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MAGNETIC 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
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Westinghouse Electric Corporation
AEROSPACE ELECTRICAL DIVISION
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NAS3-4162

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PREFACE

The work reported here was sponsored by the Nuclear Power Technology Branch of NASA Lewis Research Center under Contract NAS 3-4162. Mr. R. A. Lindberg of NASA has provided the Technical Management for the program. 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 area of contribution, since, in many cases, it was in several. Those who actively contributed during the total program are recognized below:

Westinghouse Aerospace Electrical Division	Westinghouse Research and Development Center	Eitel-McCullough Inc.
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Credit for handling the publication of these documents is given R. J. Heine.

SUMMARY

This Topical Report accomplished under NASA Contract NAS 3-4162 contains thermophysical, magnetic and mechanical property data on magnetic materials of interest to advanced space electric power systems. It represents a thorough search of the recent world's literature on this subject and a bibliographic record on this topic.

Only a meager amount of reliable design data was found in the literature in the 500 - 1600°F temperature range on this subject. Therefore, tests were run under consistent guidelines to provide these data. Over 500 specimens were prepared and tested and 7300 test points evaluated at elevated temperature. Over 99 percent of the data presented here were run during this program.

Thermophysical tests conducted included: specific heat, electrical resistivity, thermal expansion and thermal conductivity. Magnetic tests included: d-c magnetization, a-c magnetization; core loss; and constant-current, flux-reset properties for high quality saturable core reactors. These were run on forgings, castings, and different thicknesses of laminations of each material. Some properties were tested in both the stress-relief annealed condition as well as the magnetic-field annealed condition. Mechanical properties tested included: tensile and compressive strength, elongation and modulus; Poisson's ratio; creep in vacuum, inert gas and air; fatigue and fatigue under a steady stress.

Typical applications for magnetic materials are discussed and various materials are suggested for these applications. The maximum operating temperature is presented along with the mechanical and magnetic properties which may limit the application.

In general, the magnetic materials can be grouped into three temperature ranges together with their fields of application.

1. 600-800°F. Most materials qualify for this temperature range. However, Cubex alloy (3-1/4% Si-Fe, doubly oriented) is preferred for use in stators at inductions up to 18 kilogauss. H-11 steel (5% Cr, 1% Mo, Fe) and Maraging steel (15-18% Ni, 8-9% Co, Fe) are recommended for rotors, and Supermendur (2% V, 49% Co, 49% Fe) in controls using high quality, saturable-core reactors.

2. 800-1100°F Hiperco 27 alloy (27% Co, Fe) is suggested for high inductions and Cubex alloy for inductions up to 15 - 18 kilogauss in stators. In rotors, H-11 steel qualifies for lower temperatures and Nivco alloy (approximately 72% Co, 23% Ni) for the higher temperatures in this range. Supermendur and Cubex alloys can be used for controls with Cubex preferred for the higher temperatures.

3. 1100-1400°F Hiperco 27 alloy is recommended for stators and Nivco alloy for rotors in this temperature range.

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SECTION I

INTRODUCTION

This report presents the magnetic, mechanical and thermo-physical properties on magnetic materials suitable for application to advanced space electric power systems. It was conducted under NASA Contract NAS 3-4162 for the Lewis Research Center and is one of three topical reports prepared on Magnetic Materials (NASA-CR-54091), Electrical Conductor and Insulation Materials (NASA-CR-54092), and Bore Seal Materials (NASA-CR-54093).

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 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 magnetic materials is outlined in Appendix B where over 150 significant references are listed in a punched-card format. Included is a key word or descriptor and a code number which identifies the property information available in each reference. Reference numbers prefaced by LM or RM in the text are also listed in Appendix B.

In general, little information was found in the literature which could be used. In a few cases, desirable data was found; but because test conditions, test atmospheres, and sample geometry and history were not listed, these data were not always considered of sufficient reliability to warrant their reporting. Therefore, almost all data presented represents testing accomplished during the program. Reference to NAS 3-4162 is given on all data run on this program. Other sources are also given credit. References prefixed LM or RM are found in Appendix B.

This Topical Report is divided into three discussion areas. The first is a Technical Discussion which describes the applications of electrical materials to advanced space electric power systems. This is followed by a discussion of the selected materials and the observations made during the test program.

A second area defines the material specifications, specimen configurations and test procedures followed during the program. The third area presents the data. This last section does not contain a discussion so that it can be used as a design manual. It includes a master index for all properties, and each material has a summary which can be used as a guide in material selection. This summary was thought 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 desired properties of magnetic materials for high-temperature space power system components should approach those of the magnetic materials used in conventional power systems. Because designs at high-temperature are influenced by the material properties, the mechanical and magnetic properties must be well documented so any design study is meaningful.

Laminated and forged materials used in rotating parts must have high-strength capabilities, particularly in resisting creep, to be suitable for high temperature operation. Good magnetic properties are desirable but are secondary to physical properties which are necessary for a long-life, dimensionally-stable rotor.

Stator laminations are not normally subjected to high mechanical stresses, so the magnetic properties can predominate, such as high magnetic flux density with reasonably low magnetizing forces and low losses. The same magnetic parameters apply to transformers, which are static devices.

The magnetic amplifier requires a magnetic material which has a square hysteresis loop. It is wound as tape into a toroidal core. Although materials for this application are limited, a few are available which show promise at high temperatures. These materials possess little physical strength, but the magamp is a static device so this characteristic is less important.

The solenoid included in this report has only d-c flux in its magnetic circuit. Therefore, magnetic losses are not important and the primary requirement is that the magnetic circuit be able to carry a substantial amount of flux with low magnetizing forces.

2. Specific Applications to Electric Apparatus

The following paragraphs 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 design at this state of development.

The component drawings presented in this section illustrate the most likely manner in which the materials under consideration can be used. Part temperatures are based on (a) coolant temperature, (b) calculations from previous design 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 against which material properties can be evaluated. Two coolant temperatures were chosen, 600°F and 1000°F, except for the solenoid and magamp where temperatures of 300°F and 1000°F were chosen. The lower temperature being representative of control apparatus where other components such as semiconductors limit the temperature capability.

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 temperatures.

The coils of the stator are wound with clad magnet wire to prevent oxidation due to the high temperature and alkali metal contamination of the conductor.

Insulation required for the stator winding takes the form of an insulation coating for the conductor and rigid or flexible as a ground insulation. 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.

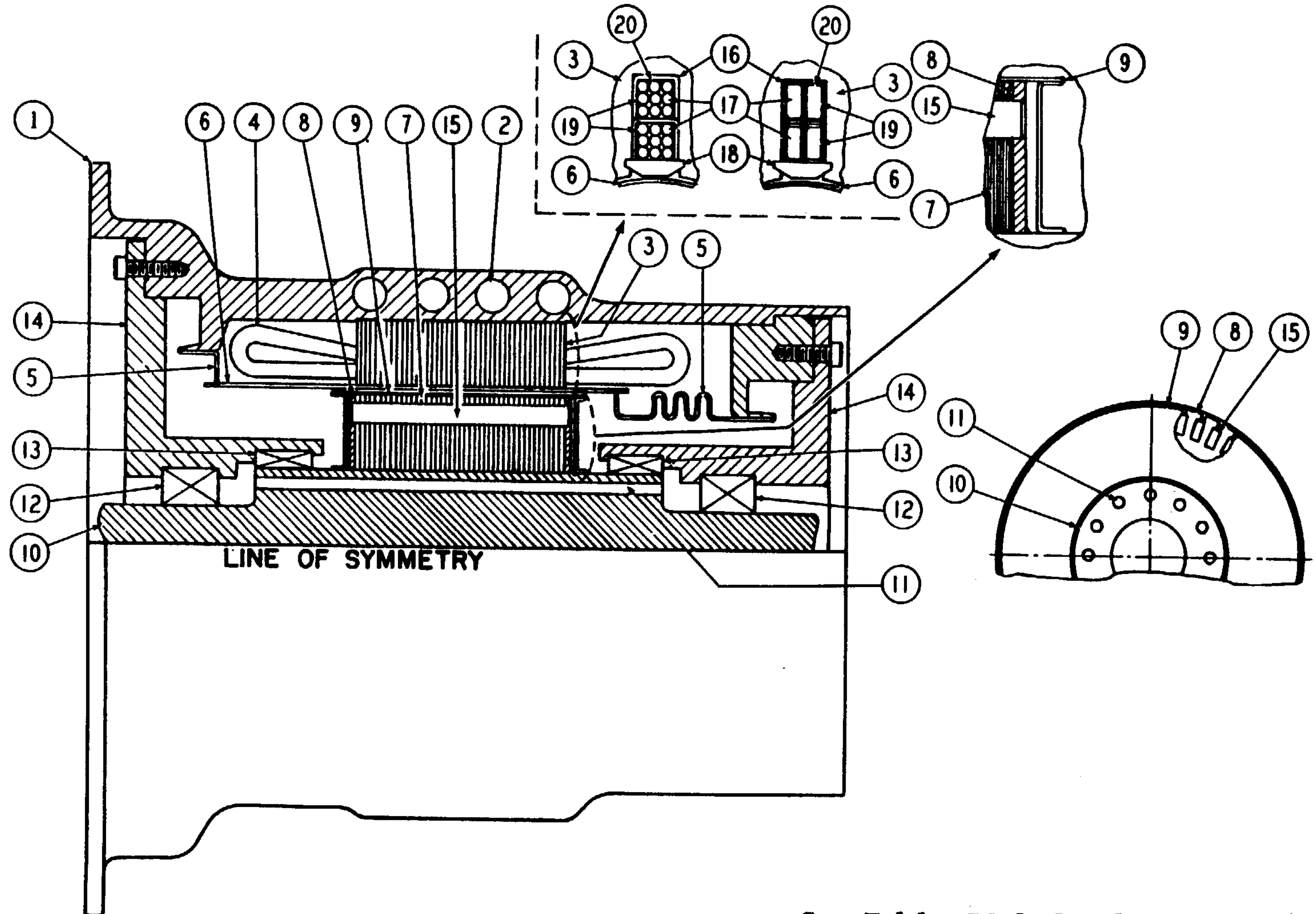
Rotor conductors are made of clad material, but insulation is not required, either for the conductors in the slots or for the end ring, because the electrical potential is low and the lamination insulation will provide sufficient dielectric strength.

Figure II-1 shows a typical design of a motor suitable for operation in a high temperature, liquid alkali-metal system. Table II-1 is a list identifying the major parts and features of 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 protected 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 either be hermetically sealed or open to the space vacuum. Heat generated in the motor is removed by using liquid metal as a coolant. Coolant flow passages (Items 11 and 2) are provided in the rotor shaft and stator housing. Bearings and seals are shown in the motor but are not covered in this discussion.

Consideration of stress because of rotation is also necessary in the selection of a satisfactory material. Since rotational stresses are considered more critical in the generator application, typical rotational stress are shown in the discussion of the generator.

Figure II-2 is another sketch of the motor which emphasizes the areas where magnetic materials are used. The rotor shaft (Item 10) is a non-magnetic material but it has been cross-hatched for clarity. Stator laminations are shown as Item 3 and rotor laminations as Item 7. Table II-2 is a list of magnetic materials showing the suitability of each material for use in the rotor or stator when used either in hermetically sealed chambers or exposed to space vacuum.

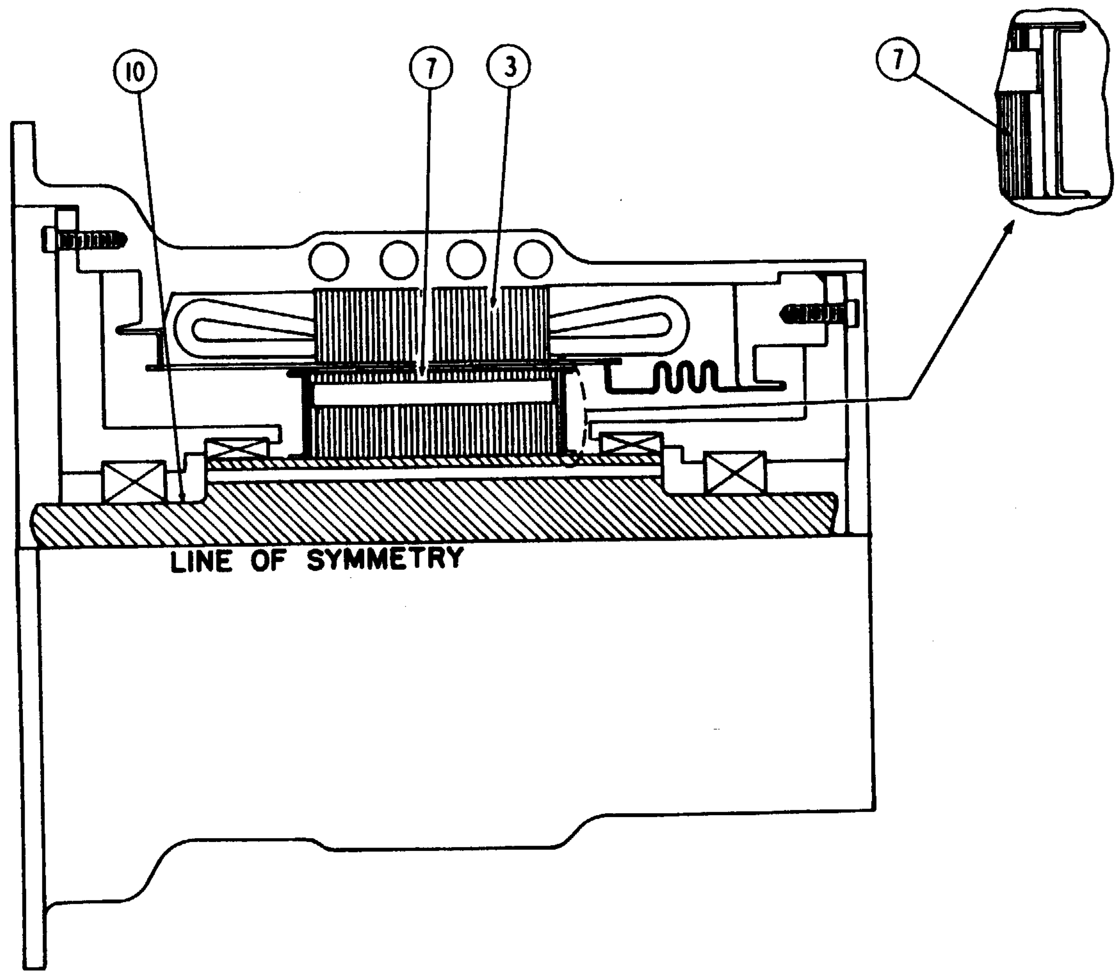


See Table II-1 for legend

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

TABLE II-1. Details of A-C Motor Assembly

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



See Table II-1 for legend

FIGURE II-2. A-C Motor, Magnetic Material Usage

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

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Rotor Magnetic and Mechanical Suitability			Stator Laminations Magnetic Suitability	
		Sealed	Open to Vacuum	Magnetic 950°F(5)	Magnetic 1350°F(6)	Typical Creep Values (0.4% at 10,000 hrs)	900°F(5)	1300°F(6)
IV.A.	Cubex Alloy							
	0.006 Inch Laminations	1100	1100	1	3	4	1	3
	0.011 Inch Laminations	1100	1100	1	3	4	1	3
IV.B.	Hiperco 50 Alloy							
	0.004 Inch Laminations	1100	1100	1	3	4	1	3
	0.008 Inch Laminations	1100	1100	1	3	4	1	3
	Supermendur							
	0.006 Inch Laminations	1100	1100	1	3	4	1	3
IV.C.	Hiperco 27 Alloy							
	0.004 Inch Laminations	1400	1400	1	4	11,500 psi at 950°F	1	1
	0.008 Inch Laminations	1400	1400	1	4	11,500 psi at 950°F	1	1
IV.E.	Maraging Steel, 15%							
	0.014 Inch Laminations	750	750	3	3	160,000 psi at 750°F	3	3
	0.025 Inch Laminations	750	750	3	3	160,000 psi at 750°F	3	3
IV.F.	H-11 Steel, R_c 45							
	~~0.025~~ 0.014 Inch Laminations	1100	1100	1	3	23,000 psi at 950°F	1	3
	~~0.050~~ 0.025 Inch Laminations	1100	1100	1	3	23,000 psi at 950°F	1	3
IV.G.	Nivco Alloy							
	0.014 Inch Laminations	1250	1250	1	3	90,000 psi at 950°F	1	3
	0.025 Inch Laminations	1250	1250	1	3	90,000 psi at 950°F	1	3

Legend
1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Material is unsuitable at this temperature for use in parts subjected to high rotational stresses.
5. Anticipated part temperature in °F with coolant temperature of 600°F.
6. Anticipated part temperature in °F with coolant temperature of 1000°F.

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 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 able to carry flux at high temperature without requiring excessive excitation. Pole face losses must be kept low, either by using a laminated pole face or by cutting circumferential slots in the pole face.

The coils of the stator are wound with clad magnetic wire to prevent oxidation because of the high-temperature and alkali-metal contamination of the conductor.

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

Figure II-3 shows a typical design of a radial-gap inductor generator capable of operation in a high-temperature, liquid alkali-metal system. Table II-3 is a list identifying the major parts and features in the generator.

The rotor (Item 10) as shown is 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 inter-laminar insulation, and a cast magnetic housing (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 hermetically sealed chamber.

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 housing. Bearings and seals are indicated in the drawing but are not covered in this discussion.

Figure II-4 is another sketch of the generator which emphasizes the areas where magnetic materials are used. The rotor pole (Item 7) is an integral part of the shaft and is of solid construction. Stator laminations are shown as Item 3 and the magnetic housing is shown as Item 15. Table II-4 is a tabulation of magnetic materials and material forms indicating the suitability of each material for use in the generator rotor and stator when used either in hermetically sealed chambers or exposed to space vacuum. Creep and fatigue will be the limiting mechanical properties in choosing a rotor material. Creep increments of 0.2 percent and 0.4 percent were used as base lines in the present material study. Allowable creep must be traded off against other mechanical and electrical properties for each specific application.

The following shows typical rotor stresses in terms of rotor diameter and rotational speed. These stresses were calculated for a solid drum rotor rather than for a specific generator rotor design. The formulas used were as follows: (1)

$$S_t = \frac{3-2\mu}{8(1-\mu)} \varrho\omega^2 \left(b^2 - \frac{1+2\mu}{3-2\mu} r^2\right) \frac{1}{144} \quad \text{(Tangential Stress)}$$

$$S_r = \frac{3-2\mu}{8(1-\mu)} \varrho\omega^2 \left(b^2 - r^2\right) \frac{1}{144} \quad \text{(Radial Stress)}$$

where
μ = Poissons ratio
ω = radians per second rotational speed
ϱ = density, slugs per cubic foot
b = outer radius, feet
r = radius in feet at which stress is being calculated

when $r = 0$, $S_t = S_r$

Table of Typical Stress Levels

Rotor Diameter (inches)	Speed - (RPM) 5,000 (psi)	10,000 (psi)	15,000 (psi)
10	2,300	9,180	20,600
15	5,190	20,700	46,500
20	9,260	37,000	83,000

(1) Jennings and Rogers, "Gas Turbine Analysis and Practice", McGraw-Hill, 1953, page 393

Additional information on generator rotor stresses can be found in "Space Electric Power Systems Study, Final Report - Volume 2", Contract NAS 5-1234.

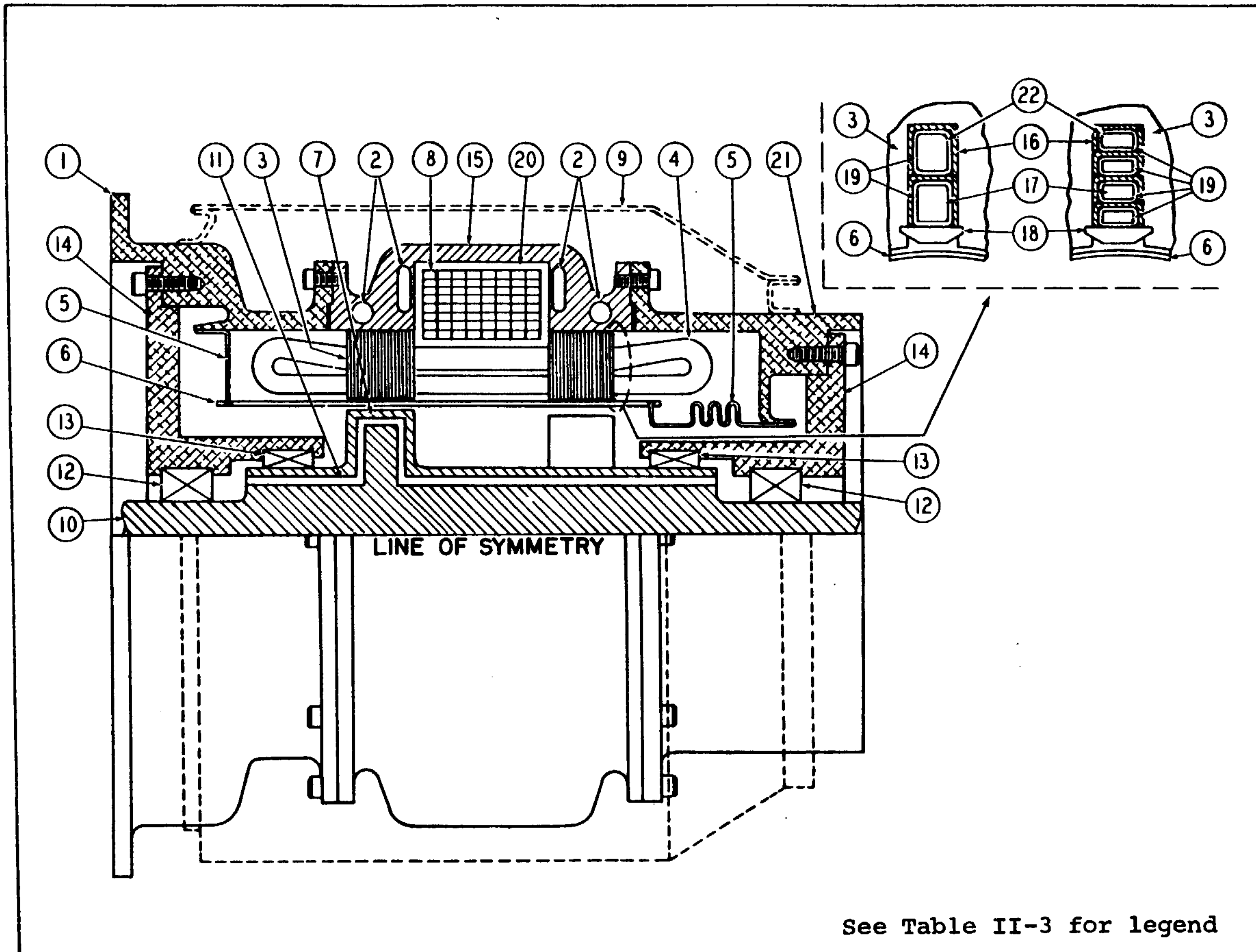
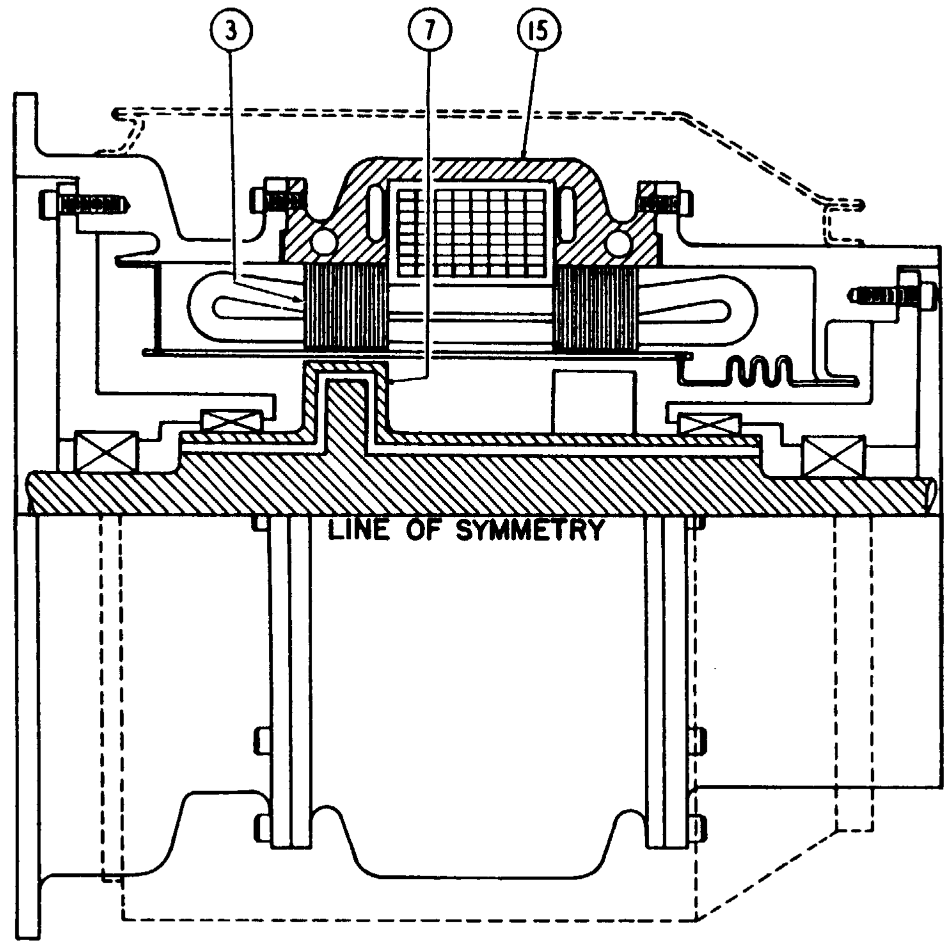


FIGURE II-3. A-C Generator, General Assembly

TABLE II-3. Details of A-C Generator Assembly

Item No.	Description	Item No.	Description
1	Bracket	12	Bearing - Shaft, Rotor
2	Passage - Coolant, Stator	13	Seal - Shaft
3	Laminations - Stator, AC	14	Carrier - Bearing & Seal
4	Winding - Stator, AC	15	Frame - Magnetic
5	Bore Seal - End Piece, Metal	16	Insulation - Slot, Stator Winding
6	Bore Seal - Cylinder, Ceramic	17	Conductor - Stator
7	Pole - Rotor	18	Retainer - Winding, Slot
8	Coil - Field, DC	19	Cladding - Conductor
9	Shield - If Inert Gas Cover Used	20	Insulation - Coil, DC
10	Rotor	21	Bracket
11	Passage - Coolant, Rotor	22	Insulation - Conductor, Stator



See Table II-3 for legend

FIGURE II-4. A-C Generator, Magnetic Material Usage

TABLE II-4. Magnetic Material Usage, A-C Generator

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Rotor Magnetic and Mechanical Suitability			Stator Magnetic Suitability			
				Magnetic		Typical Creep Values	Frame		Laminations	
		Sealed	Open to Vacuum	950°F(5)	1350°F(6)	(0.4% at 10,000 hrs)	750°F(5)	1150°F(6)	900°F(5)	1300°F(6)
IV.A.	Cubex Alloy									
	0.006 Inch Laminations	1100	1100	1	3	4	3	3	1	3
	0.011 Inch Laminations	1100	1100	1	3	4	3	3	1	3
IV.B.	Hiperco 50 Alloy									
	0.004 Inch Laminations	1100	1100	1	4	4	3	3	1	1
	0.008 Inch Laminations	1100	1100	1	4	4	3	3	1	1
	Supermendur									
	0.006 Inch Laminations	1100	1100	1	3	4	3	3	1	3
IV.C.	Hiperco 27 Alloy									
	0.004 Inch Laminations	1400	1400	3	3	11,500 psi at 950°F	3	3	1	1
	0.008 Inch Laminations	1400	1400	3	3	11,500 psi at 950°F	3	3	1	1
	Forging, Annealed, Vacuum Melted	1400	1400	1	4	11,500 psi at 950°F	1	1	3	3
	Castings, Annealed, Air Melted	1400	1400	1	4	11,500 psi at 950°F	1	1	3	3
IV.D.	1% Si-Fe, AMS 5210									
	Casting	1300	1300	1	3	4	1	1	3	3
IV.E.	Maraging Steel, 15%									
	Forging	750	750	3	3	160,000 psi at 750°F	1	3	3	3
	0.014 Inch Laminations	750	750	3	3	160,000 psi at 750°F	3	3	3	3
	0.025 Inch Laminations	750	750	3	3	160,000 psi at 750°F	3	3	3	3
IV.F.	H-11 Steel, R_c 45									
	Forging	1100	1100	1	3	23,000 psi at 950°F	1	3	1	3
	~~0.025~~ 0.014 Inch Laminations	1100	1100	1	3	23,000 psi at 950°F	3	3	1	3
	~~0.050~~ 0.025 Inch Laminations	1100	1100	1	3	23,000 psi at 950°F	3	3	1	3
IV.G.	Nivco Alloy									
	Forging	1250	1250	1	3	90,000 psi at 950°F	1	1	3	3
	0.014 Inch Laminations	1250	1250	1	3	90,000 psi at 950°F	3	3	1	3
	0.025 Inch Laminations	1250	1250	1	3	90,000 psi at 950°F	3	3	1	3

Legend
1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Material is unsuitable at this temperature for use in parts subjected to high rotational stresses.
5. Anticipated part temperature in °F with coolant temperature of 600°F
6. Anticipated part temperature in °F with coolant temperature of 1000°F

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 or 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.

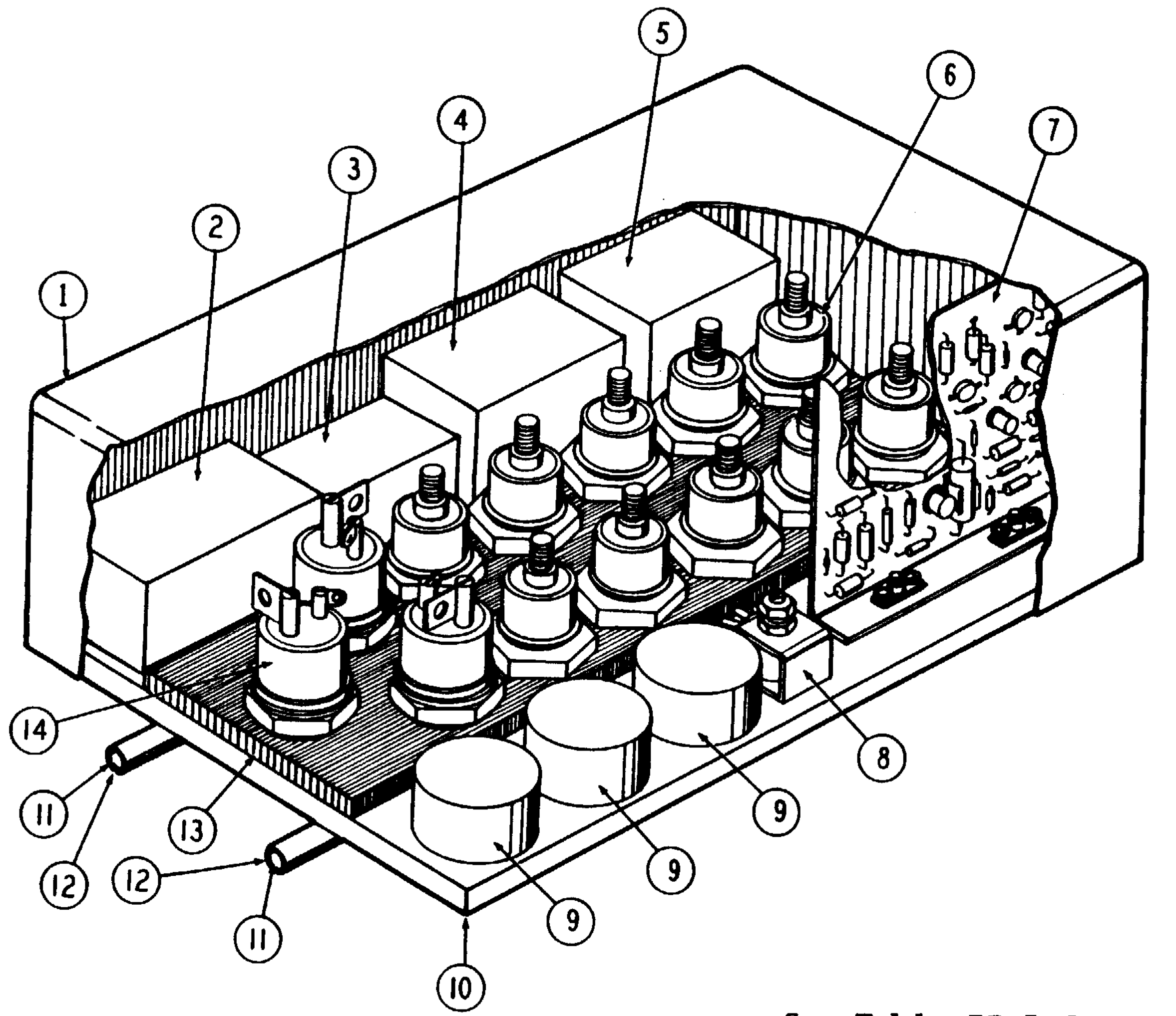
The usual exciter-regulator contains a power transformer to provide power for the field of the a-c generator. The power transformer occupies a substantial portion of the exciter-regulator package and also contributes significantly to the losses. Further, available materials permit building a transformer 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.

