinal axis.

Westinghouse Dwg. Ref. No. 627A087

FIGURE III. B-3. Thermal Conductivity Specimen - Wire Only

2. Electrical Insulation Materials

The specimens were prepared by appropriate molding, pressing, shearing, or grinding as indicated in the material configuration summary itemized in Section III. B-2 and in test specifications listed in Table III. B-2. In instances where no specimen figure number is given, the specimen has been described in the appropriate test specification.

TABLE III. B-2. Summary of Specimen Configurations and Test Methods - Electrical Insulation Materials

Material Form	Type of Test	Specimen Figure Number[a]	Test Specification or Method
	Thermophysical Tests		
Laminates, Encapsulations, & Moldings	Density	--	ASTM D792. See Section III. C. 2. a.
Encapsulations	Shrinkage	--	By difference in Specific Gravity
Sheet, Laminates, Molding	Thermal Conductivity	III. B-4	ASTM C177
Wire	Thermal Conductivity	III. B-5	See Section III. C. 2. b.
Inorganic Laminates, Encapsulations, & Moldings	Thermal Expansion	III. B-6	ASTM C372
Organic Laminates, Encapsulations, & Moldings	Thermal Expansion	III. B-6	ASTM D696
Organic Laminates	Water Absorption	III. B-7	ASTM D570
Organic Moldings	Water Absorption	III. B-8	ASTM D570
Inorganic Laminates & Moldings	Water Absorption	III. B-9	ASTM C373

(a) Unless otherwise specified, all dimensions on the figures are in inches.

TABLE III. B-2. Summary of Specimen Configurations and Test Methods - Electrical Insulation Materials (Continued)

Material Form	Type of Test	Specimen Figure Number(a)	Test Specification or Method
	<u>Electrical Tests</u>		
Organic Laminates	Arc Resistance	III. B-10	ASTM D495
Sheet, Laminates Encapsulants	Dielectric Constant	III. B-10	ASTM D150
Sheet, Laminate	Electric Strength	III. B-10	ASTM D149
Organic Magnet Wire	Electric Strength	--	MIL-W-583 paragraph 4. 7. 3. 2
Inorganic Magnet Wire	Electric Strength	--	MIL-W-583 paragraph 4. 7. 3. 3
Organic Magnet Wire	Insulation Life	--	IEEE No. 57
Inorganic Magnet and Lead Wires	Insulation Life	III. B-11	ASTM D149 using Bifilar Coils. See Section III. C. 2. c.
Organic Sheet Insulation	Insulation Life	III. B-12	ASTM D1830
Organic Laminates	Insulation Life	III. B-12	ASTM D149
Inorganic Flexible Sheet	Insulation Life	III. B-10	ASTM D149
Inorganic Rigid Laminates	Insulation Life	--	ASTM D1829. See Section III. C. 2. d.
Organic Encapsulants	Insulation Life	--	ASTM D257.
Inorganic Encapsulants	Insulation Life	--	See Section III. C. 2. d.
Interlaminar Insulation	Insulation Life	--	See Section II. B. 3. g.
Sheet, Laminates, Moldings	Power Factor	--	Calculated from Dielectric Constant
Sheet Organic Laminates, Moldings plus Encapsulants	Volume Resistivity	--	ASTM D257, See Section III. C. 2. e.
Inorganic Laminates, Moldings plus Encapsulants	Volume Resistivity	--	ASTM D1829. See Section III. C. 2. e.

(a) Unless otherwise specified, all dimensions on the figures are in inches.

TABLE III. B-2. Summary of Specimen Configurations and Test Methods - Electrical Insulation Materials (Continued)

Material Form	Type of Test	Specimen Figure Number(a)	Test Specification or Method
	Mechanical Tests		
Magnet Wire	Abrasion Resistance	--	NEMA MW5
Lead Wire	Abrasion Resistance	--	See Section III. C. 2. f.
Sheet Insulation	Abrasion Resistance	III. B-13	ASTM D1175 (RPDH) See Section III. C. 2. g.
Organic Magnet Wire	Adhesion	--	MIL-W-583, paragraph 4. 7. 10. 1
Inorganic Magnet Wire	Adhesion	--	Progressively Sized Mandrels
Laminates	Compressive Strength	III. B-14	ASTM D759
Moldings, Organic Encapsulants	Compressive Strength	III. B-15	ASTM D759
Inorganic Moldings, Inorganic Encapsulants	Compressive Strength	III. B-16	ASTM D759
Organic Magnet Wire	Cut-Through Resistance	--	MIL-W-583, paragraph 4. 7. 11. 1 & see Section III. C. 2. h.
Sheet Insulation & Inorganic Magnet Wire	Cut-Through Resistance	--	See Section III. C. 2. h.
Laminates, Moldings	Elastic Modulus in Flexure	III. B-17	ASTM D790
Laminate, Organic Moldings	Impact Strength	III. B-18 III. B-19	ASTM D256 ASTM D256
Inorganic Moldings	Impact Strength	III. B-19	ASTM D256
Laminates, Moldings	Flexural Strength	III. B-16	ASTM D790
Sheet, Laminates	Tensile Strength	III. B-20	ASTM D902
Magnet Wire	Thermal Shock	--	MIL-W-853, paragraph 4. 7. 6
Encapsulant	Thermal Shock	--	See Section III. C. 2. i.
	Weight Loss in Vacuum and Heat	--	See Section III. C. 2. j.

(a) Unless otherwise specified, all dimensions on the figures are in inches.

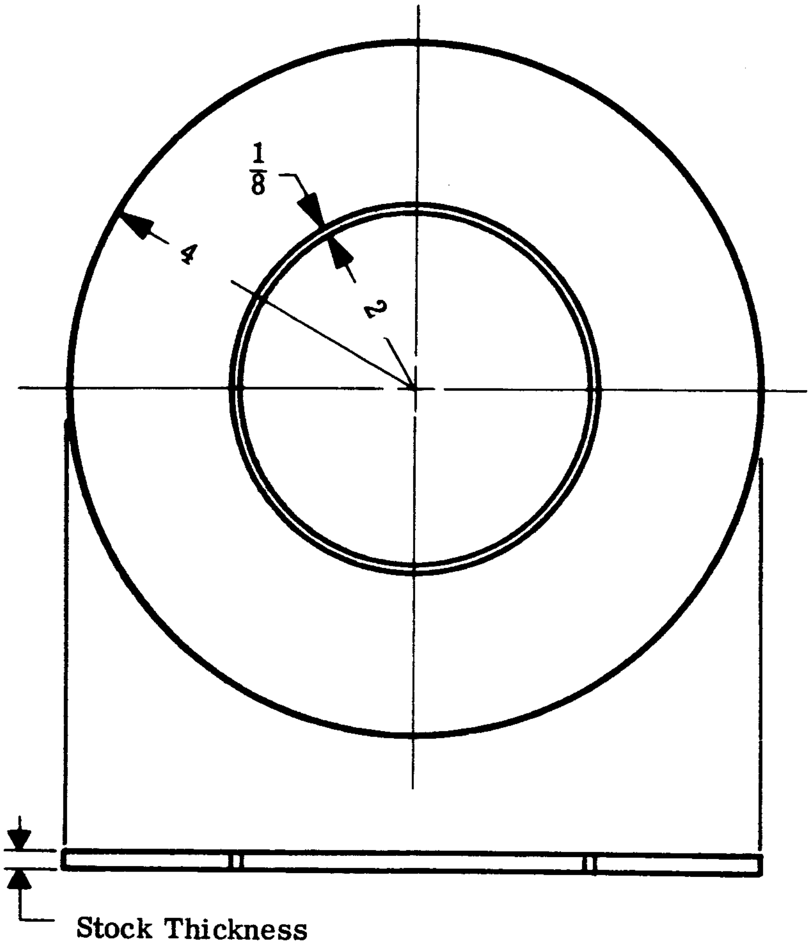


FIGURE III.B-4. Thermal Conductivity Test Specimen, Guarded Hot Plate Method

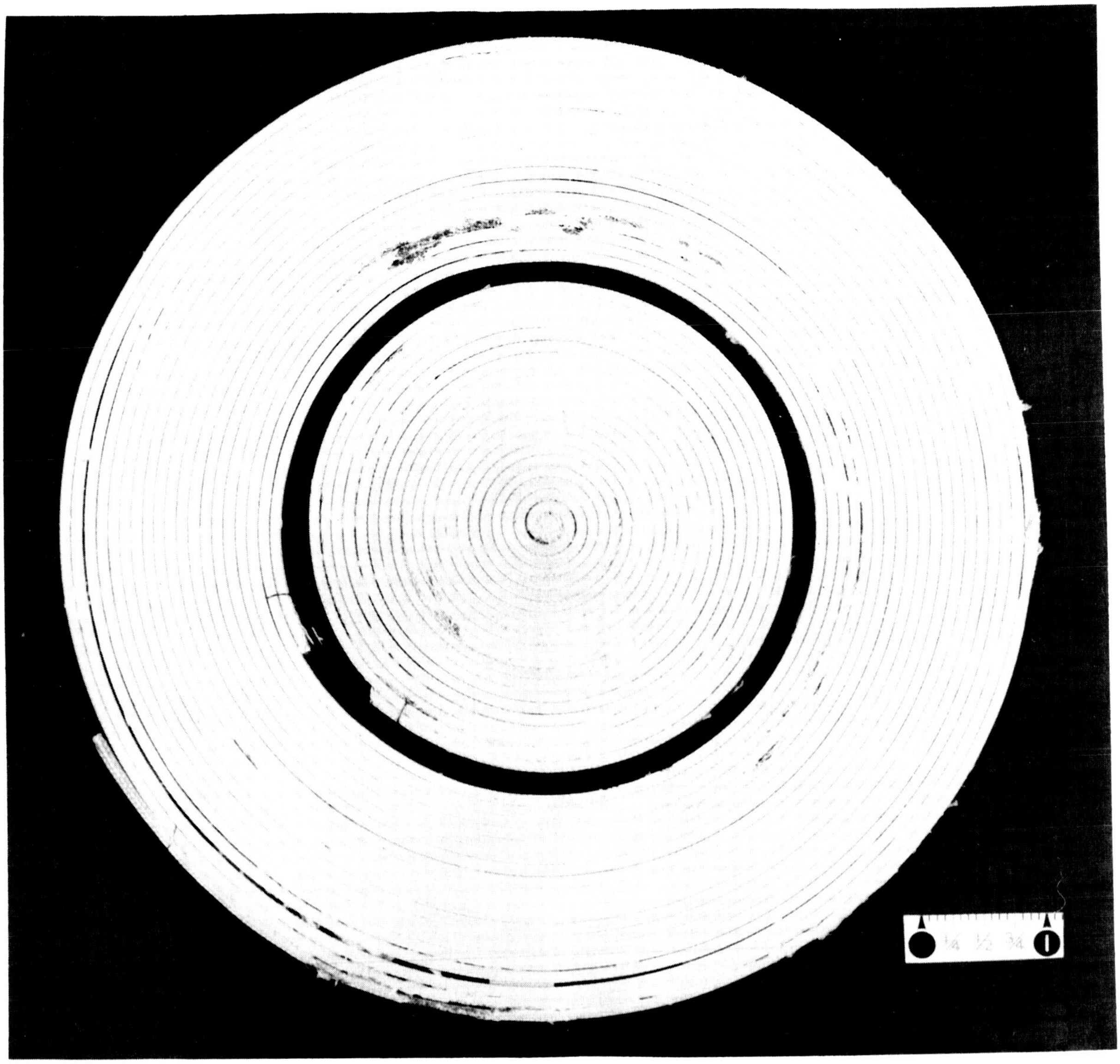
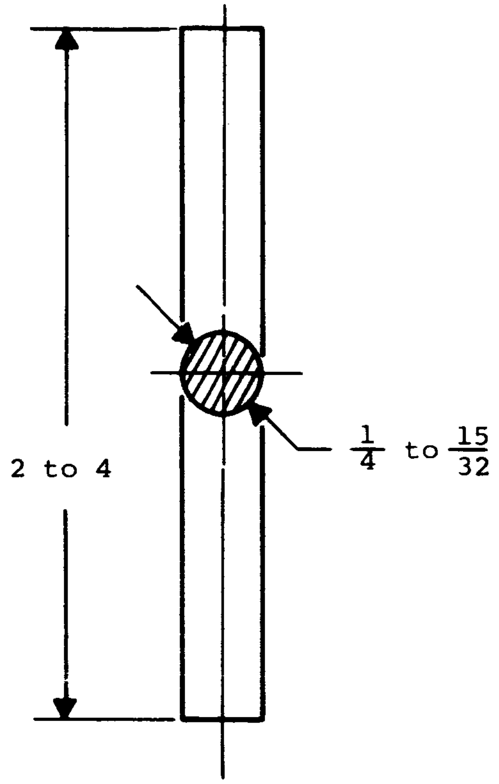
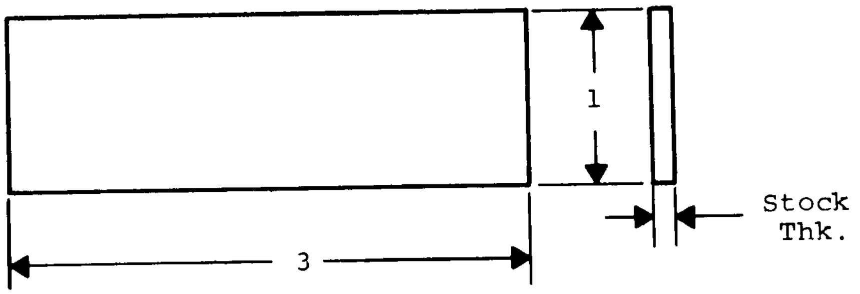


FIGURE III. B-5. Thermal Conductivity Specimen for Insulated Wire



Westinghouse Dwg. Ref. No. EDSK 319794

FIGURE III. B-6. Thermal Expansion Specimen for Electrical Insulations

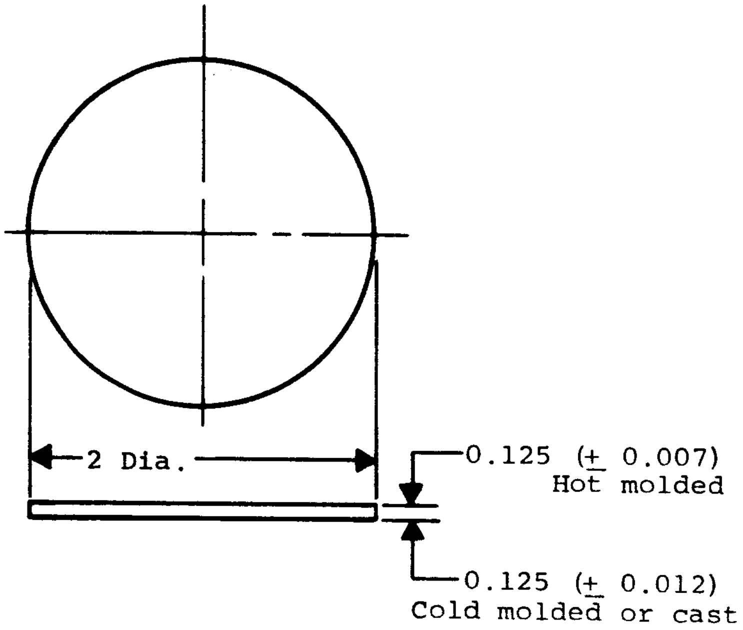


Sheet Plastics

The test specimens actually used for water absorption tests on plastics were, in several cases, irregularly shaped and of non-uniform cross section.

Westinghouse Dwg. Ref. No. EDSK 319797

FIGURE III.B-7. Water Absorption Specimen for Organic Laminates

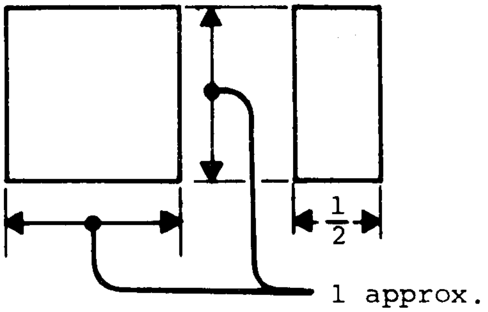


Molded Plastics

The test specimen for rods shall be 1 inch long for rods 1 inch O.D. or less, and 1/2 inch long for larger diameter rods.

Westinghouse Dwg. Ref. No. EDSK 319797

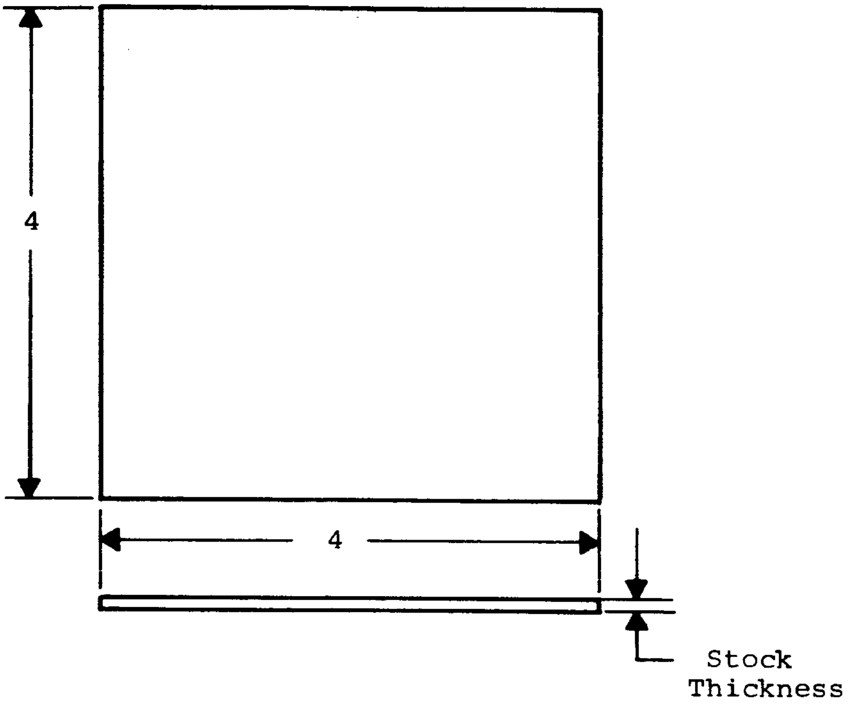
FIGURE III. B-8. Water Absorption Specimen for Organic Moldings



Surfaces unglazed, freshly fractured surfaces as much as is practical, min. wt. 2 oz.

Westinghouse Dwg. Ref. No. EDSK 319796

FIGURE III.B-9. Water Absorption Specimen for Inorganic Rigid Insulations



Westinghouse Dwg. Ref. No. EDSK 319799

FIGURE III. B-10. Electrical Test Specimen for Organic Laminates

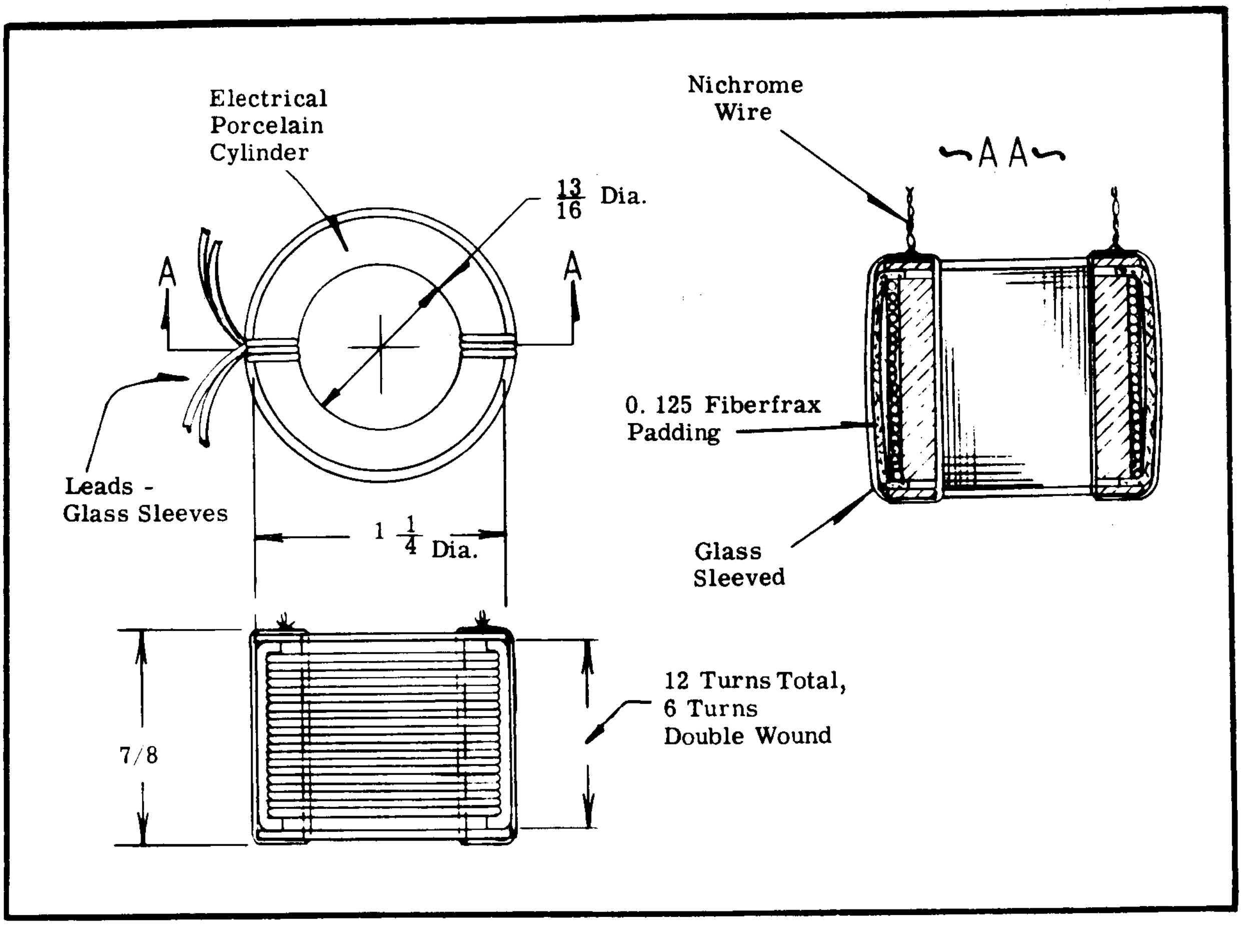


FIGURE III. B-11. Insulation Life Specimen for Inorganic Magnet Wires

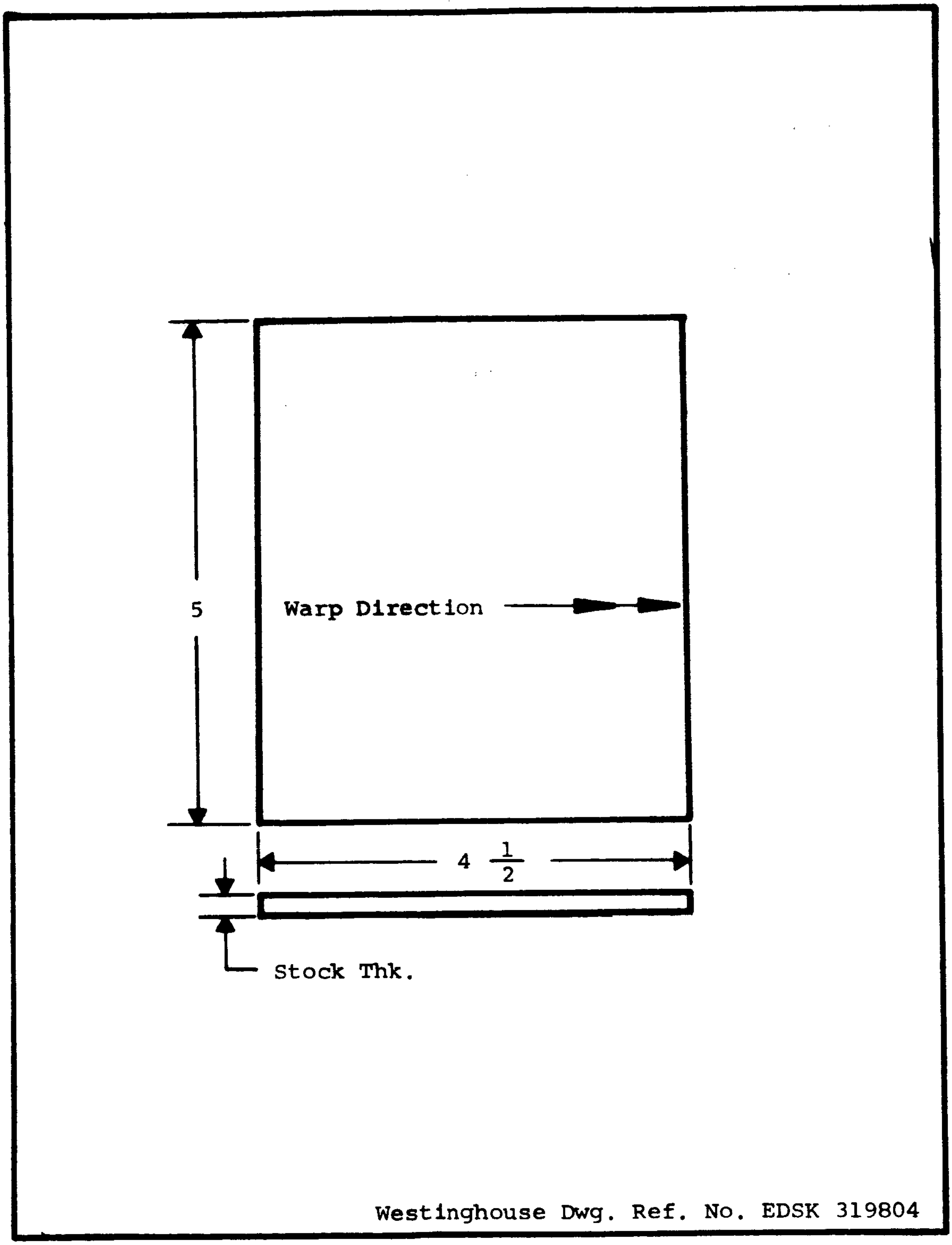


FIGURE III. B-12. Insulation Life Specimen for Organic Sheet Insulation

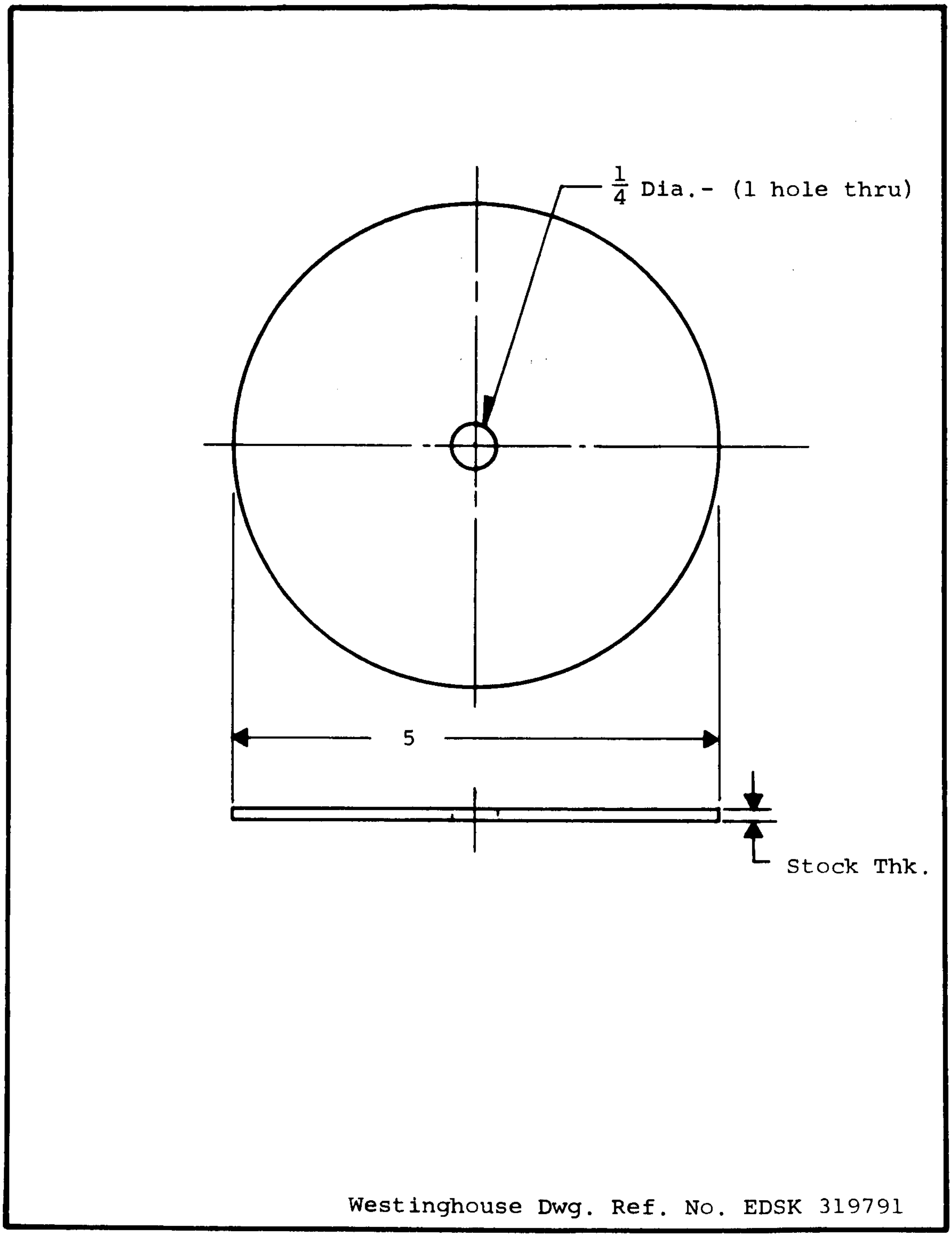
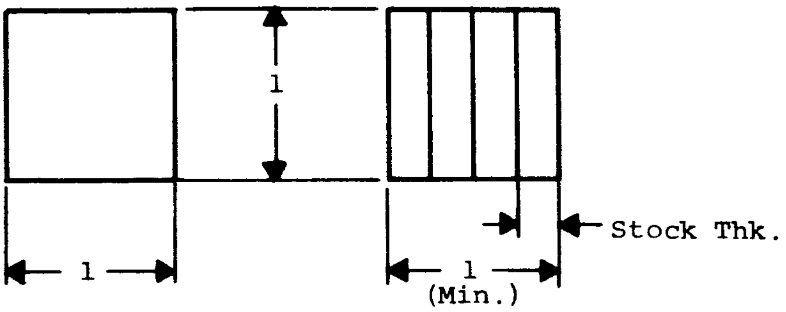


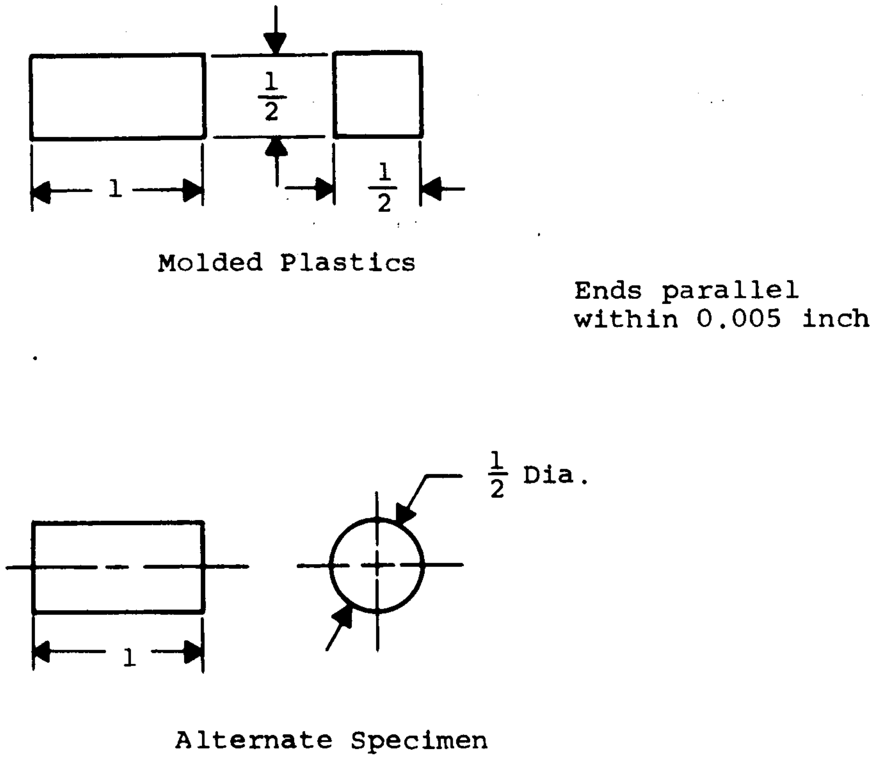
FIGURE III. B-13. Abrasion Resistance Specimen for Sheet Insulation



Rigid Sheet Plastics

Westinghouse Dwg. Ref. No. EDSK 319793

FIGURE III. B-14. Compressive Strength Specimen for Laminates



NOTE: If O.D. is more than 1/2 inch but less than 1 inch, length to be 2 inches.

Westinghouse Dwg. Ref. No. EDSK 319793

FIGURE III. B-15. Compressive Strength Specimens for Organic Moldings and Encapsulants

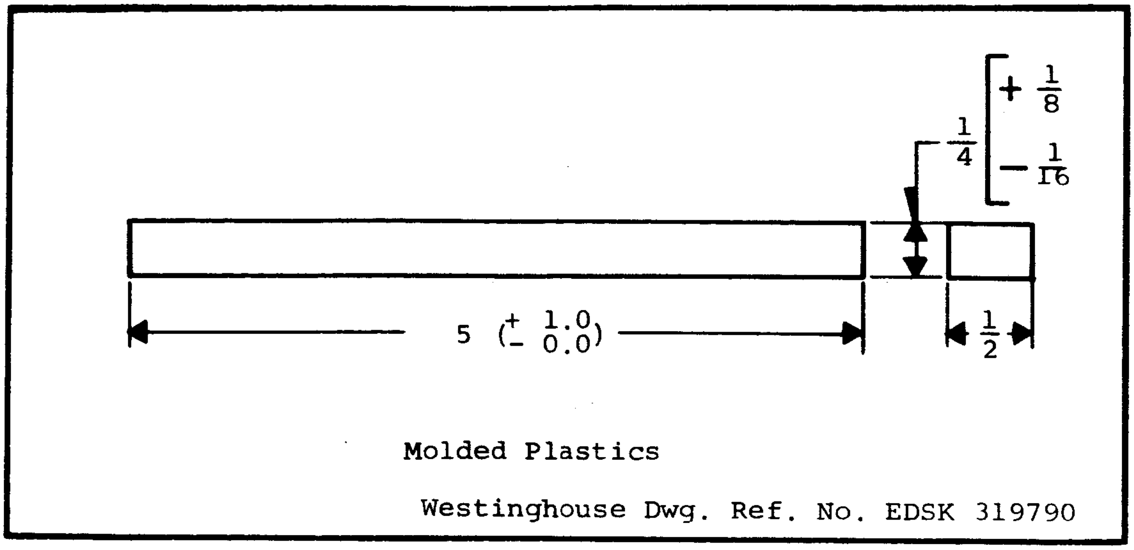


FIGURE III. B-16. Compressive and Flexural Strength Specimen for Molded Insulations

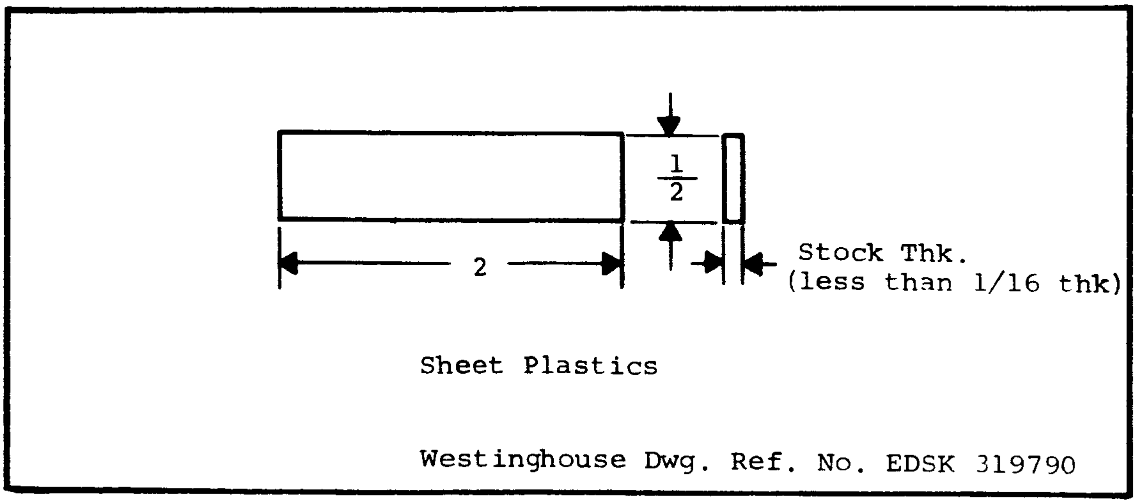
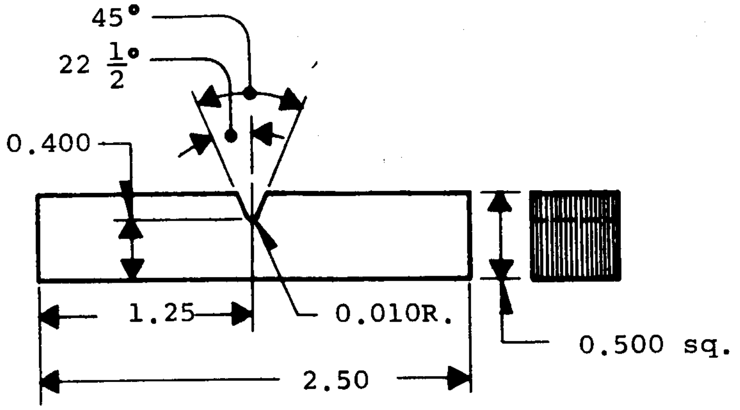


FIGURE III. B-17. Elastic Modulus in Flexure Specimen for Laminates and Moldings



NOTE 1. Pieces less than 1/16 inch thick must be laminated together with a suitable adhesive that does not effect the impact value. (See ASTM D256-56)

2. Pieces more than 1/16 inch thick should be stacked together to form a specimen 1/2 inch thick, but they need not be bonded.

Westinghouse Dwg. Ref. No. 627A090

FIGURE III.B-18. Impact Strength Specimen for Organic Laminates and Moldings

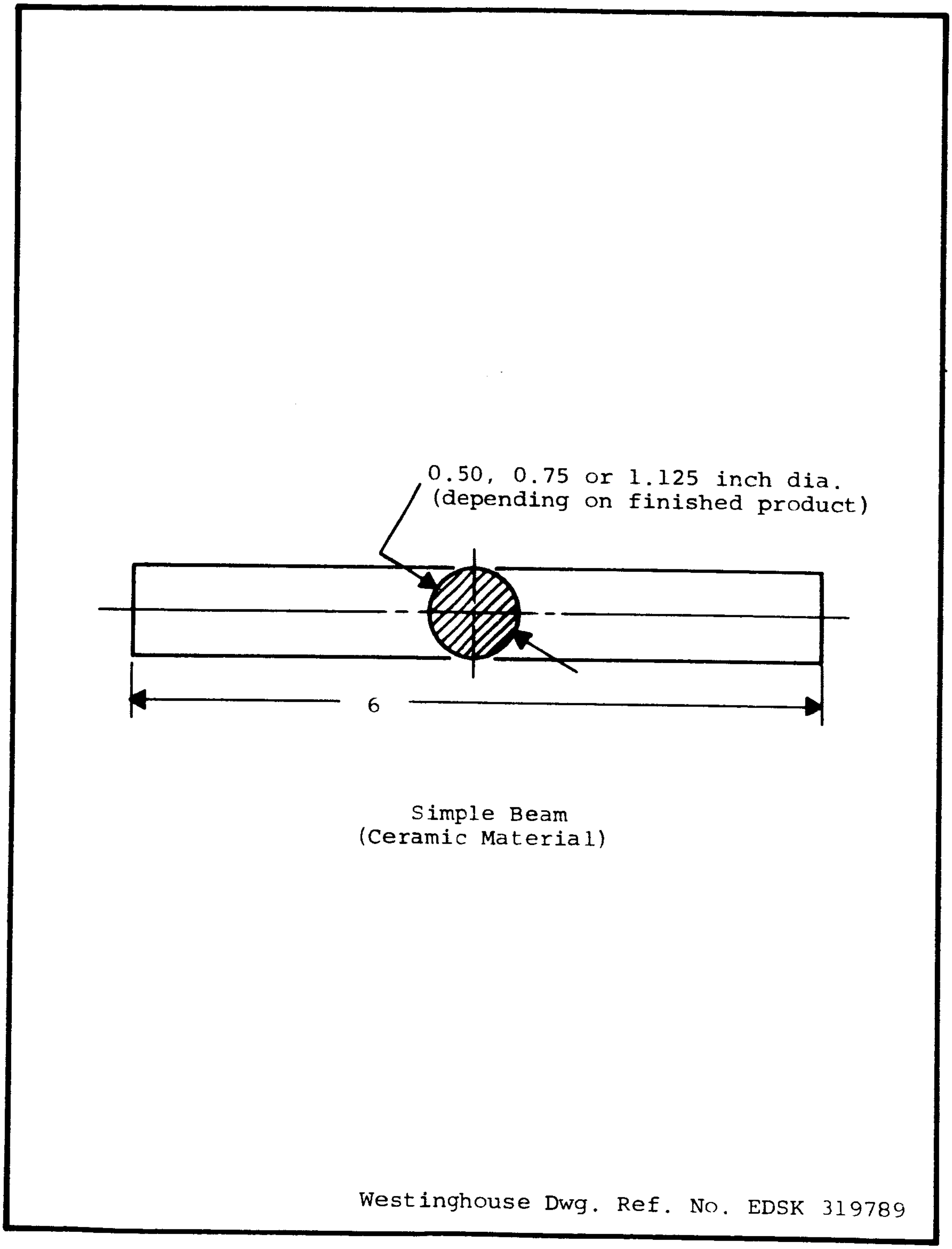
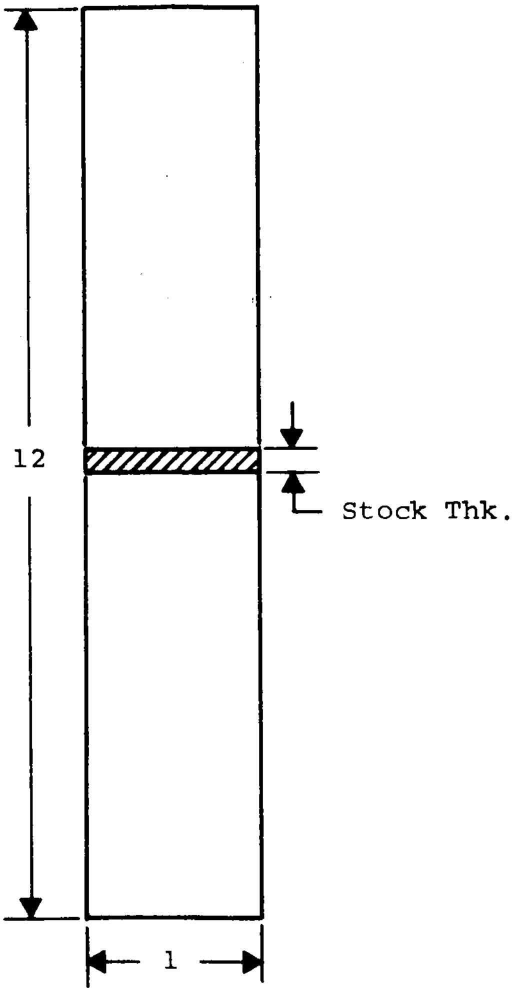


FIGURE III. B-19. Impact Strength Specimen for Inorganic Moldings



Westinghouse Dwg. Ref. No. EDSK 319802

FIGURE III. B-20. Tensile Strength Specimen for Sheet Insulation and Laminates

C. TEST PROCEDURES

1. Conductors

The test procedures used for the conductor portion of NAS 3-4162 followed the ASTM specifications and are listed in Table III.B-1. However, a detailed account of special procedures follows.

a. ELECTRICAL RESISTIVITY

The standard Kelvin Bridge method of ASTM B70 was used for all measurements of electrical resistivity on NAS 3-4162. One refinement was added to ensure accurate data; a vacuum of 1×10^{-4} torr constituted the test atmosphere. Strip and wire materials were wound on a five-eighths inch diameter quartz mandrel, and the balance of the materials simply supported in the furnace hot zone. A Leeds and Northrup Kelvin Bridge was used in measuring the resistance. Short pieces of alumel wire were used in the furnace hot zone and silver wire in the room temperature zone as lead wires. Resistance welding was used to fix the alumel leads to the specimens. The elevated temperature tests were conducted in a vacuum of 4×10^{-5} torr and the average temperature variation over the two inch-long coil was less than ± one percent. All the samples were heated at a rate of 10°F per minute and the resistance of each specimen was measured at 100°F increments with increasing and decreasing temperatures. Preliminary tests on a sample of TD nickel wire showed that the resistance measured at this heating rate duplicated the results obtained by soaking at each temperature increment for twenty minutes. For this reason, all other specimens were tested at a constant heating rate of 10°F per minute. In all tests the integrity of the elevated temperature leads was checked at room temperature by comparing the resistance measured with the special, high-temperature leads and the resistance measured using the standard, room-temperature clamps.

The Kelvin Bridge used for these measurements had a resolution of 10^{-8} ohms.

b. THERMAL EXPANSION

The thermal expansion measurements were made in a quartz-tube dilatometer in which the specimen was heated with a resistance wound furnace. The furnace is stationary, while the horizontal tube and associated measuring apparatus can be moved in and out of the furnace on a rail. The quartz tube is slotted at the closed end so that a two inch long specimen can be placed in it with one end contacting the bottom. A quartz rod, attached to a Statham linear-displacement transducer, is in contact with the other end of the specimen. As the specimen expands, the quartz rod moves, and the transducer measures the amount of movement. The transducer is an unbonded Wheatstone bridge circuit whose sensitivity can be varied by regulating the voltage input. Length changes as small as one micro-inch can be measured. The output of the transducer is recorded on one axis of a Moseley recorder; the output of a chromel-alumel thermocouple wired to the specimen is recorded on the other axis of the Moseley recorder. The resultant curve is then corrected for the expansion of quartz. The temperature rise of the specimen is programmed at 3°C per minute using a Leeds and Northrup program controller. Argon gas is continuously flooded over the specimen to prevent oxidation at the higher temperatures.

c. THERMAL CONDUCTIVITY

This property was only measured on as drawn dispersion-strengthened copper, using the comparison bar technique. In this method the specimen, one-half inch in diameter by four and one-half inches long, is fixed to a heater block through a snug tapered fit. The other end of the specimen is fixed through a threaded connection to a comparison bar of nickel, one-half inch in diameter by four inches long, whose thermal conductivity is known. A heat sink, cooled by circulating water, is fixed to the free end of the nickel rod. The nickel and specimen rod assembly is held in a vertical position with the heater at the bottom. The rod system is surrounded with alumina insulation which is enclosed with a two and one-half inch diameter shield. The shield is made from type 302 stainless steel and nickel. The stainless steel portion is as long as the specimen, and the nickel is as long as the comparison bar. The nickel and stainless steel sections are butt welded with the joint in line with the speciment nickel joint.

A heater is fixed around the shield circumference at this point. Three chromel-alumel thermocouples are fixed to the specimen, the first one-half inch down from the nickel joint and the remaining two at one inch intervals below the first. Four thermocouples are fixed to the comparison bar, the first one-half inch above the specimen joint and the other three at one inch intervals above the first. Seven thermocouples are similarly placed on the shield at the same height as those on the bars. The entire assembly is set on alumina insulation which is on a steel base plate and surrounded with a five inch inside diameter Transite tube. The area between the shield and the Transite tube is filled with alumina insulation. A bell jar is placed around the Transite pipe and the system evacuated.

As the heater temperature rises, the specimen temperature rises, and heat flows up the specimen through the joint and to the water sink at the end of the nickel bar. Unidirectional heat flow up the specimen is obtained by adjusting the heaters on the shield and the heater block, and the water flow. The thermocouples on the bar and shield at the same height are maintained at equal temperatures, and this prevents radial heat flow. After these conditions have been established for about four hours at a test temperature, all thermocouples on the comparison bar and the specimen are read and recorded. The thermal conductivity of the specimen is then computed.

d. TENSILE PROPERTIES

All properties which are normally determined in tension and compression were determined in strict accordance with ASTM procedures. Strain rated were 0.005 inches/inch-minute to the yield strength and 0.05 inches/inch-minute above the yield.

e. CREEP TESTING

All creep testing performed on NAS 3-4162 exceeded the ASTM specifications for creep in an inert argon atmosphere. The additional attention to detail was mandatory if reliable creep strains of 0.20 and 0.40 percent were to be obtained in the desired times. Both spring and lever machines were used and specimens were thermocoupled and instrumented with an extensometer. A number of checks were performed during the program to verify the performance of the creep test equipment.

Two pieces of Billet No. 4C804T1 were obtained from the Creep Rupture Specimen Bank of the ASTM/ASME Joint Committee on

Effect of Temperature on Properties of Metals. These pieces were sectioned and tested according to instructions. The mean rupture life in spring machines was 102 hours and the mean rupture life in lever machines was 116 hours. Both values fall within the 95 percent confidence limits established by the Committee for this material. The material used for these tests was type 304 stainless steel and it was tested in the following manner. The samples were placed in the machines heated to 1300°F, and left unloaded overnight. The following morning the temperature was raised to 1350°F, held for one hour and then the specimens were loaded to 13,500 psi.

f. STABILITY TESTING

Stability tests were performed on the various conductors at temperatures of 800, 1000, and 1600°F in air or argon atmosphere depending on the test temperature and the specific conductor. All 1600°F tests were conducted in argon and all 800°F tests were conducted in air. The atmosphere tests were conducted in double-wall containers to eliminate the possibility of specimen loss due to failure of one of the capsules.

Duplicate twenty-four inch lengths of resistivity samples were wound together (into a coil) over a three-quarter inch mandrel, removed from the mandrel, and placed inside a Vycor capsule. Each capsule was evacuated three times and back-filled with a partial pressure of argon gas and sealed. The pressure was calculated to exert one atmosphere of pressure on the capsule walls at 1000 or 1600°F. The fill pressure depended on the test temperature. The sealed capsules were loaded into stainless steel secondary capsules which were welded and an argon line was attached to each secondary capsule. Stability testing was performed in electrically heated furnaces. Specimen temperature was controlled by checking the internal temperature of the retort and then controlling the furnace temperature to achieve the desired internal temperature. Air stability testing was performed in carefully baffled electric furnaces with the duplicate wound coils supported on mandrels to separate them from other types of conductors being aged in the same furnace. Room temperature resistivity was measured after test and compared with an initial value measured on one control sample wire.

g. INERT GAS PURITY

Argon gas used for all tests requiring inert-gas protection was certified to the following analysis by the Air Reduction Company.

Oxygen	10 ppm maximum
Hydrogen	5 ppm maximum
Nitrogen	40 ppm maximum
Carbonaceous gases	3 ppm maximum
Dew Point	-80°F maximum

2. Electrical Insulation Materials

Section III. B. 2. described the specimen configuration and listed the standard test methods used in this program. This section describes the non-standard test procedures which were necessary for adequate evaluation of material properties.

a. DENSITY - LAMINATES, ENCAPSULATIONS, AND MOLDINGS

The density tests were performed according to ASTM D792. Paragraph 6 (a) of that specification states: "The test specimen shall consist of a piece of the material cut to any convenient shape such that the specimen will fit in the test apparatus and weigh from 1 to 5 grams."

b. THERMAL CONDUCTIVITY - MAGNET AND LEAD WIRES

The apparent transverse thermal conductivity of insulated wires was determined according to ASTM C177 with a significant modification in specimen configuration. The normal sheet specimens were discs four inches in diameter associated with surrounding guard ring specimens measuring eight inches outside diameter and four and a quarter inches inside diameter as shown in Figure III. B-4. As a means of obtaining a comparative value for thermal conductivity of coated wire, spiral windings of the sample wire were prepared as illustrated in Figure III. B-5. The tests were performed on a model TCFG-R18 thermal conductivity tester developed by Dynatech Corporation with some modification by Westinghouse. The device is a guarded hot-plate apparatus in which a four-inch diameter flat main heater is surrounded by a two-inch wide circular guard heater. The function of the guard heater is to eliminate radial outward heat losses and to force the heat generated in the main heater in a unidirectional flow through the two test specimens which are placed on either side of a flat plate circular heater assembly. The main heater power is varied by use of an adjustable autotransformer which is, in turn, supplied from a constant voltage regulator.

The guard heater is controlled so that the temperature of the sample surface adjacent to the main heater is identical with that of the test specimen surface adjacent to the guard heater. A thermal balance is maintained between the main and guard heater by use of a star differential thermocouple. The junctions of the star alternate between the main and guard heater surface so as to produce opposing emf outputs from each junction. Thus, when the guard and main temperatures coincide, a net balance between the guard and main heater produces a null signal from the star thermocouple.

To provide for heat rejection and to produce a desired temperature gradient across the samples, liquid-cooled heat sinks are placed adjacent to the sample outer surfaces. For higher temperature operation, various insulating materials may be placed between the samples and their corresponding heat sinks. Temperatures at various points on the sample can be obtained from the reading on a potentiometer. These temperatures are also recorded on a multi-point Minneapolis-Honeywell multivolt recorder to aid in determining when equilibrium has been reached.

The thickness of the specimen is not critical but generally a higher conductivity material will require that a thicker specimen be used to obtain a reasonable temperature difference across the sample. Thermocouples are installed in various locations on either face of the two specimens; one on each face of each specimen in the main heater area. Four additional thermocouples are in the main heater area to insure that an average temperature measurement is used since small variations sometimes occur, especially in non-homogeneous or anisotropic materials; and to provide extra thermocouples in case any one thermocouple should become discontinuous during a test. Four thermocouples are also located on the guard section of the samples or the surface facing the guard heater which serves as an independent check on the star differential thermocouple.

Two identical specimens are required to run a test. Each specimen is approximately eight inches in outside diameter. The temperature difference across the sample is maintained in the range between 40 and 150°F. If the temperature difference is less than 40°F, thermocouple inaccuracies become important, and if greater than 150°F, the data represents an average conductivity rather than an instantaneous value. The latter is important especially if the conductivity versus temperature is not linear.

Thermal conductivity is computed from (1) the temperature on each face of the two specimens, and (2) total power input into the main heater. The test area of the specimen is fixed (four-inch diameter) and the thickness is measured.

It is recommended in the study of a particular insulation application that thermal conductivity be determined using the wire specimen encapsulated with a compatible compound. This would be closely representative of the conditions encountered in the typical wound apparatus.

c. INSULATION LIFE - INORGANIC MAGNET AND LEAD WIRES

Insulation life of wire insulations are most often determined by subjecting carefully prepared windings to proof testing at a preset voltage. Organic wire enamels are tested as noted in Table III.B-2 in the form of pairs of wire twisted together. This method is described in detail in IEEE 57 test specification. The twisted pair technique is not well-suited for inorganic wire insulation evaluation. The preparation of twisted pairs includes some elongation of the wire and coating in an attempt to simulate the effects of winding machinery. The inorganic magnet wire coatings do not elongate thus producing cracks and some separation of the insulation from the conductor. Therefore, to evaluate these coatings in a more representative manner, the following technique was used. A pair of specimen wires were wound, side by side, in a single layer on a refractory core. Care was taken to maintain even tension and parallel alignment of the bifilar windings. Specimen design is shown in Figure III. B-11.

Five coils per wire type were proof-tested every 200 hours at 200 volts and 60 cycles per second. The summary sheets in Section V. A. report the life data determined by this method.

Lead wire specimens were prepared as bifilar windings similar to those described above. The specimens were proof-tested at 750 volts at 200 hour intervals. Section V. B. contains the life data for the two lead wires examined.

d. INSULATION LIFE - INORGANIC RIGID LAMINATES AND INORGANIC ENCAPSULANTS

Volume resistivity measurements were used as indication of insulation life for inorganic rigid laminates and the inorganic encapsulants. The specimens were aged in air at temperatures established at the beginning of the program and believed representative of practical use temperatures. The electrical tests were performed according to ASTM D257 as stated in Section III. C. 2. e. Volume Resistivity. The specimens were approximately 0. 1 to 0. 25 inch thick. The particular specimen thickness is reported in Section V., Material Properties Summary. The electrodes were painted-on silver suspension of one square inch area. These electrodes were not satisfactory at exposure temperatures above 900°F and required replacement with gold electrodes on the latter stages of aging.

e. VOLUME RESISTIVITY - INORGANIC RIGID LAMINATES AND INORGANIC ENCAPSULANTS

Volume resistivity measurements were made according to ASTM D257. Paragraph 6 (b) of that specification states: "for the measurement of volume resistance, the test specimen may have any practical form which allows the use of a third electrode to guard against error from surface effects, when necessary. Material test specimens shall be in the form of flat plates, tapes, or tubes."

f. ABRASION RESISTANCE - LEAD WIRE

Abrasion tests normally performed upon enameled wire are not suitable for heavily jacketed wires such as lead wire. A modification in method of applying typical forces to the insulation coating has been used by Westinghouse for abrasion testing of glass-served and wrapped wires. The apparatus, shown in Figure III. C-1 consists of twelve bars one-half inch in diameter and

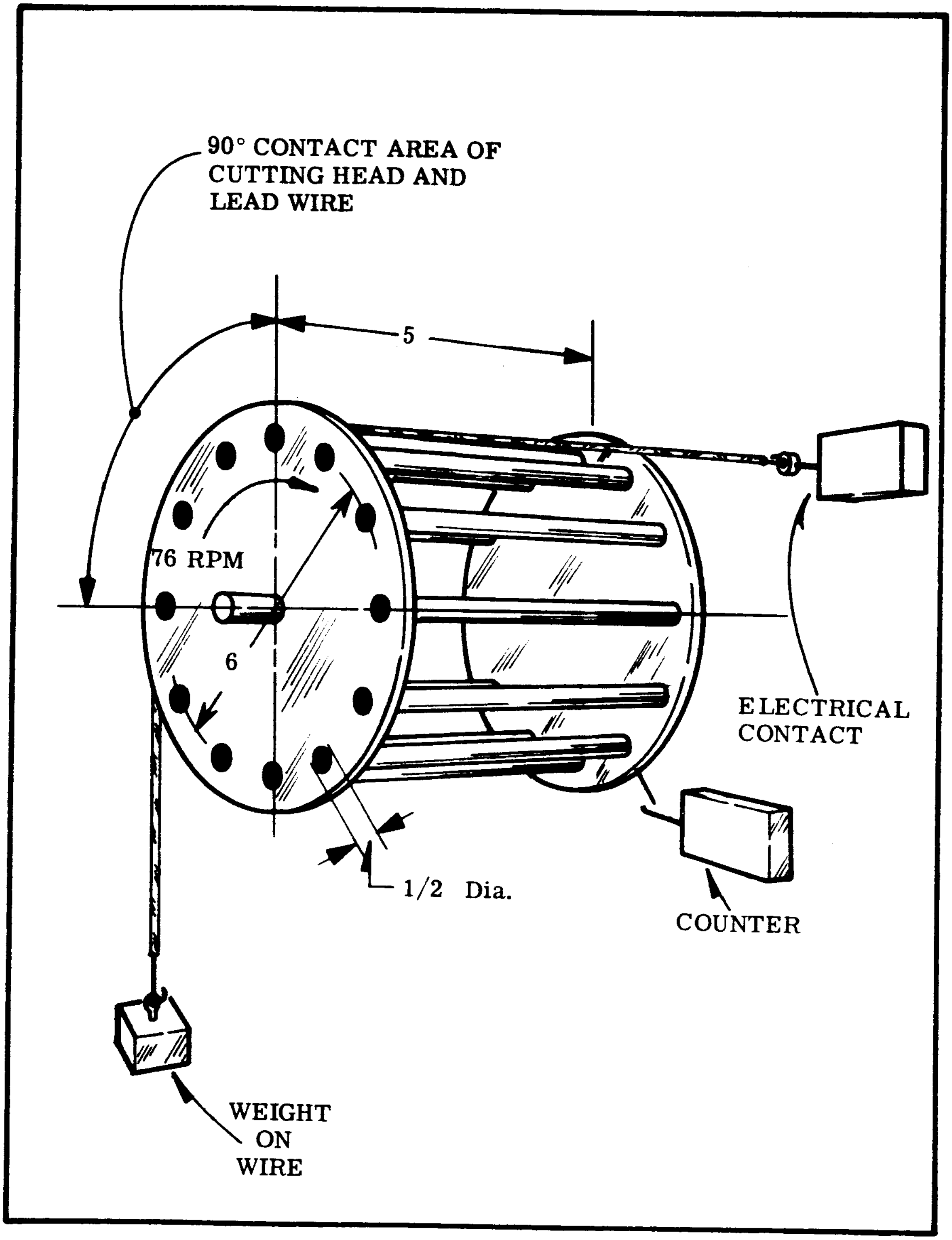


FIGURE III.C-1. Lead Wire Abrasion

two inches long. These bars are equally spaced near the periphery of two laminated plastic discs and connected electrically to ground. The diameter of the circle of center lines of these bars is six inches. The assembled cage revolves at 76 rpm. The specimen wire is attached to an electrical contact and then passed over a ninety degree arc of the revolving cutting head described above. A weight is suspended on the end of the wire to maintain pressure on the cutting head. As the insulation wears, electrical contact is finally attained and the rotating ceases automatically. The data is reported in the number of revolutions of the cutting head to abrade through the insulation with a given weight attached to the wire.

g. ABRASION RESISTANCE - SHEET INSULATION

The abrasion resistance of flexible sheet insulation is not usually determined by standard tests. During winding and other manufacturing operations and during service, some abrasion is encountered. A means of comparison of relative durability was sought. The rotary platform, double head method, described in ASTM D1175 appeared to be most suited. Specimens, as shown in Figure III. B-13, are easily prepared and repetitive tests may be determined readily. The size of the specimens permitted determination of electric strength before and after the abrasion testing. The abrasive medium selected was the CS17F grade wheel. Wheel loading weights and number of wear cycles were varied as shown in the applicable data summary sheets. Electrical tests were performed with one-quarter inch electrodes and rapid rate of voltage rise.

h. CUT THROUGH RESISTANCE - SHEET INSULATION AND MAGNET WIRE

Numerous devices have been proposed and operated to compare and evaluate the resistance of electrical insulation to deformation or cut through which may lead to premature electrical breakdown. The devices include those which vary temperature with pressure held constant and the reverse, in which loading is varied and temperature maintained at a controlled steady value or at a controlled rate of rise. The breakdown event is generally signaled by completion of an electrical circuit. The test systems have varied in the voltage imposed upon the test specimen. Voltages used for the proof test have ranged from a few volts to a few kilovolts.

In the test performed in NAS3-4162 weight and voltage were held constant as the test assembly was heated at a reproducible rate of rise. The test assembly is illustrated in Figure III.C-2.

The test wires used in this evaluation were bare 18 AWG nickel wire. The test wires were connected to a 110-volt, 60 cycle, a-c circuit, passing through an elapsed time meter. Loadings, times of failure, and final temperature attained are reported in the applicable material summary. This method is recommended for comparison of organic sheet and wire insulations. It appears to be satisfactory for inorganic wire coatings but inorganic sheet may yield excessively erratic values.

i. THERMAL SHOCK-ENCAPSULATION COMPOUNDS

Thermal shock caused by rapid transition from different ambient temperatures, produces mechanical stresses which may be too severe for some material systems. Organic encapsulations were evaluated by the Minnesota Mining and Manufacturing Company's washer test. This method is described in RI 239.

A version of this test method was used for the inorganic compounds evaluated in this program.

Cakes of compounds were prepared which included one-half inch hexagonal steel bar emerging vertically from the material. A test consists of three cycles of heating to maximum temperature at a rate of approximately 10°F per minute and immediate removal to room temperature. The two maximum test temperatures were 1200 and 1600°F. The number and magnitude of cracking were the rating criteria.

j. WEIGHT LOSS IN VACUUM

An apparatus has been assembled for measuring weight-loss rates in vacuum for electrical insulation materials at temperatures up to 1600°F. It has incorporated into it a magnetic balance which makes possible a continuous determination of weight-loss without loss of vacuum at intervals to remove and reweigh the specimen. The apparatus is represented schematically in Figure III.C-3.

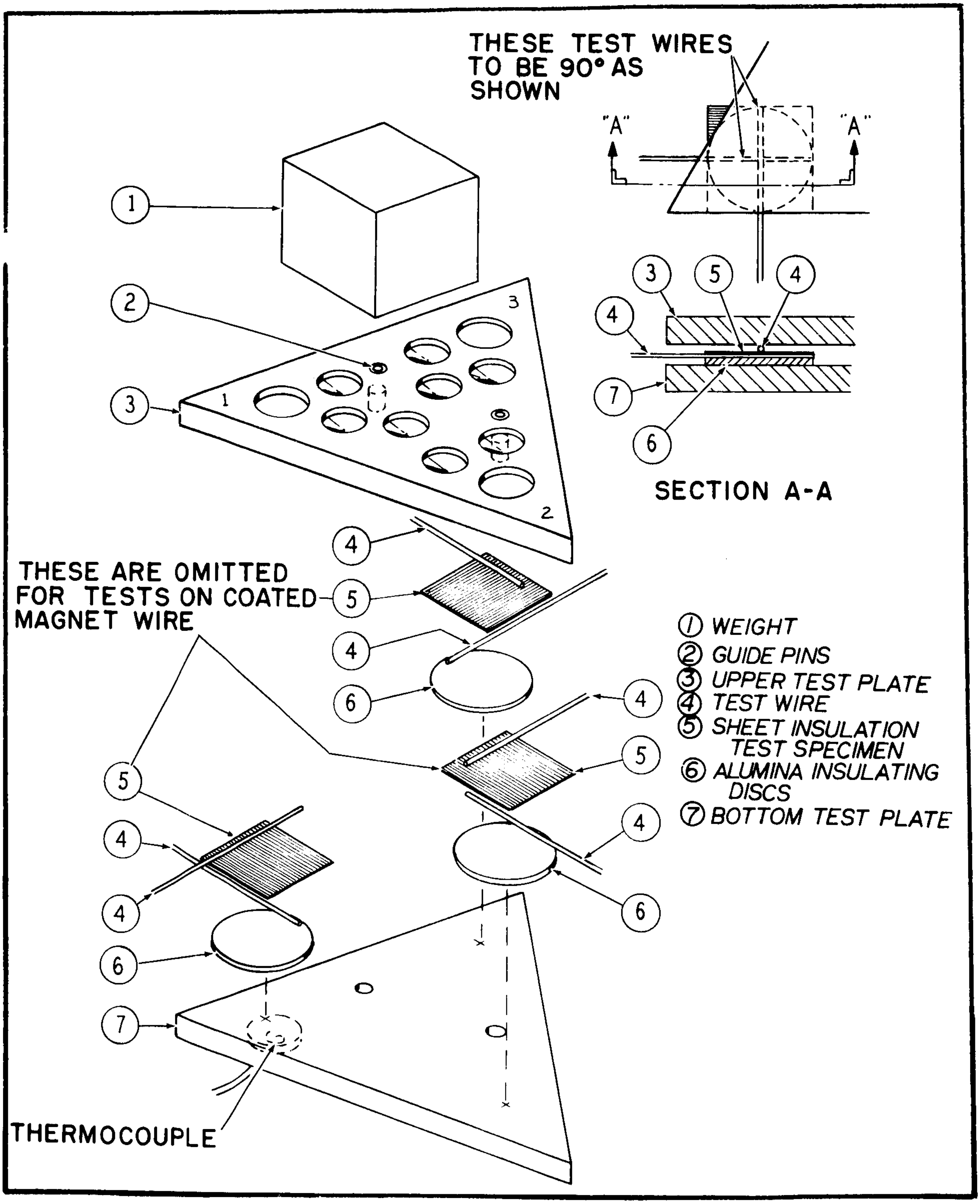


FIGURE III. C-2. Cut-Through Test Assembly

A loss in weight of the sample is reflected and measured by measuring the decreased coil current required to keep the balance at equilibrium. A very sensitive variable leak has been built into the system to allow determinations to be made at various pressures and in any desired atmosphere. The use of two liquid nitrogen traps in conjunction with the forepump and diffusion pump have produced a vacuum of 5×10^{-7} torr in this system.

The amount of water or other solvent absorbed on a sample is greatly dependent not only on the extent of cure it has received, but also on its storage history. For this reason, the weight-loss "zero point" of all inorganic samples was taken after they had been heated for 16 hours at 212°F under vacuum in the test apparatus. The temperature was then raised to that required in the test. The sample was held at test temperature for at least 21 hours or until a definite weight-loss trend was established. Most of the loss took place within the first three hours. The results of the weight-loss tests are plotted as milligrams-lost-per-square-centimeter of sample surface versus time-in-hours at stated temperature and pressure. Most of the measurements were made at pressures in the 10^{-5} to 10^{-6} torr range.

One insulation, 92M rigid sheet, was tested at 10^{-6} torr and also in a helium atmosphere of 10^{-3} torr to determine if there is any significant difference in weight-loss at these two pressures. These curves are shown in Figures V.D. 1-12 and V.D. 1-13. The similarity of the amount of weight-loss at these two pressures, at 1560°F, indicates that reducing the pressure any further would have little or no effect on the weight-loss. This similarity in weight-loss is to be expected since even at room temperature and 10^{-3} torr, the molecular population density is very low. At these conditions, the average distance which an escaping molecule travels before encountering another molecule is of the order of centimeters. At 10^{-4} and 10^{-5} torr this distance increases to 50 and 500 centimeters, respectively. At higher temperatures, this distance is even greater. So, for all practical purposes, a molecule leaving the surface at 10^{-5} torr is as lost to the insulation body as it would be at pressures encountered in deep space. Because of these considerations, no measurements were made at pressures lower than 10^{-6} torr.

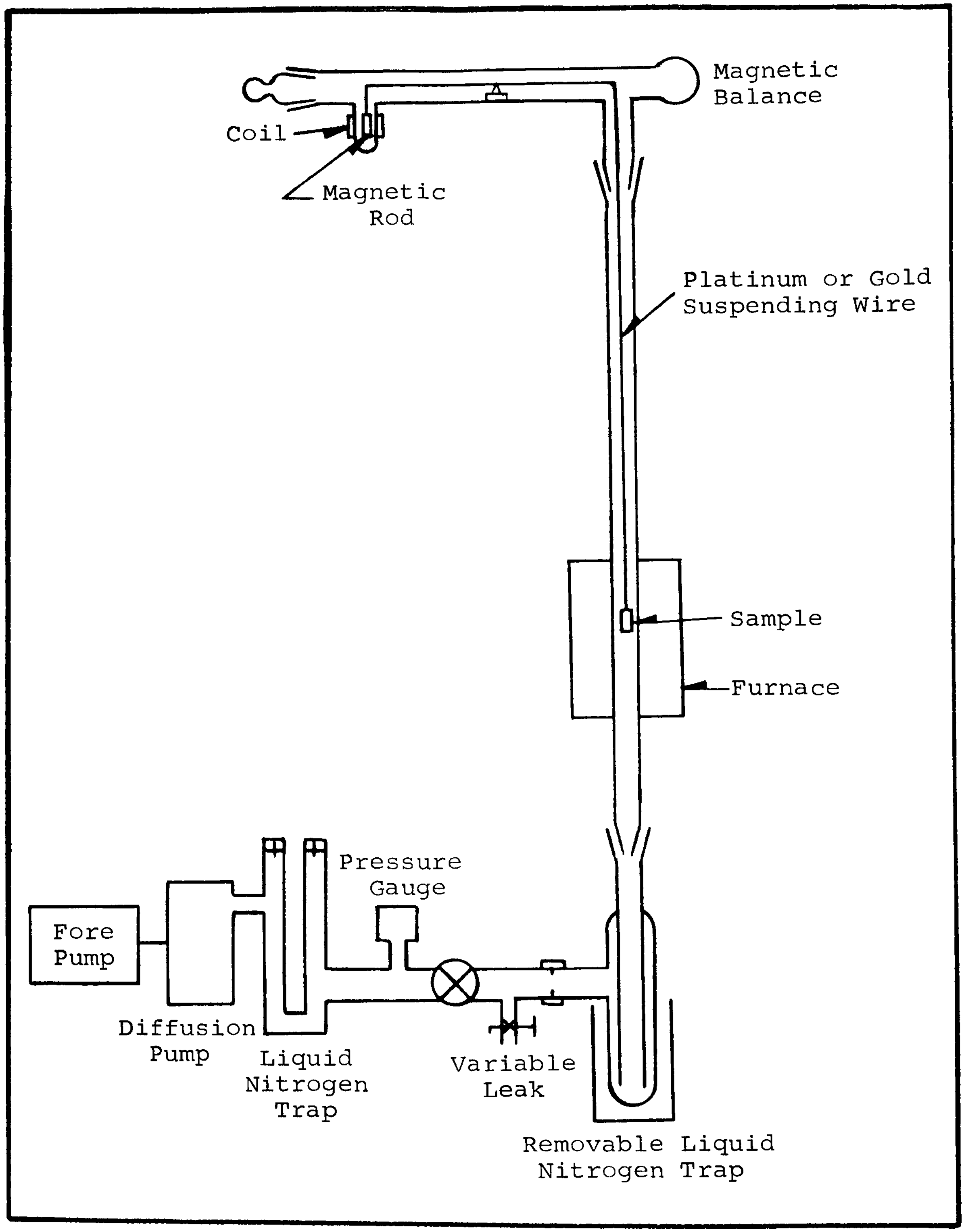


FIGURE III. C-3. Vacuum Weight Loss Apparatus

In a tubular chamber such as used, the wall temperature becomes a factor. Cold walls collect the molecules given off. However, walls at temperatures higher than the specimen temperature reject most of the outgassed molecules which strike the hot wall. The molecules then either are carried off to the pump, or to the cold wall zone, or return to the specimen. The molecular collection capacity represented by the sum of the large area of cold wall plus the pumping volume is many times larger than the capacity for the hot wall area to return outgassed molecules to the specimen. Thus, the error induced by limited hot-wall area in this assembly is negligible for weight-loss studies of this time duration.

SECTION I V

ELECTRICAL CONDUCTOR MATERIALS PROPERTIES SUMMARIES

This section presents the electrical conductor material properties. Table I V-1 is an index of the electrical conductor material properties by page number. The property data for each material are classified as thermophysical, electrical, and mechanical. Each material presentation is headed by a MATERIALS PROPERTIES SUMMARY where a synopsis of important parameters is available. This is valuable in screening and selecting those properties warranting further detailed analysis. This summary is thought important because the data presented in tabular and graphic form on each material are quite extensive.

The figure and table number system used in presenting and categorizing data is as follows:

I V. A-1

Section

Figure No. or Table No. within each of the seven conductor types

A. Nickel-clad copper

B. Type 321 stainless-steel-clad silver

C. Type 304 stainless-steel-clad zirconium copper

D. Cube Alloy (copper - 1 volume percent beryllia)

E. Dispersion-strengthened nickel (TD Nickel)

F. Inconel 600-clad, columbium-barrier dispersion-strengthened copper (copper - 1 volume percent beryllia)

G. Inconel 600-clad silver

No text is included in this section so that it can be used as a design manual. The technical discussion on each material can be obtained in Section I I. B. 2 where the same letter (substituting a, b, c & etc.) corresponding to the material letter given above can be consulted for specific comments on the material. The references are given on each figure or table crediting the source of data.

In preparing for the experiment, an analysis was made of the test to be conducted. All equipment calibrations were checked to insure that they were traceable to the Bureau of Standards or other accepted standards. Test procedures were evaluated so that systematic errors could be minimized. Test points were selected to provide the best statistical inference. Since the broad scope of the program required an exceedingly large number of tests, it was not possible to minimize all the random errors. In general, sufficient replication was undertaken in those areas where additional confidence was needed. It is expected that all systematic errors should fall within two percent of the reported data.

A least-square, curve fit program for the IBM 7040 computer was applied to much of the data. In addition, the computer calculated polynomial equations from first order to fifth order. The respective errors for each tabulated point was then calculated. From this information the equation which best fit the test data was selected. In general, the order selected would yield an error of five percent or less. Selected polynomial expressions are printed on their respective curves for ease in using the data in computer programs or in rigorous hand calculations.

Stability tests on certain conductor materials are presented. Because of the sensitivity of these tests, a technical understanding of the material is important. Therefore, an interpretation of these characteristics can be found in paragraph II. B. 1. a.

TABLE IV-1. Index To Electrical Conductor Material Properties By Page Number

MATERIAL NAME	I. THERMOPHYSICAL PROPERTIES					II. ELECTRICAL PROPERTIES		III. MECHANICAL PROPERTIES	
	Material Property Summary	Density	Solidus Temperature	Thermal Conductivity	Thermal Expansion	Electrical Resistivity	Aging Tests	Tensile Properties	Creep
A. Nickel-Clad Copper	175	175	175	(a)	180	179	175	181, 182	(a)
B. Type 321 Stainless-Steel-Clad Silver	183	183	183	(a)	190	189	183	191, 192	(a)
C. Type 304 Stainless-Steel-Clad Zirconium Copper	193	193	193	(a)	204	202, 203	193	205, 206	(a)
D. Cube Alloy (Copper - 1 Volume Percent Beryllia)	207	207	207	217	218	216	208	219, 220 221, 222	223, 224 225
E. Dispersion-Strengthened Nickel (TD Nickel)	227	227	227	233	234	232	228	235	236
F. Inconel 600-Clad Columbium-Barrier, Dispersion-Strengthened Copper	237	237	237	245	244	243	238	246, 247	(a)
G. Inconel 600-Clad Silver	248	248	248	257	256	254	255	258, 259	(a)

(a) - Not Determined

ELECTRICAL CONDUCTOR MATERIALS PROPERTIES SUMMARY

A. NICKEL-CLAD COPPER (28 PERCENT)

Availability:	Commercial
Nominal Composition:	Oxygen-free high-conductivity copper clad with 'A' nickel. Clad is approximately 28 percent of conductor area.

I. Thermophysical Properties

A. Density 0. 320 lb/cu in - 8. 89 grams/cc

B. Solidus temperature of lowest melting constituent. 1980°F

C. Electrical Resistivity

Temperature (°F)	Resistivity (ohm-cm)(RC5)
72	2.56×10^{-6}
500	4.33×10^{-6}
800	6.15×10^{-6}
1000	7.32×10^{-6}

D. Thermal Expansion (100–1000°F) 10.0×10^{-6} in/in-°F

II. Electrical Properties

A. Effect of time at temperature on resistivity at temperature. (No. 18 AWG wire)

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at Temperature (ohm-cm)(RC47)
752	100	Air	6.35×10^{-6}
752	500	Air	6.35×10^{-6}
752	1000	Air	6.35×10^{-6}

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at Temperature (ohm-cm)(RC47)
932	100	Air	7.2×10^{-6}
932	500	Air	7.2×10^{-6}
932	1000	Air	7.2×10^{-6}
1112	100	Air	8.1×10^{-6}
1112	500	Air	8.3×10^{-6}
1112	1000	Air	8.6×10^{-6}

III. Mechanical Properties

A. Tensile Properties of No. 10 AWG wire. Strain Rate = 0.005 in/in-min. to yield and 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	10,500 psi
b.	Tensile strength	40,200 psi
c.	Elongation in 2 inches	35.4 percent

2. At 500°F

a.	0.20 percent offset yield strength	9,000 psi
b.	Tensile Strength	31,400 psi
c.	Elongation in 2 inches	32.4 percent

3. At 800°F

a.	0.20 percent offset yield strength	8,950 psi
b.	Tensile strength	24,800 psi
c.	Elongation in 2 inches	29.7 percent

4. At 1000°F

a.	0.20 percent offset yield strength	7,050 psi
b.	Tensile strength	13,950 psi
c.	Elongation in 2 inches	31.7 percent

B. Creep

Use of this material under heavy mechanical loads is not anticipated.

TABLE I V. A-1. Electrical Resistivity of Aged and Unaged Nickel-Clad (28 Percent of Cross-Sectional Area) Copper Wire. See Figure II. B-2.

Test Temperature (°F)	Test Time (hours)	Test Atmosphere	Resistivity at Temperature (ohm-cm)
		Aged Wire	
752	100	Air	6.35×10^{-6}
752	500	Air	6.35×10^{-6}
752	1000	Air	6.35×10^{-6}
932	100	Air	7.20×10^{-6}
932	500	Air	7.20×10^{-6}
932	1000	Air	7.20×10^{-6}
1112	100	Air	8.10×10^{-6}
1112	500	Air	8.30×10^{-6}
1112	1000	Air	8.60×10^{-6}
		Unaged Wire(a)	
72			2.56×10^{-6}
500			4.33×10^{-6}
800			6.15×10^{-6}
1000			7.32×10^{-6}

(a) As Drawn.

(Reference: RC5, RC47)

TABLE I V. A-2. Tensile Test Data for Nickel-Clad Copper Wire. Cladding is 28 Percent of Conductor Cross-Sectional Area.

Test: ASTM E21 - Strain Rate: 0.005 in/in-min to yield then 0.05 in/in-min to failure

Specimen No.	Diameter (Inches)	Test Temperature (°F)	0.02 Percent Offset Yield Strength (Psi)	0.20 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	0.1019	72	6,400	10,450	40,000	35.4	66.5
2	0.1016	72	8,150	9,900	40,050	34.6	84.5
3	0.1015	72	9,400	11,100	40,800	36.3	74.8
4	0.1018	500	5,300	8,250	32,100	31.6	54.1
5	0.1019	500	6,850	9,700	30,650	33.1	56.7
6	0.1016	800A	8,250	10,100	25,700	27.6	51.2
7	0.1020	800A	6,250	7,350	24,500	30.1	47.4
8	0.1018	800A	7,750	9,400	24,250	31.4	61.7
9	0.1018	1000A	4,800	6,500	13,550	31.4	68.7
10	0.1019	1000A	4,950	6,750	14,250	31.0	61.8
11	0.1015	1000A	5,350	7,850	14,850	32.7	63.9

A = Argon Atmosphere. All others tested in air.

(Reference: NAS 3-4162)

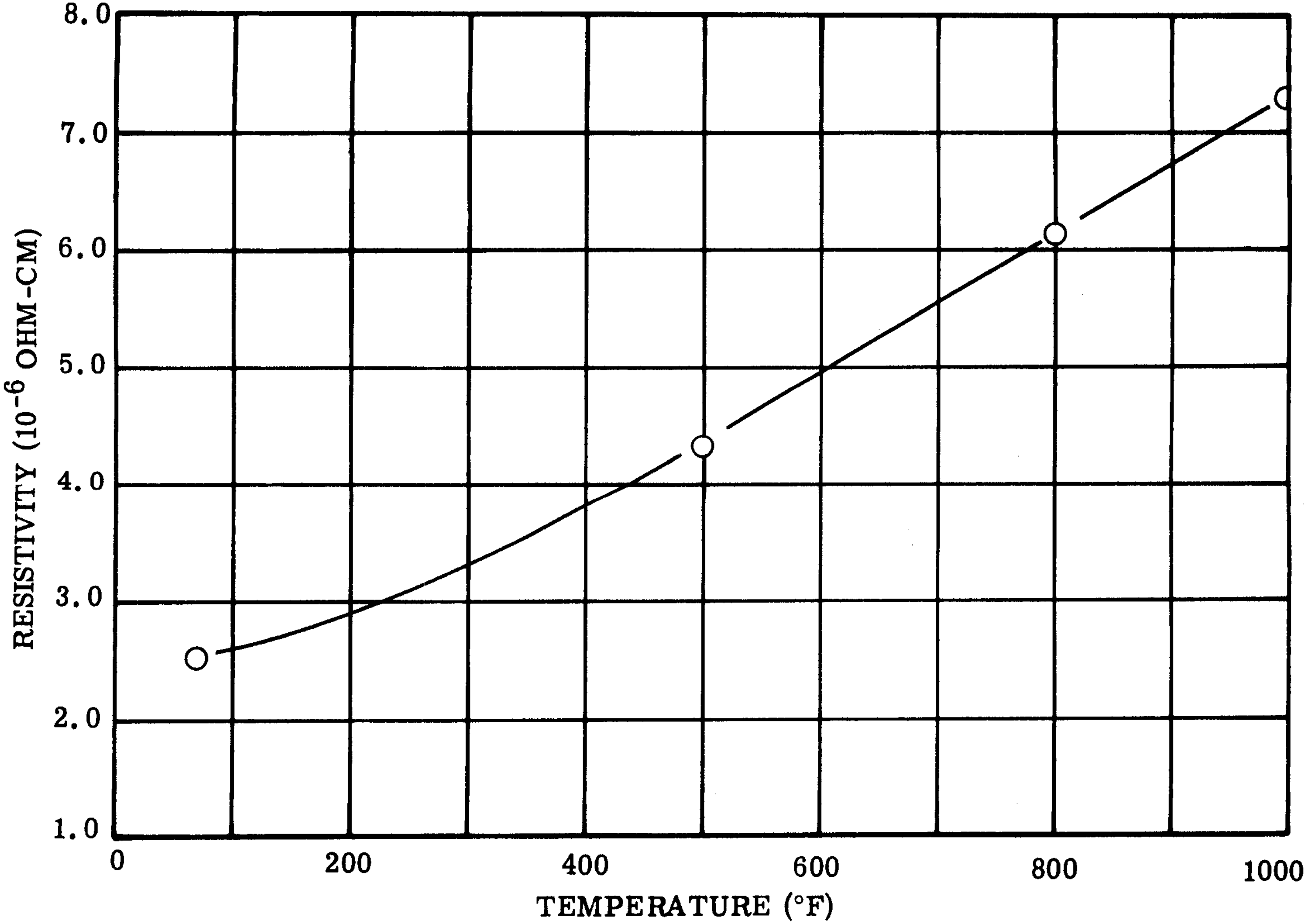


FIGURE IV.A-1. Electrical Resistivity of Nickel-Clad (28 Percent of Area) No. 18 AWG Copper Wire. Tested in Air. (Reference: RC5)

Figure IV.A-1. Electrical Resistivity - Nickel-Clad Copper

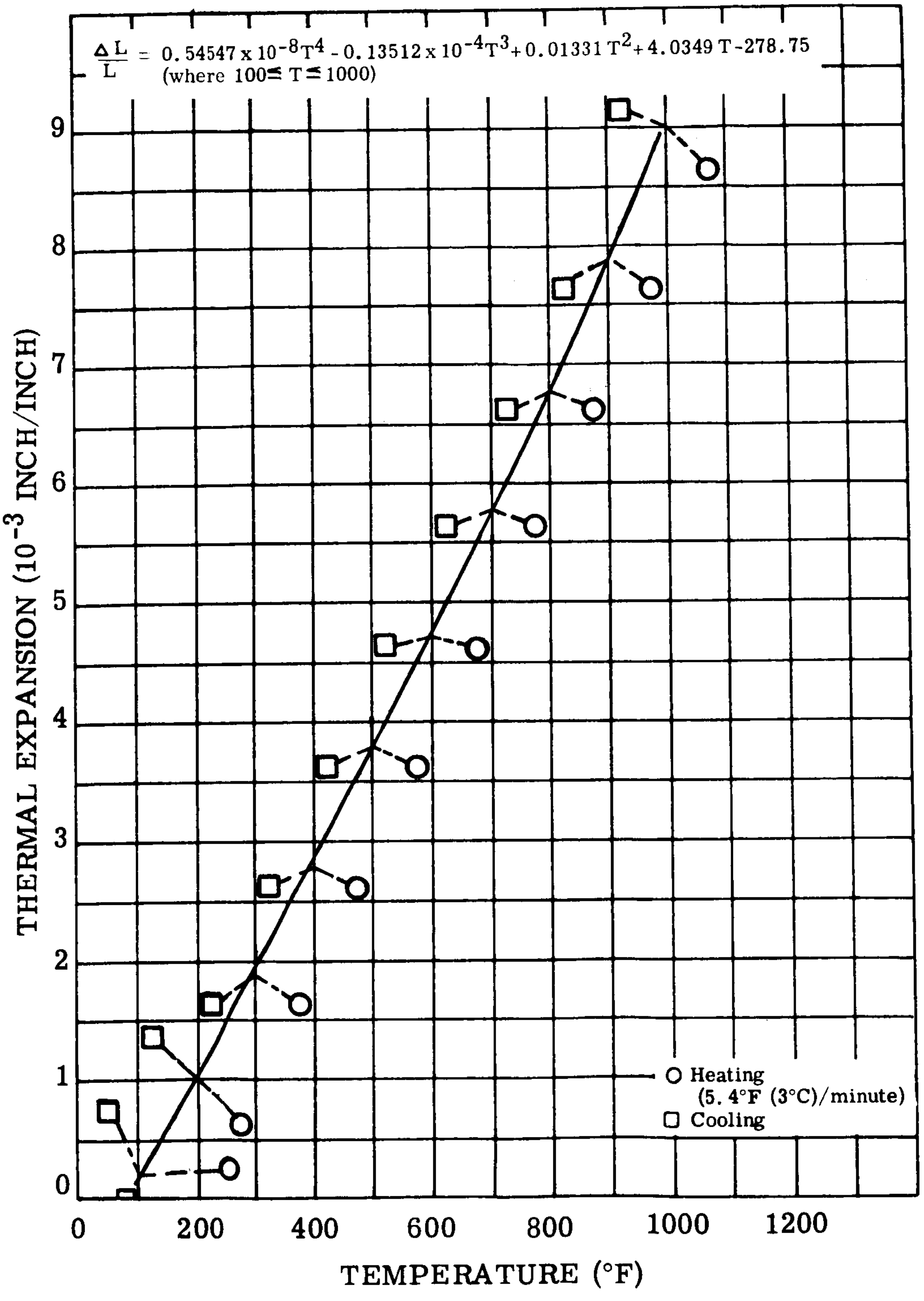
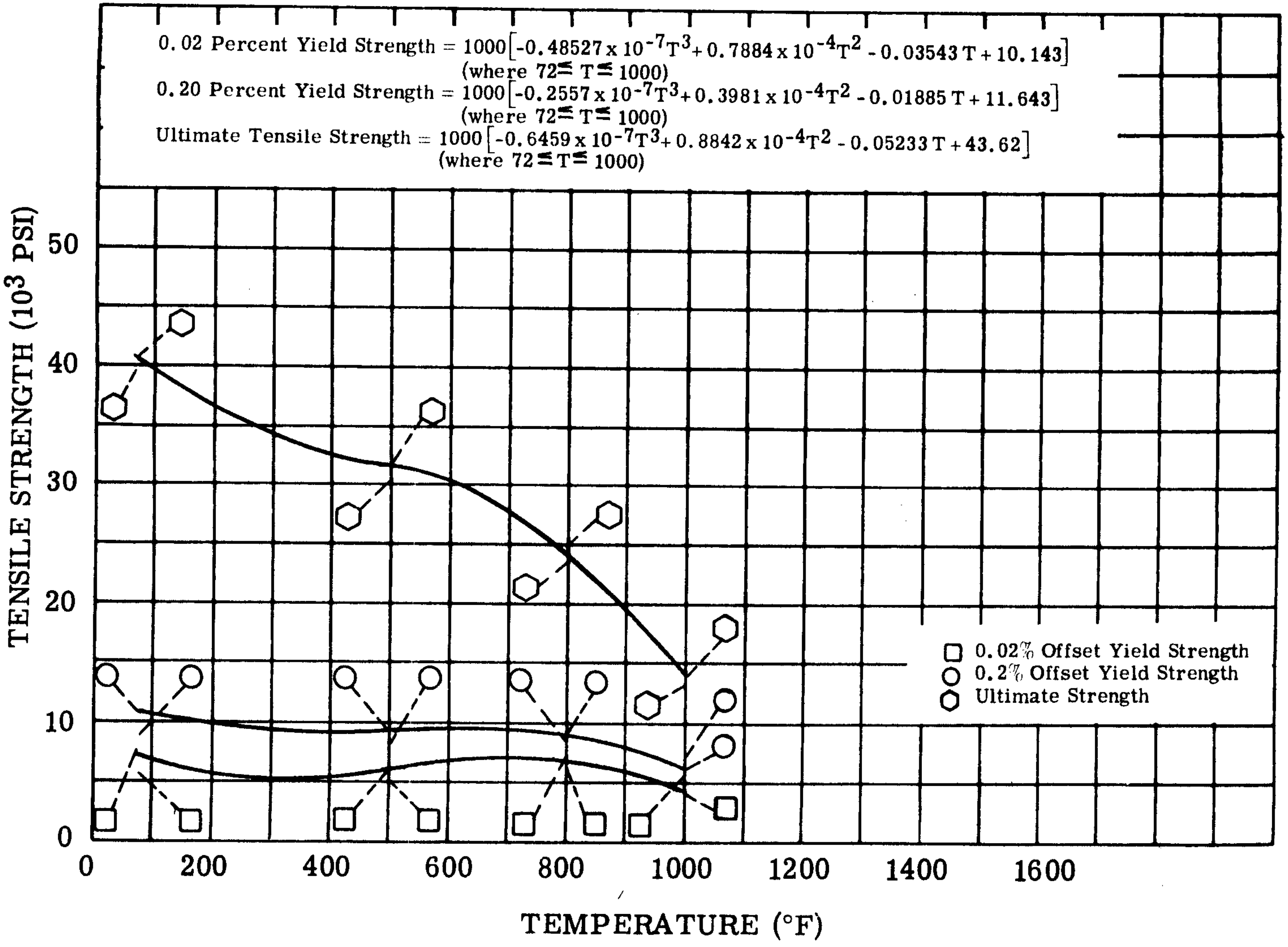


FIGURE IV.A-2. Thermal Expansion, Nickel-Clad (28 Percent of Area) Copper, 10 Gage Wire. Tested in Argon (Reference: NAS 3-4162)

Figure IV.A-2. Thermal Expansion - Nickel-Clad Copper



0.02 Percent Yield Strength = $1000\left[-0.48527 \times 10^{-7}T^3 + 0.7884 \times 10^{-4}T^2 - 0.03543\,T + 10.143\right]$ (where $72 \leq T \leq 1000$)

0.20 Percent Yield Strength = $1000\left[-0.2557 \times 10^{-7}T^3 + 0.3981 \times 10^{-4}T^2 - 0.01885\,T + 11.643\right]$ (where $72 \leq T \leq 1000$)

Ultimate Tensile Strength = $1000\left[-0.6459 \times 10^{-7}T^3 + 0.8842 \times 10^{-4}T^2 - 0.05233\,T + 43.62\right]$ (where $72 \leq T \leq 1000$)

FIGURE IV.A-3. Tensile Strengths, 0.100 Inch Diameter Nickel-Clad (28 Percent Area) Copper Wire. Tests at 800°F and Above Made in Argon; All Others in Air. Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure IV.A-3. Tensile Strength - Nickel-Clad Copper

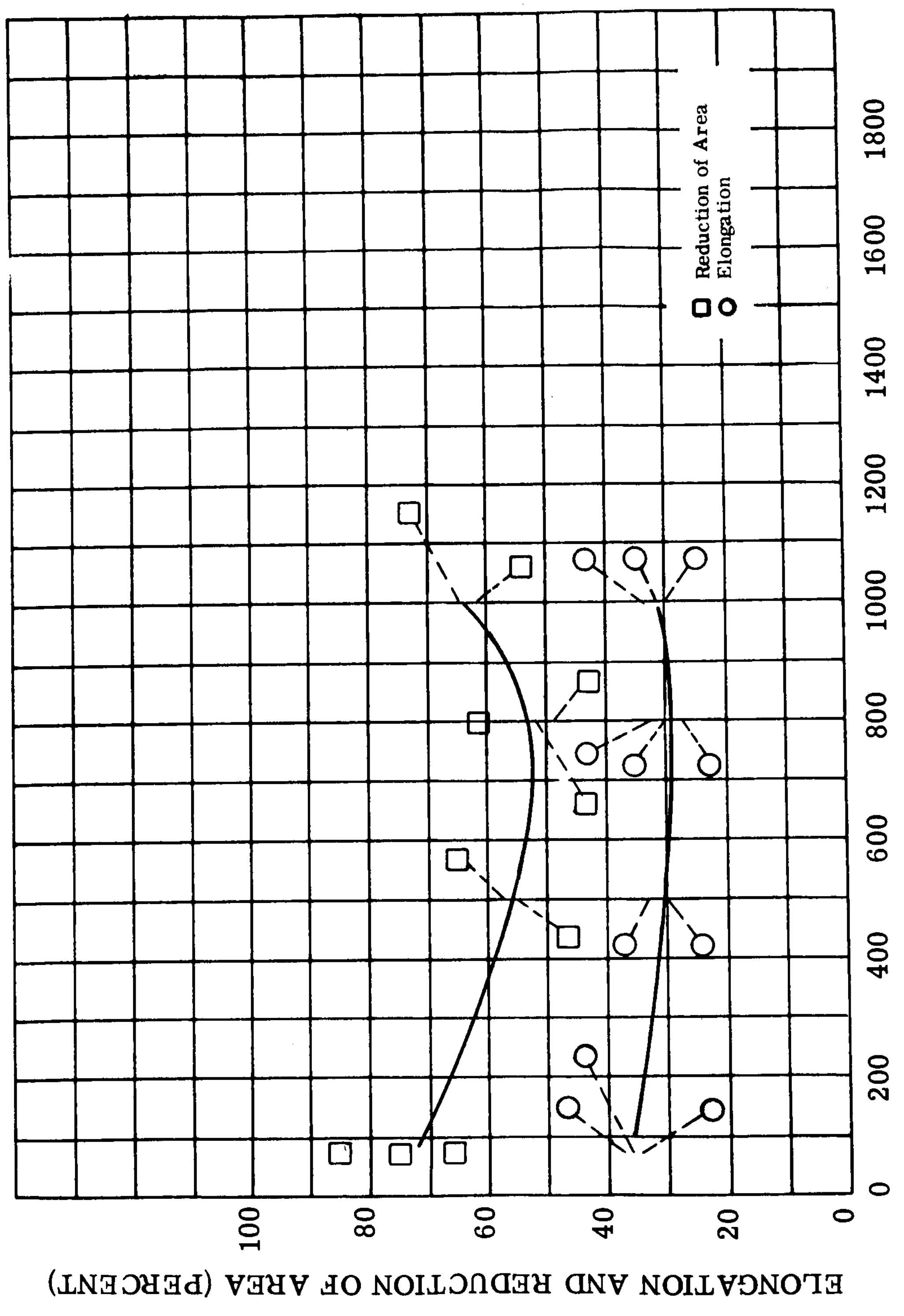


FIGURE IV.A-4. Ductility, 0.100 Inch Diameter Nickel-Clad (28 Percent of Area) Copper Wire. Tests at 800°F and Above Made in Argon, All Others in Air. Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure (Reference: NAS 3-4162)

Figure IV.A-4. Ductility - Nickel-Clad Copper

ELECTRICAL CONDUCTOR MATERIALS PROPERTIES SUMMARY

B. TYPE 321 STAINLESS-STEEL-CLAD SILVER

Availability:	Semi-commercial pilot quantities available from Sylvania Electric Products Corp., Parts Division, Warren, Pa.
Nominal Composition:	Fine silver(1), clad with aerospace quality type 321 stainless steel. Clad is approximately 28 percent of conductor area.

I. Thermophysical Properties

A. Density 0.353 lb/cu in - 9.83 grams/cc

B. Solidus temperature at lowest melting constituent 1760°F

C. Electrical Resistivity (No. 18 AWG wire)

Temperature (°F)	Resistivity (ohm-cm)
76	2.45×10^{-6}
500	4.31×10^{-6}
821	5.99×10^{-6}
1017	6.87×10^{-6}
1408	9.13×10^{-6}

D. Thermal Expansion (72-1300°F) 11.11×10^{-6} in/in-°F

II. Electrical Properties

A. Effect of time at temperature on room temperature resistivity. (No. 18 AWG wire)

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 76°F (ohm-cm)
800	1000	Air	2.44×10^{-6}
800	2000	Air	2.40×10^{-6}

(1) 99.9 percent silver - Concise Chemical and Technical Dictionary. Chemical Publishing Company, Brooklyn, N. Y., 1947 Ed., p. 837

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 76°F (ohm-cm)
1000	100	Air	2.41×10^{-6}
1000	500	Air	2.44×10^{-6}
1000	1000	Air	2.43×10^{-6}
1000	2022	Air	2.49×10^{-6}
1600	100	Argon	2.75×10^{-6}
1600	500	Argon	5.89×10^{-6}
1600	1000	Argon	6.52×10^{-6}
1600	2000	Argon	5.56×10^{-6}

III. Mechanical Properties

A. Tensile Properties of No. 10 AWG wire.
Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	16,600 psi
b.	Tensile strength	47,900 psi
c.	Elongation in 2 inches	29.8 percent

2. At 500°F

a.	0.20 percent offset yield strength	14,400 psi
b.	Tensile strength	31,100 psi
c.	Elongation in 2 inches	14.5 percent

3. At 800°F

a.	0.20 percent offset yield strength	12,450 psi
b.	Tensile strength	26,300 psi
c.	Elongation in 2 inches	18.2 percent

4. At 1000°F

a.	0.20 percent offset yield strength	11,800 psi
b.	Tensile strength	22,000 psi
c.	Elongation in 2 inches	20.8 percent

5. At 1400°F

a.	0.20 percent offset yield strength	6,500 psi
b.	Tensile strength	10,550 psi
c.	Elongation in 2 inches	27.4 percent

6. At 1600°F

a.	0.20 percent offset yield strength	2,100 psi
b.	Tensile strength	3,950 psi
c.	Elongation in 2 inches	67.4 percent

B. Creep

Use of this material under heavy mechanical loads is not anticipated.

TABLE IV.B-1. Electrical Resistivity, Type 321 Stainless-Steel-Clad (28 Percent of Area) Silver Wire Tested in Vacuum (10^{-5} torr) See Figure IV.B-1.

Test: ASTM B193

Specimen No. 1, Continuous Heating and Cooling(1)

Wire Diameter - 0.040 Inches, Test Length - 23.24 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
76	14.722	2.45	71.63
200	16.564	2.75	63.67
300	18.762	3.12	56.21
400	23.330	3.88	45.20
500	25.949	4.31	40.64
600	29.526	4.91	35.72
708	32.534	5.41	32.42
821	36.062	5.99	29.24
918	38.614	6.42	27.31
1017	41.341	6.87	25.51
1100	44.860	7.46	23.51
1200	47.917	7.97	22.01
1300	51.221	8.51	20.59
1408	54.939	9.13	19.20
1500	57.674	9.59	18.29
1600	62.540	10.40	16.86
1541	60.474	10.05	17.44
1449	57.162	9.50	18.45
1292	51.024	8.48	20.67
1100	45.654	7.59	23.10
900	39.416	6.55	26.76
700	33.112	5.50	31.85
500	26.850	4.46	39.28
300	21.315	3.54	49.48
200	18.158	3.02	58.08
76	14.672	2.44	71.88

1. Heating and cooling rates 10°F per minute.
2. International Annealed Copper Standard
   $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE I V. B-2. Electrical Resistivity at 76°F of Aged Type 321 Stainless-Steel-Clad Fine Silver Wire. See Figures II. B-1, -3, -4, -5. Cladding is 28 Percent of Conductor Area.

Aging Temperature[(1)] (°F)	Aging Time (Hours)	Resistivity at 76°F (Ohms/Cir Mil Ft)	Resistivity at 76°F (Microhm-Cm)	Conductivitv (Percent IACS)[(2)]
800	1000	14.70	2.44	72.13
800	2000	14.46	2.40	73.30
1000	100	14.50	2.41	72.80
1000	500	14.70	2.44	71.69
1000	1000	14.62	2.43	72.41
1000	2022	14.99	2.49	70.61
1600	100	16.56	2.75	63.85
1600-1760	500	35.42	5.89	30.48[(3)]
1600-1760	1000	39.23	6.52	26.97[(3)]
1600	2000	33.42	5.56	31.72

1. Samples aged in air at 800° and 1000°F and in Argon at 1600°F. Test Specimen wire No. 18 AWG Wire.

2. International Annealed Copper Standard $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm.

3. Evidence of melting was observed at the ends of the test wires.

(Reference: NAS 3-4162)

TABLE IV. B-3. Tensile Test Data for 321 Stainless-Steel-Clad Silver Conductor Wire. Cladding is 28 Percent of Conductor Area.

Test: ASTM E21 - Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure

Specimen No.	Diameter (Inches)	Test Temperature (°F)	0.02 Percent Offset Yield Strength (Psi)	0.20 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	0.1010	72	12,500	18,350	48,700	27.9	59.8
2	0.1006	72	7,550	14,400	47,900	34.4	58.2
3	0.1006	72	12,800	17,100	47,100	27.2	58.2
4	0.1003	500	9,600	14,800	32,000	15.7	12.2
5	0.1005	500	9,500	13,800	30,950	13.8	12.5
6	0.1000	500	9,550	14,500	30,300	13.9	22.5
7	0.1010	800A	7,850	12,400	26,450	18.6	34.1
8	0.1010	800A	7,950	12,500	26,200	17.7	32.5
9	0.1009	1000A	8,500	12,200	22,900	20.3	41.7
10	0.1005	1000A	7,800	11,350	21,050	21.3	42.7
11	0.1006	1400A	4,950	6,350	10,700	27.3	92.8
12	0.1010	1400A	B	B	10,500	27.4	93.9
13	0.1006	1400A	4,900	6,800	10,450	28.3	92.8
14	0.1010	1600A	1,500	2,350	4,350	68.4	92.3
15	0.1009	1600A	1,150	1,900	3,550	66.3	96.9

A = Argon Atmosphere. All others tested in air.

B = Curve unreliable. Extensometer slipped.

(Reference: NAS 3-4162)

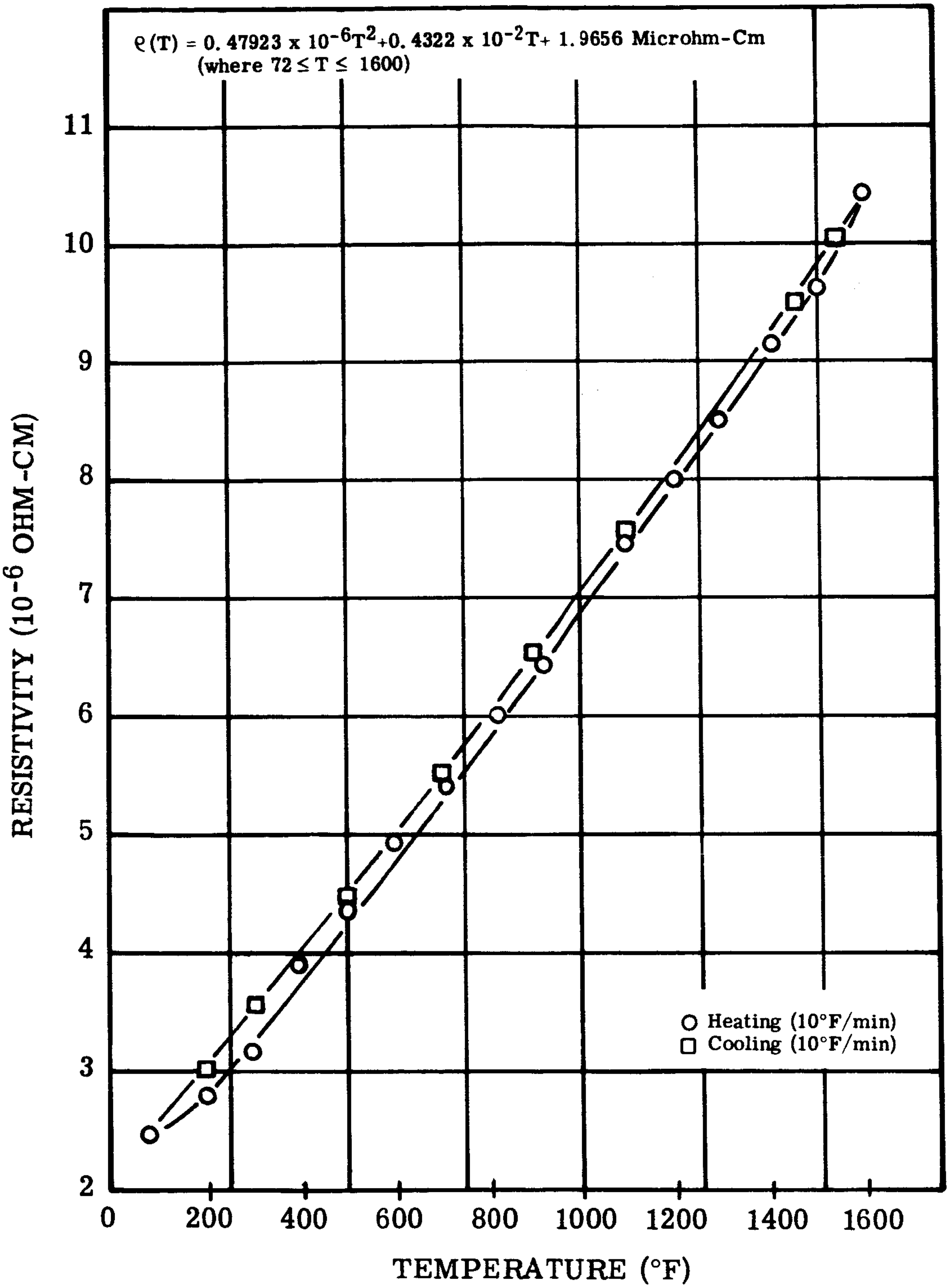


FIGURE IV. B-1. Electrical Resistivity of Type 321 Stainless-Steel-Clad (28 Percent of Area) Silver. Vacuum Test. (Reference: NAS 3-4162)

Figure IV. B-1. Electrical Resistivity - Stainless-Steel-Clad Silver

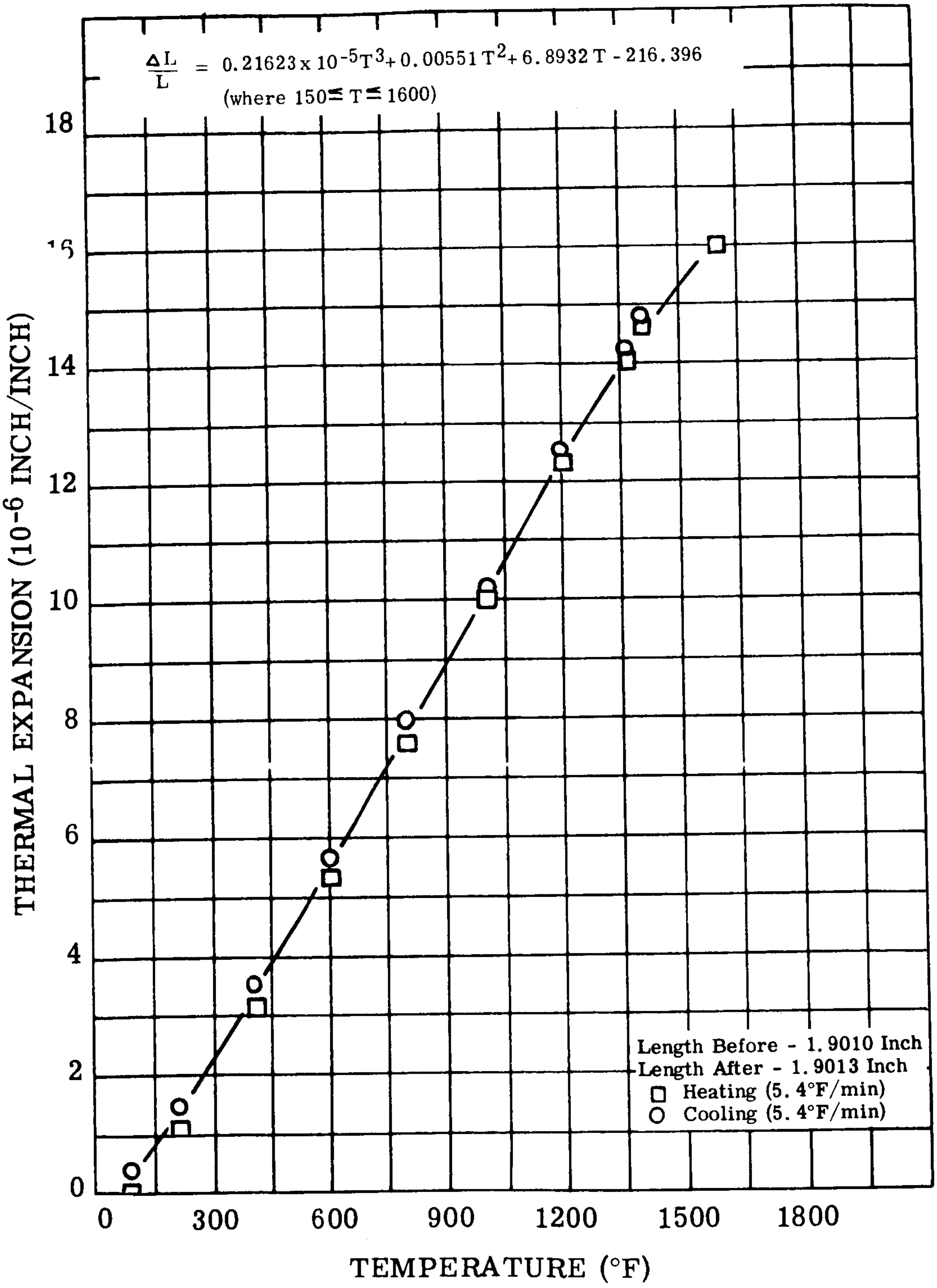


FIGURE IV.B-2. Thermal Expansion, Type 321 Stainless-Steel-Clad (28 Percent of Area) Silver, 10 Gage Wire. Tested in Argon. (Reference: NAS 3-4162)

Figure IV.B-2. Thermal Expansion - Stainless-Steel-Clad Silver

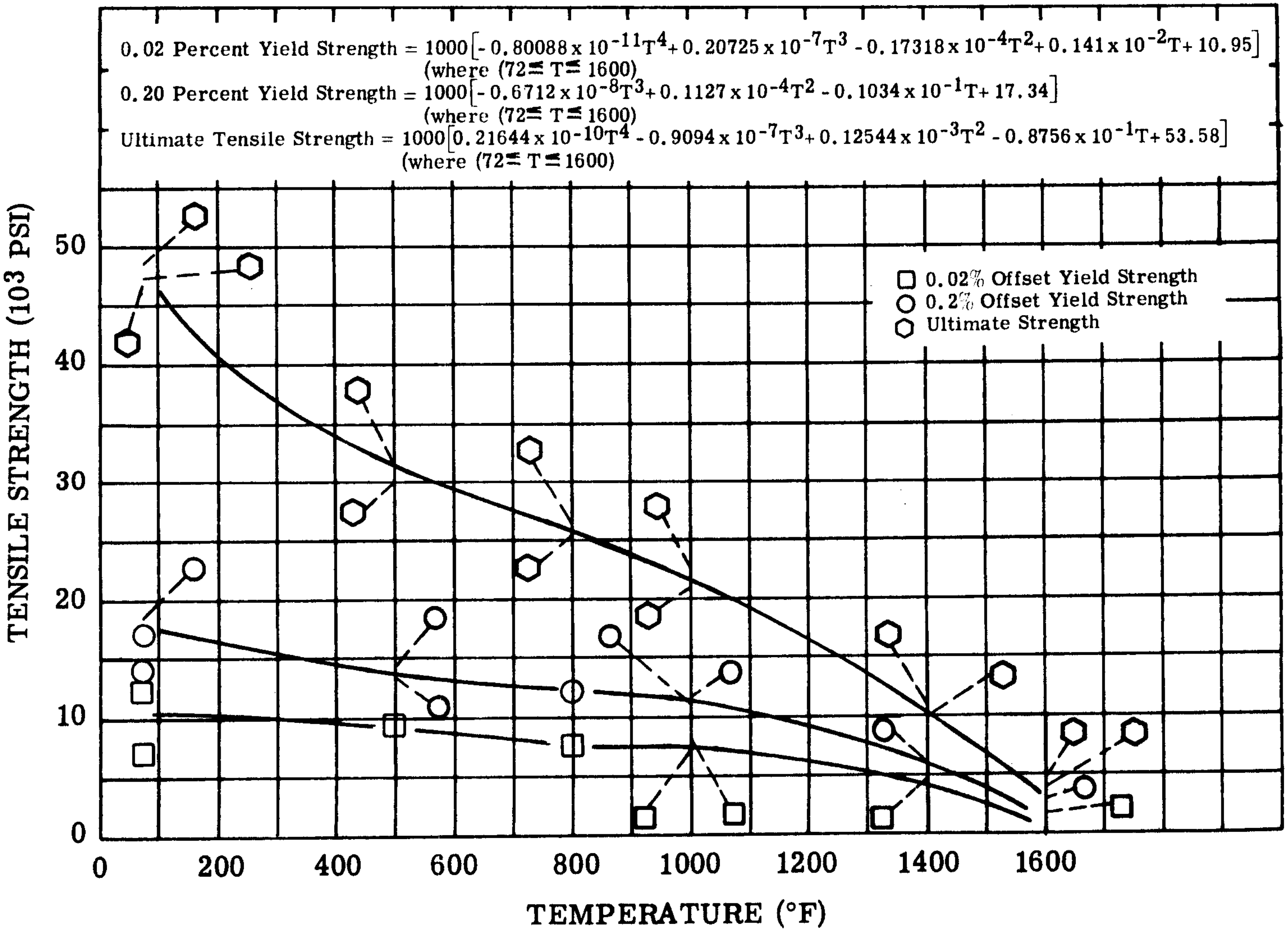


FIGURE IV. B-3. Tensile Strengths, 0.100 Inch Diameter Type 321 Stainless-Steel-Clad (28 Percent of Area) Silver Wire. All tests in Argon at 800°F and Above. Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure. (Reference: NAS 3-4162)

Figure IV. B-3. Tensile Strength - Stainless-Steel-Clad Silver

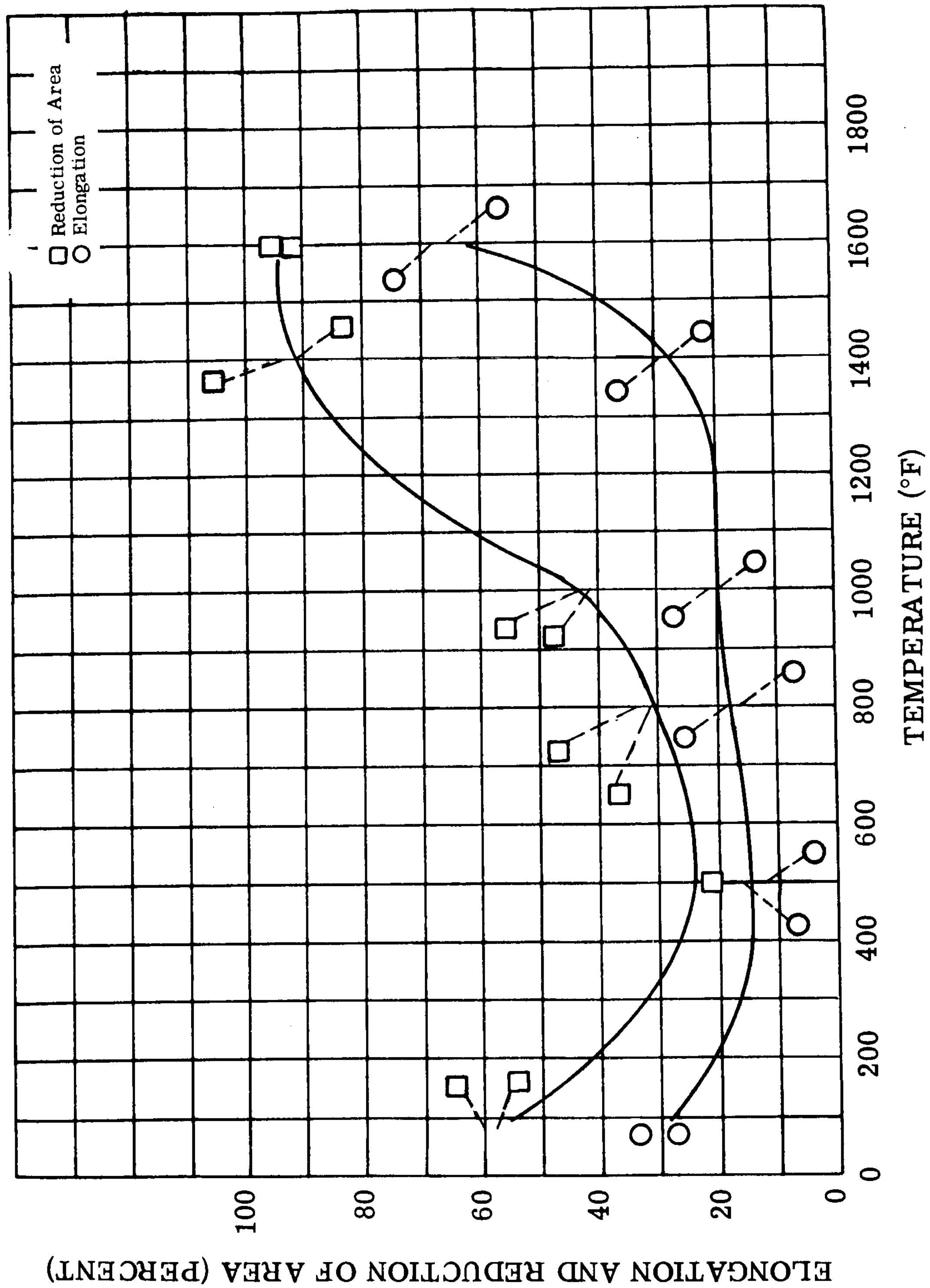


FIGURE IV.B-4. Ductility, 0.100 Inch Diameter Type 321 Stainless-Steel-Clad (28 Percent of Area) Silver Wire. All Tests in Argon at 800°F and Above. Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure. (Reference: NAS 3-4162)

Figure IV.B-4. Ductility - Stainless-Steel-Clad Silver

ELECTRICAL CONDUCTOR MATERIALS PROPERTY SUMMARY

C. TYPE 304 STAINLESS-STEEL-CLAD ZIRCONIUM COPPER

Availability:	Semi-commercial pilot quantities available from Sylvania Electric Products Corp., Parts Division, Warren, Pa.
Nominal Composition:	Copper - 0.15 percent zirconium clad with aerospace quality type 304 stainless steel. Clad is approximately 28 percent of conductor area.

I. Thermophysical Properties

A. Density 0.313 lb/cu in 8.70 grams/cc

B. Solidus temperature of lowest melting constituent. 1724°F

C. Electrical Resistivity (No. 18 AWG wire)

Temperature (°F)	Resistivity (ohm-cm)
77 - as rec'd R. T.	4.12×10^{-6}
500	6.31×10^{-6}
800 - aged specimens only	7.79×10^{-6}
1000	7.99×10^{-6}
1400	10.37×10^{-6}

D. Thermal Expansion (75-1600°F) 8.46×10^{-6} in/in-°F

II. Electrical Properties

A. Effect of time at temperature on room temperature resistivity (No. 18 AWG wire).

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 77°F (ohm-cm)
800	1000	Air	2.61×10^{-6}
800	2000	Air	2.58×10^{-6}

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 77°F (ohm-cm)
1000	500	Air	2.65×10^{-6}
1000	1000	Air	2.64×10^{-6}
1000	2022	Air	2.70×10^{-6}
1600	100	Argon	4.98×10^{-6}
1600	500	Argon	7.11×10^{-6}
1600	1000	Argon	7.41×10^{-6}
1600	2000	Argon	7.75×10^{-6}

III. Mechanical Properties

A. Tensile Properties of No. 10 AWG wire. Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	19,750 psi
b.	Tensile strength	51,000 psi
c.	Elongation in 2 inches	39.5 percent

2. At 500°F

a.	0.20 percent offset yield strength	15,950 psi
b.	Tensile strength	37,100 psi
c.	Elongation in 2 inches	24.6 percent

3. At 800°F

a.	0.20 percent offset yield strength	15,600 psi
b.	Tensile strength	36,700 psi
c.	Elongation in 2 inches	21.4 percent

4. At 1000°F

a.	0.20 percent offset yield strength	15,250 psi
b.	Tensile strength	27,550 psi
c.	Elongation in 2 inches	22.8 percent

5. At 1400°F

a.	0.20 percent offset yield strength	9,000 psi
b.	Tensile strength	13,300 psi
c.	Elongation in 2 inches	17.5 percent

6. At 1600°F

a.	0.20 percent offset yield strength	4,850 psi
b.	Tensile strength	7,100 psi
c.	Elongation in 2 inches	13.2 percent

B. Creep

Use of this material under heavy mechanical loads is not anticipated.

TABLE IV.C-1. Electrical Resistivity, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium-Copper Wire in Vacuum (10^{-5} torr) (First Test) See Figure IV.C-1.

TEST: ASTM B193

Specimen No. 1, Continuous Heating and Cooling(1)

Wire Diameter - 0.0405 Inches, Test Length - 23.48 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
77	24.763	4.12	42.66
200	28.418	4.72	37.17
307	31.771	5.28	33.25
400	34.579	5.75	30.55
500	37.933	6.31	27.85
600	41.026	6.82	25.75
700	44.094	7.33	23.96
809	46.860	7.79	22.54
900	48.235	8.02	21.90
975	48.017	7.98	21.99
1000	48.084	7.99	21.97
1102	50.130	8.33	21.07
1202	54.028	8.98	19.55
1300	58.060	9.65	18.19
1400	62.402	10.37	16.93
1500	66.476	11.05	15.89
1600	72.051	11.98	14.66
1450	65.051	10.81	16.24
1240	56.081	9.32	18.84
1050	49.082	8.16	21.52
986	47.776	7.78	22.58
950	45.561	7.57	23.18
910	44.161	7.34	23.92
834	41.621	6.92	25.38
650	35.409	5.89	29.83
450	28.963	4.81	36.47
250	22.424	3.73	47.11
150	19.105	3.18	55.29
79	16.648	2.77	63.77

1. Heating and Cooling rates 10°F per minute
2. International Annealed Copper Standard
   $\rho_{68^\circ F}$ = 1.7241 x 10-6 Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV.C-2. Electrical Resistivity, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium-Copper Wire in Vacuum (10^{-5} torr) (First Test)

TEST: ASTM B193

Specimen No. 2, Continuous Heating and Cooling(1)

Wire Diameter - 0.0405 Inches, Test Length - 23.47 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
77	24.379	4.05	43.41
200	27.323	4.54	38.74
300	30.887	5.13	34.27
405	34.049	5.66	31.08
515	37.747	6.28	28.04
600	40.490	6.73	26.14
700	43.559	7.24	24.30
805	46.344	7.70	22.84
900	48.063	7.99	22.02
950	48.147	8.00	21.98
1000	48.256	8.02	21.93
1100	49.899	8.30	21.21
1300	58.244	9.68	18.17
1400	62.898	10.46	16.83
1505	67.553	11.23	15.67
1600	73.038	12.14	14.49
1450	65.364	10.87	16.19
1250	56.609	9.41	18.70
1044	48.994	8.14	21.60
840	41.890	6.96	25.27
650	35.600	5.92	29.73
450	29.185	4.85	36.27
250	22.593	3.76	46.85
150	19.339	3.21	54.73

1. Heating and Cooling rates 10°F per minute

2. International Annealed Copper Standard
$\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV. C-3. Electrical Resistivity, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium-Copper Wire in Vacuum (10^{-5} torr) (Second Test) See Figures IV. C-1 and IV. C-2

Test: ASTM B193

Specimen No. 1, Continuous Heating and Cooling(1)

Wire Diameter - 0.0405 Inches, Test Length - 23.48 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
79	16.648	2.77	63.77
203	20.328	3.38	52.22
319	24.310	4.04	43.67
402	27.077	4.50	39.21
500	30.430	5.06	34.89
611	33.657	5.60	31.54
707	37.220	6.19	28.52
800	40.364	6.71	26.30
900	43.801	7.28	24.24
1000	46.877	7.79	22.65
1113	50.758	8.44	20.91
1200	53.902	8.96	19.70
1300	57.674	9.59	18.41
1400	62.201	10.34	17.07
1500	66.946	11.13	15.86
1603	73.141	12.16	14.51
1450	65.504	10.89	16.21
1238	55.956	9.30	18.97
1043	49.166	8.17	21.59
850	42.325	7.04	25.08
650	35.652	5.93	29.78
450	29.122	4.84	36.45
250	21.938	3.65	48.39
170	19.700	3.27	53.89
77	17.143	2.85	61.69

1. Heating and Cooling rates 10°F per minute
2. International Annealed Copper Standard
   $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV.C-4. Electrical Resistivity, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium-Copper Wire in Vacuum (10^{-5} torr) (Second Test)

TEST: ASTM B193

Specimen No. 2, Continuous Heating and Cooling(1)

Wire Diameter - 0.0405 Inches, Test Length - 23.47 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
79	16.756	2.79	63.36
200	19.457	3.23	54.56
300	23.692	3.94	44.81
400	27.004	4.49	39.31
500	30.543	5.08	34.76
614	34.133	5.67	31.10
711	37.487	6.23	28.32
800	40.498	6.73	26.21
905	44.155	7.34	24.04
1000	47.023	7.28	22.58
1100	50.151	8.34	21.17
1200	54.344	9.03	19.53
1300	58.244	9.68	18.23
1400	62.848	10.45	16.89
1500	67.763	11.27	15.67
1600	73.482	12.22	14.45
1450	66.287	11.02	16.01
1246	57.279	9.52	18.53
1050	49.497	8.23	21.45
850	42.469	7.06	25.00
644	35.810	5.95	29.65
450	29.512	4.91	35.97
250	22.643	3.76	46.88
150	19.515	3.24	54.40

1. Heating and Cooling rates 10°F per minute

2. International Annealed Copper Standard
$\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV.C-5. Electrical Resistivity at 72°F of Aged Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium-Copper Wire.
See Figures II.B-3 to II.B-5

Aging Temperature(1) (°F)	Aging Time (Hours)	Resistivity at 72°F (Ohms/Cir Mil Ft)	Resistivity at 72°F (Microhm-Cm)	Conductivitv (Percent IACS)(2)
800	1000	15.68	2.61	67.60
800	2000	15.51	2.58	68.20
1000	500	15.90	2.65	66.46
1000	1000	15.86	2.64	66.75
1000	2022	16.24	2.70	65.34
1600	100	29.91	4.98	35.47
1600	500	42.72	7.11	24.67
1600	1000	44.57	7.41	23.72
1600	2000	46.58	7.75	22.60

1. Sample aged in air at 800° and 1000°F and in Argon at 1600°F.
Test Specimens were 18 gage (AWG) wire.

2. International Annealed Copper Standard
$\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE I V. C-6. Tensile Test Data for Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper Wire (10 AWG Wire)

Test: ASTM E21 - Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure

Specimen No.	Test Temperature(1) (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	72	14,900	19,950	51,050	39.2	50.1
2	72	13,250	19,550	50,950	39.8	59.4
3	500	12,250	16,250	37,200	23.4	58.1
4	500	11,750	15,650	36,950	25.8	63.2
5	800	12,350	15,300	37,350	22.9	47.2
6	800	13,750	15,850	26,050	20.0	48.7
7	1000	12,950	15,300	27,850	23.7	(a)
8	1000	12,500	15,200	27,250	21.8	39.7
9	1400	7,050	8,950	13,250	17.1	28.5
10	1400	7,250	9,100	13,500	17.9	33.4
11	1600	4,100	4,900	7,200	12.6	23.3
12	1600	3,900	4,800	7,050	13.9	28.5

1. All tests made in air.

(a) The measurement of reduction of area on this specimen was unreliable.

(Reference: NAS 3-4162)

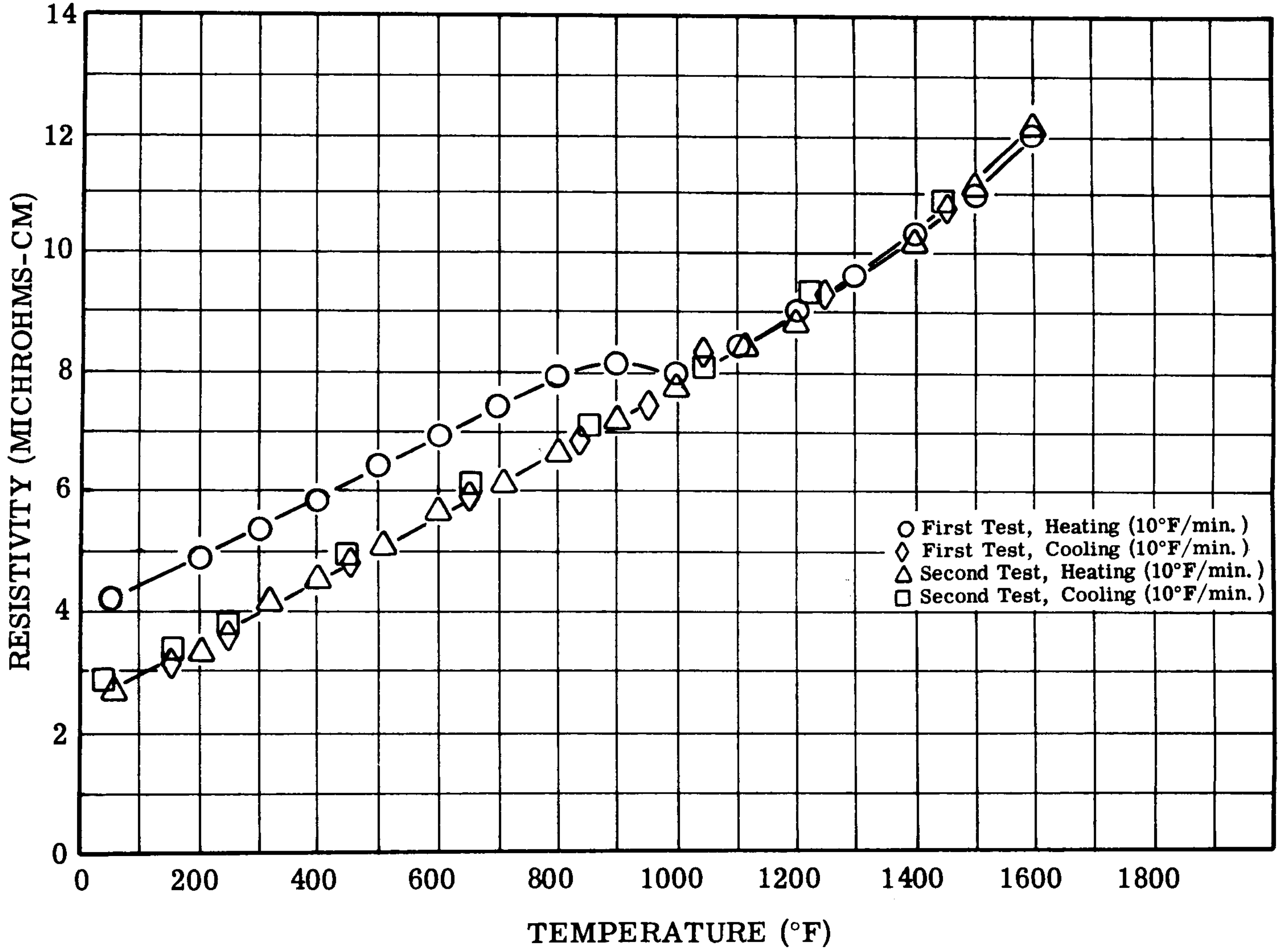


FIGURE I V. C-1. Electrical Resistivity Versus Temperature of Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper. Specimen No. 1, Vacuum Tested. See Tables I V. C-1 and I V. C-3. (No. 18 AWG Wire)(Reference: NAS 3-4162)

Figure I V. C-1. Electrical Resistivity - Stainless-Steel-Clad Zr Copper

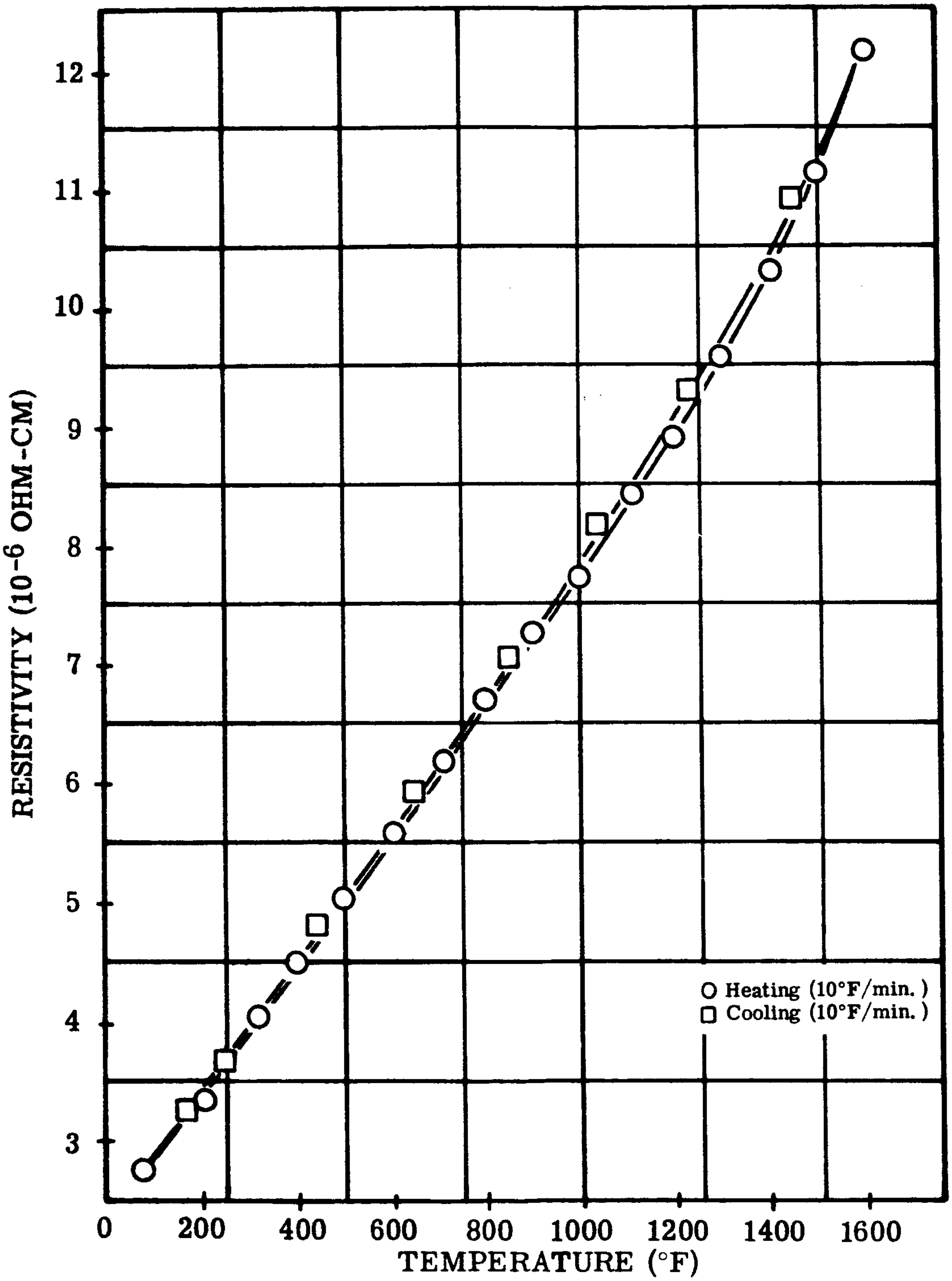


FIGURE IV. C-2. Electrical Resistivity of Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper. Specimen No. 1, Second Test, Vacuum Test. (No. 18 AWG Wire)(Reference: NAS 3-4162)

Figure IV. C-2. Electrical Resistivity - Stainless-Steel-Clad Zr Copper

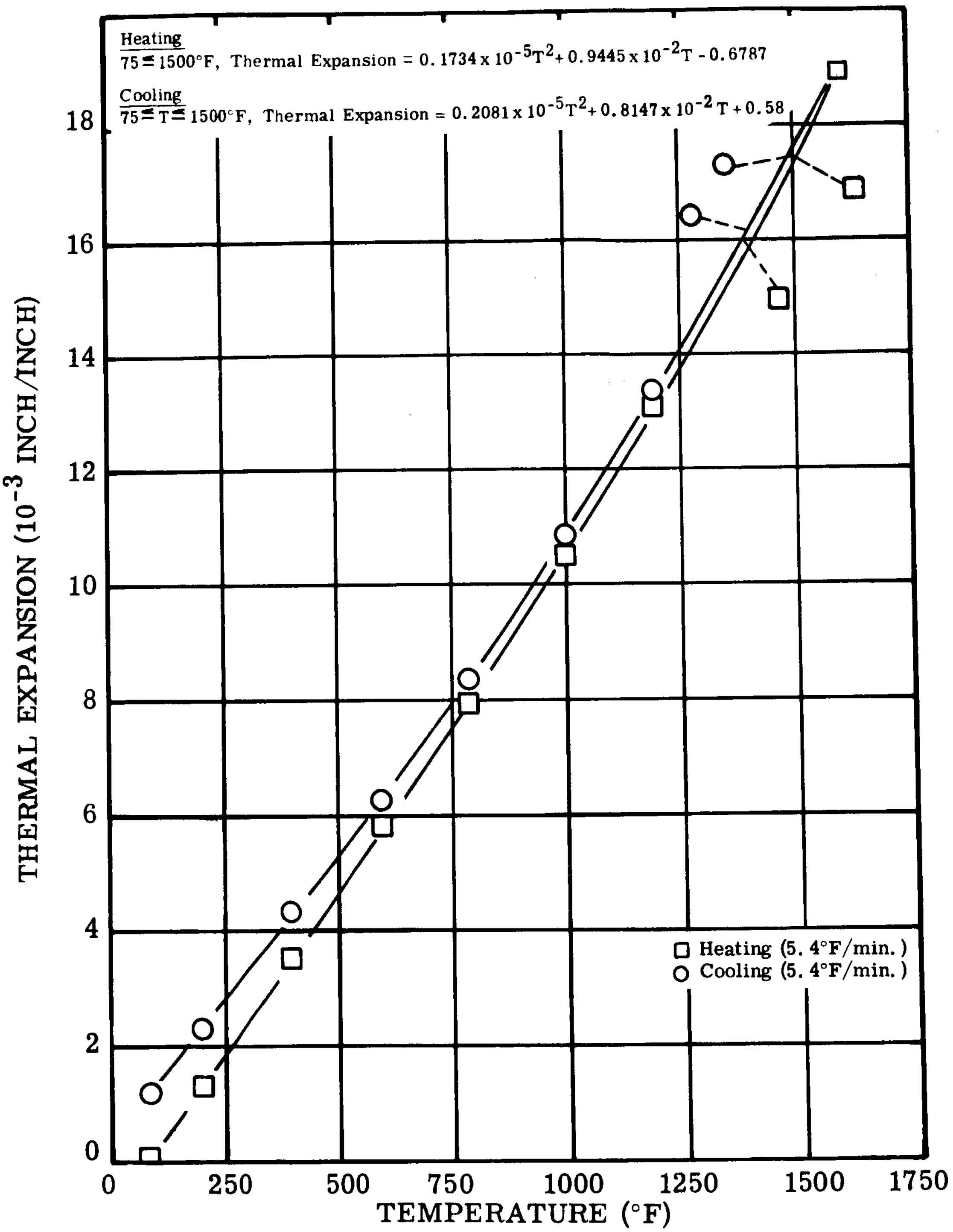


FIGURE IV. C-3. Thermal Expansion of Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper Tested in Argon. (No. 18 AWG Wire) (Reference: NAS 3-4162)

Figure IV.C-3. Thermal Expansion - Stainless-Steel-Clad Zr Copper

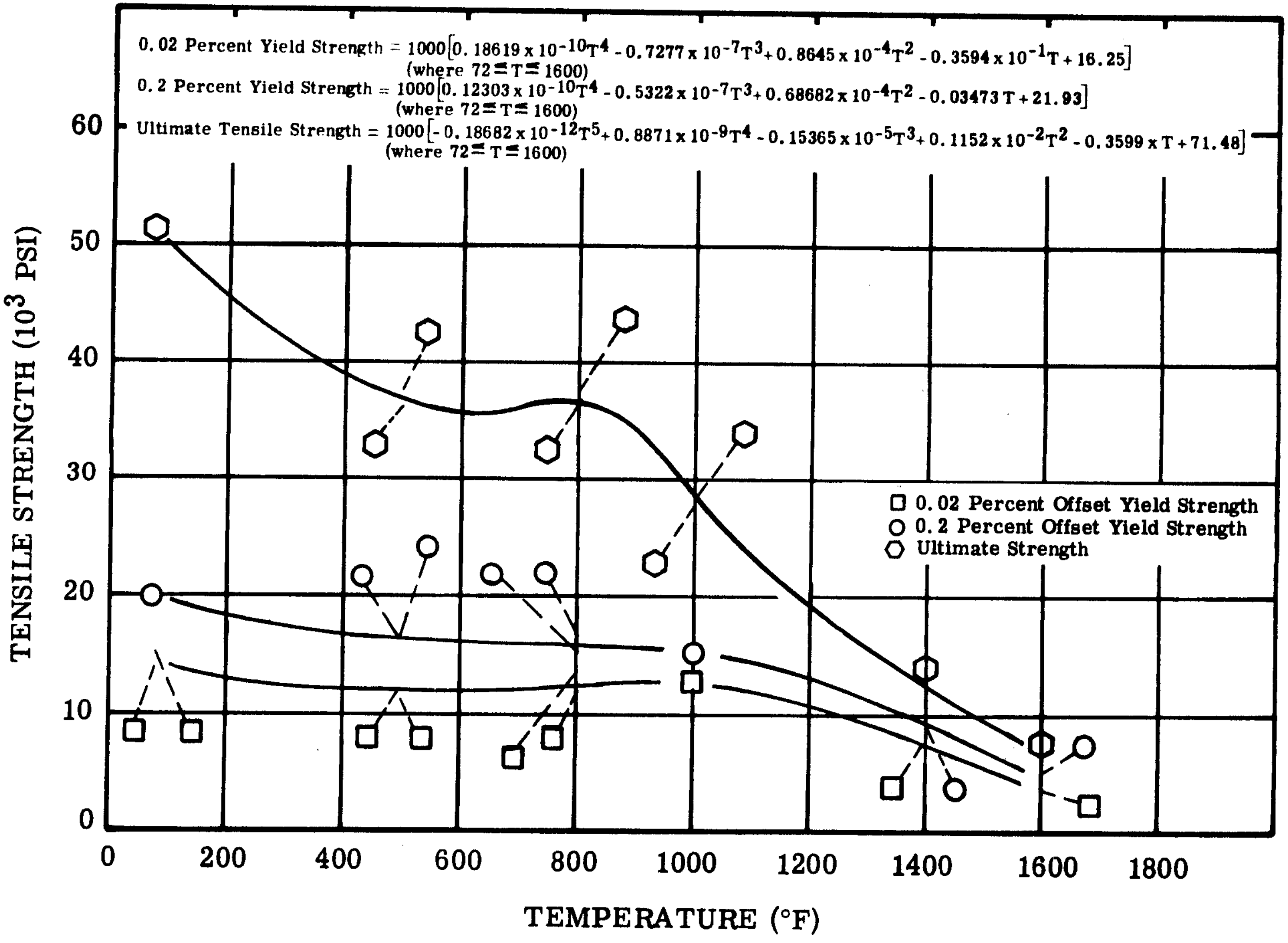


FIGURE I V. C-4. Tensile Strength, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper, No. 10 AWG Wire. Tested in Air. Strain Rate: 0.005 in/in-min. Then 0.05 in/in-min. to Failure. (Reference: NAS 3-4162)

Figure I V. C-4. Tensile Strength - 304 Stainless-Steel-Clad Zirconium Copper

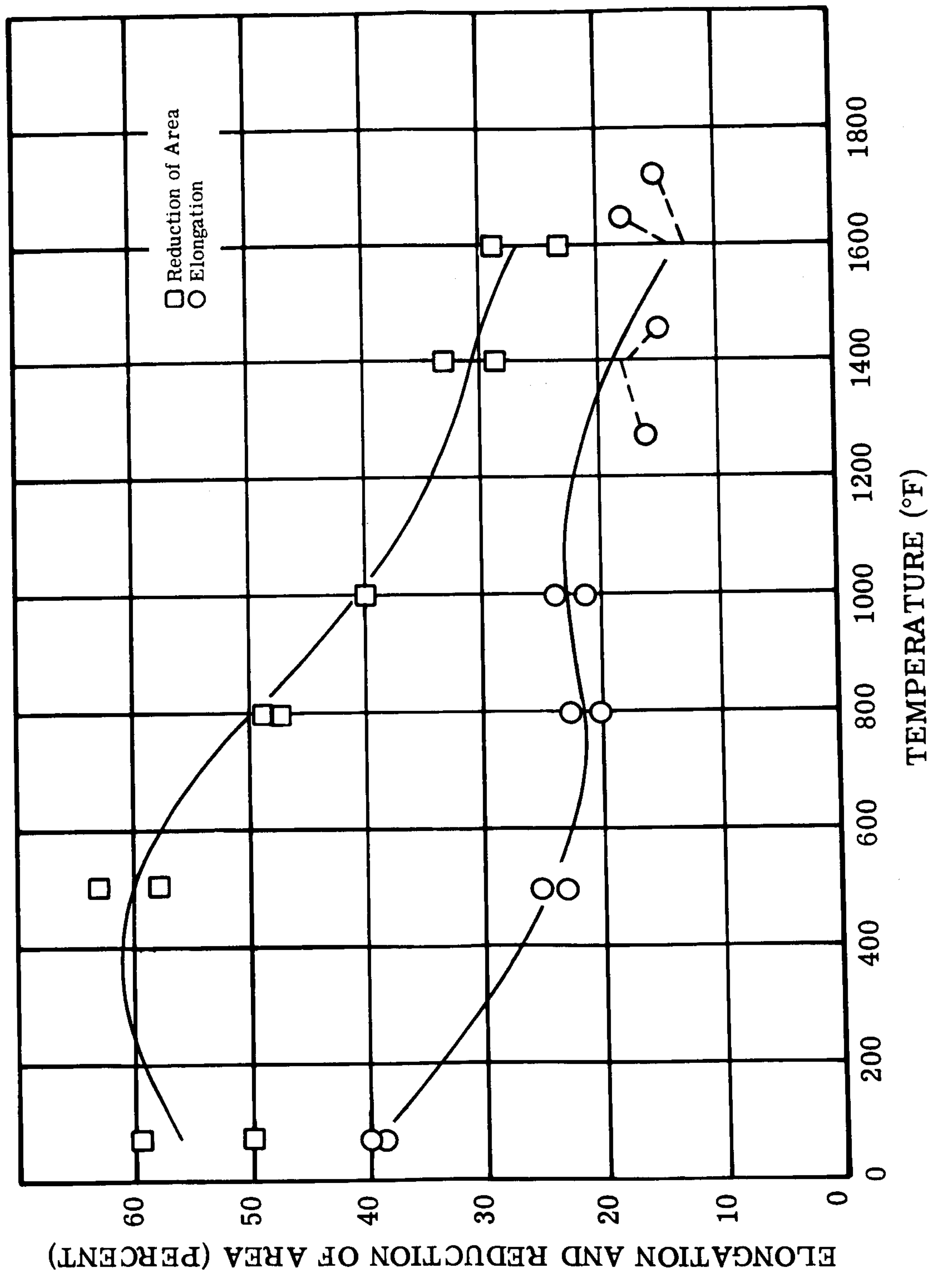


FIGURE IV. C-5. Tensile Ductility, Type 304 Stainless-Steel-Clad (28 Percent of Area) Zirconium Copper, No. 10 AWG Wire. Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure. Tested in Air. (Reference: NAS 3-4162)

Figure IV.C-5. Tensile Ductility - 304 Stainless-Steel-Clad Zirconium Copper

ELECTRICAL CONDUCTOR MATERIALS PROPERTIES SUMMARY

D. DISPERSION-STRENGTHENED COPPER "CUBE ALLOY"

Availability:	Semi-commercial pilot quantities available from Handy and Harman Inc., New York, N. Y.
Nominal Composition:	Copper - 1 volume percent Beryllia

I. Thermophysical Properties

A. Density 0.317 lb/cu in 8.83 grams/cc

B. Solidus temperature of lowest melting constituent. 1980°F

C. Electrical Resistivity

Temperature (°F)	Resistivity (ohm-cm)
72	2.04×10^{-6}
500	3.63×10^{-6}
800	4.79×10^{-6}
1000	5.62×10^{-6}
1600	8.42×10^{-6}

D. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
72	128.3
500	124.8
800	122.5
1000	119.6
1600	113.8(1)

E. Thermal Expansion (77°-1300°F) 11.3×10^{-6} in/in-°F

---

(1) Extrapolated

II. Electrical Properties

A. Effect of time at temperature on room temperature resistivity. (No. 18 AWG wire)

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 72°F (ohm-cm)
800	500	Air	2.07×10^{-6}
800	1000	Air	2.08×10^{-6}
800	2000	Air	2.04×10^{-6}
1000	500	Air	2.01×10^{-6}
1000	1000	Air	2.03×10^{-6}
1600	100	Argon	2.01×10^{-6}
1600	500	Argon	2.09×10^{-6}
1600	1000	Argon	2.08×10^{-6}
1600	2000	Argon	2.13×10^{-6}

III. Mechanical Properties

A. Tensile Properties (No. 10 AWG wire). Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	62,400 psi
b.	Tensile strength	80,700 psi
c.	Elongation in 2 inches	11.5 percent

2. At 500°F

a.	0.20 percent offset yield strength	55,500 psi
b.	Tensile strength	67,300 psi
c.	Elongation in 2 inches (measured after test)	7.4 percent

3. At 800°F

a.	0.20 percent offset yield strength	50,750 psi
b.	Tensile strength	52,250 psi
c.	Elongation in 2 inches (measured after test)	1.4 percent

4. At 1000°F

a.	0.20 percent offset yield strength		42,350 psi
b.	Tensile strength		42,350 psi
c.	Elongation in 2 inches (measured after test)		1.6 percent

5. At 1400°F

a.	0.20 percent offset yield strength	-	failed before 0.2 percent yield
b.	Tensile strength		28,900 psi
c.	Elongation in 2 inches (measured after test)		0.4 percent

6. At 1600°F

a.	0.20 percent offset yield strength	-	failed before 0.2 percent yield
b.	Tensile strength		24,300 psi
c.	Elongation in 2 inches (measured after test)		0.3 percent

B. Creep

The creep data obtained on Cube Alloy was not sufficient to abstract here.

TABLE IV.D-1. Electrical Resistivity, Dispersion-Strengthened Copper Wire in Vacuum (10^{-5} torr) (As Drawn Condition)

TEST: ASTM B193

Specimen No. 1, Continuous Heating(1)

Wire Diameter - 0.040 Inches, Test Length - 23.23 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
77	12.472	2.07	84.39
100	12.703	2.11	82.86
200	14.381	2.39	73.19
300	16.364	2.72	64.32
400	18.621	3.10	56.52
523	21.158	3.52	49.74
600	23.059	3.83	45.64
700	24.795	4.12	42.45
800	27.638	4.59	38.08
900	30.010	4.99	35.07
1000	32.398	5.39	32.48
1114	35.456	5.89	29.68
1200	38.019	6.32	27.68
1300	40.994	6.81	25.67
1400	43.878	7.29	23.98
1528	47.498	7.90	22.16

NOTE: Test leads separated from the specimen at 1550°F. This test repeated using a modified technique to attach the leads to the specimen.

1. Heating rate 10°F per minute
2. International Annealed Copper Standard $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV.D-2. Electrical Resistivity, Dispersion-Strengthened Copper Wire in Vacuum (10^{-5} torr) (As Drawn Condition) See Figure IV.D-1.

TEST: ASTM B193

Specimen No. 2, Continuous Heating and Cooling(1)

Wire Diameter - 0.040 Inches, Test Length - 23.24 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
76	12.269	2.04	86.06
200	14.937	2.48	70.69
307	16.887	2.81	62.53
400	19.415	3.23	54.39
500	21.811	3.63	48.41
600	24.124	4.01	43.77
700	26.437	4.39	39.94
800	28.825	4.79	36.63
907	31.394	5.22	33.63
1000	33.831	5.62	31.21
1100	36.351	6.04	29.05
1200	38.879	6.46	27.16
1319	41.638	6.92	25.36
1400	44.530	7.40	23.71
1500	47.372	7.88	22.29
1600	50.652	8.42	20.85
1450	46.513	7.73	22.70
1250	40.788	6.78	25.89
1050	35.484	5.90	29.76
850	30.370	5.05	34.77
650	25.627	4.26	41.20
432	20.861	3.47	50.62
250	16.482	2.74	64.06
150	14.136	2.35	74.70

1. Heating and Cooling rates 10°F per minute

2. International Annealed Copper Standard
   $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV.D-3. Electrical Resistivity at 72°F of Aged Dispersion-Strengthened Copper Wire. See Figures II.B-3 to II.B-5.

Aging Temperature(1) (°F)	Aging Time (Hours)	Resistivity at 72°F (Ohms/Cir Mil Ft)	Resistivity at 72°F (Microhm-Cm)	Conductivity (Percent IACS)(2)
800	500	12.45	2.07	85.21
800	1000	12.50	2.08	85.29
800	2000	12.23	2.04	86.65
1000	500	12.13	2.01	86.91
1000	1000	12.21	2.03	86.67
1000	2022	12.20	2.03	86.66
1600	100	12.08	2.01	87.73
1600	500	12.56	2.09	83.89
1600	1000	12.51	2.08	84.51
1600	2000	12.81	2.13	82.40

1. Sample aged in air at 800° and 1000°F and in Argon at 1600°F. Test Specimens were 18 gage (AWG) wire.

2. International Annealed Copper Standard (Reference: NAS 3-4162)
$\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

TABLE I V. D-4. Tensile Test Data for Dispersion-Strengthened Copper Wire. See Figures I V. D-4 through I V. D-6.

Test: ASTM E21 - Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure

Specimen No.	Diameter (Inches)	Test Temperature (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	0.1002	72	40,950	62,850	80,600	14.4	62.9
2	0.1002	72	41,300	62,000	80,750	8.7	33.0
3	0.1003	500	38,550	54,350	66,850	6.2	33.2
4	0.1005	500	41,000	56,600	67,800	8.6	36.6
5	0.1005	800A	40,650	50,950	53,950	1.4	0.5
6	0.1005	800A	43,150	50,550	50,550	1.5	6.8
7	0.1003	1000A	35,900	42,350	52,350	1.6	17.7
8	0.1003	1000A	27,800	B	40,450	1.5	4.6
9	0.1003	1400A	28,500	B	30,400	0.5	0.6
10	0.1003	1400A	24,450	B	27,450	0.3	0.4
11	0.1003	1600A	20,750	B	24,300	0.3	0.6
12 C	0.1003	1600A	-	-	-	-	-

A = Argon atmosphere. All others tested in air.
B = Specimen failed before 0.2 percent offset yield was reached.
C = Specimen slipped in grips and on rerun broke in grips. No additional material available.

(Reference: NAS 3-4162)

TABLE IV.D-5. Basic Data for Dispersion-Strengthened Copper

From Handy and Harman Product Data Sheet 1964	
Ultimate tensile strength at room temperature	80,000-90,000 psi
0.2 percent offset yield strength at room temperature	75,000-85,000 psi
Percent elongation (Strain rate not given)	6-8
Percent reduction of area at fracture	40-50
Modulus of Elasticity	18.7×10^6 psi
Electrical Conductivity (percent of copper)	85

Initial Room Temperature Test Data From Sylvania Electric Products Corporation After Drawing. (Reference: NAS 3-4162)		
Final Wire Diameter	0.1006	0.0401 inch
Mechanical Properties (Strain rates not given)		
As hard drawn		
Percent elongation	7.0	1.5
Tensile strength	95,000 psi	91,000 psi
As stress relieved (1300°F, 1.5 hours in hydrogen)		
Percent elongation	12.0	8.0
Yield strength	67,500 psi	69,000 psi
Tensile strength	79,000 psi	79,000 psi
Electrical Resistance (ohm-cm) Annealed 1.5 hours, dry hydrogen 1300°F		1.96×10^{-6}

TABLE I V. D-6. Creep Data for Dispersion-Strengthened Copper Wire (As Drawn)

Test: ASTM E139

Temperature (°F)	1000	1100	1100
Stress (psi)	30,000	28,000	33,000
Duration of Test (hours)	1193	983(a)	7.30(d)
Total Creep Strain (percent)	0.08	0.261	0.0283
Time to Cause 0.2 Percent Creep Strain (hours)	(c)	410	(c)
Time to Cause 0.4 Percent Creep Strain (hours)	(c)	1420(b)	(c)
Plastic Strain Obtained on Loading Specimen (percent)	0.0275	0	0.0117
Test Atmosphere	Argon	Argon	Argon
See Strain-Time Plot in Figure IV.D-	8	9	10

(a) - Test incomplete
(b) - Extrapolated value
(c) - Did not reach
(d) - Rupture time

(Reference: NAS 3-4162)

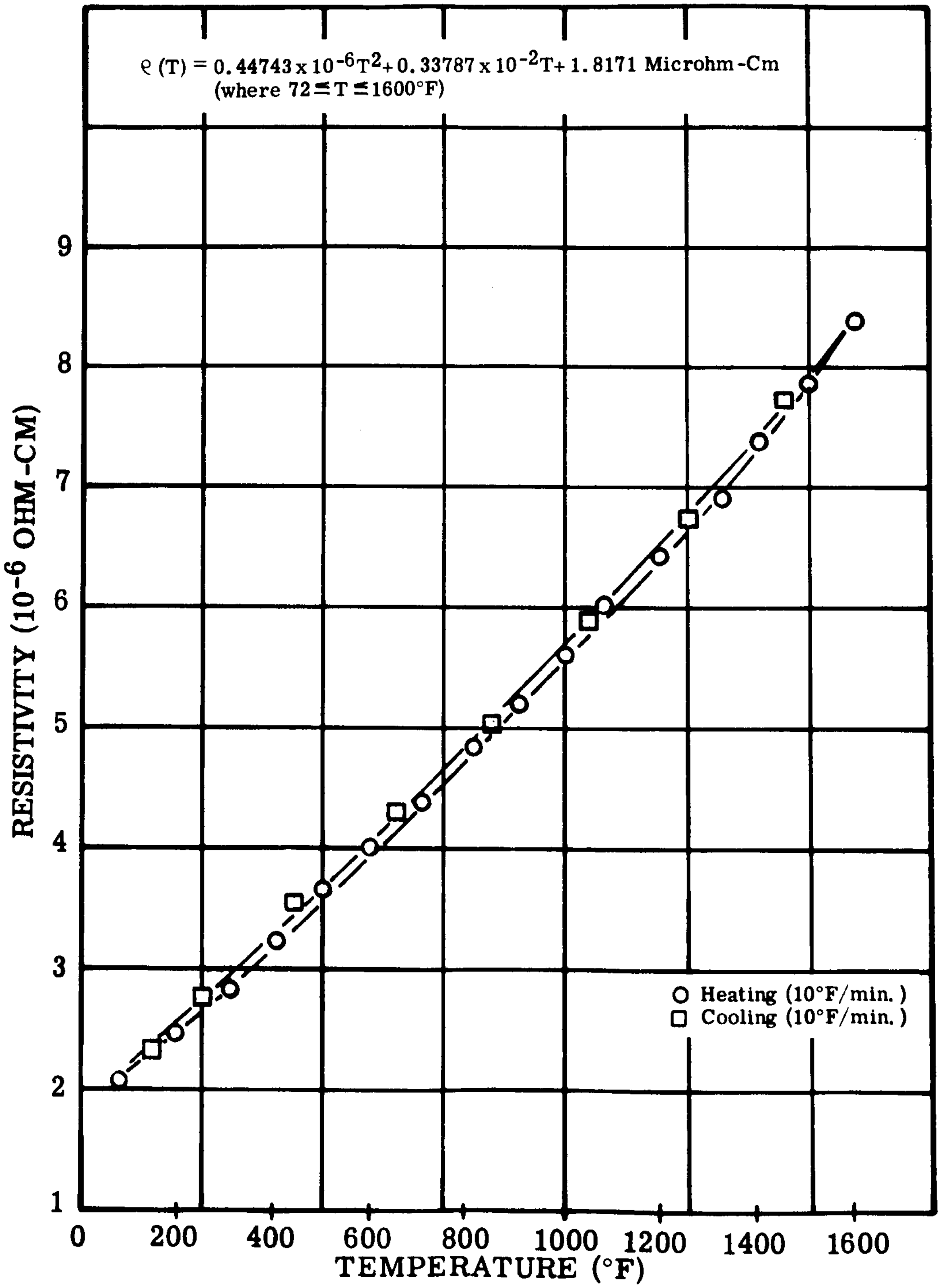


FIGURE IV.D-1. Electrical Resistivity of Dispersion Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire (As Drawn) Specimen No. 2, Vacuum Test. No. 18 AWG Wire (Reference: NAS 3-4162)

Figure IV.D-1. Electrical Resistivity - Dispersion-Strengthened Copper

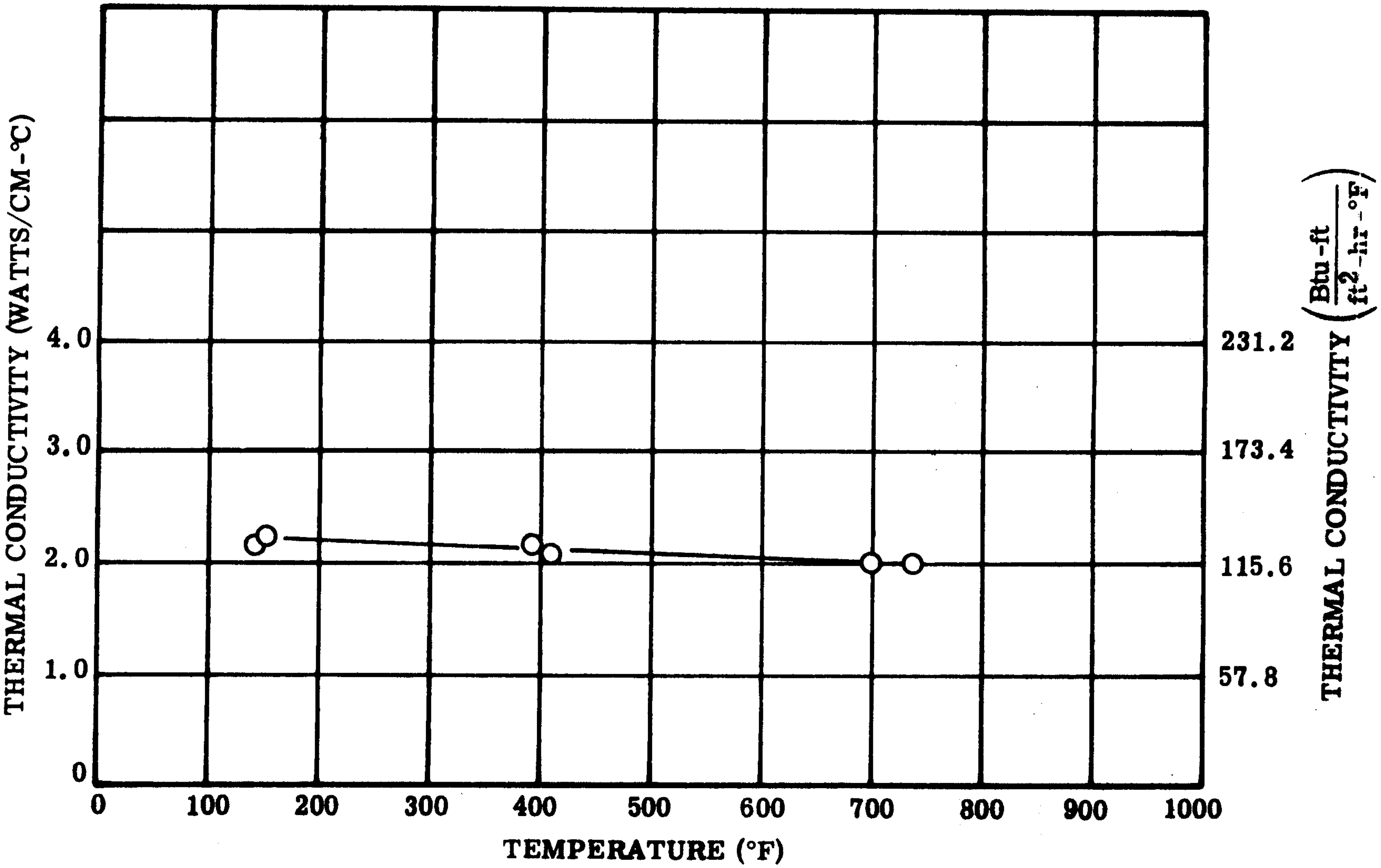


FIGURE I V.D-2. Thermal Conductivity of Dispersion Strengthened Copper Wire (Copper - 1 Volume Percent Beryllia) Vacuum Tested. (No. 18 AWG Wire)(Reference: NAS 3-4162)

Figure IV.D-2. Thermal Conductivity - Dispersion-Strengthened Copper

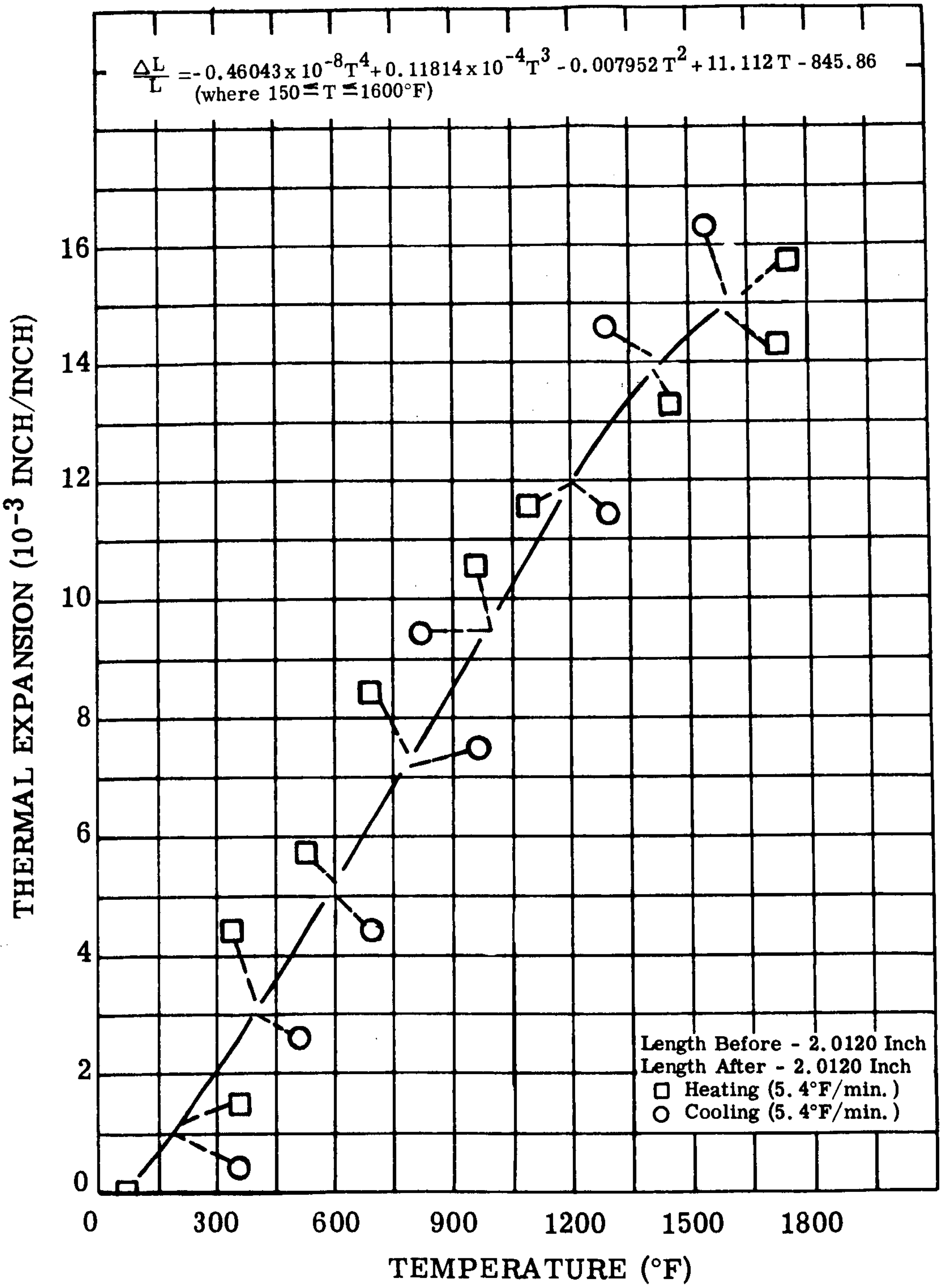


FIGURE IV.D-3. Thermal Expansion, Dispersion-Strengthened Copper, (Copper - 1 Volume Percent Beryllia) No. 10 AWG Wire, (As Drawn) Tested in Argon. (Reference: NAS 3-4162)

Figure IV.D-3. Thermal Expansion - Dispersion-Strengthened Copper

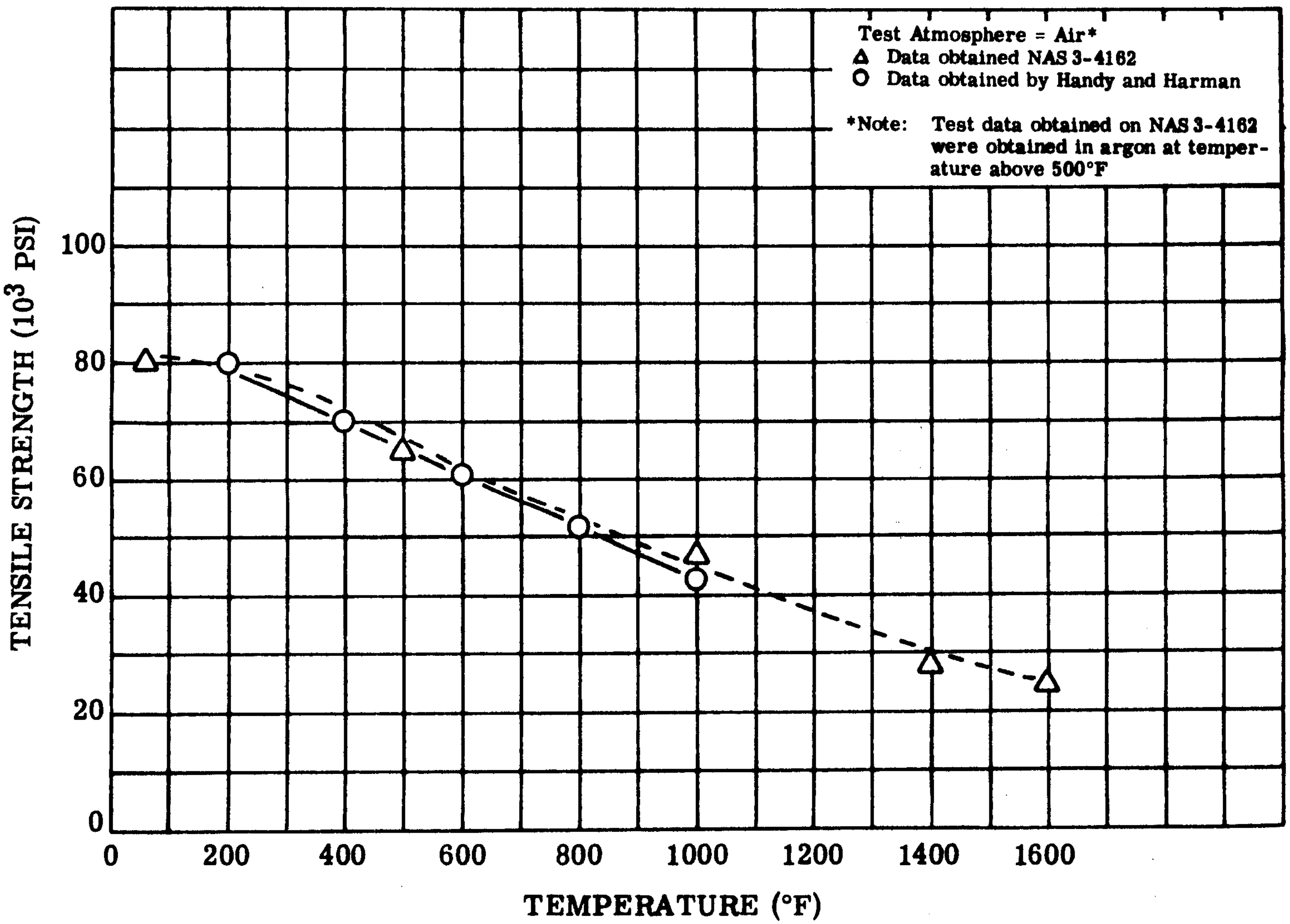


FIGURE I V. D-4. Tensile Strength, 0. 100 inch Diameter Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia) Wire. Strain Rate: 0. 005 in/in-min. to Yield Then 0. 05 in/in-min. to Failure. (Reference: Handy and Harman Data Sheet and NAS 3-4162)

Figure I V.D-4. Tensile Strength - Dispersion-Strengthened Copper

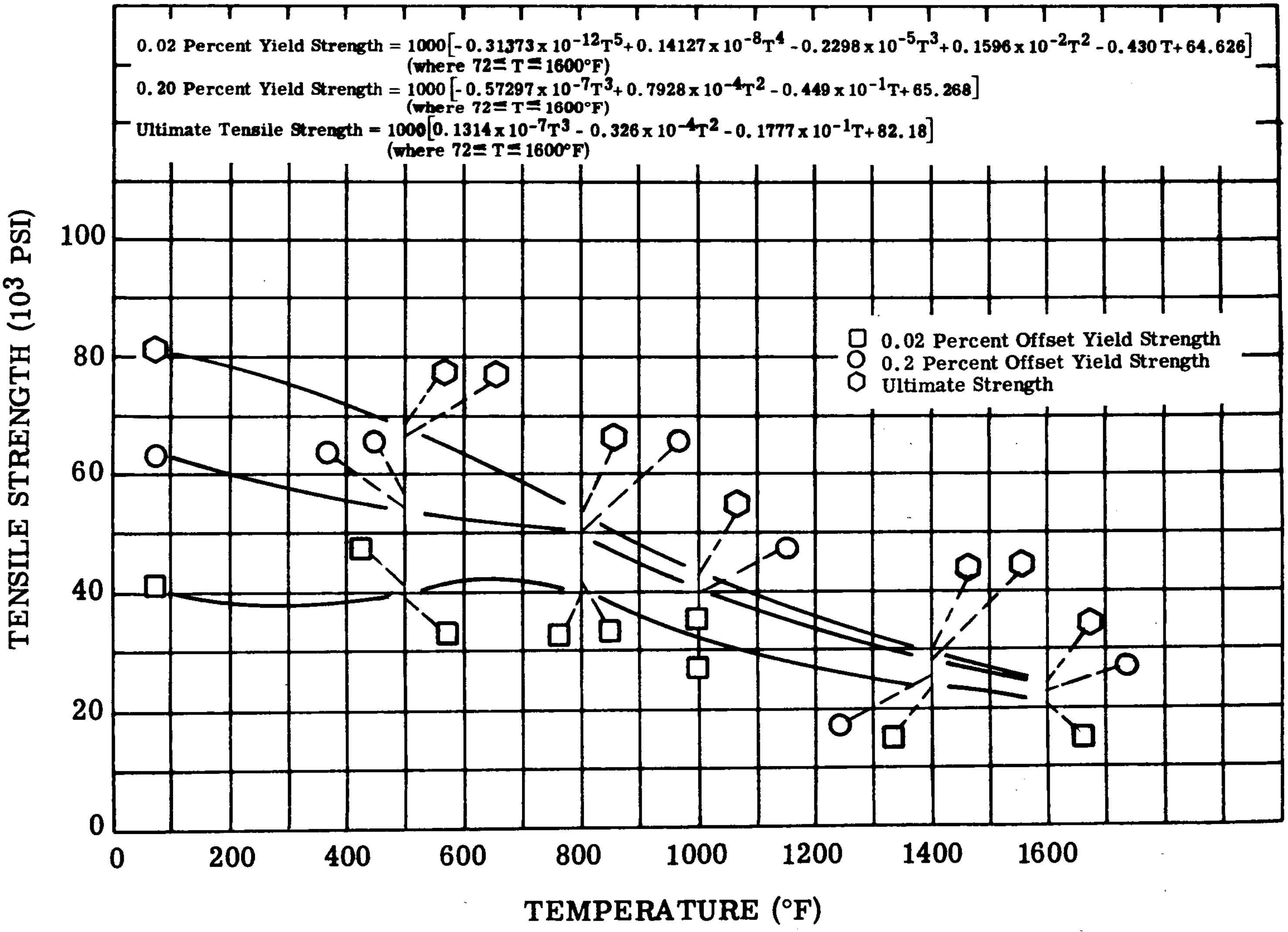


FIGURE I V. D-5. Tensile Strength, Dispersion-Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire Tests at 800°F and Above Made in Argon, All Others in Air. Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure (No. 10 AWG Wire)(Reference: NAS 3-4162)

Figure I V.D-5. Tensile Strength - Dispersion-Strengthened Copper

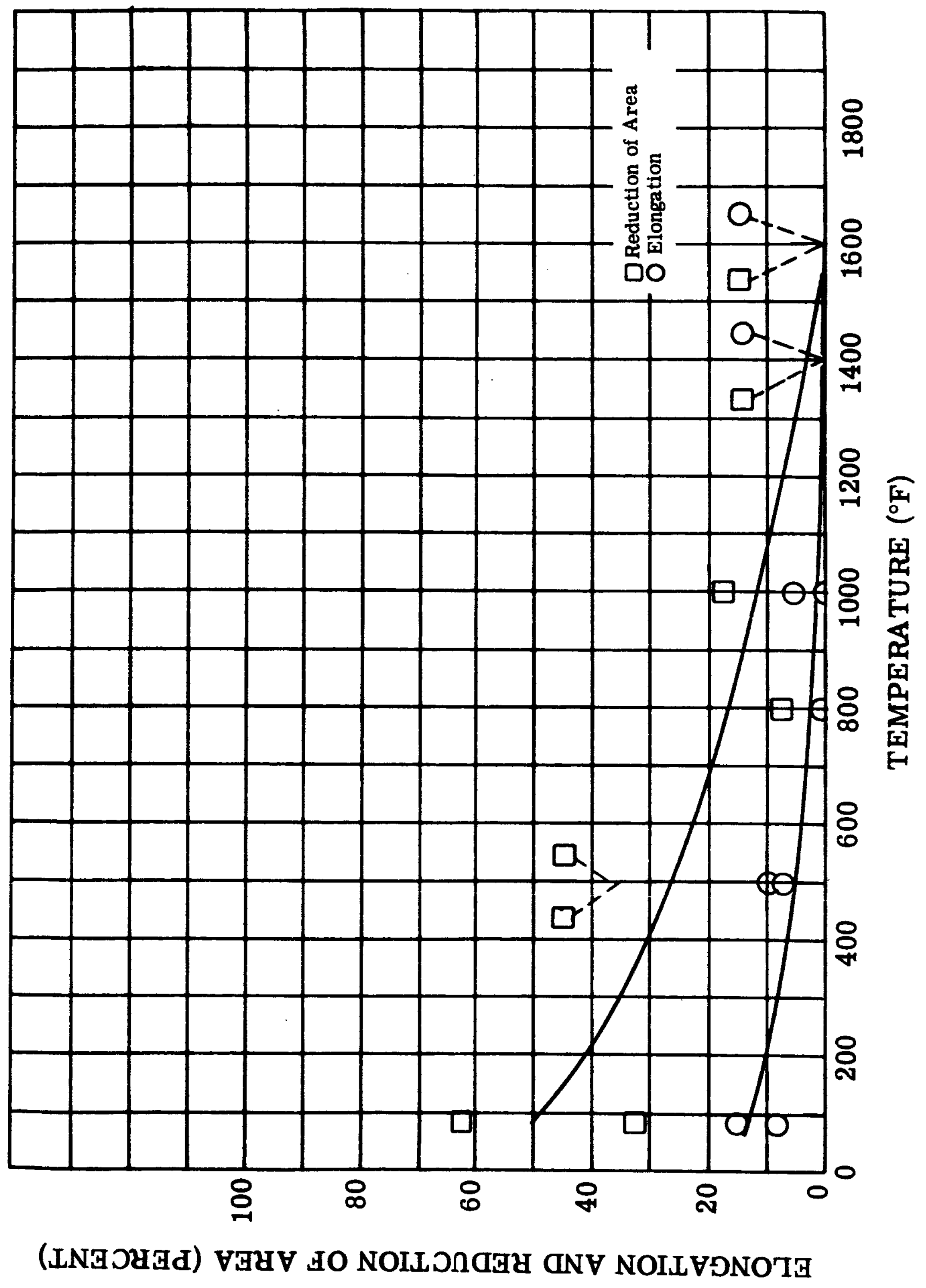


FIGURE I V. D-6. Tensile Ductility, Dispersion-Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire. Tests Above 500°F Made in Argon, all Others in Air. (No. 10 AWG Wire) Strain Rate: 0.005 in/in-min. to Yield Then 0.05 in/in-min. to Failure. (Reference: NAS 3-4162)

Figure I V. D-6. Ductility - Dispersion Strengthened Copper

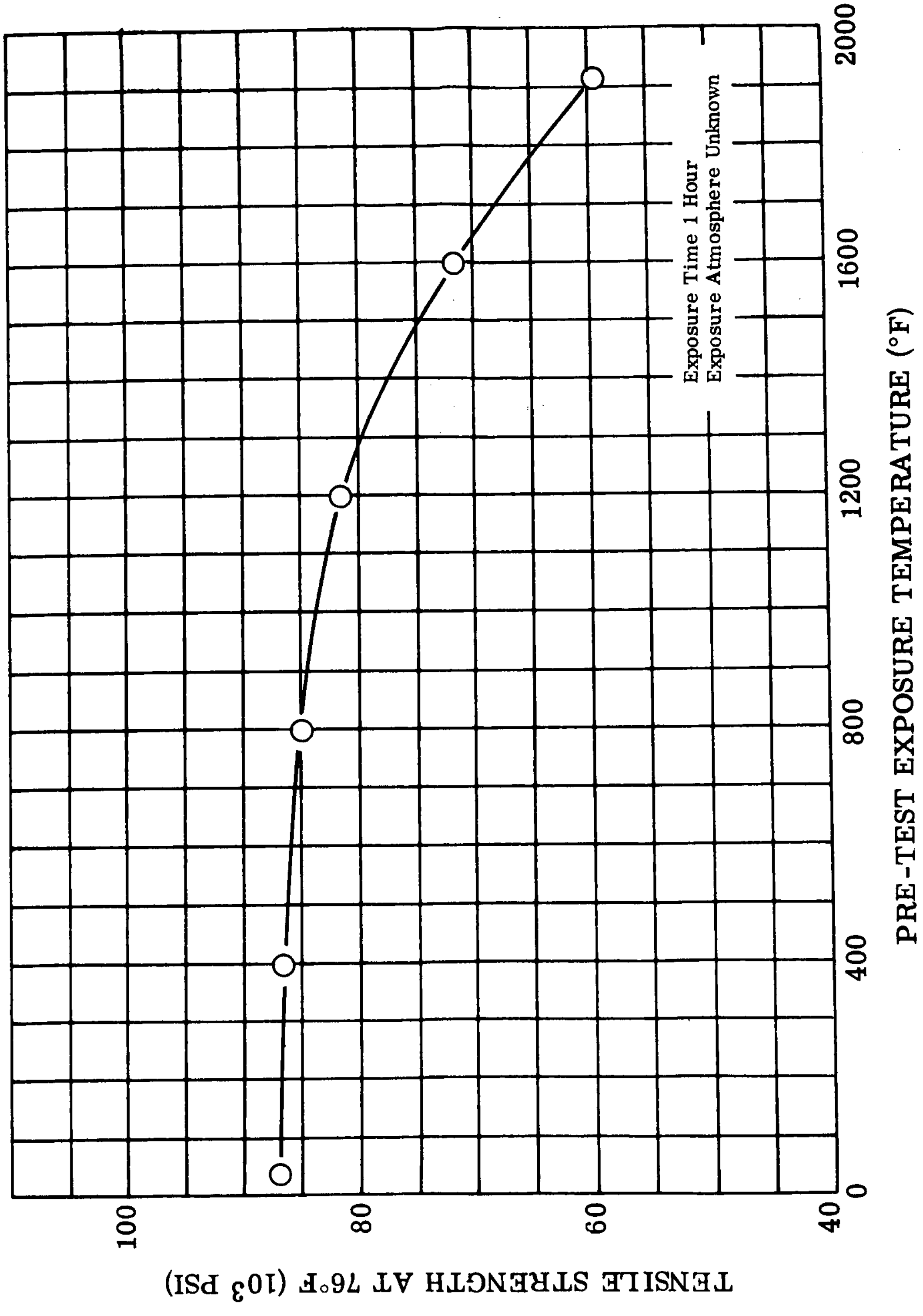


FIGURE I V. D-7. Room Temperature Tensile Strength of Dispersion-Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire After a One Hour Exposure at the Indicated Temperature. Strain Rate and Wire Size Not Known. (Reference: Handy and Harman Data Sheet, 1964)

Figure IV.D-7. Tensile Strength After Aging - Dispersion-Strengthened Copper

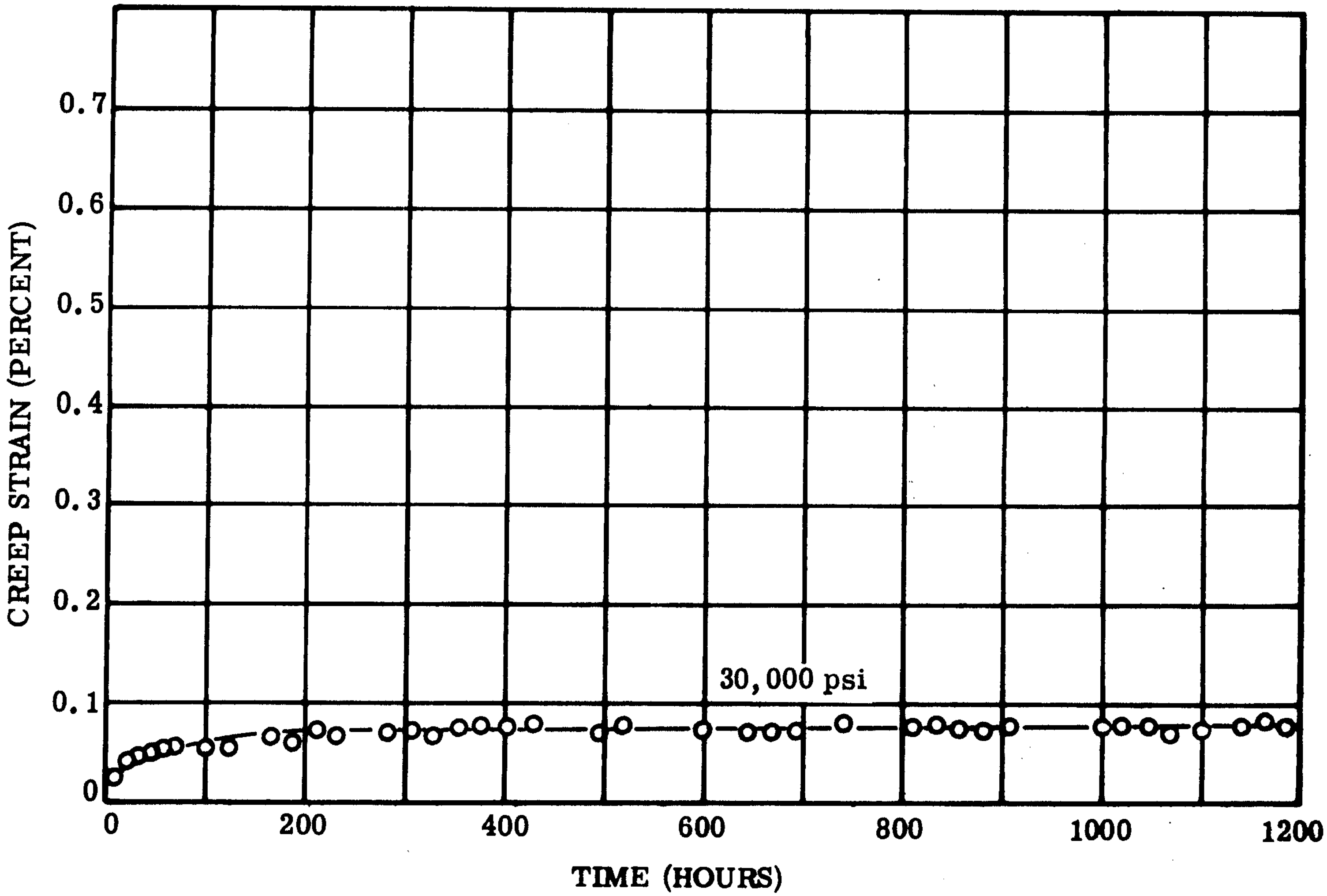


FIGURE I V. D-8. Creep at 30,000 psi Stress of Dispersion-Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire (As Drawn Condition), Tested in Argon at 1000°F. See Table I V. D-6. (No. 10 AWG Wire) (Reference: NAS 3-4162)

Figure I V. D-8. Creep Dispersion-Strengthened Copper

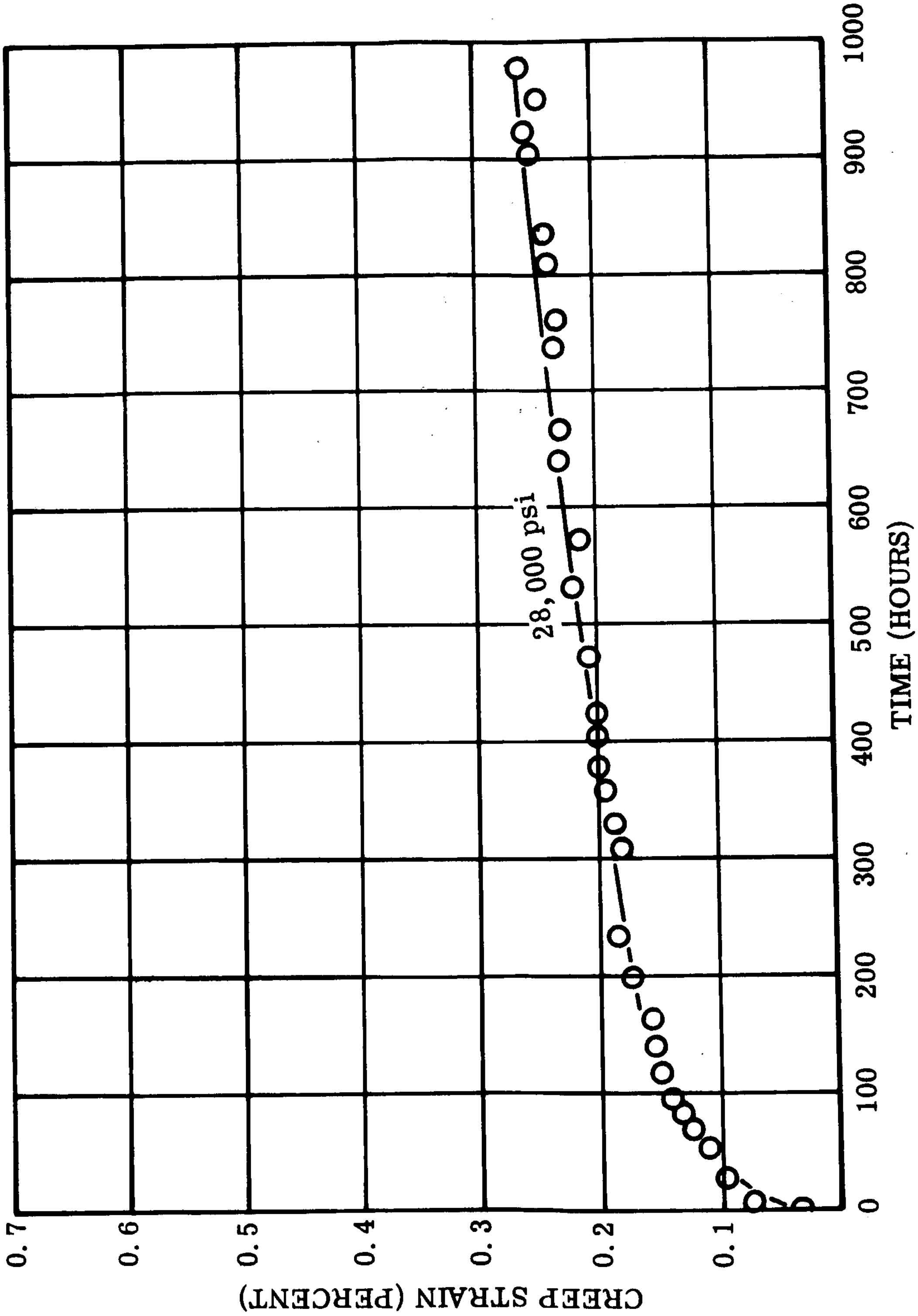


FIGURE I V. D-9. Creep at 28,000 psi Stress of Dispersion-Strengthened (Copper - 1 Volume Percent Beryllia) Copper Wire (As Drawn). Tested in Argon at 1100°F. (No. 10 AWG Wire) See Table I V. D-6. (Reference: NAS 3-4162)

Figure I V. D-9. Creep Dispersion-Strengthened Copper

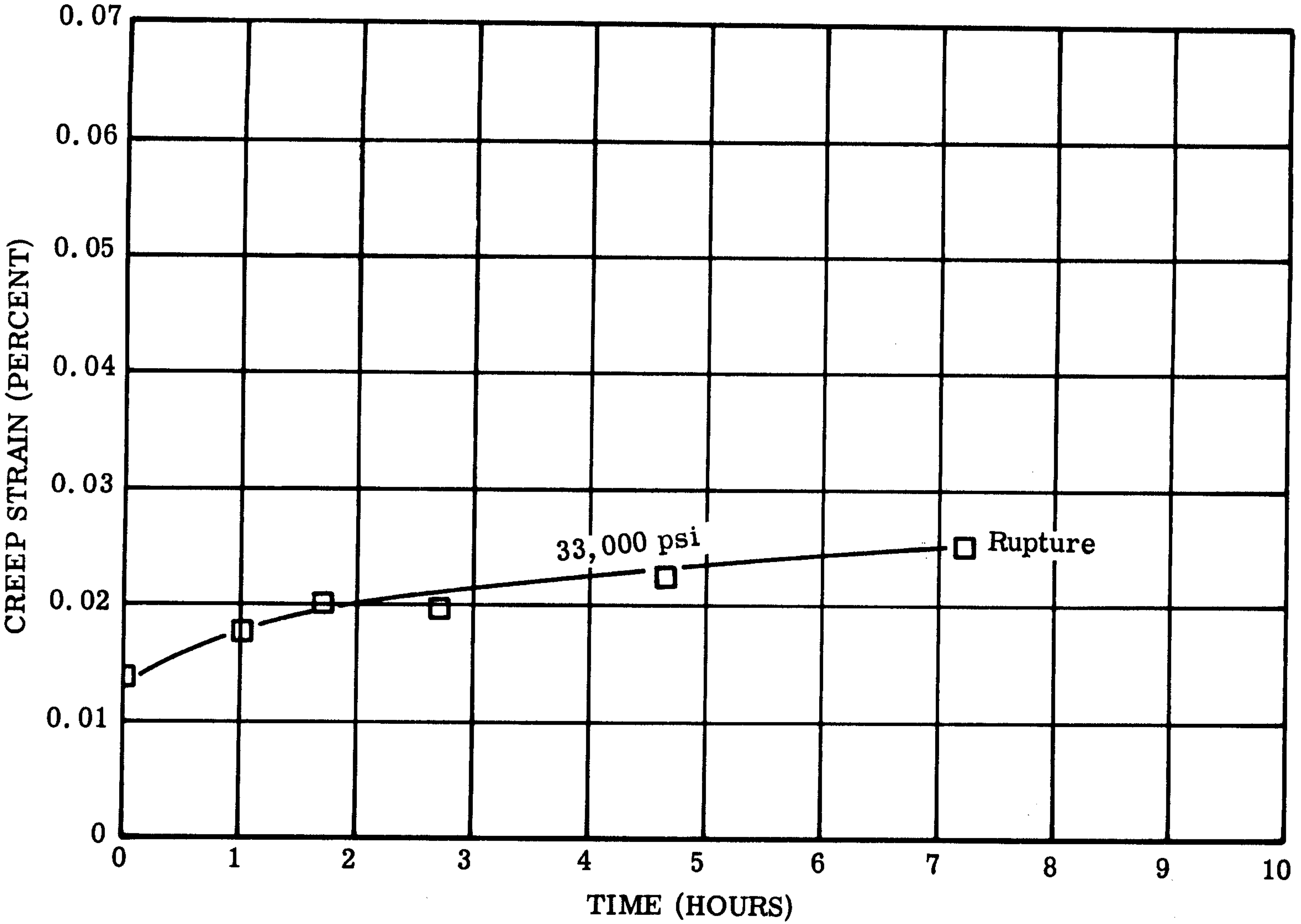


FIGURE I V. D-10. Creep at 33,000 psi Stress of Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia) Wire, As Drawn. Tested in Argon at 1100°F. (No. 10 AWG Wire) See Table I V. D-6. (Reference: NAS 3-4162)

Figure I V. D-10. Creep Dispersion-Strengthened Copper

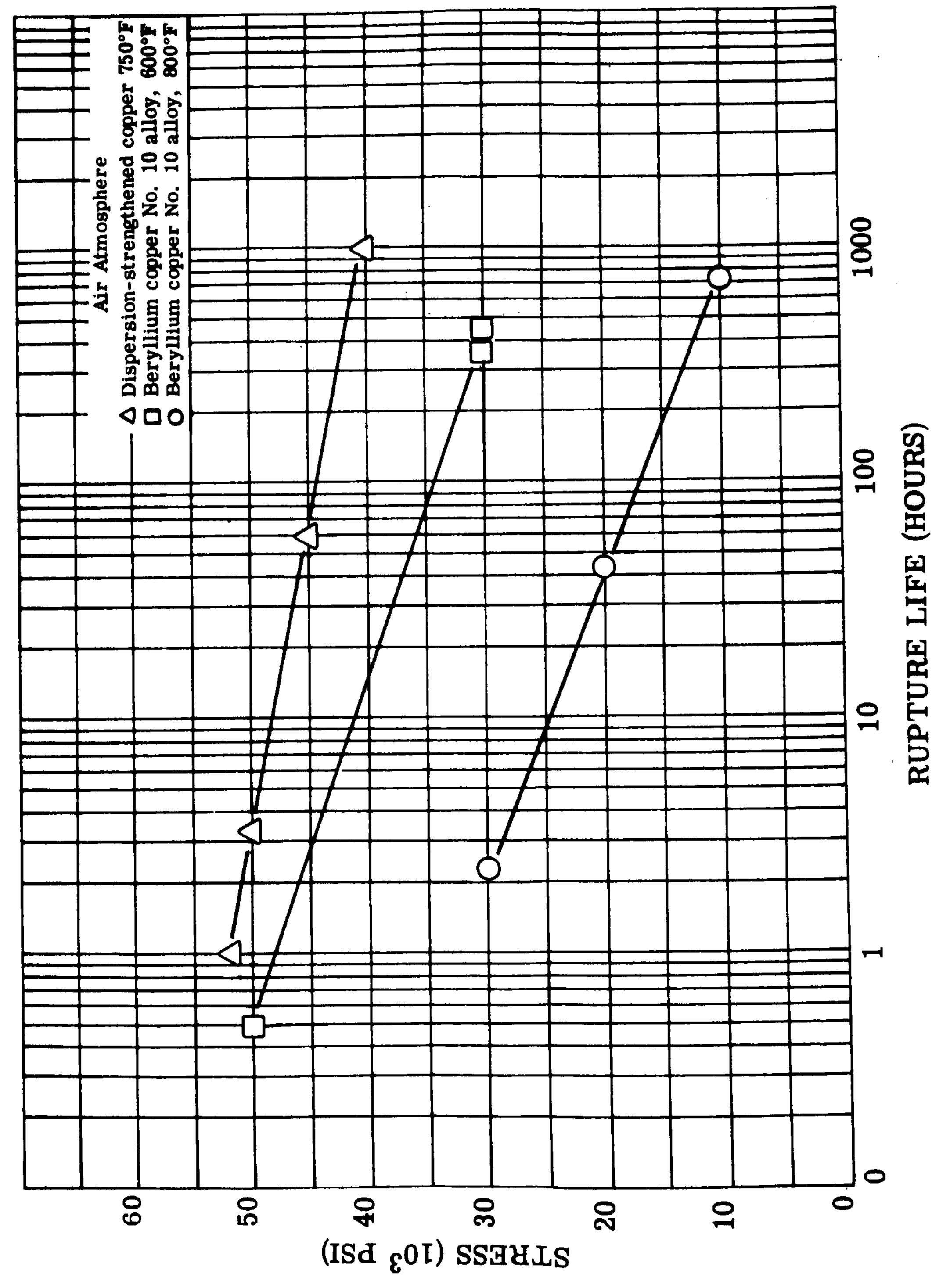


FIGURE IV.D-11. 750°F Stress Versus Time to Rupture for Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia) Wire Compared to the 600°F and 800°F Properties of Standard Beryllium Copper No. 10 Alloy Rod. (Reference: Handy and Harman Data Sheet on 'Cube' (1964) and Westinghouse Data on Beryllium Copper, 1963)

Figure IV.D-11. Stress Rupture Comparisons - Dispersion-Strengthened and Beryllium - Coppers

E. DISPERSION-STRENGTHENED NICKEL (TD NICKEL)

Availability:	Commercial from E. I. duPont de Nemours & Co.
Nominal Composition:	Nickel - 2 volume percent Thoria

I. Thermophysical Properties

A. Density 0.322 lb/cu in 9.04 grams/cc

B. Solidus temperature of lowest melting constituent. 2600°F

C. Electrical Resistivity of As Drawn Wire

Temperature (°F)	Resistivity (ohm-cm)
76	7.57×10^{-6}
500	19.69×10^{-6}
800	32.60×10^{-6}
1000	36.60×10^{-6}
1600	45.75×10^{-6}

D. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
72	48.5
500	32.0
800	25.5
1000	24.8
1600	27.0

E. Thermal Expansion $= 0.5434 \times 10^{-5} T^2 + 0.8393 \times 10^{-4} T + 7.35$ where $150°F \leq T \leq 610°F$

Thermal Expansion $= 0.2719 \times 10^{-5} T^2 - 0.486 \times 10^{-2} T + 11.21$ where $610°F \leq T \leq 1600°F$

II. Electrical Properties

A. Effects of time and temperature on room temperature resistivity.

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 75°F (ohm-cm)
76 (As Drawn)	0	Air	7.57×10^{-6}
800	1000	Air	7.73×10^{-6}
800	2000	Air	7.67×10^{-6}
1000	500	Air	7.48×10^{-6}
1000	1000	Air	7.52×10^{-6}
1000	2000	Air	7.52×10^{-6}
1600	100	Argon	7.69×10^{-6}
1600	500	Argon	7.47×10^{-6}
1600	1000	Argon	7.51×10^{-6}
1600	2000	Argon	7.45×10^{-6}

III. Mechanical Properties

A. Tensile Properties of No. 10 AWG wire. Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	50,500 psi
b.	Tensile strength	66,000 psi
c.	Elongation	17.0 percent

2. At 500°F

a.	0.20 percent offset yield strength	41,000 psi
b.	Tensile strength	50,000 psi
c.	Elongation	14.5 percent

3. At 800°F

a.	0.20 percent offset yield strength	34,000 psi
b.	Tensile strength	40,000 psi
c.	Elongation	12.0 percent

4. At 1000°F

a.	0.20 percent offset yield strength	31,000 psi
b.	Tensile strength	34,000 psi
c.	Elongation	11.0 percent

5. At 1400°F

a.	0.20 percent offset yield strength	25,000 psi
b.	Tensile strength	26,000 psi
c.	Elongation	7.0 percent

6. At 1600°F

a.	0.20 percent offset yield strength	22,000 psi
b.	Tensile strength	22,000 psi
c.	Elongation	6.0 percent

B. Creep (duPont Data Sheet TD Nickel)

1.	Stress required to produce 0.50 percent plastic strain in 1000 hours at 1600°F	11,500 psi
2.	Stress required to produce 0.50 percent plastic strain in 10,000 hours at 1600°F	9,000 psi
3.	Stress required to produce 1.00 percent plastic strain in 1000 hours at 1600°F	12,000 psi
4.	Stress required to produce 1.00 percent plastic strain in 10,000 hours at 1600°F	9,500 psi

TABLE IV.E-1. Electrical Resistivity of As Drawn TD Nickel Wire, in Vacuum (10^{-5} torr)

TEST: ASTM B193

Specimen No. 1, Continuous Heating (Rate, 10°F Per Minute)

Wire Diameter - 0.040 Inches, Test Length - 23.02 Inches(1)

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
76	45.539	7.57	23.14
100	47.549	7.90	22.16
205	60.510	10.06	18.35
300	75.898	12.62	13.88
400	95.165	15.82	11.07
504	118.435	19.69	8.99
600	144.290	23.99	7.30
700	178.069	29.60	5.92
800	196.085	32.60	5.37
900	208.929	34.73	5.04
1000	220.189	36.60	4.79
1100	231.031	38.41	4.56
1224	243.292	40.44	4.33
1321	252.633	41.99	4.17
1441	264.894	44.04	3.98

Same Specimen as in Above Test. Soaked For 10 Minutes at Test Temperature Before Measurement on Both Heating and Cooling Cycles. Heating and Cooling Rates were 10°F Per Minute.