Figure II-5 is an assembly drawing showing the components which make up an exciter-regulator, and Table II-5 lists the components of the exciter-regulator.

Another component which is intimately associated physically with the exciter-regulator is the magnetic amplifier (magamp). When used in conjunction with sensitive components, such as semiconductors, a 300°F coolant may be required. If the magamp is separated from the sensitive components a higher coolant temperature is possible.

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 which restricts mechanical strain on the magnetic material. 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.



See Table II-5 for legend

FIGURE II-5. Exciter-Regulator, General Assembly

TABLE II-5. Details of Exciter-Regulator Assembly

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

Insulation is required on the windings as an insulation 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-6 is a drawing of a typical magamp design and Table II-6 lists 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.

Figure II-6 (Cross-Section A-A) is a cross-section drawing showing the magnetic tape laminations (Item 6) and some details of the windings. Table II-7 is a tabluation of magnetic materials and material forms showing the suitability of each material for use in the magamp core. Since it is possible that these devices may operate either in a vacuum or a hermetically sealed chamber, the suitability of each material for both conditions are shown in Table II-7.

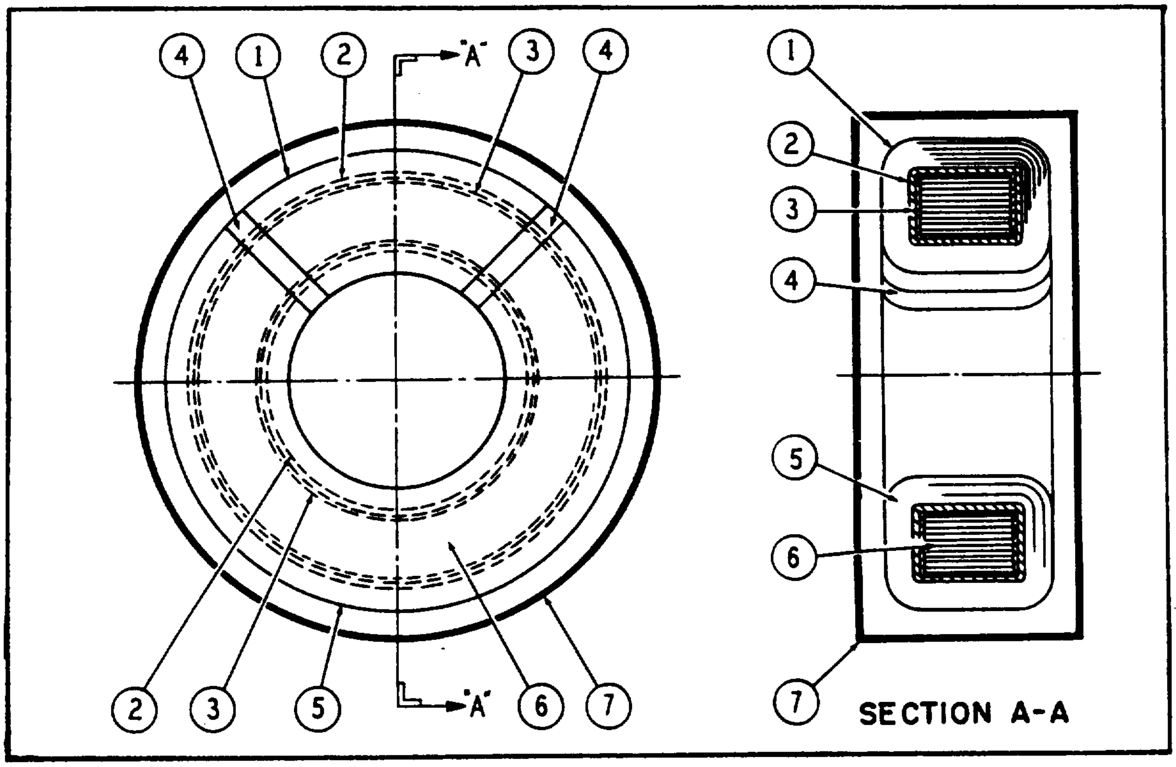


FIGURE II-6. Magamp, General Assembly and Cross-Section

TABLE II-6. Details of Magnetic Amplifier

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

TABLE II-7. Magnetic Material Usage, Magamp

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Core Tape and Laminations Magnetic Suitability	
		Sealed	Open to Vacuum	565°F (4)	1350°F (5)
IV.A.	Cubex				
	0.002 Inch Tape	1100	1100	1	3
	0.006 Inch Tape	1100	1100	1	3
	0.006 Inch Laminations	1100	1100	1	3
	0.011 Inch Laminations	1100	1100	1	3
	0.002 Inch Tape Magnetic Anneal, Toroid	1100	1100	1	3
	0.006 Inch Tape Magnetic Anneal, Toroid	1100	1100	1	3
IV.B.	Supermendur				
	0.002 Inch Tape, Toroid, Small	800	800	1	3
	0.002 Inch Tape, Toroid, Large	800	800	1	3
	0.006 Inch Laminations	800	800	1	3

Legend

1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Anticipated part temperature in °F with coolant temperature of 300°F.
5. Anticipated part temperature in °F with coolant temperature of 1000°F.

d. SOLENOID

The solenoid is a semi-static d-c device in that it 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 hermitically sealed container. Actuation and de-actuation is accomplished by very short current applications and the solenoid is latched closed magnetically. Two environmental temperatures of 300°F and 1000°F were chosen. The first is characteristic of applications where the solenoid is used with sensitive components such as semiconductors. The 1000°F is characteristic of the temperature expected if the solenoid was removed from the area of the sensitive components. No internal cooling provisions are required because the heat generated is small.

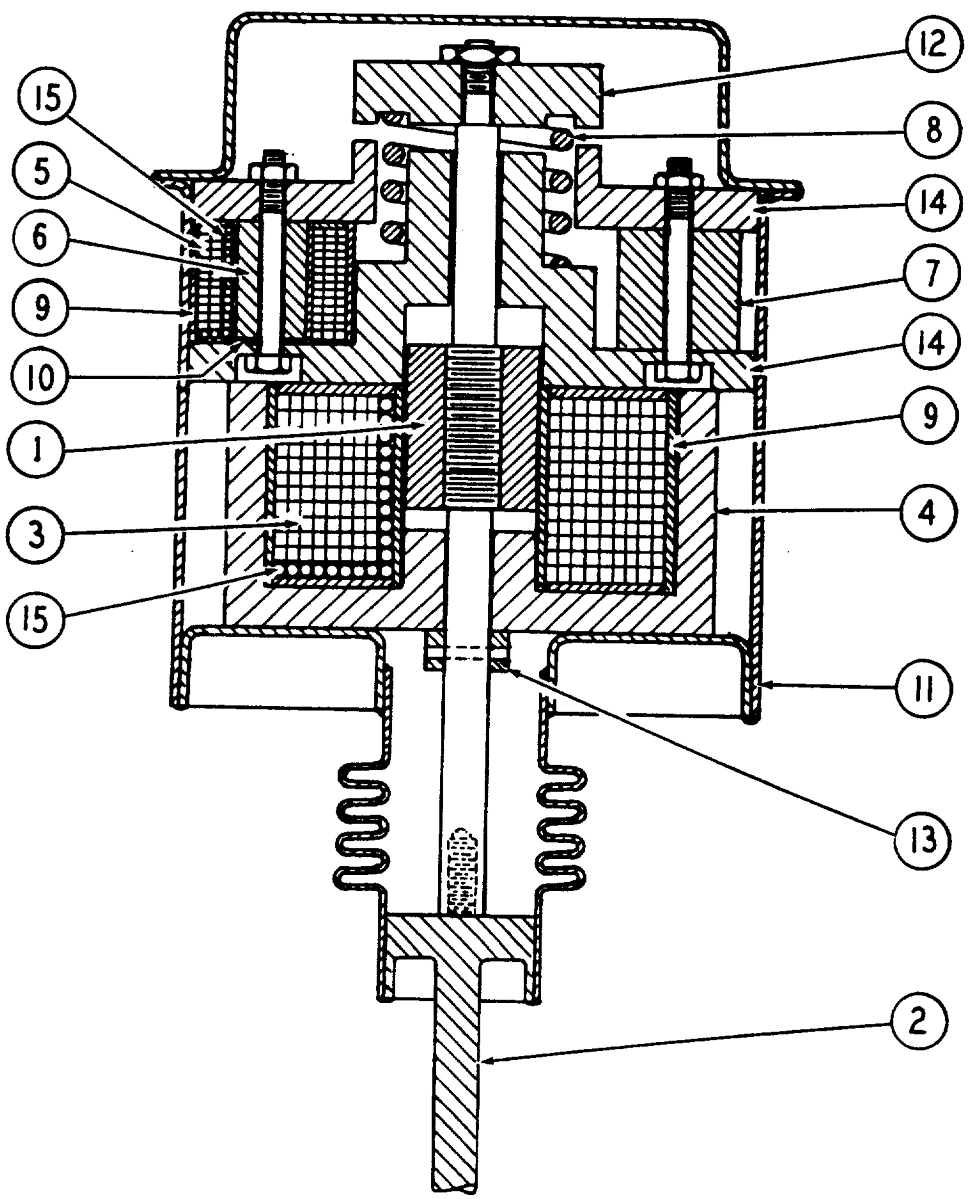
The nature of the solenoid application is such that the magnetic materials are all solid rather than laminated. The magnetic circuits carry only d-c flux so magnetic flux losses are relatively unimportant. It is important that the magnetic circuits be able to carry a substantial amount of flux with low-magnetizing 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 coating on the conductor and in sheet or molded form as a ground insulation.

Figure II-7 is a drawing of a typical d-c solenoid capable of operation in a high-temperature, liquid alkali-metal system. Table II-8 is a list identifying the major parts and features in 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 magnet (Item 7), which holds 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, which diverts the permanent magnet flux from the latch plate and allows the spring to return the actuator rod to its original position.



See Table II-8 for legend

FIGURE II-7. Solenoid, General Assembly

TABLE II-8. Details of Solenoid Assembly

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

Figure II-8 is another sketch of the solenoid which emphasizes the areas where magnetic materials are used. Since d-c magnetic properties are the main requirement, only one material covered by this study (1%, Si-Fe AMS 5210) is satisfactory for this application. Table II-9 shows the temperature capability for this material. Although this design shows only a hermetically sealed application, the possibility of this material being exposed to a space vacuum is recognized and suitability of the material for this condition is also shown on Table II-9.

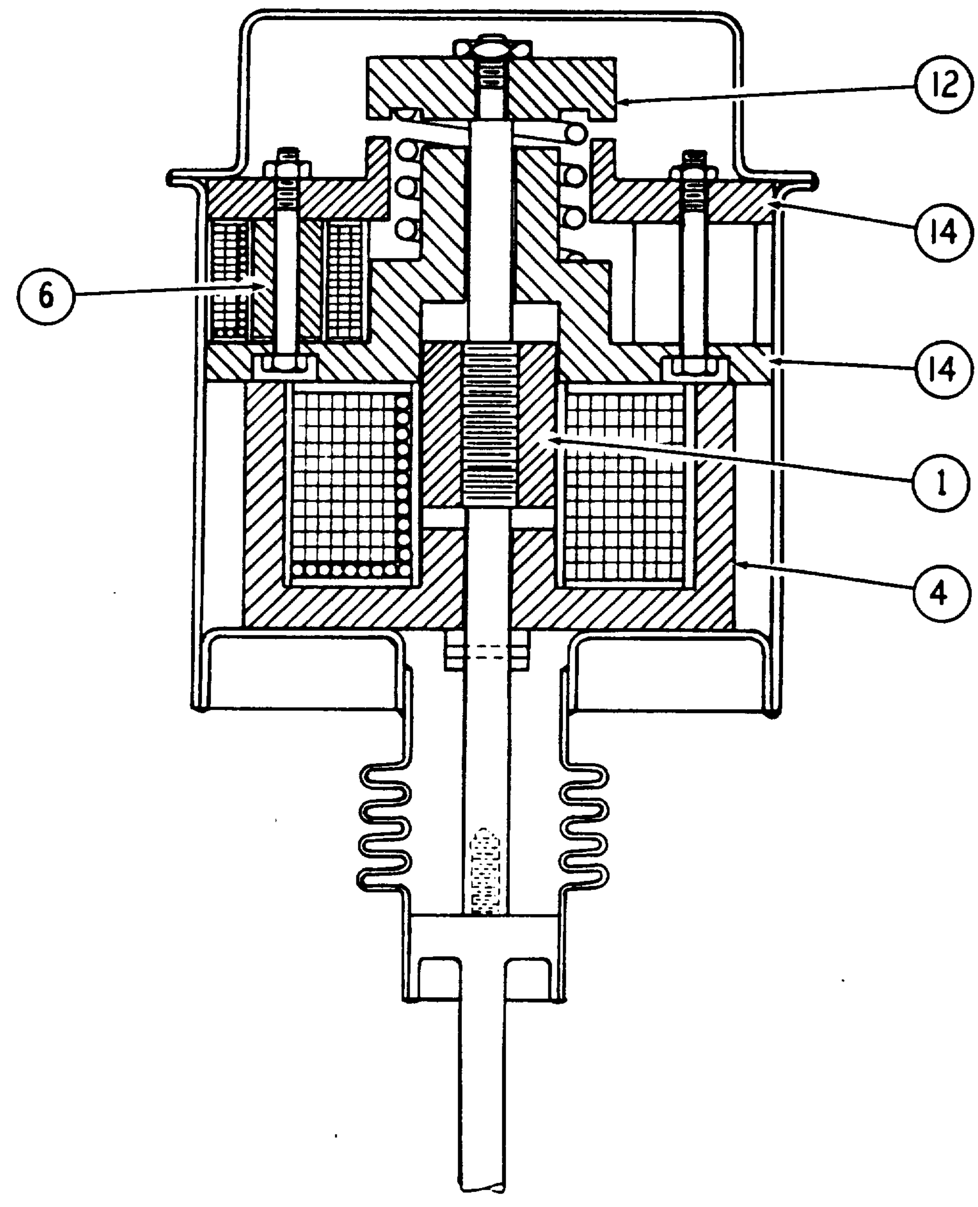


FIGURE II-8. Solenoid, Magnetic Materials

TABLE II-9. Magnetic Material Usage, D-C Solenoid

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Plunger, Core, & Latch Magnetic and Mechanical Suitability	
		Sealed	Open to Vacuum	300°F(4)	1000°F(5)
IV.D.	1% Silicon Iron AMS 5210	1300	1300	1	1

Legend

1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Anticipated part temperature in °F with solenoid in a 300°F environment with no internal cooling.
5. Anticipated part temperature in °F with solenoid in a 1000°F environment with no internal cooling.

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.

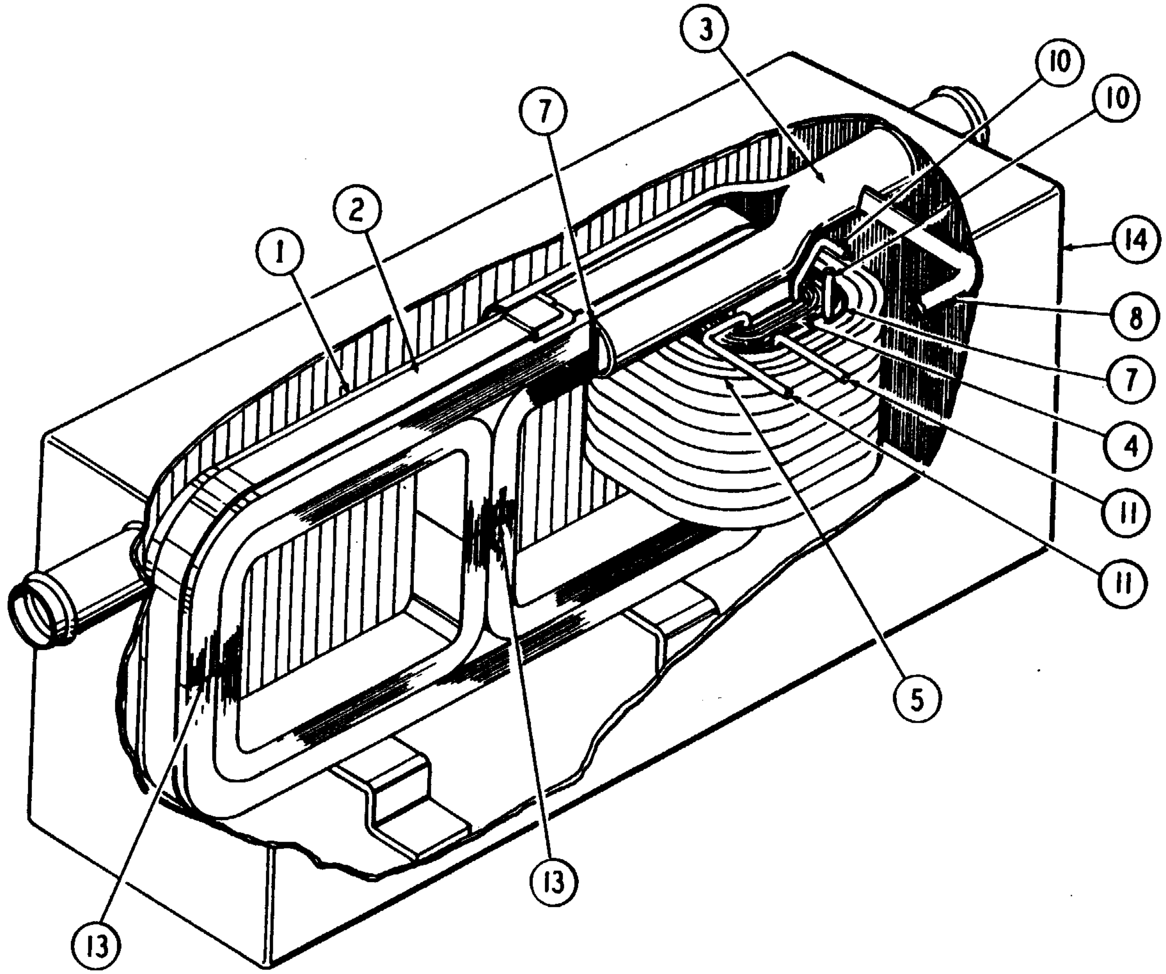
The coils of the transformer are wound with magnet wire. A clad coil material is used to meet the system temperature requirements.

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.

Figure II-9 is a drawing of a typical three-phase transformer design, and Table II-10 lists the various parts and features of the 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-10 is a cross-section drawing showing the magnetic core (Item 1), and some details of the coils and coolant passages. Table II-11 is a tabulation of magnetic materials and material forms showing the suitability of each material for use in the transformer core. This table shows suitability of the materials used in the transformer either in a hermetically sealed chamber or exposed to a space vacuum.

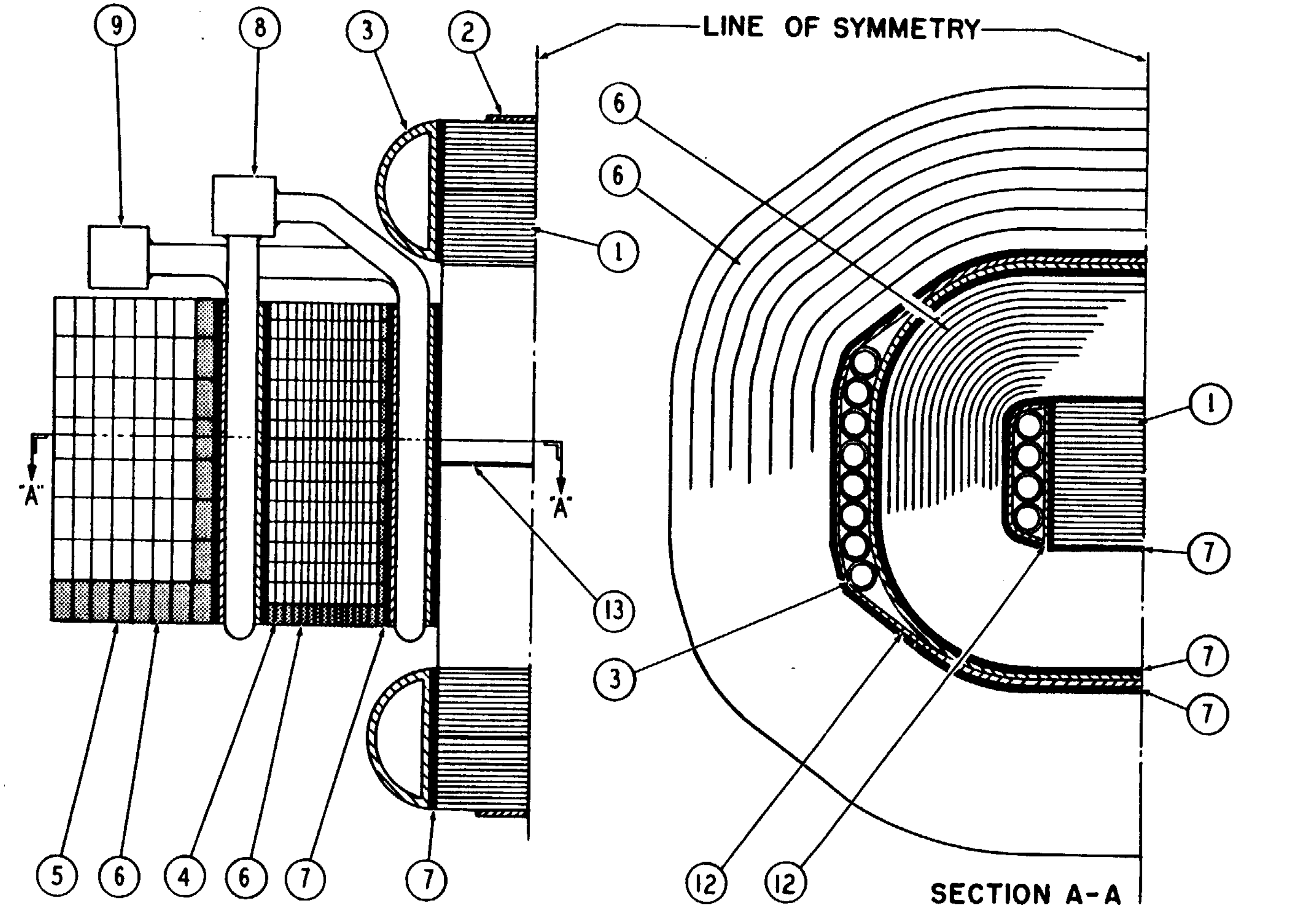


See Table II-10 for legend

FIGURE II-9. Transformer, General Assembly

TABLE II-10. Details of Transformer Assembly

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



See Table II-10 for legend

FIGURE II-10. Transformer, Cross Section

TABLE II-11. Magnetic Material Usage, Transformer

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Core Tape and Laminations Magnetic Suitability	
		Sealed	Open to Vacuum	750°F(4)	1150°F(5)
IV.A.	Cubex Alloy				
	0.002 Inch Tape	1100	1100	1	3
	0.006 Inch Tape	1100	1100	1	3
	0.006 Inch Laminations	1100	1100	1	3
	0.011 Inch Laminations	1100	1100	1	3
	0.002 Inch Tape, Magnetic Field Annealed	1100	1100	1	3
	0.006 Inch Tape, Magnetic Field Annealed	1100	1100	1	3
IV.B.	Hiperco 50 Alloy				
	0.004 Inch Laminations	1100	1100	1	3
	0.008 Inch Laminations	1100	1100	1	3
	Supermendur				
	0.002 Inch Laminations	1100	1100	1	3
	0.006 Inch Laminations	1100	1100	1	3
IV.C.	Hiperco 27 Alloy				
	0.004 Inch Tape	1400	1400	1	1
	0.008 Inch Laminations	1400	1400	1	1

Legend

1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Anticipated part temperature in °F with coolant temperature of 600°F.
5. Anticipated part temperature in °F with coolant temperature of 1000°F.

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-11 is a drawing of a typical linear-type electromagnetic pump design. Table II-12 lists the various parts and features of the 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.

Figures II-12 and II-13 are cross section drawings showing the magnetic laminations (Item 4) and some details of the cooling tubes. Table II-13 shows the suitability of various magnetic materials for this application.

Additional discussion on various types of electromagnetic pumps and the power conditioning requirement is contained in NASA Report No. CR-54139, by J. Verkamp entitled, "Electromagnetic Alkali-Metal Pump Research Program". This work was conducted in 1964 at the General Electric Corporation under Contract NAS 3-2543.

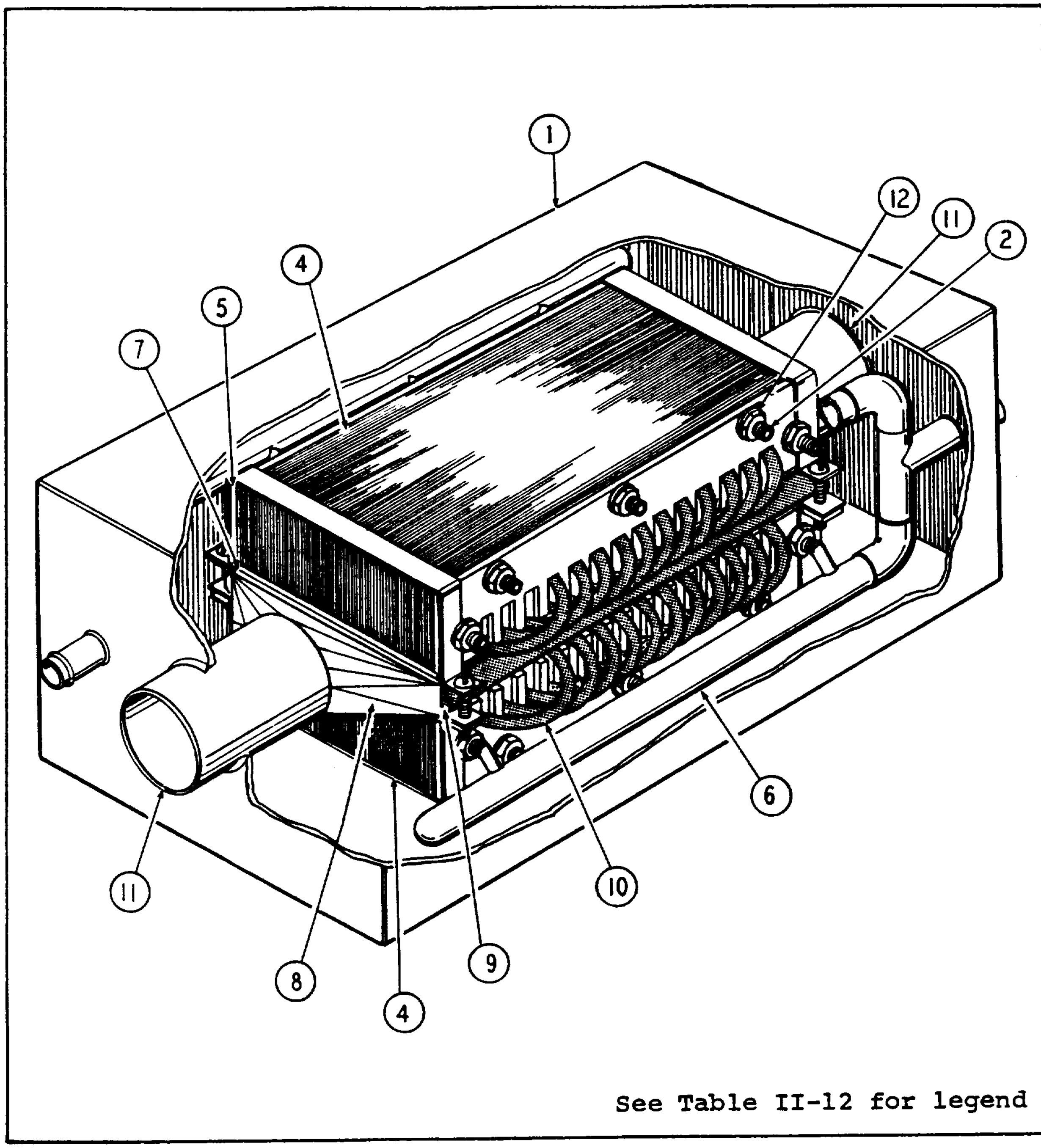
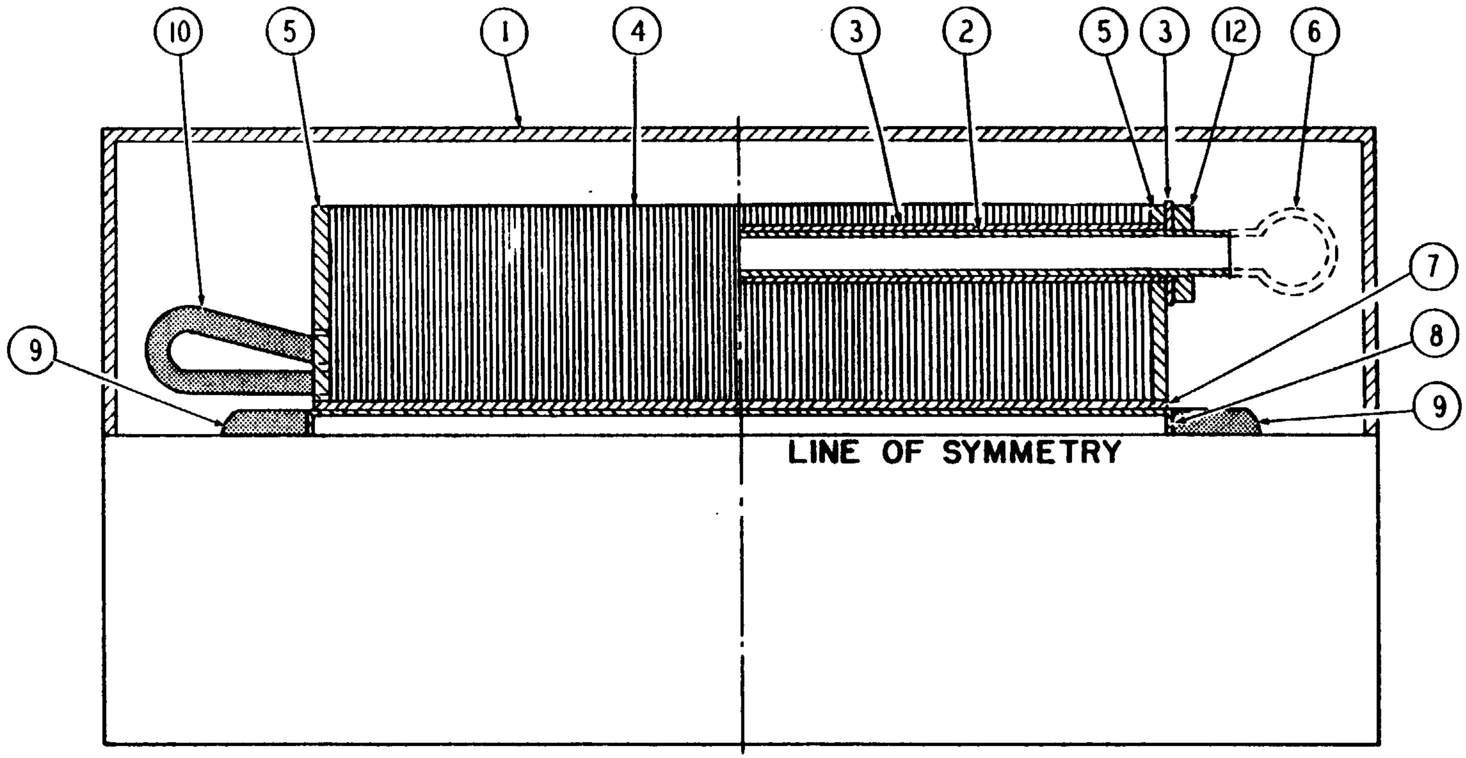