Wire Diameter - 0.040 Inches, Test Length - 23.16 Inches(1)

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
75	45.279	7.53	23.26
321	82.900	13.78	12.71
463	113.738	18.91	9.26
695	183.374	30.48	5.74
980	220.099	36.59	4.79
1291	250.606	41.66	4.20
1600	275.228	45.75	3.83
1375	255.000	42.39	4.13
874	206.918	34.40	5.09
593	148.888	24.75	7.08
314	85.552	14.22	12.31
75	45.354	7.54	23.21

1. In the continuous heating test, leads separated from the test specimen between between 1450 and 1500°F. It was not possible to replace the leads at exactly the same spot for the soaking test, hence the different test length.
2. International Annealed Copper Standard
   $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV. E-2. Electrical Resistivity of Aged TD Nickel Wire at 75°F

Aging Temperature(1) (°F)	Aging Time (Hours)	Resistivity at 75°F (Ohms/Cir Mil Ft)	Resistivity at 75°F (Microhm-Cm(2))	Conductivity (Percent IACS)(3)
800	1000	46.48	7.73	22.75
800	2000	46.12	7.67	22.99
1000	500	45.02	7.48	23.41
1000	1000	45.24	7.52	23.36
1000	2000	45.24	7.52	23.36
1600	100	46.25	7.69	22.95
1600	500	44.93	7.47	23.45
1600	1000	45.17	7.51	23.36
1600	2000	44.83	7.45	23.50

1. Sample aged in air at 800° and 1000°F and in Argon at 1600°F. Test Specimens were No. 18 AWG Wire.

2. 75°F Resistivity of TD Nickel = 7.54×10^{-6} Ohm-Cm (Table IV. E-1, 2nd Test)

3. International Annealed Copper Standard.
   $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

(Reference: NAS 3-4162)

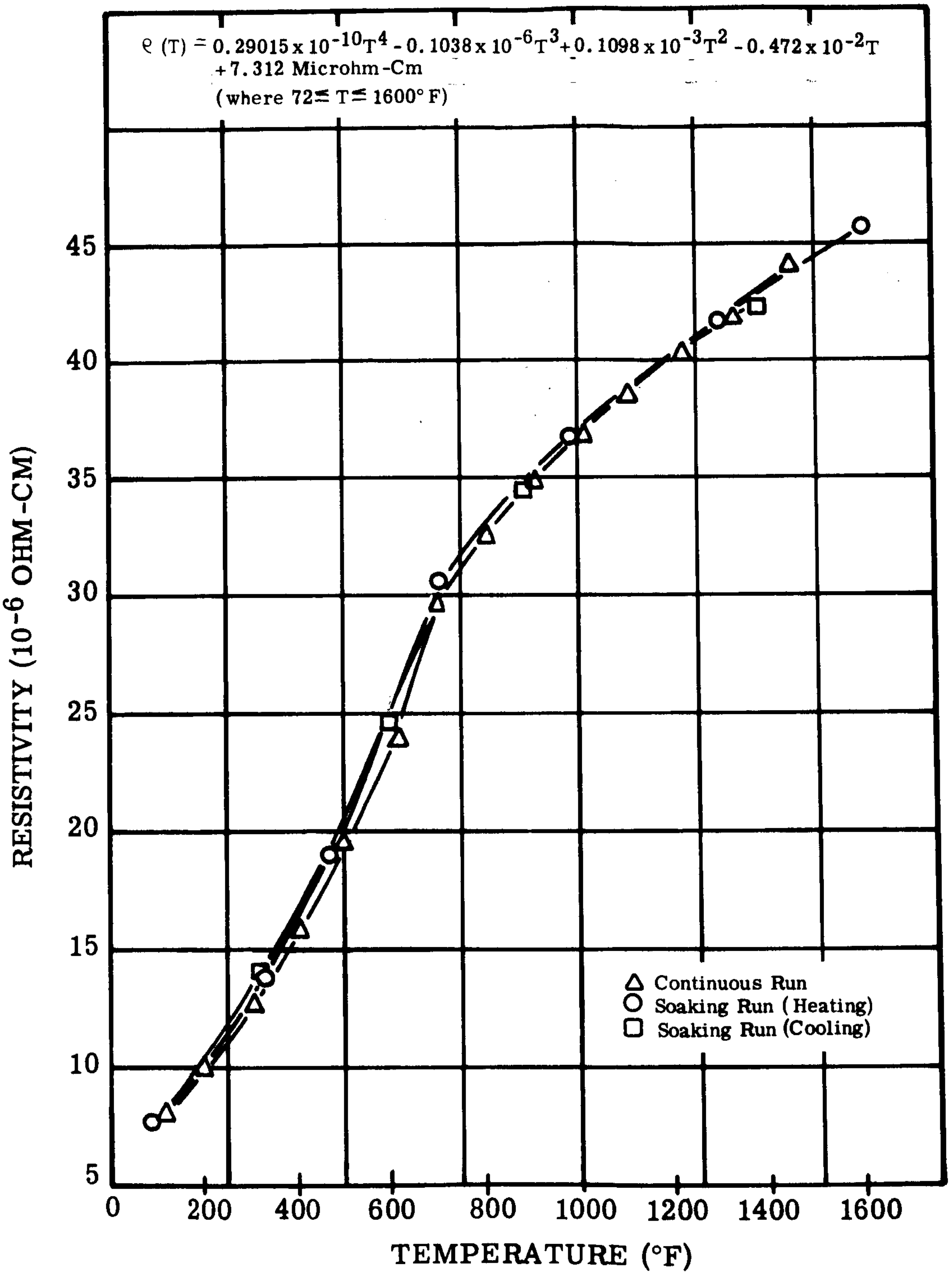


FIGURE IV. E-1. Electrical Resistivity of TD Nickel, No. 18 AWG Wire in As Drawn Condition. Vacuum Test 10^{-5} torr. (Reference: NAS 3-4162)

Figure IV. E-1. Electrical Resistivity - TD Nickel

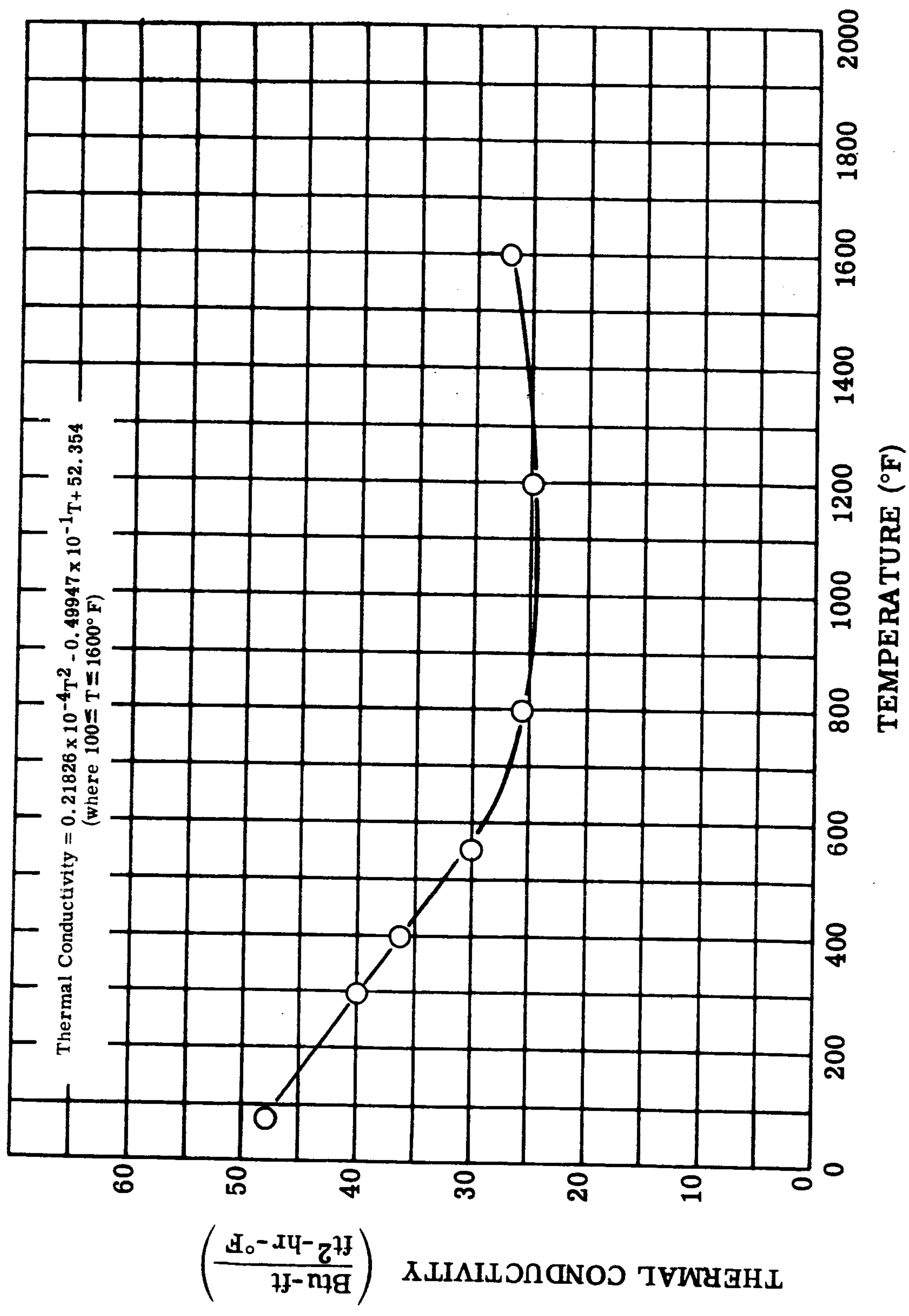


FIGURE IV.E-2. Thermal Conductivity of TD Nickel. (Reference: Westinghouse Electric Corp., Astronuclear Laboratory)

Figure IV.E-2. Thermal Conductivity - TD Nickel

Figure IV. E-3. Thermal Expansion (Estimated) - TD Nickel

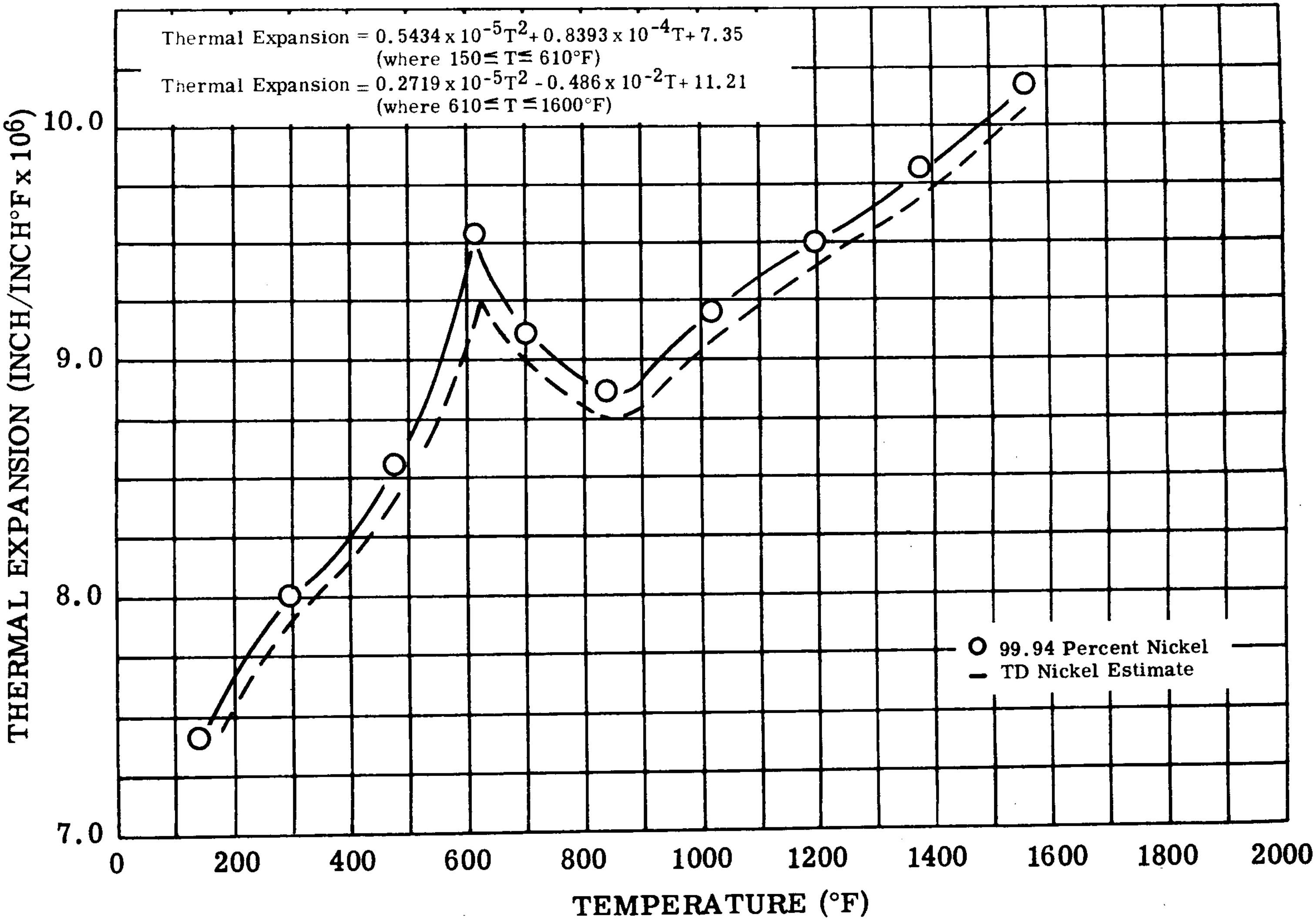


FIGURE IV. E-3. Thermal Expansion of Annealed 99.94 Percent Nickel and an Estimate for TD Nickel. (Reference: Nickel and Nickel Alloys, NBS Circular 592, United States Department of Commerce, page 20)

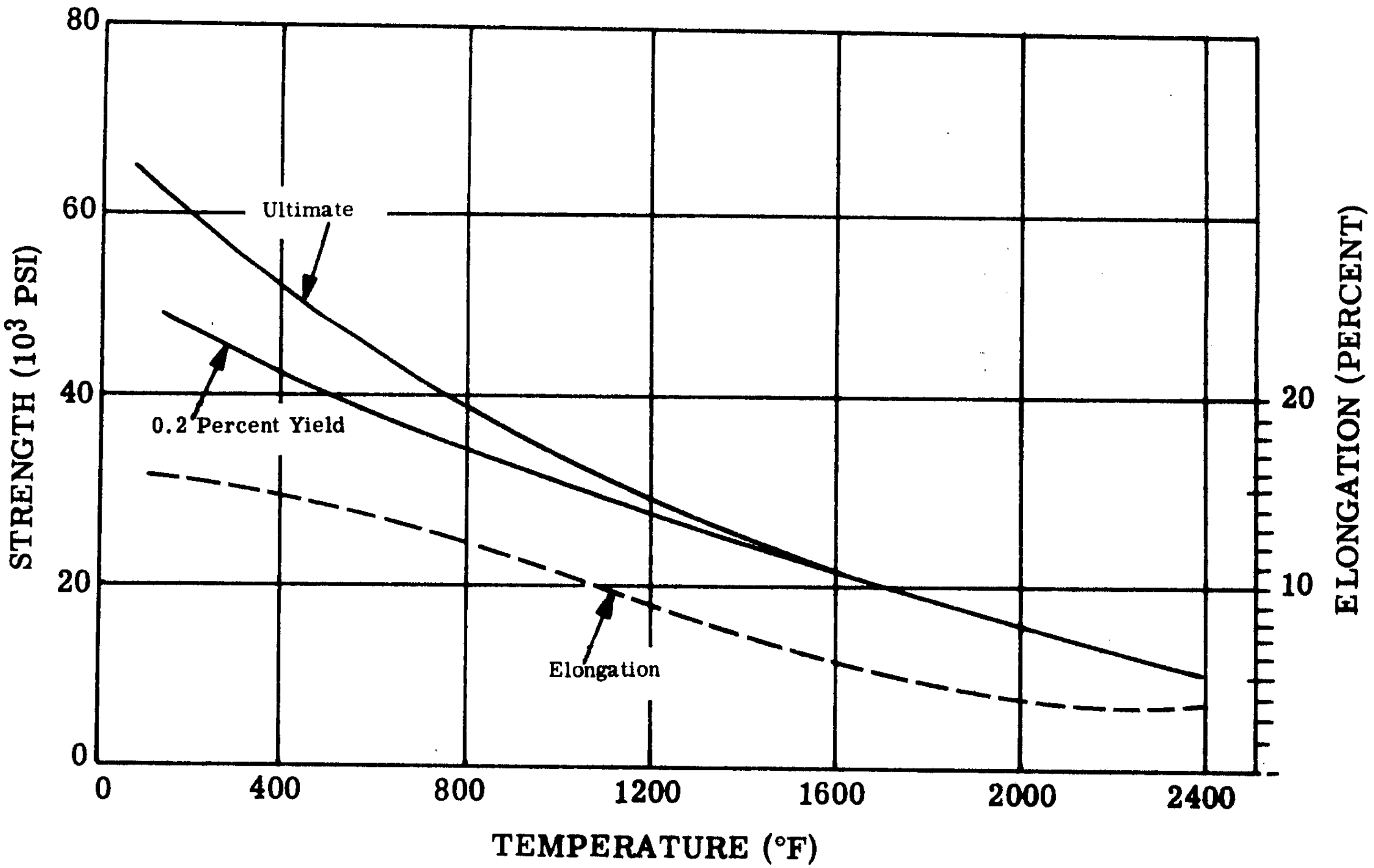


FIGURE IV. E-4. Mechanical Properties of TD Nickel at Elevated Temperatures. Strain Rate Not Available. (Reference: RC57)

Figure IV. E-4. Mechanical Properties - TD Nickel

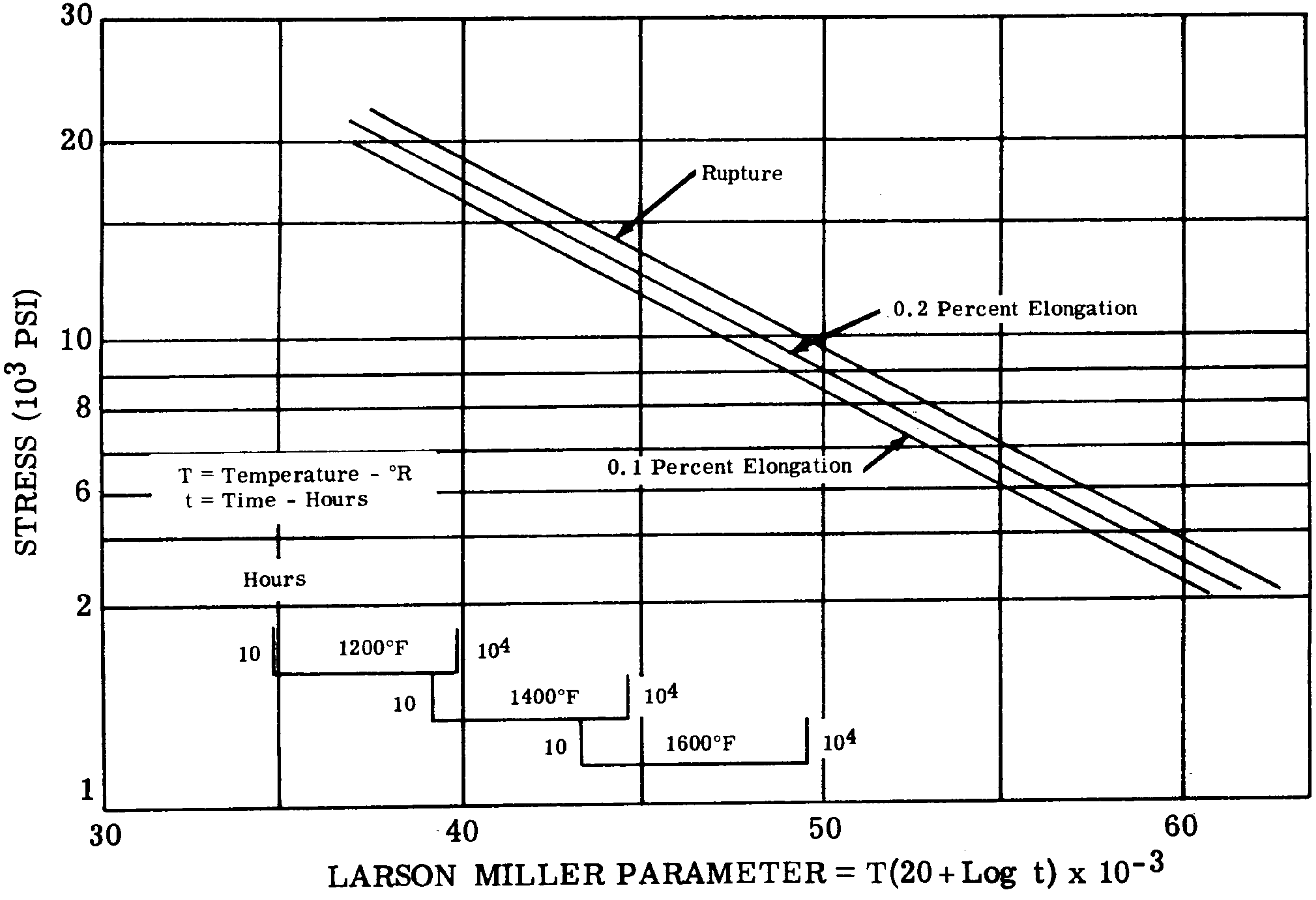


FIGURE IV. E-5. Creep and Stress Rupture Behavior, TD Nickel Bar. Test Atmosphere: Air. (Reference: RC57)

Figure IV. E-5. Creep Rupture - TD Nickel

F. INCONEL 600-CLAD COLUMBIUM-BARRIER DISPERSION-STRENGTHENED COPPER

Availability:	Semi-commercial pilot quantities are available from Sylvania Electric Products Corp., Parts Division, Warren, Pa.
Nominal Composition:	Handy and Harman dispersion-strengthened copper clad with Inconel 600 with a columbium diffusion barrier-layer. The Inconel clad area approximates 28 percent and the columbium-barrier layer area 8-9 percent.

I. Thermophysical Properties

A. Density 0.315 lb/cu in 8.77 grams/cc

B. Solidus temperature of lowest melting constituent. 1980°F

C. Electrical Resistivity

Temperature (°F)	Resistivity (ohm-cm)
72	3.38×10^{-6}
500	5.75×10^{-6}
800	7.58×10^{-6}
1000	8.78×10^{-6}
1400	11.47×10^{-6}
1600	12.90×10^{-6}

D. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
72	107.5
500	94.2
800	92.5
1000	92.5
1400	92.5
1600	92.5 (1)

(1) Extrapolated

E.	Thermal Expansion (75-1600°F)	11.42 x 10^{-6} in/in-°F

II. Electrical Properties

A. Effects of time and temperature on room temperature resistivity.

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 75°F (ohm-cm)
800	1000	Air	3.19 x 10^{-6}
800	2000	Air	3.42 x 10^{-6}
1000	100	Air	3.18 x 10^{-6}
1000	500	Air	3.13 x 10^{-6}
1000	1000	Air	3.13 x 10^{-6}
1000	2022	Air	3.15 x 10^{-6}
1600	100	Argon	3.17 x 10^{-6}
1600	500	Argon	3.69 x 10^{-6}
1600	1000	Argon	3.80 x 10^{-6}
1600	2000	Argon	3.93 x 10^{-6}

III. Mechanical Properties

A. Tensile Properties of No. 10 AWG wire. Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

1. At 72°F

a.	0.20 percent offset yield strength	52,000 psi
b.	Tensile strength	73,600 psi
c.	Elongation in 2 inches	28.7 percent

2. At 500°F

a.	0.20 percent offset yield strength	46,740 psi
b.	Tensile strength	57,700 psi
c.	Elongation in 2 inches	20.9 percent

3. At 800°F

a.	0.20 percent offset yield strength	41,950 psi
b.	Tensile strength	48,100 psi
c.	Elongation in 2 inches	10.2 percent

4. At 1000°F

a.	0.20 percent offset yield strength	40,000 psi
b.	Tensile strength	41,000 psi
c.	Elongation in 2 inches	4.4 percent

5. At 1400°F

a.	0.20 percent offset yield strength	26,400 psi
b.	Tensile strength	27,300 psi
c.	Elongation in 2 inches	1.9 percent

6. At 1600°F

a.	0.20 percent offset yield strength	18,500 psi
b.	Tensile strength	18,500 psi
c.	Elongation in 2 inches	1.6 percent

B. Creep

No creep data are available on this particular construction, but an approximation may be made from the dispersion-strengthened copper creep data given in Section IV. D. and creep data for Inconel 600. When a need for such information arises, actual creep data must be obtained.

TABLE IV. F-1. Electrical Resistivity, Inconel 600-Clad (28 Percent of Area) Columbium-Barrier (8 Percent of Area), Dispersion-Strengthened Copper Wire (Copper -1 Volume Percent Beryllia), As Drawn, in Vacuum (10^{-5} torr)

TEST: ASTM B193

Specimen No. 1, Continuous Heating and Cooling(1)

Wire Diameter - 0.0405 Inches, Test Length - 23.47 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
76	20.320	3.38	51.90
200	23.776	3.95	44.36
300	27.507	4.57	38.34
400	31.114	5.17	33.90
505	34.971	5.81	30.16
610	38.838	6.46	27.16
703	42.192	7.01	24.99
800	45.622	7.58	23.12
900	49.312	8.20	21.39
1008	53.170	8.84	19.84
1100	56.902	9.46	18.54
1200	60.802	10.11	17.35
1300	64.911	10.79	16.25
1400	69.020	11.47	15.28
1500	73.423	12.21	14.36
1600	77.574	12.90	13.60
1450	71.410	11.87	14.77
1250	63.401	10.54	16.64
1050	55.585	9.24	18.97
850	47.970	7.97	21.99
650	40.700	6.77	25.91
450	33.294	5.53	31.68
250	26.434	4.39	39.90
150	23.272	3.87	45.32
76	19.272	3.20	54.73

1. Heating and Cooling rates 10°F per minute

2. International Annealed Copper Standard
   ρ 68°F = 1.7241×10^{-6} Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV. F-2. Electrical Resistivity at 72°F of Aged Inconel 600-Clad (28 Percent of Area) Columbium-Barrier (8 Percent of Area) Dispersion-Strengthened Copper Wire. (Copper - 1 Volume Percent Beryllia)(No. 18 AWG Wire)
See Figures II. B-3 to II. B-5

Aging Temperature(1) (°F)	Aging Time (Hours)	Resistivity at 72°F (Ohms/Cir Mil Ft)	Resistivity at 72°F (Michrohm-Cm)	Conductivity (Percent IACS)(2)
As Drawn	0	20.33	3.38	51.01
800	1000	19.19	3.19	54.05
800	2000	20.57	3.42	50.41(3)
1000	100	19.13	3.18	54.22
1000	500	18.83	3.13	55.08
1000	1000	18.83	3.13	55.08
1000	2022	18.95	3.15	54.73
1600	100	19.07	3.17	54.39
1600	500	22.20	3.69	46.72
1600	1000	22.86	3.80	45.37
1600	2000	23.64	3.93	43.87

1. Sample aged in air at 800° and 1000°F and in Argon at 1600°F. Test Specimens were 18 gage AWG Wire.

2. International Annealed Copper Standard. $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

3. Cladding separated from base metal.

(Reference: NAS 3-4162)

TABLE I V. F-3. Tensile Test Data on Inconel 600-Clad (28 Percent of Area) Columbium-Barrier (8 Percent of Area) Dispersion-Strengthened Copper Wire (Copper - 1 Volume Percent Beryllia)(No. 10 AWG Wire)

Test: ASTM E21 - Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure

Specimen No.	Test Temperature(1) (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	72	45,450	51,800	73,650	29.3	47.7
2	72	49,800	52,200	73,550	28.0	47.7
3	500	33,450	46,700	58,050	21.8	49.2
4	500	34,950	46,800	57,300	20.0	40.3
5	800	26,950	41,950	47,450	10.7	22.3
6	800	27,100	41,950	48,800	9.6	30.8
7	1000	37,200	40,450	41,200	7.0	17.0
8	1000	31,200	39,600	40,800	1.9	20.6
9	1400	16,100	26,700	27,950	2.0	5.9
10	1400	16,250	26,100	26,700	1.7	9.6
11	1600	11,500	18,100	18,100	2.0	7.7
12	1600	11,850	18,850	18,900	1.2	3.9

1. All tests made in air.

(Reference: NAS 3-4162)

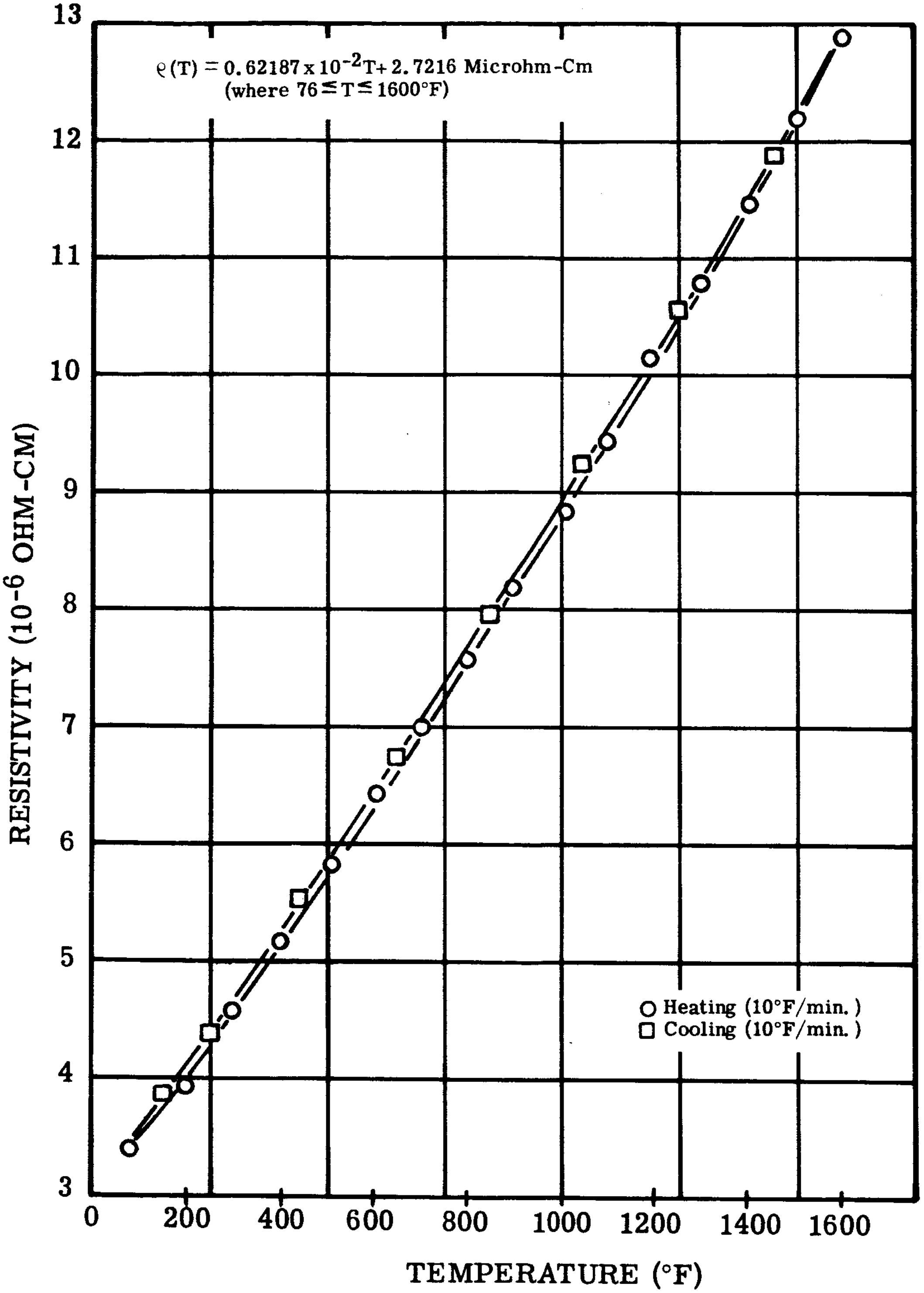


FIGURE I V. F-1. Electrical Resistivity of Inconel 600 (28 Percent of Area) Columbium-Barrier (8 Percent of Area) Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia) Vacuum Test. (Reference: NAS 3-4162)

Figure I V. F-1. Electrical Resistivity - Inconel 600-Cb Clad DS Copper

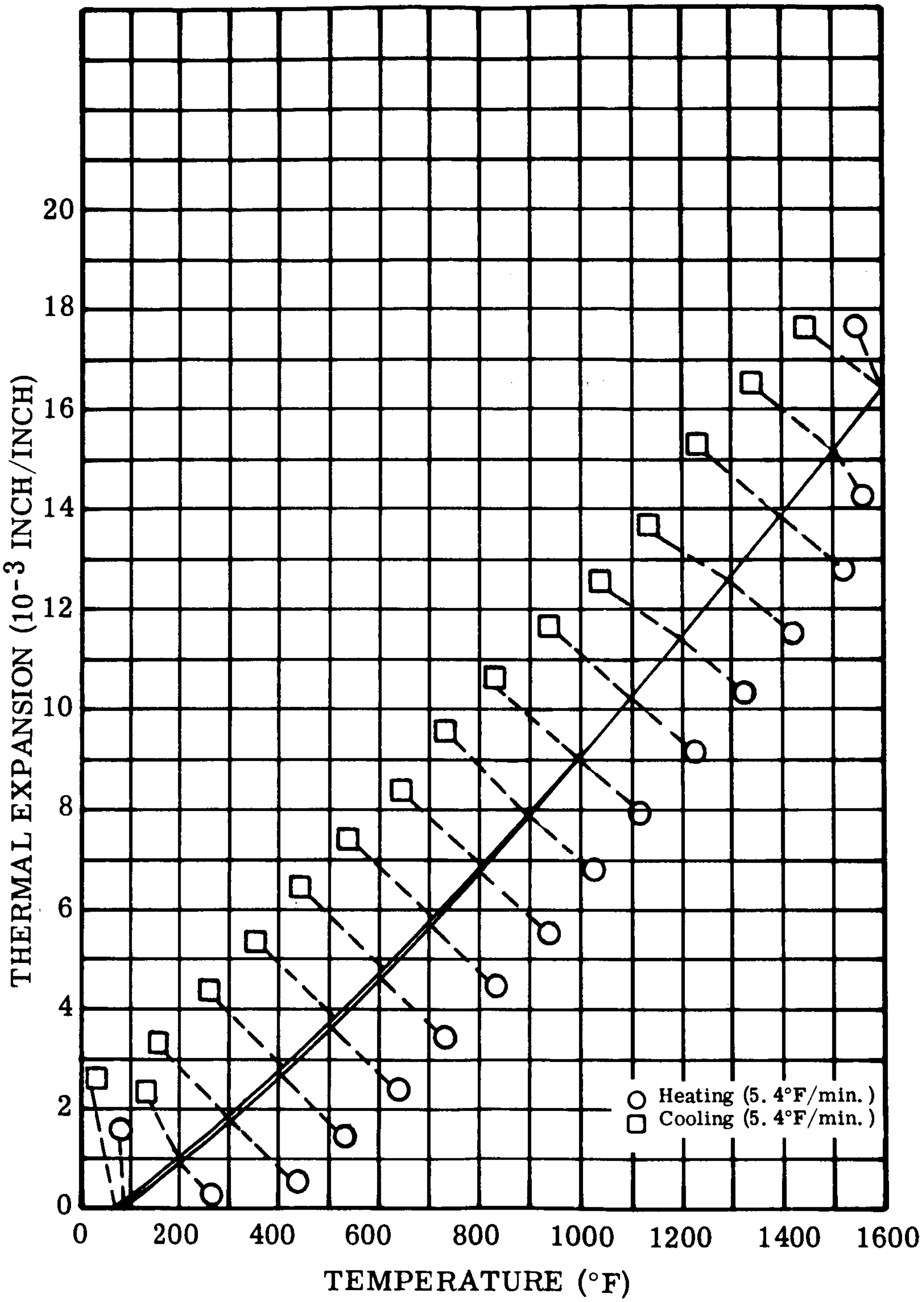


FIGURE I V. F-2. Thermal Expansion, Inconel 600-Clad (28 Percent of Area) Columbium-Barrier (8 Percent of Area) Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia). Tested in Argon. (No. 18 AWG Wire) (Reference: NAS 3-4162)

Figure I V. F-2. Thermal Expansion - Inconel 600-Cb Clad DS Copper

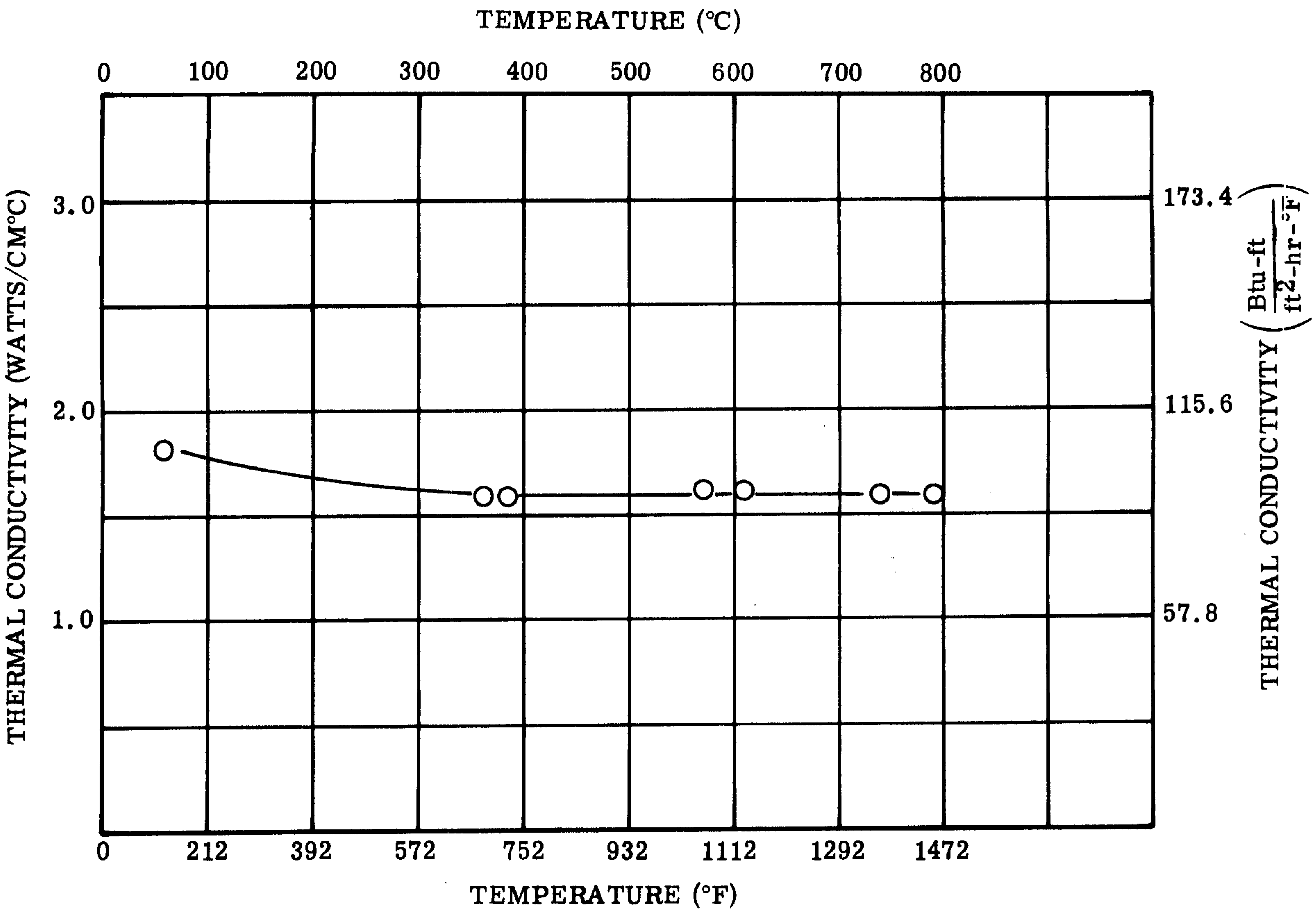


FIGURE I V. F-3. Thermal Conductivity of Inconel 600-Clad (28 Percent of Area) Columbium Barrier (8 Percent of Area) Dispersion-Strengthened Copper (Copper - 1 Volume Percent Beryllia) Wire. (No. 18 AWG Wire) In Vacuum. (Reference: NAS 3-4162)

Figure I V. F-3. Thermal Conductivity - Inconel 600-Cb Clad DS Copper

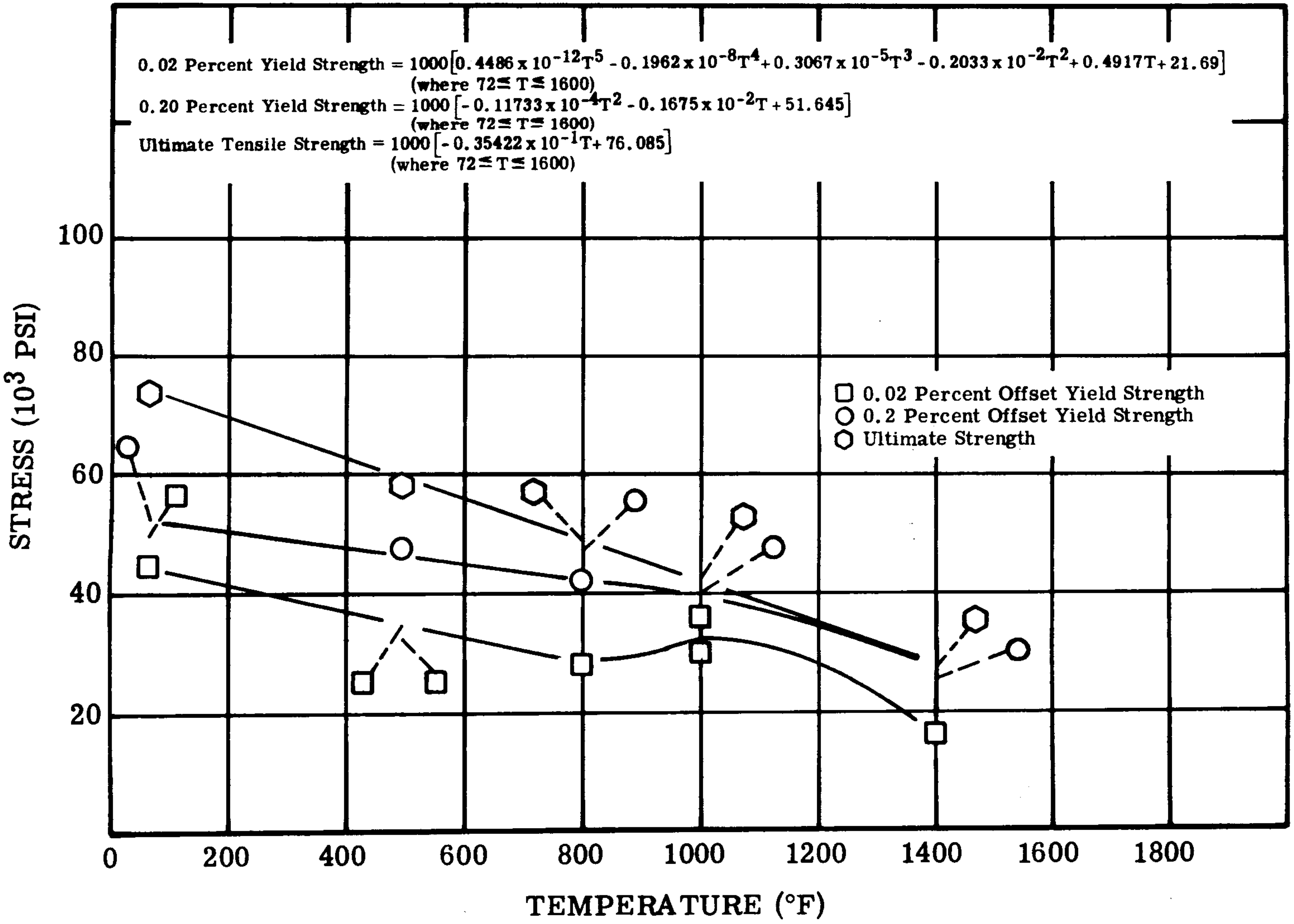


FIGURE IV. F-4. Tensile Strength, Inconel 600-Clad (28 Percent of Area) Columbium Barrier (8 Percent of Area) Dispersion-Strengthened Copper Wire (Copper - 1 Volume Percent Beryllia) No. 10 AWG Wire. Test Made in Air. Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure IV. F-4. Tensile Strength - Inconel 600-Cb Clad DS Copper

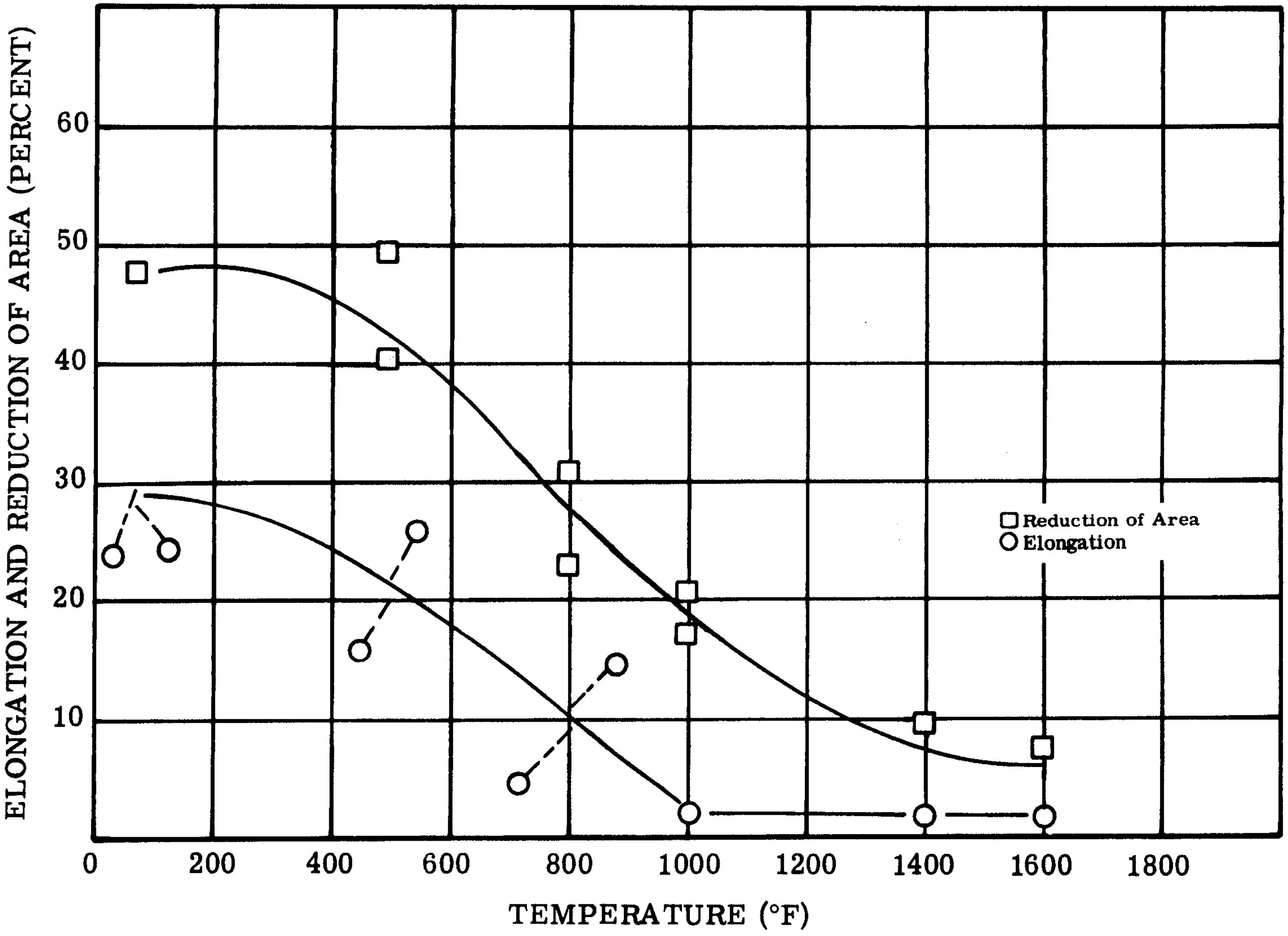


FIGURE I V. F-5. Tensile Ductility, Inconel 600-Clad (28 Percent of Area) Columbium Barrier (8 Percent of Area) Dispersion-Strengthened Copper Wire (Copper - 1 Volume Percent Beryllia)(No. 10 AWG Wire) Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure. Tests Made in Air. (Reference: NAS 3-4162)

Figure I V. F-5. Ductility - Inconel 600-Cb Clad DS Copper

G. INCONEL 600-CLAD SILVER(1)

Availability:	Semi-commercial pilot quantities available from Sylvania Electric Products, Parts Division, Warren, Pa.
Nominal Composition:	Fine silver(2) clad with Inconel 600 alloy. Clad is approximately 28 percent of conductor area.

I. Thermophysical Properties

A. Density 0.356 lb/cu in 9.93 grams/cc

B. Solidus temperature of lowest melting constituent. 1760°F

C. Electrical Resistivity

Temperature (°F)	Resistivity (ohm-cm)
72	2.44×10^{-6}
500	4.34×10^{-6}
800	5.80×10^{-6}
1000	6.79×10^{-6}
1600	10.21×10^{-6}

D. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
72	164.7
500	141.6

(1) Inconel 600 cladding was chosen for its improved oxidation resistance in comparison to nickel. Nickel-clad silver exhibits similar electrical and stability properties. (See RC5 and RC47 for additional discussion.)

(2) Fine silver by definition is 99.9% pure silver. Concise Chemical and Technical Dictionary, Chemical Publishing Company, Brooklyn, N. Y. 1947

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
800	136.4
1000	128.9
1600	98.8(1)

E. Thermal Expansion (75-1600°F) 11.2×10^{-6} in/in-°F

II. Electrical Properties

A. Effects of time and temperature on room temperature resistivity.

Aging Temperature (°F)	Aging Time (hours)	Test Atmosphere	Resistivity at 72°F (ohm-cm)
800	1000	Air	2.45×10^{-6}
800	2000	Air	2.37×10^{-6}
1000	500	Air	2.37×10^{-6}
1000	1000	Air	2.36×10^{-6}
1000	2022	Air	2.40×10^{-6}
1600	100	Argon	2.54×10^{-6}
1600-1760(2)	500	Argon	5.37×10^{-6}
1600-1760(2)	1000	Argon	3.99×10^{-6}
1600-1760(2)	2000	Argon	4.40×10^{-6}

III. Mechanical Properties

A. Tensile Properties (10 AWG wire). Strain Rate: 0.005 in/in-min. to yield then 0.05 in/in-min. to failure.

---

(1) Extrapolated

(2) Evidence of melting on ends of wires, indicating furnace exceeded desired temperature. (See Text.)

1. At 72°F

a.	0.20 percent offset yield strength	20,400 psi
b.	Tensile strength	45,600 psi
c.	Elongation in 2 inches	24.4 percent

2. At 500°F

a.	0.20 percent offset yield strength	18,300 psi
b.	Tensile strength	33,950 psi
c.	Elongation in 2 inches	12.7 percent

3. At 800°F

a.	0.20 percent offset yield strength	16,300 psi
b.	Tensile strength	33,650 psi
c.	Elongation in 2 inches	16.6 percent

4. At 1000°F

a.	0.20 percent offset yield strength	16,000 psi
b.	Tensile strength	29,750 psi
c.	Elongation in 2 inches	14.5 percent

5. At 1400°F

a.	0.20 percent offset yield strength	8,500 psi
b.	Tensile strength	11,000 psi
c.	Elongation in 2 inches	24.7 percent

6. At 1600°F

a.	0.20 percent offset yield strength	4,050 psi
b.	Tensile strength	5,750 psi
c.	Elongation in 2 inches	8.3 percent

C. Creep

Use of this material under heavy mechanical loads is not anticipated.

TABLE IV.G-1. Electrical Resistivity, As Drawn, Inconel 600-Clad (28 Percent of Area) Silver Wire in Vacuum (10^{-5} torr)

TEST: ASTM B193

Specimen No. 1, Continuous Heating and Cooling(1)

Wire Diameter - 0.040 Inches, Test Length - 23.41 Inches

Temperature (°F)	Resistivity (Ohms/Cir Mil Ft)	Resistivity (Microhm-Cm)	Conductivity (Percent IACS)(2)
77	14.656	2.44	72.10
200	17.191	2.86	71.47
300	20.340	3.38	51.95
400	23.194	3.86	45.56
500	26.130	4.34	40.44
600	29.099	4.84	36.31
700	32.044	5.33	32.98
800	34.914	5.80	30.27
902	38.031	6.32	27.79
1000	40.860	6.79	25.86
1100	44.002	7.31	24.01
1200	47.159	7.84	22.41
1300	50.481	8.39	20.93
1400	53.844	8.94	19.63
1500	57.173	9.50	18.48
1600	61.422	10.21	17.20
1450	56.181	9.34	18.81
1250	49.538	8.24	21.33
1050	43.264	7.19	24.42
850	37.096	6.17	28.49
650	30.977	5.15	34.11
450	24.318	4.04	43.45
250	19.659	3.27	53.75
171	17.223	2.86	61.35
77	14.328	2.38	73.75

1. Heating and Cooling rates 10°F per minute

2. International Annealed Copper Standard
   ρ 68°F = 1.7241×10^{-6} Ohm-Cm

(Reference: NAS 3-4162)

TABLE IV. G-2. Electrical Resistivity at 72°F of Aged Inconel 600-Clad (28 Percent of Area) Silver Wire. See Figures II. B-3 to II. B-5.

Aging Temperature(1) (°F)	Aging Time (Hours)	Resistivity at 72°F (Ohms/Cir Mil Ft)	Resistivity at 72°F (Microhm-Cm)	Conductivity (Percent IACS)(2)
As Drawn	0	14.68	2.44	70.66
800	1000	14.74	2.45	70.37
800	2000	14.26	2.37	72.75
1000	500	14.26	2.37	72.75
1000	1000	14.20	2.36	73.06
1000	2022	14.44	2.40	72.84
1600	100	15.28	2.54	67.88
1600-1760	500(3)	32.50	5.37	32.11
1600-1760	1000(3)	24.00	3.99	43.21
1600-1760	2000(3)	26.47	4.40	39.18

1. Sample aged in air at 800° and 1000°F and in Argon at 1600°F. Test Specimens were No. 18 AWG Wire.

2. International Annealed Copper Standard. $\rho_{68°F} = 1.7241 \times 10^{-6}$ Ohm-Cm

3. Evidence of melting on specimen ends.

Reference: NAS 3-4162)

TABLE I V. G-3. Tensile Test Data for Inconel 600-Clad (28 Percent of Area) Silver Wire (No. 10 AWG Wire)

Test: ASTM E21 - Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure

Specimen No.	Test Temperature (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Reduction of Area (Percent)
1	72	14,350	20,100	49,950	26.1	54.7
2	72	15,000	20,850	45,300	22.7	54.7
3	500	12,350	18,000	33,700	13.2	30.8
4	500	13,500	18,600	34,200	12.2	35.7
5	800	10,250	16,250	33,850	16.1	37.2
6	800	10,500	16,300	33,450	17.1	27.5
7	1000	10,550	15,600	29,100	13.5	40.3
8	1000	10,600	16,400	30,450	15.6	37.2
9	1400	6,600	7,850	9,500	26.1	32.5
10	1400	7,850	9,250	12,500	23.3	35.7
11	1600	3,850	4,350	6,250	11.0	22.3
12	1600	3,150	3,750	5,250	5.6	20.6

NOTE: All tests made in air

(Reference: NAS 3-4162)

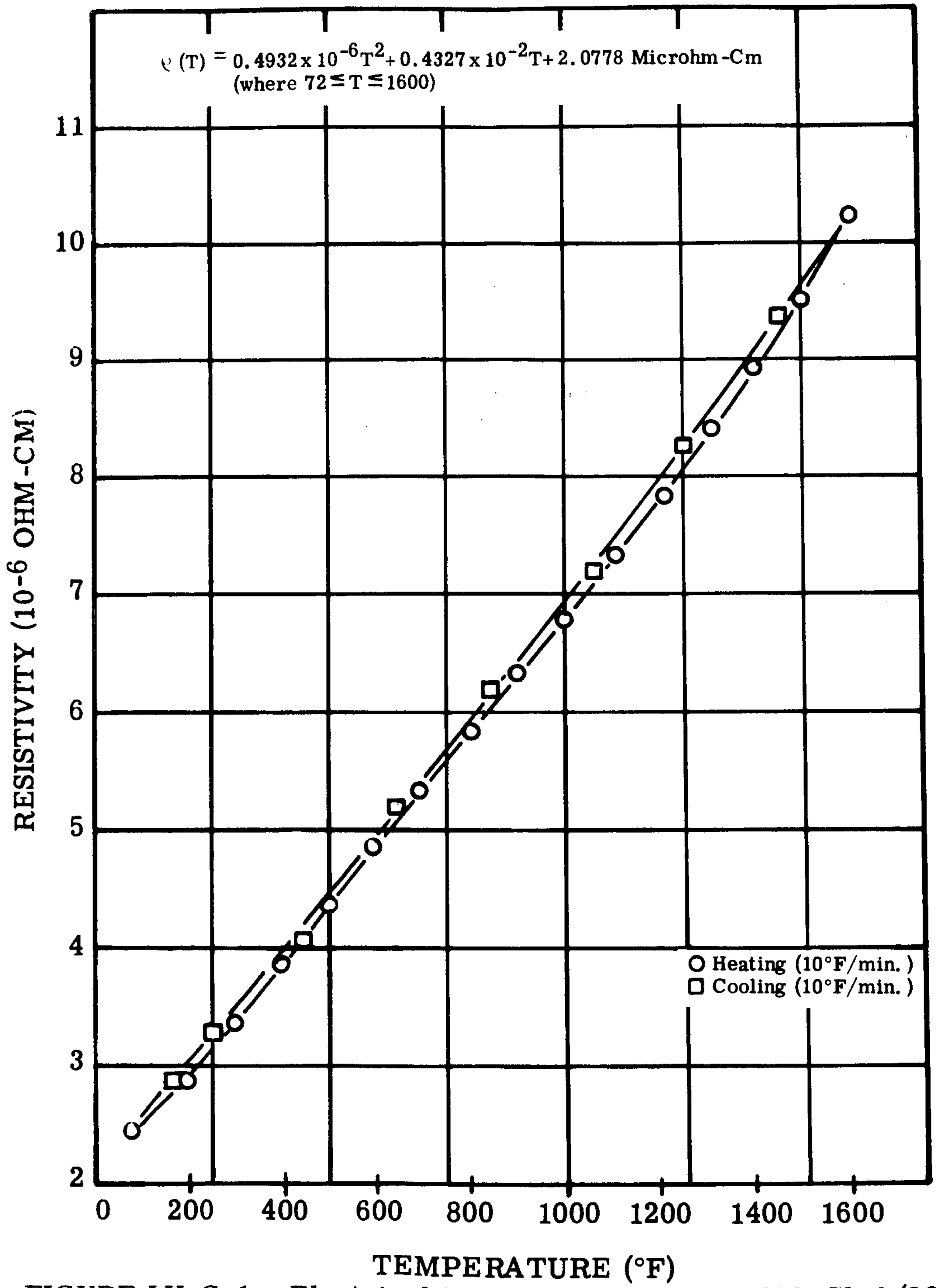


FIGURE IV. G-1. Electrical Resistivity of Inconel 600-Clad (28 Percent of Area) Silver. Vacuum Test. (Wire Size No. 18 AWG) (Reference: NAS 3-4162)

Figure IV.G-1. Electrical Resistivity - Inconel 600-Clad Silver

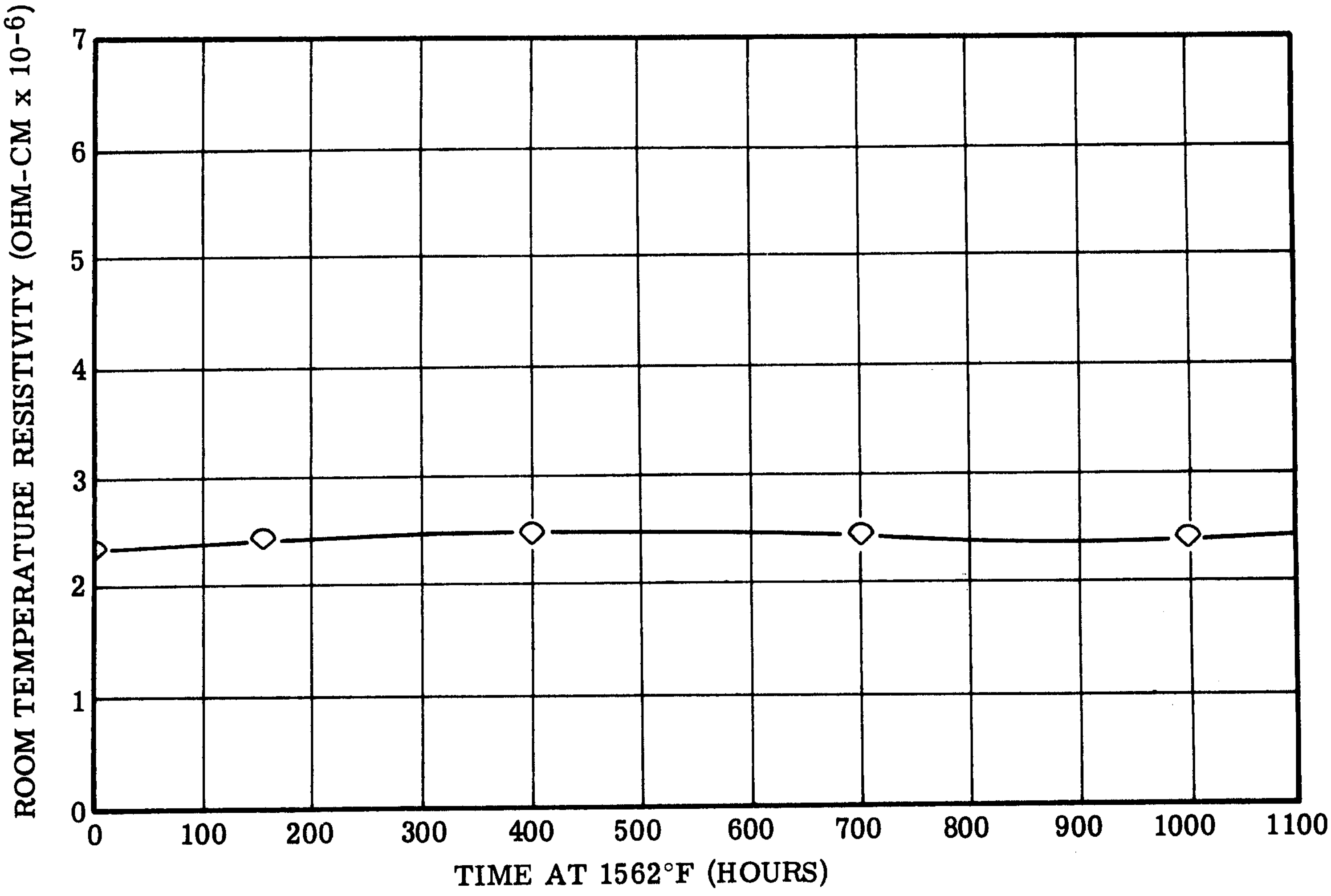


FIGURE I V. G-2. Inconel Clad (25 Percent of Area) Silver - Room Temperature Resistivity After Aging at 1562°F (Atmosphere Not Listed) (Reference: RC-5)

Figure I V. G-2. Stability Data - Inconel Clad Silver

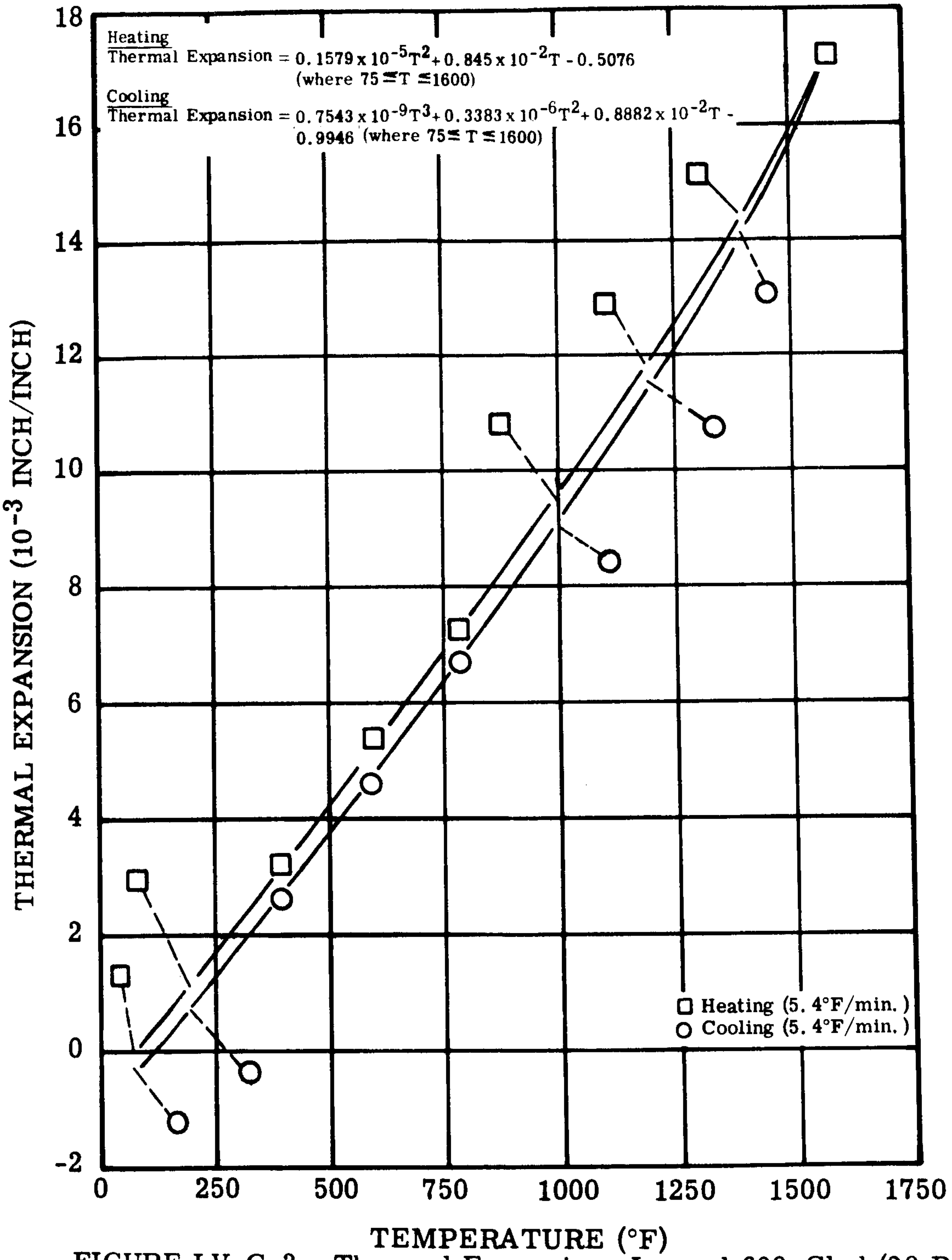


FIGURE I V. G-3. Thermal Expansion, Inconel 600-Clad (28 Percent of Area) Silver Tested in Argon. (Wire Size, No. 10 AWG)(Reference: NAS 3-4162)

Figure I V. G-3. Thermal Expansion - Inconel 600-Clad Silver

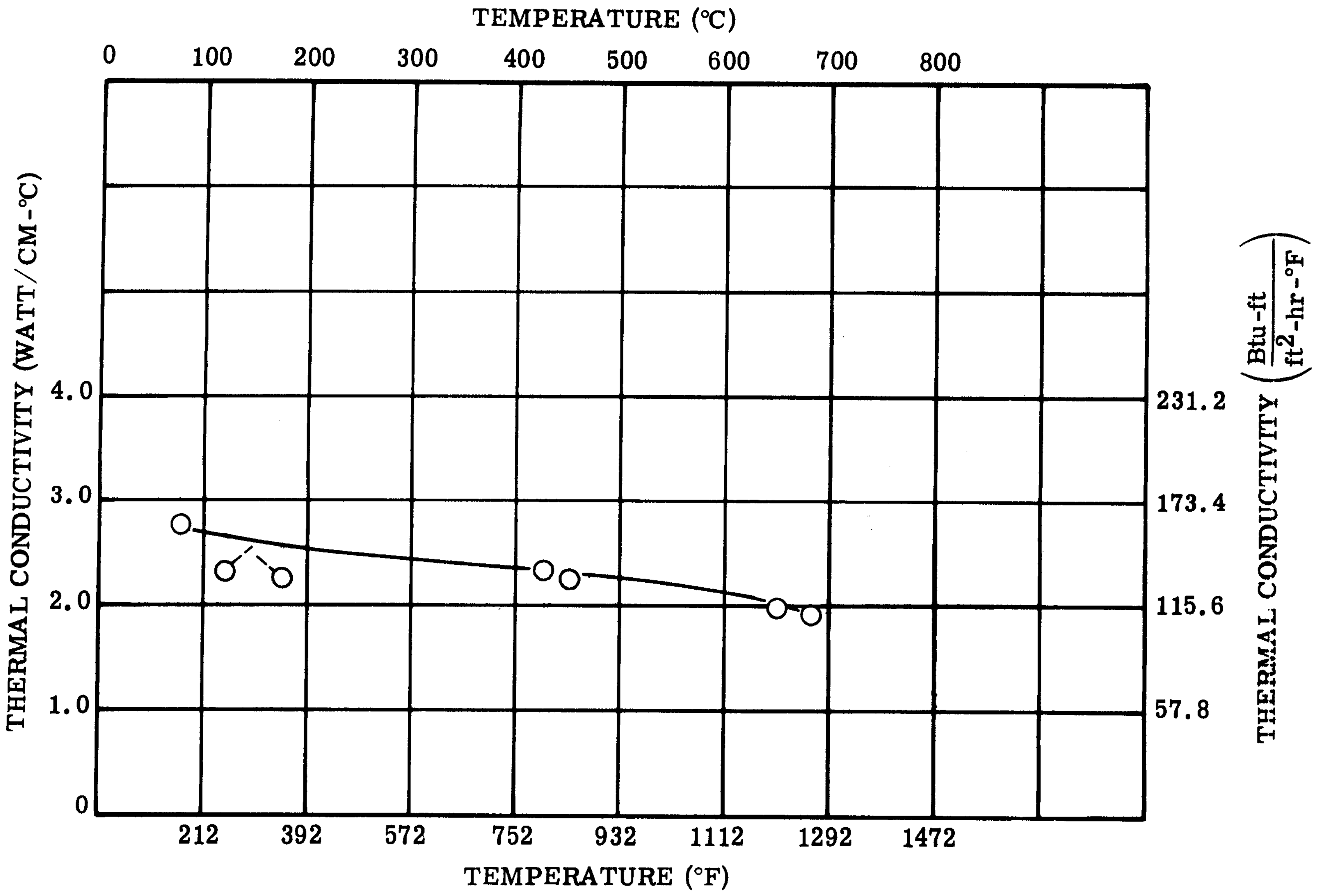


FIGURE I V. G-4. Thermal Conductivity of Inconel 600-Clad (28 Percent of Area) Silver Wire in Vacuum. (Reference: NAS 3-4162)

Figure I V.G-4. Thermal Conductivity - Inconel 600-Clad Silver

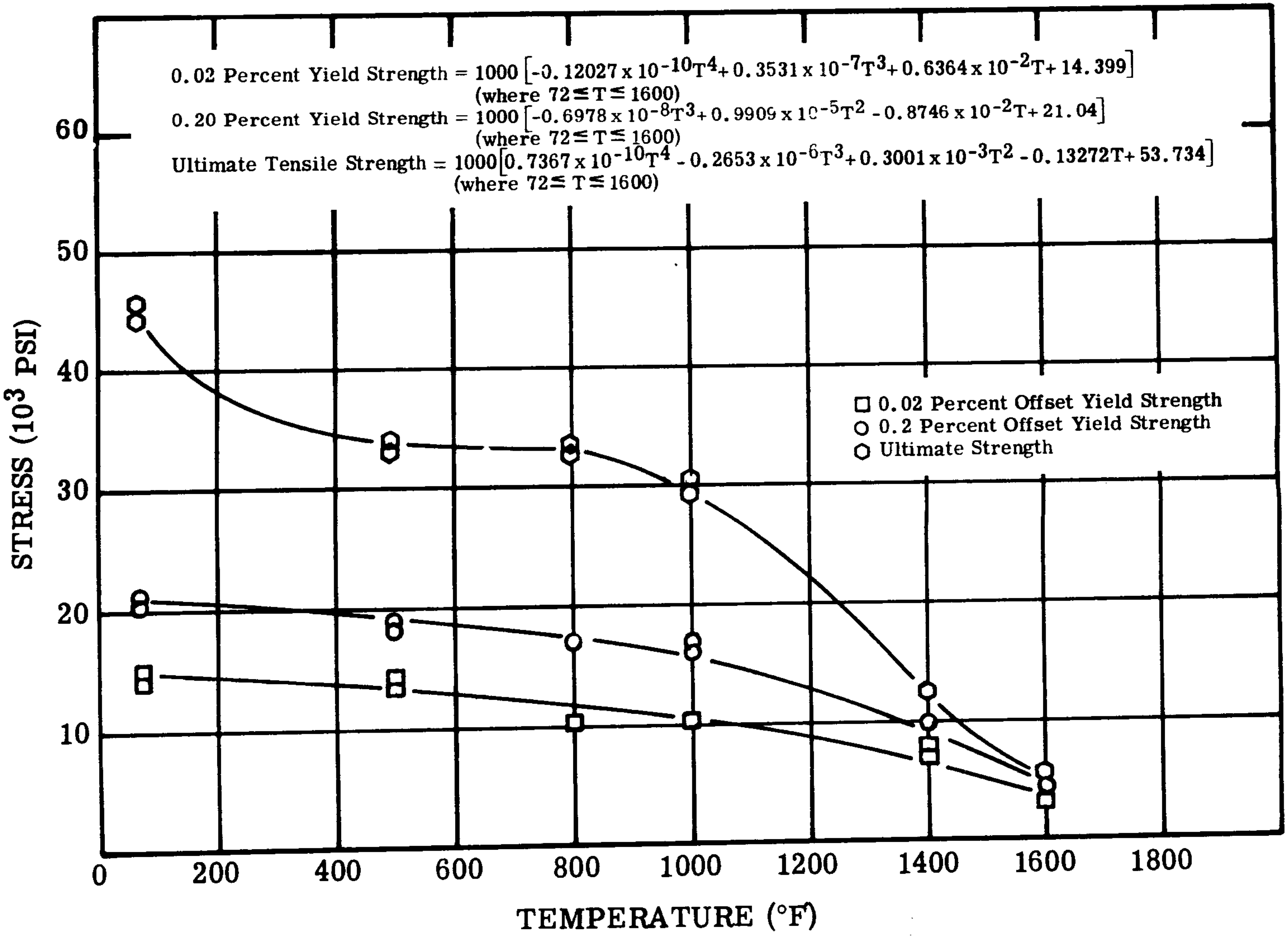


FIGURE I V. G-5. Tensile Strength, Inconel 600-Clad (28 Percent of Area) Silver Wire (No. 10 AWG Wire). Tested in Air. Strain Rate: 0.005 in/in-min to Yield Then 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure I V.G-5. Tensile Strength - Inconel 600-Clad Silver

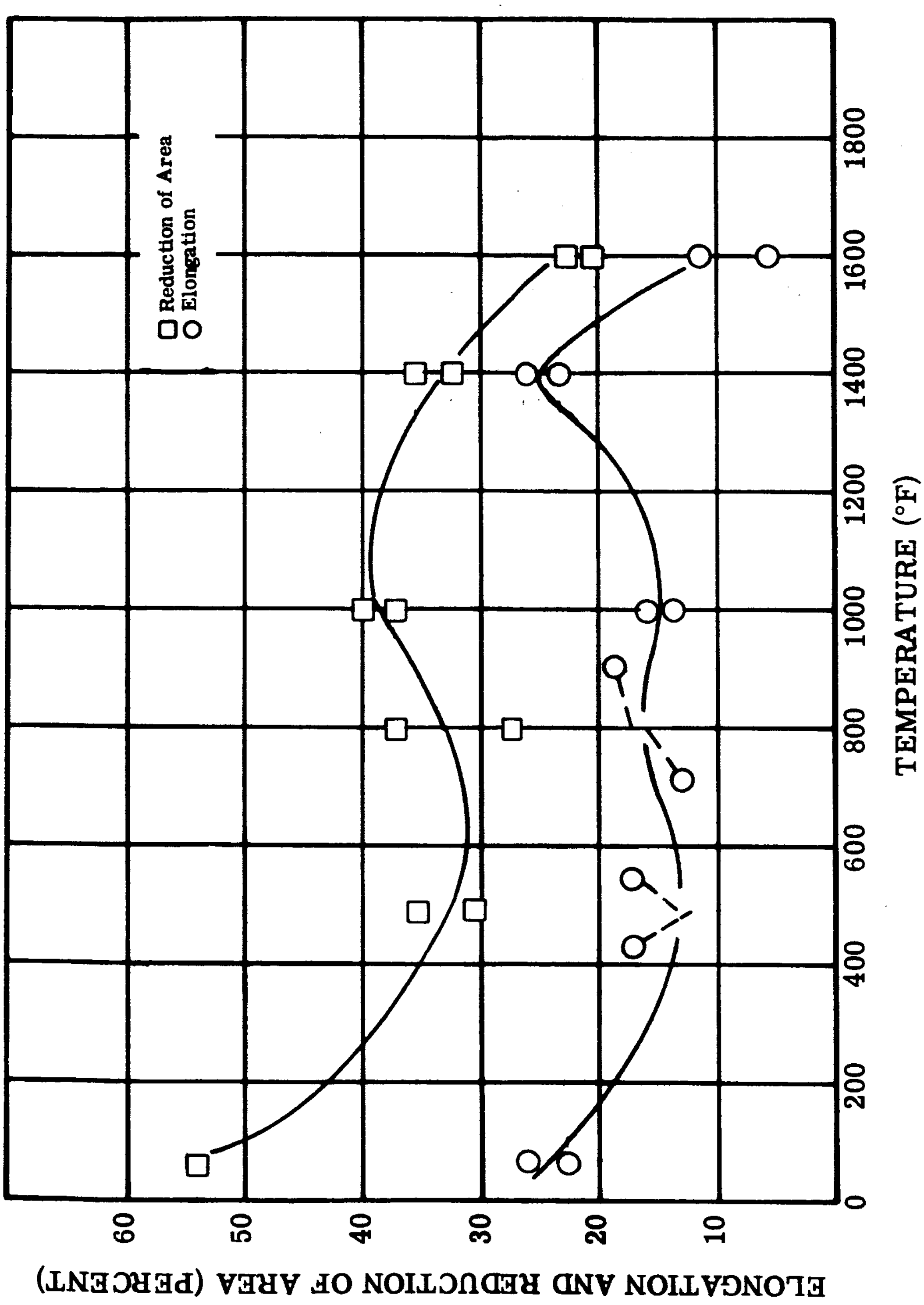


FIGURE I V. G-6. Tensile Ductility, Inconel 600-Clad (28 Percent of Area) Silver Wire (No. 10 AWG Wire). Tested in Air. Strain Rate: 0.005 in/in-min to Yield, Then 0.05 in/in-min. to Failure. (Reference: NAS 3-4162)

Figure I V.G-6. Tensile Ductility - Inconel 600-Clad Silver

SECTION V

ELECTRICAL INSULATION MATERIALS PROPERTIES SUMMARIES

This section presents the electrical insulation material properties. Table V-1 is an index of the electrical insulation material properties by page number. The property data for each material are classified as thermophysical, electrical, mechanical, and compatibility. Each material presentation is headed by a MATERIALS PROPERTIES SUMMARY where a synopsis of important parameters is available. This is valuable in screening and selecting those properties warranting further detailed analysis. This summary is thought important because the data presented in tabular and graphic form on each material are quite extensive.

The figure and table numbering system used in presenting and categorizing data is as follows:

V.A.1-1

Section	A. Magnet Wire	1. Polyimide Enamel 2. Anacote 3. Anadur 4. Ceramic-Eze 5. Westinghouse R2554B	Figure No. or Table No. within each of the seven material categories
	B. Lead Wire	1. Glass Fiber-Asbestos 2. Glass Fiber-Mica	
	C. Sheet Insulation, Flexible	1. Polyimide-Film 2. Polyimide-Glass 3. Mica-Glass, Silicone Resin Bonded 4. Synthetic Mica Paper 5. Silicate Fiber Paper	
	D. Rigid Insulation, Laminated	1. Asbestos, Boron Phosphate Bonded 2. Diphenyl Oxide-Glass 3. Epoxy-Glass 4. Phenolic-Glass	

5. Polybenzimidazole-Glass
6. Polyimide-Glass
7. Mica

E. Rigid Insulation, Molded or Pressed
   1. Alumina, 99.5 percent
   2. Alumina, 99 percent
   3. Alumina, 94 percent
   4. Alumina, 99.8 percent 0.25 percent MgO
   5. Beryllia, 99.8 percent
   6. Epoxy Premix
   7. Polyester Premix
   8. Polyimide

F. Compounds, Encapsulation
   1. Anacap
   2. Epoxy
   3. Sauereisen 8
   4. Silicone Foam
   5. Urethane Foam
   6. W839

G. Interlaminar Insulation
   1. Aluminum Orthophosphate
   2. Aluminum Orthophosphate plus Mica and Bentonite
   3. M-305 Glass

No text is included in this section so it can be used as a design manual. The technical discussion on each material can be obtained in paragraph II. B. 3(). () where the same letter and number (substituting a, b, c, etc.; and 1, 2, 3, etc.) corresponding to the material type and specific material given above can be consulted for specific comments on the material.

References are given on each curve or table crediting the source of data. NAS 3-4162 is the reference given for data obtained on this program.

In preparing for the experiments, an analysis was made of the test to be conducted. All equipment calibrations were checked to insure that they were traceable to the Bureau of Standards or other accepted procedures. Test procedures were evaluated so that systematic errors could be minimized. Test points were selected to provide the best statistical inference. Since the broad scope of the program required an exceedingly large number of tests, it was not possible to minimize all the random errors. In general, sufficient replication was undertaken in those areas where additional confidence was needed.

It is expected that all systematic errors should fall within 2 percent of the reported data.

A least-squares, curve fit program for the IBM-7040 computer was applied to selected portions of the data. In addition, the computer calculated polynomial equations from first order to fifth order. The respective errors for each tabulated point was calculated. From this information the equation which best fit the test data was selected; that is, the equation of lowest order which would yield an error of five percent or less.

Selected polynomial expressions are printed on their respective curves for ease in using the data in computer programs or in rigorous hand calculations.

Electrical stability tests are presented in this section also. Because of the sensitivity of these tests, a technical understanding of the materials is desirable; therefore, a discussion of this property can be found in paragraphs II. B. 1 and II. B. 3.

TABLE V-1. Index to Electrical Insulation Material Properties by Page Number

MATERIAL FORM		I. THERMOPHYSICAL				
Material Name	Material Property Summary	Density	Shrinkage	Thermal Conductivity	Thermal Expansion	Water Absorption
A. MAGNET WIRE						
1. Polyimide Enamel	267	(b)	(b)	271	(b)	(b)
2. Anacote	275	(b)	(b)	(a)	(b)	(b)
3. Anadur	279	(b)	(b)	283	(b)	(b)
4. Ceramic-Eze	287	(b)	(b)	292	(b)	(b)
5. R2554B	295	(b)	(b)	300	(b)	(b)
B. LEAD WIRE						
1. Glass Fiber-Asbestos	304	(b)	(b)	307	(b)	(b)
2. Glass Fiber-Mica	311	(b)	(b)	315	(b)	(b)
C. SHEET INSULATION-FLEXIBLE						
1. Polyimide-Film	319	319	(b)	324	(b)	(b)
2. Polyimide-Glass	331	(a)	(b)	336	(b)	(b)
3. Mica-Glass-Silicone Resin Bonded	342	(a)	(b)	346	(b)	(b)
4. Synthetic Mica Paper	352	(a)	(b)	357	(b)	(b)
5. Silicate Fiber Paper	363	(a)	(b)	367	(b)	(b)
D. RIGID INSULATION-LAMINATED						
1. Asbestos-Boron Phosphate-Bonded	373	373	(b)	379	380	374
2. Diphenyl Oxide-Glass	392	392	(b)	397	398	392
3. Epoxy-Glass	408	408	(b)	413	414	415, 416
4. Phenolic-Glass	424	424	(b)	424	424	424
5. Polybenzimidazole-Glass	435	(a)	(b)	(a)	(a)	(a)
6. Polyimide-Glass	441	441	(b)	446	447	442
7. Mica	454	454	(b)	460	461	454
E. RIGID INSULATION, MOLDED OR PRESSED						
1. Alumina, 99.5 Percent	468	468	(b)	473	474	(a)
2. Alumina, 99 Percent	477	477	(b)	483	484	(a)
3. Alumina, 94 Percent	490	490	(b)	494	495	(a)
4. Alumina, 99.8 Percent, 0.25 MgO	499	499	(b)	502	503	(a)
5. Beryllia, 99.8 Percent	509	509	(b)	515	516	(a)
6. Epoxy Premix	522	522	(b)	526	527	522
7. Polyester Premix	530	530	(b)	536	537	531
8. Polyimide	545	545	(b)	545	545	545
F. COMPOUNDS, ENCAPSULATION						
1. Anacap	552	552	552	(a)	556	552
2. Epoxy	561	561	561	566	567	562
3. Sauereisen 8	573	573	573	578	579	573
4. Silicone Foam	587	587	(b)	587	587	587
5. Urethane Foam	598	598	(b)	598	(a)	(a)
6. W839	600	600	600	605	606	601
G. INTERLAMINAR INSULATION						
1. Aluminum Orthophosphate (c)	614	(b)	(b)	(a)	(b)	(b)
2. Aluminum Orthophosphate plus Mica plus Bentonite (c)	614	(b)	(b)	(a)	(b)	(b)
3. Glass, M305	614	(b)	(b)	(a)	(b)	(b)

(a) - Not Determined
(b) - Not Applicable
(c) - The compatibility with Cubex magnetic alloy of the aluminum-orthophosphate-based interlaminar insulations, G1 and G2, was studied and is reported in Section V.G., page 614.

TABLE V-1. Index to Electrical Insulation Material Properties by Page Number

MATERIAL FORM	II. ELECTRICAL						III. MECHANICAL							IV. COMPATIBILITY		
Material Name	Arc Resistance	Dielectric Constant	Electric Strength	Insulation Life	Power or Dissipation Factor	Insulation Resistance or Volume Resistivity	Abrasion Resistance	Compressive Strength or Cut-Through Resistance	Elastic Modulus or Modulus of Rupture	Flexural Strength	Impact Strength	Tensile Strength	Thermal Shock	Chemical Resistance	Nuclear Radiation Resistance	Weight Loss in Vacuum and Heat
A. MAGNET WIRE																
1. Polyimide Enamel	(b)	(b)	272	268	(a)	273	269	269	(b)	(b)	(b)	(b)	269	269	270	274
2. Anacote	(b)	(b)	275	(a)	(a)	278	276	276	(b)	(b)	(b)	(b)	277	(a)	(a)	(a)
3. Anadur	(b)	(b)	284	280	(a)	285	281	281	(b)	(b)	(b)	(b)	281	282	282	286
4. Ceramic-Eze	(b)	(b)	293	288	(a)	288	289	289	(b)	(b)	(b)	(b)	290	290	290	294
5. R2554B	(b)	(b)	301	296	(a)	302	297	297	(b)	(b)	(b)	(b)	298	298	299	303
B. LEAD WIRE																
1. Glass Fiber-Asbestos	(b)	(b)	308	(a)	(b)	309	306	306	(b)	(b)	(b)	(b)	(a)	306	306	310
2. Glass Fiber-Mica	(b)	(b)	316	312	(b)	317	313	313	(b)	(b)	(b)	(b)	(a)	313	314	318
C. SHEET INSULATION-FLEXIBLE																
1. Polyimide-Film	(b)	325	326	327	328	329	321	322	(b)	(b)	(b)	322	(b)	322	322	330
2. Polyimide-Glass	(b)	337	332	338	339	340	333	334	(b)	(b)	(b)	334	(b)	334	334	341
3. Mica-Glass-Silicone Resin Bonded	(b)	347	348	343	349	350	344	345	(b)	(b)	(b)	345	(b)	345	345	351
4. Synthetic Mica Paper	(b)	358	359	353	360	361	354	355	(b)	(b)	(b)	355	(b)	355	355	362
5. Silicate Fiber Paper	(b)	368	369	365	370	371	366	366	(b)	(b)	(b)	366	(b)	366	366	372
D. RIGID INSULATION-LAMINATED																
1. Asbestos-Boron Phosphate-Bonded	374	381	382	383	384	385	(b)	386	377	387, 388	377	378	(b)	378	378	389-391
2. Diphenyl Oxide-Glass	393	399	400	401	402	403	(b)	395	395	404-406	396	(a)	(b)	396	396	407
3. Epoxy-Glass	409	417	418	419	420	421	(b)	411	411	422	412	(a)	(b)	412	412	423
4. Phenolic-Glass	424	425	425	425	(a)	425	(b)	430	426	427, 432	428	433, 434	(b)	429	429	(a)
5. Polybenzimidazole-Glass	(a)	438	(a)	(a)	439	(a)	(b)	436	436	436, 440	(a)	(a)	(b)	(a)	(a)	(a)
6. Polyimide-Glass	442	448	449	450	452	451	(b)	444	445	445	445	(a)	(b)	445	445	453
7. Mica	455	462	463	464	465	457	(b)	457	458	466	458	(a)	(b)	458	459	467
E. RIGID INSULATION, MOLDED OR PRESSED																
1. Alumina, 99.5 Percent	(b)	(a)	469	(a)	470	470	(b)	470	475	476	471	(a)	(b)	471	471	(a)
2. Alumina, 99 Percent	(b)	485	478	(a)	478, 479	486	(b)	479	488	489	480	(a)	(b)	480	481	(a)
3. Alumina, 94 Percent	(b)	496	491	(a)	491	492	(b)	492	497	498	492	(a)	(b)	493	493	493
4. Alumina, 99.8 Percent, 0.25 MgO	500	504	500	(a)	(a)	500	(b)	500	508	506, 507	(a)	(a)	(b)	501	501	(a)
5. Beryllia, 99.8 Percent	(b)	517	510	511	511	518	(b)	519	520	521	512	(a)	(b)	512	513	(a)
6. Epoxy Premix	523	523	523	(a)	(a)	523	(b)	523	524	524	524	528	(b)	524	524	529
7. Polyester Premix	531	538	539	540, 541	543	542	(b)	533	534	534	534	(a)	(b)	534	535	544
8. Polyimide	545	546	546	(a)	550	547	547	548	548	548	548	549	(b)	549	549	549
F. COMPOUNDS, ENCAPSULATION																
1. Anacap	(a)	553	557	558	554	554	(b)	559	(a)	555	(b)	(b)	(a)	555	555	560
2. Epoxy	564	568	569	563	570	571	(b)	564	(a)	565	(b)	(b)	565	565	565	572
3. Sauereisen 8	(a)	580	581	582	584	583	(b)	585	(a)	576	(b)	(b)	(a)	576	577	586
4. Silicone Foam	(a)	592	593	594	588, 595	596	(b)	590	(b)	(b)	(b)	(b)	(b)	591	591	597
5. Urethane Foam	(a)	598	(a)	(a)	(a)	(a)	(b)	599	(b)	(b)	(b)	(b)	(b)	599	599	599
6. W839	(a)	607	608	609	611	610	(b)	612	(a)	603	(b)	(b)	603	603	604	613
G. INTERLAMINAR INSULATION																
1. Aluminum Orthophosphate(c)	(b)	(b)	(b)	618, 623	(b)	616, 623	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(a)
2. Aluminum Orthophosphate plus Mica plus Bentonite(c)	(b)	(b)	(b)	619, 623	(b)	616, 623	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(a)
3. Glass, M305	(b)	(b)	(b)	620, 621, 623	(b)	616, 623	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(a)

(a) - Not Determined
(b) - Not Applicable
(c) - The compatibility with Cubex magnetic alloy of the aluminum-orthophosphate-based interlaminar insulations, G1 and G2, was studied and is reported in Section V.G., page 614.

① ② 266

ELECTRICAL INSULATION MATERIALS PROPERTIES SUMMARY

A. MAGNET WIRE

1. POLYIMIDE ENAMEL

This material is an organic enamel, coated on copper electrical conductor.

Availability:	The resin solution is produced by DuPont and is applied to round and rectangular conductors by all major magnet wire producers.
Description:	Polyimide enamel (ML) is an organic resin related to the nylon family. It is best described as an aromatic polyimide resin based on pyromellitic dianhydride. The conductor in this program was electrolytic tough pitch copper with 100 percent International Annealed Copper Standard minimum conductivity.

I. Thermophysical Properties

A. Thermal Conductivity, apparent, transverse

Enamel Thickness, 0.0015 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
212	0.171
344	0.198
476	0.222

II. Electrical Properties

A. Electric Strength No. 18 AWG heavy build wire

Enamel Thickness, 0.0015 Inch

Temperature (°F)	Frequency (cps)	Volts/mil (average)
77	60	3,883
77	400	3,250
77	3200	Corona discharge No breakdown at 1187
392	60	3,133
392	400	2,511
392	3200	Corona discharge No breakdown at 1140
482	60	2,194
482	400	1,800
482	3200	Corona discharge No breakdown at 1386

B. Insulation Life (1000V, 400 cps, Proof Test)

Enamel Thickness, 0.0015 Inch

Temperature (°F)	Hours	
392	100,000	(LI2)
428	>20,000	
500	12,000	

C. Insulation Resistance

Enamel Thickness, 0.0015 Inch

Temperature (°F)	Frequency	Megohms
77	DC	2×10^8
77	400 cps	45,500
77	3200 cps	4,495
392	DC	200,000
392	400 cps	12,100
392	3200 cps	2,900
482	DC	70,000
482	400 cps	11,000
482	3200 cps	4,040

III. Mechanical Properties

A. Abrasion Resistance

Enamel Thickness, 0.0015 Inch

1. Abrasion scrape per NEMA MW15.	15 strokes	(LI64)
2. Unilateral scrape per NEMA MW5.	1200-1400 grams	(LI12)

B. Adhesion (Snap-NEMA MW5)	Passed	(LI63)
C. Cut-Through Resistance per MIL-W-583, paragraph 4.7.11.1	932°F	(LI64)

D. Thermal Shock; ΔT/t >500°F/minute

1. Bend 1X; age 1 hour at 952°F	Passed	(LI64)
2. Bend 3X; after 15 percent elongation	Passed	(LI64)

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance	References
1. Aliphatic Hydrocarbons	Good	(LI2)(LI12) (LI63)(LI64) (LI67)(LI141)
2. Aromatic Hydrocarbons	Good	(LI2)(LI12) (LI63)(LI64) (LI141)
3. Organic Acids	Good	(LI12)(LI64)
4. Chlorinated Solvents including Refrigerants	Good	(LI2)(LI12)
5. Alcohols, Esters and Ketones	Good	(LI2)(LI12) (LI63)(LI141)
6. Mineral Acids	Good	(LI2)(LI12) (LI63)(LI141)
7. Alkaline Solutions	Attacked	(LI2)(LI12) (LI63)(LI141)

B. Nuclear Radiation Resistance

Polyimide-coated magnet wire displays good nuclear radiation resistance. Such wire was exposed to 3×10^9 rads or 3×10^{11} ergs/gram (°C) of gamma radiation in a Van de Graaff generator. No embrittlement of the film was observed. (LI60)

Other samples of similar wire were irradiated in a reactor gamma field of 5×10^7 roentgens per hour. The electrical resistance value of the insulation was reduced from 10^{12} ohms to 10^7 ohms. The electrical tests were performed at 500°F and 500 volts on the wire wrapped about a conducting mandrel. After completion of the exposure, the resistance recovered to a value of 2×10^9 ohm. (LI279)

C. Vacuum Weight Loss at Elevated Temperature

24 hours at 482°F and 10^{-5} to 10^{-6} torr	0.06 percent

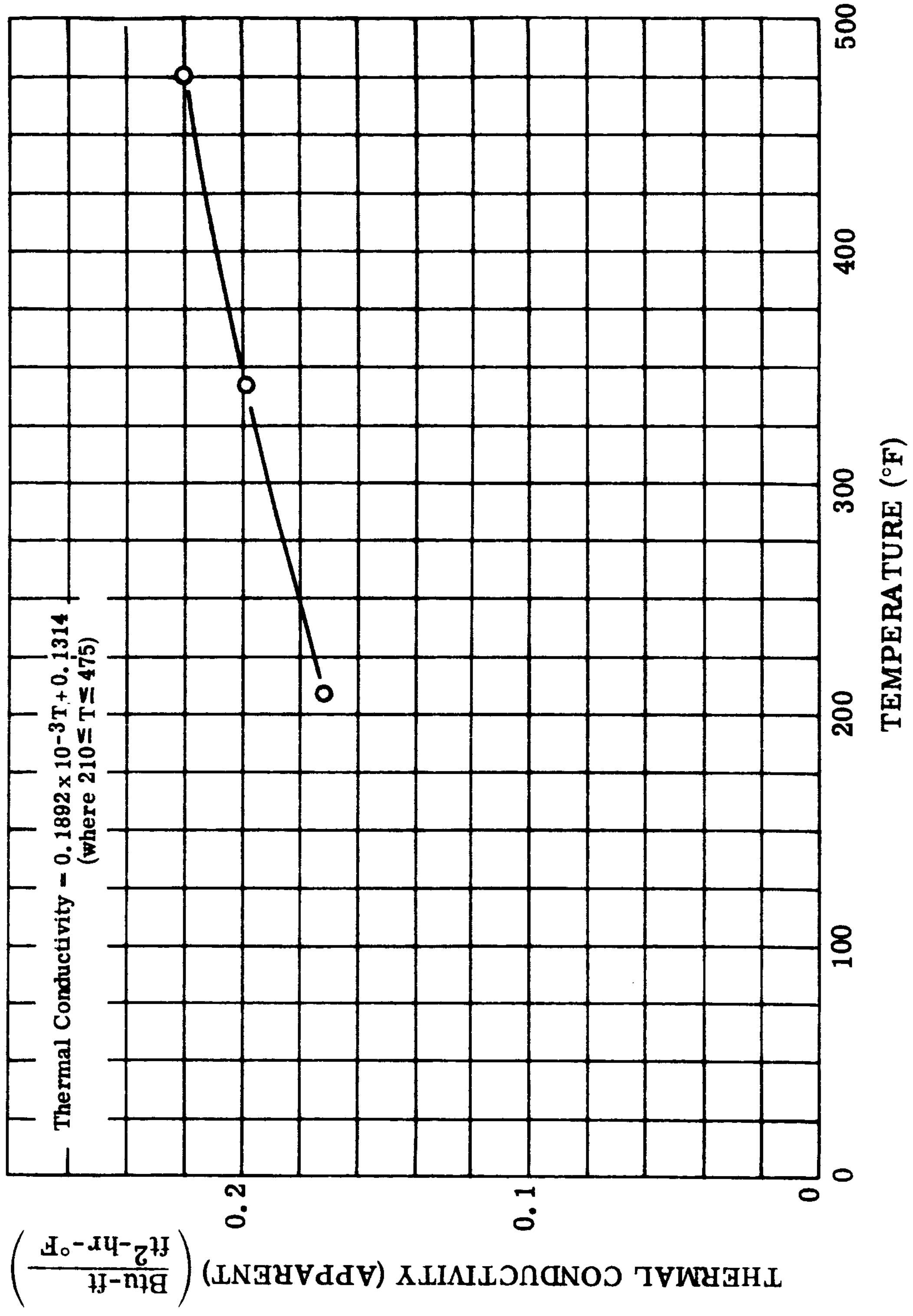


FIGURE V.A.1-1. Transverse Thermal Conductivity (Apparent) of Organic Insulated Magnet Wire, Polyimide Enamel, in Air. Enamel Thickness, 0.0015 Inch on 0.0403 Inch Diameter Copper Wire. (Reference: NAS 3-4162)

Figure V.A.1-1. Thermal Conductivity - Magnet Wire - Polyimide

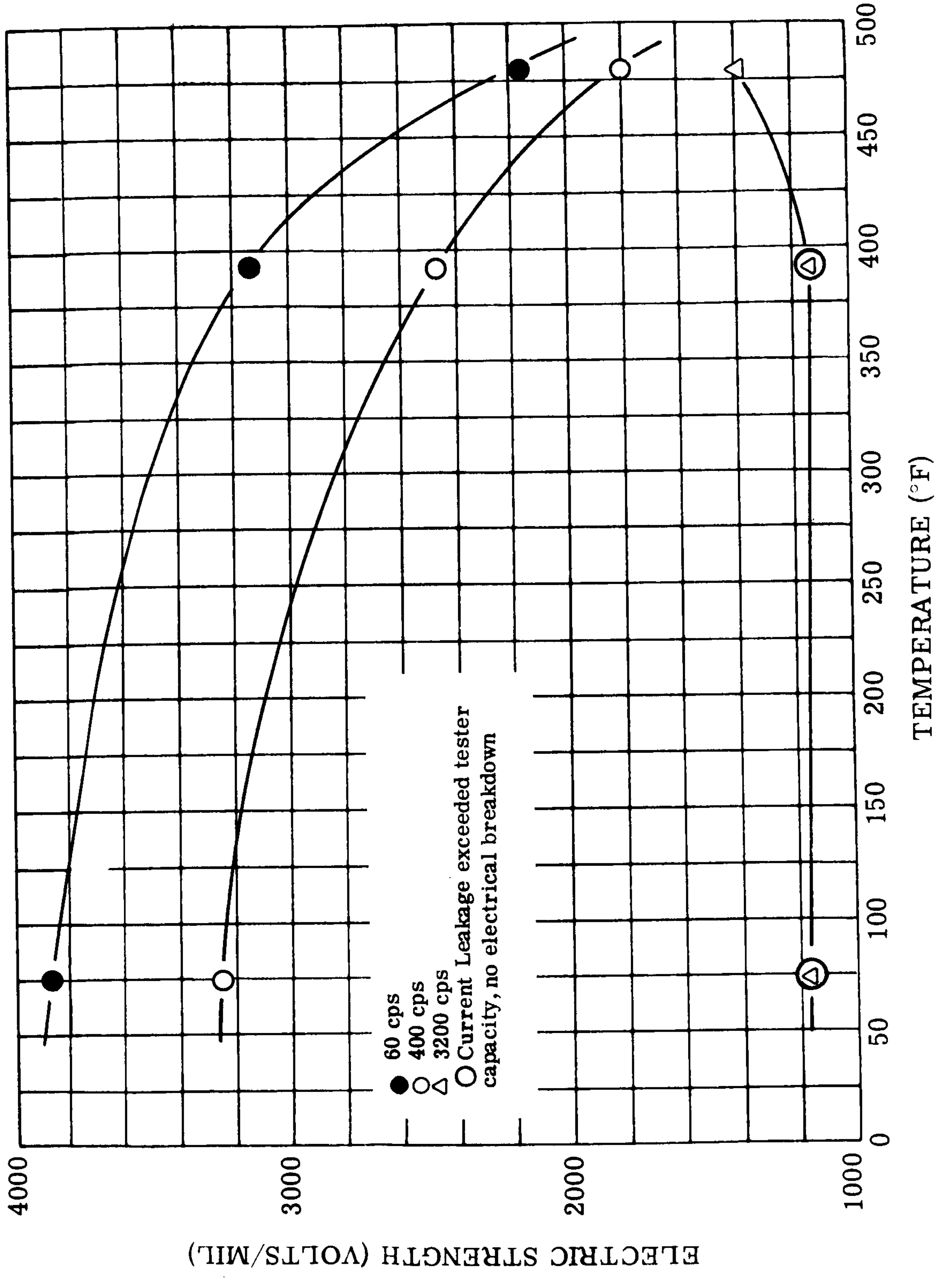


FIGURE V.A.1-2. Electric Strength of Organic Insulated Magnet Wire, Polyimide Enamel, In Air. Enamel Thickness, 0.0015 Inch on 0.0403 Inch Diameter Copper Wire. (Reference: NAS3-4162)

Figure V.A.1-2. Electric Strength - Magnet Wire - Polyimide

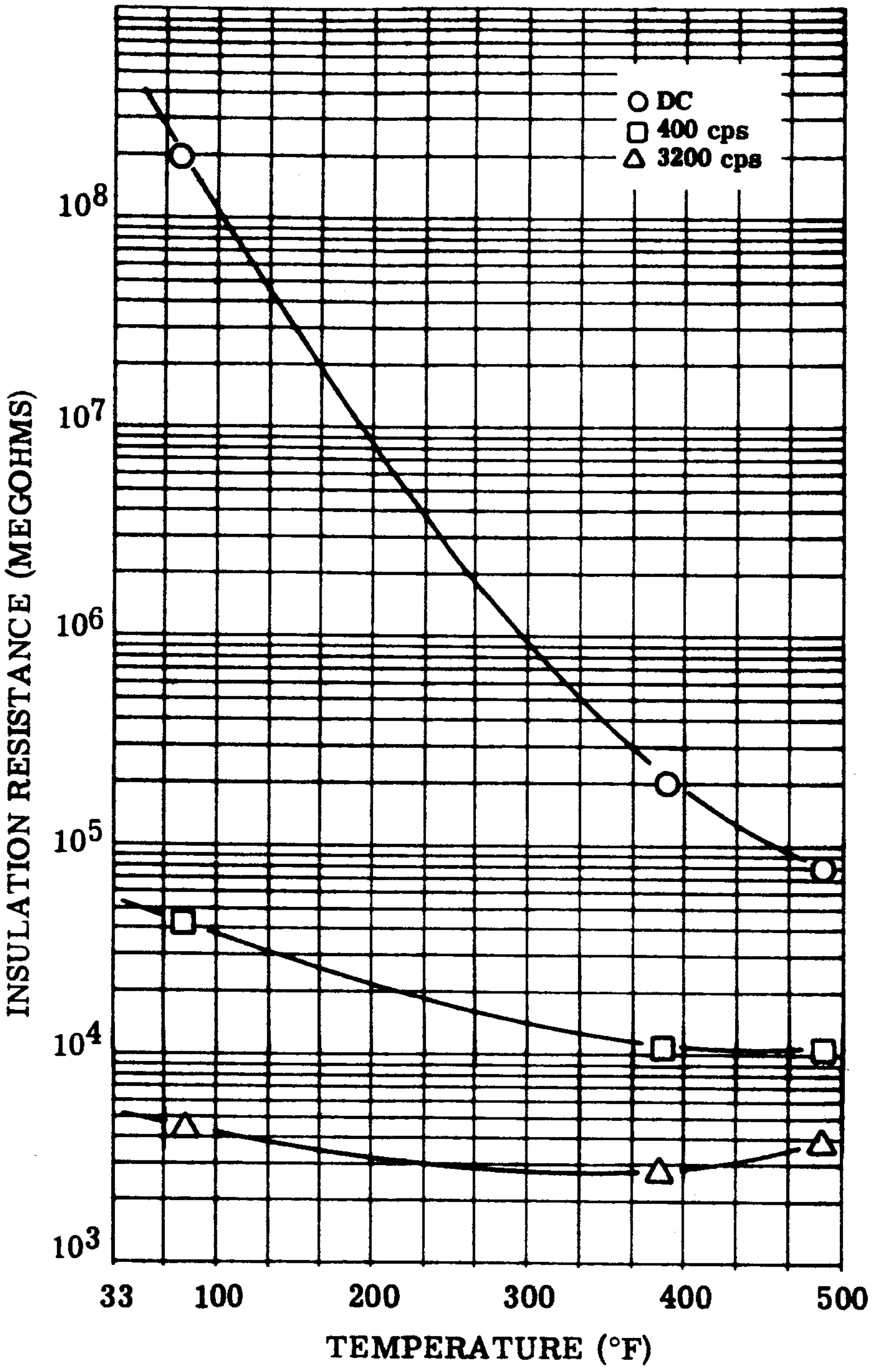


FIGURE V.A.1-3. Insulation Resistance of Organic Insulated Magnetic Wire, Polyimide Enamel, in Air. Enamel Thickness, 0.0015 Inch on 0.0403 Inch Diameter Copper Wire. (Reference: NAS 3-4162)

Figure V.A.1-3. Insulation Resistance - Magnet Wire - Polyimide

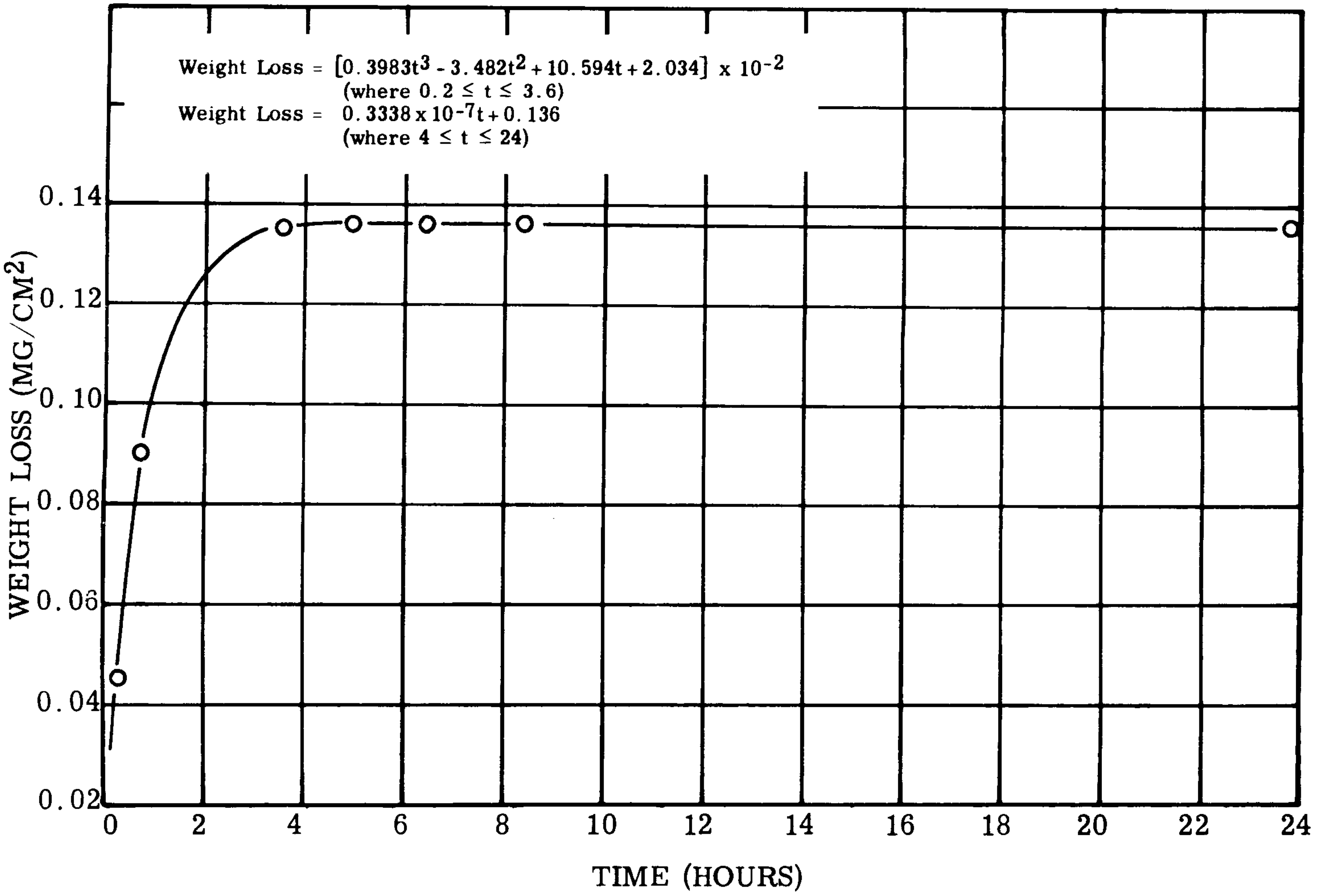


FIGURE V.A.1-4. Weight Loss at 482°F and 10^{-5} to 10^{-6} Torr of Organic Insulated Magnet Wire, Polyimide Enamel. Enamel Thickness, 0.0015 Inch on 0.0403 Inch Diameter Copper Wire. (Reference: NAS 3-4162)

Figure V.A.1-4. Weight Loss - Magnet Wire - Polyimide

2. ANACOTE MAGNET WIRE

Anacote is a clad conductor with an enamel coating of glass-and-ceramic-pigmented resin. The results of tests reported in Section III, MECHANICAL PROPERTIES, indicates that Anacote has winding property characteristics which limit its usage. Since other magnet wires examined in this program offer superior performance, a complete evaluation of Anacote was not conducted.

Availability:	Anacote is available from Anaconda Wire and Cable Company.
Description:	The coating is a resin-bonded mixture of glass frit and refractory oxides applied to either clad or plated conductors. The conductor in this program was 28 percent nickel-clad copper of 0.0403 inch diameter.

I. Thermophysical Properties

No thermophysical properties were determined.

II. Electrical Properties

A. Electric Strength (per Anaconda Wire and Cable Co.)

Enamel Thickness, 0.0018 Inch

Breakdown voltage at 1000°F 150 to 250 volts

B. Insulation Resistance and Resistivity

Enamel Thickness, 0.0018 Inch

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
77	DC	1.8×10^9	1.0×10^{13}
212	DC	5.3×10^8	3.0×10^{12}
392	DC	5.3×10^7	3.0×10^{11}
500	DC	1.1×10^7	6.2×10^{10}
572	DC	2.6×10^6	2.0×10^{10}
752	DC	4.3×10^5	2.4×10^9
932	DC	4.5×10^4	2.5×10^8
1112	DC	5.3×10^3	3.0×10^7

III. Mechanical Properties

A. Abrasion Resistance at 77°F

Enamel Thickness, 0.0018 Inch

1. 0.016 inch diameter needle, 600 grams	6 strokes
2. 0.039 inch diameter needle, 600 grams	31 strokes

B. Adhesion

Enamel Thickness, 0.0018 Inch

1. Per Anaconda Wire and Cable Co. — 2X bend OK
2. Test performed in NAS 3-4162 indicated that Anacote warmed to 110 to 120°F could be wound satisfactorily.

Temperature (°F)	
77	9X bend OK
100	4X bend OK

C. Cut-Through Resistance

Enamel Thickness, 0.0018 Inch

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
1. No Prebake	0.5	*	5	165	275
			2	120	200
			0	77	77
2. No Prebake	0.5	*	12	200	320
			13	216	340
			15	240	370

(1) Force in pounds is presented for individual pressure points.
(2) One asterisk (*) indicates that uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F)	
				Specimen	Furnace
3. 1 hour at 860°F	0.5	*	4	(3)	(3)
			5		
			6.5		
4. 1 hour at 932°F	0.5	*	0	(3)	(3)
			0		
			0		
5. No Prebake	0.5	**	12	356	570
			11	330	530
			11	330	530
6. 1 hour at 572°F	0.5	**	42	903	1000
			39	862	970
			43	921	1010

D. Thermal Shock (77°F to temperature to 77°F)

Enamel Thickness, 0.0018 Inch

Bend Diameter (inches)	500°F	932°F
0.1875	Passed	failed, enamel spalled
0.125	Failed by splitting	failed, enamel spalled

---

(1) Force in pounds in presented for individual pressure points.

(2) One asterisk (*) indicates that uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

(3) These failures occurred at approximately the temperature reported for the first determination.

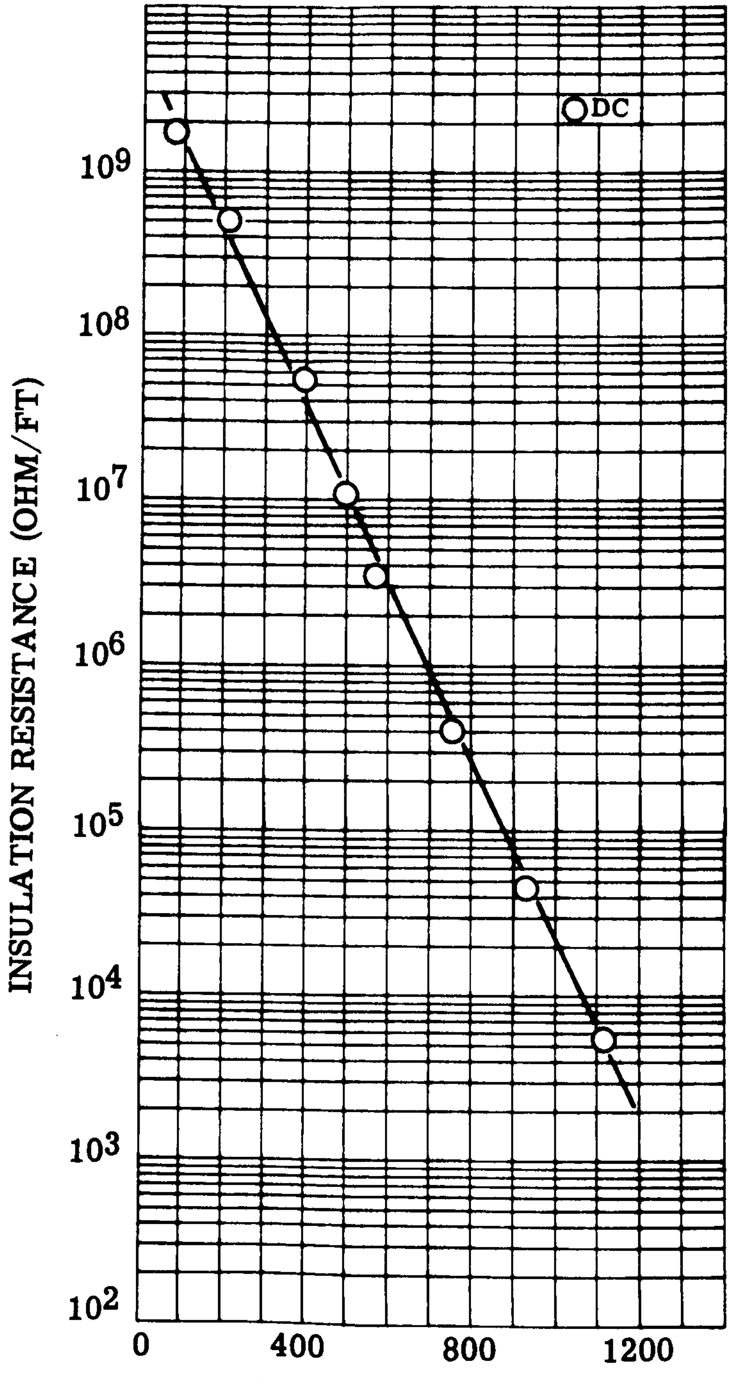


FIGURE V.A.2-1. Insulation Resistance of Inorganic Insulated Magnet Wire, Anacote, in Air. Enamel Thickness, 0.0018 Inch 0.0403 Inch Diameter, 28 Percent Nickel-Clad Copper Wire. (Reference: LI298)

Figure V.A.2-1. Insulation Resistance - Magnet Wire - Anacote

3. ANADUR MAGNET WIRE

Anadur is a fiber-glass-served conductor to which has been applied a resin sizing loaded with fusible glass and ceramic frit.

Availability:	Anaconda Wire and Cable Company applies this insulation system to a variety of plated and clad round conductors.
Description:	The insulation is composed of fiber glass, fusible glass frit, and refractory oxide powders retained on the conductor during winding by a resin binder. Subsequent firing of the wound apparatus fuses the glass frit to serve as a rigid binder. The conductor used in this program was 28 percent nickel-clad copper of 0.0403 inch diameter.

I. Thermophysical Properties

A. Thermal Conductivity (apparent transverse)

Insulation Thickness, 0.0068 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
39	0.334
744	0.229
1016	0.305

II. Electrical Properties

A. Electric Strength

Insulation Thickness, 0.0068 Inch

Temperature (°F)	Frequency	Total Volts
500	DC	770
500	400 cps	530
500	3200 cps	430

Temperature (°F)	Frequency	Total Volts
932	DC	430
932	400 cps	360
932	3200 cps	420
1112	DC	690
1112	400 cps	420
1112	3200 cps	410

B. Insulation Life

Insulation Thickness, 0.0068 Inch

200 volt, 60 cycle proof test after aging, 5 samples per test

Temperature (°F)	Hours	Number of Samples Passed
932	1000	5
1112	1000	5

C. Insulation Resistance and Resistivity

Insulation Thickness, 0.0068 Inch

Temperature (°F)	Frequency	Insulation Resistance (Ohms/ft)	Resistivity (Ohms-cm)
500	DC	1.4×10^{10}	1.1×10^{13}
500	400 cps	1.3×10^{8}	1.0×10^{11}
500	3200 cps	2.5×10^{7}	2.0×10^{10}
932	DC	5.4×10^{7}	4.3×10^{10}
932	400 cps	1.9×10^{7}	1.5×10^{10}
932	3200 cps	3.8×10^{6}	3.0×10^{9}
1112	DC	6.3×10^{6}	5.0×10^{9}
1112	400 cps	6.3×10^{6}	5.0×10^{9}
1112	3200 cps	2.0×10^{6}	1.6×10^{9}

III. Mechanical Properties

A. Abrasion Resistance at 77°F

Insulation Thickness, 0.0068 Inch

1. 0.016 diameter needle, 600 grams	30 strokes
2. 0.039 diameter needle, 600 grams	158 strokes

B. Adhesion

6X bend passed

Insulation Thickness 0.0068 Inch

C. Cut-Through Resistance (Anadur)

Pretreatment	Force (lbs)[1]	Number of Insulation Layers[2]	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
1 hour at 932°F	0.5	*	294 (3)	1200	1200
			294	1200	1200
			294	1200	1200
1 hour at 932°F	2	*	480 (3)	1200	1200
			480	1200	1200
			480	1200	1200

D. Thermal Shock (77°F to temperature to 77°F, ΔT >500°F/minute)

Bend Diameter (inches)	500°F	932°F
0.1875	Passed	Passed
0.125	Passed	Passed

---

(1) Force in pounds is presented for individual pressure points.

(2) One asterisk (*) indicates that uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

(3) No failure - Testing discontinued.

IV. Compatibility Properties

A. Chemical Resistance

In the unfired condition, Anadur has good moisture resistance and good to fair resistance to acidic or alkaline exposure. The organic solvent resistance of unfired Anadur is poor because of the organic resin binder. After firing, this insulation system has good organic solvent resistance and good to fair resistance to acid or alkali.

The fired coating materials themselves have fair moisture resistance. However, firing produces a porous material structure that can absorb moisture readily. This situation lowers the electrical resistance of the insulation which can cause electrical malfunction.

B. Nuclear Radiation Resistance

The manufacturer describes Anadur as being capable of operation in a gamma flux rate of 10^8 - 10^9 rads per hour and a neutron flux of 10^{13} neutrons per cm^2 per second. (Reference: Anaconda Wire and Cable Company Performance Specification CS1200 System Components, dated August 1963.)

C. Vacuum Weight Loss at elevated temperature

24 hours at 1112°F and 10^{-5} to 10^{-6} torr	0.04 percent

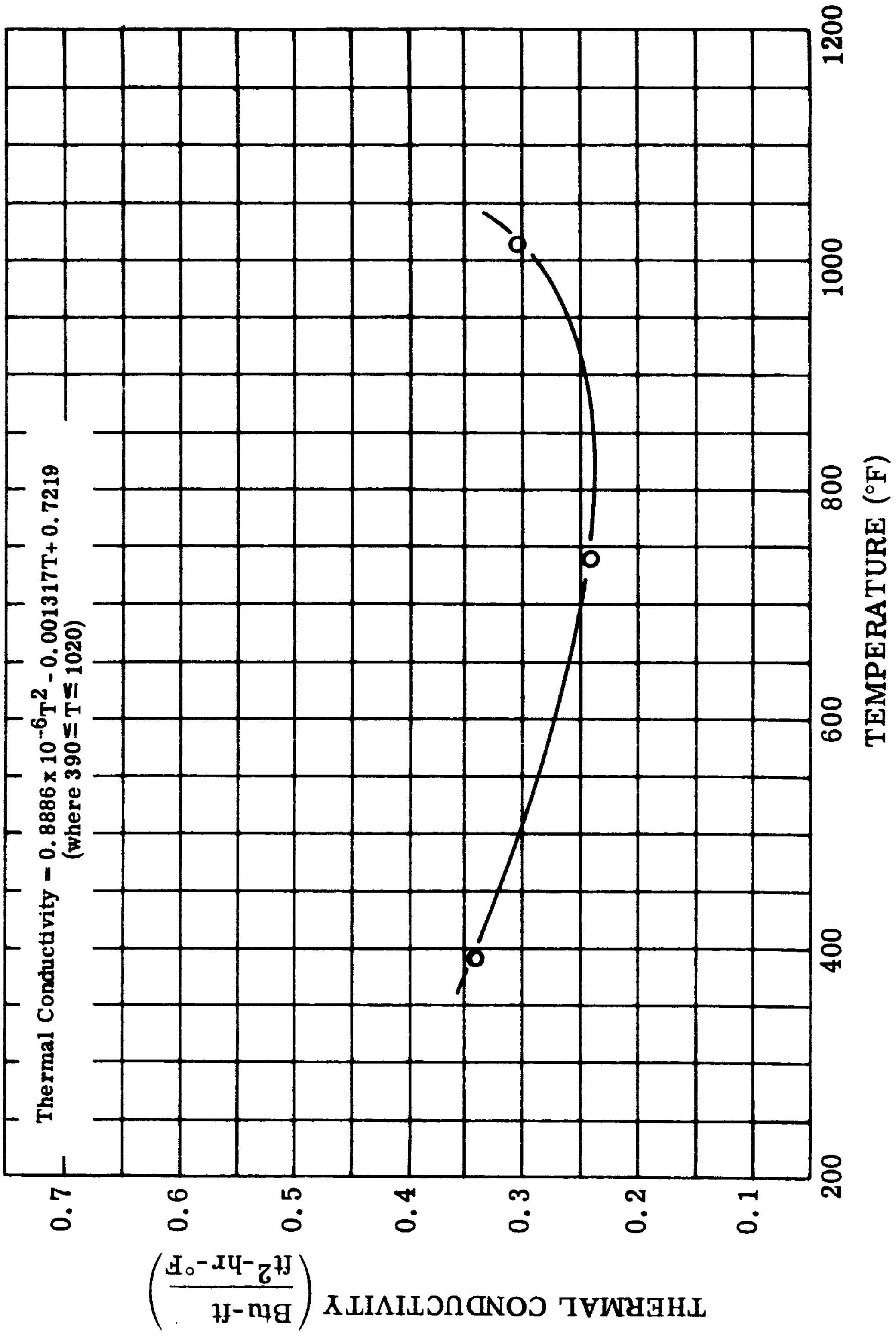


FIGURE V.A.3-1. Transverse Thermal Conductivity (Apparent) of Inorganic Insulated Magnet Wire, Anadur, in Air. Insulation Thickness, 0.0068 Inch on 0.0403 Inch Diameter, 28 Percent Nickel-Clad Copper Wire. (Reference: NAS 3-4162)

Figure V.A.3-1. Thermal Conductivity - Magnet Wire - Anadur

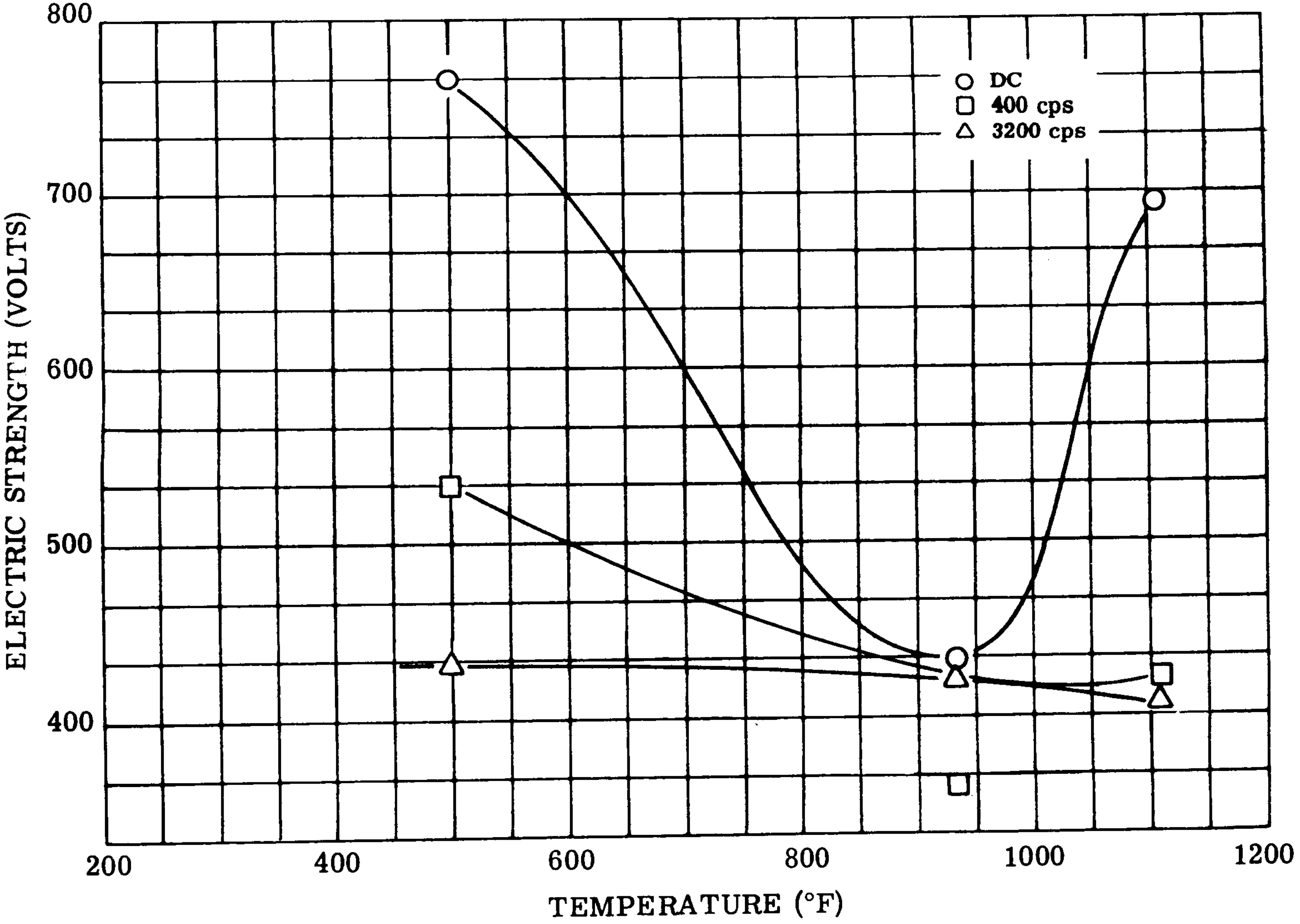


FIGURE V.A. 3-2. Electric Strength of Inorganic Insulated Magnet Wire, Anadur, in Air. Insulation Thickness, 0.0068 Inch on 0.0403 Inch Diameter, 28 Percent Nickel-Clad Copper Wire. (Reference: NAS 3-4162)

Figure V.A. 3-2. Electrical Strength - Magnet Wire - Anadur

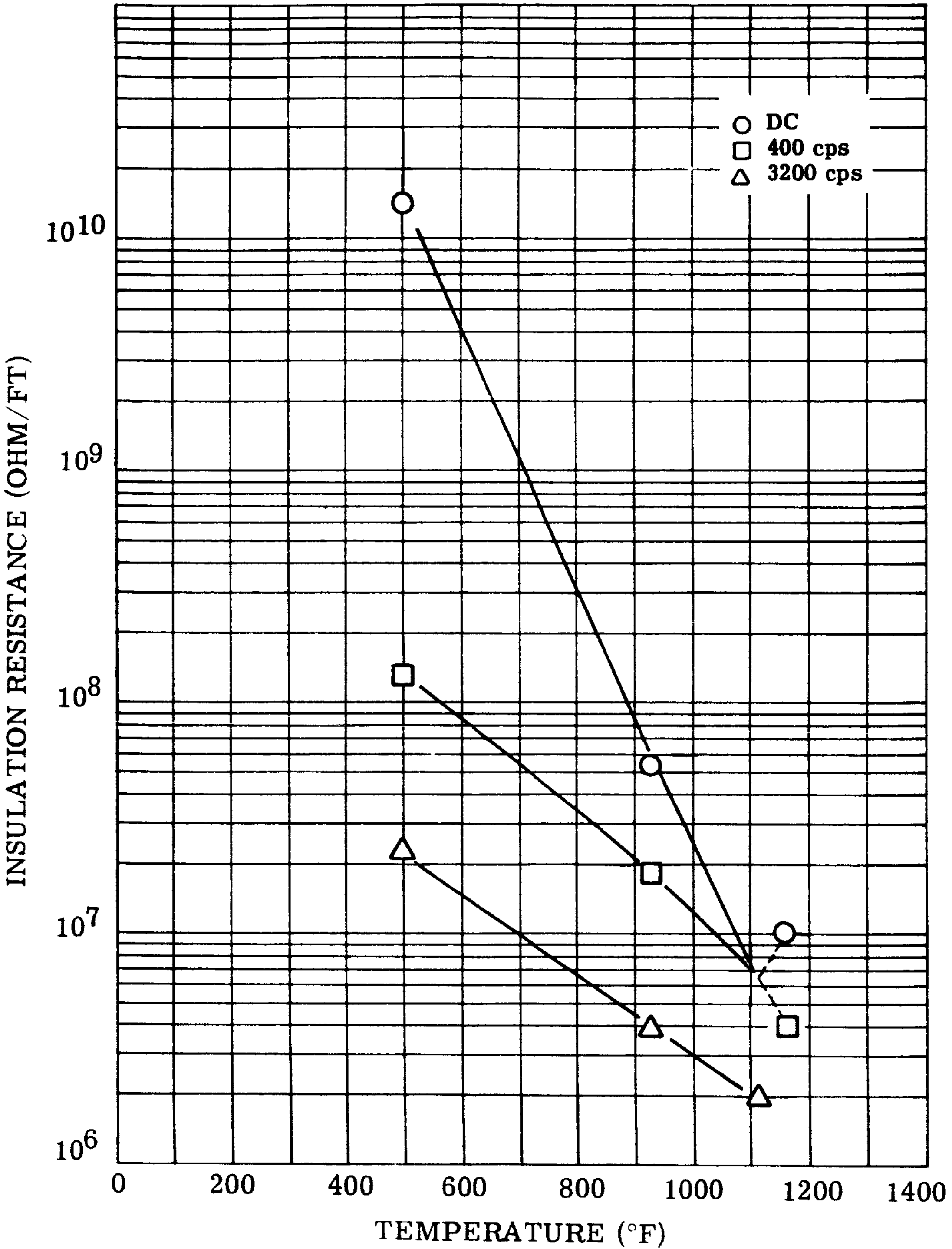


FIGURE V.A.3-3. Insulation Resistance of Inorganic Insulated Magnet Wire, Anadur. Insulation Thickness, 0.0068 Inch on 0.0403 Inch Diameter, 28 Percent Nickel-Clad Copper Wire. (Reference: NAS 3-4162)

Figure V.A.3-3. Insulation Resistance - Magnet Wire - Anadur

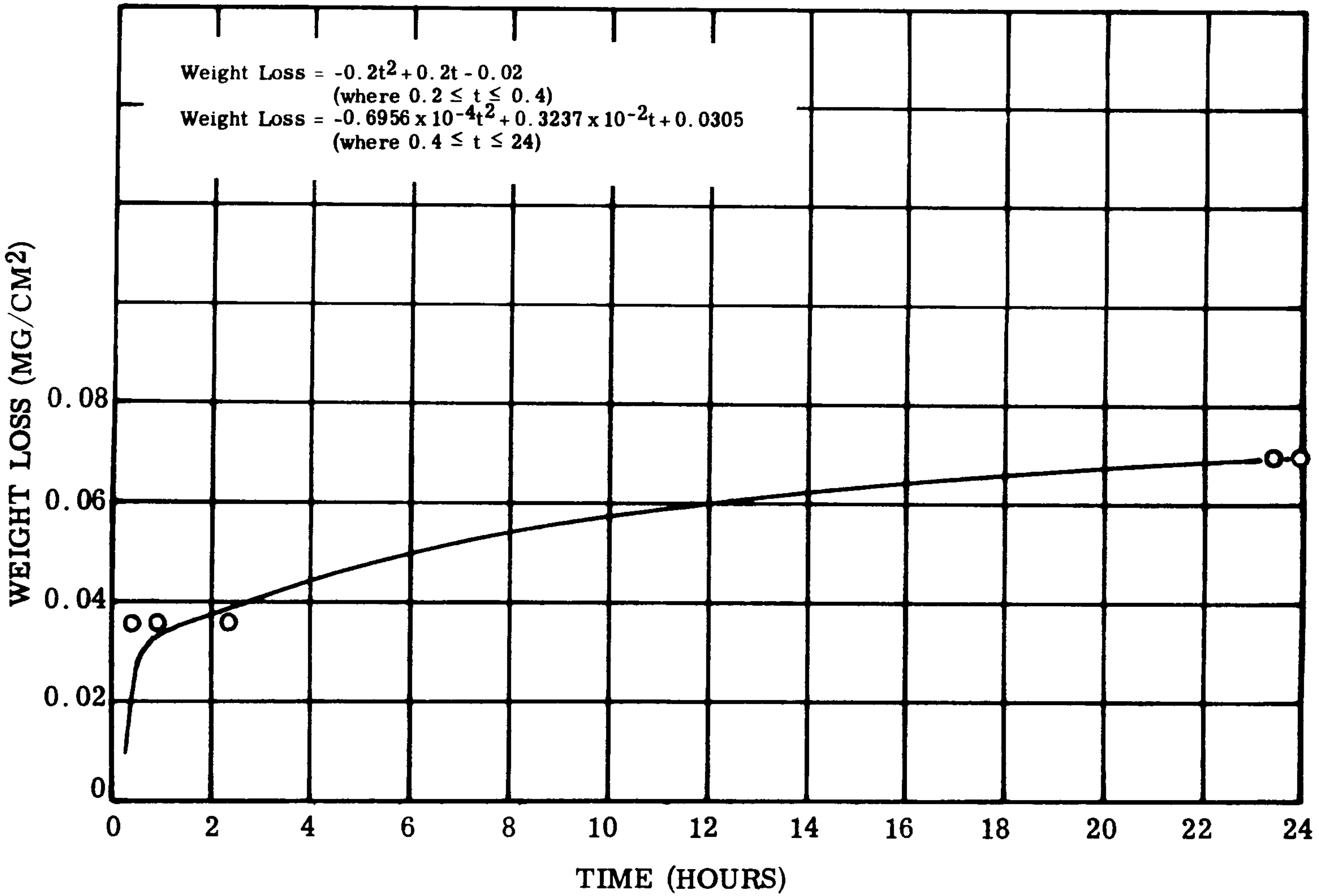


FIGURE V.A.3-4. Weight Loss at 1112°F and 10^{-5} to 10^{-6} Torr of Inorganic Insulated Magnet Wire, Anadur. Insulation Thickness, 0.0068 Inch on 0.0403 Inch Diameter, 28 Percent Nickel-Clad Copper Wire. (Reference: NAS 3-4162)

Figure V.A.3-4. Weight Loss - Magnet Wire - Anadur

4. CERAMIC-EZE MAGNET WIRE

Ceramic-Eze is an inorganic enameled magnet wire. The insulation film is dense and crack-free if the conductor has not been elongated.

Availability:	Ceramic-Eze is available from Phelps Dodge Copper Products Corporation.
Description:	Ceramic-Eze is a fused glass coating which contains a mixture of refractory oxides. The coating is very thin, in the order of 0.0003 inches per side and is over-coated with an organic resin layer to improve windability prior to firing. The 28 percent nickel-clad copper conductor was 0.0201 inch in diameter.

I. Thermophysical Properties

A. Thermal Conductivity, apparent, transverse

Insulation Thickness, 0.0003 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
393	0.298
734	0.239
1103	0.314

II. Electrical Properties

A. Electric Strength

Insulation Thickness, 0.0003 Inch

Temperature (°F)	Frequency	Total Volts
500	DC	200
500	400 cps	210
500	3200 cps	200
932	DC	30
932	400 cps	80
932	3200 cps	110

Temperature (°F)	Frequency	Total Volts
1112	DC	30
1112	400 cps	40
1112	3200 cps	30

B. Insulation Life

Insulation Thickness, 0.0003 Inch

200 volt, 60 cps proof test after aging, 5 samples per test.

Temperature (°F)	Hours	Number of Samples Passed
932	200	5
932	400	4
932	600	4
932	800	4
932	1000	3
1112	200	2
1112	400	0
1112	600	-
1112	800	-

C. Insulation Resistance and Resistivity

Insulation Thickness, 0.0003 Inch

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
500	DC	7.6×10^8	1.5×10^{13}
500	400 cps	3.3×10^7	6.3×10^{11}
500	3200 cps	8.3×10^6	1.6×10^{11}
932	DC	*	
932	400 cps	*	
932	3200 cps	*	

*The test potential of 500 volts used for resistance determination produced electrical breakdown of the test specimens.

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
1112	DC	*	
1112	400 cps	*	
1112	3200 cps	*	

*The test potential of 500 volts used for resistance determination produced electrical breakdown of the test specimens.

III. Mechanical Properties

A. Abrasion Resistance (at 77°F, 0.016 inch needle, 600 grams)

Insulation Thickness, 0.0003 Inch

Average	103 strokes
High	288 strokes
Low	4 strokes

B. Adhesion (bend test at 77°F) Passes 3X to 1X

Insulation Thickness, 0.0003 Inch

Some crazing occurs on both compression and tension sides without lifting or spalling.

C. Cut-Through Resistance - Ceramic-Eze

Insulation Thickness, 0.0003 Inch

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
No Prebake	0.5	*	35	680	840
			39	760	915
			40	771	930

(1) Forces in pounds are presented for individual pressure points.
(2) One asterisk (*) indicates that uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
No Prebake	0.5	**	46	904	1010
			55	1025	1105
			50	968	1160
1 hour at 932°F	0.5	**	49	962	1060
			45	914	1010
			48	952	1050

D. Thermal Shock (77°F to temperature to 77°F, ΔT >500°F/minute)

Insulation Thickness, 0.0003 Inch

Bend Diameter (inches)	500°F	932°F
0.1875	Passed	Passed
0.125	Passed	Passed

IV. Compatibility Properties

A. Chemical Resistance

In the unfired condition, Ceramic-Eze shows good resistance to water, acid, alkali, and organic solvents. After exposure to temperatures between 600°F and 1200°F, the organic solvent, acid, and water resistance remains good. Alkali resistance is fair to poor. (Reference: Phelps-Dodge Data Sheet)

B. Nuclear Radiation Resistance

The radiation resistance of Ceramic-Eze is limited by the glassy continuous phase in the coating. Fused glass is limited to about 10^{18} fast neutrons/cm^2 where moderate damage begins to occur. (Reference: Radiation Effects Information Center Report No. 34.)

(1) Forces in pounds are presented for individual pressure points.

(2) One asterisk (*) indicates that uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisk (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

C. Vacuum Weight Loss at Elevated Temperature

24 hours at 1112°F and 10^{-5} to 10^{-6} torr	0.06 percent

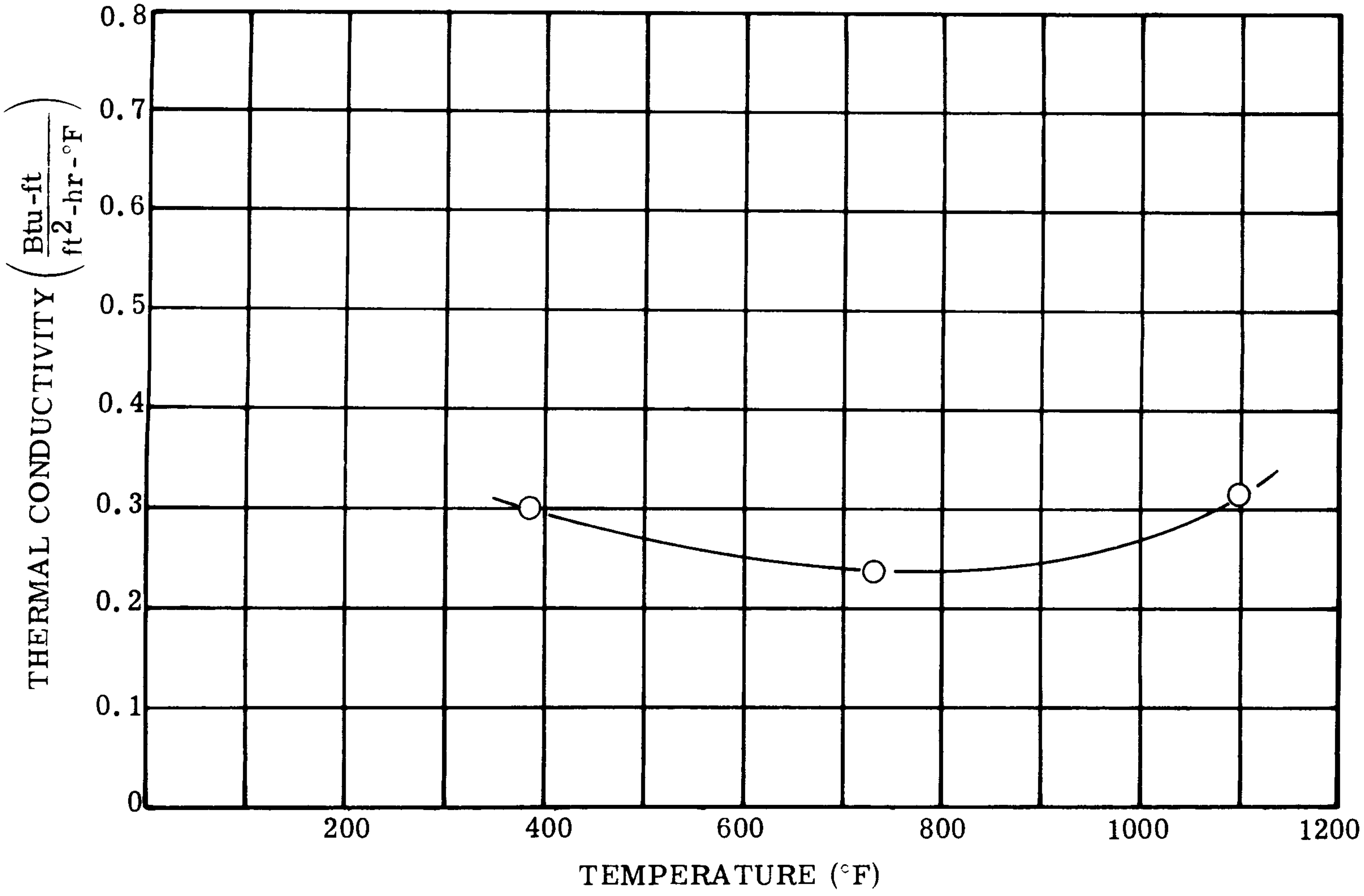


FIGURE V.A.4-1. Transverse Thermal Conductivity (Apparent) of Inorganic Insulated Magnet Wire, Ceramic-Eze, in Air. Insulation Thickness, 0.0003 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0201 Inch Diameter. (Reference: NAS 3-4162)

Figure V.A.4-1. Thermal Conductivity - Magnet Wire - Ceramic-Eze

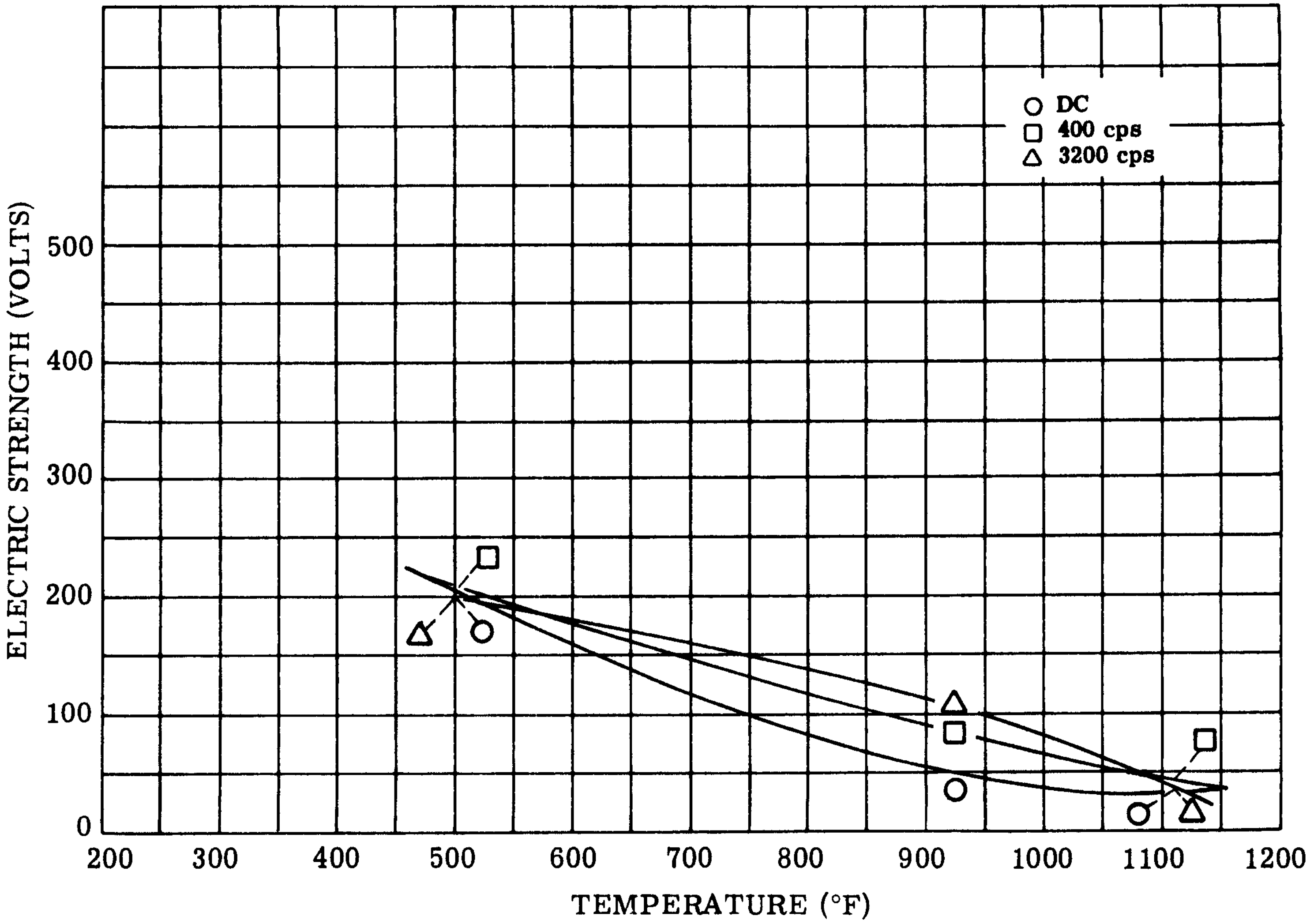


FIGURE V.A.4-2. Electric Strength of Inorganic Insulated Magnet Wire, Ceramic-Eze, in Air. Insulation Thickness, 0.0003 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0201 Inch Diameter. (Reference: NAS 3-4162)

Figure V.A.4-2. Electric Strength - Magnet Wire - Ceramic-Eze

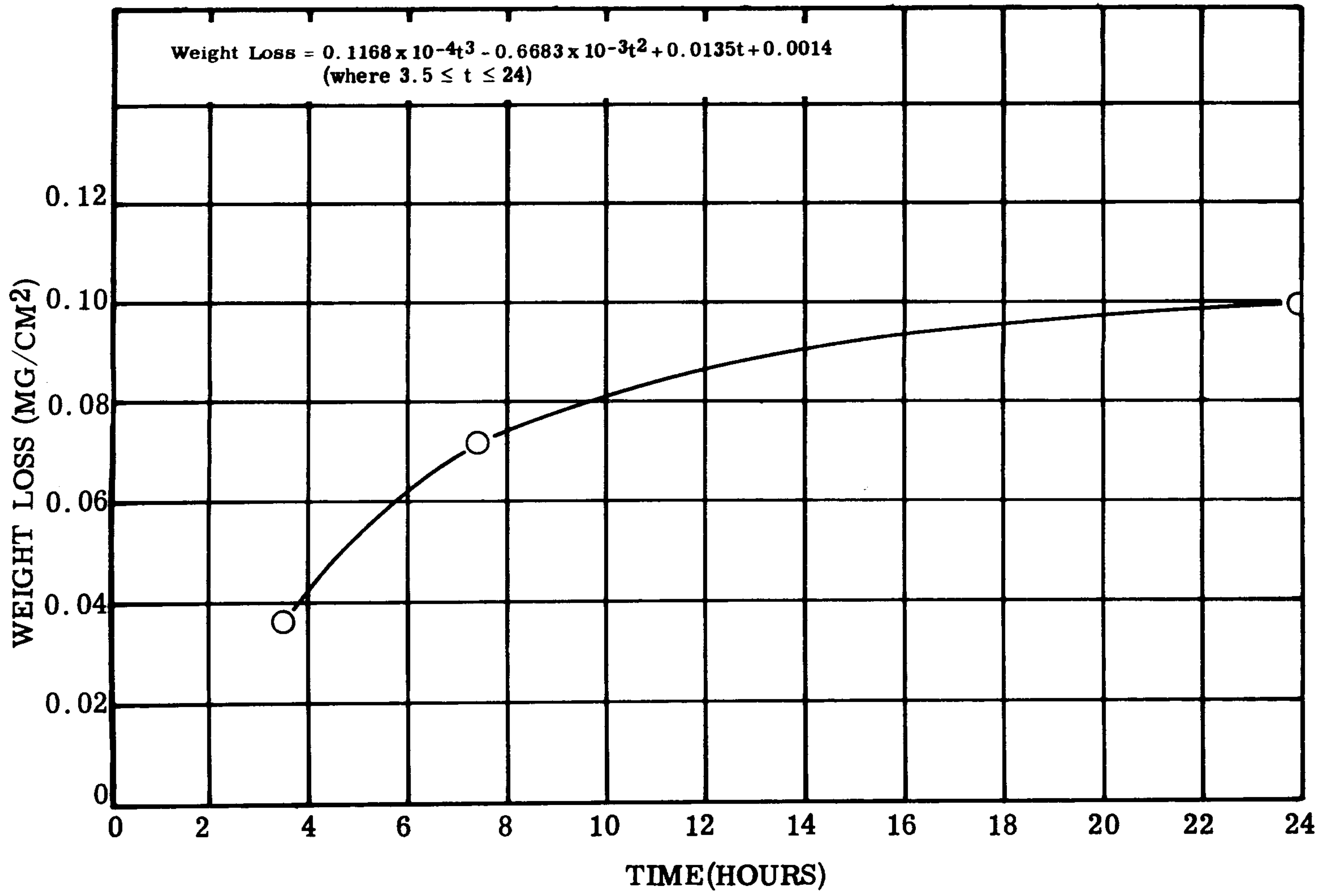


FIGURE V.A.4-3. Weight Loss of Inorganic Insulated Magnet Wire, Ceramic-Eze, at 1112°F and 10^{-5} - 10^{-6} torr. Insulation Thickness, 0.0003 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0201 Inch Diameter. (Reference: NAS 3-4162)

Figure V.A.4-3. Weight Loss- Magnet Wire - Ceramic-Eze

5. WESTINGHOUSE R2554B MAGNET WIRE

R2554B Magnet Wire is an enameled conductor which resists operating temperatures up to about 1000°F. The materials which constitute the insulating enamel are incorporated into an organic vehicle for application.

Availability:	R2554B magnet wire is available from Westinghouse Electric Corporation, Copper Wire Department, on plated or clad conductors.
Description:	The composition of R2554B includes refractory oxides and glass frit bonded to a plated or clad conductor by an organic resin vehicle. The resin is destroyed during early stages of firing in air and leaves no carbonaceous residue. The composition of the glass frit is such that fusion is achieved in final firing at 1250°F. The conductor used in this program was 28 percent nickel-clad copper of 0.0403 inch diameter.

I. Thermophysical Properties

A. Thermal Conductivity, apparent, transverse

Insulation Thickness, 0.0019 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
409	0.422
733	0.381
1116	0.507

II. Electrical Properties

A. Electrical Strength

Insulation Thickness, 0.0019 Inch

Temperature (°F)	Frequency	Total Volts
500	DC	470
500	400 cps	270
500	3200 cps	250*
932	DC	450
932	400 cps	190*
932	3200 cps	260*
1112	DC	490
1112	400 cps	230*
1112	3200 cps	300*

*Not a breakdown. Leakage current exceeded 30 ma.

B. Insulation Life

Insulation Thickness 0.0019 Inch

200 volt, 60 cycle proof test after aging, 5 samples per test.

Temperature (°F)	Hours	Number of Samples Passed
932	1000	5
1112	1000	5

C. Insulation Resistance and Resistivity

Insulation Thickness, 0.0019 Inch

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
500	DC	1.3×10^{10}	3.4×10^{13}
500	400 cps	7.9×10^{7}	2.1×10^{11}
500	3200 cps	2.1×10^{7}	5.6×10^{10}
932	DC	2.7×10^{8}	7.2×10^{11}
932	400 cps	1.9×10^{7}	5.0×10^{10}
932	3200 cps	4.8×10^{6}	1.3×10^{10}

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
1112	DC	1.3×10^{7}	3.4×10^{10}
1112	400 cps	5.0×10^{6}	1.3×10^{10}
1112	3200 cps	1.5×10^{6}	4.0×10^{9}

III. Mechanical Properties

A. Abrasion Resistance

Insulation Thickness, 0.0019 Inch

1. 77°F, 0.016 inch diameter needle, 600 grams	5 strokes
2. 77°F, 0.039 inch diameter needle, 600 grams	Greater than 2000 strokes

B. Adhesion at 77°F

4X passed

C. Cut-Through Resistance - R2554B

Insulation Thickness, 0.0019 Inch

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
1 hour at 932°F	0.5	*	55	1048	1130
			27	577	780
			0	120	120
1 hour at 932°F	0.5	**	87	1202	1210
			51	1018	1090
			71	1188	1210
No Prebake	0.5	**	33	741	880
			32	719	860
			37	800	920

(1) Forces in pounds are presented for individual pressure points.

(2) One asterisk (*) indicates that an uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

Pretreatment	Force (1) (lbs)	Number of Insulation Layers (2)	Time to Failure (min)	Maximum Temperature (°F) Specimen	Maximum Temperature (°F) Furnace
1 hour at 572°F	0.5	**	71-79 (3)	1202	1210
			354 (4)	1202	1210
			354 (4)	1202	1210

D. Thermal Shock (77°F to temperature to 77°F, ΔT >500°F/minute)

Bend Diameter (inches)	500°F	932°F
0.1875	2 passed, 1 failed by splitting on tension side	3 failed
0.125	3 failed by splitting on tension side	3 failed

IV. Compatibility

A. Chemical Resistance

In the unfired condition, the insulation has good moisture resistance, fair resistance to acid and alkaline materials, and fair to poor resistance to organic solvents. After firing, the insulation has good resistance to water, acidic solutions, and organic solvents. The resistance of R2554B to alkaline contaminants is generally poor. The fired coating displays the typical density range of sintered ceramic films. Thus, with careful selection of compatible encapsulation materials and processing, a fairly dense coating can be achieved.

---

(1) Forces in pounds are presented for individual pressure points.

(2) One asterisk (*) indicates that an uninsulated nickel wire (18 AWG) was applied cross-wise against the test wire. Two asterisks (**) indicate that the force was applied by pressing one insulated wire specimen cross-wise against a second similar insulated wire specimen.

(3) High leakage for eight minutes.

(4) No failure, testing discontinued.

B. Nuclear Radiation Resistance

R2554B magnet wire contains boron in the glass portion of the coating. The presence of boron permits the use of R2554B under a gamma dose of about 10^{10} rad and a neutron dose in the range of 10^{18} nvt at an energy greater than 0.1 mev. (Reference: Radiation Effects Information Center Report No. 34.)