FIGURE II-11. Electromagnetic Pump, General Assembly

TABLE II-12. Details of Electromagnetic Pump Assembly

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



See Table II-12 for legend

FIGURE II-12. Electromagnetic Pump, Cross Section

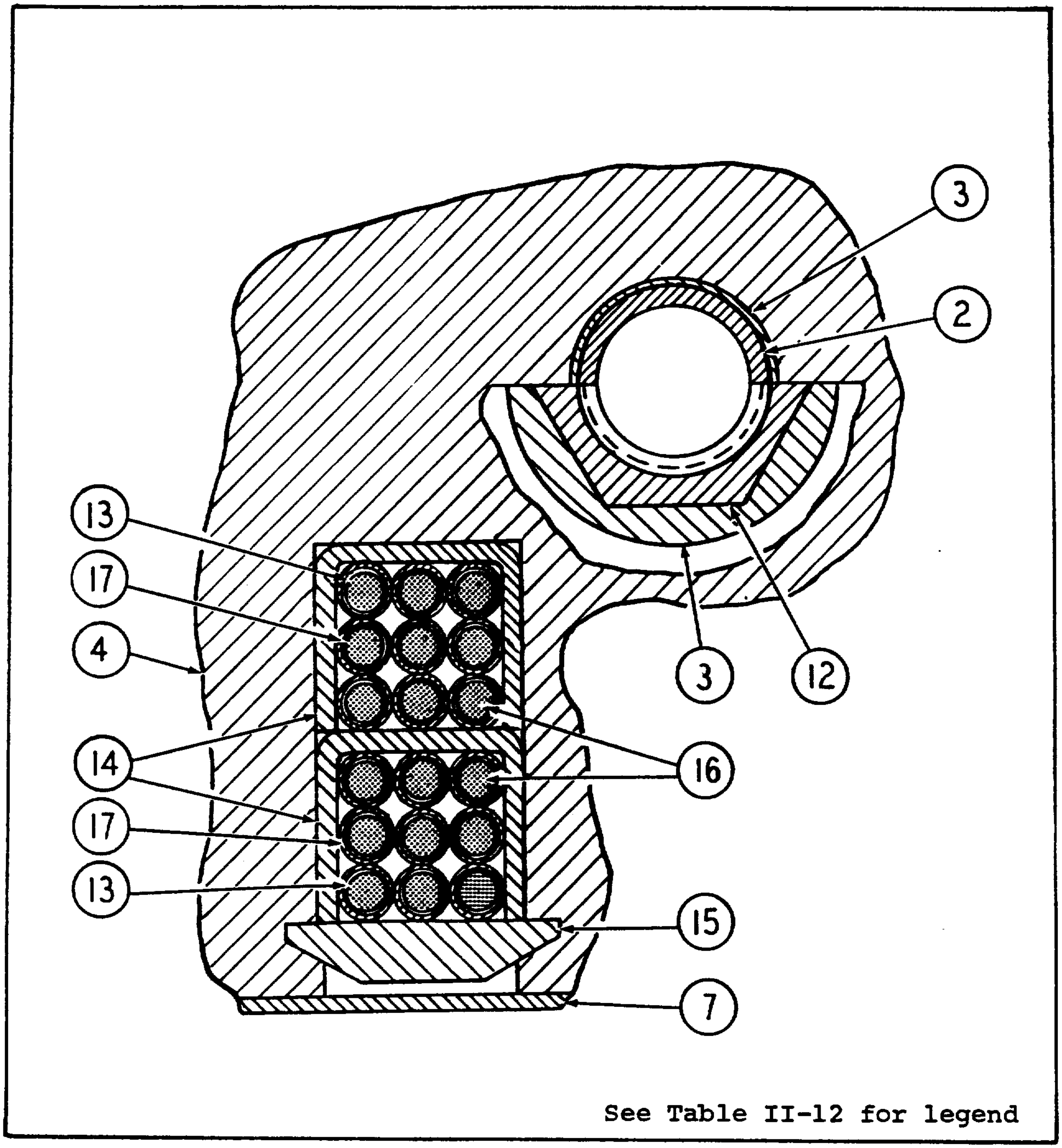


FIGURE II-13. Electromagnetic Pump, Stator Slot and Magnetic Core Detail

TABLE II-13. Magnetic Material Usage, Electromagnetic Pump

Location of Material Property Summary	Material	Maximum Useful Material Temperature - °F		Stator Laminations	
		Sealed	Open to Vacuum	900°F(4)	1100°F(5)
IV.A.	Cubex Alloy				
	0.006 Inch Laminations	1100	1100	1	1
	0.011 Inch Laminations	1100	1100	1	1
IV.B.	Hiperco 50 Alloy				
	0.004 Inch Laminations	1100	1100	1	1
	0.008 Inch Laminations	1100	1100	1	1
	Supermendur				
	0.006 Inch Laminations	1100	1100	1	1
IV.C.	Hiperco 27 Alloy				
	0.004 Inch Laminations	1400	1400	1	1
	0.008 Inch Laminations	1400	1400	1	1

Legend

1. Satisfactory
2. Marginal
3. Unsatisfactory
4. Anticipated part temperature °F with coolant temperature of 600°F.
5. Anticipated part temperature °F with coolant temperature of 1000°F.

B. DISCUSSION OF MATERIAL PROPERTIES.

1. General Discussion of Magnetic Material Properties

Efficient operation of space power systems requires unusual combinations of properties in magnetic materials including satisfactory behavior at temperatures up to 1400°F and above and at frequencies up to 3200 cps. In order to improve our design knowledge on the potential capabilities of those existing magnetic materials which are suitable in space power systems, additional information was needed regarding their behavior at various temperatures and frequencies. The present program was designed to fulfill this need.

Depending upon specific requirements of different system components, the following major groups of magnetic materials were considered in this study:

a. Materials for the stator core: Ring Laminations of Hiperco 27 alloy (27% Co-Fe) and Hiperco 50 alloy (2%V, 49% Co, 49% Fe) as well as of Cubex, a doubly-oriented 3-1/4% Si-Fe alloy, are suitable materials for advanced applications. Major magnetic requirements include a high-flux carrying capacity and low-core losses at high temperatures; only serviceable mechanical properties are required for these low-stressed parts.

b. Materials for the rotor core: Forgings and ring laminations of H-11 Steel (5% Cr, 1% Mo, Fe), 15 and 18% Ni Maraging steels, and Nivco alloy (approximately 72% Co, 23% Ni and certain other elements), represent characteristic rotor materials. A solid or laminated rotor for a generator or motor is subjected to high rotational speeds which place high strength as the primary material requirement at elevated temperature. A generator rotor material, for example, is expected to possess a high-creep strength at operating temperatures, preferably under 0.4 percent strain in 10,000 hours at stresses in excess of 40,000 psi. Although magnetic requirements are secondary for the solid rotor core, an induction exceeding 8 to 10 kilogauss at operating temperature under normal excitation conditions is expected. The rotor pole pieces are subject to losses which suggest that they might be either "slotted" or built from laminations since their magnetic performance requirements are more critical than their mechanical needs.

c. Materials for controls and electronic applications, including magnetic amplifiers: Tape and ring laminations of Supermendur (domain oriented 2%V, 49% Co, 49% Fe) and Cubex alloy, are suitable materials. High saturation, high permeability, combined with a square hysteresis loop are desirable in these specific applications.

d. Pole material for standard control apparatus: AMS 5210 (1% Si-Fe) casting was considered primarily because of its lower losses and better casting characteristics and higher resistivity than iron.

The detailed data obtained in this study are presented in Section IV. The following are some general comments, together with a discussion of the materials considered in the study with respect to their magnetic and mechanical stability and capability in different temperature ranges.

The magnetic properties of the single-phase materials, such as Cubex and Hiperco 27, followed the patterns expected at high temperatures. As the temperature increased, the magnetization curves rose more quickly at lower fields, and then flattened out and saturated at lower inductions. In addition, coercive force, residual induction and core loss decreased with increasing temperature. The excitation (volt-amperes per pound) curves at high inductions followed the opposite trend. The steep drop in high-field induction begins in Cubex alloy above 1100°F. At this temperature however, Hiperco 27 alloy still has an induction of 21 kilogauss.

As shown in Figures IV.C.II-11, 28, 37 and IV.A.II-9, 76, 77 respectively, Hiperco 27 and Cubex alloy were not affected by the 1000 hours stability test at 1000°F. The d-c and a-c magnetic properties of both alloys, which were measured at room temperature after the stability test, showed no significant change from those measured before testing. A decrease in the magnetic properties measured at 1000°F is in line with an expected short-time reversible change with temperature. The tensile properties of these two materials followed the general pattern for solid solution alloys. At an elevated temperature below 1/2 Tm* there is a considerable change in slope and the decrease in strength with increasing temperature becomes more rapid. It is important to

*1/2 Tm refers to half the temperature range, in °K, between absolute zero and the melting point.

observe that Hiperco 27 alloy displayed a relatively high-creep strength at 900°F, surpassing that of Maraging steel at the temperature as shown in Figure II-14.

The materials in which a phase change takes place at test temperatures showed some deviations from the above pattern. These materials differ from Cubex and Hiperco 27 alloys in which the Curie point and the limitations in solid solution strength determine the limits of their magnetic and mechanical capabilities at high temperatures. The capabilities of alloys with phase changes are controlled primarily by the phase changes and the temperatures at which they occur. These materials include Hiperco 50 alloy and Supermendur which, at elevated temperatures, undergo an atomic ordering (and probably a phase addition due to the presence of vanadium), as well as all three high-strength materials: Nivco alloy, H-11 steel and Maraging steels, in which precipitation of one or several new phases makes a major contribution to high-temperature strength. In Maraging steels, the temperature capability of magnetic and mechanical properties is controlled by the reversion to austenite.

The primary deviations from initial magnetic properties were measured as an increase in coercive force with a corresponding effect on core loss, both at the temperature where structural change takes place and at room temperature, after exposure to a critical high temperature. In mechanical properties, the high-temperature phase change brought about either a decrease in strength, such as in the high strength alloys, or an increase in strength in the lower strength alloys, such as Hiperco 50 alloy. This latter effect caused an increase in tensile strength over a certain temperature region such as in Supermendur. These phase changes were also reflected in the thermophysical properties which caused a peak in the specific heat of Hiperco 50 alloy and Supermendur.

As expected, stability testing at 1000°F for 1000 hours resulted in major changes in the magnetic properties of H-11 steel and 15 percent nickel Maraging steel (Figures IV.F.II-2 and IV.E.II-2 respectively).

The coercive force of H-11 steel decreased steadily during stability testing. After test the room temperature value was lower than that originally measured. However, Maraging steel exhibited a considerable increase in coercive force and a decrease in high-field induction at both 1000°F and room temperature after testing. The continuous decrease in the coercive force of H-11 steel is a sign of overaging of the complex carbide precipitates and continued tempering of Martensite This overaging and tempering results in an overall relaxation of internal stresses. In addition, the overaging also removed many of the obstacles to domain wall movement. While the above changes are generally beneficial to the magnetic properties, the creep strength decreases accordingly.

The structural change in Maraging steel at 1000°F is based primarily on partial reversal of the ferrite matrix to austenite. Since austenite is non-magnetic, it dilutes the magnetic matrix and, as can be seen from the stability results, the high-field induction value was lowered. Reverted austenite apparently creates enough stress, in certain crystallographic positions with respect to the matrix and in certain particle sizes, to increase the coercive force considerably. The data obtained in this study, particularly the magnetization curves for 1100°F, show that a decrease in nickel content from 18 to 15 percent nickel raises the temperature capability of Maraging steels. The results from the 1000-hour stability test indicate that the temperature limit of the 15 percent nickel material lies below 1000°F, probably between 750 and 850°F.

Nivco alloy (Figure IV.G.II-2) was included in the group of materials tested for magnetic stability at 1000°F. No magnetic aging was observed for Nivco at 1000°F, primarily because the precipitation hardening reaction of this material takes place considerably above the stability test temperature. However, annealing Nivco at 1100°F and 1400°F (Figure IV.G.II-1) resulted in a structural change, probably overaging, and brought about a considerable decrease in the coercive force both at temperature and at room temperature after exposure. It also increased the room temperature value of the high-field induction.

No stability tests were conducted on Hiperco 50 alloy and Supermendur. However, literature review and short time tests in this program indicate that structural changes take place in these materials at elevated temperature. For instance, Hiperco 50 shows a considerable increase in the room temperature coercive force after exposure to 1400°F. This may be associated with the strain or with rearrangements in the atom positions, both brought about by an atomic ordering reaction which for 50 percent cobalt-iron occurs at temperatures up to 1350°F. Tests on Supermendur, both in this study and in previous Westinghouse programs, indicate that the effects of the ordering reaction, together with the associated changes in magnetic properties, may occur at temperatures as low as 700°F. This lowers the temperature capability of these materials considerably below that of Hiperco 27 and Cubex alloys. (Reference: RM9, RM29.)

Graphical information on mechanical properties is displayed in the Larson-Miller creep curves for each material in Section IV. Creep data at 0.4 percent creep strain for rotor-type materials and Hiperco 27 alloy at temperature up to 1100°F as a function of temperature are shown in Figure II-14.

Nivco alloy required a stress of 70,000 psi to produce 0.4 percent creep strain at 1100°F in 10,000 hours. This surpasses the temperature capability of all other materials tested. The 15 percent nickel Maraging steel has outstanding creep strength at 700°F, but a temperature increase to 900°F brings about a rapid decrease in its creep strength. The H-11 steel has very useful creep strength of about 90,000 psi at 800°F, but loses it rapidly as the temperature increases.

Figure II-15 displays the high-field induction of all the materials tested as a function of temperature. At 1400°F, both Hiperco alloys reached an induction of 18 to 18.5 kilogauss and Nivco an induction of about 10 kilogauss.

Core loss data of the high-saturation materials are shown in Figures II-16 and 17. At 1100°F and inductions below 18 kilogauss the Cubex alloy competes successfully with both Hiperco alloys. However, above 1100°F Hiperco 27 appears to be the best choice for stator core material. Hiperco 50 should not be considered for high temperatures because of magnetic stability problems.

In considering the above data, the following grouping of the materials may be made with respect to three temperature ranges.

1) <u>600°F - 800°F</u>. Most materials qualify for this temperature range. However, Cubex alloy is preferred for use in stators at inductions up to 18 kilogauss. H-11 steel and Maraging steel are recommended for rotors, and Supermendur for control devices.

2) <u>800°F - 1100°F</u>. Hiperco 27 alloy is suggested for high inductions and Cubex alloy for inductions up to 15 - 18 kilogauss in stators. H-11 steel qualifies for the lower temperatures and Nivco alloy for the higher temperatures in this range. Supermendur and Cubex alloys can be used for controls with Cubex preferred for the higher temperatures.

3) <u>1100°F - 1400°F</u>. Hiperco 27 alloy is recommended for stators and Nivco alloy for rotors in this temperature range.

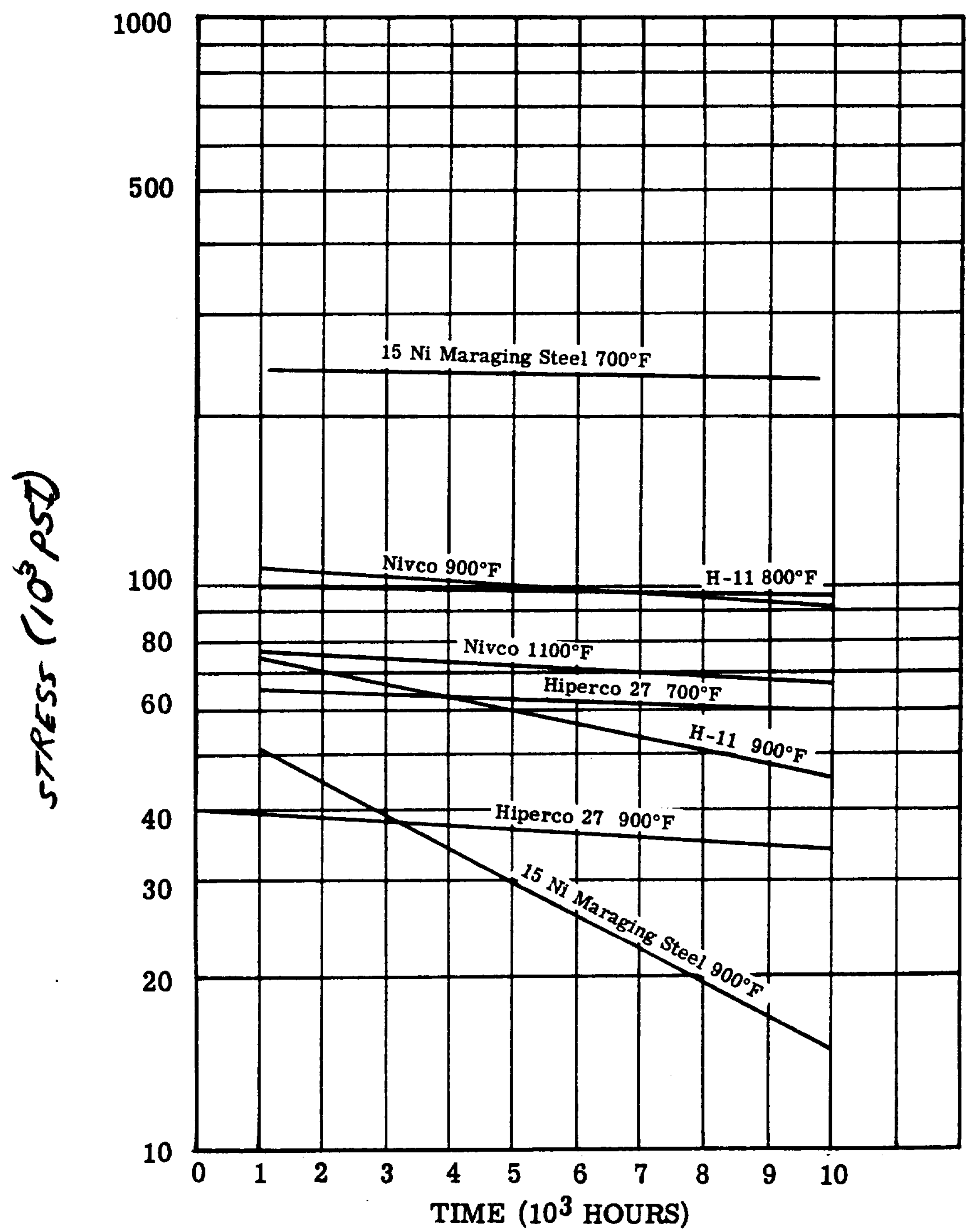


FIGURE II-14. Comparison of Stresses Required to Produce 0.4 Percent Creep Strain at the Indicated Temperature. Data Extrapolated from Larson-Miller Presentations. (Reference: NAS 3-4162)

Figure II-14. Creep-Summary Data Sheet

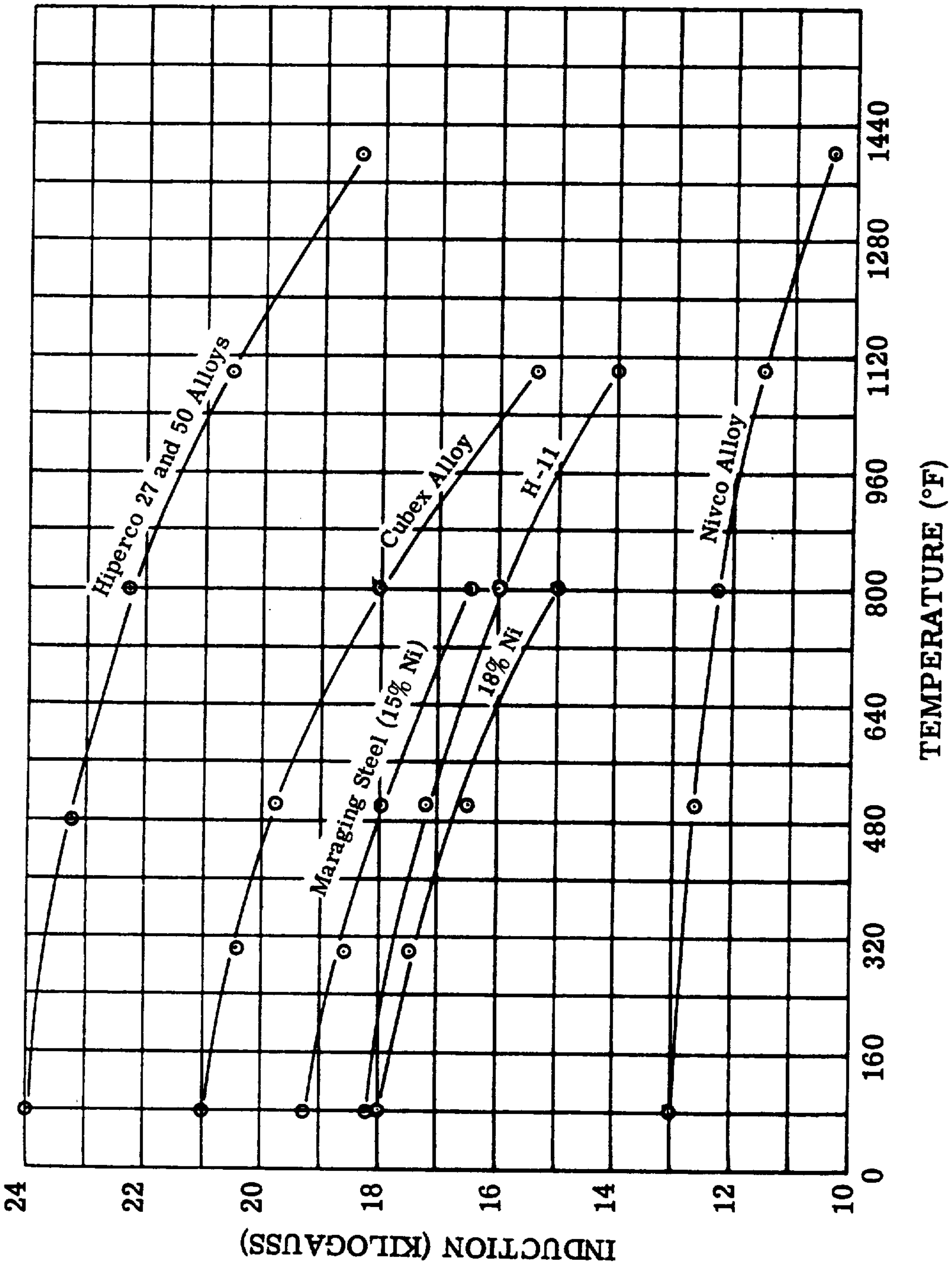


FIGURE II-15. Summary of Induction for Materials Tested at a Magnetization of 250 to 300 Oersteds as a Function of Temperature (Reference: NAS 3-4162)

Figure II-15. Maximum Induction Summary - Magnetic Materials

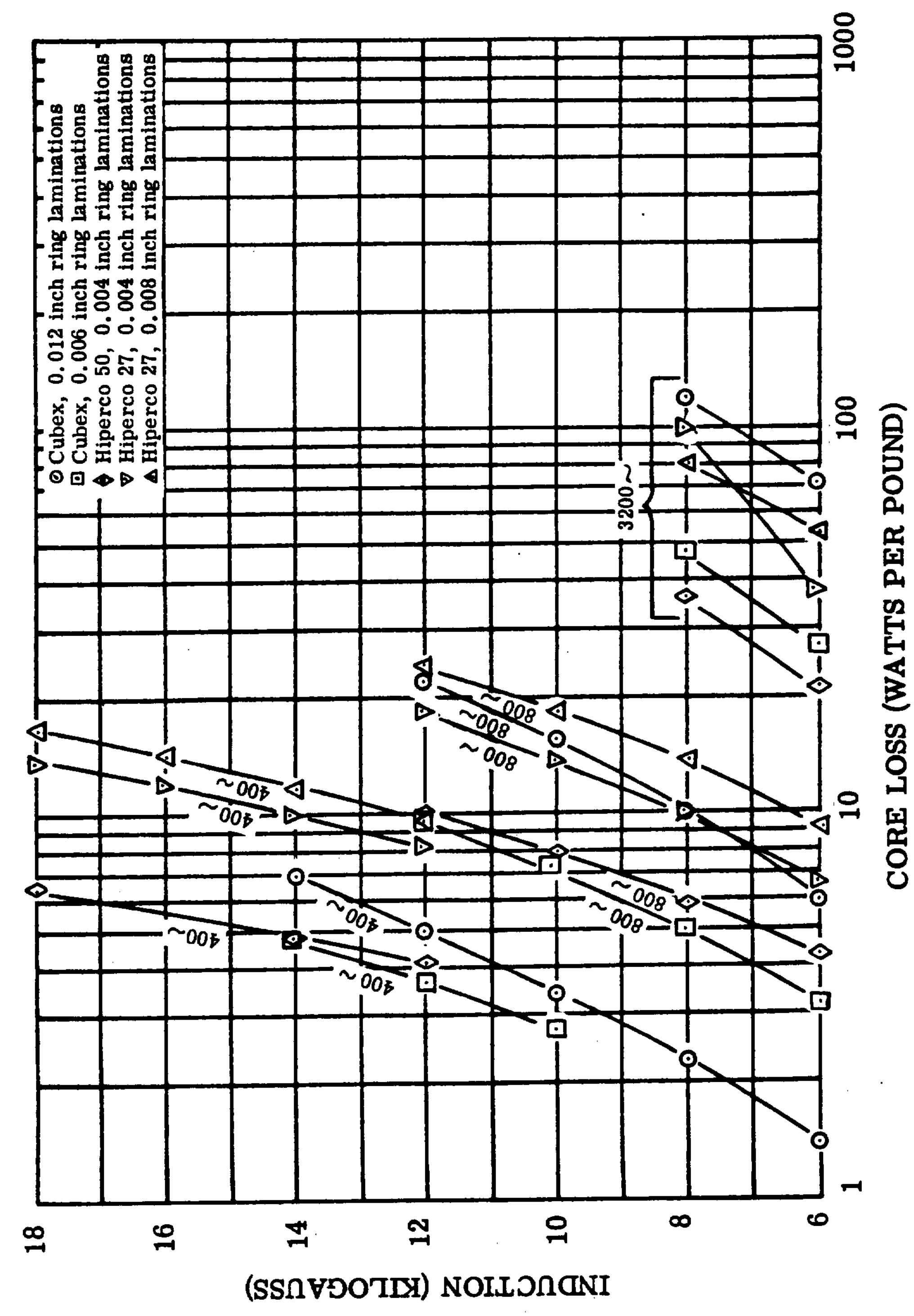


FIGURE II-16. Summary of Core Loss 400 to 3200 C.P.S.; Alloys as Indicated Tested in Argon at 1100°F. (Reference: NAS 3-4162)

Figure II-16. Core Loss, 400 to 3200 C.P.S. Material Summary

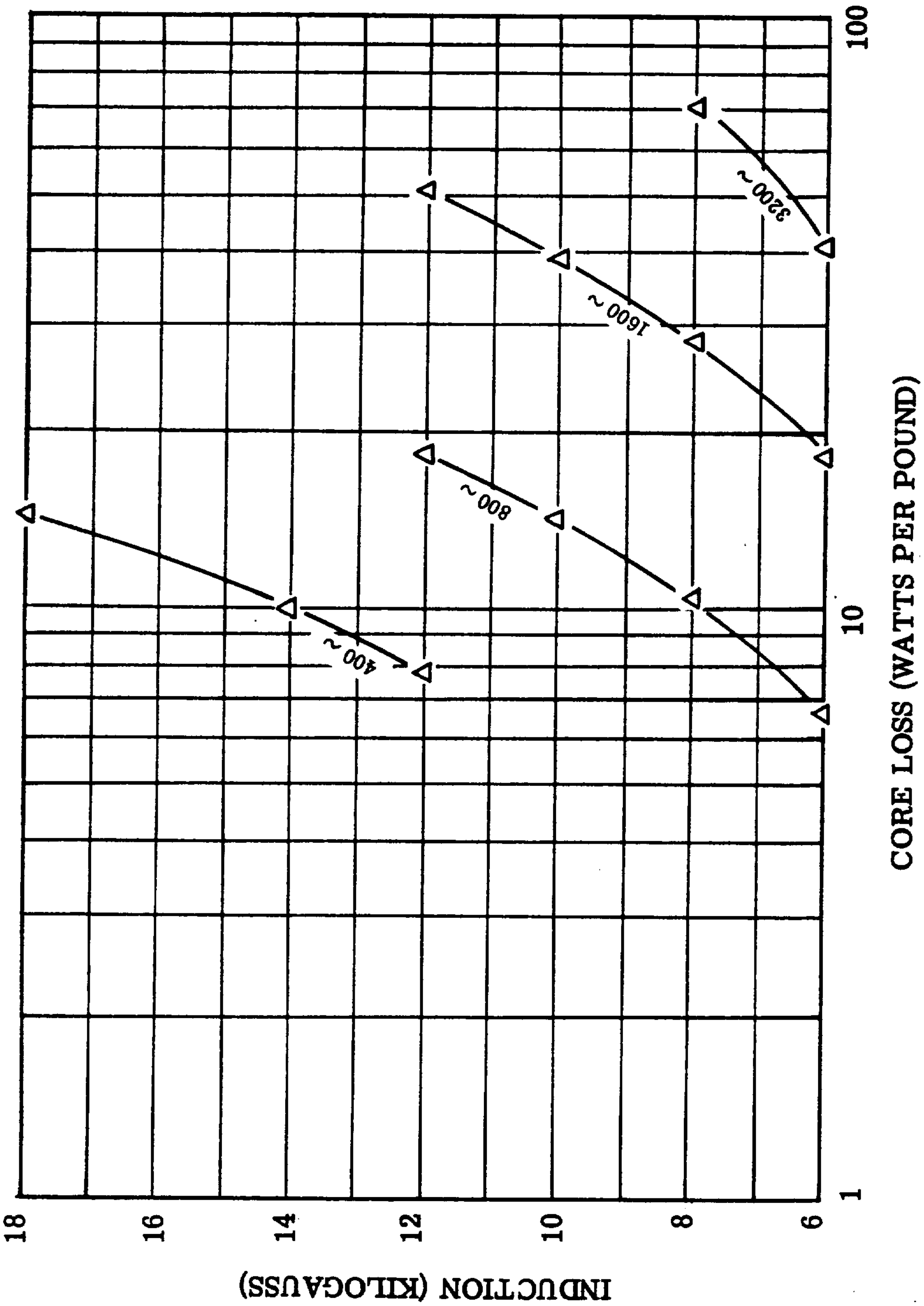


FIGURE II-17. Core Loss 400 to 3200 C.P.S. Hiperco 27 Alloy, 0.008 Inch Laminations
Test Atmosphere: Argon at 1400°F
(Reference: NAS 3-4162)

Figure II-17. Core Loss, 400 to 3200 C.P.S. Hiperco Alloy

2. Nuclear Effects on Magnetic Materials

The combined effects of nuclear radiation and a high-temperature environment are an important factor in determining the overall capability of a space power system. Limited information is available on these combined environments showing that grain-oriented silicon-iron performs satisfactorily under these conditions. Temperature was the predominant factor influencing performance. These are also indications that the nuclear radiation effect decreases as the temperature is raised.

Published information on radiation levels of 10^{17} nvt on metals and alloys indicates that structural changes are primarily responsible for changes in structure-sensitive magnetic properties. These include coercive force and permeability. Structural changes induced by irradiation include the disordering effect on an originally ordered material, introduction of imperfections in the lattice, acceleration of precipitation reactions, etc. Gordon(1) observed that only the softest magnetic materials, with a coercive force of less than 0.5 oersteds, were significantly affected by irradiation. This results in an increase in the coercive force and a decrease in squareness in the hysteresis loop. Most of the alloys evaluated in this manner came from those regions of the nickel-iron systems where atomic ordering takes place. Gordon also observed that radiation-induced changes in magnetic properties were not affected by time, but that reheat treatment of irradiated cores restored the original pre-irradiation properties.

As a result of the above observations, it is assumed that both silicon-iron alloys covered in this study should not be seriously affected by nuclear radiation. The same should be true of Hiperco 27 alloy, even though cobalt-containing materials are expected to be subject to secondary beta and gamma radiation caused by the radioactive decay of cobalt 60. Hiperco 50 alloy and Supermendur are expected to be radiation sensitive because of the ordering reaction which takes place in 50 percent cobalt iron.