C. Vacuum Weight Loss at elevated temperature

24 hours at 1112°F, 10^{-6} torr	0.06 percent

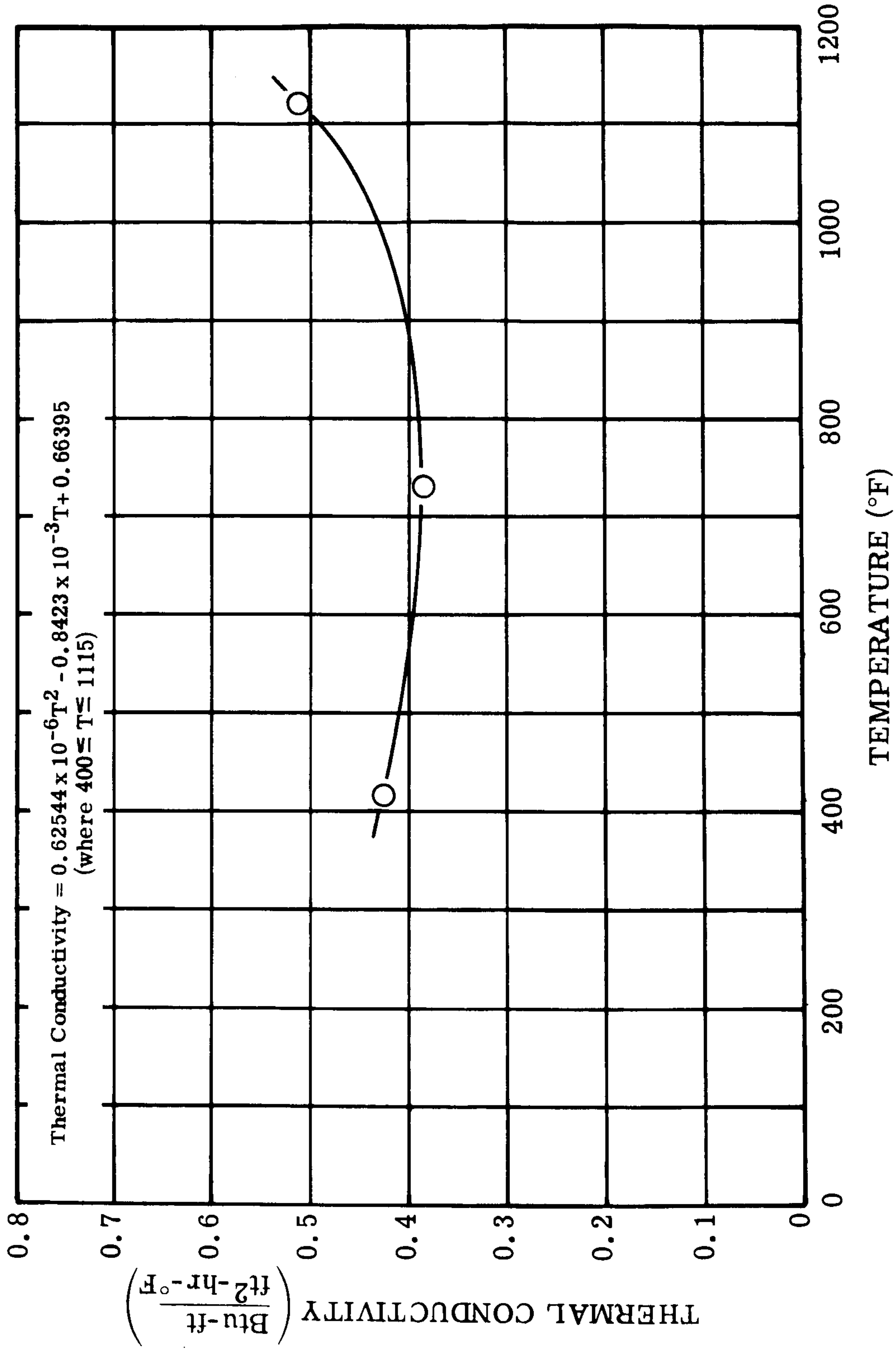


FIGURE V.A.5-1. Transverse Thermal Conductivity (Apparent) of Inorganic Insulated Magnet Wire, R2554B, in Air. Insulation Thickness, 0.0019 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0403 Inch Diameter. (Reference: NAS3-4162)

Figure V.A.5-1. Thermal Conductivity - Magnet Wire - R2554B

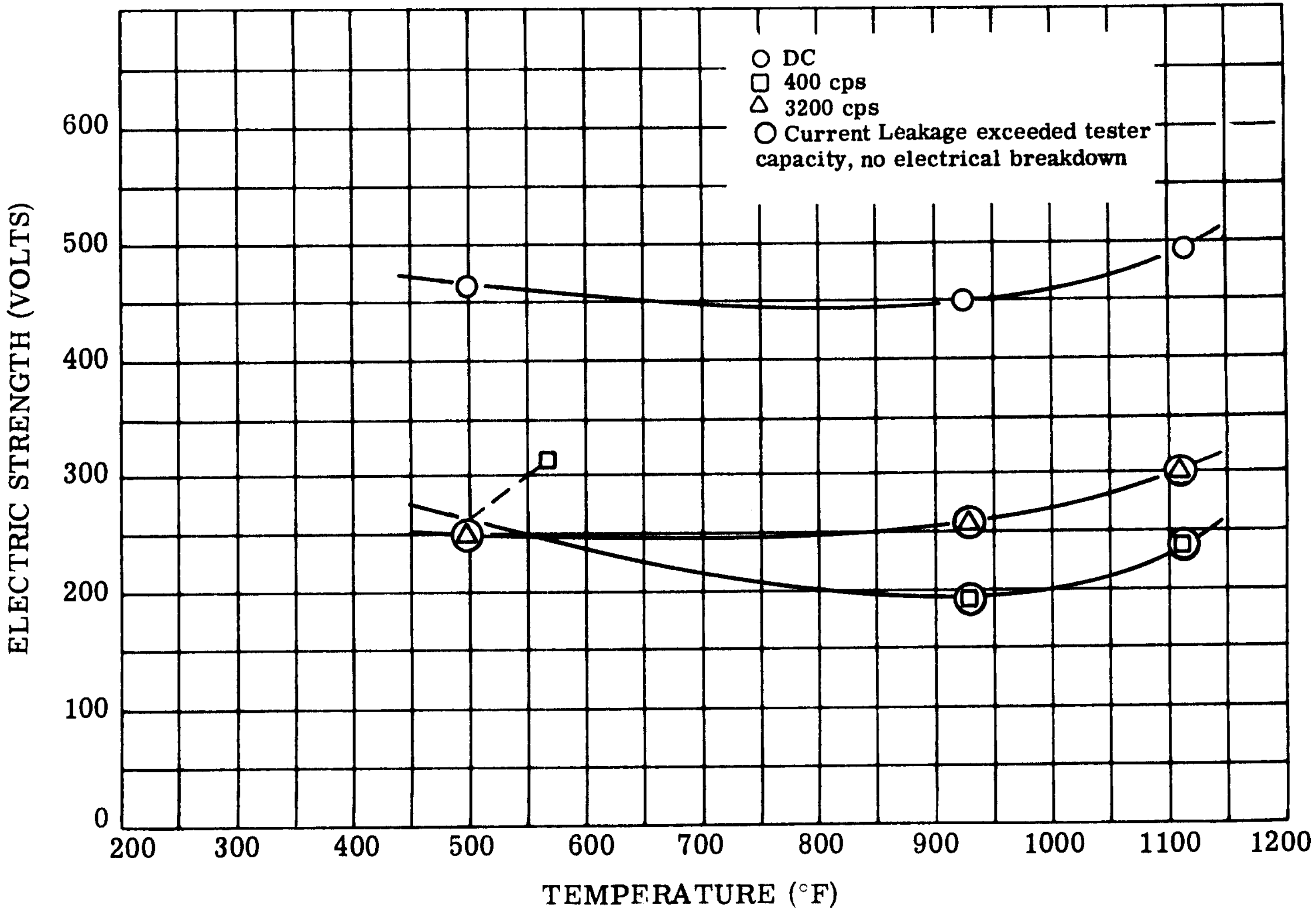


FIGURE V.A.5-2. Electric Strength of Inorganic Insulated Magnet Wire, R2554B, in Air. Insulation Thickness, 0.0019 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0403 Inch Diameter. (Reference: NAS 3-4162)

Figure V.A.5-2. Electric Strength - Magnet Wire - R2554B

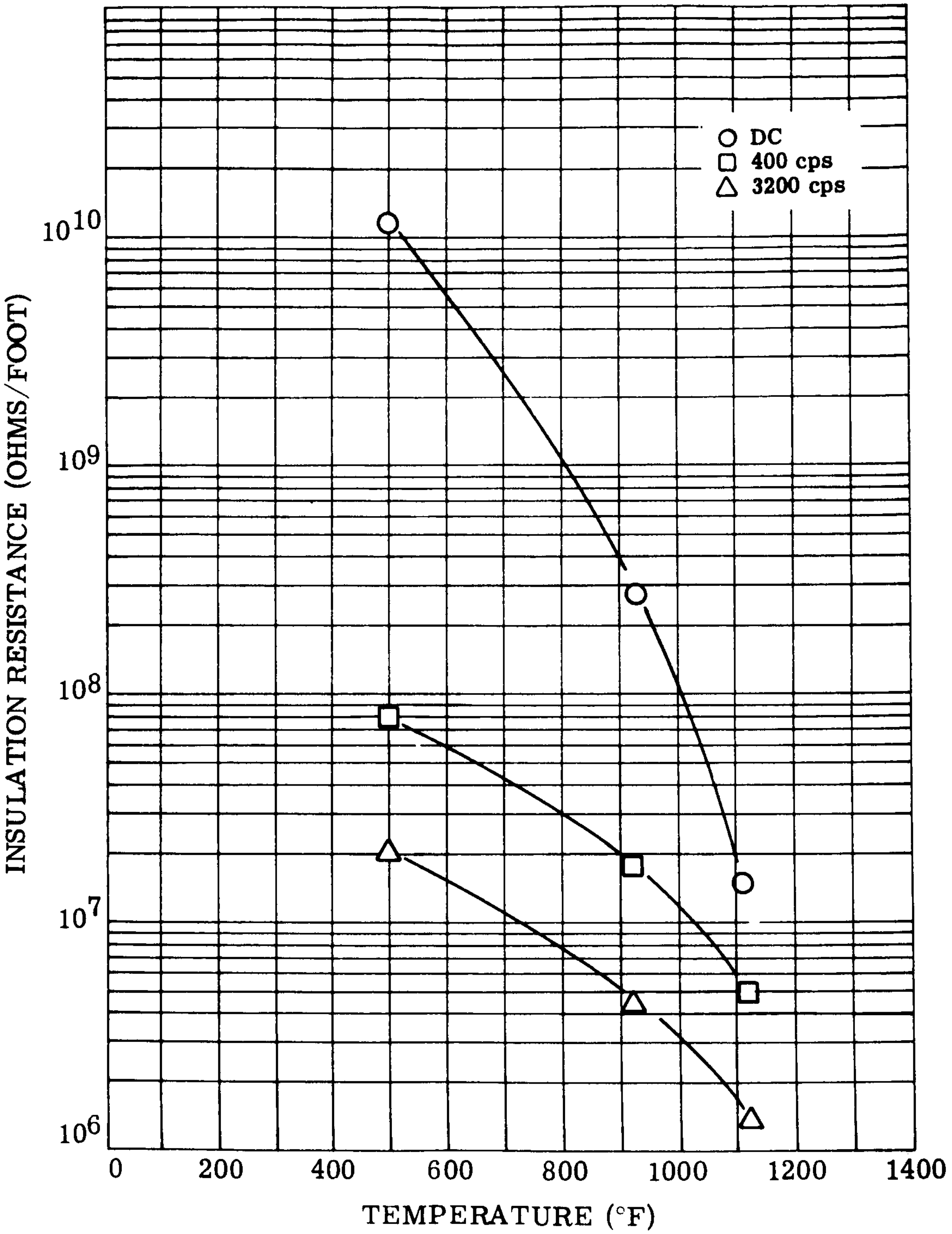


FIGURE V.A.5-3. Insulation Resistance of Inorganic Insulated Magnet Wire, R2554B, in Air. Insulation Thickness, 0.0019 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0403 Inch Diameter. (Reference: NAS3-4162)

Figure V.A.5-3. Insulation Resistance - Magnet Wire - R2554B

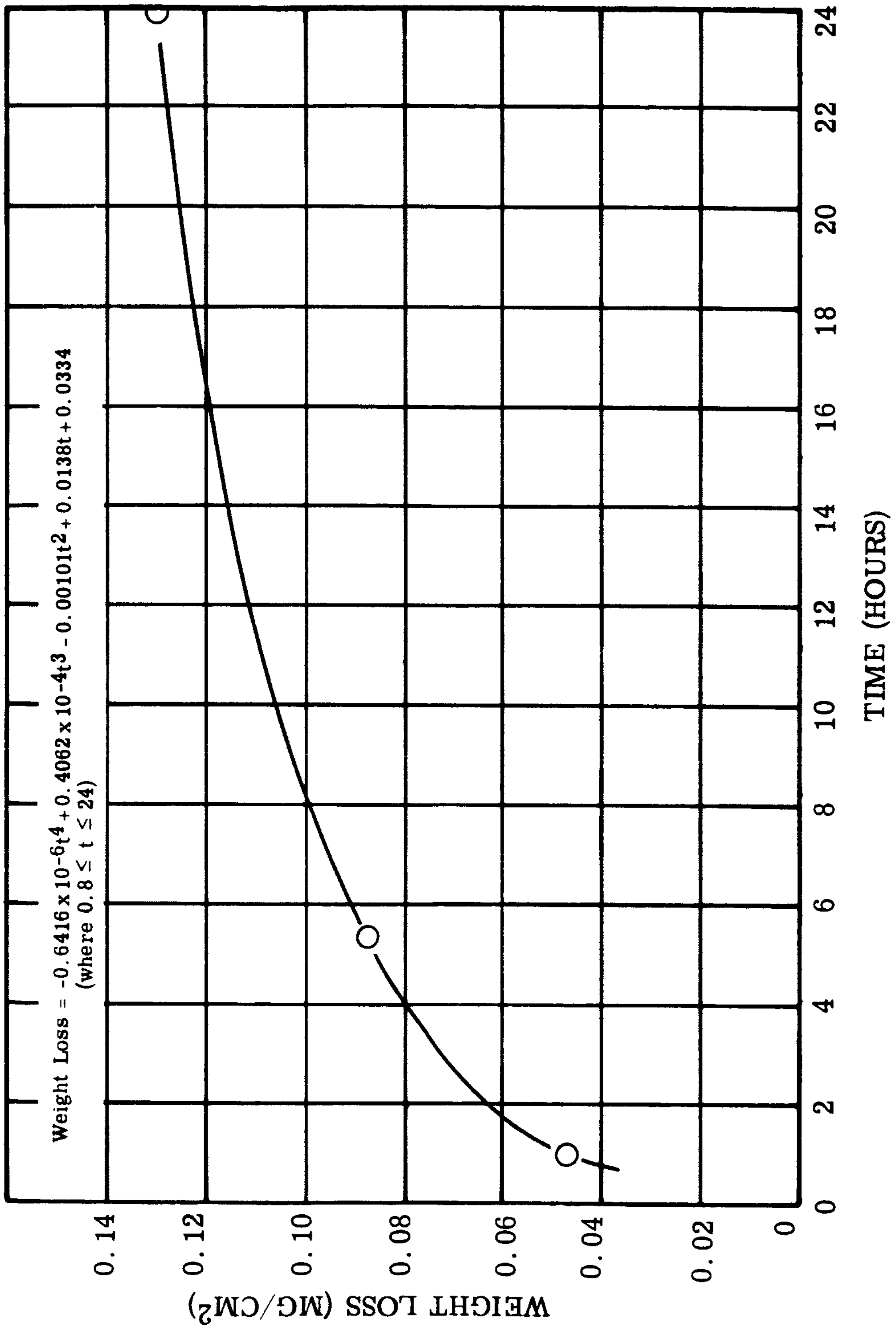


FIGURE V.A.5-4. Weight Loss at 1112°F and 10^{-5} to 10^{-6} Torr of Inorganic Insulated Magnet Wire, R2554B. Insulation Thickness, 0.0019 Inch on 28 Percent Nickel-Clad Copper Wire of 0.0403 Inch Diameter. (Reference: NAS 3-4162)

Figure V.A.5-4. Weight Loss - Magnet Wire - R2554B

B. LEAD WIRE

1. GLASS FIBER - ASBESTOS LEAD WIRE

Glass fiber-asbestos lead wire is a nickel-plated copper, stranded conductor covered with a braided and treated asbestos fiber. This insulation is designed to achieve flexibility and good electrical strength.

Availability:	Glass fiber-asbestos lead wire is available from the Continental Wire Corporation of York, Pa., and is identified as Type AA lead wire with asbestos braid covering.
Description:	The insulation of Continental AA lead wire consists of E-glass reinforced mica tape wrapping overlaid with asbestos braid. The asbestos braid is treated with silicone resin to afford moisture resistance and flexibility during handling prior to exposure at temperatures above approximately 800°F. The conductor consisted of seven strands of 0.016 inch diameter nickel-plated copper with approximately 0.0002 inch of nickel plating per strand.

I. Thermophysical Properties

A. Thermal Conductivity, apparent, transverse.

Insulation Thickness, 0.0684 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
369	0.338
691	0.324
1340	0.204

II. Electrical Properties

A. Electrical Strength

Insulation Thickness, 0.0684 Inch

Temperature (°F)	Frequency	Total Kilovolts
500	DC	3.0
500	400 cps	2.3
500	3200 cps	2.5
932	DC	2.6*
932	400 cps	1.9
932	3200 cps	1.65
1598	DC	1.9*
1598	400 cps	2.6
1598	3200 cps	2.8

*Not a breakdown, leakage current exceeded 5 ma.

B. Insulation Resistance and Resistivity

Insulation Thickness, 0.0684 Inch

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
500	DC	1.5×10^{10}	2.3×10^{12}
500	400 cps	9.1×10^{7}	1.4×10^{10}
500	3200 cps	2.0×10^{7}	3.2×10^{9}
932	DC	2.4×10^{7}	3.7×10^{9}
932	400 cps	3.3×10^{6}	5.1×10^{8}
932	3200 cps	1.2×10^{6}	1.8×10^{8}
1292	DC	9.8×10^{6}	1.5×10^{8}
1292	400 cps	7.8×10^{5}	1.2×10^{8}
1292	3200 cps	3.7×10^{5}	5.6×10^{7}

III. Mechanical Properties

A. Abrasion Resistance at 77°F of Unfired Lead Wire. (Repeated scrape with special lead wire head, shown in Figure III. C-1).

3 pound loading	1600 strokes
9 pound loading	116 strokes

B. Cut-Through Resistance	Fair if no vibration or relative motion is encountered on the fired lead wire.

IV. Compatibility Properties

A. Chemical Resistance

In the unfired condition, this lead wire has good moisture resistance and fair resistance to acid and alkali exposure. The solvent resistance is fair to poor. After firing, the moisture resistance is poor because of the porous nature of the refractory covering. Solvent resistance is good.

B. Nuclear Radiation Resistance

The radiation resistance of mica, glass fiber, and asbestos is good up to a level of about 10^{10} ergs per gram (C), and 10^{17} fast neutrons/cm^2. At this radiation level the glass begins to degrade mechanically. Severe damage begins at about 10^{12} ergs per gram (C) and 10^{19} fast neutrons/cm^2. (LI296)

C. Vacuum Weight Loss at Elevated Temperature

1. 24 hours at 932°F and 10^{-5} to 10^{-6} torr	10.6 percent
2. 24 hours at 1600°F and 10^{-5} to 10^{-6} torr	12.1 percent

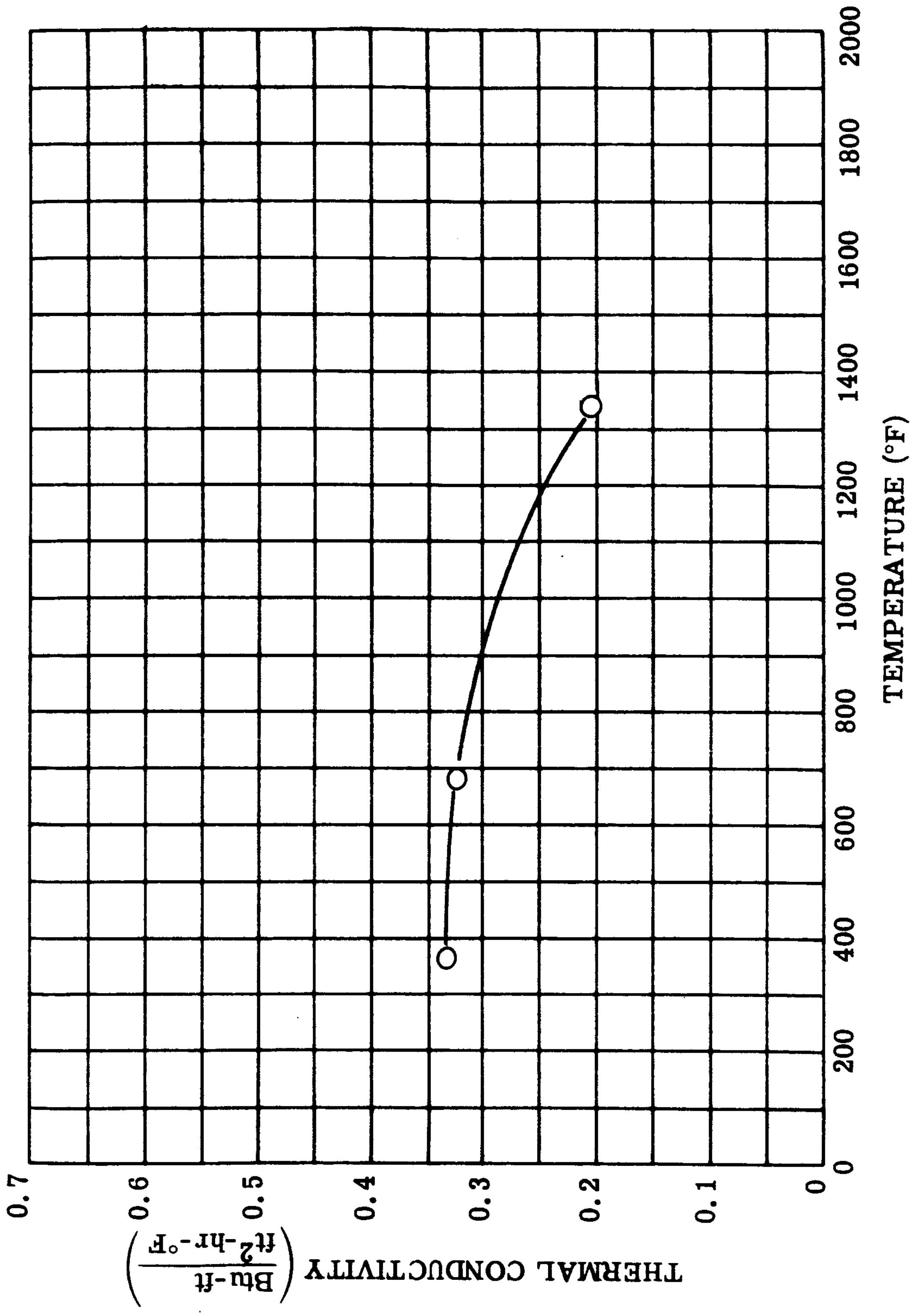


FIGURE V. B. 1-1. Transverse Thermal Conductivity (Apparent) of Inorganic Insulated Lead Wire, Glass Asbestos, in Air. Insulation Thickness, 0.0684 Inch on Stranded Nickel-Plated Copper Wire, Seven Strands of 0.016 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V. B. 1-1. Thermal Conductivity - Lead Wire - Glass Asbestos

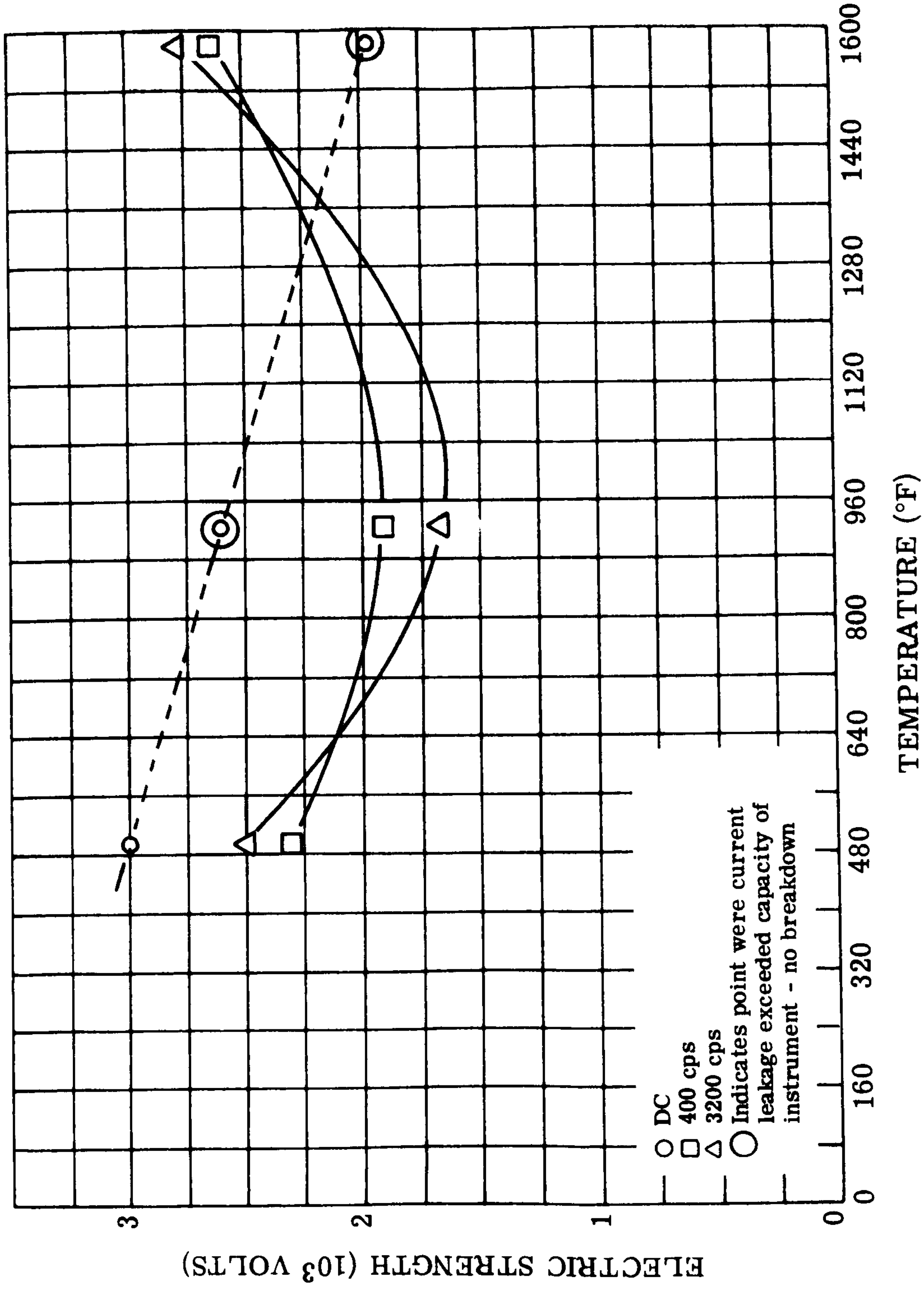


FIGURE V.B.1-2. Electric Strength of Inorganic Insulated Lead Wire, Glass Asbestos, in Air. Insulation Thickness, 0.0684 Inch on Stranded Nickel-Plated Copper Wire, Seven Strands of 0.016 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V.B.1-2. Electric Strength - Lead Wire - Glass Asbestos

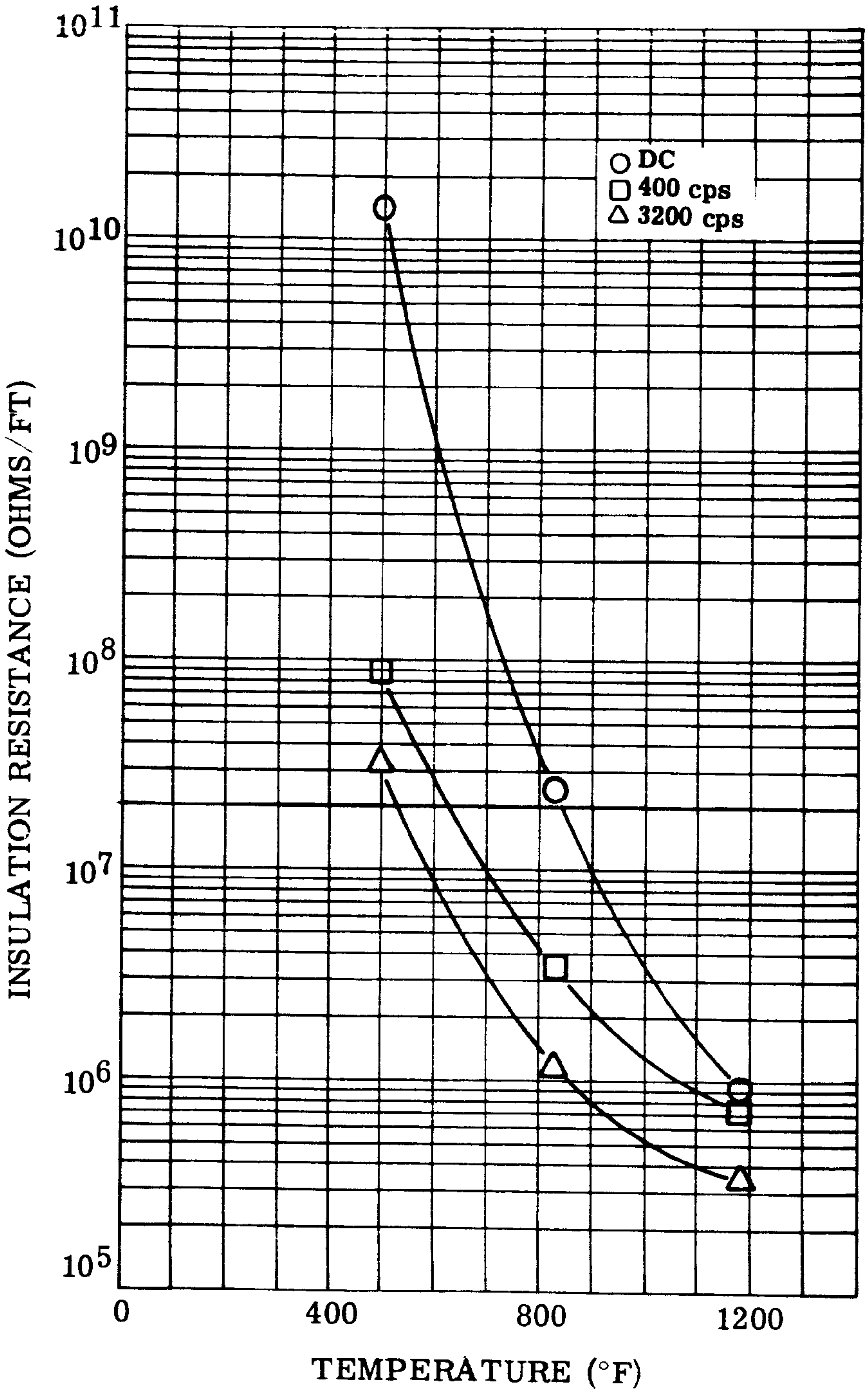


FIGURE V. B. 1-3. Insulation Resistance of Inorganic Insulated Lead Wire, Glass Asbestos, in Air. Insulation Thickness, 0.0684 Inch on Stranded Nickel-Plated Copper Wire, Seven Strands of 0.016 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V. B. 1-3. Insulation Resistance - Lead Wire - Glass Asbestos

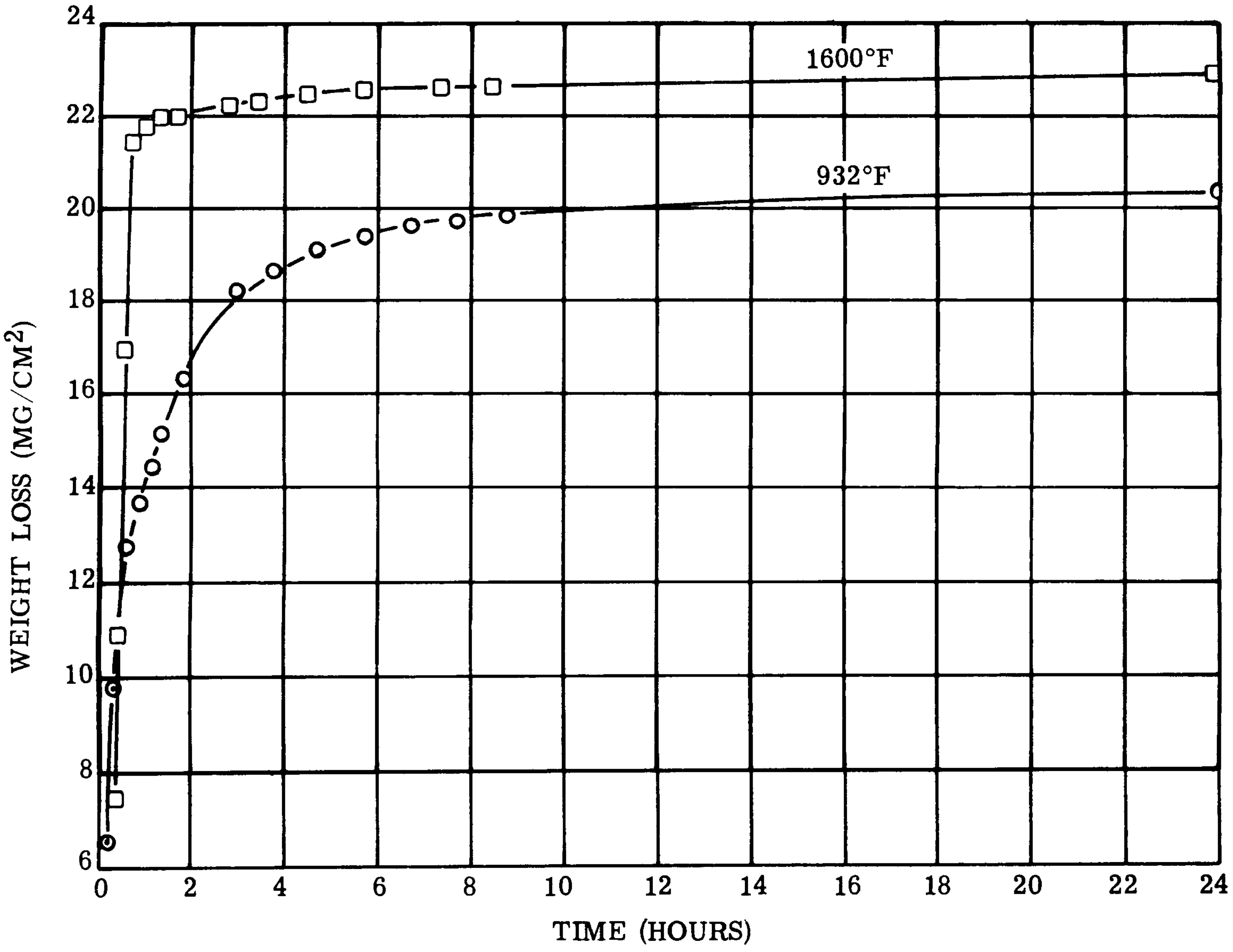


FIGURE V. B. 1-4. Weight Loss at 932°F, 1600°F, and 10^{-5} to 10^{-6} Torr of Inorganic Insulated Lead Wire, Glass Asbestos. Insulation Thickness, 0.0684 Inch on Stranded Nickel-Plated Copper Wire, Seven Strands of 0.016 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V. B. 1-4. Weight Loss - Lead Wire - Glass Asbestos

2. GLASS FIBER - MICA LEAD WIRE

Glass fiber - mica lead wire is a high temperature resistant wire for use up to 1100°F and in nuclear radiation. Its rated voltage is 600 volts.

Availability:	Mica-Temp lead wire is available from Rockbestos Wire and Cable Company. All lead wires are stranded and available in even numbered sizes from 22 to 4 AWG equivalent. Sizes 16 to 22 are available in stock, larger sizes are made on order. Other sizes are available on request.
Description:	Mica-Temp lead wire is made from stranded nickel-clad copper wire. The initial electrical insulation is a reinforced muscovite mica tape. The outer insulation is an E-glass braid coated with a heat-resistant finish of silicone resin. Other protected copper conductors have been used by the producer. The conductor used in this program consisted of nineteen strands of 0.0114 inch diameter nickel-plated copper with approximately 0.0002 inch of nickel plating per strand.

I. Thermophysical Properties

A. Thermal Conductivity, apparent, transverse.

Insulation Thickness, 0.020 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
509	0.332
900	0.414
1250	0.421

II. Electrical Properties

A. Electric Strength

Insulation Thickness, 0.020 Inch

Temperature (°F)	Frequency	Total Kilovolts
500	DC	6.0
500	400 cps	3.65
500	3200 cps	3.50
932	DC	2.5
932	400 cps	1.7
932	3200 cps	1.6
1292	DC	1.1
1292	400 cps	0.78
1292	3200 cps	0.62

B. Insulation Life

Insulation Thickness, 0.020 Inch

750 volts, 60 cycle proof test after aging, 5 samples per test

Temperature (°F)	Hours	Number Samples Passed
1112	200	5
1112	400	5
1112	600	5
1112	800	5
1112	1000	*
1292	200	5
1292	400	4
1292	600	0

*Samples destroyed by furnace failure.

C. Insulation Resistance and Resistivity

Insulation Thickness, 0.020 Inch

Temperature (°F)	Frequency	Insulation Resistance (ohms/ft)	Resistivity (ohms-cm)
500	DC	1.5×10^9	6.1×10^{11}
500	400 cps	2.6×10^8	1.1×10^{11}
500	3200 cps	4.5×10^7	2.2×10^{10}
932	DC	1.4×10^8	5.7×10^{10}
932	400 cps	1.1×10^7	4.5×10^9
932	3200 cps	3.6×10^6	1.5×10^9
1112	DC	2.2×10^7	9.0×10^9
1112	400 cps	4.5×10^6	1.8×10^9
1112	3200 cps	1.4×10^6	5.7×10^8

III. Mechanical Properties

A. Abrasion Resistance at 77°F of unfired Lead Wire
(Repeated scrape with lead wire head, shown in Figure III. C-1.)

3 pounds loading	373 strokes
9 pounds loading	40 strokes

B. Cut-Through Resistance	Fair, if no vibration or relative motion is encountered on the fired lead wire.

IV. Compatibility Properties

A. Chemical Resistance

In the unfired condition, this lead wire has fair resistance to moisture, acid, and alkali exposure. The solvent resistance is fair. After firing, the moisture resistance is poor because of the porous nature of the refractory covering. Solvent resistance is good.

B. Nuclear Radiation Resistance

(LI296)

The nuclear radiation resistance of the glass fiber mica construction is good up to a flux level of about 10^{10} ergs per gram (C) and 10^{17} fast neutrons/cm^2. At this radiation level, the glass begins to degrade mechanically. Severe damage begins at about 10^{12} ergs per gram (C) and 10^{19} fast neutrons/cm^2 at room temperature but radiation tolerance is improved at high temperatures such as 1000-1200°F.

C. Vacuum Weight Loss at elevated temperature

1. 24 hours at 932°F and 10^{-5} to 10^{-6} torr	3.9 percent
2. 24 hours at 932°F and 24 hours at 1292°F and 10^{-5} to 10^{-6} torr	4.1 percent

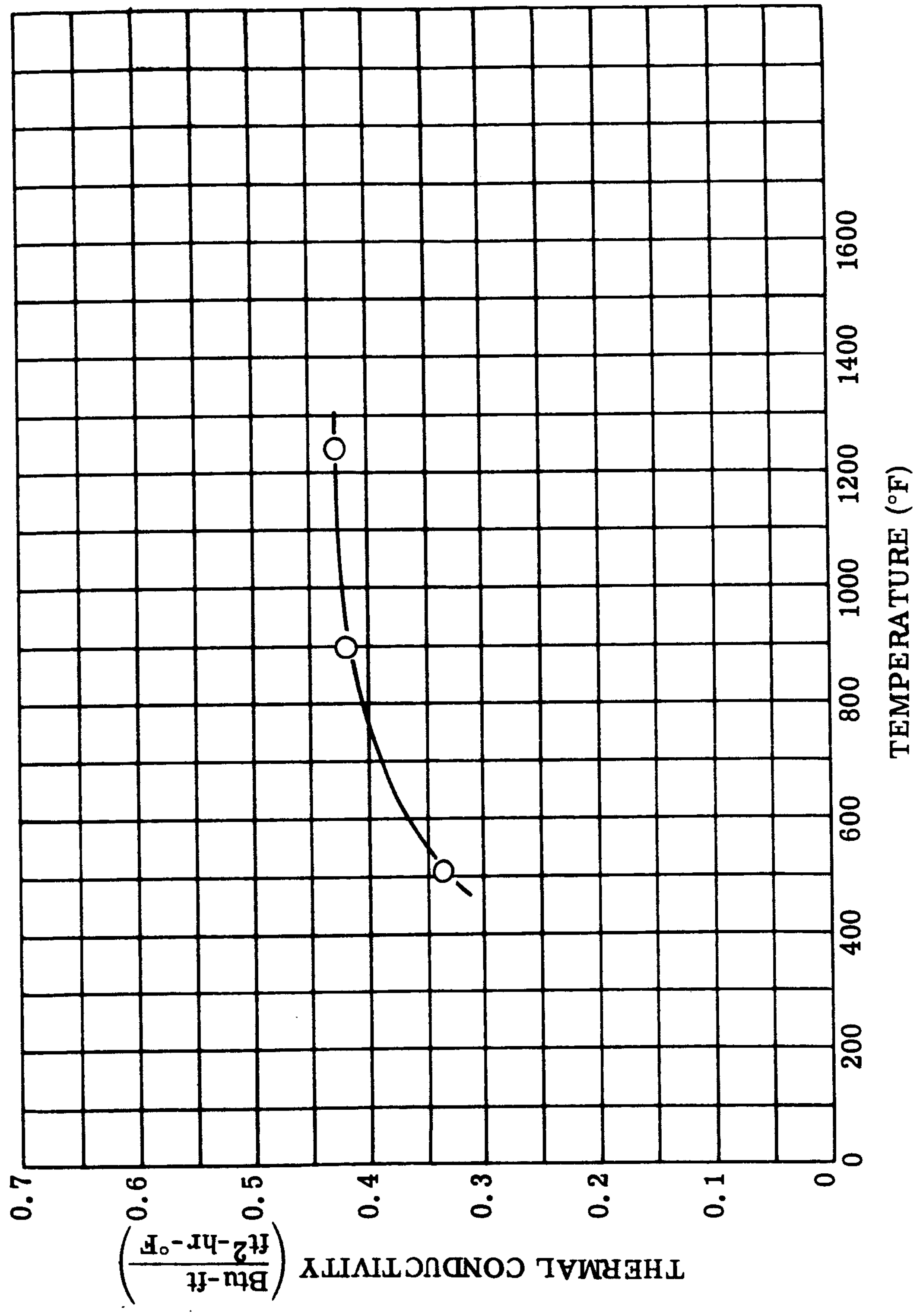


FIGURE V.B.2-1. Transverse Thermal Conductivity (Apparent) of Inorganic Insulated Lead Wire, Mica Glass, in Air. Insulation Thickness, 0.020 Inch on Stranded Nickel-Plated Copper Wire, Nineteen Strands of 0.0114 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V.B.2-1. Thermal Conductivity - Lead Wire - Mica Glass

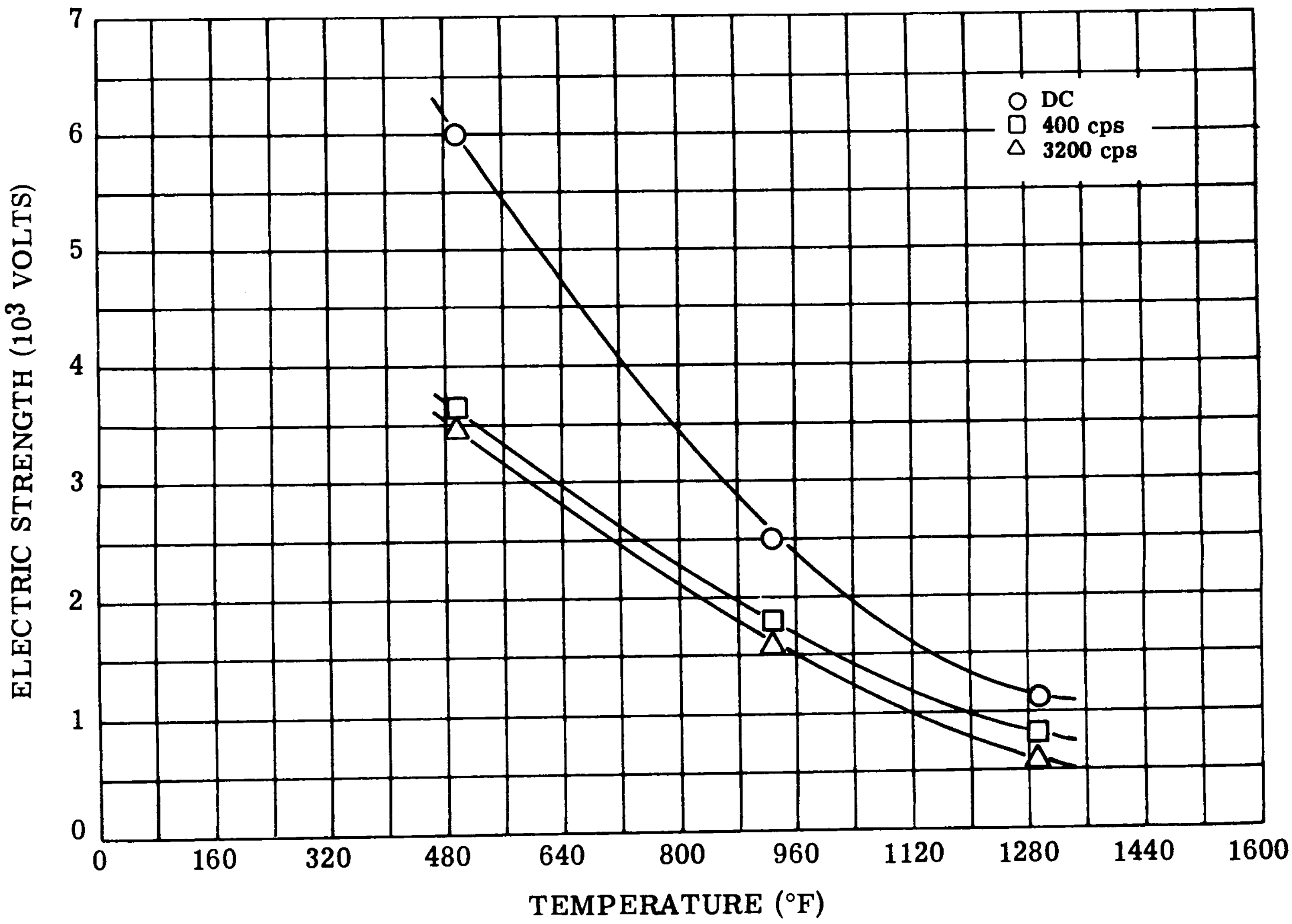


FIGURE V. B. 2-2. Electric Strength of Inorganic Insulated Lead Wire, Mica Glass in Air. Insulation Thickness, 0.020 Inch on Stranded Nickel-Plated Copper Wire, Nineteen Strands of 0.0114 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V. B. 2-2. Electric Strength - Lead Wire - Mica Glass

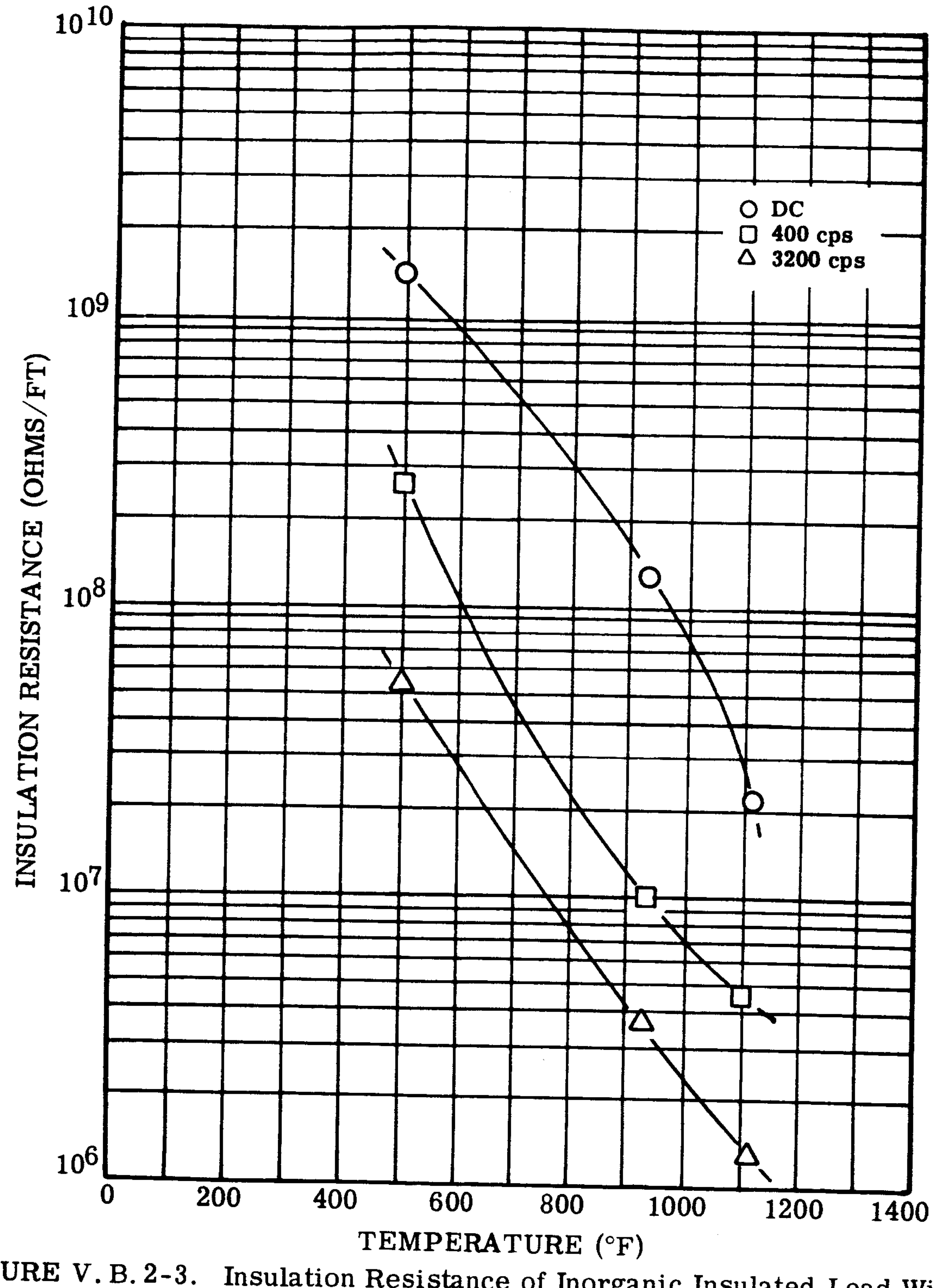


FIGURE V. B. 2-3. Insulation Resistance of Inorganic Insulated Lead Wire, Mica Glass, in Air. Insulation Thickness, 0.020 Inch on Stranded Nickel-Plated Copper Wire, Nineteen Strands of 0.0114 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V. B. 2-3. Insulation Resistance - Lead Wire - Mica Glass

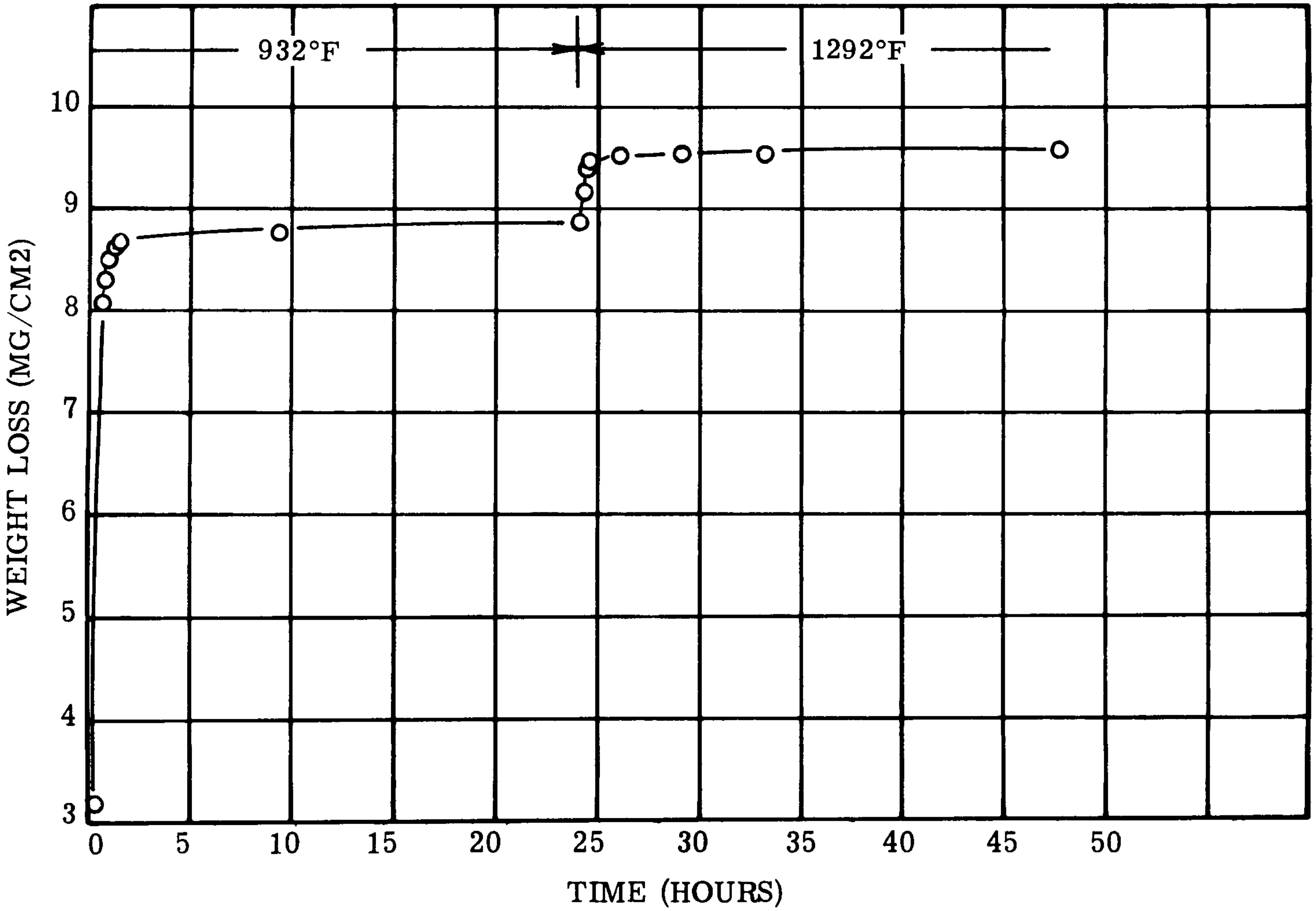


FIGURE V. B. 2-4. Weight Loss at 932°F and 1292°F at 10^{-5} to 10^{-6} Torr, of Inorganic Insulated Lead Wire, Mica Glass. Insulation Thickness, 0.020 Inch on Stranded Nickel-Plated Copper Wire, Nineteen Strands of 0.0114 Inch Diameter Each. (Reference: NAS 3-4162)

Figure V.B.2-4. Weight Loss - Lead Wire - Mica Glass

C. SHEET INSULATION, FLEXIBLE

1. POLYIMIDE FILM FLEXIBLE SHEET INSULATION

Polyimide film (H-Film) is used as primary slot insulation and as a conductor wrapping material. It has good chemical, thermal, and mechanical properties up to 550°F.

Availability:	Polyimide film insulation is available in several thicknesses from E.I. duPont de Nemours and Company and is identified as H-Film.
Description:	H-Film is a polyimide resin formed by the reaction of a dianhydride with a diamine. It is unsupported by any filler. The material in these tests was 0.002 inch thick.

I. Thermophysical Properties

A. Thermal Conductivity

Specimen Thickness, 0.002 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
214	0.025
355	0.032

B. Density 0.0496 lb/cu in. (LI90)

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.002 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
72	400	3.64
72	3200	3.64
392	400	3.22
392	3200	3.21
482	400	3.23
482	3200	3.23

B. Electric Strength

Specimen Thickness, 0.002 Inch

Temperature (°F)	Frequency (cps)	Volt/mil (average)
75	60	4500
75	400	3162
75	3200	2337
392	60	3412
388	400	2575
394	3200	1587
489	60	2133
489	400	1775
494	3200	1550

C. Insulation Life

Specimen Thickness, 0.002 Inch

300 volts per mil proof test

Temperature (°F)	Hours
392	13,440*
482	7,728*
527	5,717
572	627

*Westinghouse Data

D. Power Factor

Specimen Thickness, 0.002 Inch

Temperature (°F)	Frequency (cps)	Percent
72	400	0.119
392	400	0.143
482	400	0.391
72	3200	0.166
392	3200	0.087
482	3200	0.066

E. Volume Resistivity

Specimen Thickness, 0.002 Inch

Temperature (°F)	Frequency	Resistivity (ohms-cm)
72	DC	5.67×10^{16}
72	400 cps	1.22×10^{12}
72	3200 cps	1.04×10^{11}
392	DC	5.41×10^{13}
392	400 cps	1.10×10^{12}
392	3200 cps	2.07×10^{11}
482	DC	1.37×10^{12}
482	400 cps	3.05×10^{11}
482	3200 cps	2.36×10^{11}

III. Mechanical Properties

A. Abrasion Resistance

Abrasion resistance at 77°F as determined by change in average total electrical strength caused by abrading with CS17F Taber wheel with 500 gram load. The specimen thickness was 0.002 inch.

Unabraded	9000 volts
After 500 cycles	6300 volts
Percent decrease of electric strength	30 percent
After 1000 cycles	6325 volts
Percent decrease in electric strength	29.8 percent
Appearance	dulled surface - no gloss

B. Cut-Through Resistance

No failure in 0.002 inch thick specimens between crossed wire in 45 hours at 500°F under 5.4 pounds pressure and 110 volts.

C. Tensile Strength (77°F)

20,000 psi (LI90)

Specimen Thickness, 0.002 Inch

IV. Compatibility Properties

A. Chemical Resistance

This insulation displays outstanding chemical resistance to organic solvents. Acid resistance is good with the exception of concentrated sulfuric acid which dissolves the resin. Alkaline solutions degrade polyimide resins in varying degrees, depending upon concentration. It is recommended that alkaline exposure be avoided. Moisture resistance is fair to good.

B. Nuclear Radiation Resistance

(LI296)
(RI609)

Polyimide resin is one of the most radiation resistant polymers known. When tested as a film, it showed good retention of tensile strength and excellent stability to radiation both in air and in vacuum. After exposure to 3 x 10^{10} ergs per gram (C) in air, the tensile strength value dropped only from 19,470 psi to 17,903 psi. Exposure to the same radiation level in vacuum resulted in a tensile strength of 18,877 psi. The original elongation value of 128 percent decreased as a result of the irradiation in air to 83 percent and in the vacuum environment to 103 percent.

Some additional detailed exposure data is presented in Section V. C. 2 on Polyimide-Glass system.

C. Vacuum Weight Loss at elevated temperature

26 hours at 482°F and 10^{-5} to 10^{-6} torr	0.66 percent

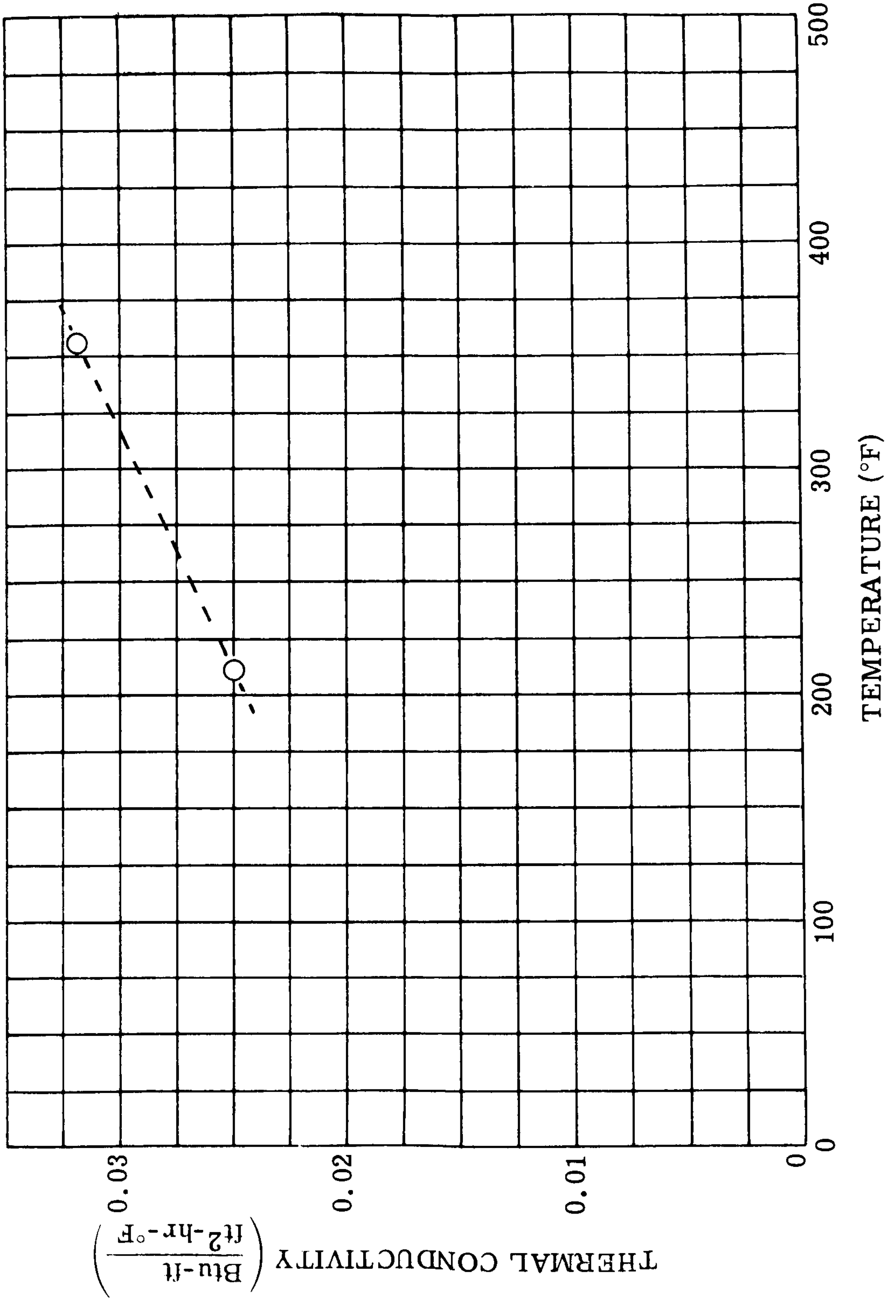


FIGURE V.C.1-1. Thermal Conductivity of Flexible Sheet Insulation, Polyimide Film, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS3-4162)

Figure V.C.1-1. Thermal Conductivity - Flexible Sheet - Polyimide Film

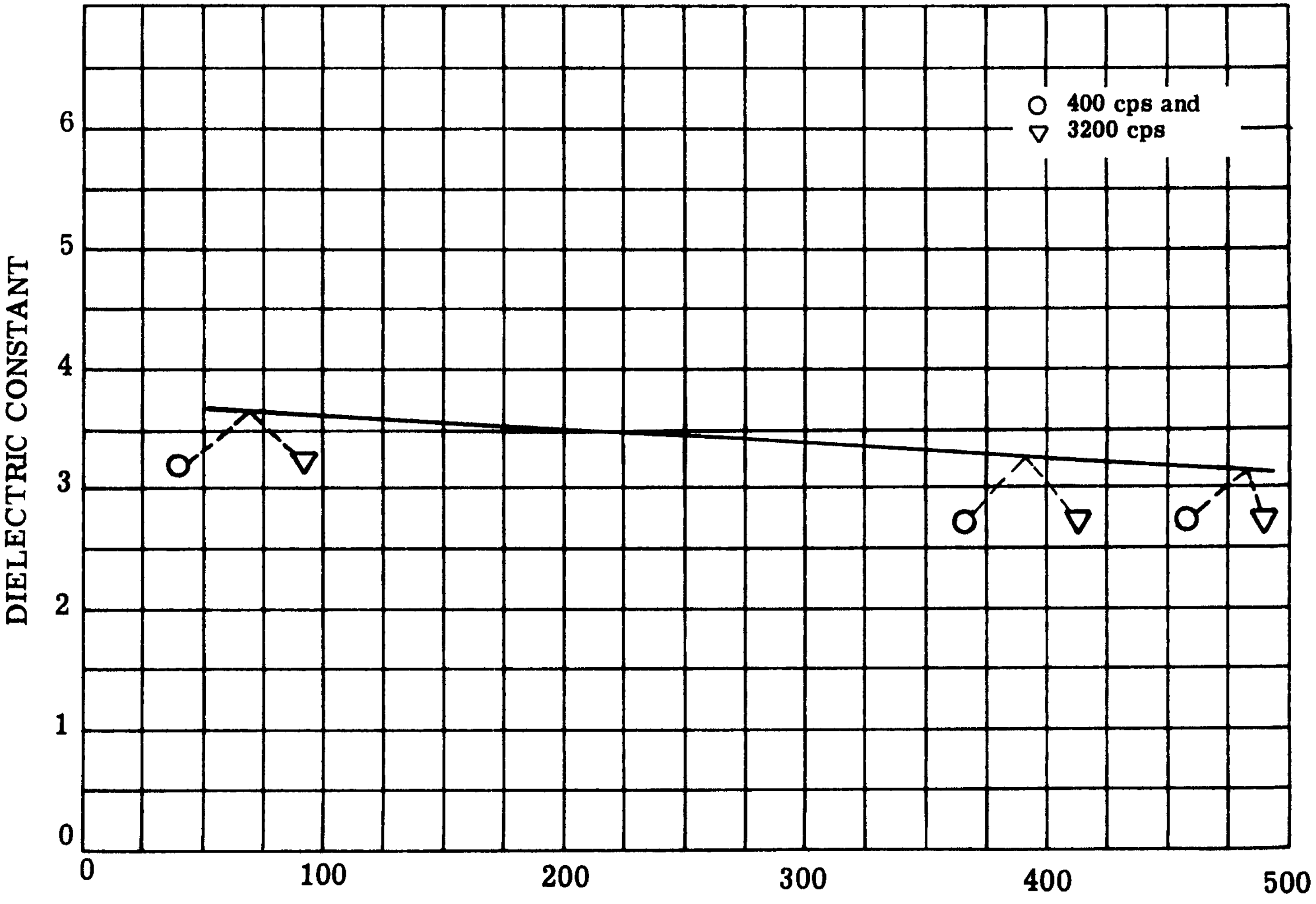


FIGURE V.C.1-2. Dielectric Constant Flexible Sheet Insulation, Polyimide Film, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V.C.1-2. Dielectric Constant - Flexible Sheet - Polyimide Film

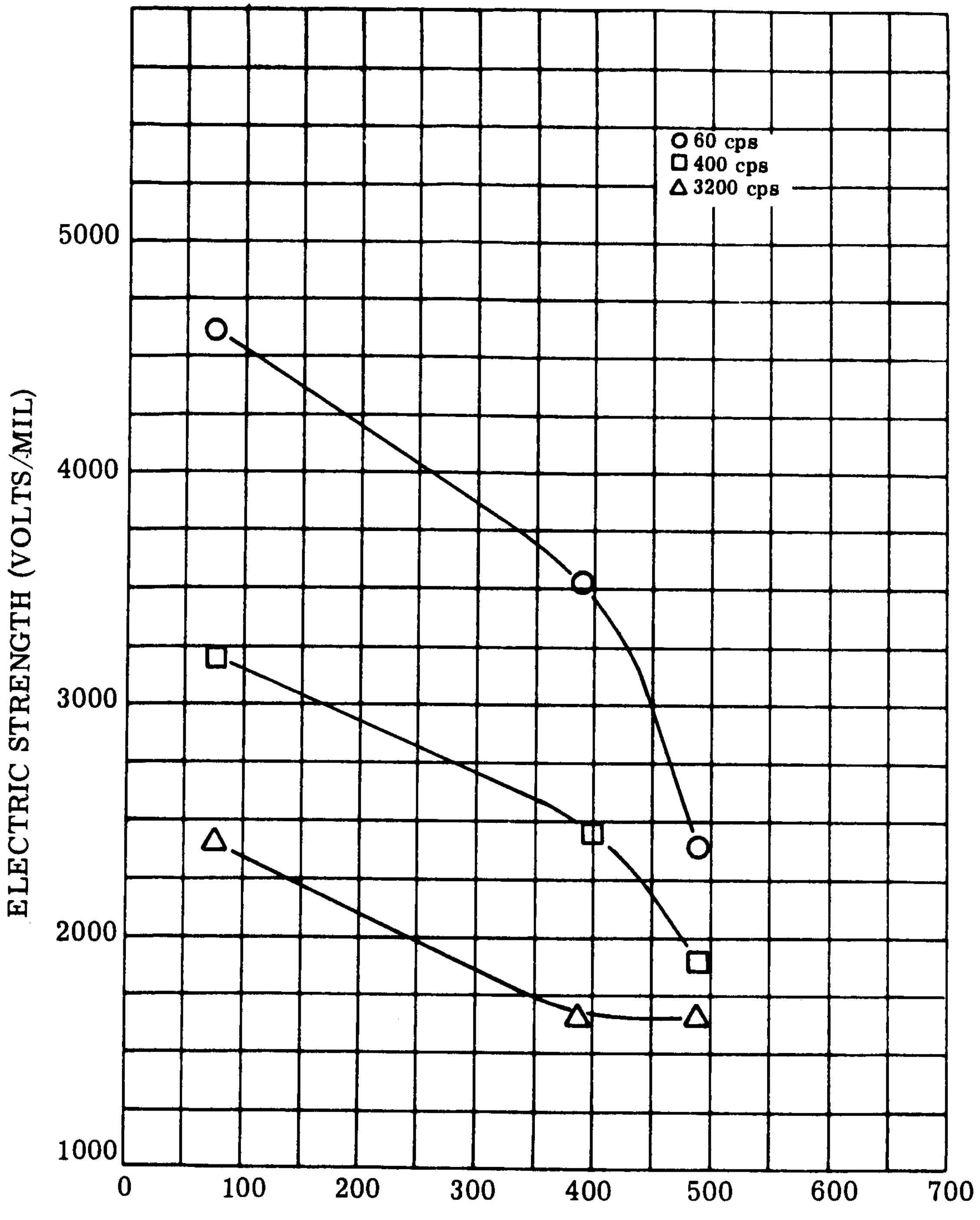


FIGURE V. C. 1-3. Electric Strength Flexible Sheet Insulation, Polyimide Film, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V. C. 1-3. Electric Strength - Flexible Sheet - Polyimide Film

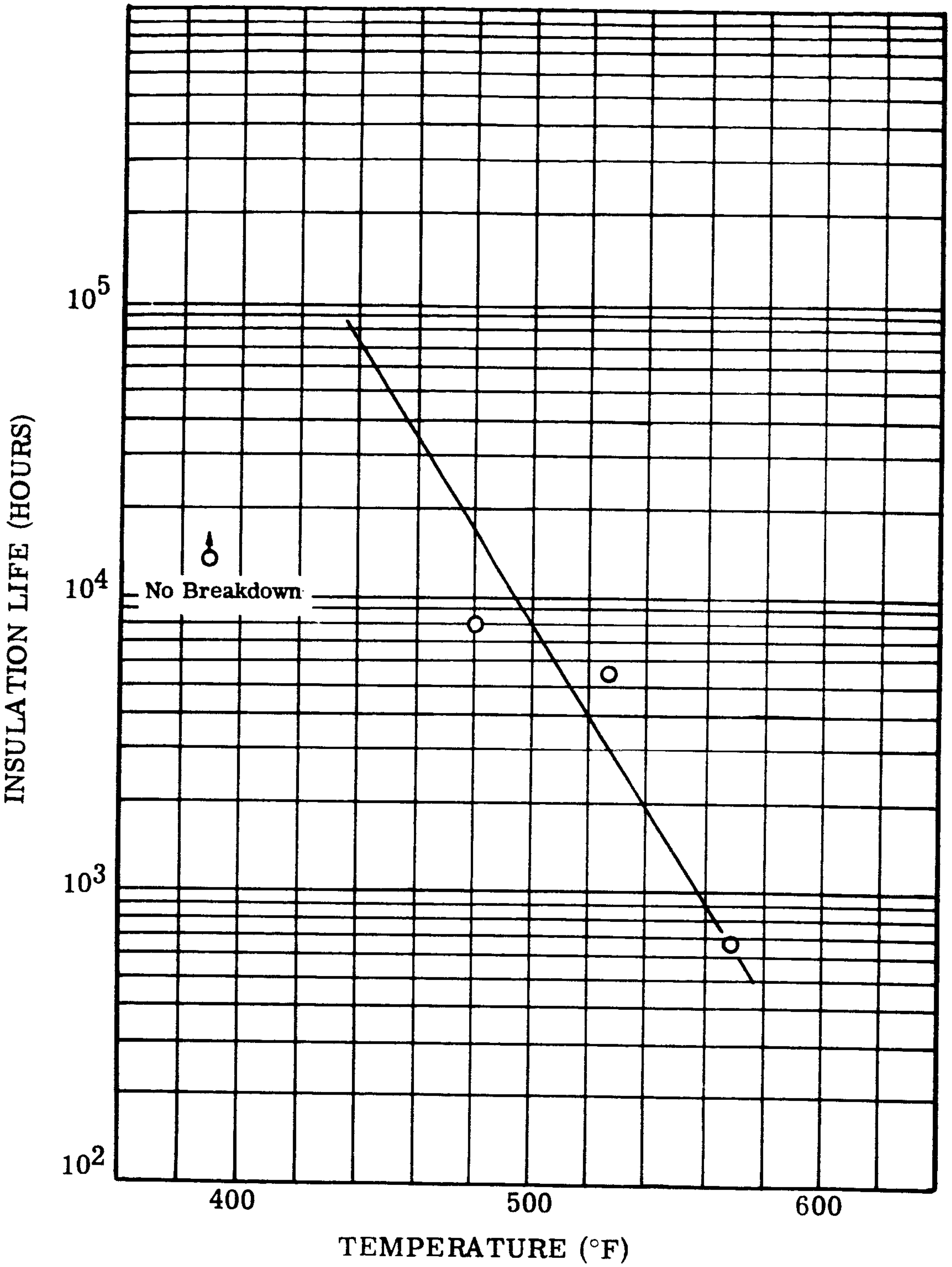


FIGURE V.C.1-4. Insulation Life of Flexible Sheet Insulation Polyimide Film-300 Volts Per Mil Proof with Curved Electrode, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V.C.1-4. Insulation Life - Flexible Sheet - Polyimide Film

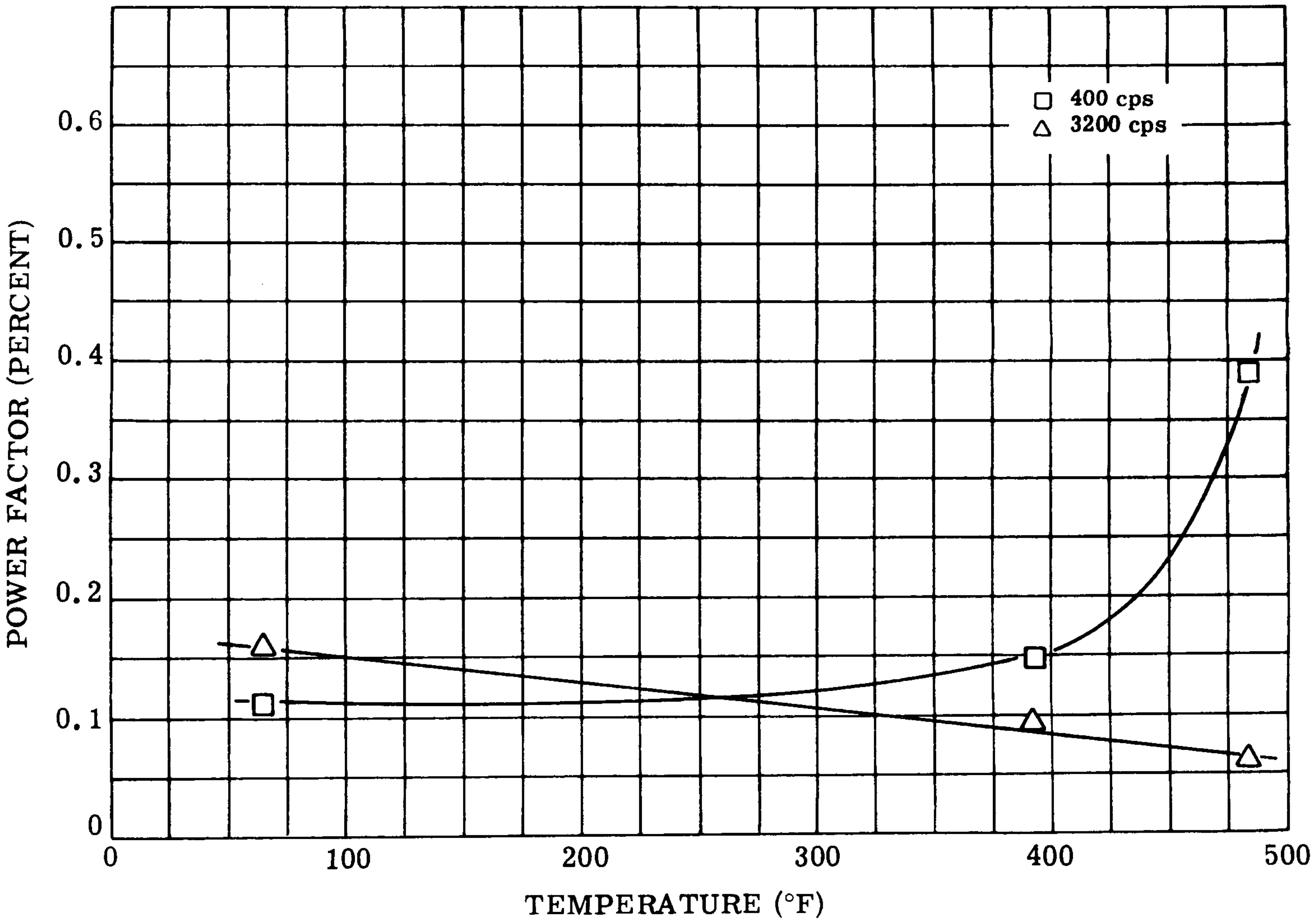


FIGURE V. C. 1-5. Power Factor of Flexible Sheet Insulation, Polyimide Film, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V. C. 1-5. Power Factor - Flexible Sheet - Polyimide Film

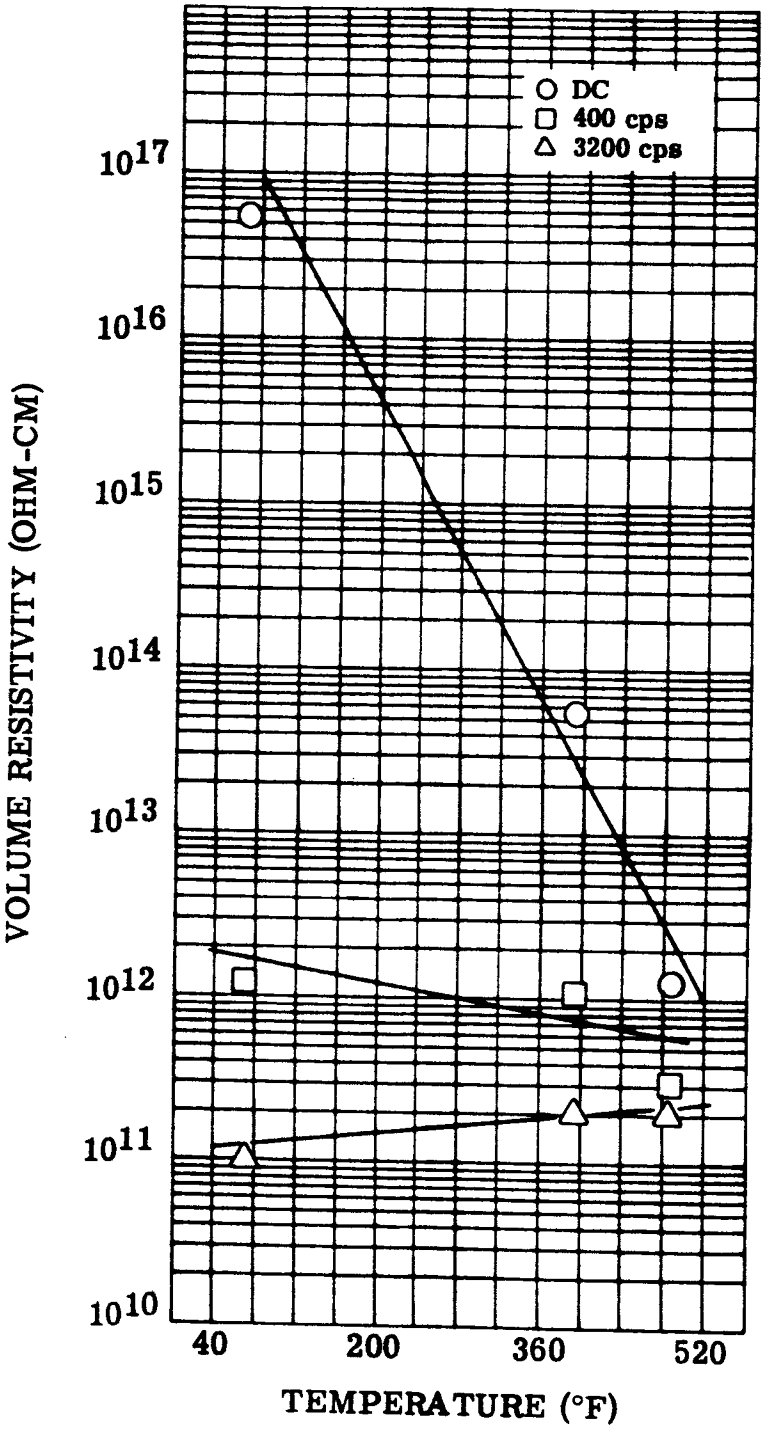


FIGURE V. C. 1-6. Volume Resistivity of Flexible Sheet Insulation, Polyimide Film, in Air. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V. C. 1-6. Volume Resistivity - Flexible Sheet - Polyimide Film

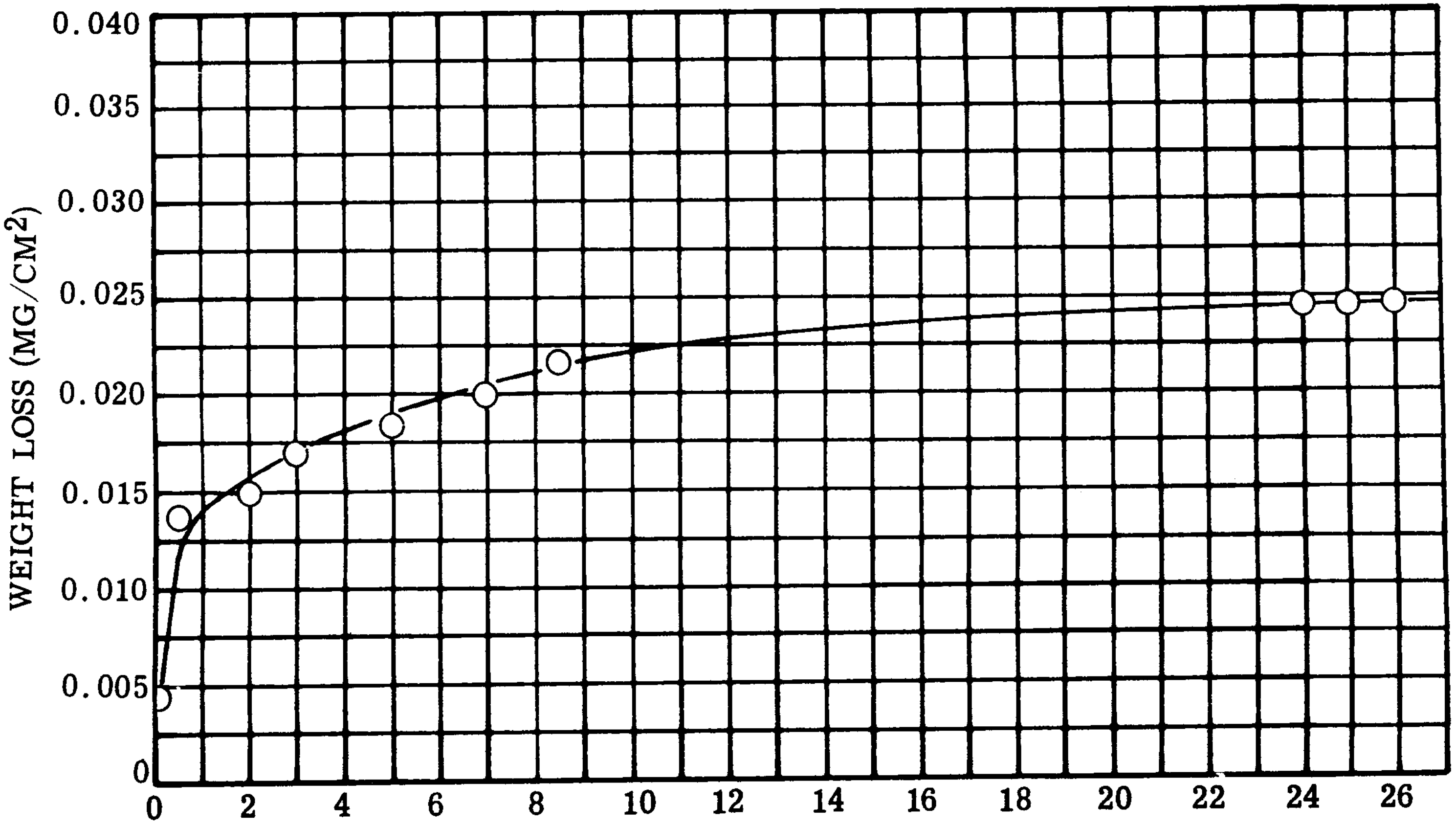


FIGURE V.C. 1-7. Weight Loss at 482°F and 10^{-5} to 10^{-6} Torr, of Flexible Sheet Insulation, Polyimide Film. Specimen Thickness, 0.002 Inch. (Reference: NAS 3-4162)

Figure V.C. 1-7. Weight Loss - Flexible Sheet - Polyimide Film

2. POLYIMIDE-GLASS, FLEXIBLE SHEET INSULATION - PYRE-ML, GRADES 6508 AND 6518

Two grades of polyimide treated glass fabric are described in this summary. The grade 6518 was introduced in an effort by the manufacturer to improve tear strength and flexibility and has been useful in aircraft stator winding operations.

Availability:	Polyimide treated glass fabric (Pyre-ML) is available in a range of thicknesses and grades from E.I. duPont de Nemours and Company.
Description:	Pyre-ML is composed of E-glass-fiber-cloth, treated with multiple applications of the polyimide resin (ML). In grade 6508, the fibers are well wetted by the resin during impregnation and curing, producing a dense sheet material. The fibers in grade 6518 are not completely penetrated and wetted during the resin treatment. This modified material is a more flexible product. When 6518 is creased, fewer glass fibers are broken than in 6508. This reduced breakage is beneficial to quality of wound apparatus.

I. Thermophysical Properties

A. Thermal Conductivity

Specimen Thickness for Grade 6518, 0.010 Inch Thick

Temperature (°F)	Grade 6508	Grade 6518
239	-	$0.026 \frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
514	-	$0.056 \frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Temperature (°F)	Frequency (cps)	Grade 6508	Grade 6518
72	400	4.87	4.03
72	3200	4.86	4.41
392	400	4.56	3.87
392	3200	4.54	4.03
482	400	4.66	3.98
482	3200	4.63	3.96

B. Electric Strength

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Temperature (°F)	Frequency (cps)	Grade 6508 Volts/mil (avg)	Grade 6518 Volts/mil (avg)
72	60	710	650
72	400	639	548
72	3200	551	491
392	60	748	653
392	400	632	561
392	3200	515	492
482	60	751	647
482	400	637	593
482	3200	466	455

C. Insulation Life

300 volts per mil proof test

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Temperature (°F)	Grade 6508 (hours)	Grade 6518 (hours)
428	13,000*	-
482	8,300	-
528	4,300	-
572	420	-

*No failures - tests were discontinued.

D. Power Factor

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Temperature (°F)	Frequency (cps)	Grade 6508 (percent)	Grade 6518 (percent)
72	400	0.180	0.120
72	3200	0.204	0.146
392	400	0.484	0.354
392	3200	0.430	0.228
482	400	0.846	0.686
482	3200	0.506	0.309

E. Volume Resistivity

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Temperature (°F)	Frequency	Grade 6508 (ohm-cm)	Grade 6518 (ohm-cm)
72	DC	6.98×10^{14}	6.73×10^{15}
72	400 cps	5.20×10^{11}	9.33×10^{11}
72	3200 cps	5.85×10^{10}	9.40×10^{10}
392	DC	7.52×10^{12}	3.19×10^{13}
392	400 cps	2.10×10^{11}	3.55×10^{11}
392	3200 cps	2.92×10^{10}	6.23×10^{10}
482	DC	1.08×10^{12}	1.74×10^{12}
482	400 cps	1.14×10^{11}	1.65×10^{11}
482	3200 cps	2.38×10^{10}	4.56×10^{10}

III. Mechanical Properties

A. Abrasion Resistance

Abrasion resistance at 77°F as determined by change in average total electrical strength caused by abrading with CS17F Taber wheel with no additional weight.

Specimen Thickness for Grade 6508, 0.010 Inch Thick
Specimen Thickness for Grade 6518, 0.011 Inch Thick

Condition	Grade 6508 Electric Strength (volts)	Grade 6518 Electric Strength (volts)
Unabraded	7450	6539
After 500 cycles	4075	4388
Percent decrease in electrical strength	45.3 percent	32.9 percent
Appearance	Severe peeling of resin film - no apparent damage.	Some scuffing and film detachment.

B. Cut-Through Resistance

No failure in specimens between crossed wires in 25 hours at 500°F under 5.4 pounds pressure and 110 volts.

C. Tensile Strength

Grade 6508 (0.010 inch thick)	338 lb/in width
Grade 6518 (0.011 inch thick)	138 lb/in width

IV. Compatibility

A. Chemical Resistance (Grades 6508 and 6518)

This insulation displays outstanding chemical resistance to organic solvents. Acid resistance is good with the exception of concentrated sulfuric acid which dissolves ML. Alkaline solutions degrade ML in varying degrees, depending upon concentration. It is recommended that alkaline exposure of polyimide resin systems be avoided. Moisture resistance is fair to good. (Reference: duPont Electrical Insulation Products Technical Bulletin No. 6 and Westinghouse Test Data.)

B. Nuclear Radiation Resistance

Pyre-ML coated fabrics have shown good resistance to ionizing radiation. This table shows the effect of various dosages of 2 Mev electrons on the electrical properties of the 4 mil coated product. (Reference: duPont Electrical Insulation Products Technical Bulletin No. 6.)

Dosage (Megarads)	0	1000	2000	3000
Dissipation Factor at 10^3 cps	0.0062	0.0310	0.0259	0.0388
Dielectric Constant at 10^3 cps	3.5	3.4	3.9	4.2
Volume Resistivity (Ohm-cm)	6.5×10^{14}	5.8×10^{14}	5.3×10^{14}	3.1×10^{14}
Electric Strength (Volts/mil)	1700	1610	1720	1695

Motorettes which were made with a complete Pyre-ML insulation system appeared unchanged after exposure to similar dosages of gamma ray at 1.33 and 1.17 Mev in a cobalt garden. About 500 hours exposure were required for 3000 megarads dosage. Voltage breakdowns of these motorettes unexposed and after exposure were as follows:

Dosage (Megarads)	0	1000	2000	3000
Dielectric Strength (Volts/mil)	1460	1280	900	1350

C. Vacuum Weight Loss at elevated temperature (Grade 6508)

24 hours at 482°F and 10^{-5} to 10^{-6} torr 0.28 percent

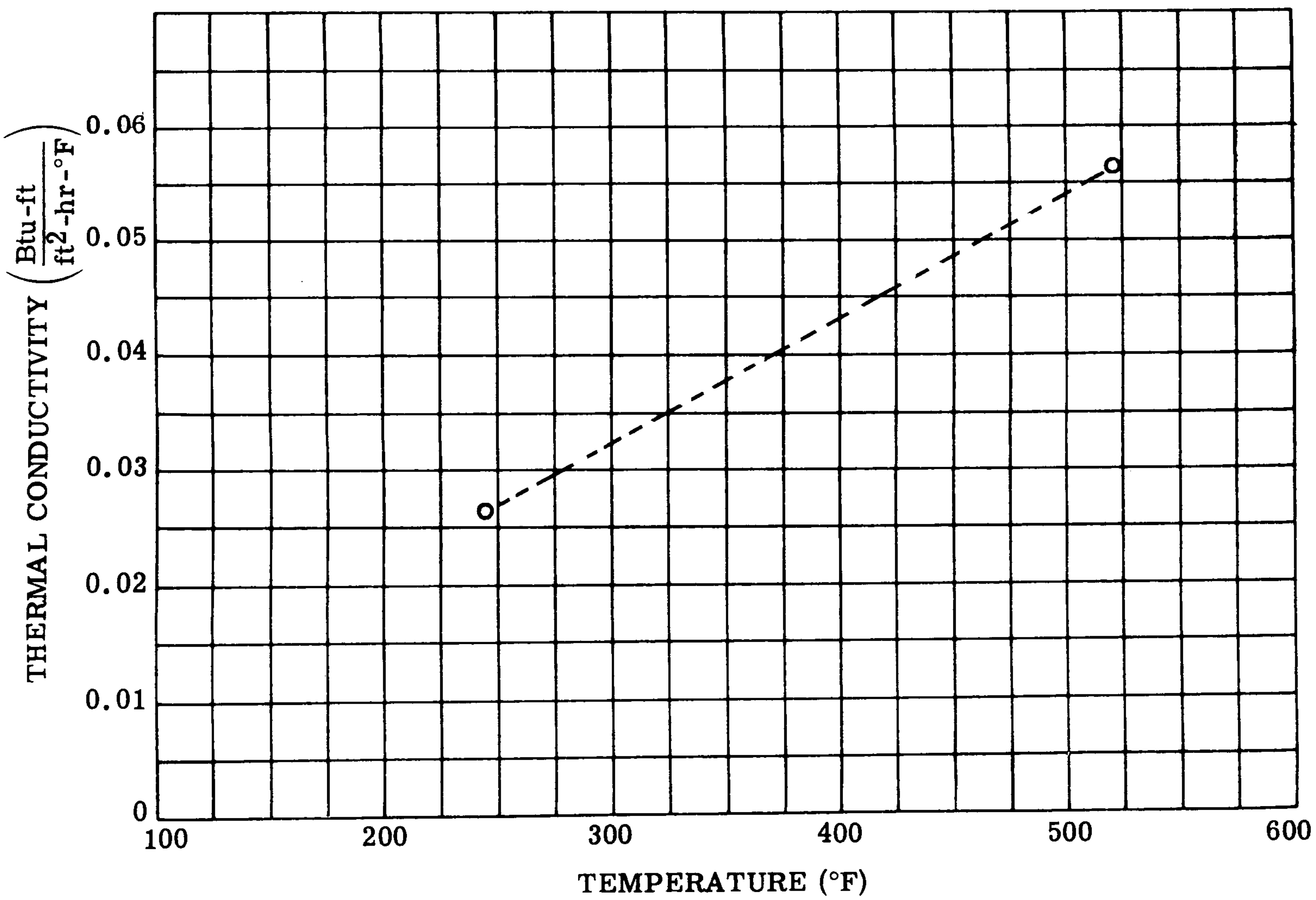


FIGURE V.C.2-1. Thermal Conductivity of Organic Flexible Sheet Insulation, Polyimide Glass, Grade 6518, in Air. Specimen Thickness, 0.011 Inch. (Reference: NAS 3-4162)

Figure V.C.2-1. Thermal Conductivity - Flexible Sheet - Polyimide Glass

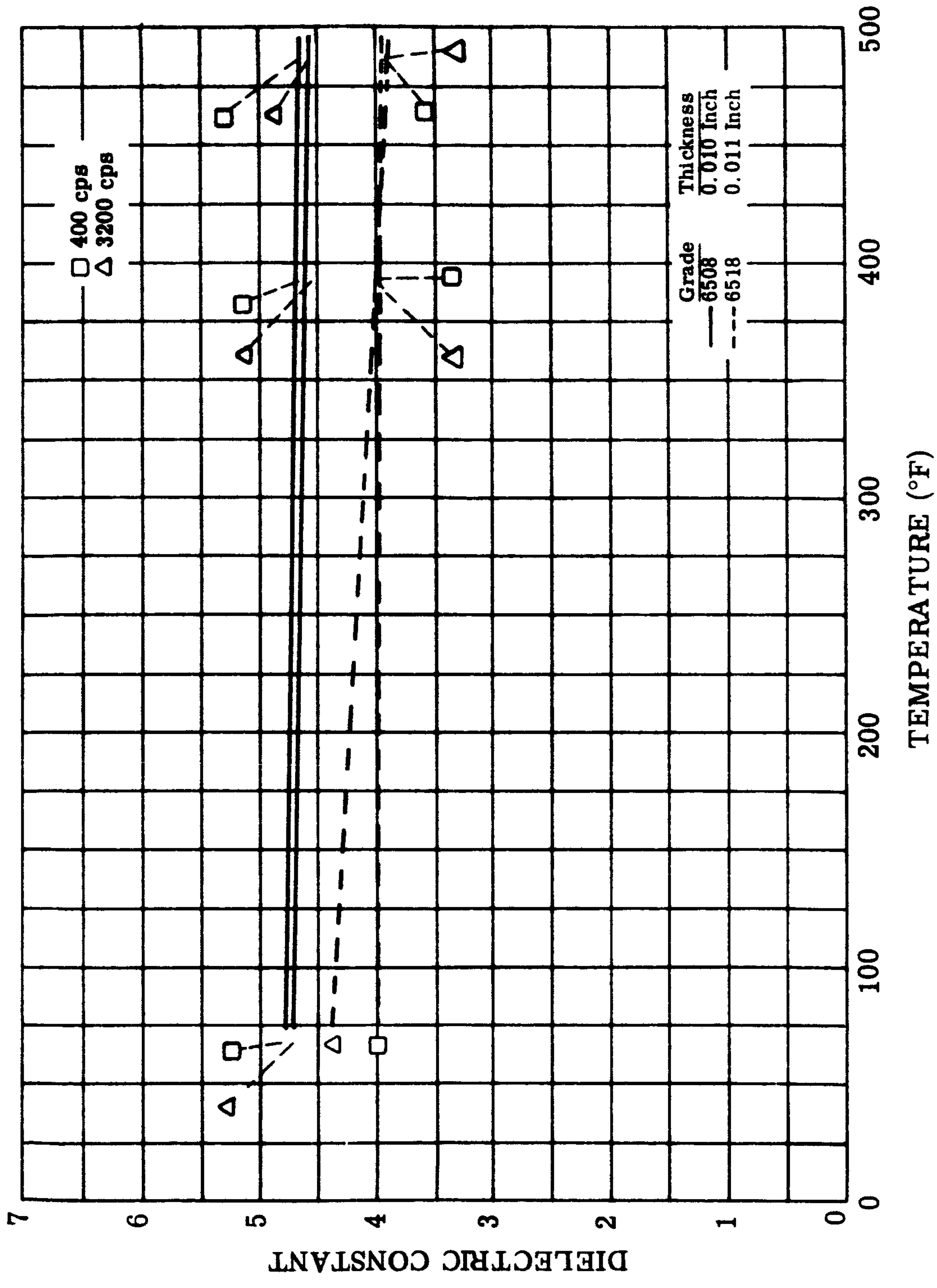


FIGURE V.C.2-2. Dielectric Constant of Organic Flexible Sheet Insulation, Polyimide Glass, in Air. (Reference: NAS 3-4162)

Figure V.C.2-2. Dielectric Constant - Flexible Sheet - Polyimide Glass

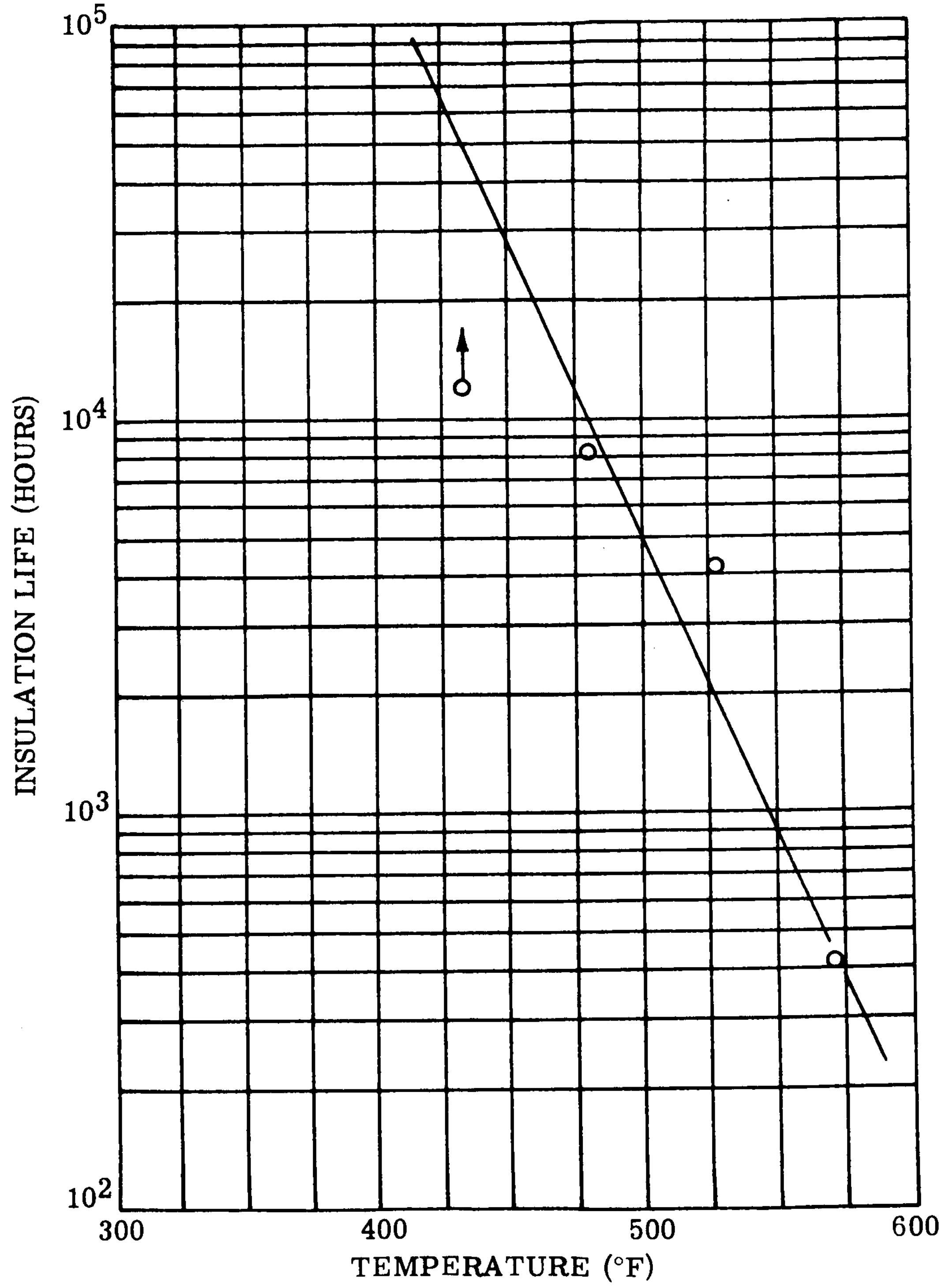


FIGURE V.C.2-3. Insulation Life of Sheet Insulation - Flexible Polyimide Glass - Grade 6508 - 300 Volts Per Mil Proof Test, in Air. Specimen Thickness, 0.010 Inch. (Reference: NAS 3-4162)

Figure V.C.2-3. Insulation Life - Flexible Sheet - Polyimide Glass

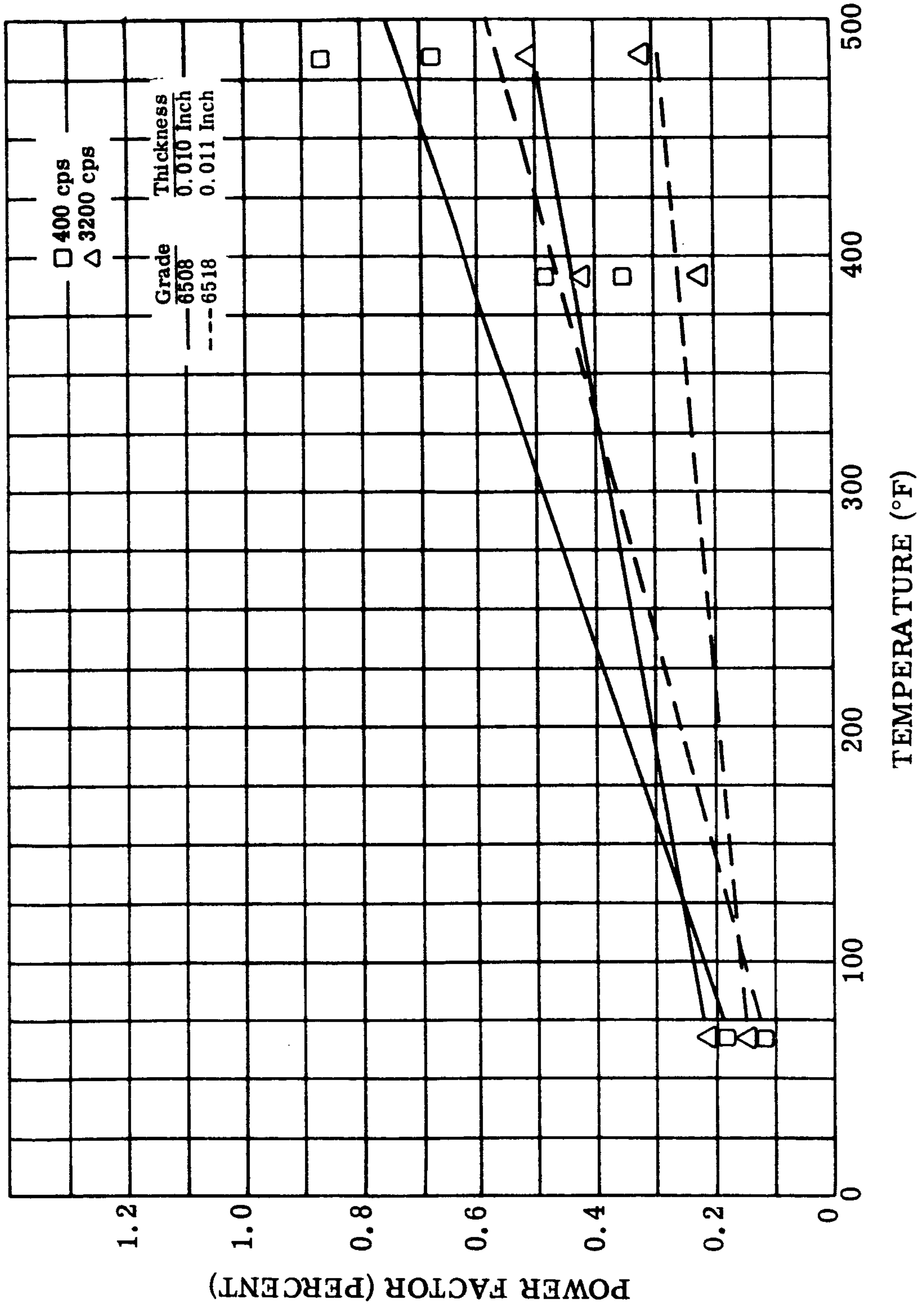


FIGURE V.C.2-4. Power Factor of Organic Flexible Sheet Insulation, Polyimide Glass, in Air. (Reference: NAS3-4162)

Figure V.C.2-4. Power Factor - Flexible Sheet - Polyimide Glass

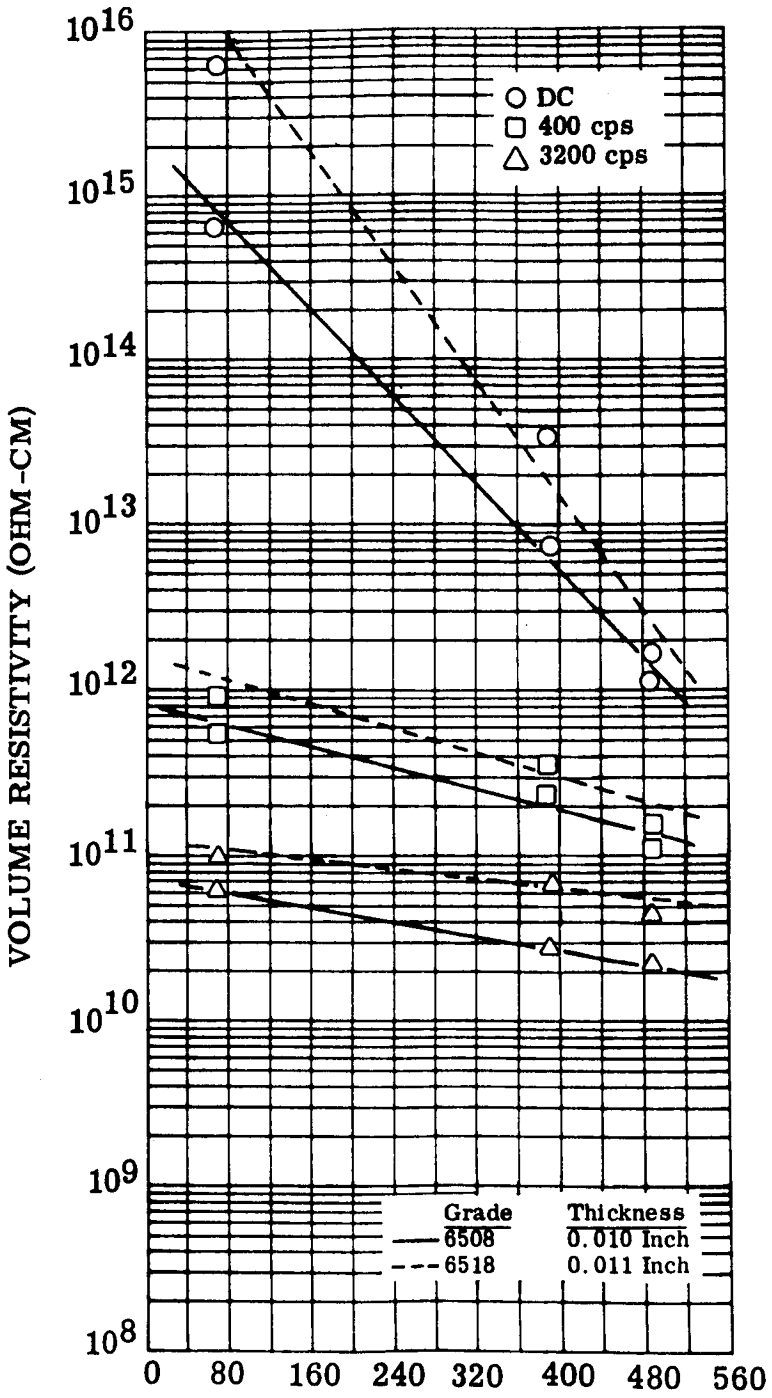


FIGURE V.C.2-5. Volume Resistivity of Organic Flexible Sheet Insulation, Polyimide Glass, in Air. (Reference: NAS 3-4162)

Figure V.C.2-5. Volume Resistivity - Flexible Sheet - Polyimide Glass

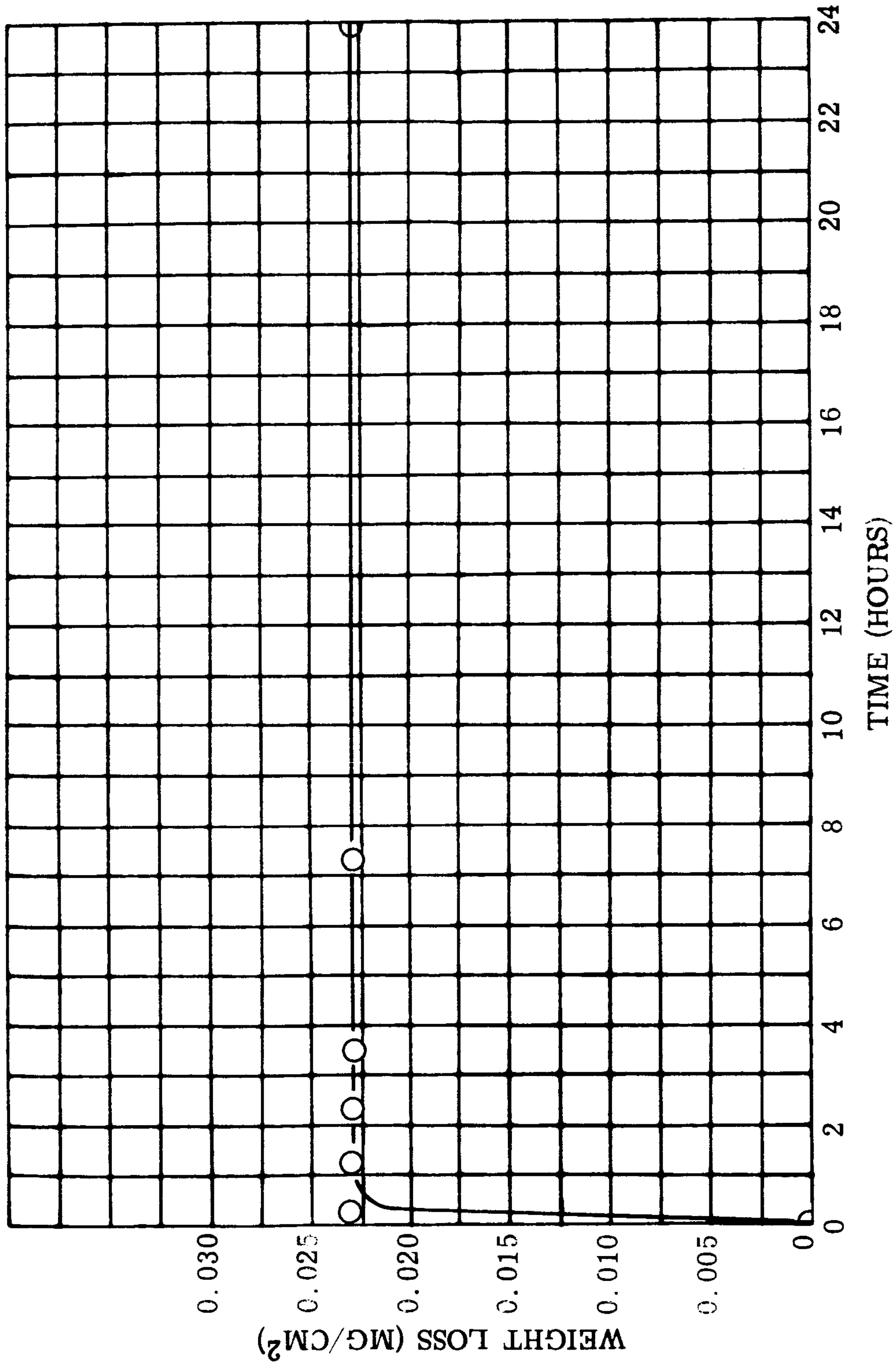


FIGURE V.C.2-6. Weight Loss of Organic Flexible Sheet Insulation, Polyimide Glass, Grade 6508 at 482°F, 10^{-5} to 10^{-6} Torr. Specimen Thickness, 0.010 Inch. (Reference: NAS 3-4162)

Figure V.C.2-6. Weight Loss - Flexible Sheet - Polyimide Glass

3. MICA-GLASS, SILICONE RESIN BONDED FLEXIBLE SHEET INSULATION

This insulation is a glass-cloth-backed phlogopite mica paper bonded with silicone varnish. It is recommended for use up to 1000°F. It is also resistant to hard vacuum and nuclear radiation. This material is recommended where flexibility and tear strength are required.

Availability:	This insulation is available in development quantities from the insulation department of Westinghouse Electric Corporation, Research and Development Center, in thicknesses of 4 and 7 mils.
Description:	This material is composed of phlogopite mica paper, E-glass cloth and a silicone varnish, Dow Corning DC997, and is 0.0045 inch thick. The paper is identified as 2.8 mil integrated mica paper, produced by Macallen Co.

I. Thermophysical Properties

A. Thermal Conductivity

Specimen Thickness, 0.0045 Inch Thick

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
479	0.032
950	0.035
1267	0.012

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.0045 Inch Thick

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	5.5
500	3200	6.2

Temperature (°F)	Frequency (cps)	Dielectric Constant
932	400	7.1
932	3200	6.2
1292	400	6.5
1292	3200	3.4

B. Electric Strength (Rate of rise - 500 volts/second).

Specimen Thickness, 0.0045 Inch Thick

Temperature (°F)	Frequency	Volts/mil
500	DC	407
500	400 cps	177
500	3200 cps	370
932	DC	156
932	400 cps	195
932	3200 cps	300
1292	DC	141
1292	400 cps	126
1292	3200 cps	166

C. Insulation Life

Specimen Thickness, 0.0045 Inch Thick

725 volts, 60 cycles proof test after aging, 5 samples per test.

Temperature (°F)	Hours	Number of Samples Passed
932	200	4
932	1000	3
1292	200	0

D. Power Factor

Specimen Thickness, 0.0045 Inch Thick

Temperature (°F)	Frequency (cps)	Percent
500	400	4.5
500	3200	3.6
932	400	22.4
932	3200	9.5
1292	400	85.5
1292	3200	57.4

E. Volume Resistivity

Specimen Thickness, 0.0045 Inch Thick

Temperature (°F)	Frequency	Ohm-cm
500	DC	3.4×10^{12}
500	400 cps	1.9×10^{10}
500	3200 cps	2.6×10^{9}
932	DC	2.1×10^{10}
932	400 cps	2.9×10^{9}
932	3200 cps	1.0×10^{9}
1292	DC	9.8×10^{8}
1292	400 cps	4.1×10^{8}
1292	3200 cps	2.4×10^{8}

III. Mechanical Properties

A. Abrasion Resistance

Abrasion resistance at 77°F as determined by change in average total electrical strength caused by abrading with CS17F Taber wheel with 500 gram load. The specimen thickness was 0.0045 inch.

Condition	Electrical Strength
Unabraded	1730 volts
After 500 cycles	650 volts
Percent decrease of electric strength	62 percent

B. Cut-Through Resistance

Specimens 0.0045 Inch Thick

Cut-through resistance was determined using constant pressure of approximately 300 psi, applied through a 0.040 inch diameter steel ball. Amount of damage was to be rated by relative current leakage values at varied temperatures and electrical potentials. The data was not consistent or meaningful and thus not worthy of inclusion in this report.

C. Tensile Strength (77°F)

3.7 mils thick	33.4 lb/in width

IV. Compatibility Properties

A. Chemical Resistance

In the unfired condition as it is applied, this sheet insulation has good moisture resistance and poor solvent resistance. During firing at 900°F, all resinous material is driven off, leaving inorganic insulating material in the desired shape. Further forming is not recommended because of the inflexible nature of the mica glass composite.

B. Nuclear Radiation Resistance

The combination of glass and mica does not encounter serious damage until exposed to a level of about 10^{10} ergs per gram (C) and 10^{17} fast neutrons/cm^2. The borosilicate glass is the most sensitive material here. (LI296)

C. Vacuum Weight Loss at elevated temperature

1. 22.5 hours at 932°F	0.26 percent
2. 22.5 hours at 932°F and 38 hours at 1112°F	0.47 percent

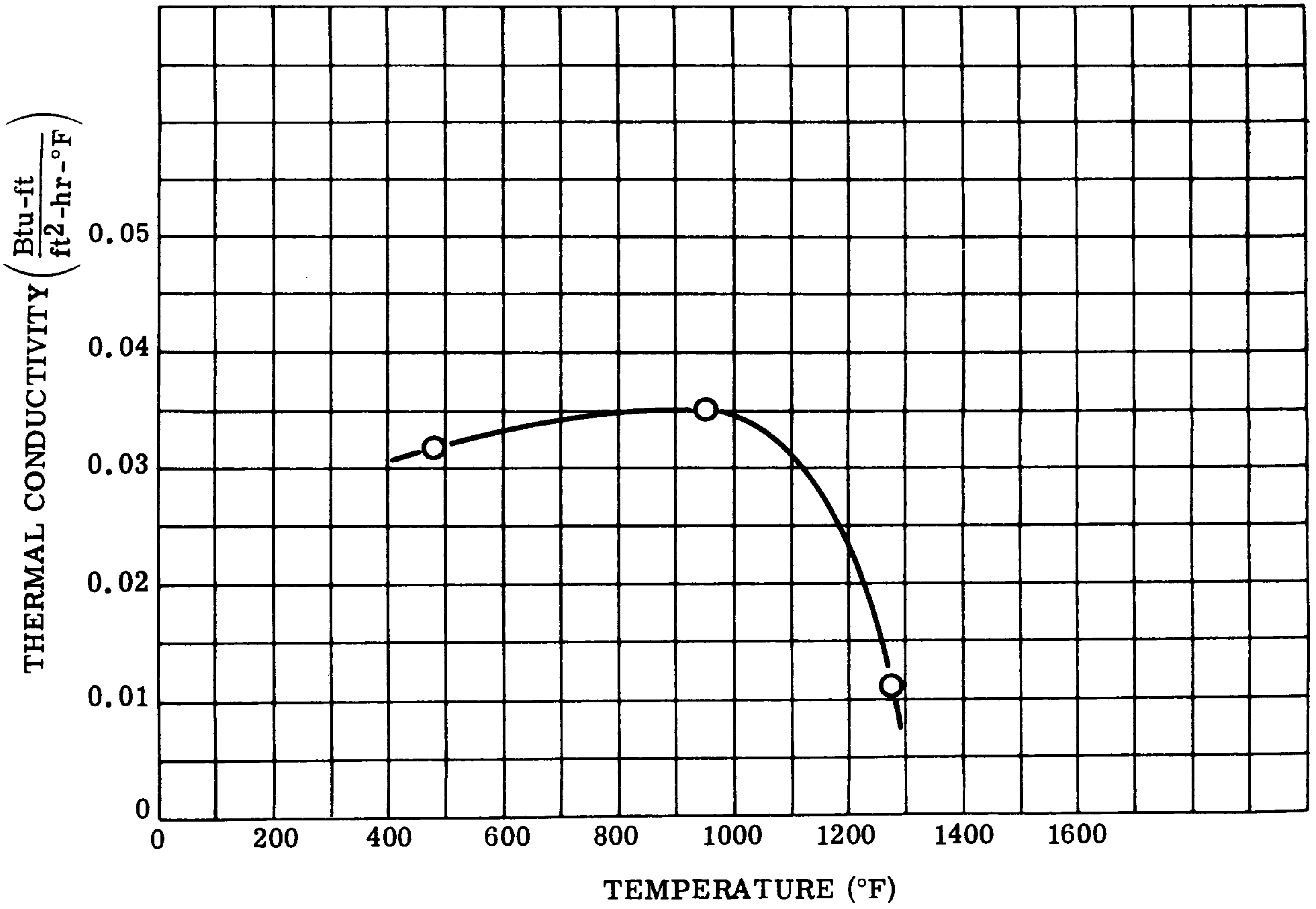


FIGURE V.C.3-1. Thermal Conductivity of Inorganic Flexible Sheet Insulation, Mica Glass Silicone Bonded, in Air. Specimen Thickness, 0.0045 Inch. (Reference: NAS 3-4162)

Figure V.C.3-1. Thermal Conductivity - Flexible Sheet - Mica Glass

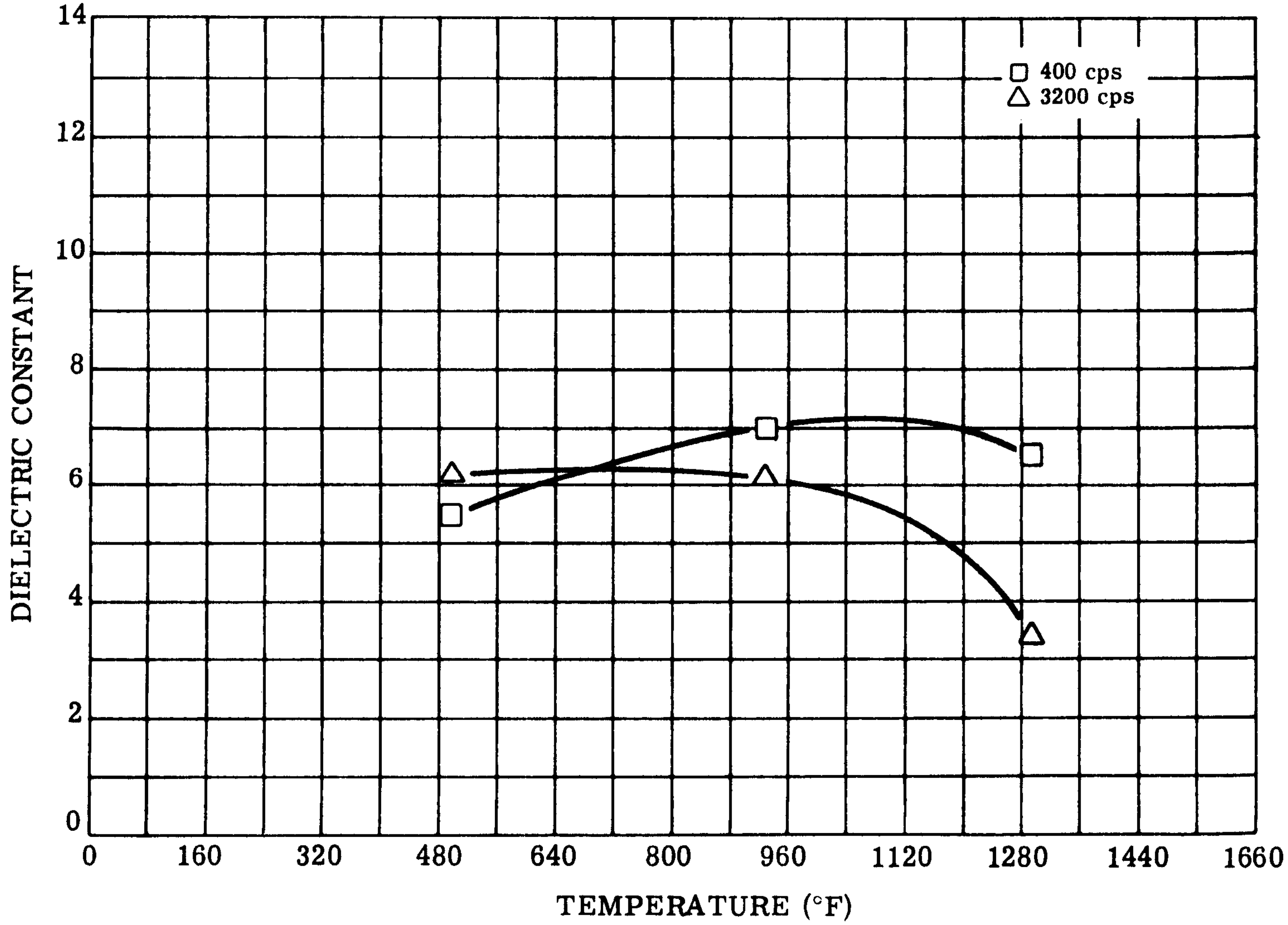


FIGURE V. C. 3-2. Dielectric Constant of Inorganic Flexible Sheet Insulation, Mica Glass, Silicone Bonded, in Air. Specimen Thickness, 0.0045 Inch. (Reference: NAS 3-4162)

Figure V.C.3-2. Dielectric Constant - Flexible Sheet - Mica Glass

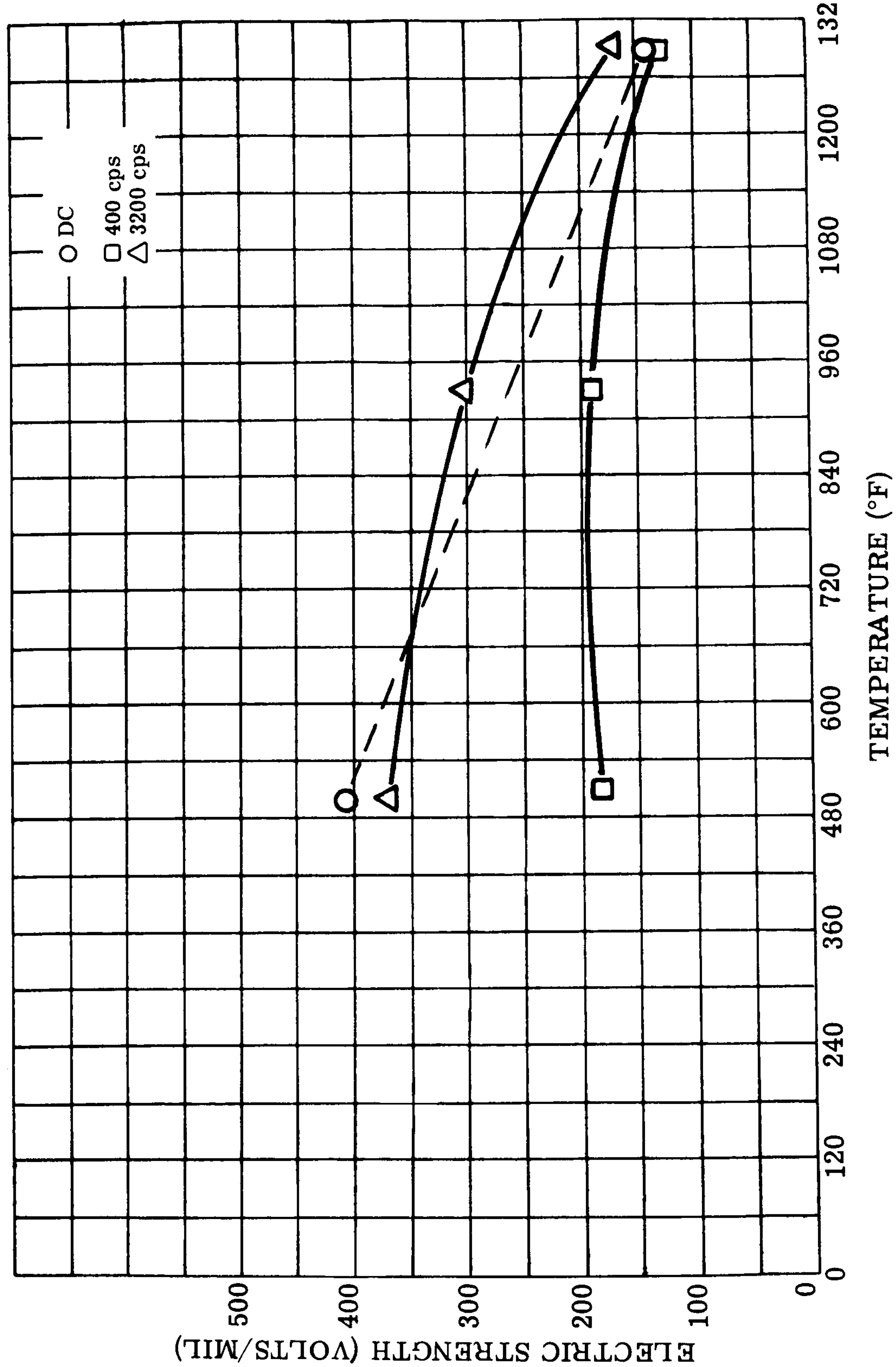


FIGURE V.C.3-3. Electric Strength of Inorganic Flexible Sheet Insulation, Mica Glass Silicone Bonded, in Air. Specimen Thickness, 0.0045 Inch. (Reference: NAS 3-4162)

Figure V.C.3-3. Electric Strength - Flexible Sheet - Mica Glass

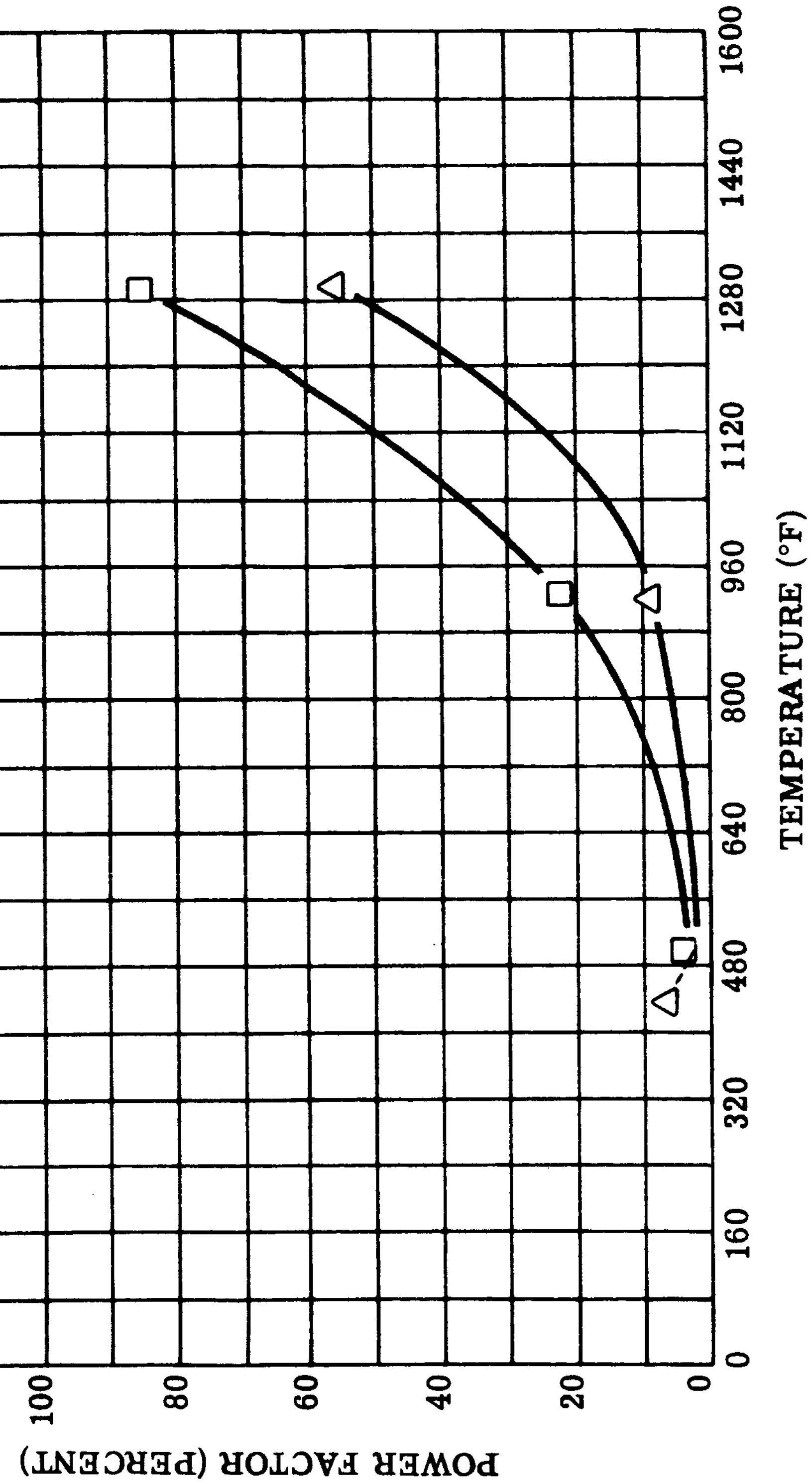


FIGURE V.C.3-4. Power Factor of Inorganic Flexible Sheet Insulation, Mica Glass Silicone Bonded, in Air. Specimen Thickness, 0.004 Inch. (Reference: NAS3-4162)

Figure V.C.3-4. Power Factor - Flexible Sheet - Mica Glass

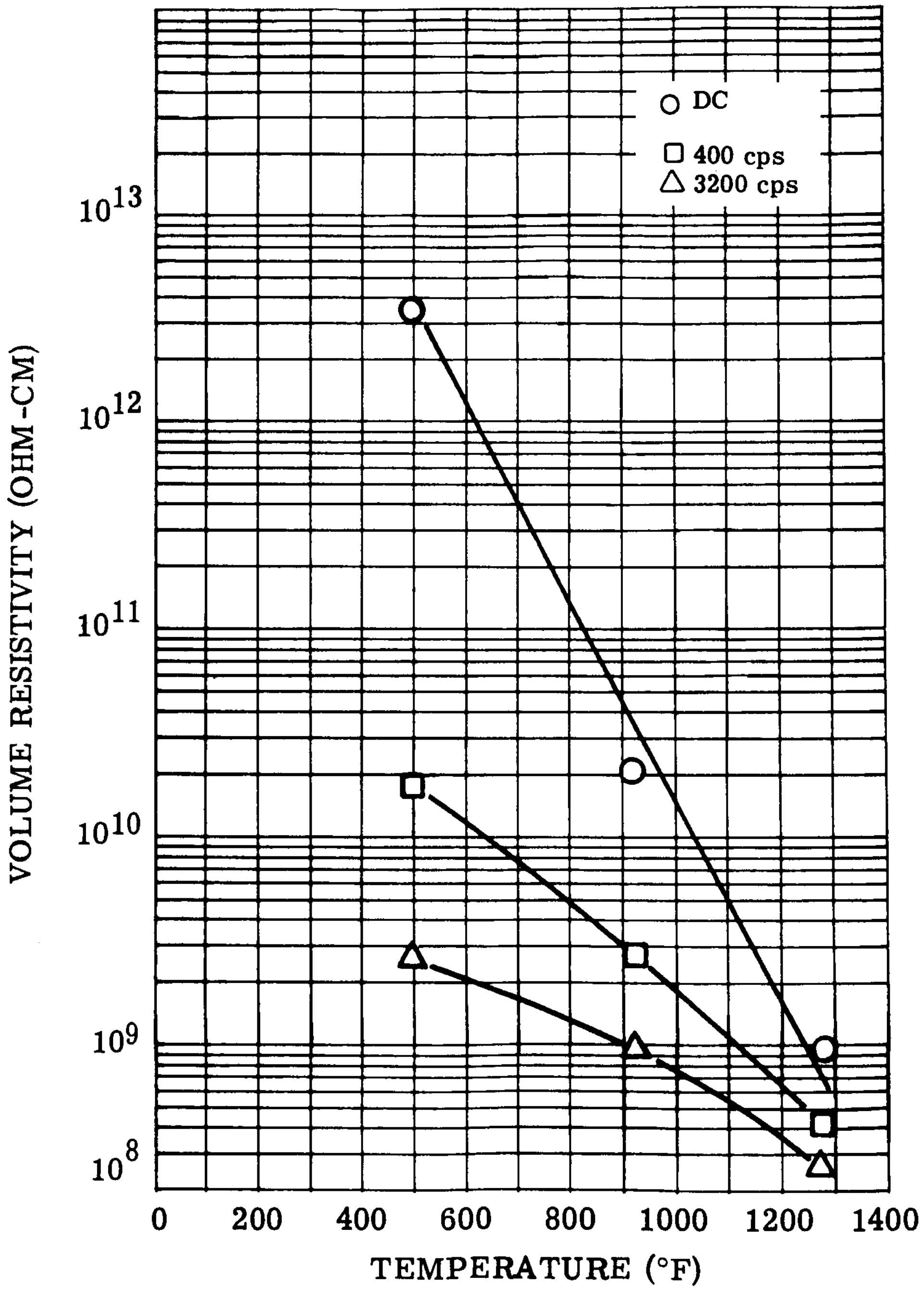
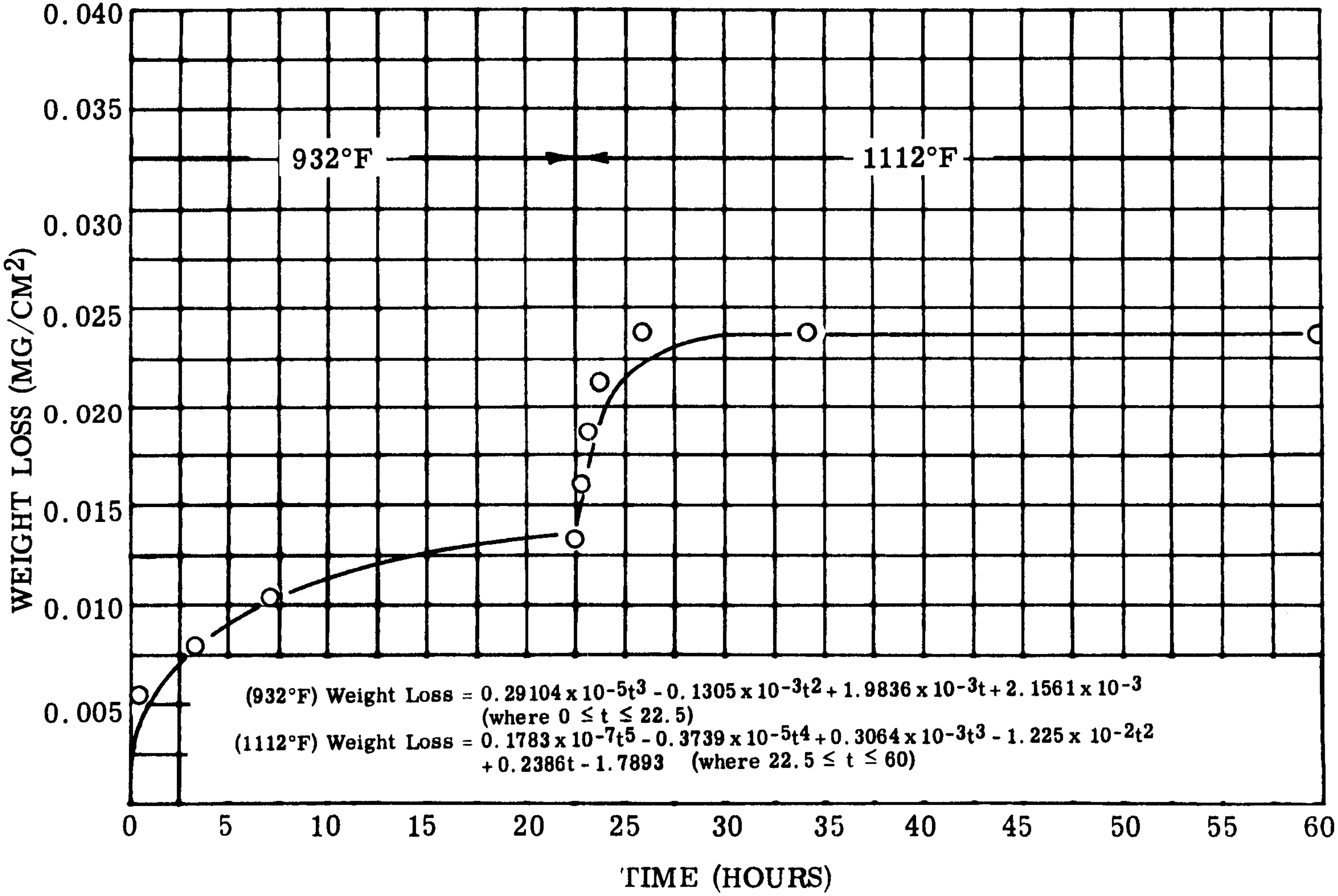


FIGURE V.C.3-5. Volume Resistivity of Inorganic Flexible Sheet Insulation, Mica Glass Silicone Bonded, in Air. Specimen Thickness, 0.004 Inch. (Reference: NAS 3-4162)

Figure V.C.3-5. Volume Resistivity - Flexible Sheet - Mica Glass



(932°F) Weight Loss $= 0.29104 \times 10^{-5}t^3 - 0.1305 \times 10^{-3}t^2 + 1.9836 \times 10^{-3}t + 2.1561 \times 10^{-3}$
(where $0 \leq t \leq 22.5$)

(1112°F) Weight Loss $= 0.1783 \times 10^{-7}t^5 - 0.3739 \times 10^{-5}t^4 + 0.3064 \times 10^{-3}t^3 - 1.225 \times 10^{-2}t^2 + 0.2386t - 1.7893$ (where $22.5 \leq t \leq 60$)

FIGURE V. C. 3-6. Weight Loss at 932°F and 1112°F at 10^{-5} to 10^{-6} Torr of Inorganic Flexible Sheet Insulation, Mica Glass Silicone Bonded. Specimen Thickness, 0.0045 Inch. (Reference: NAS 3-4162)

Figure V. C. 3-6. Weight Loss - Flexible Sheet - Mica Glass

4. SYNTHETIC MICA PAPER FLEXIBLE SHEET INSULATION

Synthetic mica paper (Burnil CM-1) is a synthetic paper resistant to temperatures up to 1800°F. Electrical applications are limited to temperatures below 1200°F. It is flexible, non-porous and has a slippery surface. This type is calendered and contains no additional reinforcement.

Availability: Burnil is available from the Minnesota Mining and Manufacturing Company. The paper is available in widths up to nine inches and thicknesses up to 0.020 inch. Two grades are available, reinforced and non-reinforced. The non-reinforced paper can be obtained in either a calendered or non-calendered form.

Description: The Burnil paper CM-1, is composed of synthetic-mica platelets of a complex composition of lithium magnesium silicate, $xMg_2LiSi_4O_{10}F_2$ (where x = Li or Na). The paper contains about 4.5 percent water which is eliminated at 230°F but is rapidly picked up from the air at room temperature. A very small amount of organic sizing material is present on the paper.

I. Thermophysical Properties

A. Thermal Conductivity

Specimen Thickness, 0.0102 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
494	0.044
925	0.073
1578	0.196

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.0102 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	2.7
500	3200	2.6
932	400	4.6
932	3200	3.8
1598	400	(1)
1598	3200	(1)

B. Electrical Strength (rate of rise 500 volts/second)

Specimen Thickness, 0.0102 Inch.

Temperature (°F)	Frequency	Volts/mil
500	DC	568
500	400 cps	290
500	3200 cps	235 (2)
932	DC	110(3)
932	400 cps	208
932	3200 cps	169
1598	400 cps	24 (2)

C. Insulation Life

Specimen Thickness, 0.0102 Inch

875 volts, 60 cycles proof test after aging, 5 samples per test.

Temperature (°F)	Hours	Number of Samples Passed
932	1000	5
1598	300	0

---

(1) Excessive current leakage
(2) Not a breakdown, current exceeded 30 ma.
(3) Not a breakdown, current exceeded 5 ma.

D. Power Factor

Specimen Thickness, 0.0102 Inch

Temperature (°F)	Frequency (cps)	Percent
500	400	4.1
500	3200	3.5
932	400	93
932	3200	57

E. Volume Resistivity

Specimen Thickness, 0.0102 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	3.7×10^{11}
500	400 cps	4.0×10^{10}
500	3200 cps	6.0×10^{9}
932	DC	7.4×10^{8}
932	400 cps	3.8×10^{8}
932	3200 cps	2.0×10^{8}
1598	DC	1.8×10^{7}
1598	400 cps	1.1×10^{7}
1598	3200 cps	1.4×10^{7}

III. Mechanical Properties

A. Abrasion Resistance

Abrasion resistance at 77°F as determined by change in electrical leakage at 1000 volts potential caused by abrading with CS17F Taber wheel with 125 and 500 gram load. The specimen thickness was 0.0102 inch.

Condition	Leakage at 1000 volts
Unabraded	1500 microamps
After 500 cycles with 125 grams	1450 microamps
Percent increase in leakage	-3 percent
After 500 cycles with 500 grams	∞ at 1000 volts 1650 at 850 volts
Percent increase in leakage	∞

These results indicate a high degree of abrasion resistance for this inorganic insulation material.

B. Cut-Through Resistance

Cut-through resistance was determined using constant pressure of approximately 300 psi, applied through a 0.040 inch diameter steel ball. The specimen thickness was 0.0102 inch. Amount of damage was to be rated by relative current leakage values at varied temperatures and electrical potentials. The data was not consistent or meaningful and thus not worthy of inclusion in this report.

C. Tensile Strength (77°F)

0.0102 mils thick 8.6 lb/in width

IV. Compatibility Properties

A. Chemical Resistance

This synthetic mica composition has good resistance to organic solvent and moisture attack. Resistance to acid and alkaline solutions is poor. (Reference: 3M Company Burnil Data Sheet.)

B. Nuclear Radiation Resistance

(LI296)

Mild radiation damage is encountered in mica paper at a flux level of about 1010 ergs per gram (C) and 10^{17} fast neutrons/cm^2. Severe damage with serious loss of electrical properties occurs at 10^{12} ergs per gram (C) and 10^{19} fast neutrons/cm^2.

C. Vacuum Weight Loss at elevated temperature

1.	932°F for 24 hours	0.12 percent
2.	932°F for 24 hours and 1598°F for 48 hours	5 percent

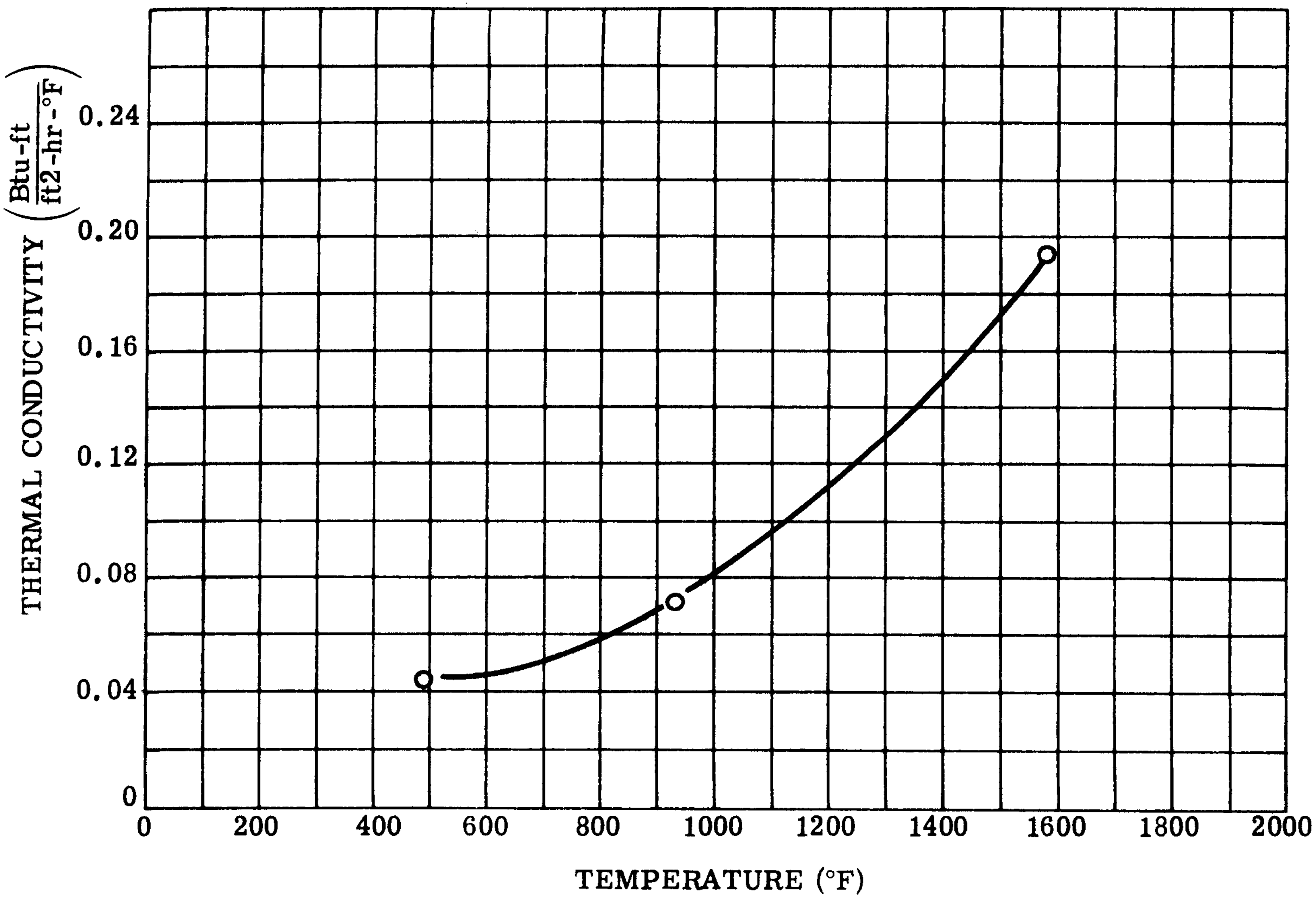


FIGURE V.C.4-1. Thermal Conductivity of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper, in Air. Specimen Thickness, 0.0102 Inch. (Reference: NAS 3-4162)

Figure V.C.4-1. Thermal Conductivity - Flexible Sheet - Synthetic Mica

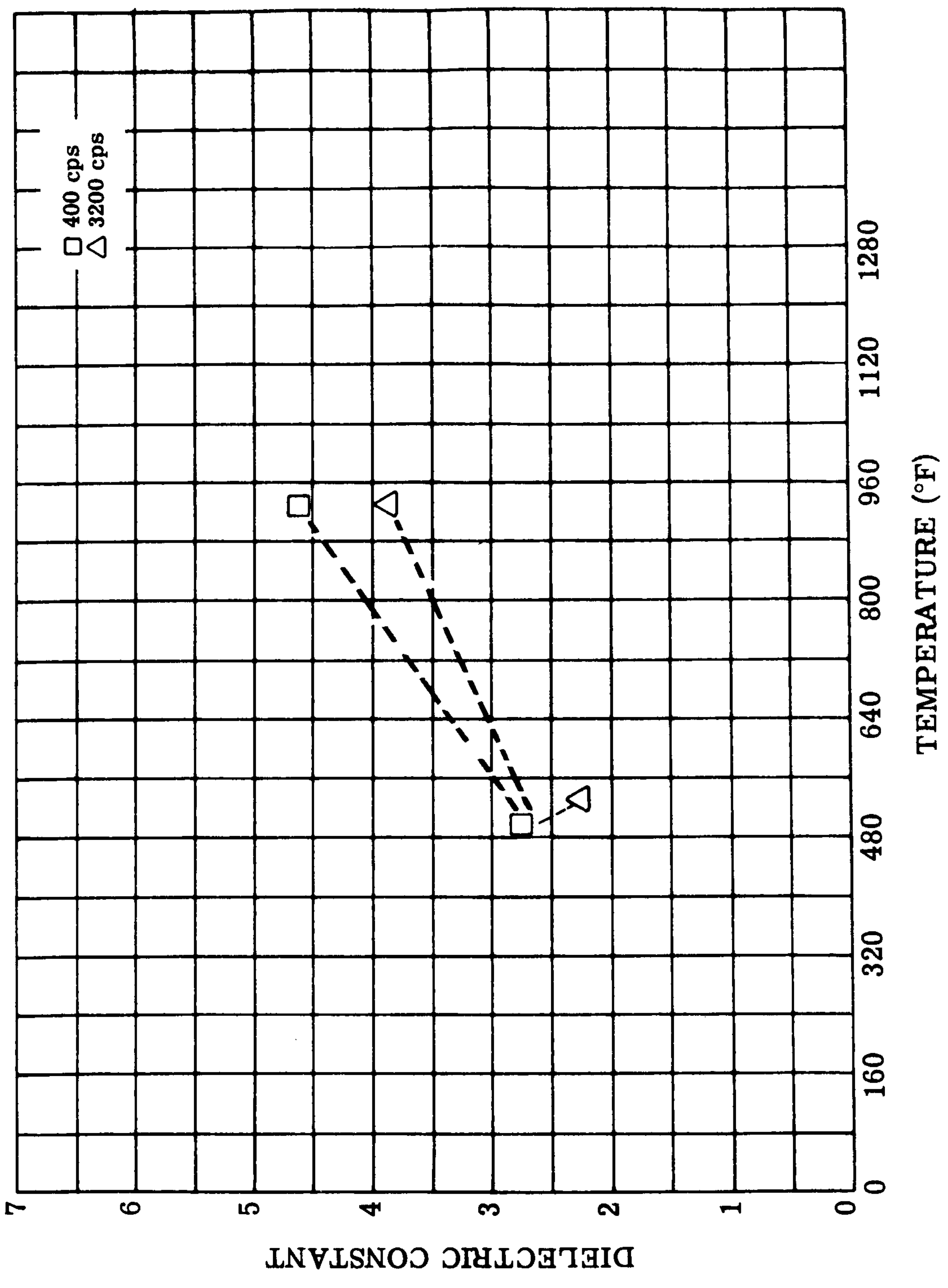


FIGURE V.C.4-2. Dielectric Constant of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper, in Air. Specimen Thickness, 0.0102 Inch. (Reference: NAS 3-4162)

Figure V.C.4-2. Dielectric Constant - Flexible Sheet - Synthetic Mica

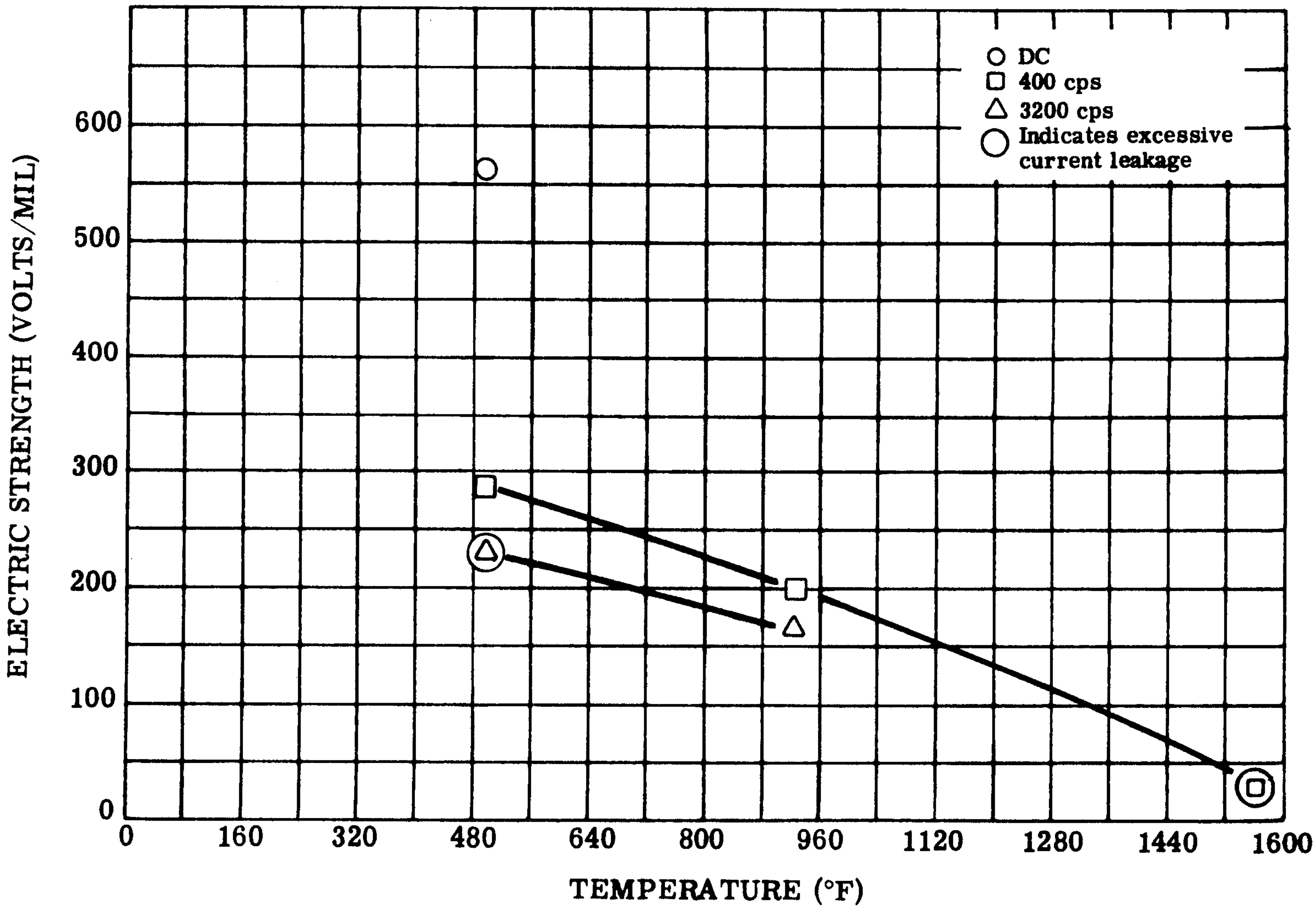


FIGURE V.C.4-3. Electric Strength of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper, in Air. Specimen Thickness, 0.0102 Inch. (Reference: NAS 3-4162)

Figure V.C.4-3. Electric Strength - Flexible Sheet - Synthetic Mica

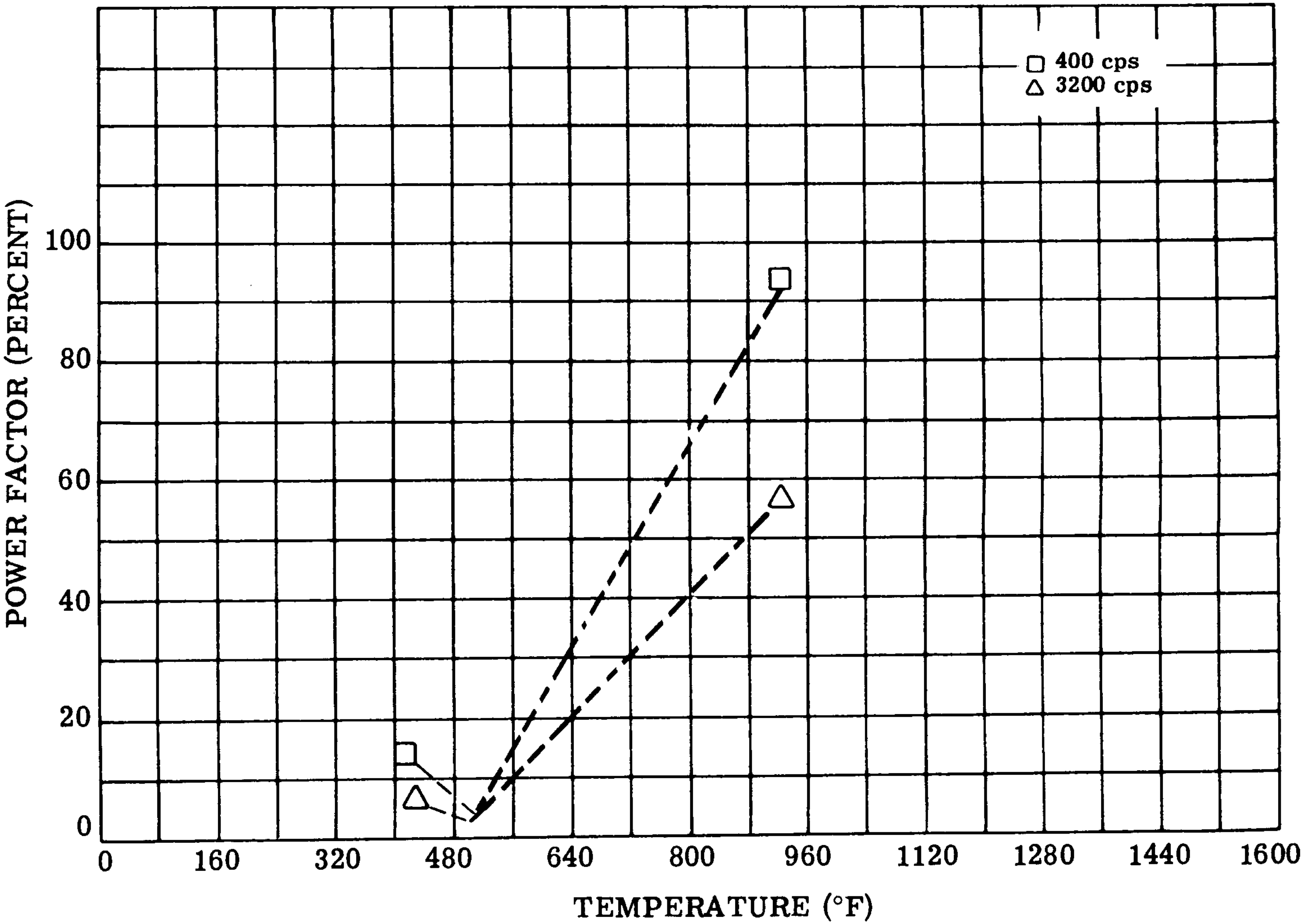


FIGURE V.C.4-4. Power Factor of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper, in Air. Specimen Thickness, 0.0102 Inch. (Reference: NAS 3-4162)

Figure V.C.4-4. Power Factor - Flexible Sheet - Synthetic Mica

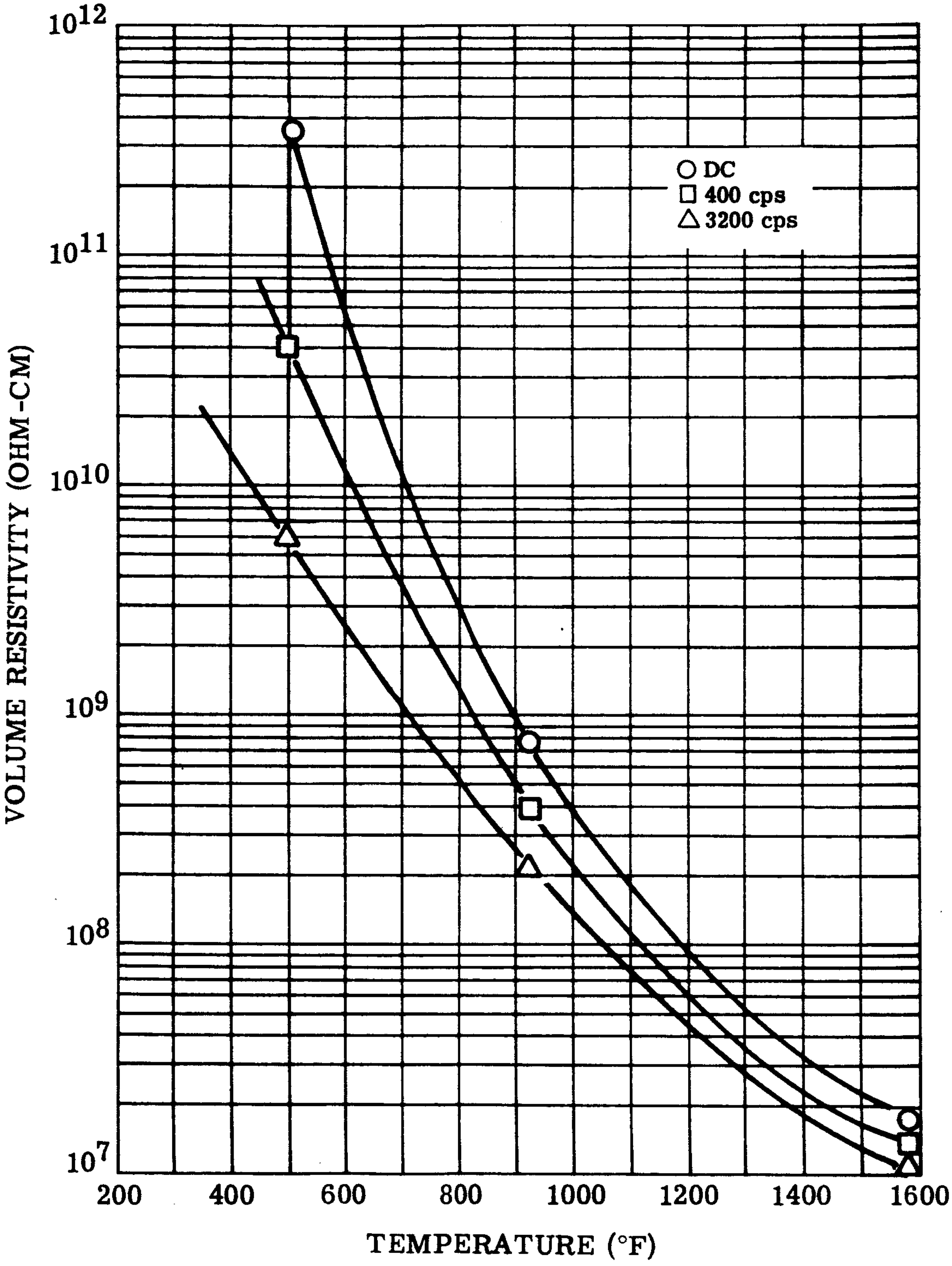


FIGURE V.C.4-5. Volume Resistivity of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper. Specimen Thickness, 0.0102 Inch. (Reference: NAS 3-4162)

Figure V.C.4-5. Volume Resistivity - Flexible Sheet - Synthetic Mica

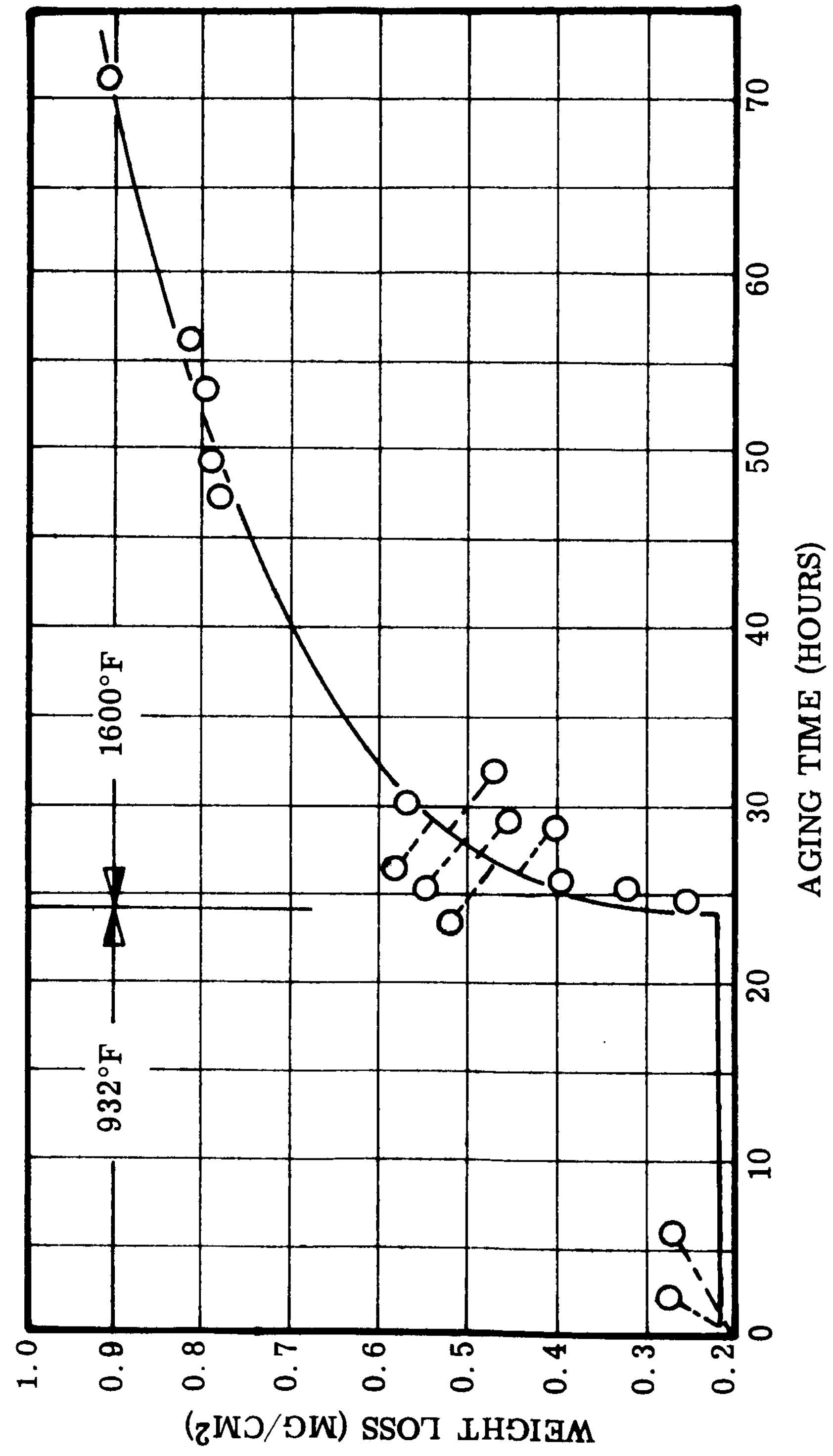


FIGURE V.C.4-6. Weight Loss, 932°F, 1600°F and 10^{-5} to 10^{-6} Torr of Inorganic Flexible Sheet Insulation, Synthetic Mica Paper. Specimen Thickness, 0.0102 Inch. (Reference: NAS3-4162)

Figure V.C.4-6. Weight Loss - Flexible Sheet - Synthetic Mica

5. SILICATE FIBER PAPER FLEXIBLE SHEET (FIBERFRAX)

Fiberfrax ceramic fiber paper is a flexible, light weight, insulating material in roll or sheet form. It is resistant to temperatures up to 2300°F and unaffected by thermal shock. However, primary electrical insulation applications are limited to 1200°F.

Availability: Fiberfrax is commercially available from the Carborundum Company, Ceramic Fiber Project, Research and Development Division. The paper is stocked in thicknesses of 0.020, 0.040, and 0.080 inch. Two grades are available, one containing 5 percent organic binder and the other with no binder.

Description: Fiberfrax paper is composed of an alumina-silica fiber. The composition is: Al_2O_3 51 percent, SiO_2 47 percent, B_2O_3 0.6 percent, Na_2O 0.6 percent, and MgO, CaO, Fe_2O_3 0.5 percent. Average fiber diameter is 2.5 microns. The fiber melts or sinters at 2500°F. After long exposure above 2000°F, the amorphous glassy structure changes to a crystalline structure. One type has a five percent organic binder for added strength. Fiberfrax examined in this program was approximately 0.020 inch thick and contained no binder.

I. Thermophysical Properties

A. Thermal Conductivity

Specimen Thickness, 0.020 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
600	0.043
1000	0.061
1400	0.079
1800	0.102
2000	0.113

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.025 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	1.08
500	3200	1.07
932	400	1.65
932	3200	1.30
1598	400	(1)
1598	3200	(1)

B. Electrical Strength (rate of rise 500 volts/second)

Specimen Thickness, 0.025 Inch

Temperature (°F)	Frequency	Volts/mil (average)
500	DC	110
500	400 cps	98
500	3200 cps	104
932	DC	53 (2)
932	400 cps	39
932	3200 cps	40
1598	DC	20 (2)
1598	400 cps	38
1598	3200 cps	42

---

(1) Current leakage excessive

(2) Not a breakdown, current exceeded 5 ma.

C. Insulation Life

Specimen Thickness, 0.025 Inch

600 volts, 60 cycles proof test after aging, 5 samples per test.

Temperature (°F)	Hours	Number of Samples Passed
932	1000	5
1598	200	0

D. Power Factor

Specimen Thickness, 0.025 Inch

Temperature (°F)	Frequency (cps)	Percent
500	400	2.0
500	3200	1.5
932	400	37.1
932	3200	20.6
1598	400	(1)
1598	3200	(1)

E. Volume Resistivity

Specimen Thickness, 0.025 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	1.6×10^{13}
500	400 cps	2.0×10^{11}
500	3200 cps	1.4×10^{10}
932	DC	6.2×10^{9}
932	400 cps	2.6×10^{9}
932	3200 cps	7.8×10^{8}

(1) Current leakage excessive.

Temperature (°F)	Frequency	Ohm-cm
1598	DC	7.6×10^4
1598	400 cps	3.5×10^4
1598	3200 cps	3.5×10^4

III. Mechanical Properties

A.	Abrasion Resistance	Poor
	Specimen Thickness, 0.020 Inch	
B.	Cut-Through Resistance	Poor
	Specimen Thickness, 0.020 Inch	
C.	Tensile Strength (77°F)	
	17.3 mils thick (20 mil nominal)	0.42 lb/in width

IV. Compatibility Properties

A. Chemical Resistance

According to the manufacturer, Fiberfrax is described as "highly resistant to most chemicals, including many strong acids." (Reference: Carborundum Bulletin CFB1-D160-2.)

B. Nuclear Radiation Resistance

Fiberfrax insulation resistance decreases uniformly as the integrated radiation increases until it reaches a minimum value of several thousand ohms. The total neutron dose to reach this resistance plateau is approximately 10^{19} fast neutrons/cm^2. (Reference: Radiation Effects Information Center Report No. 2.)

C. Vacuum Weight Loss at elevated temperature

1.	24 hours at 932°F and 10^{-5} to 10^{-6} torr	1.5 percent
2.	24 hours at 932°F and 10^{-5} to 10^{-6} torr followed by 24 hours at 1598°F and 10^{-5} to 10^{-6} torr	1.6 percent

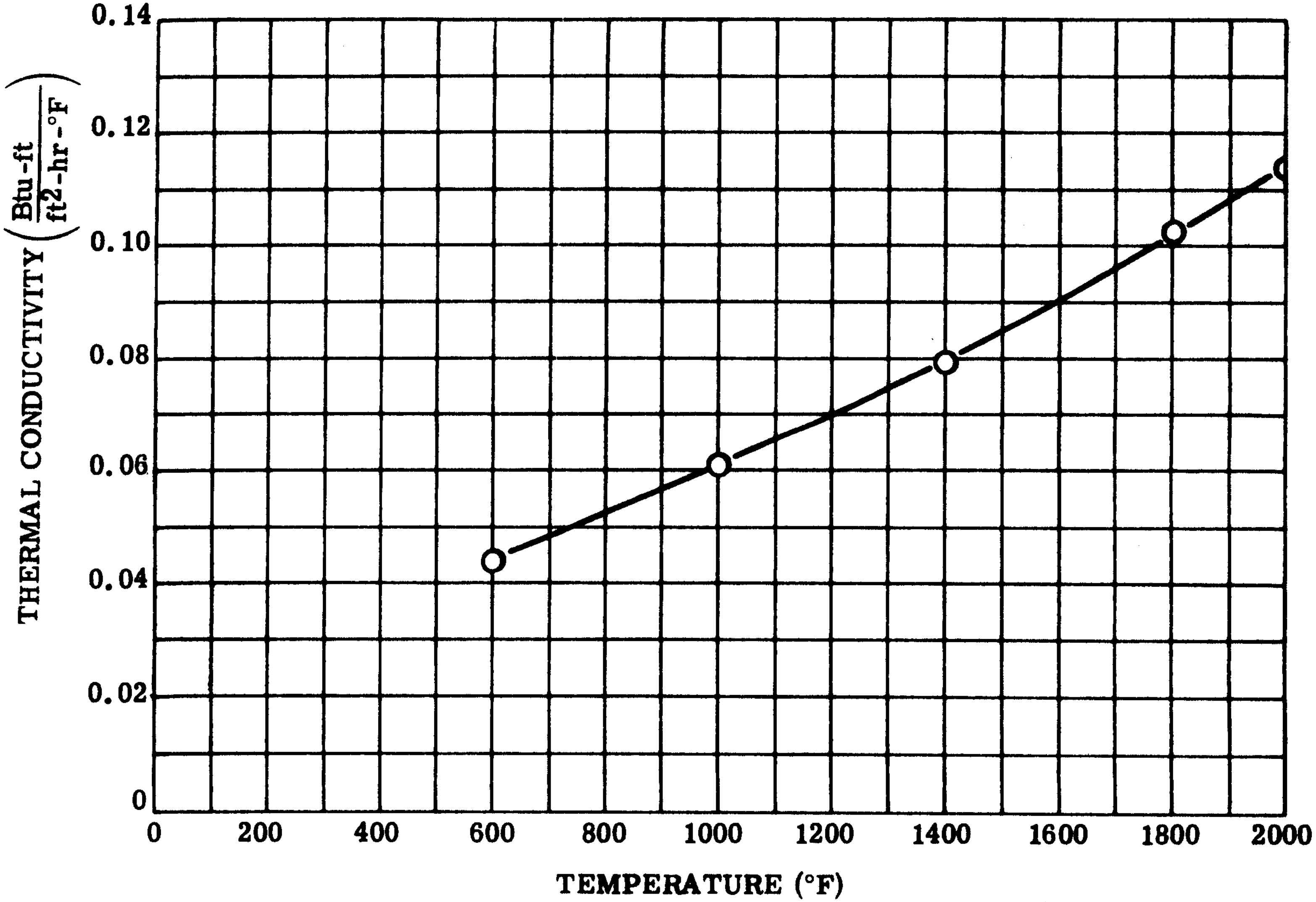


FIGURE V.C.5-1. Thermal Conductivity of Inorganic Flexible Sheet Insulation, Silicate Fiber. Specimen Thickness, 0.020 Inch. (Reference: NAS 3-4162)

Figure V.C.5-1. Thermal Conductivity - Flexible Sheet - Silicate Fiber

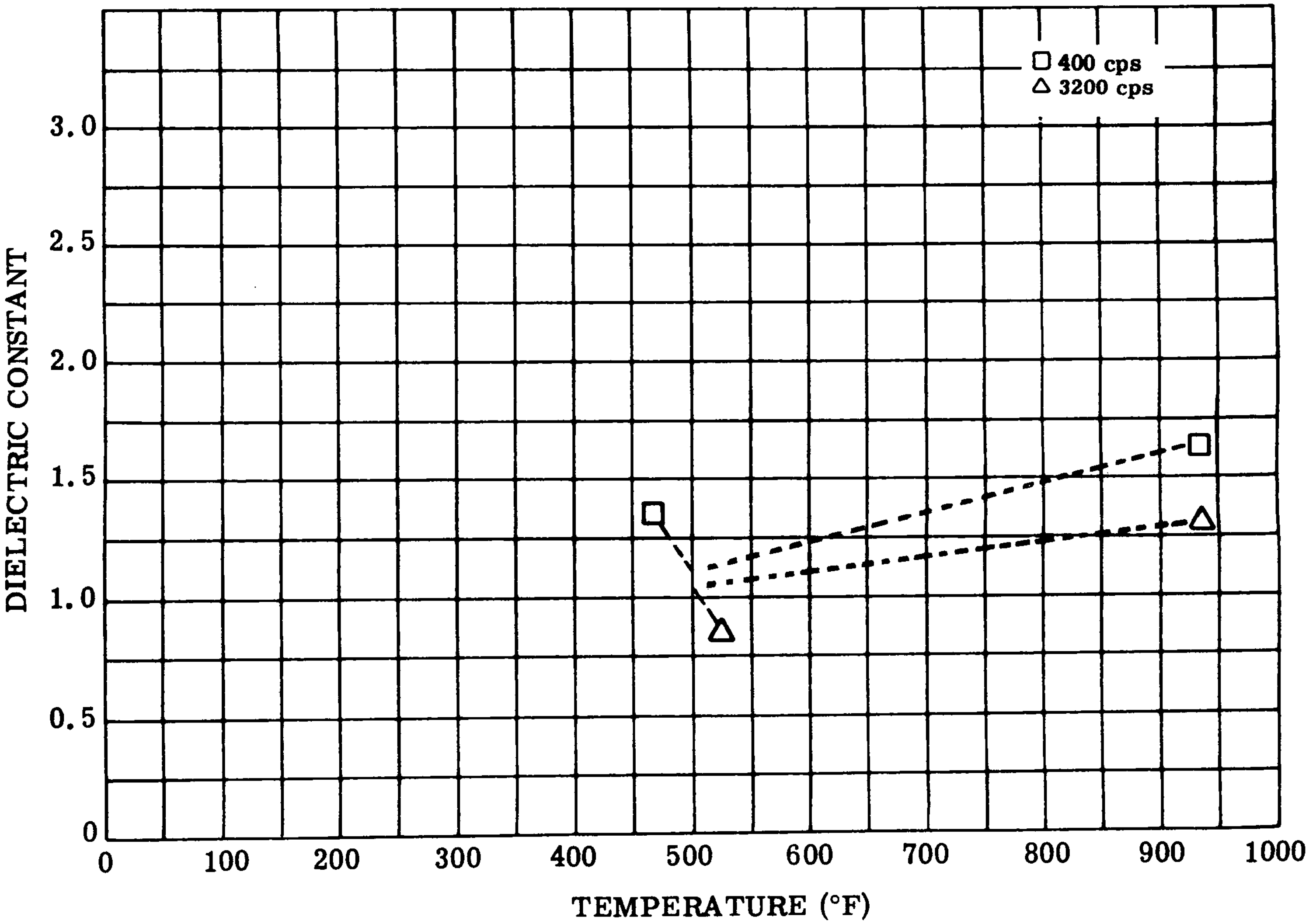


FIGURE V.C.5-2. Dielectric Constant of Inorganic Flexible Sheet Insulation, Silicate Fiber, in Air. Specimen Thickness, 0.025 Inch. (Reference: NAS 3-4162)

Figure V.C.5-2. Dielectric Constant - Flexible Sheet - Silicate Fiber

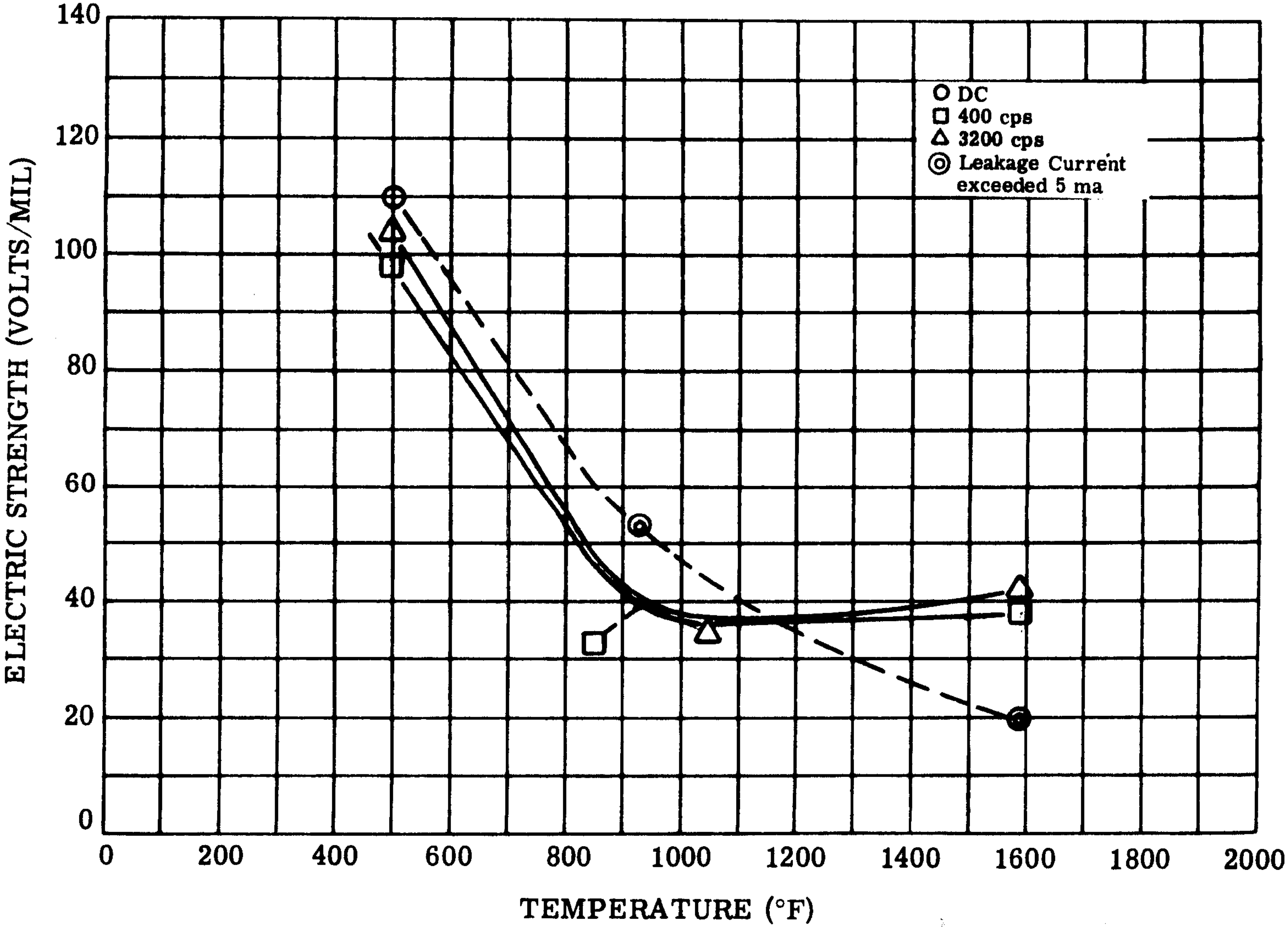


FIGURE V.C.5-3. Electric Strength of Inorganic Flexible Sheet Insulation, Silicate Fiber, in Air. Specimen Thickness, 0.025 Inch. (Reference: NAS 3-4162)

Figure V.C.5-3. Electric Strength - Flexible Sheet - Silicate Fiber

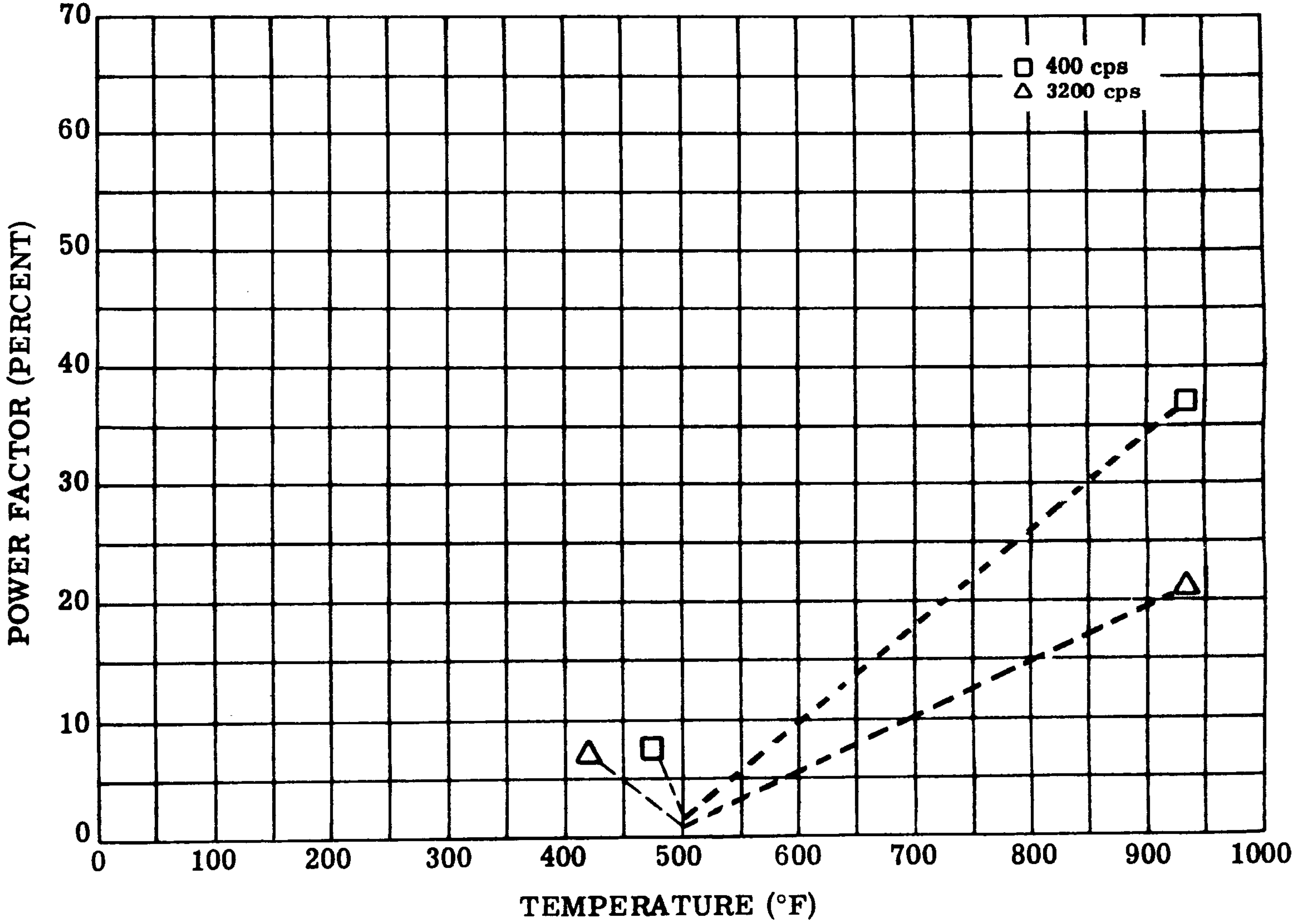


FIGURE V.C.5-4. Power Factor of Inorganic Flexible Sheet Insulation, Silicate Fiber, in Air. Specimen Thickness, 0.025 Inch. (Reference: NAS3-4162)

Figure V.C.5-4. Power Factor - Flexible Sheet - Silicate Fiber

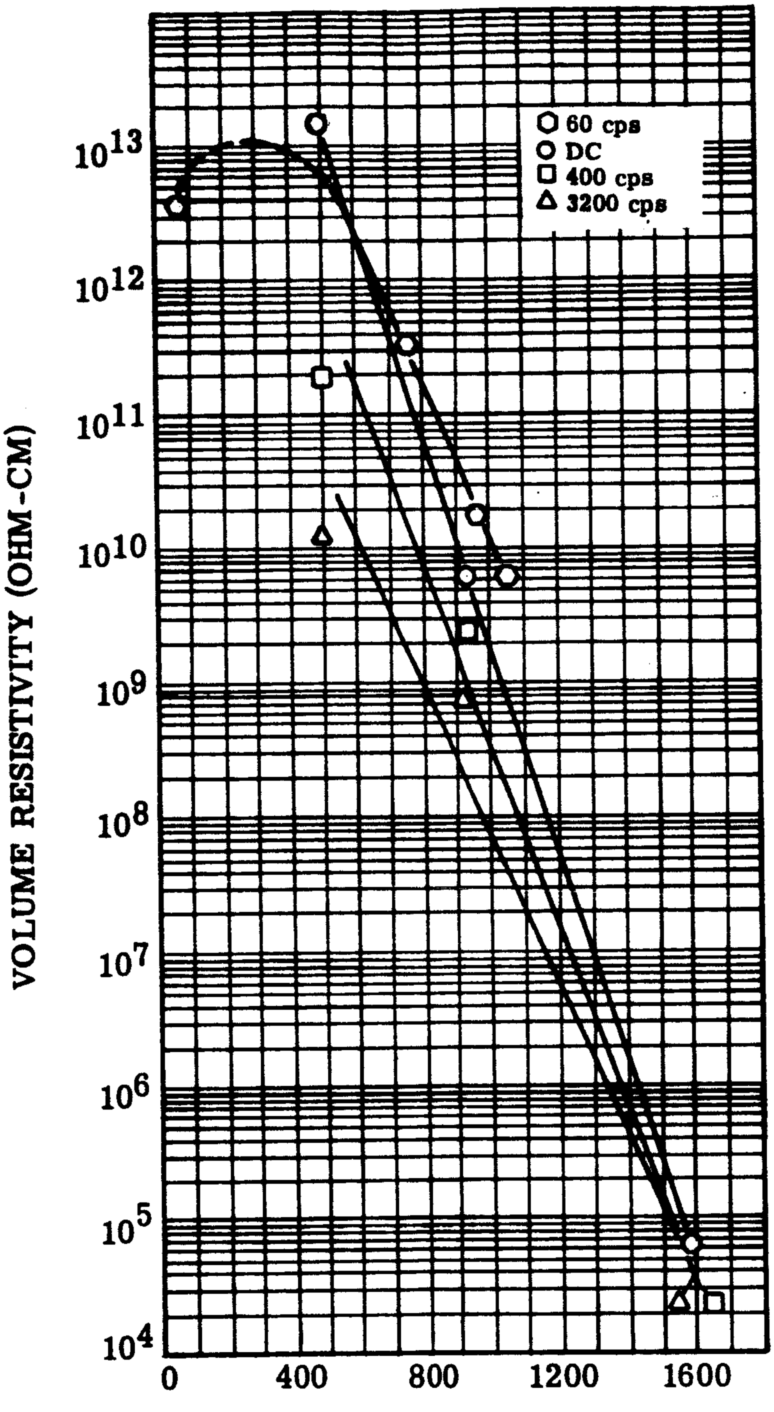


FIGURE V.C.5-5. Volume Resistivity of Inorganic Flexible Sheet Insulation, Silicate Fiber, in Air. Specimen Thickness, 0.025 Inch. (Reference: NAS 3-4162; RI714)

Figure V.C.5-5. Volume Resistivity - Flexible Sheet - Silicate Fiber

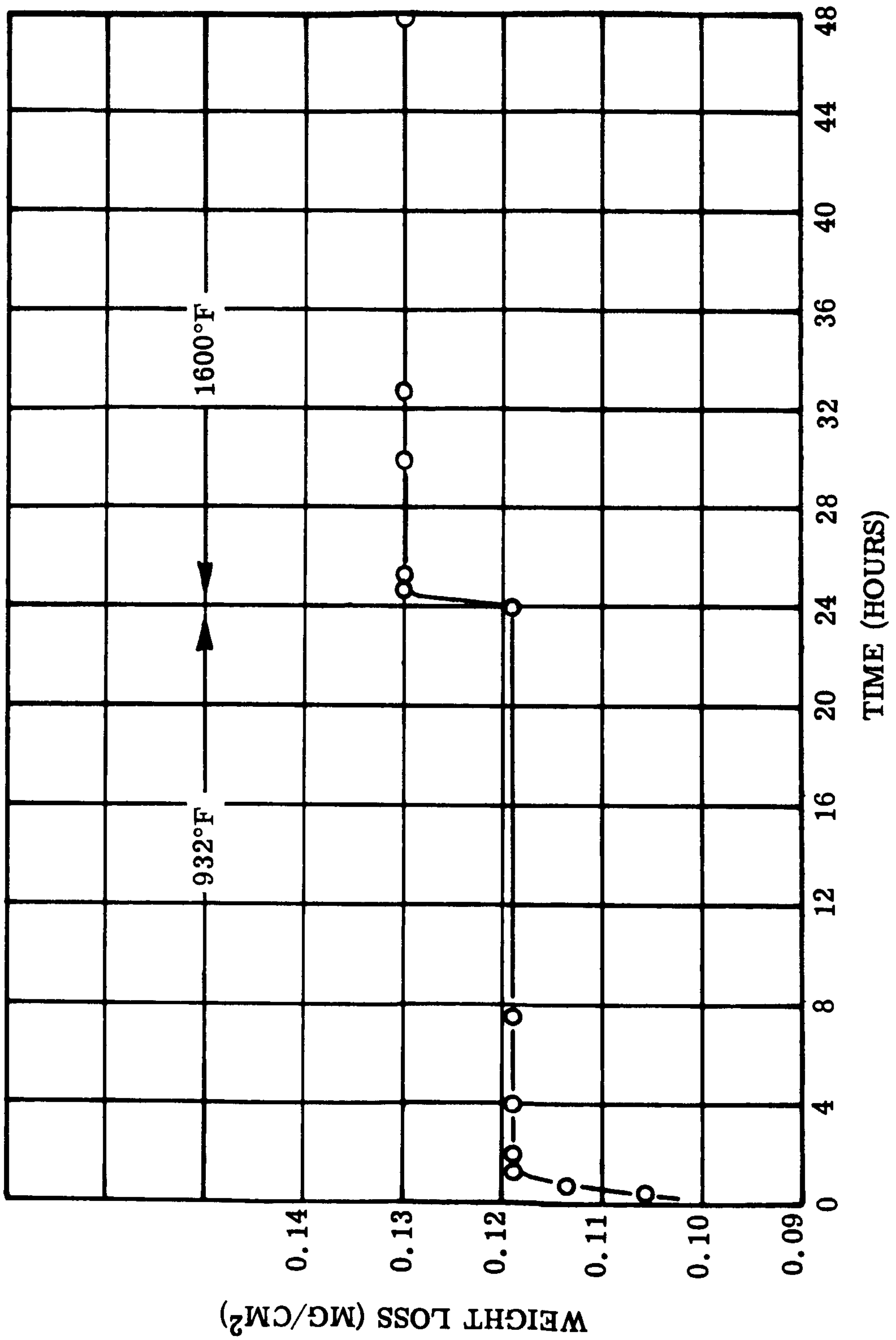


FIGURE V.C.5-6. Weight Loss at 932°F, 1600°F, and 10^{-5} to 10^{-6} Torr of Inorganic Flexible Sheet Insulation, Silicate Fiber. Specimen Thickness, 0.020 Inch. (Reference: NAS 3-4162)

Figure V.C.5-6. Weight Loss - Flexible Sheet - Silicate Fiber

D. RIGID INSULATION, LAMINATED

1. ASBESTOS - BORON PHOSPHATE BONDED, INSULATION LAMINATE

Asbestos - Boron phosphate bonded material, known as 92M, was primarily developed as a structural material. As may be noted below, it has high mechanical strength and moderate electrical strength with good retention of properties during heat aging.

Availability:	The material has been prepared in various forms for specific applications by Westinghouse Electric Corporation, Research and Development Center and is available from there in sample quantities.
Description:	The laminate is composed of long fiber chrysotile asbestos paper impregnated and laminated with boron phosphate solution as a binder. The composition of chrysotile asbestos is $3MgO \cdot 2SiO_2 \cdot 2H_2O$ and is applied as a paper identified as RPD40 by the producer, Raybestos-Manhattan. The inorganic binder is prepared as a water solution of ammonia pentaborate and diammonium phosphate which results in 28 percent available boron phosphate.

I. Thermophysical Properties

A. Density (77°F) (lb/cu inch) 0.065

Specific Gravity (77°F) 1.79

B. Thermal Conductivity

Specimen Thickness, 0.25 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
477	0.214
728	0.230
1130	0.261

C. Coefficient of Thermal Expansion

Specimen Dimensions, 0.125 x 0.5 x 2.0 Inches

Temperature Range (°F)	inch/inch-°F
75 to 570	2.85×10^{-6}
570 to 1110	3.8×10^{-6}
75 to 1112	3.5×10^{-6}

D.	Water Absorption (77°F)(weight percent)	7.7
E.	Porosity (volume percent)	25-30

II. Electrical Properties

A. Arc Resistance (77°F) (seconds) 300 (RI704)

Specimen Thickness, 0.100 Inch

B. Dielectric Constant

Specimen Thickness, 0.100 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
482	400	26
482	3200	17
932	400	64
932	3200	27
1112	400	125
1112	3200	36

C. Electric Strength

Temperature (°F)	Frequency	Volts/mil
932	DC	70 (1)
932	400 cps	32
932	3200 cps	41

(1) No breakdown, overcurrent breaker set at 5 ma.

Temperature (°F)	Frequency	Volts/mil
1112	DC	60 (1)
1112	400 cps	33
1112	3200 cps	41
1600	DC	23 (1)
1600	400 cps	39 (2)
1600	3200 cps	36

D. Insulation Life

Specimen Thickness, 0.100 Inch

Temperature (°F)	Hours	DC Volume Resistivity (ohm-cm)
932	1	1.1×10^{8}
932	200	6.4×10^{8}
932	400	6.3×10^{8}
932	600	6.3×10^{8}
932	800	9.7×10^{9}
932	1000	1.2×10^{9}
932	1000 (3)	4.4×10^{8}
1112	1	1.2×10^{7}
1112	200	7.3×10^{7}
1112	400	2.4×10^{7}
1112	600	1.0×10^{6}
1112	800	1.6×10^{7}
1112	1000	1.4×10^{7}
1112	1000 (3)	1.1×10^{7}

E. Power Factor

Specimen Thickness, 0.100 Inch

(1) No breakdown, overcurrent breaker set at 5 ma.
(2) No breakdown, overcurrent breaker set at 30 ma.
(3) Rechecked at temperature with new electrode.

Temperature (°F)	Frequency (cps)	Percent
500	400	3.2
500	3200	2.7
932	400	85.5
932	3200	66.3
1112	400	98
1112	3200	95

F. Volume Resistivity

Specimen Thickness, 0.100 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	4.4×10^{10}
500	400 cps	4.5×10^{8}
500	3200 cps	1.2×10^{8}
932	DC	1.1×10^{8}
932	400 cps	4.0×10^{7}
932	3200 cps	2.2×10^{7}
1112	DC	1.2×10^{7}
1112	400 cps	6.2×10^{6}
1112	3200 cps	5.0×10^{6}

III. Mechanical Properties

A. Compressive Strength

Specimen Thickness, 0.125 Inch
Strain Rate, 0.05 inch/inch-minute to failure

Temperature (°F)	Psi
77	44,400
932	37,800
1112	23,850

B. Elastic Modulus in Flexure

Specimen Thickness, 0.125 Inch

Temperature (°F)	Psi
77	4.9×10^6
932	3.6×10^6
1112	2.9×10^6

C. Flexural Strength

(RI704)

Specimen Thickness, 0.125 Inch
Strain Rate, 0.05 inch/inch-minute to failure

Temperature (°F)	Psi
77	27,700
662	25,400
752	25,700
932	22,262
1112	15,237

D. Flexural Strength after aging

Specimen Thickness, 0.125 Inch
Strain Rate, 0.05 inch/inch-minute to failure

Hours at Temperature	Aging and Test Temperatures 662°F	752°F	932°F	1112°F
0	25,400 psi	25,700 psi	22,262 psi	15,237 psi
100	26,055 psi	25,310 psi	17,300 psi	7,160 psi
200	24,255 psi	20,230 psi	15,400 psi	6,175 psi
500	20,950 psi	20,740 psi	13,900 psi	4,650 psi
1000	22,500 psi	20,500 psi	12,300 psi	5,050 psi

E. Impact Strength (77°F)

Specimen Thickness, 0.125 Inch

1. Izod Notched (ft-lb/in notch)	2.0
2. Charpy Notched (ft-lb/in notch)	1.86

F. Tensile Strength

Specimen Thickness, 0.125 Inch

Temperature (77°F)	12,460 psi

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Alkaline Solutions	Fair
Acid Solutions	Poor
Organic Materials	Good
Water	Fair
Boiling Water	Fair

B. Nuclear Radiation Resistance

The nuclear radiation resistance of composites of this type is dependent in part upon the performance of the constituents and in part on the combination. The constituent most sensitive to nuclear degradation is the boron phosphate binder. The composite, 92M, is expected to withstand successfully a gamma dose of about 2×10^{10} R and a neutron dose in the range of 4×10^{18} nvt at an energy greater than 0.1 mev, since no interaction of degradation products is predicted.

C. Vacuum Weight Loss at elevated temperature

1. 24 hours at 932°F and 10^{-5} to 10^{-6} torr	5.2 percent
2. 24 hours at 932°F and 24 hours at 1112°F and 10^{-5} to 10^{-6} torr	6.7 percent
3. 8.5 hours at 1560°F and 10^{-6} torr	7.1 percent
4. 8.5 hours at 1560°F and 10^{-3} torr	7.5 percent

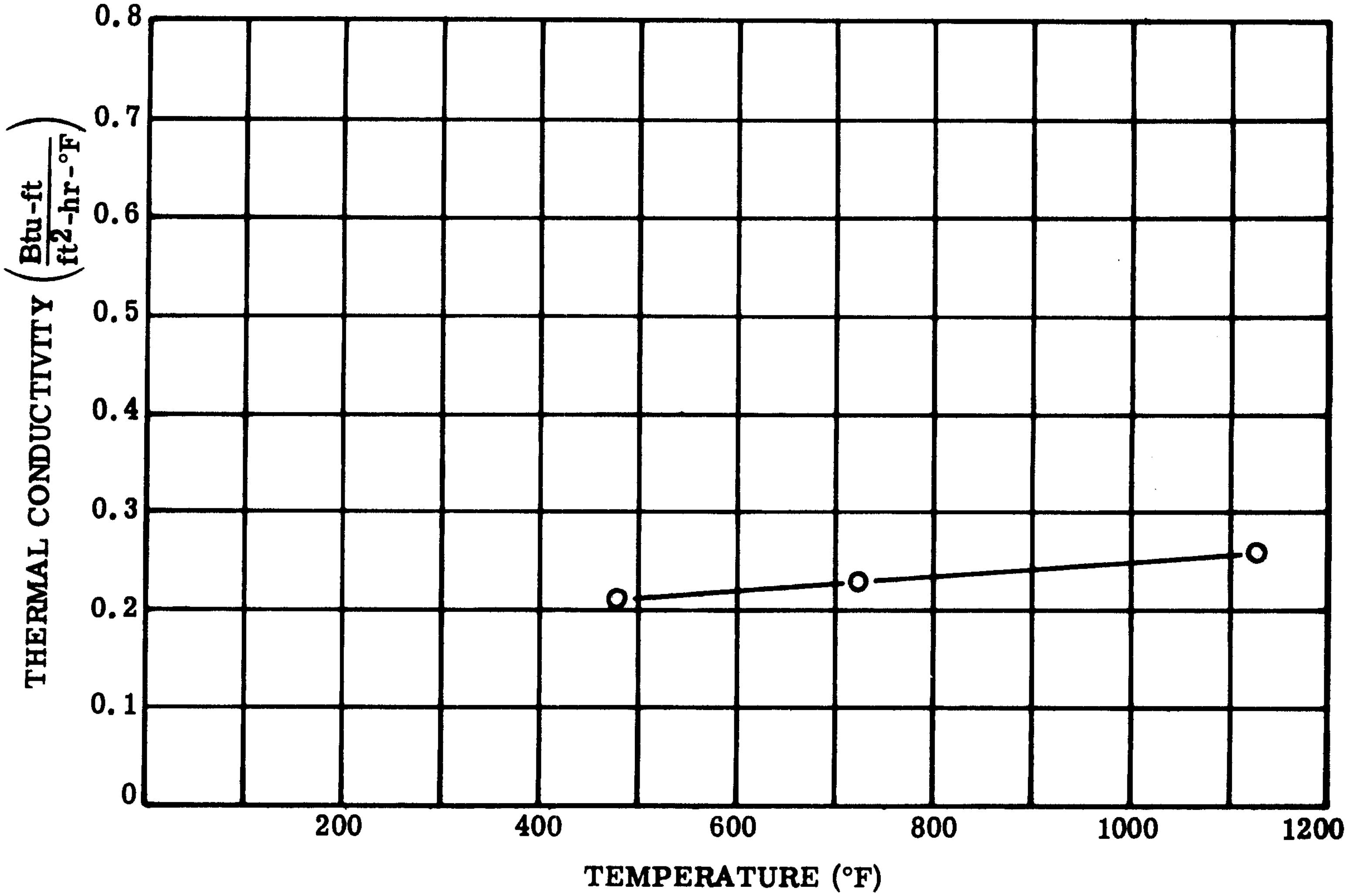


FIGURE V.D. 1-1. Thermal Conductivity of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.25 Inch. (Reference: NAS 3-4162)

Figure V.D. 1-1. Thermal Conductivity - Rigid Sheet - BPO_4 Asbestos

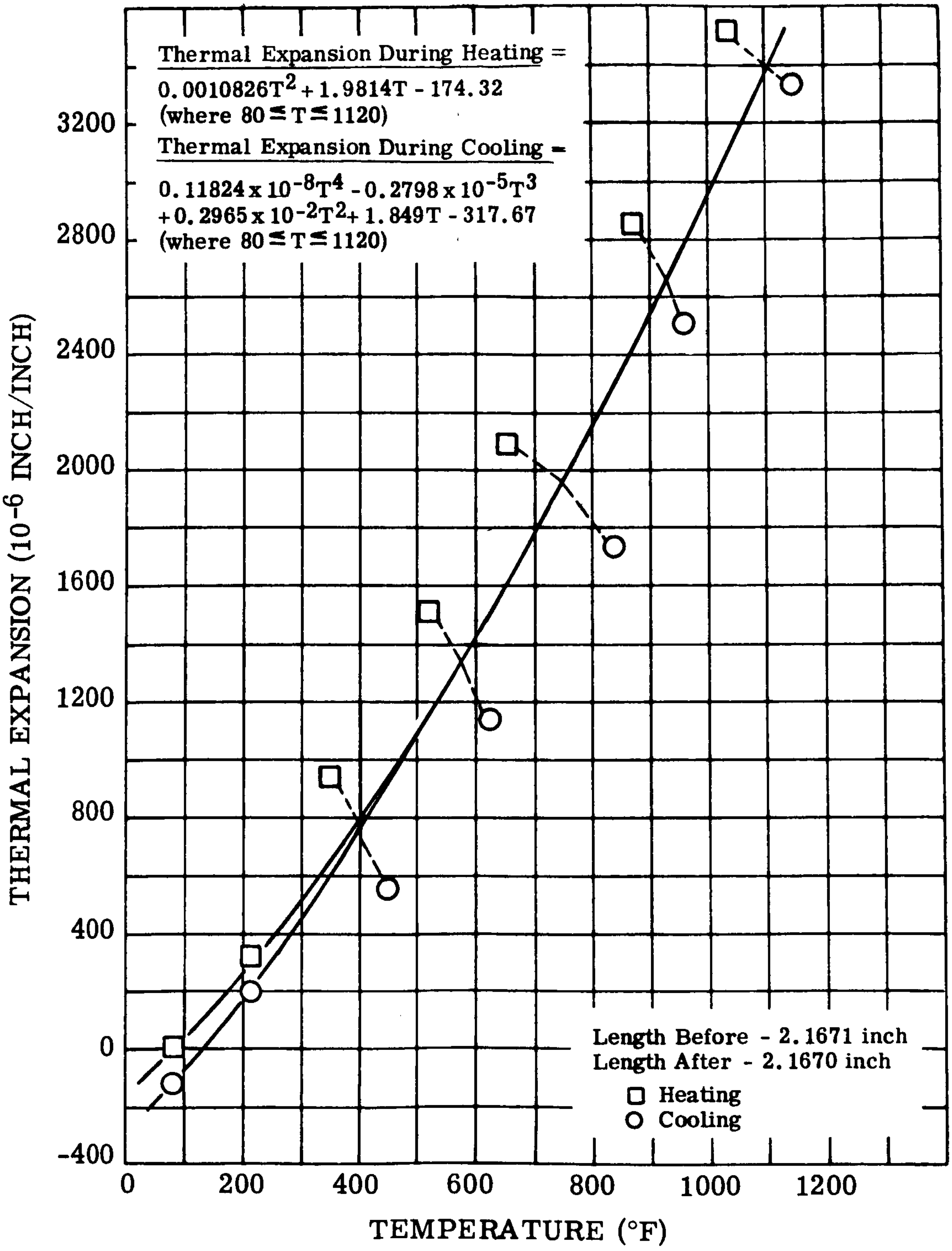


FIGURE V.D.1-2. Linear Thermal Expansion of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Argon Atmosphere. Specimen Dimensions, 0.125 x 0.5 x 2.0 Inches. (Reference: NAS 3-4162)

Figure V.D.1-2. Thermal Expansion - Rigid Sheet - BPO_4 Asbestos

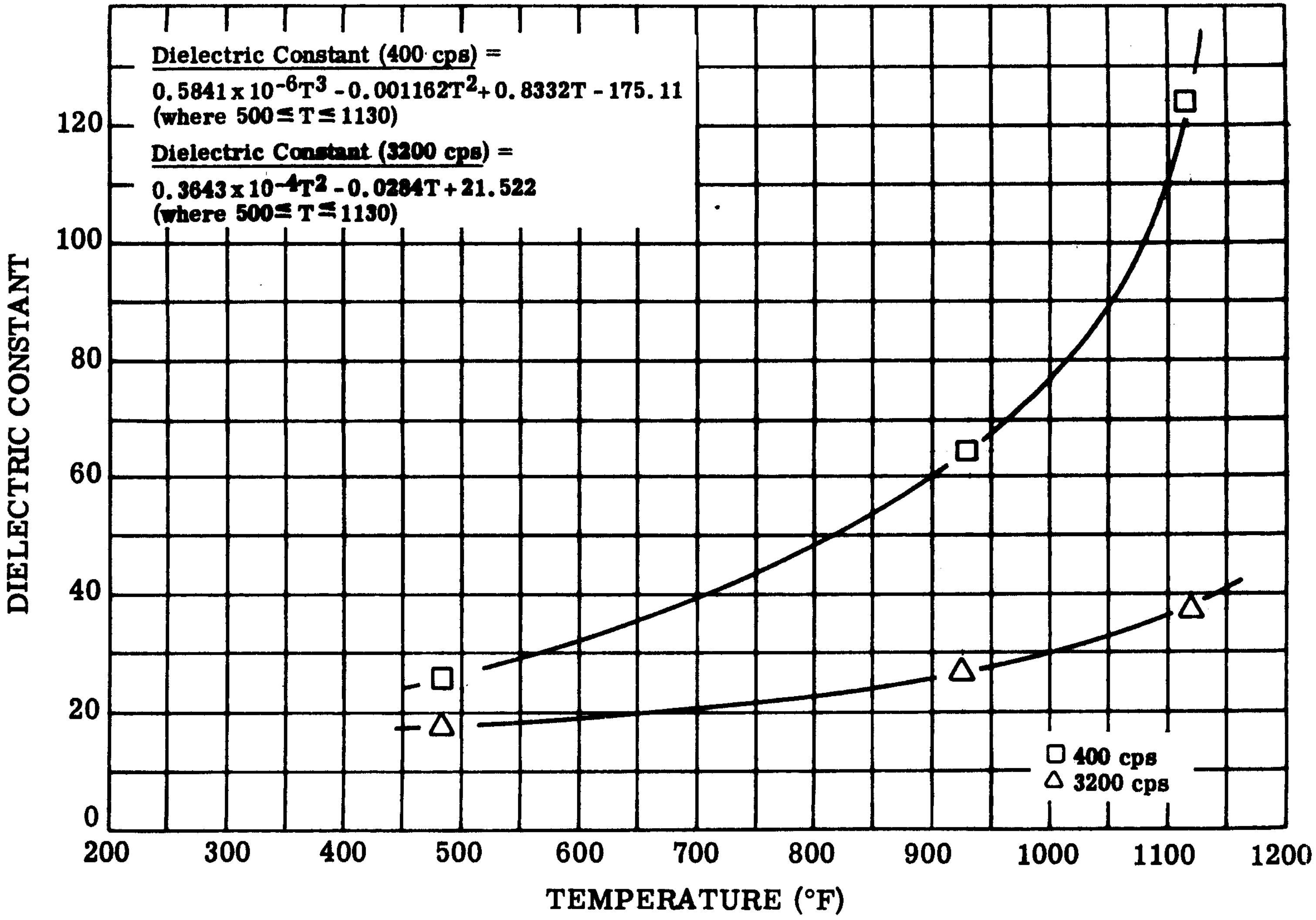


FIGURE V.D. 1-3. Dielectric Constant of Inorganic Rigid Sheet, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.100 Inch. (Reference: NAS 3-4162)

Figure V.D. 1-3. Dielectric Constant - Rigid Sheet - BPO_4 Astestos

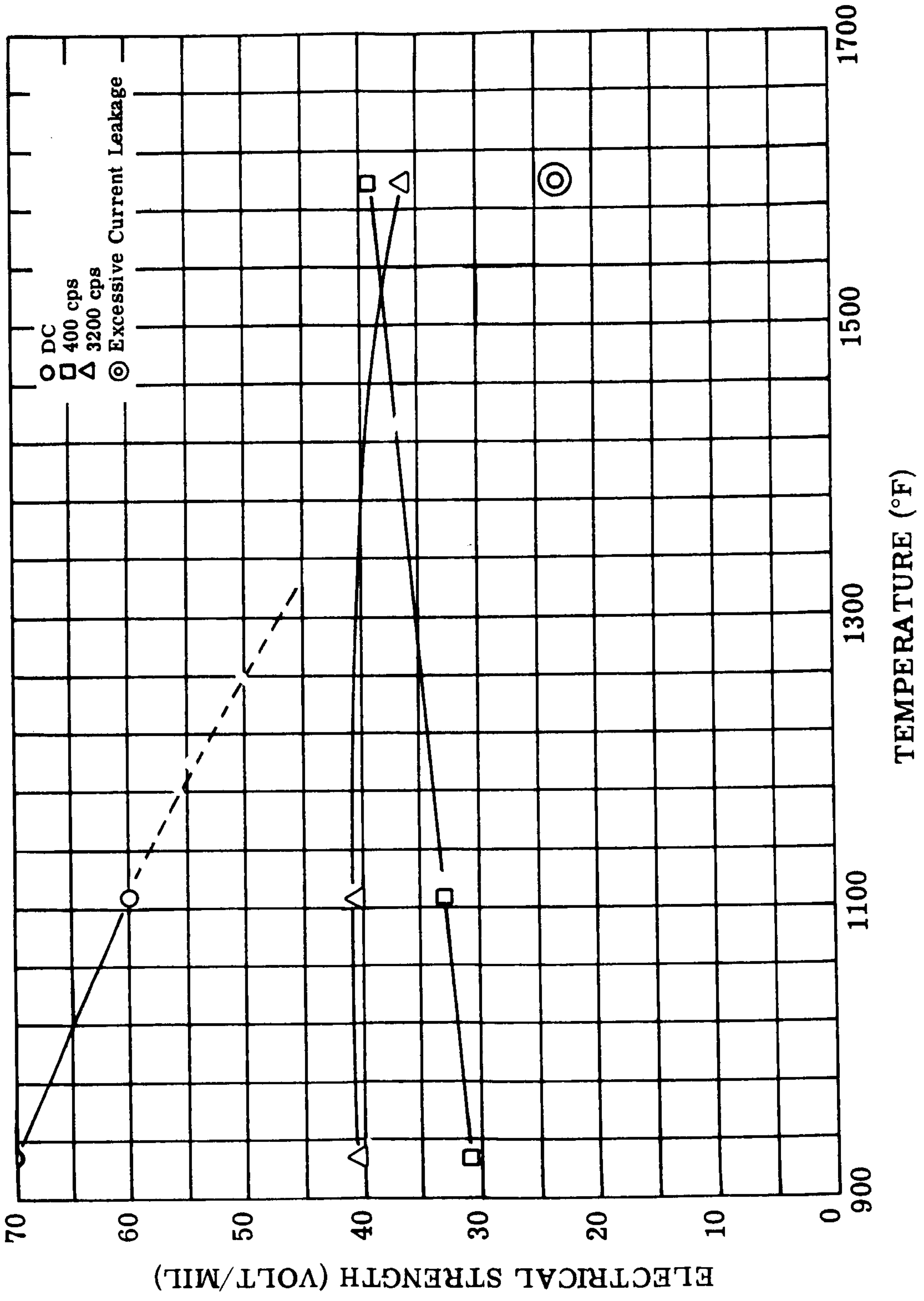


FIGURE V.D.1-4. Electric Strength of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.100 Inch. (Reference: NAS 3-4162)

Figure V.D.1-4. Electric Strength - Rigid Sheet - BPO_4 Asbestos

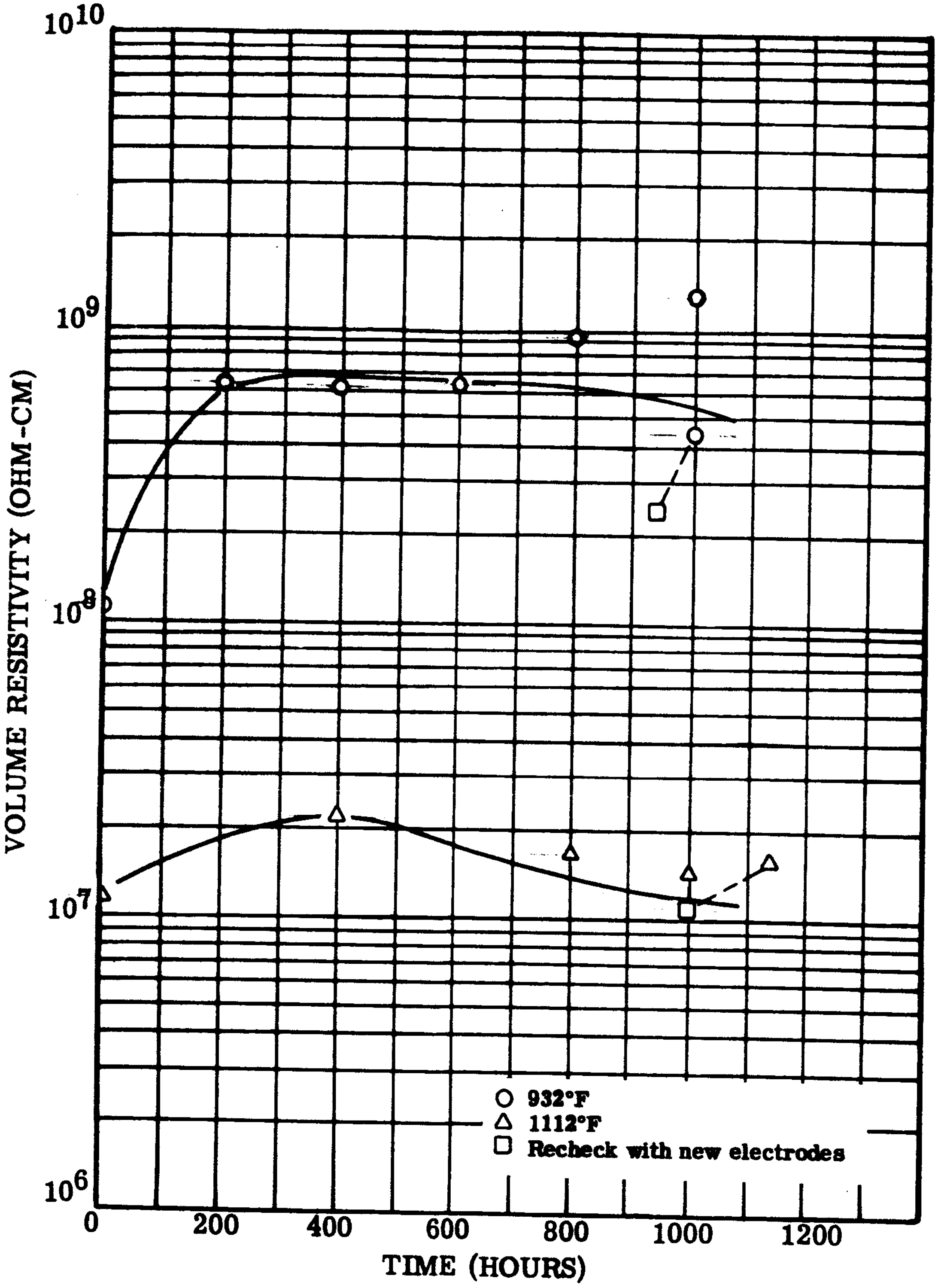


FIGURE V.D. 1-5. Insulation Life of Inorganic Rigid Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.100 Inch. (Reference: NAS 3-4162)

Figure V.D. 1-5. Insulation Life - Rigid Sheet - BPO4 Asbestos

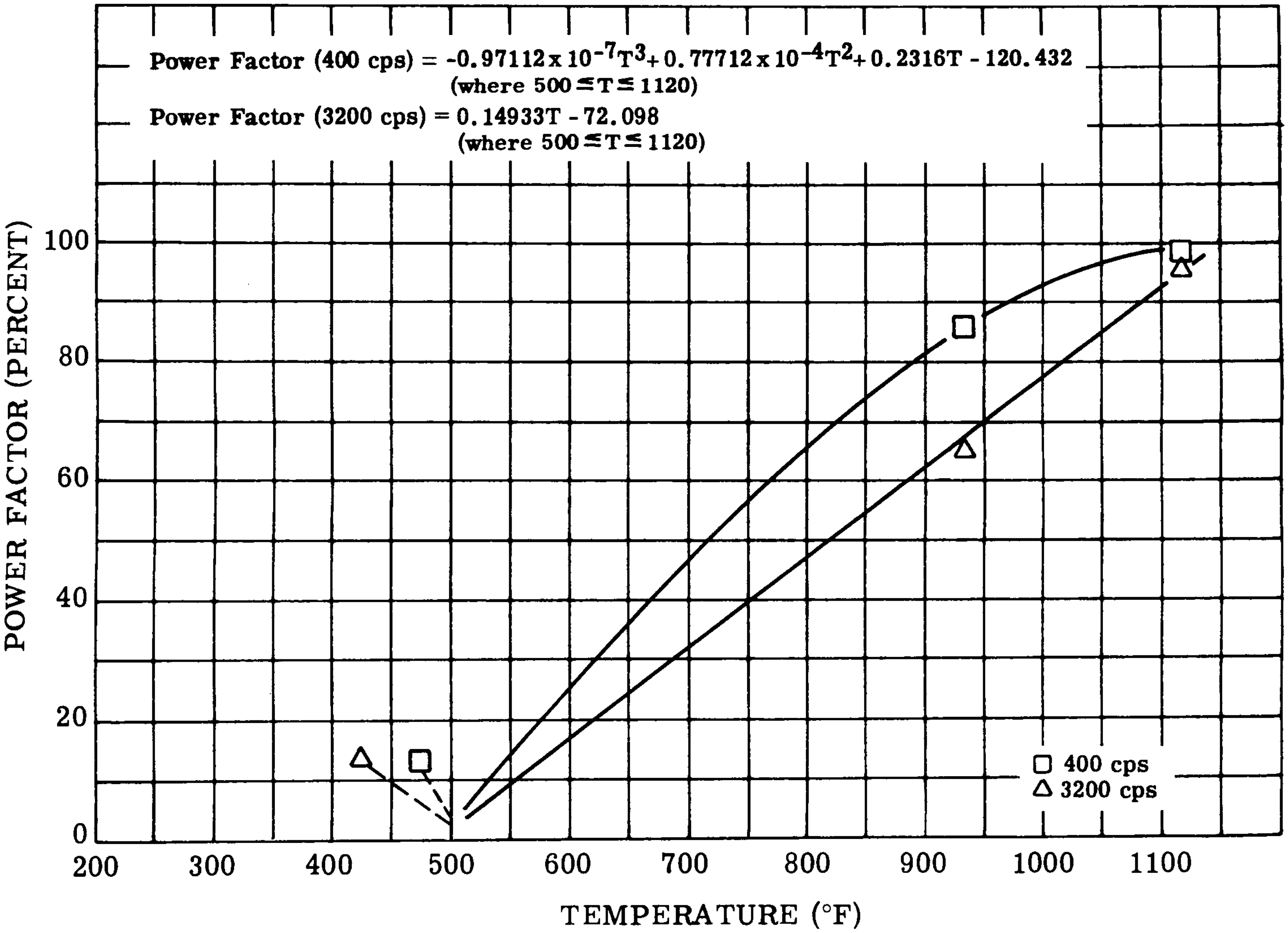


FIGURE V.D.1-6. Power Factor of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.100 Inch. (Reference: NAS 3-4162)

Figure V.D.1-6. Power Factor - Rigid Sheet - BPO4 Asbestos

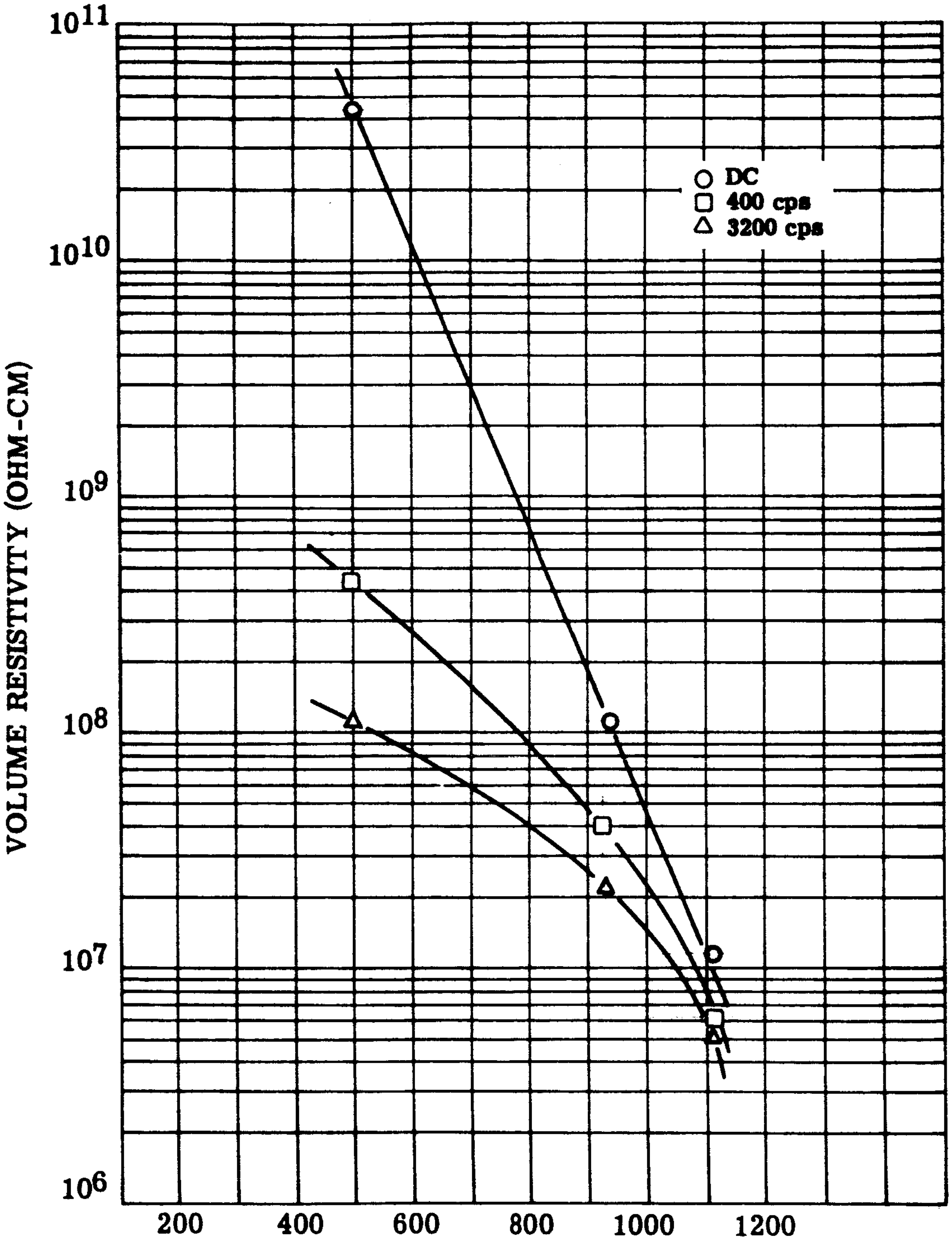


FIGURE V.D.1-7. Volume Resistivity of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.100 Inch. (Reference: NAS 3-4162)

Figure V.D.1-7. Volume Resistivity - Rigid Sheet - BPO_4 Asbestos

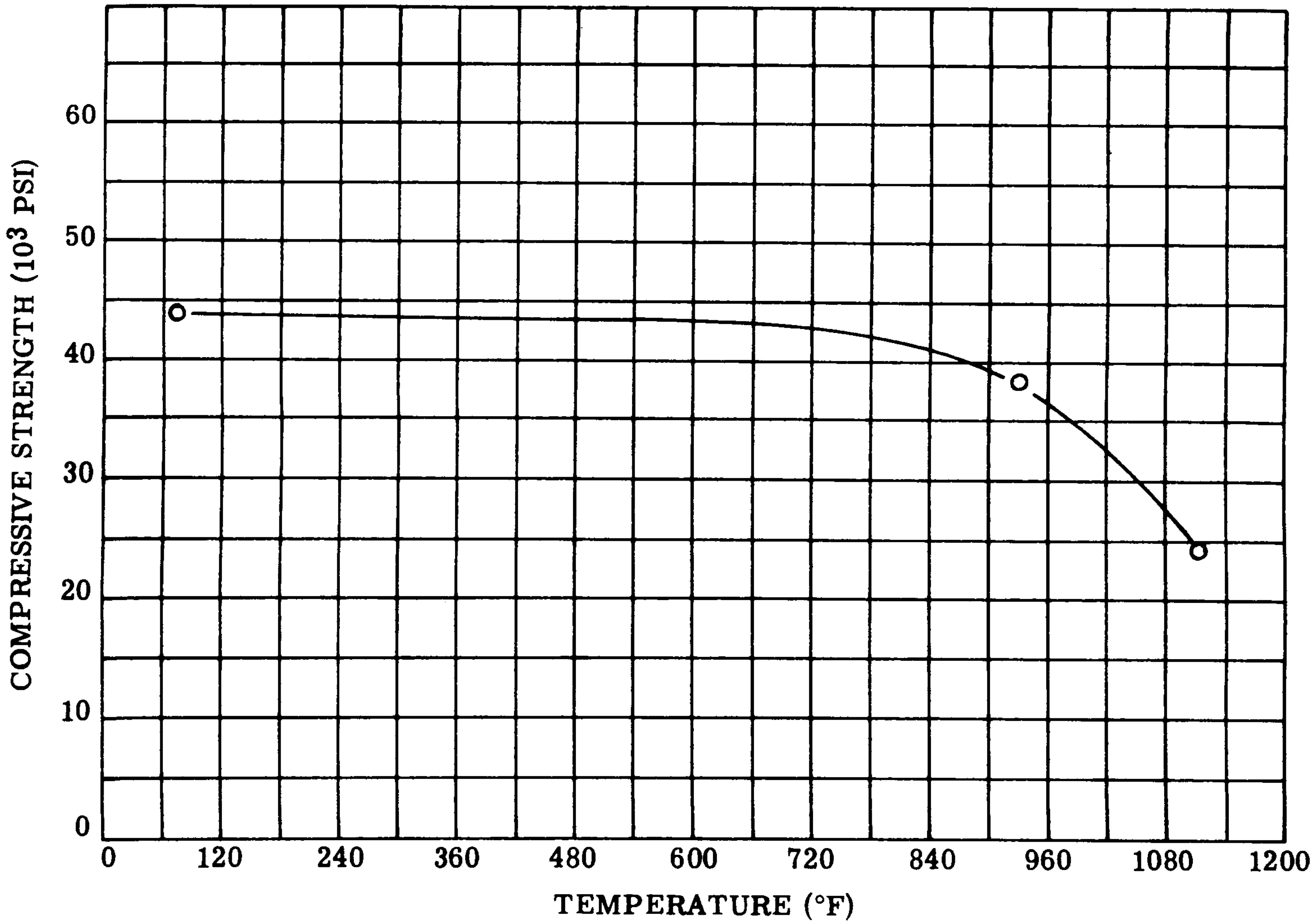


FIGURE V.D. 1-8. Compressive Strength of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos, in Air. Specimen Thickness, 0.125 Inch. Strain Rate: 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure V.D. 1-8. Compressive Strength - Rigid Sheet - BPO4 Asbestos

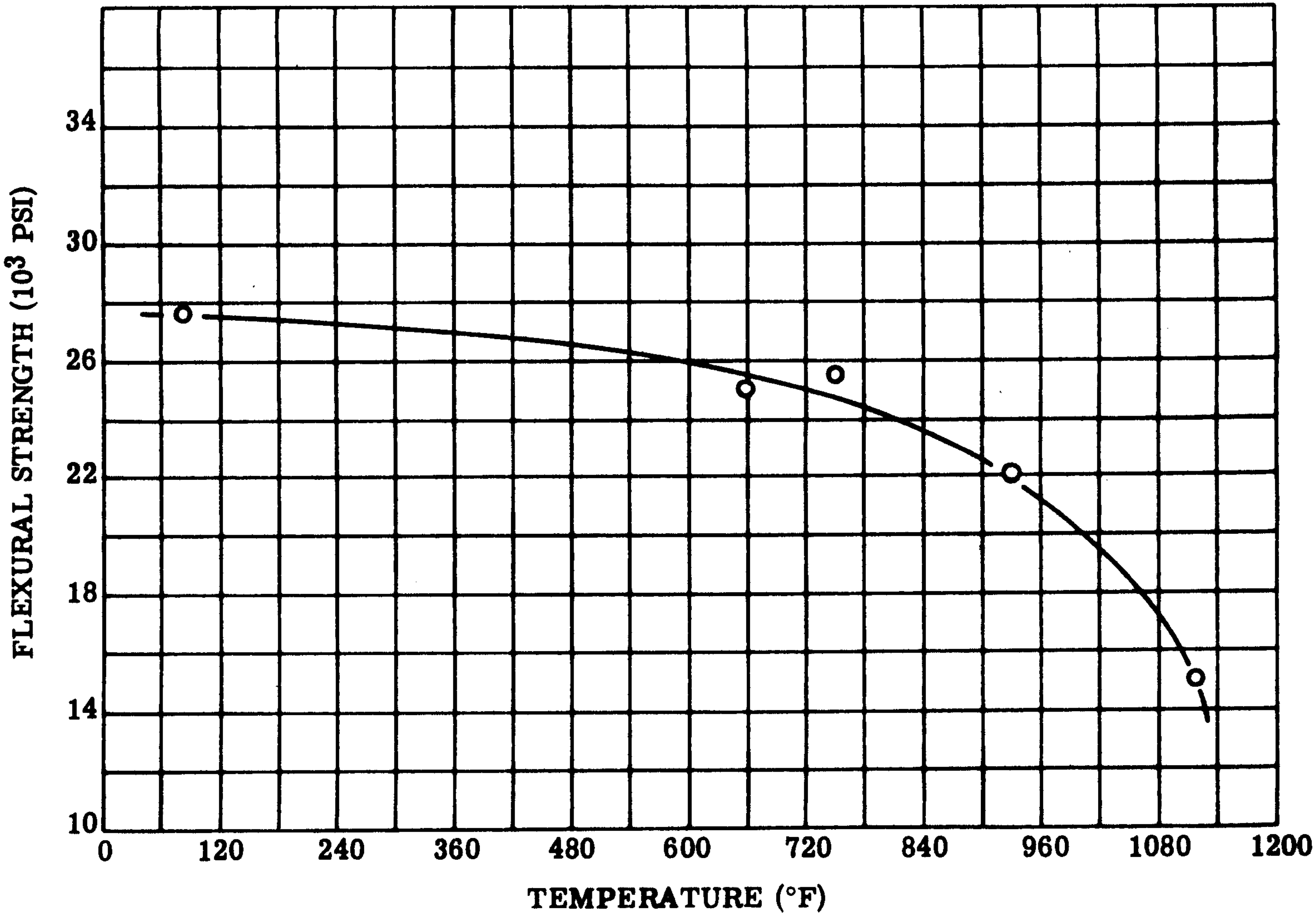


FIGURE V.D.1-9. Flexural Strength of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. Tested at Temperature in Air. Specimen Thickness, 0.125 Inch. Strain Rate: 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure V.D.1-9. Flexural Strength - Rigid Sheet - BPO_4 Asbestos

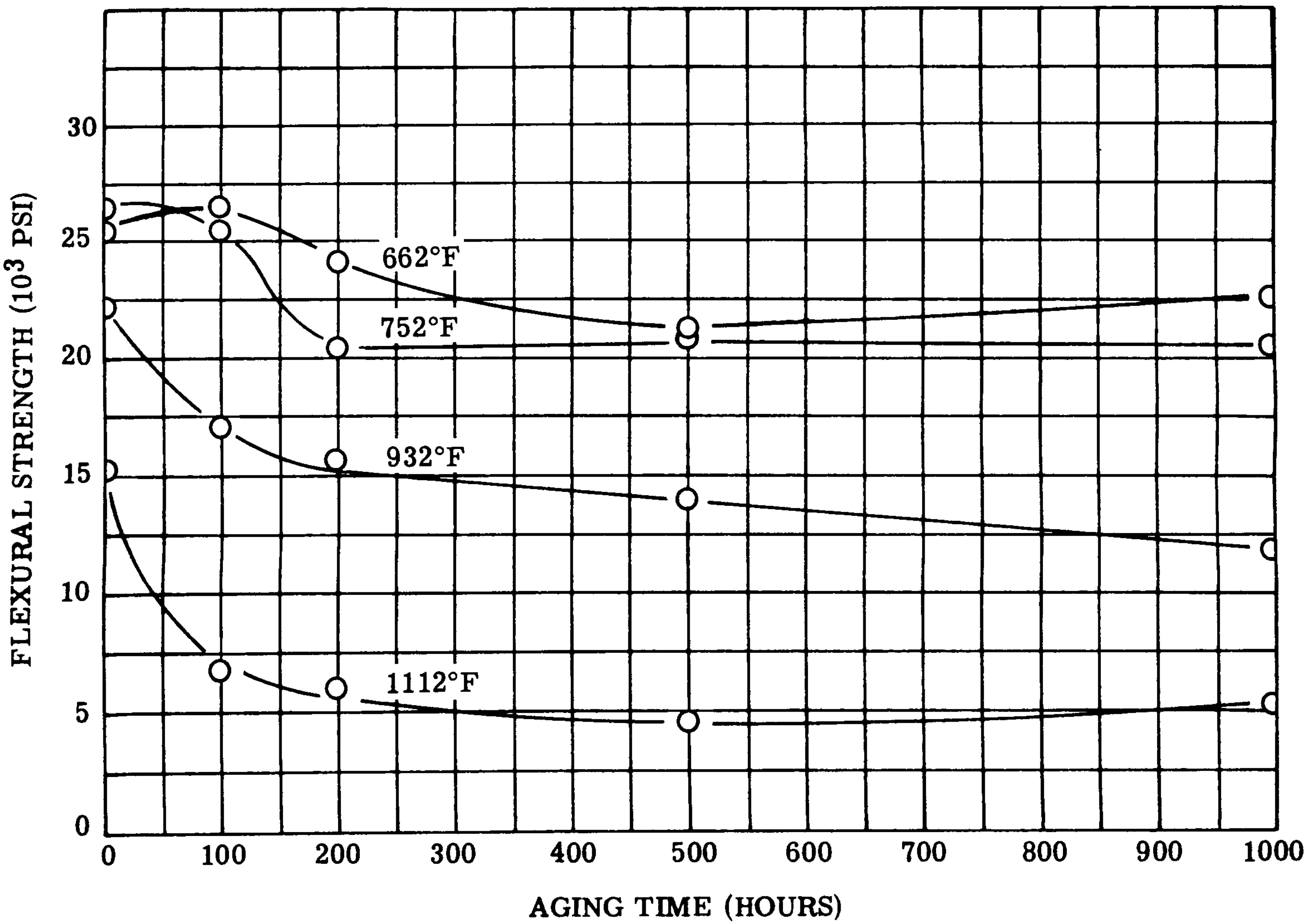


FIGURE V.D. 1-10. Flexural Strength After Aging of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. Tested at Temperature in Air. Specimen Thickness, 0.125 Inch. Strain Rate: 0.05 in/in-min to Failure. (Reference: NAS 3-4162)

Figure V.D. 1-10. Aged Flexural Strength - Rigid Sheet - BPO_4 Asbestos

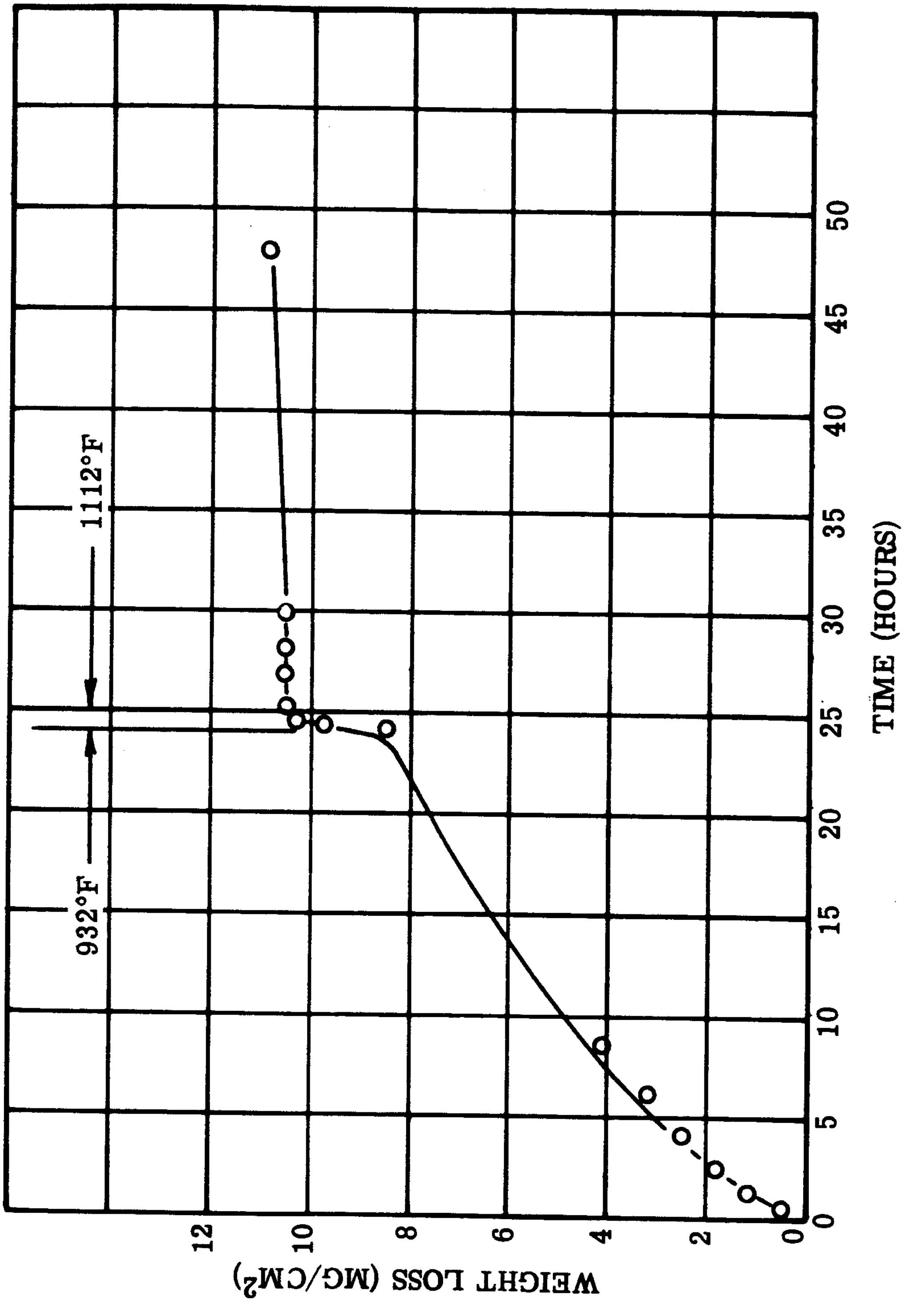


FIGURE V.D. 1-11. Weight Loss at 932°F, 1112°F and 10^{-5} to 10^{-6} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D. 1-11. Weight Loss - Rigid Sheet - BPO_4 Asbestos

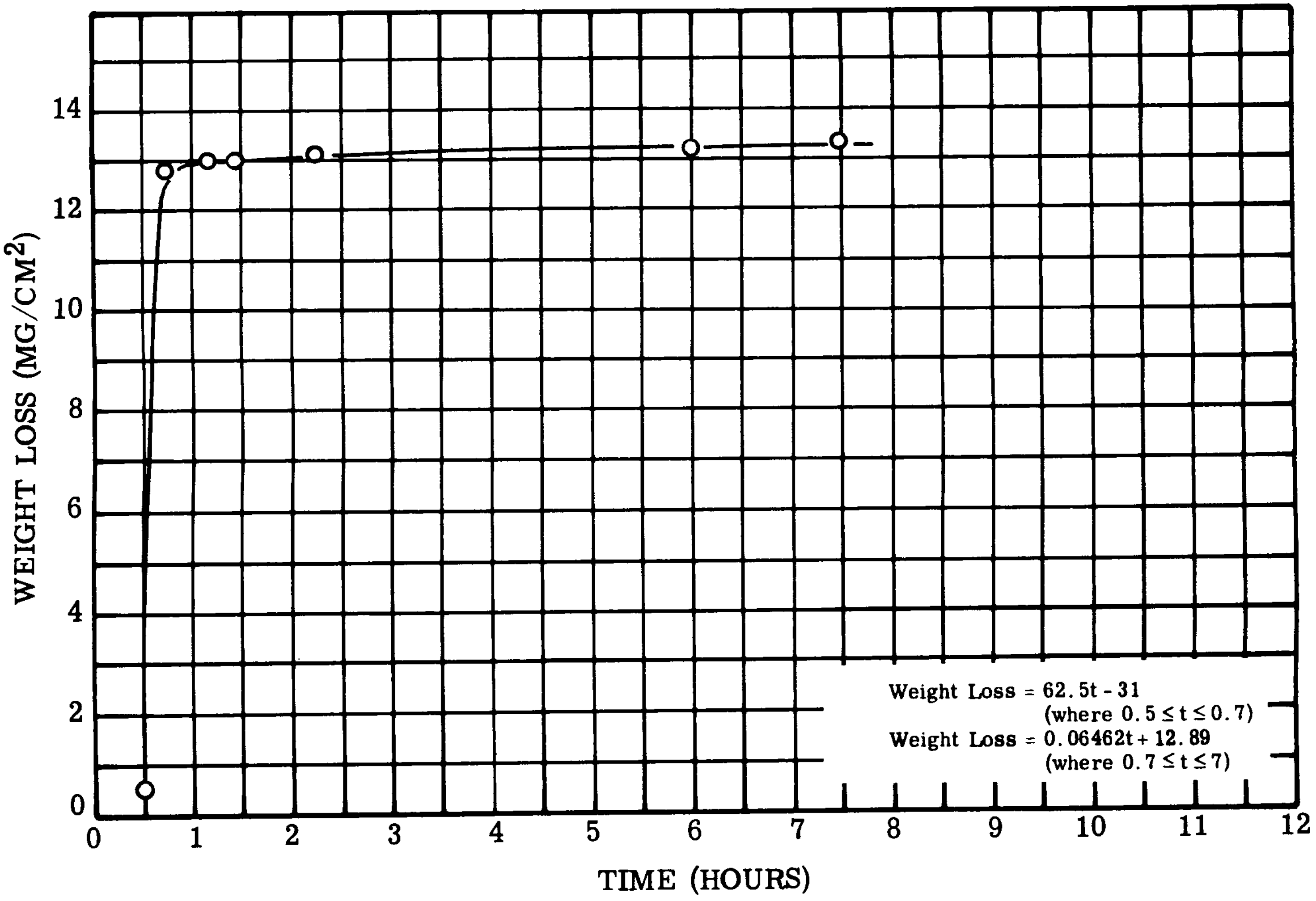


FIGURE V.D.1-12. Weight Loss at 1560°F and 10^{-3} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D.1-12. Weight Loss - Rigid Sheet - BPO_4 Asbestos

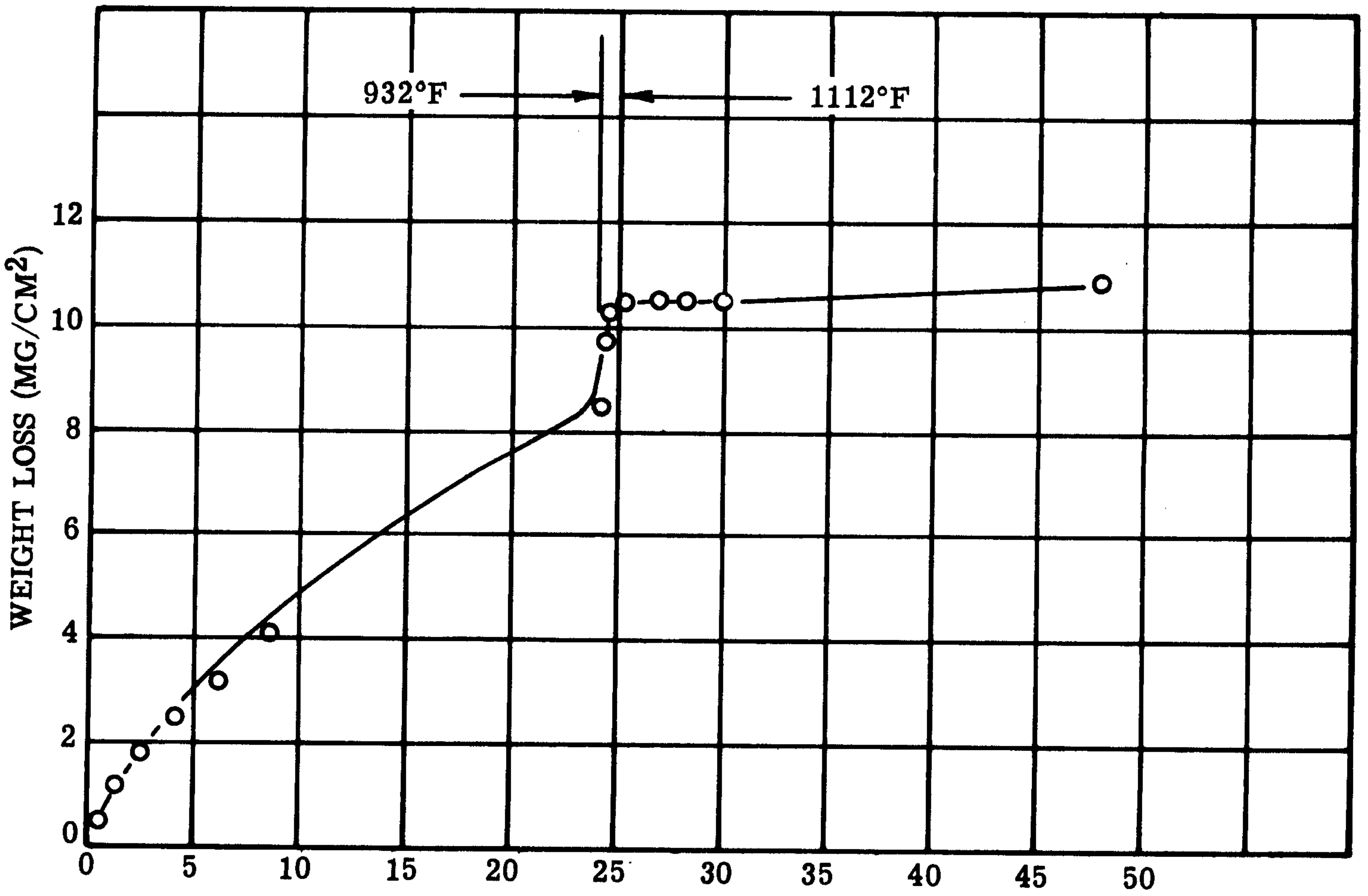


FIGURE V.D.1-11. Weight Loss at 932°F, 1112°F and 10^{-5} to 10^{-6} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D.1-11. Weight Loss - Rigid Sheet - BPO_4 Asbestos

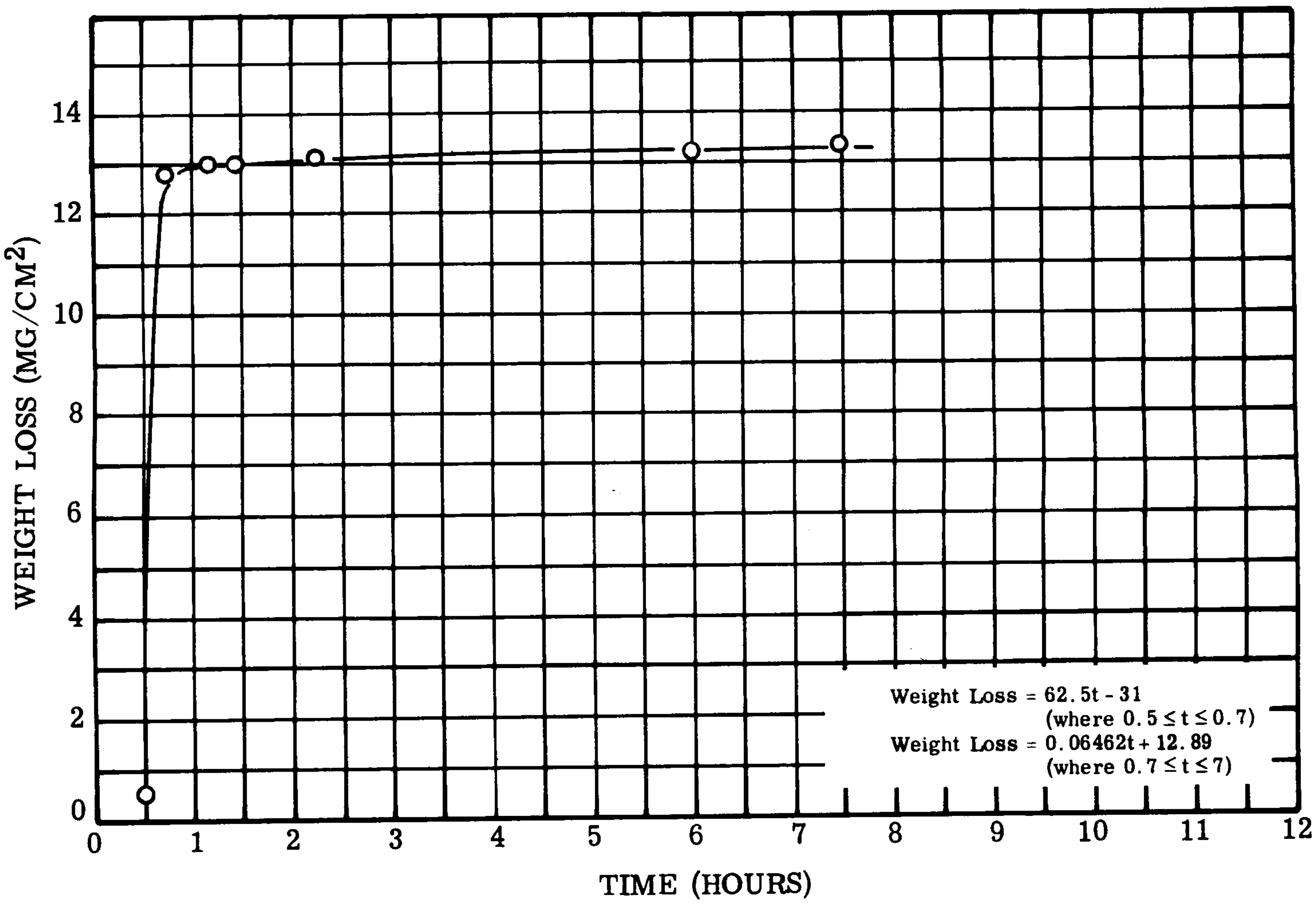


FIGURE V.D.1-12. Weight Loss at 1560°F and 10^{-3} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D.1-12. Weight Loss - Rigid Sheet - BPO_4 Asbestos

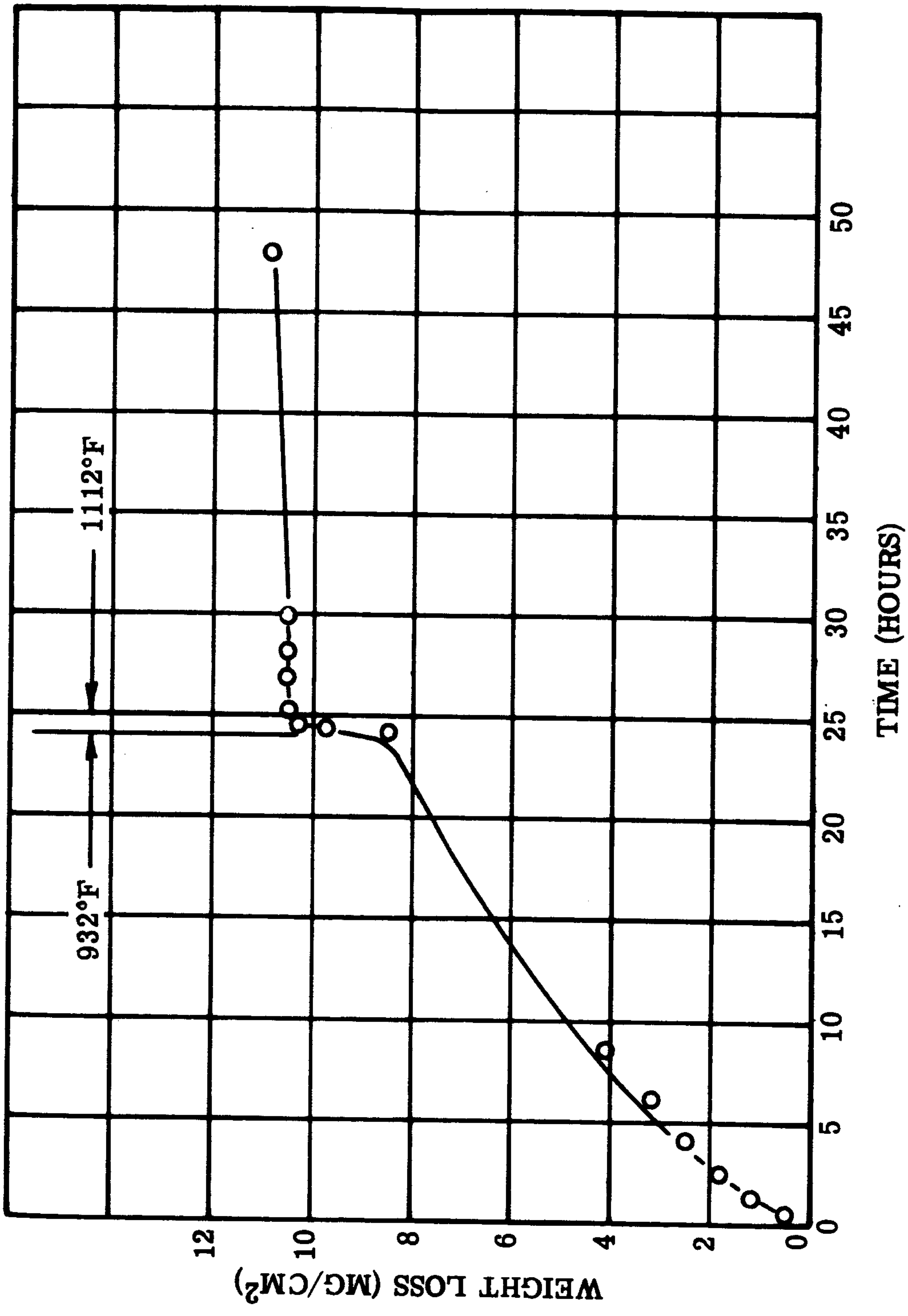


FIGURE V.D.1-11. Weight Loss at 932°F, 1112°F and 10^{-5} to 10^{-6} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D.1-11. Weight Loss - Rigid Sheet - BPO_4 Asbestos

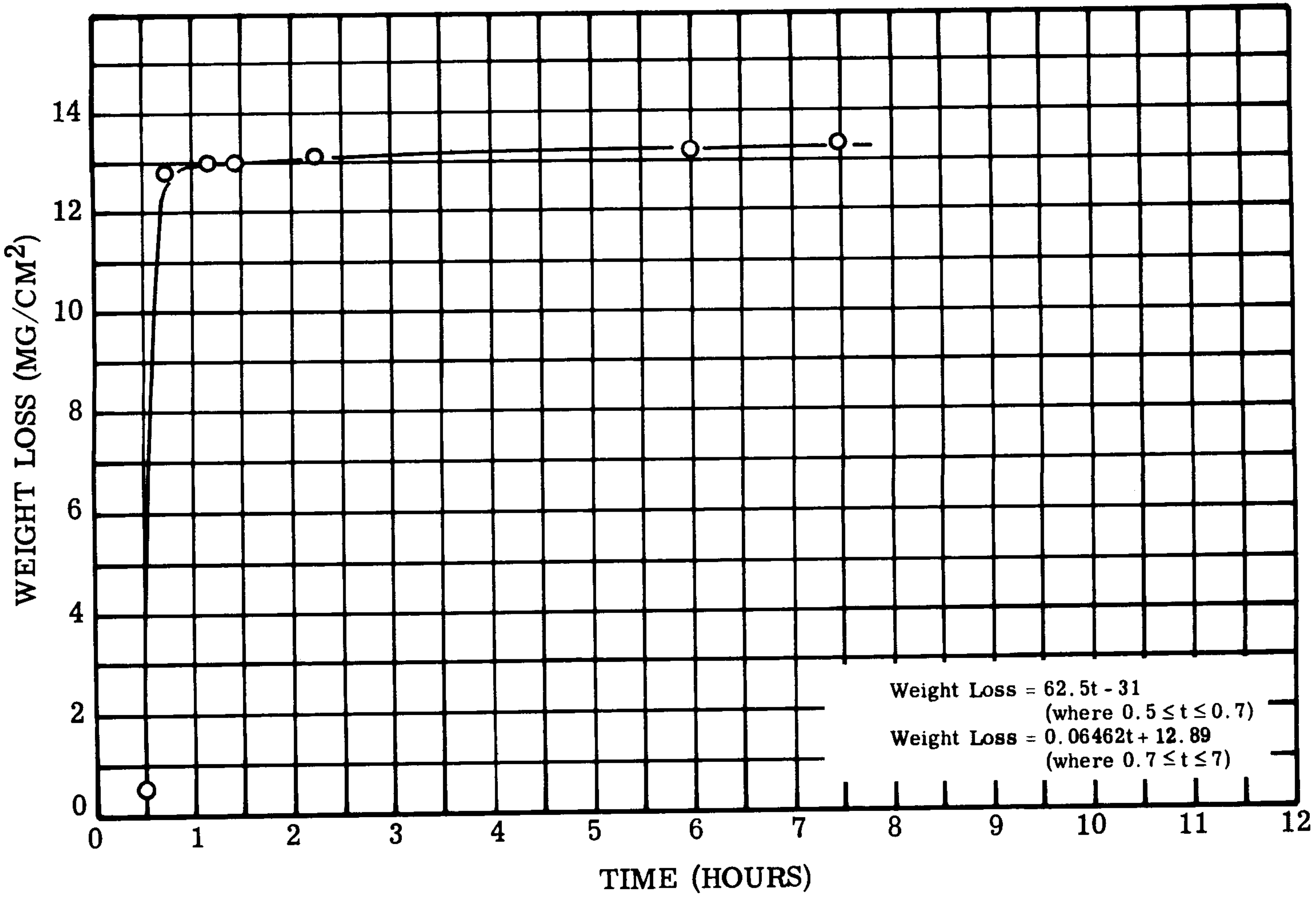


FIGURE V.D.1-12. Weight Loss at 1560°F and 10^{-3} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D.1-12. Weight Loss - Rigid Sheet - BPO_4 Asbestos

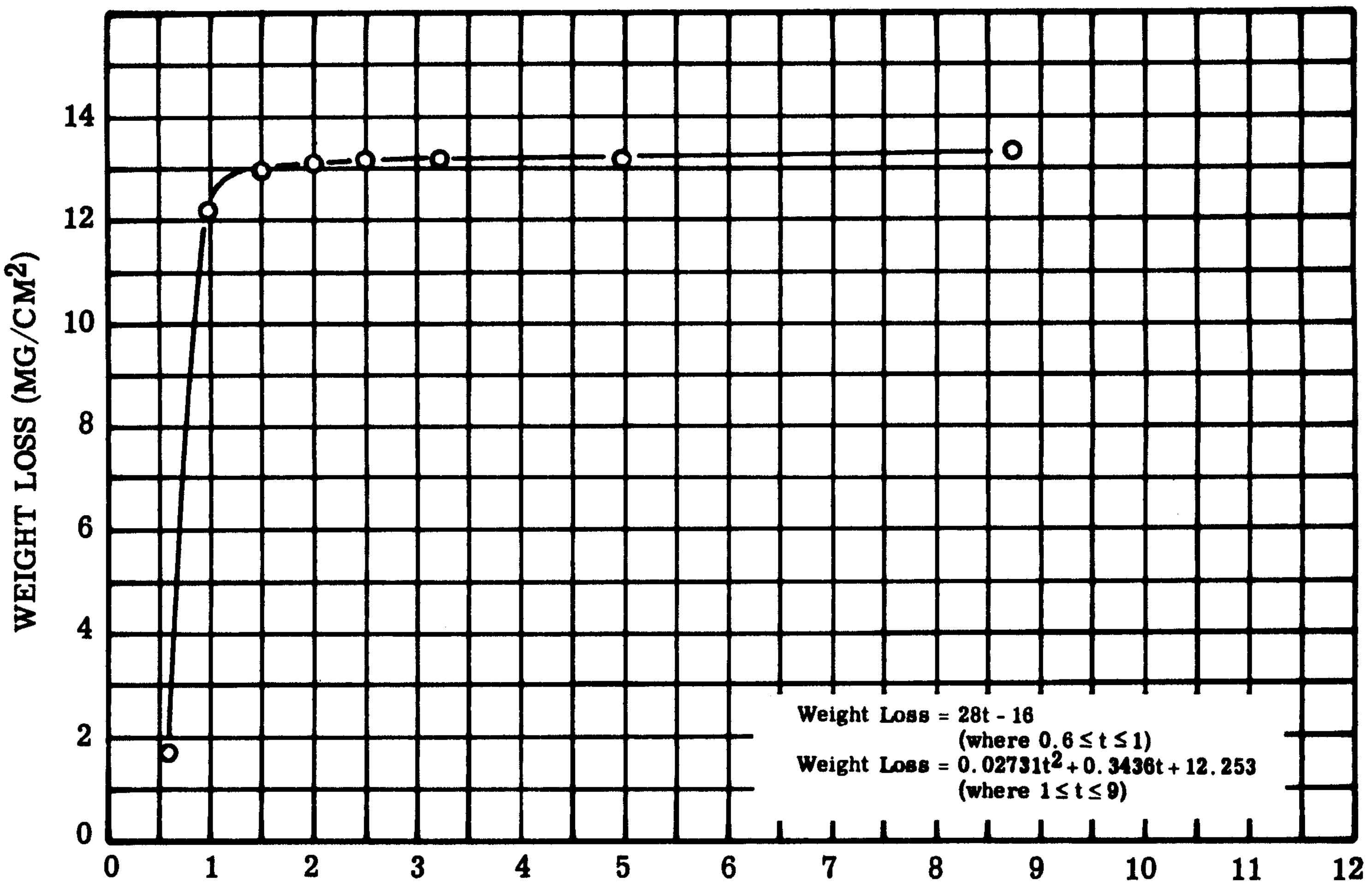


FIGURE V.D. 1-13. Weight Loss at 1560°F and 10^{-6} Torr of Inorganic Rigid Sheet Insulation, Boron Phosphate Bonded Asbestos. (Reference: NAS 3-4162)

Figure V.D. 1-13. Weight Loss - Rigid Sheet - BPO_4 Asbestos

2. DIPHENYL OXIDE - GLASS, RIGID INSULATION, LAMINATED

Diphenyl oxide-glass (Doryl laminate H-17511) is an organic laminating resin on glass cloth which is consolidated with heat and pressure to form the desired shapes.

Availability:	This material is available from Westinghouse Electric Corporation, Micarta Division, as Micarta Doryl H-17511.
Description:	Doryl H-17511 is a polymer of diphenyl oxide coated on style 181-A1100 E-glass cloth.

I. Thermophysical Properties

A. Density (77°F)(lb. cu inch) 0.068

Specimen Thickness, 0.125 Inch

B. Thermal Conductivity

Specimen Thickness, 0.25 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
134	0.0678
253	0.1040
357	0.1218

C. Coefficient of Thermal Expansion

Specimen Thickness, 0.25 Inch

Temperature Range (°F)	inch/inch-°F
77 to 350	6.9×10^{-6}
350 to 77	6.9×10^{-6}

D. Water Absorption (77°F)(weight percent) 0.352

Specimen Thickness, 0.125 Inch

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) 22

B. Dielectric Constant

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	400	4.98
77	3200	4.92
392	400	5.28
392	3200	5.05
482	400	5.33
482	3200	5.05

C. Electric Strength

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency	Volts/mil
77	DC	1332
77	400 cps	576
77	3200 cps	>384
392	DC	1015
392	400 cps	561
392	3200 cps	>376
482	DC	1197
482	400 cps	588
482	3200 cps	280 (1)

(1) This value determined in air with a 1 inch electrode. The remainder were determined in oil, 2 inch electrode.

D. Power Factor

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency (cps)	Percent
72	400	2.23
72	3200	0.83
74	1×10^6	0.009 (1)
74	1×10^6	0.011 (2)
392	400	5.32
392	3200	2.57
482	400	6.98
482	3200	2.74

E. Volume Resistivity

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency	Ohm-cm
77	DC	9.67×10^{14}
77	400 cps	4.06×10^{10}
77	3200 cps	1.37×10^{10}
392	DC	2.24×10^{12}
392	400 cps	1.59×10^{10}
482	DC	3.05×10^{11}
482	400 cps	1.22×10^{10}
482	3200 cps	4.06×10^{9}

(1) Specimens were conditioned for 48 hours at 74°F at a 50 percent relative humidity prior to testing.

(2) Specimens were immersed in water at 74°F for 24 hours prior to test.

III. Mechanical Properties

A. Compressive Strength

Specimen Thickness, 0.125 Inch

Temperature (°F)	Psi
77	70,726
350	56,400

B. Elastic Modulus in Flexure

Specimen Thickness, 0.125 Inch

Temperature (°F)	Psi
77	3.06×10^6
350	2.64×10^6
400	2.29×10^6

C. Flexural Strength (RI217)

Specimen Thickness, 0.125 Inch
Strain Rate, 0.009 inch/inch-minute to failure

Temperature (°F)	Psi
77	69,333
350	59,633
400	42,700

D. Flexural Strength after aging (RI217)

Hours at 482°F	Flexural Strength Tested at 482°F	Flexural Strength Tested at 73°F After Aging at 482°F
1	25,000 psi	72,000 psi
200	42,000 psi	50,000 psi
400	38,500 psi	44,000 psi

Hours at 482°F	Flexural Strength	
	Tested at 482°F	Tested at 73°F After Aging at 482°F
600	35,000 psi	39,000 psi
800	31,500 psi	34,500 psi
1000	27,000 psi	30,000 psi
2625	2,000 psi	4,000 psi

E.	Impact Strength (70°F)(ft-lb/in)	7.0

IV. Compatibility Properties

A. Chemical Resistance

The organic solvent resistance of diphenyl oxide-glass laminate is very good. Moisture, alkali, and acid resistances are also good.

B. Nuclear Radiation Resistance

The radiation resistance of diphenyl oxide-glass laminate is good. The resin is satisfactory at a gamma radiation level of about 10^9 rads or 10^{11} ergs gram (C).

C. Vacuum Weight Loss at elevated temperature

24 hours at 482°F and 10^{-6} torr	1.4 percent

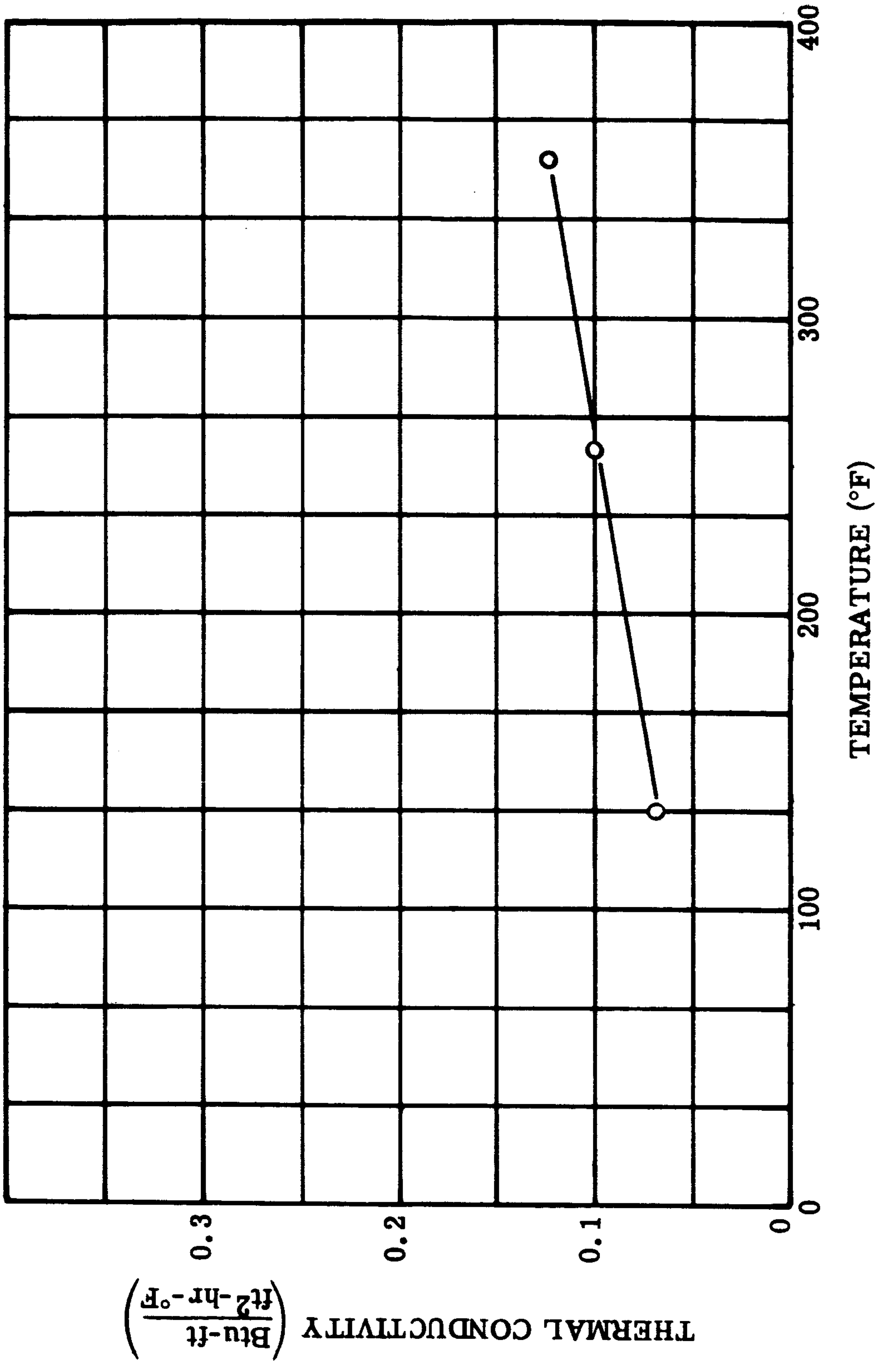


FIGURE V.D.2-1. Thermal Conductivity of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, in Air. Specimen Thickness, 0.25 Inch. (Reference: NAS 3-4162)

Figure V.D.2-1. Thermal Conductivity - Laminate - Diphenyl Oxide

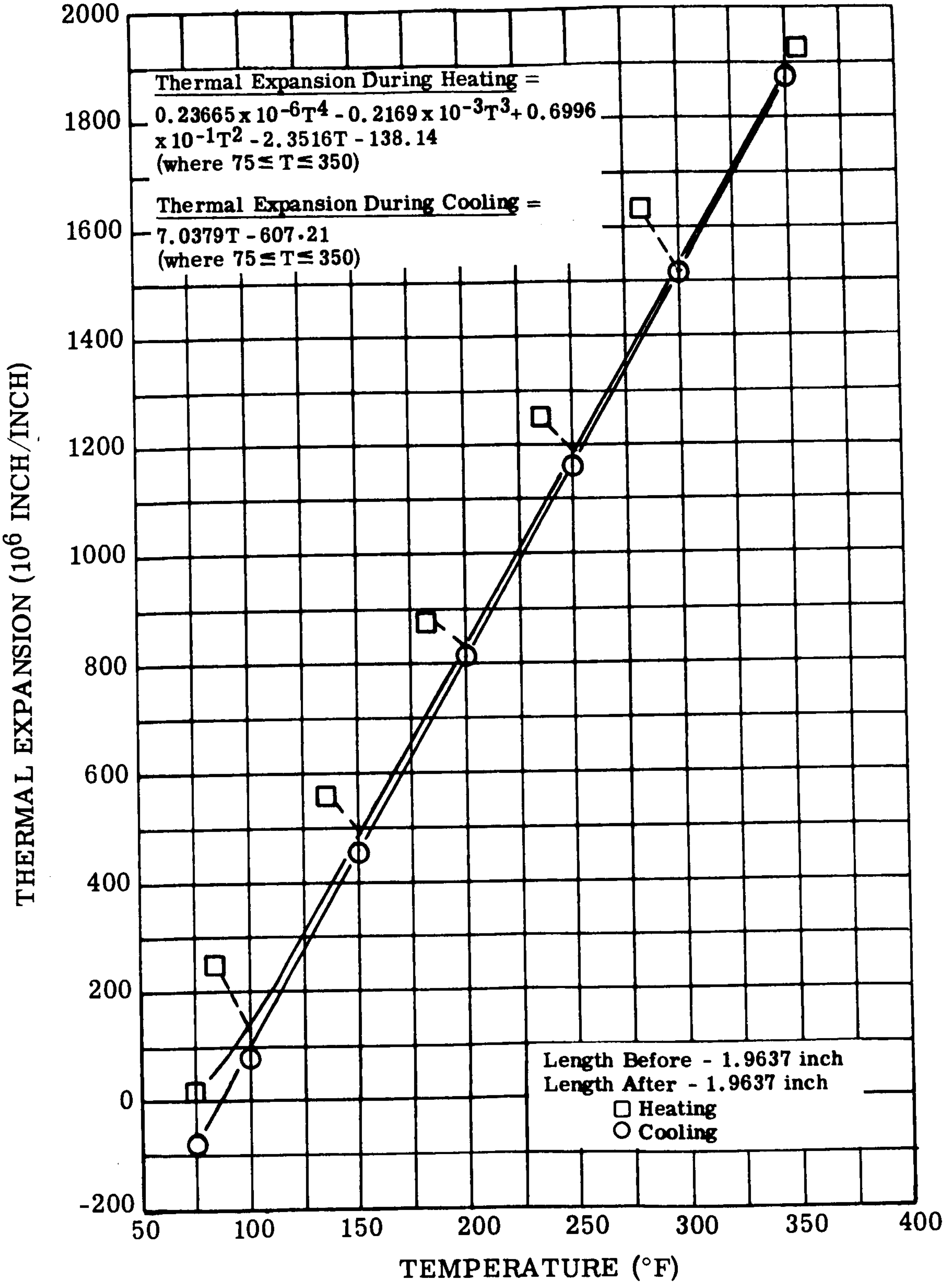


FIGURE V.D. 2-2. Thermal Expansion of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, in Air. Specimen Thickness, 0.25 Inch. (Reference: NAS 3-4162)

Figure V.D. 2-2. Thermal Expansion - Laminate - Diphenyl Oxide

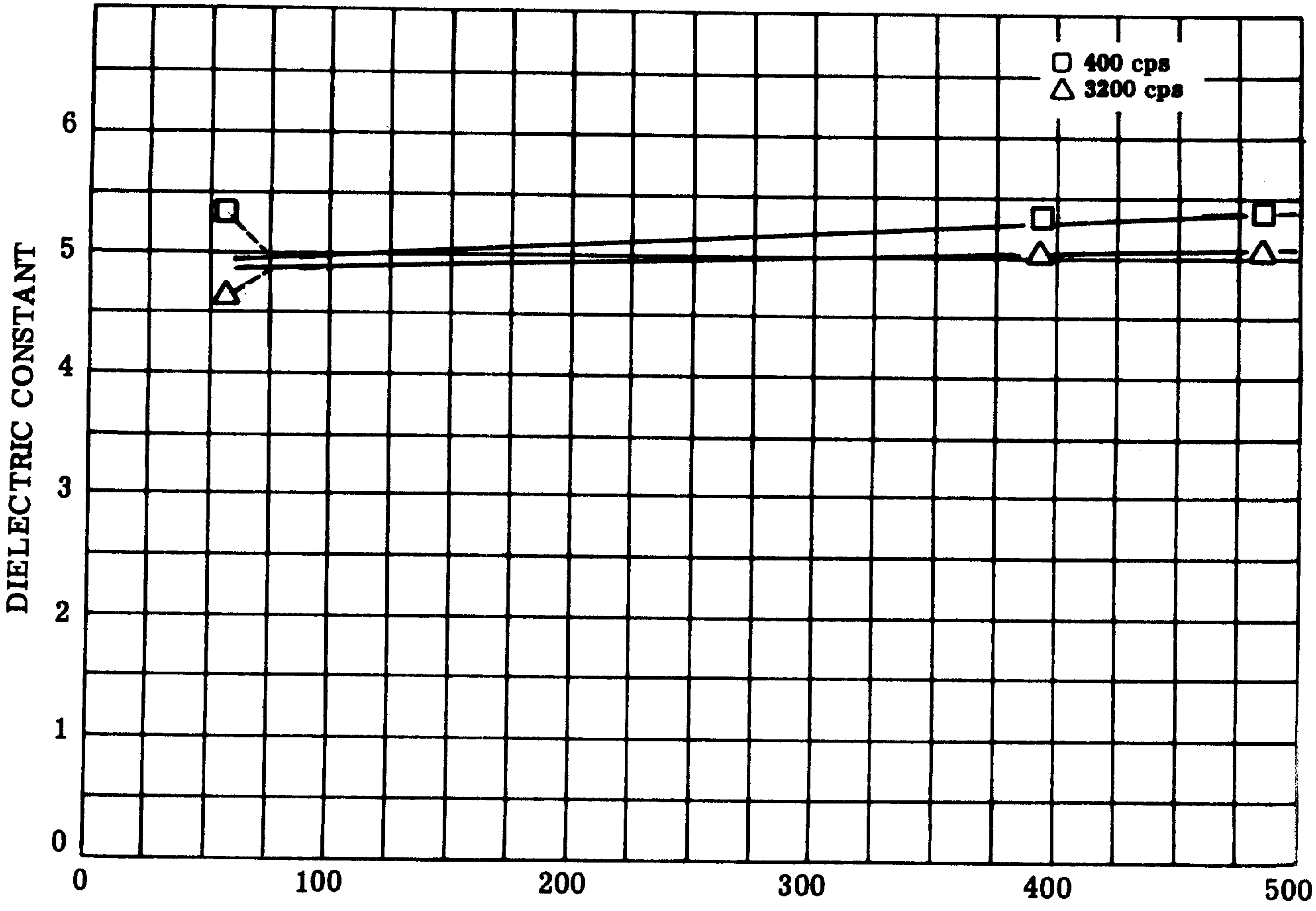


FIGURE V.D.2-3. Dielectric Constant of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, in Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D.2-3. Dielectric Constant - Laminate - Diphenyl Oxide

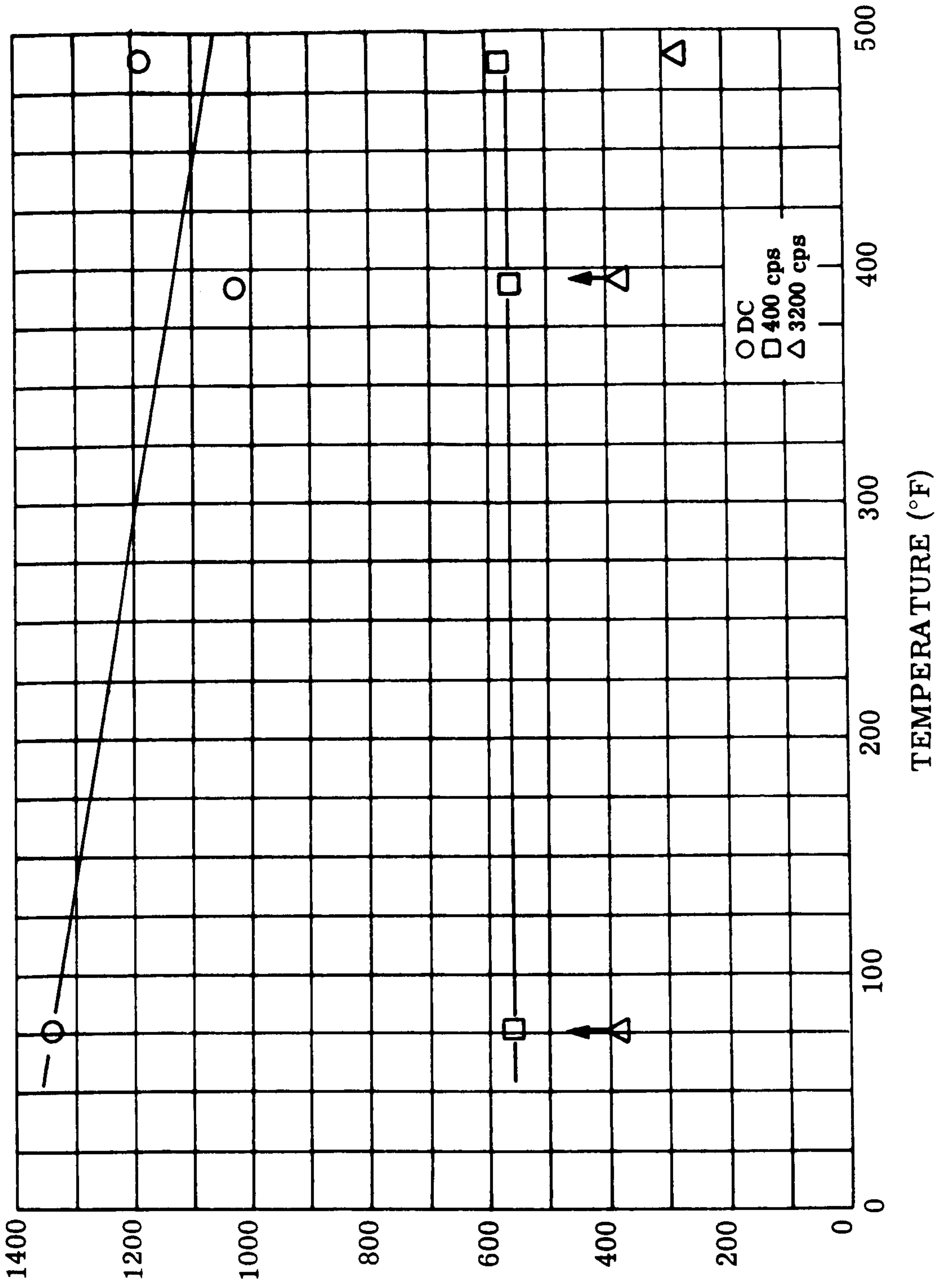


FIGURE V.D. 2-4. Electric Strength of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, In Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D. 2-4. Electric Strength - Laminate - Diphenyl Oxide

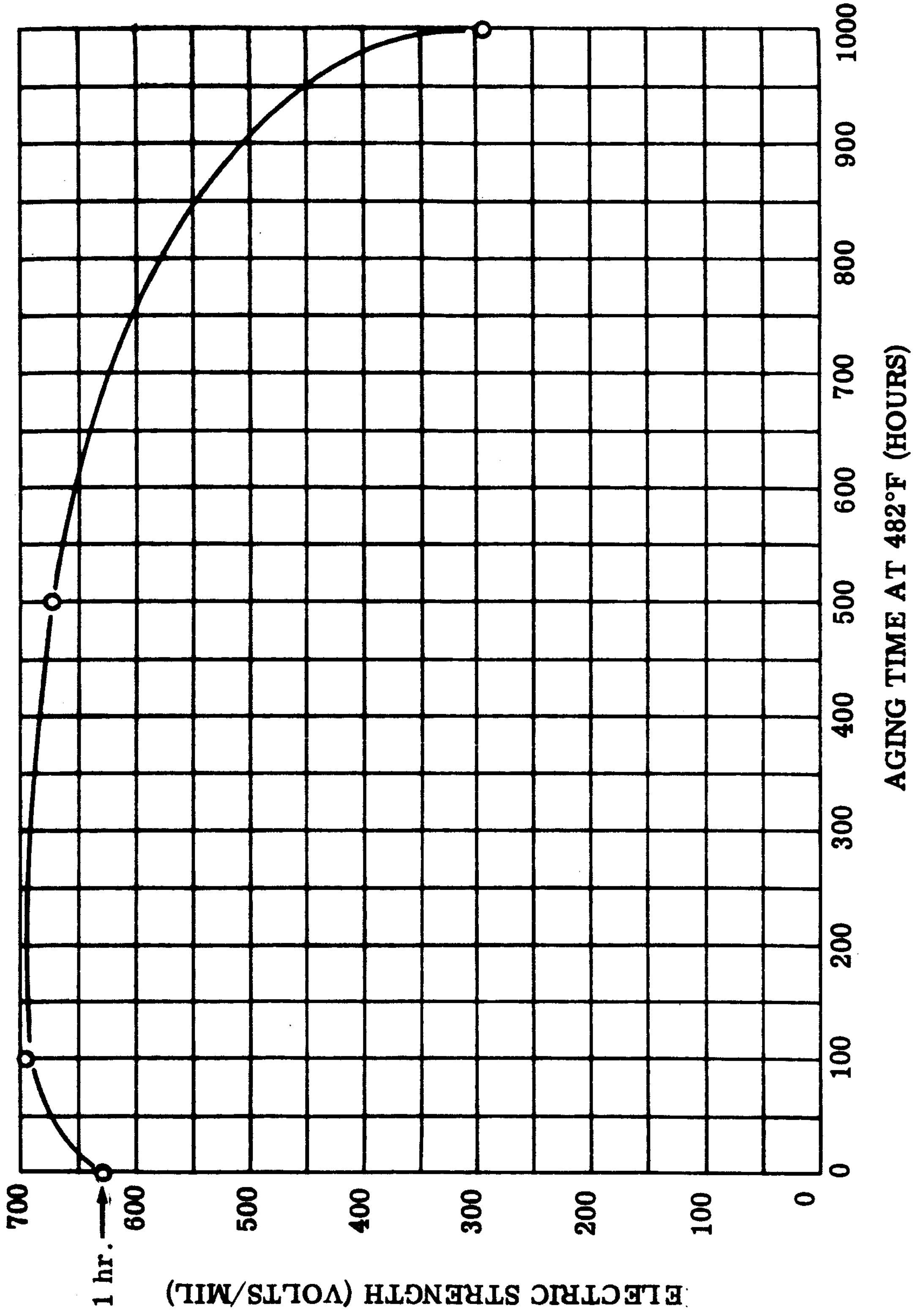


FIGURE V.D.2-5. Insulation Life (Electric Strength), After Air Aging, of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, Tested at 73°F. Specimen Thickness, 0.063 Inch. (Reference: RI217)

Figure V.D.2-5. Insulation Life - Laminate - Diphenyl Oxide

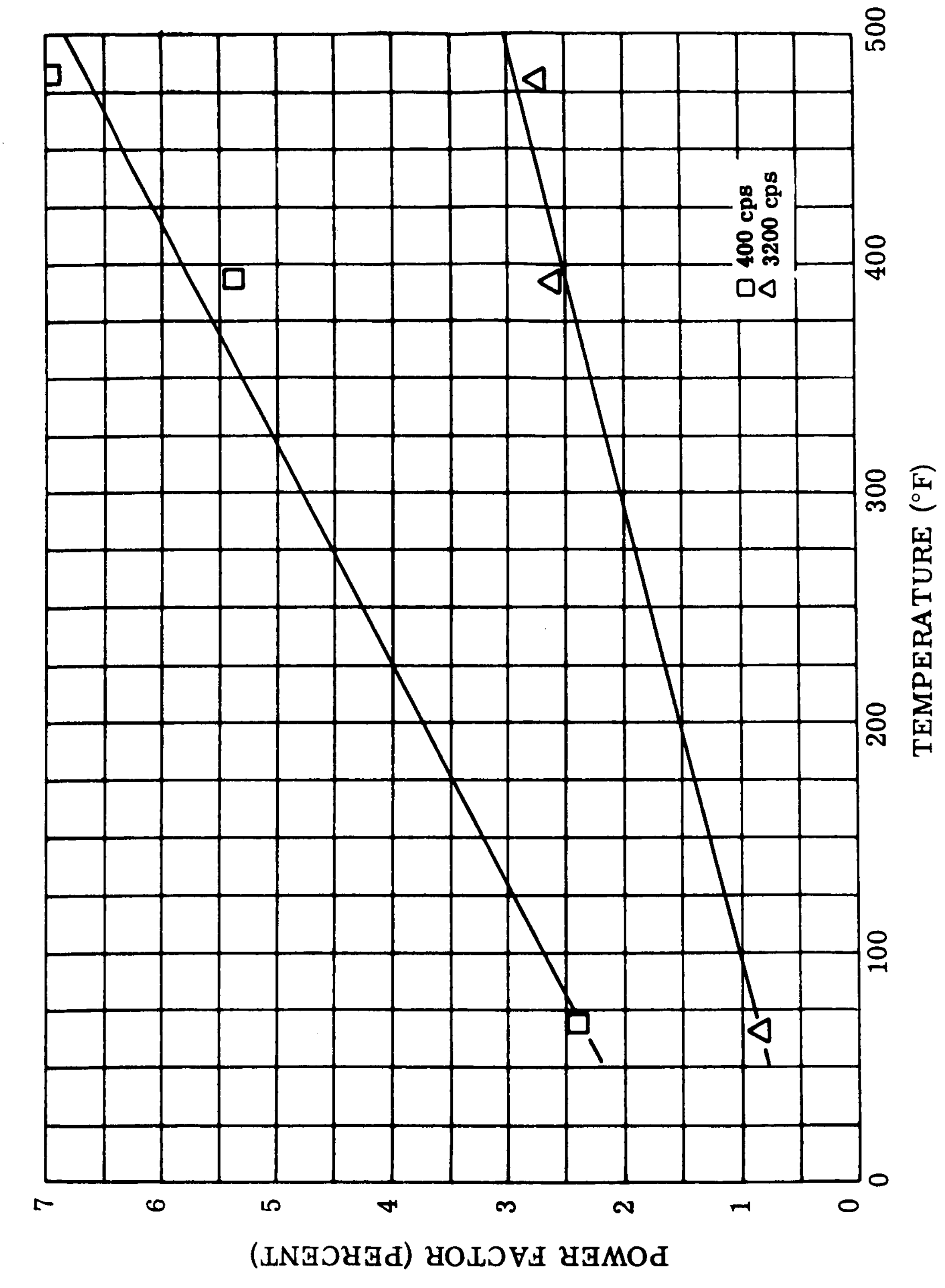


FIGURE V.D.2-6. Power Factor of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, in Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D.2-6. Power Factor - Laminate - Diphenyl Oxide

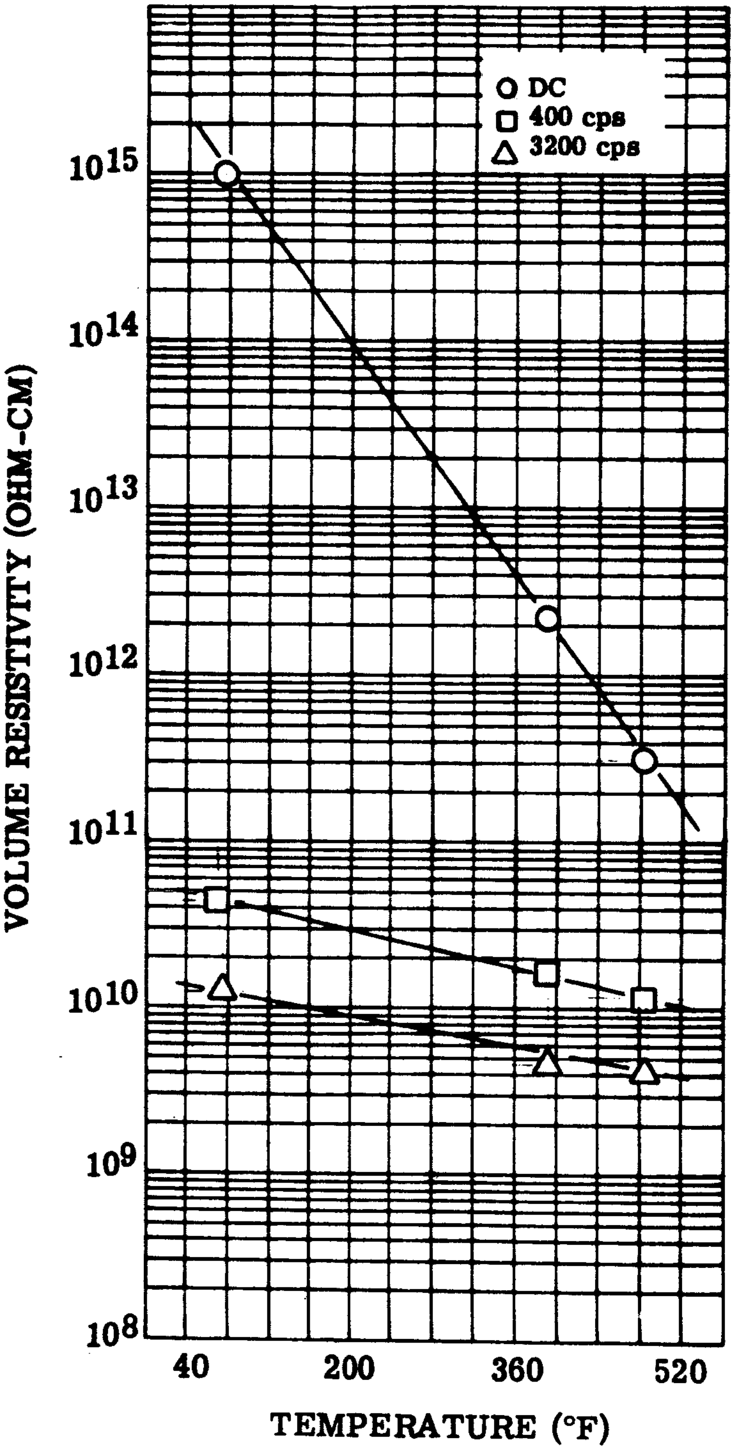


FIGURE V.D.2-7. Volume Resistivity of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, in Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D.2-7. Volume Resistivity - Laminate - Diphenyl Oxide

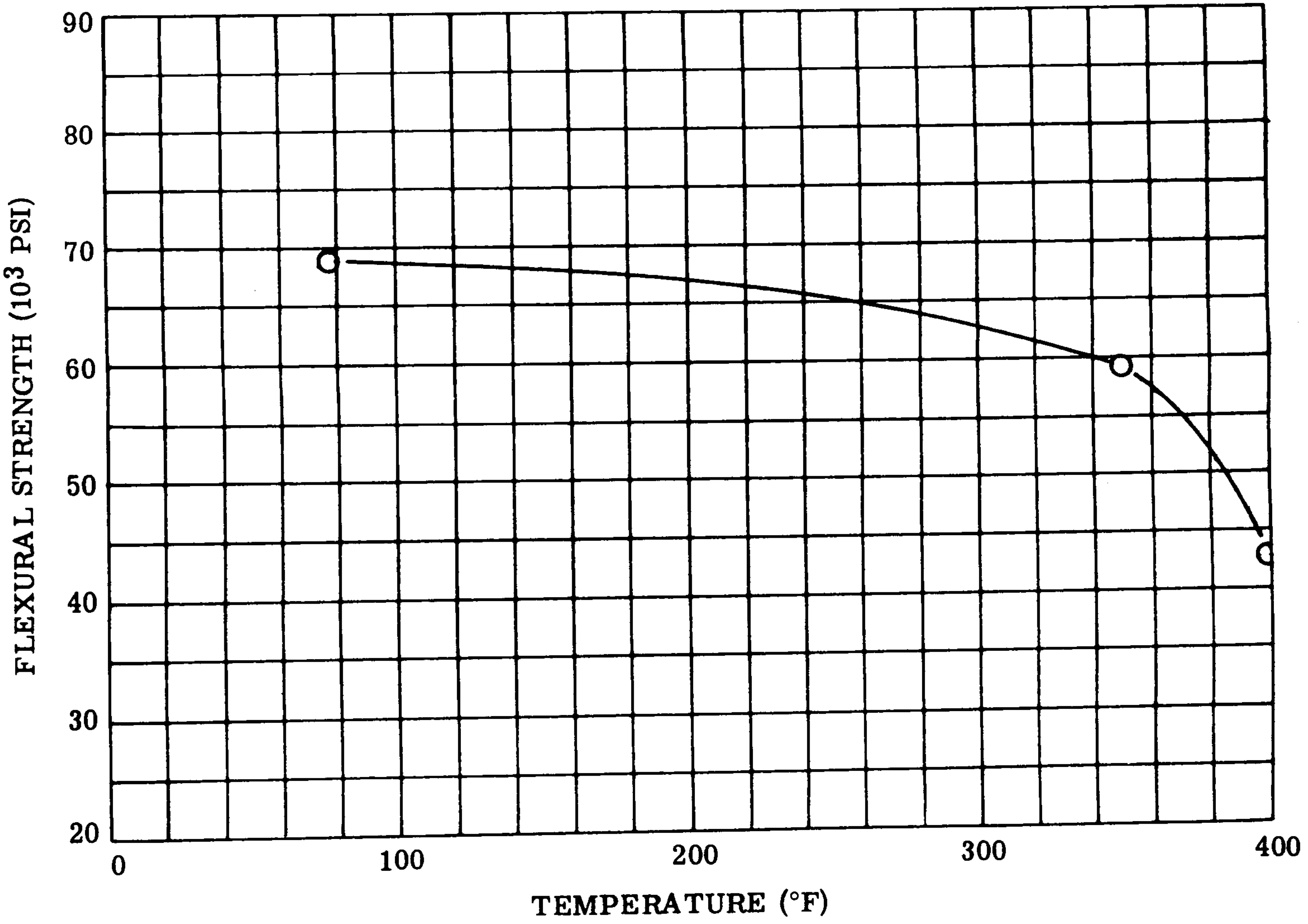


FIGURE V.D.2-8. Flexural Strength Versus Temperature of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, Tested in Air. Specimen Thickness, 0.125 Inch. (Reference: RI217)

Figure V.D.2-8. Flexural Strength - Laminate - Diphenyl Oxide

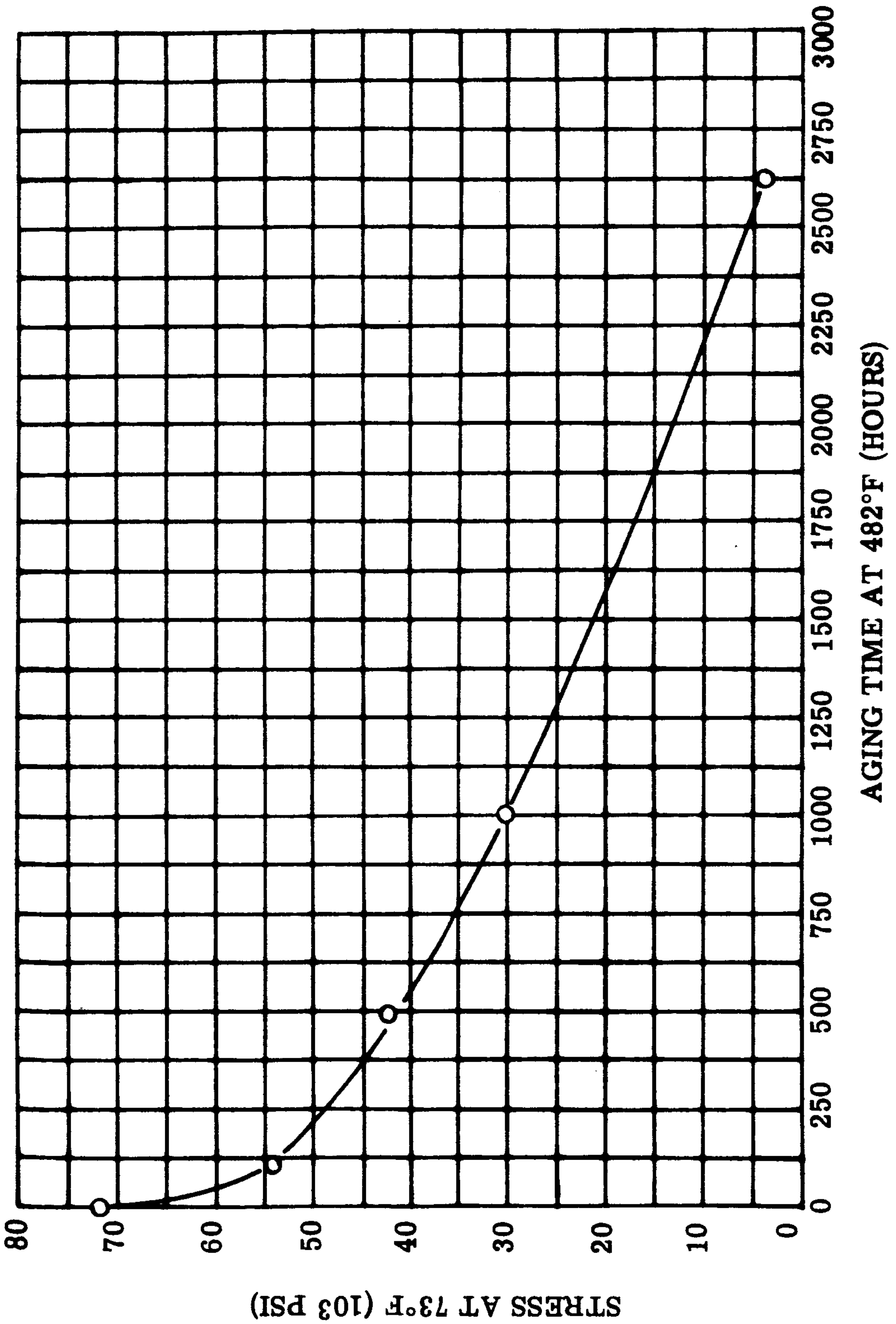


FIGURE V.D.2-9. Flexural Strength, After Air Aging, of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, Tested at 73°F in Air. Specimen Thickness, 0.125 Inch. (Reference: RI217)

Figure V.D.2-9. Aged Flexural Strength - Laminate - Diphenyl Oxide

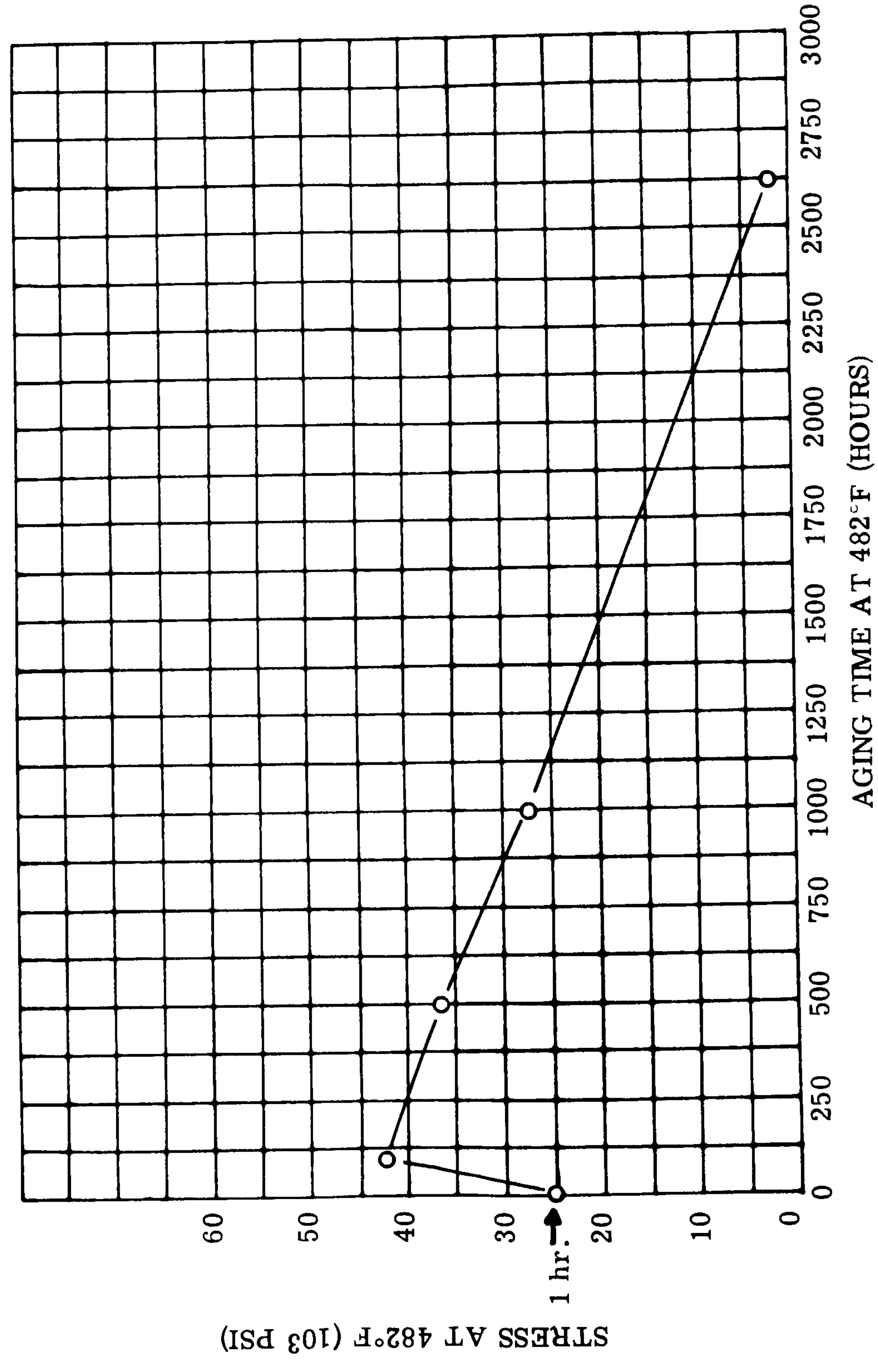


FIGURE V.D.2-10. Flexural Strength After Air Aging of Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass, Tested in Air at 482°F. Specimen Thickness, 0.125 Inch. (Reference: RI217)

Figure V.D.2-10. Aged Flexural Strength at Temperature - Laminate - Diphenyl Oxide

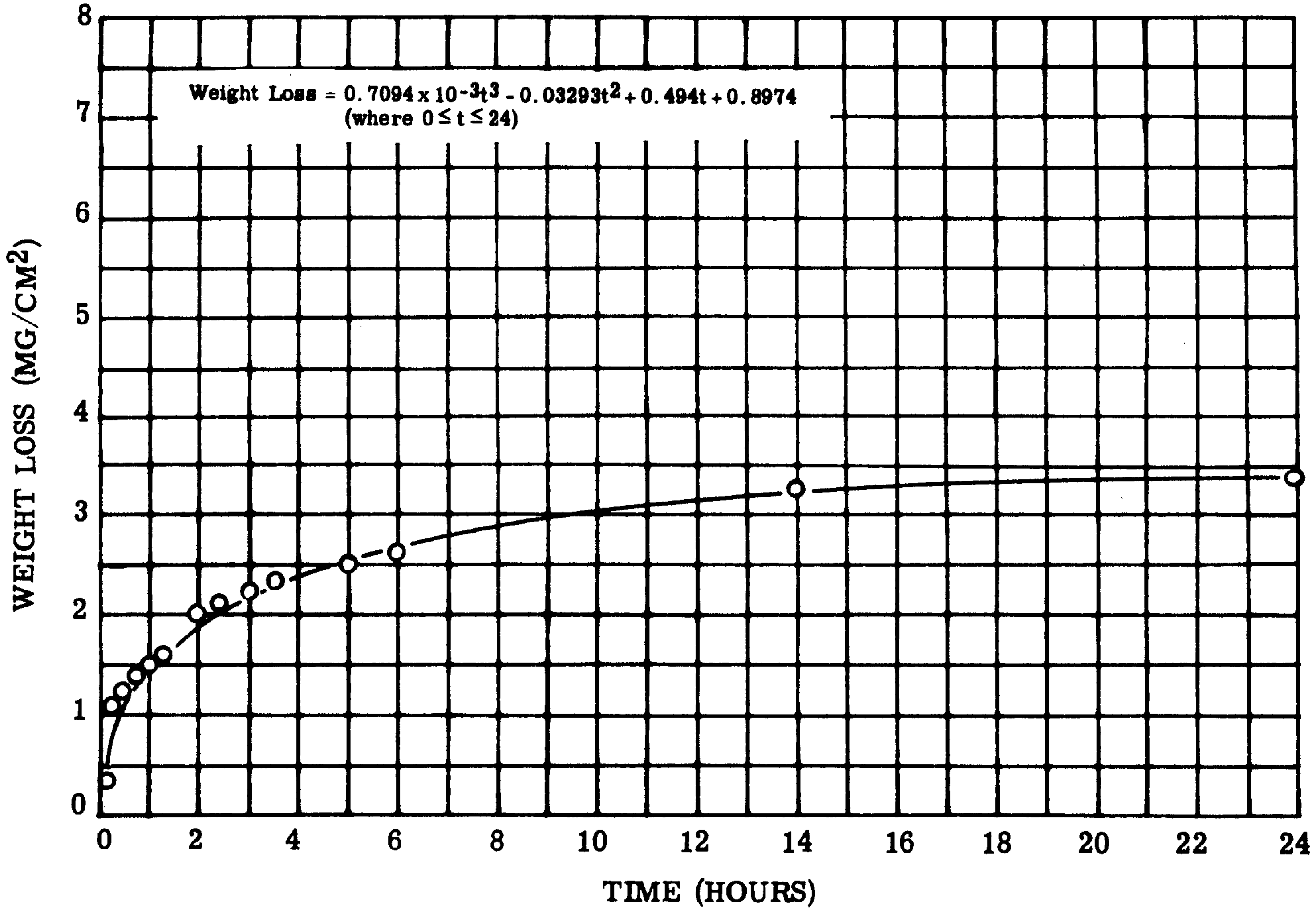


FIGURE V.D.2-11. Weight Loss at 482°F and 10^{-5} to 10^{-6} Torr for Rigid Organic Insulation, Laminated, Diphenyl Oxide-Glass. Specimen Thickness, 0.063 Inch (Reference: NAS 3-4162)

Figure V.D.2-11. Weight Loss - Laminate - Diphenyl Oxide

3. EPOXY-GLASS, RIGID INSULATION, LAMINATED

Epoxy-glass laminate (H-2497) is an organic laminating resin on glass cloth which is pressed under heat to form the desired shape.

Availability:	This material is available from Westinghouse Electric Corporation, Micarta Division, as Micarta H-2497 (G-11) in the form of molded plates or shapes.
Description:	This material is an organic anhydride cured epoxy resin, coated on Style 181, Volan A treated glass cloth. It is cured at 320°F and 200 psi for 20 minutes.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.07

Specimen Thickness, 0.125 Inch

B. Thermal Conductivity

Specimen Thickness, 0. 125 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
132	0.091
205	0.107
322	0.119

C. Coefficient of Thermal Expansion

Specimen Thickness, 0.125 Inch

Temperature Range (°F)	inch/inch-°F
77 to 350	7.60×10^{-6}
350 to 77	8.00×10^{-6}

D. Water Absorption (77°F)(weight percent) 0.095

Specimen Thickness, 0.125 Inch

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) 61.5

B. Dielectric Constant

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	400	5.02
77	3200	4.66
392	400	5.71
392	3200	5.08
482	400	7.08
482	3200	5.60

C. Electric Strength

Specimen Thickness, 0.063 Inch

Temperature (°F)	Frequency	Volts/mil
77	DC	1219
77	400 cps	503
77	3200 cps	> 351
392	DC	>1313
392	400 cps	522
392	3200 cps	306 (1)
482	DC	>1125
482	400 cps	271 (2)
482	3200 cps	> 328

---

(1) Air test with a 1 inch electrode. The balance of the tests were made in oil with a 2 inch electrode.

(2) Sample defective.

D. Insulation Life

This determination of insulation life was based upon electric strength tests of 0.063 inch thick specimens. Tests were performed at 77°F after aging at indicated times and temperatures.

The electric strength values reported below were taken from the referenced curves and are estimated values.

Time (hours)	Electric Strength (volts/mil) After Aging at; 329°F	392°F	436°F	482°F
0	680	680	680	680
100	690	710	100	90
420	-	-	-	80
1000	820	90	-	-
1600	-	-	90	-
10000	820	-	-	-
15000	710	-	-	-

E. Power Factor

Specimen Thickness, 0.125 Inch

Temperature (°F)	Frequency (cps)	Percent
72	400	5.02
72	3200	2.50
290	400	11.00
290	3200	6.00
482	400	42.00
482	3200	12.00

F. Volume Resistivity

Specimen Thickness, 0.125 Inch

Temperature (°F)	Frequency	Ohm-cm
77	DC	4.32×10^{15}
77	400 cps	1.57×10^{10}
77	3200 cps	4.32×10^{9}

Temperature (°F)	Frequency	Ohm-cm
392	DC	1.95×10^{12}
392	400 cps	6.92×10^{9}
392	3200 cps	1.59×10^{9}
482	DC	6.10×10^{9}
482	400 cps	1.40×10^{9}
482	3200 cps	7.50×10^{8}

III. Mechanical Properties

A. Compressive Strength

Specimen Thickness, 0.125 Inch

Temperature (°F)	Psi
77	74,750
350	46,283

B. Elastic Modulus in Flexure

Specimen Thickness, 0.125 Inch

Temperature (°F)	Psi
77	3.36×10^{6}
350	2.71×10^{6}

C. Flexural Strength

Specimen Thickness, 0.125 Inch
Strain Rate: 0.007 inch/inch-minute to failure

Temperature (°F)	Psi
77	71,400
350	52,300

D. Flexural Strength After Aging

Specimen Thickness, 0.125 Inch

Hours at Temperature	Aging and Test Temperature, 350°F
200	50,883 psi
400	48,633 psi
600	16,050 psi
800	19,383 psi
1000	18,533 psi

E. Impact Strength (77°F) (ft-lb/inch) 13.7

IV. Compatibility Properties

A. Chemical Resistance

Epoxy resins with anhydride catalysts are noted for their good alkali resistance. Moisture and acid resistance are fair to good. Organic solvent resistance is good except for halogenated solvents.

B. Nuclear Radiation Resistance

Epoxy resins, reinforced with glass cloth, and catalyzed with anhydridex have been successfully exposed to a gamma radiation level of 10^{10} ergs per gram (C) in vacuum environment of 10^{-7} torr. (LI296)

C. Vacuum Weight Loss at 350°F

80 hours at 10^{-6} torr	1.32 percent

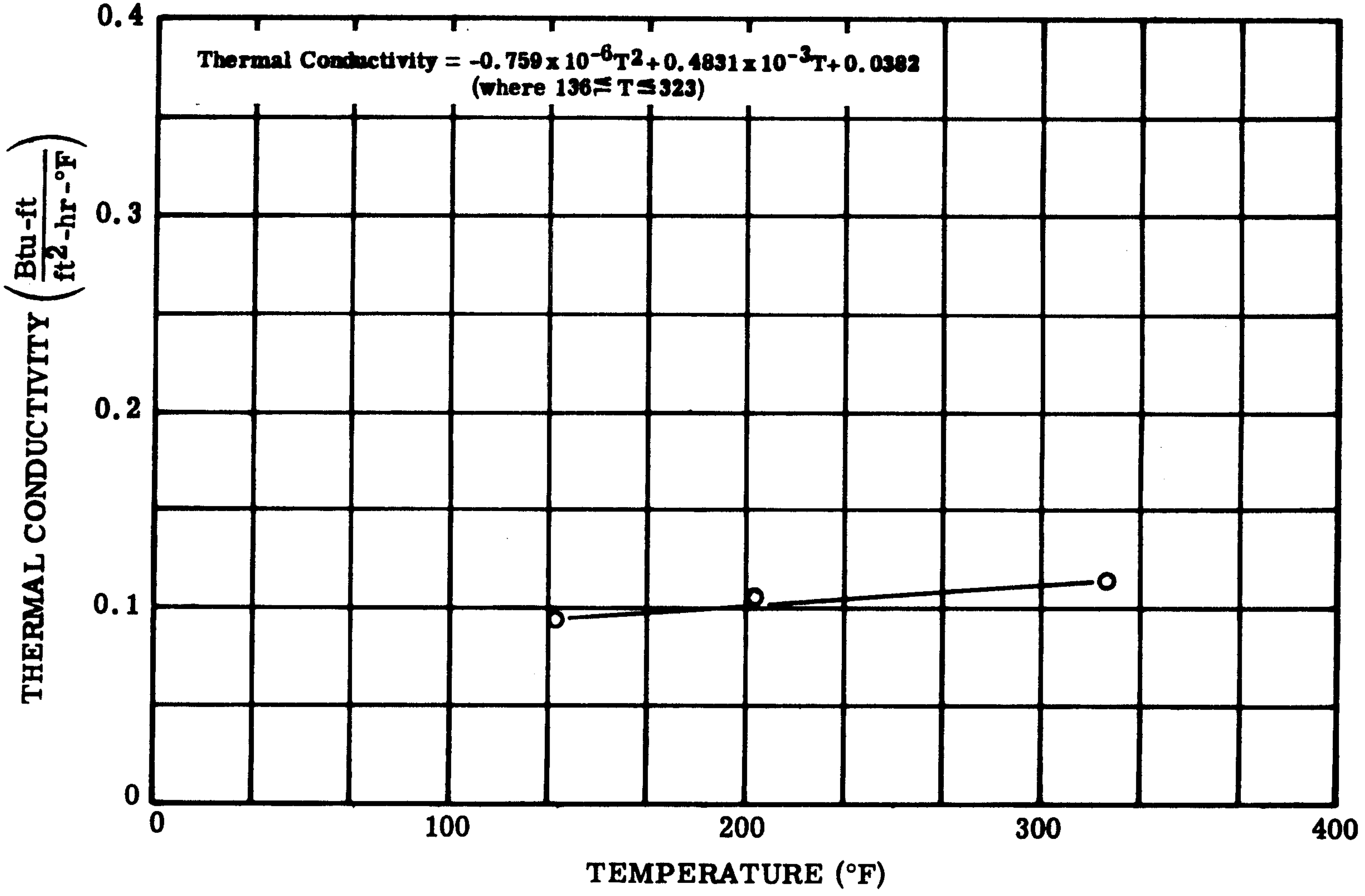


FIGURE V.D. 3-1. Thermal Conductivity of Rigid Organic Insulation, Laminated, Epoxy Glass Grade G-11, in Air. Specimen Thickness, 0. 125 Inch. (Reference: NAS 3-4162)

Figure V.D. 3-1. Thermal Conductivity - Laminate - Epoxy Glass

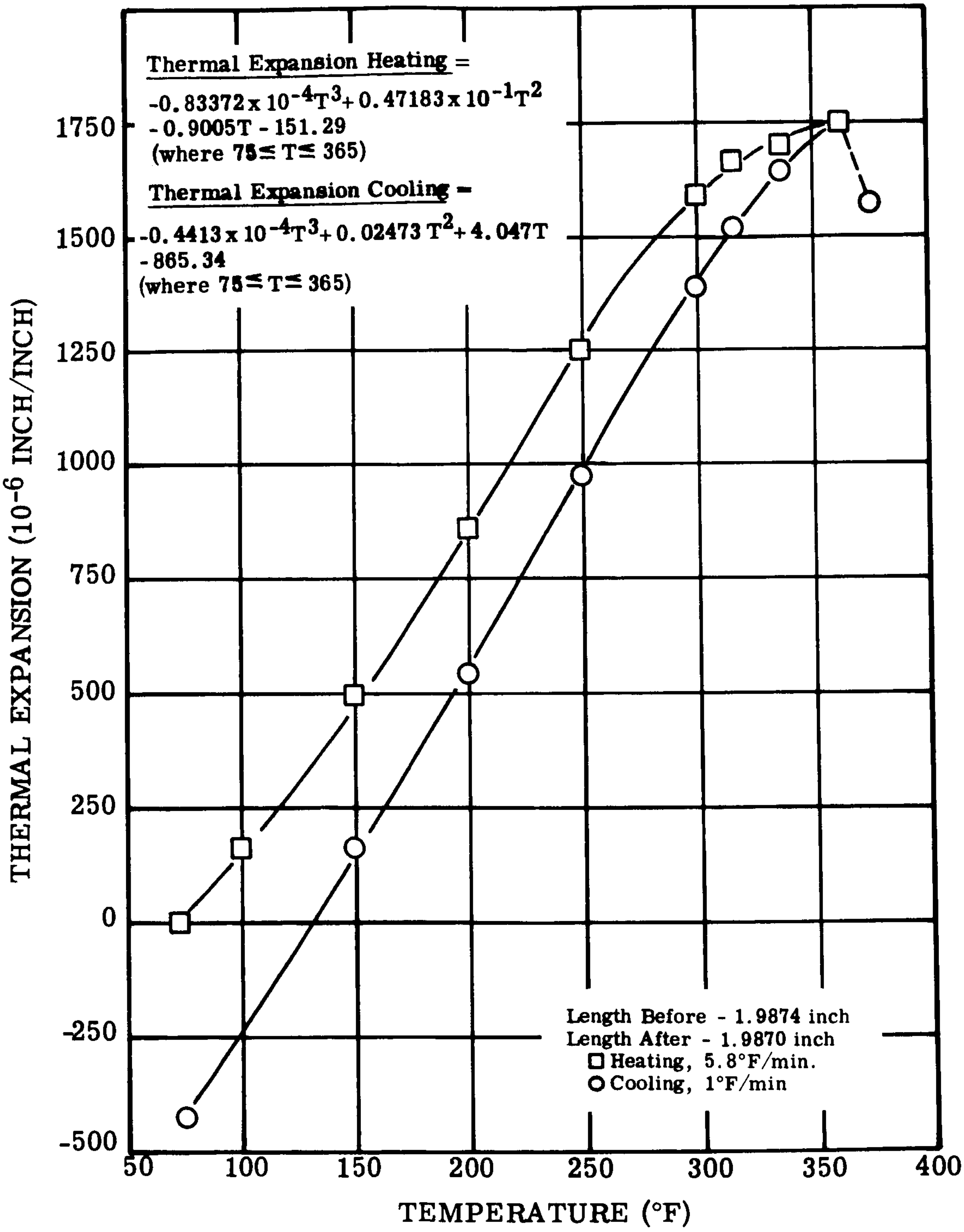


FIGURE V.D. 3-2. Thermal Expansion of Rigid Organic Insulation, Laminated, Epoxy Glass Grade G-11, in Air. Specimen Thickness, 0. 125 Inch. (Reference: NAS 3-4162)

Figure V.D. 3-2. Thermal Expansion - Laminate - Epoxy Glass

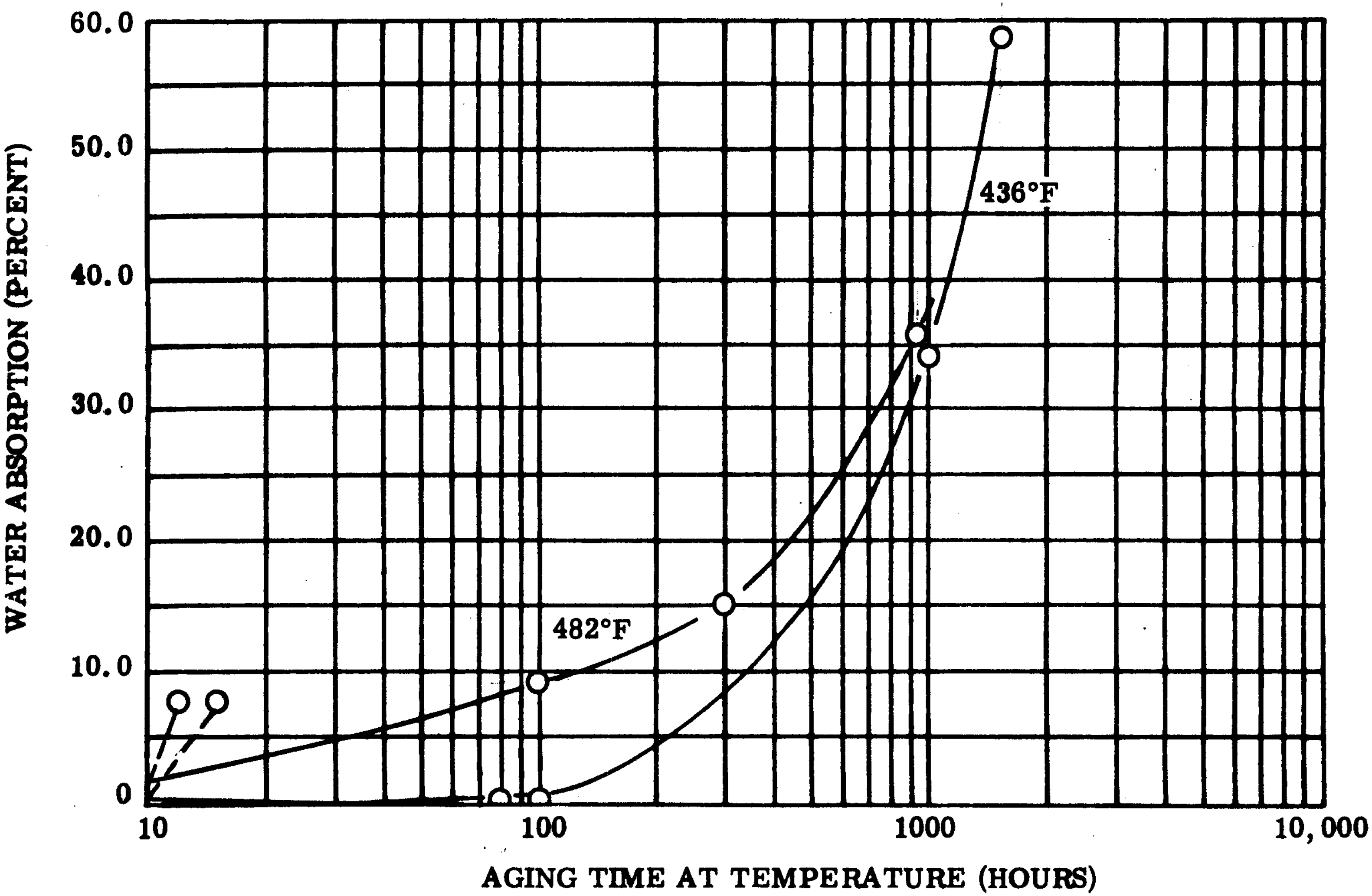


FIGURE V.D.3-3. Water Absorption of Aged Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, Tested in Air at Room Temperature. Specimen Thickness, 0.125 Inch. (Reference: RI252)

Figure V.D.3-3. Water Absorption - Laminate - Epoxy Glass

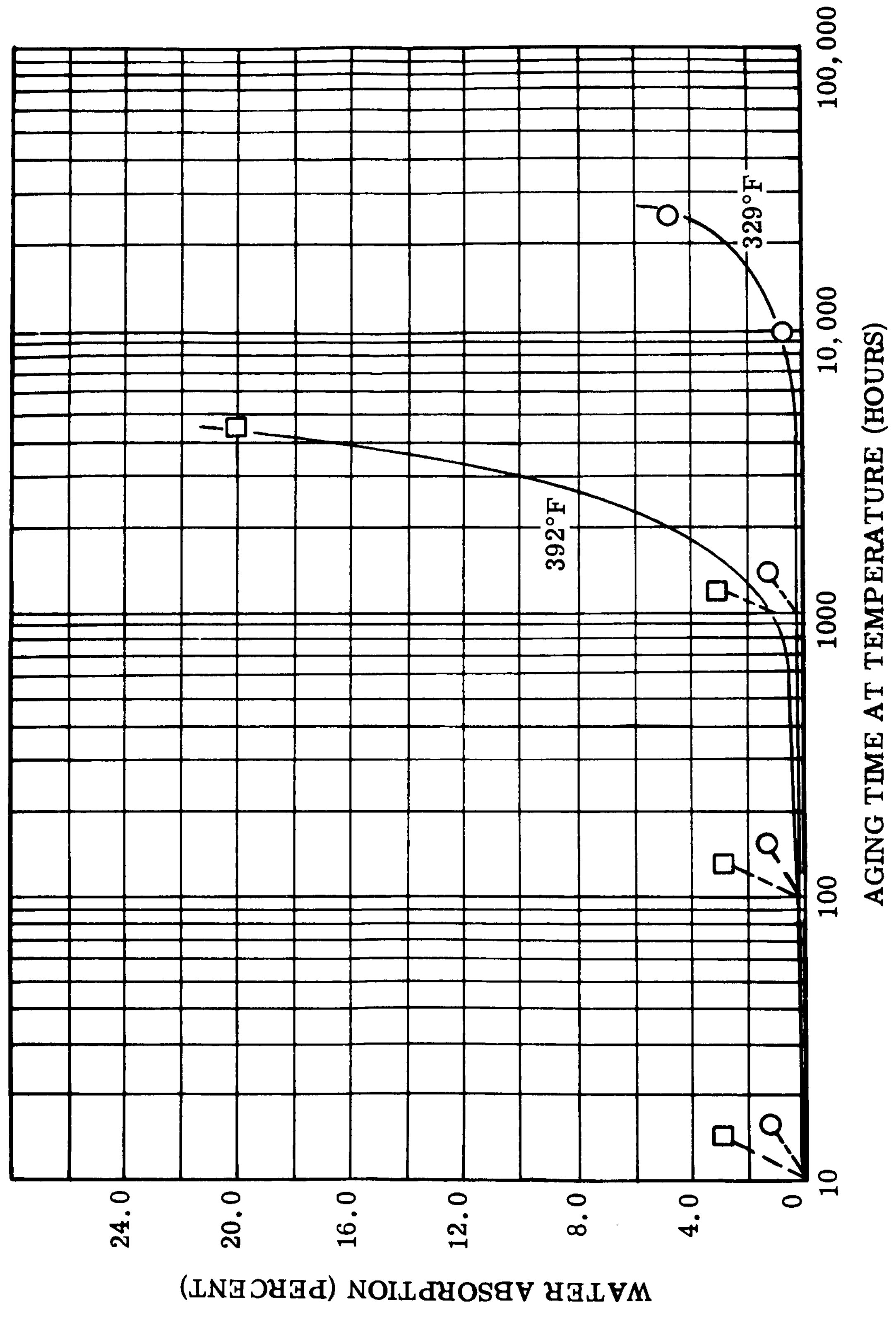


FIGURE V.D.3-4. Water Absorption After Air Aging of Rigid Organic Insulation, Laminated, Epoxy Glass Grade G-11, Tested in Air at Room Temperature. Specimen Thickness, 0.125 Inch. (Reference: RI252)

Figure V.D.3-4. Water Absorption - Laminate - Epoxy Glass

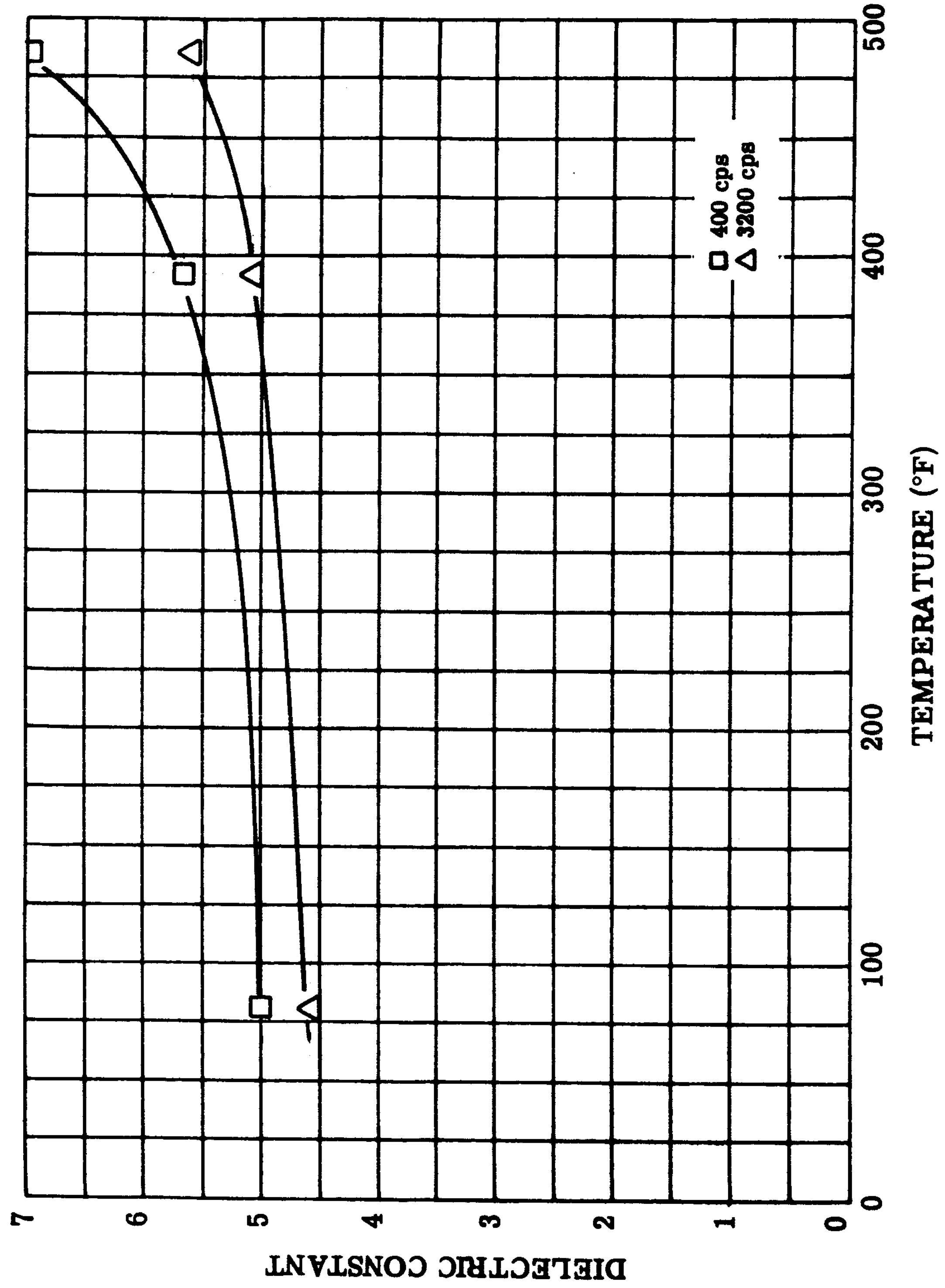


FIGURE V.D.3-5. Dielectric Constant of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, in Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D.3-5. Dielectric Constant - Laminate - Epoxy Glass

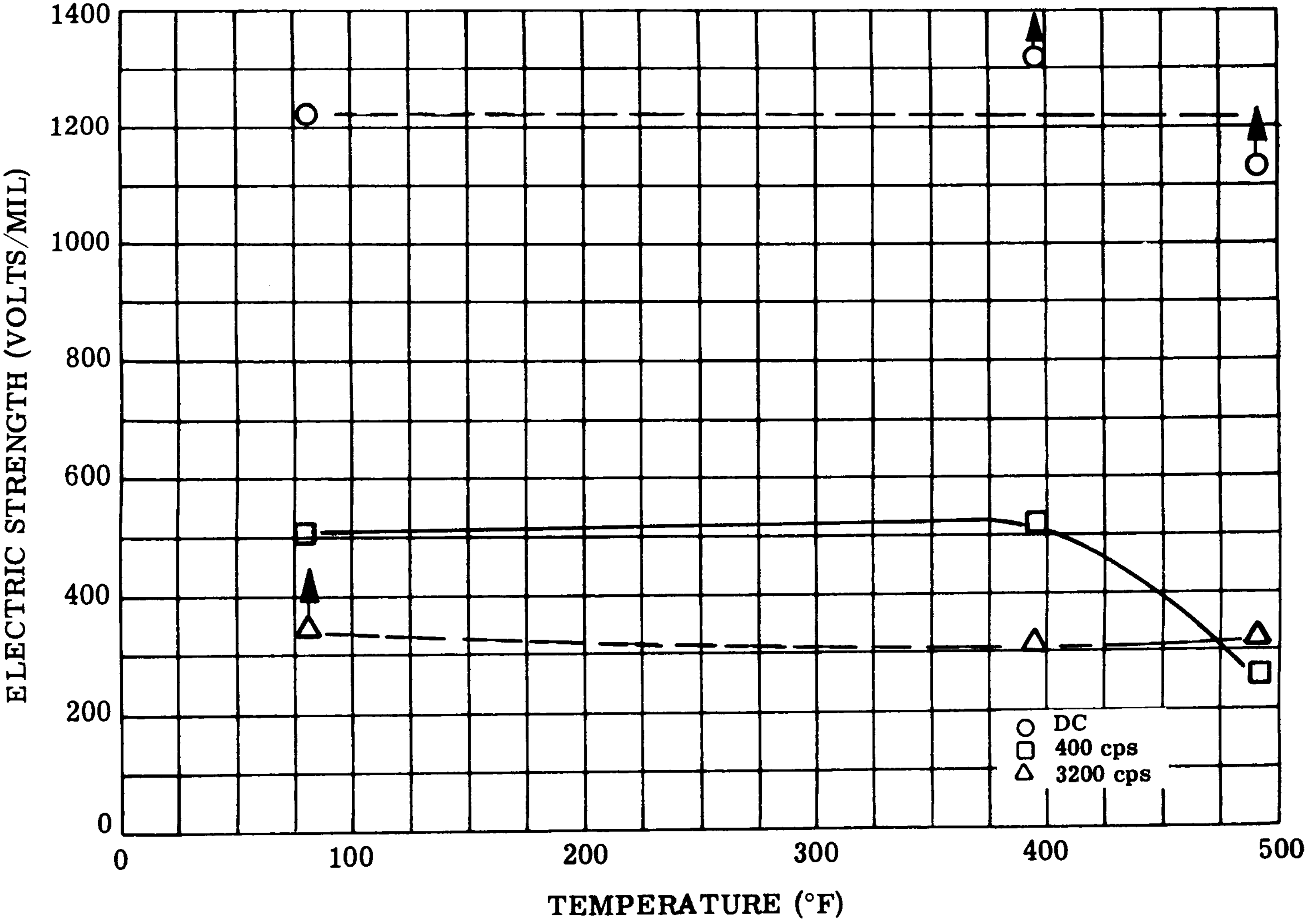


FIGURE V.D.3-6. Electric Strength of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, in Air. Specimen Thickness, 0.063 Inch. (Reference: NAS 3-4162)

Figure V.D.3-6. Electric Strength - Laminate - Epoxy Glass

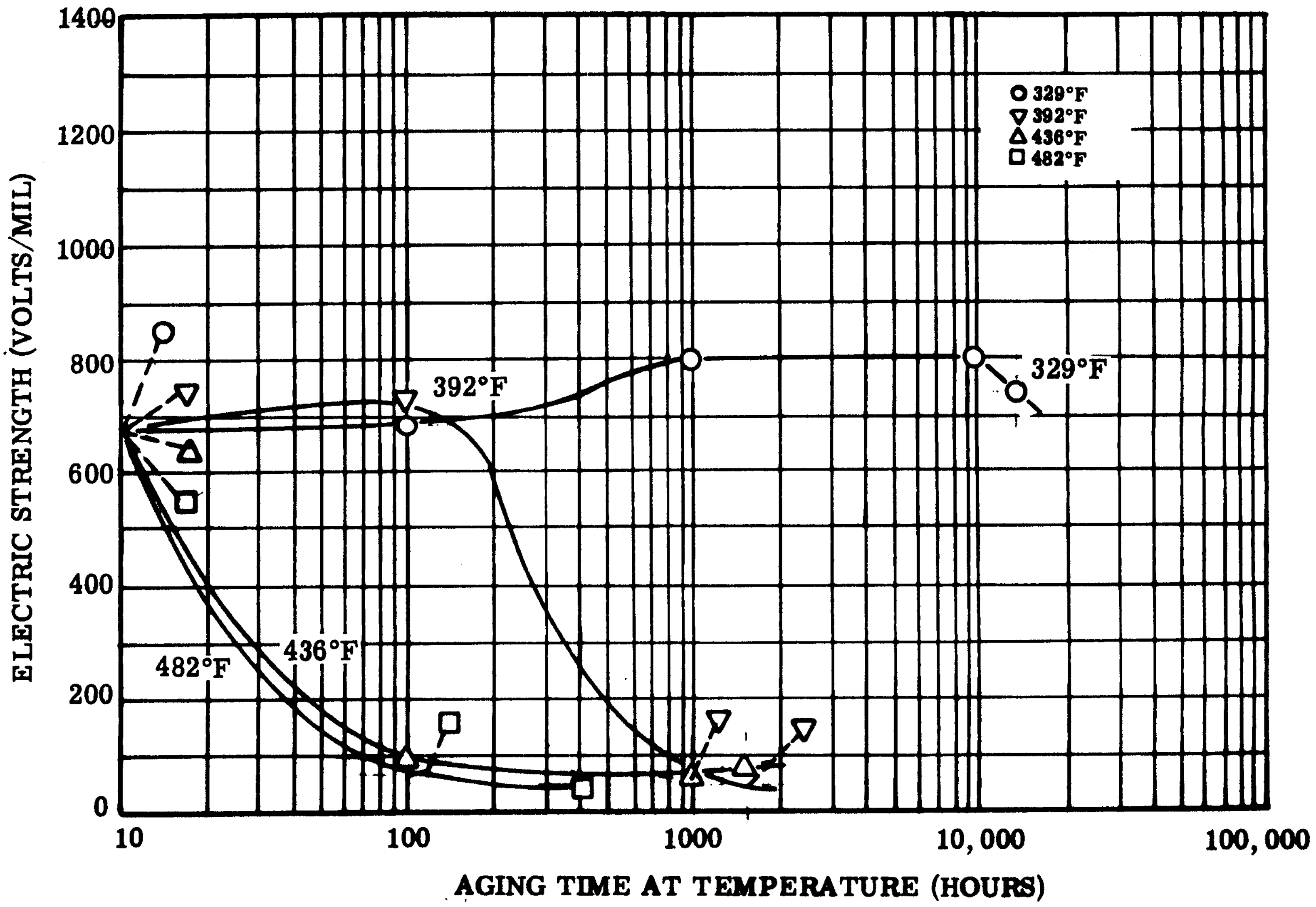


FIGURE V.D.3-7. Insulation Life (Electric Strength) After Air Aging of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, Tested at Room Temperature. Specimen Thickness, 0.063 Inch. (Reference: RI252)

Figure V.D.3-7. Insulation Life - Laminate - Epoxy Glass

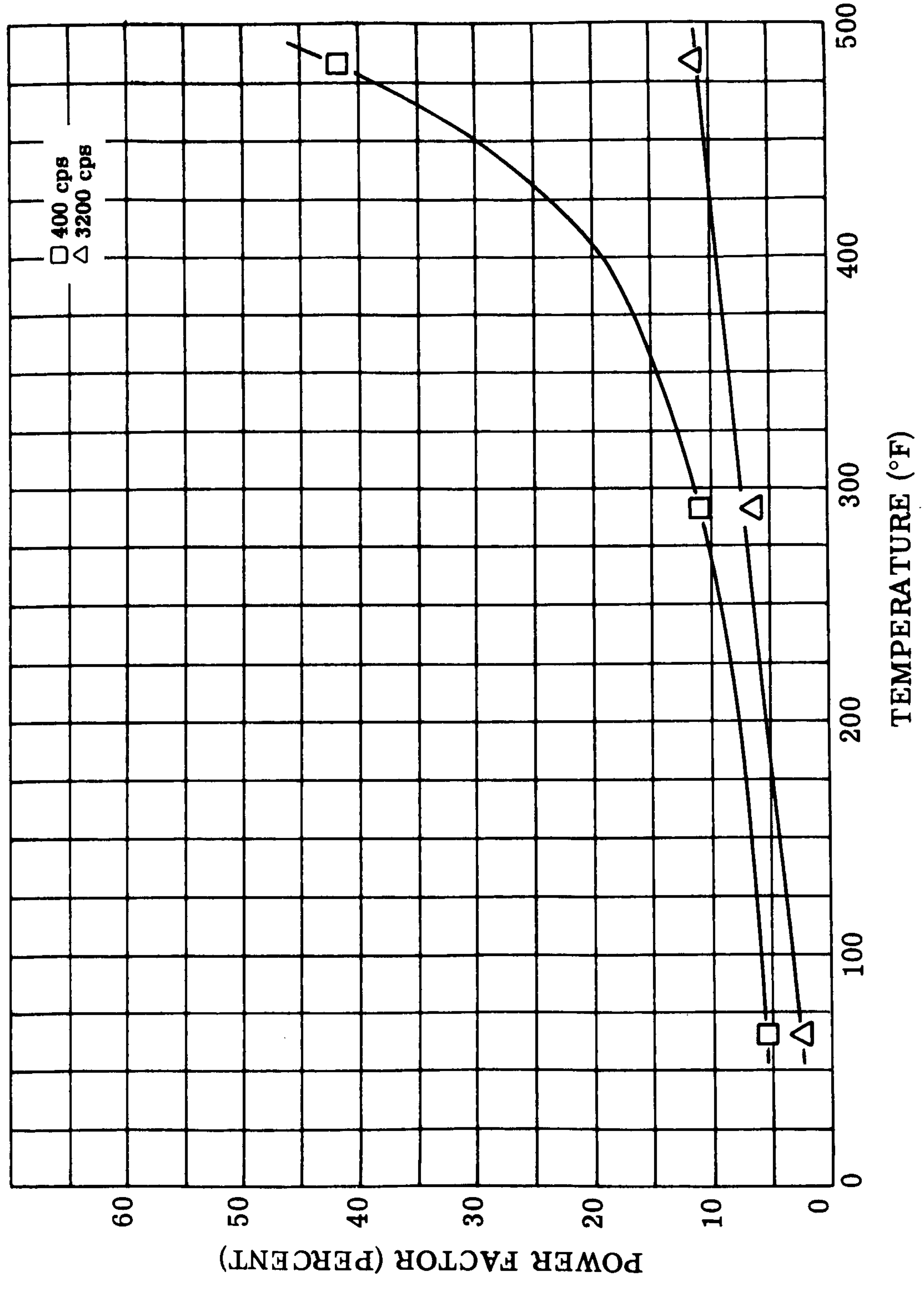


FIGURE V.D.3-8. Power Factor of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS3-4162)

Figure V.D.3-8. Power Factor - Laminate - Epoxy Glass

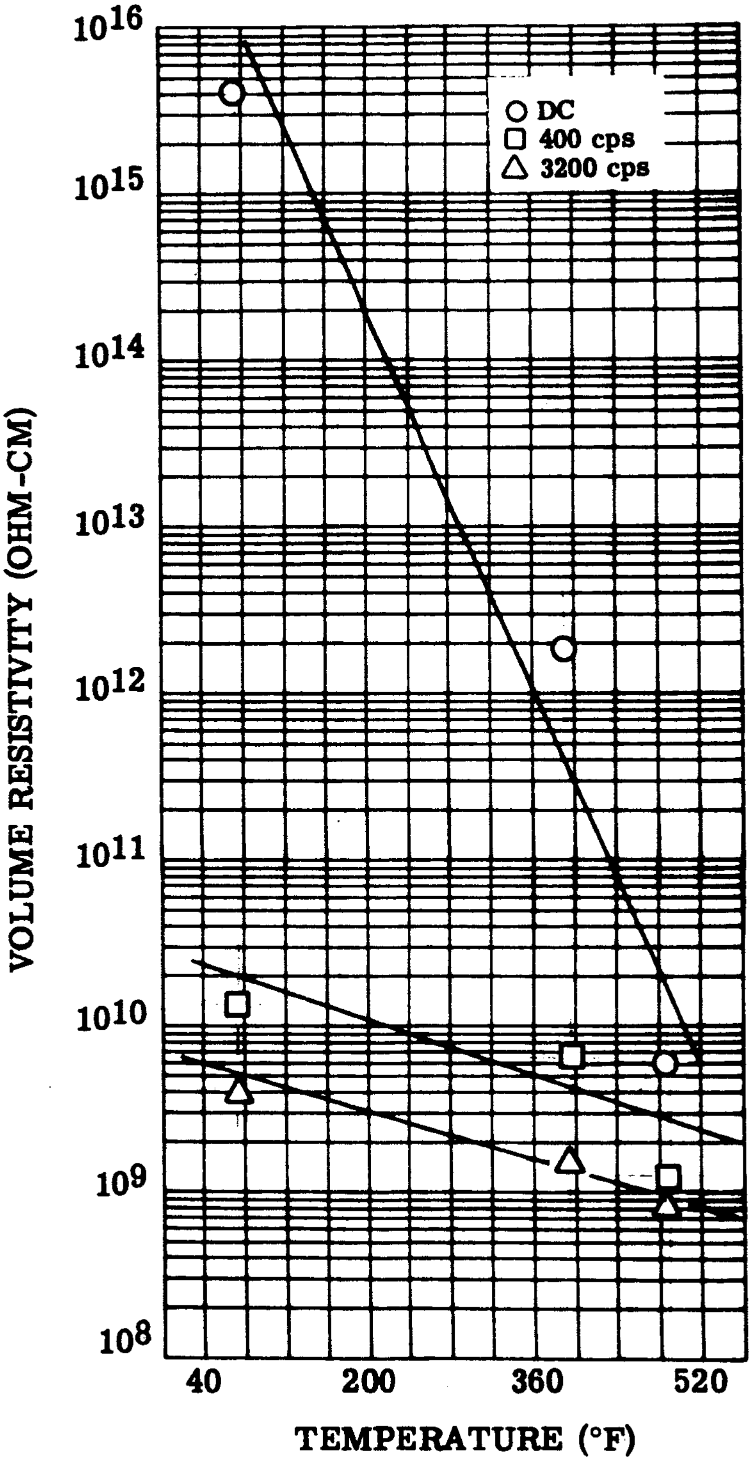


FIGURE V.D. 3-9. Volume Resistivity of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D. 3-9. Volume Resistivity - Laminate - Epoxy Glass

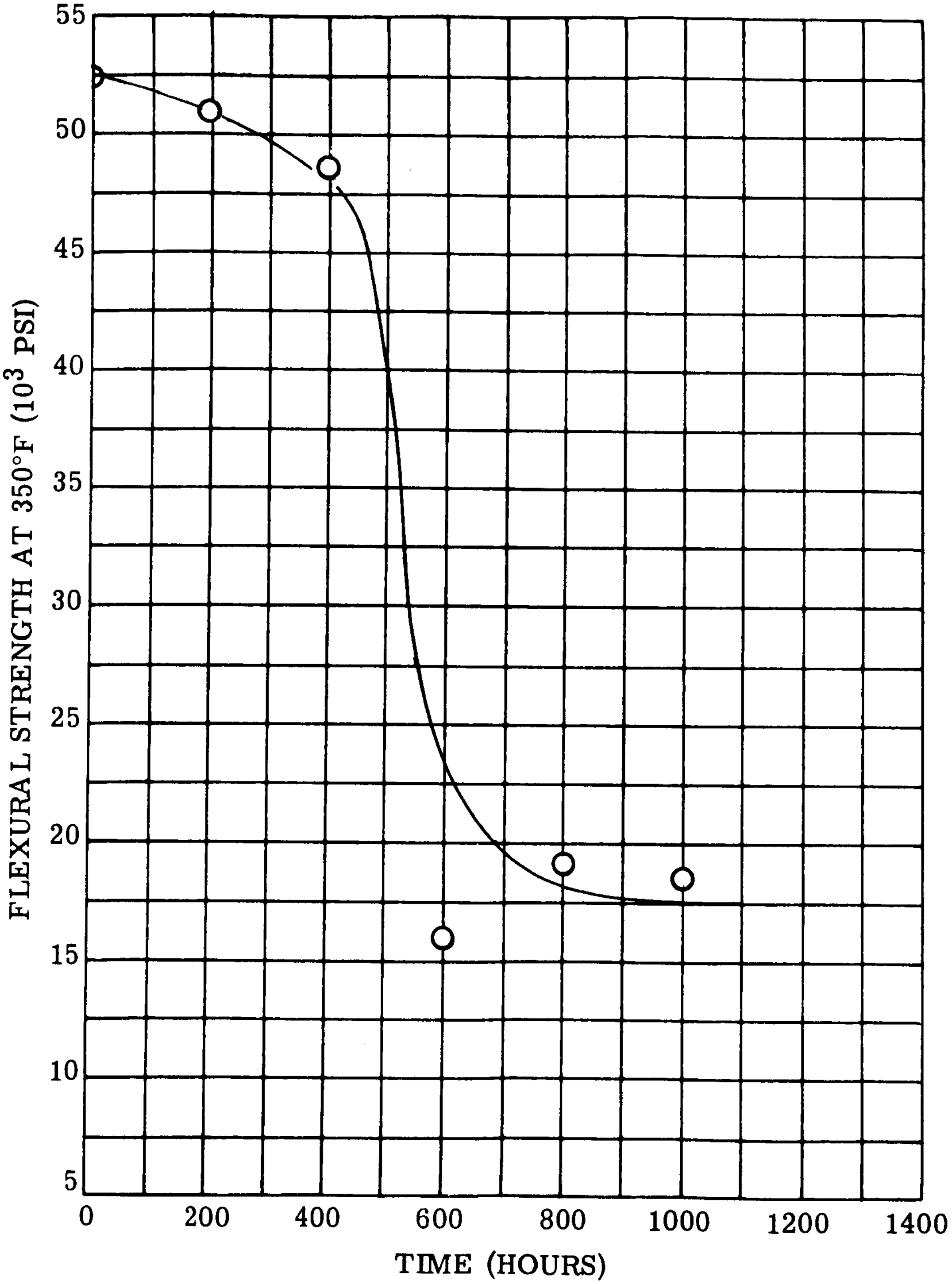


FIGURE V.D. 3-10. Flexural Strength After Air Aging at 350°F of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11, Tested in Air at 350°F. Specimen Thickness 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D. 3-10. Aged Flexural Strength - Laminate - Epoxy Glass

Figure V.D. 3-11. Weight Loss - Laminate - Epoxy Glass

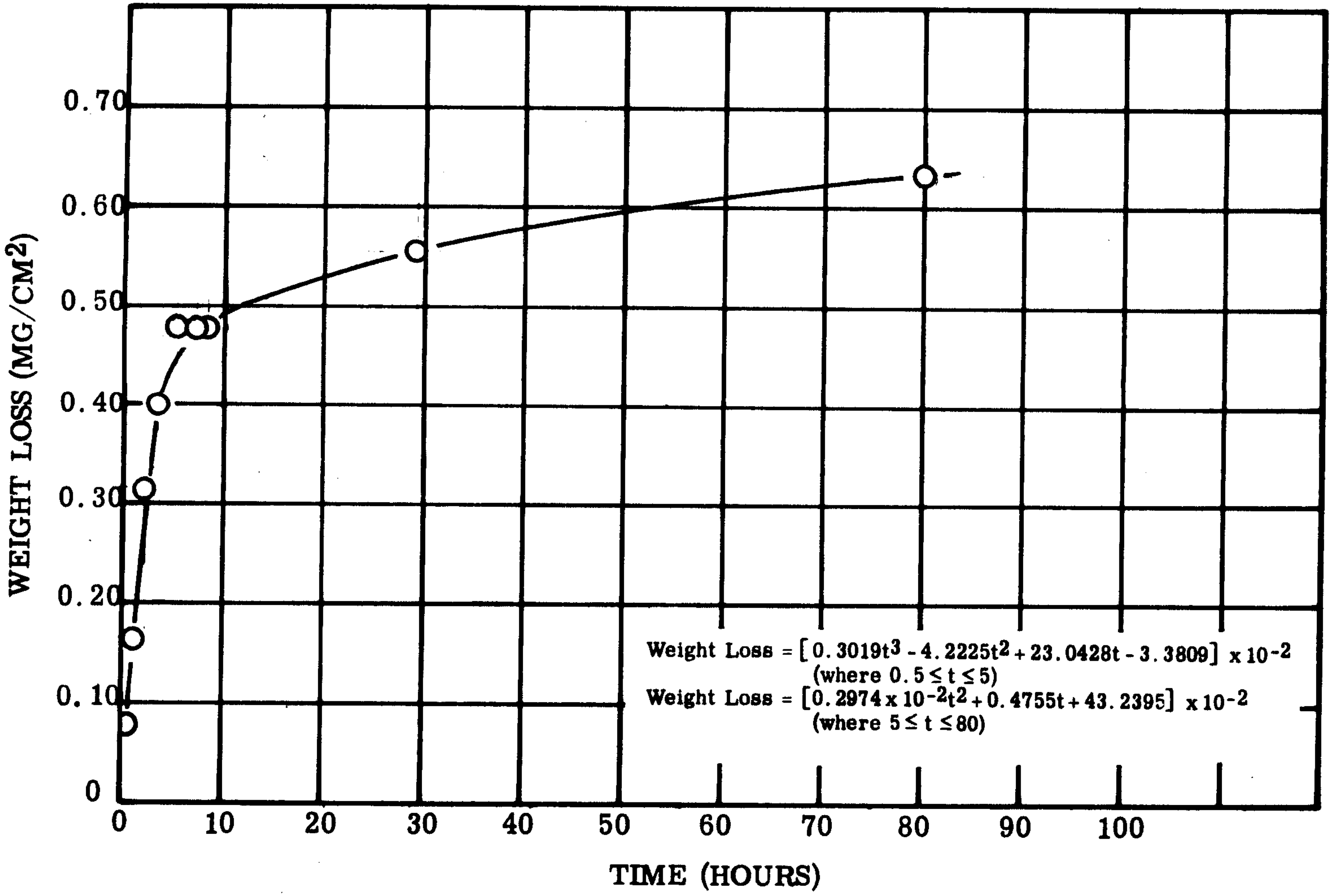


FIGURE V.D. 3-11. Weight Loss at 350°F and 10^{-5} to 10^{-6} Torr of Rigid Organic Insulation, Laminated, Epoxy Glass, Grade G-11. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

4. PHENOLIC-GLASS, RIGID INSULATION, LAMINATED

Phenolic-glass laminate (91LD) is an organic resin coated on glass cloth and is used in forming the desired shapes under pressure at elevated temperature and pressure.

Availability:	This material can be obtained from U.S. Polymeric Chemicals Incorporated under the trade name Poly-Preg 91-LD in the form of impregnated fabrics or molded shapes.
Description:	The phenolic resin is formed by the condensation reaction of phenol and formaldehyde. The resin is impregnated on style 181-A1100 glass cloth. The laminates are molded under contact pressure at 250°F for 2 minutes and then at 500 psi and 275°F for 20 minutes. The laminate should be post-cured in air for improved properties. The post-cure schedule depends upon the laminate thickness and is only supplied upon request to U.S. Polymeric Chemicals Incorporated.

I. Thermophysical Properties

A.	Density (77°F) (lb/cu inch)	0.07	(RI505)
B.	Thermal Conductivity (77°F)	0.15 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$	(RI509)
C.	Thermal Expansion		
	77°F to 500°F	5.5 x 10^{-6} in/in-°F	(RI509)
D.	Water Absorption (77°F) (weight percent)	0.5	

II. Electrical Properties

A.	Arc Resistance (77°F)	Tracks	(RI509)

B. Dielectric Constant (RI509)

Specimen Thickness, 0.125 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	1×10^6	4.0
482	1×10^6	3.98

C. Electric Strength (RI509)

Temperature (°F)	Frequency (cps)	Volts/mil
77	60	350

D. Insulation Life (RI509)

Dielectric Constant and Power Factor versus Temperature in Air

Aging Conditions	Test Temperature (°F)	Frequency (cps)	Dielectric Constant	Sine δ
none	77	1×10^6	4	0.0098
none	77	1×10^7	3.57	0.010
1/2 hour at 500°F	500	1×10^6	3.98	0.0055
1/2 hour at 500°F	500	1×10^7	4.16	0.0126
200 hours at 500°F	500	1×10^6	2.60	0.0048

E. Volume Resistivity (RI517)

Temperature (°F)	Frequency	Ohm-cm
77	DC	1.25×10^{12}

III. Mechanical Properties

A. Compressive Strength

(RI517)

1. Compressive Strength (Perpendicular to Laminations)

Specimen Dimensions, 0.125 thick x 0.5 x 3.125 inches

Temperature (°F)	Psi
77	50,000
500	46,200

2. Compressive Strength After Aging

Percent of Room Temperature Compressive Strength (Perpendicular to Laminations) (Specimen Dimensions, 0.125 thick x 0.5 x 3.125 inches)

Time	Aging and Test Temperature						
(hours)	300°F	400°F	500°F	600°F	700°F	800°F	900°F
0.5	95	72	54	42	35	22	10
2	--	--	--	--	--	--	0
3	--	--	--	--	--	2	
5	--	--	--	48	--	--	
7	--	--	--	--	5	0	
10	--	78	75	--	--		
25	98	--	78	18	0		
70	--	--	68	--			
100	--	77	--	2			
200	--	--	20	--			
350	--	--	12	--			
1000	88	70	6	--			

B. Elastic Modulus in Flexure

(RI517)

Temperature (°F)	Psi
77	4.8×10^6
500	3.77×10^6

C. Flexural Strength

1. Flexural Strength at 77°F 87,000 psi (RI517)

2. Flexural Strength at Elevated Temperature (RI516)

Specimen Thickness, 0.125 Inch

Time	Flexural Strength (10^3 psi) Aged and Tested at Indicated Temperature							
(hours)	300°F	400°F	500°F	600°F	700°F	800°F	900°F	1000°F
0.17	32.46	33.71	26.89	16.13	14.96	9.21	9.85	--
0.5	35.62	34.35	22.07	14.21	14.27	8.65	7.10	0
2	--	--	--	--	--	--	0	
3	--	--	--	--	10.0	--		
4	--	--	--	--	--	0		
8	--	--	28.06	11.15	--			
12	--	--	--	--	0			
48	--	--	--	3.44				
98	29.77	26.91	19.04	--				
168	--	--	--	0				
240	--	--	19.33					
1000	27.58	28.88	0					

D. Flexural Modulus After Aging (RI516)

Specimen Thickness, 0.125 Inch

Time	Flexural Modulus (10^6 psi) Aged and Tested at Indicated Temperature						
(hours)	300°F	400°F	500°F	600°F	700°F	800°F	900°F
0.17	3.44	3.08	2.73	2.19	1.89	1.70	1.64
0.5	3.43	3.11	2.88	2.31	1.97	1.65	1.63
2	--	--	--	--	--	--	0
3	--	--	--	--	1.61	--	
4	--	--	--	--	--	0	
8	--	--	3.20	2.23	--		
12	--	--	--	--	0		
48	--	--	--	1.16			
98	3.59	3.40	3.14				
168	--	--	--	0			
240	--	--	2.29				
1000	3.54	3.25	0				

E. Impact Strength (77°F)(ft-lb/inch) 15

F. Tensile Strength (RI516)

1. Tensile Strength at 77°F 45,860 psi

2. Tensile Strength (Parallel to Warp) After Aging
Specimen Thickness, 0.125 Inch

Time (hours)	Percent of Room Temperature Tensile Strength (Parallel to Warp) Aging and Test Temperature 300°F	400°F	500°F	600°F	700°F	800°F	900°F
0.5	87.2	91.9	94.4	91.8	79.6	46.7	0
3	--	--	--	--	--	0	
5	--	--	--	90.9	--		
7	--	--	--	--	43.3		
24	87.6	94.0	--	45.2	0		
72	--	--	73.2	--			
98	--	--	--	0			
360	--	--	40.9				
1000	87.5	86.4	16.5				

3. Tensile Strength (45° Angle to Warp) After Aging
Specimen Thickness, 0.125 Inch

Time (hours)	Percent of Room Temperature Tensile Strength (45° Angle to Warp) Aging and Test Temperature 300°F	400°F	500°F	600°F	700°F	800°F	900°F
0.5	84.7	77.9	67.7	59.7	44.1	14.1	0
3	--	--	--	--	--	0	
5	--	--	--	50.7	--		
7	--	--	--	--	0		
24	84.2	80.0	--	13.6			
72	--	--	44.7	--			
98	--	--	--	0			
360	--	--	0				
1000	87.3	54.0					

IV. Compatibility Properties

A. Chemical Compatibility

Phenolic resins of this type are resistant to aliphatic organic solvents but are attacked in varying degrees by ketones, aromatic, and halogenated solvents. Acid resistance of the phenolics is fair to good. Alkaline solutions will generally attack the resin, while moisture resistance is fair to good.

B. Nuclear Radiation Resistance

(LI295)
(LI296)

Unreinforced phenolic resins are embrittled and weakened to 50 percent of original strength when they are exposed to gamma radiation at an approximate level of 3×10^{10} ergs per gram (C). Filled or inorganically reinforced phenolic resin compositions offer better radiation resistance. Degradation of about 25 percent is observed when a filled-phenolic is exposed to gamma radiation levels as high as 3.9×10^{11} ergs per gram (C).