High-strength materials may experience an acceleration of overaging due to nuclear radiation, but this effect may be conteracted by high-temperature exposure. From the meager data available of the effects on the creep or fatigue behavior of

(1)Gordon, D.E., "Magnetic Cores and Permanent Magnets in Hyper-Environments", Proceedings of the Institute of Environmental Sciences, page 205, 1960.

metals, irradiation does not increase the creep rate of most metals to any extent.

3. Detailed Discussion of Materials

a. CUBEX ALLOY

A summary of Cubex alloy properties is presented in Section IV.A. Cubex alloy is a high-purity, 3-1/4 percent, silicon-iron which is processed to achieve what is known as "cube on face" orientation. The material responds to annealing in a magnetic field which imparts further improved magnetic properties to the alloy. Cubex alloy, however, is commonly used in the stress-relief-annealed condition in rotating machinery with the field-annealed material being reserved for high-performance transformers and magnetic amplifiers.

1) Specific Heat

At temperatures between 72° and 572°F, the specific heat of Cubex alloy is nearly constant as shown in Figure IV.A.I-1. Above 572°F, the specific heat increases exponentially to a value of 0.222 Btu/lb-°F at 1112°F.

2) Thermal Conductivity

The thermal conductivity of Cubex alloy was measured over the range of 72°-1320°F and was found nearly constant as shown in Figure IV.A.I-2.

3) Electrical Resistivity

The electrical resistivity of Cubex alloy was measured over the range of 77° to 1100°F. A plot of resistivity versus temperature is shown in Figure IV.A.I-3.

4) Magnetic Properties

The magnetic properties of different forms of Cubex alloy were measured at temperatures to 1100°F and at frequencies of 60, 400, 800, 1600 and 3200 cps. A list of test-sample forms and material sizes are repeated here for clarification:

a) Rowland ring

(1) 0.006 inch thick sheet
(2) 0.011 inch thick sheet

b) Tape-wound toroid

(1) 3-1/2 inch I.D. x 4 inch O.D.

(a) 0.002 inch thick tape
(b) 0.006 inch thick tape

(2) 1 inch I.D. x 1-1/4 inch O.D.

(a) 0.002 inch thick tape

A sample from each tape-wound configuration was magnetic-field annealed (MFA) and the balance stress-relief annealed (SRA). Plots of the magnetic test data for Rowland ring and toroid tape-wound samples are shown in Figures IV.A.II-1 to IV.A.II-77.

Coercive force, residual induction and core loss decreased with increasing test temperature for all samples. Room temperature inductions of 16 and 17 kilogauss were obtained on 0.006 inch thick and 0.011 inch thick stack type Rowland ring samples of Cubex alloy at a field of 10 oersteds (Figures IV.A.II-7 and 8). Increasing the field to 300 oersteds raised the induction for the ring samples to 21 kilogauss. At 1100°F, the induction of both Rowland ring samples had decreased to 12.8 kilogauss at 10 oersteds and 15.5 kilogauss at 300 oersteds. The coercive force of both lamination thicknesses decreased from room temperature values of 0.1 oersteds (0.011 inch) and 0.18 oersted (0.006 inch) to 0.06 oersted at 1100°F. The 72°F d-c magnetic properties were not changed by exposure to 1100°F in argon for short times or for times up to 1000 hours at 1000°F in argon (Figure IV.A.II-9). The a-c properties were unchanged after 1000 hours stability test (Figures IV.A.II-76 and IV.A.II-77).

Cubex core-loss data are summarized in Table IV.A.II-1. These data are shown for 70°F and 1100°F at all the test frequencies. Test samples were both stress-relief and field annealed. Core loss decreases with increasing temperature and increases with frequency. Core loss is also decreased by decreasing the alloy stock thickness. The decrease, which is attributed to increasing temperature, amounts to 60 percent of the initial room temperature 400 cps value at 15 kilogauss. The amount of decrease in low induction core loss is less at the higher frequencies. The core loss values obtained on ring laminations were somewhat higher than those obtained for the tape wound toroids because of grain orientation effects discussed earlier. The 72°F losses measured on field annealed 0.002 inch thick tape-wound toroids were slightly lower than losses measured on stress-relief annealed toroids. The effect of field annealing gradually disappeared as the test temperature nears 1100°F.

The effect of increasing temperature on exciting volt-amperes was opposite the effect of temperature on core loss at all test frequencies.

Constant-current, flux-reset (CCFR) properties (400 cps sine wave) were measured at room temperature, 500°F and 1100°F for tape thicknesses of 0.002 and 0.006 inches thick, for two different annealing treatments (stress-relief anneal and magnetic-field anneal), and for two toroid sizes. The results indicate that: (a) magnetic field annealing slightly improves the properties of 0.002 inch thick tape but the amount of improvement decreases with temperature; (b) the 0.002 inch thick tape has better CCFR properties than does the 0.006 inch thick tape. The CCFR properties of Cubex tapes decrease with temperature in a pattern which is similar to that observed for other Cubex magnetic properties. The room temperature CCFR properties, after exposure to 1100°F, show practically no adverse effect of the heating cycle on CCFR properties of both tape gages except for a slight decrease in the loop squareness for a few samples. Table IV.A.II-2 is a summary of CCFR properties.

5) Poisson's Ratio

Poisson's ratio data for 0.011 inch thick Cubex alloy are presented in Table IV.A.III-1. Considerable scatter in the data had been expected because of normal, large-grain size of the alloy.

The summary of data presented in Table IV.A.III-1 shows that the measured values of Poisson's ratio are influenced by the location of the strain gages. Strains measured in a single grain differ from strains measured across the grain boundaries between adjacent grains.

Published information on the measurement of Poisson's ratio for some materials notes an effect of applied stress on the measured value. No such effect was noted in the Cubex alloy data.

6) Tensile and Compressive Properties

A tabulation of longitudinal and transverse tensile and compressive properties for Cubex alloy are presented in Tables IV.A.III-2 and IV.A.III-3 and plotted in Figures IV.A.III-1 to IV.A.III-5. These data are typical of soft high-purity materials except for the unexplainably low modulus of elasticity at all test temperatures. Both the tensile and compressive strength properties of Cubex alloy are isotropic and the tensile ductility anisotropic. However, at no temperature does the elongation of Cubex alloy fall below 10 percent.

b. SUPERMENDUR AND HIPERCO 50 ALLOYS

Summaries of the properties for these materials are located in Section IV.B.

1) Specific Heat

Specific heat data for Supermendur rolling stock are plotted in Figure IV.B.I-1. Supermendur exhibits a constant specific heat up to about 700°F and then shows a rapid increase. The inflection point on this curve is indicative of changes occurring within the alloy. In the case of Supermendur, 750°F corresponds to the order-disorder temperature of the alloy.

The specific heat of Hiperco 50 alloy was not measured for this program since it was expected that the specific heat of both Supermendur and Hiperco 50 alloy would be equivalent. This assumption may not be valid since the vanadium content of the Hiperco 50 alloy was double that of Supermendur.

2) Electrical Resistivity

Electrical resistivity data for 0.002 inch thick Supermendur tape (field-annealed) are given in Table IV.B.I-1. Because room-temperature measurements had shown that the resistivity of the ribbon might vary as much as three percent from the end of a wound toroid to the center, complete tests were made on specimens from both locations. The change in resistivity with temperature was found to be essentially the same in both.

3) Magnetic Properties

a) Hiperco 50 Alloy

Hiperco 50 alloy was tested as ring laminations in two thicknesses, 0.004 inch and 0.008 inch (Figures IV.B.II-1 to IV.B.II-18). Although both samples were annealed at the same time, the measured d-c properties were quite different. Room-temperature properties for the 0.004 inch thick sample were: coercive force, 0.616 oersteds, residual induction, 10.9 kilogauss, and an induction of 18.8 kilogauss at a magnetizing force of 10 oersteds. For the 0.008 inch thick sample, the properties were: coercive force, 2.74 oersteds, residual induction, 6.6 kilogauss, and induction of 9.6 kilogauss at 10 oersteds. It is not known why the annealing cycle did not develop the correct magnetic properties in the 0.008 inch thick material.

Up to 1400°F, both the magnetization curves and coercive forces for 0.004 inch thick ring laminations are characteristic of the alloy. At 1100°F, the coercive force decreased to 0.31 oersteds. Also at 1100°F the induction decreased to 18 and 21.5 kilogauss at magnetization intensities of 10 and 300 oersteds respectively. However, at both 1400°F and at room temperature after exposure to 1400°F, the coercive force increased, indicating that some permanent structural change had taken place in the material during elevated temperature exposure. The induction values at 1400°F were 16 and 18.4 kilogauss for field intensities of 10 and 250 oersteds respectively.

The core-loss data, as a function of temperature, follow the same temperature dependent trend as did the coercive force data. At a frequency of 400 cps, room-temperature core losses of 11.5 and 8.6 watts/pound were observed at inductions of 18 and 15 kilogauss respectively. Core loss decreased to 6.5 and 5.3 watts/pound at 1100°F, but subsequently increased to 17 and 12 watts/pound at 1400°F. This pattern was reversed at temperatures up to 1100°F for exciting volt-amperes. These data illustrate the competing mechanisms of core loss and permeability. At 3200 cps, the core loss at 8 kilogauss was 55 and 37 watts/pound at 72°F and 1100°F respectively. The corresponding exciting volt-ampere values were 185 and 109 volt-amperes/pound.

b) Supermendur

The magnetic properties of Supermendur were measured at temperatures to 800°F and at frequencies to 3200 cps on 0.002 inch thick tape wound toroids and on 1/2 inch high stacks of 0.006 inch thick ring laminations. Two different size tape-wound toroids were tested. Properties at elevated temperature were measured in argon.

At 500°F (Figure IV.B.II-19) the coercive force of the large 0.002 inch thick tape-wound toroid decreased from its room-temperature value of 0.33 to 0.2 oersteds; the residual induction increased from 18.2 to 20.3 kilogauss which resulted in increased loop squareness. When the temperature was increased to 800°F, the coercive force increased and the remanent induction decreased. The decrease in magnetic properties was evident in the room-temperature measurements made after exposure to 800°F. An increase in coercive force to 0.4 oersteds and a 40 percent decrease in remanent induction to 7.5 kilogauss was observed after Supermendur was heated to 800°F. The core loss and exciting volt-ampere data were affected similarly, particularly over the frequency range of 800 through 3200 cps. Both core loss and exciting volt-amperes increased gradually with increasing temperature while the slope of their curves decreased as the test frequency increased, as shown on Figure IV.B.II-22 to IV.B.II-45.

The core loss data were obtained on the large (four inch) 0.002 inch thick tape-wound toroid. The small 1-1/4 inch toroid was tested at 72°F only. The d-c properties of the smaller toroid were similar to those measured on the large toroid. However, the core loss and exciting volt-amperes of the small toroid were twice those measured on the 4 inch toroid. The 1/2 inch high stack of 0.006 inch thick ring laminations did not exhibit the increase in squareness noted in the data for the tape-wound toroids tested at 500°F. The coercive force measured on the Rowland ring sample gradually increased with temperature and was combined with a simultaneous decrease in residual induction. Magnetization curves obtained at temperature show less deviation from the room-temperature curve than do those for 0.002 inch thick tape-wound toroids. The core loss and exciting volt-ampere curves obtained at different temperatures are close together.

CCFR tests (400 cps) were conducted in air at 72°F, and in argon at 500° and 1100°F. All specimens were placed in non-magnetic, stainless steel core boxes where an argon atmosphere could be maintained. Fiberfrax insulation was wrapped around the specimens and the core boxes. CCFR test results are listed in Table IV.B.II-1.

The room-temperature peak induction values (B_m) were reached in a field of 5 oersteds (H_m) and ranged from 18.15 to 20.10 kilogauss for a 1/2 inch stack of

0.006 inch ring laminations and from 21.7 to 22.8 kilogauss for 0.002 inch thick tape toroids. Induction values obtained on the small toroids were higher than those measured on the large toroids. Other CCFR properties measured on samples of both gages were similar, except for sample No. 1 of 0.002 inch thick tape, where the H_o values (a property comparable to coercive force) ranged from 0.6 to 0.65 oersteds. The loop squareness ratio of all samples was from 0.825 to 0.925.

Loop squareness improved at 500°F for most specimens and decreased slightly at 1100°F. The loop width followed the general pattern discussed earlier, i.e., the width decreases with increasing temperature, reaching H_o value of 0.42 to 0.52 oersteds at 1100°F. However, the room-temperature value of H_o for all CCFR properties was badly degraded by exposure at 1100°F. All samples showed a considerable increase in H_o, raising its value to one oersted. A decrease in B_m and squareness was noted in most samples.

Significant changes occurred in the CCFR properties as the test temperature was increased. These changes were particularly pronounced at 500°F where both increases or decreases in B_m were observed. This change is the result of atomic ordering and phase changes which take place at elevated temperatures in the iron-cobalt alloy system. However, the inconsistency in the trend of the changes observed at 500°F appears to be associated with the heat treatment of the samples. Note that a change was observed in the slope of the 500°F d-c magnetization curve obtained on the small tape wound toroid and that there was an improvement in loop squareness. Therefore, use of Supermendur above 500°F is not recommended for critical applications where predictable performance is required.

4) Tensile Properties

The Supermendur and Hiperco 50 alloy materials have been compiled together in this report for the purpose of making a direct comparison of properties. Supermendur and Hiperco

50 alloy nominally contain 49 percent each of cobalt and iron with an addition of 2 percent vanadium for improved workability. Supermendur, however, was analyzed and found to contain only one percent vanadium. The commercial specification and technical literature call for a vanadium content of 1.5 to 2.5 percent. While it was not known what the exact effect of the low vanadium content would be, no major differences were anticipated between the properties of Supermendur and Hiperco 50 alloy. It was surprising to note the unusually high ultimate tensile strength of the annealed 0.006 inch thick Supermendur sheet obtained at all test temperatures except room temperature, see data Table IV.B.III-2 and Figures IV.B.III-5 and IV.B.III-6. The pseudo-binary phase diagram of iron-cobalt versus vanadium calls for a two phase field at vanadium contents above about 1.5 percent. If the second phase existed in the samples of two percent vanadium Hiperco 50 alloy, the strain-hardening coefficient for that material could easily have been much less than that of the single phase Supermendur. Note that the tensile strength of both materials increases with temperature, and that the Hiperco 50 alloy must be heated above 1100°F before the tensile strength falls below the 72°F strength. Neither material has much ductility as shown in Figures IV.B.III-3, IV.B.III-4, and IV.B.III-6.

c. HIPERCO 27 ALLOY (VACUUM MELTED FORGED BAR AND INVESTMENT CAST BAR)

A summary of the properties of these materials is located in Section IV.C.

1) Specific Heat

Specific heat for both the vacuum melted and investment cast alloy are plotted in Figure IV.C.I-1. Differences between the two curves are probably caused by differences in grain size and impurity content.

2) Electrical Resistivity

A listing of the electrical resistivity versus temperature for vacuum melted forged Hiperco 27 alloy is presented in Table IV.C.I-1 and is plotted in Figure IV.C.I-2. These data are uniform and have negligible hysteresis.

3) Magnetic Properties

Three basic forms of Hiperco 27 alloy were tested: 1) An investment cast ring; 2) Vacuum melted forged bar and; 3) Two lamination thicknesses (4 and 8 mil). The magnetic properties of all three forms of Hiperco 27 alloy changed with increasing test temperature in a manner typical of single phase alloys.

The d-c properties of Hiperco 27 alloy samples conformed to the suppliers published product literature with the exception of relatively high 72°F coercive force values of 5.12 and 3.40 oersteds for both the forged and cast rings. A larger grain size may be responsible for the lower coercive force of the casting as compared with the forging. Both solid rings approach an induction of 24 kilogauss in a field of 300 oersteds at 72°F (Figures IV.C.II-1 and 2).

The 72°F coercive force values for the laminated ring samples were between 1.4 and 1.7 oersteds (Figures IV.C.II-3 through 11). The corresponding induction value for the sheet material approached 24 kilogauss in a field of 300 oersteds. Hiperco 27 alloy loss decreased with increasing temperature to 1400°F at all test frequencies. The core-loss values for the two lamination thicknesses were relatively close at a frequency of 400 cps but did diverge slowly as the test frequency increased. At 400 cps and 18 kilogauss, the 0.008 inch thick ring laminations had a core loss of 16.2 and 14.3 watts/pound at 1100°F and 1400°F respectively (Figure IV.C.II-33).

One problem observed with Hiperco 27 alloy laminations in 1400°F tests was the apparent deterioration of the interlaminar insulation which, in turn, caused a considerable increase in core loss at inductions above 12 kilogauss. Testing of additional samples after improvement and re-application of the interlaminar insulation was necessary. Table IV.C.II-1 gives test program details and results. An analysis of the data of Table IV.C.II-1 shows that interlaminar insulation of the original (sample No. 1) Hiperco 27 alloy sample was inadequate. The high core-loss condition was improved, particularly at high induction by recoating as observed in sample No. 2. However, after again improving the insulation application methods, there was still a slight increase in room temperature core loss at inductions above 12 kilogauss for samples No.'s 3, 4 and 5 after exposure to 1400°F. This change in core loss is probably the result of changes in grain size and orientation resulting in a decrease of the coercive force and a leveling off of the magnetization curve at high inductions. The d-c properties of the Hiperco 27 alloy samples listed in Table IV.C.II-1 show no appreciable change in the room temperature data after exposure to 1400°F. The coercive force, which is considered a sensitive indicator of structural changes, showed even lower temperature values for all samples after exposure to 1400°F. Electrical resistivity measurements conducted after test displayed no appreciable changes in the material after exposure to 1400°F or after insulation recoating. Photomicrographs showed only slight oxidation of the sample surface with minor penetration of oxygen along grain boundaries. Only data on 0.008 inch thick laminations for samples three and four are given since these data are the most characteristic when adequate interlaminar insulation is present. The magnetic properties of Hiperco 27 alloy are presented on Figures IV.C.II-1 through IV.C.II-37.

4) Poisson's Ratio

The Poisson's ratio data for vacuum melted forged Hiperco 27 alloy are presented in Table IV.C.III-1. Six average values were obtained on two separate specimens . Individual values were obtained for every 250 pounds of specimen load up to a stress of 48,450 psi. Two longitudinal and two transverse strain gages were cemented to each side of the sample. Hiperco 27 alloy is a fine-grained material and was not expected to cause difficulties in the measurement of Poisson's ratio. The data for several test runs are plotted on Figures IV.C.III-1 through IV.C.III-6.

5) Tensile Properties

The tensile properties, including modulus of elasticity for the Hiperco 27 alloy materials, are shown in data form in Tables IV.C.III-2 and IV.C.III-3 and are plotted in Figures IV.C.III-7 through IV.C.III-11.

Duplicate tension tests were made on both forms of the alloy at room temperature, 500°F, 700°F, 1000°F and 1400°F. The room temperature, 500°F and 700°F tests were run in air; one of the 1000°F tests on vacuum melted material was run in a flooded-argon atmosphere and the others in air to determine the effect of oxidation at 1000°F. No significant differences in tensile properties were observed. The 1400°F tests were run in a chamber flooded with argon.

A low indicated yield strength was noted on one room temperature test on vacuum melted Hiperco 27 alloy. The yield strength of this sample was a yield point rather than 0.20 percent off-set yield strength. No explanation of the appearance of the yield point can be offered. The short-time elevated temperature tensile data appears to show no effect of test atmosphere on the properties of Hiperco 27 alloy.

An expected drop in the elevated temperature ductility for Hiperco 27 alloy (Figures IV.C.III-8 and IV.C.III-11) occurs in the temperature range between 700°F and 1400°F. This drop is observed in nearly all materials[2] and marks the temperature range at which vacancies are generated and move to grain boundaries but are not subsequently annihilated by recrystallization. The mode of fracture changes from transgranular to intergranular and back to transgranular over this temperature range.

Only the low room temperature ductility of the cast material deserves mention since it is a condition common to as cast and annealed Hiperco 27 alloy. The elevated temperature ductility of cast Hiperco 27 alloy was at minimum at 1000°F.

The compressive strength properties of the vacuum melted material are presented in Table IV.C.III-4 and are plotted in Figures IV.C.III-12 and IV.C.III-13. Elevated temperature compressive modulus data for Hiperco 27 alloy are higher than for the tensile modulus.

(2) Reid, B. J., Greenwood, J. N., "Intergranular Cavitation in Stressed Copper Nickel Alloys", AIME Transactions, Vol. 212, No. 4, page 503, August 1958.

6) Creep

Creep data for Air, Argon and Vacuum Tested Hiperco 27 alloy Material (Vacuum Melted and Investment Cast Materials) are presented as Larson-Miller plots in Figures IV.C.III-14 and IV.C.III-16 for 0.2 and 0.4 creep strain. It is apparent from these plots that the vacuum melted material (Figure IV.C.III-14) was not affected by the test atmosphere. The investment cast material was, however, improved by testing in a vacuum (Figure IV.C.III-16). No effects of the vacuum tests were noted on the before and after test gas analysis performed on any of the materials studied in NAS 3-4162. It is concluded that the greater creep resistance of the vacuum tested Hiperco 27 alloy casting was due to the absence of surface oxygen which apparently contributed to lower strength for the air tested investment material. The creep of the vacuum-melted alloy was not affected by the testing atmosphere.

On the basis of tests completed, Hiperco 27 alloy lacks the strength required to determine 10,000 hour strength at and above 1400°F. For those who prefer it, the creep data are presented as log-log plots of stress versus time and are shown in Figures IV.C.III-15 and IV.C.III-17.

The stress was raised on some of the test specimens when little or no creep could be measured or recorded during test. These data are considered valid for the strains involved.

Tables IV.C.III-5 through IV.C.III-10 and Figures IV.C.III-18 through IV.C.III-29 show tabulations and plots of creep data at various temperature and stress levels. These plots show the stage of creep for each specimen at the time(s) the data points were obtained.

d. ONE PERCENT SILICON-IRON INVESTMENT CAST MATERIAL

A summary of the properties for this material is located in Section IV.D.

1) Specific Heat

The specific heat of AMS 5210 is presented in Figure IV.D.I-1. This property remains fairly constant to 572 -662°F and then increases exponentially to a value of 0.155 Btu/ft-°F at 932°F.

2) Magnetic Properties

Only d-c properties were measured on this material. The change in properties with temperature followed the pattern observed for other silicon-irons. Residual induction, coercive force and induction at 250 oersteds decreased with increasing temperature while permeability at two kilogauss first decreased and then increased with increasing temperature. There was little change in the magnetization curve after temperature cycling to 1100°F, though coercive force increased by 15 percent. At 1100°F the coercive force decreased from 1.05 oersteds at room temperature to 0.58 oersteds and the induction for 250 oersteds from 19.2 to 16.7 kilogauss. D-C Test Data are presented in Figures IV.D.II-1 and IV.D.II-2.

3) Tensile Properties

The tensile properties of AMS 5210 are presented in Table IV.D.III-1 and Figures IV.D.III-1 and IV.D.III-2. The cast bars were annealed in accordance with AMS 5210 before testing. No clarification of the tensile data is required for this material. The expected ductility minimum of AMS 5210 occurs at 500°F. This material, like several of the other soft magnetic materials, is not intended for use under high stresses.

e. MARAGING STEELS (15 PERCENT NICKEL AND 18 PERCENT NICKEL GRADES)

Summaries of the properties of these materials are located in Section IV. E. Until recently, the Maraging steels have been available in three basic grades containing 25, 20, and 18 percent nickel. The 18 percent nickel grade is available in three subgrades referred to by nominal yield strengths as 200, 250 and 280* Ksi as determined by the titanium, cobalt, and molybdenum content. Now, a fourth basic grade has been introduced, the 15 percent nickel grade. This steel possesses better stability and higher strength at elevated temperature. The improved stability is attributed to the lower nickel and higher molybdenum content.

At the time NAS 3-4162 was initiated, no elevated temperature a-c or d-c magnetic properties were available for 18 percent nickel grade, but the elevated-temperature mechanical properties were well documented. Such was not the case for the 15 percent nickel grade. Consequently, tests were planned which would determine the elevated temperature magnetic properties of the 18 percent nickel, 250 grade, and the magnetic properties and 1000°F magnetic stability of the 15 percent nickel grade. The discussion of the properties found in the literature as well as those obtained on NAS 3-4162 follows.

1) Magnetic Properties

In this program magnetic tests were conducted at temperatures up to 800°F on 0.014 inch thick laminations of 18 percent nickel and 0.016 inch thick laminations of 15 percent nickel Maraging steels (Figures IV. E. II-3 to IV. E. II-5 and IV. E. II-7 to IV. E. II-9, respectively). In addition, a 1000 hour at 1000°F stability test was performed on a solid ring of 15 percent nickel Maraging steel. These data are plotted in Figure IV. E. II-2. On another program (LM529) magnetic tests were performed on 15 and 18 percent Maraging steel forgings at temperatures up to 1100°F (Figures IV. E. II-1 and IV. E. II-6).

*This grade is commercially known as the 300 grade.

The data obtained on forgings, particularly the magnetization curves for 1100°F, show that a decrease in nickel content from 18 to 15 percent nickel raises the temperature capability of Maraging steels. The results from the 1000 hour stability test (Figure IV.E.II-2) indicate that the temperature limit of the 15 percent nickel Maraging steel lies below 1000°F, probably between 750 and 850°F. At 700°F, both the 15 percent nickel and 18 percent nickel Maraging steel forgings reach an induction of 16 kilogauss in a field of 300 oersteds and display a coercive force of 16 to 18.6 oersteds.

Test data on sheet material (Figures IV.E.II-5 and IV.E.II-9) show little difference in core loss versus grade. Respective core-loss values for 0.016 inch and 0.014 inch thick laminations respectively of 15 and 18 percent nickel Maraging steels are 218 and 195 watts/pound at room temperature; 200 and 208 at 500°F; 195 and 190 at 800°F; and 213 and 243 at room temperature, after 800°F. Contrary to the 18 percent nickel material, no significant changes in room-temperature values of the coercive force and high-field induction occur in 15 percent nickel Maraging steel laminations after exposure to 800°F. These values for the latter material are 22.6 and 19.6 oersteds and 19.3 and 16.6 kilogauss for room temperature and 800°F respectively.

2) Tensile Properties

The tensile properties of both grades of Maraging steel are shown in Tables IV.E.III-1 and IV.E.III-2 and are plotted in Figure IV.E.III-1. The elastic modulus of the 18 percent 250 grade is shown in Figure IV.E.III-2. Selection of the 18 percent 250 grade rather than the 300 grade was based on the superior ductility, impact strength and overall mechanical similarity of the 18 percent 250 to the 15 percent 280 grade even though the 15 percent material is basically a higher strength alloy. Note the extremely high 800°F and 1000°F strength of the 15 percent grade. These elevated strength data are higher than obtained on any other Maraging steel.

3) Creep

Larson-Miller plots for creep of the 15 and 18 percent nickel grades are shown in Figures IV.E.III-3 and IV.E.III-5 respectively. The creep data for the 15 percent nickel are shown in Table IV.E.III-3 and are plotted as stress-time curves in Figure IV.E.III-4 and Figures IV.E.III-6 through IV.E.III-14. Creep data for both grades were obtained on material solution heat-treated at 1500°F and aged at 900°F. It should be noted that, according to the International Nickel Company, the creep properties of the 15 percent nickel grade may be improved when the material is solution annealed at 1800°F and then aged at 900°F. The lower temperature solution treatment was selected for this program because it was the commonly accepted heat treatment suggested by the supplier.

The Maraging steel creep data have allowed the following to be concluded:

a) The 15 percent nickel grade is not adversely affected by air contamination during testing to 900°F. Vacuum test data fell on the curves generated with air test data.

b) The start of reversion from martensite to austenite in the 15 percent grade appears to start between 700°F and 800°F and is apparently well underway at 900°F.

c) The creep rate of the 18 percent grade is well above that of the 15 percent grade especially at 800°F and 900°F.

The vacuum creep data are also presented on the Larson-Miller plot (Figure IV.E.III-3) for the 15 percent grade. Plots of creep-time data are included in Figures IV.E.III-6 through IV.E.III-14 and they will be useful to those who wish to know the stage of creep for each specimen at the time the data points were obtained.

3) Fatigue

A room temperature S-N curve taken from the literature on 18 percent nickel material is shown in Figure IV.E.III-15. Melting technique is an important variable influencing the fatigue properties of the maraging steels. It is therefore important to consider this factor when selecting any grade of Maraging steel for any given application.

f. AISI GRADE H-11 STEEL AMS 6487 (BAR AND FORGINGS) AND AMS 6437 (SHEET)

A summary of H-11 properties is located in Section IV.F. When H-11 was first studied as a candidate material for high-stress applications at moderately elevated (800°F) temperatures, it was selected because of its strength and strength retention characteristics at elevated temperature. The magnetic properties of this alloy at high hardness (Rockwell C52) levels were at best, marginal. Subsequent work by Frost, et al (LM 529) on the heat treatment and mechanical properties of H-11 achieved acceptable magnetic properties and managed to maintain the strength at a high level. Actually, the elevated-temperature creep strength of the H-11 at the lower hardness (Rockwell C45) was better than the creep strength of the material heat treated to the most commercially used hardness (Rockwell C52). This improvement in creep characteristics is probably the result of a finely dispersed, carbide precipitate formed during high-temperature tempering which has the effect of increasing the creep resistance of the martensitic matrix.

1) Magnetic Properties

Figures IV.F.II-1 to IV.F.II-12 present d-c and a-c properties of this material. The changes in coercive force and permeability with increasing temperature follow the same general pattern in both forged and sheet materials. At 250 oersteds, an induction value of over 18 kilogauss is reached at room temperature. The coercive force decreases to 15 oersteds at 1100°F. As discussed previously in this report, on stability testing at 1000°F for 1000 hours, there was a progressive increase in permeability (Figure IV.F.II-2). In general, the d-c magnetic properties improved with time at temperature.

As the gage thickness decreased there was no change in coercive force. There was little difference in losses between the 0.014 inch thick and 0.025 inch thick sheet materials at either room or elevated temperature. Surprisingly, the 0.025 inch thick sheet displayed somewhat lower losses than those measured for the 0.014 inch thick sheet (reference Figures IV.F.II-7, IV.F.II-11 and IV.F.II-12 for comparative data).

2) Tensile Properties

The tensile properties of AMS 6487 are listed in Table IV.F.III-1 and are plotted in Figure IV.F.III-1. These data were taken from LM 529 and represent typical values obtained for material from different heats at a nominal hardness of Rockwell C45.

3) Creep

As pointed out in the introduction to the H-11 section, a large amount of tensile and creep data were obtained from LM 529. These creep data are presented and discussed here since a specific creep program was not planned for NAS 3-4162 in anticipation of the availability of data from LM 529. A sheet-material creep program was included on NAS 3-4162 since no data on H-11 sheet were available on material thinner than 0.050. The technology required to produce 0.014 and 0.025 inch AMS 6437 was also needed and subsequently developed as indicated in Section III. Creep data on sheet material were obtained on samples taken transverse to the rolling direction since the transverse creep properties were expected to be most affected by processing 0.050 inch material into thinner gage sheet. In addition, creep test checks were made using selected longitudinal samples. The sheet specimens were hardened to Rockwell C45. Creep data for bar and sheet material are shown in Tables IV.F.III-2 through IV.F.III-5. The sheet and vacuum creep on forged material data were obtained on NAS 3-4162 and the bar data in air were obtained from LM 529. All air and vacuum-creep data so obtained on different lots of AMS 6487, heat treated to Rockwell C45, are shown in the Larson-Miller plot, Figure IV.F.III-2.

Creep data obtained on H-11 sheet are shown in similar Larson-Miller plots in Figures IV. F.III-4 and IV. F.III-5. The strain-time curves for tests in air are presented in Figures IV. F.III-7 through IV. F.III-11. These are useful in determining the transition from first to second stage creep. A comparison of air and vacuum creep data for bar material, as compared to sheet material in air, is plotted on Figure IV. F.III-3.

From the above data, the following conclusions are made:

a) The creep properties of AMS 6437 (H-11 sheet) are isotropic at a hardness level of Rockwell C44.5 - 45.5 and are equivalent to those obtained on bar.

b) Bar material (AMS 6487) is not adversely affected by testing in air or vacuum atmosphere up to 1000°F and a vacuum of 10^{-6} torr.

c) At 900°F and 10,000 hours, a characteristic stress of 45,000 psi for 0.4 percent extension is realized from Larson-Miller extrapolations.

4) Fatigue

A tabulation of the 800° and 1000°F fatigue data obtained on NAS 3-4162 are presented in Tables IV. F.III-6 through IV. F.III-8. These data are plotted on Figures IV. F.III-14 through IV. F.III-17. Fatigue data were obtained at stress ratios (A) of 0.25 and 2.00. The stress ratio (A) is defined as the ratio of alternating stress to mean stress. Modified Goodman diagrams of these fatigue data are shown in Figures IV. F.III-12 and IV. F.III-13. No points are located on the X axis of these plots since no known material property measurement (yield, tensile, creep, or stress rupture strength) would be meaningful. The shape of these modified Goodman plots do not always follow the usual trends, and no explanation for their shape can be offered. H-11 is notch sensitive under all conditions of test, although the degree of sensitivity is noticeably lessened by the application of a superimposed static stress. A word of caution on H-11;

this alloy is extremely sensitive to decarburization during heat treatment. Several lots of fatigue specimens were lost due to decarburization during heat treatment. As little as 0.001 inch of decarburization can adversely affect the quality test data. H-11 should be heat treated only in atmospheres which will not cause either carburization or decarburization.

g. NIVCO ALLOY

A summary of Nivco alloy properties is given in Section IV.G.

1) Specific Heat

The specific heat data for forged Nivco alloy are presented graphically in Figure IV.G.I-1. A constant value for specific heat of 0.102 calories/gram-°C (or Btu/lb-°F) was measured at temperatures to 300°C (572°F). Above 300°C, the curve behaves exponentially and reaches a specific heat of 0.156 calories/gram-°C at 700°C (0.156 Btu/lb-°F at 1292°F).

2) Electrical Resistivity

The electrical-resistivity test results for Nivco alloy sheet are listed in Table IV.G.I-1 and IV.G.I-2. Resistivity measurements were made during both heating and cooling to and from 1600°F respectively. The first test showed a degree of hysteresis as shown in Figure IV.G.I-2. The second test plot, Figure IV.G.I-3, shows the electrical-resistivity results for forged Nivco alloy in the equilibrium condition, in which the cooling curve followed the heating curve exactly.

3) Magnetic Properties

Tests on forged stock show that coercive force and residual induction as well as permeability at high inductions decrease with increasing temperature; however, permeability at low inductions increases with increasing temperature. After the test at 1400°F, the room temperature coercive force was 8.9 oersteds, a reduction from the 11.5 oersteds measured initially. After stability testing (Figure IV.G.II-2) for 1000 hours at 1000°F, the magnetic properties of the Nivco alloy forging were virtually unchanged indicating that the material is stable at this temperature.

Changes in the d-c properties of 0.014 inch and 0.025 inch thick laminations follow the same trend with increasing temperature as those measured for the forging. However, coercive force of sheet materials is considerably higher (40.3 and 35.5 oersteds at room temperature for 0.014 inch and 0.025 inch thick laminations respectively) at both room and elevated temperatures. There is little difference in core-loss values for both sheet thicknesses in spite of different gages. At 400 cps and 8 kilogauss, the core-loss values for 0.014 inch and 0.025 inch thick laminations, respectively, are: 158 and 135 watts/pound at room temperature and 46 and 44 watts/pound at 1400°F. Upon return to room temperature, the losses are 84 and 88 watts/pound after exposure to 1400°F (Figures IV.G.II-6 and IV.G.II-8). A considerable decrease in coercive force appears to be primarily responsible for the decrease in losses at room temperature. This phenomenon was previously mentioned.

4) Tensile Properties

The short time elevated temperature tensile properties for forged Nivco alloy are tabulated in Table IV.G.III-1 and are graphically shown by Figures IV.G.III-1 and IV.G.III-2. The room temperature tensile properties for forged Nivco alloy show the 0.2 percent offset yield strength to be approximately 68 percent of the ultimate strength. The 0.2 percent yield strength and ultimate strength do not dip appreciably up to 1100°F. Nivco alloy over-ages rapidly at 1400°F and 1600°F.

The short time elevated temperature properties of 0.025 inch thick transverse Nivco sheet are shown in Table IV.G.III-2 and Figures IV.G.III-3 and IV.G.III-4. Note that the room temperature 0.2 percent offset yield strength is 95 percent of the ultimate strength, as compared to 68 percent of tensile strength for bar. This ratio is reduced continuously with temperature to a value of 78 percent at 1100°F.

5) Creep Tests

Creep test results for forged Nivco alloy are tabulated in Tables IV.G.III-3 through IV.G.III-6 and plotted in Figures IV.G.III-5 through IV.G.III-22. The 900°F and 1100°F tests required stresses above the yield strength of the alloy to produce 0.2 and 0.4 percent creep strain in 1000 hours or less. Creep testing above a material's yield strength introduces scatter not normally encountered in creep data. However, the data obtained in this manner could be easily fit to smooth curves in both Larson-Miller and stress-time data plots. Initially, Nivco alloy did not appear to be adversely affected by the test atmosphere whether the atmosphere was air or argon (see Figure IV.G.III-6). However, creep resistance was affected when the alloy was tested in air above 1400°F or in vacuum above 900°F as shown in the Larson-Miller plots of Figure IV.G.III-5. The Larson-Miller plots were prepared after a parameter constant of 30 had been calculated for Nivco alloy. The Larson-Miller plot shows that it requires an apparent stress of 80,000 psi to produce 0.4 percent creep strain in 10,000 hours at 1000°F.

Table IV.G.III-7 and Figures IV.G.III-23 through IV.G.III-25 are for 0.025 inch thick transverse Nivco sheet. The 0.2 and 0.4 percent creep strains were produced at stresses which are lower than required to produce equivalent deformations in forged Nivco bar. These data were obtained on samples which had been reheat treated for improved creep strength. A large amount of initial creep data were obtained on samples which had been simply cold finished and then aged after solution heat treatment. These samples possessed extremely low creep strength. Data on the low strength materials are included for reference only and should not be used except for comparison purposes. Creep strength for the sheet Nivco samples was improved after the remaining test specimens were re-solution heat treated at 1900°F, 175°F above the nominal solution treatment temperature of the material (1725°F), and subsequently aged for 25 hours at 1225°F to produce maximum hardness. It was assumed that the initial low creep strength of the Nivco sheet was connected with the cold finishing operation used on Nivco sheet after solution annealing.

Shop practice for making magnetic alloy sheet usually requires the materials to be cold finished. The Nivco used for this program was bought in the solution heat treated and cold finished condition. A controlled research program is required to completely restore the creep properties of Nivco sheet to the level achieved with bar stock. Creep test results on the reheat treated material are shown in the summary in Section IV.G. The inclusion of the creep-time curves of Figures IV.G.III-9 through IV.G.III-25 should be of benefit to those who wish to know the stage of creep for each specimen at the time the data points were obtained.

6) Fatigue Tests

Fatigue data for forged Nivco alloy bar are listed in Tables IV.G.III-8 through IV.G.III-10. The fatigue tests were conducted on smooth and notched bar specimens at temperatures of 900°F, 1000°F, and 1100°F using stress ratios (A) of infinity and 0.25. Figures IV.G.III-27 through IV.G.III-32 are S-N curves representing smooth and notched-bar fatigue lives at different stresses. The notched-bar properties are 30,000 to 40,000 psi below the smooth-bar stresses at a stress ratio of infinity. These data show the expected notch sensitivity of forged Nivco alloy. At a stress ratio of 0.25 the notched and unnotched fatigue properties for forged Nivco alloy are improved. The notched sensitivity is almost eliminated, and an increase of 50,000 to 60,000 psi maximum stress is obtained. The only deviation in the improved fatigue properties occurs after 10^6 cycles at 1100°F. At this test condition, the forged Nivco alloy gives indications of becoming notch sensitive.

Table IV.G.III-10 contains the tabulated data used to construct the modified Goodman type diagram, Figure IV.G.III-26. This figure shows the deviation between smooth and notched-bar fatigue properties at 1100°F for 10^7 cycles for a stress ratio of 0.25.

SECTION III

MATERIALS, PREPARATION AND TEST PROCEDURES

A. MATERIAL SPECIFICATIONS AND PREPARATION

A list of the magnetic materials, their sources, and purchasing specifications is provided below.

Material and Form	Source	Product Specification
Westinghouse Cubex alloy; 6 and 12 mil sheet and 2 and 6 mil tape wound cores. (3Si-Fe)	Westinghouse Research and Development Center, Pittsburgh 35, Pa., and Westinghouse Specialty Transformer Division, Beaver, Pa.	No commercial specification available.
Supermendur; 2 mil tape, 6 mil sheet and 2V-Permendur bar. (49Fe-49Co-2V)	Arnold Engineering Corp., Marengo, Ill.	Arnold Engineering Product Specification for Supermendur with Westinghouse core-loss requirement.
Hiperco 50 Alloy; 4 and 8 mil sheet. (49Fe-49Co-2V)	Westinghouse Materials Manufacturing Dept., Blairsville, Pa.	Westinghouse Product Specification.
Hiperco 27 Alloy; 4 and 8 mil sheet bar and casting (27Co-Fe)	As above.	Westinghouse Product Specification.
Iron One-percent silicon investment casting.	Hitchener Manufacturing Co., Milford, N.H.	AMS 5210

Material and Form	Source	Product Specification
Nivco alloy sheet and bar (23Ni-1.1Zr-1.8Ti-Co)	Westinghouse Research and Development Center, Pittsburgh 35, Pa., and Westinghouse Materials Manufacturing Dept., Blairsville, Pa.	No commercial specification available.
Maraging steel bar and sheet. (15-18Ni-Co-Mo-Fe)	Allegheny Ludlum Steel Corp.	Allegheny Ludlum Product Specification Almar 15 and Almar 18
AISI Grade H-11 sheet; 0.050 inch thick premium quality material. (5Cr-1Mo-1V-Fe)	Universal Cyclops Steel Corp., Rerolled to 0.014 and 0.025 inch and heat treated by Westinghouse Research and Development Center, Pittsburgh 35, Pa.	AMS 6437
AISI Grade H-11; bar and forgings premium quality material. (5Cr-1Mo-1V-Fe)	Universal Cyclops Steel Corp.	AMS 6487

Three of these materials, Nivco alloy, H-11, and 15 percent Maraging steel in thin-gage sheet, were not commercially available at the time this program was started. Consequently, sheet rolling technology was developed to produce limited quantities of both alloys for this program. A detailed account of the rolling procedures is given in subsequent paragraphs.

1. Nivco Alloy Sheet Preparation

Starting material for the Nivco strip consisted of a 5 inch x 5 inch x 10 inch long forged bar which was subsequently hot forged at 1850-2100°F to a 5/8 inch by 5 inch slab. The slabs were then hot rolled to 0.125 inch strip. A heavy, tenacious oxide which formed on the alloy during the hot-rolling operation was removed by grit blasting and pickling in a mixture of 35 percent HCl, 50 percent HNO_3, and 15 percent water.

After pickling, the 0.125 inch strip was cold rolled in an 8 inch x 8 inch, two-high mill to 0.062 inch thick and annealed at 1825°F in dry hydrogen.

The cold rolling proceeded in the two-high mill to 0.025 inch thick where half the strip was again annealed and finished in a four-high mill to 0.015 inch. The 0.015 inch strip was skin-passed, two-high to achieve a flat product.

2. H-11 (AMS 6437) Sheet Preparation

The as received, 0.050 inch thick, annealed H-11 certified to meet AMS 6437 was cold rolled in a two-high mill directly to 0.025 inch. Half the material was finished to 0.015 inch on the four-high mill and flattened by a final two-high pass. No intermediate anneals were required on the H-11 material.

3. 15 and 18 Percent Maraging Steel Sheet Preparation

The starting material was a 10 pound, one-inch-thick, round bar of 15% nickel Maraging steel which was hot rolled after heating in hydrogen at 1850°F. No difficulty was experienced in preparing the 0.100 inch strip. The strip material was cooled to 1500°F, held for 15 minutes, and water quenched to 72°F. After hot rolling, the as quenched strip was cold rolled to 0.022 where it was re-solution annealed at 1500°F, quenched, pickled and cold rolled to 0.016 inches. The rolling was done in a two-high mill. After punching and deburring, the laminations were aged for 3 hours at 900°F in hydrogen and coated with aluminum-orthophosphate.

The 18-percent nickel Maraging steel sheet was supplied in the punched and fully heat treated condition.

B. TEST SPECIMEN PREPARATION

A series of drawings showing typical examples of mechanical and thermophysical test specimens are presented in Figures III-1 to III-30. Unless otherwise specified, all dimensions shown on the drawings are in inches.

1. Solid D-C Test Ring

All the heat treatable alloys were machined to 0.020 inch oversize, heat treated, finish machined, and ground to size. The heat treatments used on the different alloys are listed later in this section.

2. Rowland-Ring Test Samples

The sheet materials were blanked and pierced with precision dies to hold deburring to a minimum. After blanking, all laminations (except those of

Supermendur, which were returned to Arnold Engineering Corp. for further processing) were degreased and insulated with one coat of aluminum-orthophosphate to prevent sticking during magnetic-field annealing or stress-relief annealing. Unless otherwise specified, all samples were stress-relief annealed (SRA). A second coat of aluminum-orthophosphate was applied after annealing as an interlaminar insulation. When deburring was necessary, the rings were passed through an automatic belt sander.

All the finished cores were wound with insulated wire and tested. Wire selection depended on the test temperature and the driving voltages. Nickel coated copper wire insulated with Westinghouse 2554B insulation was used for tests to 1100°F and 100 volts. Above these limits Anadur wire from the Anaconda Wire and Cable Company was used.

3. Mechanical and Thermophysical Test Specimens

a. Smooth-Bar Specimens

1) Rough machine to 0.020 inch oversize
2) Heat treat when required
3) Rough grind to 0.008 inch oversize
4) Finish grind in 0.0002 inch steps to 0.001 inch oversize with coolant and polish with 180, 400, and 600 grit abrasive as necessary to achieve the specified finish and size.
5) When specified, lap to the indicated finish.

b. Notched-Bar Specimens

1) After heat-treatment, rough machine the notch to 0.010 inch oversize.
2) Finish machine the notch to size with a carbide-tipped cutting tool which has been exactly ground to the notch contour.
3) Finish and polish, using an appropriate string impregnated with abrasive for finishing the notch, being careful not to alter the notch contour by lingering in the notch. All fatigue specimens shall be longitudinally polished.

c. Specimen Heat Treatment

1) H-11 Bar

Preheat the test bars to 1200°-1300°F, transfer to a hydrogen-gas atmosphere furnace and heat to 1850° ± 25°F. Hold at temperature for one hour and air quench to room remperature. Temper the parts three times in air at 1120°-1140°F for three, 1-1/2 hour, periods to achieve a final hardness of Rockwell C44 to C45.5.

2) One-Percent Silicon-Iron Annealed per AMS5210

3) Westinghouse Nivco Alloy Bar and Sheet Magnetic Test Specimens

Heat to 1725°±15°F in an air atmosphere, hold at temperature 1 hour and water quench. Age-harden at 1225°±5°F for 25 hours in air to a minimum hardness of Rockwell C36.

4) Hiperco 27 Alloy (Sheet, Bar, Forgings and Castings)

This material was ordered in the fully annealed condition. (See page 298, paragraph E for typical annealing cycle.)

5) H-11 Sheet (Rowland Rings and Mechanical Test Specimens)

H-11, 0.014 inch and 0.025 inch sheet was obtained in the annealed and cold rolled condition. The as-rolled sheet was punched and blanked, deburred, degreased and coated on both sides with aluminum-orthophosphate to prevent sticking during heat treatment. The heat treatment was conducted in a hydrogen-atmosphere furnace in which the atmosphere dewpoint is maintained at a maximum dewpoint of -40°F. The punched laminations were held between two plates and preheated to 1200°-1300°F and then transferred to a hydrogen atmosphere furnace held at 1850°±25°F. Time at temperature was one hour and was followed by an air-blast quench. As quenched, the sheet has a hardness of Rockwell C60 (converted from Rockwell 15N).

Hydrogen gas also acted as the protective gas during tempering at 1050°-1125°F. Three 1-1/2 hour temper cycles were required to bring the hardness to nominal Rockwell C45 and to effect complete transformation of austenite to martensite. After heat treatment, the rings were recoated on both sides with aluminum-orthophosphate and wound for magnetic test. Mechanical test sheet specimens were heat treated as above; however, the aluminum-orthophosphate treatments were omitted, and the samples dusted with high-purity alumina to prevent sticking.

6) Nivco Alloy Sheet (Mechanical Test Specimens Only)

The Nivco Sheet, 0.014 inch and 0.025 inch thick, was initially solution heat treated in air, water quenched, pickled, and cold finished (76 percent reduction of area). Nivco sheet in the solution-annealed condition requires a 25-hour air age at 1225°±5°F to achieve a minimum hardness of Rockwell C38. Actual hardness achieved on trial samples approached Rockwell C43 (converted from Rockwell 15N). However, these samples exhibited extremely poor creep resistance and were subsequently re-solution heat treated at 1900°F in hydrogen, water quenched and aged as above in dry hydrogen.

C. TEST PROCEDURES

A summary tabulation of the magnetic materials tested, type of test, drawing reference number, and test method or specification is found in Table III-1. Different size specimens were frequently run for the same general type test because of the materials high strength or because of size limitations such as imposed by sheet materials. A discussion of the many different tests and procedures follows.

1. Thermophysical Properties

a. Specific Heat

Precise measurements of specific heat were made in a drop-water calorimeter according to a method described by J. Valentich of the Westinghouse Research Laboratories. (1) The only specimen requirement for measurement of specific heat is that a compact mass of approximately 30 grams be available for test.

Oxidation was prevented by sealing the specific-heat specimens in evacuated, quartz capsules. During normal testing, the specimen temperature was measured with a platinum-rhodium thermocouple mounted in a quartz well inserted halfway down the center of the specimen. Since quartz is not as good a heat conductor as the metal, it was necessary to determine the difference in temperature between the quartz well and the specimens. To do this, a 1/16 inch diameter hole was drilled in a standard copper specimen to within 3/16 inch of the quartz well, and thermocouples were positioned in both the specimen and the quartz well. Temperatures were recorded at both locations as the specimen was taken through a complete test. The quartz cover on the bottom of the specimen was left out in the test to facilitate the placement of the thermocouple in the specimen. The results show that the temperatures in the quartz well and in the specimen were within one percent except at 1500°F where they differ by about 1.5 percent. This means that the thermocouple in the quartz well measures the specimen temperature with good accuracy over the entire testing temperature range. No difficulties were encountered during any of the measurements of specific heat.

b. Electrical Resistivity

The standard Kelvin Bridge method of ASTM B-70 was used for all measurements of electrical resistivity. One refinement was added to ensure accurate data, a vacuum of 10^{-4} torr constituted the test atmosphere. Strip and wire materials were wound on a 5/8 inch diameter quartz mandrel and the balance of the materials simply supported in the furnace hot zone.

(1) Valentich, J. - "Equipment and Methods for the Continuous Measurement of Heat Content of Metals to 1100°C". Westinghouse Materials Engineering Report No. 5973-3031, Westinghouse Electric Corporation, East Pittsburgh, Pa., 19 November 1959.

TABLE III-1. Test Procedures (Sheet 1 of 2)

Material	Type of Test	Figure[1] No.	Drawing Number	Test Method
A. Thermophysical and Mechanical Tests:				
H-11 Forging	Axial Fatigue	III-24	627A543	ASTM STP 91
H-11 Forging	Axial Fatigue	III-25	627A544	ASTM STP 91
H-11 Forging	Creep	III-1	29810	ASTM 139
H-11 Forging	Creep	III-17	927A084	ASTM E139
H-11 Sheet	Creep	III-16	627A083	ASTM E139
H-11 Sheet	Creep	III-28	743A602	ASTM E139
Nivco Alloy Forging	Axial Fatigue	III-26	627A543	ASTM STP 91
Nivco Alloy Forging	Axial Fatigue	III-25	627A544	ASTM STP 91
Nivco Alloy Forging	Specific Heat	III-11	627A075	Drop-Water Calorimeter
Nivco Alloy Forging	Electrical Resistivity	III-10	627A074	ASTM B70 Kelvin Bridge
Nivco Alloy Forging	Tensile	III-12	627A076	ASTM E21
Nivco Alloy Forging	Creep	III-13	627A077	ASTM E139
Nivco Alloy Forging	Creep	III-20	627A251	ASTM E139
Nivco Alloy Forging	Creep	III-19	627A084	ASTM E139
Nivco Alloy Sheet	Creep	III-16	627A083	ASTM E139
Nivco Alloy Sheet	Creep	III-28	743A602	ASTM E139
Nivco Alloy Sheet	Tensile	III-16	627A083	ASTM E21
15% Maraging Steel	Creep	III-2	319686	ASTM E139
15% Maraging Steel	Creep	III-3	319687	ASTM E139
15% Maraging Steel	Creep	III-17	627A084	ASTM E139
Hiperco 27 Alloy Cast	Creep	III-9	319938	ASTM E139
Hiperco 27 Alloy Cast	Specific Heat	III-11	627A075	Drop-Water Calorimeter
Hiperco 27 Alloy Forging	Creep	III-22	627A253	ASTM E139
Hiperco 27 Alloy Forging	Creep	III-17	627A084	ASTM E139
Hiperco 27 Alloy Forging	Creep	III-21	627A252	ASTM E139
Hiperco 27 Alloy Forging	Tensile	III-12	627A076	ASTM E21
Hiperco 27 Alloy Forging	Compression	III-26	627A555	ASTM E9

1. Unless otherwise specified, all dimensions are in inches.

TABLE III-1. Test Procedures (Sheet 2 of 2)

Material	Type of Test	Figure(1) No.	Drawing Number	Test Method
Hiperco 27 Alloy Forging	Specific Heat	III-11	627A075	Drop-Water Calorimeter
Hiperco 27 Alloy Forging	Electric Resistivity	III-10	627A074	ASTM B70 Kelvin Bridge
Hiperco 27 Alloy Sheet	Poisson's Ratio	III-14	627A078	ASTM E132
Hiperco 50 Alloy Sheet	Tensile	III-15	627A079	ASTM E21
Cubex Alloy Sheet	Specific Heat	III-19	627A089	Drop-Water Calorimeter
Cubex Alloy Sheet	Thermal Conductivity	III-18	627A088	Comparison Bar
Cubex Alloy Sheet	Tensile	III-15	627A079	ASTM E21
Cubex Alloy Sheet	Compression	III-27	627A556	ASTM E21
Cubex Alloy Sheet	Poisson's Ratio	III-14	627A078	ASTM E132
1% Silicon-Iron	Tensile	III-9	319938	ASTM E21
1% Silicon-Iron	Specific Heat	III-11	627A075	Drop-Water Calorimeter
Supermendur	Specific Heat	III-11	627A075	Drop-Water Calorimeter
Supermendur	Electrical Resistivity	III-23	627A254	ASTM B70 Kelvin Bridge
Supermendur	Tensile	III-15	627A079	ASTM E21
B. Magnetic Tests				
All materials	Normal Induction and Hysteresis of Magnetic Materials	III-7	319734	ASTM A341
		III-4	319688	ASTM A341
		III-6	319720	ASTM A341
		III-5	319689	ASTM A341
		III-8	319805	ASTM A341
All materials	A-C Magnetic Properties	III-4	319688	ASTM A343
		III-6	319720	ASTM A343
		III-5	319689	ASTM A343
		III-8	319688	ASTM A343
Supermendur and Cubex Alloy	Constant-Current Flux-Reset Properties	III-4	319805	AIEE No. 430, 431, 432
		III-8		AIEE No. 430, 431, 432

1. Unless otherwise specified, all dimensions are in inches.

A Leeds and Northrup Kelvin Bridge was used to measure 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 5 x 10^{-5} torr and the average temperature variation over the 2 inch coil length was less than ± 1 percent. All the samples were heated at a rate of 10°F/min 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 to measure the resistivity of the specimens has a resolution of 10^{-8} ohms. Resistivity was computed and reported in ohm-cm.

c. Thermal Expansion

The thermal expansion measurements were made in a quartz-tube dilatometer in which the specimen is heated with a resistance wound furnace. The furnace and tube are orientated in a horizontal position. The furnace is stationary while the 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 2 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 the 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 recorder. The resultant curve is then corrected for the expansion of quartz. The temperature rise of the specimen is pre-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

d. Thermal Conductivity

This property was only measured on one material, using the comparison bar technique. In this method the specimen, 1/2 inch in diameter by 4-1/2 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, 1/2 inch in diameter by 4 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 2-1/2 inch diameter shield. The shield is made from 302 stainless steel and nickel. The stainless steel portion is as long as the specimen, and the nickel portion is as long as the comparison bar. The nickel and stainless steel sections are but welded and the joints located as to be in line with the specimen nickel joint. A heater is fixed around the shield circumference at this joint. Three chromel-alumel thermocouples are fixed to the specimen, the first is 1/2 inch down from the nickel joint and the remaining two at 1 inch intervals below the first. Four thermocouples are fixed to the comparison bar, the first is 1/2 inch above the specimen joint and the other three at 1 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 5 inch I.D. 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 by adjusting the water flow. The thermocouples on the bar and shield at the same height are maintained at equal temperatures to prevent 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.

2. Magnetic Tests

The test methods used in performance of this contract followed the general ASTM test methods. Slight modifications were made in the details in order to adapt the methods to the geometry of the test specimens and/ or permit their use at high temperatures and high inductions, rather than the room temperature techniques applicable only to the basic test method.

a. D-C Tests

D-C tests were made according to ASTM A341 for both solid, Rowland ring and wound toroid ring specimens.

b. A-C Tests

A-C tests were made in accordance with the standard ASTM A343 wattmeter method with the exception that the samples were ring samples wound with primary and secondary windings rather than Epstein samples. High sensitivity reflecting type wattmeters were used for all a-c tests.

c. Power Supplies

Tests at 400, 800 and 1600 cycles per second were made utilizing a variable frequency motor generator set having a rated output of 7.5 kva, 3 phase at 120 volts. Frequency was measured with a Hewlett-Packard electronic counter and was controlled to ± 1 cycle/sec. Tests at 3200 cycles per second were made with a Westinghouse 25 KW power amplifier driven by a Hewlett-Packard oscillator. When necessary, feedback could be applied to the amplifier to maintain a sinusoidal waveform.

d. Elevated Temperature Atmosphere Chambers

Oxidation protection for the specimens was afforded by a number of welded retorts which were constructed to fit in available laboratory ovens and furnaces. Type 304 stainless steel was used for the

1100°F boxes and Inconel 600 for the 1400°F boxes. The lid joints of the atmosphere chambers were machined and ground for a close, tight, fit.

The many lead wires from each specimen were brought through a Transite plug located in the pipe leading from the atmosphere chambers. All joints were further sealed with a high-temperature Saureisen cement. A second tube was provided as a gas outlet and lead to a bubbler to prevent back-diffusion. Specimen temperature was controlled or measured by a thermocouple placed on the actual test rings and wound into the maze of windings as an integral part of the specimen

e. Special Winding Techniques

In order to make both a-c and d-c tests to 1400°F at frequencies to 3200 cps on the same sample, a series of unique winding techniques were devised. It was also desired to have a peak magnetizing force of at least 250 oersteds for the d-c tests. The selection of this force automatically set the minimum number of turns for the primary windings. To complicate matters, the voltage capability of the available a-c power supplies dictated the maximum number of turns which could be used for the high-frequency tests. After a series of insulation failures at high temperature, a novel winding technique was devised which proved completely satisfactory. It was as follows:

1) Where possible, sample area was reduced to reduce voltage requirements for high frequency testing.
2) The primary windings were sectionalized to reduce induced voltage during high frequency testing.
3) Use of Anaconda Wire and Cable's Anadur insulated nickel-clad copper wire.
4) Use of fiberfrax mat insulation backed by glass tape for insulation between layers of the windings.
5) Use of ceramic tubes to bring all lead wires through the winding.

f. Constant Current Flux Reset Testing (CCFR)

All CCFR tests at room and elevated temperature followed the procedures described in AIEE test specifications 430, 431, and 432. Since relatively few turns were required, commercial high temperature lead wires were used for conductors. An atmosphere box similar to that described in paragraph d. above was used for the elevated temperature tests.

3. Mechanical Properties

a. Tensile Property Measurements

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

Some difficulty was encountered in the measurement of Poisson's ratio and compressive strength of Cubex alloy. The latter presented a problem because it is only available in thin sheet gages which made awkward specimens. Poisson's ratio measurements on Cubex alloy were further complicated by the extremely large grain size and the anisotropy associated with large grain size in grain oriented materials. Although the above materially contributed to the observed scatter, the source and amount of the scatter were determined by placing eight strain gages on each of two Poisson's ratio sheet specimens. Normally, only four strain gages are required for accurate strain measurements. The eight gages were arranged as shown in Figures III-29 and III-30. Note that the gages were placed in both the longitudinal and transverse directions on a single grain as well as across the grain boundaries.

The Baldwin-Lima-Hamilton type A-7 gages were mounted on the sample with Duco Cement, and were chosen for their size, stability, and ease of mounting.

For accuracy, a Wiedeman-Baldwin Mark B-20 testing machine was used in conjunction with a Budd, digital, strain indicator. Strains were recorded at numerous load increments with each set of readings made at constant load.

Tests made on the above specimens revealed variations in Poisson's ratio within different grains in both directions as well as across different grain boundaries. No difficulties were encountered in the measurement of Poisson's ratio on materials other than Cubex alloy.

b. Creep Testing

All creep testing performed on NAS 3-4162 exceeded the ASTM specifications for creep testing in air, inert atmosphere, or vacuum. 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 the above tests was type 304 stainless steel and 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 the specimens loaded to 13,500 psi and tested to rupture.

The vacuum creep test equipment was checked for pressure, leak rates and gas analysis before testing was started. A record was kept of pressure during each test. An analysis of the gases in the chamber are listed in Table III-2. The blank-off leak rate is also given in Table III-2. Actual measured gas transfer rates measured by a cryogenic pump and a mass spectrometer are an order of magnitude greater showing that the chamber is providing some of the pumping. The leak rates were checked at the beginning of each test both at ambient temperature and test temperature. All pressures were maintained well within the specified limits of 1×10^{-5} torr maximum pressure. A pressure of 1.5×10^{-7} torr was typical of normal pressures obtained at 1600°F within a chamber.

TABLE III-2. Gas Transfer (Mol Percent)

Temperature	H_2	CO	N_2	O_2	CO_2	Other Hydro-carbons	Blank-off Leak Rate $\frac{\text{CC-ATM}}{\text{Sec}}$
Room Temperature	6.63	--	30.39	8.23	31.35	23.40	$1\text{-}2 \times 10^{-6}$
1600°F	34.19	22.92	14.79	3.41	10.19	14.5	$1\text{-}2 \times 10^{-6}$

As a final precaution, and in accordance with a recommended Materials Advisory Board procedure, a piece of dead soft columbium having a Vickers hardness (10 KG) of 42.1 was exposed at 2200°F for one hour in the creep machine under test vacuum. The final hardness was 43.1 attesting to the fact that the vacuum quality met existing Materials Advisory Board specifications.

After proving the quality of the vacuum test chambers, it was decided to check for possible change in the creep specimens which might affect the measured creep rates. To do this, the creep properties of air, argon, and vacuum creep specimens were compared and gas analysis of both the tested and untested vacuum test specimens were made for oxygen and carbon. This analysis is presented in Table III-3. No changes in oxygen or carbon content were observed. The slight differences between the values listed on Table III-3 are due to standard experimental errors. Before starting the vacuum creep tests, base line data were obtained first in air and argon using extensometers on the specimens. The stresses and test temperatures selected for vacuum testing were taken from Larson-Miller plots of the air test data since the vacuum tests were expected to check the air and argon data. Because of equipment limitations, the extensometer could not be fastened directly to the vacuum test specimens but was connected to the machine crosshead. The vacuum test extensometer data were then corrected for linkage errors. The creep strain rate obtained in this manner agreed with those obtained using extensometers on the specimens.