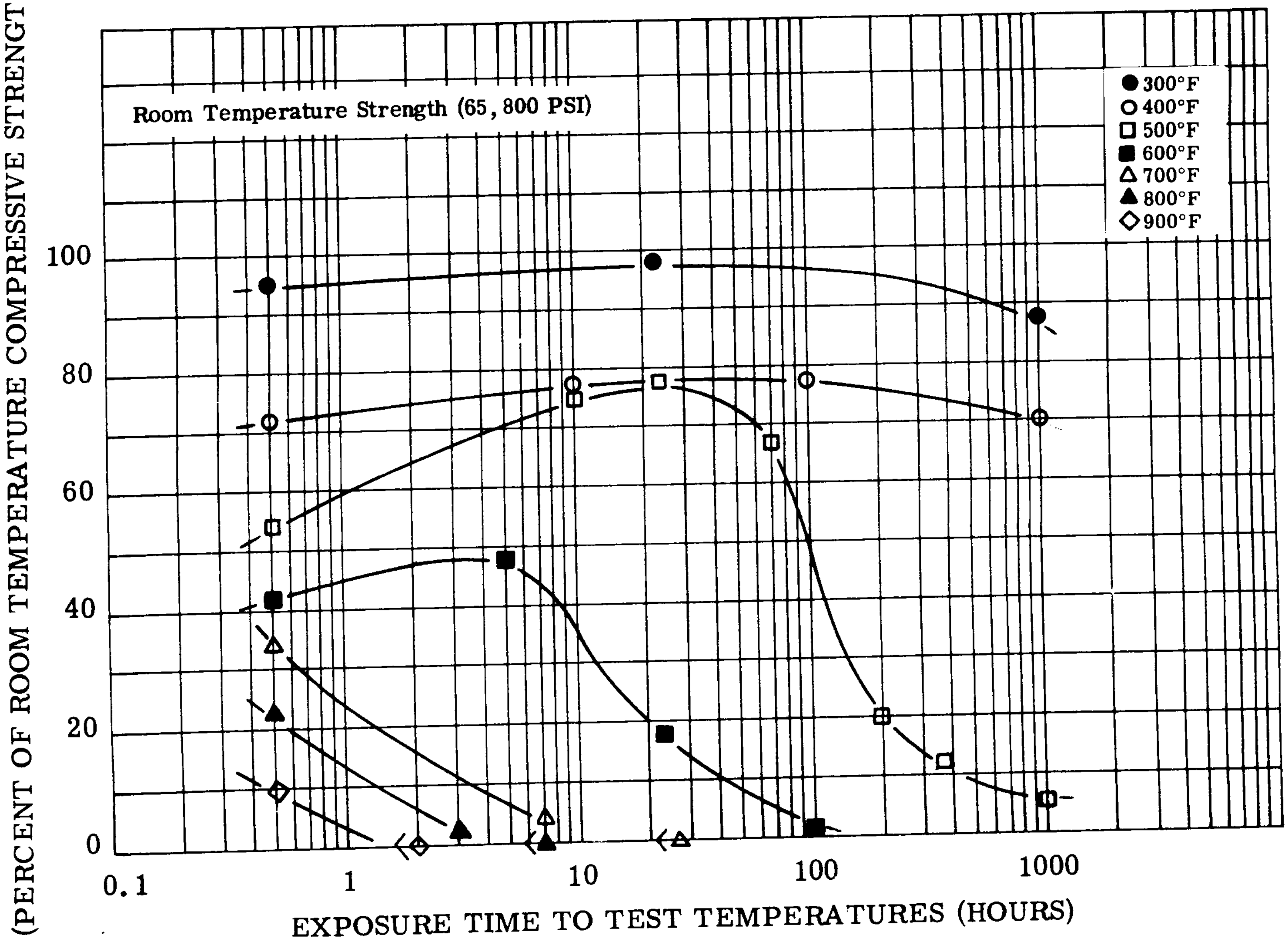


FIGURE V.D.4-1. Compressive Strength, Perpendicular to Laminations, of Rigid Organic Insulation, Laminated, Phenolic Glass (91LD), in Air. Specimen Dimensions, 0.125 Thick x 0.5 x 3.125 Inches. (Reference: RI516)

Figure V.D.4-1. Compressive Strength - Laminate - Phenolic Glass

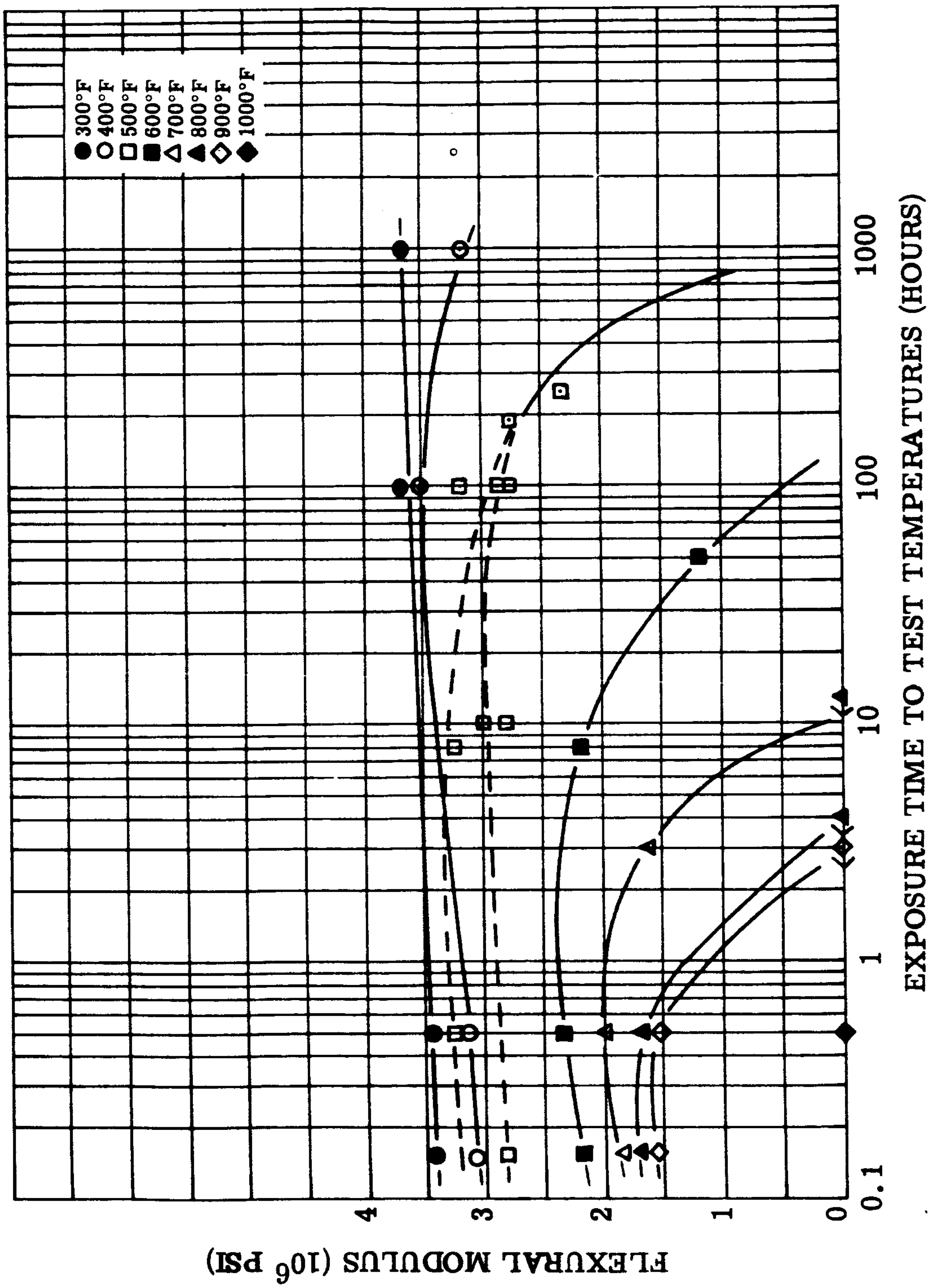


FIGURE V.D.4-2. Flexural Modulus of Rigid Organic Insulation, Laminated, Phenolic Glass (91LD), in Air. (Reference: RI516)

Figure V.D.4-2. Flexural Modulus versus Temperature - Laminate - Phenolic Glass

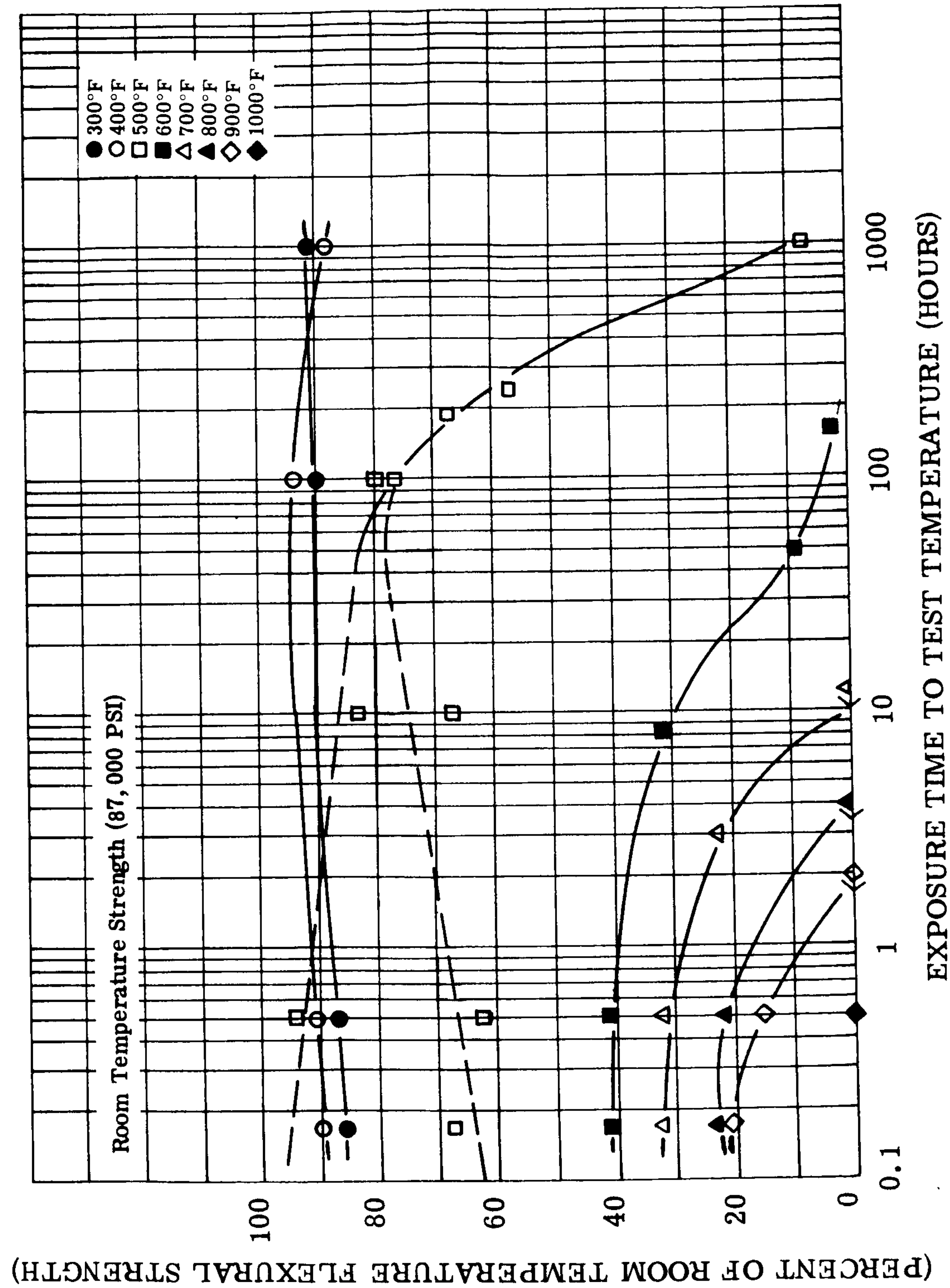


FIGURE V.D. 4-3. Flexural Strength of Rigid Organic Insulation, Laminated, Phenolic Glass (91LD), in Air. (Reference: RI516)

Figure V.D. 4-3. Aged Flexural Strength - Laminate - Phenolic Glass

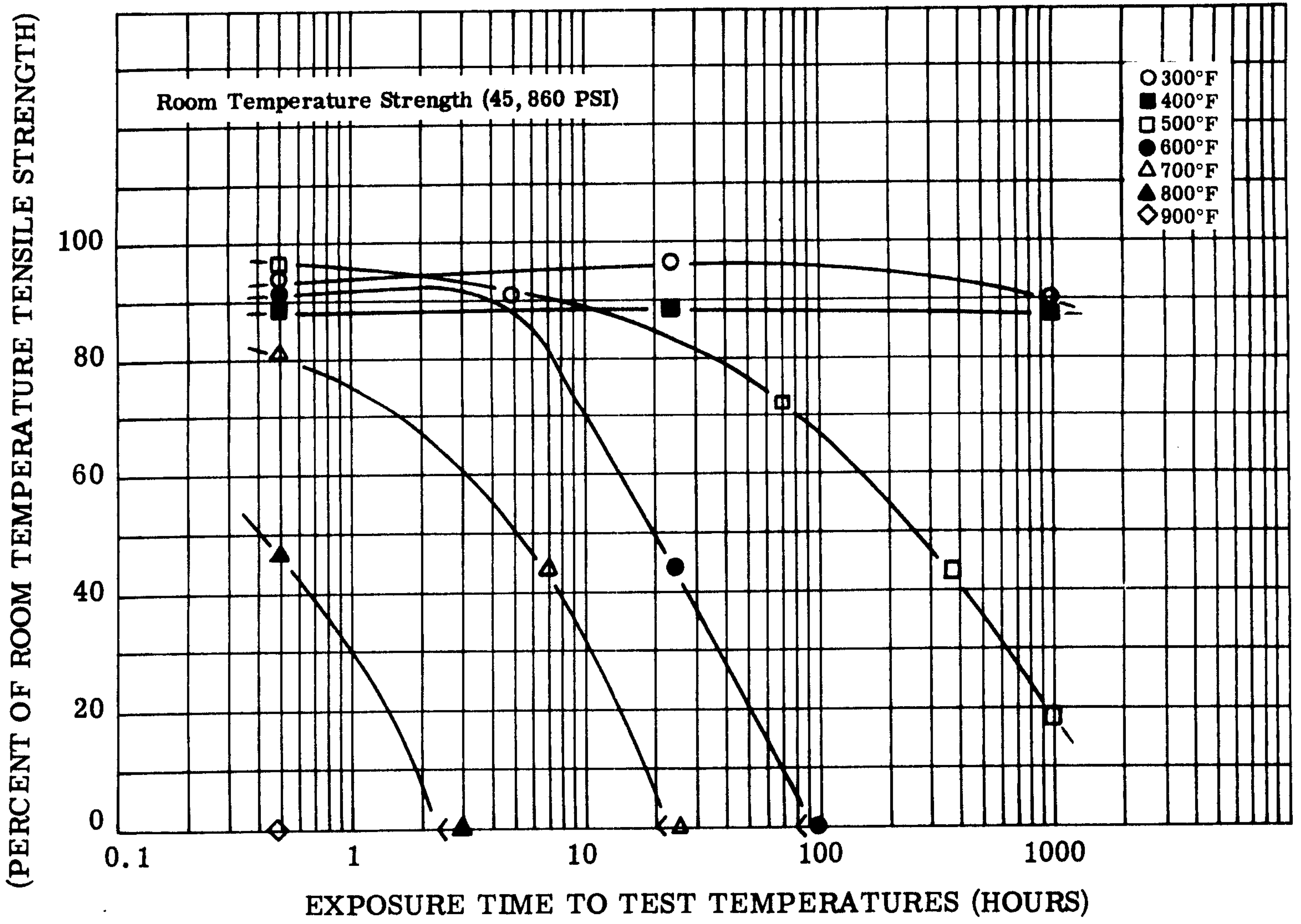


FIGURE V.D.4-4. Tensile Strength of Rigid Organic Insulation, Parallel to Warp, Laminated, Phenolic Glass (91LD), in Air. (Reference: RI516)

Figure V.D.4-4. Tensile Strength versus Temperature - Laminate - Phenolic Glass

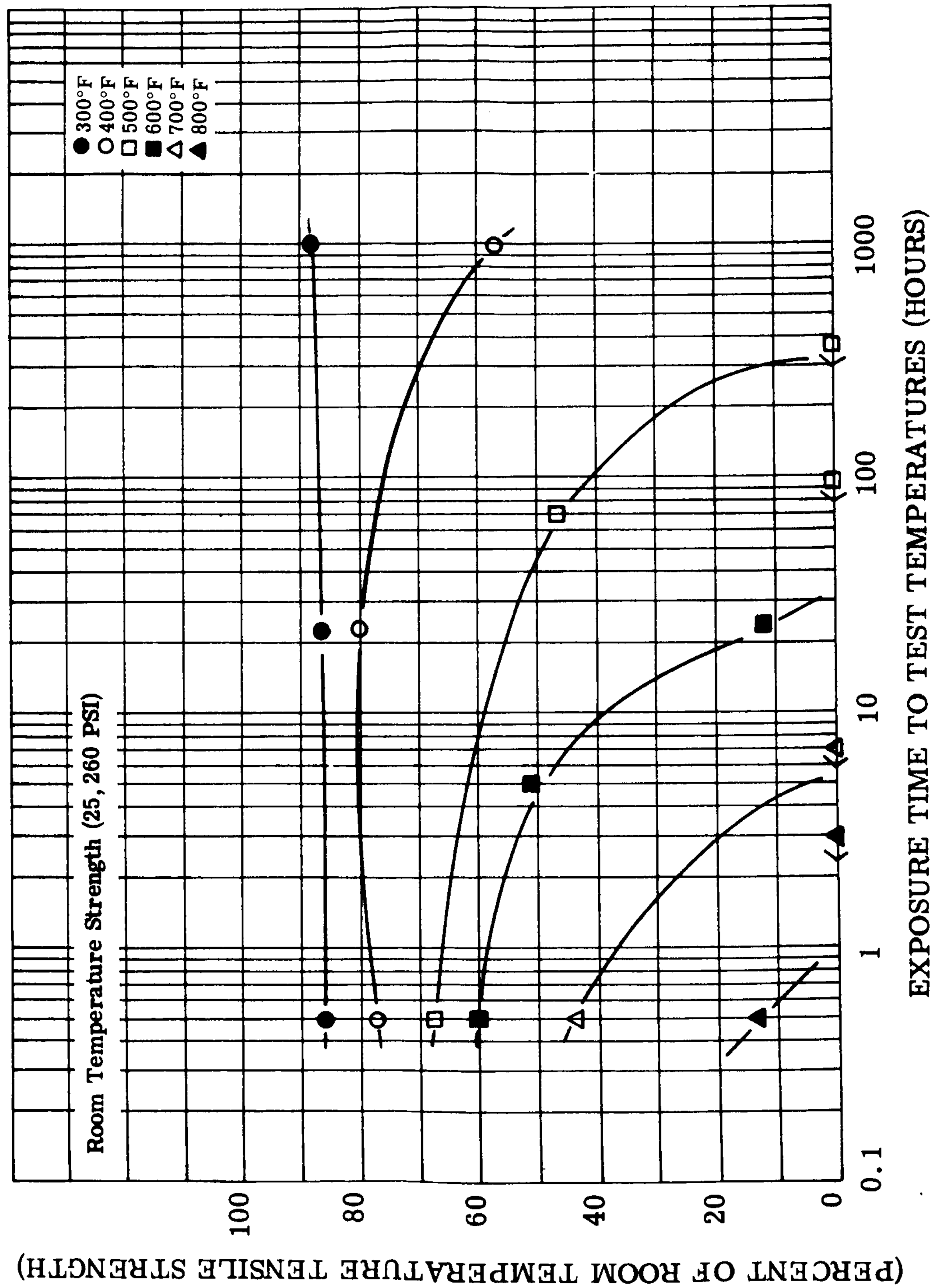


FIGURE V.D.4-5. Tensile Strength at 45° Angle to Warp, of Rigid Organic Insulation, Laminated, Phenolic Glass (91LD), in Air. (Reference: RI516)

Figure V.D.4-5. Tensile Strength 45° Angle versus Temperature - Laminate - Phenolic Glass

5. POLYBENZIMIDAZOLE-GLASS, RIGID INSULATION, LAMINATED

Polybenzimidazole-glass laminate (Imidite 1850) is an organic polyaromatic laminating resin coated on glass cloth and processed with heat and pressure to form laminated shapes.

Availability:	This material is available from the Narmco Materials Division of Whittaker Corporation, as Imidite 1850. Treated cloth is also available.
Description:	The laminates are made with a nine ounce satin weave glass cloth. The resin content is 40 ± 5 percent. The laminates are cured at 250°F and 200 psi contact pressure, followed by 700°F and 200 psi for 3 hours. The laminates are post-cured in nitrogen according to the following schedule: 24 hours at 600°F, 24 hours at 650°F, 24 hours at 700°F, 24 hours at 750°F, 8 hours at 800°F.

I. Thermophysical Properties

None measured in NAS 3-4162

II. Electrical Properties

(RI124)

A. Dielectric Constant (60 cps)

Temperature (°F)	Dielectric Constant
100	4.89
200	4.87
300	4.84
400	4.82
500	4.79
600	4.75

B. Dissipation Factor (RI124)

Temperature (°F)	Dissipation Factor (tan δ)
100	0.00675
200	0.00690
300	0.00710
400	0.00720
500	0.00735
600	0.00750

III. Mechanical Properties (RI125)

A. Compressive Strength

Temperature (°F)	Psi
77	50,000
500	40,000

B. Elastic Modulus in Flexure (RI224)

Specimen Thickness, 0.020 Inch

Temperature (°F)	Psi
77	5.5×10^6
500	5.0×10^6

C. Flexural Strength and Elastic Modulus After Aging (RI225)

Specimen Thickness, 0.020 Inch
Multiple test values are shown for each test condition.

Aging and Test Temperature	Flexural Strength (psi)	Elastic Modulus in Flexure (psi)
As received, 70°F	108,350	4.8×10^6
	114,250	5.19×10^6

Aging and Test Temperature	Flexural Strength (psi)	Elastic Modulus in Flexure (psi)
Aged 1/2 hour at 600°F and tested at 600°F	116,400	4.27×10^6
	115,100	4.33×10^6
Aged 24 hours at 600°F and tested at 600°F	80,350	4.15×10^6
	94,150	4.35×10^6
	64,900	4.09×10^6
Aged 100 hours at 600°F and tested at 600°F	23,300	4.01×10^6
	26,400	3.42×10^6
	21,400	3.59×10^6
Aged 250 hours at 600°F and tested at 600°F	3,350	1.32×10^6
	2,550	1.28×10^6
	2,500	1.21×10^6
Aged 250 hours at 600°F and tested at 70°F	3,100	1.27×10^6
	3,050	1.47×10^6
	3,700	1.49×10^6
Aged 298 hours at 600°F and tested at 600°F	1,200	0.61×10^6
	1,150	0.51×10^6
	1,200	0.45×10^6
Aged 298 hours at 600°F and tested at 70°F	1,450	0.54×10^6
	1,450	0.54×10^6
	700	0.32×10^6

D. Flexural Strength (RI224)

Temperature (°F)	Psi
70	115,000
500	100,000

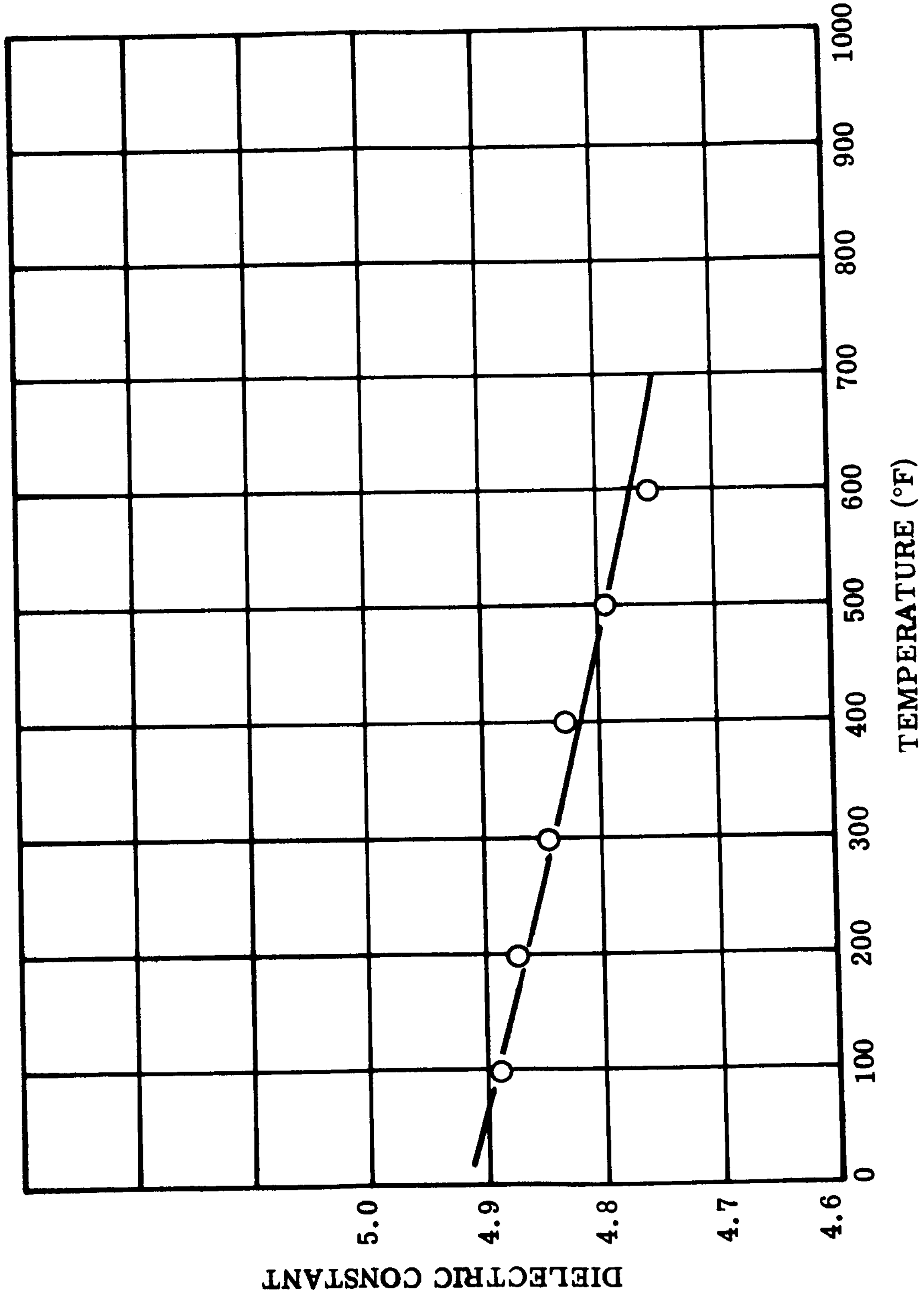


FIGURE V.D.5-1. Dielectric Constant at 60 cps of Rigid Organic Insulation, Laminated, Polybenzimidazole, in Air. (Reference: RI124)

Figure V.D.5-1. Dielectric Constant - Laminate - Polybenzimidazole

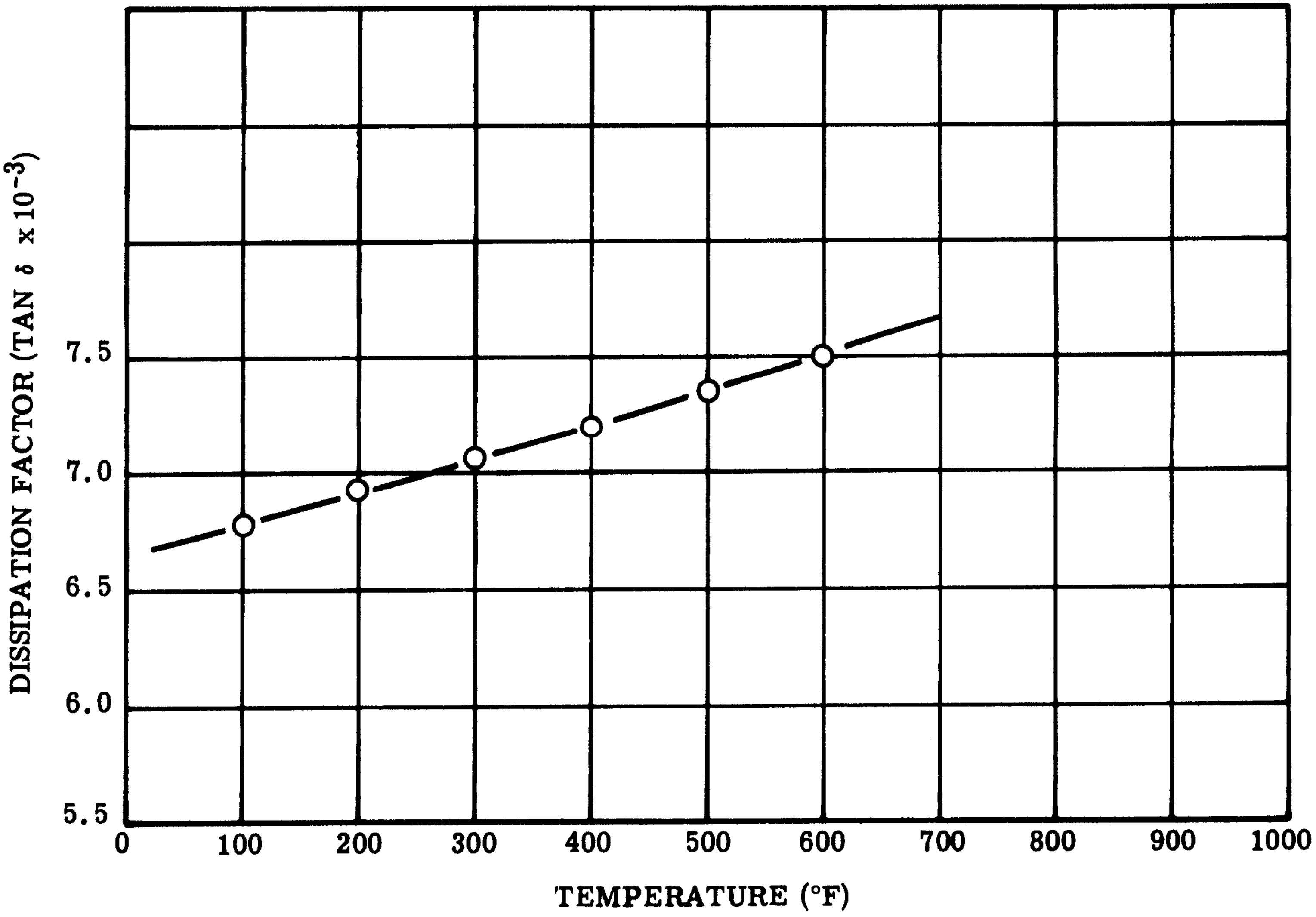
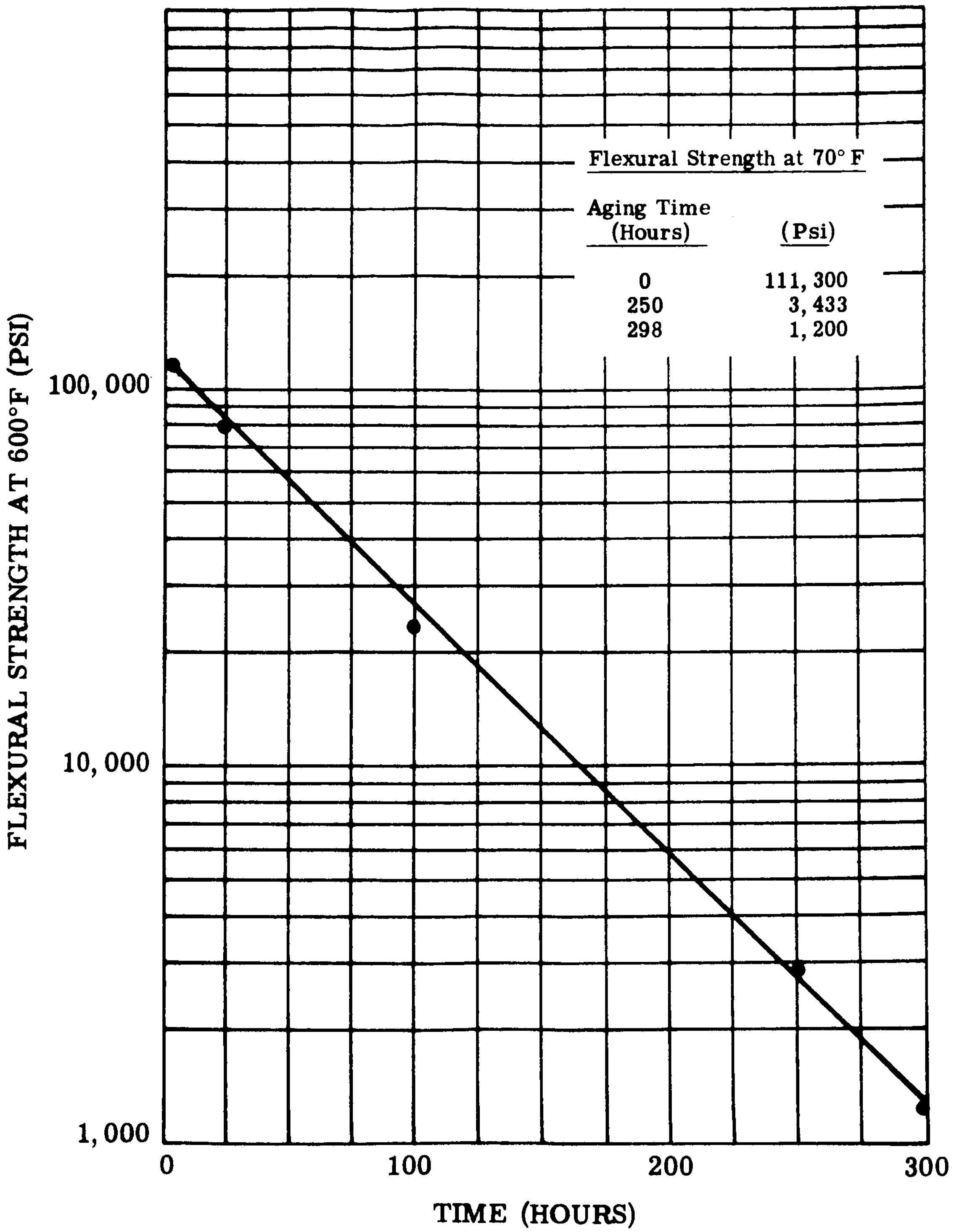


FIGURE V.D.5-2. Dissipation Factor at 60 cps of Rigid Organic Insulation, Laminated, Polybenzimidazole, in Air. (Reference: RI124)

Figure V.D.5-2. Dissipation Factor - Laminate - Polybenzimidazole



Flexural Strength at 70° F

Aging Time (Hours)	(Psi)
0	111,300
250	3,433
298	1,200

FIGURE V.D.5-3. Flexural Strength After Air Aging at 600°F of Rigid Organic Insulation, Laminated, Polybenzimidazole, Tested in Air at 600°F. (Reference: RI225)

Figure V.D.5-3. Aged Flexural Strength at Temperature - Laminate - Polybenzimidazole

6. POLYIMIDE-GLASS RIGID INSULATION, LAMINATED

Polyimide-glass laminate (Polyimide polymer I-8) is an organic laminating resin impregnated into glass cloth and pressed at elevated temperature to form the desired shapes.

Availability:	Polyimide I-8 is available from Westinghouse Electric Corporation, Micarta Division. It can be obtained as a laminate or a wire enamel.
Description:	Polyimide I-8 is the reaction product of m-phenylenediamine and 3, 3', 4, 4'- benzophenone-tetracarboxylic dianhydride. The polymer was impregnated into glass cloth (style 181-A1100) and laminates were pressed for 30 minutes at 716°F and 200 psi. The resin content in the laminates was 36 percent and thickness was 0.125 inch.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.080

Specimen Thickness, 0.125 Inch

B. Thermal Conductivity

Specimen Thickness, 0.125 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
202	0.108
419	0.129
607	0.130

C. Coefficient of Thermal Expansion

Specimen Thickness, 0.125 Inch

Temperature Range (°F)	inch/inch-°F
77 to 300	3.3×10^{-6}
300 to 500	5.8×10^{-6}
500 to 77	5.6×10^{-6}

D. Water Absorption (77°F)(average percent) 4.72

Specimen Thickness, 0.125 Inch

II. Electrical Properties

A. Arc Resistance (77°F)(average seconds) 42

B. Dielectric Constant

Specimen Thickness, 0.125 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	400	3.43
77	3200	3.41
392	400	3.31
392	3200	3.28
482	400	3.37
482	3200	3.32

C. Electrical Strength

Specimen Thickness, 0.125 Inch

Temperature (°F)	Frequency	Volts/mil
77	DC	1372
77	400 cps	510
77	3200 cps	376 (1)

(1) Tests made in air with a 1 inch diameter electrode, all other tests made in oil with a 2 inch diameter electrode.

Temperature (°F)	Frequency	Volts/mil
392	DC	1126
392	400 cps	607
392	3200 cps	386 (1)
482	DC	1164
482	400 cps	623
482	3200 cps	278 (1)

D. Insulation Life (Frequency, 400 cps)

Aging and Test Temperature (°F)	Aging Time at Temperature (hours)	Electric Strength (volts/mil)
527	0	500
527	200	437
527	400	458
527	600	456
527	800	463
527	1000	449
572	200	447
572	400	441
572	600	445
572	800	370
572	1000	413
617	200	422
617	400	406
617	600	445
617	800	348
617	1000	380

(1) Tests made in air with a 1 inch diameter electrode, all other tests made in oil with a 2 inch diameter electrode.

E. Volume Resistivity

Temperature (°F)	Frequency	Ohm-cm
77	DC	1.5×10^{15}
77	400 cps	8.1×10^{11}
77	3200 cps	1.1×10^{11}
392	DC	1.8×10^{14}
392	400 cps	1.8×10^{11}
392	3200 cps	3.1×10^{10}
482	DC	1.9×10^{13}
482	400 cps	8.9×10^{10}
482	3200 cps	2.0×10^{10}

F. Power Factor

Temperature (°F)	Frequency (cps)	Percent
72	400	0.168
72	3200	0.160
392	400	0.741
392	3200	0.558
482	400	1.50
482	3200	0.823

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	57,150
600	38,366

B. Elastic Modulus in Flexure

Temperature (°F)	Psi
77	2.5×10^6
600	1.6×10^6

C. Flexural Strength After Aging

Temperature (°F)	Aging Time (hours)	Psi
600	100	10,700
600	250	12,900
600	500	11,700
600	750	10,800
600	1000	10,500
600	1500	12,100

D. Impact Strength (77°F)(ft-lb/inch)	4.5

E. Flexural Strength

Temperature (°F)	Psi
77	35,600
600	23,600

IV. Compatibility Properties

A. Chemical Resistance

Resistance to organic solvents is very good. Resistance to water and dilute acids is good but alkaline solution resistance is fair to poor.

B. Nuclear Radiation Resistance

Polyimide resins have good resistance to gamma nuclear radiation up to about 10^9 rads or 10^{11} ergs per gram (C).

C. Weight Loss in Vacuum with Heat at 403°F

24 hours	1.3 percent

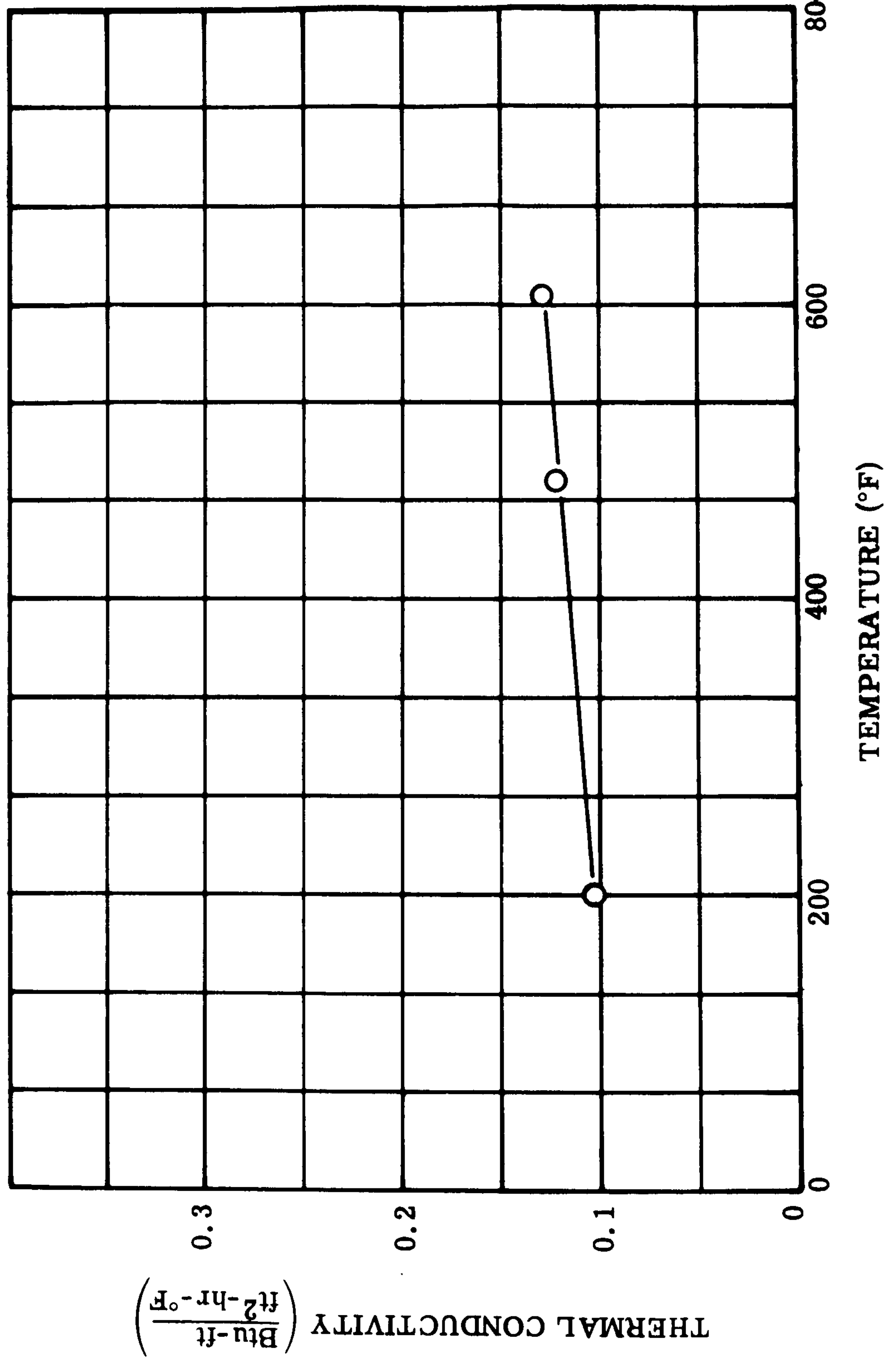


FIGURE V.D.6-1. Thermal Conductivity of Rigid Organic Insulation, Laminated, Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS3-4162)

Figure V.D. 6-1. Thermal Conductivity - Laminate - Polyimide Glass

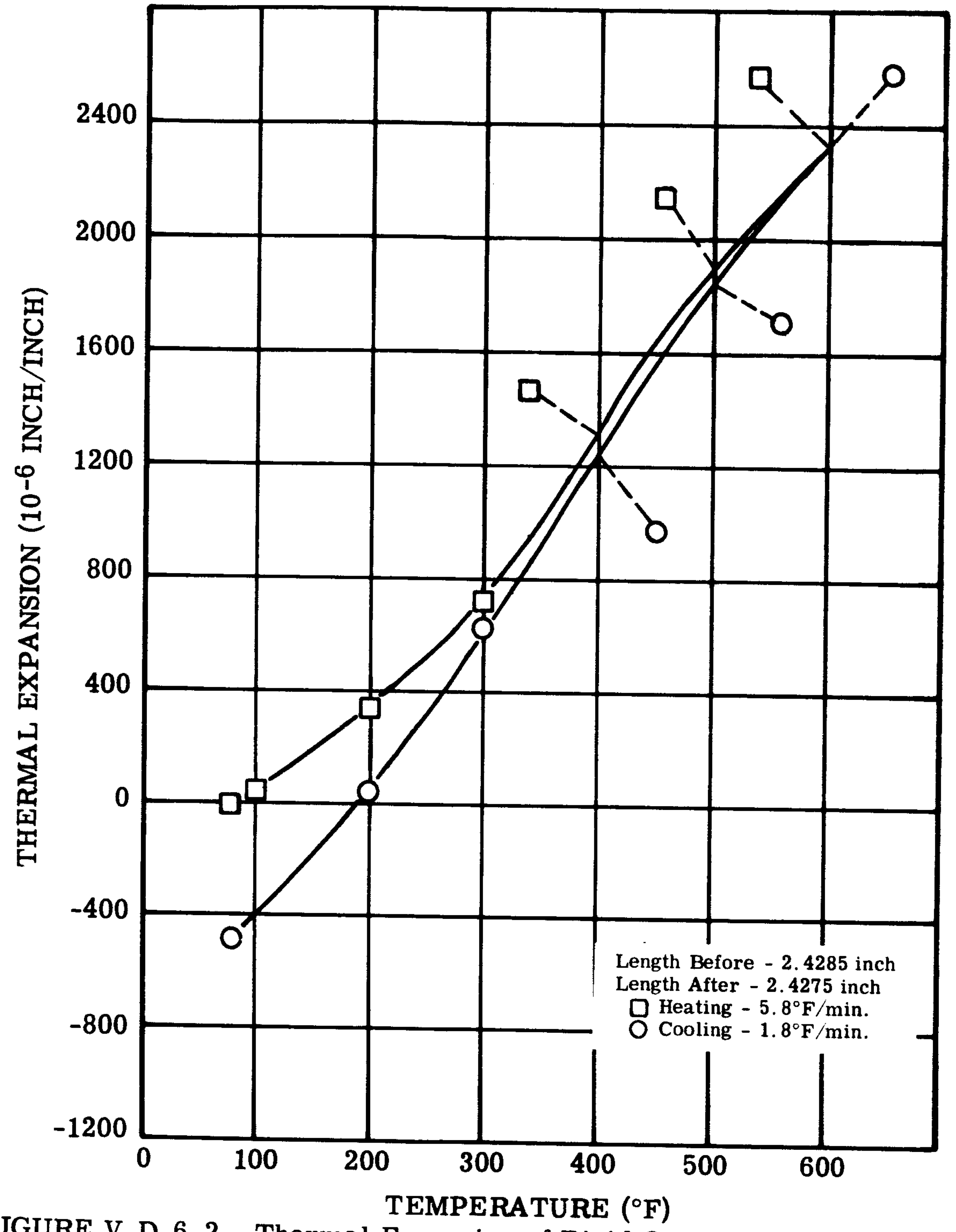


FIGURE V.D.6-2. Thermal Expansion of Rigid Organic Insulation, Laminated, Polyimide Glass. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-2. Thermal Expansion - Laminate - Polyimide Glass

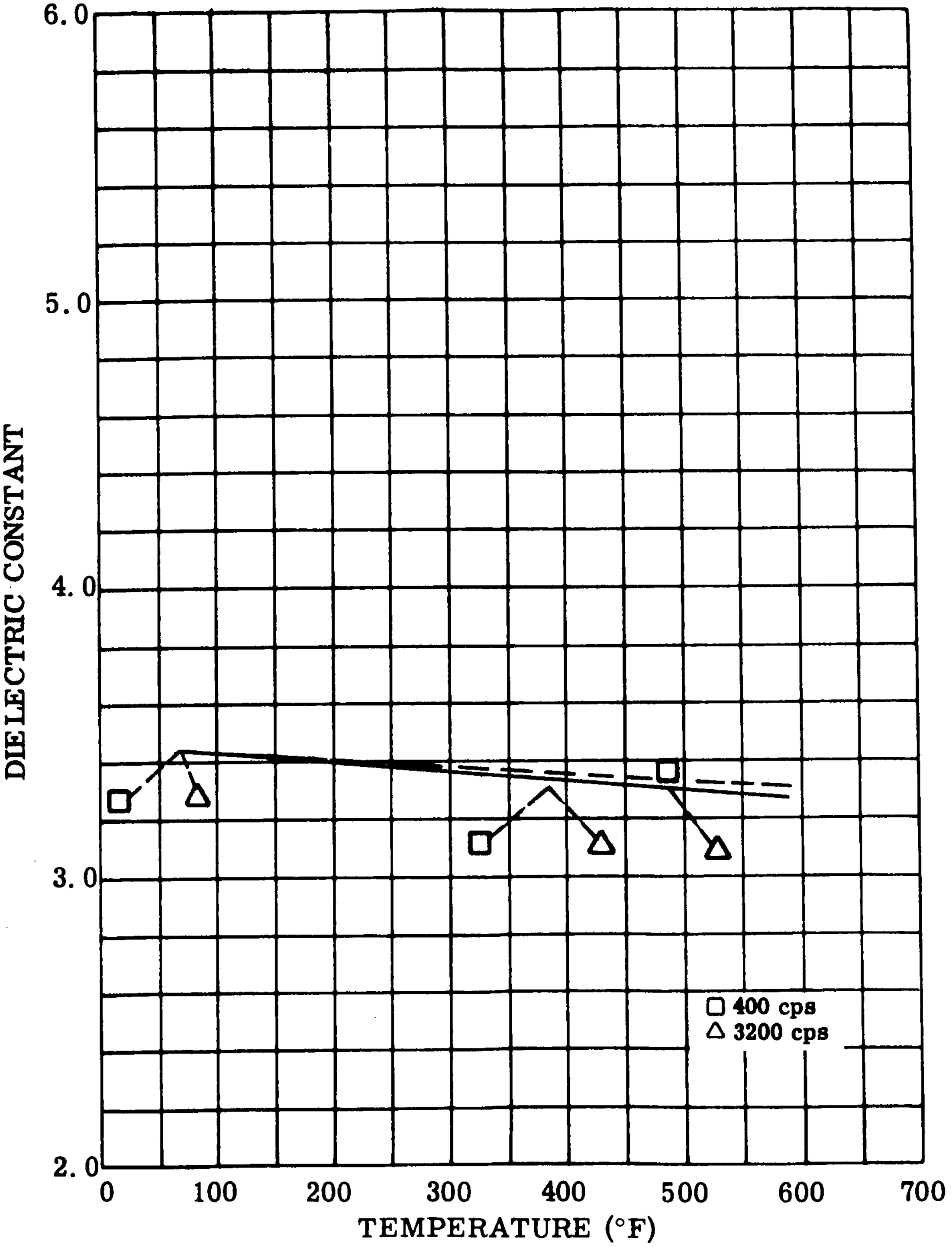


FIGURE V. D. 6-3. Dielectric Constant of Rigid Organic Insulation, Laminated Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V. D. 6-3. Dielectric Constant - Laminate - Polyimide Glass

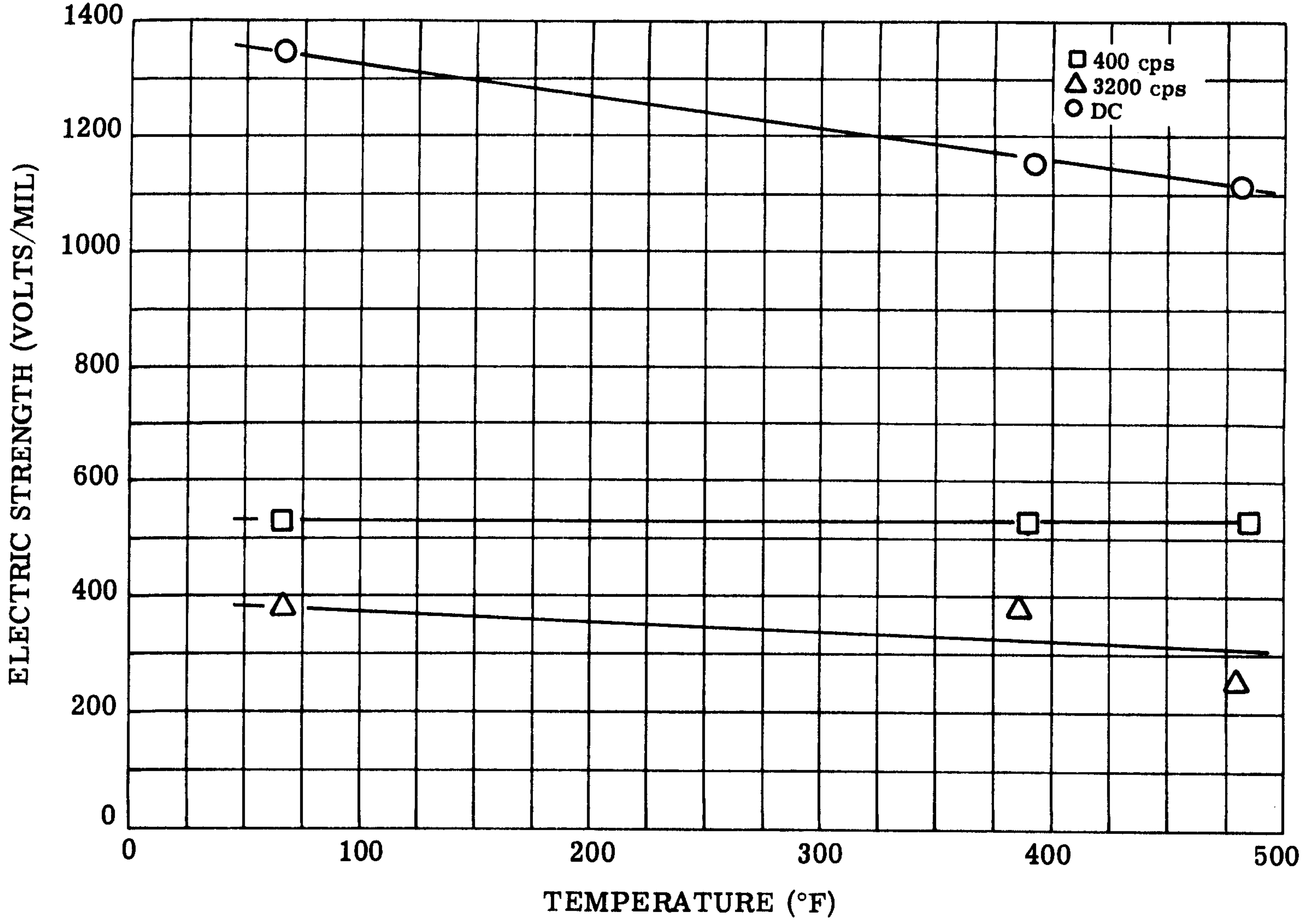


FIGURE V.D.6-4. Electric Strength of Rigid Organic Insulation, Laminated, Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-4. Electric Strength - Laminate - Polyimide Glass

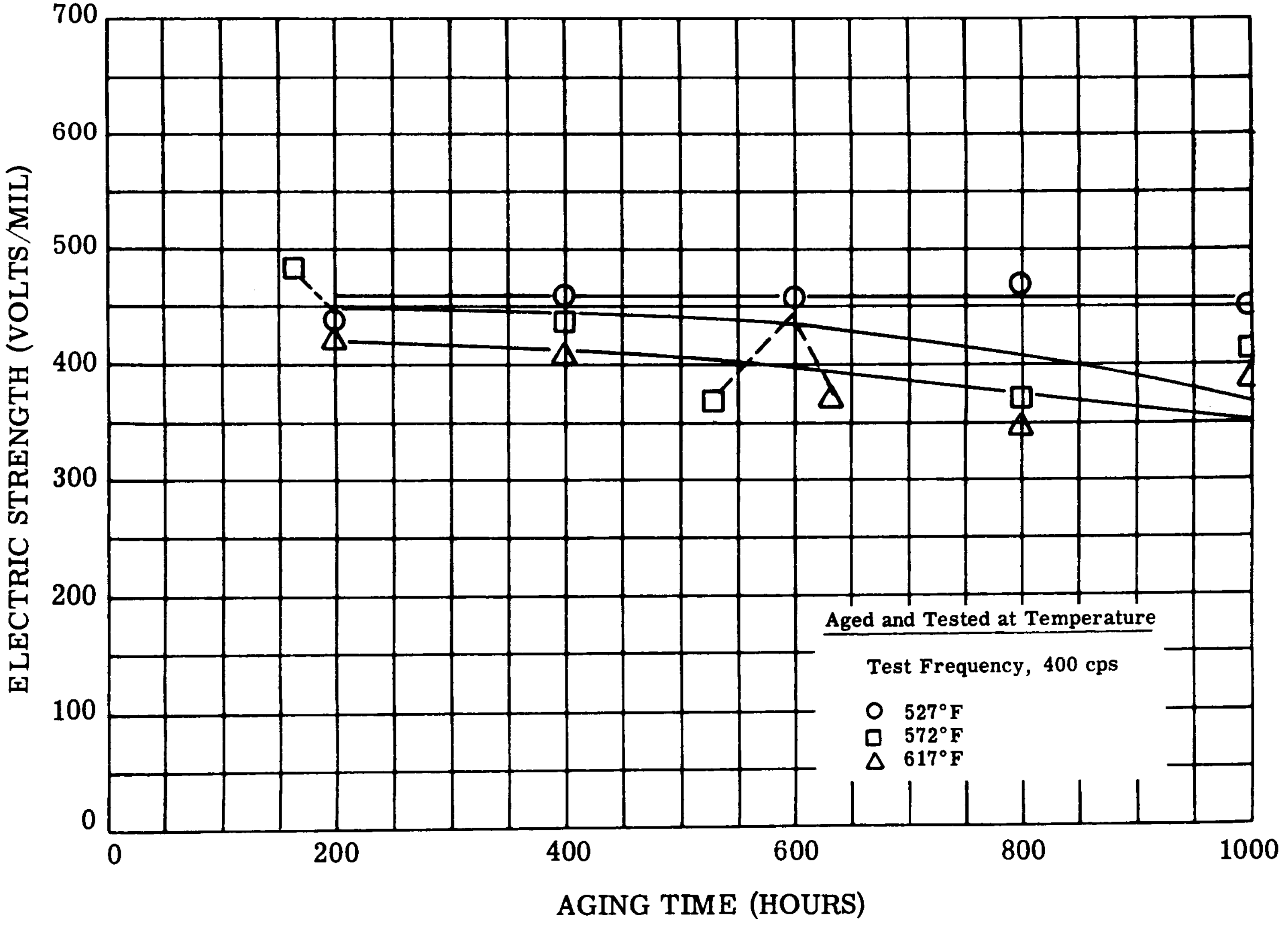


FIGURE V.D.6-5. Insulation Life of Rigid Organic Insulation, Laminated, Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-5. Insulation Life - Laminate - Polyimide Glass

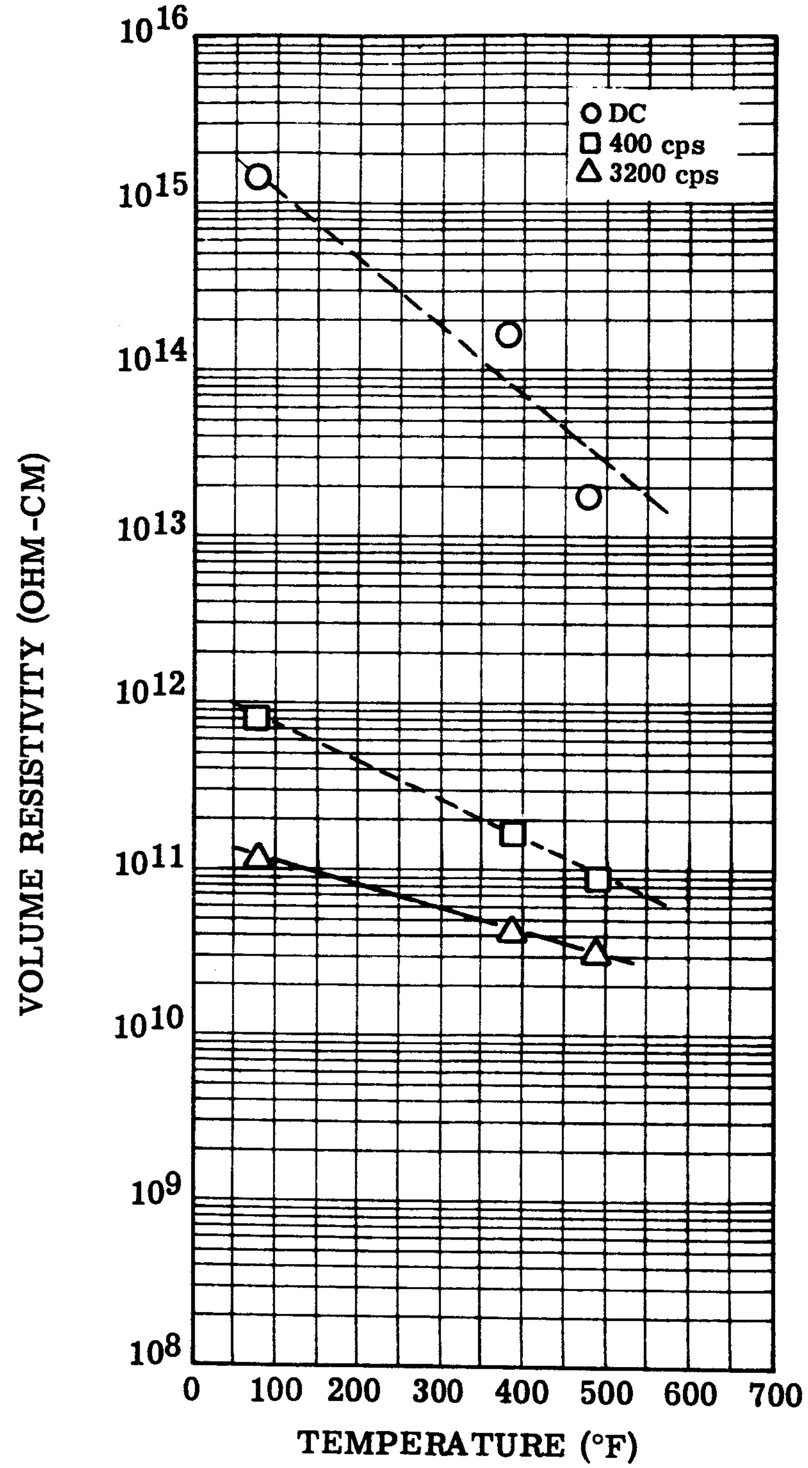


FIGURE V.D.6-6. Volume Resistivity, Rigid Organic Insulation, Laminated, Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-6. Volume Resistivity - Laminate - Polyimide Glass

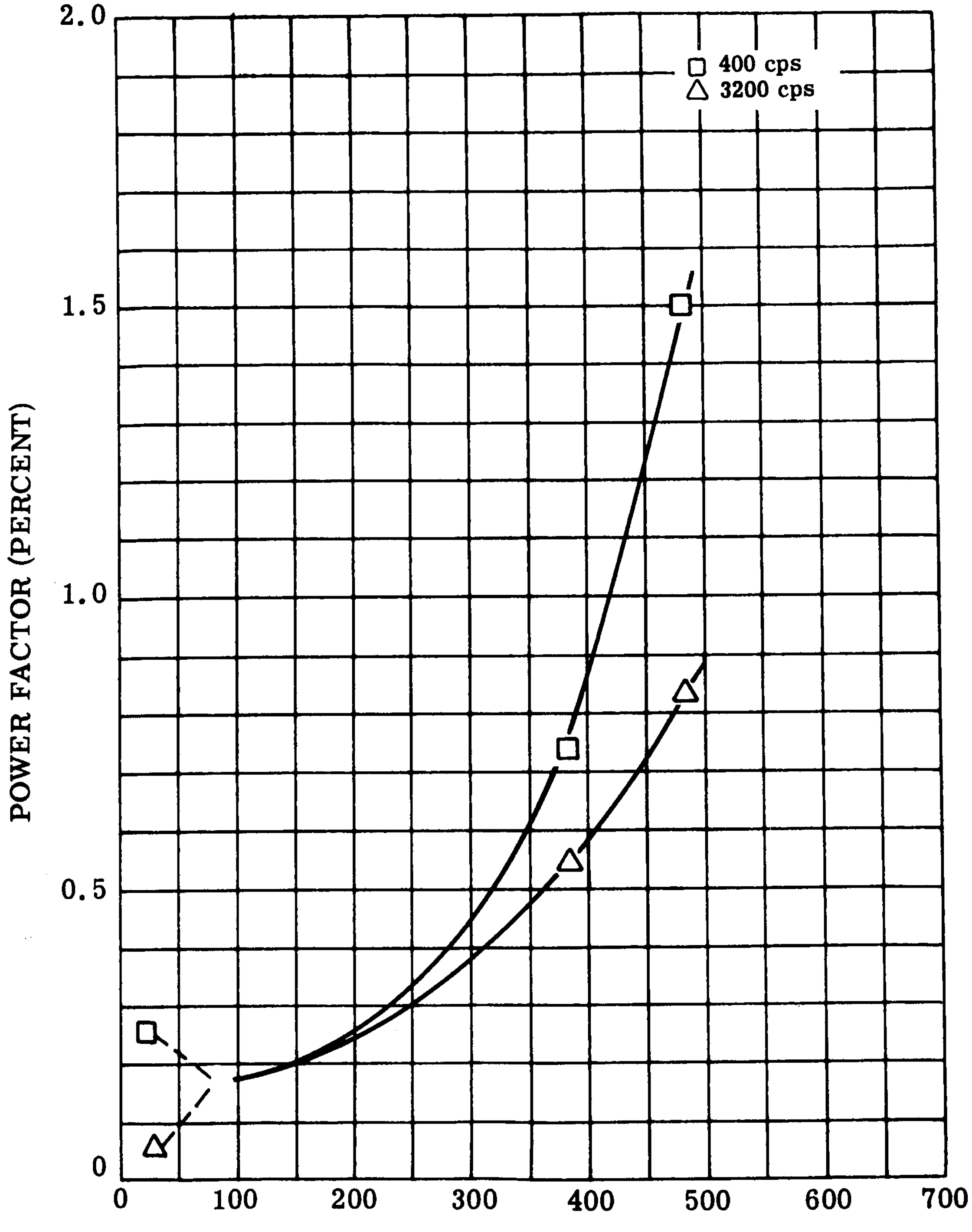


FIGURE V.D.6-7. Power Factor of Rigid Organic Insulation, Laminated, Polyimide Glass, in Air. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-7. Power Factor - Laminate - Polyimide Glass

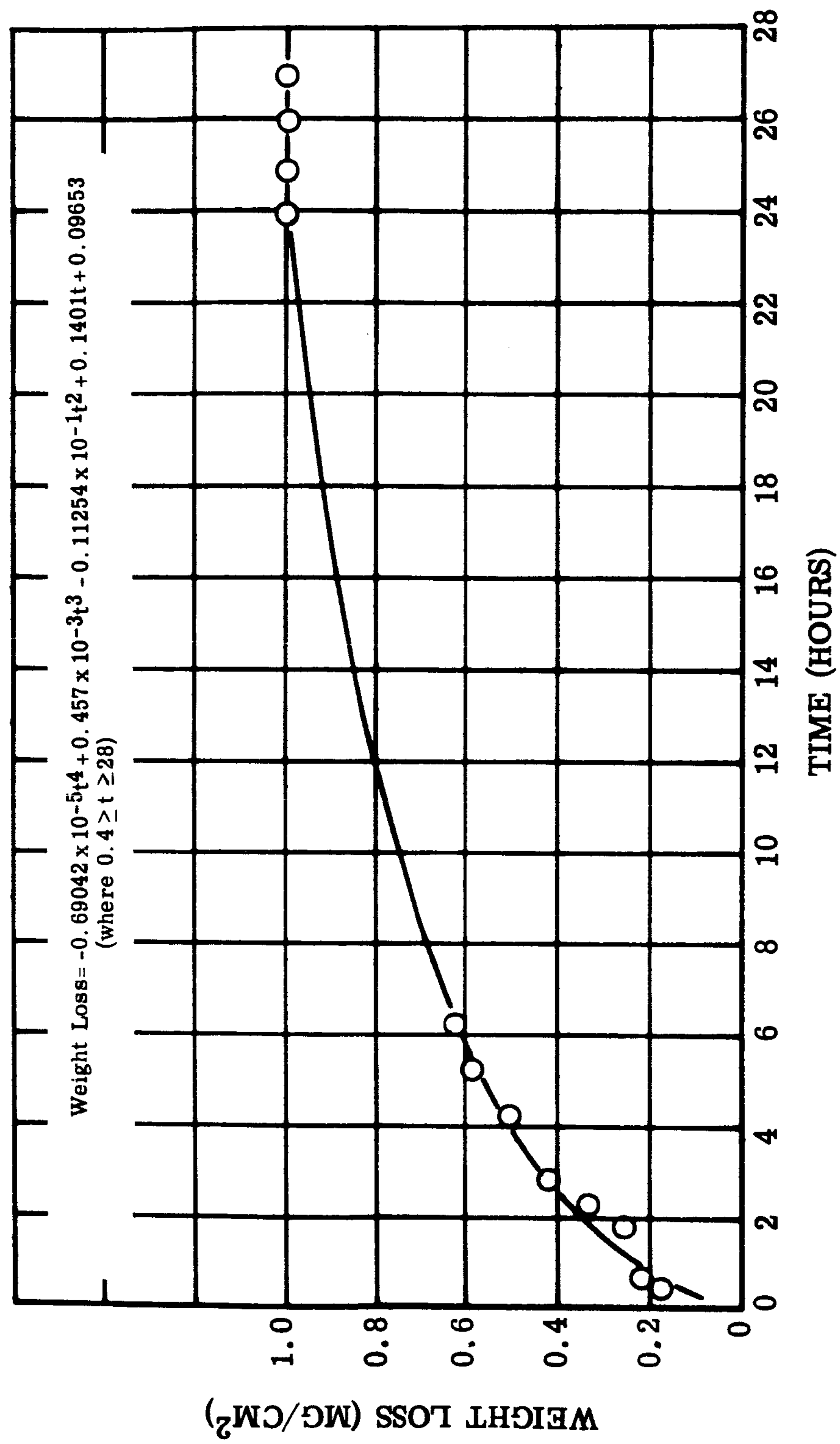


FIGURE V.D.6-8. Weight Loss at 600°F and 10^{-5} to 10^{-6} Torr of Rigid Organic Insulation, Laminated, Polyimide Glass. Specimen Thickness, 0.125 Inch. (Reference: NAS 3-4162)

Figure V.D.6-8. Weight Loss - Laminate - Polyimide Glass

7. MICA, RIGID INSULATION, LAMINATED

This material is an inorganically bonded mica which is suitable for long life operation at 1200°F in a primary electrical insulation application.

Availability:	General Electric Corporation, Insulating Materials Department.
Description:	Mica Mat (78300) is a rigid mica plate bonded with an inorganic material. The laminate meets NEMA grade 9-P.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.075

Specimen Thickness, 0.012 Inch

B. Thermal Conductivity

Specimen Thickness, 0.012 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
500	0.085
932	0.087
1526	0.084

C. Coefficient of Thermal Expansion (average) (parallel to laminations)

Specimen Thickness, 0.012 Inch

Temperature Range (°F)	inch/inch-°F
77 to 1100 (heating)	4.75×10^{-6}
1100 to 1600 (heating)	10.1×10^{-6}
1600 to 77 (cooling)	2.4×10^{-6}

D. Water Absorption (77°F)(average percent) 7.01

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) >420 (RI716)

Tested per ASTM D495-56T

B. Dielectric Constant (RI716)

Specimen Thickness, 0.012 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
72	60	4.6
482	60	4.2
482	400	3.3
482	3200	2.7
932	60	12.0
932	400	9.9
932	3200	5.8
1598	400	32
1598	3200	28

C. Electric Strength

Specimen Thickness, 0.012 Inch

Temperature (°F)	Frequency	500 volts/sec (volts/mil)	Stepwise (volts/mil)
500	DC	2640	2290
500	400 cps	1310	1028
500	3200 cps	637	549
932	DC	1160	1145
932	400 cps	770	488
932	3200 cps	397	353
1112	DC	565	-
1112	400 cps	495	-
1112	3200 cps	352	-

Temperature (°F)	Frequency	500 volts/sec (volts/mil)	Stepwise (volts/mil)
1600	DC	31 (1)	-
1600	400 cps	-	-
1600	3200 cps	59 (2)	-

D. Insulation Life

Specimen Thickness, 0.012 Inch

Aging and Test Temperature (°F)	Aging Time (hours)	DC Volume Resistivity (ohm-cm)
1112	1	5.5×10^8
1112	200	1.1×10^8
1112	400	7.8×10^7
1112	600	8.7×10^7
1112	800	8.1×10^7
1112	1000	5.5×10^7
1112	1000 (3)	3.8×10^7
1600	1	2.7×10^8
1600	200	6.75×10^9
1600	400	3.9×10^8
1600	600	2.5×10^8
1600	800	2.8×10^6
1600	1000	4.6×10^5
1600	1000 (3)	9.1×10^5

E. Power Factor

Specimen Thickness, 0.012 Inch

Temperature (°F)	Frequency (cps)	Percent
500	400	5.8
500	3200	2.2

(1) Not a breakdown. Leakage exceeded 5 ma breaker setting.
(2) Not a breakdown. Leakage exceeded 30 ma breaker setting.
(3) Retested with new electrode.

Temperature (°F)	Frequency (cps)	Percent
932	400	45.1
932	3200	36.7
1600	400	99.98
1600	3200	99.2

F. Volume Resistivity (RI716)

Specimen Thickness, 0.012 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	4.7×10^{12}
500	400 cps	2.3×10^{10}
500	3200 cps	9.4×10^{9}
932	DC	4.5×10^{9}
932	400 cps	7.6×10^{8}
932	3200 cps	2.3×10^{8}
1600	DC	2.7×10^{8}
1600	400 cps	2.7×10^{6}
1600	3200 cps	2.7×10^{6}

III. Mechanical Properties

A. Compressive Strength (800°F) (RI716)

Specimen Thickness, 0.012 Inch

1.	Perpendicular to laminations	45,000 psi
2.	Parallel to laminations	20,000 psi

B. Elastic Modulus in Flexure

Specimen Thickness, 0.012 Inch

Temperature (°F)	Psi
77	5.6×10^6
932	4.7×10^6
1600	0.6×10^6

C. Elastic Modulus in Flexure at 932°F

After 800 hours aging at 932°F	4.2×10^6 psi

D. Impact Strength (77°F)

1. IZOD (ft-lb/inch notch)	0.56
2. CHARPY (ft-lb/inch width)	0.60

E. Flexural Strength

Temperature (°F)	Strain Rate to Failure (inch/inch-minute)	Psi	
77	0.006	20,650	
932	0.01	19,800	
1600	0.004	5,280	
77	-	28,000	(RI716)

IV. Compatibility Properties

A. Chemical Resistance (RI716)

This material displays good resistance to water immersion and organic solvents. Resistance to acid and alkaline solutions is poor.

B. Nuclear Radiation Resistance (RI716)

1. Electron Exposure

Electrons/cm^2	Flexural Strength (psi)
none	33,800
6.23 x 10^6 (energy level not known)	32,500

2. Gamma Photon Exposure

Roentgens	Flexural Strength (psi)
none	28,000
1 x 10^7	27,700
5 x 10^7	27,000
1 x 10^8	26,800

C. Vacuum Weight Loss at Elevated Temperature

1. 24 hours at 932°F, 10^{-6} torr	0.15 percent
2. 24 hours at 932°F plus 24 hours at 1600°F, 10^{-6} torr	2.6 percent

Figure V.D.7-1. Thermal Conductivity - Laminate - Mica

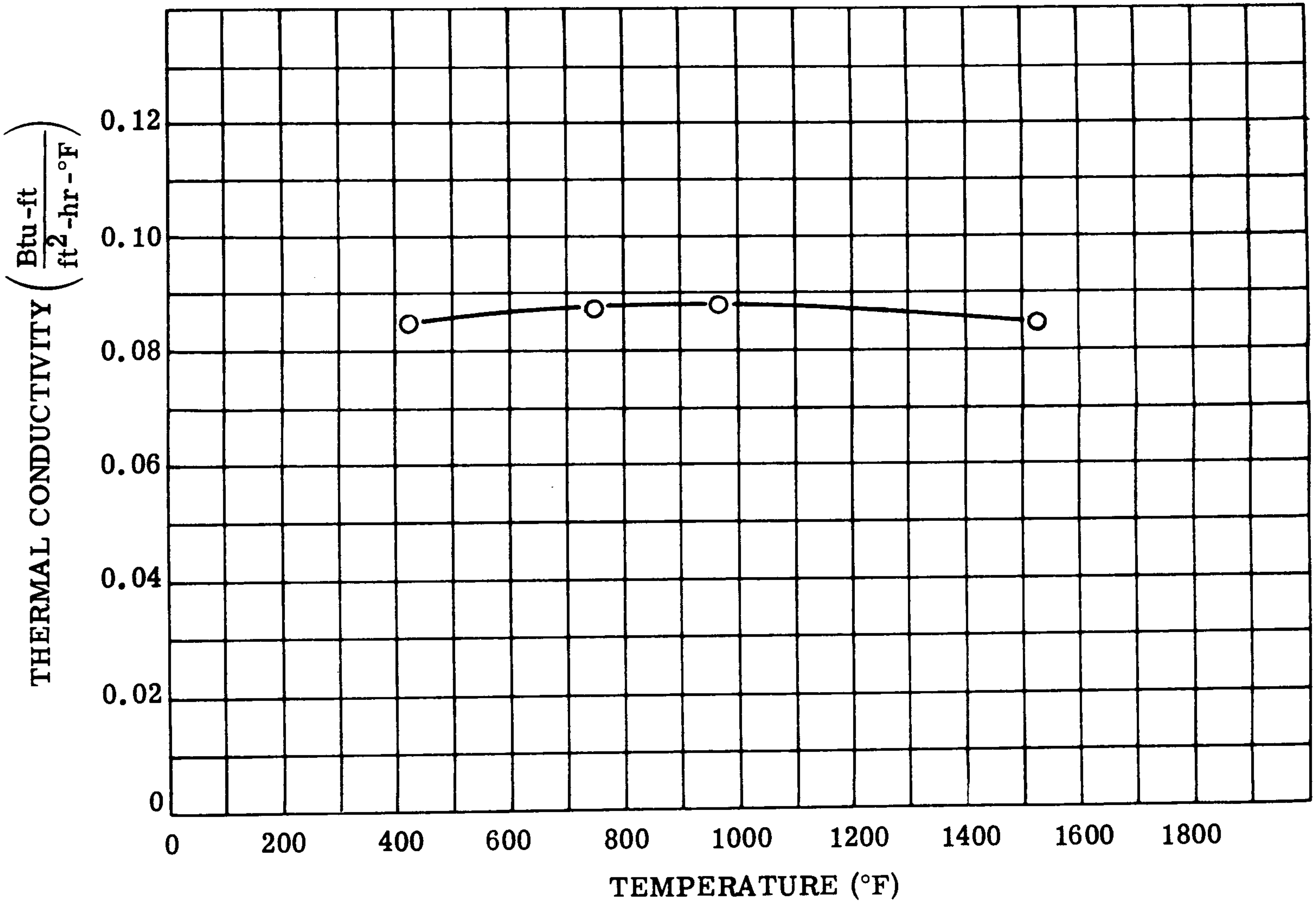
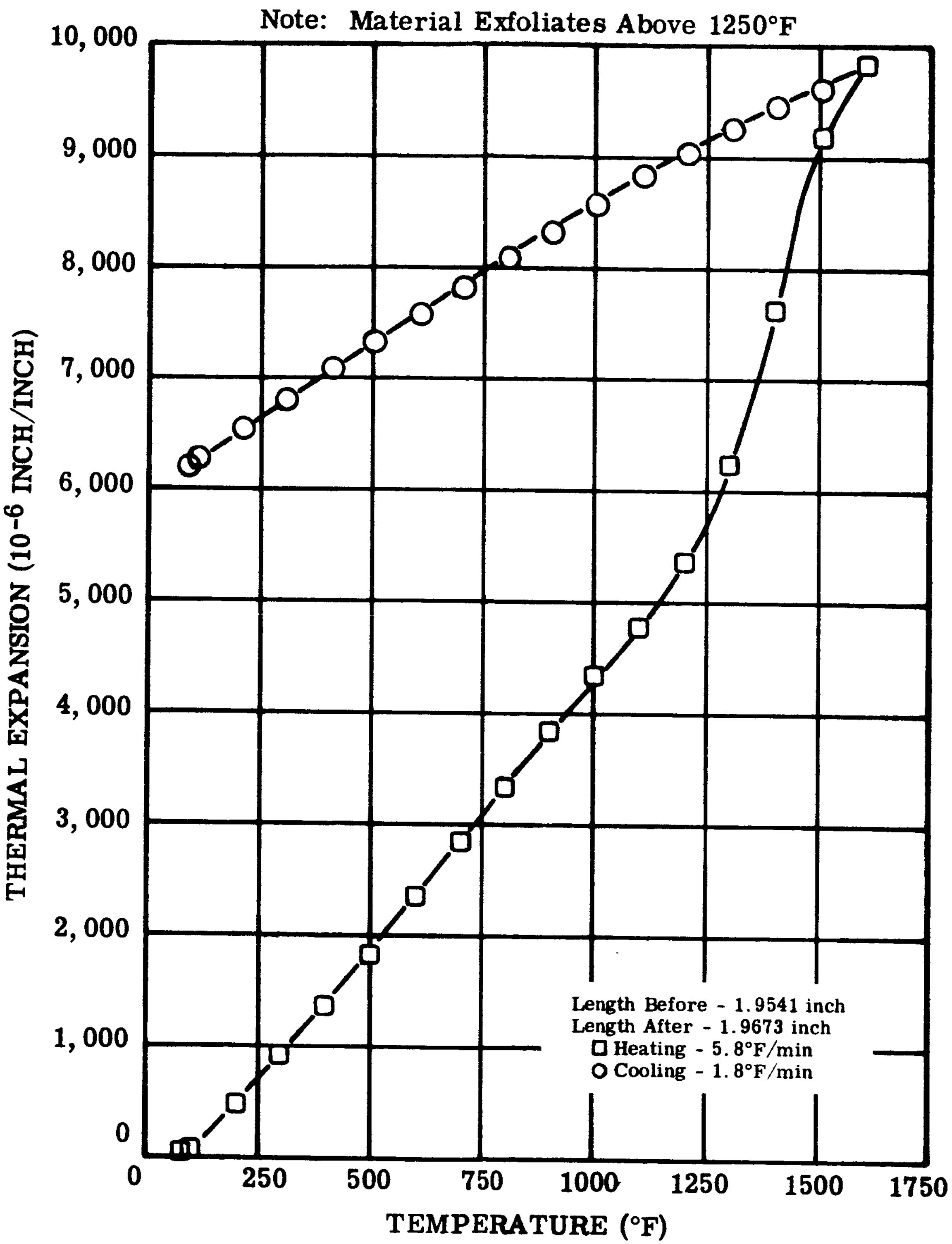


FIGURE V.D.7-1. Thermal Conductivity of Rigid Inorganic Insulation, Laminated Mica, Measured Perpendicular to Laminations in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)


Note: Material Exfoliates Above 1250°F

Length Before - 1.9541 inch
Length After - 1.9673 inch
□ Heating - 5.8°F/min
○ Cooling - 1.8°F/min

FIGURE V.D.7-2. Thermal Expansion of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)

Figure V.D.7-2. Thermal Expansion - Laminate - Mica

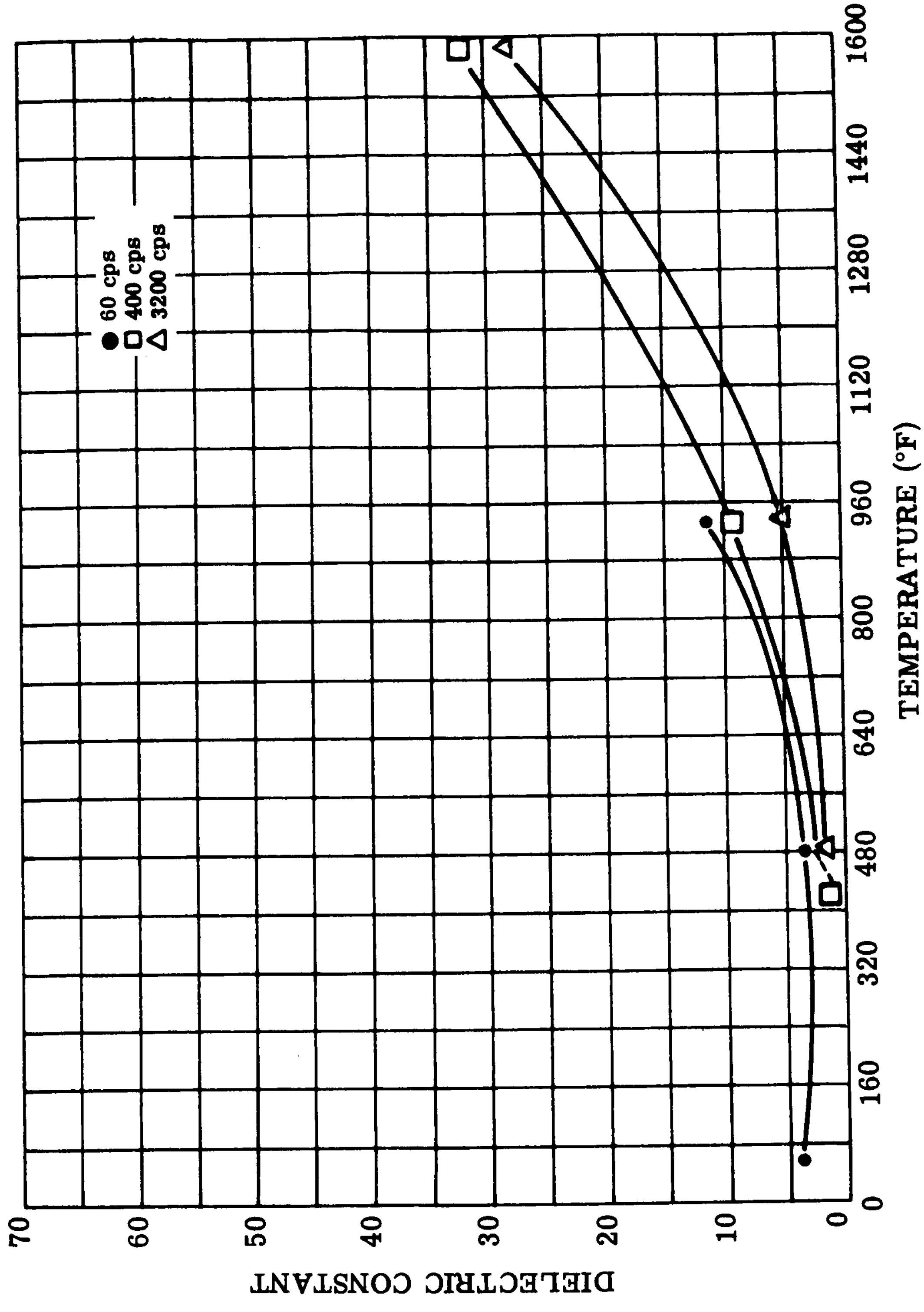


FIGURE V.D.7-3. Dielectric Constant of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: RI716)

Figure V.D.7-3. Dielectric Constant - Laminate - Mica

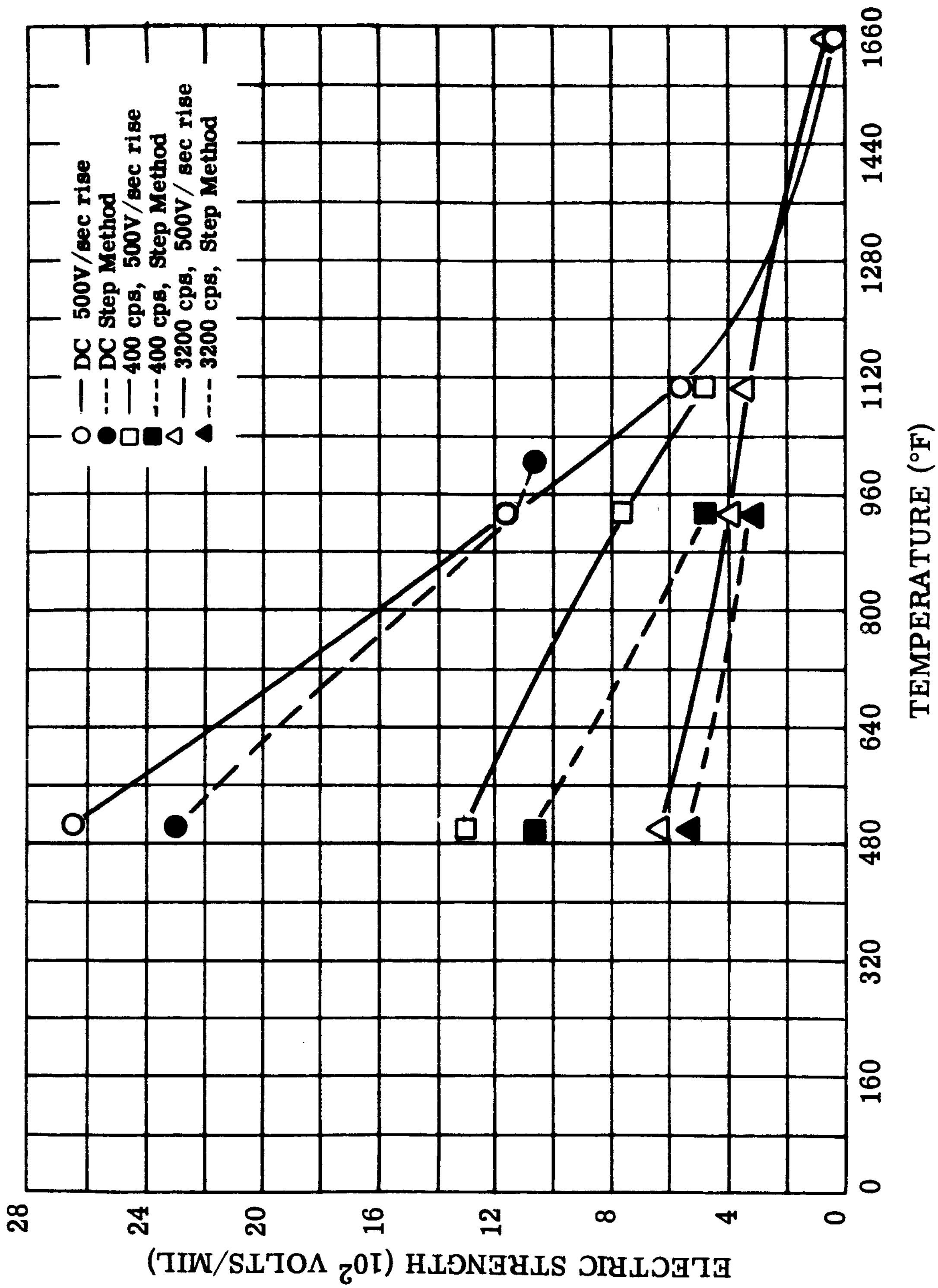


FIGURE V.D.7-4. Electric Strength of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS3-4162)

Figure V.D.7-4. Electric Strength - Laminate - Mica

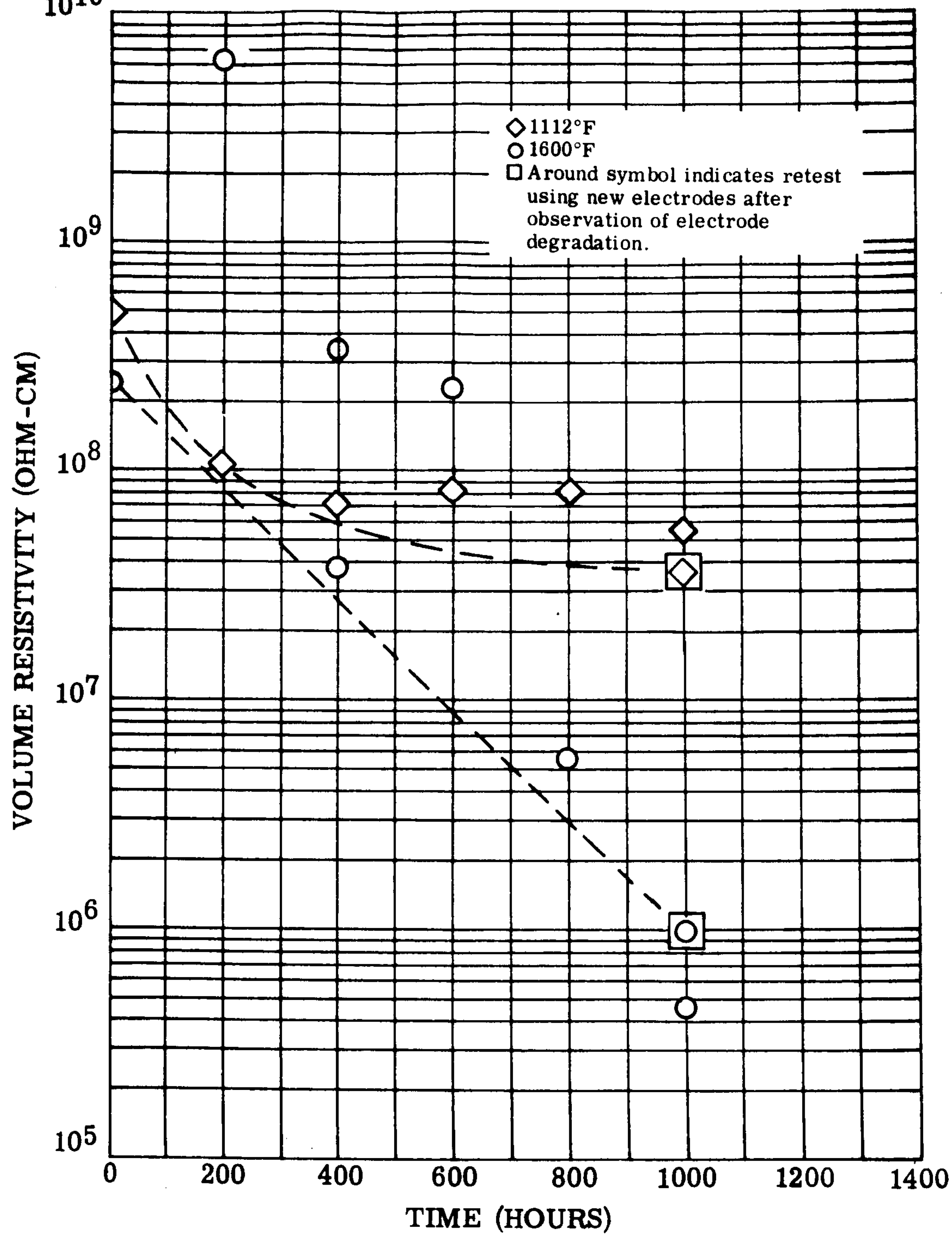


FIGURE V. D. 7-5. Insulation Life of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)

Figure V.D.7-5. Insulation Life - Laminate - Mica

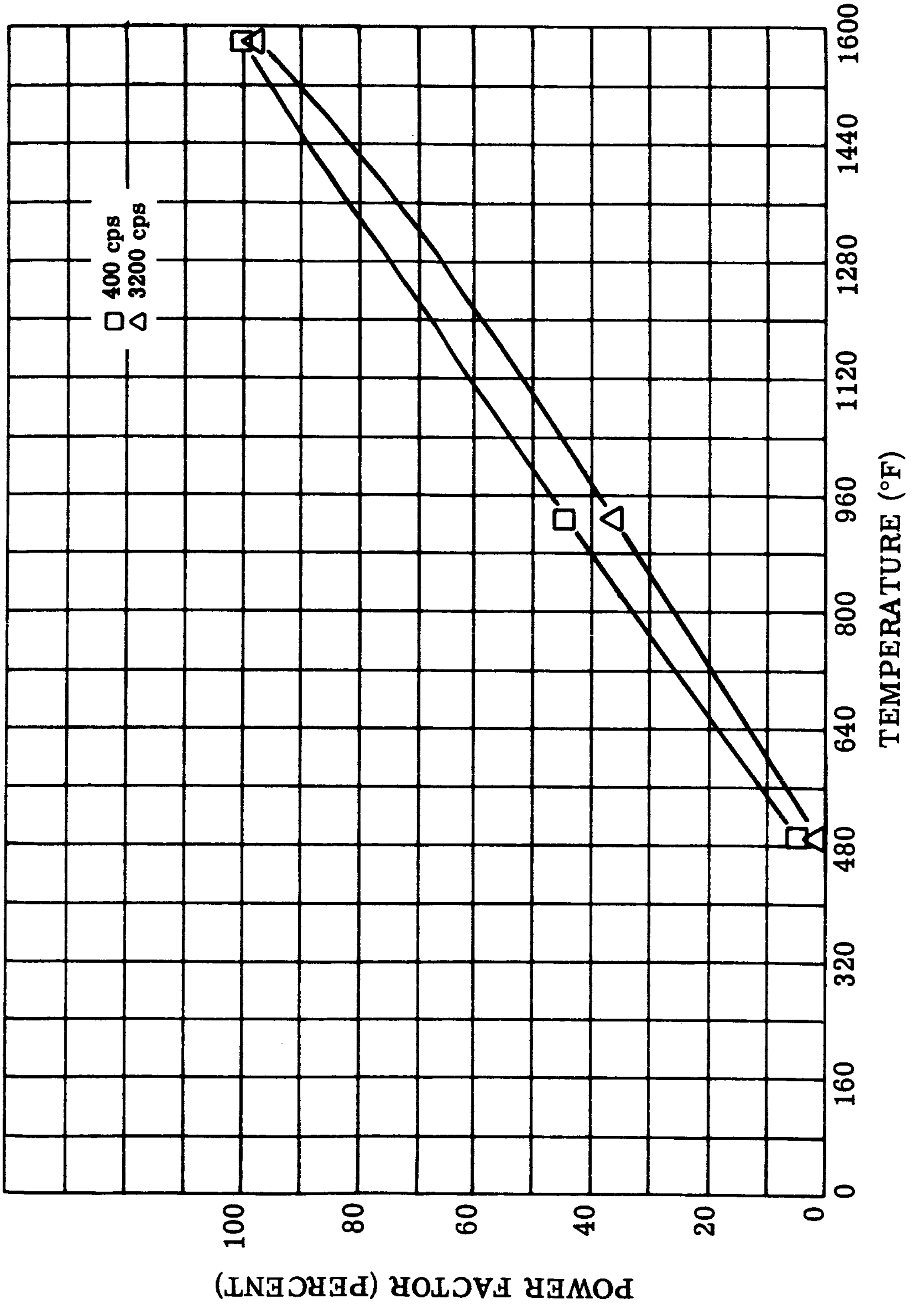
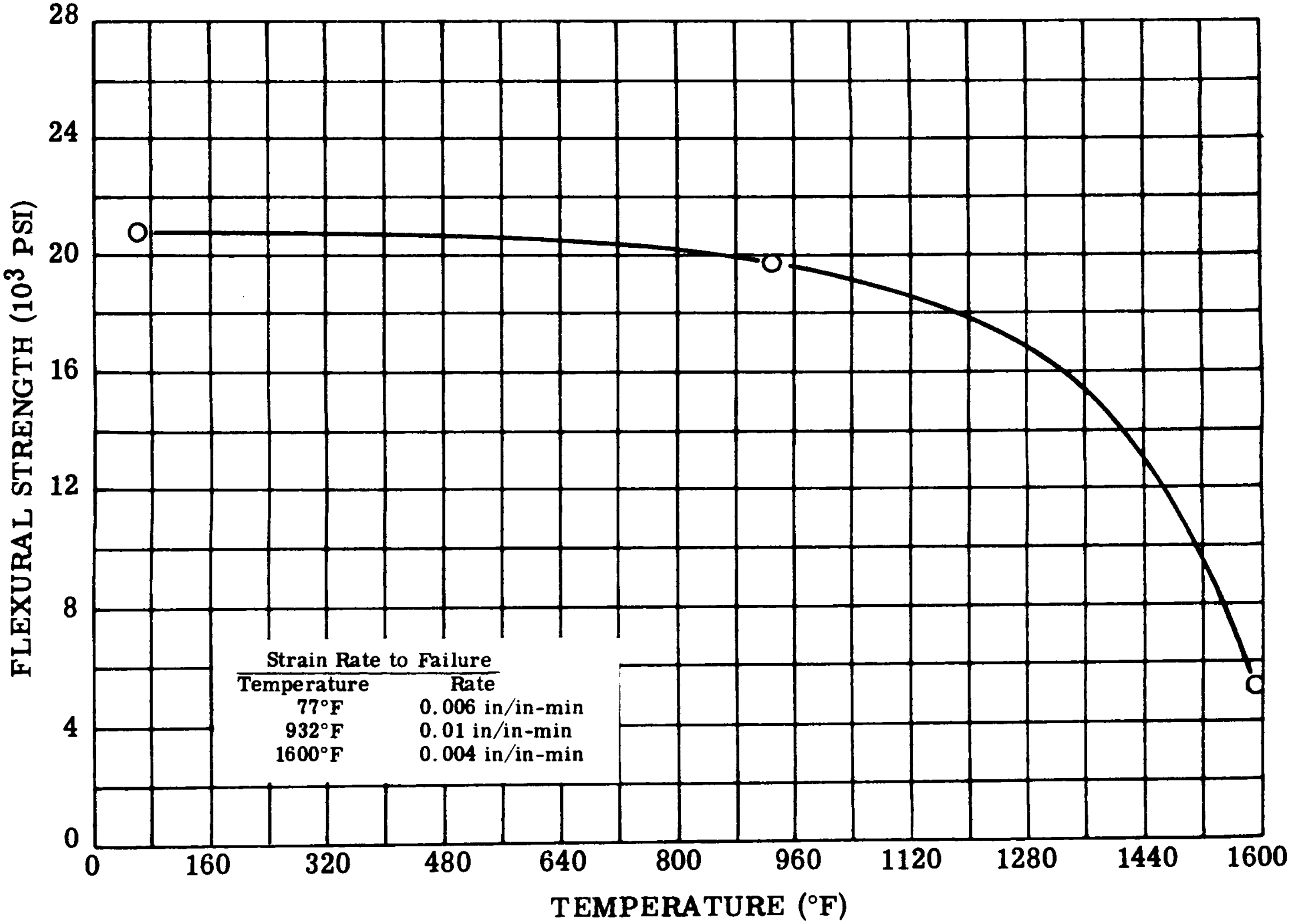


FIGURE V. D. 7-6. Power Factor of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)

Figure V.D.7-6. Power Factor - Laminate - Mica

Figure V.D.7-7. Flexural Strength - Laminate - Mica



Strain Rate to Failure

Temperature	Rate
77°F	0.006 in/in-min
932°F	0.01 in/in-min
1600°F	0.004 in/in-min

FIGURE V. D. 7-7. Flexural Strength of Rigid Inorganic Insulation, Laminated Mica, in Air. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)

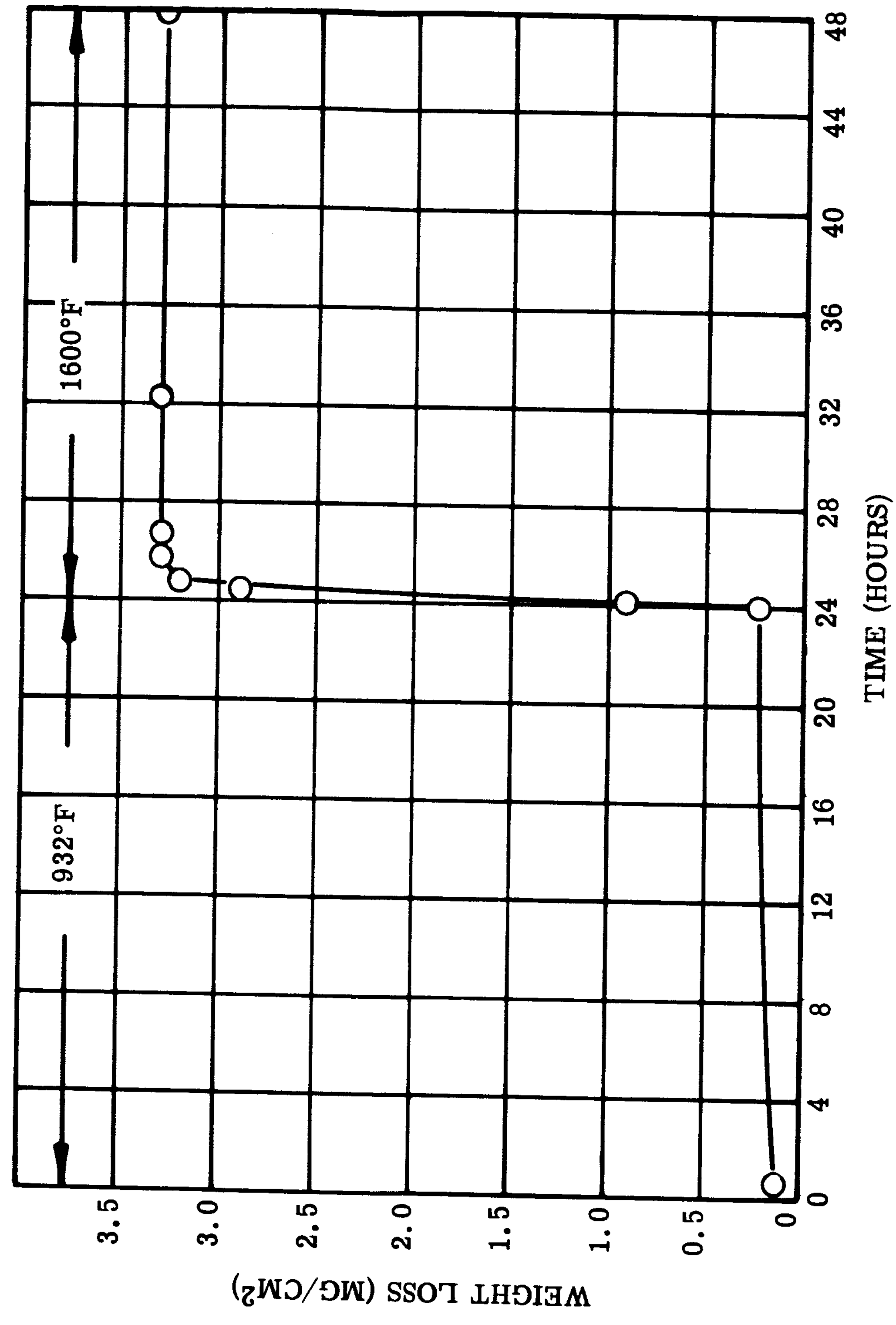


FIGURE V. D. 7-8. Weight Loss at 932°F and 1600°F at 10^{-5} to 10^{-6} Torr, for Rigid Inorganic Insulation, Laminated Mica. Specimen Thickness, 0.012 Inch. (Reference: NAS 3-4162)

Figure V.D. 7-8. Weight Loss - Laminate - Mica

E. RIGID INSULATION, MOLDED OR PRESSED

1. 99.5 PERCENT ALUMINA, RIGID INSULATION

Alumina, 99.5 percent Al_2O_3, is used in electrical and electronic applications in pressed, extruded, and ground shapes.

Availability: This material is commercially available from several suppliers in extruded or pressed shapes.

Composition: (Nominal)

99.5% Al_2O_3
0.2 - 0.3% S_iO_2
0 - 0.2% MgO
0 - 0.2% Cr_2O_3
0 - 0.02% Fe_2O_3

Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer.

I. Thermophysical Properties

A.	Density (77°F)(lb/cu inch)	0.137 - 0.140
	Specific Gravity (77°F)	3.80 - 3.89

B. Specific Heat (LI146)

Temperature (°F)	Btu/lb-°F
500	0.258
930	0.281
1600	0.312

C. Thermal Conductivity (LI271)

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
500	10
930	6
1600	4

D. Coefficient of Thermal Expansion (LI271)

Temperature Range (°F)	inch/inch-°F
70 to 500	3.95×10^{-6}
500 to 1000	4.6×10^{-6}
1000 to 1600	5×10^{-6}

II. Electrical Properties

A. Electric Strength

Composition and/or Thickness	Temperature (°F)	Frequency (cps)	Volts/mil	
				(LI185)
0.250 inch	72	60	220-245	
0.125 inch	72	60	330	
0.050 inch	72	60	400	
High purity Alumina of unknown composition	77	60	400	(LI295)
	500	60	400	
	932	60	140	
	1600	60	46	
Sapphire, >99.5% 0.005 Inch	1100	DC	1840 (1)	(Reference: NASA-CR-54357)

---

(1) Value was determined in vacuum of 3×10^{-7} torr.

B. Dissipation Factor

Temperature (°F)	Frequency (mc)	Dissipation Factor	
77	1	0.001	(LI271)
932	1	0.0023	
77	215	0.00005	(LI146)
500	215	0.0001	
932	215	0.00015	
1600	215	0.0003	

C. Volume Resistivity (LI251)

Temperature (°F)	Frequency	Ohm-cm
930	DC	2×10^{11}
1112	DC	6×10^{8}
1600	DC	4.5×10^{6}

For additional information on electrical properties, see references LI295 and LI251.

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi	
77	400,000	(LI146)
932	200,000	(LI273)
1600	185,000	(LI273)

B. Elastic Modulus

Temperature (°F)	Psi	
77	52×10^{6}	(LI146) (LI273)
1600	48×10^{6}	(LI273)

C. Impact Strength (Izod) (1)

1. 77°F full swing method	8.92 ± 4.56 ft-lbs/inch
2. 77°F incremental swing	7.73 ± 1.60 ft-lbs/inch

D. Flexural Strength (LI146)

Temperature (°F)	Psi
72	52×10^3
930	53×10^3
1600	47×10^3

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Acid and alkaline solutions	Excellent
Organic solvents	Excellent
Alkali metals	Fair to Good

B. Nuclear Radiation Resistance (LI296)

No significant change in dielectric constant or volume resistivity is noted when exposed to neutron flux levels of 2×10^{20} n/cm^2 (energy level unspecified) and 5.1×10^7 ergs/grams (C) of gamma radiation.

---

(1) Private communication from A.J. Monack, Newark College of Engineering, Newark, N.J.

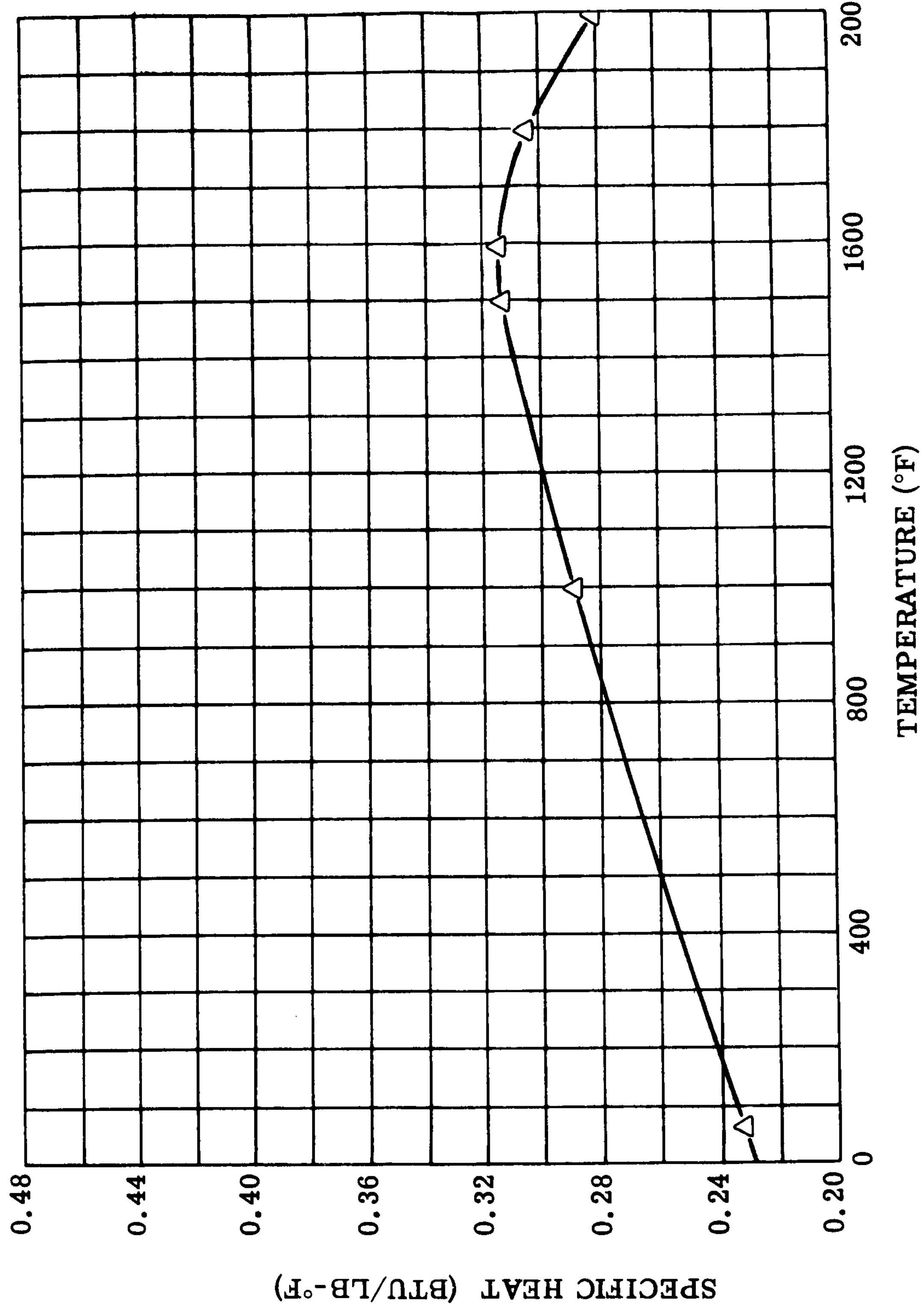


FIGURE V. E. 1-1. Specific Heat of Rigid Insulation Alumina, 99.5 Percent.
(Reference: LI 146)

Figure V. E. 1-1. Specific Heat - Alumina, 99.5%

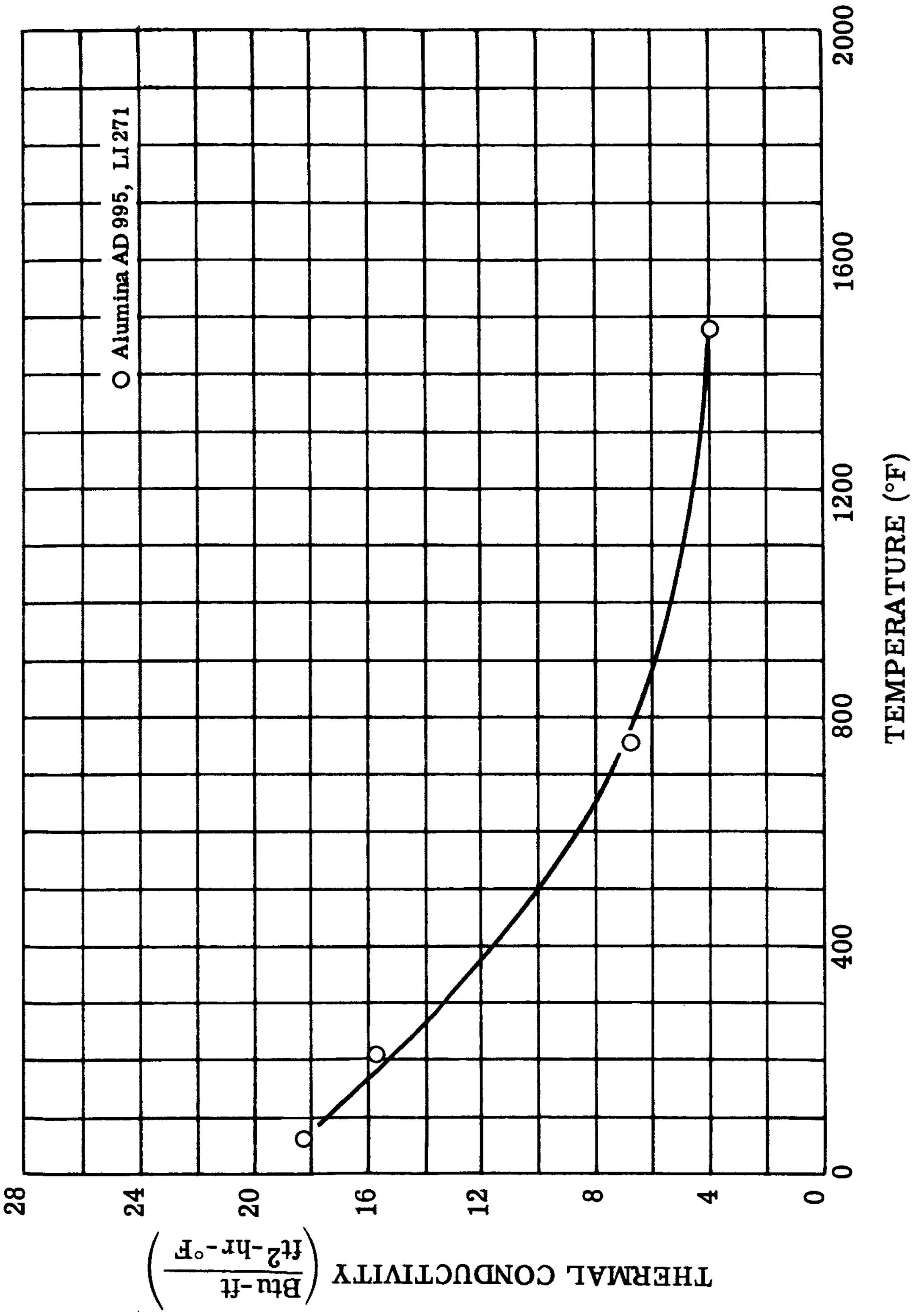


FIGURE V. E. 1-2. Thermal Conductivity of Rigid Insulation Alumina, 99.5 Percent. (Reference: LI 271)

Figure V. E. 1-2. Thermal Conductivity - Alumina, 99.5%

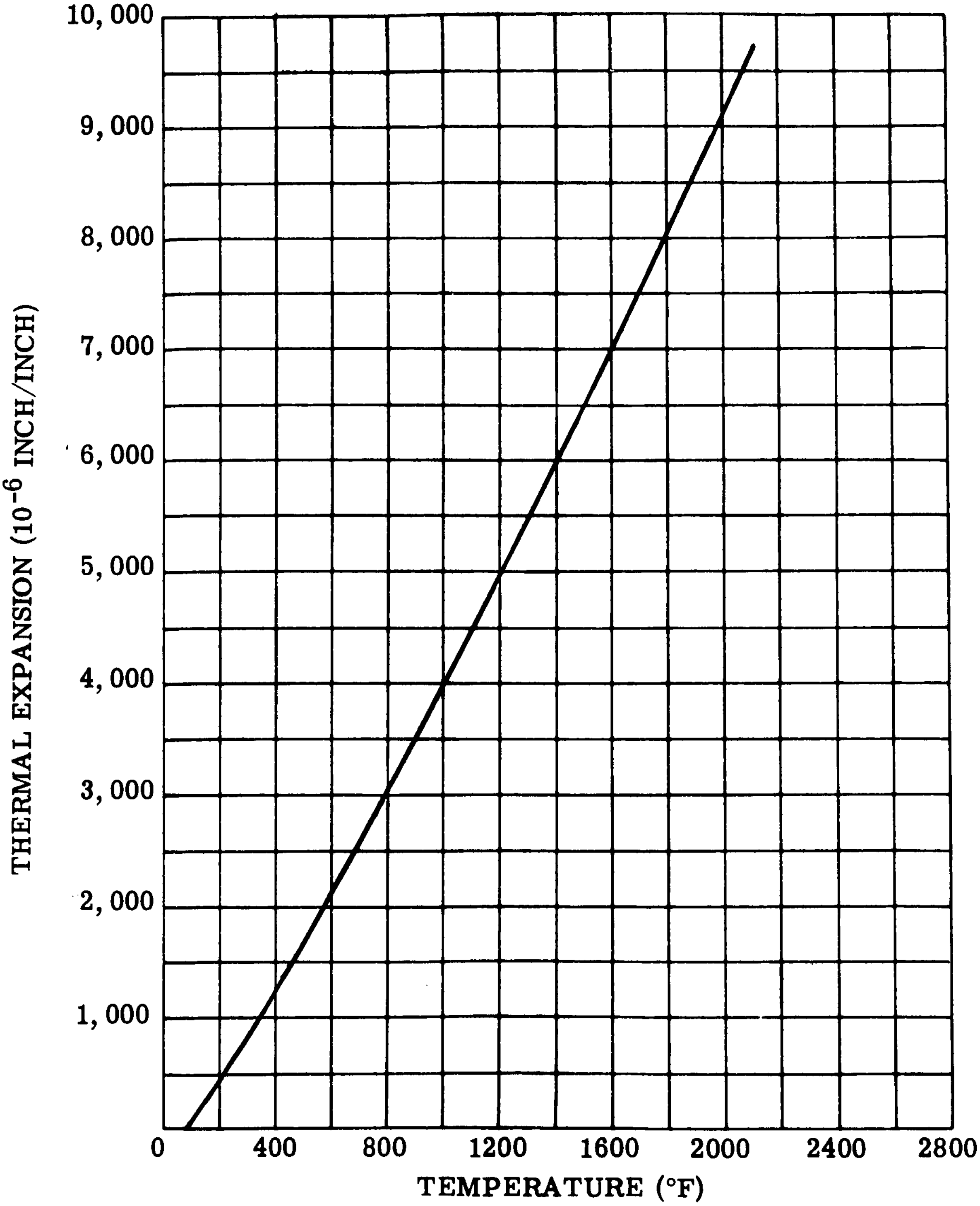


FIGURE V.E.1-3. Thermal Expansion of Rigid Insulation Alumina, 99.5 Percent. (References: LI146, LI271)

Figure V.E.1-3. Thermal Expansion - Alumina, 99.5%

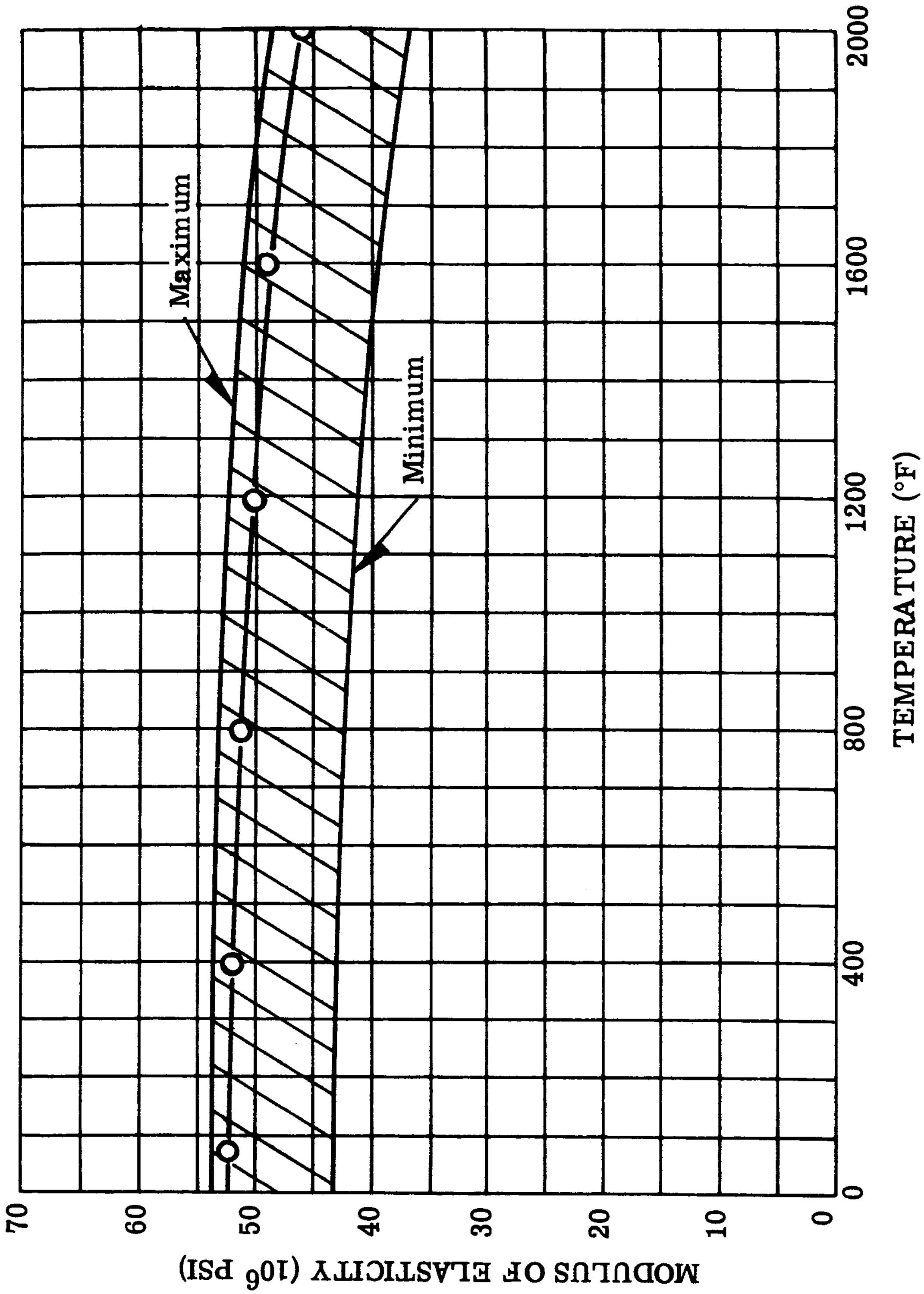


FIGURE V. E. 1-4. Modulus of Elasticity of Rigid Insulation Alumina, 99.5 Percent. (Reference: LI 146, LI 273)

Figure V. E. 1-4. Modulus of Elasticity - Alumina, 99.5%

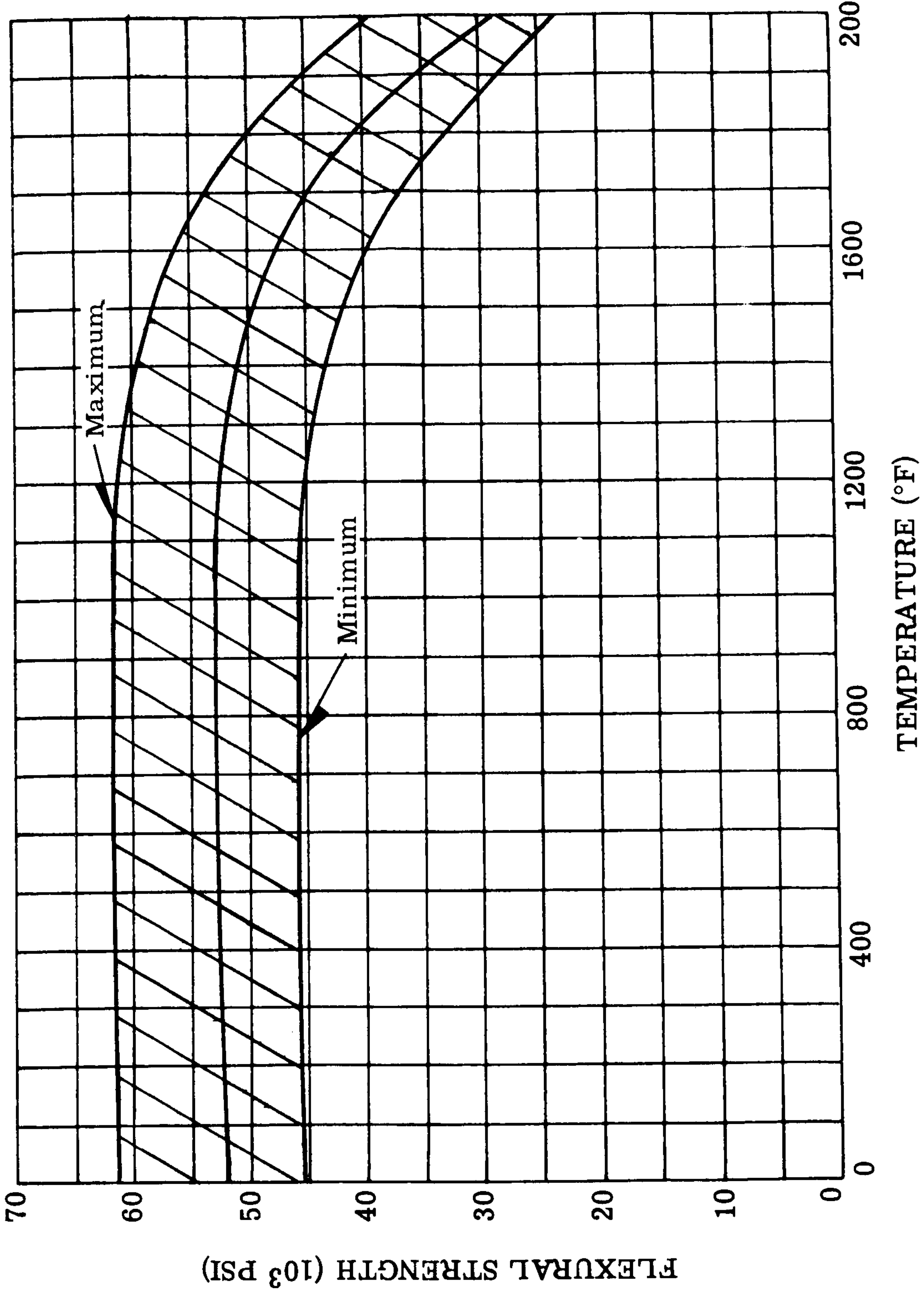


FIGURE V.E.1-5. Flexural Strength of Rigid Insulation Alumina, 99.5 Percent. (Curve, Reference: LI146)

Figure V.E.1-5. Flexural Strength - Alumina, 99.5%

2. 99 PERCENT ALUMINA, RIGID INSULATION

Alumina, 99 percent Al_2O_3, is used in electrical and electronic applications in pressed, extruded, and ground shapes.

Availability: This material is commercially available from several suppliers, extruded or pressed, in a variety of shapes and sizes.

Composition: (Nominal)

99% Al_2O_3
0.1 - 0.5% S_iO_2
0.3 - 1% CaO
0.0 - 0.2% MgO

Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer.

I. Thermophysical Properties

A. Density (77°F)(lb/cu-inch) 0.136 - 0.140

Specific Gravity (77°F) 3.78 - 3.90 (LI271)

B. Specific Heat (LI146)

Temperature (°F)	Btu-lb-°F
500	0.255
930	0.280
1600	0.310

C. Thermal Conductivity (LI146) (LI271)

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
500	9
930	5
1600	3.5

D. Coefficient of Thermal Expansion (LI146) (LI271)

Temperature Range (°F)	inch/inch-°F
70 to 500	3.4×10^{-6}
500 to 1000	5.0×10^{-6}
1000 to 1600	5.2×10^{-6}

II. Electrical Properties

A. Dielectric Constant (LI16) (RI35)

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	10
500	3200	9.8
930	400	13
930	3200	11
1600	400	60
1600	3200	35

B. Electric Strength

Thickness (inch)	Temperature (°F)	Frequency (cps)	Volts/mil	
0.250	72	60	220-440	(LI251)
0.125	72	60	330	(LI251)
0.050	72	60	325-400	(LI251)
0.125	72	DC	860	(LI271)
0.050	72	DC	1000	(LI271)

C. Dissipation Factor

Temperature (°F)	Frequency	Dissipation Factor	
77	100 cps	0.00102	(LI251)
77	1000 cps	0.00123	
77	215 mc	0.00018	(LI146)

Temperature (°F)	Frequency	Dissipation Factor
500	215 mc	0.0002
932	215 mc	0.00025
1600	215 mc	0.00043

D. Power Factor

Temperature (°F)	Frequency (cps)	Percent	
72	100	0.00112	(LI251)
72	1000	0.00110	
72	10000	0.00108	

E. Volume Resistivity

Temperature (°F)	Frequency	Ohm-cm	
930	DC	1×10^{11}	(LI251)
930	400 cps	4×10^{5}	(RI35)
930	3200 cps	1×10^{5}	(RI35)
1112	DC	1×10^{10}	(LI251)
1112	400 cps	6×10^{4}	(RI35)
1112	3200 cps	2×10^{4}	(RI35)
1600	DC	1×10^{7}	(LI251)
1600	400 cps	1×10^{2}	(RI35)
1600	3200 cps	4×10^{2}	(RI35)

For additional information on electrical properties, see references LI295 and LI251.

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi	
77	340, 000	(LI221)
932	209, 000	(LI273)
1600	185, 000	(LI273)

B. Elastic Modulus

Temperature (°F)	Psi	
77	51×10^6	(LI146)
1600	47×10^6	(LI146)

C. Impact Strength

At 77°F	7.9 in-lb	(LI221)

D. Flexural Strength

Temperature (°F)	Psi	
72	53, 000	(LI146) (LI271)
930	53, 000	
1600	43, 000	

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Acid and alkaline solutions	Excellent
Organic solvents	Excellent
Alkali metals	Poor at 1000°F

B. Nuclear Radiation Resistance (LI296)

No significant change in dielectric constant, or volume resistivity as noted when exposed to flux levels of 2×10^{20} fast neutrons/cm^2 and 5.1×10^7 ergs per gram (C) of gamma radiation.

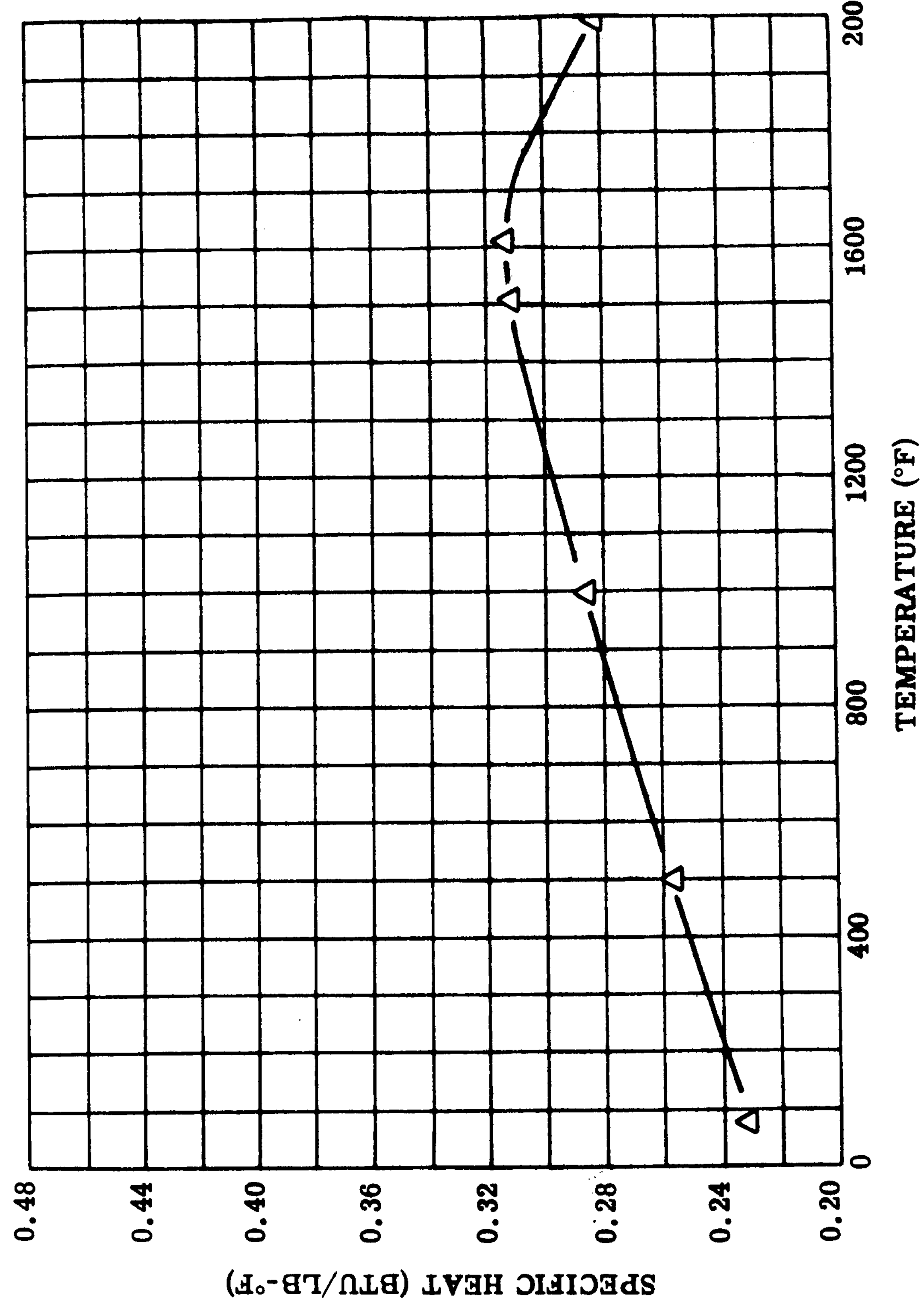


FIGURE V. E. 2-1. Specific Heat of Rigid Inorganic Insulation Alumina, 99 Percent. (Reference: LI 146)

Figure V. E. 2-1. Specific Heat - Rigid Insulation - Alumina, 99%

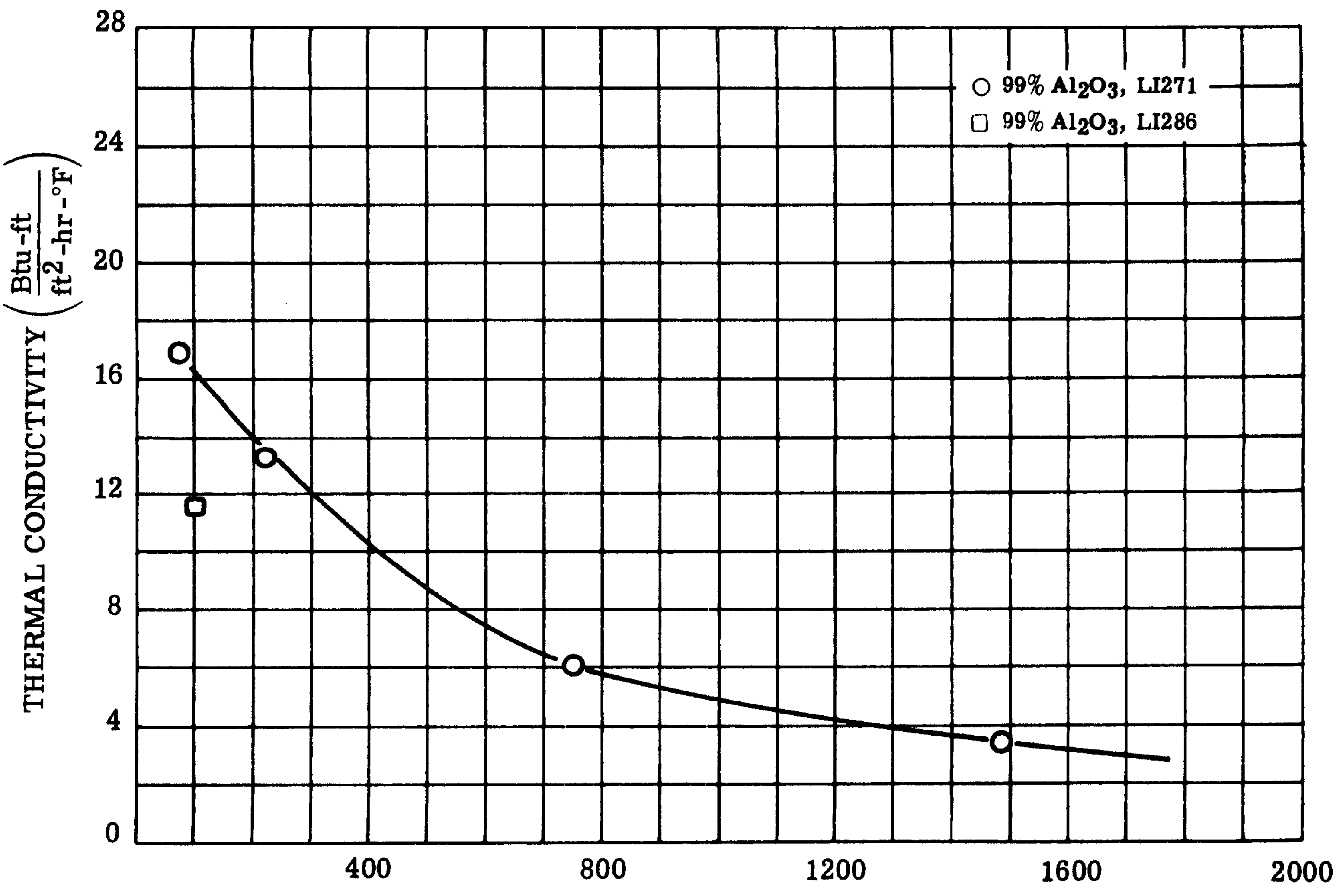


FIGURE V. E. 2-2. Thermal Conductivity of Rigid Inorganic Insulation Alumina, 99 Percent. (Reference: LI 146, LI 271, LI 286)

Figure V. E. 2-2. Thermal Conductivity - Rigid Insulation - Alumina, 99% Percent.

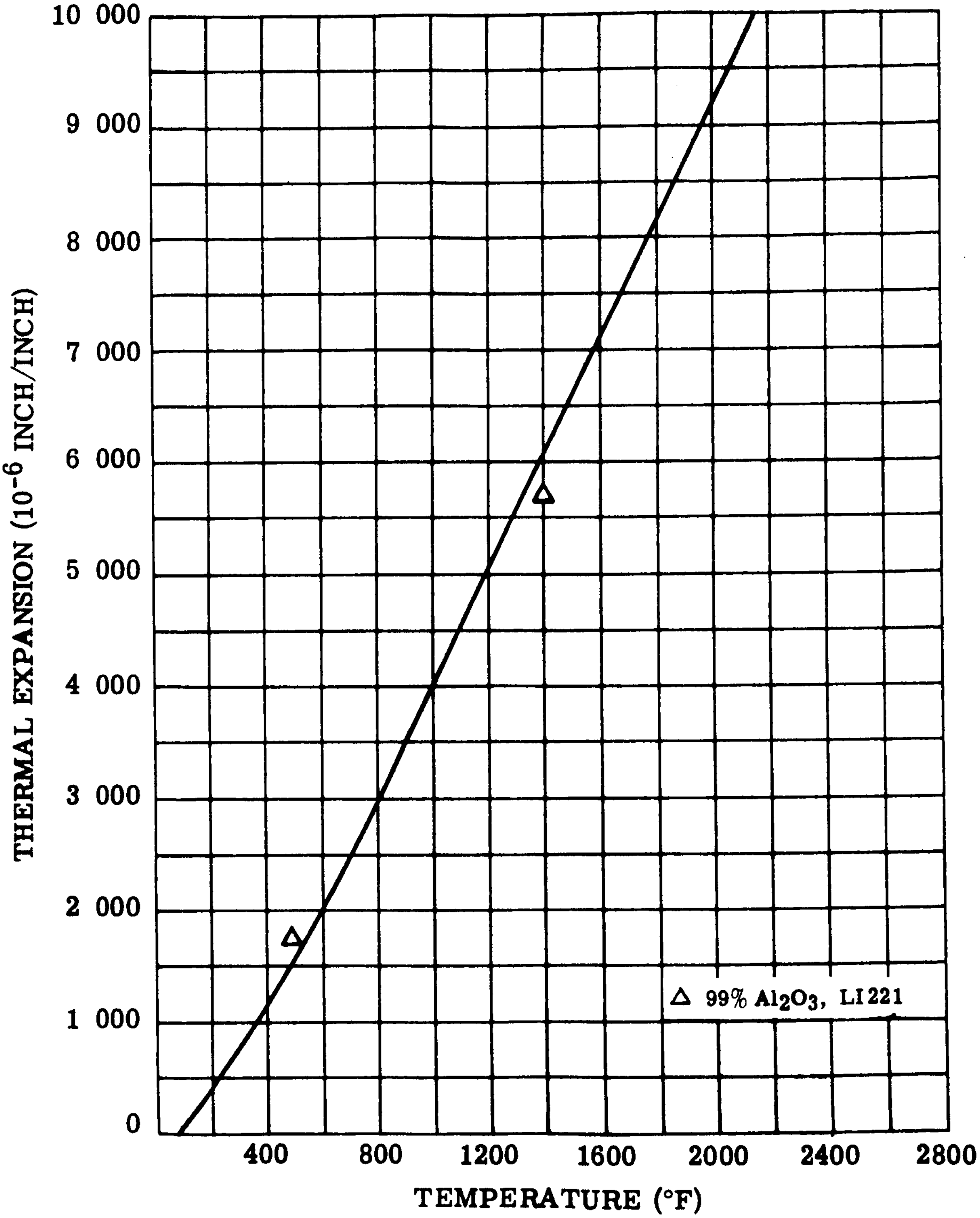


FIGURE V.E.2-3. Thermal Expansion of Rigid Inorganic Insulation Alumina, 99 Percent. (Reference: LI146, LI271)

Figure V.E.2-3. Thermal Expansion - Rigid Insulation - Alumina, 99%

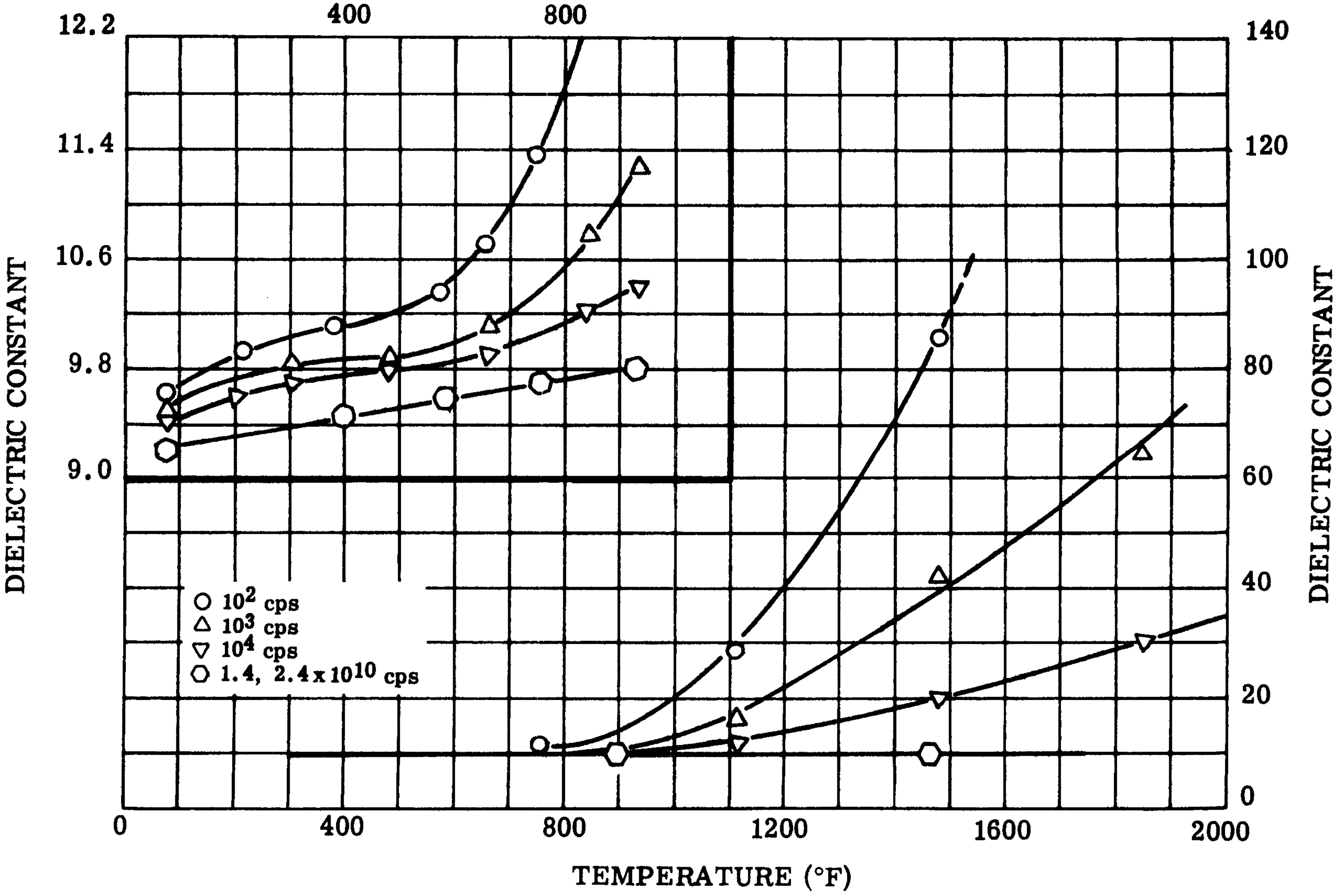


FIGURE V. E. 2-4. Dielectric Constant of Rigid Inorganic Insulation Alumina, 99 Percent (Reference: RI 35, LI 16)

Figure V. E. 2-4. Dielectric Constant - Rigid Insulation - Alumina, 99%

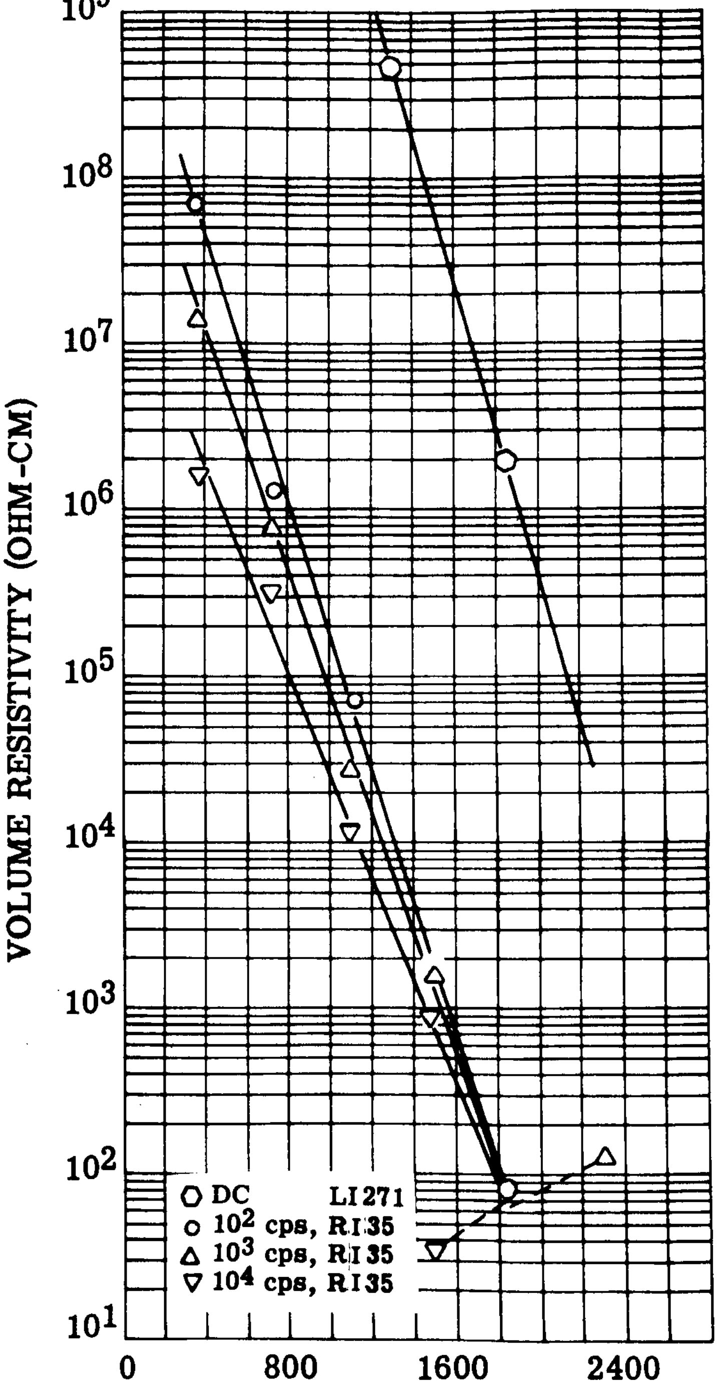


FIGURE V. E. 2-5. Volume Resistivity of Rigid Inorganic Insulation, Alumina 99 Percent. (Reference: RI 35)

Figure V. E. 2-5. Volume Resistivity - Rigid Insulation - Alumina 99%

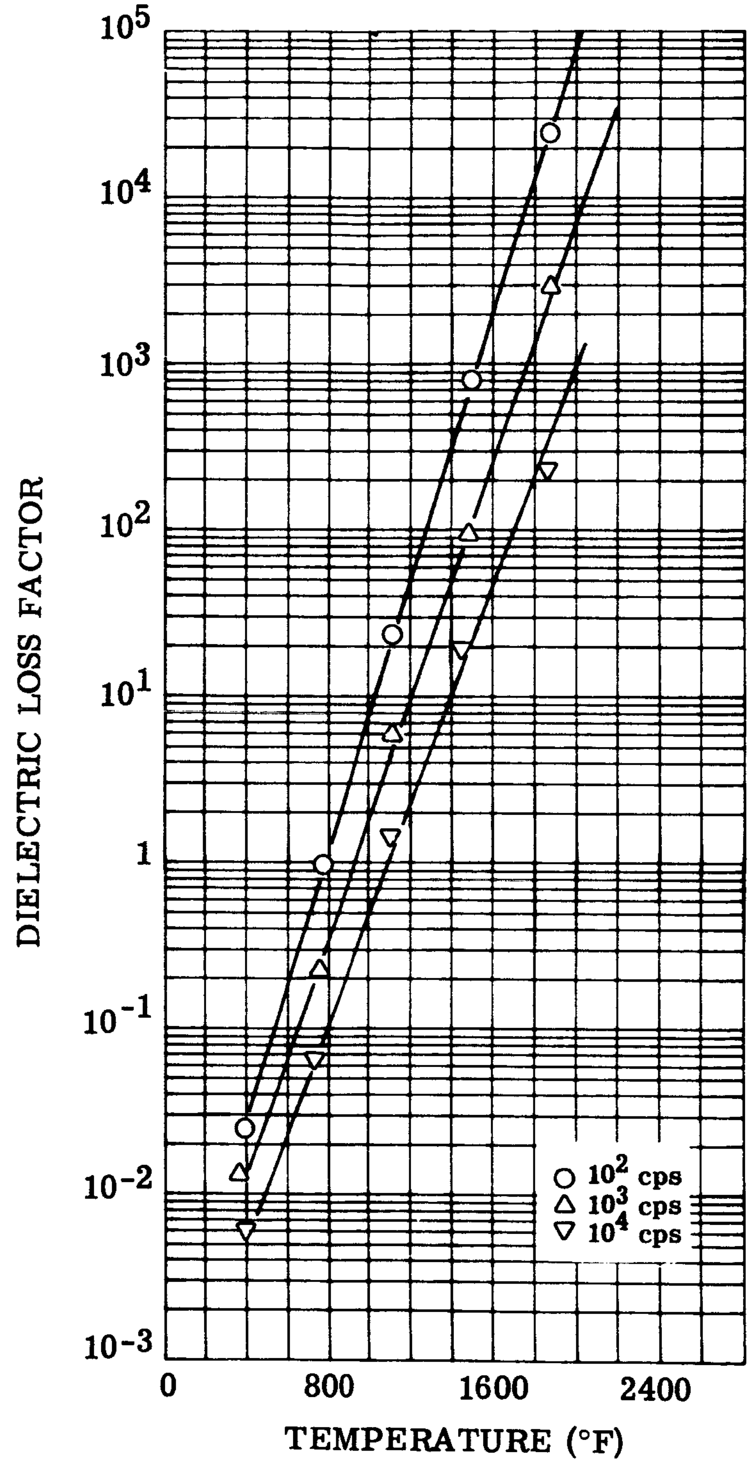


FIGURE V.E.2-6. Dielectric Loss Factor of Rigid Inorganic Insulation, Alumina, 99 Percent. (Reference: RI35)

Figure V.E.2-6. Dielectric Loss Factor - Rigid Insulation - Alumina, 99%

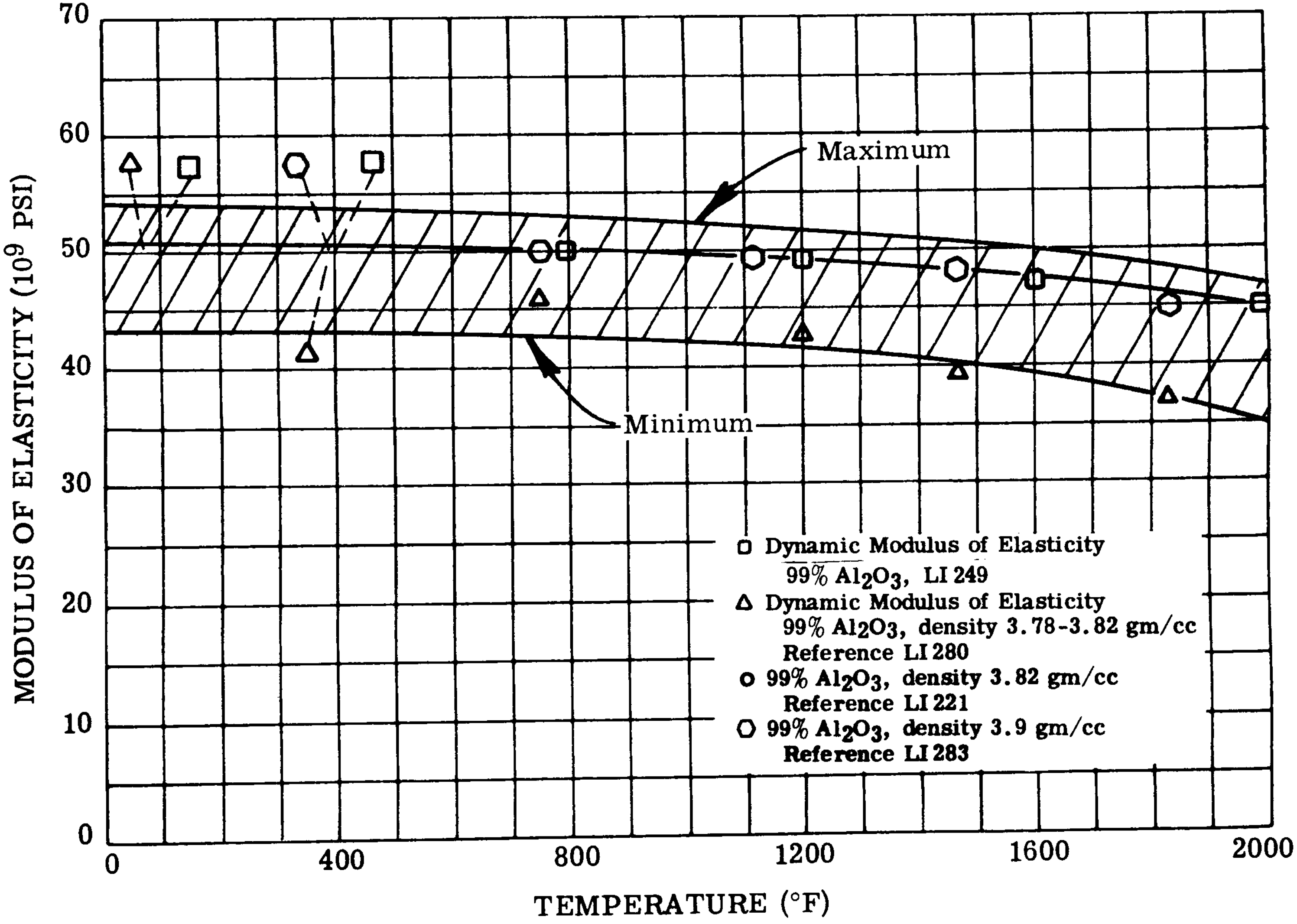


FIGURE V. E. 2-7. Modulus of Elasticity of Rigid Inorganic Insulation Alumina, 99 Percent.

Figure V. E. 2-7. Modulus of Elasticity - Rigid Insulation - Alumina, 99%

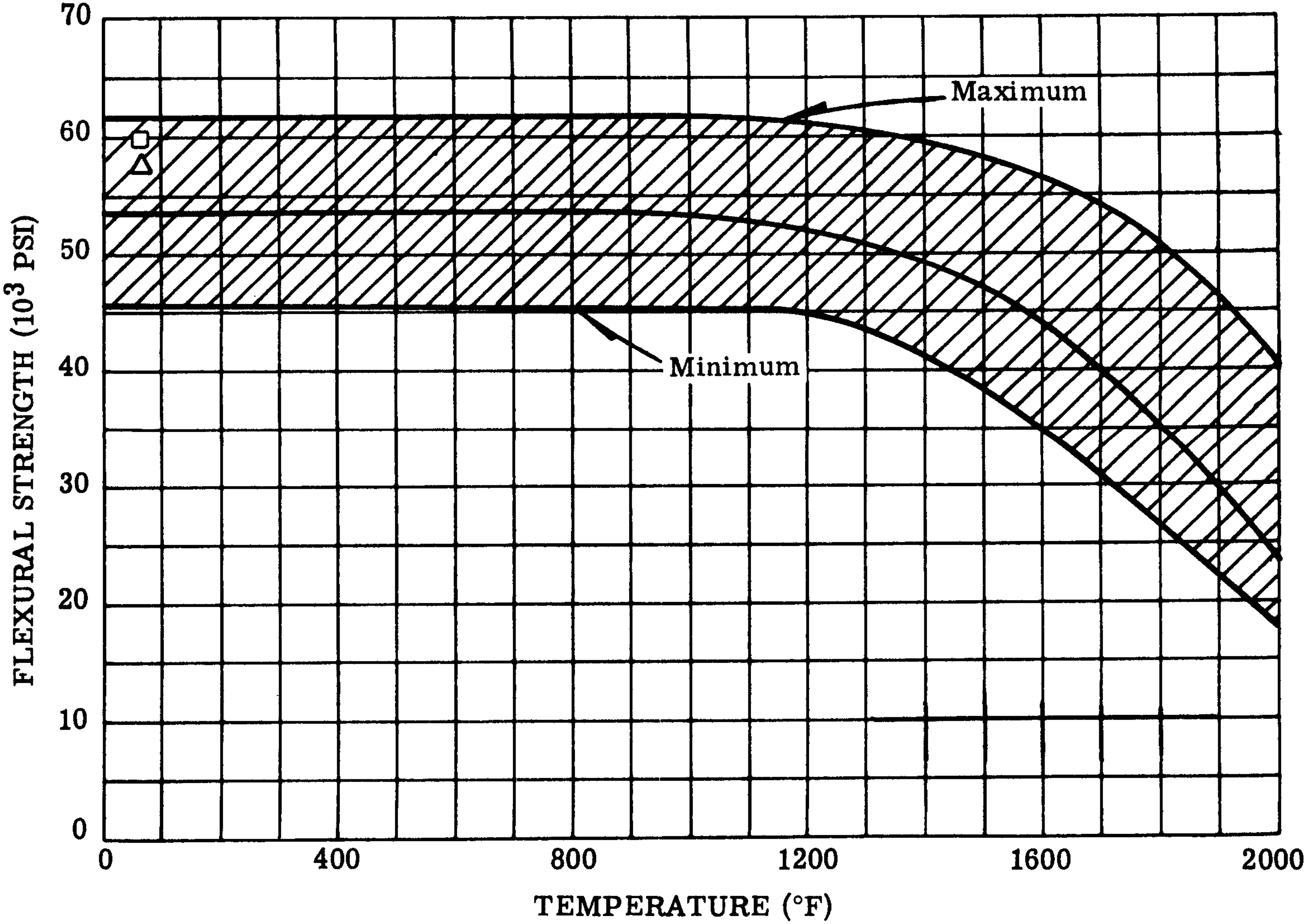


FIGURE V. E. 2-8. Flexural Strength of Rigid Inorganic Insulation Alumina, 99 Percent. (Curve, Reference: LI146)

Figure V. E. 2-8. Flexural Strength - Rigid Insulation - Alumina, 99%

3. 94 PERCENT ALUMINA, RIGID INSULATION

Alumina, 94 percent Al_2O_3, is used in electrical and mechanical applications in pressed, extruded, and ground shapes.

Availability: This material is commercially available from several sources in extruded or pressed shapes.

Composition: (Nominal)

94% Al_2O_3
0.5 - 4% SiO_2
1 - 3% CaO
0.2 - 1% MgO

Range of major modifiers or contaminants vary approximately within limits shown depending on manufacturer.

I. Thermophysical Properties

A.	Density (77°F)(lb/cu inch)	0.129 - 0.130	(LI201) (LI271)
	Specific Gravity (77°F)	3.57 - 3.62	

B. Specific Heat (LI271)

Temperature (°F)	Btu-lb-°F
200	0.21

C. Thermal Conductivity (LI201) (LI271)

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
500	6
930	3.9
1600	3

D. Coefficient of Thermal Expansion (LI146) (LI201) (LI271)

Temperature Range (°F)	inch/inch-°F
70 to 500	3.5×10^{-6}
500 to 1000	4.5×10^{-6}
1000 to 1600	4.85×10^{-6}

II. Electrical Properties

A. Dielectric Constant (LI16) (LI251)

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	9.3
500	3200	9.2
930	400	13
930	3200	11

B. Electric Strength

Thickness (inch)	Temperature (°F)	Frequency (cps)	Volts/mil	
0.250	72	60	230	(LI251)
0.125	72	60	330	(LI271)
0.050	72	60	500	(LI271)
0.025	72	60	550	(LI271)

C. Dissipation Factor

Temperature (°F)	Frequency	Dissipation Factor	
77	100 cps	0.00105	(LI251)
77	100 cps	0.00018	
77	215 mc	0.00085	(LI146)
500	215 mc	0.00105	
932	215 mc	0.00175	
1600	215 mc	0.0038	

D. Volume Resistivity (LI251)

Temperature (°F)	Frequency	Ohm-cm
930	DC	3×10^{10}
1112	DC	2×10^{9}
1600	DC	2×10^{7}

For additional information on electrical properties, see references LI295 and LI251.

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi	
77	300,000 to 315,000	(LI221) (LI201)
932 (by interpolation)	190,000	(LI273)
1600 (by interpolation)	180,000	(LI273)

B. Elastic Modulus

Temperature (°F)	Psi
77	41×10^{6}
1600	36×10^{6}

C. Impact Strength (Charpy) (LI201) (LI221)

At 77°F 6.5 - 7.6 in-lb

D. Flexural Strength

Temperature (°F)	Psi	
72	46×10^{3}	(LI271) (LI201)
2000	15×10^{3}	(LI271)

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Acid and alkaline solutions	Good
Organic solvents	Excellent
Alkali Metals	Poor at 900°F

B. Nuclear Radiation Resistance

(LI296)

10^{19} fast neutrons/cm^2	Moderate damage
10^{11} ergs per gram (C) of gamma radiation	Moderate damage
10^{21} fast neutrons/cm^2	Severe damage
10^{13} ergs per gram (C) of gamma radiation	Severe damage

C. Weight Loss in Vacuum with Heat

1. 8 hours at 930°F	None detectible
2. 24 hours at 1600°F	None detectible

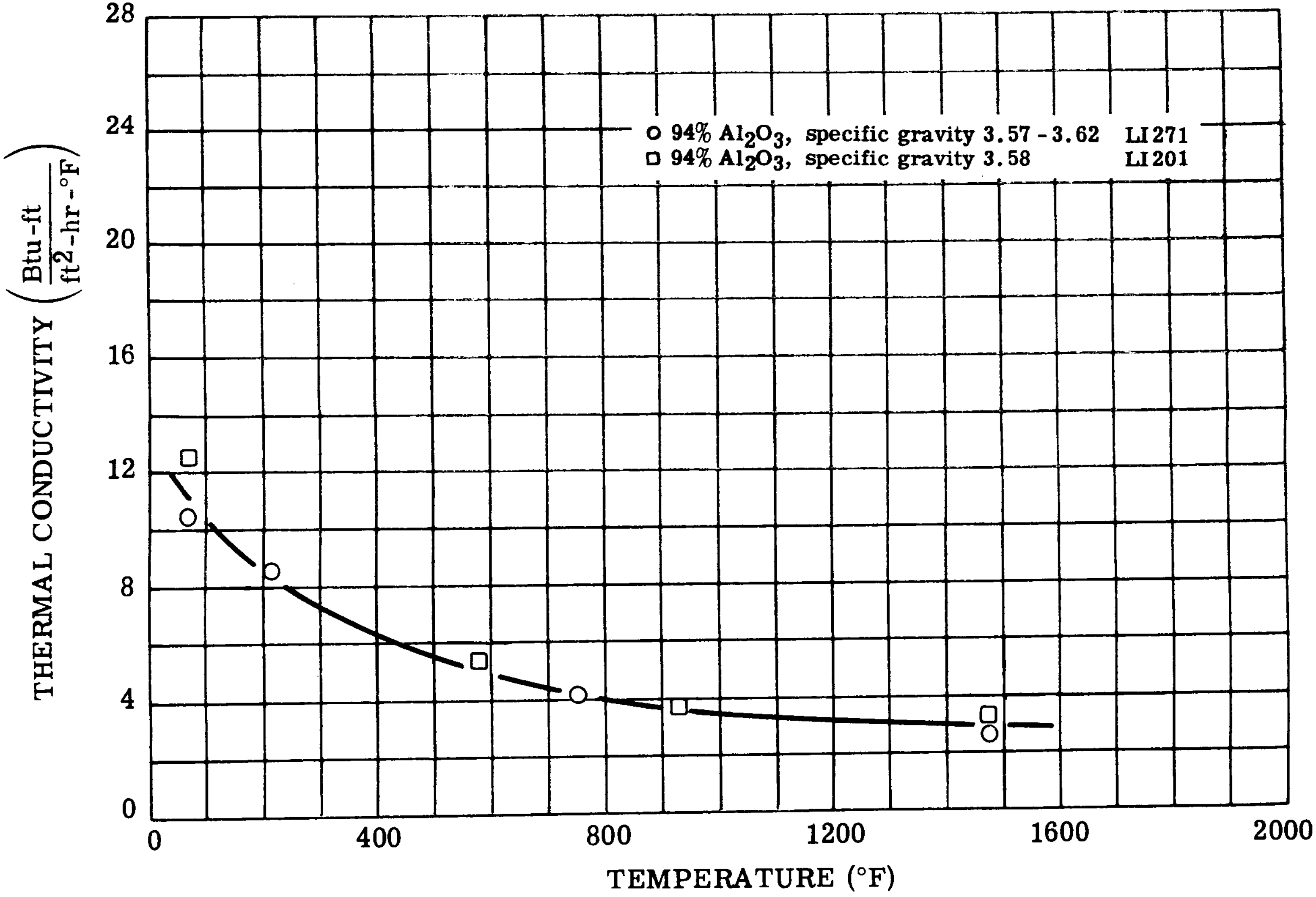


FIGURE V. E. 3-1. Thermal Conductivity of Rigid Inorganic Insulation Alumina, 94 Percent. (Reference: (LI201, LI271)

Figure V. E. 3-1. Thermal Conductivity - Rigid Insulation - Alumina, 94%

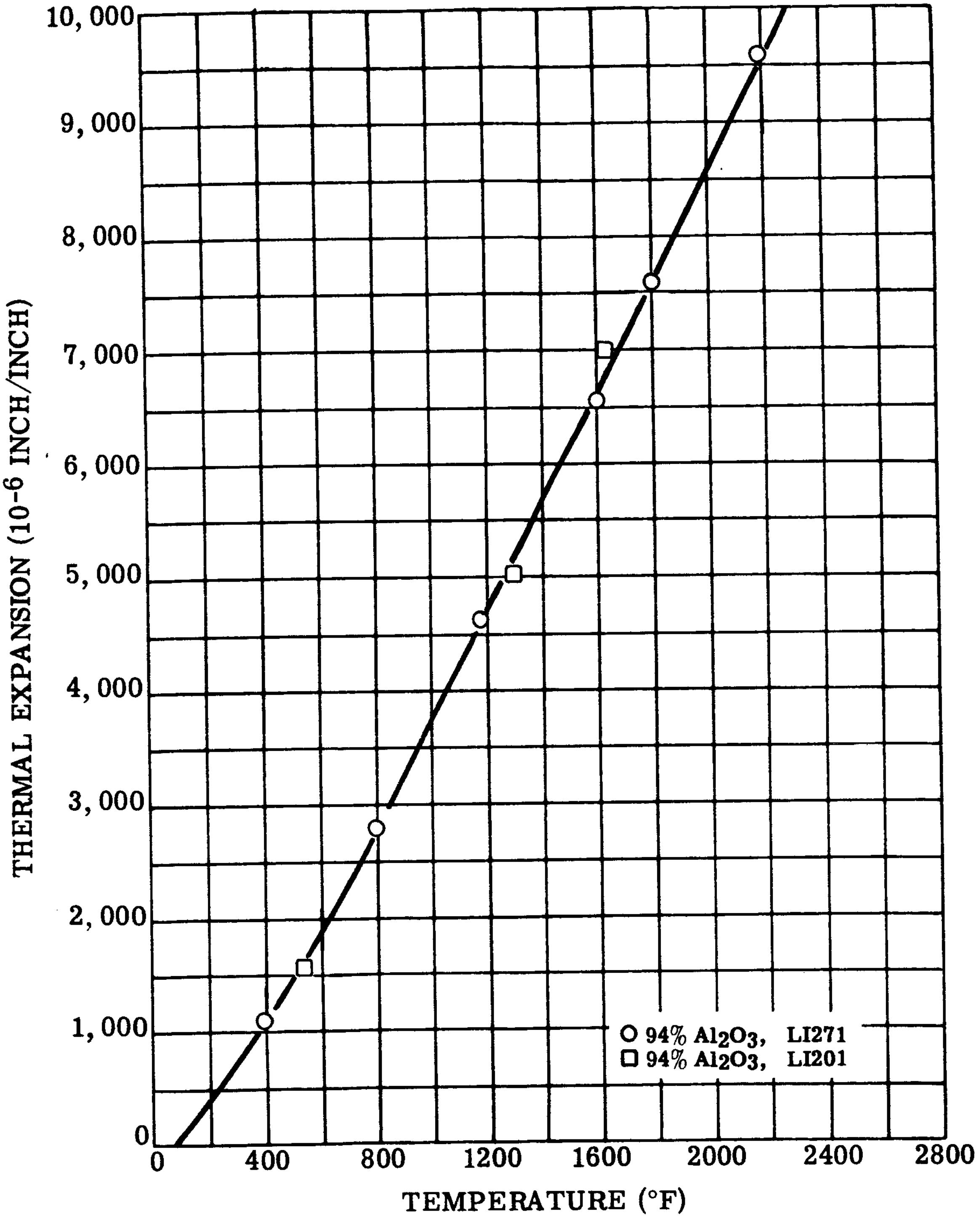


FIGURE V. E. 3-2. Thermal Expansion of Rigid Inorganic Insulation
Alumina, 94 Percent
(Curve, Reference: LI146)

Figure V. E. 3-2. Thermal Expansion - Rigid Insulation - Alumina, 94%

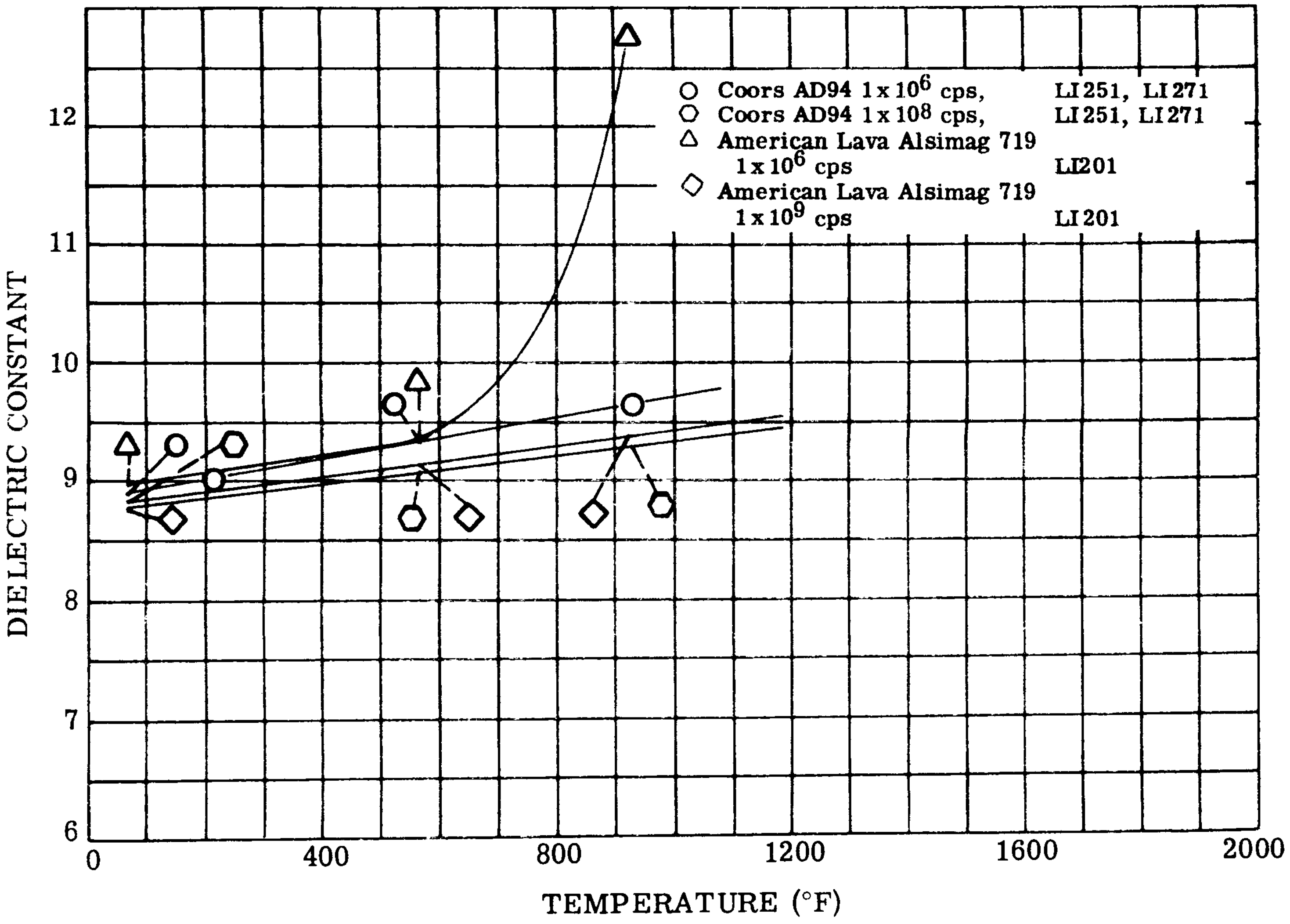


FIGURE V.E.3-3. Dielectric Constant at High Frequencies of Rigid Inorganic Insulation Alumina, 94 Percent, Density 3.57 to 3.62.

Figure V.E.3-3. Dielectric Constant - Rigid Insulation - Alumina 94%

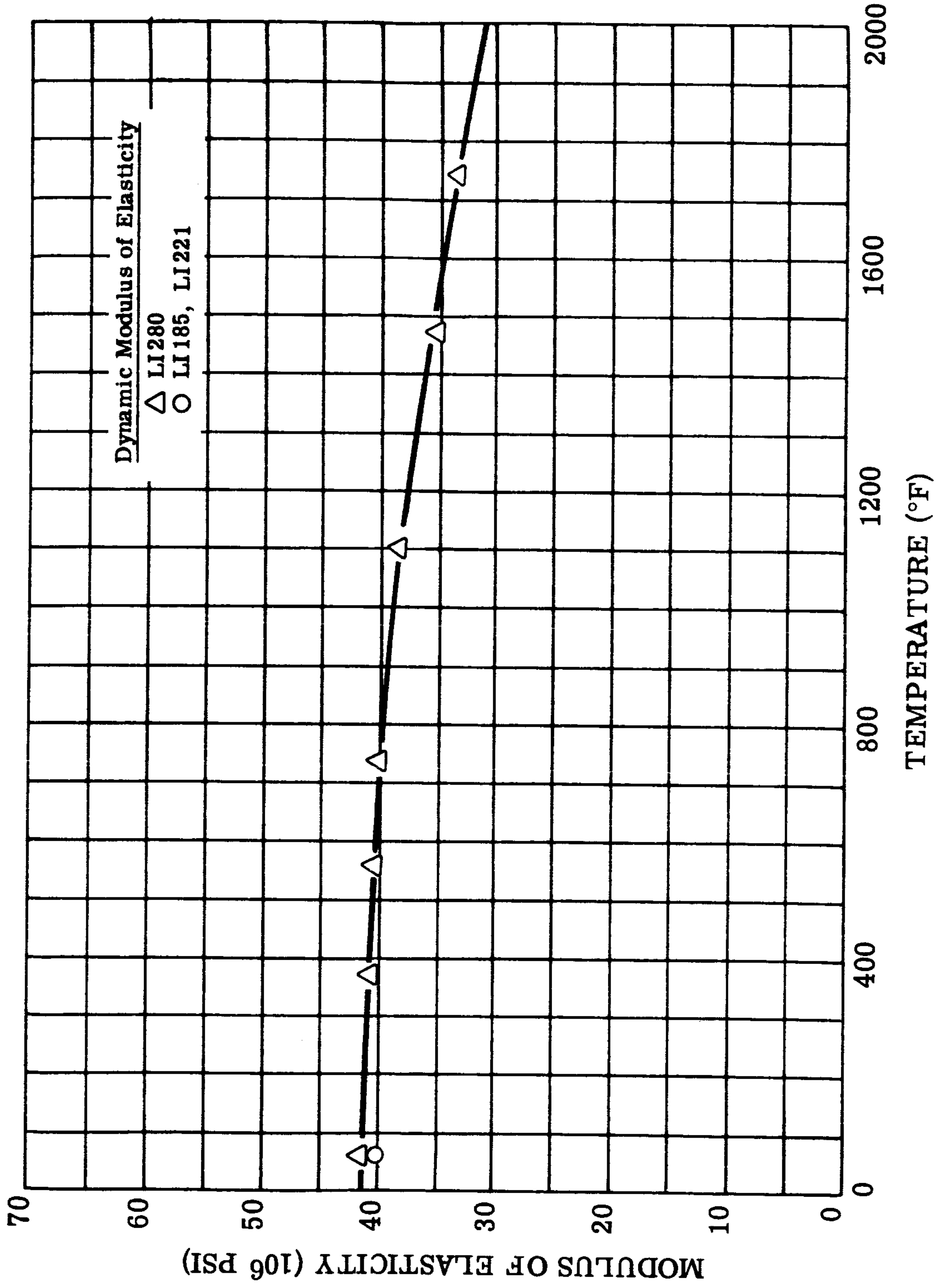


FIGURE V. E. 3-4. Modulus of Elasticity of Rigid Inorganic Insulation, Alumina 94 Percent.

Figure V. E. 3-4. Modulus of Elasticity - Rigid Insulation - Alumina, 94%

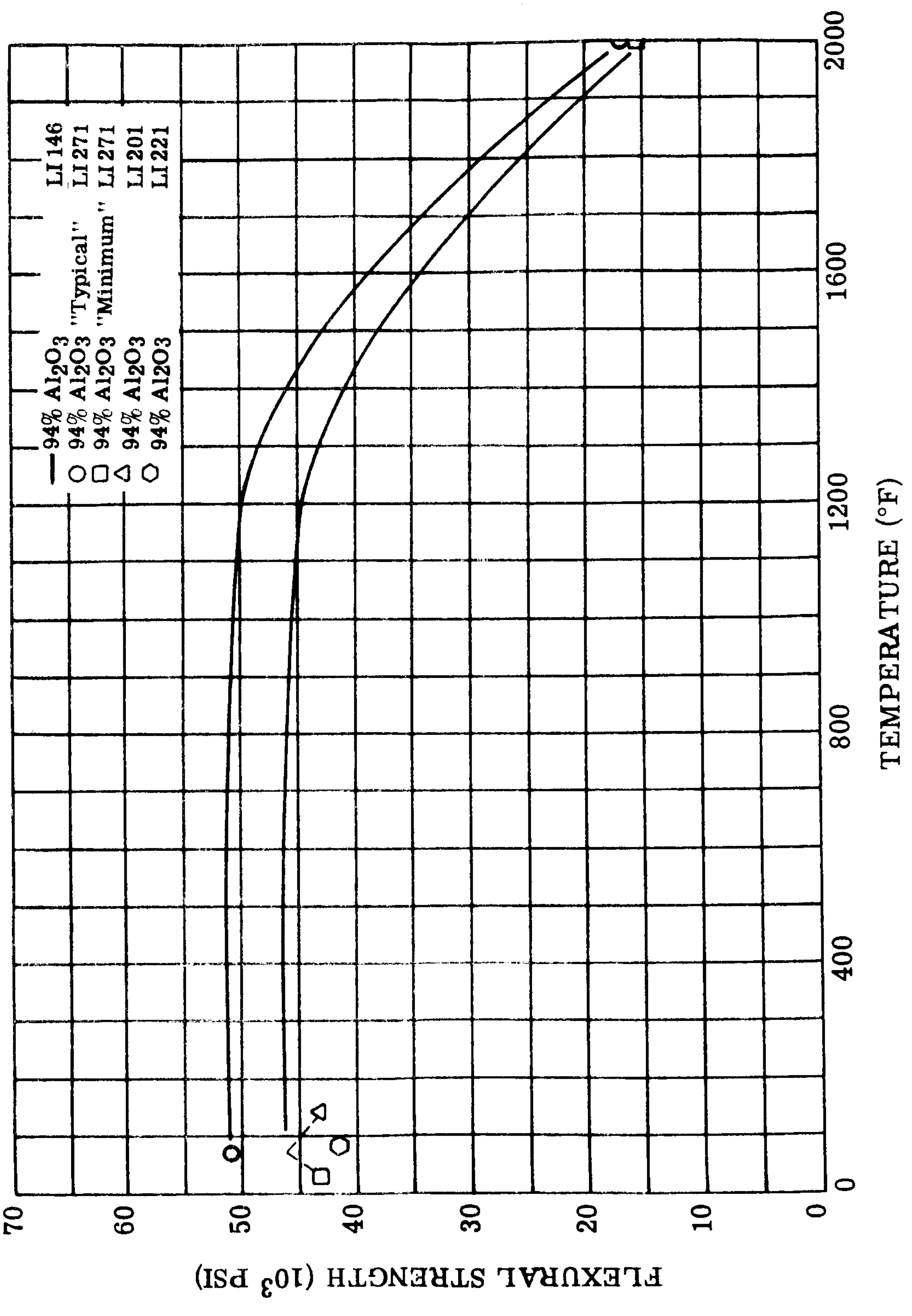


FIGURE V. E. 3-5. Flexural Strength of Rigid Inorganic Insulation Alumina, 94 Percent. (Curve, Reference: LI146)

Figure V. E. 3-5. Flexural Strength - Rigid Insulation - Alumina, 94%

4. 99.8 PERCENT ALUMINA, 0.25 MgO, RIGID INSULATION

Alumina, 99.8 percent Al_2O_3, 0.25 percent MgO, is used in lighting and other electrical applications.

Availability:	This composition of alumina is available commercially from General Electric Company in various shapes and is identified as Lucalox.
Composition:	99.8% Al_2O_3 0.15 - 0.25% MgO 0.002 - 0.04% CaO 0.05% S_iO_2

I. Thermophysical Properties

A.	Density (77°F)(lb/cu inch)	1.043
	Specific Gravity (77°F)	3.98
B.	Specific Heat (1)	0.32 Btu/lb-°F

C. Thermal Conductivity (LI205)

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
500	8
930	5
1600	2

D. Coefficient of Thermal Expansion (LI205)

Temperature Range (°F)	inch/inch-°F
70 to 500	3.5×10^{-6}
500 to 1000	4.6×10^{-6}
1000 to 1600	5.3×10^{-6}

---

(1) General Electric Research Laboratory.

II. Electrical Properties

A. Arc Resistance (at 77°F) >500 sec (LI251)

B. Dielectric Constant (RI35)

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	11
500	3200	11
930	400	13
930	3200	12
1600	400	80
1600	3200	35

C. Electric Strength (0.020 inch thick) (LI251) (LI205)

Temperature (°F)	Frequency	Volts/mil
68	DC	1770

D. Volume Resistivity

Temperature (°F)	Frequency	Ohm-cm
930	DC	1.7×10^{12}
1112	DC	2×10^{10}
1600	DC	8.5×10^{6}

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi	
77	300,000	(LI205)
2880	36,000	(LI50)

B. Elastic Modulus

Temperature (°F)	Psi	
77	56×10^6	(LI205)
930	54×10^6	(LI50)
1600	51×10^6	(LI205)

C. Flexural Strength

Temperature (°F)	Psi	
72	45,000	(LI205)
930	39,000	(LI50)
1600	37,000	(LI50)

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Acid or alkaline solutions	Excellent
Organic Solvents	Excellent
Alkali metals	Good

B. Nuclear Radiation Resistance

No significant change in dielectric constant or volume resistivity is anticipated when exposed to flux levels of 2×10^{20} fast neutrons/cm^2. An integrated fast neutron flux of 10^{19} to 10^{20} neutrons/cm^2, however, will result in some deterioration of the physical properties of insulation materials containing a high percentage of alumina. (Reference: Radiation Effects Information Center Report No. 34, LI 146.)

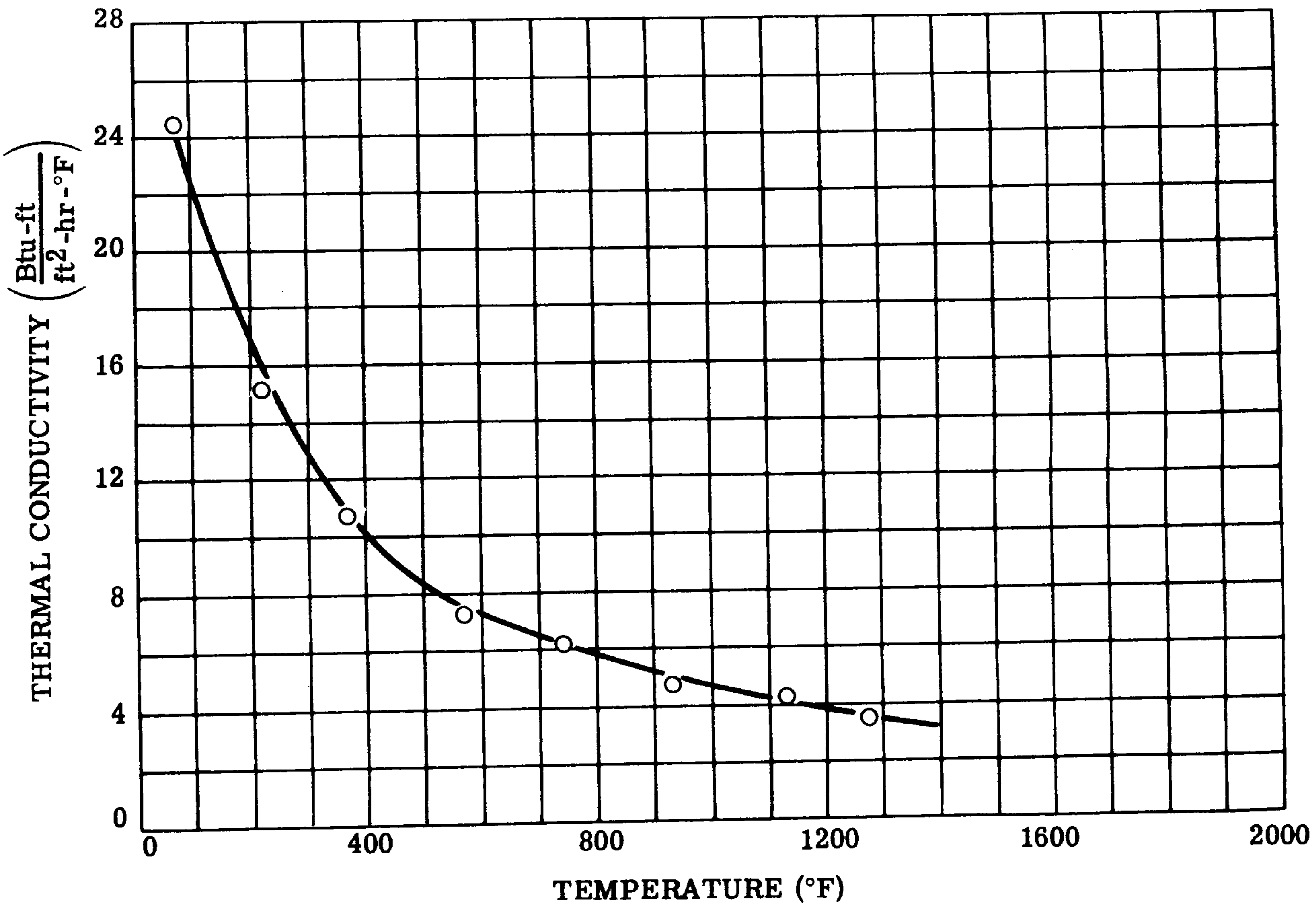


FIGURE V. E. 4-1. Thermal Conductivity of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO. (Reference: LI205)

Figure V.E.4-1. Thermal Conductivity - Rigid Insulation - 99.8 Alumina, 0.25 MgO

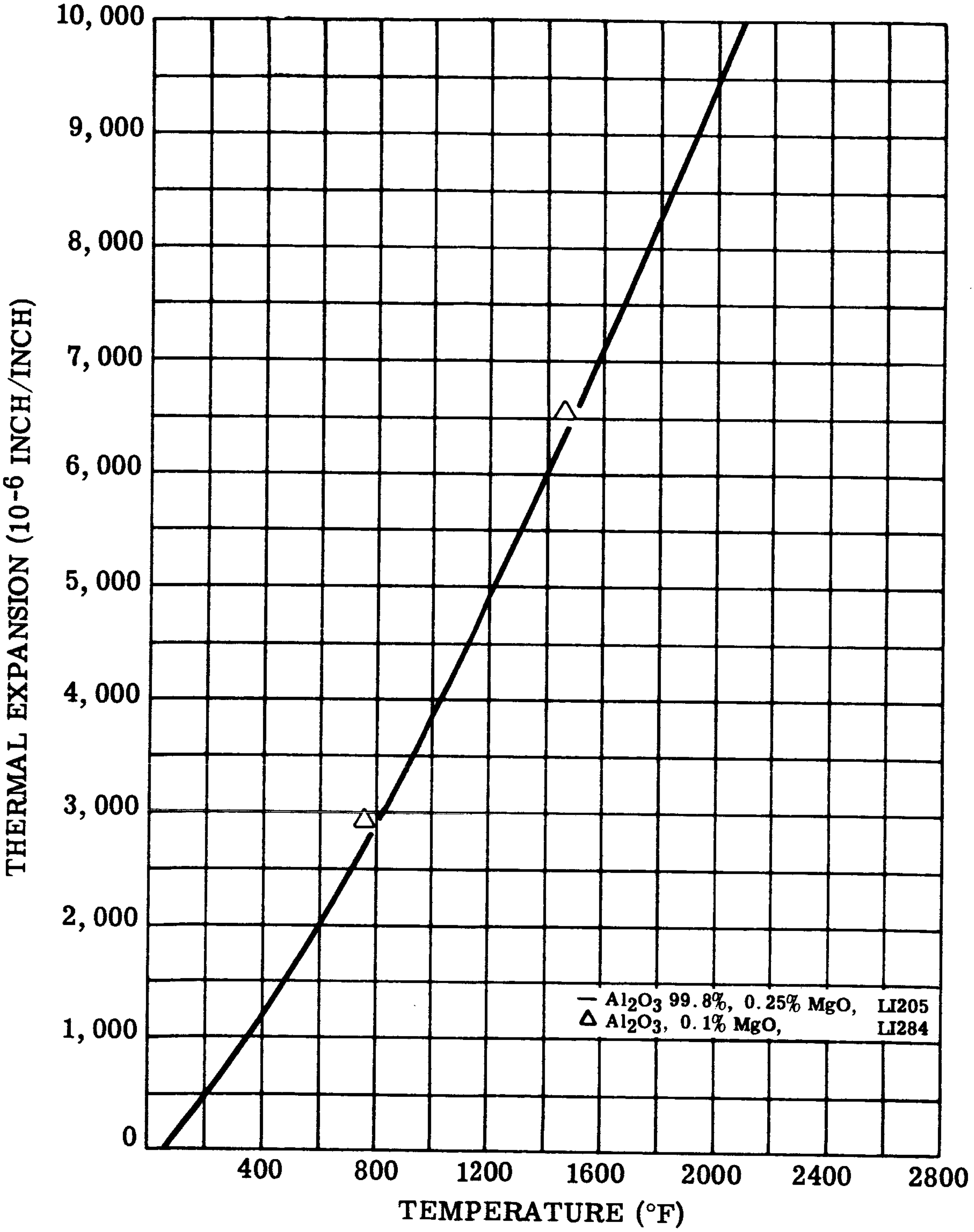


FIGURE V.E.4-2. Thermal Expansion of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO. (Curve, Reference: LI205)

Figure V.E.4-2. Thermal Expansion - Rigid Insulation - 99.8 Alumina, 0.25 MgO

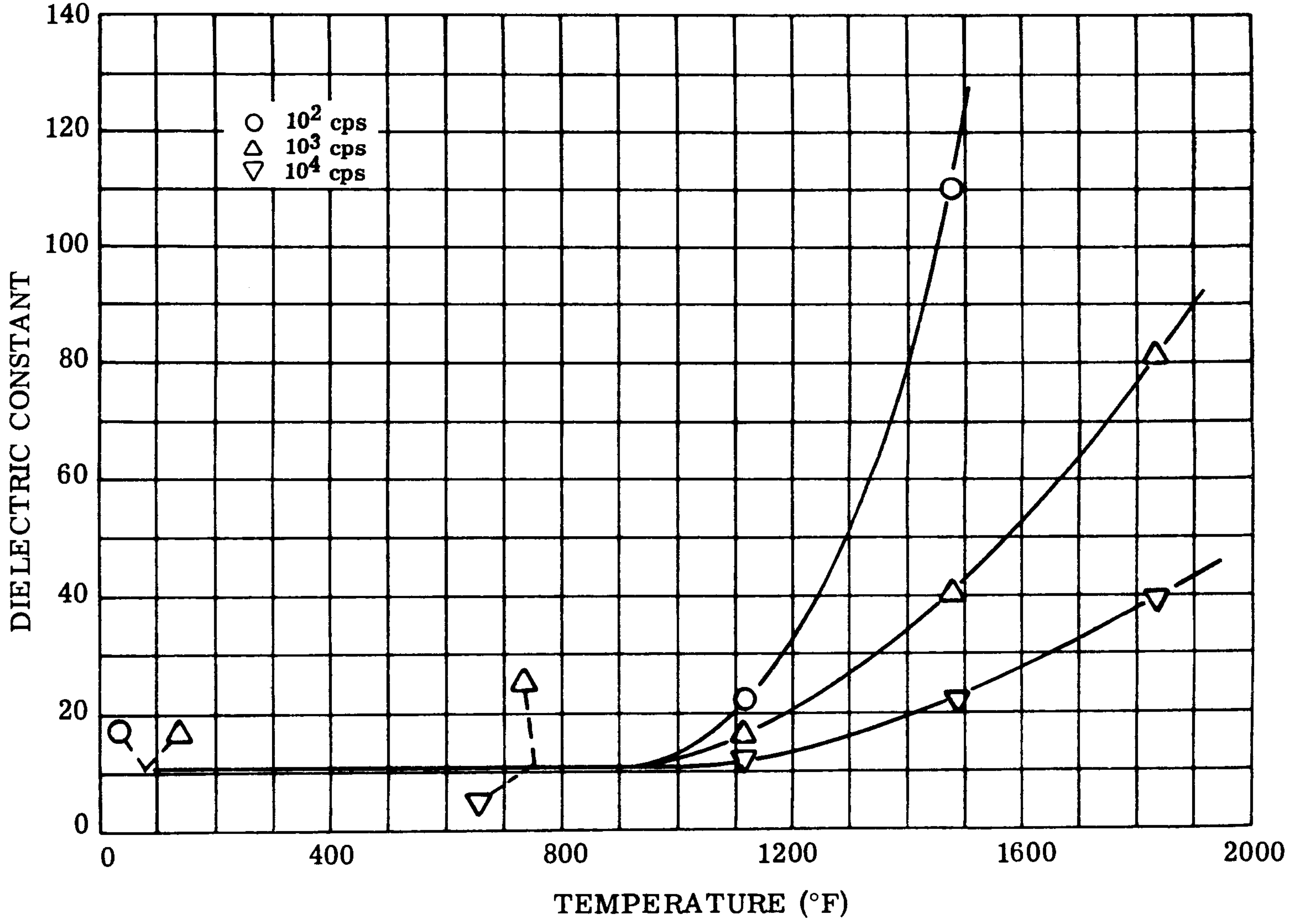


FIGURE V.E.4-3. Dielectric Constant of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO. (Reference: RI35)

Figure V.E.4-3. Dielectric Constant - Rigid Insulation - 99.8 Alumina, 0.25 MgO

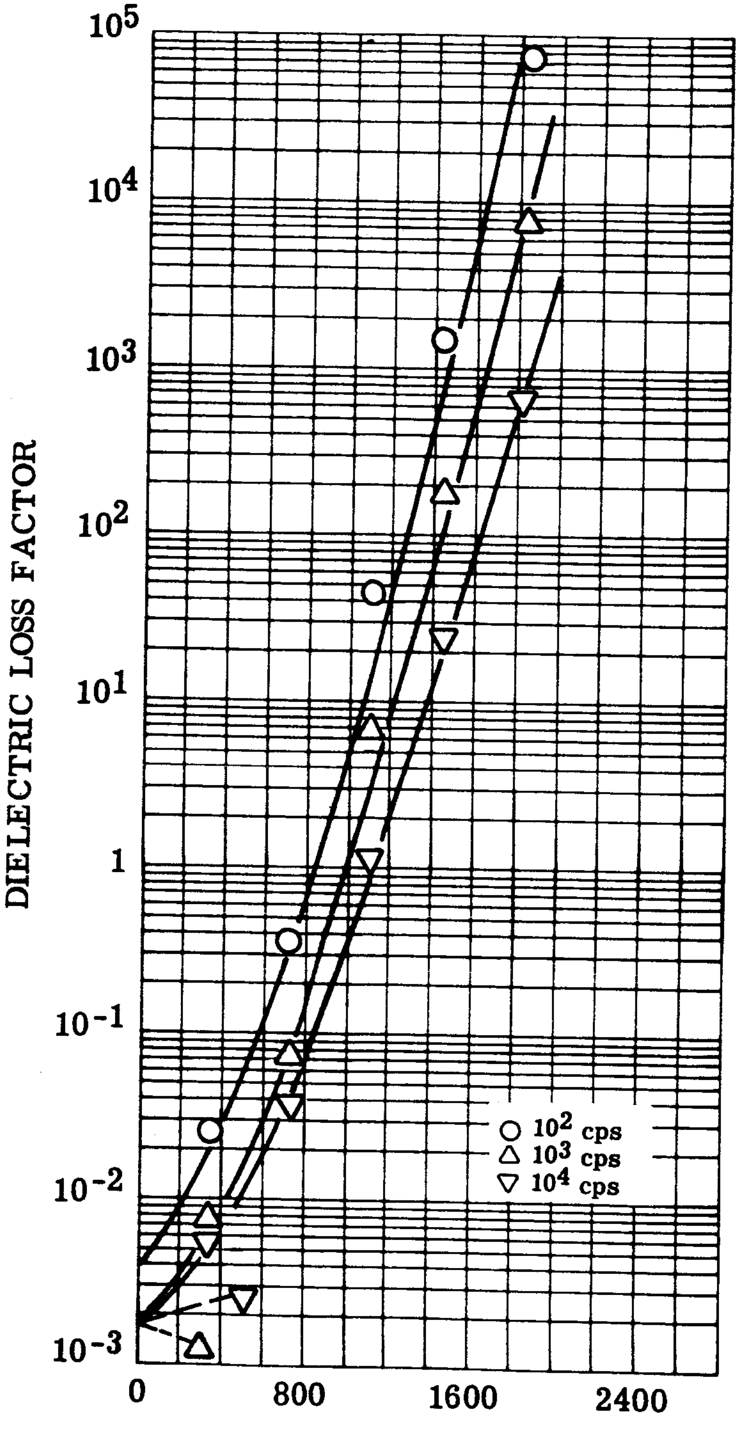


FIGURE V. E. 4-4. Dielectric Loss Factor of Rigid Inorganic Insulation, 99.8 Percent Alumina, 0.25 MgO. (Reference: RI 35)

Figure V. E. 4-4. Dielectric Loss Factor - Rigid Insulation - 99.8 Alumina, 0.25 MgO

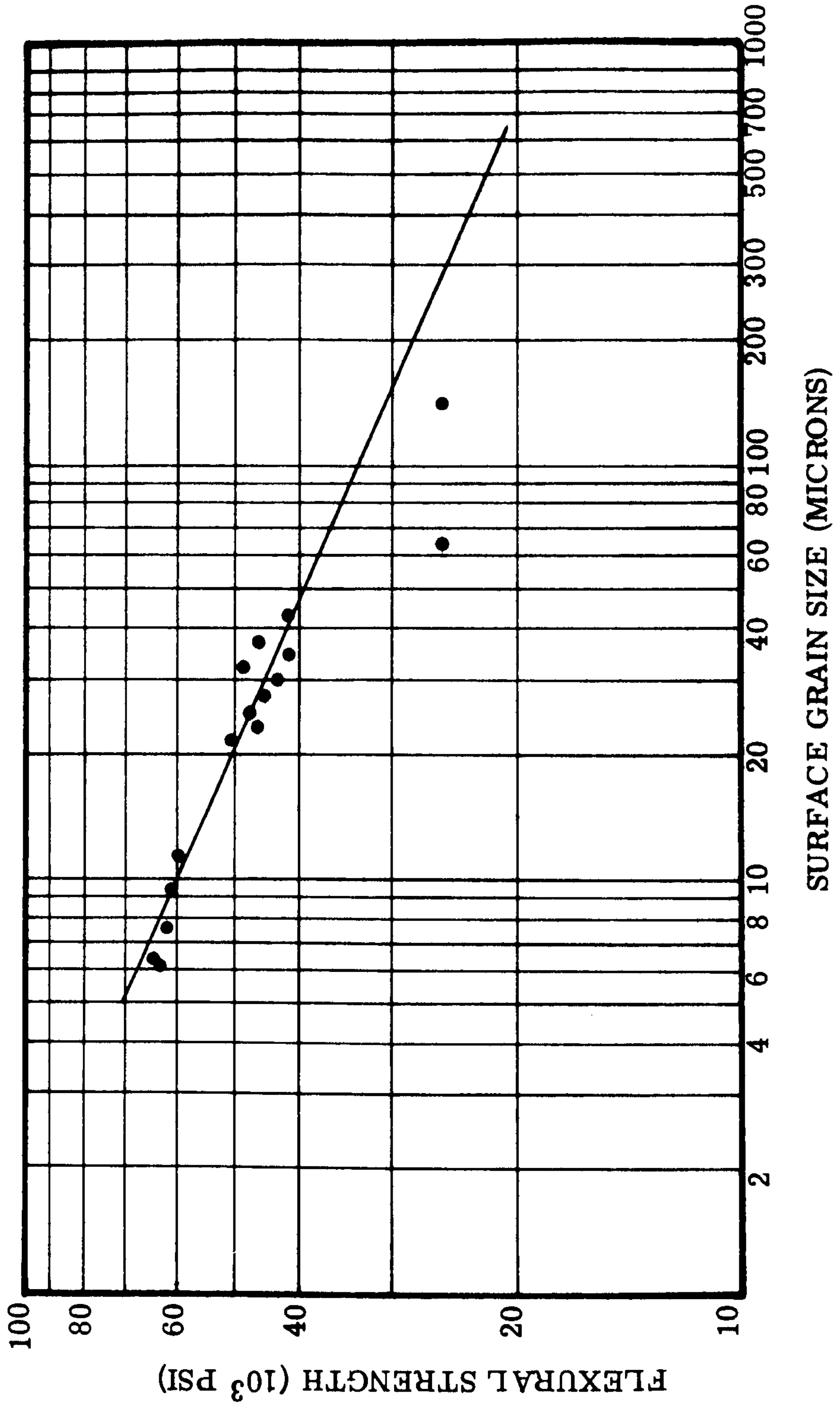


FIGURE V.E.4-5. Flexural Strength of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO, as a Function of Surface Grain Size. (Reference: LI50)

Figure V.E.4-5. Flexural Strength versus Grain Size - Rigid Insulation - 99.8 Alumina, 0.25 MgO

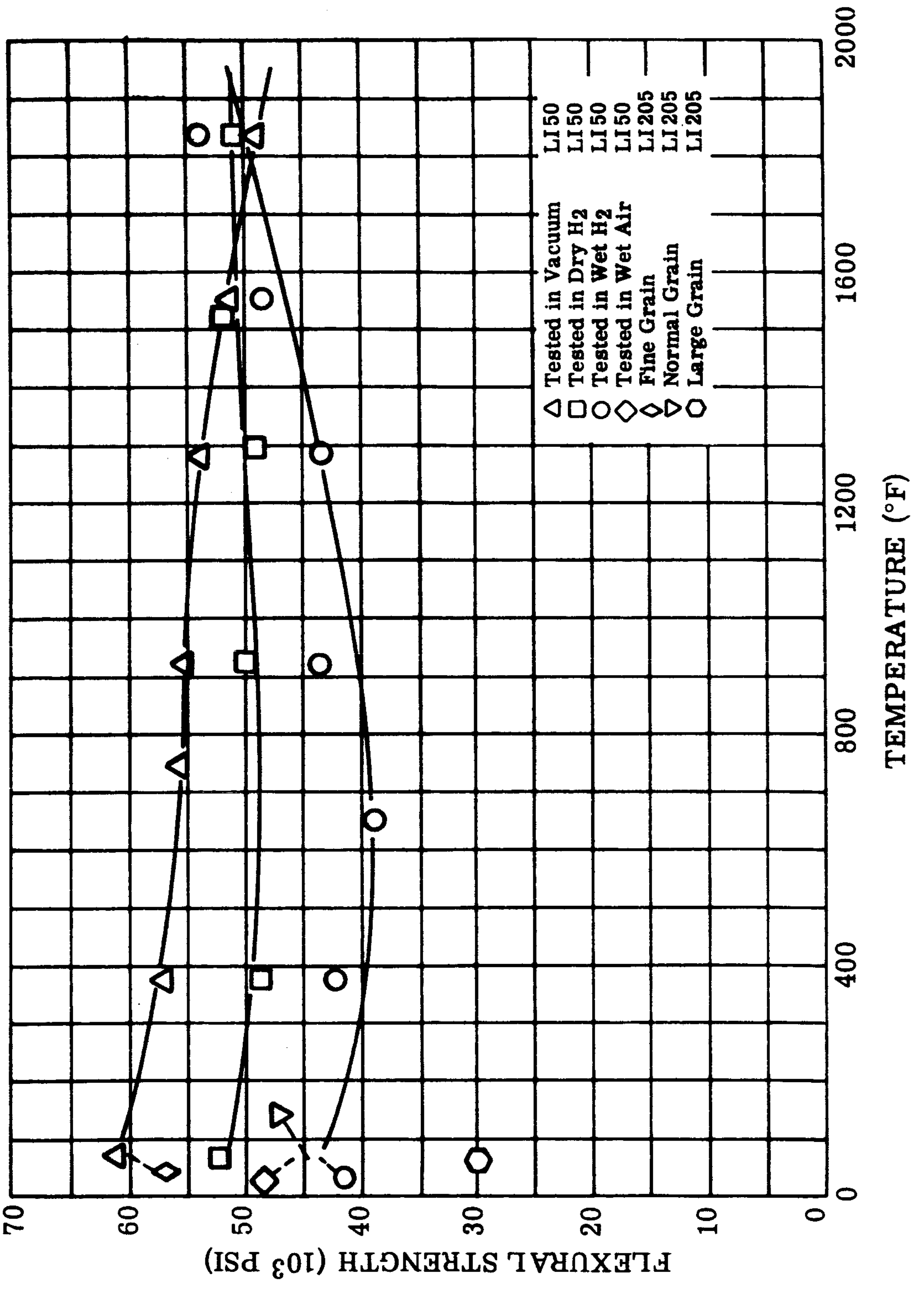


FIGURE V.E.4-6. Flexural Strength of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO.

Figure V.E.4-6. Flexural Strength - Rigid Insulation - 99.8 Alumina, 0.25 MgO

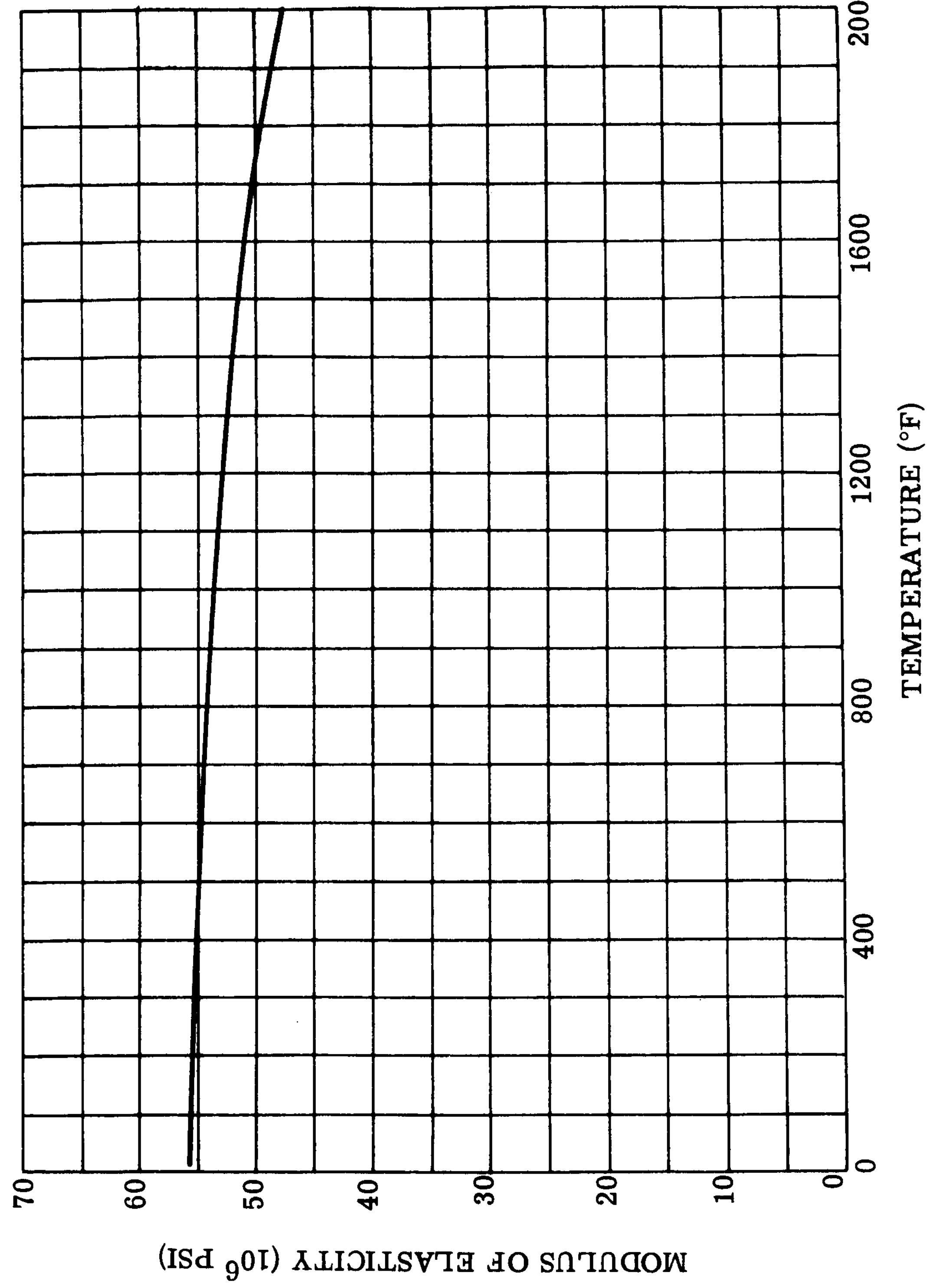


FIGURE V.E. 4-7. Modulus of Elasticity of Rigid Inorganic Insulation 99.8 Percent Alumina, 0.25 MgO. (Reference: LI50, LI205)

Figure V.E. 4-7. Modulus of Elasticity - Rigid Insulation - 99.8 Alumina, 0.25 MgO

5. 99.8 PERCENT BERYLLIA, RIGID INSULATION

Beryllia, 99.8 percent, is used in electrical and electronic applications where high thermal conductivity or chemical inertness is desired.

Availability: Beryllia, 99.8 percent, is available commercially in various pressed shapes including tubes.

Composition:

99.8%	BeO	Approximate upper limits
150 PPM	Al	
100 PPM	Fe	
100 PPM	Si	
80 PPM	Ca	
1000 PPM	MgO	

Other elements - Ag, Cu, Cr, Mn, Mo, Na, Ni, Zn, less than 30 PPM.
- B, Cd, Co, K, Li, Pb, less than 10 PPM.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.104

Specific Gravity (77°F) 2.90

B. Specific Heat

Temperature (°F)	Btu/lb-°F	
500	0.31	(LI277)
930	0.36	

C. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$	
500	73	(LI277)
930	38	
1600	18	

D. Coefficient of Thermal Expansion

Temperature Range (°F)	inch/inch-°F	
70 to 500	3.5×10^{-6}	(LI277)
500 to 1000	4.5×10^{-6}	
1000 to 1600	5.1×10^{-6}	

II. Electrical Properties

A. Dielectric Constant

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	7.1 (1)
500	3200	7.1 (1)
930	400	7.8 (1)
930	3200	7.6 (1)
1600	400	-
1600	3200	-

B. Electric Strength

1. Electric Strength, 0.25 inch electrode (Specimen Thickness 0.125 Inch)

Temperature (°F)	Frequency (cps)	Volts/mil
930	400	35
1112	400	66 (3)
1112	3200	66 (3)
1600	400	14 (2)

(1) These values are for cold pressed and sintered beryllia with density of 2.89 g/cu cm.

(2) Tripped current breaker because of low resistivity.

(3) Flashed over edge of specimen at this reading.

2. Electric Strength (Specimen Thickness, 0.0045 Inch)

Temperature (°F)	Frequency (cps)	Volts/mil
1100	DC	762-1665 (1)

C. Dissipation Factor

Temperature (°F)	Frequency	Dissipation Factor	
77	300 mc	0.0001	(LI277)
77	10 kmc	0.0009	
600	10 kmc	0.0011	
1200	10 kmc	0.0006	
1200	10 kmc	0.0004	

D. Insulation Life (LI261)

During 100 hour exposure in hydrogen-argon mixture at 1400°F, there was essentially no change in d-c resistivity.

E. Volume Resistivity

Temperature (°F)	Frequency	Ohm-cm
930	DC	3×10^{10}
1112	DC	5.3×10^{9}
1600	DC	3×10^{8}

For additional information on electric properties, see references LI295 and LI232.

---

(1) Value was determined in vacuum of 3×10^{-7} torr on beryllia of >99.5 percent purity on NAS 3-6465 and reported in NASA CR-54357.

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi	
77	200,000	(LI271)
932	130,000	(LI187)
1600	50,000	

B. Elastic Modulus

Temperature (°F)	Psi	
77	53×10^6	(LI186)

C. Impact Strength

Temperature (°F)	ft-lb
77	2.8

D. Flexural Strength

Temperature (°F)	Psi
77	32,000
500	32,000
930	35,000
1600	36,500

IV. Compatibility Properties

A. Chemical Resistance

Exposure	Resistance
Cold mineral acids	Excellent
Hot mineral acids	Fair
Water vapor at 2200°F	Fair
Organic solvents	Excellent
Alkali metals	Good

B. Nuclear Radiation Resistance

No major damage encountered below 10^{20} fast neutrons except for some loss in thermal conductivity. Slight damage may be removed by annealing at 1800 to 2700°F. (Reference: Radiation Effects Information Center Report No. 34, LI296).

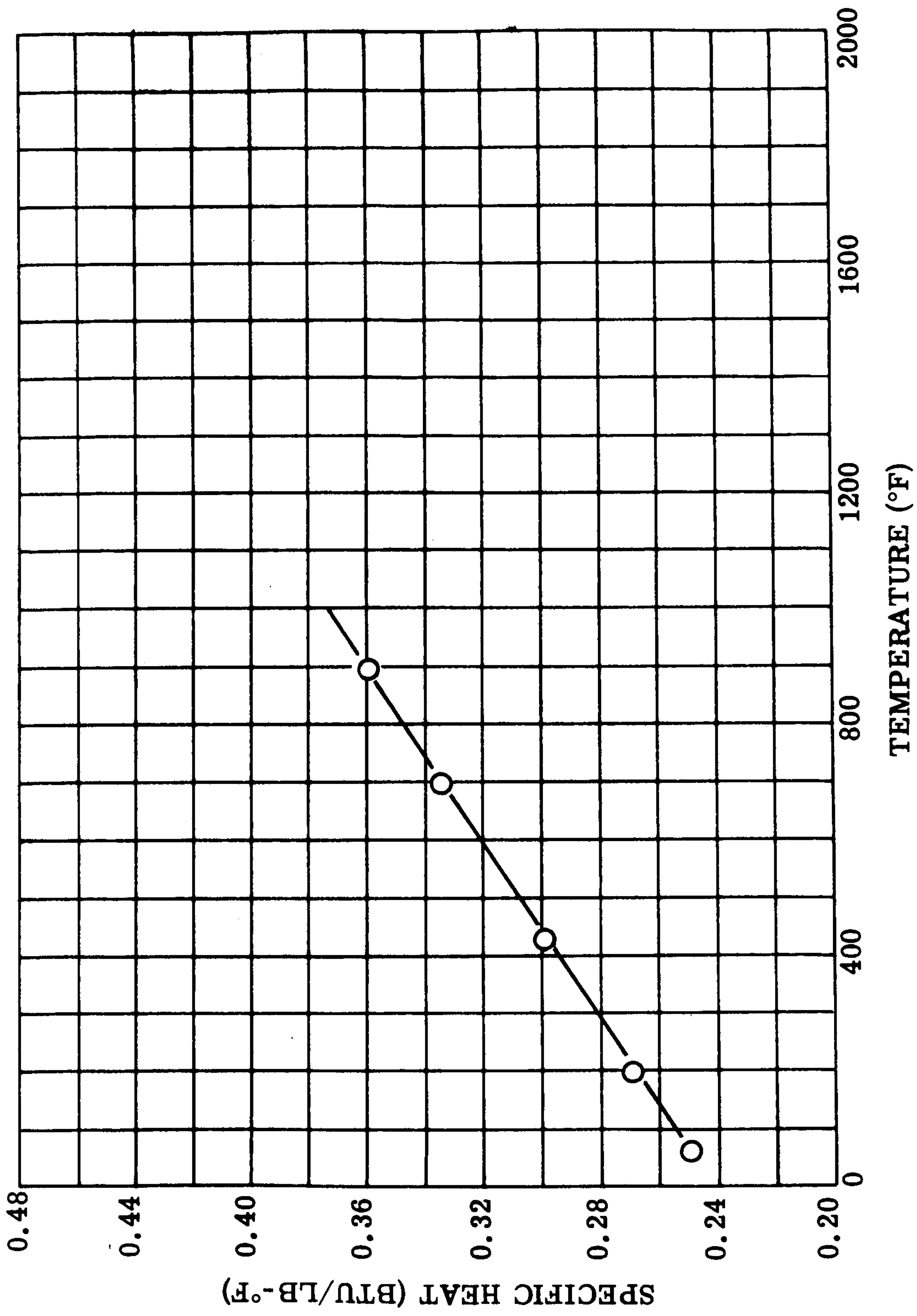


FIGURE V.E.5-1. Specific Heat of Rigid Inorganic Insulation Beryllia, 99.8 Percent.
(Reference: LI277)

Figure V.E.5-1. Specific Heat - Rigid Insulation - Beryllia, 99.8%

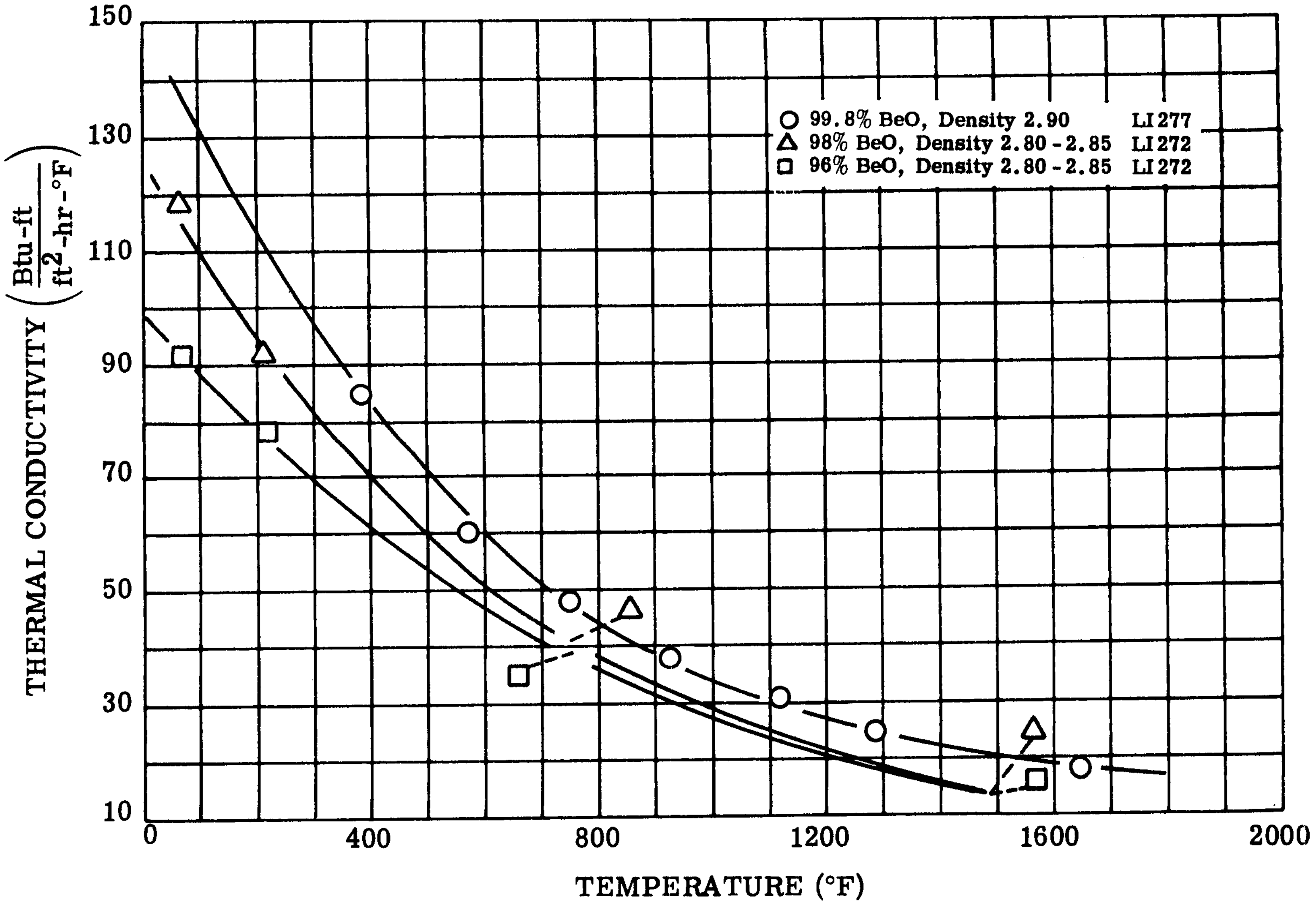


FIGURE V. E. 5-2. Thermal Conductivity of Rigid Inorganic Insulation Beryllia, 99.8 Percent, Density 2.90 (Plus Two Ceramic Compositions of Lower Beryllia Content For Comparison).

Figure V. E. 5-2. Thermal Conductivity - Rigid Insulation - Beryllia, 99.8%

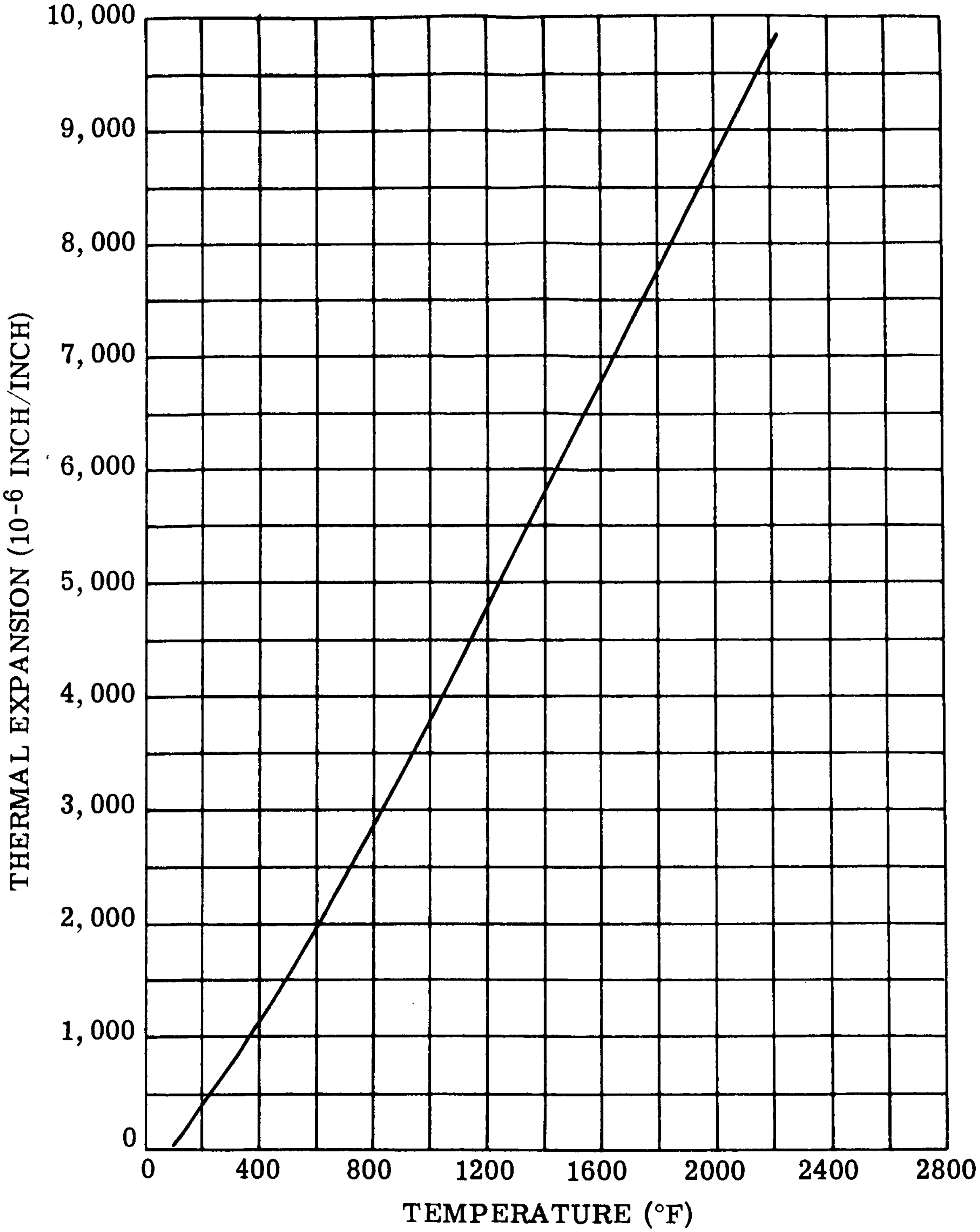


FIGURE V.E.5-3. Thermal Expansion on Heating of Rigid Inorganic Insulation Beryllia, 99.8 Percent, Density 2.90. (Reference: LI277)

Figure V.E.5-3. Thermal Expansion - Rigid Insulation - Beryllia, 99.8%

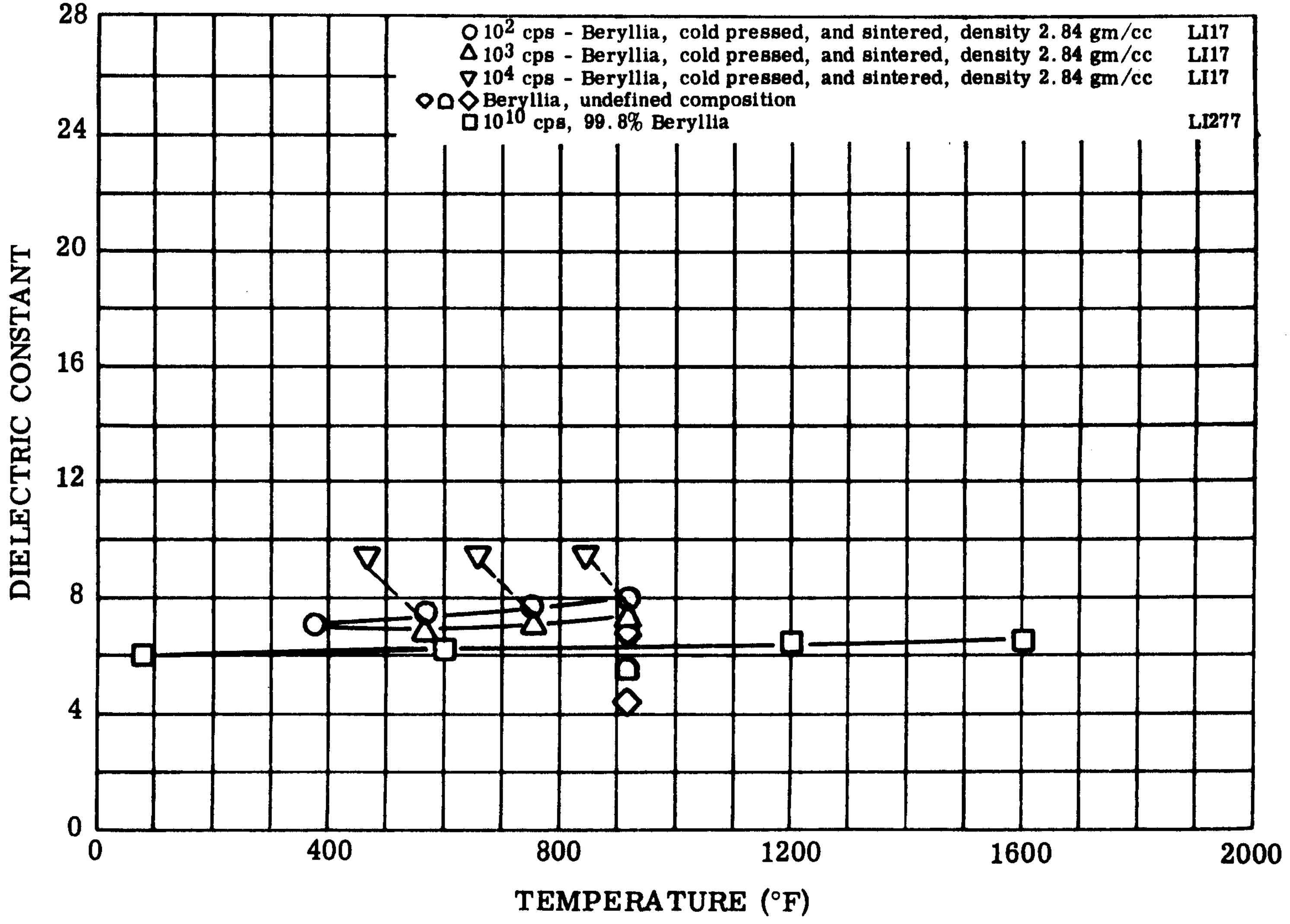


FIGURE V.E.5-4. Dielectric Constant of Rigid Inorganic Insulation Beryllia, 99.8 Percent. (Plus Three Undefined Beryllia Compositions for Comparison)

Figure V.E.5-4. Dielectric Constant - Rigid Insulation - Beryllia, 99.8%

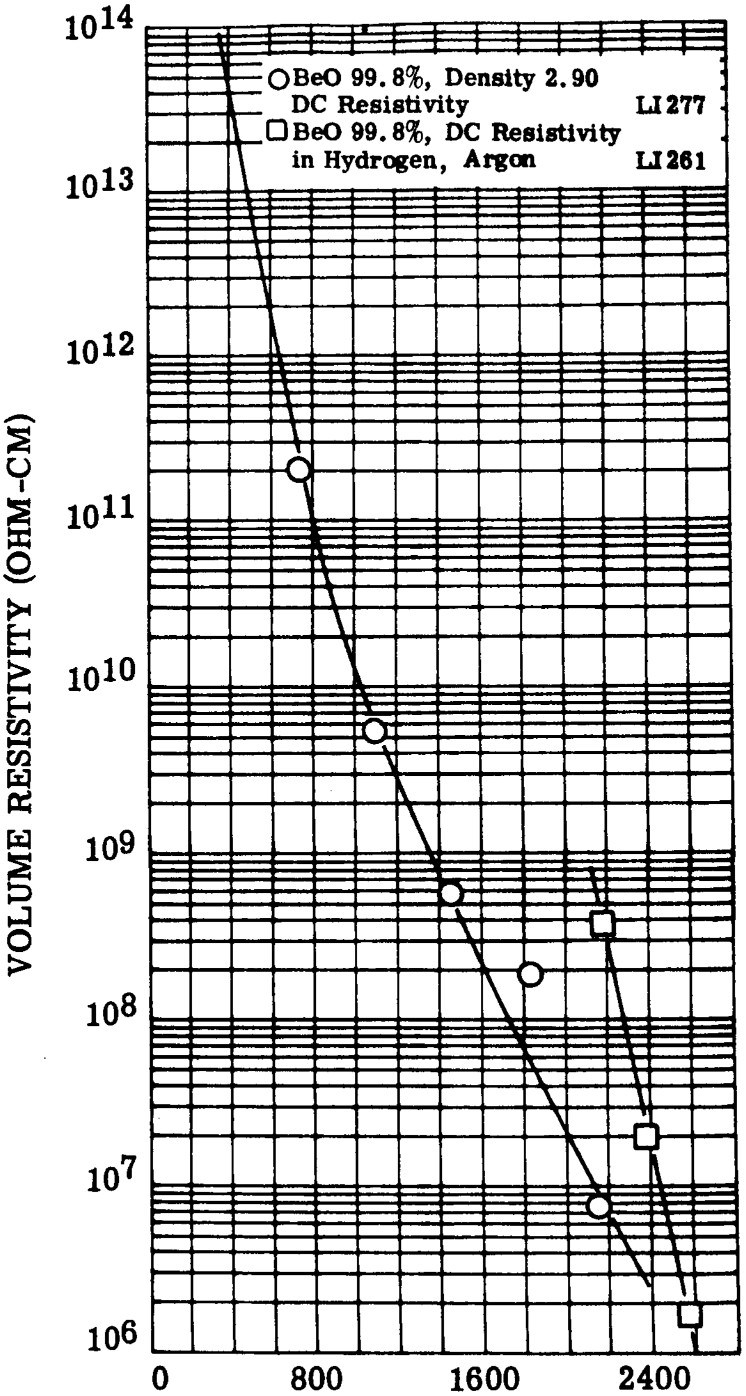


FIGURE V. E. 5-5. Volume Resistivity of Rigid Inorganic Insulation, Beryllia, 99.8 Percent. (Reference: LI 277)

Figure V. E. 5-5. Volume Resistivity - Rigid Insulation - Beryllia, 99.8%

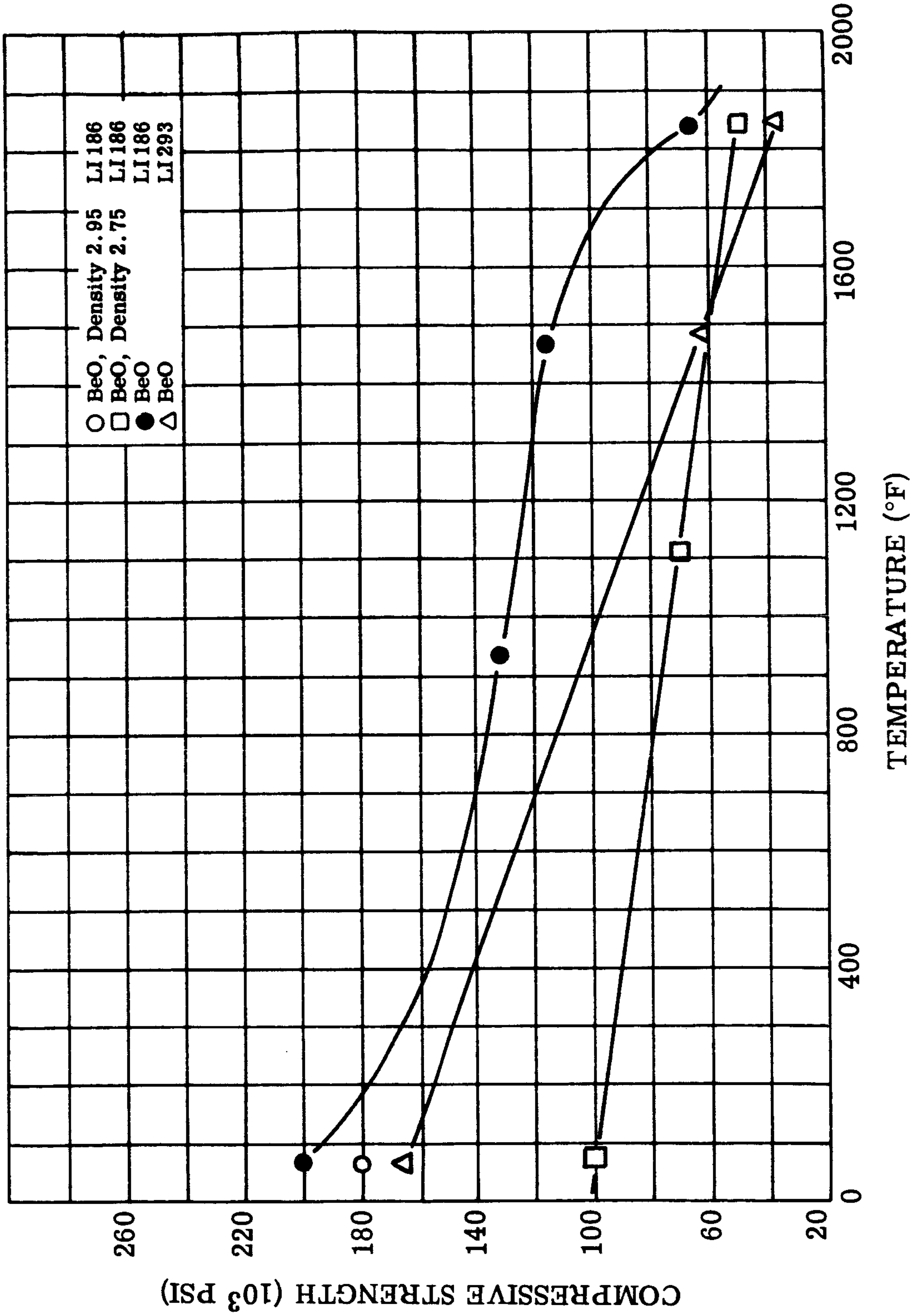


FIGURE V. E. 5-6. Compressive Strength of Rigid Inorganic Insulation Beryllia, 99.8 Percent

Figure V. E. 5-6. Compressive Strength - Rigid Insulation - Beryllia, 99.8%

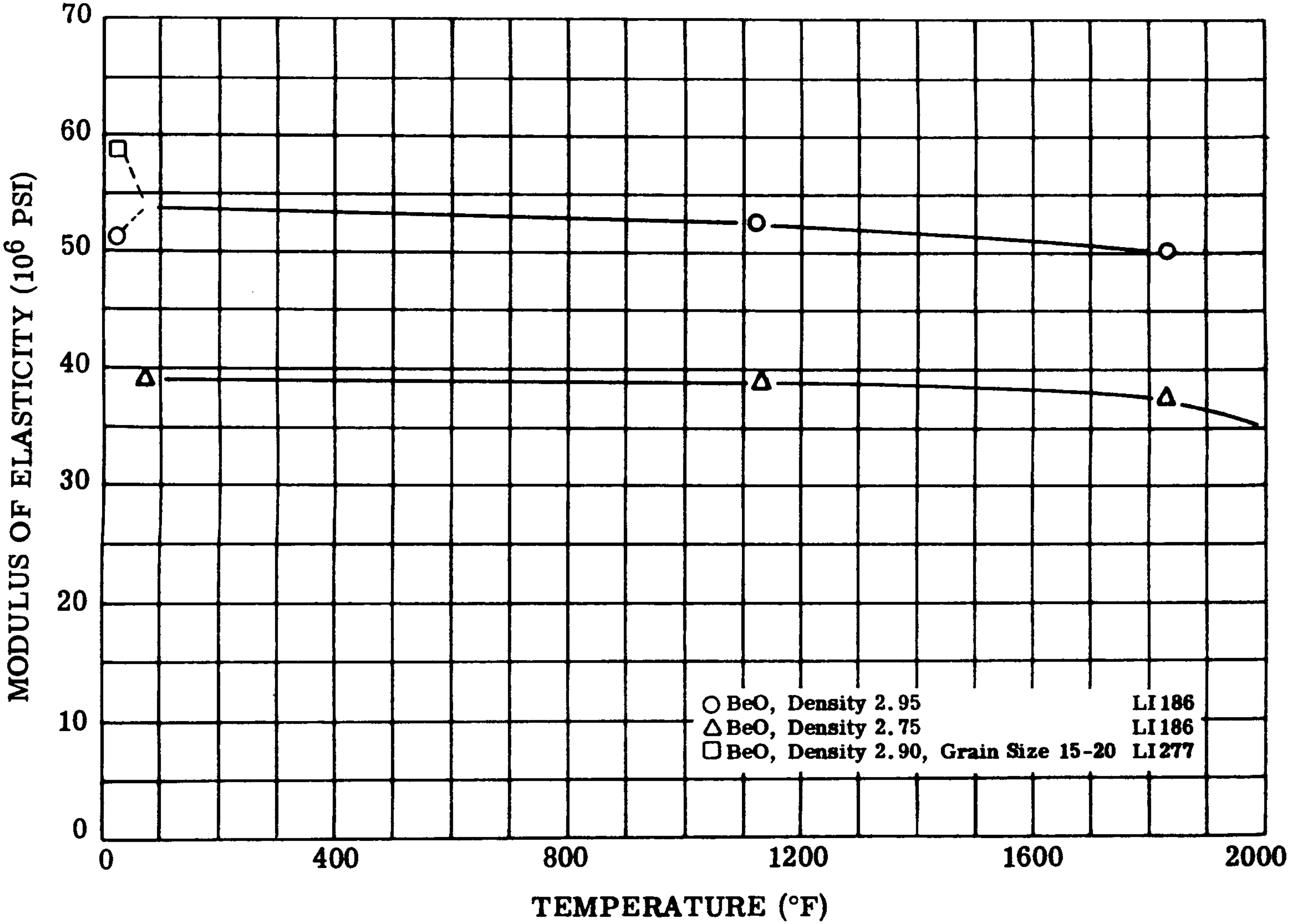


FIGURE V.E.5-7. Modulus of Elasticity of Rigid Inorganic Insulation Beryllia, 99.8 Percent.

Figure V.E.5-7. Modulus of Elasticity - Rigid Insulation - Beryllia, 99.8%

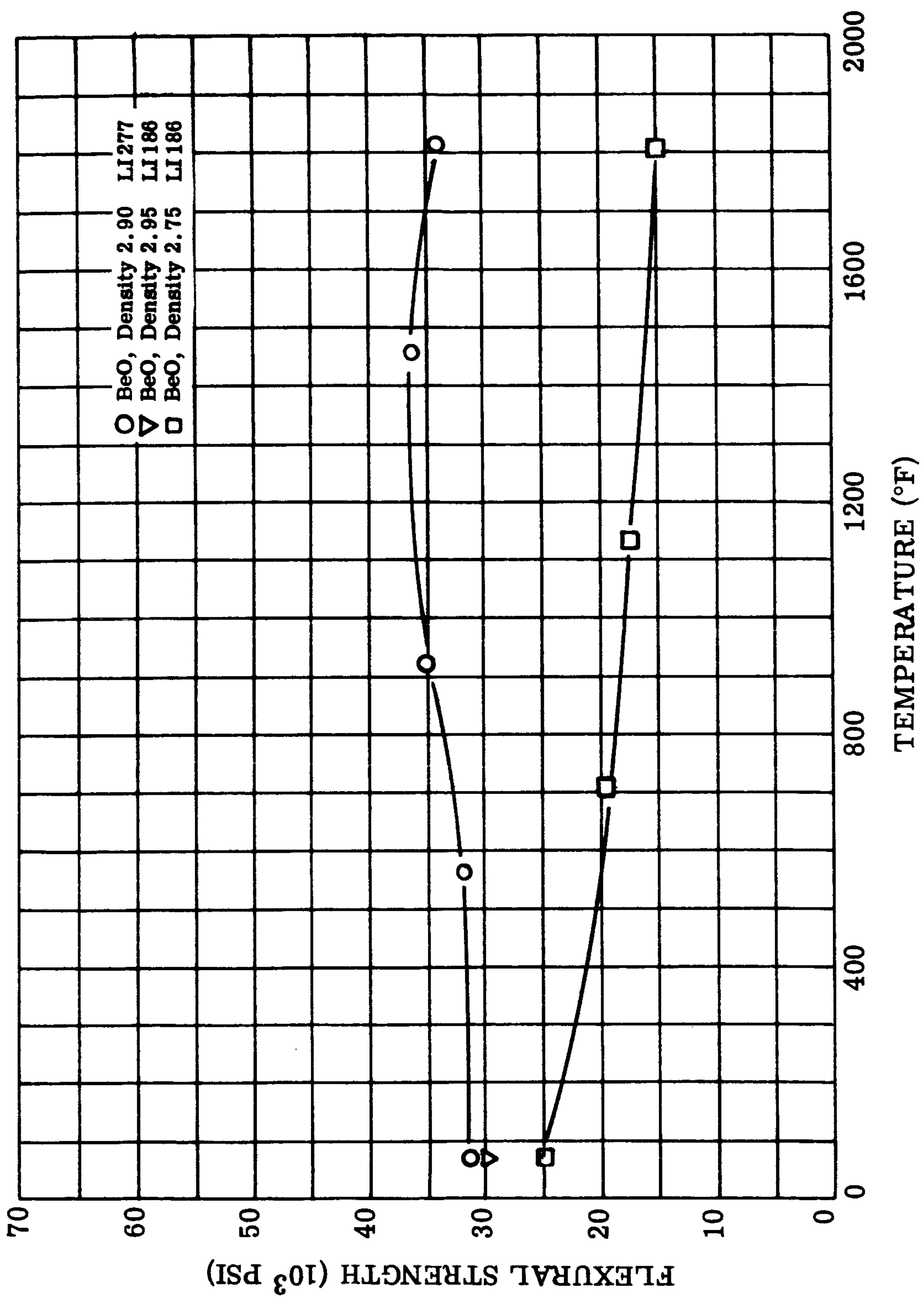


FIGURE V.E.5-8. Flexural Strength of Rigid Inorganic Insulation Beryllia, 99.8 Percent. (Reference: LI 277)

Figure V.E.5-8. Flexural Strength - Rigid Insulation - Beryllia, 99.8%

6. EPOXY PREMIX, RIGID INSULATION

Epoxy Premix (Scotchply 1100) is a high strength, glass fiber reinforced epoxy molding compound.

Availability:	This material is available from the Minnesota Mining and Manufacturing Company as Scotchply Type 1100.
Description:	This material is epoxy based and is 37 percent by weight resin and the balance is 1/2 inch long E-glass fibers. The compound should be preheated to 200°F for 4 minutes and molded by compression or transfer for 20 minutes at 330°F (1/8 inch section).

I. Thermophysical Properties

A. Density (lb/cu inch) 0.065 (RI160)

Specimen Thickness, 0.125 Inch

B. Thermal Conductivity

Specimen Thickness, 0.25 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
212	0.111
266	0.133
288	0.140

C. Coefficient of Thermal Expansion (RI160)

Specimen Thickness, 0.25 Inch

Temperature Range (°F)	inch/inch-°F
77 to 300	6.35×10^{-6}
300 to 77	6.35×10^{-6}

D. Water Absorption (77°F)(percent) 0.053 (RI160)

Specimen Thickness, 0.125 Inch

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) 125 (RI160)

B. Dielectric Constant (RI160)

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	100	5.5

C. Electric Strength (RI160)

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Volts/mil
77	60	360

D. Volume Resistivity

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Ohm-cm
77	500 DC	3.8×10^{15}

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	34,333
300	3,017

B. Elastic Modulus in Flexure

Temperature (°F)	Psi
77	2.78×10^6
300	0.43×10^6

C. Flexural Strength

Temperature (°F)	Psi
77	39,833
300	5,280

D. Flexural Strength at 300°F After Aging at 300°F

Time (hours)	Psi
200	6,000
400	5,900
600	3,867
800	5,983
1000	7,180

E. Impact Strength (77°F)(ft-lb/inch)	30

IV. Compatibility Properties

A. Chemical

Epoxy resins have outstanding alkali resistance. Moisture and acid resistance is fair to good. Solvent resistance is good except for the halogenated solvents.

B. Nuclear Radiation Resistance

Glass reinforced epoxy resins have been successfully exposed to a gamma radiation level of 10^{10} ergs per gram (C) in a vacuum environment of 10^{-7} torr. (Reference: Radiation Effects Information Center Report No. 34, LI296.)

C. Weight Loss in Vacuum with Heat

10 hours at 482°F, 10^{-6} torr	15.3 percent

Note: The temperature of this determination was excessive for epoxy molding compounds. The test conditions were selected to demonstrate organic resin performance under hard vacuum when heated beyond its normal maximum temperature. Compound was withdrawn from complete testing for the reasons presented in Section II.B.3.e.6. However, this compound is satisfactory and useful for long term operation at 250°F.

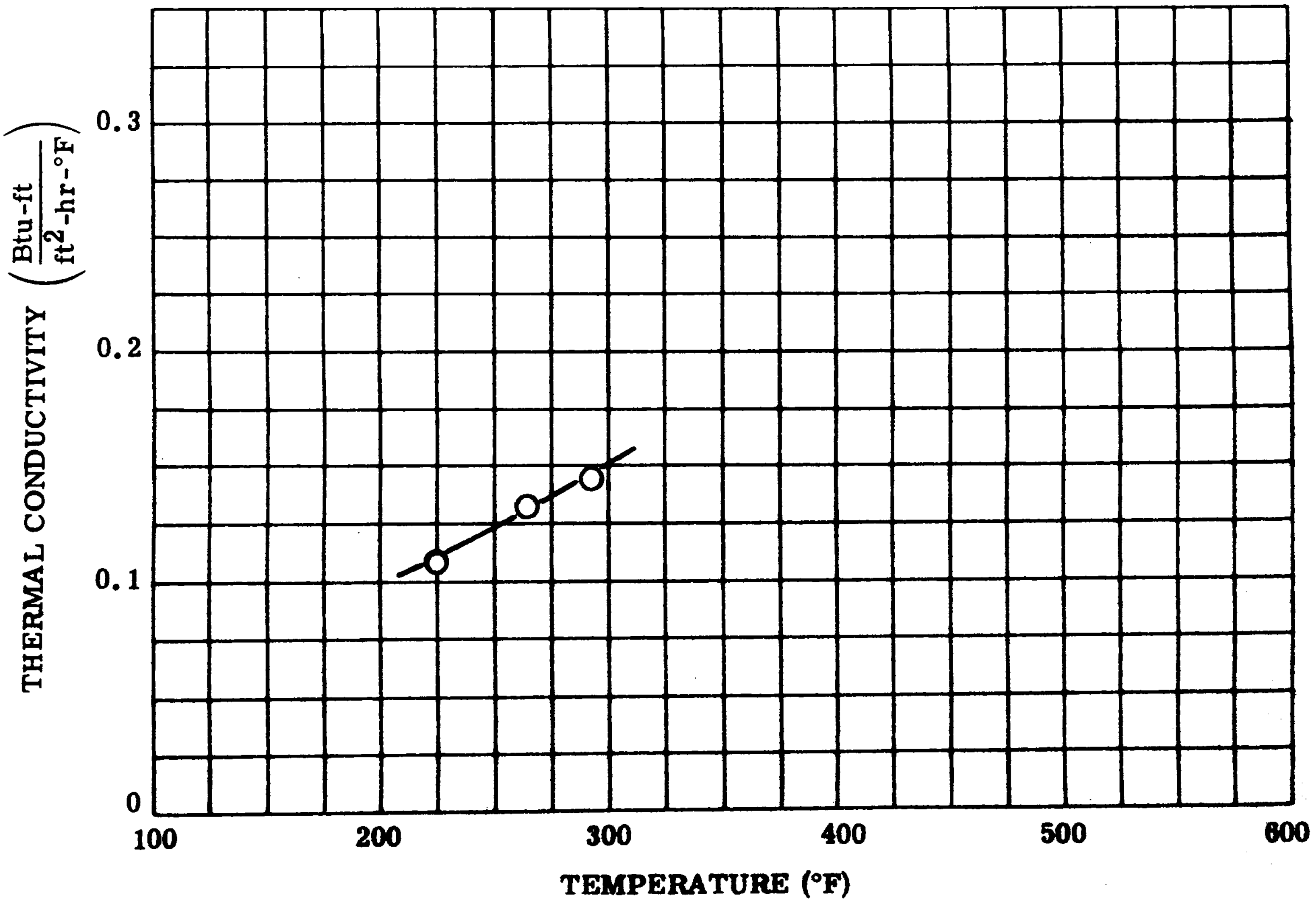


FIGURE V. E. 6-1. Thermal Conductivity of Rigid Organic Insulation, Molded, Epoxy Premix, in Air. Specimen Thickness, 0.25 Inch. (Reference: NAS 3-4162)

Figure V.E. 6-1. Thermal Conductivity - Molding Compound - Epoxy Premix

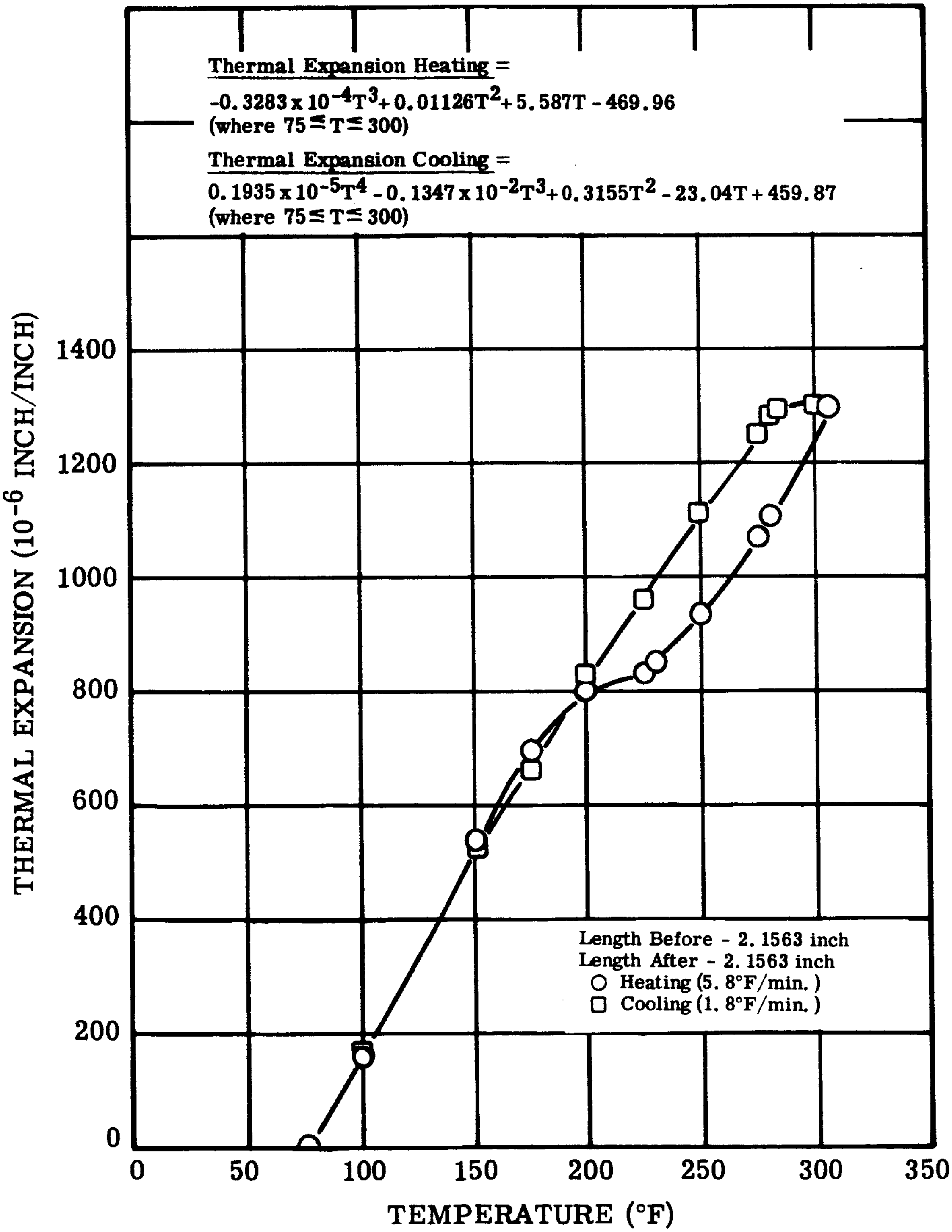


FIGURE V. E. 6-2. Thermal Expansion of Rigid Organic Insulation, Molded, Epoxy Premix in Air. Specimen Thickness, 0. 25 Inch. (Reference: NAS 3-4162)

Figure V. E. 6-2. Thermal Expansion - Molding Compound - Epoxy Premix

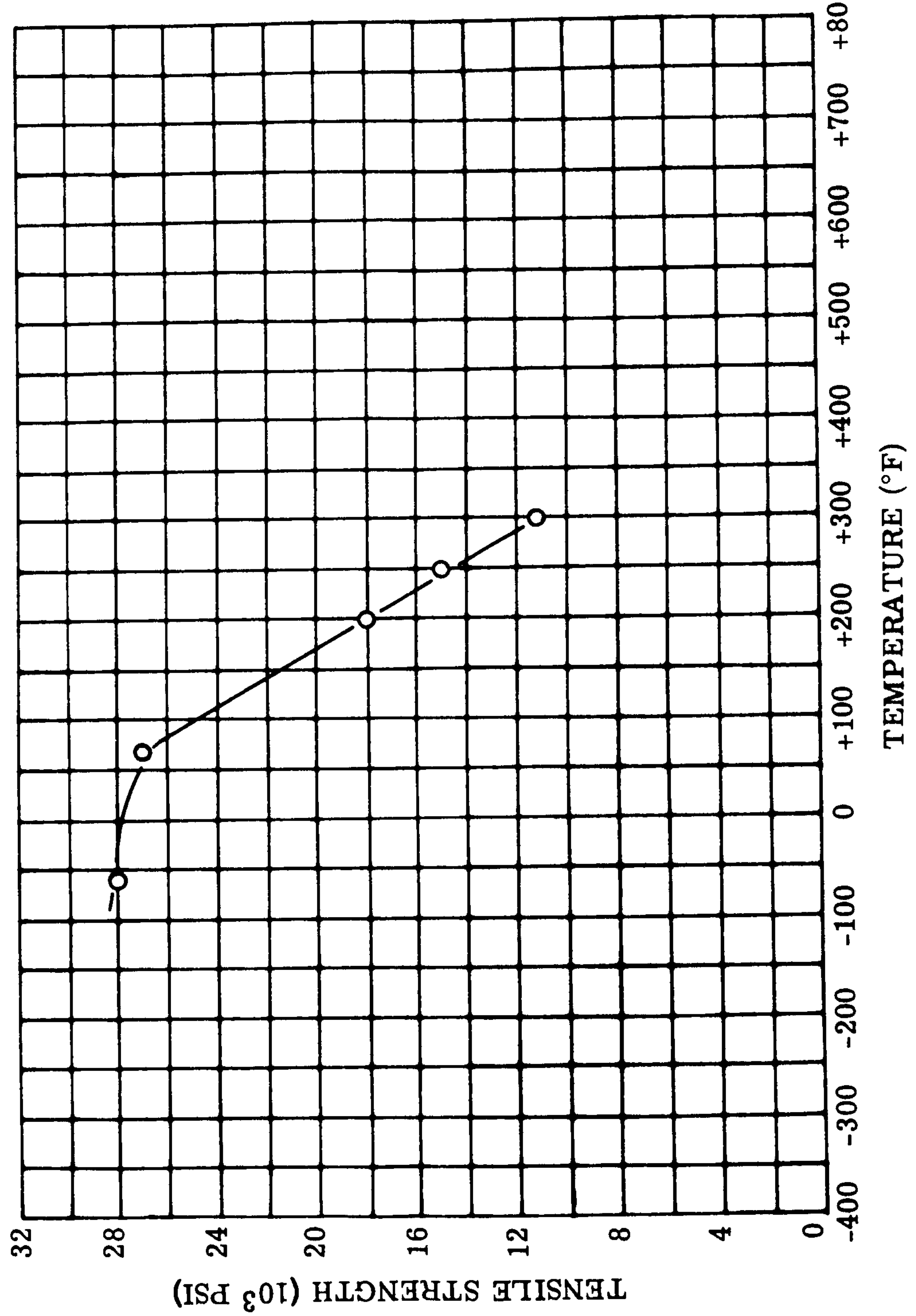


FIGURE V. E. 6-3. Tensile Strength of Rigid Organic Insulation, Molded, Epoxy Premix, Aged 0.5 Hours at Temperature in Air. (Reference: RI 160)

Figure V. E. 6-3. Tensile Strength - Molding Compound - Epoxy Premix

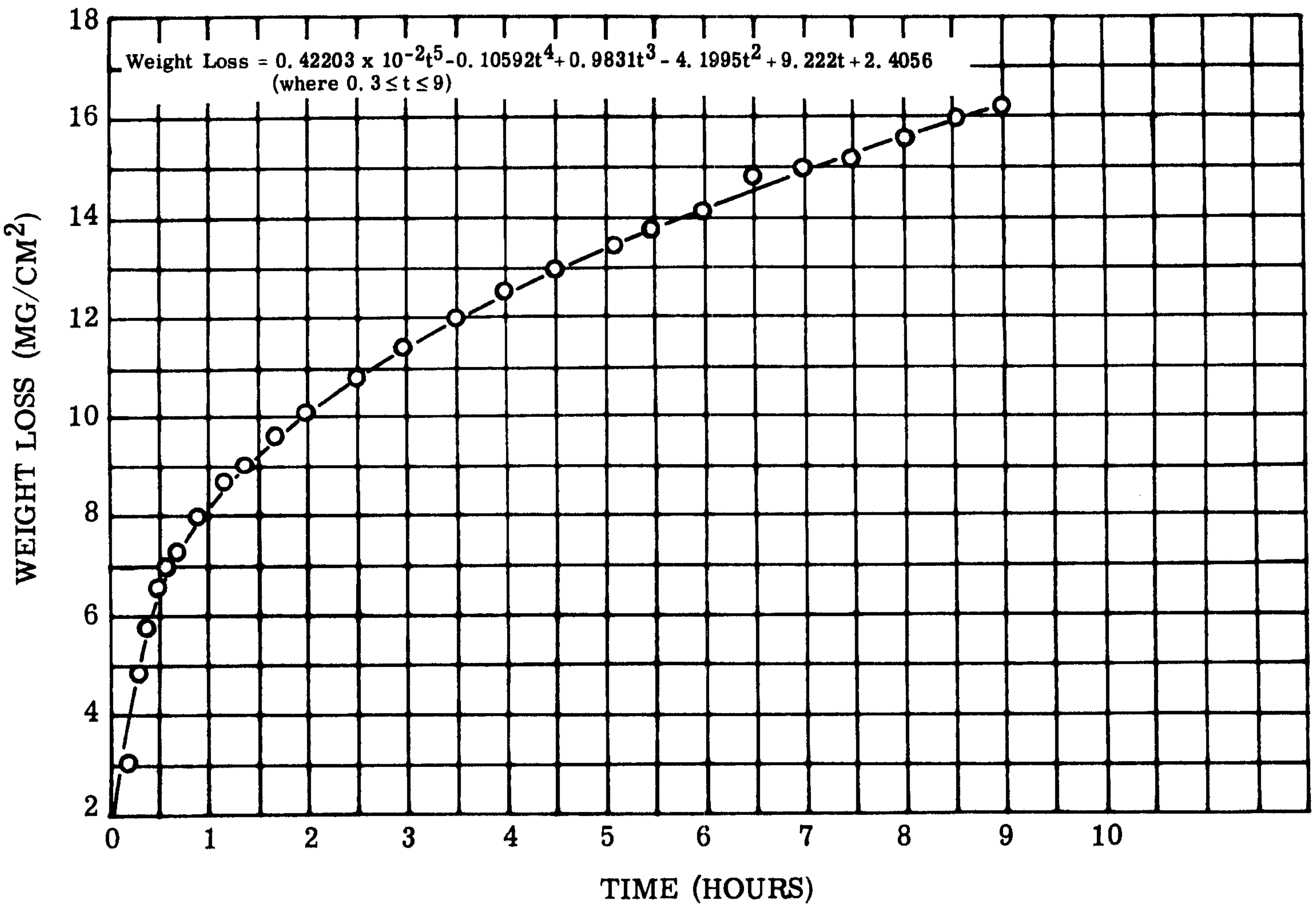


FIGURE V. E. 6-4. Weight Loss of Rigid Organic Insulation, Molded, Epoxy Premix at 482°F and 10^{-5} to 10^{-6} Torr. (Reference: NAS 3-4162)

Figure V. E. 6-4. Weight Loss - Molding Compound - Epoxy Premix

7. POLYESTER PREMIX, RIGID INSULATION

Polyester Premix (Plaskon 751) is a glass fiber reinforced polyester molding compound of intermediate impact strength. It can be compression or transfer molded with heat and pressure to form a wide variety of shapes.

Availability:	This material is available from the Plastics Division, Allied Chemical Company, as Plaskon Alkyd Molding Compound 751.
Description:	Plaskon 751 is a E-glass fiber and mineral-filled, polyester molding compound. It has a bulk factor greater than 1 and is molded in matched metal dies at 300°F and 1000 psi for 5 minutes (1/8 inch section).

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.078

B. Thermal Conductivity

Specimen Thickness, 0.064 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
130	0.561
170	0.548
212	0.528
223	0.525
280	0.510

C. Coefficient of Thermal Expansion

Specimen Thickness, 0.064 Inch

Temperature Range (°F)	inch/inch-°F
77 to 280	8.25×10^{-6}
280 to 77	10.00×10^{-6}

D. Water Absorption (77°F)(average percent) 0.42

Specimen Thickness, 0.064 Inch

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) 141

B. Dielectric Constant

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	400	6.36
77	3200	6.30
392	400	11.1
392	3200	7.97
482	400	11.5
482	3200	12.2

C. Electric Strength

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Volts/mil
72	DC	1155
72	400 cps	425
72	3200 cps	291 (1)
392	DC	402
392	400 cps	408
392	3200 cps	165 (1)
482	DC	200 (1)
482	400 cps	107 (1)
482	3200 cps	102 (1)

(1) These tests in air and 1 inch electrodes. All others in oil and 2 inch electrodes.

D. Insulation Life

1. Electric Strength at 60 cps and 400°F

(Reference: Allied Chemical)

Time (hours)	Electric Strength (Short Time) (volts/mil)	Electric Strength (Step by Step) (volts/mil)
0	405	290
168	360	300
280	390	-
480	350	210

2. Electric Strength at 400 cps and 212°F, 257°F, and 302°F

Specimen Thickness, 0.064 Inch

Aging and Test Temperature (°F)	Aging Time at Temperature	Electric Strength (volts/mil)
212	Original (1)	440
212	200 hours	456
212	400 hours	464
212	600 hours	459
212	800 hours	432
212	1000 hours	475
257	Original (1)	450
257	200 hours	452
257	400 hours	448
257	600 hours	496
257	800 hours	475
257	1000 hours	455
302	Original (1)	450
302	200 hours	486
302	400 hours	472
302	600 hours	467
302	800 hours	501
302	1000 hours	449

(1) Original Data interpolated from Figure V.E.7-4.

E. Volume Resistivity

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Ohm-cm
77	DC	7.61×10^{14}
77	400 cps	9.02×10^{10}
77	3200 cps	1.23×10^{10}
392	DC	5.85×10^{9}
392	400 cps	7.00×10^{8}
392	3200 cps	3.69×10^{8}
482	DC	5.34×10^{8}
482	400 cps	1.14×10^{8}
482	3200 cps	6.35×10^{7}

F. Power Factor

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Percent
72	400	0.77
72	3200	0.69
392	400	53.5
392	3200	20.5
482	400	96.0
482	3200	61.2

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	18,083
300	5,533

B. Elastic Modulus in Flexure

Temperature (°F)	Psi
77	2.33×10^6
300	0.74×10^6

C. Flexure After Aging (77°F)

Temperature (°F)	Time (hours)	Flexure (psi)
300	200	8350
300	400	9033
300	600	9067
300	800	8933
300	1000	10360

D. Impact Strength (77°F)(ft-lb/inch of notch) 4.52

E. Flexural Strength

Temperature (°F)	Psi
77	18,350
300	6,633

IV. Compatibility Properties

A. Chemical Resistance

This polyester premix has good organic solvent resistance and good resistance to water. Its resistance to acids and alkalies is fair to good, depending on concentration and temperature.

B. Nuclear Radiation Resistance

Polyester resins are only moderately resistant to nuclear radiation. Exposure to a fast neutron dose of 10^{17} will reduce tensile and impact strength values to about 50 percent of original level. The reaction is predominately chain scission which results in severe loss of mechanical properties. (Reference: RI 608 and Radiation Effects Information Center Report No. 34, LI 296.)

C. Weight Loss in Vacuum with Heat

28 hours at 300°F, 10^{-6} torr	0.57 percent

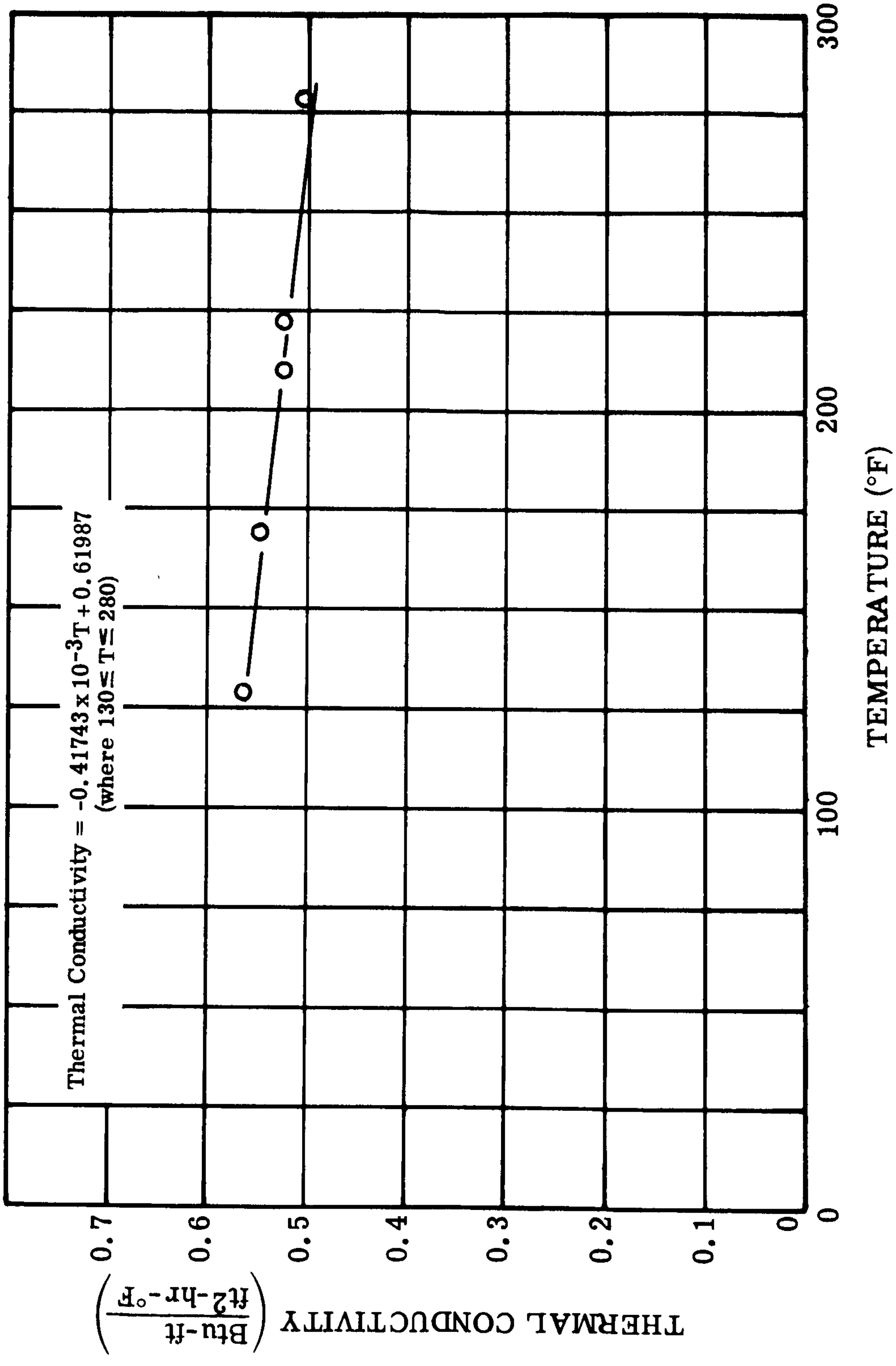


FIGURE V. E. 7-1. Thermal Conductivity of Rigid Organic Molded Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. E. 7-1. Thermal Conductivity - Molded Insulation - Polyester Premix

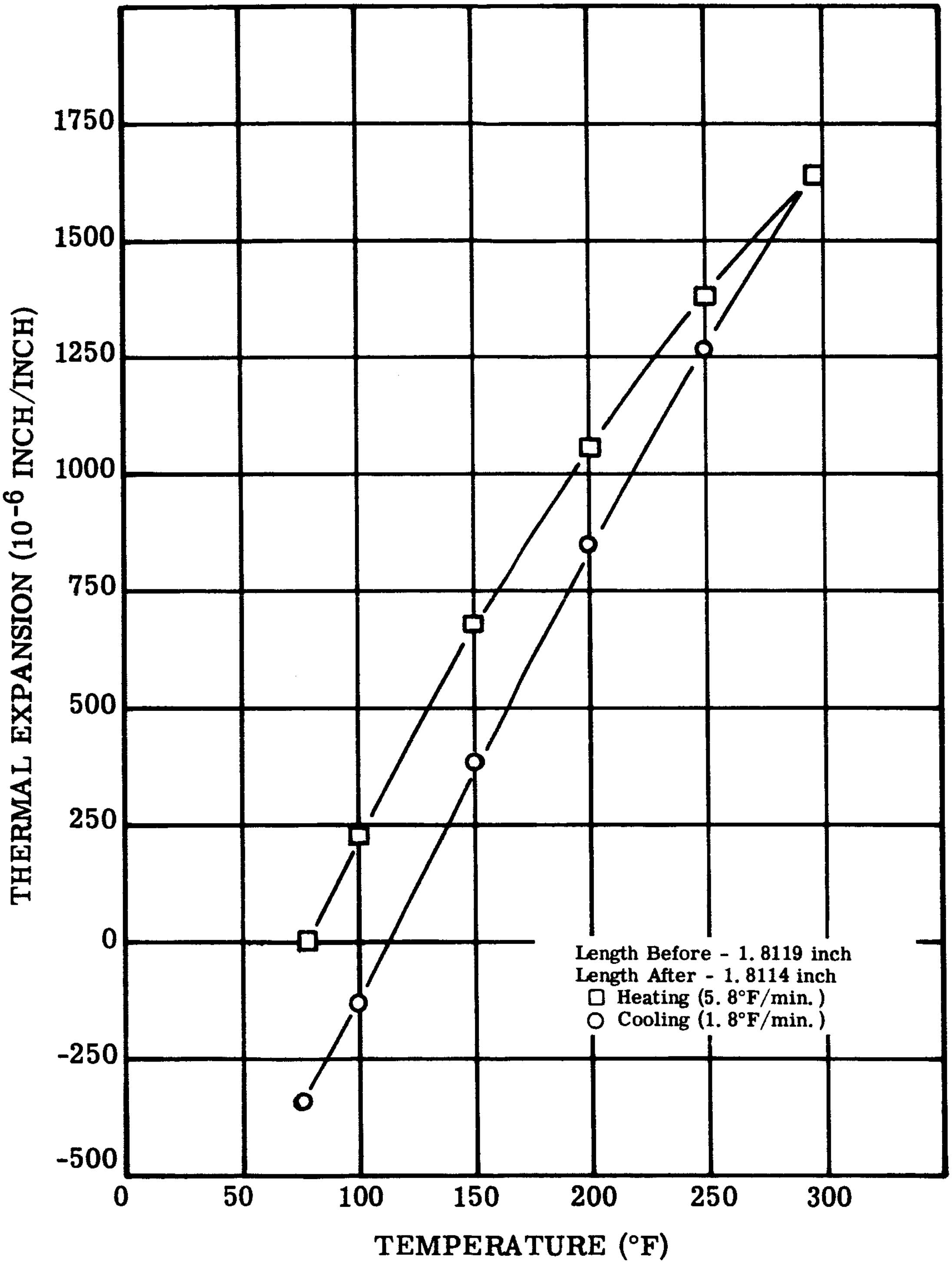


FIGURE V.E.7-2. Thermal Expansion of Rigid Organic Molded Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V.E.7-2. Thermal Expansion - Molded Insulation - Polyester Premix

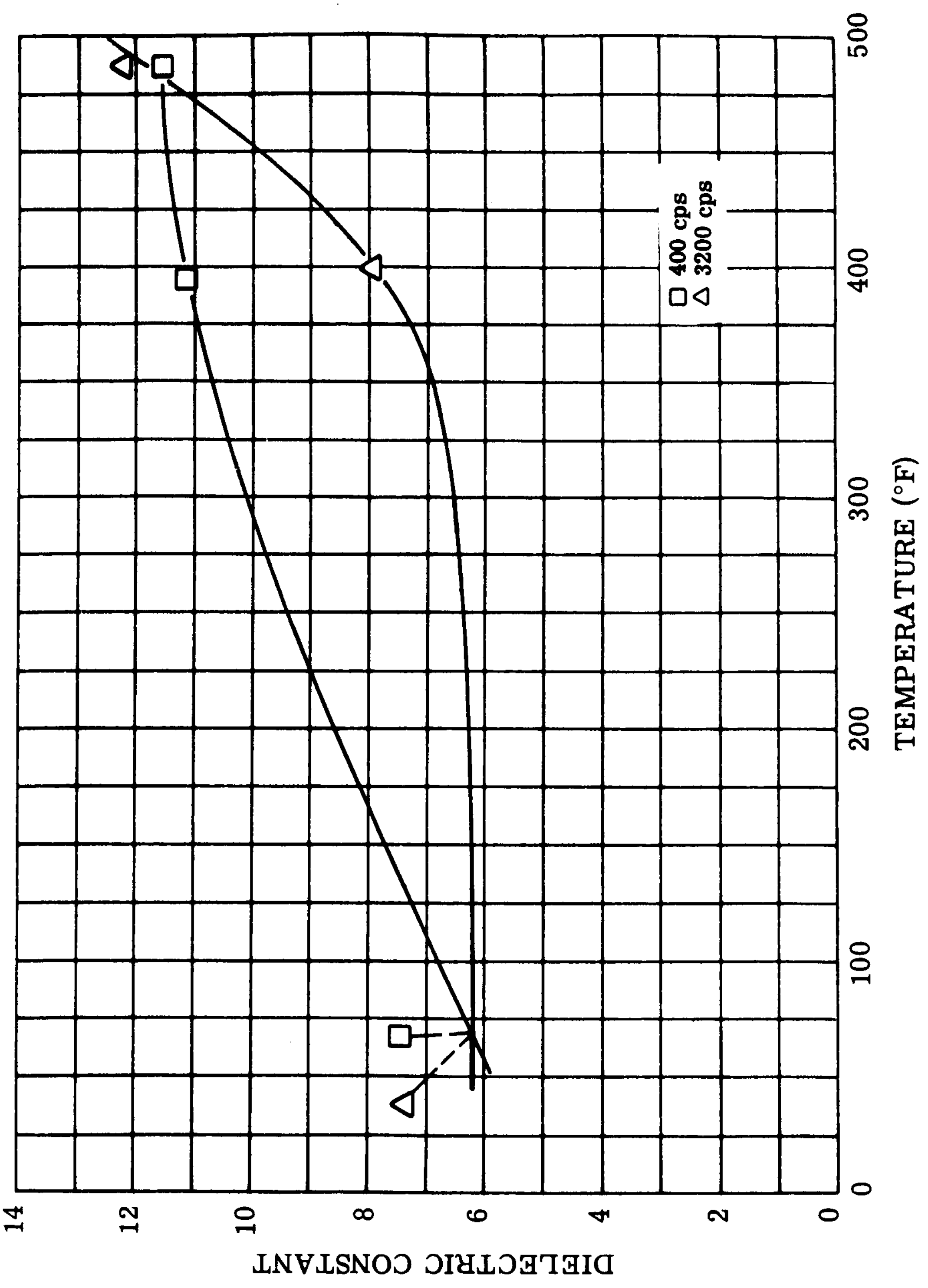


FIGURE V.E.7-3. Dielectric Constant of Rigid Organic Molded Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS3-4162)

Figure V.E.7-3. Dielectric Constant - Molded Insulation - Polyester Premix

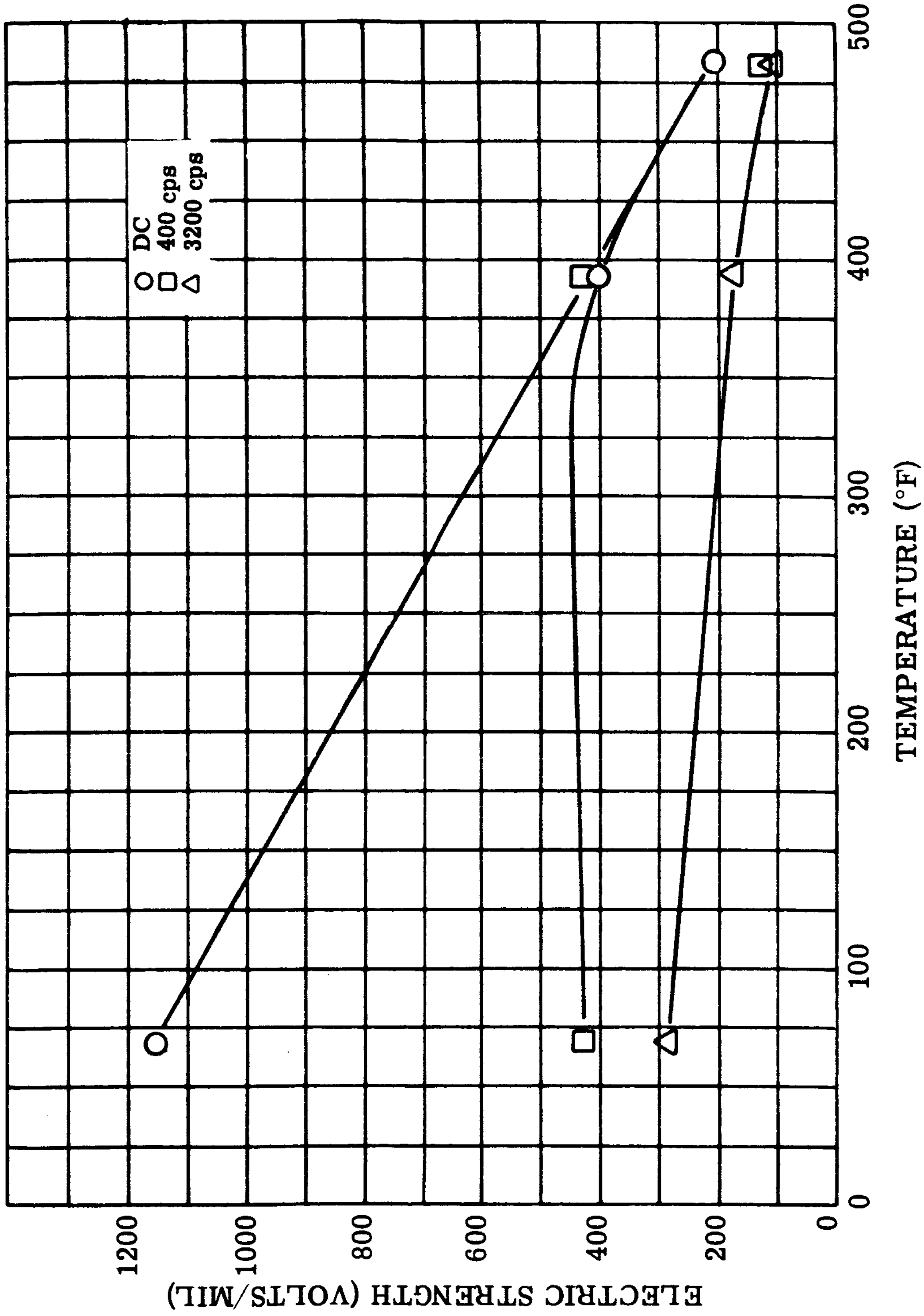


FIGURE V.E.7-4. Electric Strength of Rigid Organic Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS3-4162)

Figure V.E.7-4. Electric Strength - Molded Insulation - Polyester Premix

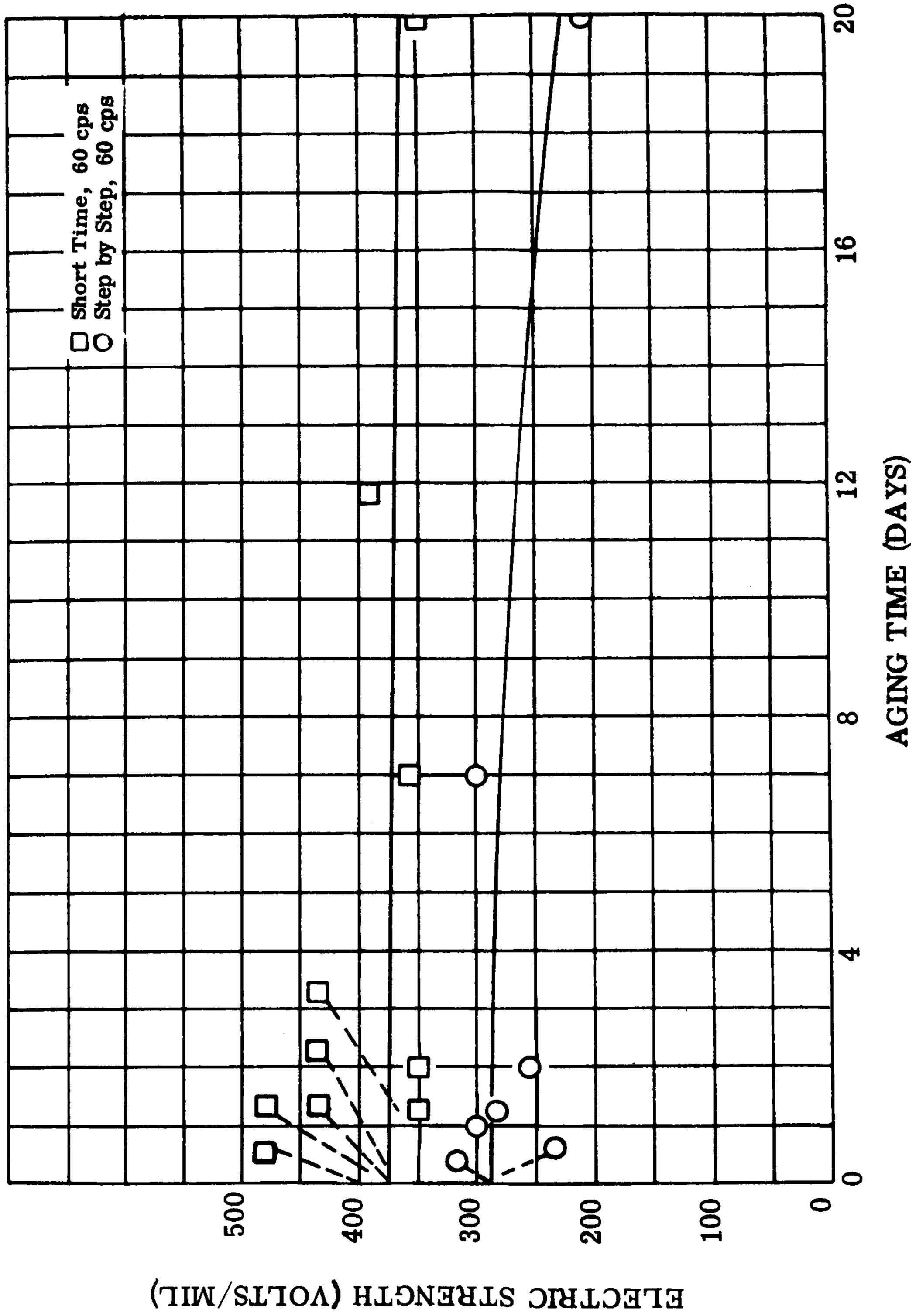


FIGURE V.E.7-5. Insulation Life at 400°F of Rigid Organic Molded Insulation, Polyester Premix, in Air. (Reference: Allied Chemical)

Figure V.E.7-5. Insulation Life - Molded Insulation - Polyester Premix

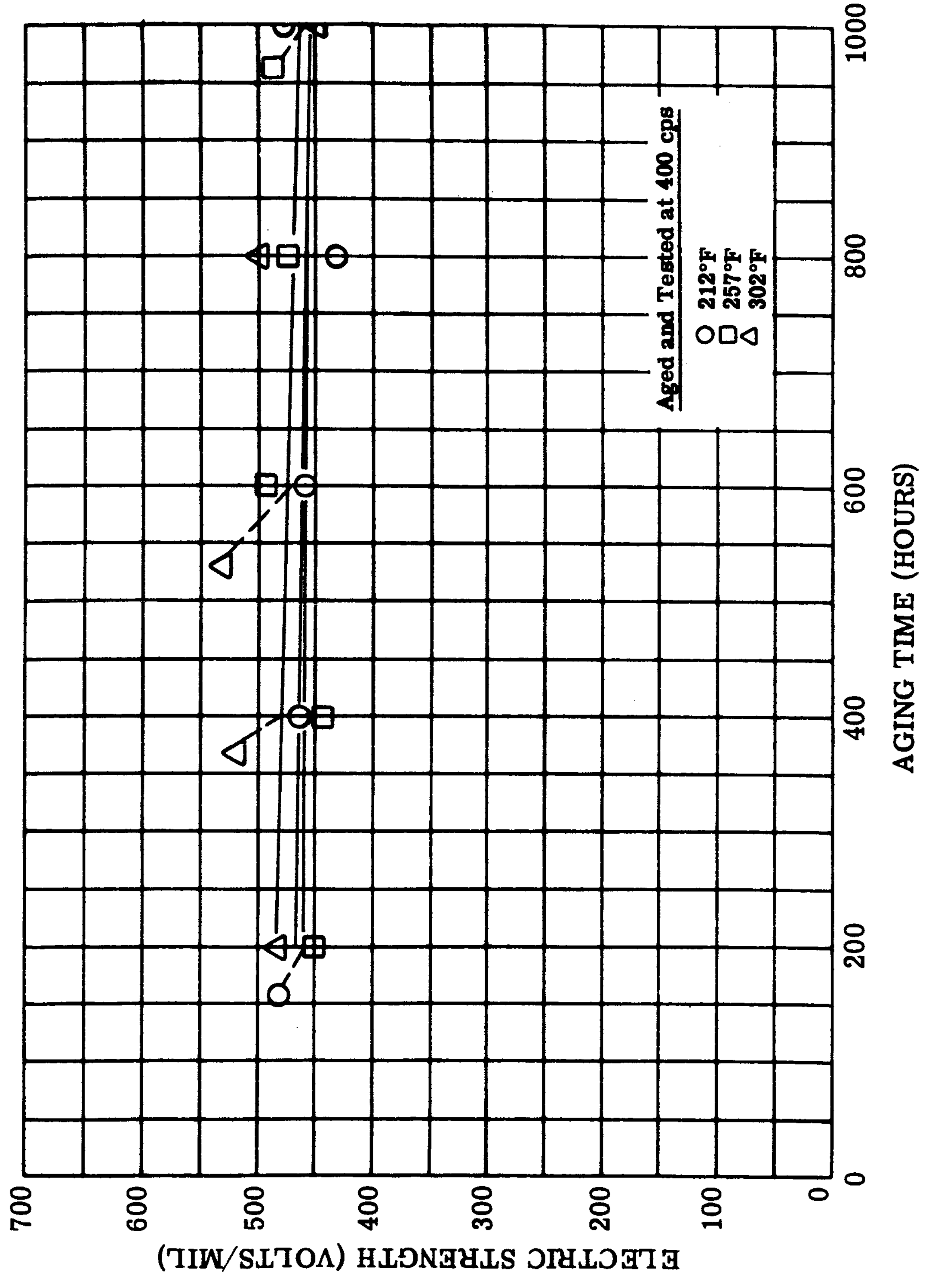


FIGURE V.E.7-6. Insulation Life of Rigid Organic Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS3-4162)

Figure V.E.7-6. Insulation Life - Molded Insulation - Polyester Premix

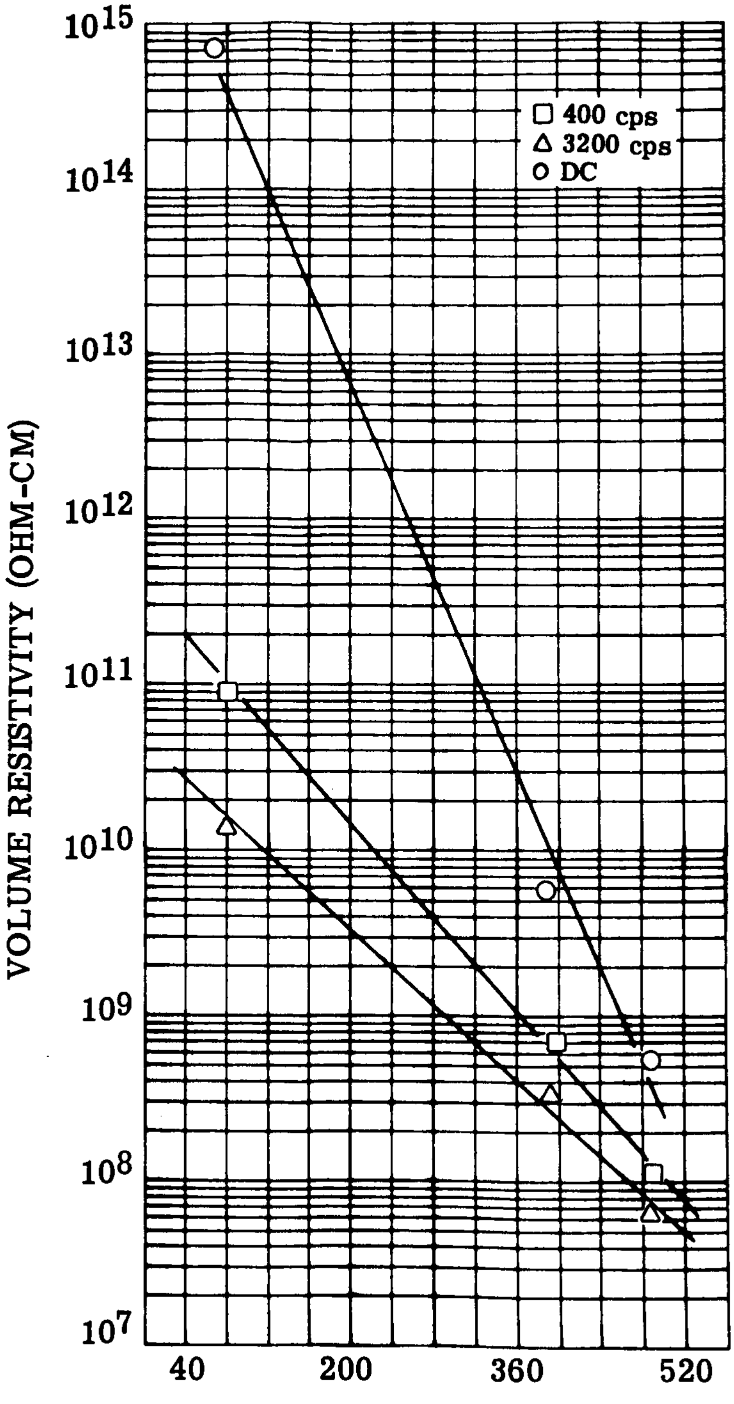


FIGURE V. E. 7-7. Volume Resistivity of Rigid Organic Molded Insulation, Polyester Premix, In Air. Specimen Thickness 0.064 Inch. (Reference: NAS 3-4162)

Figure V. E. 7-7. Volume Resistivity - Molded Insulation - Polyester Premix

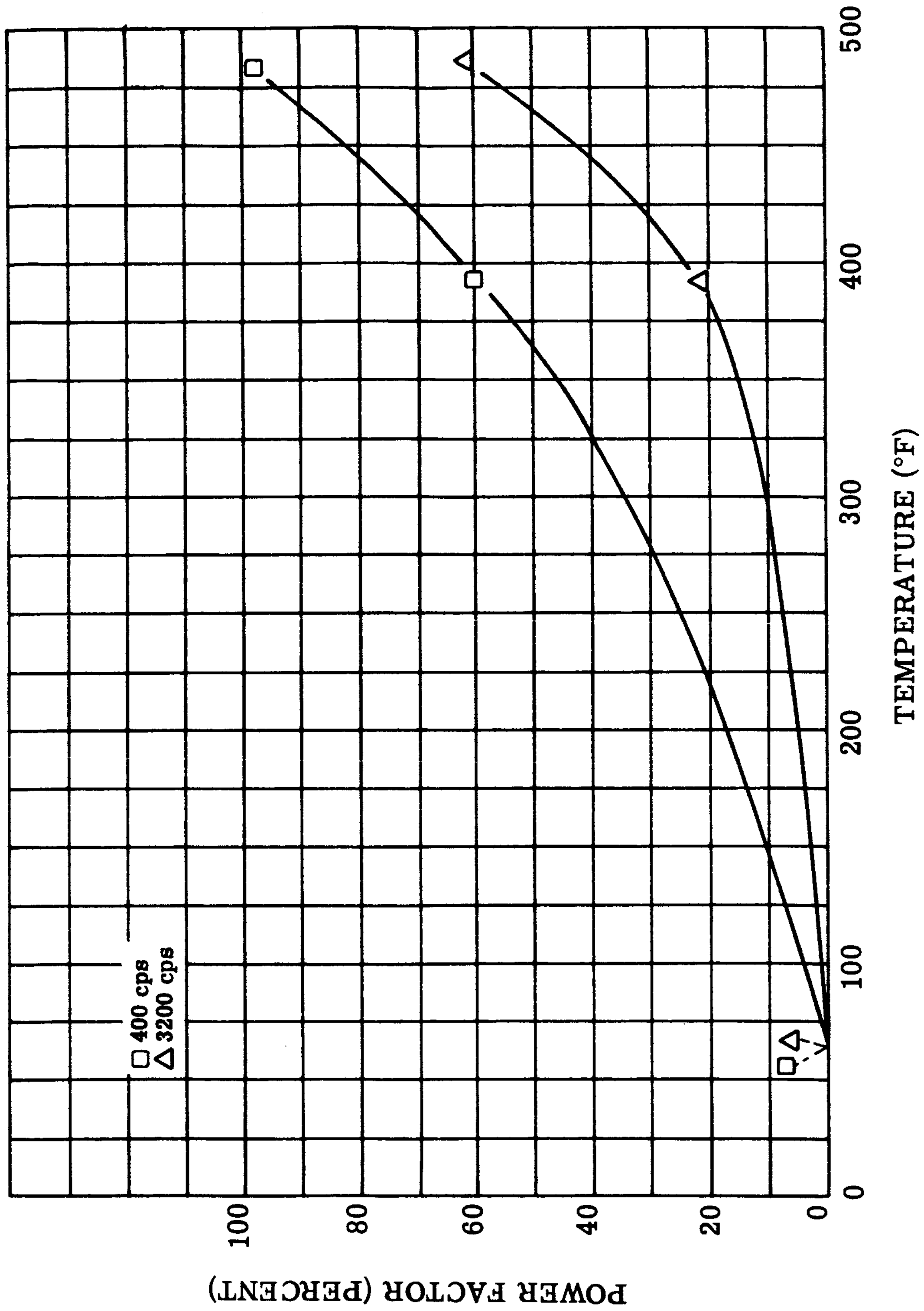


FIGURE V.E.7-8. Power Factor of Rigid Organic Molded Insulation, Polyester Premix, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V.E.7-8. Power Factor - Molded Insulation - Polyester Premix

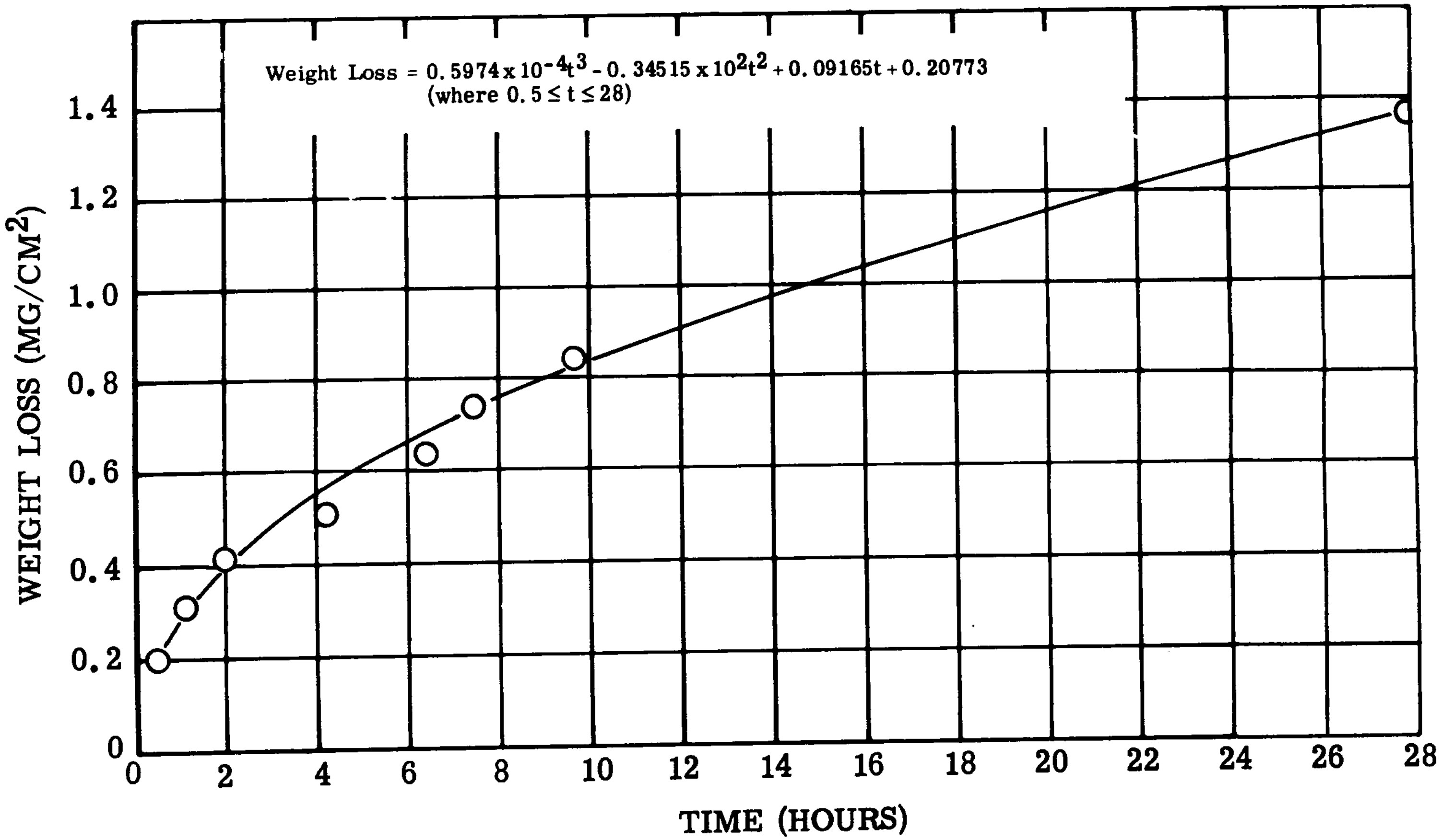


FIGURE V. E. 7-9. Weight Loss at 300°F and 10^{-5} to 10^{-6} torr, of Rigid Organic Molded Insulation, Polyester Premix. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. E. 7-9. Weight Loss - Molded Insulation - Polyester Premix

8. POLYIMIDE, RIGID INSULATION

Vespel polyimide moldings are formed in regular shapes. Complex parts are machined from simple molded shapes. The material was formerly known as Polymer SP.

Availability:	This material is available from E.I duPont de Nemours and Company, in the form of molded blocks, bars, and cylinders.
Composition:	The material is an aromatic polyimide, the reaction product of a dianhydride and a diamine. The material reported on in this summary was not filled, but filled moldings are available.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.051 (RI121)

B. Thermal Conductivity (212°F) 0.18 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$

C. Coefficient of Thermal Expansion (RI121)

Temperature Range (°F)	inch/inch-°F
73 to 212	28.5×10^{-6}
73 to 392	29.8×10^{-6}
73 to 572	32.4×10^{-6}
73 to 752	35.4×10^{-6}

D. Water Absorption (RI121)

24 hours at 73°F	0.31 percent
48 hours at 122°F	0.82 percent
50% relative humidity to equilibrium	1.0 percent

II. Electrical Properties

A. Arc Resistance (77°F)(seconds) 185 (tracks)

B. Dielectric Constant (RI121)

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	60	3.26
77	1000	3.24
212	60	3.24
212	1000	3.24
392	60	3.18
392	1000	3.16
74	100	3.47
74	10000	3.46
74	1 x 10^6(1) (2)	3.7
212	1 x 10^6(1)	3.6
347	1 x 10^6(1)	3.4
437	1 x 10^6(1)	3.4
527	1 x 10^6(1)	3.4
572	1 x 10^6(1)	3.4

Notes:

1. At 10^6 cps, the sample was dried at 302°F for 2 hours, then tested over range of 74°F to 572°F. This yielded a dielectric constant of 3.4.

2. The sample containing 3.2 percent absorbed water was tested at 74°F and 10^6 cps, which yielded a dielectric constant of 4.82.

C. Electric Strength (RI121)

Composition	Temperature (°F)	Volts/mil
0.080 inch thick	77	570
0.030 inch thick	77	1100
0.003 inch thick	77	4100

D. Power Factor (RI122) (RI123)

Temperature (°F)	Frequency (cps)	Percent
77	60	0.0013
77	1×10^3	0.0016
74	1×10^6	0.008
212	60	0.0005
212	1×10^3	0.0005
212	1×10^6	0.007
347	1×10^6	0.003
392	60	0.04
392	1×10^3	0.003
437	1×10^6	0.003
527	1×10^6	0.008
572	1×10^6	0.05

E. Volume Resistivity

Temperature (°F)	Frequency	Ohm-cm
77	DC	5.0×10^{16}
392	DC	5.4×10^{13} (1)
482	DC	1.4×10^{12} (1)

III. Mechanical Properties

A. Abrasion Resistance (Bearing properties at PV limit 110,000) (RI120)

Wear constant	40×10^{-10}	(RI120)
Wear against 1025 mild steel	Excellent	
Coefficient friction for 1025 steel, in air at RT, velocity of 834 feet per minute	0.08-0.015	(RI121)

(1) Estimated from Data for Film (see Section V.C.1)

Coefficient plane sliding friction for polished SS 1/2 inch/minute and 1/16 psi is

At atmosphere pressure	0.17
At 5 x 10^{-8} mm Hg	0.13

B. Compressive Strength (77°F) 24,400 psi (RI121)

C. Elastic Modulus in Flexure (RI121)

Temperature (°F)	Psi
77	0.45 x 10^6
572	0.22 x 10^6
707	0.10 x 10^6

D. Flexural Modulus (RI121)

Temperature (°F)	Psi
-310	5.2 x 10^5
73	4.5 x 10^5
392	2.3 x 10^5
482	2.1 x 10^5
707	1.0 x 10^5

E. Impact Strength (RI120) (RI121)

Temperature (°F)	Notched (ft-lb/in)	Unnotched (ft-lb/in)
-112	0.50	-
73	0.70	9.6
482	0.90	11.8

F. Flexural Strength (RI120)

Temperature (°F)	Psi
77	14,900
509	8,000

G. Tensile Strength (RI120)

Temperature (°F)	Tensile (psi)	Elongation (percent)
77	13,000 ± 2000	4.5
302	9,700	4.8
482	7,000	4.6
600	5,000	-
752	3,500	-

H. Heat Distortion Temperature

ASTM D648, 264 pounds per square inch >473°F (RI121)

IV. Compatibility Properties

A. Chemical Resistance (RI121)

Polyimide resin in the molded form is insoluble in organic solvents. It is resistant to water and dilute acid solutions. Strong acids and most alkaline solutions produce moderate to severe damage.

B. Nuclear Radiation Resistance (RI121)

Threshold damage occurs at 7 x 10^9 rads in a 2 Mev Van de Graaff generator beam. Some embrittlement developed after 1500 hours when exposed to 10^{11} rads at 347°F.

C. Weight Loss in Vacuum

26 hours at 482°F and 10^{-5} to 10^{-6} torr 0.66 percent

(This value was determined on resin film of the same chemistry as the molded material. The curve is shown in Figure V.C.1-7).

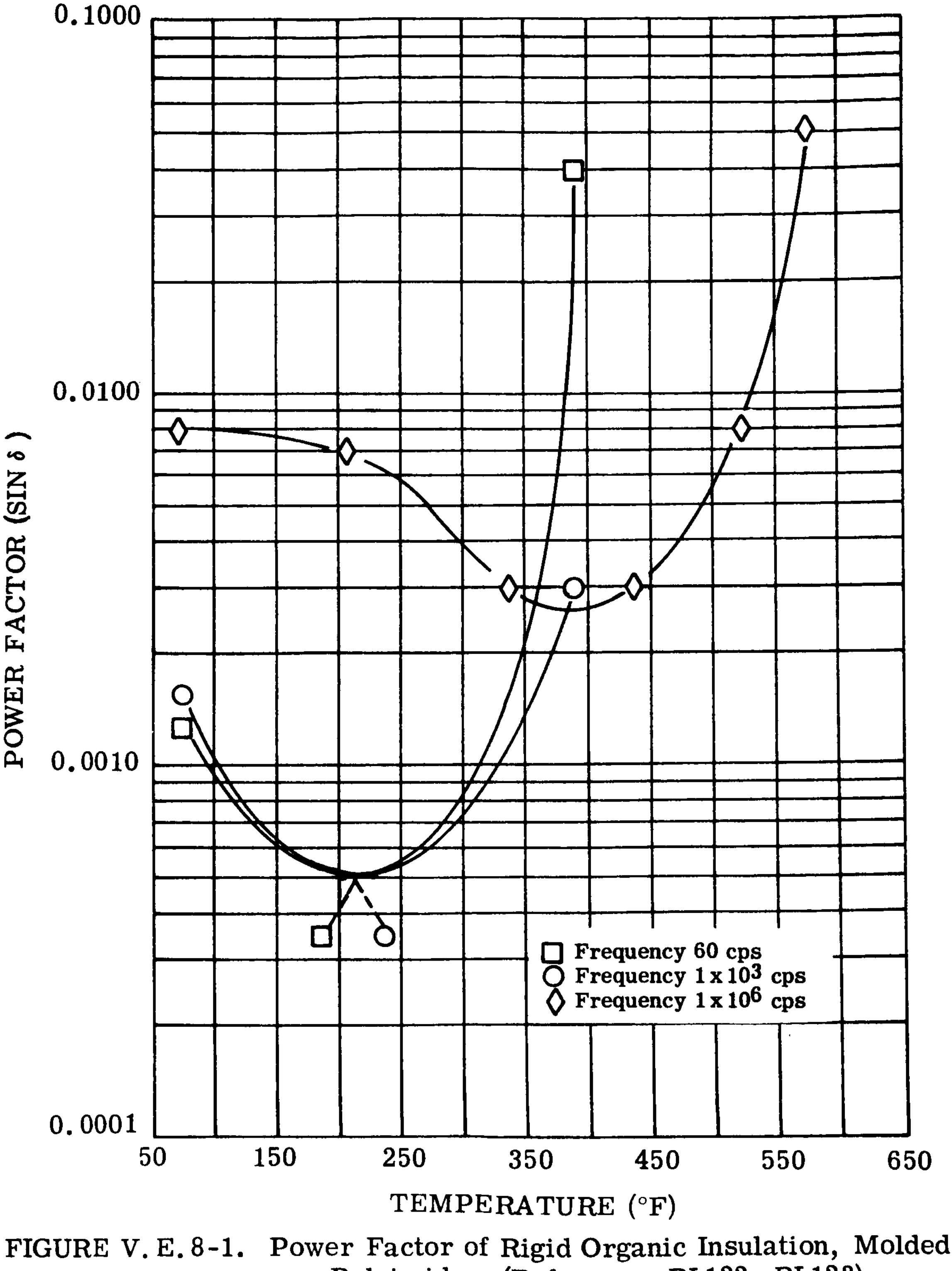


FIGURE V. E. 8-1. Power Factor of Rigid Organic Insulation, Molded, Polyimide. (Reference: RI 122, RI 123)

Figure V. E. 8-1. Power Factor - Rigid Insulation, Molded - Polyimide

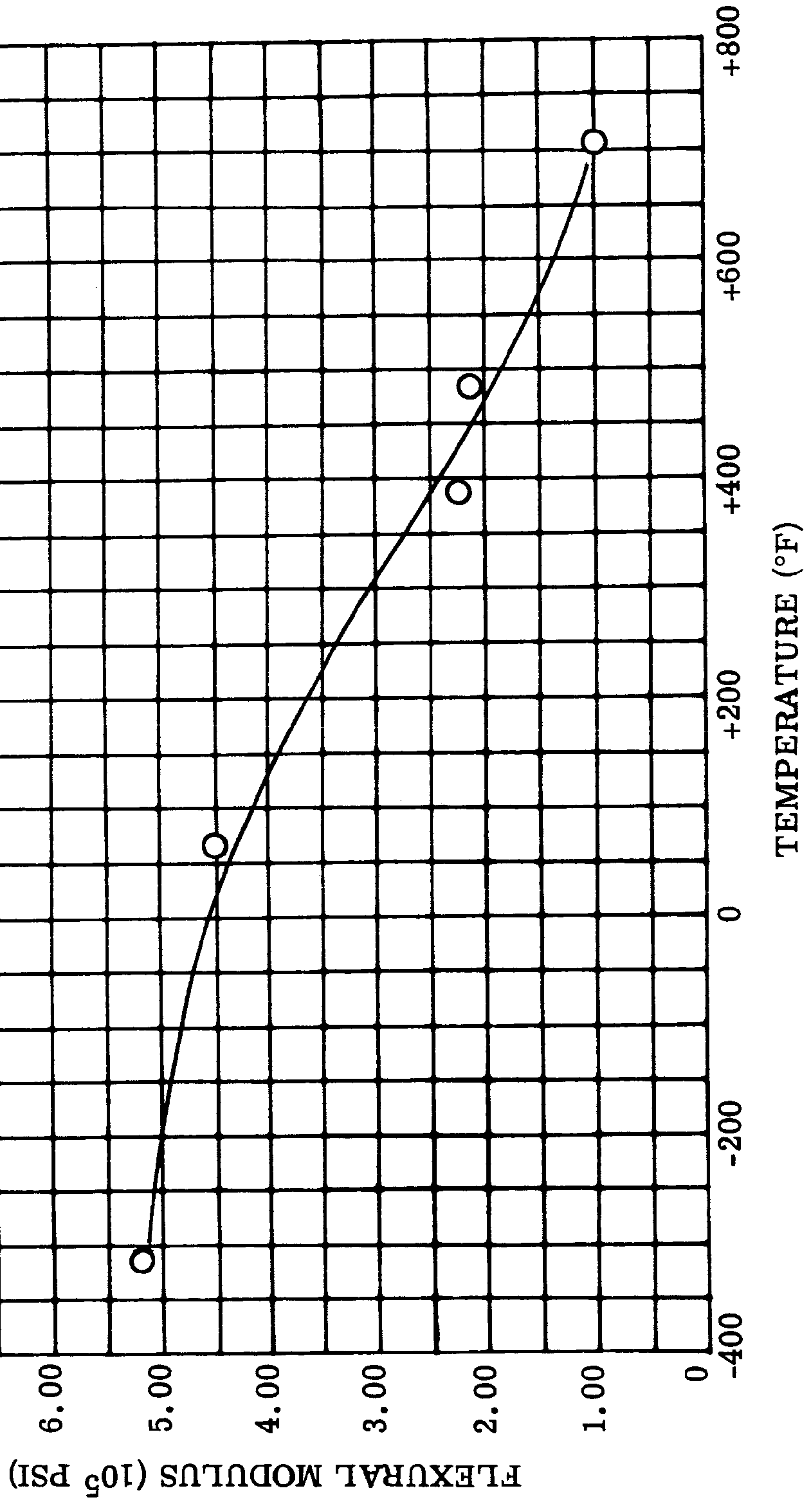


FIGURE V. E. 8-2. Flexural Modulus of Rigid Organic Insulation, Molded Polyimide. (Reference: RI 121)

Figure V. E. 8-2. Flexural Modulus - Rigid Insulation, Molded - Polyimide

F. COMPOUNDS, ENCAPSULATION

1. ANACAP ENCAPSULATION COMPOUND

Anacap is a potting and encapsulating ceramic compound intended for operation in high temperature, radiation, and vacuum environments as a part of the Anaconda CS 1200 insulation system.

Availability:	Anacap is available from Anaconda Wire and Cable Company and is supplied as a slurry in metal containers.
Description:	The exact composition is unavailable from the manufacturer. The manufacturer describes it as a combination of several refractory oxides and glass and cementatious bonding materials.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.099

B. Shrinkage (percent of cast length)

Temperature (°F)	Percent
77 (Green)	24.25
1292 (after firing)	total shrinkage 25.1

C. Coefficient of Thermal Expansion

Temperature Range (°F)	inch/inch-°F
77 to 1055 (heating)	4.4×10^{-6}
1055 to 1200 (volumetric change)	
1200 to 77 (cooling)	4.6×10^{-6}

D. Water Absorption (77°F)(percent) 18.1

II. Electrical Properties

A. Dielectric Constant

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	30
500	3200	32

Test discontinued above 500°F because of high loss and instability.

B. Electric Strength

Specimen Thickness, 0.15 Inch

Temperature (°F)	Frequency	Volts/mil
500	DC	32 (1)
500	400 cps	42
500	3200 cps	39
1112	DC	4 (2)
1112	400 cps	10 (2)
1112	3200 cps	6 (2)

Electric Strength tests at a higher temperature discontinued because of low values at 1112°F.

C. Insulation Life

Specimen Thickness, 0.15 Inch

---

(1) Not a breakdown, current exceeded 5 ma.
(2) Not a breakdown, current exceeded 30 ma.

Aging and Test Temperature (°F)	Aging Time at Temperature	Resistivity (ohm-cm)
1112	1 hour	3.5×10^6
1112	200 hours	3.9×10^5
1112	400 hours	5.4×10^5
1112	600 hours	9.5×10^5
1112	800 hours	2.5×10^5
1112	1000 hours	9.8×10^5
1112	1000 hours (1)	3.7×10^4
1292	1 hour	5.0×10^4
1292	200 hours	2.3×10^5
1292	400 hours	1.0×10^7
1292	600 hours	7.1×10^6
1292	800 hours	1.8×10^7
1292	1000 hours	1.7×10^7
1292	1000 hours (1)	1.1×10^5

D. Volume Resistivity

Specimen Thickness, 0.15 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	1.7×10^7
500	400 cps	1.5×10^7
500	3200 cps	1.2×10^7
932	DC	$<3.5 \times 10^6$

E. Power Factor

Temperature (°F)	Frequency (cps)	Percent
500	400	99.4
500	3200	85

---

(1) Retest with new gold electrodes. The original silver electrodes failed during test exposure.

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	6,630
932	4,670
1202	5,850

B. Flexural Strength (77°F) 3,085 psi

IV. Compatibility Properties

A. Chemical Resistance

After firing, this encapsulation has good organic solvent resistance and fair to good resistance to acids and alkalis. Water resistance is an electrical problem because of the porosity of the ceramic structure, however, the fired ceramic structure does have good moisture resistance. Some Anacap-insulation windings have been glass-coated to seal the surface against moisture with some success. (Reference: Anaconda Wire and Cable Company Data Sheet on CS 1200.)

B. Nuclear Radiation Resistance

Anaconda states that when Anacap is used as a part of the CS 1200 high-temperature insulation system, it is capable of operating in gamma radiation levels of 10^8 - 10^9 rads per hour and 10^{13} neutrons per square centimeter per second for one thousand hours without adversely affecting the performance of the compound. (Reference: Anaconda Wire and Cable Company Data Sheet on CS 1200.)

C. Weight Loss in Vacuum with Heat

24 hours at 932°F	0.15 percent
24 hours at 932°F plus 24 hours at 1202°F	0.22 percent

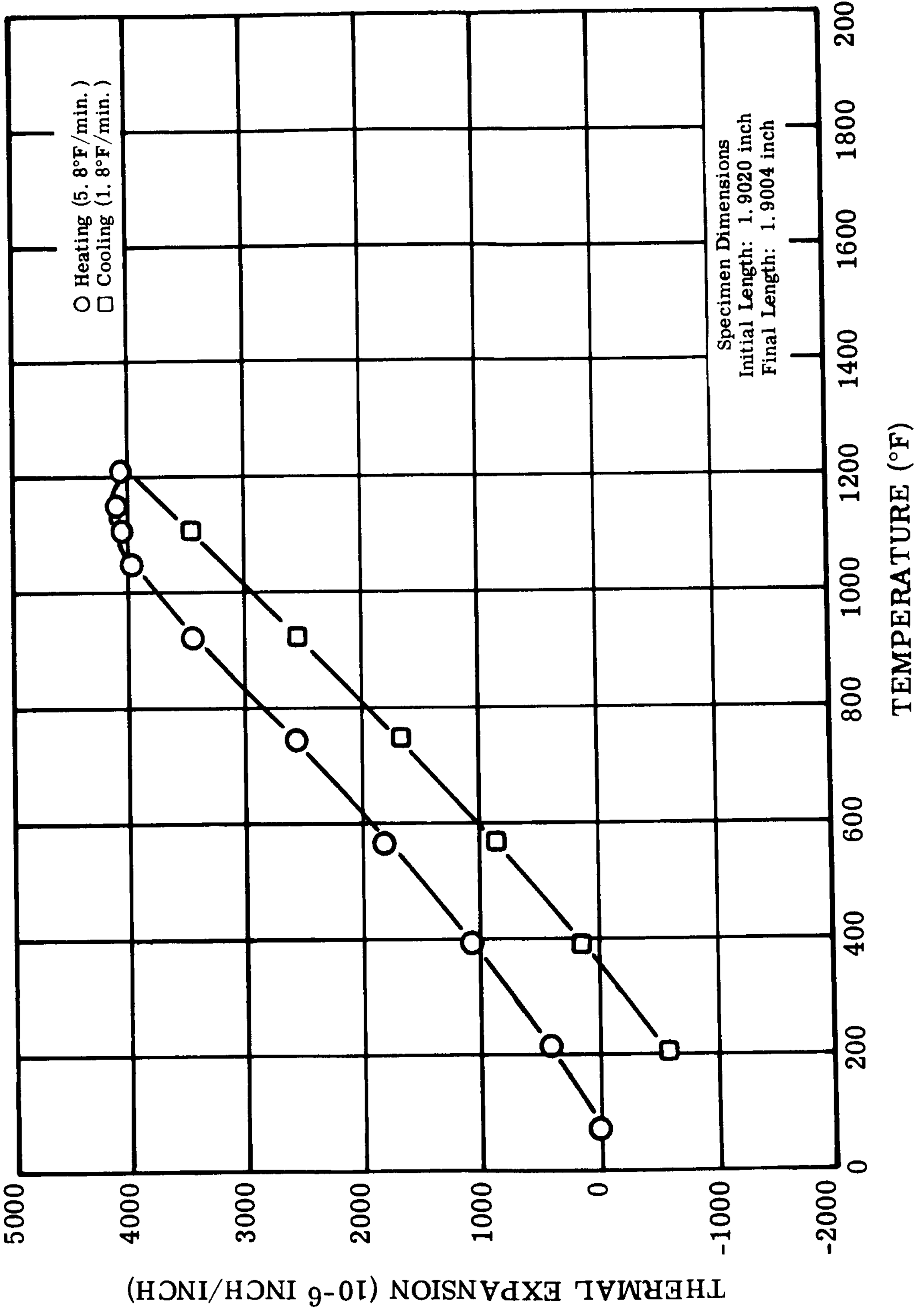


FIGURE V.F. 1-1. Thermal Expansion of Inorganic Encapsulation Compound, Anacap. (Reference: NAS3-4162)

Figure V.F. 1-1. Thermal Expansion - Encapsulation Compound - Anacap

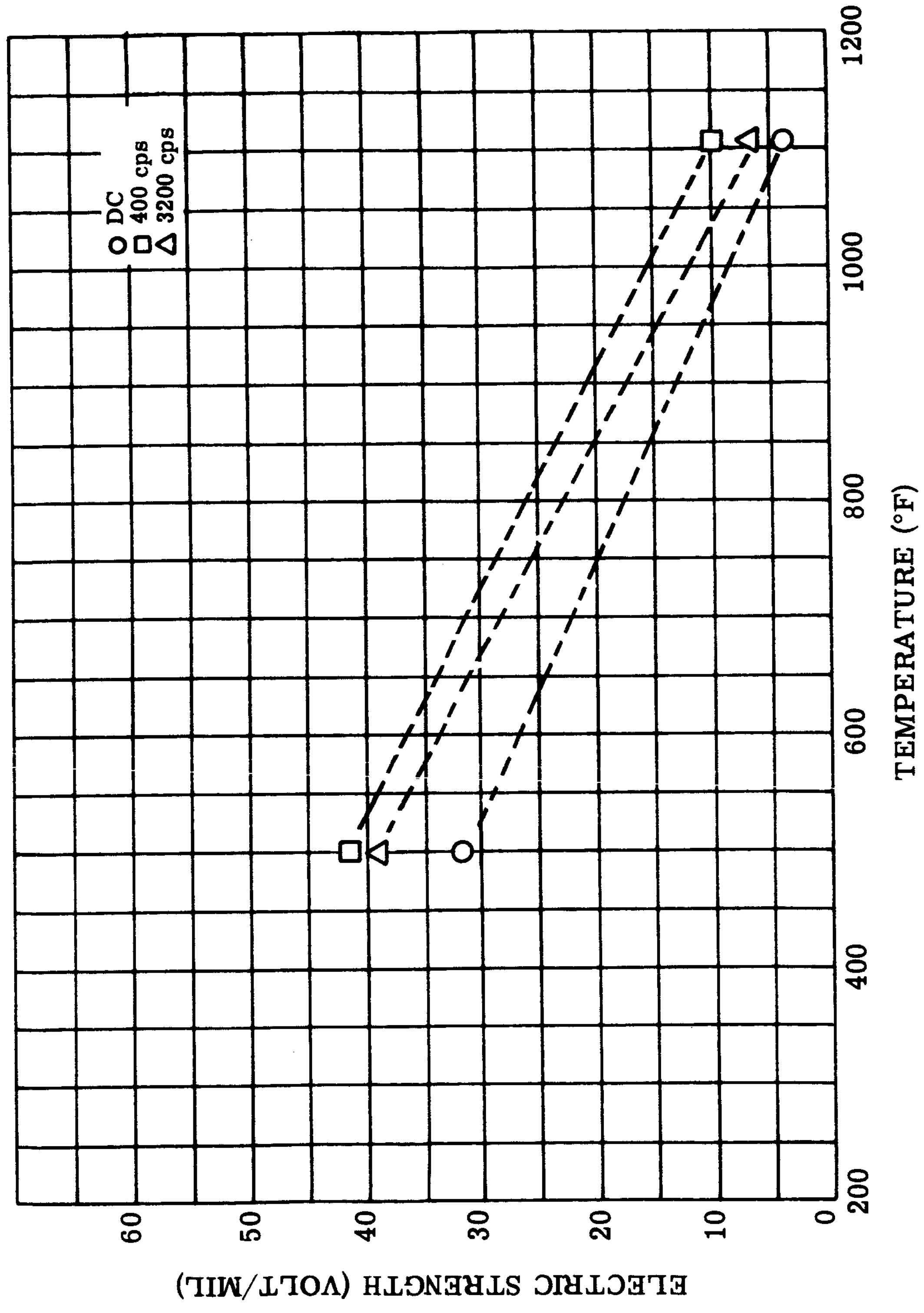


FIGURE V. F. 1-2. Electric Strength of Inorganic Encapsulation Compound, Anacap. (Reference: NAS 3-4162)

Figure V. F. 1-2. Electric Strength - Encapsulation Compound - Anacap

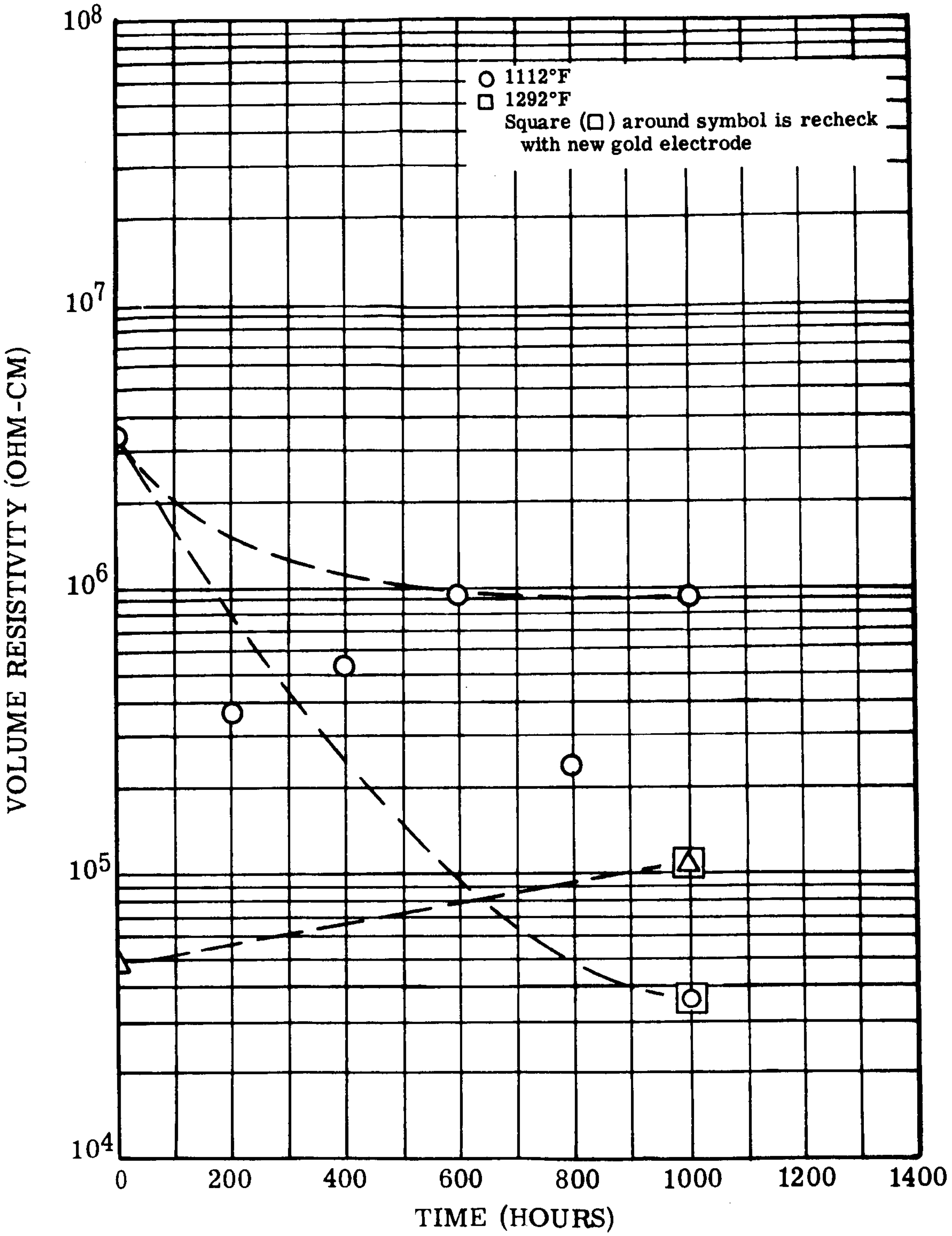


FIGURE V. F. 1-3. Insulation Life of Inorganic Encapsulation Compound, Anacap, in Air. Specimen Thickness, 0.15 Inch. (Reference: NAS 3-4162)

Figure V. F. 1-3. Insulation Life - Encapsulation Compounds - Anacap

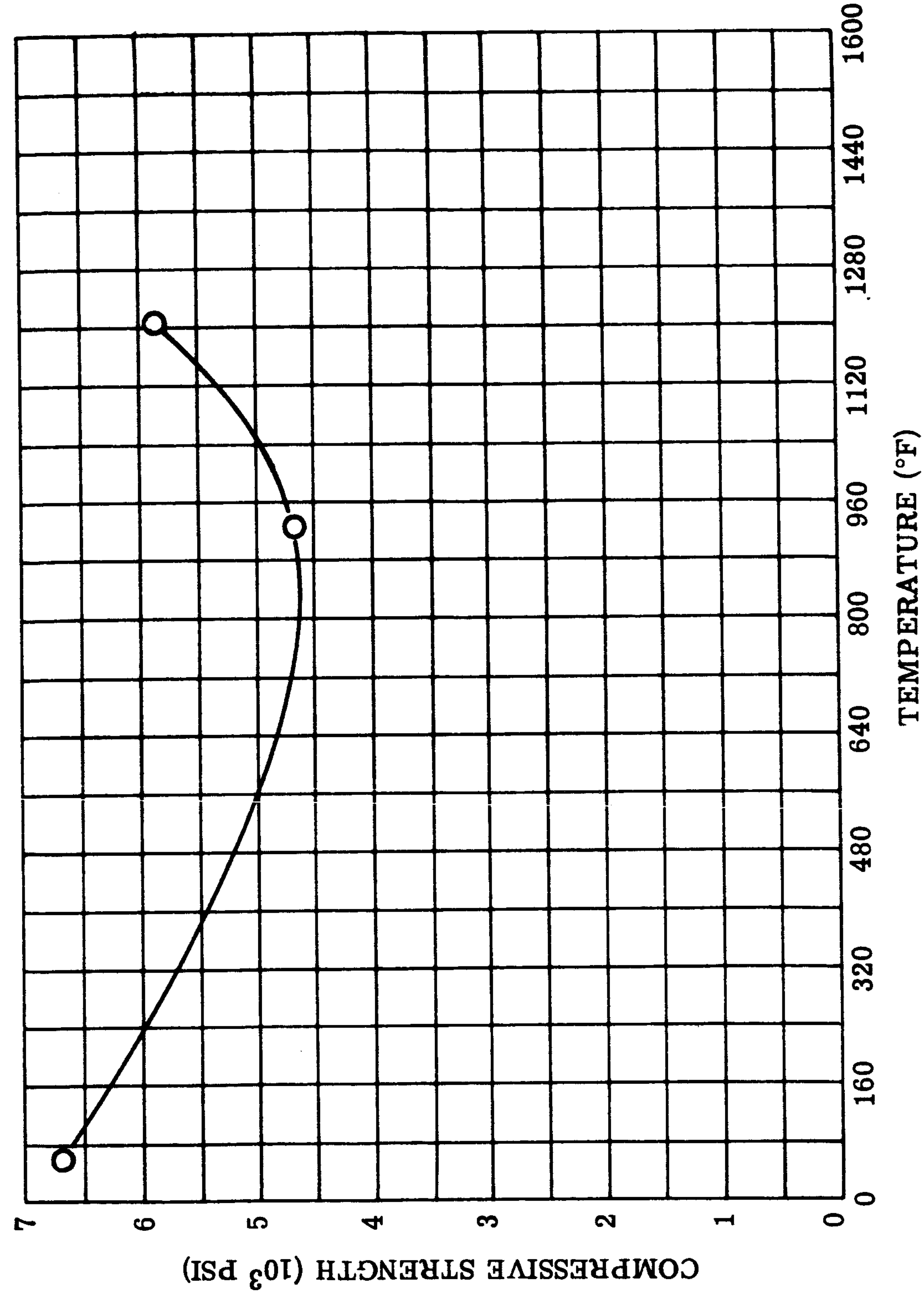


FIGURE V.F.1-4. Compressive Strength of Inorganic Encapsulation Compound, Anacap.
(Reference: NAS 3-4162)

Figure V.F.1-4. Compressive Strength - Encapsulation Compound - Anacap

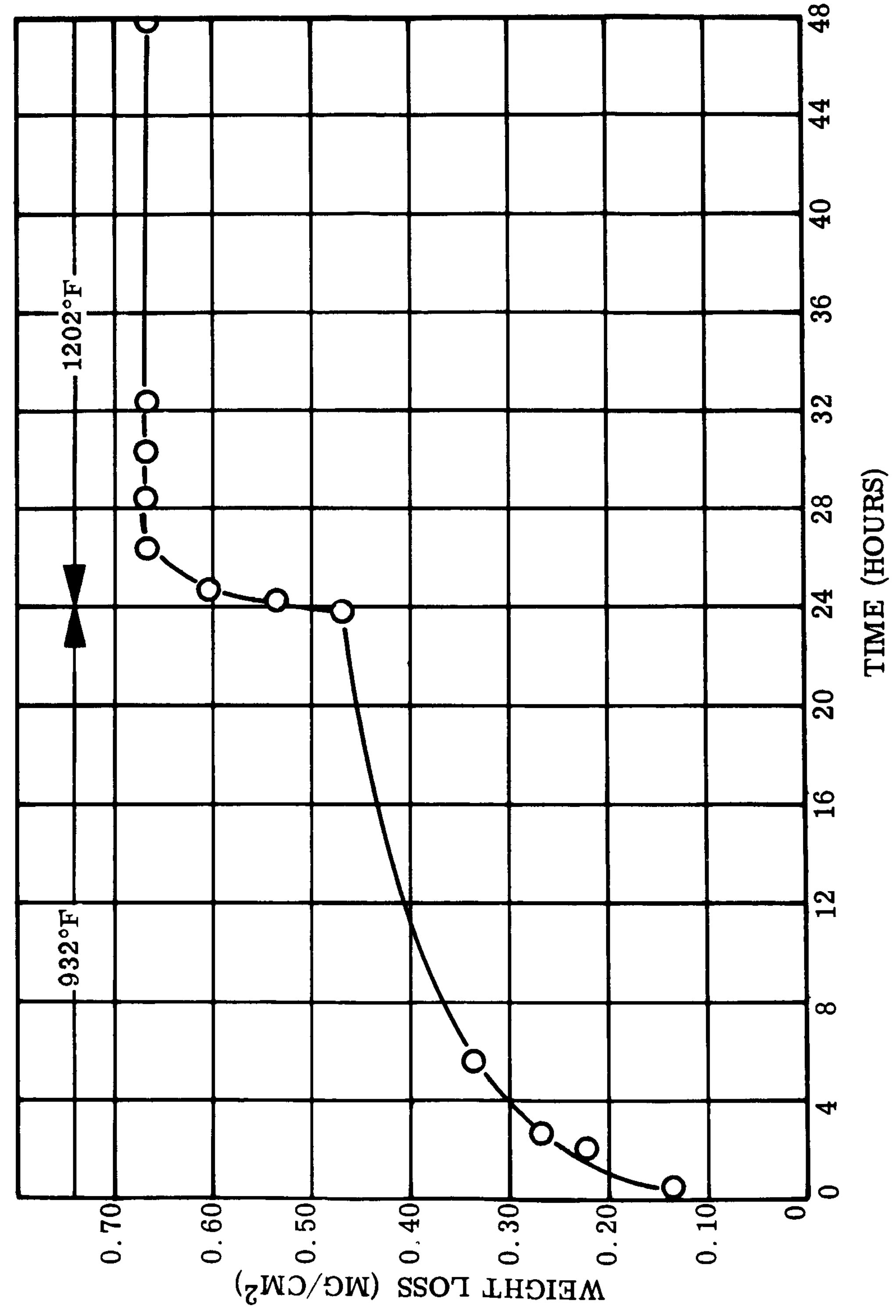


FIGURE V. F. 1-5. Weight Loss at 932°F, 1202°F and 10^{-5} to 10^{-6} Torr of Inorganic Encapsulation Compound, Anacap. (Reference: NAS 3-4162)

Figure V. F. 1-5. Weight Loss - Encapsulation Compound - Anacap

2. EPOXY ENCAPSULATION COMPOUND

Epoxy encapsulation compound is a high temperature epoxy casting compound with mineral filler.

Availability: The material can be obtained from the Hysol Corporation as Hysol C9-4186 and Hardener H5-3537.

Description: The resin is filled with 65 percent mineral filler. The hardener is an anhydride. The viscosity of the resin is 200,000 centipoise at 77°F and the epoxy equivalent is 618. Twenty-nine (29) parts by weight of hardener are added to 100 parts of resin. Recommended cure is 2 hours at 260°F followed by 2 hours at 300°F and 2 hours at 390°F.

I. Thermophysical Properties

A.	Density (lb/cu inch)	0.059	(RI240)
B.	Shrinkage (77°F)(inch/inch)	0.007	(RI240)

C. Thermal Conductivity

Specimen Thickness, 0.25 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
150	0.312
223	0.317
274	0.295
347	0.303

D. Coefficient of Thermal Expansion

Specimen Thickness, 0.25 Inch

Temperature Range (°F)	inch/inch-°F
75 to 200	23.6×10^{-6}
200 to 320	33.3×10^{-6}

E. Water Absorption (77°F)(percent) 0.26

Specimen Thickness, 0.125 Inch

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	400	3.74
77	3200	3.73
392	400	4.86
392	3200	4.64
482	400	4.90
482	3200	4.63

B. Electric Strength

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Volts/mil
77	DC	2297
77	400 cps	534
77	3200 cps	>363
392	DC	992
392	400 cps	525
392	3200 cps	>361
482	DC	494
482	400 cps	491
482	3200 cps	228 (1)

(1) This test in air, 1 inch electrodes. The rest in oil, 2 inch electrode.

C. Power Factor

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Percent
77	400	0.43
77	3200	0.56
392	400	5.30
392	3200	4.69
482	400	35.3
482	3200	6.00

D. Insulation Life (400 cps)

Specimen Thickness, 0.064 Inch

Aging and Test Temperature (°F)	Time (hours)	Electric Strength (volts/mil)
212	Original (1)	525
212	200	562
212	400	537
212	600	491
212	800	530
212	1000	457
257	Original (1)	525
257	200	546
257	400	485
257	600	504
257	800	513
257	1000	474

(1) Original Data interpolated from Figure V.F.2-4.

Aging and Test Temperature (°F)	Time (hours)	Electric Strength (volts/mil)
302	Original (1)	520
302	200	506
302	400	528
302	600	549
302	800	461
302	1000	554

E. Arc Resistance (77°F)(seconds) 181

F. Volume Resistivity

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Ohm-cm
77	DC	9.77×10^{15}
77	400 cps	3.30×10^{11}
77	3200 cps	2.80×10^{10}
392	DC	1.21×10^{12}
392	400 cps	1.85×10^{10}
392	3200 cps	2.54×10^{9}
482	DC	9.90×10^{9}
482	400 cps	2.54×10^{9}
482	3200 cps	1.95×10^{9}

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
75	26,300
300	12,333

---

(1) Original Data interpolated from Figure V. F. 2-4.

B.	Flexural Strength	12,000 psi (RI240)
C.	Tensile Strength	8,000 psi (RI240)

D. Thermal Shock

Three cycles of room temperature to 300°F to room temperature. Specimens are moved without delay between temperature environments and are held at each temperature for two hours	Failed first cycle

IV. Compatibility Properties

A. Chemical Resistance

The acid, alkali and moisture resistance of this epoxy compound is good. Organic solvent resistance is good except for halogenated solvents. (Reference: Hysol Corporation Data Sheets.)

B. Nuclear Radiation Resistance (LI296)

Nuclear radiation tests have not been performed on this composition, however, similar formulations have been exposed and reported upon. In exposures of 10^{10} ergs per gram (C) of gamma radiation, in air, the compressive strength and shear strength was increased. When in the same flux, but in vacuum, these properties decreased. Electrical properties were degraded by exposures above 10^{10} ergs per gram (C) of gamma radiation.

C. Weight Loss in Vacuum with Heat

24 hours at 302°F and 10^{-5} to 10^{-6} torr	0.23 percent

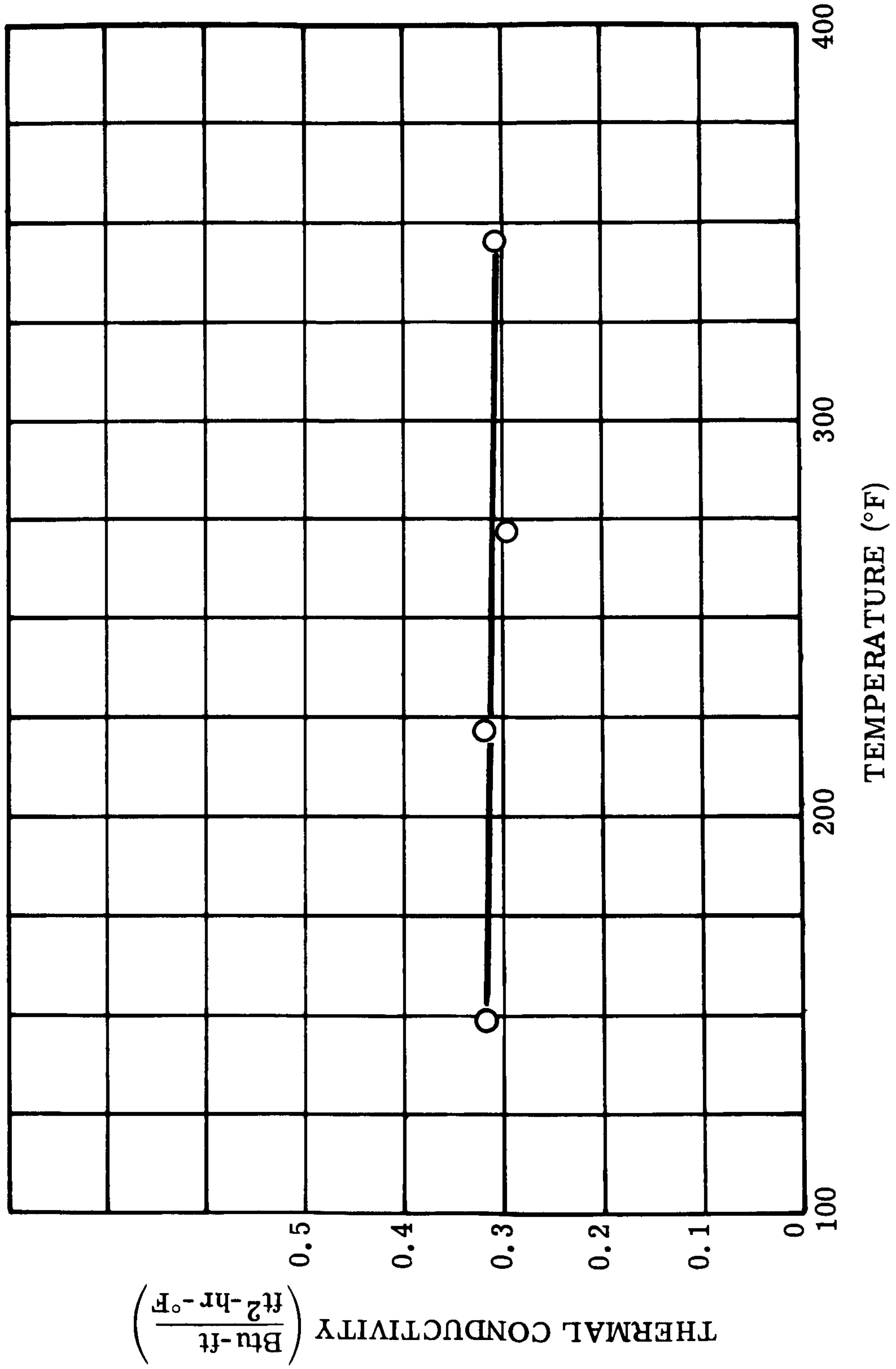


FIGURE V. F. 2-1. Thermal Conductivity of Organic Encapsulating Compound, Epoxy, in Air. Specimen Thickness, 0. 25 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-1. Thermal Conductivity - Encapsulating Compound - Epoxy

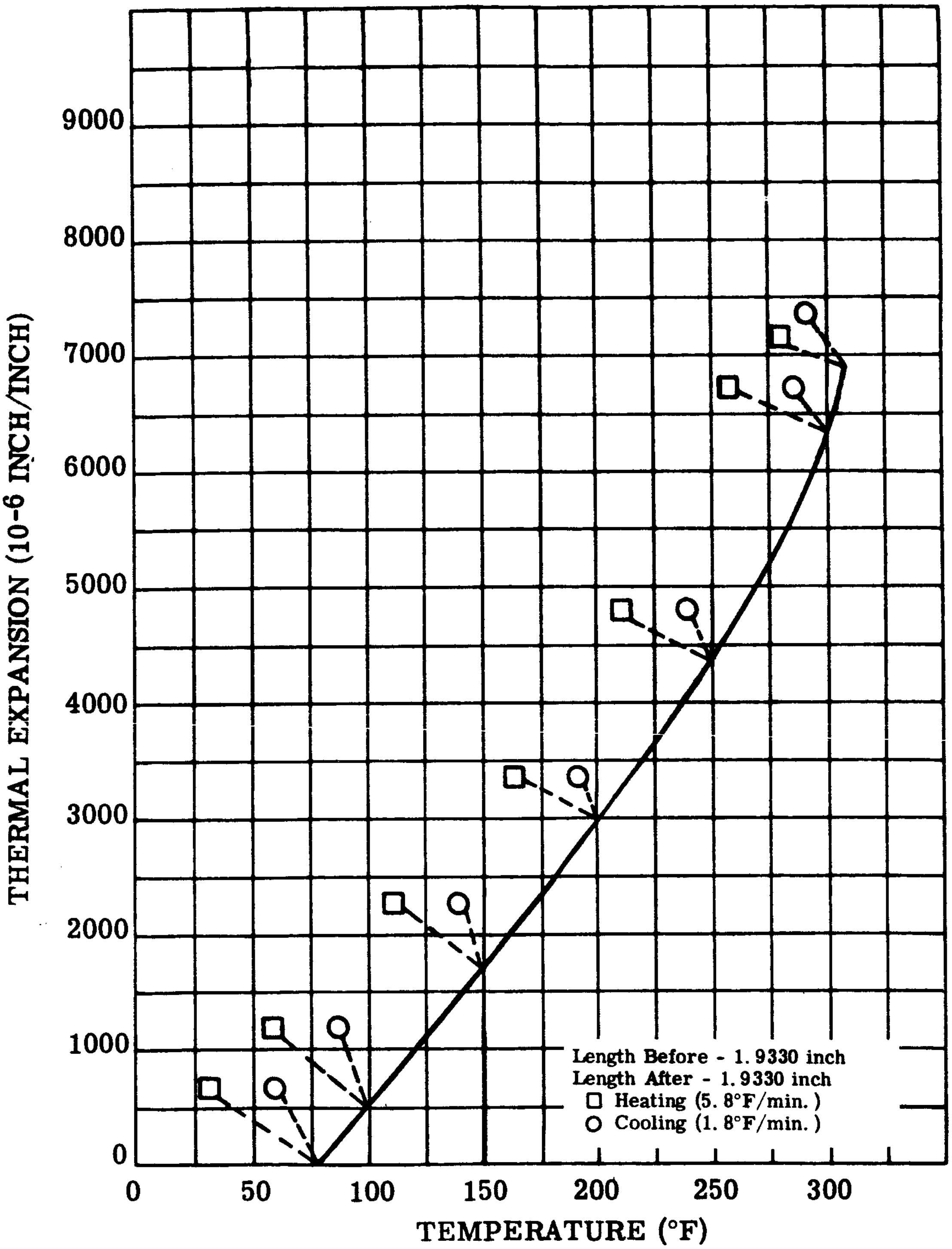


FIGURE V. F. 2-2. Thermal Expansion of Organic Encapsulation Compound, Epoxy, in Air. Specimen Thickness, 0.25 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-2. Thermal Expansion - Encapsulation Compound - Epoxy

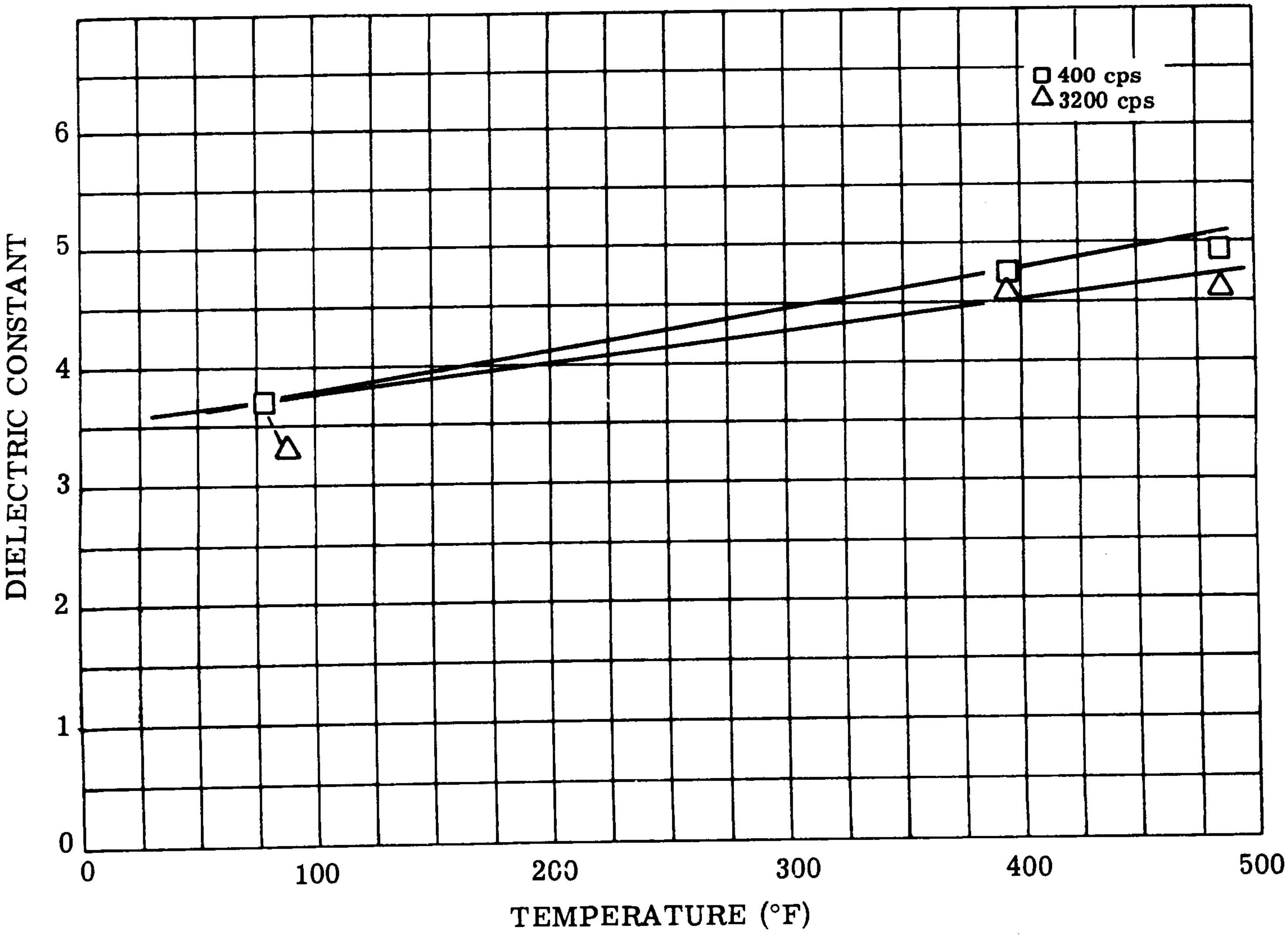


FIGURE V. F. 2-3. Dielectric Constant of Organic Encapsulation Compound, Epoxy, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-3. Dielectric Constant - Encapsulation Compound - Epoxy

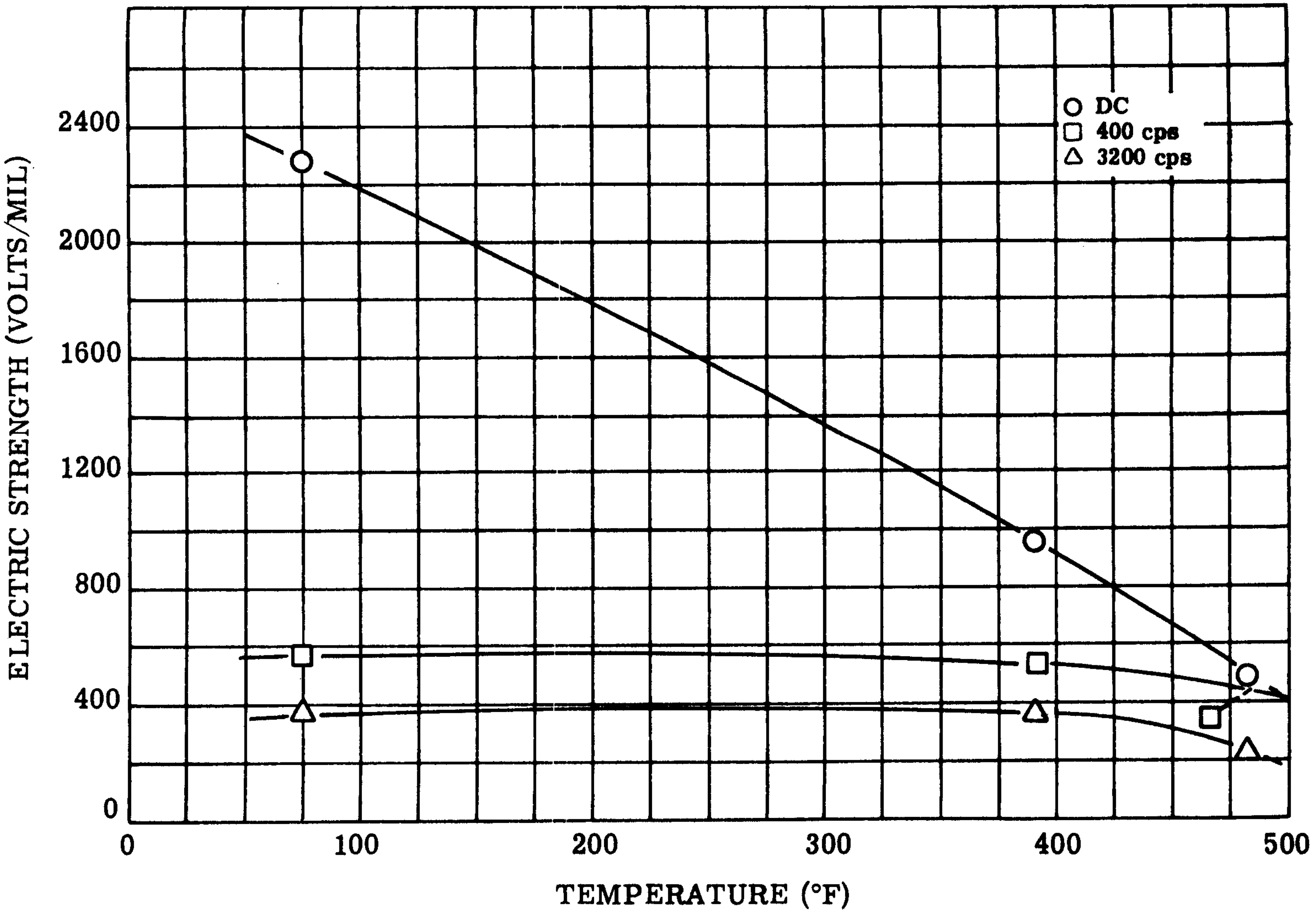


FIGURE V. F. 2-4. Electric Strength of Organic Encapsulating Compound, Epoxy, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-4. Electric Strength - Encapsulation Compound - Epoxy

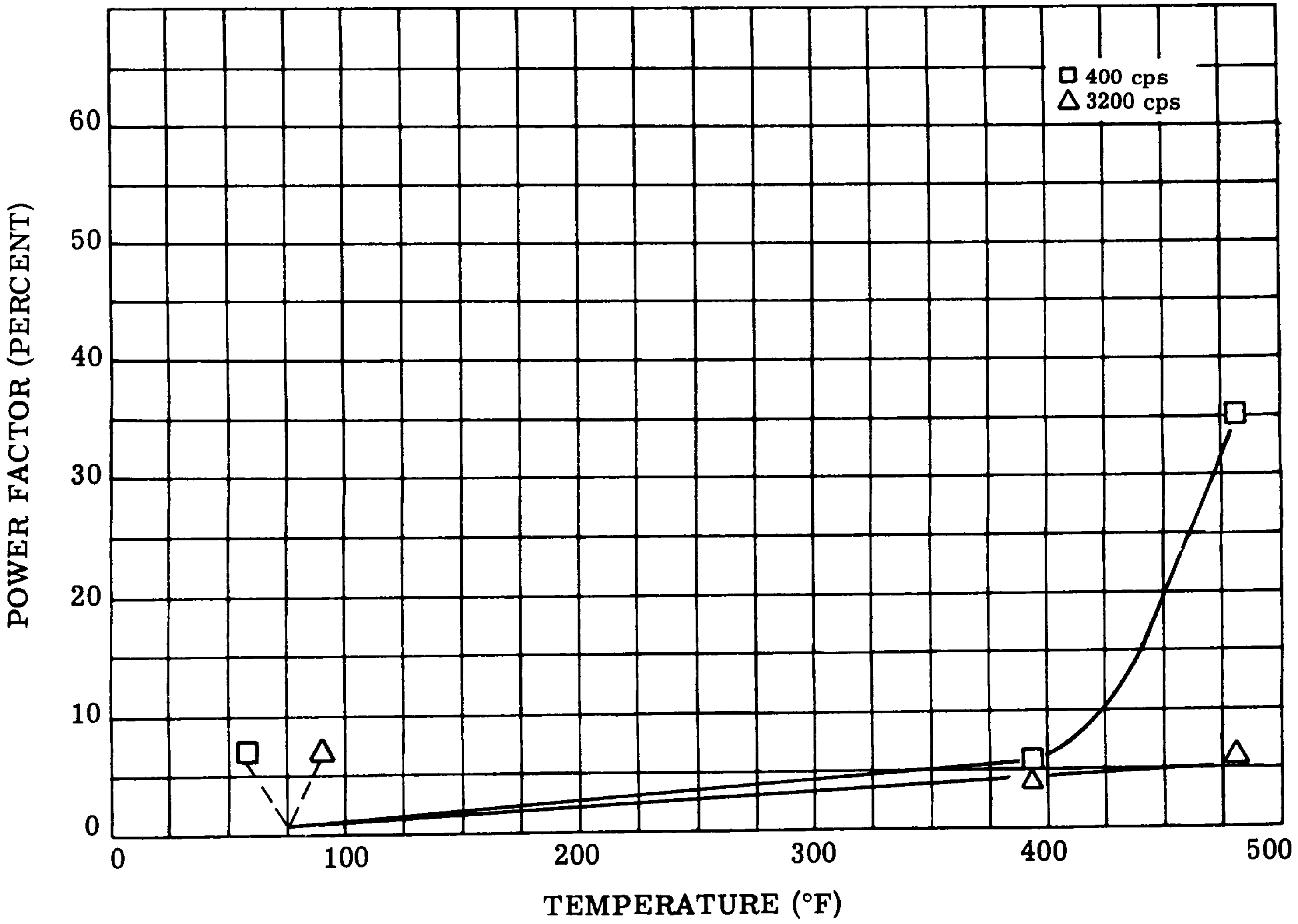


FIGURE V. F. 2-5. Power Factor of Organic Encapsulation Compound, Epoxy, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-5. Power Factor - Encapsulation Compound - Epoxy

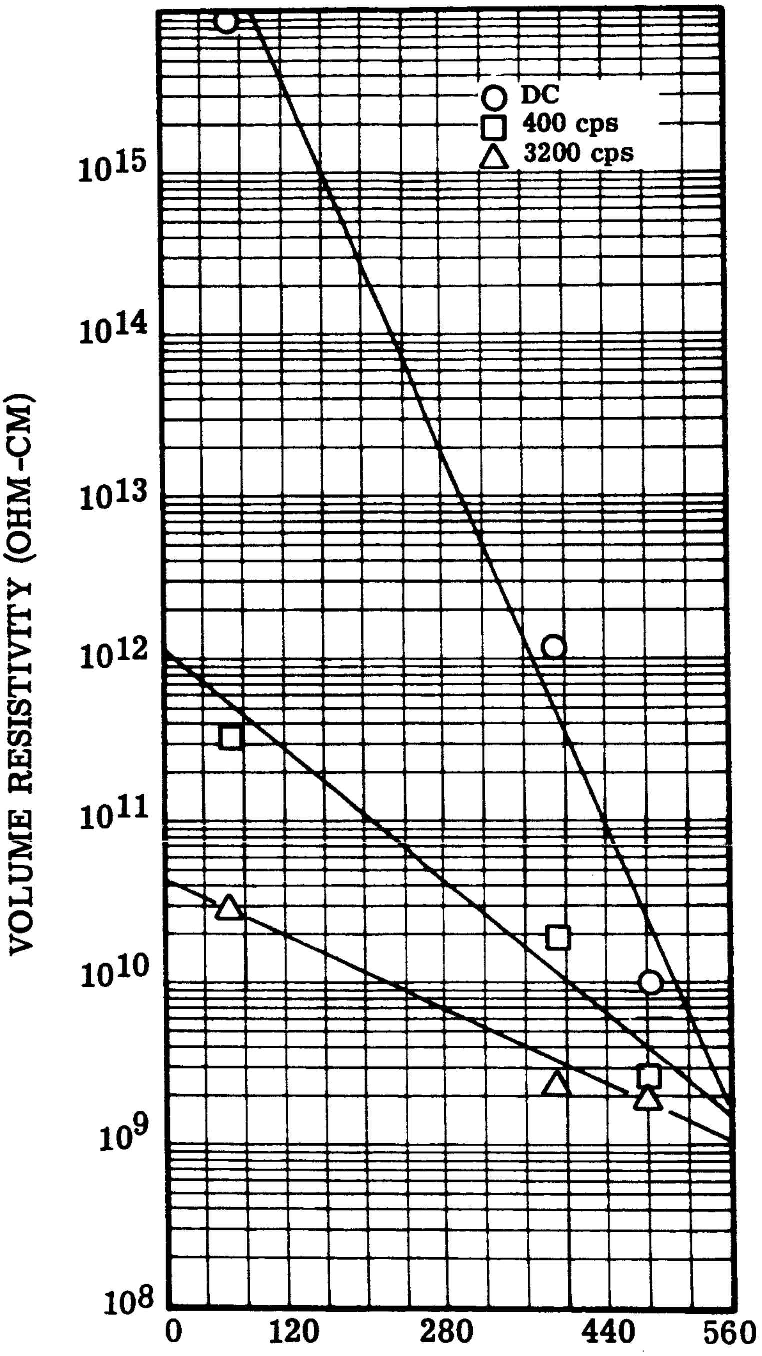


FIGURE V. F. 2-6. Volume Resistivity of Organic Encapsulation Compound, Epoxy, in Air. Specimen Thickness, 0.064 Inch. (Reference: NAS 3-4162)

Figure V. F. 2-6. Volume Resistivity - Encapsulation Compound - Epoxy

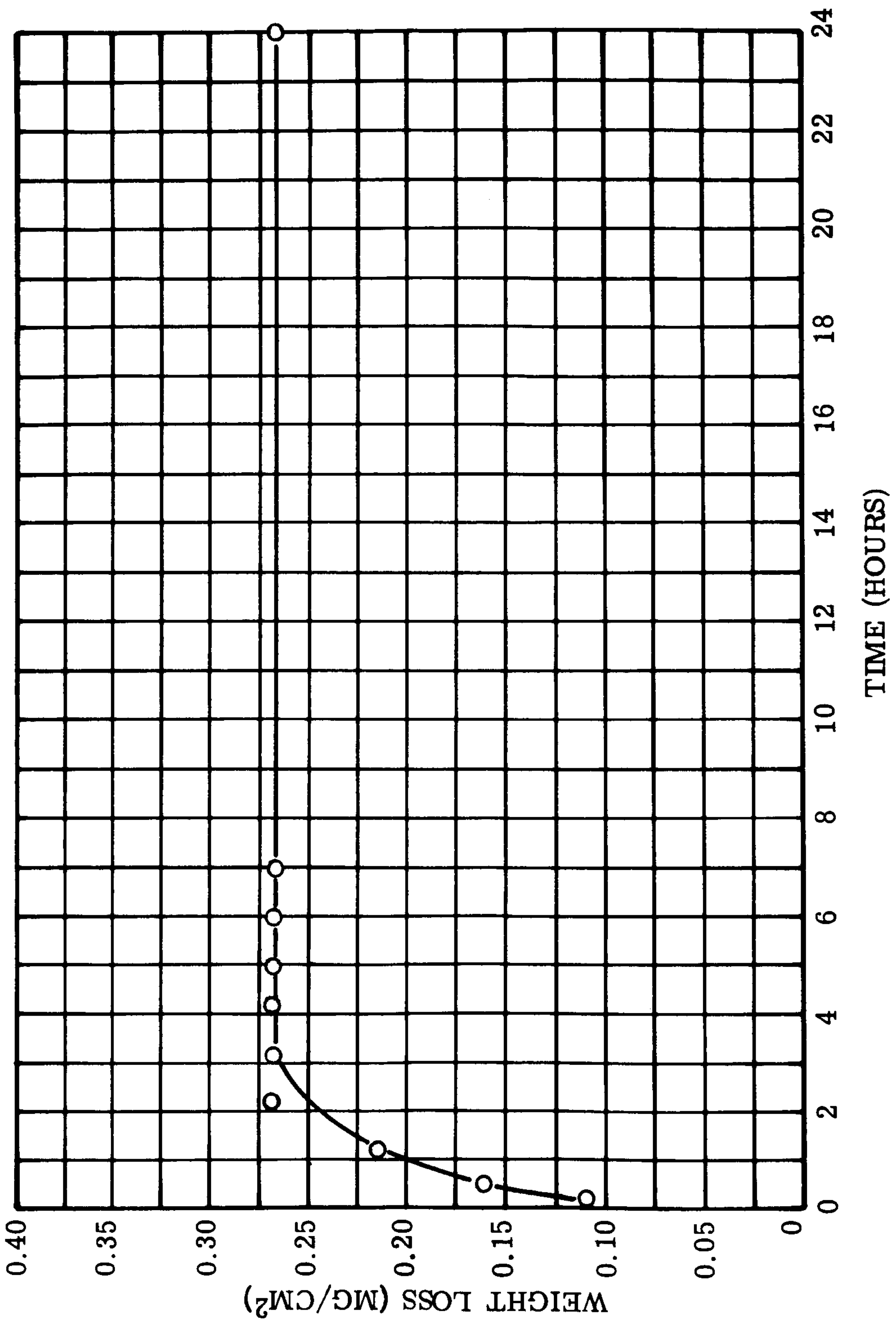


FIGURE V. F. 2-7. Weight Loss at 302°F and 10^{-5} to 10^{-6} Torr of Organic Encapsulating Compound, Epoxy. (Reference: NAS 3-4162)

Figure V. F. 2-7. Weight Loss - Encapsulation Compound - Epoxy

3. SAUEREISEN NO. 8 ENCAPSULATION COMPOUND

Sauereisen No. 8 is an electrical insulating cement of refractory materials. It is recommended by the manufacturer for electrical devices subjected to high temperatures and thermal shock. The compound hardens without heat.

Availability:	This encapsulation compound is available from Sauereisen Cement Company as a dry powder.
Description:	The compound is composed of magnesium oxide, zirconium silicate and magnesium ammonium phosphate. To apply, sufficient water is added to achieve desired working consistency.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.10

B. Shrinkage (percent)

77°F (Green)	0
After firing to 932°F	0.9

C. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
438	0.320
959	0.350
1530	0.443

D. Coefficient of Thermal Expansion

Temperature Range (°F)	inch/inch-°F
77 to 1600	3.1×10^{-6}
1600 to 77	3.1×10^{-6}

E. Water Absorption (77°F)(percent) 15

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.25 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	7.7
500	3200	7.1
932	400	43
932	3200	28
1382	400	53
1382	3200	32

B. Electric Strength (Rise of 500V/sec)

Specimen Thickness, 0.25 Inch

Temperature (°F)	Frequency	Volts/mil
500	DC	63
500	400 cps	39
500	3200 cps	37
932	DC	34 (1)
932	400 cps	30
932	3200 cps	34 (2)
1382	DC	31 (1)
1382	400 cps	30
1382	3200 cps	25

(1) Not a breakdown, current exceeded 5 ma.
(2) Not a breakdown, current exceeded 30 ma.

C. Insulation Life

Aging and Test Temperature (°F)	Aging Time at Temperature	Resistivity (ohm-cm)
1112	1 hour	3.8×10^7
1112	200 hours	5.2×10^8
1112	400 hours	1.4×10^8
1112	600 hours	2.1×10^8
1112	800 hours	8.1×10^7
1112	1000 hours	1.4×10^8
1112	1000 hours (1)	4.8×10^7
1292	1 hour	3.0×10^7
1292	200 hours	5.4×10^8
1292	400 hours	6.7×10^7
1292	600 hours	3.2×10^7
1292	800 hours	4.2×10^7
1292	1000 hours	1.3×10^7
1292	1000 hours (1)	5.8×10^5

D. Volume Resistivity

Specimen Thickness, 0.20 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	1.0×10^{11}
500	400 cps	6.3×10^9
500	3200 cps	1.8×10^9
932	DC	6.0×10^7
932	400 cps	4.8×10^7
932	3200 cps	2.6×10^7
1382	DC	2.9×10^7
1382	400 cps	2.1×10^7
1382	3200 cps	1.3×10^7

(1) Retest using new gold electrodes. The original silver electrodes failed during test exposure.

E. Power Factor

Temperature (°F)	Frequency (cps)	Percent
500	400	9.8
500	3200	4.5
932	400	91.0
932	3200	62.0
1382	400	97.3
1382	3200	81.0

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	4,133
932	4,217
1382	4,500

B. Flexural Strength (77°F)	750 psi
C. Pot Life	50 minutes

IV. Compatibility Properties

A. Chemical Resistance

The cured compound has good resistance to organic solvents and moisture. Because of porosity, this compound is not an adequate moisture barrier and must be dry to attain satisfactory electrical properties. The acid and alkali resistance is good.

B. Nuclear Radiation Resistance

Based upon chemical composition and performance of similar formulations, this compound could be expected to withstand approximately 2 x 10^{10} roentgens of gamma radiation and a fast neutron dose of 1 x 10^{18} nvt.