TABLE III-3. Total Oxygen Analysis of Vacuum Creep Test Specimens

Material	Specimen	Test Temperature (°F)	Test Stress (psi)	Test Time (hrs)	Percent Oxygen	Percent Carbon
AMS6487(H-11) Forging (Bar)	As received	-	-	-	0.0048*	0.42
					0.0015**	-
	V1	1000	33,000		0.0024	-
	V2	900	90,000	170	0.0026	-
	V3	850	100,000	502	0.0013	-
	V4	1000	37,000	650	0.0019	0.40
Nivco Forging (Bar)	As received	-	-	-	0.0008	0.0040
	V1	1400	16,000	5	0.0012	-
	V2	1400	8,000	163	0.0012	-
	V3	1100	85,000	496	0.0007	0.0048
	V4	1100	80,000	356	0.0009	-
15 % Maraging Steel (Bar)	As received	-	-	-	0.0023	0.0062
	V1	900	60,000	502	0.0007	-
	V2	900	90,000	192	0.0010	-
	V3	800	107,500	283	0.0007	0.0061
Hiperco 27 Forging (Bar)	As received	-	-	-	0.0015	0.0051
	V1	1100	12,000	498	0.0017	-
	V2	900	46,000	340	0.0017	-
	V3	700	70,000	498	0.0016	0.0056
	V4	1100	7,000	211	0.0015	-
Hiperco 27 Investment Castings	As received	-	-	-	0.0087	-
	V1	1100	8,000	405	0.0060	-
	V2	700	36,800	212	0.0075	-
	V3	900	32,000	308	0.0079	-
	V4	1100	11,000	168	0.0078	-

*Taken near surface
**Taken near center

The creep strain was also measured after test at room temperature as an additional check on all the air and vacuum test data. In all cases the creep strain observed by extensometer agreed with that measured at room temperature within experimental error. The vacuum creep strains found at the end of the test also verified this observation.

The test program on H-11 and Nivco alloy sheet was planned to check data already available for bar stock rather than to establish basic creep properties. Because there is often a difference between properties measured in the transverse and longitudinal directions of sheet, the majority of specimens were selected for test in that direction considered most likely to be affected, namely the transverse.

The creep data for H-11 were obtained by means of measured elongation resulting from stressing test samples for given lengths of time at temperature. The current tests were made in the same manner with stress and temperature selected to duplicate tests already completed on the forged alloy on another program (LM529). Extensometers were used on the Nivco alloy sheet to check data obtained on NAS 3-4162 for forged bars.

Combination smooth and notched bar creep test specimens ($K_t = 3.0$) were mixed in with smooth bar test specimens for nearly all materials to determine possible notch-sensitivity. Only two of the 150 creep samples suffered a notch failure. These two samples, both Nivco, appeared to be defective and were disregarded.

c. Fatigue Testing

All fatigue tests run on this program were planned in an air atmosphere. The decision to air-test the H-11 and Nivco alloys was made when the literature failed to provide master air-atmosphere fatigue data on either of the above alloys. A large amount of inert-gas atmosphere fatigue data has been obtained for other alloys on the Maritime Gas Cooled Reactor Program.[2] These data showed a modest effect of atmosphere purity on the fatigue life of various nickel and iron-base, high-temperature alloys. However, both

(2) Wall, F. J., "Metallurgical Development for 1500°F MGCR Gas Turbine", Maritime Gas Cooled Reactor Project Engineering Report, Westinghouse Electric Corp., Lester, Pa., February 1964.

beneficial and adverse effects of the purified test atmosphere on the alloys studied were noted. In general, effects were found to be a function of grain size, alloy composition, and test-atmosphere purity. A comprehensive study like that performed on the MGCR Program is beyond the scope and time limitations of this program. It was decided to obtain the best possible base-line, air-atmosphere data from which a detailed atmosphere test program could be planned if such data became a necessity. Several high-purity argon-atmosphere tests were made to check the alloys of interest on this program for this sensitivity, and to alert the designer to these trends. A similar check had also been done early in the creep program with no significant differences in the measured property observed in either case except at temperatures over 1400°F. All fatigue specimen notch geometry was calculated to give a stress concentration (K_t) of three.

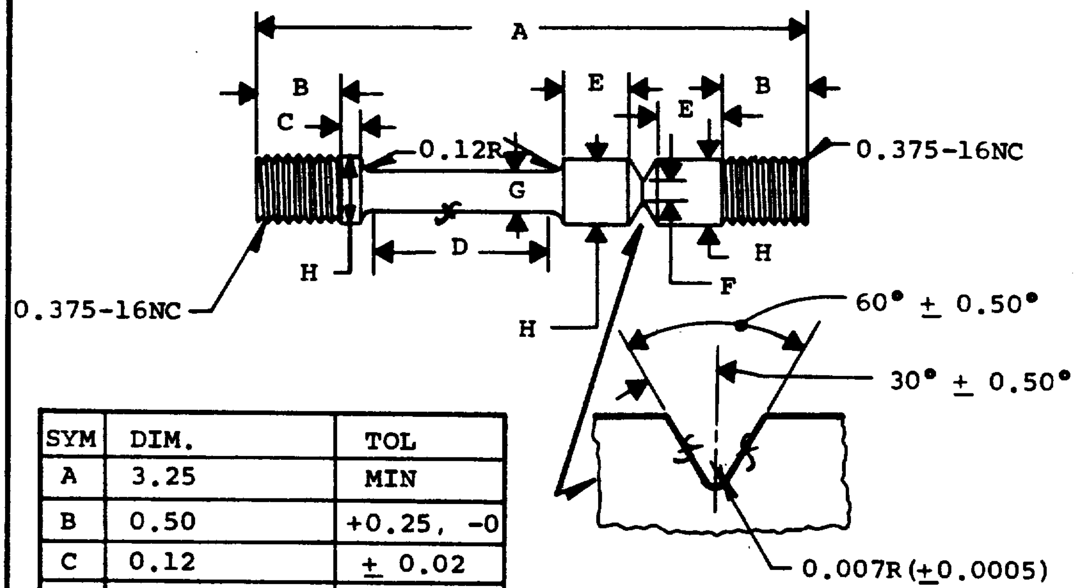
The fatigue specimens were mounted into a 5-to-1 stress multiplying fixture and assembled into a Sonntag Model SF-1U fatigue machine for test. Specimen eccentricity, with respect to the center line of the grips, was held to less than 0.00025 inch. A specimen, previously calibrated in a tensile machine, was used with a visicorder and amplifier to check the dynamic calibration of the fatigue machine.

Dynamic creep tests which combined the effects of static stress and alternating stress were conducted to permit the presentation of Modified Goodman Diagrams.

4. 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 Max.
Hydrogen	5 PPM Max.
Nitrogen	40 PPM Max.
Carbonaceous Gases	3 PPM Max.
Dew Point	-80°F



SYM	DIM.	TOL
A	3.25	MIN
B	0.50	+0.25, -0
C	0.12	± 0.02
D	1.000	± 0.010
E	0.38	± 0.03
F	0.252 DIA	± 0.001
G	0.252 DIA	± 0.001
H	0.38 NOM	--

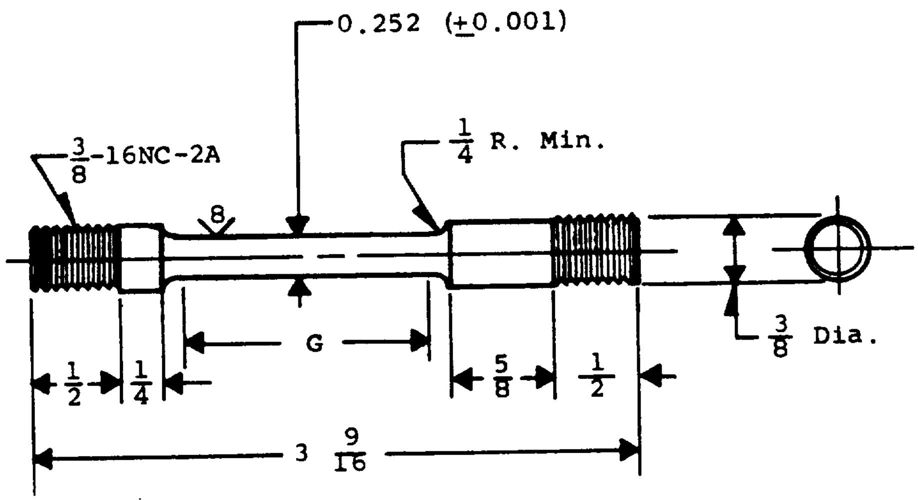
NOTE - Finish specimen to ∇8 or better on all "ʄ" surfaces.

NOTE - The difference between Dims. "F" & "G" shall not exceed 0.001 inch.

NOTE - Taper gauge length "D" to center so that dia "G" at ends of gauge length exceeds dia "G" at center of gauge length by not less than 0.0005 inch nor more than 0.001 inch.

Westinghouse Dwg. Ref. No. EDSK 29810

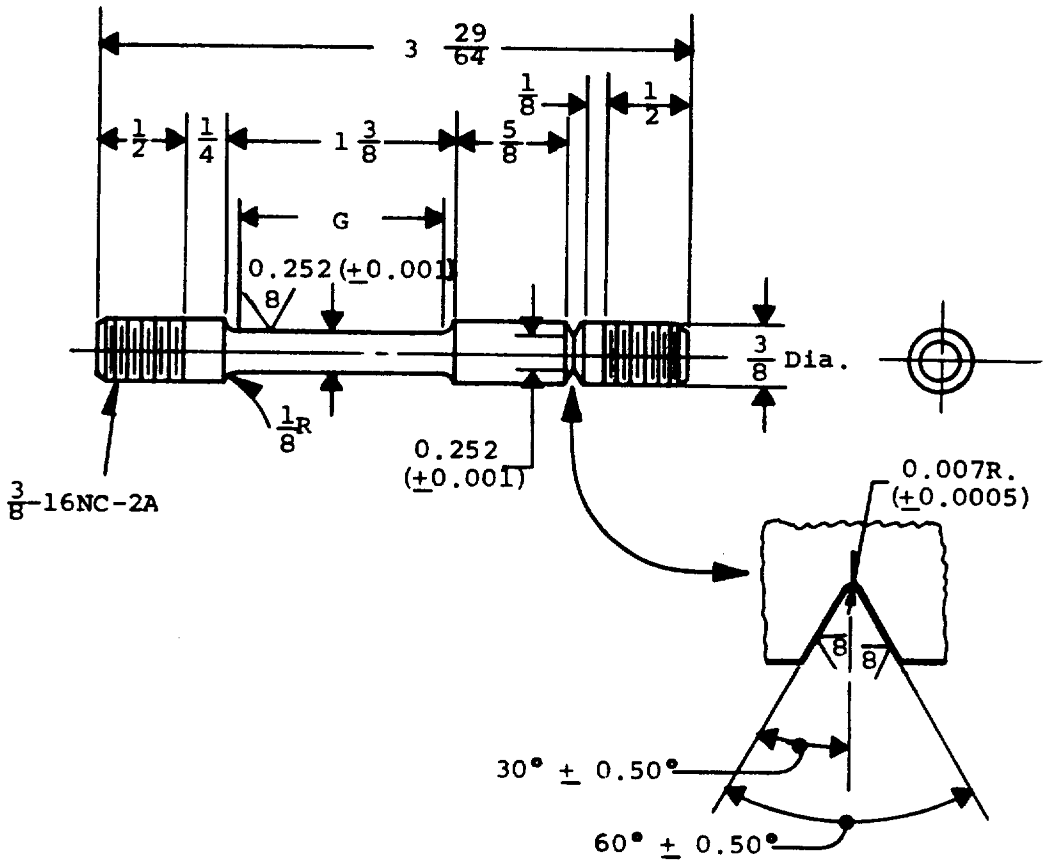
FIGURE III-1. Combination Bar Creep-Rupture Specimen for High Strength Materials



NOTE: Taper gauge length "G" to center so that the diameter at the ends of the gauge length exceeds the diameter at the center of the gauge length by not less than 0.0005 inch nor more than 0.001 inch.

Westinghouse Dwg. No. Ref. EDSK 319686

FIGURE III-2. Tensile-Creep Specimen for High Strength Materials



NOTE: The difference between the 0.252 inch (±0.001) dimensions shall not exceed 0.001 inch.

NOTE: Taper gauge length "G" to center so that the diameter at the ends of the gauge length exceeds the diameter at the center of the gauge length by not less than 0.0005 inch nor more than 0.001 inch.

Westinghouse Drawing Ref. No. EDSK 319687

FIGURE III-3. Combination Bar Creep-Rupture Specimen for High Strength Materials

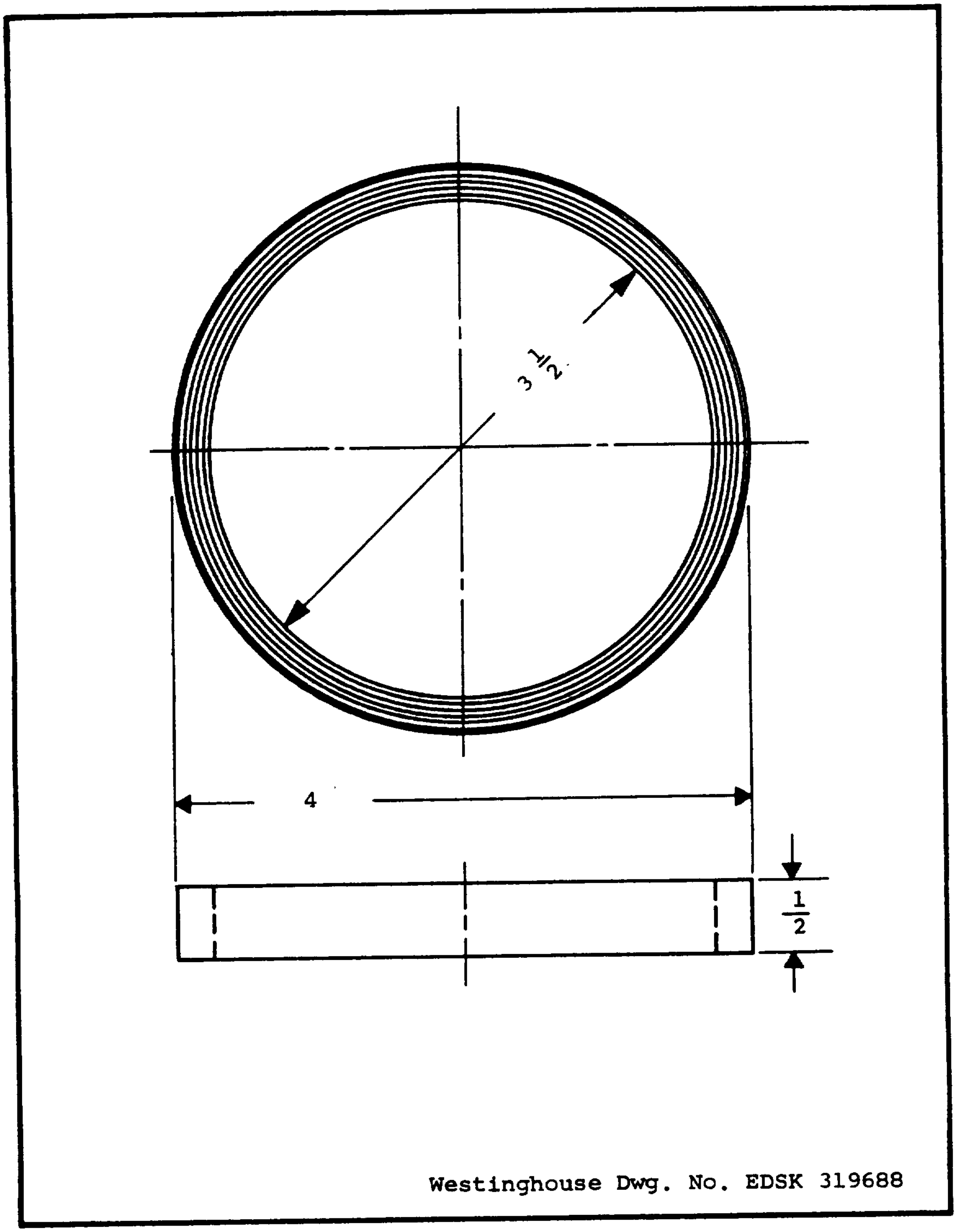


FIGURE III-4. Tape Wound Toroid for Magnetic Tests

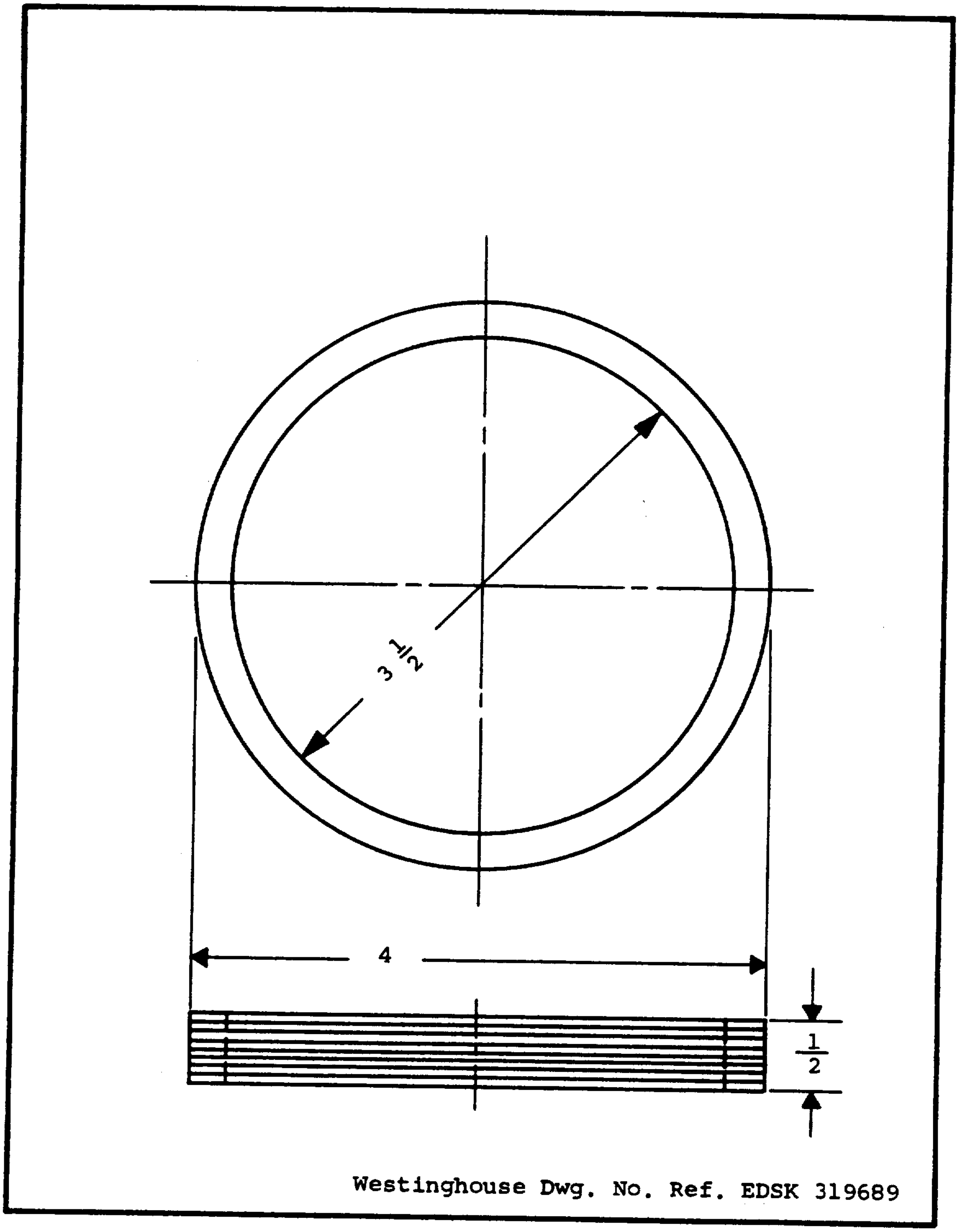
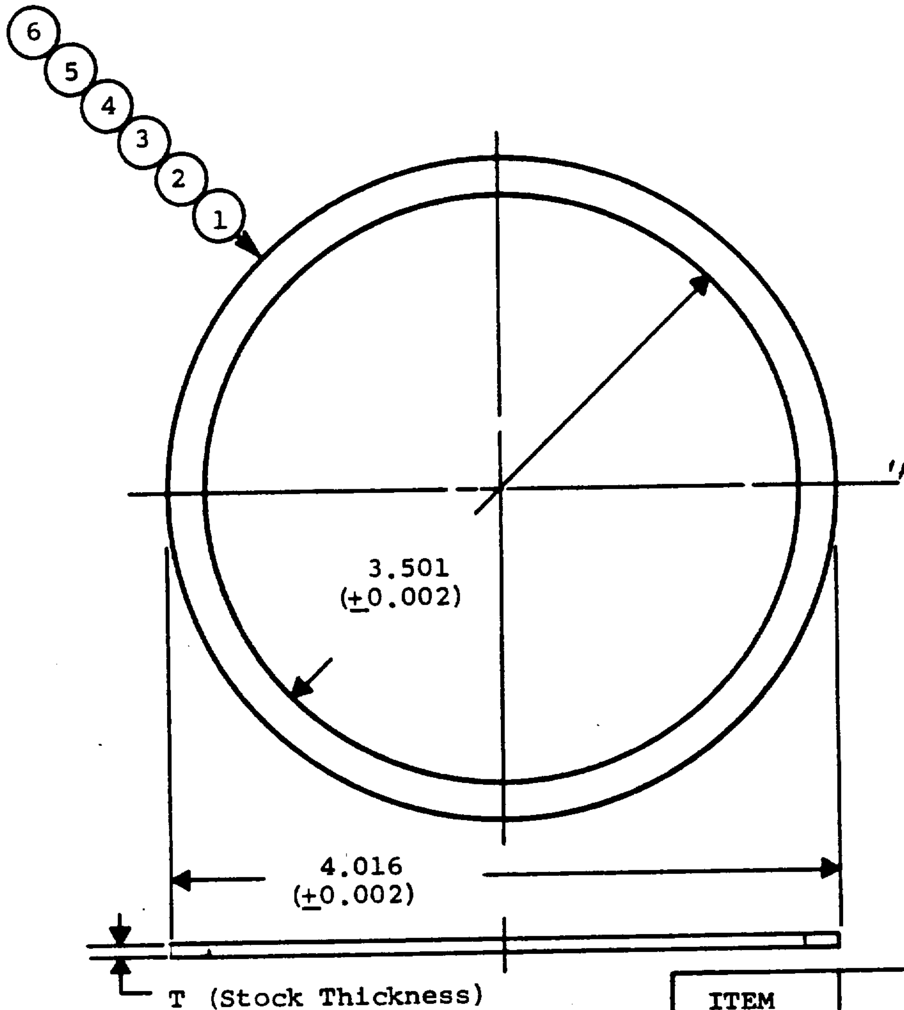


FIGURE III-5. Stacked Rowland Ring Sample for Magnetic Testing of Laminated Material



Diameters to be concentric within 0.005 inch Total Indicator Reading.

ITEM	T
1	0.004
2	0.006
3	0.008
4	0.012
5	0.014
6	0.025

Westinghouse Dwg. No. Ref. EDSK 319720

FIGURE III-6. Rowland Ring Lamination

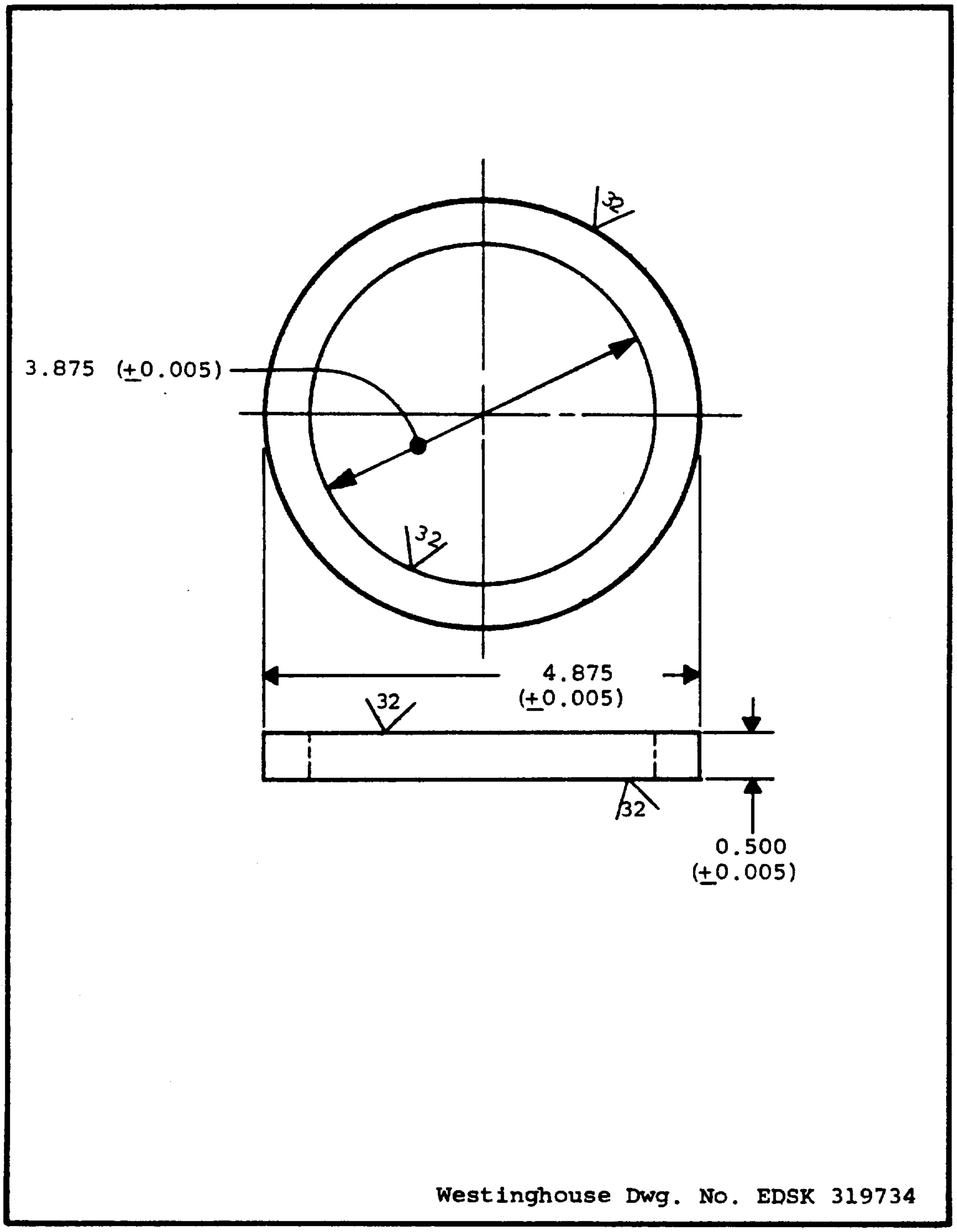


FIGURE III-7. Solid Ring for Direct Current Magnetic Testing

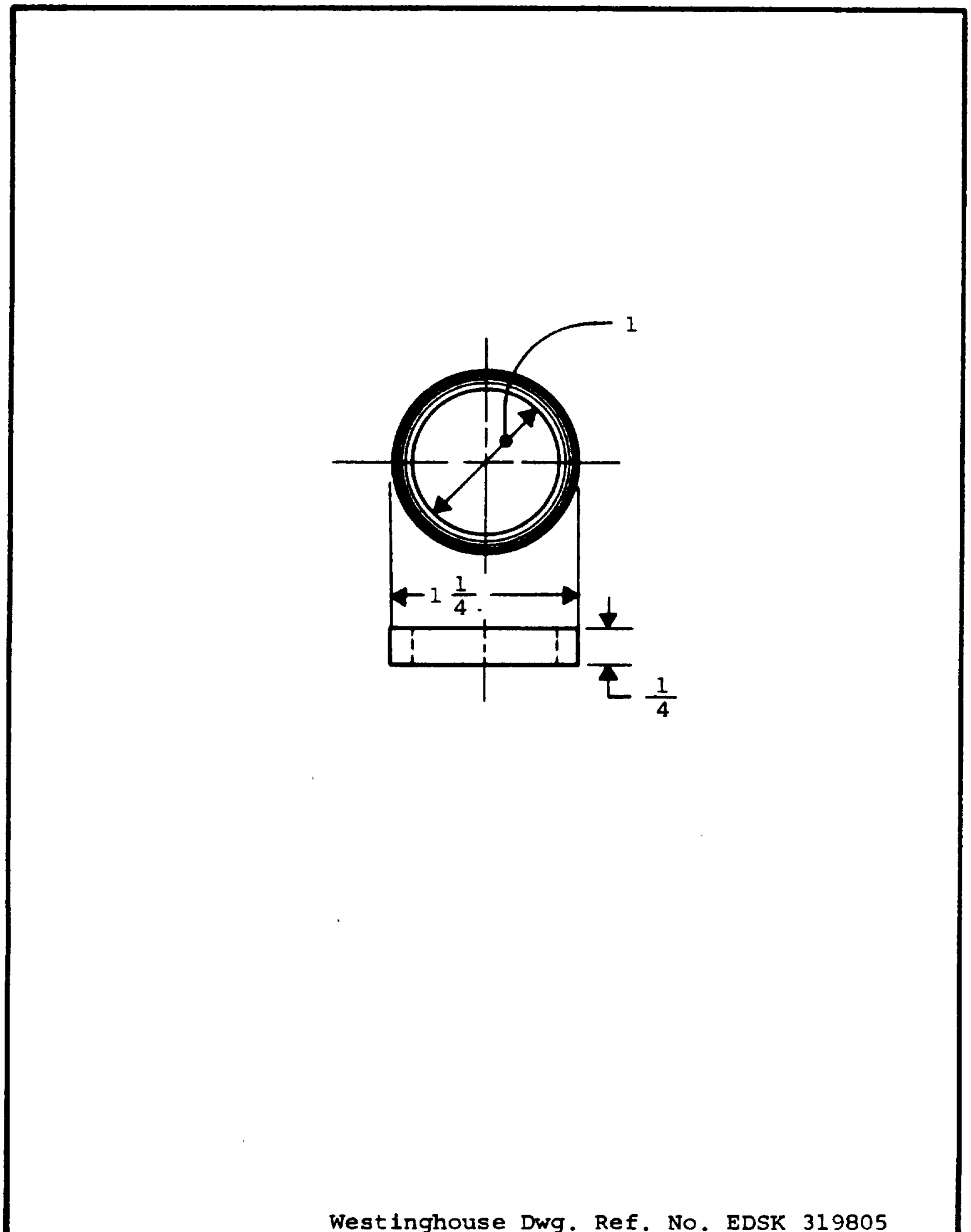
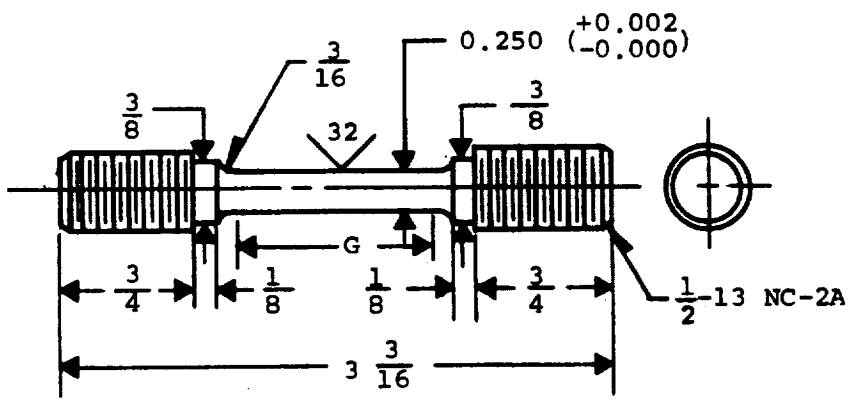


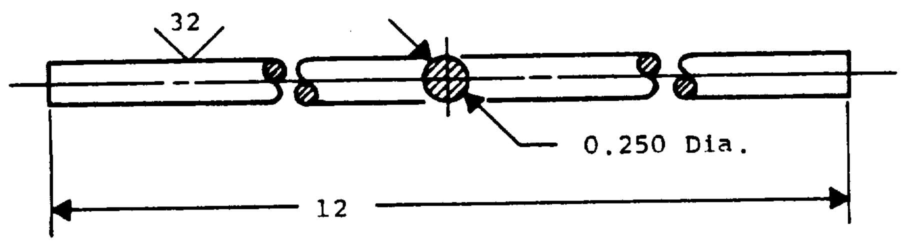
FIGURE III-8. Tape Wound Toroid for Magnetic Testing



NOTE: Taper gauge length "G" to center so that the diameter at the ends of the gauge length exceeds the diameter at the center of the gauge length by not less than 0.0005 inch nor more than 0.002 inch.