C. Weight Loss in Vacuum with Heat

24 hours at 932°F, 0.68 mg/cm^2	0.16 percent
24 hours at 932°F and 24 hours at 1382°F, 1.08 mg/cm^2	0.28 percent

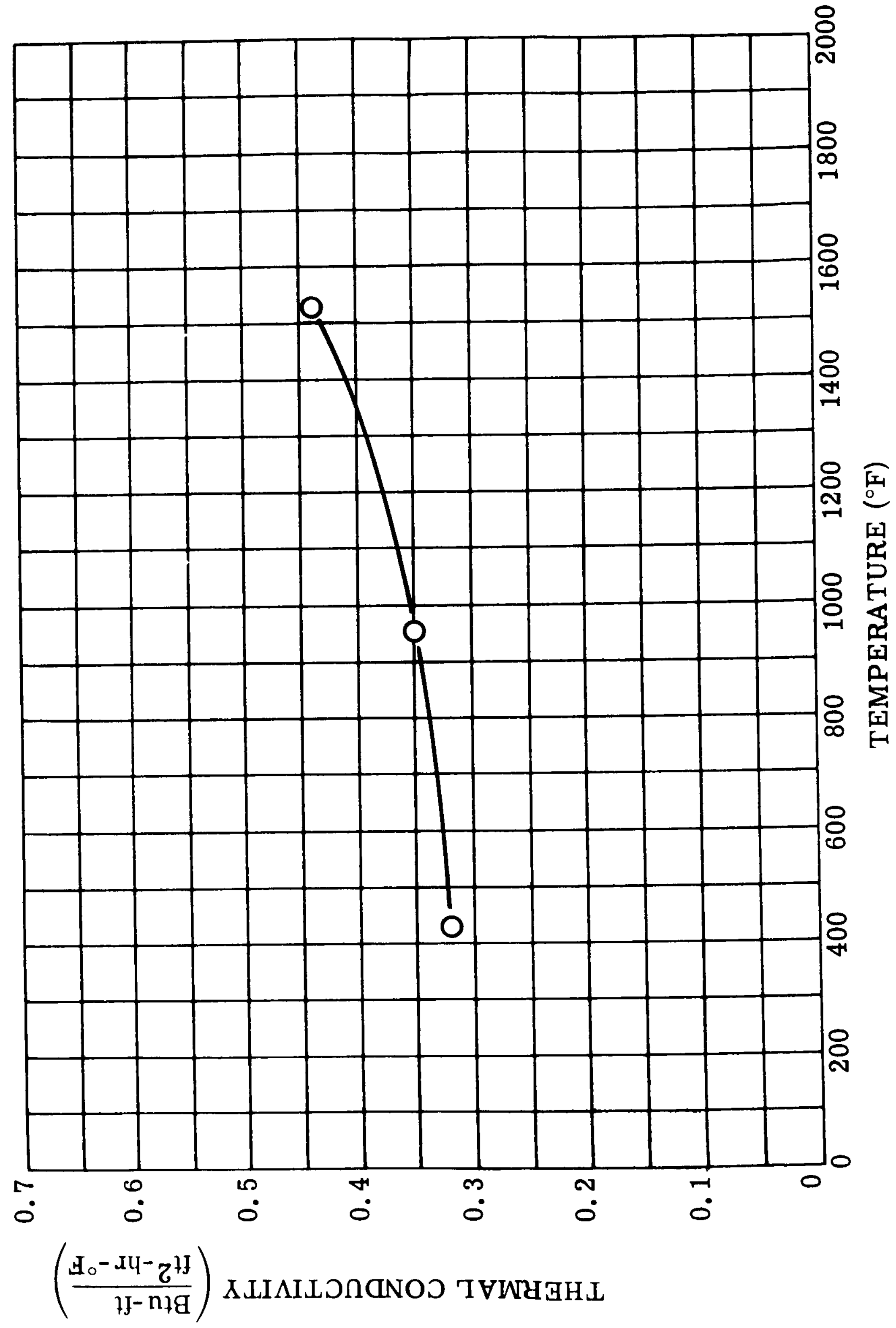


FIGURE V. F. 3-1. Thermal Conductivity of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-1. Thermal Conductivity - Encapsulation Compound - Sauereisen 8

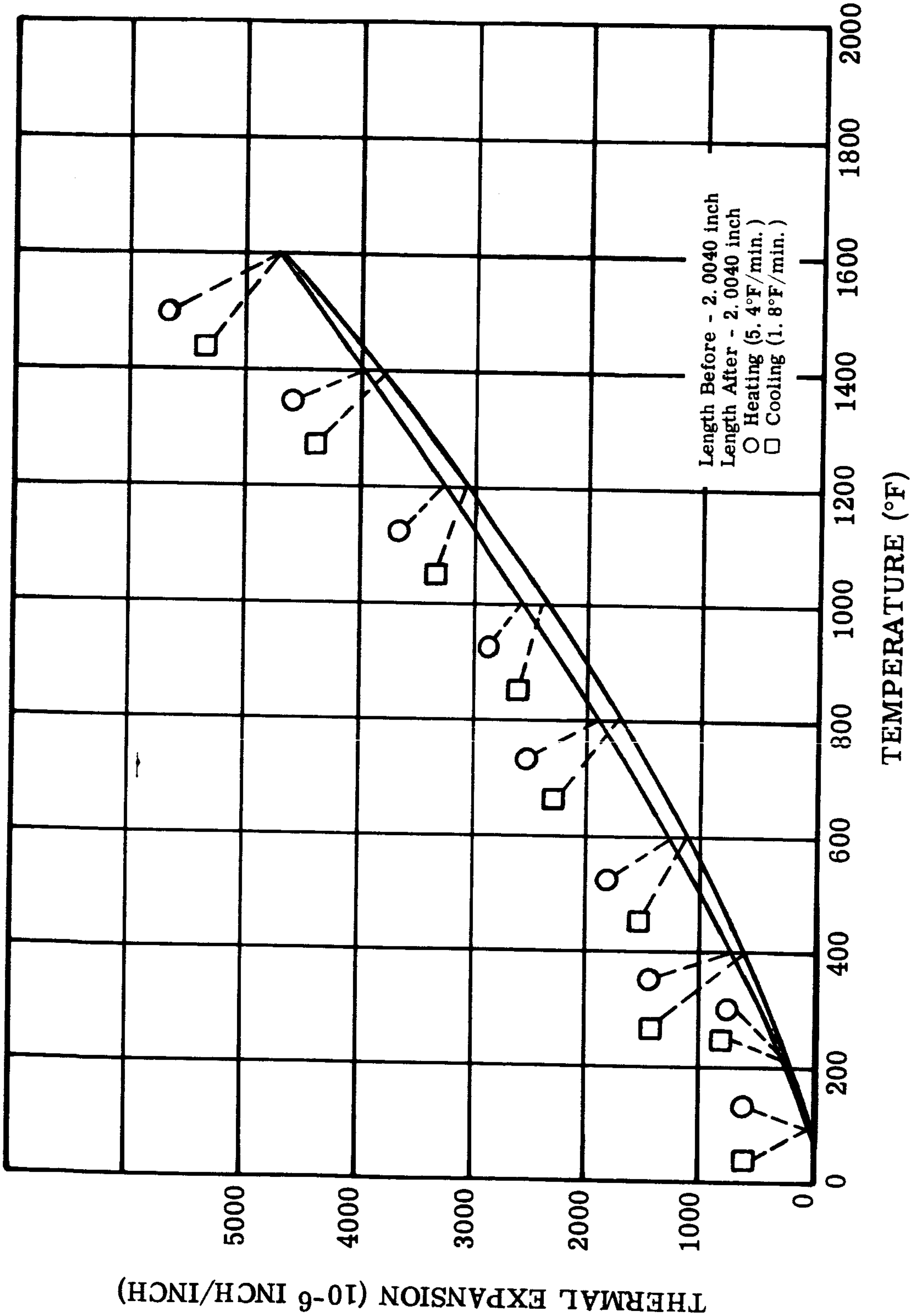


FIGURE V.F.3-2. Thermal Expansion of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V.F.3-2. Thermal Expansion - Encapsulating Compound - Sauereisen 8

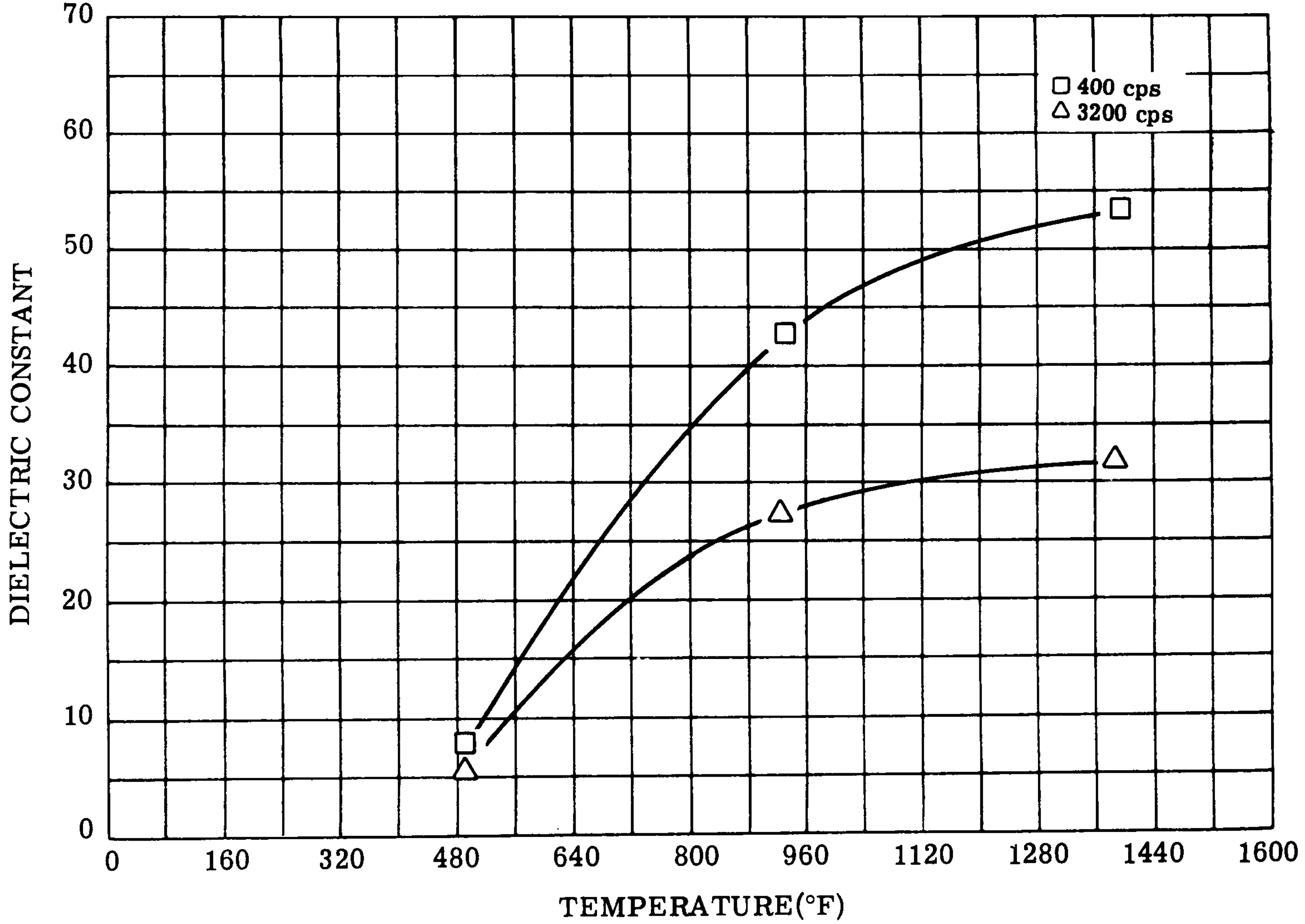


FIGURE V. F. 3-3. Dielectric Constant of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-3. Dielectric Constant - Encapsulation Compound - Sauereisen 8

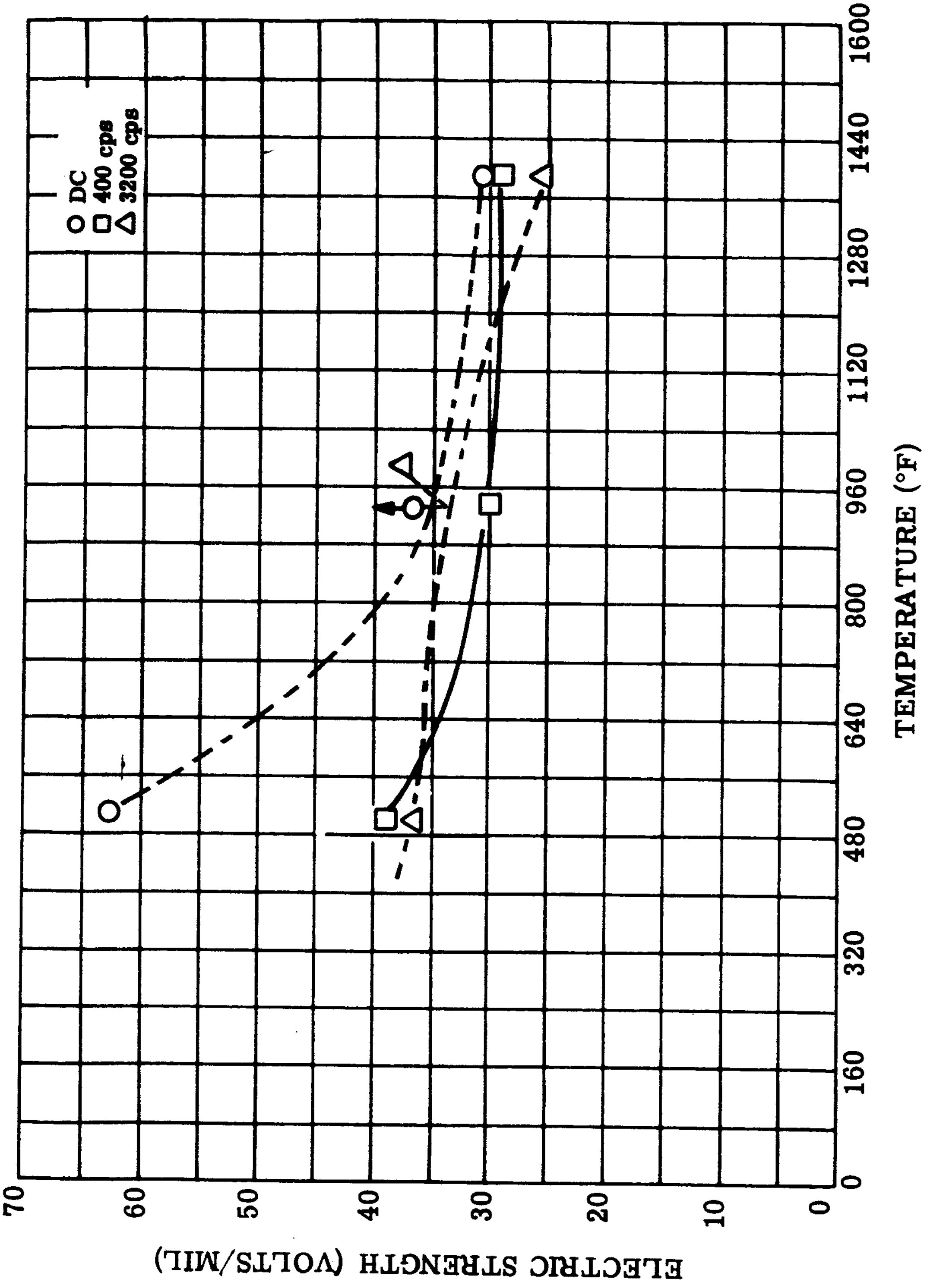


FIGURE V. F. 3-4. Electric Strength of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-4. Electric Strength - Encapsulation Compound - Sauereisen 8

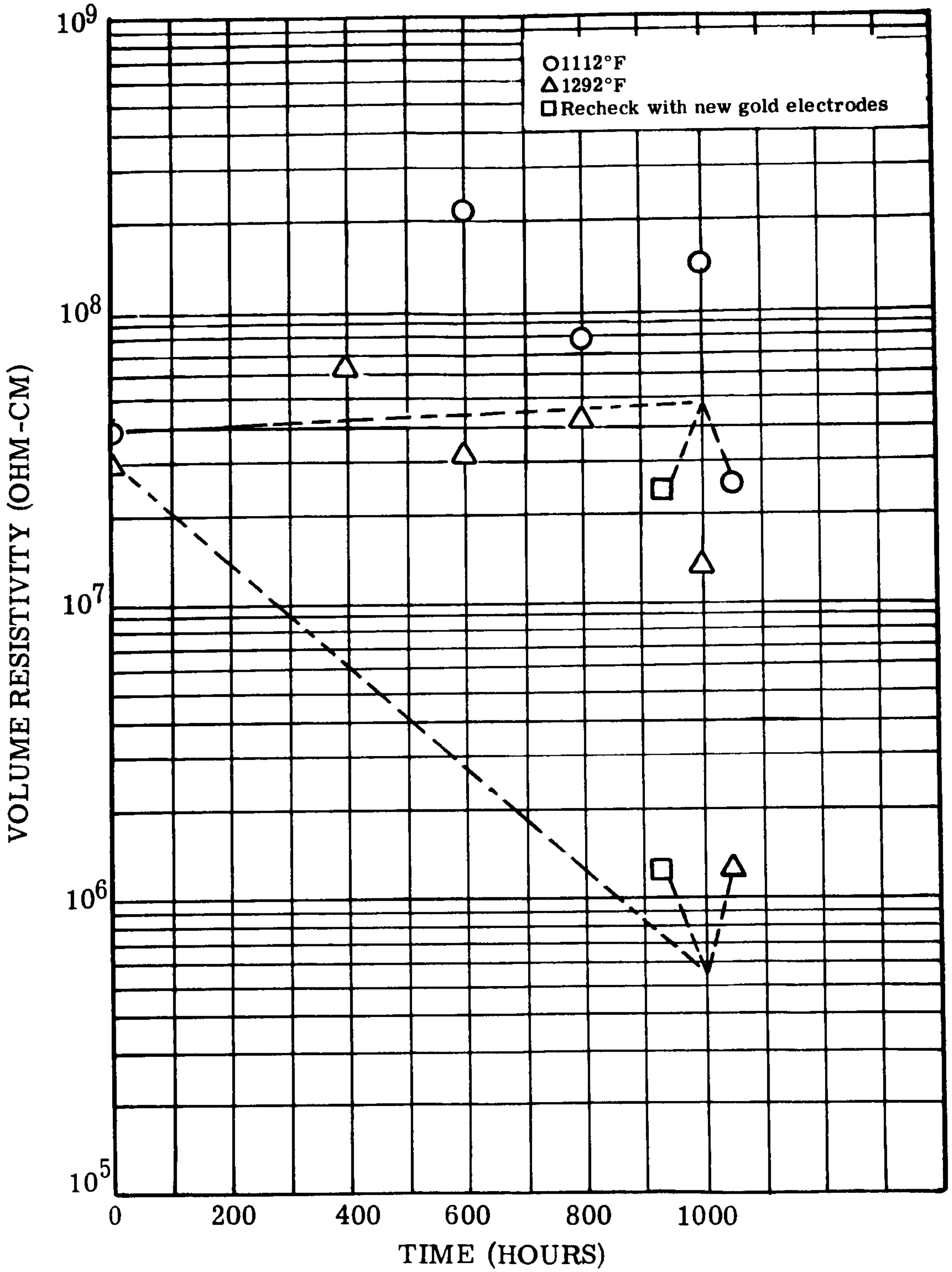


FIGURE V. F. 3-5. Insulation Life of Inorganic Encapsulation Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-5. Insulation Life - Encapsulation Compound - Sauereisen 8

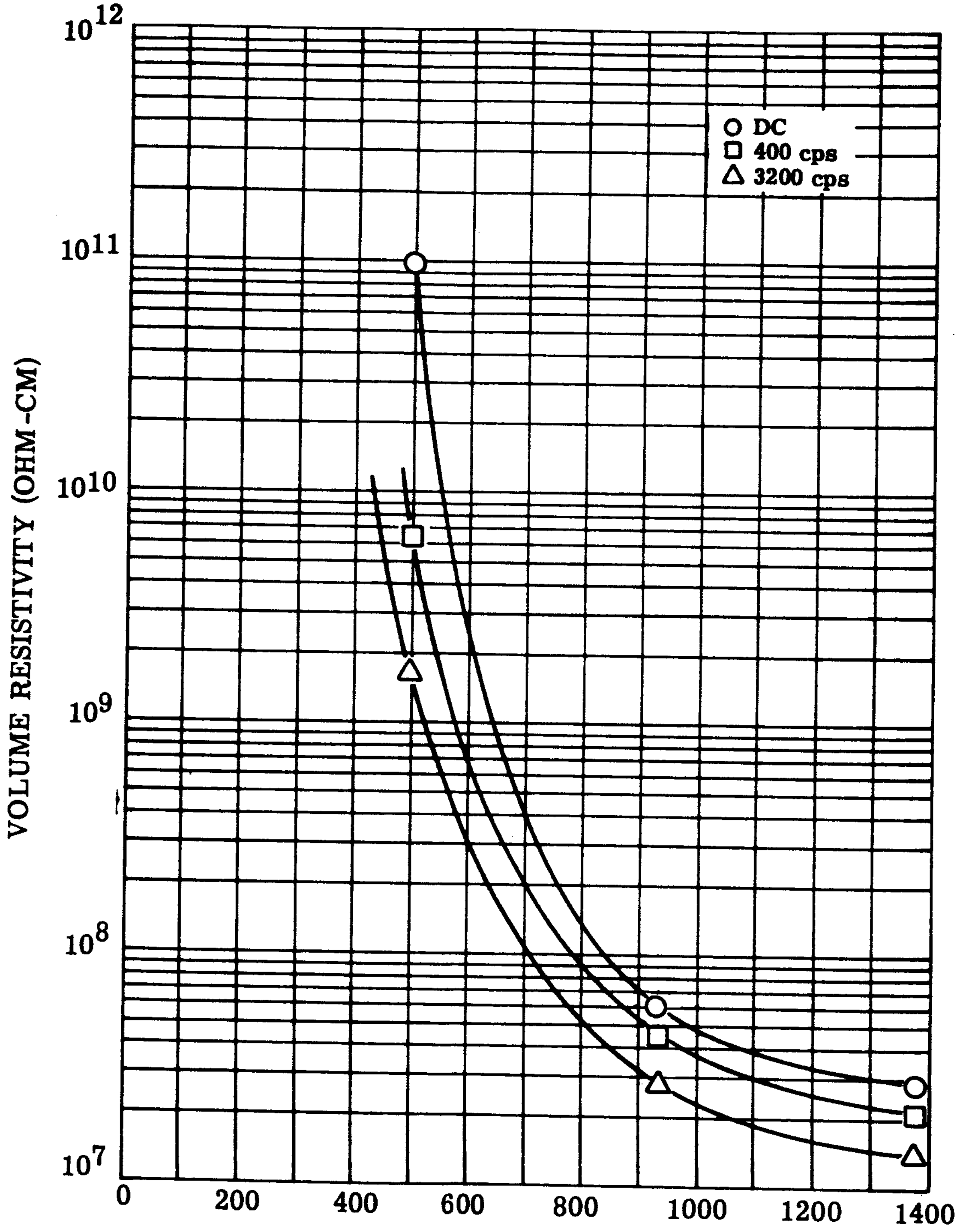


FIGURE V. F. 3-6. Volume Resistivity of Inorganic Encapsulating Compound, Sauereisen 8, in Air. Specimen Thickness, 0. 20 Inch. (Reference: NAS 3-4162)

Figure V. F. 3-6. Volume Resistivity - Encapsulating Compound - Sauereisen 8

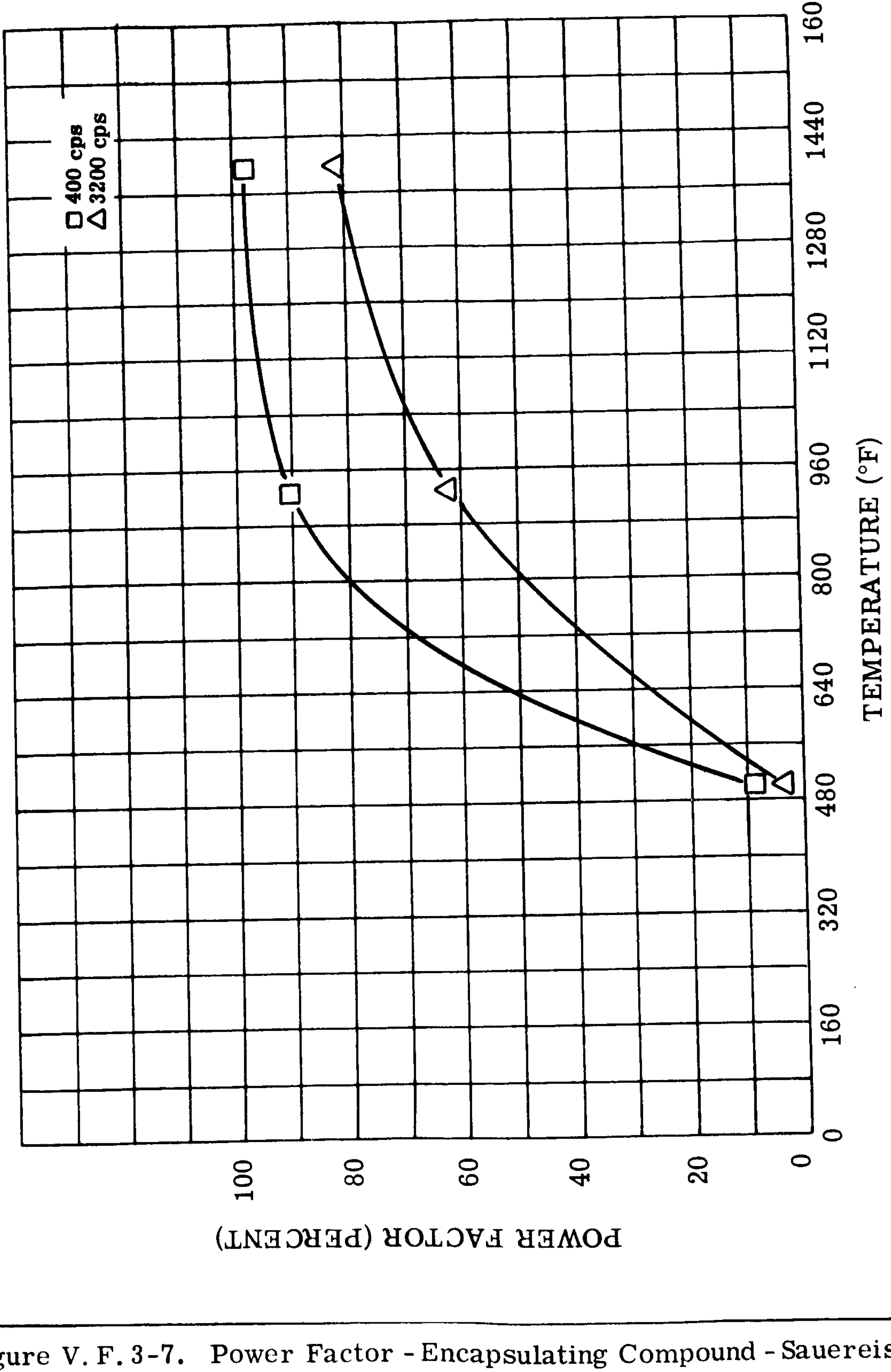


FIGURE V.F.3-7. Power Factor of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-7. Power Factor - Encapsulating Compound - Sauereisen 8

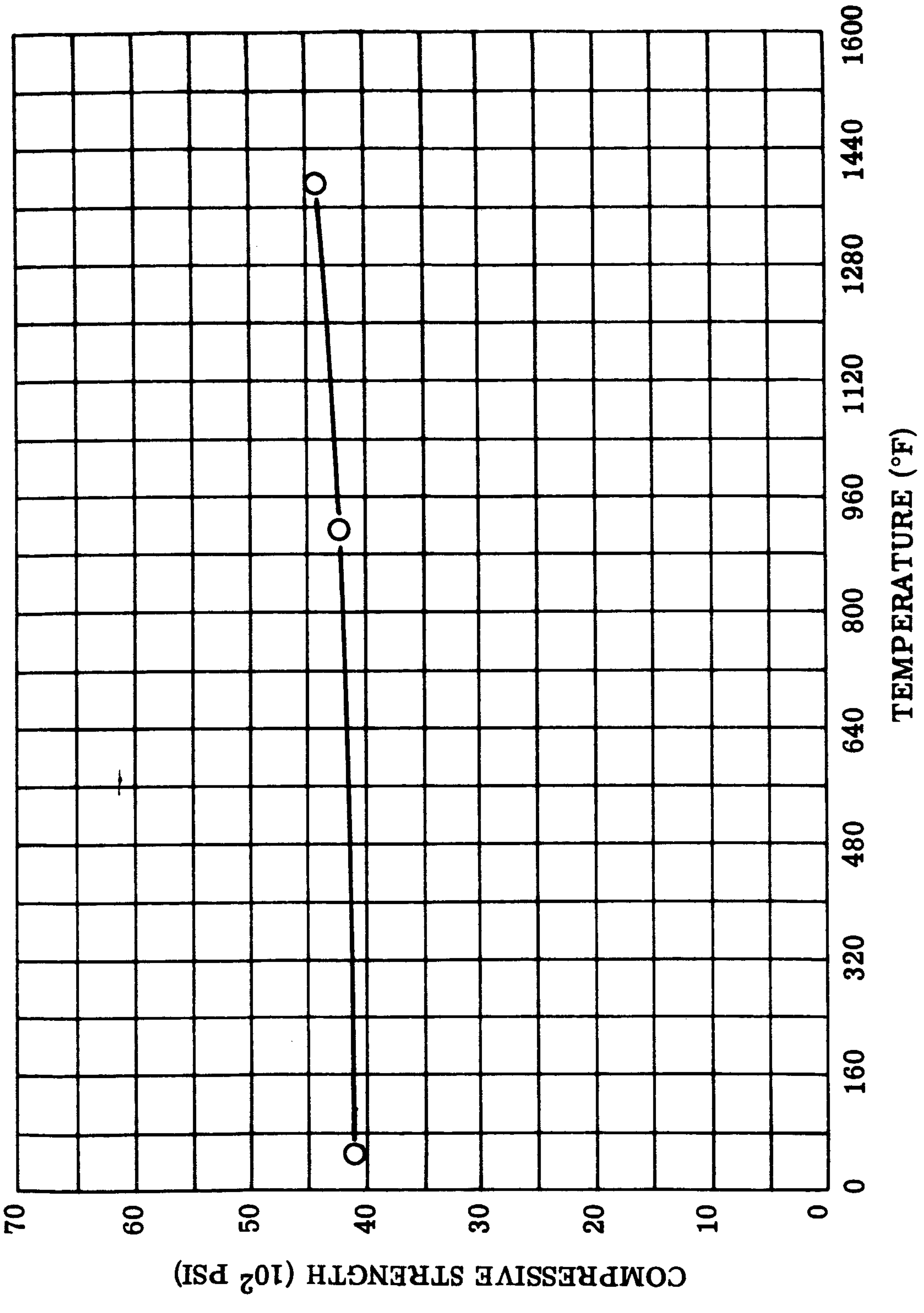


FIGURE V. F. 3-8. Compressive Strength of Inorganic Encapsulating Compound, Sauereisen 8, in Air. (Reference: NAS 3-4162)

Figure V. F. 3-8. Compressive Strength - Encapsulating Compound - Sauereisen 8

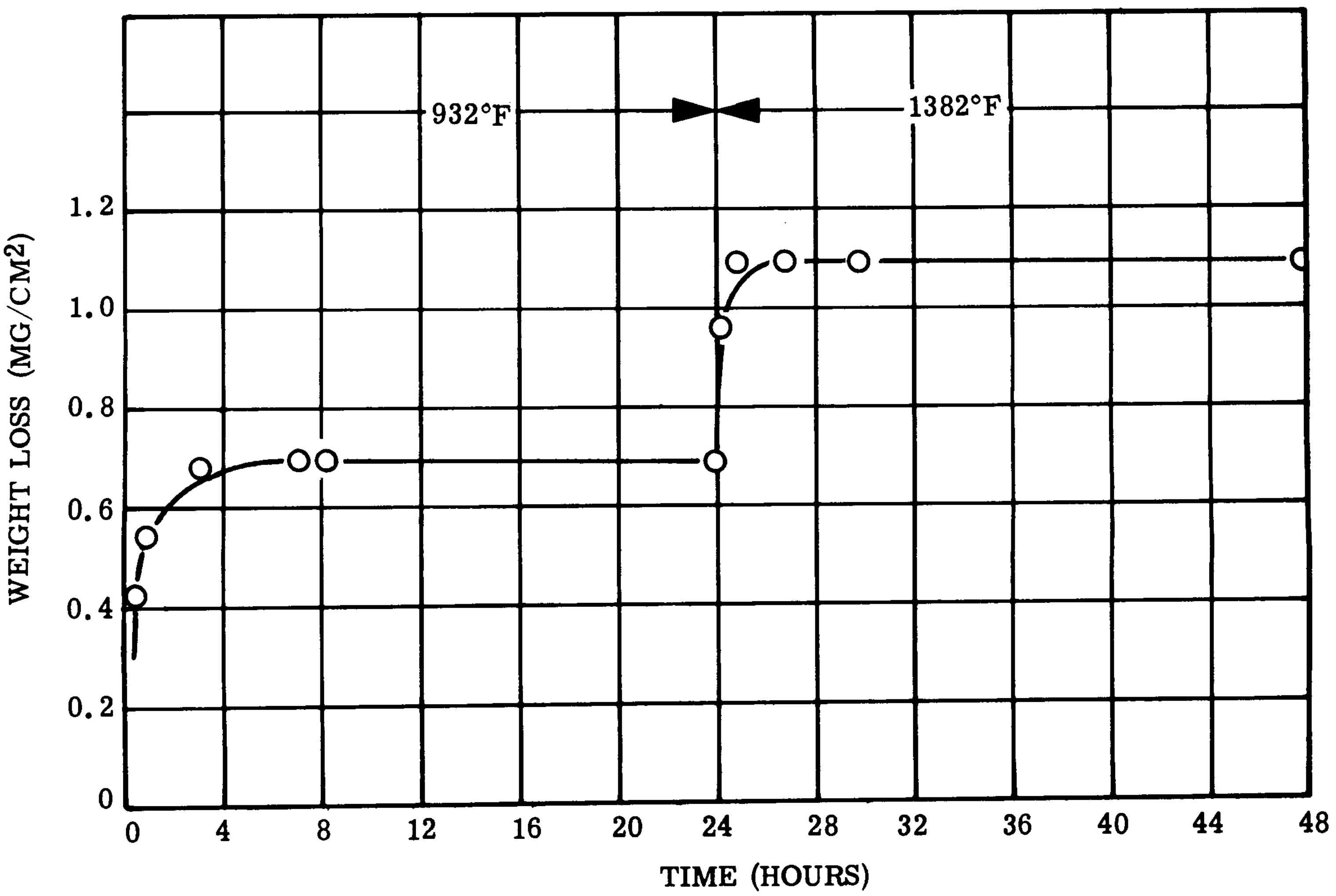


FIGURE V. F. 3-9. Weight Loss of Inorganic Encapsulating Compound, Sauereisen 8, at 938°F, 1382°F and 10^{-5} to 10^{-6} Torr. (Reference: NAS 3-4162)

Figure V. F. 3-9. Weight Loss - Encapsulation Compound - Sauereisen 8

4. SILICONE FOAM ENCAPSULATION COMPOUND

Silicone foam (XR-5017) is an organic material which can be foamed at room or elevated temperature.

Availability:	Scotchcast brand resin XR-5017 is available from Minnesota Mining and Manufacturing Co., Electrical Products Division.
Description:	XR-5017 is a two part silicone rubber foam activated by mixing 100 parts by weight of Part A (white) to 4 parts by weight of Part B (brown). The foam can be poured immediately and cures in 24 hours at room temperature or in 1/2 hour at 250°F.

I. Thermophysical Properties

A. Density (77°F)(lb/cu foot) 20 - 25

B. Thermal Conductivity (RI206)

Specimen Thickness, 0.125 Inch

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
212	0.039
392	0.046

C. Coefficient of Thermal Expansion

Specimen Thickness, 0.125 Inch

Temperature Range (°F)	inch/inch-°F
77 to 392	0.32×10^{-5}
392 to 77	0.35×10^{-5}

D. Water Absorption (77°F)(percent) 0.01 (RI206)

Specimen Thickness, 0.25 Inch

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.064 Inch

	Temperature (°F)	Frequency (cps)	Dielectric Constant	
1.	77	400	1.60	
	77	3200	1.60	
	392	400	1.53	
	392	3200	1.48	
	482	400	1.51	
	482	3200	1.47	
2.	86	100	2.4	(RI207)
	140	100	2.2	
	194	100	2.2	
	248	100	2.2	
	302	100	2.2	
	356	100	2.4	

B. Dissipation Factor at 100 cps (RI207)

Temperature (°F)	Tan δ
86	0.001
140	0.05
194	0.08
248	0.19
302	0.19
356	0.32

C. Electric Strength

All tests were performed in air using electrodes - 500V/second rise. Specimen thickness was 0.064 inch.

Temperature (°F)	Frequency	Volts/mil
77	DC	139
77	400 cps	88
77	3200 cps	>92
392	DC	87
392	400 cps	56
392	3200 cps	65
482	DC	61
482	400 cps	44
482	3200 cps	42

D. Insulation Life

Specimen Thickness, 0.064 Inch

Aging and Test Temperature (°F)	Aging Time at Temperature	Electric Strength (volts/mil)
347	Original (1)	60
347	200 hours	60
347	400 hours	51
347	600 hours	55
347	800 hours	>60
347	1000 hours	>56
392	Original (1)	56
392	200 hours	56
392	400 hours	No test
392	600 hours	55
392	800 hours	53
392	1000 hours	45

---

(1) Interpolated from Figure V. F. 4-2.

E. Power Factor

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency (cps)	Percent
72	400	0.089
72	3200	0.079
392	400	1.99
392	3200	1.34
482	400	1.73
482	3200	1.87

F. Volume Resistivity

Specimen Thickness, 0.064 Inch

Temperature (°F)	Frequency	Ohm-cm
77	DC	8.6×10^{13}
77	400 cps	3.3×10^{12}
77	3200 cps	4.5×10^{11}
392	DC	1.4×10^{13}
392	400 cps	1.6×10^{11}
392	3200 cps	2.8×10^{10}
482	DC	1.6×10^{13}
482	400 cps	1.7×10^{11}
482	3200 cps	2.0×10^{10}

III. Mechanical Properties

A. Compressive Strength (1)

---

(1) ASTM D1621 - Stress at 10 percent deflection.

Temperature (°F)	Psi
77	6.11
400	3.10

B. Compressive Deflection at 77°F (ASTM D575)

(RI706)

Deflection (percent)	Psi
25	12.2
50	26.1

C. Compression Set at 77°F (ASTM D395 Method B)

At 50 percent compression	15.4 percent

IV. Compatibility Properties

A. Chemical Resistance

Moisture resistance is very good. Acid and alkali resistance is fair to good. Organic solvent resistance is fair to poor. Aromatic or chlorinated solvent attack is particularly severe. (Reference: 3M Company Product Data.)

B. Nuclear Radiation Resistance

Silicone elastomers are generally strengthened by gamma irradiation at levels up to about 10^8 to 10^9 ergs per gram (C). Severe increase in the hardness of silicone elastomers are noted in REIC Report No. 34 as a result of irradiation. (LI296)

C. Weight Loss in Vacuum at Elevated Temperature

Aging XR-5017 for 24 hours at 392°F produced a loss of 6.1 mg/cm^2, or a 7.2 percent weight loss. Weight loss was calculated using the apparent surface area of the test sample. This value would have been much lower were the actual surface area of the foamed material known and used in the weight loss calculation.

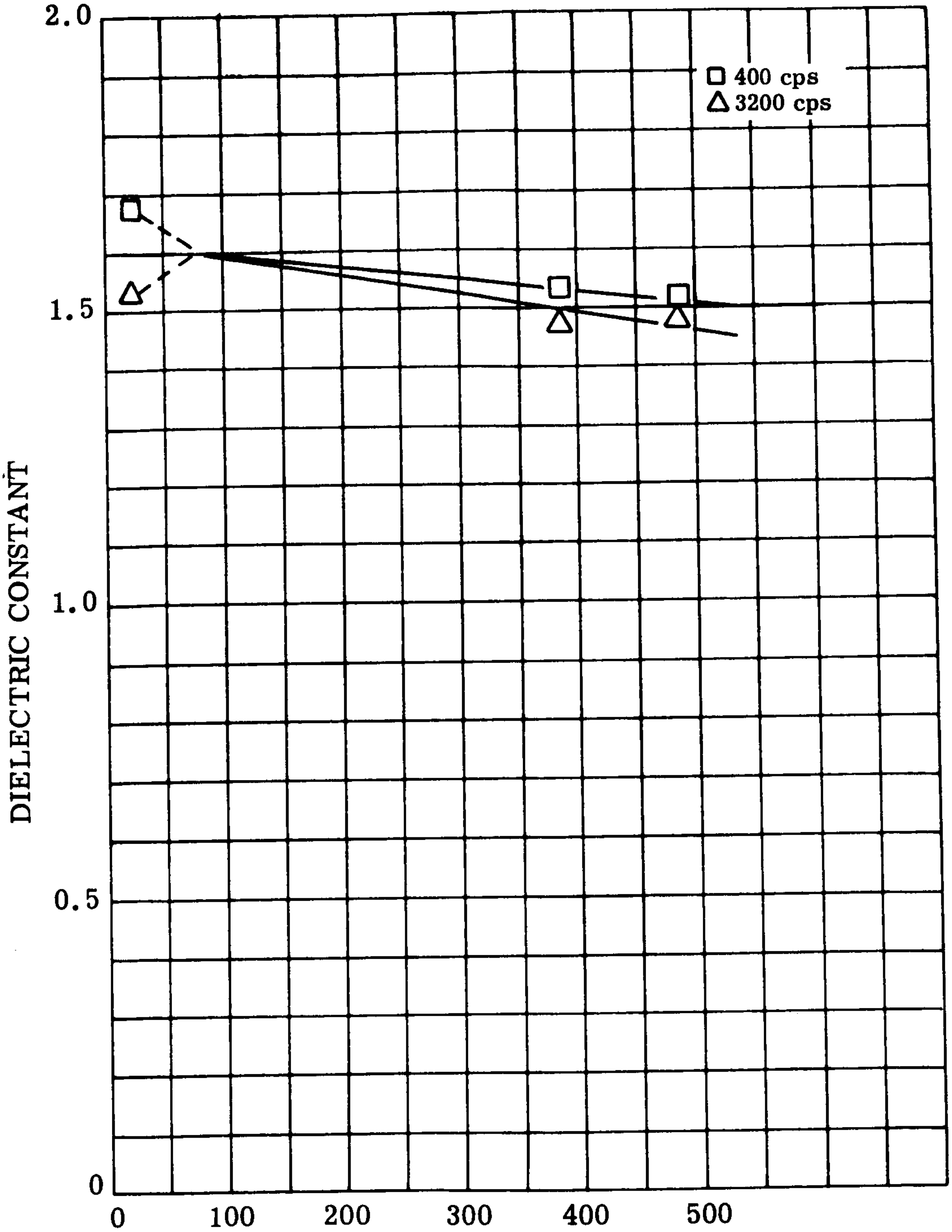


FIGURE V.F.4-1. Dielectric Constant of Organic Encapsulation Compound, Silicone Foam, in Air. Specimen Thickness, 0.064 Inch; Specimen Density, 20-25 lb/cu ft. (Reference: NAS 3-4162)

Figure V.F.4-1. Dielectric Constant - Encapsulation Compound - Silicone Foam

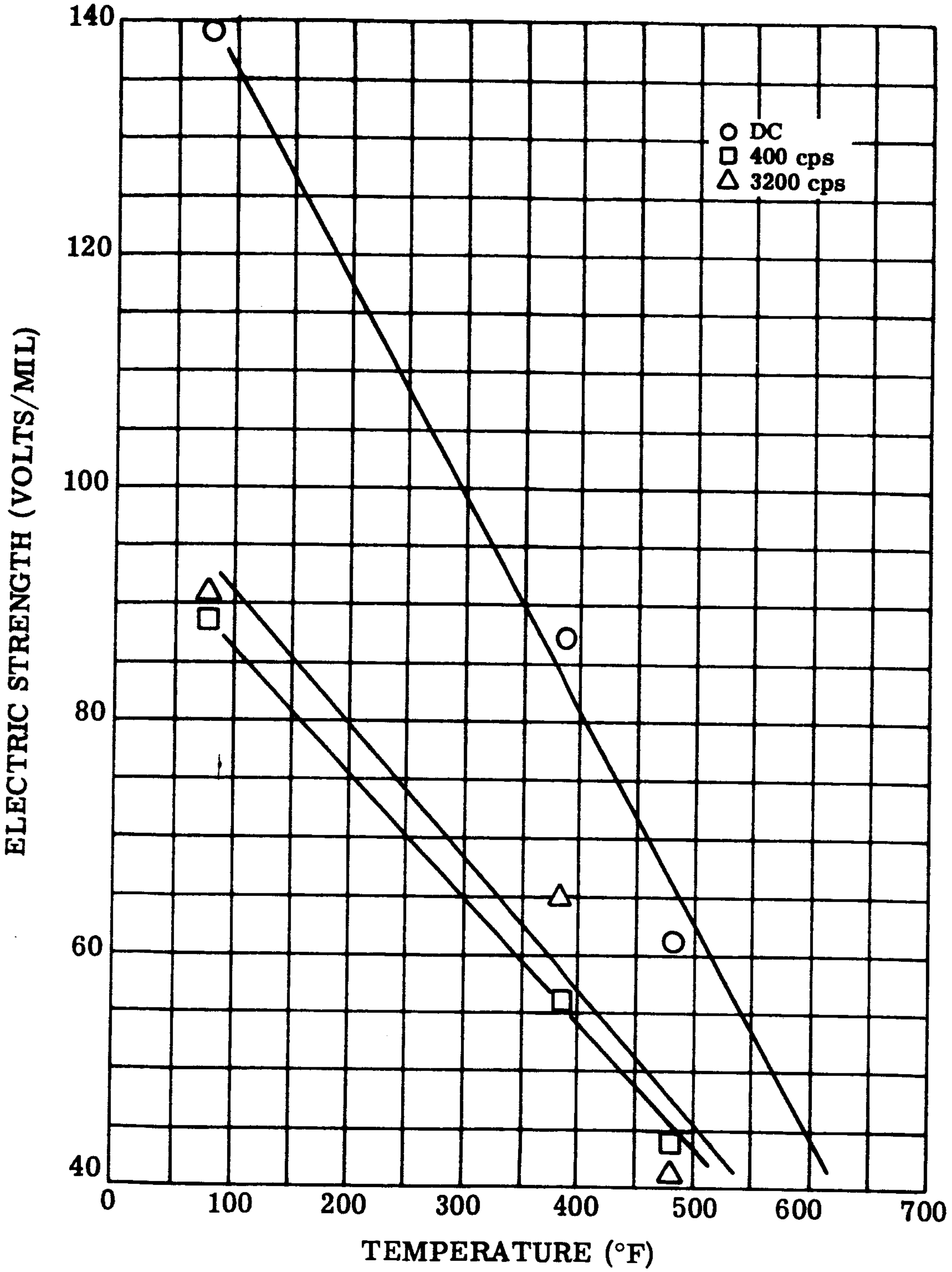


FIGURE V. F. 4-2. Electric Strength of Organic Encapsulation Compound, Silicone Foam, in Air. Specimen Thickness, 0.064 Inch; Specimen Density, 20-25 lb/cu ft. (Reference: NAS 3-4162)

Figure V. F. 4-2. Electrical Strength - Encapsulation Compound - Silicone Foam

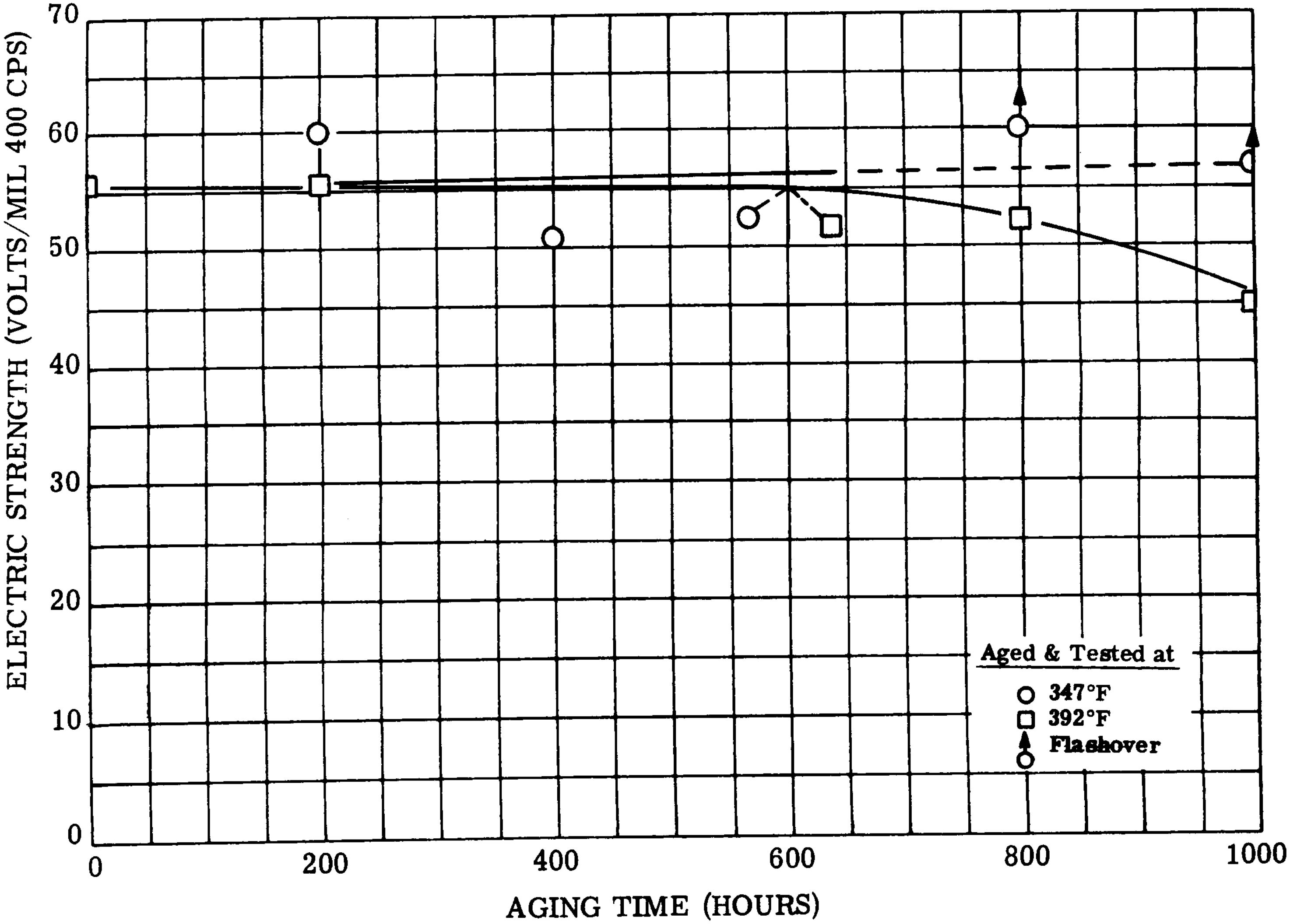


FIGURE V. F. 4-3. Insulation Life of Organic Encapsulation Compound, Silicone Foam, in Air. Specimen Thickness, 0.064 Inch; Specimen Density, 20-25 lb/cu ft. (Reference: NAS 3-4162)

Figure V. F. 4-3. Insulation Life - Encapsulation Compound - Silicone Foam

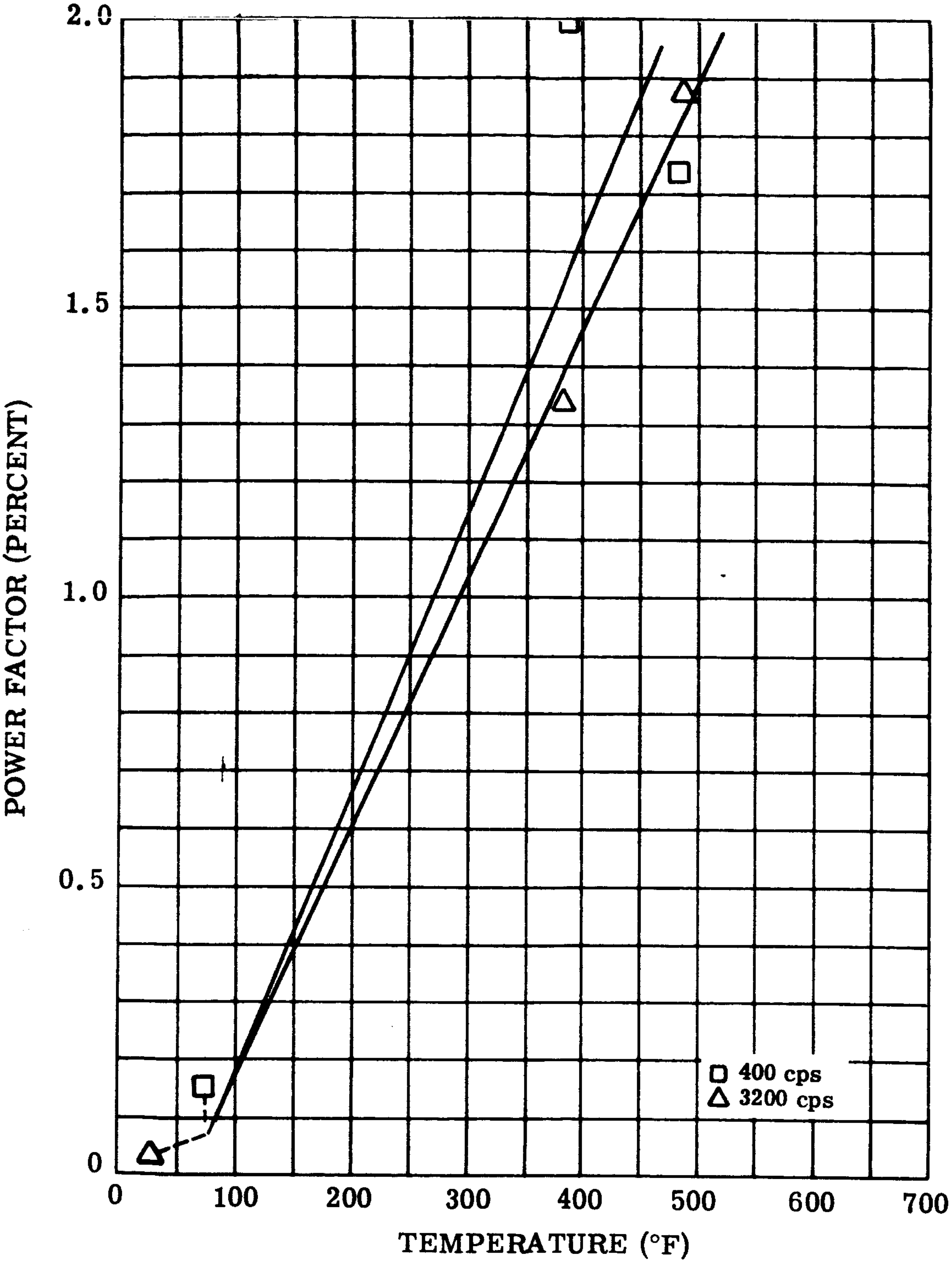


FIGURE V. F. 4-4. Power Factor of Organic Encapsulation Compound, Silicone Foam, in Air. Specimen Thickness, 0.064 Inch; Specimen Density, 20-25 lb/cu ft. (Reference: NAS 3-4162)

Figure V. F. 4-4. Power Factor - Encapsulation Compound - Silicone Foam

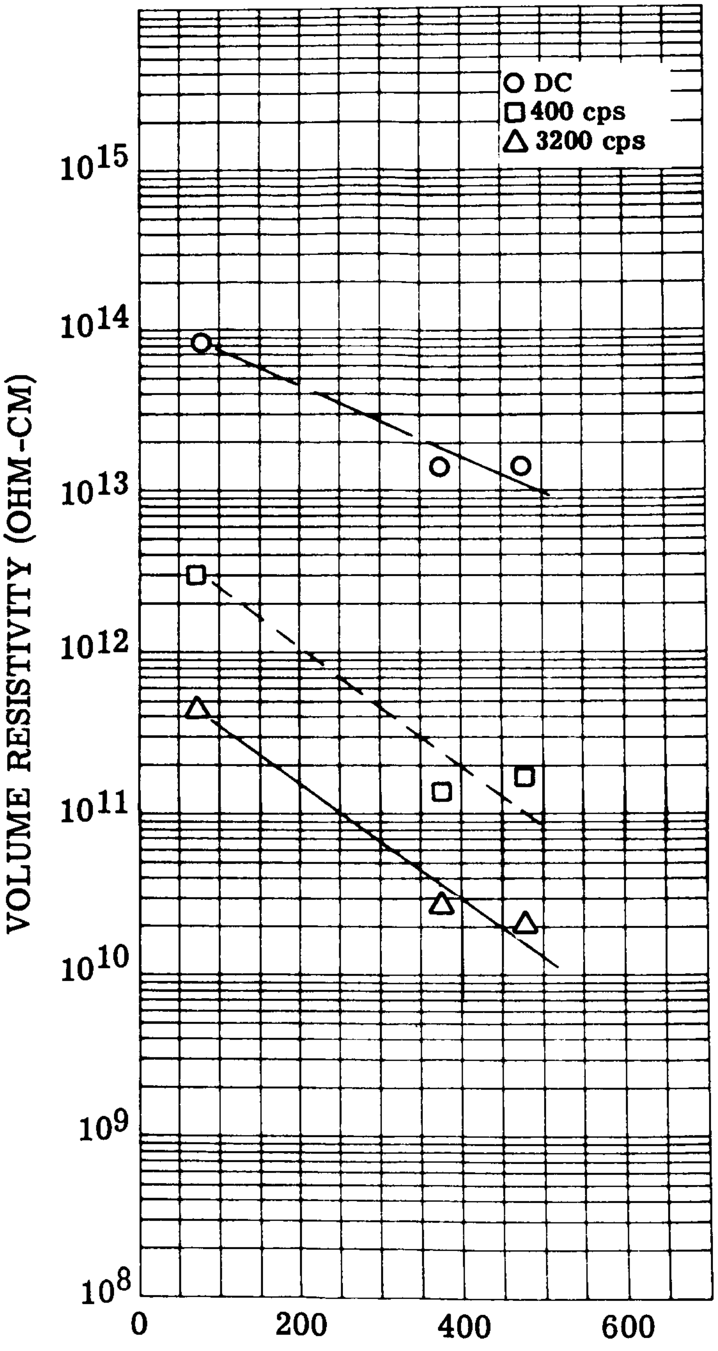


FIGURE V. F. 4-5. Volume Resistivity of Organic Encapsulation Compound, Silicone Foam, in Air. Specimen Thickness, 0.064 Inch; Specimen Density, 20-25 lb/cu ft. (Reference: NAS 3-4162)

Figure V. F. 4-5. Volume Resistivity - Encapsulation Compound - Silicone Foam

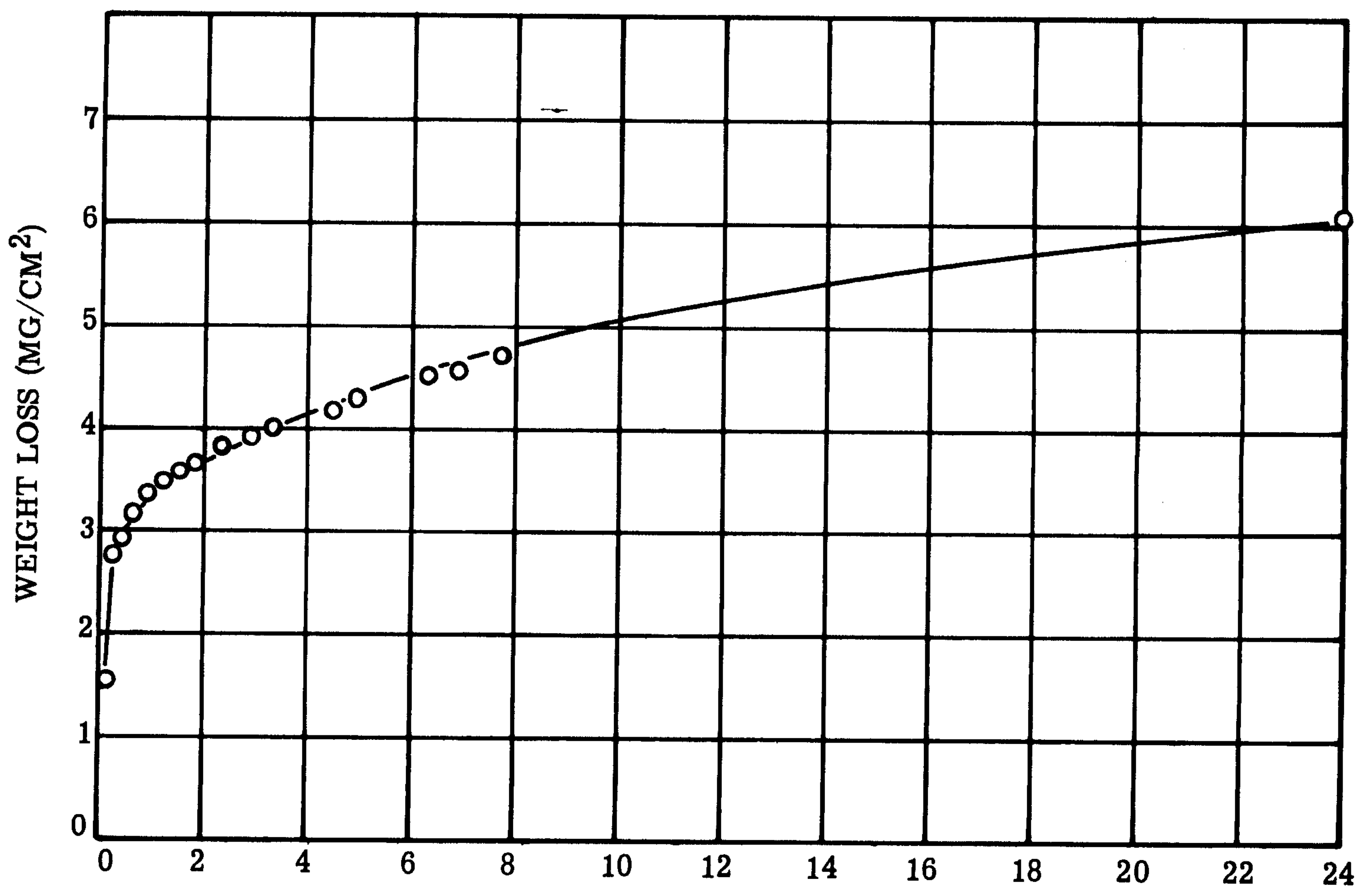


FIGURE V. F. 4-6. Weight Loss at 400°F and 10^{-5} to 10^{-6} torr of Organic Encapsulation Compound, Silicone Foam. Specimen Density, 20-25 lb/cu. ft. (Reference: NAS 3-4162)

Figure V. F. 4-6. Weight Loss - Encapsulation Compound - Silicone Foam

5. URETHANE FOAM ENCAPSULATION COMPOUND

Urethane foam is an organic polymeric material formed by the reaction of a di-isocyanate with a polyester. The data presented in this summary is based on Carthane 1008 of Carwin Corporation which has been withdrawn from the market during this program. The basic formulation with slight modification is now being produced by Flexible Products Company.

Availability:	This foam is available from Flexible Products Company as Flexipol 9020/8122-2 high temperature foam. It is available as a 2 component system which can be foamed in place or used as foam sheets or blocks.
Description:	This foam is a two part system containing an isocynate based on polymethylene polyphenylisocyanate (PAPI). The foaming action is caused by the evolution of water occurring as a result of the polyester-isocyanate reaction. The reaction is self-induced and requires no baking.

I. Thermophysical Properties

A.	Density (77°F)(lb/cu foot)	5 to 18	(RI288)
B.	Thermal Conductivity		(RI288)

Specimen Density, 3 lb/cu ft

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
325	0.26

II. Electrical Properties

A. Dielectric Constant (RI288)

Specimen Density, 8 lb/cu ft

Temperature (°F)	Frequency (cps)	Dielectric Constant
77	60	1.14
392	60	1.18

III. Mechanical Properties (RI288)

A. Compressive Strength

Specimen Density, 8 lb/cu ft

Temperature (°F)	Psi
77 (ASTM D1621)	210
500	175

IV. Compatibility Properties

A. Chemical Resistance (RI198)

Urethane resins have good solvent and moisture resistance. Acid and alkali resistance is fair to good.

B. Nuclear Radiation Resistance (LI296)

Flexible urethane foams are hardened slightly by exposure to flux levels of about 10^9 ergs per gram (C) of gamma radiation. Severe damage to the electrical properties of urethane foams is reported to occur at a radiation level of 10^{10} ergs per gram (C) of gamma radiation.

C. Weight Loss in Vacuum (LI297)

A total weight loss value of 4.7 percent for a polyurethane paint film exposed at 205°F for 650 hours in a vacuum of 5×10^{-8} torr has been reported. The slope of the weight loss curve at 650 hours was 0.0006 percent loss per hour. This foamed composition would perform in a similar fashion but the very large surface area of a foam must be accounted for.

6. ENCAPSULATION COMPOUND W-839

W-839 is a potting and encapsulating compound, which is recommended by its manufacturer for use in electrical systems at temperatures up to 1200°F. The compound is resistant to both nuclear radiation and hard vacuum but is specifically designed for high physical strength and long pot life.

Availability:	This encapsulating compound is available in experimental quantities from the Insulation Department of Westinghouse Research and Development Laboratories.
Description:	This material is composed of zirconium silicate and aluminum orthophosphate. For application purposes, water may be added.

I. Thermophysical Properties

A. Density (77°F)(lb/cu inch) 0.12

B. Shrinkage, Volume (77°F)(percent)

Before Firing	0.62
After Firing (total)	0.75

C. Thermal Conductivity

Temperature (°F)	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
395	0.484
945	0.447
1225	0.478

D. Coefficient of Thermal Expansion

Temperature Range (°F)	inch/inch-°F
77 to 1000 (heating)	2.65×10^{-6}
1000 to 1400 (volumetric change - see Figure V. F. 6-2)	
1400 to 77 (cooling)	2.7×10^{-6}

E. Water Absorption (77°F)(percent) 8.5

II. Electrical Properties

A. Dielectric Constant

Specimen Thickness, 0.20 Inch

Temperature (°F)	Frequency (cps)	Dielectric Constant
500	400	8.4
500	3200	8.2
932	400	48
932	3200	31
1382	400	83
1382	3200	48

B. Electric Strength

Specimen Thickness, 0.20 Inch

Temperature (°F)	Frequency	Volts/mil
500	DC	58
500	400 cps	43
500	3200 cps	39
932	DC	41 (1)
932	400 cps	22 (2)
932	3200 cps	16
1382	DC	47 (1)
1382	400 cps	22
1382	3200 cps	20

(1) Not a breakdown, current leakage exceeded 5 ma.
(2) Not a breakdown, current leakage exceeded 30 ma.

C. Insulation Life

Specimen Thickness, 0.20 Inch

Aging and Test Temperature (°F)	Aging Time at Temperature	Volume Resistivity (ohm-cm)
1112	1 hour	1.9×10^{7}
1112	200 hours	1.1×10^{8}
1112	400 hours	1.7×10^{8}
1112	600 hours	3.8×10^{8}
1112	800 hours	1.2×10^{8}
1112	1000 hours	1.2×10^{8}
1112	1000 hours (1)	9.0×10^{8}
1292	1 hour	1.0×10^{7}
1292	200 hours	2.1×10^{8}
1292	400 hours	1.3×10^{8}
1292	600 hours	1.3×10^{8}
1292	800 hours	1.9×10^{8}
1292	1000 hours	1.5×10^{8}
1292	1000 hours (1)	5.2×10^{7}

D. Volume Resistivity

Specimen Thickness, 0.20 Inch

Temperature (°F)	Frequency	Ohm-cm
500	DC	8.1×10^{11}
500	400 cps	1.1×10^{10}
500	3200 cps	2.0×10^{9}
932	DC	4.6×10^{7}
932	400 cps	3.4×10^{7}
932	3200 cps	1.9×10^{7}
1382	DC	8.0×10^{6}
1382	400 cps	5.5×10^{6}
1382	3200 cps	4.8×10^{6}

(1) Retest using new gold electrodes. The original silver electrodes failed during test exposure.

E. Power Factor

Temperature (°F)	Frequency (cps)	Percent
500	400	4.4
500	3200	3.6
932	400	98.2
932	3200	79.3
1382	400	99.5
1382	3200	92.6

III. Mechanical Properties

A. Compressive Strength

Temperature (°F)	Psi
77	12,733
932	20,200
1382	9,783

B. Flexural Strength (77°F)	4,025 psi

C. Thermal Shock (5/8 inch hex bar)

Failed after one cycle 77°F to 1200°F to 77°F
Heating, 15°F per minute.
Cooling was produced by direct removal from furnace to room temperature.

D. Pot Life at 77°F	72 hours

IV. Compatibility Properties

A. Chemical Resistance

The cured compound has good resistance to solvents and moisture. However, because of porosity, W-839 is not a good moisture barrier. Acid and alkali resistance is good.

B. Nuclear Radiation Resistance

The compound W-839 is capable of withstanding gamma radiation at a level of 2×10^{10} roentgen and a fast neutron dose of 10^{18}.

C. Weight Loss in Vacuum with Heat

24 hours at 932°F	0.26 percent
24 hours at 932°F and 24 hours at 1382°F	0.40 percent

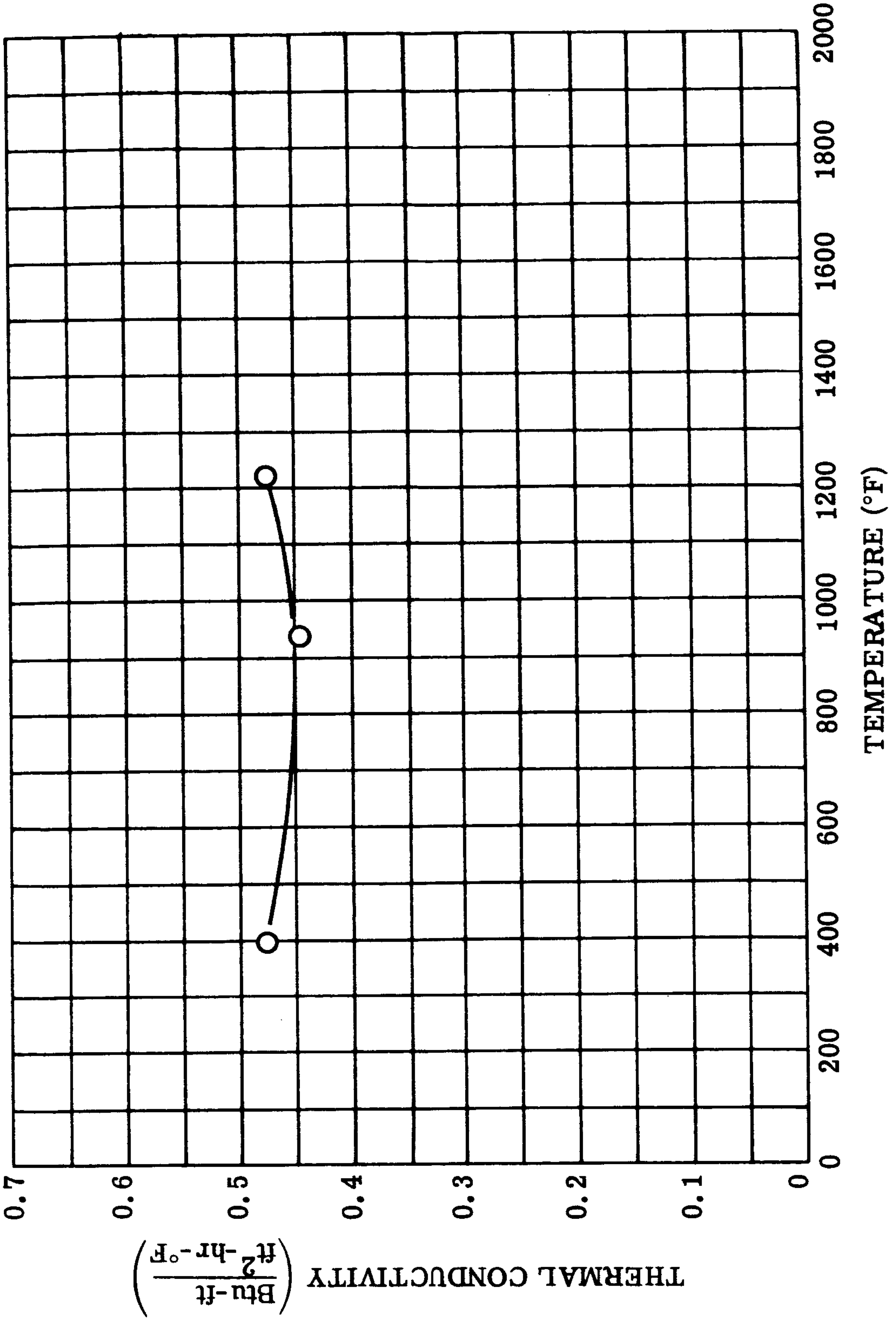


FIGURE V.F.6-1. Thermal Conductivity of Inorganic Encapsulation Compound, W-839, in Air. (Reference: NAS3-4162)

Figure V.F.6-1. Thermal Conductivity - Encapsulation Compound - W-839

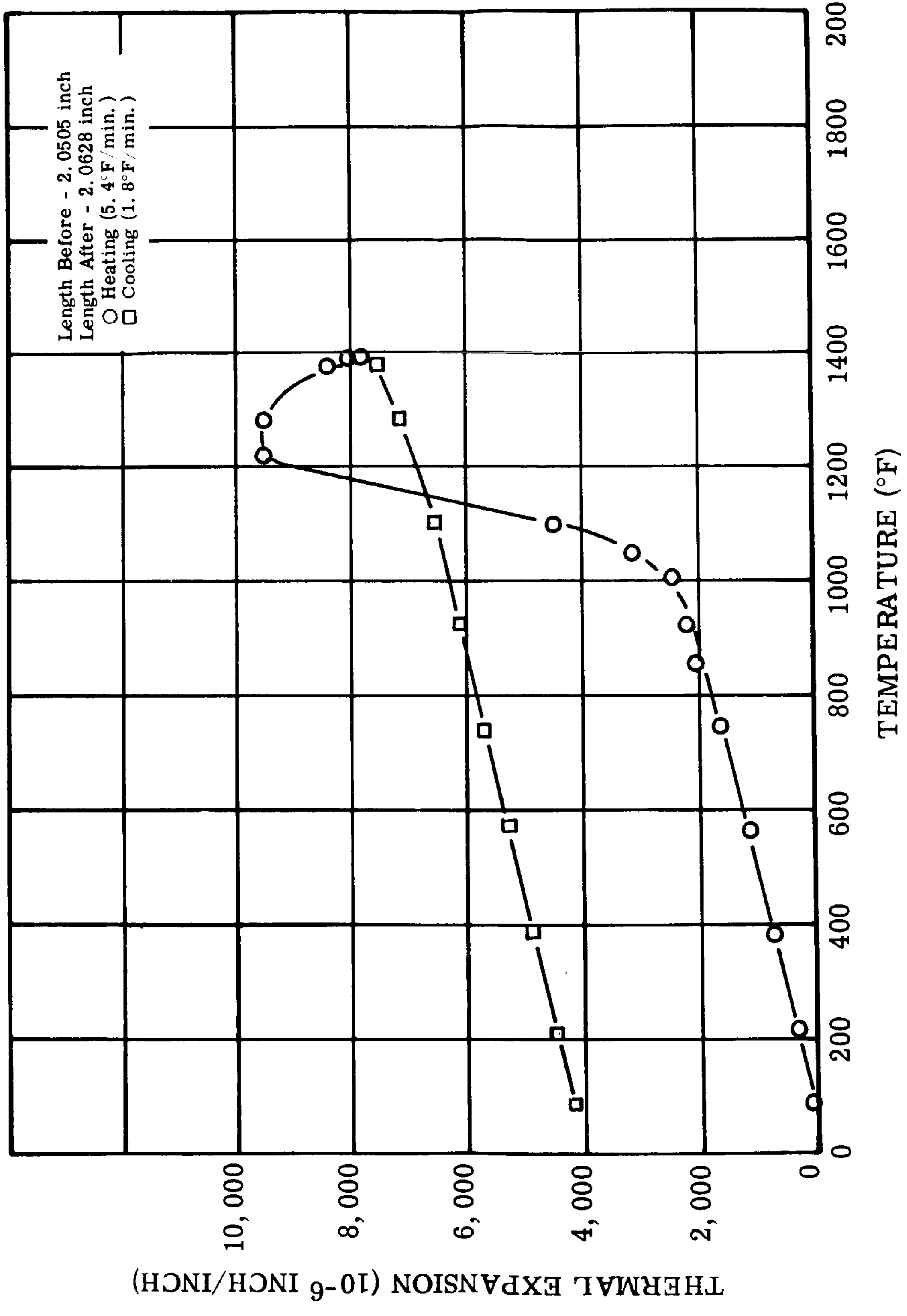


FIGURE V.F.6-2. Thermal Expansion of Inorganic Encapsulation Compound, W-839, in Air. (Reference: NAS 3-4162)

Figure V.F.6-2. Thermal Expansion - Encapsulation Compound - W-839

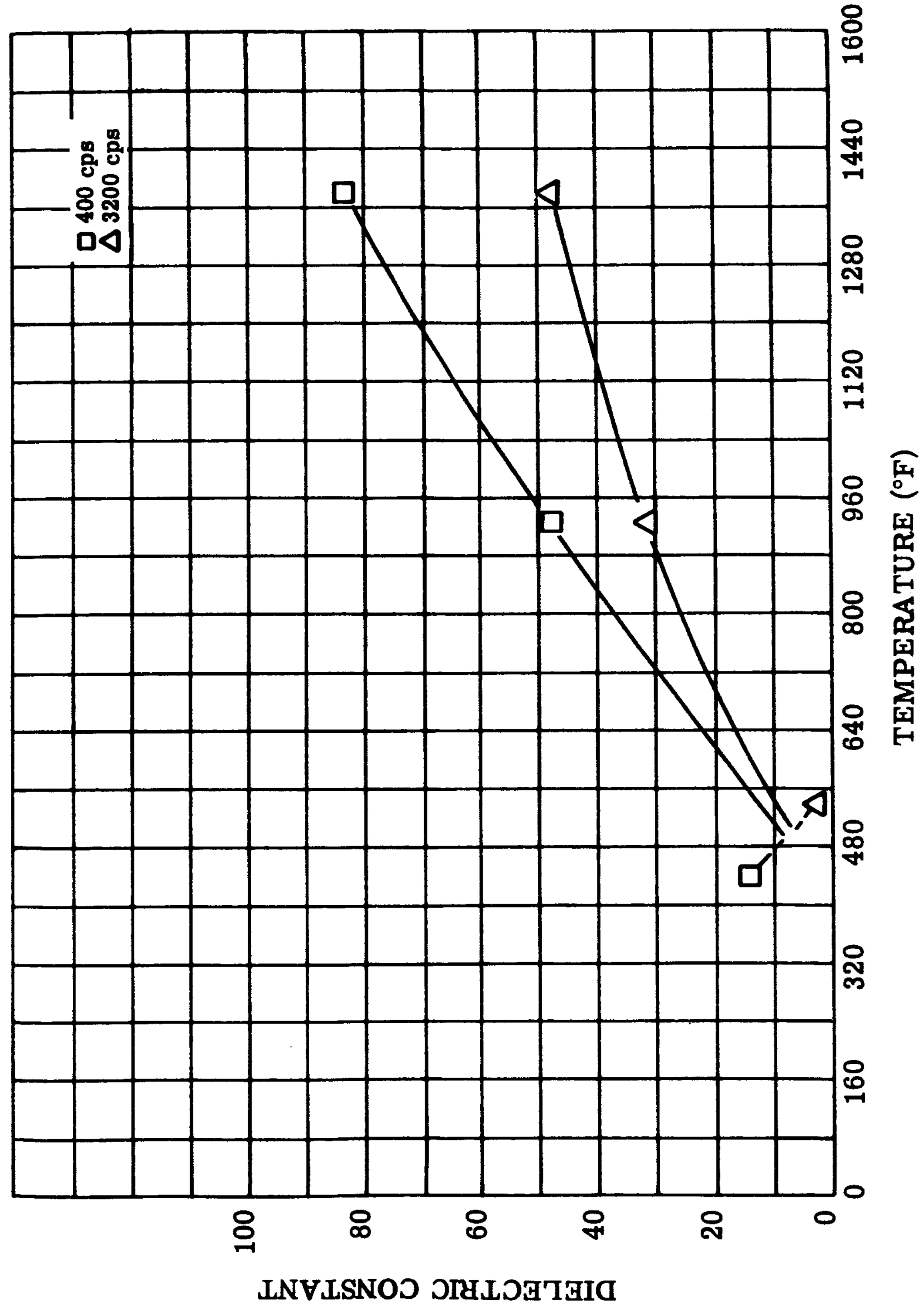


FIGURE V. F. 6-3. Dielectric Constant of Inorganic Encapsulation Compound, W-839, in Air. Specimen Thickness, 0.20 Inch. (Reference: NAS 3-4162)

Figure V. F. 6-3. Dielectric Constant - Encapsulation Compound - W-839

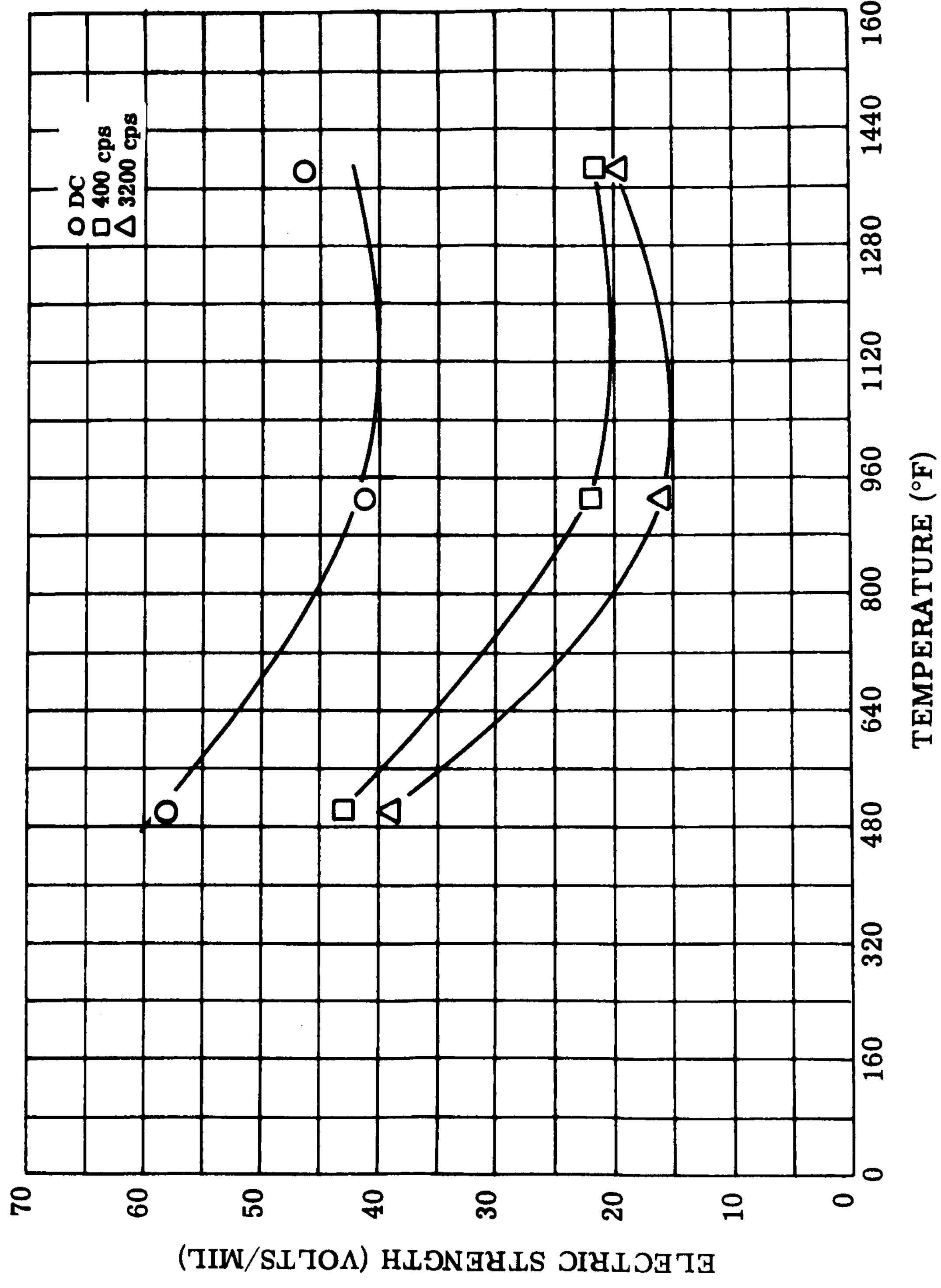


FIGURE V.F.6-4. Electric Strength of Inorganic Encapsulation Compound, W-839, in Air. Specimen Thickness, 0.20 Inch. (Reference: NAS 3-4162)

Figure V.F.6-4. Electric Strength - Encapsulation Compound - W-839

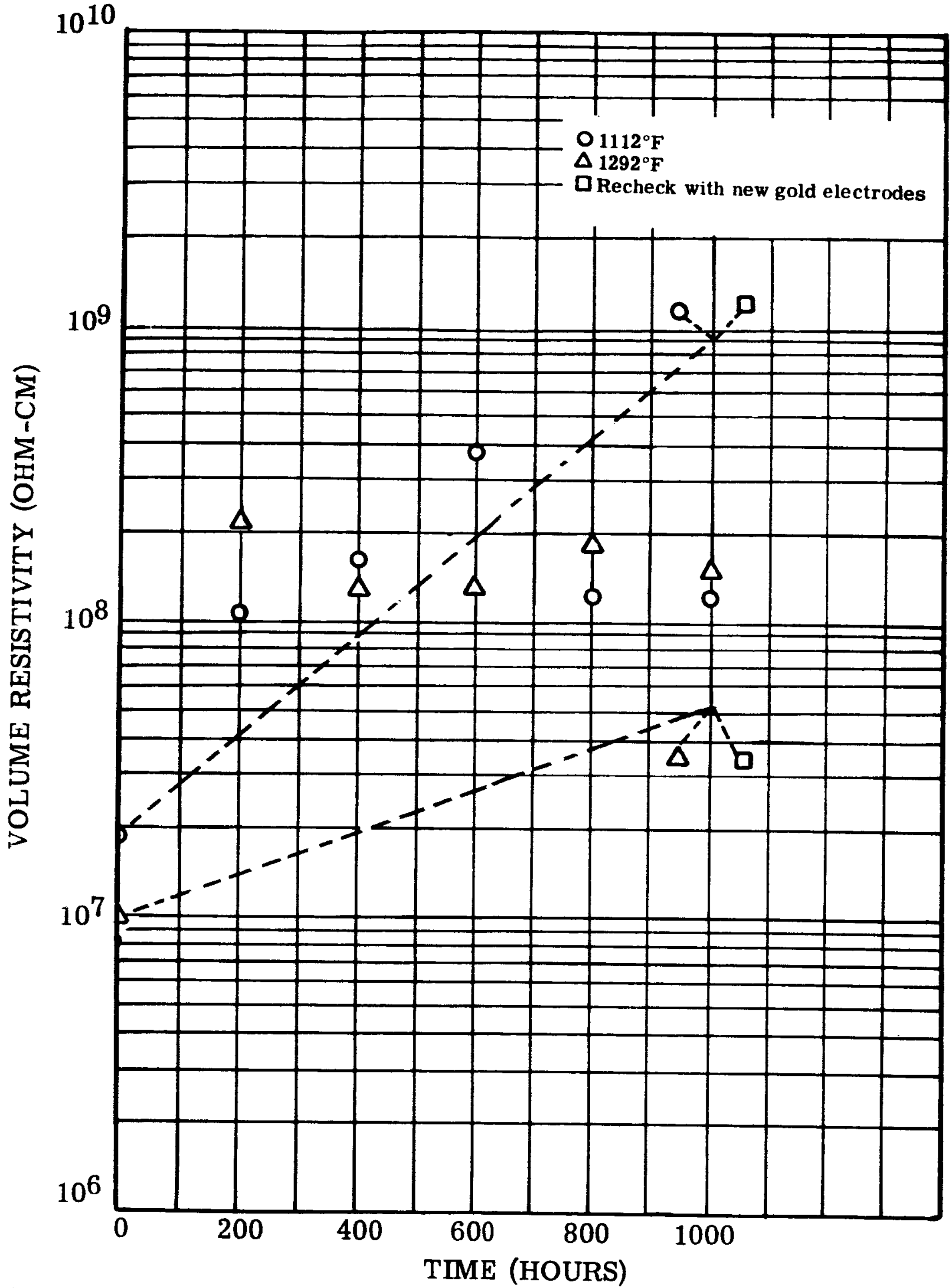


FIGURE V. F. 6-5. Insulation Life of Inorganic Encapsulation Compound, W-839, in Air. Specimen Thickness, 0.20 Inch. (Reference: NAS 3-4162)

Figure V. F. 6-5. Insulation Life - Encapsulation Compound - W-839

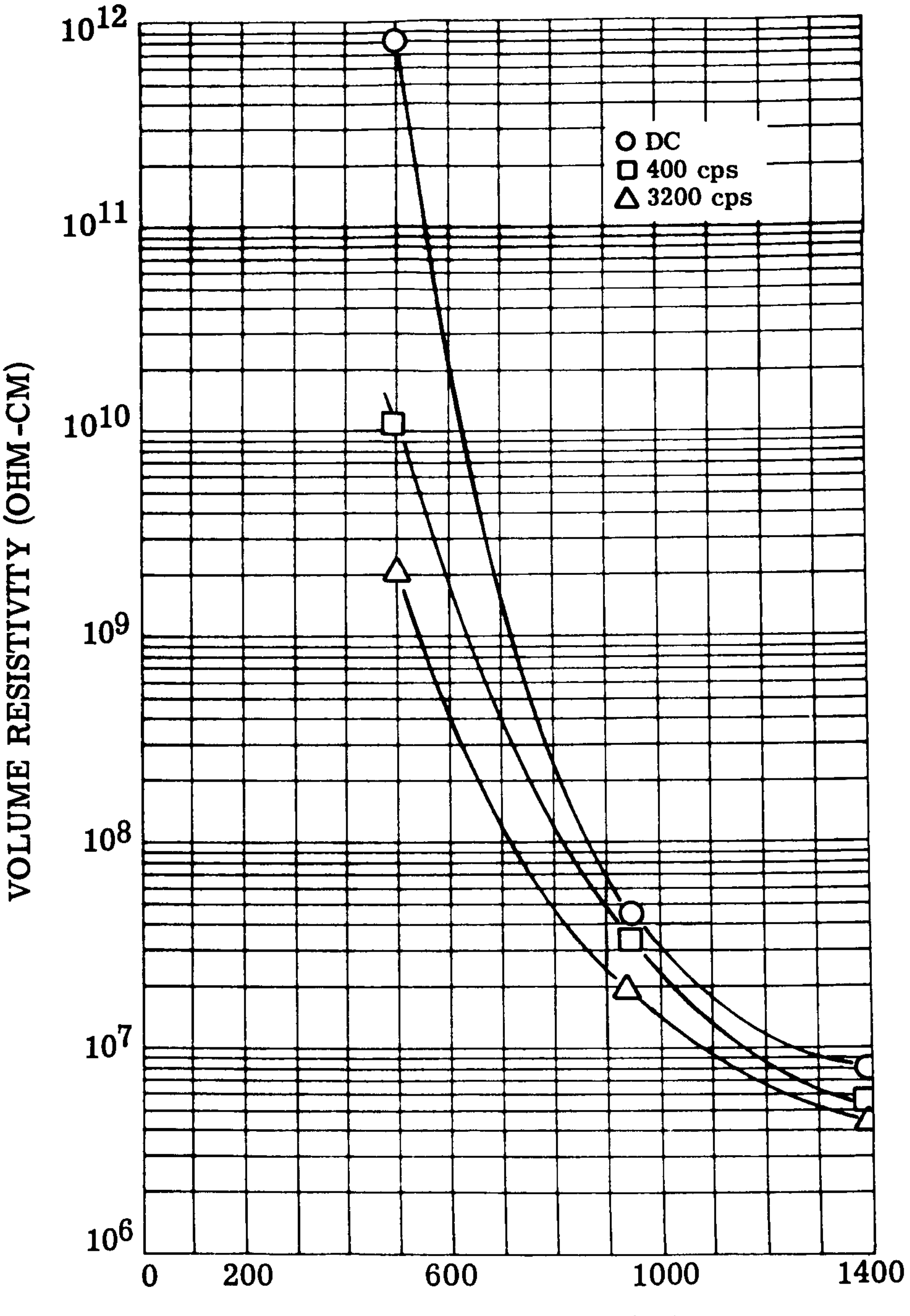


FIGURE V. F. 6-6. Volume Resistivity of Inorganic Encapsulation Compound, W-839. (Reference: NAS 3-4162)

Figure V. F. 6-6. Volume Resistivity - Encapsulation Compound - W-839

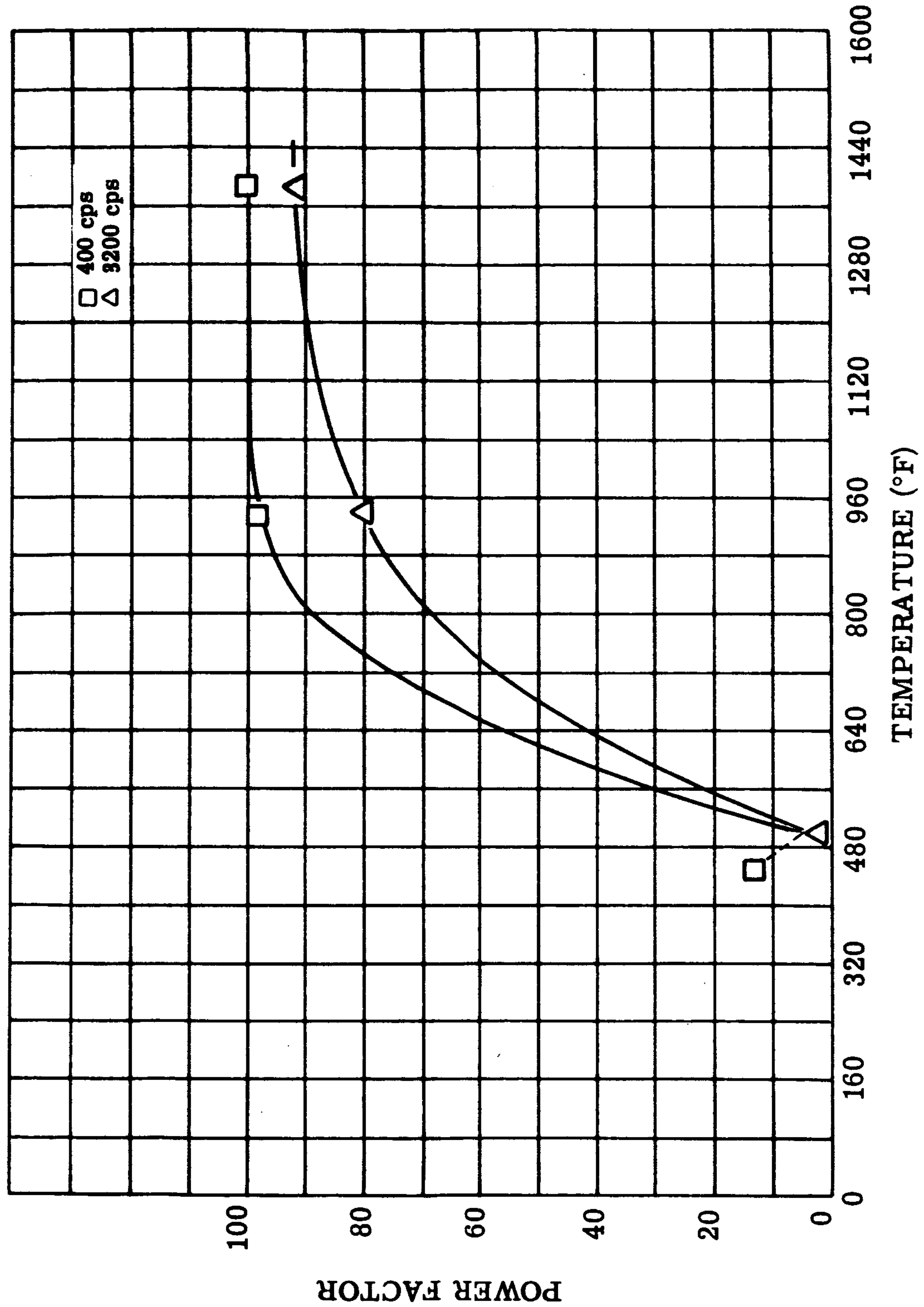


FIGURE V. F. 6-7. Power Factor of Inorganic Encapsulation Compound, W-839, in Air.
(Reference: NAS3-4162)

Figure V. F. 6-7. Power Factor - Encapsulation Compound - W-839

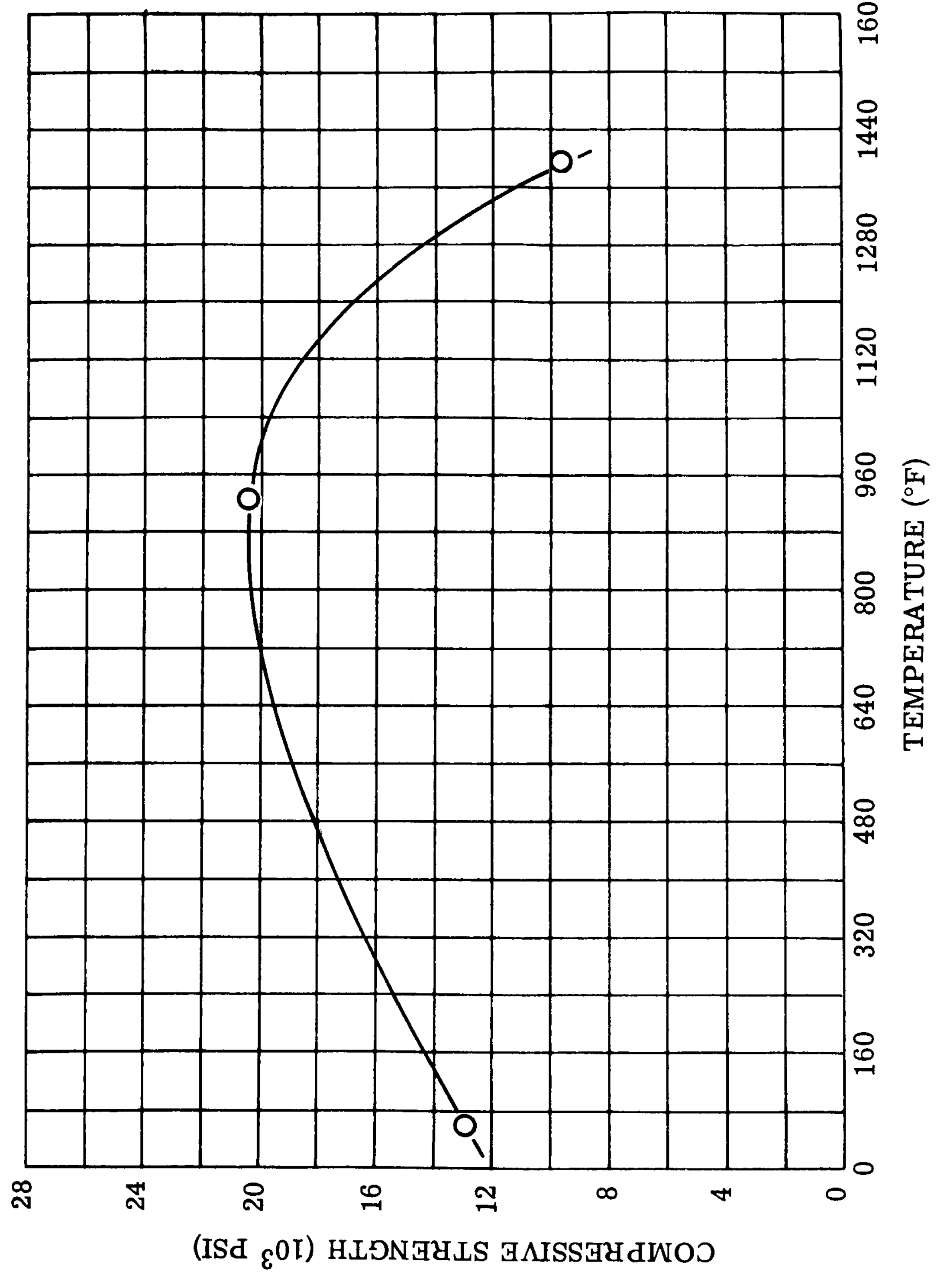


FIGURE V. F. 6-8. Compressive Strength of Inorganic Encapsulation Compound, W-839, in Air. (Reference: NAS 3-4162)

Figure V. F. 6-8. Compression Strength - Encapsulation Compound - W-839

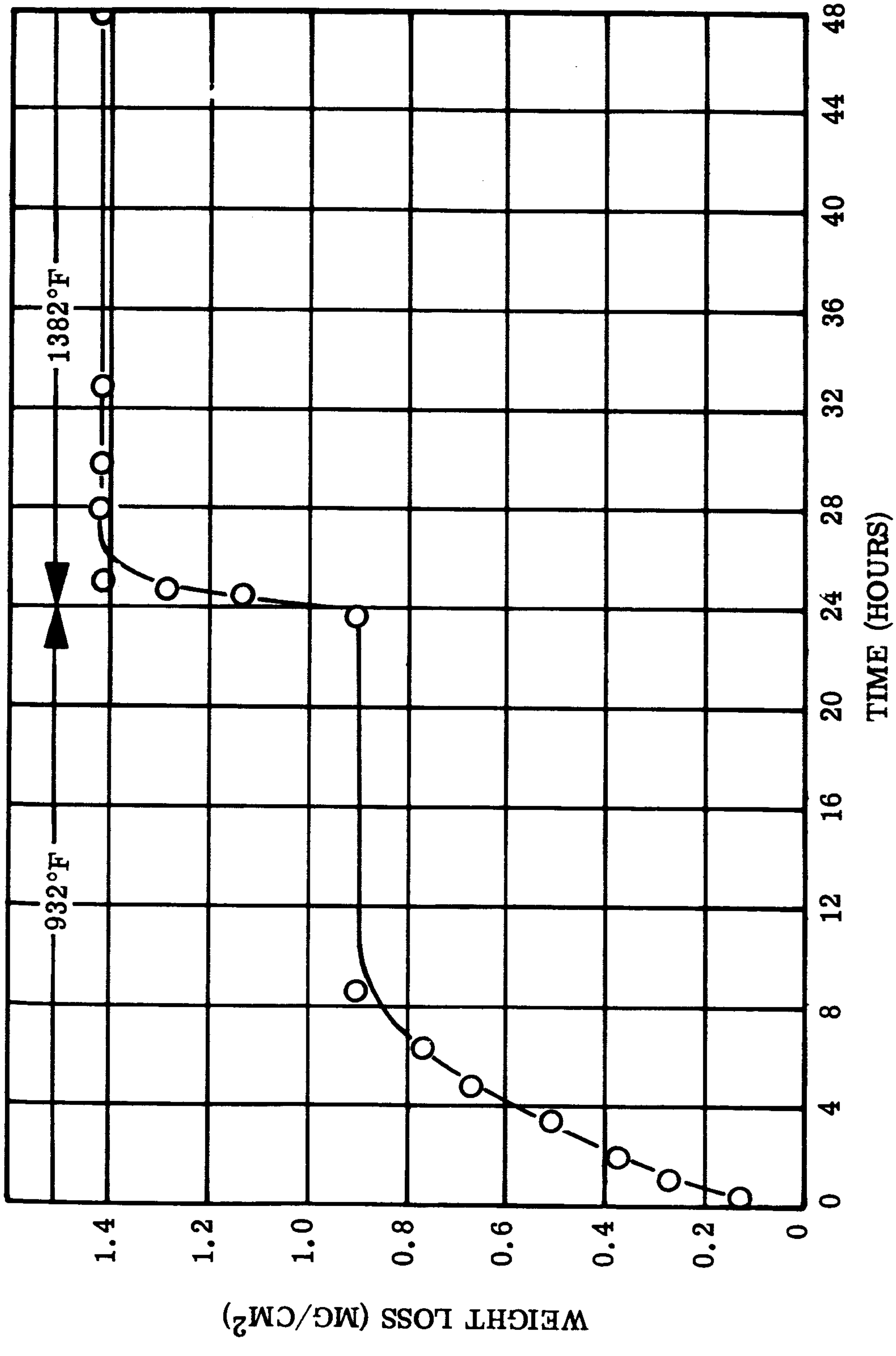


FIGURE V.F.6-9. Weight Loss of Inorganic Encapsulation Compound, W-839, at 932°F and 1382°F and 10^{-5} to 10^{-6} Torr. (Reference: NAS3-4162)

Figure V.F.6-9. Weight Loss - Encapsulation Compound - W-839

G. INTERLAMINAR INSULATIONS

Three interlaminar insulations were examined in this program. They were aluminum orthophosphate (Alkophos C), aluminum orthophosphate plus mica and bentonite (MAB), and M305 glass. The coatings were tested for interlaminar resistance as a function of time and temperature. The compatibility of Cubex magnetic alloy with the two aluminum orthophosphate-based coatings was examined. The data and comments are presented together because of the comparative nature of the test methods.

Availability:

1. Aluminum orthophosphate, also identified as Alkophos C, is available from the Monsanto Chemical Company, St. Louis, Missouri.
2. MAB is available in experimental quantities from Westinghouse Electric Corporation, Research and Development Center, Pittsburgh 35, Pennsylvania.
3. M305 glass is available in experimental quantities from Westinghouse Electric Corporation, Research and Development Center, Pittsburgh 35, Pennsylvania.

Description:

1. Aluminum orthophosphate is applied as an aqueous solution by means of a rubber roller applicator. The solution consists of 600 milliliters of aluminum orthophosphate (Alkophos C), 600 milliliters of distilled or demineralized water, and 1/2 percent wetting agent. After application, the coating is dried and then cured at approximately 750°F. The resulting coating thickness on this program was 0.11 to 0.15 mil per side.
2. Aluminum orthophosphate plus mica plus bentonite (MAB) is a filled aluminum orthophosphate solution and is applied by means of a rubber roller applicator. The solution is composed of 300 milliliters of aluminum orthophosphate, 1200 milliliters of distilled or demineralized water, 50 grams of bentonite (1), and 200 grams of -300

---

(1) This bentonite was grade KWK Volclay, obtained from American Colloid Company.

mesh phlogopite mica. After application, the coating is dried and then cured at approximately 750°F. Thickness of the coating was approximately 0.16 to 0.20 mil per side.

3. M305 glass interlaminar insulation is a modified borosilicate composition. Prior to application of the glass, the magnetic alloy specimens are cleaned and degreased, lightly etched, and nickel-flashed with approximately 0.05 gram/sq. foot of nickel. The specimens are coated by dipping into a slip (suspension) which consists of the finely ground frit (minus 400 mesh) and an alcohol vehicle. The dried and unfired, coated pieces were then inserted into a preheated furnace at 1800°F and held for about 25 seconds. Thickness of coating was approximately 0.5 mil per side.

I. Thermophysical Properties

No thermophysical properties were determined for the interlaminar coatings.

II. Electrical Properties

A. Insulation Resistance, Unaged and After a Short Aging Period

Interlaminar insulation resistance values were determined at room temperature and at 100°F intervals to 1100°F on unaged specimens and specimens aged up to 96 hours in nitrogen. In some cases, it will be noted that the lower temperature data were collected at temperatures above room temperature up to 200°F. This condition resulted because, in order to conserve test time, the large heated electrode mass was not cooled to room temperature. The insulation resistance values at 200°F were sufficiently high to permit such operation.

The test values are summarized in Tables V.G-1 and V.G-2. The data are graphically presented in Figures V.G.1, V.G.2, V.G.3, V.G.4.

TABLE V. G-1. Insulation Resistance of Heat-Aged Interlaminar Insulations Measured at 100°F

Condition	Aluminum Orthophosphate (Thickness; 0. 13 mil/side)		Aluminum Orthophosphate + Mica + Bentonite (Thickness; 0. 18 mil/side)		Glass (Thickness; 0. 5 mil/side)	
	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)
As Coated	$>10^9$	-	$>10^9$	-	$>10^9$	-
Aged 100 hours at 800°F	$>10^9$	-	$>10^9$	-	$>10^9$	-
Aged 6 to 96 hours at 1100°F	3×10^8	4×10^6	6×10^7	2.7×10^5	4×10^6	1.4×10^5
Aged 0.5 to 1 hour at 1400°F	1×10^6	1×10^5	5×10^6	2×10^5	4×10^7 (a)	6×10^6 (a)
Aged 2 to 96 hours at 1400°F	2.6×10^4	1.5×10^3	5×10^6	2×10^5	1.2×10^4 (b)	-

(Coatings were aged at elevated temperatures and tested at 100°F on Cubex magnetic alloy panels, 0.012 inch thick, 6 x 6 inches square. The $\overline{X}$ values are arithmetic averages. The aging atmosphere was nitrogen.)

(a) Specimens aged 0.5 and 8 hours at 1400°F.
(b) Specimens aged 96 hours at 1400°F.

TABLE V.G-2. Insulation Resistance of Heat-Aged Interlaminar Insulations Measured at 1100°F

Condition	Aluminum Orthophosphate (Thickness; 0.13 mil/side)		Aluminum Orthophosphate + Mica + Bentonite (Thickness; 0.18 mil/side)		Glass (Thickness; 0.5 mil/side)	
	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)	$\overline{X}$ (ohm-cm^2 per lamination)	Minimum (ohm-cm^2 per lamination)
As Coated	4×10^3	4×10^1	1.3×10^4	6.5×10^2	1×10^4	7×10^3
Aged 100 hours at 800°F	3×10^3	5×10^1	1×10^4	3.4×10^2	1×10^4	4×10^3
Aged 6 to 96 hours at 1100°F	2×10^4	1.1×10^2	5×10^3	1.9×10^2	1.3×10^4	2.2×10^2
Aged 0.5 to 1 hour at 1400°F	4×10^2	6×10^1	3×10^2	1.2×10^2	6×10^4 (a)	5×10^3 (a)
Aged 2 to 96 hours at 1400°F	1×10^2	6×10^1	3×10^2	1.2×10^2	2×10^2 (b)	1.3×10^2 (b)

(Coatings were aged at elevated temperatures and tested at 1100°F on Cubex magnetic alloy panels, 0.012 inch thick, 6 x 6 inches square. The $\overline{X}$ values are arithmetic averages. The aging atmosphere was nitrogen.)

(a) Specimens aged 0.5 and 8 hours at 1400°F.
(b) Specimens aged 96 hours at 1400°F.

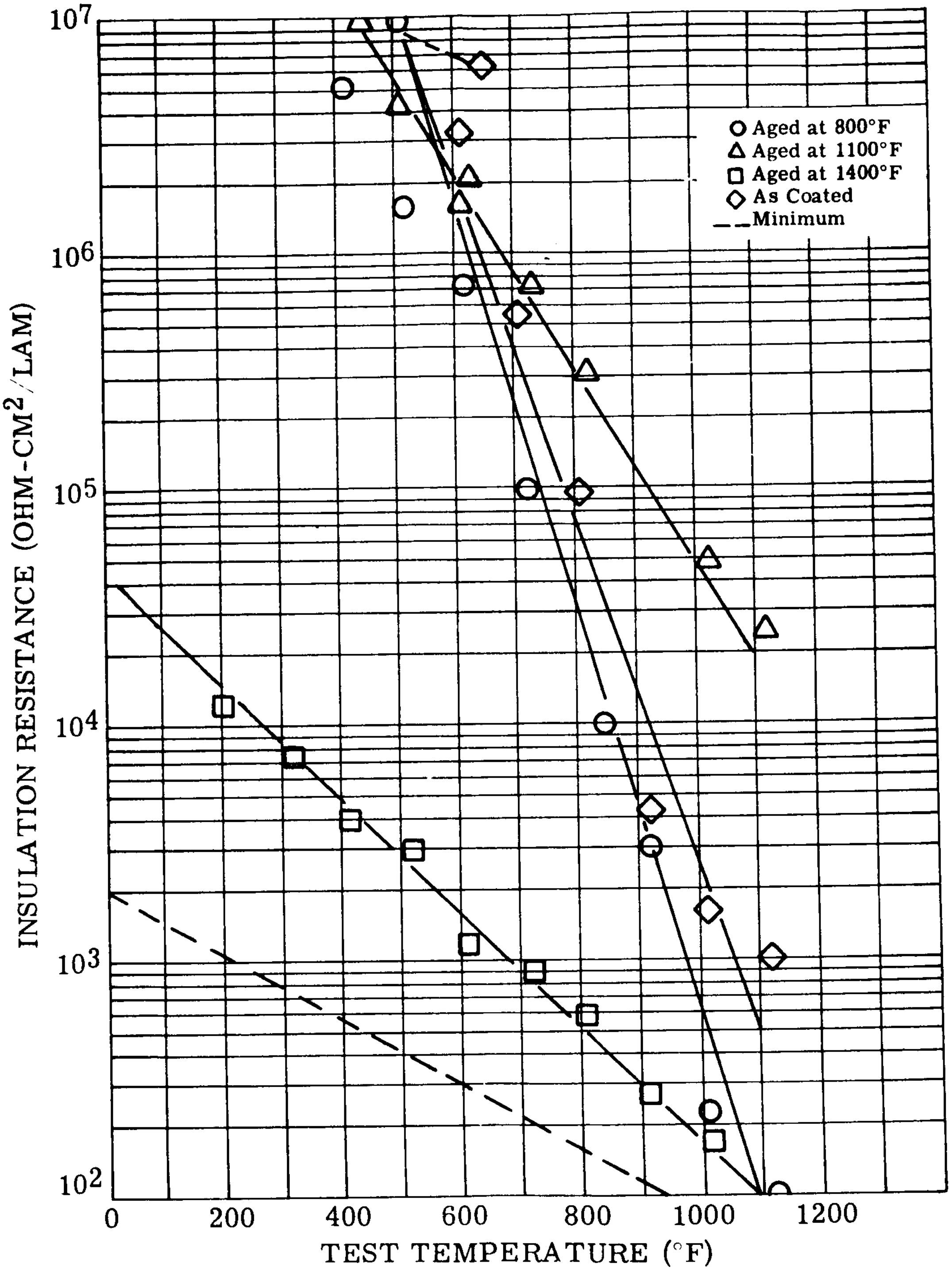


FIGURE V. G. 1. Insulation Resistance in Air of Interlaminar Insulation, Aluminum Orthophosphate, Unaged and Aged for 96 Hours at Indicated Temperatures in Nitrogen on Cubex Magnetic Alloy. Insulation Thickness 0.13 Mil Per Side. (Reference: NAS 3-4162)

Figure V.G. 1. Insulation Resistance - Interlaminar Insulation - Aluminum Orthophosphate

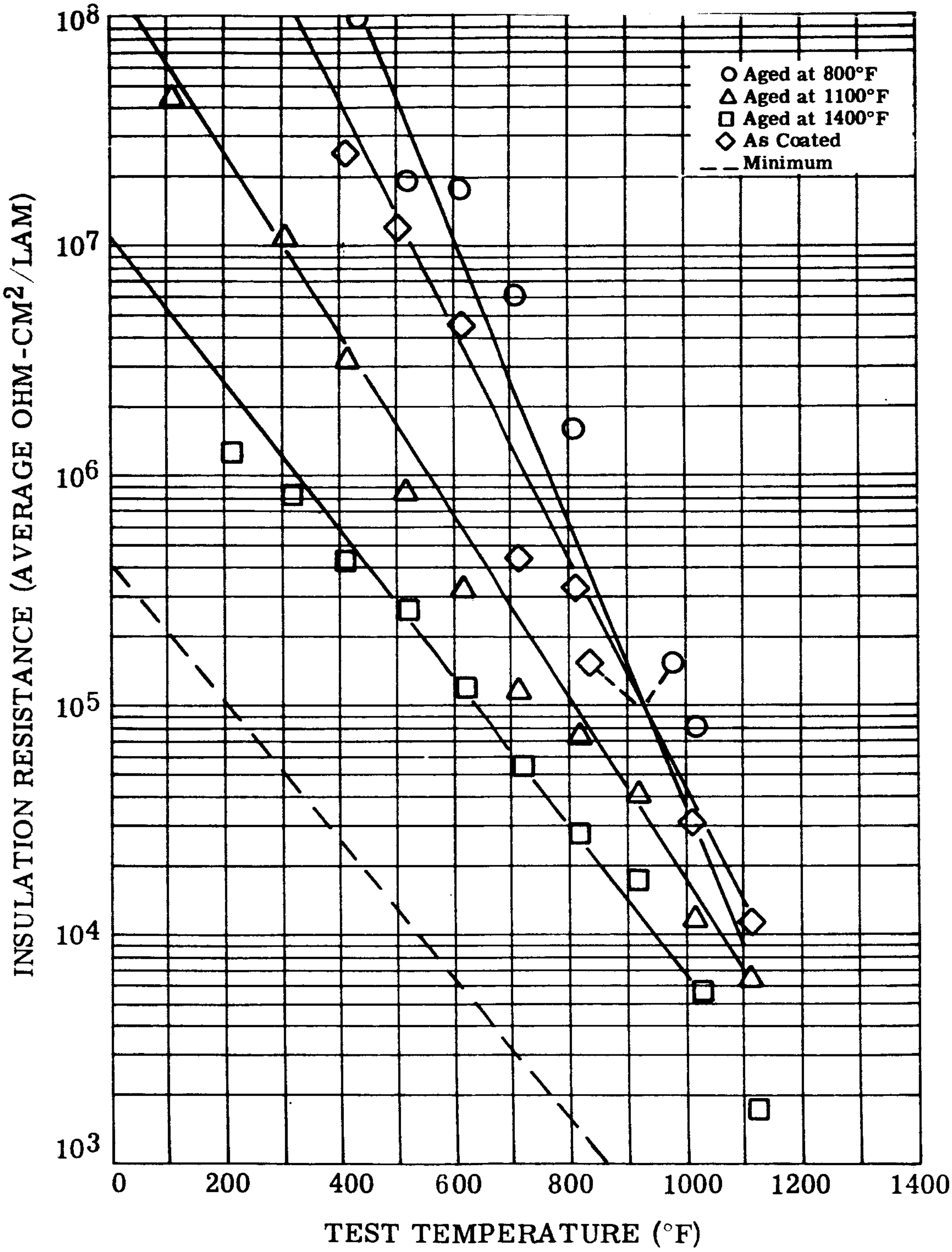


FIGURE V.G.2. Insulation Resistance in Air of Interlaminar Insulation, Aluminum Orthophosphate Plus Mica Plus Bentonite, Unaged and Aged for 96 Hours at Indicated Temperatures in Nitrogen on Cubex Magnetic Alloy. Insulation Thickness 0.18 Mil Per Side. (Reference: NAS 3-4162)

Figure V.G.2. Insulation Resistance - Interlaminar Insulation - Aluminum Orthophosphate + Mica + Bentonite

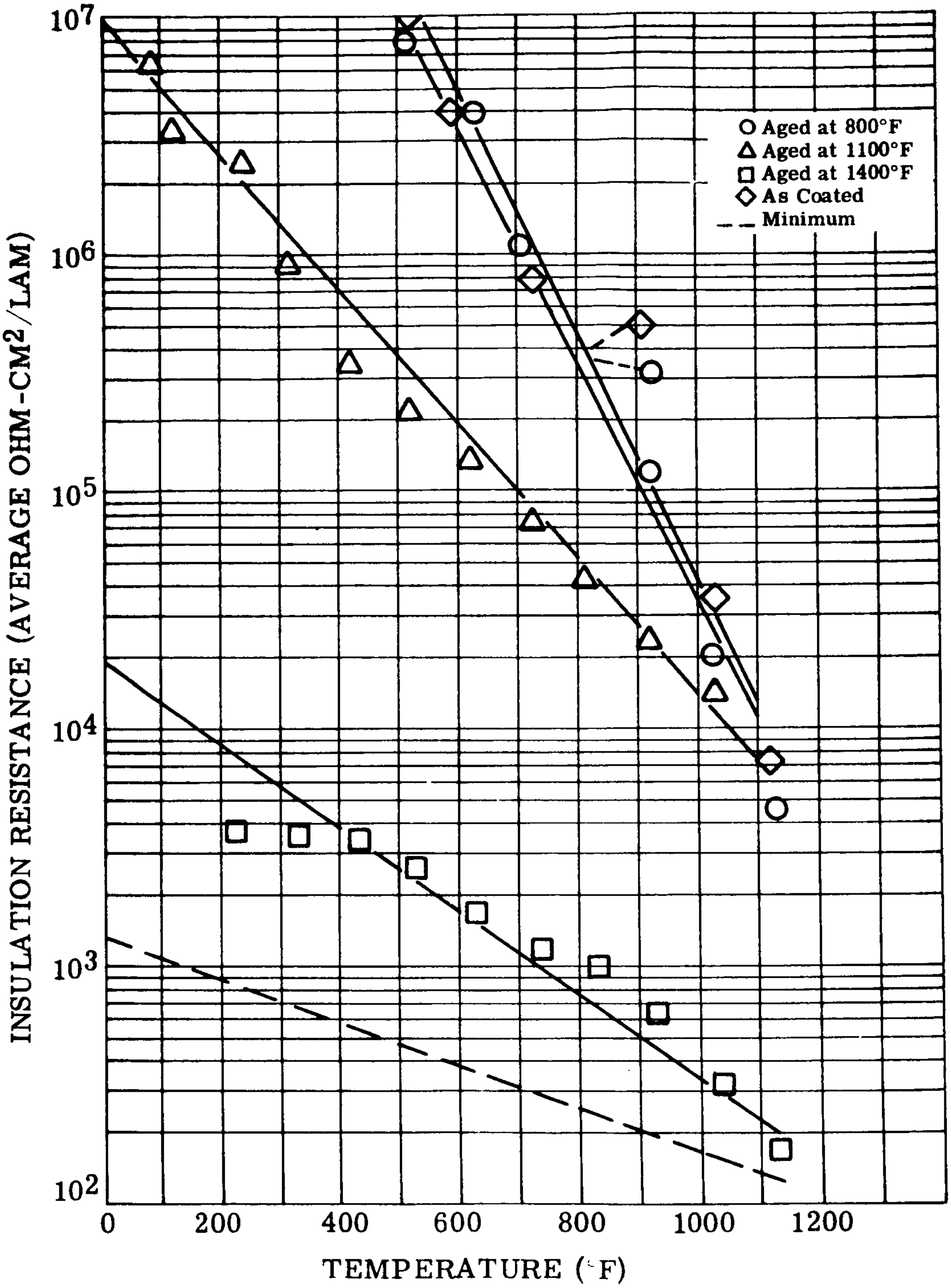


FIGURE V.G.3. Insulation Resistance in Air of Interlaminar Insulation, Glass, Unaged and Aged for 96 Hours at Indicated Temperatures in Nitrogen on Cubex Magnetic Alloy. Insulation Thickness 0.5 Mil Per Side. (Reference: NAS 3-4162)

Figure V.G.3. Insulation Resistance - Interlaminar Insulation - Glass

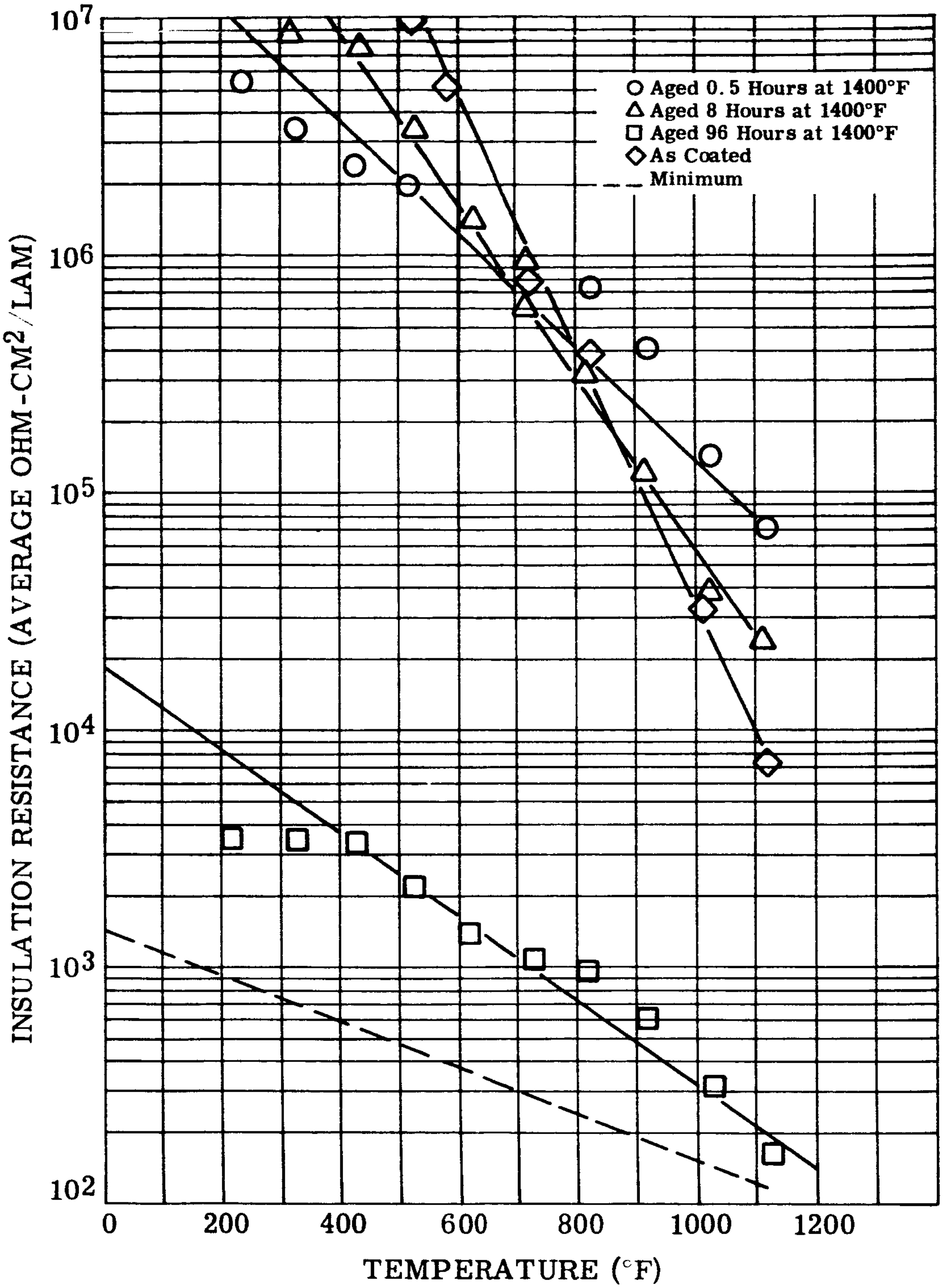


FIGURE V.G.4. Insulation Resistance of Interlaminar Insulation, Glass, Unaged and Aged in Nitrogen at 1400°F on Cubex Magnetic Alloy in Air. Insulation Thickness 0.5 Mil Per Side. (Reference: NAS 3-4162)

Figure V.G.4. Insulation Resistance - Interlaminar Insulation - Glass

B. Insulation Resistance, After Aging 1000 Hours at 1100°F in Argon

Interlaminar insulation resistance values were determined at room temperature on Cubex magnetic alloy specimens, 0.012 inch thick and 4 inches by 4 inches square. Measurements were made on unaged specimens, specimens aged 1000 hours at 1100°F, and specimens aged 1000 hours at 1400°F. The specimens were aged in argon and tested in air. The test values are summarized in Tables V.G-3 and V.G-4.

III. Mechanical Properties

No mechanical properties were determined for interlaminar coatings.

IV. Compatibility Properties

A. Compatibility of Aluminum Orthophosphate-Based Interlaminar Insulations with Annealed Cubex Magnetic Alloy

The compatibility of the two interlaminar coatings, aluminum orthophosphate and aluminum orthophosphate plus mica plus bentonite, with Cubex magnetic alloy was studied. Percent change in room temperature core loss values was determined by aging of Epstein specimens in nitrogen at elevated temperatures. The aging temperatures were 800°F, 1100°F, and 1400°F. Total aging time was 100 hours. Magnetic tests were performed at 60 cps at room temperature in accordance with ASTM A341. The data are presented in Table V.G-5. Percent changes in core loss values are presented in Tables V.G-6, V.G-7, and V.G-8 and Figures V.G.5 and V.G.6.

B. Compatibility of Interlaminar Insulation on Cubex Magnetic Alloy with Vacuum at 1100°F

Results of vacuum weight loss measurements are presented in Table V.G-9.

TABLE V.G-3. Interlaminar Insulation Life at 1100°F

Insulation	Interlaminar Insulation Resistance at 75°F					
	Face			Back		
	Insulation Thickness (mil)	Unaged (ohm-cm)	Aged (ohm-cm)	Insulation Thickness (mil)	Unaged (ohm-cm)	Aged (ohm-cm)
Aluminum Orthophosphate (Alkophos)	0.1	2.5×10^{-3}	5×10^{-2}	0.3	1.9×10^{-1}	2.2×10^{-1}
	0.1	5×10^{-3}	6×10^{-2}	0.25	1.3×10^{-1}	6.9×10^{-2}
	0.2	4×10^{-1}	5×10^{-2}	0.35	3.7×10^{-1}	1.9×10^{-1}
Aluminum Orthophosphate plus Mica plus Bentonite (MAB)	0.1	2×10^{6}	2×10^{-1}	0.25	2.6×10^{-1}	4.9×10^{-2}
	0.25	5×10^{4}	1.3×10^{-1}	0.3	1.7×10^{-1}	6.4×10^{-2}
	0.3	2×10^{4}	7.9×10^{-2}	0.4	1.5×10^{3}	1.7×10^{-1}
Glass (M305)	0.4	7.4×10^{3}	2.4×10^{1}	0.4	9.9×10^{1}	2.7×10^{1}
	0.4	9.9×10^{2}	7.4×10^{1}	0.4	9.9×10^{3}	3.3×10^{1}

Interlaminar insulation resistance was determined on coated Cubex magnetic alloy panels 4 inches by 4 inches, 0.012 inch thick. The three coatings were aluminum orthophosphate, aluminum orthophosphate plus mica plus bentonite, and glass prepared according to the sample preparation of Section V.G. Resistance measurements were made using a voltohmist and a 20.3 square centimeter, flat, circular stainless steel electrode. Pressure of the electrode on the film totaled 19 pounds. Both sides of the specimen panels were tested individually before and after aging. The specimens were aged at 1100°F in argon for 1000 hours.

(Reference: NAS3-4162)

TABLE V.G-4. Interlaminar Insulation Life at 1400°F

Insulation	Interlaminar Insulation Resistance at 75°F					
	Face			Back		
	Insulation Thickness (mil)	Unaged (ohm-cm)	Aged (ohm-cm)	Insulation Thickness (mil)	Unaged (ohm-cm)	Aged (ohm-cm)
Aluminum Orthophosphate (Alkophos)	0.1	2.5×10^{-2}	6.9×10^{-2}	0.2	9.9×10^{-3}	8.4×10^{-2}
	0.1	4.9×10^{-3}	6.4×10^{-2}	0.15	9.9×10^{-2}	7.9×10^{-2}
	0.1	4.4×10^{-2}	9.4×10^{-2}	0.1	2.5×10^{-2}	4.9×10^{-2}
Aluminum Orthophosphate plus Mica plus Bentonite (MAB)	0.3	2.5×10^{5}	3.4×10^{-1}	0.2	0.5×10^{-1}	1.1×10^{-1}
	0.4	9.8×10^{2}	1.1×10^{-1}	0.3	3.9×10^{5}	2.7×10^{-1}
	0.4	9.8×10^{6}	1.1×10^{-1}	0.2	4.4×10^{-2}	1.7×10^{-1}
Glass (M305)	0.5	4.9×10^{3}	3.9×10^{-1}	0.4	7.4×10^{4}	4.9×10^{3}
	0.4	1.5×10^{3}	5.2×10^{-1}	0.4	1.3×10^{2}	6.9×10^{-2}

Interlaminar insulation resistance was determined on coated Cubex magnetic alloy panels, 4 inches by 4 inches by 0.012 inch thick. The three coatings were aluminum orthophosphate, aluminum orthophosphate plus mica plus bentonite, and glass prepared according to the sample preparation of Section V.G. Resistance measurements were made using a voltohmist and a 20.3 square centimeter, flat, circular, stainless steel electrode. Pressure of the electrode on the film totaled 19 pounds. Both sides of the specimen panels were tested individually before and after aging. The specimens were aged at 1400°F under argon cover gas for 1000 hours.

(Reference: NAS 3-4162)

TABLE V.G-5. Core Loss and Exciting Volt-Ampere Data for Cubex Magnetic Alloy Aged with Aluminum Orthophosphate Based Interlaminar Insulations. (Aged in Nitrogen, 0.012 inch thick, tested at 60 cps and room temperature according to ASTM A341)

Interlaminar Insulation	Insulation Thickness (mils per side)	Aging Temperature (°F)	Aging Time (hours)	Core Loss (Watts Per Pound)		Exciting Volt-Amperes (Volt-Amperes Per Pound)	
				At 10 kilogauss	At 15 kilogauss	At 10 kilogauss	At 15 kilogauss
Aluminum Orthophosphate	0.13	800	0	0.370	0.778	0.395	1.03
		800	100	0.371	0.758	0.394	0.94
		1100	0	0.367	0.770	0.396	1.03
		1100	6	0.371	0.767	0.393	0.978
		1100	24	0.362	0.764	0.384	0.992
		1100	96	0.367	0.764	0.392	0.989
		1400	0	0.337	0.783	0.405	1.05
		1400	1	0.399	0.807	0.421	1.05
		1400	4	0.419	0.827	0.442	1.03
		1400	24	0.420	0.837	0.444	1.07
		1400	96	0.419	0.850	0.445	1.11
Aluminum Orthophosphate plus Mica plus Bentonite	0.18	800	0	0.370	0.773	0.395	0.976
		800	100	0.373	0.773	0.400	0.976
		1100	0	0.380	0.783	0.406	0.986
		1100	6	0.374	0.766	0.395	0.969
		1100	24	0.376	0.783	0.396	1.02
		1100	96	0.375	0.789	0.401	1.04
		1400	0	0.374	0.781	0.399	1.00
		1400	1	0.386	0.794	0.408	1.01
		1400	4	0.410	0.821	0.434	1.02
		1400	24	0.427	0.844	0.454	1.06
		1400	96	0.441	0.877	0.492	1.17
None	--	800	0	0.359	0.767	0.373	1.03
		800	100	0.367	0.780	0.393	1.05
		1100	0	0.361	0.756	0.385	0.974
		1100	6	0.390	0.803	0.412	1.03
		1100	24	0.375	0.816	0.397	1.13
		1100	96	0.392	0.867	0.432	1.33
		1400	0	0.362	0.757	0.387	0.967
		1400	1	0.380	0.767	0.400	0.971
		1400	4	0.385	0.777	0.406	0.964
		1400	24	0.409	0.804	0.433	1.00
		1400	96	0.422	0.824	0.455	1.05

TABLE V. G-6. Percent Change in 75°F Core Loss Values After Aging Aluminum Orthophosphate Coated Annealed Cubex Alloy at Various Times and Temperatures in Nitrogen.
(Insulation Thickness, 0.13 mil Per Side)

Aging Temperature (°F)	Percent Change Versus Aging Time[a]					
	(1 hr)	(4 hr)	(6 hr)	(24 hr)	(96 hr)	(100 hr)
			10 Kilogauss			
800°F	-	-	-	-	-	+0.3
1100°F	-	-	+1.1	-1.4	0	-
1400°F	+5.8	+11.1	-	-11.4	+11.4	-
			15 Kilogauss			
800°F	-	-		-	-	+2.6
1100°F	-	-	0.4	-0.8	-0.8	-
1400°F	+3.1	+5.6		+6.9	+8.6	-

(a) Percent Change = $\frac{\text{Watts/pound (as coated)} - \text{watts/pound (aged)}}{\text{Watts/pound (as coated)}} \times 100$

(Reference: NAS 3-4162)
and recent unpublished Westinghouse Data

TABLE V.G-7. Percent Change in 75°F Core Loss Values After Aging Aluminum Orthophosphate Plus Mica Plus Bentonite Coated Annealed Cubex Alloy at Various Times and Temperatures in Nitrogen.
(Insulation Thickness, 0.18 mils Per Side)

Aging Temperature (°F)	Percent Change Versus Aging Time (a)					
	(1 hr)	(4 hr)	(6 hr)	(24 hr)	(96 hr)	(100 hr)
			10 Kilogauss			
800°F	-	-	-	-	-	+0.8
1100°F	-	-	-1.6	-1.1	-1.3	-
1400°F	+3.2	+9.6	-	+14.1	+17.9	-
			15 Kilogauss			
800°F	-	-	-	-	-	0
1100°F	-	-	-2.2	0	+0.8	-
1400°F	+1.7	+5.1	-	+8.1	+12.3	-

(a) Percent Change $= \frac{\text{Watts/pound (as coated)} - \text{Watts/pound (aged)}}{\text{Watts/pound (as coated)}} \times 100$

(Reference: NAS 3-4162)
and recent unpublished Westinghouse Data

TABLE V.G-8. Percent Change in 75°F Core Loss Values After Aging Uncoated Annealed Cubex Alloy at Various Times and Temperatures in Nitrogen

Aging Temperature (°F)	Percent Change Versus Aging Time[a] (1 hr)	(4 hr)	(6 hr)	(24 hr)	(96 hr)	(100 hr)
			10 Kilogauss			
800°F	-	-	-	-	-	+2.2
1100°F	-	-	+8.0	+3.9	+8.6	-
1400°F	+5.0	+6.4	-	+13.0	+16.6	-
			15 Kilogauss			
800°F	-	-	-	-	-	+1.7
1100°F	-	-	+6.2	+7.9	+14.7	-
1400°F	+1.3	+2.6	-	+6.2	+8.9	-

(a) Percent Change $= \frac{\text{Watts/pound (as coated)} - \text{Watts/pound (aged)}}{\text{Watts/pound (as coated)}} \times 100$

(Reference: NAS 3-4162)
and recent unpublished Westinghouse Data

TABLE V.G-9. Weight Loss on Vacuum Heat Aging (24 hours at 1112°F at 10^{-6} torr)

Interlaminar Insulation on 0.012 Inch Cubex	Insulation Thickness (mil/side)	Weight Loss
1. Aluminum Orthophosphate	0.13	None
2. Aluminum Orthophosphate plus Mica plus Bentonite (MAB)	0.18	None
3. M305 Glass	0.5	None

NOTE: These specimens showed no weight loss within the accuracy of the method of measurement, which is ± 1.2 milligrams.

During the weight loss determination of these materials, no significant increase in pressure developed as the temperature was raised from the drying temperature of 212°F to test temperature. This is an indication of the absence of volatile materials.

(Reference: NAS 3-4162)

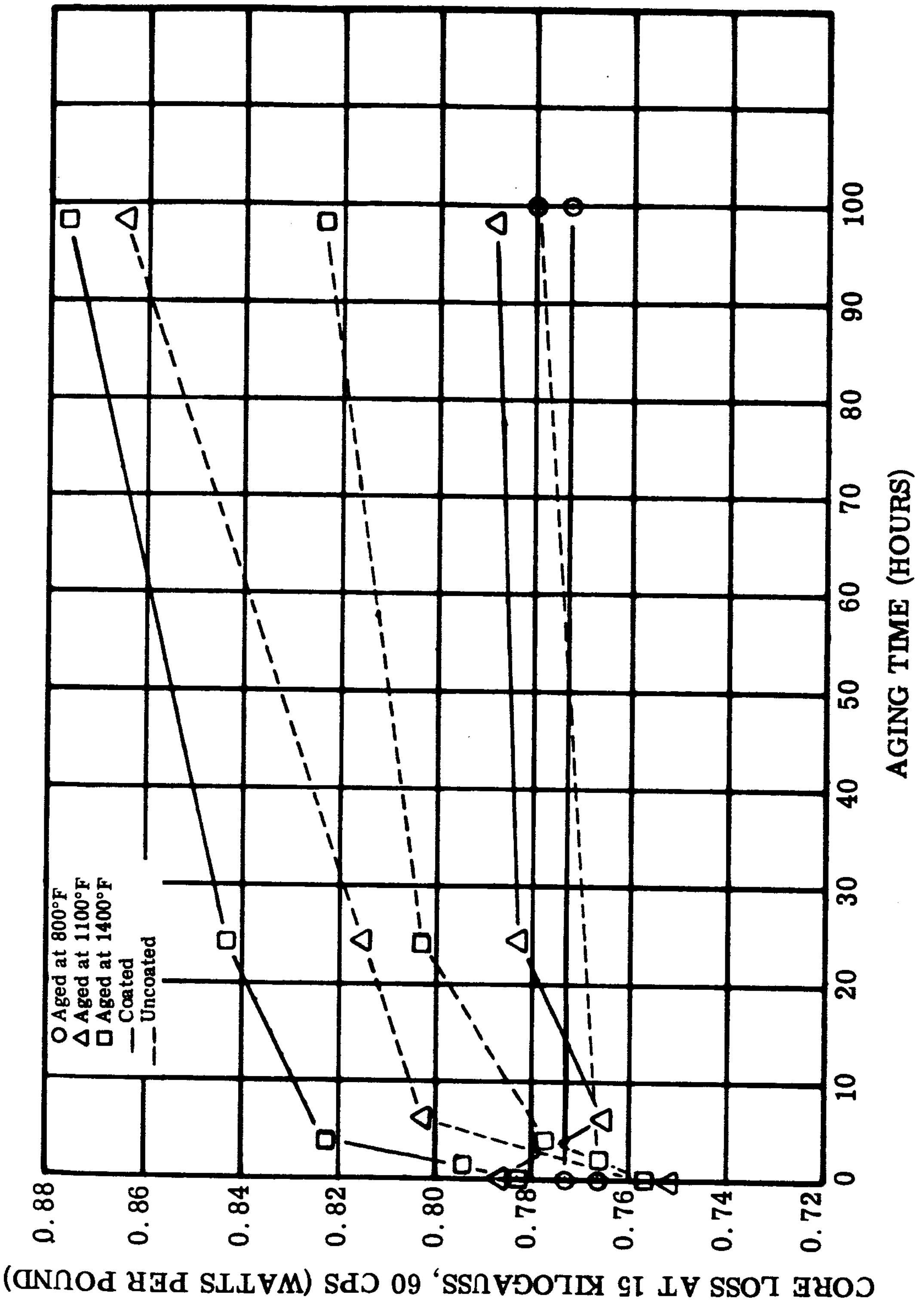


FIGURE V.G.6. Core Loss Data for Cubex Magnetic Alloy, Aged with Aluminum Orthophosphate Plus Mica Plus Bentonite Interlaminar Insulation. (Insulation Thickness, 0.18 Mil Per Side on 0.012 Inch Thick Magnetic Alloy, Tested at 60 cps, 15 Kilogauss, and Room Temperature, According to ASTM A341.) (Reference: NAS3-4162)

Figure V.G.6. Core Loss of Cubex with Aluminum Orthophosphate Plus Mica Plus Bentonite Insulation

APPENDIX A

DEFINITIONS

1.	Clad Area:	That percentage of a conductor's total cross-sectional area which is made up of a cladding material. The cladding material is usually selected for oxidation or alkali metal resistance and its metallurgical compatibility with the conductor core.
2.	Cut-Through Resistance:	The resistance of an insulating film or composite to penetration by a test object under influence of heat and/or pressure. Temperature, pressure, or time is varied with the remaining two parameters held constant. The test object is shaped in a manner to reproduce closely the anticipated application conditions.
3.	Dielectric Loss Factor:	The dielectric loss factor (or dielectric loss index) is defined as the product of the dielectric constant and the tangent of dielectric loss angle.
4.	Dissipation Factor:	The tangent of the loss angle or the cotangent of the phase angle of an insulating material. (LI295)
5.	Insulation Life:	The time of heat aging that a material or insulation system can withstand before failing a specific mechanical or electrical test. The failure point is dependent upon the intended application. This test concept is sometimes named heat endurance.
6.	Pot Life:	The length of time during which a catalyzed organic resin system or a reactive inorganic encapsulant system may be poured or worked without deterioration of desired in situ performance properties.
7.	Power Factor:	A numerical dimensionless value expressing the ratio of the power dissipated in an insulating material (watts) to the product of the effective voltage and current when tested in a sinusoidal

		electrical field under prescribed conditions of voltage gradient, frequency, temperature and previous (conditioning) treatment. The power factor numerically is equivalent to the cosine of the dielectric phase angle or the sine of the dielectric loss angle.	
8.	Thermal Conductivity, Apparent Transverse:	The thermal conductivity measured diametrically across the cross-section of the insulated conductor when the conductor is arranged in a flat spiral as illustrated in Figure III. B-8.	(LI295)

APPENDIX B

BIBLIOGRAPHY

Appendix B presents a bibliography abstracted during the literature search phase of the program. The following is a summary of the general sources consulted during the search:

References on Electrical Conductor and Insulation Materials

1) Chemical Abstracts, 1958-1962
2) Society of Plastic Industries - Reinforced Plastics Division - Annual Technical and Management Conference, 1958 to 1963
3) Plastec Report 8 - A Bibliography of Technical Conference Papers on Plastics, March 1960 - February 1961.
4) Plastec Report 11 - A Bibliography of Technical Conference Papers on Plastics, February 1961 - February 1962.
5) Plastec Report 12 - A Bibliography of the Effects of Space Environment on Plastics, July 1962.
6) AD No. 267890 - The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials, September 1961.
7) Society of Plastic Engineers Antec Reprints, 1958 to 1963
8) Applied Science and Technology Index, 1958 - 1963
9) Engineering Index, 1959 - 1962
10) Technical Abstract Bulletins - Defense Documentation Center, 1960 - 1963
11) Quarterly Progress Reports AF(657)8097
12) International Aerospace Abstracts, 1961 - 1963
13) Scientific and Technical Aerospace Reports, 1957 - 1963
14) Nuclear Science Abstracts, 1960 - 1963
15) U.S. Government Research Reports, 1960 to 1963
16) Ceramic Abstracts, 1957 - 1963
17) ASM Review of Metal Literature, 1948 - 1963
18) Current Contents of the Worlds Technical Literature, 1963
19) Metallurgical Abstracts, 1958 to 1962
20) Thermophysical Properties Research Center (TPRC)
21) Electronic Properties Research Center (EPIC)
22) Mechanical Properties Data Center (MPDC)
23) Defense Metals Information Center (DMIC)
24) WADC Technical Reports 53.373 Supplements 1-9, 1954 - 1962

25) Digest of Literature on Dielectrics, 1956 - 1961
26) EpoxyResin by Lee and Neville, McGraw-Hill 1957
27) Laminated Plastics by Duffin and Nerzig, Reinhold 1958
28) Epoxy Resins by Skeist, Reinhold 1958
29) Electronic Packaging with Resins by Harper, McGraw-Hill 1961
30) High-Temperature Plastics by Brenner, etal, Reinhold 1962
31) Insulating Materials for Design and Engineering Practice by Clark, Wiley 1962
32) Modern Dielectric Materials by J. B. Birks, Editor, Heywood Press, 1960
33) Materials Science and Technology for Advanced Applications by D. R. Mash, Editor, Prentice-Hall, 1962
34) Mechanical Properties of Ceramics, Kriegel and Palmour, Interscience 1961
35) High-Temperature Technology by Campbell, Wiley 1956
36) Materials for Missiles and Space craft, by Parket, McGraw-Hill, 1963
37) Oxide Ceramics by E. Ryshkewitch, Academic Press, 1960
38) The Physics and Chemistry of Ceramics by C. Klingsberg. Published by Gordon and Breach 1963
39) Dielectric Materials and Applications, by VonHippel, The Technology Press of MIT, Wiley 1954
40) Various in-house reports and vendor literature.

The bibliography was prepared for IBM punched cards. It deviates from the conventional practice of presenting references, but is of added value because of the additional information which it presents. Titles of papers often deceive the reader, therefore, a "keyword" or "descriptor" was defined for each reference. A code number at the end of the reference alerts the reader to the type of property information available. The code selected is as follows:

0 Not applicable to this study, but considered of sufficient general interest to warrant reporting.
1 Mechanical properties other than creep and fatigue
2 Creep
3 Fatigue combined loading
4 Welding, joining, fabricability
5 Magnetic properties
6 Thermo-physical properties other than electrical
7 Electrical properties
8 Compatibility, environmental, other than liquid metal
9 Compatibility, with liquid metal

The punched card format required three 80 column cards to complete the reference. The format used in printing follows:

Line		
1	Bibliographic Sheet No. Material Name or Descriptor	Author
2	Bibliographic Sheet No. Title	
3	Bibliographic Sheet No. Periodical, Report or Book Reference	Property Information

The property information code prints in columns 70-79 of the third line and allows a standard card sorter to be used when a search for specific properties is initiated. The cards can also be computer programmed if a more complicated search is required. The second letter of the Bibliographic Sheet Number indicates the type of material to which the reference pertains: LC or RC being electrical conductor materials and LI or RI being electrical insulation materials. The prefix L or R identifies the reviewing source which is either the Westinghouse Aerospace Electrical Division or the Westinghouse Research and Development Center respectively.

Two print outs are presented in this Appendix: One listing the references in numerical sequence; and a second listing the keywords in alphabetic order.

Topical Arrangement	Electrical Conductors Page	Electrical Insulation Page
Numerical Listing	638 to 646	656 to 699
Keyword Alphabetic Listing	647 to 655	700 to 743

```
LC1     TUNGSTEN-COPPER        MCDANIELS D L  JECH R W  WEETON J W
        STRESS STRAIN BEHAVIOR OF TUNGSTEN FIBER REINFORCED COPPER COMPOSITES
        NASA TECHNICAL NOTE D-1881 SEPT 1963                          0

LC2     850C WIRE              BOBER E S  SNAVELY W H   STAPLETON R E
        MONTHLY STATUS LETTER HOT WIRE PROJECT
        AERONAUTICAL SYS DIV AF33(657)10701 SEPT 13 1963                     7 9

LC3     CB COATED COPPER       GARDNER A R
        WHATS COMING IN CONDUCTORS TO 1000 F
        PRODUCT ENGINEERING P82-6 AUG 7 1961                              4

LC4     DH NICKEL              BONIS L J
        A NEW APPROACH TO HIGH TEMPERATURE STRENGTH
        MATERIALS IN DESIGN ENGRG P104 OCT 63                             4

LC6     NOBLE METAL DH ALLOY   GIMPL M L LAINE N R SHULTZ C W
        RESEARCH ON ELECTRICAL CONDUCTORS FOR HIGH TEMPERATURE APPLICATIONS
        FIRST QUARTERLY REPT CONTRACT AF33 657 11212 JULY 1 1963      0

LC7     CONDUCTORS-HIGH TEMP   GIMPL,M.L. CHILDS,E.E. ELIASON,L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR INC. 1ST QUAR REPT AF33(657)-11046 APR 3-JULY 5,1963   0

LC8     CONDUCTORS-HIGH TEMP   GIMPL, M.L.  CHILDS, E.E.  ELIASON, L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR INC 2ND QUAR REPT AF33(657)-11046 JULY 5-OCT 5, 1963   0

LC9     CONDUCTORS-HIGH TEMP   GIMPL, M.L.  CHILDS, E.E.  ELIASON, L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR 3RD QUAR REPT AF33(657)-11046 OCT 5-JAN 5,1964         0

LC10    CONDUCTORS GENERAL     CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR SERVICE AT 500 DEGREE C
        ELECTRICAL DESIGN NEWS JULY 1962                                1   67 9

LC11    TUNGSTEN MOLYBDENUM    FANSTEEL CORP ET AL
        ELECTRICAL RESISTIVITY OF TUNGSTEN AND MOLYBDENUM
        ELECTRICAL PROP INFORMATION CENTER DATA SHEETS DEC 1963              7
```

```
RC1     CHROMIUM CU            ZAKHAROV M V  ETAL
        CU BASE CONDUCTOR ALLOYS WITH IMPROVED ELEVATED TEMP STRENGTH
        METALLOVEDINIE 1 TERM OBRABOTKA METTALLOV V9 P25-9 SEPT 1960        1    67

RC2     CER COAT CU WIRE       LARSSEN A
        CERAMIC DIELECTRICS
        INSULATION PERIODICAL V 9,10 P27-32 SEPT 1963                       1    678

RC3     MOLYBDENUM             PELLINI W S
        MATERIALS REQUIREMENTS FOR HYPERSONIC FLIGHT VEHICLES
        JOURNAL OF METALS P954-63 DEC 1960                                0

RC4     SERVICE COND GENL      MORSE J G
        ENERGY FOR REMOTE AREAS
        SCIENCE VOL 139 NO 3560 P1175-80 MAR 22,1963                               8

RC5     CU TA OR CB BARRIER    PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850C
        TDR NO ASD TDR 63-164 ANACONDA WIRE AND CABLE CO JULY 1963          1    6789

RC6     SILVER                 RICKS H E TRUMBETTA R D
        LITERATURE SURVEY OF CONDUCTORS AND CONDUCTOR JOINING
        (W) MATERIALS ENGRG REPORT NO 5805-6183 MAY 29 1958                 12 4 678

RC7     STAINLESS CLAD CU      CARLSON C L
        ENGRG DATA ON CONDUCTORS FOR ELEVATED TEMP  500C  SERVICE
        (W) MATERIALS LABS RPT NO 6162-5627 FEB 28,1961                     12 4 678

RC8     NICKEL CLAD CU         HOWELL J R
        COMPOSITE WIRE FOR OPERATION AS ELECTRICAL CONDUCTORS AT ELEV TEMP
        PAPER AT 7TH ANNUAL WIRE AND CABLE SYMPOSIUM DEC 2,3,4,1958         1    67

RC9     STAINLESS CLAD CU      HOWELL J R
        COMPOSITE WIRES FOR OPERATION AS ELEC CONDUCTORS AT ELEVATED TEMP
        PAPER AT 7 ANNUAL WIRE AND CABLE SYMPOSIUM DEC 2,3,4,1958           1    67

RC10    COPPER                 RICKS H E  TRUMBETTA R D
        LITERATURE SURVEY OF CONDUCTORS AND CONDUCTOR JOINING
        (W) MATERIALS ENGRG RPT NO 5805-6183                                12 4 678
```

```
RC11   ZIRCONIUM CU            SAKHAROV V M  ET AL
       CU BASE CONDUCTORS WITH IMPROVED ELEVATED TEMP STRENGTH
       METALLOVEDEHIE 1 TERM OBRABOTKA V9 P22-9  SEPT 1960          1  4 67

RC12   SS CLAD CD CU           MOREDOCK A E
       PRIVATE COMMUNICATION A E MOREDOCK TO D H LANE
       PRIVATE COMMUNICATION MOREDOCK TO LANE SEPT 26,1963          123456789

RC13   CU MOLYBDENUM COAT
       NEW PROCESS FOR ELECTROCLADDING AND ELECTROFORMING REFRACTORY METALS
       PUBL OF UNION CARBIDE CORP 1963                                  4

RC14   INCONEL CLAD CU TA      UNION CARBIDE
       NEW PROCESS OF ELECTROCLADDING AND ELECTROFORMING REFRACTORY METALS
       PUBL UNION CARBIDE CORP 1963                                     4

RC15   NICKEL                  SHANINIAN P ACHTER M R
       CREEP RUPTURE OF NICKEL OF TWO PURITIES IN CONTROLLED ENVIRONMENTS
       NAVAL RESEARCH LAB RPT NO 5850 JAN 22,1963                     2

RC16   NI CLAD CU              ANON
       CERAMIC-EZE
       PUBL OF PHELPS DODGE CU PROD CORP JAN 15 1963                 0

RC17   NI CLAD CU              ANON
       NICKEL CLAD COPPER WIRE
       PUBL OF RIVERSIDE-ALLOY METAL DIV OF HK PORTER CO BULL T-3     1     7

RC18   S S CLAD CU WIRE        ANON
       STAINLESS CLAD COPPER WIRE OXALLOY 28
       TECHNICAL INFORMATION BULLETIN SYLVANIA ELEC CO JUNE 1958      1 3   7

RC19   AG CLAD CU              ANON
       MULTILAYER CLAD BASE METALS
       PUBL METALS CONTROLS DIV OF TEXAS INSTRUMENTS GP 18 MAY 1961  0

RC20   ZIRCALOY                MOCK J W
       BARRIER LAYERS TO PREVENT SOLID STATE METAL TO METAL REACTIONS
       (W) MTLS MFG DEPT RPT 359-E808-1010 MAR 9 1959                0
```

```
RC21   AL CLAD CU             CARLSON C L
       DEVELOPMENT OF AL CLAD CU MAGNET WIRE
       (W) MTLS ENGRG DEPT RPT 5602-9 FEB 29 1956                   0

RC22   COPPER                 THOMAS R H DEXTER J F
       EFFECT OF WIRE METAL ON THERMAL LIFE OF ENAMELED MAGNET WIRE
       AIEE POWER APP SYSTEMS V33 P1009-13 DEC 1957                      6

RC23   10 NI CLAD CU          CARLSON C L
       NI CLAD WIRE AS AN ELECTRICAL CONDUCTOR
       (W) MTLS ENGRG RPT 5604-2511 APR 20,1956                           78

RC24   28SS CLAD CU           PENDLETON W W
       RADIATION RESISTANT MAGNET WIRES FOR USE IN AIR AND VACUUM AT 850 DEG C
       ANACONDA WIRE AND CABLE CO RPT ASD-TDR-63-164 JULY 1963            78

RC25   INCONEL CLAD CU        PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
       ASD-TDR-63-164 ANACONDA WIRE AND CABLE CO JULY 1963                78

RC26   25INCONEL CLAD AG      PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
       ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963      1     78

RC27   INCONEL CLD CU ZR203   PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
       ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963            78

RC28   23 NI CLAD AG          PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
       ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963            78

RC29   NI PLATED CU           PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
       ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963            78

RC30   NI CLAD CU             PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
       ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963            78
```

```
RC31    NI-FE CLAD CU           PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
        ASD-TDR-63-164 REPT ANACONDA WIRE AND CABLE CO JULY 1963                 78

RC32    INCONEL CLAD DS CU      PENDLETON W W
        RADIATION RESISTANT MAGNET WIRES FOR USE IN AIR OR VACUUM AT 850 DEG C
        6 INTERIM SCIENTIFIC RPT CONTRACT AF33(657)7473 JULY 1963                78

RC33    AG-MN-NI                CARLSON C C
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP 500 DEG C SERVICE
        (W) MATERIALS ENGRG RPT 6162-5627 FEB 28 1961                         2   7

RC34    INCONEL CLAD CU         CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR SERVICE AT ELEVATED  500 DEG C  TEMP
        (W) MTLS ENGRG RPT 6162-5627 FEB 28 1961                                  7

RC35    INCONEL CLAD CU         CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP 500 DEG C SERVICE
        (W) MTLS ENGRG RPT 6162-5627 FEB 28 1961                                  7

RC36    NI CLAD CU              CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP  500 DEG C  SERVICE
        (W) MTLS ENGRG REPORT 6162-5627 FEB 28,1961                           2  78

RC37    NI PLATED CU            CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP  500 DEG C  SERVICE
        (W) MTLS ENGRG REPORT 6162-5627 FEB 28,1961                           1  78

RC38    T D NICKEL              MANNING C R ET AL
        INVESTIGATION OF A NEW NI ALLOY STRENGTHENED BY DISPERSED THORIA
        NASA LANGLEY RESEARCH CENTER PUBL TN D1944 JULY 1963                  1 4 8

RC39    MOLYBDENUM              STAFF OF CLIMAX MOLYBDENUM CO OF MICH
        MOLYBDENUM IN METAL
        TECHNICAL DATA 1960                                                 12 4 67

RC40    COPPER D S              PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR VACUUM AT 850 DEG C
        ANACONDA WIRE AND CABLE CO FIG 10 TABLE VII JULY 1963                12
```

```
RC41   MOLYBDENUM              FUSCHILLO N LINDBERG R A
       ELECTRICAL CONDUCTORS AT ELEVATED TEMPERATURES
       MELPAR ASD-TDR-62-481 JUNE 1962                                         12 4 678

RC42   CU MOLYBDENUM COATED    FUSCHILLO N LINDBERG R A
       ELECTRICAL CONDUCTORS AT ELEVATED TEMP
       MELPAR ASD-TDR-62-481 P46 JUNE 1962                                        4

RC43   COPPER D S              FUSCHILLO N LINDBERG R A
       ELECTRICAL CONDUCTORS AT ELEVATED TEMP
       MELPAR ASD-TDR-62-481 P297-98 FIG 16 17 P399 JUNE 1962                  12     7

RC44   MOSI 2 COATED CU        FUSCHILLO N LINDBERG R A
       ELECTRICAL CONDUCTORS AT ELEVATED TEMP
       MELPAR ASD-TDR-62-481 P342 374 385 JUNE 1962                                 6 8

RC46   INCONEL CLAD CU         STAFF KENTUCKY ELECTRONICS
       PRIVATE COMMUNICATION ON SOURCES OF INCONEL CLAD COPPER
       LETTER FROM KY ELECTRONICS QUEENSBORO KY TO LIMA APR 2 1963        0

RC47   28SS CLAD CU            STAFF OF PHELPS DODGE COPPER PRODUCTS CO
       RESISTIVITY CURVES
       REPORT FROM PHELPS DODGE COPPER PRODUCTS CO 1963                               7

RC48   NI CLAD CU              STAFF PHELPS DODGE COPPER PRODUCTS CO
       RESISTIVITY CURVES
       PHELPS DODGE COPPER PRODUCTS CO 1963                                           7

RC49   NI CLAD CU              STAFF PHELPS DODGE COPPER PRODUCTS CO
       DATA SHEET PHELPS DODGE COPPER PRODUCTS CO
       P/D DATA SHEET NOT DATED                                                       7

RC50   INCONEL CLAD CU         STAFF PHELPS DODGE COPPER PRODUCTS CO
       DATA SHEET FROM PHELPS DODGE COPPER PRODUCTS CO
       P/D DATA SHEET 1963                                                            7

RC51   NI CLAD SILVER          STAFF PHELPS DODGE COPPER PRODUCTS CO
       DATA SHEET FROM PHELPS DODGE COPPER PRODUCTS CO
       P/D DATA SHEET 1963                                                            7
```

```
RC52   S S CLAD COPPER        STAFF METALS AND CONTROLS DIV TEXAS INSTRUMENTS
       MULTICLAD WIRE
       BULLETIN WT-3 OF METALS AND CONTROLS DIV OF TEX INSTRU 1962      1     7

RC53   COATED COPPER          HAYNES STELLITE DIV UNION CARBIDE
       HAYNES DIFFUSION COATINGS
       PUBL F-30 190C P16 NOV 1963                                         4

RC54   STAINLESS CLD CU       SYLVANIA ELECTRIC PROD INC
       HOW SYLVANIA SHOULDERS DESIGN AND PRODUCTION PROBLEMS
       PAMPHLET NO DATE                                                    4

RC55   STAINLESS CLAD CU      SYLVANIA ELECTRIC PROD CO
       PRICES SYLVANIA ELEC PROD CO WARREN PA
       PAMPHLET P16 NOV  29 1962                                           4

RC56   COATED COPPER          GARDNER A R
       WHATS COMING IN CONDUCTORS TO 1000 DEG F
       PRODUCTS ENGINEERING P82-86 AUG 7 1961                              4

RC57   TD NICKEL              E I DUPONT CO
       TD NICKEL DISPERSION STRENGTHENED NICKEL
       PAMPHLET P44 OCT 1962 1963                                       12    78

RC58   CLAD COPPER            SYLVANIA ELEC PROD CO
       KULGRID 28
       BULLETIN OCT 1957                                                 1     7

RC61   CLAD COPPER            BISHOFF R W
       OXIDATION OF NI CLAD CU WIRE
       WESTINGHOUSE ENGRG REPORT 6031-2066 FEB 8 1960                      4   8

RC62   DS SILVER              SCHETKY L M
       DISPERSION STRENGHTENING OF SILVER
       MIT REPORT R-153 JUNE 1957                                        1     7

RC63   DS COPPER BEO          PRICE B R
       PRIVATE COMMUNICATION
       LETTER AND DATA P5 NOV  2 1961                                    1     7
```

```
RC64   STAINLESS CLAD CU      WIRE AND CABLE DIV CERRO CORP
       AEROSPACE AND ELECTRONIC WIRES AND CABLES
       PAMPHLET WIRE AND CABLE DIV CERRO CORP P18 1963                    1      8

RC66   CERAMIC COATED CU      DUCKWORTH W ET AL
       CERAMIC COATED COPPER WIRE
       AMERICAN CERAMIC SOC BULLETIN V38 P251-55 MAY 1959                0

RC67   MOLYBDENUM             GATZEK L D
       AEROSPACE MATERIALS REQUIREMENTS
       METALS ENGRG QUARTERLY V2 P16-20 FEB 1962                          123  67

RC69   MOLYBDENUM             SOUTHERN RESEARCH INSTITUTE
       THERMAL PROPERTIES 26 SOLID MATERIALS TO 5000 F OR THEIR DESTRUCTION TEMP
       ASD TDR 62-765 CONTRACT AF33(657)7319 JAN 1963                          67

RC70   STAINLESS CLAD CU      RATHEON CO WALTHAM MASS
       DEVELOPMENT OF HIGH TEMP TRANSFORMER FOR MISSILES AND AIRCRAFT
       CONTRACT NOBSR 72671 FINAL REPORT NOV 1960                           4  7

RC71   MOLYBDENUM 1/2 TI      KATTUS I R
       FEASIBILITY OF USING AVAILABLE HEAT RESISTANT MTLS FOR HYPERSONIC APPLIC
       SOUTHERN RESEARCH INSTITUTE WADC TR 59-744 V5 NOV 1960            0

RC72   STAINLESS CLAD CU      AMATEAU M F
       MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMP
       DMIC REPORT 169 AD278654 MAY 28 1962                               1       9

RC73   INCONEL CLAD CU        AMATEAU M F
       MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMP
       DMIC REPORT 169 AD2786021 MAY 28 1962                              1       9

RC74   ALLOYS HIGH TEMP       ORR P E
       THERMALPROPERTIES OF ALLOYS AT HIGH TEMPERATURES
       DDC SERIES 137 ISSUE 8 CONTRACT AF49(638)-83 MAR 1 1963           0

RC75   MOLYBDENUM TI COATED   GRAHAM R  FDG GENERAL ELECTRIC CO
       PROTECTIVE COATINGS FOR MOLYBDENUM ALLOYS
       NO R60FPD307 CONTRACT NOAS59-6026-C AD259028 MAR 1960             0
```

```
RC76    COPPER NICKEL PLATED   NORTH AMERICAN AVIATION
        DEV OF HIGH TEMPERATURE AIRCRAFT ELECTRICAL SYSTEM
        22ND BIMONTHLY REPT NA57-959-22 AF33(600)35489 MAR 1 1961          0

RC77    STAINLESS CLAD CU      AMERICAN METAL CLIMAX CO STAFF
        METAL CLAD EXTENDS COPPER CONDUCTOR RANGE TO 1300F
        OFHC NEWS PUBL OF AMERICAN METAL CLIMAX CO FEB 1963                0

RC78    CONDUCTORS COATED      MELTZER T D
        DEVELOP OF HIGH TEMP TRANSFORMERS WITH NEW CONFIGURATIONS FOR MISSLES
        FINAL REPT CONTRACT NOBSR 72671 NOV 30 1960                             7

RC79    GLASS INSULATED CU     STAFF PRODUCT ENGINEERING
        GLASS INSULATED COPPER WIRE MFG BY GLASS DEVELOPMENTS LTD LONDON ENGLAND
        PRODUCT ENGINEERING P 45 NOV 25 1963                               0
```

```
LC6     NOBLE METAL DH ALLOY   GIMPL M L LAINE N R SHULTZ C W
        RESEARCH ON ELECTRICAL CONDUCTORS FOR HIGH TEMPERATURE APPLICATIONS
        FIRST QUARTERLY REPT CONTRACT AF33 657 11212 JULY 1 1963            0

RC74    ALLOYS HIGH TEMP       ORR P E
        THERMALPROPERTIES OF ALLOYS AT HIGH TEMPERATURES
        DDC SERIES 137 ISSUE 8 CONTRACT AF49(638)-83 MAR 1 1963             0

LC7     CONDUCTORS-HIGH TEMP   GIMPL,M.L. CHILDS,E.E. ELIASON,L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR INC. 1ST QUAR REPT AF33(657)-11046 APR 3-JULY 5,1963         0

LC8     CONDUCTORS-HIGH TEMP   GIMPL, M.L.  CHILDS, E.E.  ELIASON, L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR INC 2ND QUAR REPT AF33(657)-11046 JULY 5-OCT 5, 1963         0

LC9     CONDUCTORS-HIGH TEMP   GIMPL, M.L.  CHILDS, E.E.  ELIASON, L.K.
        2000 DEGREE F POWER WIRE FOR AEROSPACE ENVIRONMENT
        MELPAR 3RD QUAR REPT AF33(657)-11046 OCT 5-JAN 5,1964               0

LC10    CONDUCTORS GENERAL     CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR SERVICE AT 500 DEGREE C
        ELECTRICAL DESIGN NEWS JULY 1962                                    1    67 9

RC78    CONDUCTORS COATED      MELTZER T D
        DEVELOP OF HIGH TEMP TRANSFORMERS WITH NEW CONFIGURATIONS FOR MISSLES
        FINAL REPT CONTRACT NOBSR 72671 NOV 30 1960                              7

RC21    AL CLAD CU             CARLSON C L
        DEVELOPMENT OF AL CLAD CU MAGNET WIRE
        (W) MTLS ENGRG DEPT RPT 5602-9 FEB 29 1956                          0

RC19    AG CLAD CU             ANON
        MULTILAYER CLAD BASE METALS
        PUBL METALS CONTROLS DIV OF TEXAS INSTRUMENTS GP 18 MAY 1961        0

RC58    CLAD COPPER            SYLVANIA ELEC PROD CO
        KULGRID 28
        BULLETIN OCT 1957                                                   1    7
```

```
RC61    CLAD COPPER            BISHOFF R W
        OXIDATION OF NI CLAD CU WIRE
        WESTINGHOUSE ENGRG REPORT 6031-2066 FEB 8 1960                        4    8

RC25    INCONEL CLAD CU        PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
        ASD-TDR-63-164 ANACONDA WIRE AND CABLE CO JULY 1963                       78

RC27    INCONEL CLD CU         PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
        ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963                   78

RC32    INCONEL CLAD DS CU     PENDLETON W W
        RADIATION RESISTANT MAGNET WIRES FOR USE IN AIR OR VACUUM AT 850 DEG C
        6 INTERIM SCIENTIFIC RPT CONTRACT AF33(657)7473 JULY 1963                 78

RC34    INCONEL CLAD CU        CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR SERVICE AT ELEVATED  500 DEG C  TEMP
        (W) MTLS ENGRG RPT 6162-5627 FEB 28 1961                                  7

RC35    INCONEL CLAD CU        CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP 500 DEG C SERVICE
        (W) MTLS ENGRG RPT 6162-5627 FEB 28 1961                                  7

RC46    INCONEL CLAD CU        STAFF KENTUCKY ELECTRONICS
        PRIVATE COMMUNICATION ON SOURCES OF INCONEL CLAD COPPER
        LETTER FROM KY ELECTRONICS QUEENSBORO KY TO LIMA APR 2 1963       0

RC50    INCONEL CLAD CU        STAFF PHELPS DODGE COPPER PRODUCTS CO
        DATA SHEET FROM PHELPS DODGE COPPER PRODUCTS CO
        P/D DATA SHEET 1963                                                       7

RC73    INCONEL CLAD CU        AMATEAU M F
        MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMP
        DMIC REPORT 169 AD2786021 MAY 28 1962                                1       9

RC8     NICKEL CLAD CU         HOWELL J R
        COMPOSITE WIRE FOR OPERATION AS ELECTRICAL CONDUCTORS AT ELEV TEMP
        PAPER AT 7TH ANNUAL WIRE AND CABLE SYMPOSIUM DEC 2,3,4,1958          1    67
```

```
RC16    NI CLAD CU              ANON
        CERAMIC-EZE
        PUBL OF PHELPS DODGE CU PROD CORP JAN 15 1963                 0

RC17    NI CLAD CU              ANON
        NICKEL CLAD COPPER WIRE
        PUBL OF RIVERSIDE-ALLOY METAL DIV OF HK PORTER CO BULL T-3       1    7

RC23    10 NI CLAD CU           CARLSON C L
        NI CLAD WIRE AS AN ELECTRICAL CONDUCTOR
        (W) MTLS ENGRG RPT 5604-2511 APR 20,1956                              78

RC30    NI CLAD CU              PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
        ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963               78

RC36    NI CLAD CU              CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP  500 DEG C  SERVICE
        (W) MTLS ENGRG REPORT 6162-5627 FEB 28,1961                       2   78

RC48    NI CLAD CU              STAFF PHELPS DODGE COPPER PRODUCTS CO
        RESISTIVITY CURVES
        PHELPS DODGE COPPER PRODUCTS CO 1963                                  7

RC49    NI CLAD CU              STAFF PHELPS DODGE COPPER PRODUCTS CO
        DATA SHEET PHELPS DODGE COPPER PRODUCTS CO
        P/D DATA SHEET NOT DATED                                              7

RC7     STAINLESS CLAD CU       CARLSON C L
        ENGRG DATA ON CONDUCTORS FOR ELEVATED TEMP  500C  SERVICE
        (W) MATERIALS LABS RPT NO 6162-5627 FEB 28,1961                  12 4 678

RC9     STAINLESS CLAD CU       HOWELL J R
        COMPOSITE WIRES FOR OPERATION AS ELEC CONDUCTORS AT ELEVATED TEMP
        PAPER AT 7 ANNUAL WIRE AND CABLE SYMPOSIUM DEC 2,3,4,1958        1    67

RC12    SS CLAD CD CU           MOREDOCK A E
        PRIVATE COMMUNICATION A E MOREDOCK TO D H LANE
        PRIVATE COMMUNICATION MOREDOCK TO LANE SEPT 26,1963              123456789
```

```
RC18    STAINLESS CLAD COPPE   R WIRE OXOLLOY 28
        STAINLESS CLAD COPPER WIRE OXALLOY 28
        TECHNICAL INFORMATION BULLETIN SYLVANIA ELEC CO JUNE 1958       1 3   7

RC24    SS CLAD CU             PENDLETON W W
        RADIATION RESISTANT MAGNET WIRES FOR USE IN AIR AND VACUUM AT 850 DEG C
        ANACONDA WIRE AND CABLE CO RPT ASD-TDR-63-164 JULY 1963               78

RC47    SS CLAD CU             STAFF OF PHELPS DODGE COPPER PRODUCTS CO
        RESISTIVITY CURVES
        REPORT FROM PHELPS DODGE COPPER PRODUCTS CO 1963                      7

RC52    S S CLAD COPPER        STAFF METALS AND CONTROLS DIV TEXAS INSTRUMENTS
        MULTICLAD WIRE
        BULLETIN WT-3 OF METALS AND CONTROLS DIV OF TEX INSTRU 1962     1     7

RC54    STAINLESS CLD CU       SYLVANIA ELECTRIC PROD INC
        HOW SYLVANIA SHOULDERS DESIGN AND PRODUCTION PROBLEMS
        PAMPHLET NO DATE                                                    4

RC55    STAINLESS CLAD CU      SYLVANIA ELECTRIC PROD CO
        PRICES SYLVANIA ELEC PROD CO WARREN PA
        PAMPHLET P16 NOV  29 1962                                           4

RC64    STAINLESS CLAD CU      WIRE AND CABLE DIV CERRO CORP
        AEROSPACE AND ELECTRONIC WIRES AND CABLES
        PAMPHLET WIRE AND CABLE DIV CERRO CORP P18 1963                 1      8

RC70    STAINLESS CLAD CU      RATHEON CO WALTHAM MASS
        DEVELOPMENT OF HIGH TEMP TRANSFORMER FOR MISSILES AND AIRCRAFT
        CONTRACT NOBSR 72671 FINAL REPORT NOV 1960                          4 7

RC72    STAINLESS CLAD CU      AMATEAU M F
        MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMP
        DMIC REPORT 169 AD278654 MAY 28 1962                            1       9

RC77    STAINLESS CLAD CU      AMERICAN METAL CLIMAX CO STAFF
        METAL CLAD EXTENDS COPPER CONDUCTOR RANGE TO 1300F
        OFHC NEWS PUBL OF AMERICAN METAL CLIMAX CO FEB 1963             0
```

```
RC80    STAINLESS CLAD CU       SAUNDERS H S
        USE OF CERAMIC MATERIALS IN HIGH TEMPERATURE ELECTRIC APPARATUS
        INSULATION PP 31-36 MAY 1963                                    0

RC31    NI-FE CLAD CU           PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
        ASD-TDR-63-164 REPT ANACONDA WIRE AND CABLE CO JULY 1963               78

RC26    25INCONEL CLAD AG       PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
        ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963         1      78

RC28    23 NI CLAD AG           PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR AND VACUUM AT 850 DEG C
        ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963                78

RC51    NI CLAD SILVER          STAFF PHELPS DODGE COPPER PRODUCTS CO
        DATA SHEET FROM PHELPS DODGE COPPER PRODUCTS CO
        P/D DATA SHEET 1963                                                    7

RC14    INCONEL CLAD CU TA      UNION CARBIDE
        NEW PROCESS OF ELECTROCLADDING AND ELECTROFORMING REFRACTORY METALS
        PUBL UNION CARBIDE CORP 1963                                       4

RC29    NI PLATED CU            PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850 DEG C
        ASD-TDR-63-164 RPT ANACONDA WIRE AND CABLE CO JULY 1963                78

RC37    NI PLATED CU            CARLSON C L
        ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP  500 DEG C  SERVICE
        (W) MTLS ENGRG REPORT 6162-5627 FEB 28,1961                     1      78

RC76    COPPER NICKEL PLATED    NORTH AMERICAN AVIATION
        DEV OF HIGH TEMPERATURE AIRCRAFT ELECTRICAL SYSTEM
        22ND BIMONTHLY REPT NA57-959-22 AF33(600)35489 MAR 1 1961       0

LC3     CB COATED COPPER        GARDNER A R
        WHATS COMING IN CONDUCTORS TO 1000 F
        PRODUCT ENGINEERING P82-6 AUG 7 1961                               4
```

```
RC53    COATED COPPER          HAYNES STELLITE DIV UNION CARBIDE
        HAYNES DIFFUSION COATINGS
        PUBL F-30 190C P16 NOV 1963                                          4

RC56    COATED COPPER          GARDNER A R
        WHATS COMING IN CONDUCTORS TO 1000 DEG F
        PRODUCTS ENGINEERING P82-86 AUG 7 1961                               4

RC66    CERAMIC COATED CU      DUCKWORTH W ET AL
        CERAMIC COATED COPPER WIRE
        AMERICAN CERAMIC SOC BULLETIN V38 P251-55 MAY 1959               0

RC13    CU MOLYBDENUM COAT
        NEW PROCESS FOR ELECTROCLADDING AND ELECTROFORMING REFRACTORY METALS
        PUBL OF UNION CARBIDE CORP 1963                                      4

RC42    CU MOLYBDENUM COATED   FUSCHILLO N LINDBERG R A
        ELECTRICAL CONDUCTORS AT ELEVATED TEMP
        MELPAR ASD-TDR-62-481 P46 JUNE 1962                                  4

RC44    MO-SI COATED CU        FUSCHILLO N  LINDBERG R A
        ELECTRICAL CONDUCTORS AT ELEVATED TEMP
        MELPAR ASD-TDR-62-481 P342 374 385 JUNE 1962                           6 8

RC10    COPPER                 RICKS H E  TRUMBETTA R D
        LITERATURE SURVEY OF CONDUCTORS AND CONDUCTOR JOINING
        (W) MATERIALS ENGRG RPT NO 5805-6183                              12 4 678

RC22    COPPER                 THOMAS R H DEXTER J F
        EFFECT OF WIRE METAL ON THERMAL LIFE OF ENAMELED MAGNET WIRE
        AIEE POWER APP SYSTEMS V33 P1009-13 DEC 1957                           6

RC43    COPPER D S             FUSCHILLO N LINDBERG R A
        ELECTRICAL CONDUCTORS AT ELEVATED TEMP
        MELPAR ASD-TDR-62-481 P297-98 FIG 16 17 P399 JUNE 1962            12     7

RC40    COPPER D S             PENDLETON W W
        RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR VACUUM AT 850 DEG C
        ANACONDA WIRE AND CABLE CO FIG 10 TABLE VII JULY 1963             12
```

```
RC63   DS COPPER BEO          PRICE B R
       PRIVATE COMMUNICATION
       LETTER AND DATA P5 NOV  2 1961                                      1     7

RC1    CHROMIUM CU            ZAKHAROV M V  ETAL
       CU BASE CONDUCTOR ALLOYS WITH IMPROVED ELEVATED TEMP STRENGTH
       METALLOVEDINIE 1 TERM OBRABOTKA METTALLOV V9 P25-9 SEPT 1960        1    67

RC5    CU TA OR CB BARRIER    PENDLETON W W
       RADIATION RESISTANT MAGNET WIRE FOR USE IN AIR OR VACUUM AT 850C
       TDR NO ASD TDR 63-164 ANACONDA WIRE AND CABLE CO JULY 1963          1    6789

RC11   ZIRCONIUM CU           SAKHAROV V M  ET AL
       CU BASE CONDUCTORS WITH IMPROVED ELEVATED TEMP STRENGTH
       METALLOVEDEHIE 1 TERM OBRABOTKA V9 P22-9  SEPT 1960                 1  4 67

RC4    SERVICE COND GENL      MORSE J G
       ENERGY FOR REMOTE AREAS
       SCIENCE VOL 139 NO 3560 P1175-80 MAR 22,1963                              8

RC79   GLASS INSULATED CU     STAFF PRODUCT ENGINEERING
       GLASS INSULATED COPPER WIRE MFG BY GLASS DEVELOPMENTS LTD LONDON ENGLAND
       PRODUCT ENGINEERING P 45 NOV 25 1963                               0

RC41   MOLYBDENUM             FUSCHILLO N LINDBERG R A
       ELECTRICAL CONDUCTORS AT ELEVATED TEMPERATURES
       MELPAR ASD-TDR-62-481 JUNE 1962                                     12 4 678

RC3    MOLYBDENUM             PELLINI W S
       MATERIALS REQUIREMENTS FOR HYPERSONIC FLIGHT VEHICLES
       JOURNAL OF METALS P954-63 DEC 1960                                 0

RC39   MOLYBDENUM             STAFF OF CLIMAX MOLYBDENUM CO OF MICH
       MOLYBDENUM IN METAL
       TECHNICAL DATA 1960                                                 12 4 67

RC67   MOLYBDENUM             GATZEK L D
       AEROSPACE MATERIALS REQUIREMENTS
       METALS ENGRG QUARTERLY V2 P16-20 FEB 1962                           123  67
```

```
RC69   MOLYBDENUM             SOUTHERN RESEARCH INSTITUTE
       THERMAL PROPERTIES 26 SOLID MATERIALS TO 5000 F OR THEIR DESTRUCTION TEMP
       ASD TDR 62-765 CONTRACT AF33(657)7319 JAN 1963                          67

RC71   MOLYBDENUM 1/2 TI      KATTUS I R
       FEASIBILITY OF USING AVAILABLE HEAT RESISTANT MTLS FOR HYPERSONIC APPLIC
       SOUTHERN RESEARCH INSTITUTE WADC TR 59-744 V5 NOV 1960           0

RC75   MOLYBDENUM TI COATED   GRAHAM R  FDG GENERAL ELECTRIC CO
       PROTECTIVE COATINGS FOR MOLYBDENUM ALLOYS
       NO R60FPD307 CONTRACT NOAS59-6026-C AD259028 MAR 1960            0

RC15   NICKEL                 SHANINIAN P ACHTER M R
       CREEP RUPTURE OF NICKEL OF TWO PURITIES IN CONTROLLED ENVIRONMENTS
       NAVAL RESEARCH LAB RPT NO 5850 JAN 22,1963                        2

LC4    DH NICKEL              BONIS L J
       A NEW APPROACH TO HIGH TEMPERATURE STRENGTH
       MATERIALS IN DESIGN ENGRG P104 OCT 63                               4

RC57   TD NICKEL              E I DUPONT CO
       TD NICKEL DISPERSION STRENGTHENED NICKEL
       PAMPHLET P44 OCT 1962 1963                                       12    78

RC38   T D NICKEL             MANNING C R ET AL
       INVESTIGATION OF A NEW NI ALLOY STRENGTHENED BY DISPERSED THORIA
       NASA LANGLEY RESEARCH CENTER PUBL TN D1944 JULY 1963             1  4   8

RC33   AG-MN-NI               CARLSON C C
       ENGINEERING DATA ON CONDUCTORS FOR ELEVATED TEMP 500 DEG C SERVICE
       (W) MATERIALS ENGRG RPT 6162-5627 FEB 28 1961                     2     7

RC6    SILVER                 RICKS H E TRUMBETTA R D
       LITERATURE SURVEY OF CONDUCTORS AND CONDUCTOR JOINING
       (W) MATERIALS ENGRG REPORT NO 5805-6183 MAY 29 1958              12 4 678

RC62   DS SILVER              SCHETKY L M
       DISPERSION STRENGHTENING OF SILVER
       MIT REPORT R-153 JUNE 1957                                       1      7
```

```
LC1     TUNGSTEN-COPPER         MCDANIELS D L  JECH R W  WEETON J W
        STRESS STRAIN BEHAVIOR OF TUNGSTEN FIBER REINFORCED COPPER COMPOSITES
        NASA TECHNICAL NOTE D-1881 SEPT 1963                                0

LC11    TUNGSTEN MOLYBDENUM     FANSTEEL CORP ET AL
        ELECTRICAL RESISTIVITY OF TUNGSTEN AND MOLYBDENUM
        ELECTRICAL PROP INFORMATION CENTER DATA SHEETS DEC 1963                   7

LC2     850C WIRE               BOBER E S  SNAVELY W H   STAPLETON R E
        MONTHLY STATUS LETTER HOT WIRE PROJECT
        AERONAUTICAL SYS DIV AF33(657)10701 SEPT 13 1963                          7 9

RC2     CER COAT CU WIRE        LARSSEN A
        CERAMIC DIELECTRICS
        INSULATION PERIODICAL V 9,10 P27-32 SEPT 1963                        1     678
```

```
LI1    IMIDE WIRE ENAMEL      ROHM A J LUDINGTON R S
       NEW POLYMIDE WIRE ENAMELS
       WESTINGHOUSE MATL ENGRG REPORT 5806-2857 JUNE 12,1958              0

LI2    IMIDE WIRE ENAMEL      STAFF WESTINGHOUSE
       SELECTED DATA ON DUPONT M1 WIRE ENAMEL AND MATL ON ML FAMILY
       WESTINGHOUSE INTERNAL REPORT 1962                                        678

LI3    IMIDE WIRE             STAFF
       DATA EXTRACTED FROM NEW YORK NAVAL SHIP YARD REPORT 4861-F-37
       NAVAL SHIP YARD BROOK N Y RPT 4861-F-37 FEB 7,1963                  1     78

LI4    IMIDE WIRE ENAMEL      NEIDEMIRE A
       TEST OF HIGH TEMP DUPONT ML ENAMELED WIRE IN HOT OILS
       WESTINGHOUSE INTERNAL REPORT NOT DATED                             0

LI5    EPOXY GLASS            FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES ASTIA RPT 265900
       DIELECTRICS LAB JOHN HOPKINS UNIV  MAY 1,1960 TO FEB 28,1961              78

LI6    ALUMINA                SMILEY W D SOBON W E HURZ F M FARLEY E D ET AL
       MECHANICAL PROPERTY SURVEY OF REFRACTORY CRYSTALLINE MTLS
       WADC TECH RPT 59-448 JAN 1960                                       12   6

LI7    BORON NITRIDE          STAFF
       SYNTHESIS AND PURIFICATION OF DIELECTRIC MATERIALS
       WESTINGHOUSE RESEARCH LAB REPORT OCT 1959 DEC 1959                 0

LI8    MICA PAPER             HARMS H B  FRASER J C
       ULTRA HIGH TEMPERATURE MINIATURIZED POWER TRANSFORMERS AND INDUCTOR MATLS
       WADC TECH RPT 57-492 ASTIA AD155527 VOL 1,2  MAY 1958                    67

LI9    CER-COAT-NI-CU-WIRE    HARMS H B  FRASER J C
       ULTRA HIGH TEMPERATURE MINIATURIZED POWER TRANSFORMERS AND INDUCTOR MTLS
       WADC 57-492 ASTIA AD15527 MAY 1958                                       67

LI10   MICA PAPER             HARMS H B  FRASER J C
       ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
       WADC TECHNICAL RPT 59-348  JULY 1959                                     67
```

```
LI11   CER-COAT-NI-CU-WIRE    HARMS H B  FRASER J C
       ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
       WADC TECH RPT 59-348  JULY 1959                                 1    67

LI12   IMIDE WIRE ENAMEL      STAFF
       TECH DATA SHEET 11 FROM THE BELDEN MFG CO
       BELDEN DATA SHEET 11  NOVEMBER 28,1960                               678

LI13   IMIDE WIRE             STAFF HI TEMP WIRES CO
       TECH DATA SHEETS FROM HI TEMP WIRES CO
       DATA SHEETS HI TEMP WIRES CO MAR 27,1961                             6 8

LI14   URETHANE FOAM          GREEN D F
       FOAMED PLASTICS ASTIA RPT 252981L
       U S NAVAL CIVIL ENGR LAB PORT HUENEME CALIF  MAR 7,1961         1    6

LI15   SILICONE FOAM          GREEN D F
       FOAMED PLASTICS ASTIA REPORT 252981L
       U S NAVAL CIVIL ENGR LAB PORT HUENEME CALIF MAR 7,1961          1    6

LI16   ALUMINUM OXIDE         VON HIPPEL
       TABLES OF DIELECTRIC MATERIALS ASTIA AD 200958
       MIT RPT LAB FOR INSUL RES TECH RPT 126 VOL VI P 7-21 JUNE 1958        7

LI17   BERYLLIA               VON HIPPEL
       TABLES OF DIELECTRIC MTLS ASTIA AD200958
       MIT LAB FOR INSUL RES TECH RPT 126 VOL VI P 22-7 JUNE 1958            7

LI18   GLASS                  VON HIPPEL
       TABLES OF DIELECTRIC MATERIALS
       ASTIA AD200958 VOL VI P 35-43  JUNE 1958                              7

LI19   AL   SILICATE FIBERS    VON HIPPEL
       TABLES OF DIELECTRIC MTLS CATALOGED BY ASTIA AS AD200958
       MIT LAB FOR INSUL RES TECH RPT 126 VOL VI P 35-43  JUNE 1958          7

LI20   EPOXY LAMINATE         VON HIPPEL
       TABLES OF DIELECTRIC MTLS CATALOGED BY ASTIA AD200958
       MIT LAB FOR INSUL RES TECH RPT 126 VOL  VI P 35-43 JUNE 1958          7
```

```
LI21   ALUMINUM OXIDE          VON HIPPEL A R
       PROGRESS REPORT NO XXIX LAB FOR INSULATION RESEARCH
       MASS INSTITUTE OF TECH REPORT P 21 JULY 1961                      7

LI22   SILICA                  MASS INSTITUTE OF TECHNOLOGY
       PROGRESS REPORT NO XXIX LAB FOR INSULATION RESEARCH
       MASS INSTITUTE OF TECH P 35 JULY 1961                             7

LI23   EPOXY COMPOUNDS         NAVAL ORD LAB STAFF
       STUDY OF HIGH TEMP POLYMERS BY ELECTRO-THERMAL ANALYSIS ASTIA 245564
       U S NAVAL ORD LAB REPORT ASTIA AD245564  JUNE 1960           0

LI24   GLASS FIBERS            OTTO W H
       PROPERTIES OF GLASS FIBERS AT ELEVATED TEMP
       NAVY BUREAU OF AERO ASTIA AD228851  SEPT 15,1959             1 3

LI25   SILICA FIBERS           OTTO W H
       PROPERTIES OF GLASS FIBERS AT ELEVATED TEMP
       NAVY BUREAU OF AERO ASTIA AD228851  SEPTEMBER 15,1959        1 3

LI26   MICA GLASS BONDED       WEBER T W
       DEVEL OF A HIGH TEMP INORG GLASS DIELEC FOR EMBEDDING ELEC PARTS
       BUREAU OF SHIPS-NAVY DEPT ASTIA AD231578  10-9-58 TO 10-9-59     67

LI27   EPOXY RESIN             MADORSKY S L STRAUSS S
       THERMAL DEGRADATION OF POLYMERS AT TEMP UP TO 1200C
       NATIONAL BUREAU OF STANDARDS MAR 1960                        0

LI28   ALUMINA                 GOLDBERG M E  HAMRE H G
       ELECTRONIC COMPONENT PARTS RESEARCH FOR 500C OPERATION
       WADC 57-362 ASTIA AD155785  JULY 1958                             7

LI29   BERYLLIA                GOLDBERG M F  HAMRE H G  NOBLE R D
       ELECTRONIC COMPONENT PARTS RESEARCH FOR 500 C OPERATION
       WADC 57-362 ASTIA AD155785 JULY 1958                              7

LI30   NI WIRE COATINGS        GOLDBERG M E  HAMRE H G  NOBLE R D
       ELECTRONIC COMPONENT PARTS RESEARCH FOR 500 C OPERATION
       WADC TECH RPT 57-362 ASTIA AD155785  JULY 1958                    7
```

```
LI31    AMIDE-IMIDE RESIN      SCALA L C
        POLYPROMELLITIMIDE MICA BONDS
        (W) RESEARCH LAB PUBLICATION FEB 1960                         0

LI32    LAM MICA PAPER         DIVENS W C
        DEVELOPMENT OF 500 C CANNED PUMP MOTOR INSULATION
        (W) RESEARCH RPT 404FF206R1  5-28-57 TO 8-31-58                1    67

LI33    MICA TAPE              DIVENS W C
        DEVELOPMENT OF 500 C CANNED PUMP MOTOR INSULATION
        (W) RESEARCH RPT 404FF206R1  P 27  5-28-57 TO 8-31-58               67

LI34    CERAMICITE WIRE COV    DIVENS W C
        DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
        (W) RESEARCH RPT 404 P 27 AUG 31,1958                         0

LI35    WIRE INORGANIC INS     VONDRACEK C H  CROOP E J
        NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
        (W) MATERIALS ENGINEERING PAPER P 5912 MAR 23,1959                   7

LI36    MICA GLASS             VONDRACEK C H CROOP E J
        NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
        (W) MATERIALS ENGINEERING PAPER P 5912 MAR 23,1959                   7

LI37    POTTING COMP-INORG     VONDRACEK C H  CROOP E J
        NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
        (W) MATERIALS ENGRG PAPER P5912 MAR 23,1957                          7

LI39    IMIDE                  FREEMAN J H FROST L W BOWER G M ET AL
        REINFORCED PLASTICS FOR LONG TIME HIGH TEMP USE
        WESTINGHOUSE RESEARCH RPT 63-931-335RI JUNE 2,1963             1

LI40    GLASS HIGH RES         HIRAYAMA C
        HIGH RESISTIVITY GLASSES
        WESTINGHOUSE RESEARCH MEMO 10-0402-2-M9 MAR 19,1959           0

LI42    INORGANIC WIRE COAT    BERGERON C G  FRIEDBERG A L  SCHWARZLOSE P E  ET AL
        HIGH TEMP ELECTRICAL INSULATING INORGANIC COAT ON WIRE
        WADC TECH RPT 58-12  MAR 1958                                        7
```

```
LI43    ALUMINA                   BERGERON C G FRIEDBERG A L SCHWARZLOSE P E
        HIGH TEMP ELECTRICAL INSULATING INORGANIC COATINGS ON WIRE
        WADC TECH RPT 58-12 TABLE III AND IV MARCH 1958                        7

LI44    BERYLLIA                   BERGERON C G  FRIEDBERG A L ET AL
        HIGH TEMPERATURE ELECTRICAL INSULATING INORGANIC COATINGS ON WIRE
        WADC RPT 58-12  TABLE IV AND III MARCH 1958                            7

LI45    LAMINATE SIO2 FIBERS      PLANT HT GIRARD R T RICE G A WISELY H R ET AL
        DEVELOPMENT OF INORGANIC BINDERS
        GEN ENGRG LAB GEN ELEC CO ASTIA AD297130 OCTOBER 27,1960           1

LI46    BERYLLIA                  PEARS C D  ALLEN J G  NEEL D S  MANN W H ET AL
        THE THERMAL PROPERTIES OF 26 SOLID MTLS TO 5000F ASTIA AD298061
        ASD TECH RPT TDR62-765 WPAFB P 94,134,163,234,290 JAN 1963            67

LI47    ALUMINA                   BORTZ S A  NELSON H R  WEIL N A ET AL
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        WADC ASD TR 61-628  APR 1962                                       1 3

LI48    BERYLLIA                  SMILEY W D  SOBON L E  HURZ R M ET AL
        MECHANICAL PROPERTY SURVEY REFRACTORY NONMETALLIC CRYSTALLINE MTLS
        WADC REPORT 59-448  JAN 1960                                       12   6

LI49    EPOXY LAMINATE            FRISCO L J
        DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
        ASTIA PUB AD256900 FEB 1961                                             78

LI50    ALUMINA                   PARICH N M
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        ASD TR 61-628 PART II  APRIL 1963                                  123

LI51    BERYLLIA                  PARIKH N M
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        ASD TR 61-628 PART II  APR 1963                                    123

LI52    ALUMINA                   FRISCO L J
        DIELECTRICS FOR SATELLITES AND SPACE VEHICLES ASTIA AD 256900
        ASTIA PUB AD 256900 P 59 73 79 FEB 1961                                 78
```

```
LI53    LAMINATES               VONDRACEK C H MOBERLY L E BERG D
        SYNTHESIS AND FORMULATION OF INORGANIC BONDED INORGANIC FIBER STRUC MTLS
        (W) REPORT ON AF CONTRACT AF33/657/7587 MAR 1963                1    6

LI54    AMIDE PAPER             HOFFMAN C
        TYPICAL PROPERTIES OF EXPERIMENTAL FIBER HT-1
        (W) INTERNAL DOCUMENT NOT DATED                                 1     78

LI55    IMIDE CASTING CPD       DUPONT STAFF
        PROPERTIES OF VESPEL FABRICATED PARTS
        DUPONT DATA SHEET MAR 23,1963                                   1    678

LI56    PHOS BONDED MICA        HARMS H B  FRASER J C
        ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
        WADC TECH RPT 59-348  JULY 1959                                      67

LI57    LAM AROMATIC AMIDE      FREEMAN J H  FROST L W  BOWER G M  TRAYNOR E J
        REINFORCED PLASTIC LAM FOR LONG TIME HIGH TEMP USE
        (W) RESEARCH RPT 63-931-335RI  JAN 2,1963                      0

LI58    AMIDE PAPER             CLAY W R  LONG W C
        PHYSICAL AND CHEMICAL PROPERTIES OF HT-1
        DUPONT PUBLICATION  MAY 1961                                    1    678

LI59    AMIDE PAPER HT-1        WENZEL R N
        TENSILE STRENGTH OF DUPONT FIBER HT-1 AFTER AGING AT ELEVATED TEMP
        (W) INTERNAL REPORT  AUG 2,1956                                 1

LI60    AMIDE PAPER HT-1        FREEMAN J H
        AROMATIC CONDENSATION POLYMERS
        (W) RESEARCH MEMO 12-0402-1-M2-X  APR 28,1960                        678

LI61    GLASS FABRIC            LEPPLA R R CARRYER R R
        POLYMIDE INS SYSTEM FOR HIGHER OPERATING TEMP MORE COMPACT UNITS
        INSULATION JUNE 1963                                                 678

LI62    IMIDE GLASS CLOTH       FREEMAN J H
        RADIATION STABILITY OF AROMATIC AMIDE-IMIDE POLYMERS
        (W) RESEARCH DATA SHEET OCT 1961                                       8
```

```
LI63    IMIDE MAGNET WIRE       PHELPS DODGE STAFF
        ML MAGNET WIRE
        PHELPS DODGE BROCHURE JUNE 15,1962                                  678

LI64    IMIDE INS WIRE          STAFF
        TYPE ML MAGNET WIRE
        GENERAL ELECTRIC DATA SHEET SEPT 1,1962                             6 8

LI65    POLYMIDE GLASS LAM      LEPPLA R R DUPONT
        PYRE M L NON-ELECTRICAL PROPERTIES FAIRFIELD
        DUPONT DATA SHEET  1962                                             6 8

LI66    IMIDE WIRE ENAMEL       STEWART R L
        LIMA MATERIALS ENGR LAB REPORT
        (W) AED MTLS ENGR REPORT 26-63  APR 8,1963                           7

LI67    IMIDE WIRE ENAMEL        WILLIAMS G J
        LETTER WITH DATA FROM BUFFALO WIRE DEPT
        (W) BUFFALO WIRE DEPT CORRESPONDENCE  SEPT 29,1961                   78

LI68    IMIDE WIRE              BUFFALO STAFF
        TYPICAL ENAMELED WIRE TEST VALUES
        (W) BUFFALO N Y REPORT SHEET JULY 20,1962                           678

LI69    IMIDE GLASS LAM         NEIDMIRE A W
        LIMA MATERIALS ENGR LAB RPT
        (W) INTERNAL REPORT AED 61-62  OCTOBER 25,1962                      67

LI70    AMIDE PAPER             ATKINSON W B
        HT-1 SYNTHETIC FIBER PAPER
        WESTINGHOUSE MATERIALS LAB PUBLICATIONS JAN 24,1961                 678

LI71    AMIDE HT-1 PAPER        NEIDEMIRE A W
        LIMA MATERIALS ENGR LAB REPORT
        (W) INTERNAL REPORT 61-62 OCTOBER 25,1962                            78

LI72    SILICA                  POULOS N E  ELKINS S R  WALTON J D
        HIGH TEMPERATURE CERAMIC STRUCTURES
        RPT OF ENGRG EXP STATION GA INSTITUTE OF TECH JAN 1962          0
```

```
LI73   CERAMICS                CAPE J A  TAYLOR R E
       THERMAL PROPERTIES OF REFRACTORY MATERIALS ASTIA AD264228
       WADD TECH RPT 60-581     JULY 1961                       0

LI74   SILICA                  DUNN S A  ROTH W P
       HIGH VISCOSITY REFRACTORY FIBERS
       BJORKSTEN RESEARCH LAB ASTIA AD264273  JULY 1961         0

LI75   MAGNESIUM OXIDE         PARKER E R  PASK J A  HIMMEL L
       DUCTILE CERAMICS FINAL RPT
       MINERALS RESEARCH LAB ASTIA AD234699 FEB 1960            0

LI76   ALUMINA                 COHEN JULIUS
       ELECTRICAL PROPERTIES OF SAPPHIRE ASTIA AD238711
       OFFICE OF NAVAL RESEARCH CONTRACT NONR-184C00  APR 1959        7

LI77   CERAMIC COMP            SMOKE E J  ET AL
       STUDY OF HIGH TEMPERATURE MTLS FINAL RPT
       NJ CERAMIC RESEARCH STATION ASTIA AD248105  1960         0

LI79   SILICA                  LAMBERTSON W A  AIKEN D B  GIRARD E H
       CONTINUOUS FILAMENT CERAMIC FIBERS
       RPT OF CARBORUNDUM CO WADD TECH RPT 60-244 AD243556 JUNE 1960  1   6

LI80   BORIDES                 VAHLDIER F W MERSOL S A
       PROPERTIES AND STRUCTURE OF BORIDES
       WRIGHT PATTERSON PUB ASD-TR-61-514 JAN 1962              0

LI81   ZIRCONIA                PULLIAM G H  LEONARD B G
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS AIRCRAFT CO WADD TECH RPT 60-338 OCT 1960          2

LI82   ALUMINA SILICA PAPER     PEARL H A  MOWAK J M  CONTI J C
       REFRACTORY INORGANIC MTLS FOR STRUCTURAL APPLICATIONS
       WRIGHT PATTERSON PUB WADC 59-432 PART II  JULY 1960      0

LI83   ALUMINA                 PULLIAM G R  LEONARD B G
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS AIRCRAFT CO  WADD TECH RPT 60-338  OCT 1960        2
```

```
LI84   MAGNESIA                 PULLIAM G R  LEONARD B G
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS AIRCRAFT CO  WADD TECH RPT 60-338  OCT 1960                 2

LI85   ALUMINA                  GIBBS P  ET AL
       SURFACE AND ENVIRONMENTAL EFFECTS ON CERAMIC MTLS
       UNIV OF UTAH WADD TECH RPT 60-473  AUG 1960                         2

LI86   ALUMINA                  SWICA J J  ET AL
       METAL FIBER REINFORCED CERAMICS
       ALFRED UNIVERSITY WADD 58-452  JAN 1960                            1

LI88   IMIDE WIRE               FREEMAN J H
       RADIATION STABILITY OF AROMATIC AMIDE-IMIDE POLYMERS
       (W) RESEARCH DATA SHEET OCTOBER 1961                                    8

LI90   IMIDE FILM               DUPONT STAFF
       H FILM
       DUPONT DATA SHEET NOV 1,1962                                       1    678

LI91   AMIDE PAPER              CLAY W R
       DUPONT CORRESPONDENCE
       DUPONT CORRESPONDENCE MAY 31,1962                                  1    67

LI92   AMIDE PAPER HT-1         HUMES K
       SUBJECT FIBER PAPER 42333AA
       (W) INTERNAL CORRESPONDENCE NOV 6,1962                                  67

LI93   AMIDE PAPER              DUPONT STAFF
       PROPERTIES AND PROCESSING OF NOMEX HIGH TEMP RESISTANT NYLON PAPER
       DUPONT BROCHURE SEPT 1963                                          1    678

LI94   AMIDE PAPER HT-1         STAFF
       NYLON FIBER FOR 500F
       MATERIALS IN DESIGN ENGR  FEB 1962                                 1    67

LI95   GLASS AMIDE-IMIDE        TRAYNOR E J
       AI-8 116 GLASS CLOTH INS FOR SLOT LINERS
       (W) INTERNAL DOC  JAN 23,1961                                      0
```

```
LI96   TITANATES              VON HIPPEL ET AL
       PROGRESS REPORT NO XXXII LAB FOR INSULATION RESEARCH MIT
       MIT REPORT JAN 1963                                               0

LI97   GLASS POLY FILM        STAFF
       PYRE ML (GENERAL PLASTICS CORP)
       GENERAL PLASTICS CORP DATA SHEET JUNE 1962                               7

LI98   POLYMIDE GLASS         STAFF
       PYRE M L POLYMIDE COATED GLASS FABRIC TECHNICAL BULLETIN 6
       DUPONT DATA SHEET  NOV 1,1961                                      1    78

LI99   INORGANIC WIRE INS     PENDLETON W W
       STANDARDIZATION OF MAGNET WIRE FOR USE AT 500F
       BUREAU OF SHIPS WASH D C ASTIA AD246151 JAN-MAR 1960                    67

LI100  INORGANIC WIRE INS     HARRIS J N  WALTON JR J D
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADD TECH RPT 58-13  MAR 1960                                     0

LI101  INORGANIC WIRE INS     WILCOX D L  BERGERON C G  SCHWARZLOSE P F ET AL
       HIGH TEMP ELECTRICAL INSULATION INORGANIC COATINGS ON WIRE
       WADC REPORT 58-12 PART III                                        0

LI102  INORGANIC WIRE INS     BERGERON C G  FRIEDBERG W L  BEALS R J  ET AL
       HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 ASTIA DOCUMENT 151079 PART I MAR 1958         0

LI103   ALUMINA               BERGERON C G  FRIEDBERG A L  BEALS R J  ET AL
       HIGH TEMPERATURE ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 ASTIA NO 151079 P 7,8      PART I MAR 1958           7

LI104  BERYLLIA               BERGERON W G FRIEDBERG A L ET AL
       HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 ASTIA DOC 151079 P 7 8 MAR 1958                      7

LI105  STAINLESS STEEL        FUGARDI J  ZAMBROW J L
       THE CLADDING AND WELDING OF STAINLESS STEEL TO MOLYBDENUM AND NIOBIUM
       WADC TECH RPT 58-674 OCT 1959                                     0
```

```
LI106  INORGANIC WIRE COAT     BERGERON C G   FRIEDBERG A L   ET AL
       HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 PART II ASTIA NO 214700 JUNE 1959         0

LI107  ALUMINA                 HARRIS,J.N.  WALTON J P
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADC 58-13 ASTIA DOC NO 216362 GA TECH  JULY 1959             0

LI109  MAGNESIA                BRISBANE A W PROJECT DIRECTOR
       STUDY OF THE PHYSICAL BASIS MECH PROPERTIES OF CERAMICS
       ASD-TDR-63-605 PART 1 AF MTLS LAB ASD AF SYS WPAFB AUG 1963   0

LI111   ALUMINA                VON HIPPEL  SMAKULA A
       PROGRESS RPT NO XXX LAB FOR INSL RESEARCH MIT
       MASS INSTITUTE OF TECH RPT JAN 1962                                7

LI112  ALUMINA                 KOEING J N
       INORGANIC DIELECTRIC RESEARCH
       NASA DOCUMENT N62-12359  FEB 1 NOV 1,1962                     0

LI113  MAGNESIA                PULLIAM G R
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS A C WADD TECH RPT 60-338 OCT 1960                       2

LI114  ALUMINA                 PULLIAM G R
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS A C WADD TECH RPT 60-338 OCT 1960                       2

LI115  GLASS PROPERTIES        KERPER M J  DILLER C C  EIMER E H
       PROPERTIES OF GLASSES AT ELEVATED TEMP
       WADC TECH REPORT 56-645 PART III  OCT 1959                    0

LI116  LAMINATE                BULLER K  KIMBALL K E
       STRENGTH PROPERTIES OF REINFORCED PLASTIC LAM AT ELEVATED TEMP
       WADC TECH RPT 59-229    SEPT 1959                             0

LI118  BERYLLIA                JOHNSON J E SMALLEY A K DUCKWORTH W H
       INVESTIGATION OF SINTERABLE POWDERS AND PROPERTIES OF BERYLLIA CERAMICS
       WADC TECH REPT 60-108 APRIL 1960                                1
```

```
LI119  BERYLLIA                SEIBLE R MASON G L
       THERMAL PROPERTIES OF HIGH TEMP MATERIALS
       WADC TECH REPT 57-468 ASTIA DOC 155607 JUNE 1958                     6

LI120  ALUMINA                 LEVINSON D W
       SEAL AND INSULATOR PROBLEMS IN THERMIONIC CONVERTERS
       ASTIA AD 273481 P 8 10 11 MAR 1962                                   67

LI121  MATERIALS GENERAL       GOLDSMITH H  HIRSCHORN J  WATERMAN E
       THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       ASTIA AD266287 WADC REPORT NO 58-476 NOV 1960                 0

LI122  ALUMINA                 VEST R W
       ELECTRICAL BEHAVIOR OF REFRACTORY OXIDES
       ASTIA DOCUMENT AD293487 MAR 1962                              0

LI124  TEFLON                  MOWERS R E
       FINAL REPORT PROGRESS OF TESTING NONMETALLIC MATERIALS AT CRYOGENIC TEMP
       ASTIA DOC 294772  DEC 1962                                    0

LI125  IMIDE                   KUSKO A  HJERKBERG P N  ET AL
       COOLING AND MATERIALS INVESTIGATION FOR AIRCRAFT GENERATORS
       ASTIA DOC AD 118086  JUNE 1956                                0

LI126  IMIDE FILM              CROSBIE R  HEWITT G W  DAKIN I W
       AGING TESTS ON DUPONT H FILM
       (W) RESEARCH REPORT 63-131-340-RI  MAR 8,1963                        67

LI127  ALUMINA                 HARRIS J N  WALTON J D JR
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADC TECH REPORT 58-13 GA TECH  MAR 1960                      0

LI128  FOAM ALUMINUM OXIDE     POWERS D J
       MOD OF RUPT THERM COND AND THERM EXPOSURE TESTS ON FOAMED A1203+ZRO
       BELL AIR REPT 63-12 (M) ASTIA DOC AD401854 MAR 1963            1     6 8

LI129  FOAM ZIRCONIUM OXIDE    POWERS D J
       MOD OF RUPT THERM COND AND THERM EXPOSURE TESTS ON FOAMED A1203+ZRO
       BELL AIR REPT 63-13 (M) ASTIA DOC AD401854 MAR 1963            1     6 8
```

```
LI130  ALUMINA                  KOENIG J H
       DEVELOPMENT OF MANUFACTURING METHODS FOR PROD OF ALUMINA RADOMES
       ASTIA DOC AD299089 P 7 11 13 JUNE 1960                          0

LI131  BERYLLIA                 BURNIKOV,P.P. BELYAYER, P.A.
       SYSTEMS WITH BERYLLIA OXIDE AND THEIR USE IN TECHNOLOGY
       ZHURMAL USESOYUZNOYE KHIMICHESKOYE OBSHCHESTOV  MAR 13,1963     0

LI132  ALUMINA                  AGER DOROTHY
       SURVEY OF LITERATURE ON PREP PURIF AND DIELECTRIC PROP ALUMINA
       (W) RESEARCH RPT 404FD316-R2 DEC 29,1958                             67

LI133  AMIDE YARN               CLAY W R  LONG W C
       PHYSICAL AND CHEMICAL PROPERTIES
       DUPONT PUBLICATION  MAY 1961                                     1    678

LI134  IMIDE WIRE ENAMEL        FREEMAN J H
       AROMATIC CONDENSATION POLYMERS
       (W) RESEARCH MEMO 12-0402-2-M2-X  APR 28,1960                        678

LI135  ALUMINA                  FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       ASTIA RPT 265900 MAY 1,1960   FEB 28,1961                             7

LI136  FLEX SHEET IMIDE IMP     FREEMAN J H
       AROMATIC CONDENSATION POLYMERS
       (W) RESEARCH MEMO 12-0402-1-M2-X  APR 28,1960                         78

LI137  IMIDE WIRE ENAM          LEPPLA R R CARRYER R R
       POLYMIDE INSULATION SYSTEM FOR HIGHER OPERATING TEMP MORE COMPACT UNITS
       INSULATION JUNE 1963                                                  78

LI140  BERYLLIA                 CHERON THEODORE
       BERYLLIUM OXIDE A LITERATURE SURVEY 1955-1961
       ASTIA AD269729 SEPT 1 1961                                      12 4 6789

LI141  IMIDE WIRE ENAM          STAFF
       PHELPS DODGE PRELIMINARY MAGNET WIRE INFORMATION BULLETIN 361
       PHELPS DODGE CI DATA SHEETS  NOV 1,1960                              678
```

```
LI142  STEATITE              VODOPYANOV K A KAROV B G
       EFFECT OF COMP HEAT AND ELEC TREAT ON THE DIEL PROP OF STEATITE CER
       IZVESTIYA VYSSAIKH UCHENYKH ZAVENDENIY FIZIKA NO 3 P55-61 1962        7

LI143  ALUMINA               PEARS C D
       EVALUATION OF TENSILE DATA FOR BRITTLE MTLS OBTAINED WITH GAS BEAR CONCENT
       ASD-TDR 63-245 MAY 1963                                          1

LI144  IMIDE INSULATED WIRE   MOBERLY L E
       DIELECTRIC TWIST THERMAL LIFE DATE
       INTERNAL WESTINGHOUSE CORRESPONDENCE OCT 28 1963                      7

LI145  ALUMINUM PHOSPHATE     OTT E ALLEN E A
       ALUMINUM PHOSPHATE COATINGS
       ASD TR 61-137 MAY 1961                                          0

LI146  ALUMINA AL203          PEDIGO ALAN ET AL
       RANDOME HANDBOOK 2ND EDITION
       NEW PRODUCTS DIV COORS PORCELAIN CO APRIL 1962                   1  45678

LI175  BERYLLIA               HESSINGER PHILIP S
       BEO BOOMS IN SPACE AGE
       REPRINT FROM RESEARCH DEVELOP TECH REPRINT NO E-60 1963          1     67

LI176  ALUMINA                HESSINGER PHILIP S
       BEO BOOMS IN SPACE AGE
       RESEARCH DEVELOPMENT TECH REPRINT NO E-60 1963                   1     67

LI177  MAGNESIA               HESSINGER PHILIP S
       BEO BOOMS IN SPACE AGE
       RESEARCH DEVELOPMENT TECH REPRINT NO E-60 1963                   1     67

LI178  BERYLLIA               LONG R E SCHOFIELD H Z
       BERYLLIA
       REPRINT FROM REACTOR HANDBOOK VOL 3 MATERIALS AECD3647 NO DATE  12     67

LI179  BERYLLIA               STAFF NATIONAL BERYLLIA CORP
       BERLOX (PER BEO) °OFF THE SHELF° TRANSISTOR HEAT SINKS
       NATIONAL BERYLLIA CORP BERYLLIA AND PURE OXIDE CER 1963          1     67
```

```
LI180  BERYLLIA                   BROSE J E DECKER R H
       BERYLLIA AIDS EQUIPMENT COOLING
       TECH REPRINT NO D-60 FROM ELECTRONIC EQUIP ENGRG 1963           1    67

LI181  BERYLLIA                   STAFF COORS CERAMIC PRODUCTS
       ADVANCED DATA SHEET
       DATA SHEET COORS CERAMIC PRODUCTS SEPT 17 1963                  1     7

LI182  BERYLLIA                   STAFF AMERICAN LAVA CORP
       CUSTOM MADE TECHNICAL CERAMICS ALSI MAG 735
       TECH DATA SHEET FROM AMERICAN LAVA CORP JAN 21 1963             1    67

LI183  BERYLLIA                   STAFF AMERICAN LAVA CORP
       CUSTOM MADE TECHNICAL CERAMICS ALSI MAG 735
       TECH DATA SHEET FROM AMERICAN LAVA CORP JAN 21 1963             1    67

LI184  BERYLLIA                   STAFF COORS CERAMIC PRODUCTS
       COORS HIGH STRENGTH BERYLLIA CERAMICS
       COORS DATA SHEET SEPT 1962                                      1    67

LI185  ALUMINA                    STAFF COORS CERAMIC PRODUCTS
       COORS DENSE HIGH STRENGTH ALUMINA CERAMICS
       COORS DATA SHEET SEPT 1962                                      1    67

LI186  BERYLLIA                   STAFF BERYLLIUM CORP
       BERYLLIUM OXIDE TECHNICAL DATA BULLETIN =3140-A
       TECH DATA SHEET BERYLLIUM CORP READING PA APR 2 1962           12    67

LI187  BERYLLIA                   STAFF NATIONAL BERYLLIA CORP
       BERLOX
       TECH DATA SHEET NATIONAL BERYLLIA CORP NO  DATE                 1    67

LI188  LAMINATES                  WIER J E PONS D
       FLEXURAL TEST OF STRUCTURAL PLASTICS AT ELEVATED TEMPERATURES
       WADC TECH REPT 53-307 ASTIA AD NO 27721 JAN 1954               0

LI189  ALUMINA                    ATLAS L M NACAO H NAKAMURA H
       CONTROL OF DIELECTRIC CONSTANT AND LOSS IN ALUMINA CERAMICS
       JOURNAL OF AMERICAN CERAMIC SOCIETY P 464 OCT 1962                    7
```

```
LI190  BERYLLIA               VON HIPPEL A R ET AL
       PROGRESS REPORT XXXI LAB FOR INSULATION RESEARCH MIT
       MASS INSTITUTE OF TECH PROGRESS REPORT JULY 1962                  7

LI191  ALUMINA                VON HIPPEL A R ET AL
       PROGRESS REPORT XXXI LAB FOR INSULATION RESEARCH MIT
       MASS INSTITUTE OF TECH PROGRESS REPORT JULY 1962                  7

LI192  ALUMINA                KNUDSEN F P
       EFFECT ON YOUNGS MODULUS OF ALUMINA
       JOUR OF AMERICAN CERAMIC SOCIETY VOL 45 NO 2 P94-5 FEB 1962    1

LI193  ALUMINA                FLORIO J V
       DIELECTRIC PROPERTIES OF ALUMINA AT HIGH TEMPERATURE
       JOURNAL OF AMER CERAMIC SOC V43 NO5 P262-67 MAY 1960              7

LI194  ALUMINA                ENGBERGAND C J ZEHMS E H
       THERMAL EXPANSION OF AL203 BEO MGO B4C SIC AND TIC ABOVE 1000C
       JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959           6

LI195  BERYLLIA               ENGBERG C J ZEHMS E H
       THERMAL EXPANSION OF AL 203 BEO MGO B4C SIC AND TIC ABOVE 1000C
       JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959           6

LI196  MAGNESIA               ENGBERG C J ZEHMS E H
       THERMAL EXPANSION OF AL 203 BEO MGO B4C SIC AND TIC ABOVE 1000C
       JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959           6

LI197  ALUMINA                LEE D W KINGERY W D
       RADIATION ENERGY TRANSFER AND THERMAL CONDUCTIVITY OF CERAMIC OXIDES
       JOURNAL OF AMERICAN CERAMIC SOC V43 NO11 P594 NOV 1960           6

LI198  MULLITE                FENSTERMACHER J E HUMMEL F A
       APPARENT RELATION BETWEEN ELASTIC MODULUS AND TRANSVERSE MODULUS OF RUPTURE
       JOURNAL OF AMERICAN CERAMIC V44 NO6 P297-298 JUNE 1961        0

LI199  ALUMINA                SPRIGGS R M
       EFFECT OF POROSITY ON ELASTIC MODULUS OF POLYCRYSTALLINE REFRAC MATERIALS
       JOURNAL OF AMERICAN CERAMIC SOCIETY P628-29 NOV  1961         1
```

```
LI200  ALUMINA                RIGTERINK R D
       CERAMIC ELECTRICAL INSULATING MATERIALS
       JOURNAL AMERICAN CERAMIC SOC V41 NO11 P501-6 NOV 1958         1     7

LI201  BERYLLIA               STAFF AMERICAN LAVA CORPORATION
       MECHANICAL AND ELECTRICAL PROPERTIES OF ALSI MAG CERAMICS
       AMERICAN LAVA CORP CHART NO 631 1963                          1    67

LI205  ALUMINA                MATHESON R R
       ADVANCEMENTS IN TECHNICAL CERAMICS
       BROCHURE JUNE 1963                                            1  4 678

LI206  BERYLLIA               STAFF COORS CO
       CURVE-THERMAL CONDUCTIVITY OF COORS BERYLLIA CERAMICS
       COORS CO LITERATURE                                               6

LI207  BERYLLIA               STAFF COORS PORCELAIN CO
       CURVE-HIGH TEMPERATURE MODULUS OF RUPTURE
       COORS PORCELAIN CO LITERATURE NOV 1963                        1

LI208  ALUMINA                COBLE R L  KINGERY W D
       EFFECT OF POROSITY ON PHYSICAL PROPERTIES OF SINTERED ALUMINA
       JOURNAL OF AMERICAN CERAMIC SOC V39 NOV 1956                 12    67

LI209  BERYLLIA               BURK M
       THERMAL CONDUCTIVITY OF BERYLLIA ROD BY MEASURING AXIAL TEMP DISTRIBUTION
       MATERIALS RESEARCH AND STANDARDS P25-28 JAN 1963                  6

LI210  LAMINATE GLASS EPOXY   WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD2452116 JULY 1960                     8

LI211  LAM POLYESTER GLASS    WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD 245211L JULY 1960                    8

LI212  LAM PHENOLIC GLASS     WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD245211L JULY 1960               1     8
```

```
LI213  MICA PHOSPHATE BOND    BARR F A  CARTHY J P
       ULTRA HIGH TEMP DIELECTRIC MTLS FOR EMBEDDING ENCAPSULATING ELEC COMPONENT
       SYNTHETIC MICA CO ASTIA AD258395 NOV 1960                           1    67

LI214  MICA PHOSPHATE BOND    BARR F A  RODNEY S
       ULTRA HIGH TEMP DIELECTRIC EMBEDDING MATERIALS
       SYNTHETIC MICA CO ASTIA 275789 APRIL 27 1962                              7

LI215  DIELECTRIC MTLS        VON HIPPEL A R
       DIELECTRIC MATERIALS AND APPLICATIONS
       J WILEY AND SONS 1954                                                     7

LI216  ALUMINA                RUSSELL A S  GITZEN W H
       ALUMINA PROPERTIES
       TECHNICAL PAPER NO 10 REVISED ALCOA 1956                           12   567

LI217  ALUMINA                LATRONICS BROCHURE
       HIGH TEMPERATURE ALUMINA
       LATRONICS BROCHURE  NOT DATED                                       1    67

LI218  BERYLLIA               FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       JOHN HOPKINS UNIV REPT SCIENCE AND TECH REPT N62-13294 1962               7

LI219  ALUMINA                FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       JOHN HOPKINS UNIV REPT SCI AND TECH REPT N62-13294 MAR1962                7

LI220  STEATITE               FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       JOHN HOPKINS UNIV REPT SCI AND TECH REPT N62-13294 MAR1962                7

LI221  ALUMINA                GLADDING MCBEAN BROCHURE
       TECHNICAL CERAMICS
       GLADDING MCBEAN BROCHURE NOT DATED                                       6

LI222  ALUMINA                GOLDSMITH A  HIRCHHORN H J ET AL
       THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       WADC TECH REPT 58-476 CERAMICS III NOV 1960                              6
```

```
LI224  MICA PHOS BONDED       BARR F A  MCCARTHY J P
       ULTRA HIGH TEMP DIELECTRIC MTLS FOR EMBEDDING ELECTRONIC COMPONENTS
       SYNTHETIC MICA CO ASTIA AD265499 FINAL REPT MAY 1961               1    67

LI225  COAT PLASMA SPRAYED    KRAMER B E  LEVINSTEIN M A  GRENIER J W
       EFFECT OF ARC PLASMA DEPOSITION ON STABILITY OF NON-METALLIC MTLS
       GENERAL ELECTRIC ASTIA AD264602 MAY 1961                          0

LI229  ALUMINA                MILEK J
       ALUMINUM OXIDE 98 PERCENT PURE (PRELIMINARY DATA)
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963              7

LI230  ALUMINA SINTERED       MILEK J
       ALUMINA OXIDE SINTERED 100 PERCENT PURE
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963              7

LI231  ALUMINA                MILEK J
       ALUMINUM OXIDE POLYCRYSTALLINE 100 PERCENT PRELIMINARY DATA
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963              7

LI232  BERYLLIA               MILEK J
       BERYLLIUM OXIDE
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO MAR 1963              7

LI233  MICA GLASS BONDED      MYCALEX CORP OF AMERICA STAFF
       ELECTRICAL PROPERTIES OF GLASS BONDED AND OTHER MICAS
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             67

LI234  EPOXY POTTING COMP.    UNION CARBIDE PLASTICS CO STAFF
       COMPARATIVE PROPERTIES OF FILLED EPOXY ELECTRICAL POTTING COMPOUNDS
       UNION CARBIDE PLASTICS CO SPEC REPT APRIL 1960                         67

LI235  MICA GLASS BONDED      HAVEG INDUSTRIES INC
       PROPERTIES OF HAVELEX MICAS
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             67

LI236  GLASS FILAMENT         OWENS CORNING FIBERGLASS CORP
       GLASS FILAMENT PROPERTY DATA
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             67
```

```
LI237  MICA GLASS BONDED      MATERIALS IN DESIGN ENGINEERING
       DIELECTRIC CONSTANT AND VOLUME RESISTIVITY FOR GLASS BONDED MICA
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO FEB 1960                  7

LI238  EPOXY RESINS           PARR F T
       LOW DENSITY FILLERS FOR EPOXY RESINS FOR EMBEDDING AIRBORNE ELEC CIRCUITS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963                67

LI239  POLYESTER              HARPER C A
       RESINS FOR EMBEDDING ELECTRONIC PACKAGING
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963                67

LI240  EPOXIES                DELMONTE J
       ARC RESISTANCE OF EPOXIES
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963                 7

LI241  MICAS GLASS BONDED     MYCALEX CORP PRIVATE COMMUNICATION
       RADIATION EXPOSURE DATA ON GLASS BONDED MICAS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963                  8

LI242  EPOXY RESINS           PARRY HARVEY L CAREY J E ET AL
       HIGH HUMIDITY INSULATION RESISTANCE OF EPOXY RESIN SYSTEMS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963                 78

LI243  INSULATORS             FRISCO L J
       FREQUENCY DEPENDENCE OF ELECTRIC STRENGTH
       ELECTRO TECHNOLOGY AUGUST 1961                                              7

LI244  SILICON OXIDE FIBERS   SCHAFER E
       SILICON OXIDE FABRICS PRELIMINARY BIBLIOGRAPHY
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963        0

LI245  GLASS FIBER PAPER      SCHAFER E
       GLASS FIBER PAPER PRELIMINARY BIBLIOGRAPHY
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963        0

LI246  FILLED EPOXY PLASTIC   SCHAFER E
       FILLED EPOXY PLASTICPRELIMINARY
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963        0
```

```
LI248  MICAS GLASS BONDED    SCHAFER E
       NATURAL AND SYNTHETIC GLASS BONDED MICA ELECTRICAL PROPERTIES
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963             7

LI249  CERAMICS GENERAL      BERLINCOURT D A
       FAILURE MECHANISMS IN CERAMIC DIELECTRICS
       RADC-TDR-63-269 FINAL REPORT APRIL 30, 1963                             7

LI250  MAGNET WIRE INORGANI  C LIUBICICH, F.A.  PINSKI, H. ET AL
       TYPE D CERAMIC COATED SOLID SILVER CONDUCTOR ULTRAHIGH TEMP MAGNET WIRE
       SECON METALS CORP PROJECT 5940 PART 26 REPT S R 0070401 1961      0

LI251  ALUMINA               MILEK, J.T.
       ALUMINUM OXIDE DATA SHEETS
       ELECTRONIC PROP INFORMATION CENTER DS-136 MAR 1964                      7

LI252  POTTING COMP-INORG    VONDRACEK C H
       AN EVALUATION OF INORGANIC POTTING COMPOUND
       WESTINGHOUSE RESEARCH PAPER 64-131-342-P2 MAR 1 1964              1    67

LI253  IMIDE-LAMINATE I-8    FREEMAN J H  FROST L W ET AL
       LAMINATES AND ADHESIVES FOR HIGH TEMPERATURE USE
       WESTINGHOUSE RESEARCH REPORT JUNE 15 1964                              6

LI254  POLYMER TEST METHOD   DAKIN T W
       HIGH VOLTAGE ELECTRICAL TESTING OF POLYMER
       WESTINGHOUSE RESEARCH REPORT 64-131-336-P1 APRIL 22 1964          0

LI255  POTTING COMP-INORG    C H VONDRACEK
       W-838 AND W-839 INORGANIC ENCAPSULATION COMPOUND
       PRIVATE CORRESPONDENCE C H VONDRACEK TO W S NEFF 6-29-64          0

LI256  CERAMICEZE WIRE       GEHRING R W
       CORRESPONDENCE FROM PHELPS DODGE WIRE CO FT WAYNE IND
       PRIVATE CORRESPONDENCE R W GEHRING TO D W WIESENBERG 6-11-64      0

LI257  ALUMINA               HAVELL R F  HOLTZ F C
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE REPT QUAR REPT 3 JUNE 4 1964                    67
```

```
LI258  BERYLIA                 HAVELL R F  HOLTZ F C
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE REPT QUAR REPT NO 3 JUNE 4 1964

LI259  MAGNESIA                HAVEL R F  HOLTZ F C
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE QUAR REPT NO 3 JUNE 4 1964                 67

LI260  ALUMINA                 HAVELL R F
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE QUAR REPT NO 2  NOV 12 1963                 7

LI261  BERYLLIA                HAVELL R F
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE SUMMARY REPT NO 2  NOV 12 1963              7

LI262  MAGNESIA                HAVELL R F
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE SUMMARY REPT NO 2  NOV 12 1963              7

LI263  INSULATION INORGAINI   C STAFF, ANACONDA
       CERAMIC COIL SYSTEM ULTRA-HIGH TEMP. INSULATION 650C
       BROCHURE, ANACONDA WIRE AND CABLE CO., 1963                        7

LI264  MICA                    KETTERER, R J
       MICA PAPER INSULATIONS
       INSULATION VOL 10 NO 9 P 24 AUG 1964                              6

LI265  POTTING COMP            DRINKARD E V O  E E SNYDER
       USER-ORIENATED DRIP GUIDE TO POTTING AND ENCAPS
       ASE TECHNICAL REPORT 61-297 AD290823 JUNE 1961                1   67

LI266  POTTING COMP            KENNEDY B W
       EFFECTS OF GAMMA RAD ON SELECTED POTTING COMP AND INSUL MATLS
       NASA TECH REPORT N64-16701 NOV 1963                                 8

LI267  ALUMINA                 STAFF
       SPUR GENERATOR DEVEL PROG PERIOD MAY-JULY 1964
       WESTINGHOUSE TECHNICAL REPT JULY 1964                         1  4  7 9
```

LI268 CERAMICS CORRUGATED STAFF
HIGH PERFORMANCE REFRACTORY STRUCTURES
3M NUCLEAR PRODUCTS BROCHURE AUG 1964 1 4 6 8

LI269 OUTGASSING SCHRANK M P BENNER F C DAS D K
THEOR AND EXPER STUDY TO DETN OUTGASSING CHARACT OF VAR MATLS
AEDC TDR64-53 MAR 1964 8

LI270 IMIDE WIRE AEROJET GENERAL STAFF
SNAP-8 MTLS REPORT FOR 1963 VOL 1 ELECT INSUL DEV
NAS5-417 MAR 1964 78

LI271 ALUMINA COORS PORCELAIN CO STAFF
COORS CERAMICS
COORS DATA SHEET 0001 REV AUG 1964 1 67

LI272 BERYLLIA COORS PORCELAIN CO STAFF
COORS CERAMICS
COORS DATA SHEET 0001 REV AUG 1964 1 67

LI273 CERAMIC OXIDES DUCKWORTH W H ET AL
REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
ASD TDR 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963 12 6

LI274 CERAMIC BORIDES DUCKWORTH W H ET AL
REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
ASD TRD 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963 12 6

LI275 CERAMIC CARBIDES DUCKWORTH W H ET AL
REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
ASD TRD 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963 12 6

LI276 CERAMIC NITRIDES DUCKWORTH W H ET AL
REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
ASD TDR 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963 12 6

LI277 BERYLLIA BRUSH BERYLLIUM CO
PROPERTIES OF HIGH PURITY BERYLLIA
COMMUNICATION R BROWN OF BRUSH TO NEFF AT W 7-17-64 12 67

```
LI278  ALUMINA                COORS PORCELAIN CO
       IMPACT STRENGTH OF COORS 99.5 ALUMINA
       COMMUNICATION E ZIEGLER OF COORS TO NEFF AT W 5-24-64            1

LI279  IMIDE                  KALAPACA H P
       LAB REPORT
       WANL-TME-109 AUGUST 1962                                             78

LI280  ALUMINA                BRIGGS D D  FERREIRA L E
       ELASTIC MODULI OF AL203 AND BEO TO 1200 C BY AN IMPROVED SONIC METHOD
       COORS PORCELAIN CO APRIL 22, 1964                                1

LI281  BERYLLIA               BRIGGS D D  FERREIRA L E
       ELASTIC MODULI OF AL203 AND BEO TO 1200 C BY AN IMPROVED SONIC METHOD
       COORS PORCELAIN CO APRIL 22, 1964                                1

LI282  ALUMINA                WACHTMAN J B  LAM D G JR
       YOUNGS MODULUS OF VARIOUS REFRACTORY MATERIALS AS A FUNCTION OF TEMP
       JOURNAL OF AMERICAN CERAMIC SOC V42(5)P254-60 MAY 1959              6

LI283  ALUMINA                SCHWARTZ B
       THERMAL STRESS FAILURE OF PURE CERAMIC OXIDES
       JOURNAL OF AMERICAN CERAMIC SOC 35(12)P325-33 DEC 1952           1    6

LI284  ALUMINA                NIELSON T H  LEIPOLD M H
       THERMAL EXPANSION IN AIR OF CERAMIC OXIDES TO 2200 C
       JPL TECH REPORT 32-297 OCT 30, 1962                                  6

LI285  ALUMINA                WESGO STAFF
       ALUMINA CERAMICS
       WESTERN GOLD AND OLATINUM CO CATALOG C-115 1962                      67

LI286  ALUMINA                ALITE STAFF
       ALITE HIGH ALUMINA
       ALITE DIV U S STONEWARE BULLETIN A-40R                           1   67

LI287  ALUMINA                DIAMONITE STAFF
       HIGH ALUMINA TECHNICAL CERAMICS
       DIAMONITE MFG CO BULLETIN 5M 1963                                1   67
```

```
LI288   ALUMINA                    KINGERY W D   PAPPIS J
        FAILURE OF CERAMICS AT ELEVATED TEMPERATURES UNDER IMPACT LOADING
        JOURNAL OF AMERICAN CERAMIC SOC V39(2)P64-66 FEB 1956             1

LI289   ALUMINA                    PAPPIS J  KINGERY W D
        ELECTRICAL PROPERTIES OF ALUMINA AT HIGH TEMPERATURE
        JOURNAL OF AMERICAN CERAMIC SOC V44(9)P459-446 SEPT 1961              6

LI290   ALUMINA                    SPRIGGS R M  MITCHELL J T  VASILOS T
        MECHANICAL PROP OF PURE DENSE AL2O3 AS A FUNCTION OF TEMP AND GRAIN SIZE
        JOURNAL OF AMERICAN CERAMIC SOC V47(7)P323-327 JULY 1964          1

LI291   ALUMINA                    HARROP P J  CREAMER R H
        THE HIGH TEMPERATURE ELECTRICAL CONDUCTIVITY OF SINGLE CRYSTAL ALUMINA
        BRITISH J APPLIED PHYSICS V14 P335-339 1963                            7

LI292   ALUMINA                    KENDALL E G  MCCLELLAND J D
        NON-METALLIC MATERIALS FOR HIGH TEMPERATURE STRUCTURAL APPLICATIONS
        ASTM ASTM PREPRINT 94B 1964                                       1    67

LI293   BERYLLIA                   KENDALL E G  MCCLELLAND J D
        NON-METALLIC MATERIALS FOR HIGH TEMPERATURE STRUCTURAL APPLICATIONS
        ASTM ASTM PREPRINT 94B 1964                                       1    67

LI294   ALUMINA                    KOVALEY A I
        MEASUREMENT OF MODULI OF ELASTICITY OF REFRACTORY MATERIALS UNDER VACUUM
        ZAVODSK LAB V28(6)P279-31 1962                                    1

LI295   INSULATION, ELECTRIC   AL CLARK F M
        INSULATING MATERIALS FOR DESIGN AND ENGINEERING PRACTICE
        J WILEY 1963                                                      1    678

LI296   RADIATION EFFECTS, N   UCLEAR  BATTELLE STAFF
        RADIATION EFFECTS STATE OF THE ART
        RAD EFFECTS INFO CENTER NO. 34 JUNE 1964                          1    678

LI297   VACUUM COMPATABILITY   D BABUSCI
        EFFECT OF TEMPERATURE AND VACUUM ON MATERIALS FOR USE IN THE SPACE ENVIRONM
        JOURNAL OF ENVIRONMENTAL SCIENCES PP23-26 AUG 1964                     8
```

```
LI298  WIRE, MAGNET           PENDLETON W
       ADVANCED MAGNET-WIRE SYSTEMS
       ELECTRO-TECHNOLOGY OCT 1963                                        78

RI1    SUPRAMICA 620          HESSINGER P S WEBER T W
       DEVELOPMENT OF A SYNTHETIC MICA CERAMIC SUITABLE FOR USE AT 750 DEG C
       BULLETIN OF AMER CERAMIC SOCIETY V39 (1) P 10-13 JAN 1960      1    67

RI2    SUPRAMICA
       MYCALEX CORP DATA SHEET
       MYCALEX CORP PRODUCT BROCHURE 1961                             1  4 67

RI3    MYKROY 1100            LIKER J MOLECULAR DIELECTRICS INC
       WHAT°S NEW WITH GLASS-BONDED MICA
       PRESENTED AT AMER CERAMIC SOC 1963 MEETING APR 29 1963              67

RI4    THERMICA               MOLECULAR DIELECTRICS INC
       THERMICA TECHNICAL SHEET
       THERMICA TECHNICAL SHEET APRIL 19,1963                              6

RI5    MICACERAM              LIKER J
       WHAT°S NEW WITH GLASS-BONDED MICA
       PRESENTED AT AMER CERAMIC SOC 1963 MEET APRIL 29 1963               67

RI6    FIBERFRAX              WALWORTH C B
       CERAMIC FIBER
       MATERIALS IN ENGRG V46(5) P 124 OCT 1957                            67

RI7    LUCALOX                WARSHAW S I NORTON F H
       DEFORMATION BEHAVIOR OF POLYCRYSTELLINE ALUMINUM OXIDE
       JOURNAL OF AMERICAN CERAMIC SOC V45 P479 OCT 1962               2

RI8    BERYLLIUM OXIDE        VONDERVOOST R R BARMORE W L
       COMPRESSIVE CREEP OF POLYCRYSTALLINE BERYLLIUM OXIDE
       JOURNAL OF AMERICAN CERAMIC SOC V46 P180 APRIL 1963             2

RI9    MYCALEX                FALOON J E
       GLASS-BONDED MICA
       MATERIALS IN DESIGN AND ENGRG V51 P96 1960                     1    67
```

```
RI10   ALUMINUM OXIDE         PREIST D H TALCATT R
       THERMAL STRESSES IN CERAMIC CYLINDERS USED IN VACUUM TUBES
       BULLETIN OF AMERICAN CERAMIC SOC V38 P99 1959                      6

RI11   BERYLLIUM OXIDE        HESSINGER P S
       BERYLIUM OXIDE BOOMS IN SPACE AGE
       NATIONAL BERYLLIUM CORP TECH REPT NO E-60 1963                1    67

RI12   BORALLOY               SKLAREW S ALBOM M J
       PYROLYTICALLY DERIVED REFRACTORY MATERIAL FOR AEROSPACE APPLICATIONS
       ANNUAL MEETING AM CERAMIC SOC APRIL 1963                      1    6

RI13   BORALLOY               HIGH TEMP MATERIALS INC
       BORALLOY DATA SHEET
       BORALLOY DATA SHEET JUNE 1962                                 1    67

RI14   BERYLLIUM OXIDE        RYSHKEWITCH E
       SINTERED BERYLLIA NATIONAL BERYLLIUM CORP
       INTERCERAM (LUBECK GERMANY) V2 P74-81 1962                    1  4 67

RI15   LUCALOX                STAFF GENERAL ELECTRIC
       TRANSLUCENT ALUMINA STAYS STRONG AT 3600 DEG F
       MATERIALS IN DESIGN ENGINEERING V57 NO4 P98 1963              1    67

RI16   BERYLLIUM OXIDE        LARSEN L R
       WHEN DESIGNING WITH CERAMIC MATERIALS
       PRODUCT ENGINEERING V32 NO22 P47 1961                         1    67

RI17   ALUMINA                COHEN JULIUS
       ELECTRICAL CONDUCTIVITY OF ALUMINA
       BULLETIN AMERICAN CERAMIC SOC V38 P441 SEPT 1959             0

RI18   ISOMICA 6-T            STAFF ELECTRICAL MFG AND ELECTRO-TECH
       ADVANCES IN FLEXIBLE AND SEMI-RIGID ELECTRICAL INSULATING MATERIALS
       ELECTRICAL MFG AND ELECTRO-TECH V66 (6) 163-180 1960               67

RI19   CRYSTAL M              STAFF ELECTRICAL MFG AND ELECTRO TECH
       ADVANCES IN FLEXIBLE AND SEMI RIGID ELECTRICAL TABULATING MATERIALS
       ELECTRO-TECH V 66 (6) 163-180 1960                                 6
```

```
RI20   SYN MICA CRYSTAL       BRADLEY A
       INSULATION FOR A RADIATION ENVIRONMENT
       INSULATION V7 NO 11 P23 1961                                           78

RI21   PURE ALUMINA CER       NATIONAL BERYLLIA CORP
       TECHNICAL DATA SHEET
       SUPPLIERS LITERATURE NOV 1961                                         67

RI22   ALUMINA ALSIMAG 748    AMERICAN LAVA CORP STAFF
       TECHNICAL DATA SHEET NO 631
       SUPPLIERS LITERATURE 1963                                             67

RI23   BERYLLIA ALSIMAG 754   AMERICAN LAVA CORP STAFF
       TECHNICAL DATA SHEET NO 631
       SUPPLIERS LITERATURE 1963                                             67

RI24   ALUMINA                PALADINA A E COBLE R L
       EFFECT OF GRAIN BOUNDARIES ON DIFFUSION CONTROLLED PROCESSES IN AL203
       JOUR OF AMERICAN CERAMIC SOC V46 NO 3 P133            1963          2     7

RI25   ALUMINA                ASD STAFF
       IMPURITY DEPENDENCE OF CREEP OF ALUMINUM OXIDE
       TECH DOCUMENTRAY REPT NO ASD TR 61-481 1962                         2

RI26   ALUCER MC ALUMINA      GIBBS P ET AL
       SURFACE AND ENVIRONMENTAL EFFECTS ON CERAMIC MATERIALS
       ASD TECH REPORT 61-182 JULY 1961                                    2

RI27   BERYLLIUM OXIDE        HESSINGER P S HAURA B
       BERYLLIUM OXIDE DIELECTRIC COMPONENTS IN AEROSPACE APPLICATIONS
       DIELECTRICS IN SPACE SYMPOSIUM WEST RESEARCH LAB P 14 6-25-63           67

RI28   GLASS BONDED MICA      MCKENZIE D B
       ELECTL MATLS AND COMPONENTS FOR AIRCRAFT POWER EQUIP OPER. AT HI TEMP
       INSTITUTION OF ELECTRICAL ENGINEERS 106A P 321 1959                0

RI29   MICA PAPER             JAVITZ A E
       TRANSFORMER INSULATION FOR EXTREME ENVIRONMENTS
       ELECTRICAL MANUF 65 NO 3 P 80 1960                                    67
```

```
RI30    BERYLLIA                RYSHKEWITCH E
        MICROSTRUCTURE OF SINTERED BERYLLIA
        TRANSACTIONS OF THE BRITISH CER SOC V59 (8) P 303 1960          0

RI31    LUCALOX                 WACHTMAN J B SCUDERI T G CLEEK G W
        LINEAR THERMAL EXPANSION OF A1203 AND THO2 FROM 100 DEG TO 1100 DEGK
        JOUR AMERICAN CERAMIC SOC V45 (7) P 319 1962                        6

RI32    LUCALOX                 MATHESON R R
        GE°S LAMP RESEARCH LEADS TO UNIQUE CERAMIC MATERIAL
        CERAMIC AGE JUNE 1963                                           1    67 9

RI33    SAPPHIRE                STAFF SPACE AERONAUTICS
        MATERIALS AND PRODUCTION REFERENCE FILE
        SPACE AERONAUTICS P61 NOV 1960                                  2

RI34    LUCALOX                 STAFF SPACE AERONAUTICS
        MATERIALS CERAMICS
        SPACE AERONAUTICS HANDBOOK SECTION HP12 1961-62                 2

R135    ALUMINA AD99            WESTPHAL W B
        DIELECTRIC CONSTANT AND LOSS MEASUREMENTS ON HIGH TEMP MTLS
        LAB FOR INSULATION RESEARCH MIT CONT AF33(616)8353 OCT 1963          7

RI100   IMIDE I-8               FREEMAN J FROST L BOWER G ET AL
        REINFORCED PLASTIC LAMINATES FOR LONG TIME TEMP USE
        WESTINGHOUSE RESEARCH REPORT 63-931-335-R3 JULY 31 1963         1    67

RI101   IMIDE I-8               FREEMAN J H
        LAMINATES FOR HIGH TEMPERATURE
        MONTHLY LETTER REPT 11 AF33(657)9078 AUG 1963                   1     7

RI120   POLYIMIDE SP            DUPONT
        S P COMPOSITIONS
        DUPONT DATA SHEET 1963                                          1     7

RI121   POLYIMIDE SP            EDITORIAL STAFF
        MORE INFORMATION ON MOLDED POLYIMIDE DUPONTS NEW HIGH TEMP THERMOPLASTIC
        PLASTICS DESIGN AND PROCESSING P21 FEB 1963                     1     7
```

```
RI122  POLYIMIDE SP           CALKINS W H
       PRIVATE CORRESPONDENCE W CALKINS TO J FREEMAN
       E I DUPONT DE NEMOURS MAY 2 1962                                    7

RI123  POLYIMIDE SP           FREEMAN J H
       PRIVATE CORRESPONDENCE J FREEMAN TO C HARPER
       WESTINGHOUSE ELEC CORP AUG 23 1962                                  7

RI124  IMIDITE 1850           STAFF
       NEW POLYMER LOOKS GOOD FOR 1000 DEG F
       MATERIALS IN DESIGN ENGINEERING MAY 1963                       1    7

RI125  IMIDITE 1850           STAFF NARMCO CORP
       NARMCO IMIDITE 1850
       DATA SHEET 1963                                                1

RI126  IMIDITE                LAVINE H H ET AL
       RESEARCH DEVELOPMENT HIGH TEMP RESINS FOR STRUCTURAL LAMINATES ADHESIVES
       QUARTERLY PROG REPT 1-4 AF33(657)8047 MAY 62 AUG 62 NOV 62     1    78

RI127  EPOXY-CAST             LEE NEVILLE
       EPOXY RESINS
       EPOXY RESINS MCGRAW HILL P 126-133 1957                        1    7

RI128  EPOXY-CAST             SKEIST J
       EPOXY RESINS
       EPOXY RESINS--REINHOLD P 46 48 51-53 1958                      1    7

RI129  EPOXY-CAST             HARPER C A
       ELECTRONIC PACKAGING WITH RESINS
       MCGRAW-HILL P 48-50 225-230 1961                               1    78

RI130  EPOXY-CAST             STAFF OF MODERN PLASTICS
       EFFECT OF GAMMA RADIATION ON EPOXY PLASTICS
       MODERN PLASTICS OCT 1957                                       1     8

RI131  EPOXY-CAST             FEILD AND ROBINSON
       PMDA IN CURING OF EPOXY RESINS
       INDUSTRIAL AND ENGINEERING CHEMISTRY V49 P369-73 1957          1    7
```

```
RI132  EPOXY CAST               KING R W ET AL
       EFFECT OF NUCLEAR RADIATIONS ON ELASTOMERIC AND PLASTIC COMPONETS
       REIC REPT 21 AF33(616) 7375 TASK 13008 PROJ1448 P27 SEPT 1 61      1    678

RI133  EPOXY CAST               COLLETTI W
       PREPARATIONS OF AN ENGINEERING MANUAL FOR ELEC EMBEDDING COMPOUNDS
       AD402 481L TAB V63-3-2 APRIL                                       1    678

RI134  EPOXY CAST               STEELE D R MATHEWS H
       PROPERTIES OF COMMERCIALLY AVAILABLE ENCAPSULATION COMPOUNDS
       AD 251 911L TAB V61-2-3 P187 MAY 1 1961                            1    7

RI135  EPOXY CAST               EHLERS G
       CORRELATION BETWEEN STRUCTURE AND THERMAL STABILITY OF EPOXY RESINS
       WADC AD245-270L TAB V61-1-1 P152 JULY 1960                         1

RI136  EPOXY CAST               YOUNG R P ARNOLD ENGINEERING DIV CENTER
       EXAMINATION OF EPOXY SYSTEMS USEFUL IN PACKAGING HIGH G RADIO TELEMETERS
       AD273-681 TAB V62-2-6 P38 JUNE 15 1962                             1    7

RI137  EPOXY CAST               BOEING CO
       ANHYDRIDE CURED EPOXY POLYMER RESINS
       AD268 980L TAR V62-1-5 MARCH 1 1962                                1

RI138  EPOXY CAST               JAFFE L D
       EFFECTS OF SPACE ENVIRONMENT UPON PLASTICS AND ELASTOMERS
       AD268 432 TAS V62-1-5 P195 NOV 16 1961                             1     8

RI139  EPOXY CAST               OWENS G
       ENCAPSULATING POTTING AND EMBEDDING MATERIALS FOR ELECTRONIC COMPONENTS
       AD265 866 TAB V62-1-2 P48 JAN 15 1962                              1    7

RI140  EPOXY CAST               OWEN H P
       MATERIAL EPOXY RESIN BASED POTTING COMPOUNDS EVALUATION OF
       AD285 158 TAB V63-1-1 P49 JAN 1 1963                               1

RI141  EPOXY GLASS LAM          NEVILLE LEE
       EPOXY RESINS
       EPOXY RESINS MCGRAW-HILL P252-60 1957                              1    7
```

```
RI142  EPOXY GLASS LAM        STAFF MODERN PLASTICS
       STRUCTURAL LAMINATES
       MODERN PLASTICS V32 P141-4 1954                                     1     7

RI143  EPOXY GLASS LAM        DUFFIN D NERZIG C
       LAMINATED PLASTICS
       REINHOLD P155 1958                                                  1

RI144  EPOXYGLASS REIN LAM    KING R W ET AL
       EFFECT OF NUCLEAR RADIATIONS ON ELASTOMERIC AND PLASTIC COMPONENTS
       REIC REPT 21 AF33(616) 7375 TASK 13008 PROJ1448 SEPT 1 1961         1    67

RI145  EPOXY LAMINATE         HOWSE P T ET AL
       THE THERMAL PROPERTIES OF SOME PLASTIC PANELS
       AD260 065 TAB V61-4-1 P55 OCT 1 1961                                     6

RI146  EPOXY LAMINATE         BOLLER K FOREST PROD LAB
       STRENGTH PROPERTIES OF REINFORCES PLASTIC LAMINATES AT ELEVATED TEMP
       AD247 437L V61-1-3 P126 FEB 1 1961                                  123

RI147  EPOXY LAMINATES        JENEAU P ET AL
       REINFORCED PLASTICS
       AD330 139 TAB V62-4-3 P85 MARCH 1 1962                              1

RI148  EPOXY LAMINATE         DEWITT E ET AL
       EFFECT OF LOW PRESSURE AT ELEVATED TEMP ON SPACE VEHICLE MATERIALS
       AD276 414 TAB F62-3-5 SEPT 1 1962                                   1    78

RI149  EPOXY LAMINATE         WYKES D W
       CYCLIC MECHANICAL PROP OF GLASS CLOTH REINFORCED POLYESTER AND EPOXY LAM
       AD270 424 TAB V62-2-1 P60 APRIL 1 1962                                3

RI150  EPOXY LAMINATE         MCBRIDE R
       LAB TECHNIQUES FOR HIGH TEMP STRUCTURAL BEHAVIOR OF REINFORCED PLASTICS
       AD265 997 TAB V62-1-2 P152 JAN 15 1962                              1

RI151  EPOXY LAMINATE         GLORIOSO S V
       MATERIAL GLASS CLOTH REINFORCED PLASTICS ROOM AND ELEVATED TEMP
       AD285 486 TAB63-1-1 P53 JAN 1 1963                                  1
```

```
RI152  EPOXY LAMINATE          GENERAL DYNAMICS
       EVAL OF STRUCTURAL PROPERTIES OF GLASS REINFORCED PLASTICS CONSTRUCTION
       AD285 484 TAB 63-1-1 P53 JAN 1 1963                                   12    7

RI153  EPOXY LAMINATE          BOLLER K H
       EFFECT OF ELEVATED TEMP ON STRENGTH PROP OF REINFORCES PLASTIC LAMINATES
       AD291 485 TAB V63-1-6 MAR 15 1963                                      1

RI154  EPOXY LAMINATE          DAVIS R T JR
       INVESTIGATION OF ELEVATED TEMP CHARACTERISTICS OF PLASTIC LAMINATES
       AD297 109L TAB 63-2-5 JUNE 1 1963                                      1

RI155  EPOXY LAMINATE          LEE H J
       RESULTS OF QUALIFICATION TESTS ON UCC ERSB-0111 TYPE 11 CLASSES 1 AND 3
       AD404 001L TAB V63-3-4 P178 AUG 15 1963                                1    7

RI156  EPOXY GLASS             FORMO J L ET AL
       EPOXY RESIN COMPOSITION CONTAINING PARA PARA DIAMINO DEPHENYLMETHANE
       HONEYWELL REGULATOR CO US PATENT 2-773-048 DEC 4 1956                  1

RI157  EPOXY PREMIX            RILEY M
       THE NEW EPOXY MOLDING MATERIALS
       MATERIALS IN DESIGN ENGINEERING V49 NO 6 JUNE 1959                     1    7

RI158  EPOXY PREMIX            SCHURB J N COAD R F
       HIGH STRENGTH FIBERGLASS-EPOXY MOLDING COMPOUND
       PROCEEDINGS SPI 17TH ANNUAL TECH CONF SECTION 5H FEB 6 1962            1    7

RI159  EPOXY PREMIX            DOYLE H J MOLBY F G
       NEW EPOXY GLASS MOLDING COMPOUND
       MATERIALS IN DESIGN ENGINEERING V47 NO 5 P106 MAY 1958                 1

RI160  EPOXY-GLASS PREMIX      MINNESOTA MINING AND MANUF STAFF
       SCOTCHPLY REINFORCED PLASTIC-TYPE 1100 HIGH STRENGTH MOLDING COMPOUND
       MINNESOTA MINING AND MANUF DATA SHEET NO 3 JUNE 10 1963                1    7

RI171  POLYESTER PREMIX        LONG J L HOOVER L P
       HEAT RESISTANCE OF ALKYD AND RELATED MOLDING COMPONENTS
       SPE JOURNAL V19 NO 10 P1090 OCTOBER 1963                               1    7
```

```
RI172  POLYESTER PREMIX        STAFF MATERIALS IN DESIGN ENGINEERING
       POLYESTER RESIN WITHSTANDS 500 F CONTINOUSLY
       MATERIALS IN DESIGN ENGINEERING V48 NO 6 P 142 NOV 1958      1

RI173  POLYESTER PREMIX        LITWIN J ET AL
       HEAT RESISTANT DIALLYL PHTHALATE POLYESTERS
       PROCEEDINGS SPI 18TH ANNUAL TECH CONFERENCE SEC 1B FEB 5 1963   1

RI174  POLYESTER-PREMIX        STAFF ALLIED CHEMICAL
       PLASKON ALKYD MOLDING COMPOUND 452
       TECHNICAL DATA REPORT 61-22 1963                                1     7

RI186  FOAM URETHANE           GREEN D F
       FOAMED PLASTICS AND OTHER SELECTED INSULATION MATERIALS
       AD252 981L TAB V61-2-4 P196 MAY 15 1961                         1

RI187  FOAM URETHANE           STEELE D V MATHEWS H
       PROPERTIES OF COMMERCIALLY AVAILABE ENCAPSULATION COMPOUNDS
       AD251 911L TAB V61-2-3 P187 MAY 1 1961                          1     7

RI188  FOAM URETHANE           RESNICK I
       RIGID FOAM PLASTICS INFORMATION MANUAL
       AD248 189 TAB V61-1-4 P38 FEB 15 1961                           1

RI189  FOAMS URETHANE          REILLY A ZWOLINSKI L
       INVESTIGATION OF THE USE OF ISOCYNATE ADDUCTS IN URETHANE FOAM
       AD277 420 TAB V62-4-1 P32 OCT 1 1962                            1

RI190  FOAM POLYURETHANE       MOORE H R
       URETHANE FOAMS FOR AEROSPACE APPLICATION
       AD237 874 TAB V62-2-6 P39 JUNE 15 1962                          1

RI191  FOAM URETHANE           JAFFE L D
       EFFECTS OF SPACE ENVIRONMENT UPON PLASTICS OR ELASTOMERS
       AD268 432 TAB V62-1-5 P195 MARCH 1962                           1      8

RI192  FOAM POLYURETHANE       RESNICK I SILVERGLEIT M
       INVESTIGATIONS OF CHARACTERISTICS OF RIGID FOAM FOR THERMAL INSULATORS
       AD266 244L TAB V62-1-3 P217 FEB 1962                            1
```

```
RI193  FOAM POLYURETHANE      PEACOCK C D
       THERMODYNAMICS POLYURETHANE INSULATION ENVIRONMENTAL COMPATABILITY
       AD285368 TAB 63-1-1 P51 JAN 1 1963                                1     8

RI194  FOAMS URETHANE         HERTZ J
       CAST FOAM INSULATION EVALUATION
       AD291 521 TAB 63-1-6 MAR 15 1963                                  1

RI195  FOAM URETHANE          STAFF MATERIALS IN DESIGN ENGINEERING
       DEVELOPMENTS IN HIGH TEMP URETHANE FOAMS
       MATERIALS IN DESIGN ENGINEERING V52 NO 1 P 11 JULY 1960           1     7

RI196  FOAM URETHANE          DAHERTY D J ET AL
       PHYSICAL PROPERTIES OF RIGID POLYURETHANE FOAMS
       CHEMISTRY AND INDUSTRY P 1340 JULY 28,1962                        1

RI197  FOAM URETHANE          POLIN R E ET AL
       PROPERTIES OF URETHANE FOAMS RELATED TO MOLECULAR STRUCTURE
       JOUR OF CHEMICAL AND ENGRG DATA V4 NO3 P 261 JULY 1959            1

RI198  FOAM URETHANE          SAUNDERS J H ET AL
       PROPERTIES OF FLEXIBLE URETHANE FOAMS
       INDUSTRIAL AND ENGRG CHEMISTRY V3 NO1 P 153 1958                  1

RI199  FOAM URETHANE          BUIST J M HURD R ET AL
       POLYURETHANE FOAMS METHODS OF PRODUCTION PROPERTIES AND APPLICATIONS
       CHEMISTRY AND INDUSTRY P 1544 DEC 17,1960                         1

RI200  FOAM URETHANE          PATTEN G A SKOCHDOPOLE R E
       ENVIROMENTAL FACTORS IN THERMAL CONDUCTIVITY OF PLASTIC FOAMS
       MODERN PLASTICS V39 NO 11 P149 JULY 1962                          1

RI201  FOAM SILICONE          GREEN D F
       FOAMED PLASTICS AND OTHER SELECTED INSULATION MATERIALS
       AD252 981L TAB V61-2-4 P196 MAY 15 1961                           1

RI202  FOAMS SILICONE         RESNICK I
       RIGID FOAM PLASTICS INFORMATION MANUAL
       AD248 189 TAB V61-1-4 P38 FEB 15 1961                             1
```

```
RI203  FOAM SILICONE          BRENNER W RILEY M
       HIGH TEMPERATURE PLASTICS
       REINHOLD P 102 1962                                             1

RI204  FOAM SILICONE          STAFF MATERIALS IN DESIGN ENGINEERING
       SILICONE FOAM INSULATES MISSILE PARTS
       MATERIALS IN DESIGN ENGINEERING V54 NO 7 P 12 DEC 1961          1

RI205  SILICONE FOAM          HOWSE P T PEARS C D
       THERMAL PROPERTIES OF REINFORCED PLASTICS
       MODERN PLASTICS V39 NO 1 P140 SEPT 1961                         1    6

RI206  MICA LAM Y-26          DIVENS W C
       DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
       (W) RESEARCH REPORT 404FF206-RI MAY 12 1959                         67

RI207  ISOMICA-6S             DIVENS W C
       DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
       (W) RES RPT 404FF206-R1 MAY 12 1959                                 67

RI216  DO RESINS              STAFF ELECTRO TECHNOLOGY
       ULTRAHIGH TEMP PLASTICS WITH REACTIVE DIPHENYL OXIDES
       ELECTRO TECHNOLOGY V68 NO 1 P14 JULY 1961                       1

RI217  DORYL LAMINATE         STAFF WESTINGHOUSE
       GRAPHS OF MECHANICAL AND ELECTRICAL PROPERTIES VS TEMPERATURE
       GRAPH ON H17511 1964                                            1    7

RI218  DORYL LAMINATE         STAFF WESTINGHOUSE
       DORYL LAMINATE
       DATA SHEET MICARTA H17511 1964                                  1    7

RI224  IMIDITE                STAFF NARMCO
       NARMCO IMIDITE 1850
       NARMCO DATA SHEET 1964                                          1

RI225  IMIDITE                TRAYNOR E S  SAMPSON R N
       CORRESPONDENCE
       WESTINGHOUSE CORRESPONDENCE FEB 4 1964                          1
```

```
RI227  EPOXY CAST             THOMAS R L
       MATERIAL POTTING COMPOUND ELECTRICAL EVALUATION OF
       AD288563 TAB V63-1-4 P70 FEB 1 1963                         1

RI228  EPOXY CAST             NY NAVAL SHIPYARD
       INVESTIGATION OF ECCCSIL PROGRESS REPORT 45
       AD293063L TAB V63-2-1 P219 AUG 9 1962                       1     7

RI229  EPOXY CAST             DALLIMARE G R
       INVESTIGATIONS OF ELECTRONIC MODULE POTTING RESINS
       AD294 977 TAB V63-2-3 MAY 1 1963                            1

RI230  CAST EPOXY             GREET J ET AL
       DIELECTRIC MATERIALS FOR HIGH TEMP APPLICATION
       AD334 3582 334 360L 334 361L AD V63-2-4 MAY 15 1963               7

RI231  CAST EPOXY             GREEN J ET AL
       DIELECTRIC MATERIALS FOR HIGH TEMP APPLICATION PROGRESS REPT 5
       AD336 206L TAB V63-3-4 P175 AUG 15 1963                           7

RI232  EPOXY CAST             PIERCE C M
       EMBEDDING MATERIALS FOR MODULAR ASSEMBLIES
       AD403 705 TECH ABSTRACT BULLETIN C P47 AUG 15 1963                7

RI233  EPOXY CAST             KING P W ET AL
       NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS
       AD267 890 TAB V62-1-4 P72 FEB 15 1962                       1      8

RI234  EPOXY CAST             BUCHOFF L S SHERWIN W R
       PROPERTIES OF HIGH TEMPERATURE EPOXY SYSTEM
       SPE ANTEC VOL VIII SECTION 2-4 JAN 30,1962                  1     7

RI235  EPOXY CAST             LEE M M
       HEAT RESISTANT ENCAPSULATING RESINS
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 22-1 JAN 1959       1     7

RI236  EPOXY CAST             EHLERS G
       CORRELATION BETWEEN STRUCTURE AND THERMAL STABILITY OF EPOXY RESINS
       POLYMER VI P 304 1960                                       1
```

```
RI237  EPOXY CAST              LEE M HODGES R D
       HEAT RESISTANT ENCAPSULATING RESINS
       PLASTICS TECHNOLOGY P43 APRIL 1960                                  1

RI238  EPOXY CAST              LEE H
       CHARACTERISTICS OF NEW 600 DEG F EPOXY COMPOUNDS
       PLASTICS WORLD V16 NO 3 P4 MARCH 1958                               1     7

RI239  EPOXY CAST              OLYPHANT M JR
       THERMAL SHOCK TESTS FOR CASTING RESINS
       FIRST NATIONAL CONF ON APPLICATION OF ELEC INSULATION 9-5-58        1

RI240  EPOXY CAST              HYSOL CORP STAFF
       HIGH HEAT DISTORTION HARDENER HYSOL H5-3537
       TECHNICAL DATA E-217E HYSOL CORP DEC 1962                           1     7

RI241  EPOXY GLASS LAMINATE    LEVINE H H
       RESEARCH AND DEVELOPMENT OF HIGH TEMP STABLE POLYMERS
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 14-1 JAN 1961               1

RI242  EPOXY GLASS LAMINATE    BRENNER W LUM D RILEY M
       HIGH TEMPERATURE PLASTICS
       REINHOLD P 33 TO 40 1962                                            1

RI243  EPOXY GLASS LAMINATE    MIGLORESE J
       EFFECT OF FINISHES ON HEAT RESISTANT PHENOLIC AND MODIFIED EPOXY LAM SYSTEM
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 7-3 JAN 1961                1     7

RI244  EPOXY GLASS LAMINATE    STAFF MATERIALS IN DESIGN ENGINEERING
       NEW HIGH TEMPERATURE EPOXY RESIN
       MATERIALS IN DESIGN ENGINEERING VOL 51 NO 1 JAN 1960                1     7

RI245  EPOXY GLASS LAMINATE    MENARD R C COOVER W
       EPOXY RESIN LAMINATES WITH HIGH THERMAL RESISTANCE
       SPE 16TH ANTEC TECHNICAL PAPERS SECTION 29-1 JAN 1960               1

RI246  EPOXY GLASS LAMINATE     SONNEBORN R H ET AL
       CONTROL OF VARIABLES IN HEAT RESISTANT GLASS REINFORCED PLASTICS
       PROCEEDINGS SPI 15TH ANNUAL TECH CONF SECTION 1F P7 FEB 2 60        1
```

```
RI247  EPOXY LAMINATE        WYNSTRA J ET AL
       STRUCTURE VERSUS ELEVATED TEMPERATURE PERFORMANCE OF EPOXY RESINS
       MODERN PLASTICS V37 NO 9 P131 MAY 1960                            1

RI248  EPOXY LAMINATE        HOWSE P T PEARS C D
       THERMAL PROPERTIES OF REINFORCED PLASTICS
       MODERN PLASTICS V39 NO1 P140 SEPT 1961                            1    6

RI249  EPOXY GLASS LAMINATE  MENARD R O COOVER W W
       EPOXY RESIN LAMINATE WITH HIGH THERMAL RESISTANCE
       SPE JOURNAL V16 NO 3 P277 MAR 1960                                1

RI250  EPOXY GLASS LAMINATE  BOLLER K H
       RESUME OF FATIQUE CHARACTERISTICS OF REINFORCED PLASTIC LAMINATES
       FOREST PRODUCTS LAB CONT AF33(657)358 ASD-TDR-63-768 JULY 1963      3

RI252  EPOXY GLASS LAMINATE  RICCITIELLO M
       PRIVATE CORRESPONDENCE M RICCITIELLO TO R N SAMPSON
       WESTINGHOUSE CORRRESPONDENCE NOV 8 1963                           1     7

RI254  EPOXY GLASS LAMINATE  STAFF WESTINGHOUSE
       MICARTA INFORMATION
       DATA SHEET BULLETIN H-2497 APRIL 8, 1959                          1     7

RI286  FOAM URETHANE         STAFF MACHINE DESIGN
       PLASTIC BOOK ISSUE
       MACHINE DESIGN P155 SEPT 20 1962                                  1     7

RI287  FOAM-URETHANE         DANCICCO V V
       HEAT RESISTANT URETHANE POLYMERS
       SPE JOURNAL V14 NO5 P34 FEB 1958                                  1

RI288  FOAM URETHANE         CARWIN CO STAFF
       DATA SHEET CPP NO 21-3
       CARWIN CO MAY 1961                                                1     7

RI327  EPOXY CAST            HILL J W
       CORRESPONDENCE TO R N SAMPSON
       HYSOL CO CORRESPONDENCE DEC 24 1963                               1
```

```
RI500   PHENOLIC LAMINATES     ANDERSON H C
        THERMAL DEGRADATION OF PHENOLIC POLYMERS
        AD260 252 TAB V61-4-1 P57 OCT 1 1961                                 1

RI501   PHENOLIC LAMINATES     PATTON R
        FABRICATION OF GLASS FABRIC PHENYL SILANE LAM FOR STRUCTURAL USE
        AD283 145L TAB V62-4-6 P215 DEC 15 1962                              1

RI502   PHENOLIC LAMINATES     FOREST PRODUCTS LAB
        STRENGTH PROPERTIES OF REINFORCES PLASTIC LAM AT ELEVATED TEMP
        AD276 189 TAB V62-3-5 P 114 SEPT 1 1962                              1

RI503   PHENOLIC LAMINATE      DEWITT E ET AL
        EFFECT OF LOW PRESSURE AT ELEVATED TEMP ON SPACE VEHICLES MATERIALS
        AD276 414 TAB V62-3-5 SEPT 1 1962                                    1     78

RI504   PHENOLIC LAMINATE      MCBRIDE R
        LAB TECHNIQUES FOR DETERMINING THE HIGH TEMP STRUCTURAL BEHAVIOR OF PLASTIC
        AD265 997 TAB V62-1-2 P152 JAN 15 1962                               1

RI505   PHENOLIC LAMINATE      STEVENS G H
        FATIGUE TEST OF PHENOLIC LAMINATE AT HIGH STRESS LEVELS AND ELEVATED TEMP
        AD265 532 TAB V62-1-2 P45 JAN 15 1962                                  3

RI506   PHENOLIC LAMINATE      BALLER K H
        ELEVATED TEMP ON STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATE
        AD291 485 TAB V63-1-6 MARK 15 1963                                   1

RI507   PHENOLIC LAMINATE      KING R W ET AL
        EFFECT OF NUCLEAR RADIATION ON ELASTROMERS AND PLASTIC COMPONENTS
        AD267 890 TAB V62-1-4 P72 FEB 15 1962                                1      8

RI508   PHENOLIC LAMINATE      LEVINE H H
        RESEARCH AND DEVELOPMENT OF HIGH TEMPERATURE STABLE POLYMERS
        SPE 17TH ANTEC TECH PAPER SECTION 14-1 JAN 1961                      1

RI509   PHENOLIC LAMINATE      BRENNER W LUM D RILEY M
        HIGH TEMPERATURE PLASTICS
        REINHOLD P 54 1962                                                   1     7
```

```
RI510  PHENOLIC LAMINATE      MIGLORESE J
       EFFECT OF FINISHES ON HEAT RESISTANT PHENOLIC AND MODIFIED EPOXY LAM SYSTEM
       SPE 17TH ANTRC TECH PAPERS SECTION 7-3 JAN 1961                      1     7

RI511  PHENOLIC LAMINATE      MIGLORESE J
       HEAT RESISTANT LAMINATES
       SPE 16TH ANTEC TECH PAPERS SECTION 27-1 JAN 1960                     1

RI512  PHENOLIC LAMINATE      HOWSE P T PEARS C D
       THERMAL PROPERTIES OF REINFORCED PLASTICS
       MODERN PLASTICS V39 NO 1 P140 SEPT 1961                              1    6

RI513  PHENOLIC LAMINATE      PLASTICS DESIGN AND PROCESSING STAFF
       HIGH TEMP PHENOLIC EXCEEDS MIL-SPEC STRENGTH REQUIREMENTS
       PLASTICS DESIGN AND PROCESSING V3 NO8 P31 AUGUST 1963                1

RI514  PHENOLIC LAMINATE      GOLDSMITH A ET AL
       HANDBOOK OF THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       MACMILLAN V4 P718-735 1961                                           1

RI515  PHENOLIC LAMINATE      KIMBALL K E
       INTERLAMINAR PROPERTIES OF FIVE PLASTIC LAMINATES
       ASTIA AD 299704 DECEMBER 1962                                        1

RI516  PHENOLIC LAMINATE      BOLLER K H
       STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATES AT ELEVATED TEMP
       AD240769 JAN 1960                                                    1

RI517  PHENOLIC LAMINATE      STAFF US POLYMERIC CORP
       POLY-PREG 91-LD IMPREGNATES
       US POLYMERIC CORP DATA SHEET SEPT 15 1959                            1     7

RI600  PLASTICS GENERAL       STAFF
       ENVIROMENTAL EFFECTS ON MATERIALS AND EQUIPMENT ABSTRACTS
       AD405 625 V63-3-5 P169 SEPT 1 1963                                   1

RI601  PLASTICS GENERAL       GOETZEL C
       SPACE MATERIALS HANDBOOK
       AD284 547 TAB 63-1-1 P208 JAN 1 1963                                 1      8
```

```
RI602  PLASTICS GENERAL       MOLZON A E
       BIBLIOGRAPHY AND CODE DESCRIPTION OF TECH CONFERENCE PAPERS ON PLASTICS
       PLASTIC REPORT 8 PLASTICS TECH EVALUATION CENTER JULY 1961        0

RI603  PLASTICS GENERAL       MOLZON A E
       BIBLIOGRAPHY AND CODE DESCRIPTION OF TECH CONFERENCE PAPERS ON PLASTICS
       PLASTIC REPT 11 PLASTICS TECH EVALUATION CENTER JUNE 1962         0

RI604  PLASTICS GENERAL       LANDRACK A H
       EFFECTS OF THE SPACE ENVIRONMENT ON PLASTIC
       PLASTIC REPORT 12 JULY 1962                                              8

RI605  PLASTICS GENERAL       KATZ I GOLDBERG I
       DIELECTRIC PROPERTIES OF REINFORCES PLASTICS AT ELEVATED TEMP
       ELECTRICAL MANUFACTURING V62 NO 6 P 72 DEC 1958                    1     7

RI606  PLASTICS GENERAL       STAFF ELECTRICAL MANUFACTURING
       HIGH TEMPERATURE CHARACTERISTICS OF THERMOSETTING LAMINATES
       ELECTRICAL MANUFACTURING V63 NO 4 APRIL 1954               .       1     7

RI607  PLASTICS               MADORSKY S L STRAUS S
       STABILITY OF THERMOSET PLASTICS AT HIGH TEMP
       MODERN PLASTICS V38 NO 6 P 134 FEB 1961                            1

RI608  PLASTICS GENERAL       BILINSKI J R LANGDON W R
       RADIATION EFFECTS HANDBOOK
       INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGRGS S-146 JUNE 63       1    78

RI609  PLASTICS GENERAL       KERLIN E E
       COMBINED EFFECTS OF RADIATION AND CRYO TEMP ON ENGRG MATERIALS
       GENERAL DYNAMICS NAS8-2450 REQUEST NO TP85-468 NOV  1962           1    78

RI700  MICA LAM PHOSPH BOND   VONDRACEK C H
       INORGANIC FLEXIBLE SHEET INSULATION FOR ELECTRICAL EQUIPMENT
       INSULATION P39 JUNE 1962                                                 7

RI701  MICANITE 6             MICA INSULATOR COMPANY
       DATA SHEET
       CLASS H AND C HIGH TEMP ELEC INSULATION 1960                             7
```

```
RI702  ISOMICA 6-S            MICA INSULATOR COMPANY
       DATA SHEET
       CLASS H AND C HIGH TEMP ELEC INSULATION 1960                         7

RI703  INORGANIC BOND MICA    STAFF
       DATA BULLETIN 1
       MACALLEN DATA SHEET APRIL 1961                                       7

RI704  PHOSPH ASBESTOS 92M    VONDRACEK C H ET AL
       BORON PHOSPHATE MATRIX FOR HIGH TEMPERATURE APPLICATIONS
       CONFERENCE STRUCTURAL PLASTICS ADHESIVES VI P106 DEC 1962       1   67

RI705  MICA LAM Y-26          STAFF NEW ENGLAND MICA CO
       Y-26 HIGH HEAT MICA PLATE
       SUPPLIERS BULLETIN 1961                                             67

RI706  FOAM SILICON           MINNESOTA MINING AND MANUF STAFF
       SCOTCHCAST BRAND RESIN XR-5017
       MINNESOTA MINING AND MANUF DATA SHEET 1964                      1    7

RI707  FOAM SILICONE          MEYER C L
       CORRESPONDENCE ON XR5017
       PRIVATE CORRESPONDENCE  DEC 24, 1963                            1    7

RI708  MICARAMIC BOND MICA    DIVENS W C
       DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
       (W) RES REPORT 404FF206-RI MAY 12,1959                              67

RI709  MICA PHOSPHATE BOND    DIVENS W C
       DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
       WESTINGHOUSE RES REPT 404FF206-RI P11 MAY 12 1959                   67

RI710  COMPOUND CA9R          DIVENS W C
       DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
       WESTINGHOUSE RES REPORT 404FF206-RI P11 MAY 12 1959                 67

RI711  PYROCERAM              MILEK J T
       PYROCERAM DATA SHEETS D S 130
       HUGHES AIRCRAFT CO AUGUST 1963                                       7
```

```
RI712  AL SILICATE FIBERS     DAVIS R L
       FIBER REINFORCEMENT RUN-DOWN
       PLASTICS WORLD V21 NO 11 P 60 NOV 1963                                       6

RI713  SILICONE BONDED MICA   DUNCAN, G.I.  FELGER, M.M.
       ELECTRICAL INSULATION PROPERTIES OF ULTRAHIGH TEMEPERATURES
       ELECTRICAL ENGINEERING APRIL 1958                                            7

RI714  PHOSPHATE BONDED MIC   A DUNCAN, G.I.  FELGAR, M.M.
       ELECTRICAL INSULATION PROPERTIES AT ULTRAHIGH TEMPERATURES
       ELECTRICAL ENGINEERING APRIL 1958                                            7

RI715  TECHNICAL DATA SHEET    1959
       FIBERFRAX           CARBORUNDUM RES AND DEVEL DIV
       TECHNICAL DATA SHEET

RI716  INOR BOND MICA MAT     STAFF G E INSUL MATLS DEPT
       TECHNICAL DATA SHEET
       TECHNICAL DATA SHEET PD-109 JUNE 1963                                      678
```

```
LI6     ALUMINA                SMILEY W D SOBON W E HURZ F M FARLEY E D ET AL
        MECHANICAL PROPERTY SURVEY OF REFRACTORY CRYSTALLINE MTLS
        WADC TECH RPT 59-448 JAN 1960                                 12   6

LI16    ALUMINA                VON HIPPEL
        TABLES OF DIELECTRIC MATERIALS ASTIA AD 200958
        MIT RPT LAB FOR INSUL RES TECH RPT 126 VOL VI P 7-21 JUNE 1958     7

LI21    ALUMINA                VON HIPPEL A R
        PROGRESS REPORT NO XXIX LAB FOR INSULATION RESEARCH
        MASS INSTITUTE OF TECH REPORT P 21 JULY 1961                       7

LI28    ALUMINA                GOLDBERG M E  HAMRE H G
        ELECTRONIC COMPONENT PARTS RESEARCH FOR 500C OPERATION
        WADC 57-362 ASTIA AD155785  JULY 1958                              7

LI43    ALUMINA                BERGERON C G FRIEDBERG A L SCHWARZLOSE P E
        HIGH TEMP ELECTRICAL INSULATING INORGANIC COATINGS ON WIRE
        WADC TECH RPT 58-12 TABLE III AND IV MARCH 1958                    7

LI47    ALUMINA                BORTZ S A  NELSON H R  WEIL N A ET AL
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        WADC ASD TR 61-628  APR 1962                                  1 3

LI50    ALUMINA                PARICH N M
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        ASD TR 61-628 PART II  APRIL 1963                             123

LI52    ALUMINA                FRISCO L J
        DIELECTRICS FOR SATELLITES AND SPACE VEHICLES ASTIA AD 256900
        ASTIA PUB AD 256900 P 59 73 79 FEB 1961                            78

LI76    ALUMINA                COHEN JULIUS
        ELECTRICAL PROPERTIES OF SAPPHIRE ASTIA AD238711
        OFFICE OF NAVAL RESEARCH CONTRACT NONR-184C00  APR 1959            7

LI82    ALUMINA SILICA PAPER    PEARL H A  MOWAK J M  CONTI J C
        REFRACTORY INORGANIC MTLS FOR STRUCTURAL APPLICATIONS
        WRIGHT PATTERSON PUB WADC 59-432 PART II  JULY 1960          0
```

```
LI83   ALUMINA                PULLIAM G R  LEONARD B G
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS AIRCRAFT CO  WADD TECH RPT 60-338  OCT 1960                 2

LI85   ALUMINA                GIBBS P  ET AL
       SURFACE AND ENVIRONMENTAL EFFECTS ON CERAMIC MTLS
       UNIV OF UTAH WADD TECH RPT 60-473  AUG 1960                         2

LI86   ALUMINA                SWICA J J  ET AL
       METAL FIBER REINFORCED CERAMICS
       ALFRED UNIVERSITY WADD 58-452  JAN 1960                            1

LI103   ALUMINA               BERGERON C G  FRIEDBERG A L  BEALS R J  ET AL
       HIGH TEMPERATURE ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 ASTIA NO 151079 P 7,8      PART I MAR 1958           7

LI107  ALUMINA                HARRIS,J.N.  WALTON J P
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADC 58-13 ASTIA DOC NO 216362 GA TECH  JULY 1959                 0

LI111   ALUMINA               VON HIPPEL  SMAKULA A
       PROGRESS RPT NO XXX LAB FOR INSL RESEARCH MIT
       MASS INSTITUTE OF TECH RPT JAN 1962                                      7

LI112  ALUMINA                KOEING J N
       INORGANIC DIELECTRIC RESEARCH
       NASA DOCUMENT N62-12359  FEB 1 NOV 1,1962                         0

LI114  ALUMINA                PULLIAM G R
       INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
       DOUGLAS A C WADD TECH RPT 60-338 OCT 1960                           2

LI120  ALUMINA                LEVINSON D W
       SEAL AND INSULATOR PROBLEMS IN THERMIONIC CONVERTERS
       ASTIA AD 273481 P 8 10 11 MAR 1962                                      67

LI122  ALUMINA                VEST R W
       ELECTRICAL BEHAVIOR OF REFRACTORY OXIDES
       ASTIA DOCUMENT AD293487 MAR 1962                                  0
```

```
LI127  ALUMINA                HARRIS J N  WALTON J D JR
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADC TECH REPORT 58-13 GA TECH  MAR 1960                   0

LI130  ALUMINA                KOENIG J H
       DEVELOPMENT OF MANUFACTURING METHODS FOR PROD OF ALUMINA RADOMES
       ASTIA DOC AD299089 P 7 11 13 JUNE 1960                     0

LI132  ALUMINA                AGER DOROTHY
       SURVEY OF LITERATURE ON PREP PURIF AND DIELECTRIC PROP ALUMINA
       (W) RESEARCH RPT 404FD316-R2 DEC 29,1958                           67

LI128  ALUMINA FOAM           POWERS D J
       MOD OF RUPT THERM COND AND THERM EXPOSURE TESTS ON FOAMED A1203+ZRO
       BELL AIR REPT 63-12 (M) ASTIA DOC AD401854 MAR 1963        1     6 8

LI135  ALUMINA                FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       ASTIA RPT 265900 MAY 1,1960   FEB 28,1961                           7

LI143  ALUMINA                PEARS C D
       EVALUATION OF TENSILE DATA FOR BRITTLE MTLS OBTAINED WITH GAS BEAR CONCENT
       ASD-TDR 63-245 MAY 1963                                    1

LI145  ALUMINUM PHOSPHATE     OTT E ALLEN E A
       ALUMINUM PHOSPHATE COATINGS
       ASD TR 61-137 MAY 1961                                     0

LI146  ALUMINA                PEDIGO ALAN ET AL
       RANDOME HANDBOOK 2ND EDITION
       NEW PRODUCTS DIV COORS PORCELAIN CO APRIL 1962             1  45678

LI176  ALUMINA                HESSINGER PHILIP S
       BEO BOOMS IN SPACE AGE
       RESEARCH DEVELOPMENT TECH REPRINT NO E-60 1963             1     67

LI185  ALUMINA                STAFF COORS CERAMIC PRODUCTS
       COORS DENSE HIGH STRENGTH ALUMINA CERAMICS
       COORS DATA SHEET SEPT 1962                                 1     67
```

```
LI189  ALUMINA                  ATLAS L M NACAO H NAKAMURA H
       CONTROL OF DIELECTRIC CONSTANT AND LOSS IN ALUMINA CERAMICS
       JOURNAL OF AMERICAN CERAMIC SOCIETY P 464 OCT 1962                    7

LI191  ALUMINA                  VON HIPPEL A R ET AL
       PROGRESS REPORT XXXI LAB FOR INSULATION RESEARCH MIT
       MASS INSTITUTE OF TECH PROGRESS REPORT JULY 1962                      7

LI192  ALUMINA                  KNUDSEN F P
       EFFECT ON YOUNGS MODULUS OF ALUMINA
       JOUR OF AMERICAN CERAMIC SOCIETY VOL 45 NO 2 P94-5 FEB 1962       1

LI193  ALUMINA                  FLORIO J V
       DIELECTRIC PROPERTIES OF ALUMINA AT HIGH TEMPERATURE
       JOURNAL OF AMER CERAMIC SOC V43 NO5 P262-67 MAY 1960                  7

LI194  ALUMINA                  ENGBERGAND C J ZEHMS E H
       THERMAL EXPANSION OF AL203  BEO MGO B4C SIC AND TIC ABOVE 1000C
       JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959                6

LI197  ALUMINA                  LEE D W KINGERY W D
       RADIATION ENERGY TRANSFER AND THERMAL CONDUCTIVITY OF CERAMIC OXIDES
       JOURNAL OF AMERICAN CERAMIC SOC V43 NO11 P594 NOV 1960                6

LI199  ALUMINA                  SPRIGGS R M
       EFFECT OF POROSITY ON ELASTIC MODULUS OF POLYCRYSTALLINE REFRAC MATERIALS
       JOURNAL OF AMERICAN CERAMIC SOCIETY P628-29 NOV  1961             1

LI200  ALUMINA                  RIGTERINK R D
       CERAMIC ELECTRICAL INSULATING MATERIALS
       JOURNAL AMERICAN CERAMIC SOC V41 NO11 P501-6 NOV 1958             1      7

LI205  ALUMINA                  MATHESON R R
       ADVANCEMENTS IN TECHNICAL CERAMICS
       BROCHURE JUNE 1963                                                1   4 678

LI208  ALUMINA                  COBLE R L  KINGERY W D
       EFFECT OF POROSITY ON PHYSICAL PROPERTIES OF SINTERED ALUMINA
       JOURNAL OF AMERICAN CERAMIC SOC V39 NOV 1956                      12    67
```

```
LI216  ALUMINA                 RUSSELL A S  GITZEN W H
       ALUMINA PROPERTIES
       TECHNICAL PAPER NO 10 REVISED ALCOA 1956                        12  567

LI217  ALUMINA                 LATRONICS BROCHURE
       HIGH TEMPERATURE ALUMINA
       LATRONICS BROCHURE  NOT DATED                                    1   67

LI219  ALUMINA                 FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       JOHN HOPKINS UNIV REPT SCI AND TECH REPT N62-13294 MAR1962             7

LI221  ALUMINA                 GLADDING MCBEAN BROCHURE
       TECHNICAL CERAMICS
       GLADDING MCBEAN BROCHURE NOT DATED                                    6

LI222  ALUMINA                 GOLDSMITH A  HIRCHHORN H J ET AL
       THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       WADC TECH REPT 58-476 CERAMICS III NOV 1960                           6

LI229  ALUMINA                 MILEK J
       ALUMINUM OXIDE 98 PERCENT PURE (PRELIMINARY DATA)
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             7

LI230  ALUMINA SINTERED        MILEK J
       ALUMINA OXIDE SINTERED 100 PERCENT PURE
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             7

LI231  ALUMINA                 MILEK J
       ALUMINUM OXIDE POLYCRYSTALLINE 100 PERCENT PRELIMINARY DATA
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             7

LI251  ALUMINA                 MILEK, J.T.
       ALUMINUM OXIDE DATA SHEETS
       ELECTRONIC PROP INFORMATION CENTER DS-136 MAR 1964                     7

LI257  ALUMINA                 HAVELL R F  HOLTZ F C
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE REPT QUAR REPT 3 JUNE 4 1964                   67
```

```
LI260  ALUMINA                  HAVELL R F
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE QUAR REPT NO 2  NOV 12 1963                      7

LI267  ALUMINA                  STAFF
       SPUR GENERATOR DEVEL PROG PERIOD MAY-JULY 1964
       WESTINGHOUSE TECHNICAL REPT JULY 1964                            1  4   7 9

LI271  ALUMINA                  COORS PORCELAIN CO STAFF
       COORS CERAMICS
       COORS DATA SHEET 0001 REV AUG 1964                               1     67

LI278  ALUMINA                  COORS PORCELAIN CO
       IMPACT STRENGTH OF COORS 99.5 ALUMINA
       COMMUNICATION E ZIEGLER OF COORS TO NEFF AT W 5-24-64            1

LI280  ALUMINA                  BRIGGS D D  FERREIRA L E
       ELASTIC MODULI OF AL2O3 AND BEO TO 1200 C BY AN IMPROVED SONIC METHOD
       COORS PORCELAIN CO APRIL 22, 1964                                1

LI282  ALUMINA                  WACHTMAN J B  LAM D G JR
       YOUNGS MODULUS OF VARIOUS REFRACTORY MATERIALS AS A FUNCTION OF TEMP
       JOURNAL OF AMERICAN CERAMIC SOC V42(5)P254-60 MAY 1959                 6

LI283  ALUMINA                  SCHWARTZ B
       THERMAL STRESS FAILURE OF PURE CERAMIC OXIDES
       JOURNAL OF AMERICAN CERAMIC SOC 35(12)P325-33 DEC 1952           1     6

LI284  ALUMINA                  NIELSON T H  LEIPOLD M H
       THERMAL EXPANSION IN AIR OF CERAMIC OXIDES TO 2200 C
       JPL TECH REPORT 32-297 OCT 30, 1962                                    6

LI285  ALUMINA                  WESGO STAFF
       ALUMINA CERAMICS
       WESTERN GOLD AND PLATINUM CO CATALOG C-115 1962                        67

LI286  ALUMINA                  ALITE STAFF
       ALITE HIGH ALUMINA
       ALITE DIV U S STONEWARE BULLETIN A-40R                           1     67
```

```
LI287  ALUMINA                DIAMONITE STAFF
       HIGH ALUMINA TECHNICAL CERAMICS
       DIAMONITE MFG CO BULLETIN 5M 1963                                  1    67

LI288  ALUMINA                KINGERY W D   PAPPIS J
       FAILURE OF CERAMICS AT ELEVATED TEMPERATURES UNDER IMPACT LOADING
       JOURNAL OF AMERICAN CERAMIC SOC V39(2)P64-66 FEB 1956              1

LI289  ALUMINA                PAPPIS J  KINGERY W D
       ELECTRICAL PROPERTIES OF ALUMINA AT HIGH TEMPERATURE
       JOURNAL OF AMERICAN CERAMIC SOC V44(9)P459-446 SEPT 1961                 6

LI290  ALUMINA                SPRIGGS R M  MITCHELL J T  VASILOS T
       MECHANICAL PROP OF PURE DENSE AL203 AS A FUNCTION OF TEMP AND GRAIN SIZE
       JOURNAL OF AMERICAN CERAMIC SOC V47(7)P323-327 JULY 1964           1

LI291  ALUMINA                HARROP P J  CREAMER R H
       THE HIGH TEMPERATURE ELECTRICAL CONDUCTIVITY OF SINGLE CRYSTAL ALUMINA
       BRITISH J APPLIED PHYSICS V14 P335-339 1963                              7

LI292  ALUMINA                KENDALL E G  MCCLELLAND J D
       NON-METALLIC MATERIALS FOR HIGH TEMPERATURE STRUCTURAL APPLICATIONS
       ASTM ASTM PREPRINT 94B 1964                                        1    67

LI294  ALUMINA                KOVALEY A I
       MEASUREMENT OF MODULI OF ELASTICITY OF REFRACTORY MATERIALS UNDER VACUUM
       ZAVODSK LAB V28(6)P279-31 1962                                     1

RI10   ALUMINA                PREIST D H  TALCATT R
       THERMAL STRESSES IN CERAMIC CYLINDERS USED IN VACUUM TUBES
       BULLETIN OF AMERICAN CERAMIC SOC V38 P99 1959                            6

RI17   ALUMINA                COHEN JULIUS
       ELECTRICAL CONDUCTIVITY OF ALUMINA
       BULLETIN AMERICAN CERAMIC SOC V38 P441 SEPT 1959                  0

RI21   ALUMINA                NATIONAL BERYLLIA CORP
       TECHNICAL DATA SHEET
       SUPPLIERS LITERATURE NOV 1961                                           67
```

```
RI22   ALUMINA ALSIMAG 748    AMERICAN LAVA CORP STAFF
       TECHNICAL DATA SHEET NO 631
       SUPPLIERS LITERATURE 1963                                               67

RI24   ALUMINA                PALADINA A E COBLE R L
       EFFECT OF GRAIN BOUNDARIES ON DIFFUSION CONTROLLED PROCESSES IN AL203
       JOUR OF AMERICAN CERAMIC SOC V46 NO 3 P133            1963          2    7

RI25   ALUMINA                ASD STAFF
       IMPURITY DEPENDENCE OF CREEP OF ALUMINUM OXIDE
       TECH DOCUMENTRAY REPT NO ASD TR 61-481 1962                         2

RI26   ALUCER MC ALUMINA      GIBBS P ET AL
       SURFACE AND ENVIRONMENTAL EFFECTS ON CERAMIC MATERIALS
       ASD TECH REPORT 61-182 JULY 1961                                    2

R135   ALUMINA AD99           WESTPHAL W B
       DIELECTRIC CONSTANT AND LOSS MEASUREMENTS ON HIGH TEMP MTLS
       LAB FOR INSULATION RESEARCH MIT CONT AF33(616)8353 OCT 1963              7

LI54   AMIDE PAPER            HOFFMAN C
       TYPICAL PROPERTIES OF EXPERIMENTAL FIBER HT-1
       (W) INTERNAL DOCUMENT NOT DATED                                     1   78

LI58   AMIDE PAPER            CLAY W R  LONG W C
       PHYSICAL AND CHEMICAL PROPERTIES OF HT-1
       DUPONT PUBLICATION  MAY 1961                                        1   678

LI59   AMIDE PAPER HT-1       WENZEL R N
       TENSILE STRENGTH OF DUPONT FIBER HT-1 AFTER AGING AT ELEVATED TEMP
       (W) INTERNAL REPORT  AUG 2,1956                                     1

LI60   AMIDE PAPER HT-1       FREEMAN J H
       AROMATIC CONDENSATION POLYMERS
       (W) RESEARCH MEMO 12-0402-1-M2-X  APR 28,1960                           678

LI70   AMIDE PAPER            ATKINSON W B
       HT-1 SYNTHETIC FIBER PAPER
       WESTINGHOUSE MATERIALS LAB PUBLICATIONS JAN 24,1961                     678
```

```
LI71    AMIDE HT-1 PAPER       NEIDEMIRE A W
        LIMA MATERIALS ENGR LAB REPORT
        (W) INTERNAL REPORT 61-62 OCTOBER 25,1962                              78

LI91    AMIDE PAPER            CLAY W R
        DUPONT CORRESPONDENCE
        DUPONT CORRESPONDENCE MAY 31,1962                                 1    67

LI92    AMIDE PAPER HT-1       HUMES K
        SUBJECT FIBER PAPER 42333AA
        (W) INTERNAL CORRESPONDENCE NOV 6,1962                                 67

LI93    AMIDE PAPER            DUPONT STAFF
        PROPERTIES AND PROCESSING OF NOMEX HIGH TEMP RESISTANT NYLON PAPER
        DUPONT BROCHURE SEPT 1963                                         1    678

LI94    AMIDE PAPER HT-1       STAFF
        NYLON FIBER FOR 500F
        MATERIALS IN DESIGN ENGR  FEB 1962                                1    67

LI31    AMIDE-IMIDE RESIN      SCALA L C
        POLYPROMELLITIMIDE MICA BONDS
        (W) RESEARCH LAB PUBLICATION FEB 1960                            0

LI133   AMIDE YARN             CLAY W R  LONG W C
        PHYSICAL AND CHEMICAL PROPERTIES
        DUPONT PUBLICATION  MAY 1961                                      1    678

LI17    BERYLLIA               VON HIPPEL
        TABLES OF DIELECTRIC MTLS ASTIA AD200958
        MIT LAB FOR INSUL RES TECH RPT 126 VOL VI P 22-7 JUNE 1958             7

LI29    BERYLLIA               GOLDBERG M F  HAMRE H G  NOBLE R D
        ELECTRONIC COMPONENT PARTS RESEARCH FOR 500 C OPERATION
        WADC 57-362 ASTIA AD155785 JULY 1958                                   7

LI44    BERYLLIA                BERGERON C G  FRIEDBERG A L ET AL
        HIGH TEMPERATURE ELECTRICAL INSULATING INORGANIC COATINGS ON WIRE
        WADC RPT 58-12  TABLE IV AND III MARCH 1958                            7
```

```
LI46    BERYLLIA                  PEARS C D  ALLEN J G  NEEL D S  MANN W H ET AL
        THE THERMAL PROPERTIES OF 26 SOLID MTLS TO 5000F ASTIA AD298061
        ASD TECH RPT TDR62-765 WPAFB P 94,134,163,234,290 JAN 1963            67

LI48    BERYLLIA                  SMILEY W D  SOBON L E  HURZ R M ET AL
        MECHANICAL PROPERTY SURVEY REFRACTORY NONMETALLIC CRYSTALLINE MTLS
        WADC REPORT 59-448  JAN 1960                                  12   6

LI51    BERYLLIA                  PARIKH N M
        STUDIES OF THE BRITTLE BEHAVIOR OF CERAMIC MATERIALS
        ASD TR 61-628 PART II  APR 1963                               123

LI104   BERYLLIA                  BERGERON W G FRIEDBERG A L ET AL
        HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
        WADC TECH RPT 58-12 ASTIA DOC 151079 P 7 8 MAR 1958                 7

LI118   BERYLLIA                  JOHNSON J E SMALLEY A K DUCKWORTH W H
        INVESTIGATION OF SINTERABLE POWDERS AND PROPERTIES OF BERYLLIA CERAMICS
        WADC TECH REPT 60-108 APRIL 1960                              1

LI119   BERYLLIA                  SEIBLE R MASON G L
        THERMAL PROPERTIES OF HIGH TEMP MATERIALS
        WADC TECH REPT 57-468 ASTIA DOC 155607 JUNE 1958                   6

LI131   BERYLLIA                  BURNIKOV,P.P. BELYAYER, P.A.
        SYSTEMS WITH BERYLLIA OXIDE AND THEIR USE IN TECHNOLOGY
        ZHURMAL USESOYUZNOYE KHIMICHESKOYE OBSHCHESTOV  MAR 13,1963     0

LI140   BERYLLIA                  CHERON THEODORE
        BERYLLIUM OXIDE A LITERATURE SURVEY 1955-1961
        ASTIA AD269729 SEPT 1 1961                                    12 4 6789

LI175   BERYLLIA                  HESSINGER PHILIP S
        BEO BOOMS IN SPACE AGE
        REPRINT FROM RESEARCH DEVELOP TECH REPRINT NO E-60 1963       1    67

LI178   BERYLLIA                  LONG R E SCHOFIELD H Z
        BERYLLIA
        REPRINT FROM REACTOR HANDBOOK VOL 3 MATERIALS AECD3647 NO DATE     12   67
```

```
LI179  BERYLLIA                  STAFF NATIONAL BERYLLIA CORP
       BERLOX (PER BEO) 'OFF THE SHELF' TRANSISTOR HEAT SINKS
       NATIONAL BERYLLIA CORP BERYLLIA AND PURE OXIDE CER 1963           1    67

LI180  BERYLLIA                  BROSE J E DECKER R H
       BERYLLIA AIDS EQUIPMENT COOLING
       TECH REPRINT NO D-60 FROM ELECTRONIC EQUIP ENGRG 1963             1    67

LI181  BERYLLIA                  STAFF COORS CERAMIC PRODUCTS
       ADVANCED DATA SHEET
       DATA SHEET COORS CERAMIC PRODUCTS SEPT 17 1963                    1     7

LI182  BERYLLIA                  STAFF AMERICAN LAVA CORP
       CUSTOM MADE TECHNICAL CERAMICS ALSIMAG 735
       TECH DATA SHEET FROM AMERICAN LAVA CORP JAN 21 1963               1    67

LI183  BERYLLIA                  STAFF AMERICAN LAVA CORP
       CUSTOM MADE TECHNICAL CERAMICS ALSIMAG 754(99.5)
       TECH DATA SHEET FROM AMERICAN LAVA CORP JAN 21 1963               1    67

LI184  BERYLLIA                  STAFF COORS CERAMIC PRODUCTS
       COORS HIGH STRENGTH BERYLLIA CERAMICS
       COORS DATA SHEET SEPT 1962                                        1    67

LI186  BERYLLIA                  STAFF BERYLLIUM CORP
       BERYLLIUM OXIDE TECHNICAL DATA BULLETIN =3140-A
       TECH DATA SHEET BERYLLIUM CORP READING PA APR 2 1962             12    67

LI187  BERYLLIA                  STAFF NATIONAL BERYLLIA CORP
       BERLOX
       TECH DATA SHEET NATIONAL BERYLLIA CORP NO   DATE                  1    67

LI190  BERYLLIA                  VON HIPPEL A R ET AL
       PROGRESS REPORT XXXI LAB FOR INSULATION RESEARCH MIT
       MASS INSTITUTE OF TECH PROGRESS REPORT JULY 1962                        7

LI195  BERYLLIA                  ENGBERG C J ZEHMS E H
       THERMAL EXPANSION OF AL 203 BEO MGO B4C SIC AND TIC ABOVE 1000C
       JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959                  6
```

```
LI201  BERYLLIA                 STAFF AMERICAN LAVA CORPORATION
       MECHANICAL AND ELECTRICAL PROPERTIES OF ALSI MAG CERAMICS
       AMERICAN LAVA CORP CHART NO 631 1963                            1    67

LI206  BERYLLIA                 STAFF COORS CO
       CURVE-THERMAL CONDUCTIVITY OF COORS BERYLLIA CERAMICS
       COORS CO LITERATURE                                                  6

LI207  BERYLLIA                 STAFF COORS PORCELAIN CO
       CURVE-HIGH TEMPERATURE MODULUS OF RUPTURE
       COORS PORCELAIN CO LITERATURE NOV 1963                          1

LI209  BERYLLIA                 BURK M
       THERMAL CONDUCTIVITY OF BERYLLIA ROD BY MEASURING AXIAL TEMP DISTRIBUTION
       MATERIALS RESEARCH AND STANDARDS P25-28 JAN 1963                     6

LI218  BERYLLIA                 FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       JOHN HOPKINS UNIV REPT SCIENCE AND TECH REPT N62-13294 1962           7

LI232  BERYLLIA                 MILEK J
       BERYLLIUM OXIDE
       ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO MAR 1963            7

LI258  BERYLLIA                 HAVELL R F  HOLTZ F C
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE REPT QUAR REPT NO 3 JUNE 4 1964

LI261  BERYLLIA                 HAVELL R F
       ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
       IIT RESEARCH INSTITUTE SUMMARY REPT NO 2  NOV 12 1963                 7

LI272  BERYLLIA                 COORS PORCELAIN CO STAFF
       COORS CERAMICS
       COORS DATA SHEET 0001 REV AUG 1964                              1    67

LI277  BERYLLIA                 BRUSH BERYLLIUM CO
       PROPERTIES OF HIGH PURITY BERYLLIA
       COMMUNICATION R BROWN OF BRUSH TO NEFF AT W 7-17-64            12    67
```

```
LI281  BERYLLIA               BRIGGS D D  FERREIRA L E
       ELASTIC MODULI OF AL203 AND BEO TO 1200 C BY AN IMPROVED SONIC METHOD
       COORS PORCELAIN CO APRIL 22, 1964                                  1

LI293  BERYLLIA               KENDALL E G  MCCLELLAND J D
       NON-METALLIC MATERIALS FOR HIGH TEMPERATURE STRUCTURAL APPLICATIONS
       ASTM ASTM PREPRINT 94B 1964                                        1    67

RI8    BERYLLIA               VONDERVOOST R R  BARMORE W L
       COMPRESSIVE CREEP OF POLYCRYSTALLINE BERYLLIUM OXIDE
       JOURNAL OF AMERICAN CERAMIC SOC V46 P180 APRIL 1963                 2

RI11   BERYLLIUM OXIDE        HESSINGER P S
       BERYLIUM OXIDE BOOMS IN SPACE AGE
       NATIONAL BERYLLIUM CORP TECH REPT NO E-60 1963                     1    67

RI12   BORALLOY               SKLAREW S ALBOM M J
       PYROLYTICALLY DERIVED REFRACTORY MATERIAL FOR AEROSPACE APPLICATIONS
       ANNUAL MEETING AM CERAMIC SOC APRIL 1963                           1    6

RI13   BORALLOY               HIGH TEMP MATERIALS INC
       BORALLOY DATA SHEET
       BORALLOY DATA SHEET JUNE 1962                                      1    67

RI14   BERYLLIA               RYSHKEWITCH E
       SINTERED BERYLLIA NATIONAL BERYLLIUM CORP
       INTERCERAM (LUBECK GERMANY) V2 P74-81 1962                         1  4 67

RI16   BERYLLIA               LARSEN L R
       WHEN DESIGNING WITH CERAMIC MATERIALS
       PRODUCT ENGINEERING V32 NO22 P47 1961                              1    67

RI23   BERYLLIA ALSIMAG 754   AMERICAN LAVA CORP STAFF
       TECHNICAL DATA SHEET NO 631
       SUPPLIERS LITERATURE 1963                                               67

RI27   BERYLLIUM OXIDE        HESSINGER P S HAURA B
       BERYLLIUM OXIDE DIELECTRIC COMPONENTS IN AEROSPACE APPLICATIONS
       DIELECTRICS IN SPACE SYMPOSIUM WEST RESEARCH LAB P 14 6-25-63           67
```

```
RI30    BERYLLIA               RYSHKEWITCH E
        MICROSTRUCTURE OF SINTERED BERYLLIA
        TRANSACTIONS OF THE BRITISH CER SOC V59 (8) P 303 1960        0

LI80    BORIDES                VAHLDIER F W MERSOL S A
        PROPERTIES AND STRUCTURE OF BORIDES
        WRIGHT PATTERSON PUB ASD-TR-61-514 JAN 1962                   0

LI7     BORON NITRIDE          STAFF
        SYNTHESIS AND PURIFICATION OF DIELECTRIC MATERIALS
        WESTINGHOUSE RESEARCH LAB REPORT OCT 1959 DEC 1959            0

LI73    CERAMICS               CAPE J A  TAYLOR R E
        THERMAL PROPERTIES OF REFRACTORY MATERIALS ASTIA AD264228
        WADD TECH RPT 60-581     JULY 1961                            0

LI274   CERAMIC BORIDES        DUCKWORTH W H ET AL
        REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
        ASD TRD 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963    12   6

LI275   CERAMIC CARBIDES       DUCKWORTH W H ET AL
        REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
        ASD TRD 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963    12   6

LI77    CERAMIC COMP           SMOKE E J  ET AL
        STUDY OF HIGH TEMPERATURE MTLS FINAL RPT
        NJ CERAMIC RESEARCH STATION ASTIA AD248105  1960              0

LI268   CERAMICS CORRUGATED    STAFF
        HIGH PERFORMANCE REFRACTORY STRUCTURES
        3M NUCLEAR PRODUCTS BROCHURE AUG 1964                          1  4 6 8

LI276   CERAMIC NITRIDES       DUCKWORTH W H ET AL
        REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
        ASD TDR 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963    12   6

LI273   CERAMIC OXIDES         DUCKWORTH W H ET AL
        REFACTORY CERAMICS A MATERIALS SELECTION HANDBOOK
        ASD TDR 63-4102 CONTRACT AF33(657)8326 TASK 738105 OCT 1963    12   6
```

```
LI249  CERAMICS GENERAL      BERLINCOURT D A
       FAILURE MECHANISMS IN CERAMIC DIELECTRICS
       RADC-TDR-63-269 FINAL REPORT APRIL 30, 1963                         7

RI710  COMPOUND CA9R         DIVENS W C
       DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
       WESTINGHOUSE RES REPORT 404FF206-RI P11 MAY 12 1959                67

RI19   CRYSTAL M             STAFF ELECTRICAL MFG AND ELECTRO TECH
       ADVANCES IN FLEXIBLE AND SEMI RIGID ELECTRICAL TABULATING MATERIALS
       ELECTRO-TECH V 66 (6) 163-180 1960                                  6

LI215  DIELECTRIC MTLS       VON HIPPEL A R
       DIELECTRIC MATERIALS AND APPLICATIONS
       J WILEY AND SONS 1954                                               7

RI216  DO RESINS             STAFF ELECTRO TECHNOLOGY
       ULTRAHIGH TEMP PLASTICS WITH REACTIVE DIPHENYL OXIDES
       ELECTRO TECHNOLOGY V68 NO 1 P14 JULY 1961                      1

LI240  EPOXIES               DELMONTE J
       ARC RESISTANCE OF EPOXIES
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963         7

LI5    EPOXY GLASS           FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES ASTIA RPT 265900
       DIELECTRICS LAB JOHN HOPKINS UNIV  MAY 1,1960 TO FEB 28,1961       78

LI23   EPOXY COMPOUNDS       NAVAL ORD LAB STAFF
       STUDY OF HIGH TEMP POLYMERS BY ELECTRO-THERMAL ANALYSIS ASTIA 245564
       U S NAVAL ORD LAB REPORT ASTIA AD245564  JUNE 1960             0

RI127  EPOXY-CAST            LEE NEVILLE
       EPOXY RESINS
       EPOXY RESINS MCGRAW HILL P 126-133 1957                        1    7

RI128  EPOXY-CAST            SKEIST J
       EPOXY RESINS
       EPOXY RESINS--REINHOLD P 46 48 51-53 1958                      1    7
```

```
RI129  EPOXY-CAST              HARPER C A
       ELECTRONIC PACKAGING WITH RESINS
       MCGRAW-HILL P 48-50 225-230 1961                                   1     78

RI130  EPOXY-CAST              STAFF OF MODERN PLASTICS
       EFFECT OF GAMMA RADIATION ON EPOXY PLASTICS
       MODERN PLASTICS OCT 1957                                           1      8

RI131  EPOXY-CAST              FEILD AND ROBINSON
       PMDA IN CURING OF EPOXY RESINS
       INDUSTRIAL AND ENGINEERING CHEMISTRY V49 P369-73 1957              1     7

RI132  EPOXY CAST              KING R W ET AL
       EFFECT OF NUCLEAR RADIATIONS ON ELASTOMERIC AND PLASTIC COMPONETS
       REIC REPT 21 AF33(616) 7375 TASK 13008 PROJ1448 P27 SEPT 1 61      1    678

RI133  EPOXY CAST              COLLETTI W
       PREPARATIONS OF AN ENGINEERING MANUAL FOR ELEC EMBEDDING COMPOUNDS
       AD402 481L TAB V63-3-2 APRIL                                       1    678

RI134  EPOXY CAST              STEELE D R MATHEWS H
       PROPERTIES OF COMMERCIALLY AVAILABLE ENCAPSULATION COMPOUNDS
       AD 251 911L TAB V61-2-3 P187 MAY 1 1961                            1     7

RI135  EPOXY CAST              EHLERS G
       CORRELATION BETWEEN STRUCTURE AND THERMAL STABILITY OF EPOXY RESINS
       WADC AD245-270L TAB V61-1-1 P152 JULY 1960                         1

RI136  EPOXY CAST              YOUNG R P ARNOLD ENGINEERING DIV CENTER
       EXAMINATION OF EPOXY SYSTEMS USEFUL IN PACKAGING HIGH G RADIO TELEMETERS
       AD273-681 TAB V62-2-6 P38 JUNE 15 1962                             1     7

RI137  EPOXY CAST              BOEING CO
       ANHYDRIDE CURED EPOXY POLYMER RESINS
       AD268 980L TAR V62-1-5 MARCH 1 1962                                1

RI138  EPOXY CAST              JAFFE L D
       EFFECTS OF SPACE ENVIRONMENT UPON PLASTICS AND ELASTOMERS
       AD268 432 TAS V62-1-5 P195 NOV 16 1961                             1      8
```

```
RI139  EPOXY CAST            OWENS G
       ENCAPSULATING POTTING AND EMBEDDING MATERIALS FOR ELECTRONIC COMPONENTS
       AD265 866 TAB V62-1-2 P48 JAN 15 1962                               1     7

RI140  EPOXY CAST            OWEN H P
       MATERIAL EPOXY RESIN BASED POTTING COMPOUNDS EVALUATION OF
       AD285 158 TAB V63-1-1 P49 JAN 1 1963                                1

RI156  EPOXY GLASS           FORMO J L ET AL
       EPOXY RESIN COMPOSITION CONTAINING PARA PARA DIAMINO DEPHENYLMETHANE
       HONEYWELL REGULATOR CO US PATENT 2-773-048 DEC 4 1956               1

RI227  EPOXY CAST            THOMAS R L
       MATERIAL POTTING COMPOUND ELECTRICAL EVALUATION OF
       AD288563 TAB V63-1-4 P70 FEB 1 1963                                 1

RI228  EPOXY CAST            NY NAVAL SHIPYARD
       INVESTIGATION OF ECCOSIL PROGRESS REPORT 45
       AD293063L TAB V63-2-1 P219 AUG 9 1962                               1     7

RI229  EPOXY CAST            DALLIMARE G R
       INVESTIGATIONS OF ELECTRONIC MODULE POTTING RESINS
       AD294 977 TAB V63-2-3 MAY 1 1963                                    1

RI230  CAST EPOXY            GREET J ET AL
       DIELECTRIC MATERIALS FOR HIGH TEMP APPLICATION
       AD334 3582 334 360L 334 361L AD V63-2-4 MAY 15 1963                       7

RI231  EPOXY CAST            GREEN J ET AL
       DIELECTRIC MATERIALS FOR HIGH TEMP APPLICATION PROGRESS REPT 5
       AD336 206L TAB V63-3-4 P175 AUG 15 1963                                   7

RI232  EPOXY CAST            PIERCE C M
       EMBEDDING MATERIALS FOR MODULAR ASSEMBLIES
       AD403 705 TECH ABSTRACT BULLETIN C P47 AUG 15 1963                        7

RI233  EPOXY CAST            KING P W ET AL
       NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS
       AD267 890 TAB V62-1-4 P72 FEB 15 1962                               1      8
```

```
RI234  EPOXY CAST              BUCHOFF L S SHERWIN W R
       PROPERTIES OF HIGH TEMPERATURE EPOXY SYSTEM
       SPE ANTEC VOL VIII SECTION 2-4 JAN 30,1962                          1     7

RI235  EPOXY CAST              LEE M M
       HEAT RESISTANT ENCAPSULATING RESINS
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 22-1 JAN 1959               1     7

RI236  EPOXY CAST              EHLERS G
       CORRELATION BETWEEN STRUCTURE AND THERMAL STABILITY OF EPOXY RESINS
       POLYMER VI P 304 1960                                               1

RI237  EPOXY CAST              LEE M HODGES R D
       HEAT RESISTANT ENCAPSULATING RESINS
       PLASTICS TECHNOLOGY P43 APRIL 1960                                  1

RI238  EPOXY CAST              LEE H
       CHARACTERISTICS OF NEW 600 DEG F EPOXY COMPOUNDS
       PLASTICS WORLD V16 NO 3 P4 MARCH 1958                               1     7

RI239  EPOXY CAST              OLYPHANT M JR
       THERMAL SHOCK TESTS FOR CASTING RESINS
       FIRST NATIONAL CONF ON APPLICATION OF ELEC INSULATION 9-5-58        1

RI240  EPOXY CAST              HYSOL CORP STAFF
       HIGH HEAT DISTORTION HARDENER HYSOL H5-3537
       TECHNICAL DATA E-217E HYSOL CORP DEC 1962                           1     7

RI327  EPOXY CAST              HILL J W
       CORRESPONDENCE TO R N SAMPSON
       HYSOL CO CORRESPONDENCE DEC 24 1963                                 1

LI234  EPOXY POTTING COMP.     UNION CARBIDE PLASTICS CO STAFF
       COMPARATIVE PROPERTIES OF FILLED EPOXY ELECTRICAL POTTING COMPOUNDS
       UNION CARBIDE PLASTICS CO SPEC REPT APRIL 1960                          67

RI157  EPOXY PREMIX            RILEY M
       THE NEW EPOXY MOLDING MATERIALS
       MATERIALS IN DESIGN ENGINEERING V49 NO 6 JUNE 1959                  1     7
```

```
RI158  EPOXY PREMIX          SCHURB J N COAD R F
       HIGH STRENGTH FIBERGLASS-EPOXY MOLDING COMPOUND
       PROCEEDINGS SPI 17TH ANNUAL TECH CONF SECTION 5H FEB 6 1962       1     7

RI159  EPOXY PREMIX          DOYLE H J MOLBY F G
       NEW EPOXY GLASS MOLDING COMPOUND
       MATERIALS IN DESIGN ENGINEERING V47 NO 5 P106 MAY 1958            1

RI160  EPOXY-GLASS PREMIX    MINNESOTA MINING AND MANUF STAFF
       SCOTCHPLY REINFORCED PLASTIC-TYPE 1100 HIGH STRENGTH MOLDING COMPOUND
       MINNESOTA MINING AND MANUF DATA SHEET NO 3 JUNE 10 1963           1     7

LI27   EPOXY RESIN           MADORSKY S L STRAUSS S
       THERMAL DEGRADATION OF POLYMERS AT TEMP UP TO 1200C
       NATIONAL BUREAU OF STANDARDS MAR 1960                            0

LI238  EPOXY RESINS          PARR F T
       LOW DENSITY FILLERS FOR EPOXY RESINS FOR EMBEDDING AIRBORNE ELEC CIRCUITS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963            67

LI242  EPOXY RESINS          PARRY HARVEY L CAREY J E ET AL
       HIGH HUMIDITY INSULATION RESISTANCE OF EPOXY RESIN SYSTEMS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963             78

RI715  FIBERFRAX             CARBORUNDUM RES AND DEVEL DIV
       TECHNICAL DATA SHEET
       TECHNICAL DATA SHEET 1959

RI6    FIBERFRAX             WALWORTH C B
       CERAMIC FIBER
       MATERIALS IN ENGRG V46(5) P 124 OCT 1957                                67

LI121  MATERIALS GENERAL     GOLDSMITH H  HIRSCHORN J  WATERMAN E
       THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       ASTIA AD266287 WADC REPORT NO 58-476 NOV 1960                    0

LI18   GLASS                 VON HIPPEL
       TABLES OF DIELECTRIC MATERIALS
       ASTIA AD200958 VOL VI P 35-43  JUNE 1958                                 7
```

```
LI61    GLASS FABRIC          LEPPLA R R CARRYER R R
        POLYMIDE INS SYSTEM FOR HIGHER OPERATING TEMP MORE COMPACT UNITS
        INSULATION JUNE 1963                                                    678

LI24    GLASS FIBERS          OTTO W H
        PROPERTIES OF GLASS FIBERS AT ELEVATED TEMP
        NAVY BUREAU OF AERO ASTIA AD228851  SEPT 15,1959                     1 3

LI245   GLASS FIBER PAPER     SCHAFER E
        GLASS FIBER PAPER PRELIMINARY BIBLIOGRAPHY
        ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963        0

LI236   GLASS FILAMENT        OWENS CORNING FIBERGLASS CORP
        GLASS FILAMENT PROPERTY DATA
        ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963             67

LI40    GLASS HIGH RES        HIRAYAMA C
        HIGH RESISTIVITY GLASSES
        WESTINGHOUSE RESEARCH MEMO 10-0402-2-M9 MAR 19,1959                0

LI115   GLASS PROPERTIES      KERPER M J  DILLER C C  EIMER E H
        PROPERTIES OF GLASSES AT ELEVATED TEMP
        WADC TECH REPORT 56-645 PART III  OCT 1959                         0

LI125   IMIDE                 KUSKO A  HJERKBERG P N  ET AL
        COOLING AND MATERIALS INVESTIGATION FOR AIRCRAFT GENERATORS
        ASTIA DOC AD 118086  JUNE 1956                                     0

LI39    IMIDE                 FREEMAN J H FROST L W BOWER G M ET AL
        REINFORCED PLASTICS FOR LONG TIME HIGH TEMP USE
        WESTINGHOUSE RESEARCH RPT 63-931-335RI JUNE 2,1963                  1

LI279   IMIDE                 KALAPACA H P
        LAB REPORT
        WANL-TME-109 AUGUST 1962                                                 78

LI55    IMIDE CASTING CPD     DUPONT STAFF
        PROPERTIES OF VESPEL FABRICATED PARTS
        DUPONT DATA SHEET MAR 23,1963                                       1    678
```

```
LI90    IMIDE FILM              DUPONT STAFF
        H FILM
        DUPONT DATA SHEET NOV 1,1962                                1   678

LI126   IMIDE FILM              CROSBIE R  HEWITT G W  DAKIN I W
        AGING TESTS ON DUPONT H FILM
        (W) RESEARCH REPORT 63-131-340-RI  MAR 8,1963                   67

LI136   FLEX SHEET IMIDE IMP    FREEMAN J H
        AROMATIC CONDENSATION POLYMERS
        (W) RESEARCH MEMO 12-0402-1-M2-X  APR 28,1960                    78

LI62    IMIDE GLASS CLOTH       FREEMAN J H
        RADIATION STABILITY OF AROMATIC AMIDE-IMIDE POLYMERS
        (W) RESEARCH DATA SHEET OCT 1961                                  8

RI100   IMIDE I-8               FREEMAN J FROST L BOWER G ET AL
        REINFORCED PLASTIC LAMINATES FOR LONG TIME TEMP USE
        WESTINGHOUSE RESEARCH REPORT 63-931-335-R3 JULY 31 1963     1   67

RI101   IMIDE I-8               FREEMAN J H
        LAMINATES FOR HIGH TEMPERATURE
        MONTHLY LETTER REPT 11 AF33(657)9078 AUG 1963               1    7

RI124   IMIDITE 1850            STAFF
        NEW POLYMER LOOKS GOOD FOR 1000 DEG F
        MATERIALS IN DESIGN ENGINEERING MAY 1963                    1    7

RI125   IMIDITE 1850            STAFF NARMCO CORP
        NARMCO IMIDITE 1850
        DATA SHEET 1963                                             1

RI126   IMIDITE                 LAVINE H H ET AL
        RESEARCH DEVELOPMENT HIGH TEMP RESINS FOR STRUCTURAL LAMINATES ADHESIVES
        QUARTERLY PROG REPT 1-4 AF33(657)8047 MAY 62 AUG 62 NOV 62  1    78

RI224   IMIDITE                 STAFF NARMCO
        NARMCO IMIDITE 1850
        NARMCO DATA SHEET 1964                                      1
```

```
RI225  IMIDITE                TRAYNOR E S  SAMPSON R N
       CORRESPONDENCE
       WESTINGHOUSE CORRESPONDENCE FEB 4 1964                              1

LI243  INSULATORS             FRISCO L J
       FREQUENCY DEPENDENCE OF ELECTRIC STRENGTH
       ELECTRO TECHNOLOGY AUGUST 1961                                            7

LI295  INSULATION, ELECTRIC   AL CLARK F M
       INSULATING MATERIALS FOR DESIGN AND ENGINEERING PRACTICE
       J WILEY 1963                                                        1    678

RI18   ISOMICA 6-T            STAFF ELECTRICAL MFG AND ELECTRO-TECH
       ADVANCES IN FLEXIBLE AND SEMI-RIGID ELECTRICAL INSULATING MATERIALS
       ELECTRICAL MFG AND ELECTRO-TECH V66 (6) 163-180 1960                     67

RI207  ISOMICA-6S             DIVENS W C
       DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
       (W) RES RPT 404FF206-R1 MAY 12 1959                                      67

RI702  ISOMICA 6-S            MICA INSULATOR COMPANY
       DATA SHEET
       CLASS H AND C HIGH TEMP ELEC INSULATION 1960                              7

LI263  INSULATION INORGAINI   C STAFF, ANACONDA
       CERAMIC COIL SYSTEM ULTRA-HIGH TEMP. INSULATION 650C
       BROCHURE, ANACONDA WIRE AND CABLE CO., 1963                               7

RI716  INOR BOND MICA MAT     STAFF G E INSUL MATLS DEPT
       TECHNICAL DATA SHEET
       TECHNICAL DATA SHEET PD-109 JUNE 1963                                    678

LI53   LAMINATES              VONDRACEK C H MOBERLY L E BERG D
       SYNTHESIS AND FORMULATION OF INORGANIC BONDED INORGANIC FIBER STRUC MTLS
       (W) REPORT ON AF CONTRACT AF33/657/7587 MAR 1963                    1    6

LI57   LAM AROMATIC AMIDE     FREEMAN J H  FROST L W  BOWER G M  TRAYNOR E J
       REINFORCED PLASTIC LAM FOR LONG TIME HIGH TEMP USE
       (W) RESEARCH RPT 63-931-335RI  JAN 2,1963                          0
```

```
LI116  LAMINATE             BULLER K  KIMBALL K E
       STRENGTH PROPERTIES OF REINFORCED PLASTIC LAM AT ELEVATED TEMP
       WADC TECH RPT 59-229    SEPT 1959                           0

LI188  LAMINATES            WIER J E PONS D
       FLEXURAL TEST OF STRUCTURAL PLASTICS AT ELEVATED TEMPERATURES
       WADC TECH REPT 53-307 ASTIA AD NO 27721 JAN 1954            0

RI217  DORYL LAMINATE       STAFF WESTINGHOUSE
       GRAPHS OF MECHANICAL AND ELECTRICAL PROPERTIES VS TEMPERATURE
       GRAPH ON H17511 1964                                         1    7

RI218  DORYL LAMINATE       STAFF WESTINGHOUSE
       DORYL LAMINATE
       DATA SHEET MICARTA H17511 1964                               1    7

LI20   EPOXY LAMINATE       VON HIPPEL
       TABLES OF DIELECTRIC MTLS CATALOGED BY ASTIA AD200958
       MIT LAB FOR INSUL RES TECH RPT 126 VOL  VI P 35-43 JUNE 1958      7

LI49   EPOXY LAMINATE       FRISCO L J
       DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
       ASTIA PUB AD256900 FEB 1961                                       78

LI210  LAMINATE GLASS EPOXY   WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD2452116 JULY 1960                    8

RI141  EPOXY GLASS LAM      NEVILLE LEE
       EPOXY RESINS
       EPOXY RESINS MCGRAW-HILL P252-60 1957                        1    7

RI142  EPOXY GLASS LAM      STAFF MODERN PLASTICS
       STRUCTURAL LAMINATES
       MODERN PLASTICS V32 P141-4 1954                              1    7

RI143  EPOXY GLASS LAM      DUFFIN D NERZIG C
       LAMINATED PLASTICS
       REINHOLD P155 1958                                           1
```

RI144 EPOXYGLASS REIN LAM   KING R W ET AL
EFFECT OF NUCLEAR RADIATIONS ON ELASTOMERIC AND PLASTIC COMPONENTS
REIC REPT 21 AF33(616) 7375 TASK 13008 PROJ1448 SEPT 1 1961   1   67

RI145 EPOXY LAMINATE   HOWSE P T ET AL
THE THERMAL PROPERTIES OF SOME PLASTIC PANELS
AD260 065 TAB V61-4-1 P55 OCT 1 1961   6

RI146 EPOXY LAMINATE   BOLLER K FOREST PROD LAB
STRENGTH PROPERTIES OF REINFORCES PLASTIC LAMINATES AT ELEVATED TEMP
AD247 437L V61-1-3 P126 FEB 1 1961   123

RI147 EPOXY LAMINATES   JENEAU P ET AL
REINFORCED PLASTICS
AD330 139 TAB V62-4-3 P85 MARCH 1 1962   1

RI148 EPOXY LAMINATE   DEWITT E ET AL
EFFECT OF LOW PRESSURE AT ELEVATED TEMP ON SPACE VEHICLE MATERIALS
AD276 414 TAB F62-3-5 SEPT 1 1962   1   78

RI149 EPOXY LAMINATE   WYKES D W
CYCLIC MECHANICAL PROP OF GLASS CLOTH REINFORCED POLYESTER AND EPOXY LAM
AD270 424 TAB V62-2-1 P60 APRIL 1 1962   3

RI150 EPOXY LAMINATE   MCBRIDE R
LAB TECHNIQUES FOR HIGH TEMP STRUCTURAL BEHAVIOR OF REINFORCED PLASTICS
AD265 997 TAB V62-1-2 P152 JAN 15 1962   1

RI151 EPOXY LAMINATE   GLORIOSO S V
MATERIAL GLASS CLOTH REINFORCED PLASTICS ROOM AND ELEVATED TEMP
AD285 486 TAB63-1-1 P53 JAN 1 1963   1

RI152 EPOXY LAMINATE   GENERAL DYNAMICS
EVAL OF STRUCTURAL PROPERTIES OF GLASS REINFORCED PLASTICS CONSTRUCTION
AD285 484 TAB 63-1-1 P53 JAN 1 1963   12   7

RI153 EPOXY LAMINATE   BOLLER K H
EFFECT OF ELEVATED TEMP ON STRENGTH PROP OF REINFORCES PLASTIC LAMINATES
AD291 485 TAB V63-1-6 MAR 15 1963   1

```
RI154  EPOXY LAMINATE         DAVIS R T JR
       INVESTIGATION OF ELEVATED TEMP CHARACTERISTICS OF PLASTIC LAMINATES
       AD297 109L TAB 63-2-5 JUNE 1 1963                                  1

RI155  EPOXY LAMINATE         LEE H J
       RESULTS OF QUALIFICATION TESTS ON UCC ERSB-0111 TYPE 11 CLASSES 1 AND 3
       AD404 001L TAB V63-3-4 P178 AUG 15 1963                            1     7

RI241  EPOXY GLASS LAMINATE   LEVINE H H
       RESEARCH AND DEVELOPMENT OF HIGH TEMP STABLE POLYMERS
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 14-1 JAN 1961              1

RI242  EPOXY GLASS LAMINATE   BRENNER W LUM D RILEY M
       HIGH TEMPERATURE PLASTICS
       REINHOLD P 33 TO 40 1962                                           1

RI243  EPOXY GLASS LAMINATE   MIGLORESE J
       EFFECT OF FINISHES ON HEAT RESISTANT PHENOLIC AND MODIFIED EPOXY LAM SYSTEM
       SPE 17TH ANTEC TECHNICAL PAPERS SECTION 7-3 JAN 1961               1     7

RI244  EPOXY GLASS LAMINATE   STAFF MATERIALS IN DESIGN ENGINEERING
       NEW HIGH TEMPERATURE EPOXY RESIN
       MATERIALS IN DESIGN ENGINEERING VOL 51 NO 1 JAN 1960               1     7

RI245  EPOXY GLASS LAMINATE   MENARD R C COOVER W
       EPOXY RESIN LAMINATES WITH HIGH THERMAL RESISTANCE
       SPE 16TH ANTEC TECHNICAL PAPERS SECTION 29-1 JAN 1960              1

RI246  EPOXY GLAS LAMINATE    SONNEBORN R H ET AL
       CONTROL OF VARIABLES IN HEAT RESISTANT GLASS REINFORCED PLASTICS
       PROCEEDINGS SPI 15TH ANNUAL TECH CONF SECTION 1F P7 FEB 2 60       1

RI247  EPOXY LAMINATE         WYNSTRA J ET AL
       STRUCTURE VERSUS ELEVATED TEMPERATURE PERFORMANCE OF EPOXY RESINS
       MODERN PLASTICS V37 NO 9 P131 MAY 1960                             1

RI248  EPOXY LAMINATE         HOWSE P T PEARS C D
       THERMAL PROPERTIES OF REINFORCED PLASTICS
       MODERN PLASTICS V39 NO1 P140 SEPT 1961                             1    6
```

```
RI249  EPOXY GLASS LAMINATE   MENARD R O COOVER W W
       EPOXY RESIN LAMINATE WITH HIGH THERMAL RESISTANCE
       SPE JOURNAL V16 NO 3 P277 MAR 1960                                   1

RI250  EPOXY GLASS LAMINATE   BOLLER K H
       RESUME OF FATIQUE CHARACTERISTICS OF REINFORCED PLASTIC LAMINATES
       FOREST PRODUCTS LAB CONT AF33(657)358 ASD-TDR-63-768 JULY 1963         3

RI252  EPOXY GLASS LAMINATE   RICCITIELLO M
       PRIVATE CORRESPONDENCE M RICCITIELLO TO R N SAMPSON
       WESTINGHOUSE CORRRESPONDENCE NOV 8 1963                              1     7

RI254  EPOXY GLASS LAMINATE   STAFF WESTINGHOUSE
       MICARTA INFORMATION
       DATA SHEET BULLETIN H-2497 APRIL 8, 1959                             1     7

LI253  IMIDE-LAMINATE I-8     FREEMAN J H  FROST L W ET AL
       LAMINATES AND ADHESIVES FOR HIGH TEMPERATURE USE
       WESTINGHOUSE RESEARCH REPORT JUNE 15 1964                                 6

LI212  LAM PHENOLIC GLASS     WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD245211L JULY 1960                      1      8

RI500  PHENOLIC LAMINATES     ANDERSON H C
       THERMAL DEGRADATION OF PHENOLIC POLYMERS
       AD260 252 TAB V61-4-1 P57 OCT 1 1961                                 1

RI501  PHENOLIC LAMINATES     PATTON R
       FABRICATION OF GLASS FABRIC PHENYL SILANE LAM FOR STRUCTURAL USE
       AD283 145L TAB V62-4-6 P215 DEC 15 1962                              1

RI502  PHENOLIC LAMINATES     FOREST PRODUCTS LAB
       STRENGTH PROPERTIES OF REINFORCES PLASTIC LAM AT ELEVATED TEMP
       AD276 189 TAB V62-3-5 P 114 SEPT 1 1962                              1

RI503  PHENOLIC LAMINATE      DEWITT E ET AL
       EFFECT OF LOW PRESSURE AT ELEVATED TEMP ON SPACE VEHICLES MATERIALS
       AD276 414 TAB V62-3-5 SEPT 1 1962                                    1     78
```

```
RI504   PHENOLIC LAMINATE      MCBRIDE R
        LAB TECHNIQUES FOR DETERMINING THE HIGH TEMP STRUCTURAL BEHAVIOR OF PLASTIC
        AD265 997 TAB V62-1-2 P152 JAN 15 1962                            1

RI505   PHENOLIC LAMINATE      STEVENS G H
        FATIGUE TEST OF PHENOLIC LAMINATE AT HIGH STRESS LEVELS AND ELEVATED TEMP
        AD265 532 TAB V62-1-2 P45 JAN 15 1962                               3

RI506   PHENOLIC LAMINATE      BALLER K H
        ELEVATED TEMP ON STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATE
        AD291 485 TAB V63-1-6 MARK 15 1963                                1

RI507   PHENOLIC LAMINATE      KING R W ET AL
        EFFECT OF NUCLEAR RADIATION ON ELASTROMERS AND PLASTIC COMPONENTS
        AD267 890 TAB V62-1-4 P72 FEB 15 1962                             1      8

RI508   PHENOLIC LAMINATE      LEVINE H H
        RESEARCH AND DEVELOPMENT OF HIGH TEMPERATURE STABLE POLYMERS
        SPE 17TH ANTEC TECH PAPER SECTION 14-1 JAN 1961                   1

RI509   PHENOLIC LAMINATE      BRENNER W LUM D RILEY M
        HIGH TEMPERATURE PLASTICS
        REINHOLD P 54 1962                                                1     7

RI510   PHENOLIC LAMINATE      MIGLORESE J
        EFFECT OF FINISHES ON HEAT RESISTANT PHENOLIC AND MODIFIED EPOXY LAM SYSTEM
        SPE 17TH ANTRC TECH PAPERS SECTION 7-3 JAN 1961                   1     7

RI511   PHENOLIC LAMINATE      MIGLORESE J
        HEAT RESISTANT LAMINATES
        SPE 16TH ANTEC TECH PAPERS SECTION 27-1 JAN 1960                  1

RI512   PHENOLIC LAMINATE      HOWSE P T PEARS C D
        THERMAL PROPERTIES OF REINFORCED PLASTICS
        MODERN PLASTICS V39 NO 1 P140 SEPT 1961                           1    6

RI513   PHENOLIC LAMINATE      PLASTICS DESIGN AND PROCESSING STAFF
        HIGH TEMP PHENOLIC EXCEEDS MIL-SPEC STRENGTH REQUIREMENTS
        PLASTICS DESIGN AND PROCESSING V3 NO8 P31 AUGUST 1963             1
```

```
RI514  PHENOLIC LAMINATE      GOLDSMITH A ET AL
       HANDBOOK OF THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
       MACMILLAN V4 P718-735 1961                                         1

RI515  PHENOLIC LAMINATE      KIMBALL K E
       INTERLAMINAR PROPERTIES OF FIVE PLASTIC LAMINATES
       ASTIA AD 299704 DECEMBER 1962                                      1

RI516  PHENOLIC LAMINATE      BOLLER K H
       STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATES AT ELEVATED TEMP
       AD240769 JAN 1960                                                  1

RI517  PHENOLIC LAMINATE      STAFF US POLYMERIC CORP
       POLY-PREG 91-LD IMPREGNATES
       US POLYMERIC CORP DATA SHEET SEPT 15 1959                          1     7

LI211  LAM POLYESTER GLASS    WAHL N E  LAPP R R
       EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS
       WADD TECH REPT 60-125 ASTIA AD 245211L JULY 1960                          8

LI65   POLYMIDE GLASS LAM     LEPPLA R R DUPONT
       PYRE M L NON-ELECTRICAL PROPERTIES FAIRFIELD
       DUPONT DATA SHEET  1962                                                 6 8

RI206  MICA LAM Y-26          DIVENS W C
       DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
       (W) RESEARCH REPORT 404FF206-RI MAY 12 1959                             67

RI700  MICA LAM PHOSPH BOND   VONDRACEK C H
       INORGANIC FLEXIBLE SHEET INSULATION FOR ELECTRICAL EQUIPMENT
       INSULATION P39 JUNE 1962                                                 7

LI45   LAMINATE SIO2 FIBERS   PLANT HT GIRARD R T RICE G A WISELY H R ET AL
       DEVELOPMENT OF INORGANIC BINDERS
       GEN ENGRG LAB GEN ELEC CO ASTIA AD297130 OCTOBER 27,1960           1

LI32   LAM MICA PAPER         DIVENS W C
       DEVELOPMENT OF 500 C CANNED PUMP MOTOR INSULATION
       (W) RESEARCH RPT 404FF206R1  5-28-57 TO 8-31-58                    1    67
```

```
RI7     LUCALOX                   WARSHAW S I NORTON F H
        DEFORMATION BEHAVIOR OF POLYCRYSTELLINE ALUMINUM OXIDE
        JOURNAL OF AMERICAN CERAMIC SOC V45 P479 OCT 1962              2

RI15    LUCALOX                   STAFF GENERAL ELECTRIC
        TRANSLUCENT ALUMINA STAYS STRONG AT 3600 DEG F
        MATERIALS IN DESIGN ENGINEERING V57 NO4 P98 1963               1    67

RI31    LUCALOX                   WACHTMAN J B SCUDERI T G CLEEK G W
        LINEAR THERMAL EXPANSION OF A1203 AND THO2 FROM 100 DEG TO 1100 DEGK
        JOUR AMERICAN CERAMIC SOC V45 (7) P 319 1962                        6

RI32    LUCALOX                   MATHESON R R
        GE'S LAMP RESEARCH LEADS TO UNIQUE CERAMIC MATERIAL
        CERAMIC AGE JUNE 1963                                          1    67 9

RI34    LUCALOX                   STAFF SPACE AERONAUTICS
        MATERIALS CERAMICS
        SPACE AERONAUTICS HANDBOOK SECTION HP12 1961-62                2

LI109   MAGNESIA                  BRISBANE A W PROJECT DIRECTOR
        STUDY OF THE PHYSICAL BASIS MECH PROPERTIES OF CERAMICS
        ASD-TDR-63-605 PART 1 AF MTLS LAB ASD AF SYS WPAFB AUG 1963  0

LI113   MAGNESIA                  PULLIAM G R
        INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
        DOUGLAS A C WADD TECH RPT 60-338 OCT 1960                      2

LI177   MAGNESIA                  HESSINGER PHILIP S
        BEO BOOMS IN SPACE AGE
        RESEARCH DEVELOPMENT TECH REPRINT NO E-60 1963                 1    67

LI84    MAGNESIA                  PULLIAM G R  LEONARD B G
        INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
        DOUGLAS AIRCRAFT CO  WADD TECH RPT 60-338  OCT 1960            2

LI196   MAGNESIA                  ENGBERG C J ZEHMS E H
        THERMAL EXPANSION OF AL 203 BEO MGO B4C SIC AND TIC ABOVE 1000C
        JOURNAL OF AMER CERAMIC SOC V42 NO 6 P300-05 JUNE 1959              6
```

```
LI259   MAGNESIA                HAVEL R F  HOLTZ F C
        ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
        IIT RESEARCH INSTITUTE QUAR REPT NO 3 JUNE 4 1964                    67

LI262   MAGNESIA                HAVELL R F
        ELECTRICAL INSULATORS FOR VERY HIGH TEMPERATURES
        IIT RESEARCH INSTITUTE SUMMARY REPT NO 2  NOV 12 1963                 7

LI75    MAGNESIUM OXIDE         PARKER E R  PASK J A  HIMMEL L
        DUCTILE CERAMICS FINAL RPT
        MINERALS RESEARCH LAB ASTIA AD234699 FEB 1960                 0

LI264   MICA                    KETTERER, R J
        MICA PAPER INSULATIONS
        INSULATION VOL 10 NO 9 P 24 AUG 1964                                  6

LI36    MICA GLASS              VONDRACEK C H CROOP E J
        NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
        (W) MATERIALS ENGINEERING PAPER P 5912 MAR 23,1959                    7

LI26    MICA GLASS BONDED       WEBER T W
        DEVEL OF A HIGH TEMP INORG GLASS DIELEC FOR EMBEDDING ELEC PARTS
        BUREAU OF SHIPS-NAVY DEPT ASTIA AD231578  10-9-58 TO 10-9-59         67

LI233   MICA GLASS BONDED       MYCALEX CORP OF AMERICA STAFF
        ELECTRICAL PROPERTIES OF GLASS BONDED AND OTHER MICAS
        ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963           67

LI235   MICA GLASS BONDED       HAVEG INDUSTRIES INC
        PROPERTIES OF HAVELEX MICAS
        ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO DEC 1963           67

LI237   MICA GLASS BONDED       MATERIALS IN DESIGN ENGINEERING
        DIELECTRIC CONSTANT AND VOLUME RESISTIVITY FOR GLASS BONDED MICA
        ELECTRONICS PROP INFORMATION CENTER HUGHES AIR CO FEB 1960            7

RI708   MICARAMIC BOND MICA     DIVENS W C
        DEVELOPMENT OF 500 DEG C CANNED PUMP MOTOR INSULATION
        (W) RES REPORT 404FF206-RI MAY 12,1959                               67
```

```
LI241  MICAS GLASS BONDED     MYCALEX CORP PRIVATE COMMUNICATION
       RADIATION EXPOSURE DATA ON GLASS BONDED MICAS
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963             8

LI248  MICAS GLASS BONDED     SCHAFER E
       NATURAL AND SYNTHETIC GLASS BONDED MICA ELECTRICAL PROPERTIES
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963             7

RI28   GLASS BONDED MICA      MCKENZIE D B
       ELECTL MATLS AND COMPONENTS FOR AIRCRAFT POWER EQUIP OPER. AT HI TEMP
       INSTITUTION OF ELECTRICAL ENGINEERS 106A P 321 1959          0

LI56   PHOS BONDED MICA       HARMS H B  FRASER J C
       ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
       WADC TECH RPT 59-348  JULY 1959                                        67

LI213  MICA PHOSPHATE BOND    BARR F A  CARTHY J P
       ULTRA HIGH TEMP DIELECTRIC MTLS FOR EMBEDDING ENCAPSULATING ELEC COMPONENT
       SYNTHETIC MICA CO ASTIA AD258395 NOV 1960                    1     67

LI214  MICA PHOSPHATE BOND    BARR F A  RODNEY S
       ULTRA HIGH TEMP DIELECTRIC EMBEDDING MATERIALS
       SYNTHETIC MICA CO ASTIA 275789 APRIL 27 1962                            7

LI224  MICA PHOS BONDED       BARR F A  MCCARTHY J P
       ULTRA HIGH TEMP DIELECTRIC MTLS FOR EMBEDDING ELECTRONIC COMPONENTS
       SYNTHETIC MICA CO ASTIA AD265499 FINAL REPT MAY 1961          1     67

RI709  MICA PHOSPHATE BOND    DIVENS W C
       DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
       WESTINGHOUSE RES REPT 404FF206-RI P11 MAY 12 1959                      67

RI714  PHOSPHATE BONDED MIC   A DUNCAN, G.I.  FELGAR, M.M.
       ELECTRICAL INSULATION PROPERTIES AT ULTRAHIGH TEMPERATURES
       ELECTRICAL ENGINEERING APRIL 1958                                       7

RI713  SILICONE BONDED MICA   DUNCAN, G.I.  FELGER, M.M.
       ELECTRICAL INSULATION PROPERTIES OF ULTRAHIGH TEMEPERATURES
       ELECTRICAL ENGINEERING APRIL 1958                                       7
```

```
LI33    MICA TAPE                  DIVENS W C
        DEVELOPMENT OF 500 C CANNED PUMP MOTOR INSULATION
        (W) RESEARCH RPT 404FF206R1  P 27  5-28-57 TO 8-31-58              67

RI703   INORGANIC BOND MICA    STAFF
        DATA BULLETIN 1
        MACALLEN DATA SHEET APRIL 1961                                      7

LI10    MICA PAPER                 HARMS H B  FRASER J C
        ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
        WADC TECHNICAL RPT 59-348  JULY 1959                               67

LI8     MICA PAPER                 HARMS H B  FRASER J C
        ULTRA HIGH TEMPERATURE MINIATURIZED POWER TRANSFORMERS AND INDUCTOR MATLS
        WADC TECH RPT 57-492 ASTIA AD155527 VOL 1,2  MAY 1958              67

RI29    MICA PAPER                 JAVITZ A E
        TRANSFORMER INSULATION FOR EXTREME ENVIRONMENTS
        ELECTRICAL MANUF 65 NO 3 P 80 1960                                 67

RI20    SYN MICA CRYSTAL           BRADLEY A
        INSULATION FOR A RADIATION ENVIRONMENT
        INSULATION V7 NO 11 P23 1961                                        78

RI705   MICA LAM Y-26              STAFF NEW ENGLAND MICA CO
        Y-26 HIGH HEAT MICA PLATE
        SUPPLIERS BULLETIN 1961                                            67

RI5     MICACERAM                  LIKER J
        WHAT'S NEW WITH GLASS-BONDED MICA
        PRESENTED AT AMER CERAMIC SOC 1963 MEET APRIL 29 1963              67

RI701   MICANITE 6                 MICA INSULATOR COMPANY
        DATA SHEET
        CLASS H AND C HIGH TEMP ELEC INSULATION 1960                        7

LI198   MULLITE                    FENSTERMACHER J E HUMMEL F A
        APPARENT RELATION BETWEEN ELASTIC MODULUS AND TRANSVERSE MODULUS OF RUPTURE
        JOURNAL OF AMERICAN CERAMIC V44 NO6 P297-298 JUNE 1961         0
```

```
RI9    MYCALEX                FALOON J E
       GLASS-BONDED MICA
       MATERIALS IN DESIGN AND ENGRG V51 P96 1960                          1   67

RI3    MYKROY 1100            LIKER J MOLECULAR DIELECTRICS INC
       WHAT'S NEW WITH GLASS-BONDED MICA
       PRESENTED AT AMER CERAMIC SOC 1963 MEETING APR 29 1963                  67

LI269  OUTGASSING             SCHRANK M P  BENNER F C  DAS D K
       THEOR AND EXPER STUDY TO DETN OUTGASSING CHARACT OF VAR MATLS
       AEDC TDR64-53 MAR 1964                                                   8

RI704  PHOSPH ASBESTOS 92M    VONDRACEK C H ET AL
       BORON PHOSPHATE MATRIX FOR HIGH TEMPERATURE APPLICATIONS
       CONFERENCE STRUCTURAL PLASTICS ADHESIVES VI P106 DEC 1962           1   67

LI225  COAT PLASMA SPRAYED    KRAMER B E  LEVINSTEIN M A  GRENIER J W
       EFFECT OF ARC PLASMA DEPOSITION ON STABILITY OF NON-METALLIC MTLS
       GENERAL ELECTRIC ASTIA AD264602 MAY 1961                           0

RI600  PLASTICS GENERAL       STAFF
       ENVIROMENTAL EFFECTS ON MATERIALS AND EQUIPMENT ABSTRACTS
       AD405 625 V63-3-5 P169 SEPT 1 1963                                  1

RI601  PLASTICS GENERAL       GOETZEL C
       SPACE MATERIALS HANDBOOK
       AD284 547 TAB 63-1-1 P208 JAN 1 1963                                1    8

RI602  PLASTICS GENERAL       MOLZON A E
       BIBLIOGRAPHY AND CODE DESCRIPTION OF TECH CONFERENCE PAPERS ON PLASTICS
       PLASTIC REPORT 8 PLASTICS TECH EVALUATION CENTER JULY 1961         0

RI603  PLASTICS GENERAL       MOLZON A E
       BIBLIOGRAPHY AND CODE DESCRIPTION OF TECH CONFERENCE PAPERS ON PLASTICS
       PLASTIC REPT 11 PLASTICS TECH EVALUATION CENTER JUNE 1962          0

RI604  PLASTICS GENERAL       LANDRACK A H
       EFFECTS OF THE SPACE ENVIRONMENT ON PLASTIC
       PLASTIC REPORT 12 JULY 1962                                              8
```

```
RI605  PLASTICS GENERAL       KATZ I GOLDBERG I
       DIELECTRIC PROPERTIES OF REINFORCES PLASTICS AT ELEVATED TEMP
       ELECTRICAL MANUFACTURING V62 NO 6 P 72 DEC 1958                    1     7

RI606  PLASTICS GENERAL       STAFF ELECTRICAL MANUFACTURING
       HIGH TEMPERATURE CHARACTERISTICS OF THERMOSETTING LAMINATES
       ELECTRICAL MANUFACTURING V63 NO 4 APRIL 1954                       1     7

RI607  PLASTICS               MADORSKY S L STRAUS S
       STABILITY OF THERMOSET PLASTICS AT HIGH TEMP
       MODERN PLASTICS V38 NO 6 P 134 FEB 1961                            1

RI608  PLASTICS GENERAL       BILINSKI J R LANGDON W R
       RADIATION EFFECTS HANDBOOK
       INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGRGS S-146 JUNE 63       1     78

RI609  PLASTICS GENERAL       KERLIN E E
       COMBINED EFFECTS OF RADIATION AND CRYO TEMP ON ENGRG MATERIALS
       GENERAL DYNAMICS NAS8-2450 REQUEST NO TP85-468 NOV  1962           1     78

LI246  FILLED EPOXY PLASTIC   SCHAFER E
       FILLED EPOXY PLASTICPRELIMINARY
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963      0

LI239  POLYESTER              HARPER C A
       RESINS FOR EMBEDDING ELECTRONIC PACKAGING
       ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963            67

RI171  POLYESTER PREMIX       LONG J L HOOVER L P
       HEAT RESISTANCE OF ALKYD AND RELATED MOLDING COMPONENTS
       SPE JOURNAL V19 NO 10 P1090 OCTOBER 1963                           1     7

RI172  POLYESTER PREMIX       STAFF MATERIALS IN DESIGN ENGINEERING
       POLYESTER RESIN WITHSTANDS 500 F CONTINOUSLY
       MATERIALS IN DESIGN ENGINEERING V48 NO 6 P 142 NOV 1958            1

RI173  POLYESTER PREMIX       LITWIN J ET AL
       HEAT RESISTANT DIALLYL PHTHALATE POLYESTERS
       PROCEEDINGS SPI 18TH ANNUAL TECH CONFERENCE SEC 1B FEB 5 1963      1
```

```
RI174   POLYESTER-PREMIX       STAFF ALLIED CHEMICAL
        PLASKON ALKYD MOLDING COMPOUND 452
        TECHNICAL DATA REPORT 61-22 1963                                    1     7

LI95    GLASS AMIDE-IMIDE      TRAYNOR E J
        AI-8 116 GLASS CLOTH INS FOR SLOT LINERS
        (W) INTERNAL DOC  JAN 23,1961                                      0

LI97    POLYIMIDE GLASS        STAFF
        PYRE ML (GENERAL PLASTICS CORP)
        GENERAL PLASTICS CORP DATA SHEET JUNE 1962                               7

LI98    POLYIMIDE              STAFF
        PYRE M L POLYMIDE COATED GLASS FABRIC TECHNICAL BULLETIN 6
        DUPONT DATA SHEET  NOV 1,1961                                       1     78

RI120   POLYIMIDE SP           DUPONT
        S P COMPOSITIONS
        DUPONT DATA SHEET 1963                                              1     7

RI121   POLYIMIDE SP           EDITORIAL STAFF
        MORE INFORMATION ON MOLDED POLYIMIDE DUPONTS NEW HIGH TEMP THERMOPLASTIC
        PLASTICS DESIGN AND PROCESSING P21 FEB 1963                         1     7

RI122   POLYIMIDE SP           CALKINS W H
        PRIVATE CORRESPONDENCE W CALKINS TO J FREEMAN
        E I DUPONT DE NEMOURS MAY 2 1962                                          7

RI123   POLYIMIDE SP           FREEMAN J H
        PRIVATE CORRESPONDENCE J FREEMAN TO C HARPER
        WESTINGHOUSE ELEC CORP AUG 23 1962                                        7

LI254   POLYMER TEST METHOD    DAKIN T W
        HIGH VOLTAGE ELECTRICAL TESTING OF POLYMER
        WESTINGHOUSE RESEARCH REPORT 64-131-336-P1 APRIL 22 1964           0

RI190   FOAM POLYURETHANE      MOORE H R
        URETHANE FOAMS FOR AEROSPACE APPLICATION
        AD237 874 TAB V62-2-6 P39 JUNE 15 1962                              1
```

```
RI192  FOAM POLYURETHANE      RESNICK I SILVERGLEIT M
       INVESTIGATIONS OF CHARACTERISTICS OF RIGID FOAM FOR THERMAL INSULATORS
       AD266 244L TAB V62-1-3 P217 FEB 1962                                1

RI193  FOAM POLYURETHANE      PEACOCK C D
       THERMODYNAMICS POLYURETHANE INSULATION ENVIRONMENTAL COMPATABILITY
       AD285368 TAB 63-1-1 P51 JAN 1 1963                                  1      8

LI265  POTTING COMP           DRINKARD E V O  E E SNYDER
       USER-ORIENATED DRIP GUIDE TO POTTING AND ENCAPS
       ASE TECHNICAL REPORT 61-297 AD290823 JUNE 1961                      1     67

LI266  POTTING COMP           KENNEDY B W
       EFFECTS OF GAMMA RAD ON SELECTED POTTING COMP AND INSUL MATLS
       NASA TECH REPORT N64-16701 NOV 1963                                        8

LI37   POTTING COMP-INORG     VONDRACEK C H  CROOP E J
       NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
       (W) MATERIALS ENGRG PAPER P5912 MAR 23,1957                                7

LI252  POTTING COMP-INORG     VONDRACEK C H
       AN EVALUATION OF INORGANIC POTTING COMPOUND
       WESTINGHOUSE RESEARCH PAPER 64-131-342-P2 MAR 1 1964                1     67

LI255  POTTING COMP-INORG     C H VONDRACEK
       W-838 AND W-839 INORGANIC ENCAPSULATION COMPOUND
       PRIVATE CORRESPONDENCE C H VONDRACEK TO W S NEFF 6-29-64          0

RI711  PYROCERAM              MILEK J T
       PYROCERAM DATA SHEETS D S 130
       HUGHES AIRCRAFT CO AUGUST 1963                                             7

LI296  RADIATION EFFECTS, N   UCLEAR  BATTELLE STAFF
       RADIATION EFFECTS STATE OF THE ART
       RAD EFFECTS INFO CENTER NO. 34 JUNE 1964                            1    678

RI33   SAPPHIRE               STAFF SPACE AERONAUTICS
       MATERIALS AND PRODUCTION REFERENCE FILE
       SPACE AERONAUTICS P61 NOV 1960                                       2
```

```
LI22    SILICA                   MASS INSTITUTE OF TECHNOLOGY
        PROGRESS REPORT NO XXIX LAB FOR INSULATION RESEARCH
        MASS INSTITUTE OF TECH P 35 JULY 1961                                  7

LI72    SILICA                   POULOS N E  ELKINS S R  WALTON J D
        HIGH TEMPERATURE CERAMIC STRUCTURES
        RPT OF ENGRG EXP STATION GA INSTITUTE OF TECH JAN 1962          0

LI74    SILICA                   DUNN S A  ROTH W P
        HIGH VISCOSITY REFRACTORY FIBERS
        BJORKSTEN RESEARCH LAB ASTIA AD264273  JULY 1961                0

LI79    SILICA                   LAMBERTSON W A  AIKEN D B  GIRARD E H
        CONTINUOUS FILAMENT CERAMIC FIBERS
        RPT OF CARBORUNDUM CO WADD TECH RPT 60-244 AD243556 JUNE 1960    1     6

LI19    AL   SILICATE FIBERS    VON HIPPEL
        TABLES OF DIELECTRIC MTLS CATALOGED BY ASTIA AS AD200958
        MIT LAB FOR INSUL RES TECH RPT 126 VOL VI P 35-43  JUNE 1958           7

LI25    SILICA FIBERS            OTTO W H
        PROPERTIES OF GLASS FIBERS AT ELEVATED TEMP
        NAVY BUREAU OF AERO ASTIA AD228851  SEPTEMBER 15,1959            1 3

RI712   AL SILICATE FIBERS       DAVIS R L
        FIBER REINFORCEMENT RUN-DOWN
        PLASTICS WORLD V21 NO 11 P 60 NOV 1963                                6

LI244   SILICON OXIDE FIBERS     SCHAFER E
        SILICON OXIDE FABRICS PRELIMINARY BIBLIOGRAPHY
        ELECTRONIC PROP INFORMATION CENTER HUGHES AIRCRAFT DEC 1963     0

RI706   FOAM SILICON             MINNESOTA MINING AND MANUF STAFF
        SCOTCHCAST BRAND RESIN XR-5017
        MINNESOTA MINING AND MANUF DATA SHEET 1964                       1     7

LI15    FOAM SILICONE            GREEN D F
        FOAMED PLASTICS ASTIA REPORT 252981L
        U S NAVAL CIVIL ENGR LAB PORT HUENEME CALIF MAR 7,1961           1     6
```

```
RI201   FOAM SILICONE           GREEN D F
        FOAMED PLASTICS AND OTHER SELECTED INSULATION MATERIALS
        AD252 981L TAB V61-2-4 P196 MAY 15 1961                           1

RI202   FOAMS SILICONE          RESNICK I
        RIGID FOAM PLASTICS INFORMATION MANUAL
        AD248 189 TAB V61-1-4 P38 FEB 15 1961                             1

RI203   FOAM SILICONE           BRENNER W RILEY M
        HIGH TEMPERATURE PLASTICS
        REINHOLD P 102 1962                                               1

RI204   FOAM SILICONE           STAFF MATERIALS IN DESIGN ENGINEERING
        SILICONE FOAM INSULATES MISSILE PARTS
        MATERIALS IN DESIGN ENGINEERING V54 NO 7 P 12 DEC 1961            1

RI205   SILICONE FOAM           HOWSE P T PEARS C D
        THERMAL PROPERTIES OF REINFORCED PLASTICS
        MODERN PLASTICS V39 NO 1 P140 SEPT 1961                           1    6

RI707   FOAM SILICONE           MEYER C L
        CORRESPONDENCE ON XR5017
        PRIVATE CORRESPONDENCE  DEC 24, 1963                              1     7

LI105   STAINLESS STEEL         FUGARDI J  ZAMBROW J L
        THE CLADDING AND WELDING OF STAINLESS STEEL TO MOLYBDENUM AND NIOBIUM
        WADC TECH RPT 58-674 OCT 1959                                    0

LI142   STEATITE                VODOPYANOV K A KAROV B G
        EFFECT OF COMP HEAT AND ELEC TREAT ON THE DIEL PROP OF STEATITE CER
        IZVESTIYA VYSSAIKH UCHENYKH ZAVENDENIY FIZIKA NO 3 P55-61 1962          7

LI220   STEATITE                FRISCO L J
        DIELECTRICS FOR SATELLITES AND SPACE VEHICLES
        JOHN HOPKINS UNIV REPT SCI AND TECH REPT N62-13294 MAR1962              7

RI1     SUPRAMICA 620           HESSINGER P S WEBER T W
        DEVELOPMENT OF A SYNTHETIC MICA CERAMIC SUITABLE FOR USE AT 750 DEG C
        BULLETIN OF AMER CERAMIC SOCIETY V39 (1) P 10-13 JAN 1960         1    67
```

```
RI2    SUPRAMICA
       MYCALEX CORP DATA SHEET
       MYCALEX CORP PRODUCT BROCHURE 1961                                  1  4 67

LI124  TEFLON                 MOWERS R E
       FINAL REPORT PROGRESS OF TESTING NONMETALLIC MATERIALS AT CRYOGENIC TEMP
       ASTIA DOC 294772  DEC 1962                                         0

RI4    THERMICA               MOLECULAR DIELECTRICS INC
       THERMICA TECHNICAL SHEET
       THERMICA TECHNICAL SHEET APRIL 19,1963                                  6

LI96   TITANATES              VON HIPPEL ET AL
       PROGRESS REPORT NO XXXII LAB FOR INSULATION RESEARCH MIT
       MIT REPORT JAN 1963                                                0

LI14   FOAM URETHANE          GREEN D F
       FOAMED PLASTICS ASTIA RPT 252981L
       U S NAVAL CIVIL ENGR LAB PORT HUENEME CALIF  MAR 7,1961             1    6

RI186  FOAM URETHANE          GREEN D F
       FOAMED PLASTICS AND OTHER SELECTED INSULATION MATERIALS
       AD252 981L TAB V61-2-4 P196 MAY 15 1961                             1

RI187  FOAM URETHANE          STEELE D V MATHEWS H
       PROPERTIES OF COMMERCIALLY AVAILABE ENCAPSULATION COMPOUNDS
       AD251 911L TAB V61-2-3 P187 MAY 1 1961                              1     7

RI188  FOAM URETHANE          RESNICK I
       RIGID FOAM PLASTICS INFORMATION MANUAL
       AD248 189 TAB V61-1-4 P38 FEB 15 1961                               1

RI189  FOAMS URETHANE         REILLY A ZWOLINSKI L
       INVESTIGATION OF THE USE OF ISOCYNATE ADDUCTS IN URETHANE FOAM
       AD277 420 TAB V62-4-1 P32 OCT 1 1962                                1

RI191  FOAM URETHANE          JAFFE L D
       EFFECTS OF SPACE ENVIRONMENT UPON PLASTICS OR ELASTOMERS
       AD268 432 TAB V62-1-5 P195 MARCH 1962                               1      8
```

RI194 FOAMS URETHANE HERTZ J
CAST FOAM INSULATION EVALUATION
AD291 521 TAB 63-1-6 MAR 15 1963 1

RI195 FOAM URETHANE STAFF MATERIALS IN DESIGN ENGINEERING
DEVELOPMENTS IN HIGH TEMP URETHANE FOAMS
MATERIALS IN DESIGN ENGINEERING V52 NO 1 P 11 JULY 1960 1 7

RI196 FOAM URETHANE DAHERTY D J ET AL
PHYSICAL PROPERTIES OF RIGID POLYURETHANE FOAMS
CHEMISTRY AND INDUSTRY P 1340 JULY 28,1962 1

RI197 FOAM URETHANE POLIN R E ET AL
PROPERTIES OF URETHANE FOAMS RELATED TO MOLECULAR STRUCTURE
JOUR OF CHEMICAL AND ENGRG DATA V4 NO3 P 261 JULY 1959 1

RI198 FOAM URETHANE SAUNDERS J H ET AL
PROPERTIES OF FLEXIBLE URETHANE FOAMS
INDUSTRIAL AND ENGRG CHEMISTRY V3 NO1 P 153 1958 1

RI199 FOAM URETHANE BUIST J M HURD R ET AL
POLYURETHANE FOAMS METHODS OF PRODUCTION PROPERTIES AND APPLICATIONS
CHEMISTRY AND INDUSTRY P 1544 DEC 17,1960 1

RI200 FOAM URETHANE PATTEN G A SKOCHDOPOLE R E
ENVIROMENTAL FACTORS IN THERMAL CONDUCTIVITY OF PLASTIC FOAMS
MODERN PLASTICS V39 NO 11 P149 JULY 1962 1

RI286 FOAM URETHANE STAFF MACHINE DESIGN
PLASTIC BOOK ISSUE
MACHINE DESIGN P155 SEPT 20 1962 1 7

RI287 FOAM-URETHANE DANCICCO V V
HEAT RESISTANT URETHANE POLYMERS
SPE JOURNAL V14 NO5 P34 FEB 1958 1

RI288 FOAM URETHANE CARWIN CO STAFF
DATA SHEET CPP NO 21-3
CARWIN CO MAY 1961 1 7

```
LI297  VACUUM COMPATABILITY   D BABUSCI
       EFFECT OF TEMPERATURE AND VACUUM ON MATERIALS FOR USE IN THE SPACE ENVIRONM
       JOURNAL OF ENVIRONMENTAL SCIENCES PP23-26 AUG 1964                       8

LI256  CERAMICEZE WIRE        GEHRING R W
       CORRESPONDENCE FROM PHELPS DODGE WIRE CO FT WAYNE IND
       PRIVATE CORRESPONDENCE R W GEHRING TO D W WIESENBERG 6-11-64      0

LI34   CERAMICITE WIRE COV    DIVENS W C
       DEVELOPMENT OF 500C CANNED PUMP MOTOR INSULATION
       (W) RESEARCH RPT 404 P 27 AUG 31,1958                             0

LI1    IMIDE WIRE ENAMEL      ROHM A J LUDINGTON R S
       NEW POLYMIDE WIRE ENAMELS
       WESTINGHOUSE MATL ENGRG REPORT 5806-2857 JUNE 12,1958             0

LI2    IMIDE WIRE ENAMEL      STAFF WESTINGHOUSE
       SELECTED DATA ON DUPONT M1 WIRE ENAMEL AND MATL ON ML FAMILY
       WESTINGHOUSE INTERNAL REPORT 1962                                    678

LI3    IMIDE WIRE             STAFF
       DATA EXTRACTED FROM NEW YORK NAVAL SHIP YARD REPORT 4861-F-37
       NAVAL SHIP YARD BROOK N Y RPT 4861-F-37 FEB 7,1963                1    78

LI4    IMIDE WIRE ENAMEL      NEIDEMIRE A
       TEST OF HIGH TEMP DUPONT ML ENAMELED WIRE IN HOT OILS
       WESTINGHOUSE INTERNAL REPORT NOT DATED                            0

LI12   IMIDE WIRE ENAMEL      STAFF
       TECH DATA SHEET 11 FROM THE BELDEN MFG CO
       BELDEN DATA SHEET 11  NOVEMBER 28,1960                               678

LI13   IMIDE WIRE             STAFF HI TEMP WIRES CO
       TECH DATA SHEETS FROM HI TEMP WIRES CO
       DATA SHEETS HI TEMP WIRES CO MAR 27,1961                             6 8

LI134  IMIDE WIRE ENAMEL      FREEMAN J H
       AROMATIC CONDENSATION POLYMERS
       (W) RESEARCH MEMO 12-0402-2-M2-X  APR 28,1960                        678
```

LI137 IMIDE WIRE ENAM LEPPLA R R CARRYER R R
POLYMIDE INSULATION SYSTEM FOR HIGHER OPERATING TEMP MORE COMPACT UNITS
INSULATION JUNE 1963 78

LI141 IMIDE WIRE ENAM STAFF
PHELPS DODGE PRELIMINARY MAGNET WIRE INFORMATION BULLETIN 361
PHELPS DODGE CI DATA SHEETS NOV 1,1960 678

LI144 IMIDE INSULATED WIRE MOBERLY L E
DIELECTRIC TWIST THERMAL LIFE DATE
INTERNAL WESTINGHOUSE CORRESPONDENCE OCT 28 1963 7

LI63 IMIDE MAGNET WIRE PHELPS DODGE STAFF
ML MAGNET WIRE
PHELPS DODGE BROCHURE JUNE 15,1962 678

LI64 IMIDE INS WIRE STAFF
TYPE ML MAGNET WIRE
GENERAL ELECTRIC DATA SHEET SEPT 1,1962 6 8

LI66 IMIDE WIRE ENAMEL STEWART R L
LIMA MATERIALS ENGR LAB REPORT
(W) AED MTLS ENGR REPORT 26-63 APR 8,1963 7

LI67 IMIDE WIRE ENAMEL WILLIAMS G J
LETTER WITH DATA FROM BUFFALO WIRE DEPT
(W) BUFFALO WIRE DEPT CORRESPONDENCE SEPT 29,1961 78

LI68 IMIDE WIRE BUFFALO STAFF
TYPICAL ENAMELED WIRE TEST VALUES
(W) BUFFALO N Y REPORT SHEET JULY 20,1962 678

LI69 IMIDE GLASS LAM NEIDMIRE A W
LIMA MATERIALS ENGR LAB RPT
(W) INTERNAL REPORT AED 61-62 OCTOBER 25,1962 67

LI88 IMIDE WIRE FREEMAN J H
RADIATION STABILITY OF AROMATIC AMIDE-IMIDE POLYMERS
(W) RESEARCH DATA SHEET OCTOBER 1961 8

```
LI270  IMIDE WIRE            AEROJET GENERAL STAFF
       SNAP-8 MTLS REPORT FOR 1963 VOL 1 ELECT INSUL DEV
       NAS5-417 MAR 1964                                                   78

LI35   WIRE INORGANIC INS    VONDRACEK C H  CROOP E J
       NEW INORGANIC INSULATION FOR 500C ELECTRICAL EQUIPMENT
       (W) MATERIALS ENGINEERING PAPER P 5912 MAR 23,1959                   7

LI99   INORGANIC WIRE INS    PENDLETON W W
       STANDARDIZATION OF MAGNET WIRE FOR USE AT 500F
       BUREAU OF SHIPS WASH D C ASTIA AD246151 JAN-MAR 1960                67

LI100  INORGANIC WIRE INS    HARRIS J N  WALTON JR J D
       HIGH TEMPERATURE INSULATION FOR WIRE
       WADD TECH RPT 58-13  MAR 1960                                 0

LI101  INORGANIC WIRE INS    WILCOX D L  BERGERON C G  SCHWARZLOSE P F ET AL
       HIGH TEMP ELECTRICAL INSULATION INORGANIC COATINGS ON WIRE
       WADC REPORT 58-12 PART III                                    0

LI102  INORGANIC WIRE INS    BERGERON C G  FRIEDBERG W L  BEALS R J  ET AL
       HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 ASTIA DOCUMENT 151079 PART I MAR 1958     0

LI106  INORGANIC WIRE COAT   BERGERON C G  FRIEDBERG A L  ET AL
       HIGH TEMP ELEC INS INORGANIC COATINGS ON WIRE
       WADC TECH RPT 58-12 PART II ASTIA NO 214700 JUNE 1959         0

LI42   INORGANIC WIRE COAT   BERGERON C G  FRIEDBERG A L  SCHWARZLOSE P E  ET AL
       HIGH TEMP ELECTRICAL INSULATING INORGANIC COAT ON WIRE
       WADC TECH RPT 58-12  MAR 1958                                        7

LI250  MAGNET WIRE INORGANI  C LIUBICICH, F.A.  PINSKI, H. ET AL
       TYPE D CERAMIC COATED SOLID SILVER CONDUCTOR ULTRAHIGH TEMP MAGNET WIRE
       SECON METALS CORP PROJECT 5940 PART 26 REPT S R 0070401 1961  0

LI11   CER-COAT-NI-CU-WIRE   HARMS H B  FRASER J C
       ULTRA HIGH TEMP (500C) POWER TRANSFORMERS AND INDUCTORS
       WADC TECH RPT 59-348  JULY 1959                                1    67
```

```
LI9     CER-COAT-NI-CU-WIRE    HARMS H B  FRASER J C
        ULTRA HIGH TEMPERATURE MINIATURIZED POWER TRANSFORMERS AND INDUCTOR MTLS
        WADC 57-492 ASTIA AD15527 MAY 1958                                     67

LI30    NI WIRE COATINGS       GOLDBERG M E  HAMRE H G  NOBLE R D
        ELECTRONIC COMPONENT PARTS RESEARCH FOR 500 C OPERATION
        WADC TECH RPT 57-362 ASTIA AD155785  JULY 1958                          7

LI298   WIRE, MAGNET           PENDLETON W
        ADVANCED MAGNET-WIRE SYSTEMS
        ELECTRO-TECHNOLOGY OCT 1963                                            78

LI81    ZIRCONIA               PULLIAM G H  LEONARD B G
        INFLUENCE OF ENVIRONMENT ON CERAMIC PROPERTIES
        DOUGLAS AIRCRAFT CO WADD TECH RPT 60-338 OCT 1960                  2

LI129   FOAM ZIRCONIUM OXIDE   POWERS D J
        MOD OF RUPT THERM COND AND THERM EXPOSURE TESTS ON FOAMED A1203+ZRO
        BELL AIR REPT 63-13 (M) ASTIA DOC AD401854 MAR 1963               1    6 8
```