Westinghouse Dwg. Ref. No. EDSK 319938

FIGURE III-9. Tensile-Creep Specimen for Investment Cast Materials



Westinghouse Dwg. Ref. No. 627A074

FIGURE III-10. Electrical Resistivity Specimen

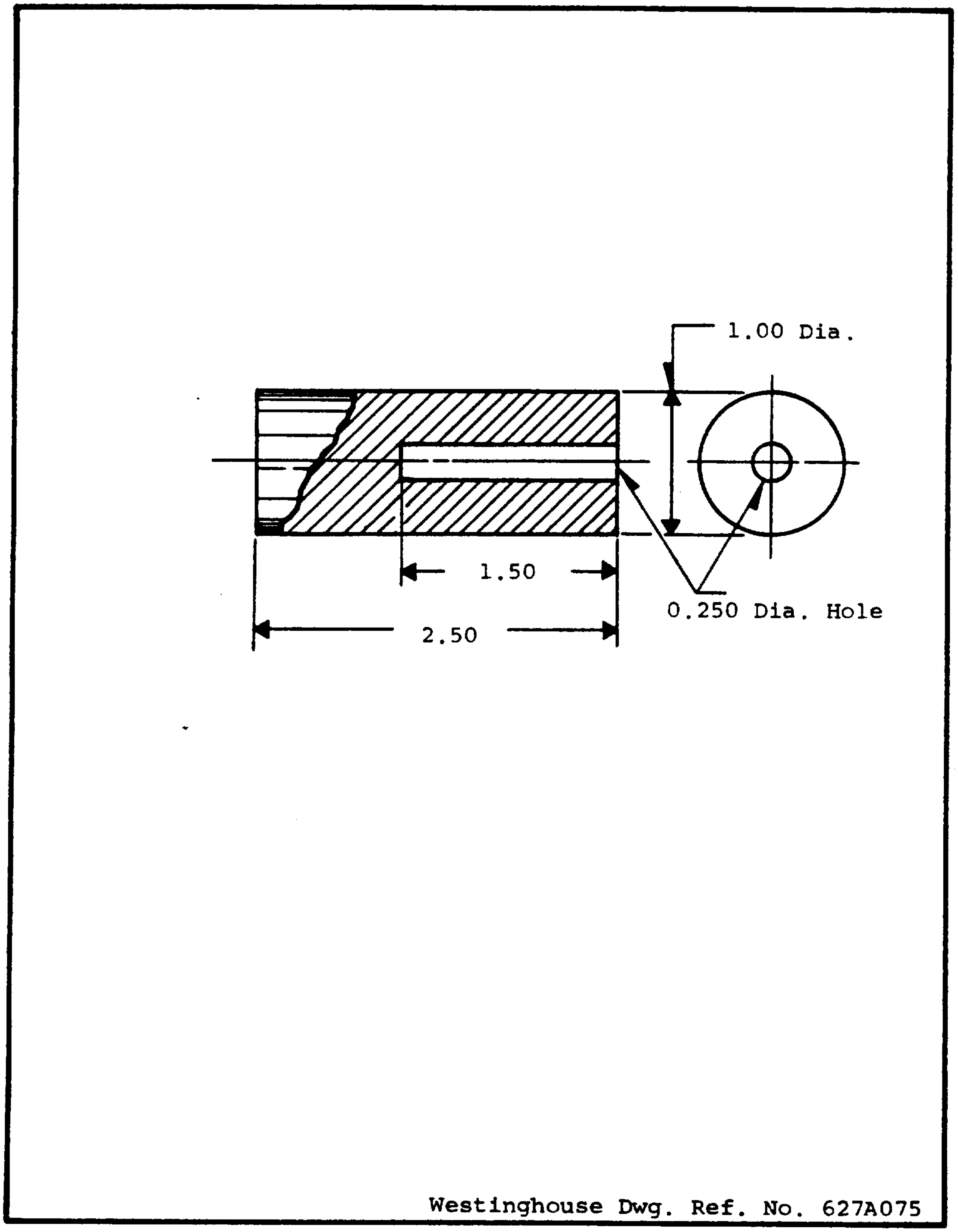


FIGURE III-11. Specific Heat Specimen

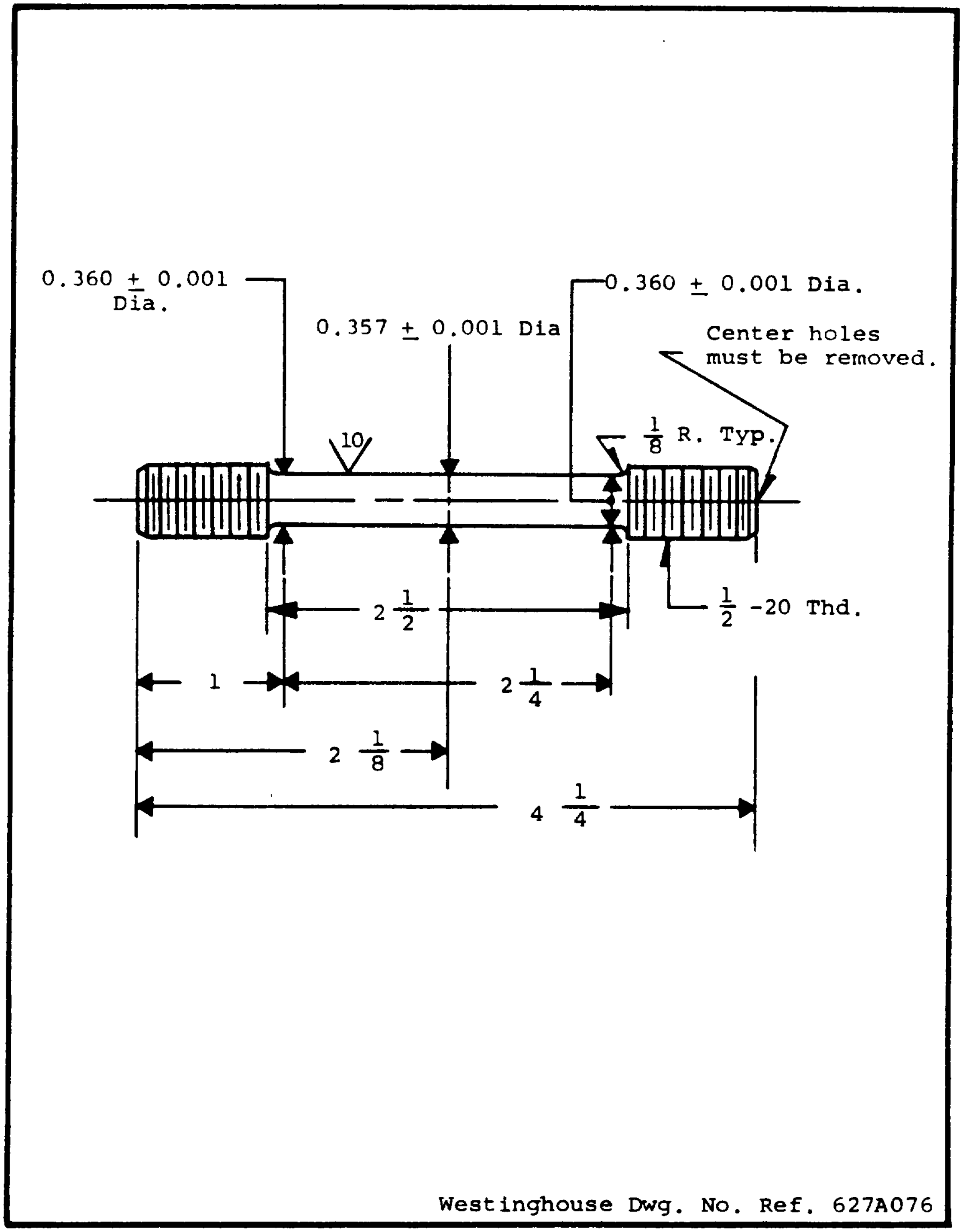


FIGURE III-12. Tensile-Creep Specimen for Moderate Strength Materials

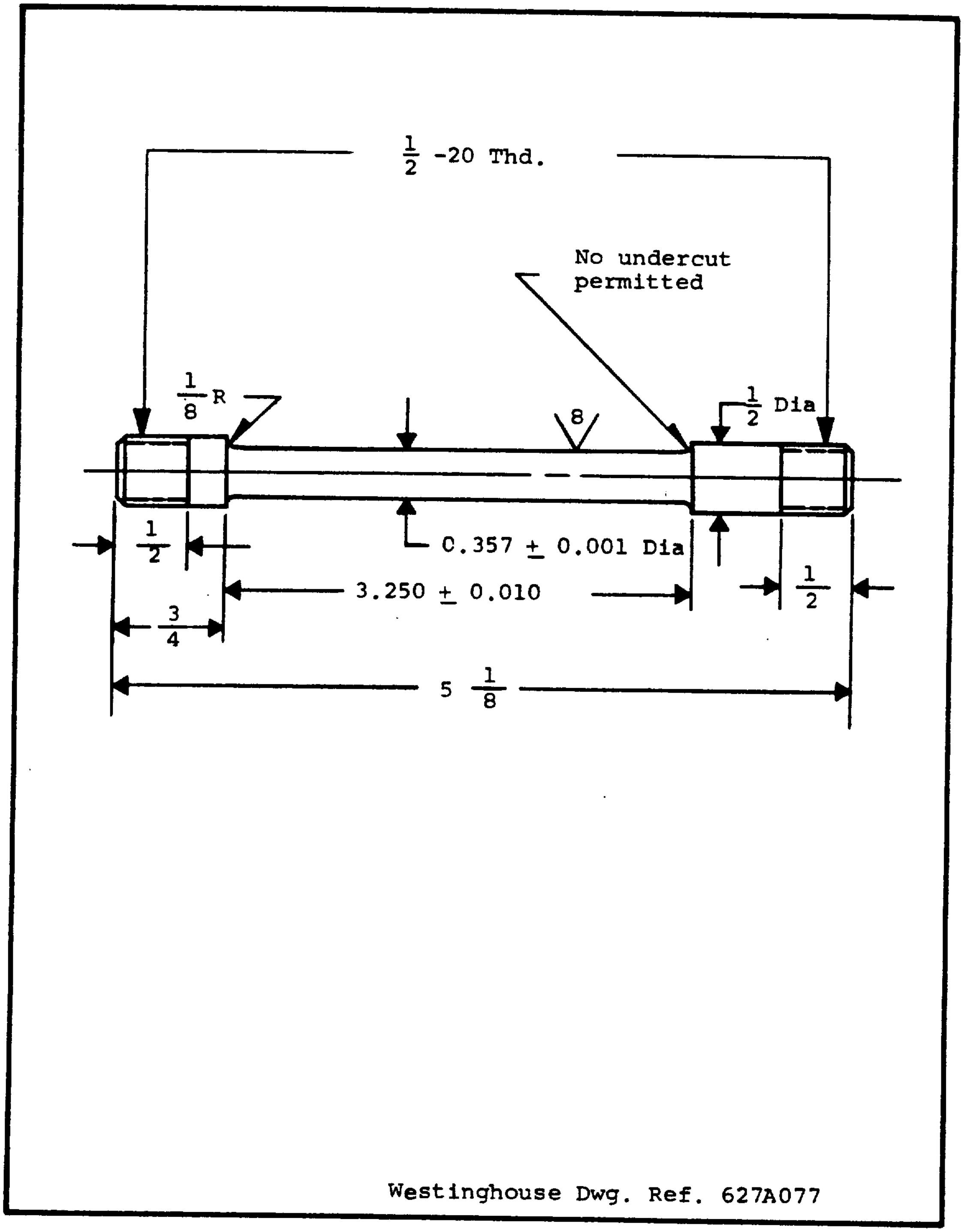


FIGURE III-13. Creep Specimen for Moderate Strength Materials

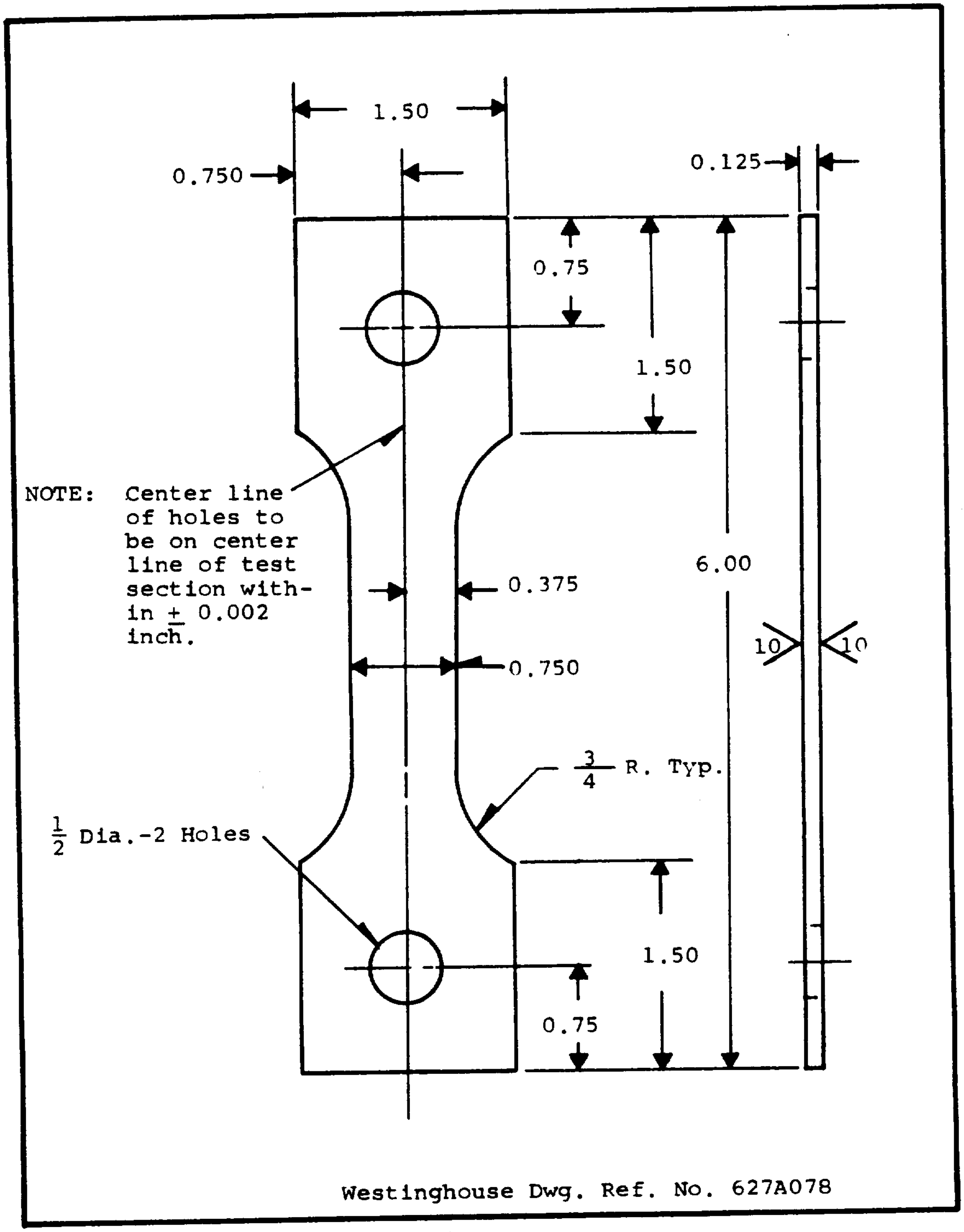


FIGURE III-14. Poisson's Ratio Specimen

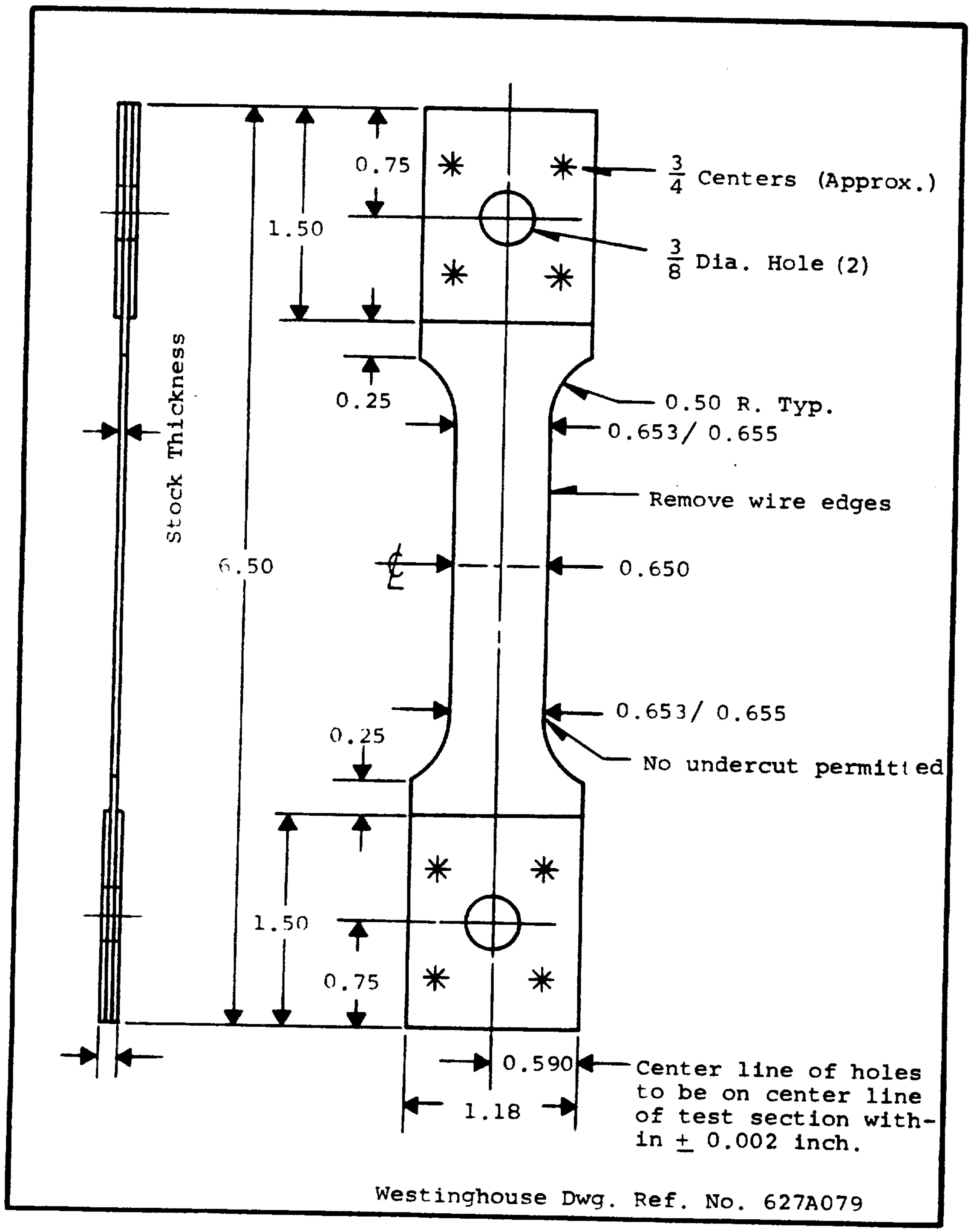


FIGURE III-15. Tensile-Creep Specimen for Sheet Materials

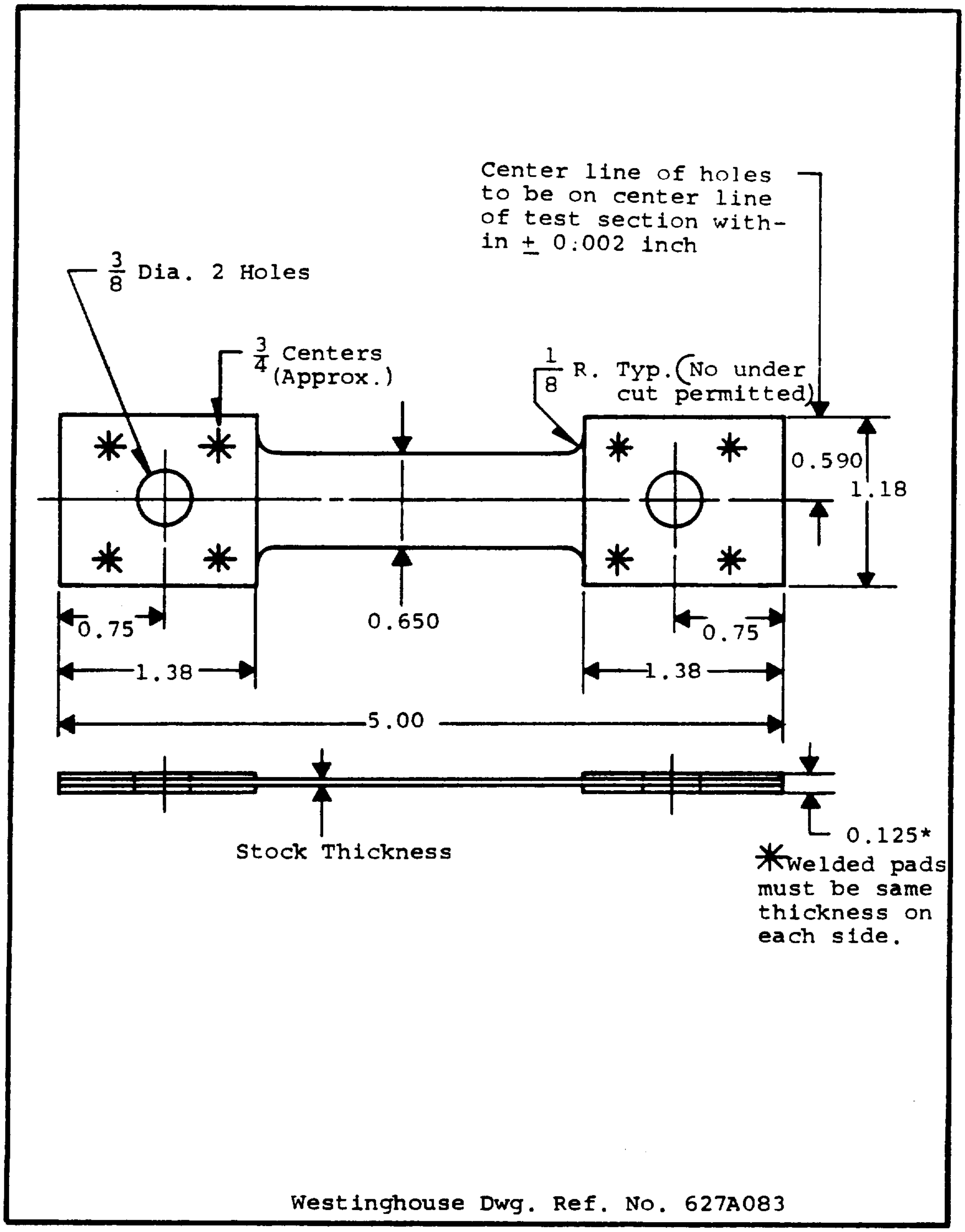
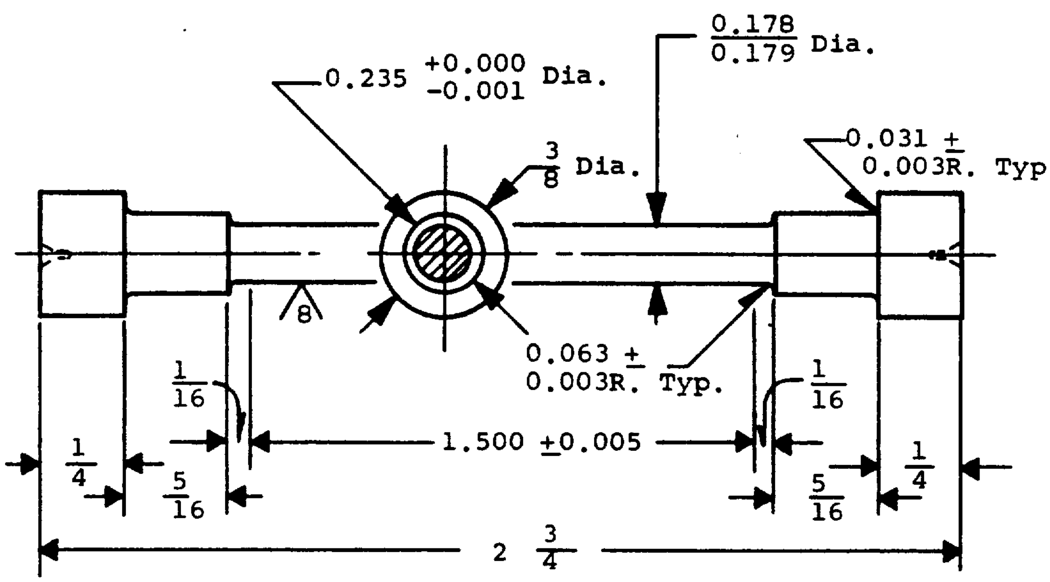


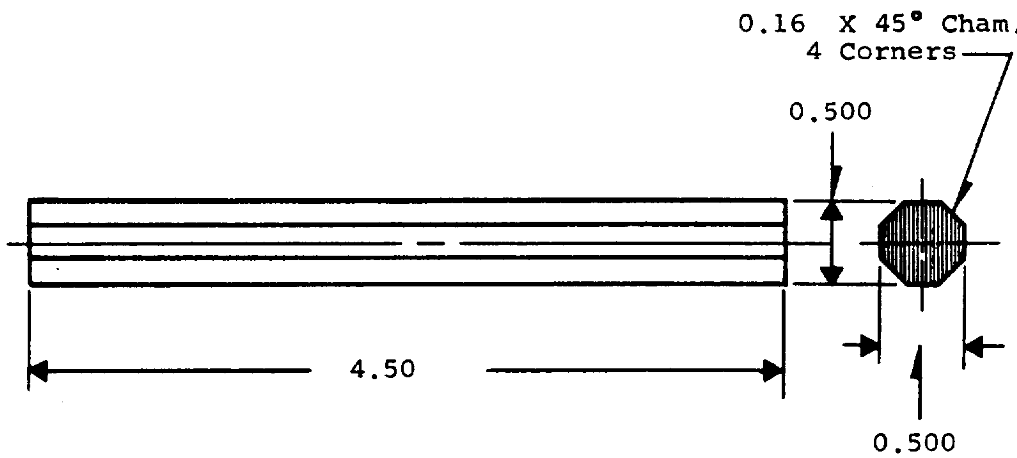
FIGURE III-16. Tensile-Creep Specimen, Sheet Materials for Transverse Specimens Taken from Narrow Sheet



NOTE: Eccentricity on end centers must not exceed 0.0005 inch.

Westinghouse Dwg. Ref. No. 627A084

FIGURE III-17. Vacuum Creep Specimen - All Bar Materials



Laminations heliarc welded before grinding to finish dimensions.

Westinghouse Dwg. Ref. No. 627A088

FIGURE III-18. Thermal Conductivity Specimen for Sheet Materials Only

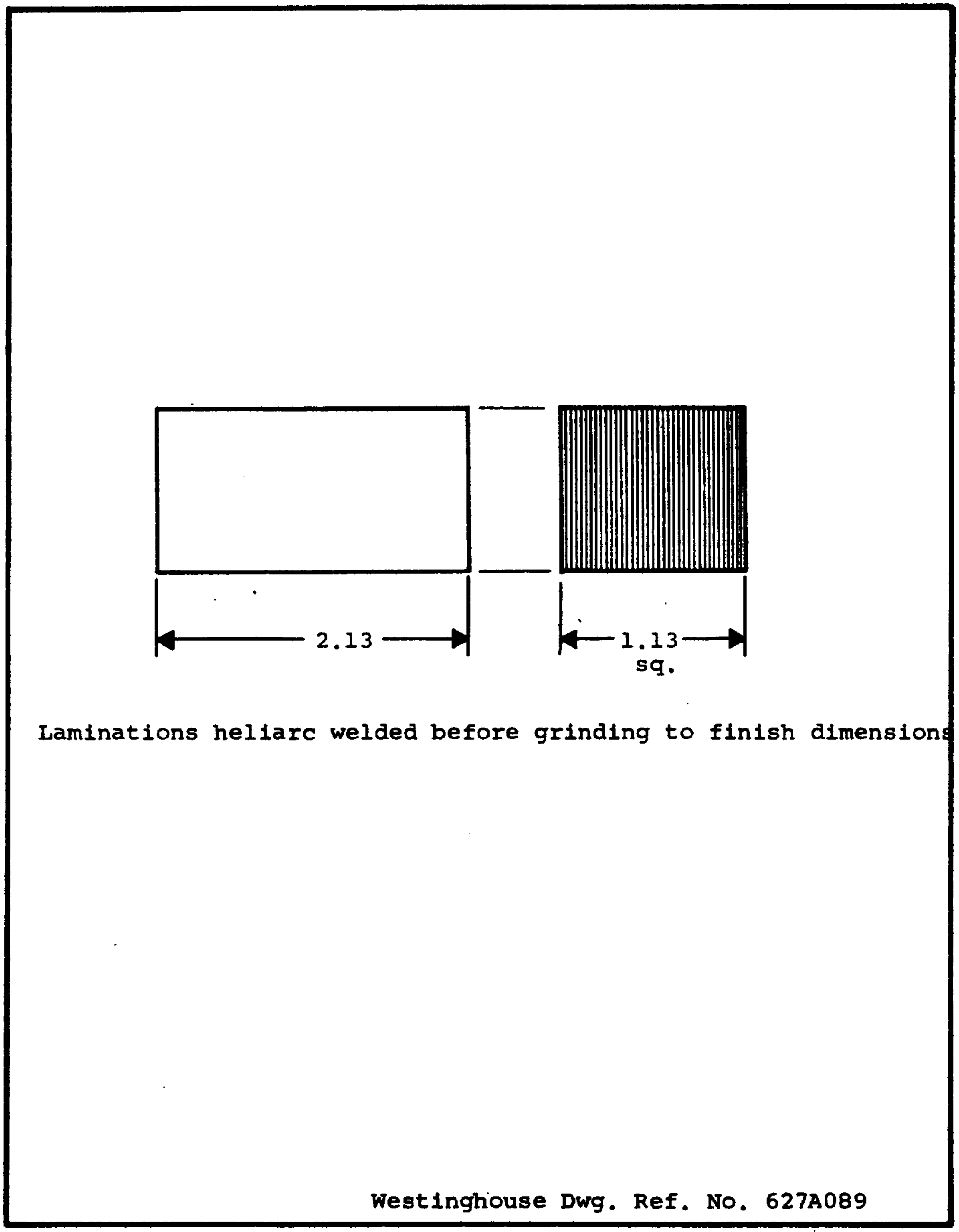


FIGURE III-19. Specific Heat Specimen for Sheet Materials Only

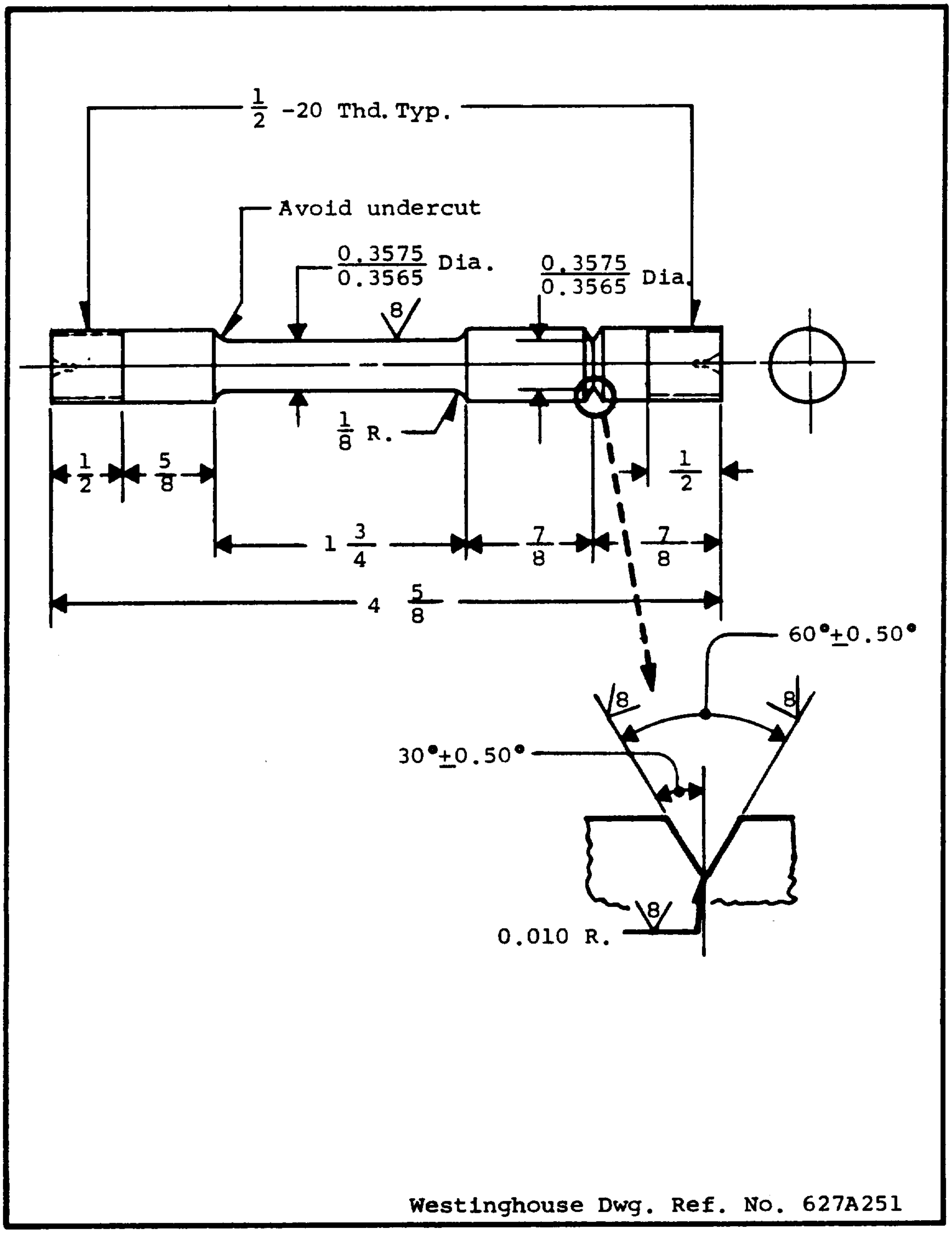


FIGURE III-20. Combination Bar Creep-Rupture Specimen for Moderate Strength Materials

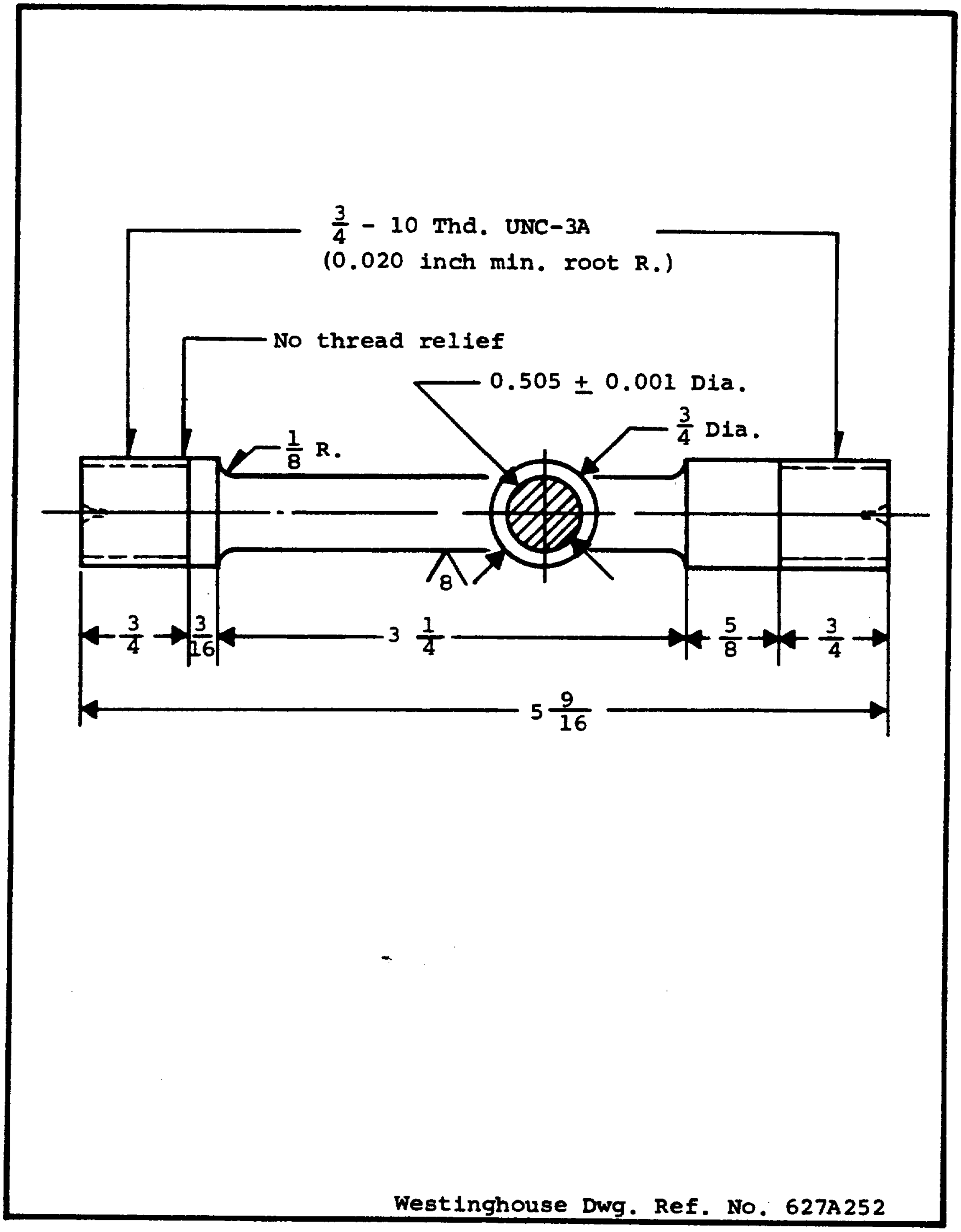


FIGURE III-21. Tensile-Creep Specimen for Low Strength Materials

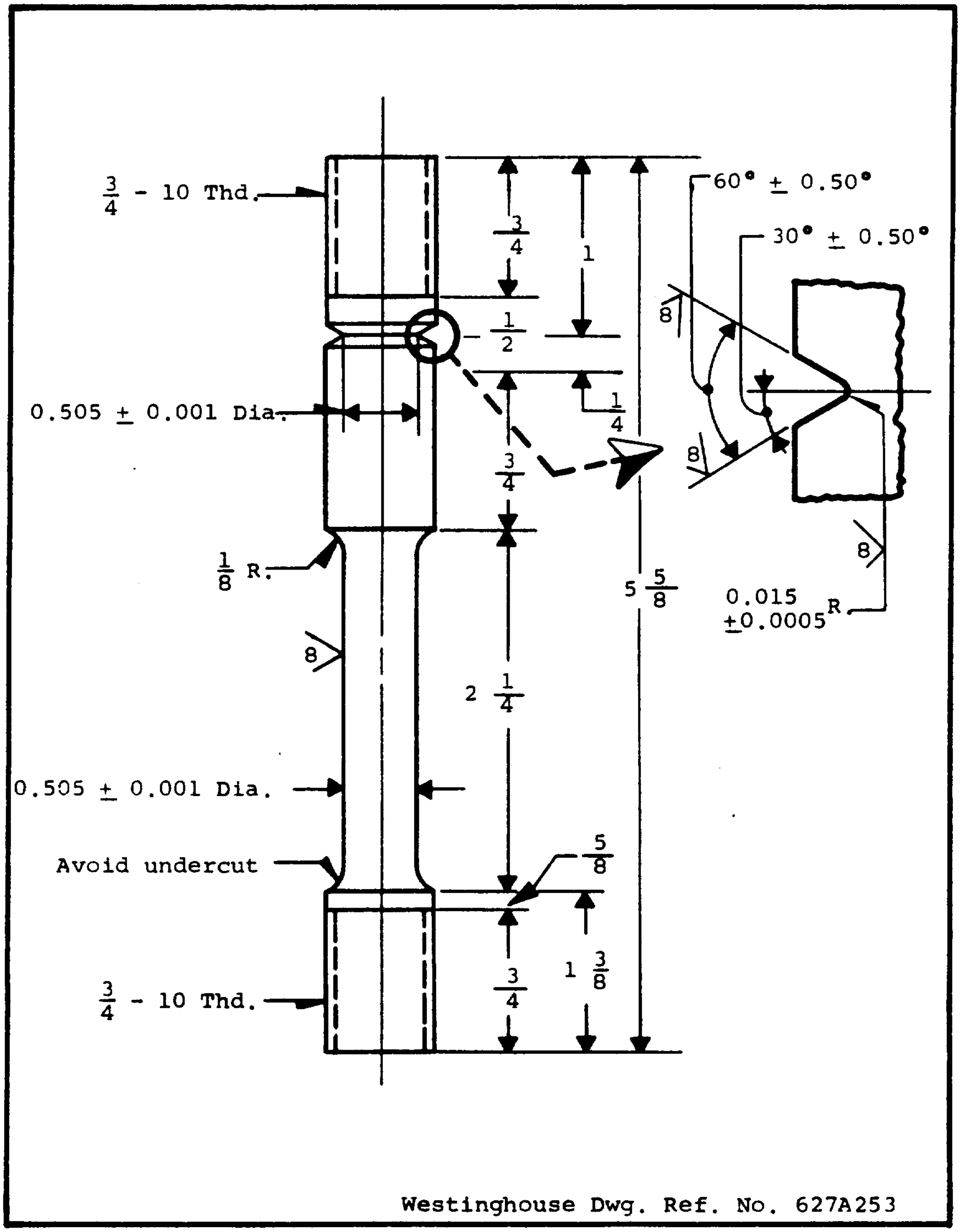


FIGURE III-22. Combination Bar Creep-Rupture Specimen for Low Strength Materials

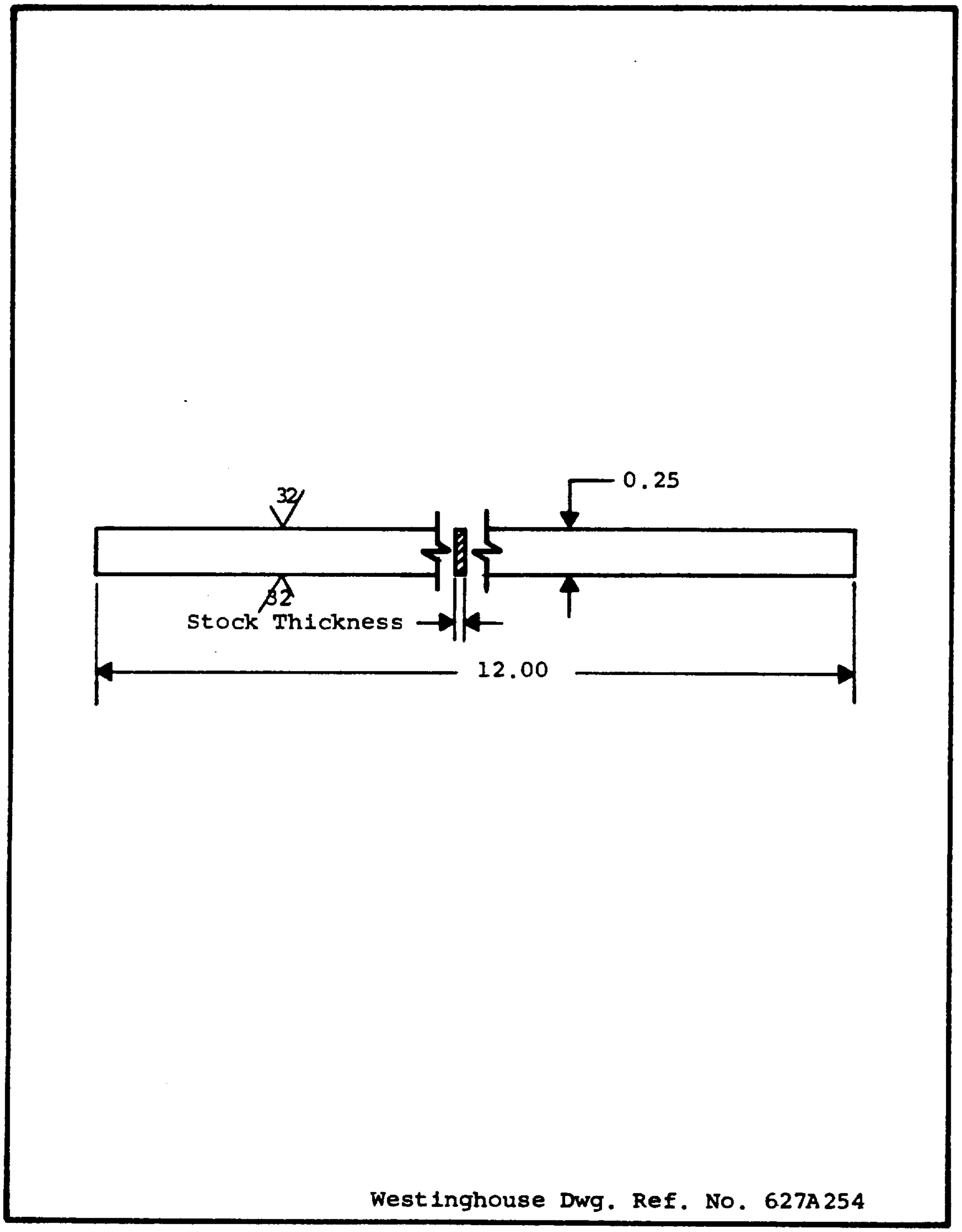


FIGURE III-23. Electrical Resistivity Specimen for Sheet Only

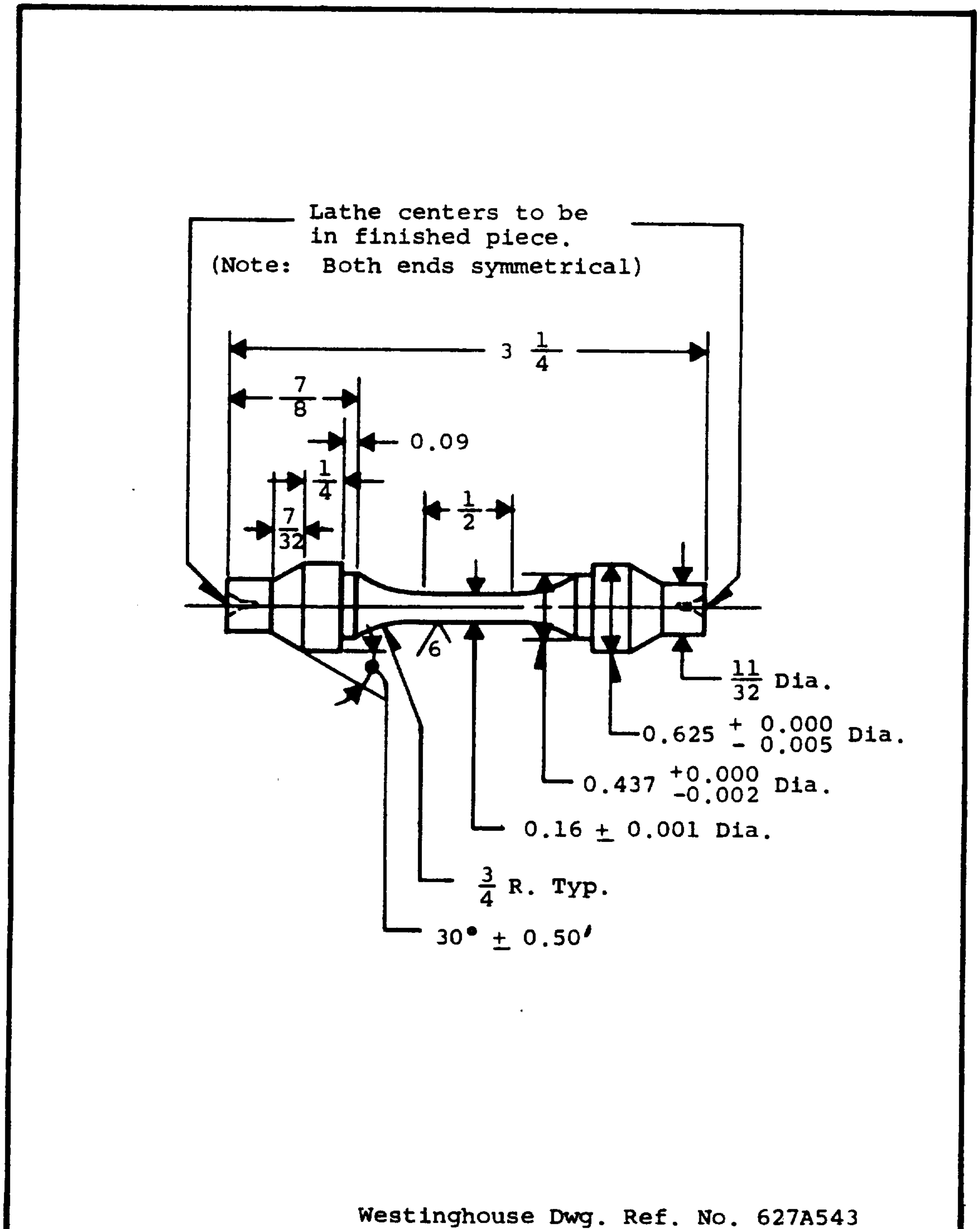


FIGURE III-24. Axial Fatigue Specimen - Smooth Bar

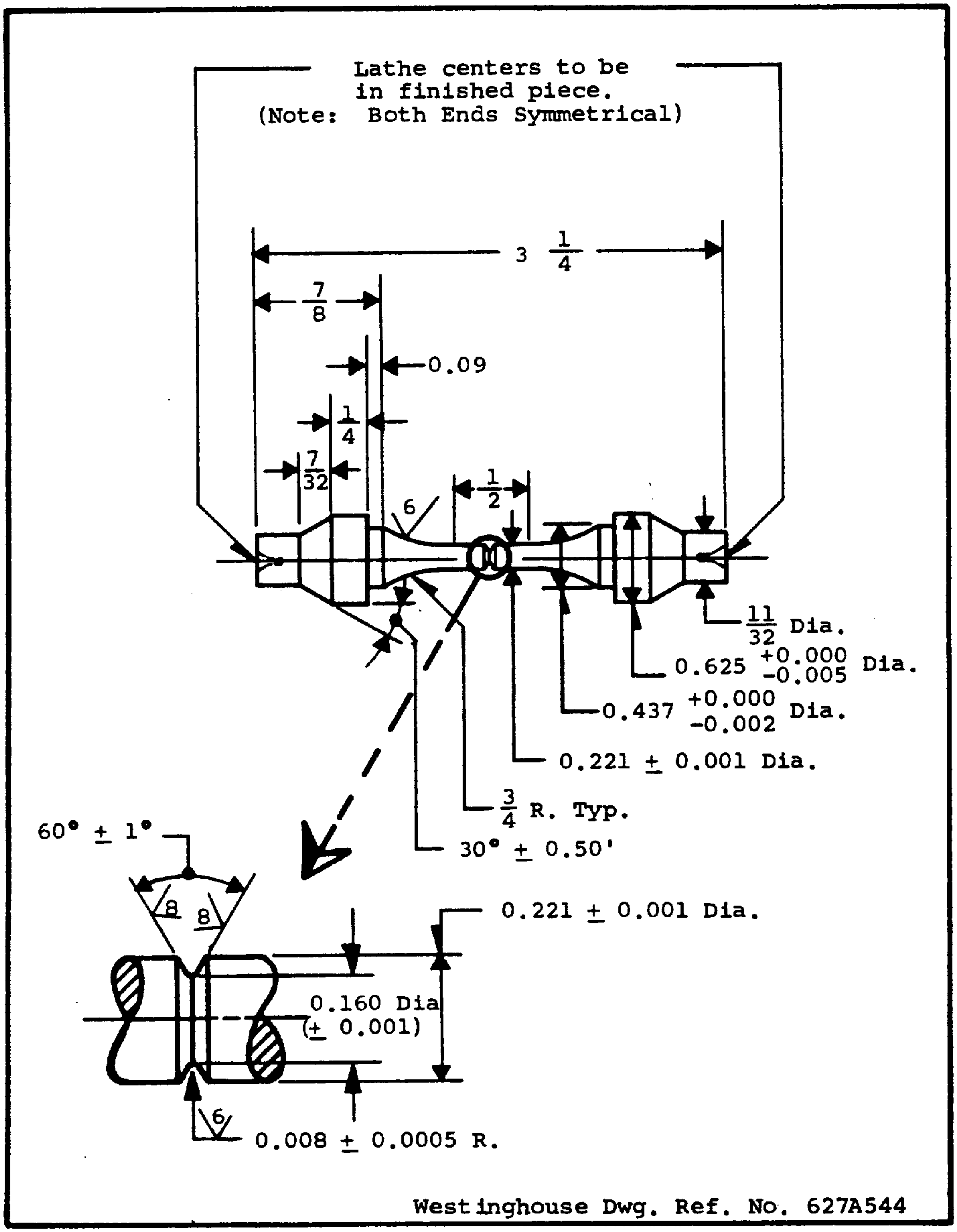


FIGURE III-25. Axial Fatigue Specimen - Notched Bar

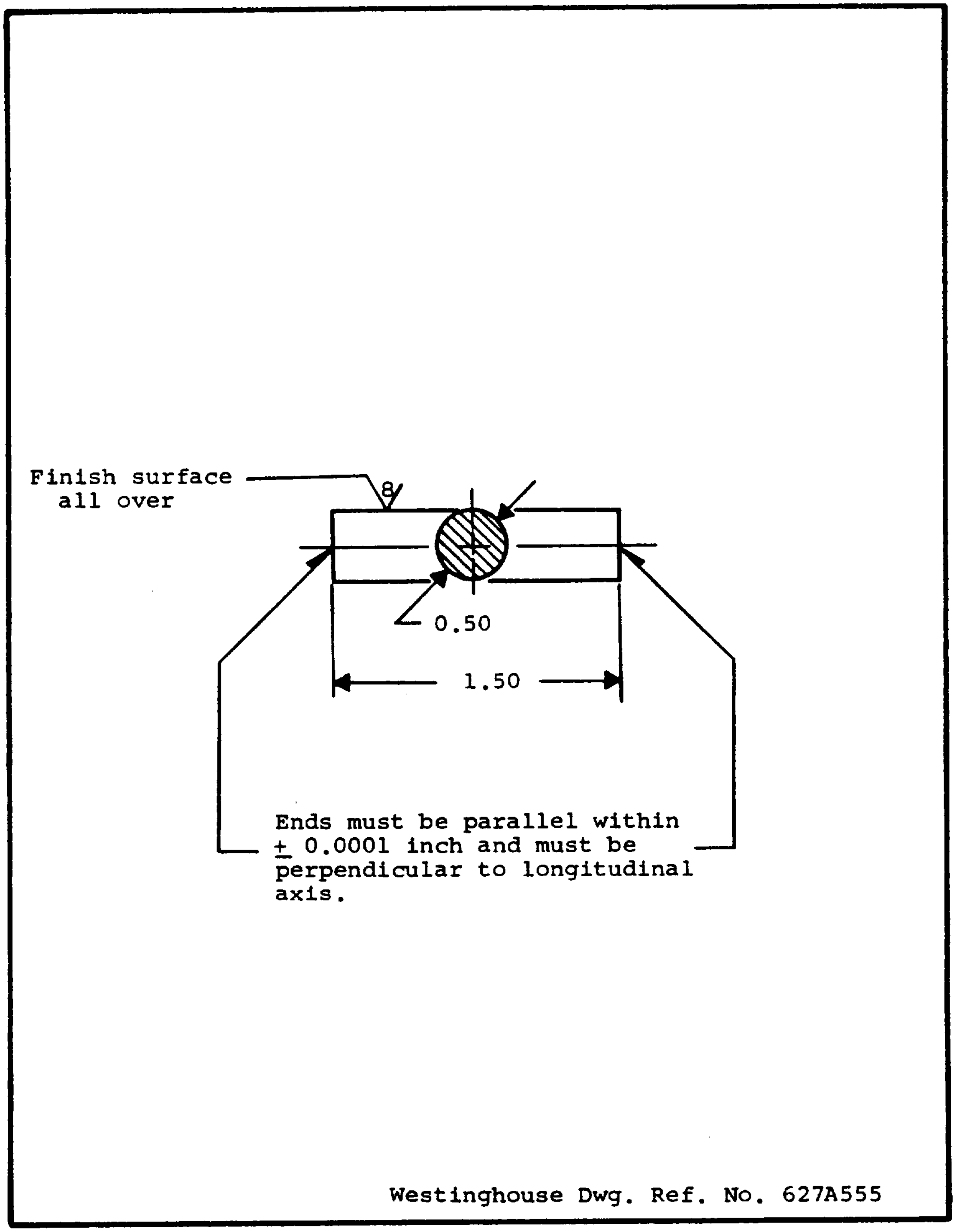


FIGURE III-26. Compressive Test Specimen for Bar Stock

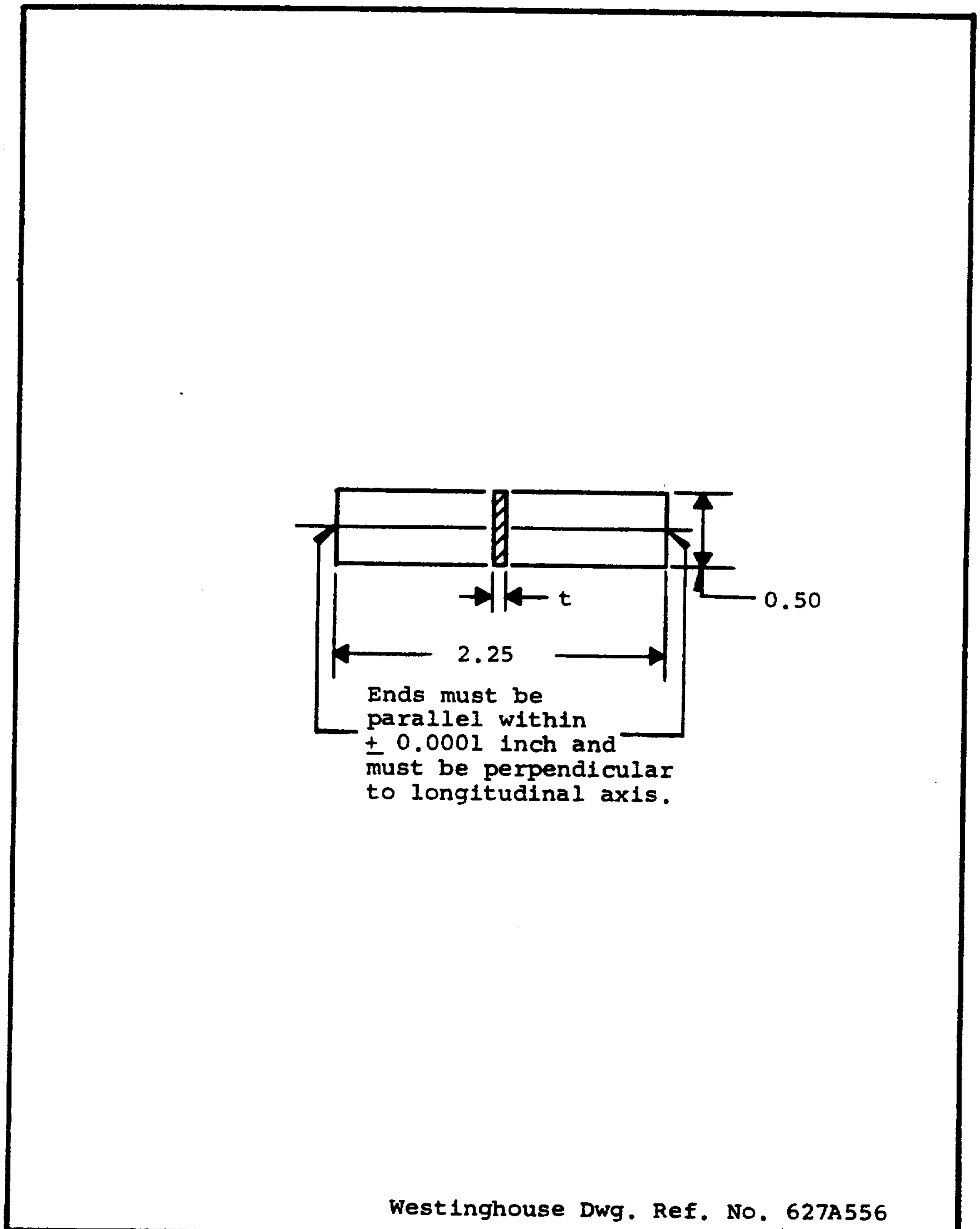


FIGURE III-27. Compressive Test Specimen for Sheet Materials

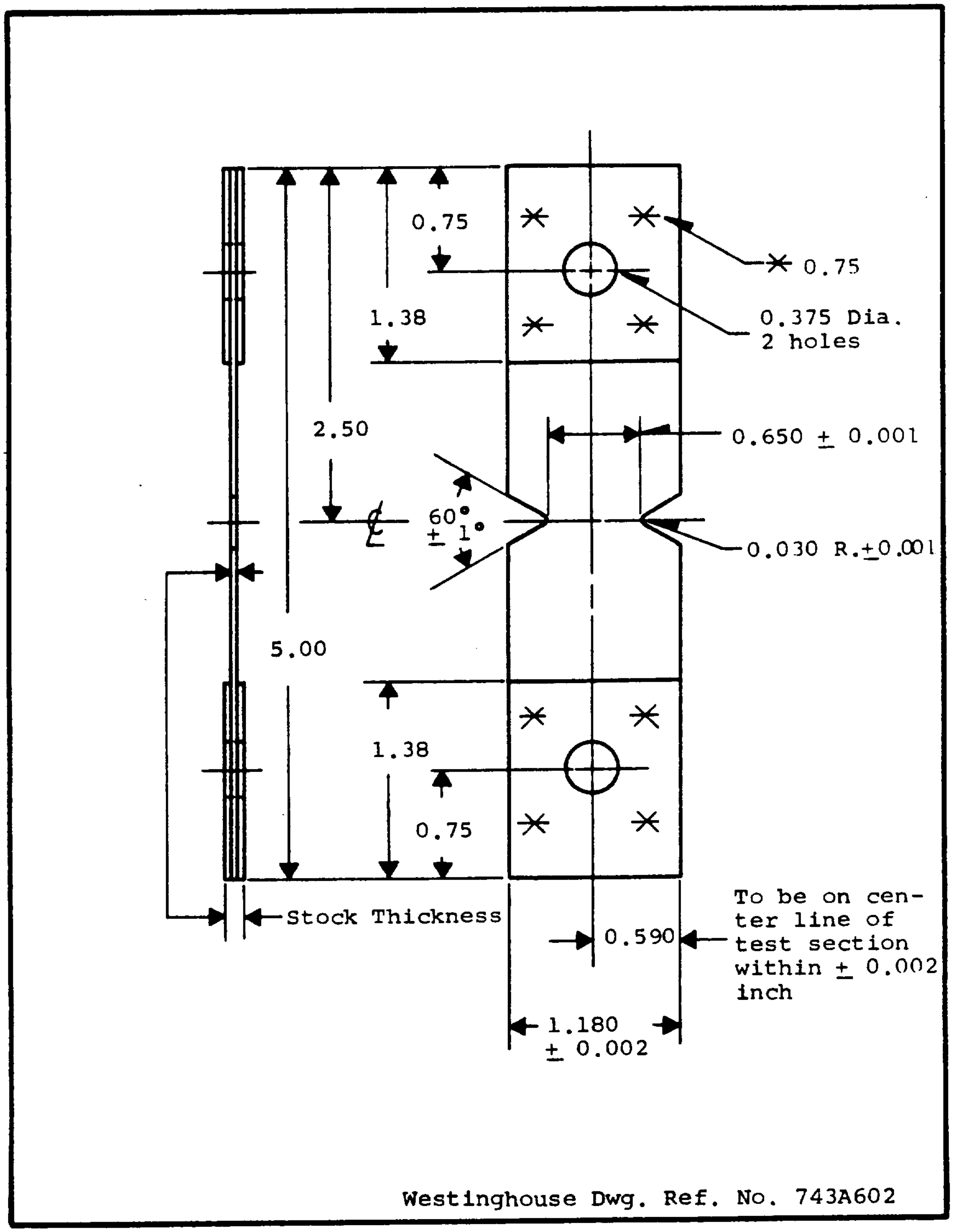


FIGURE III-28. Notched Creep Specimen for Sheet Materials

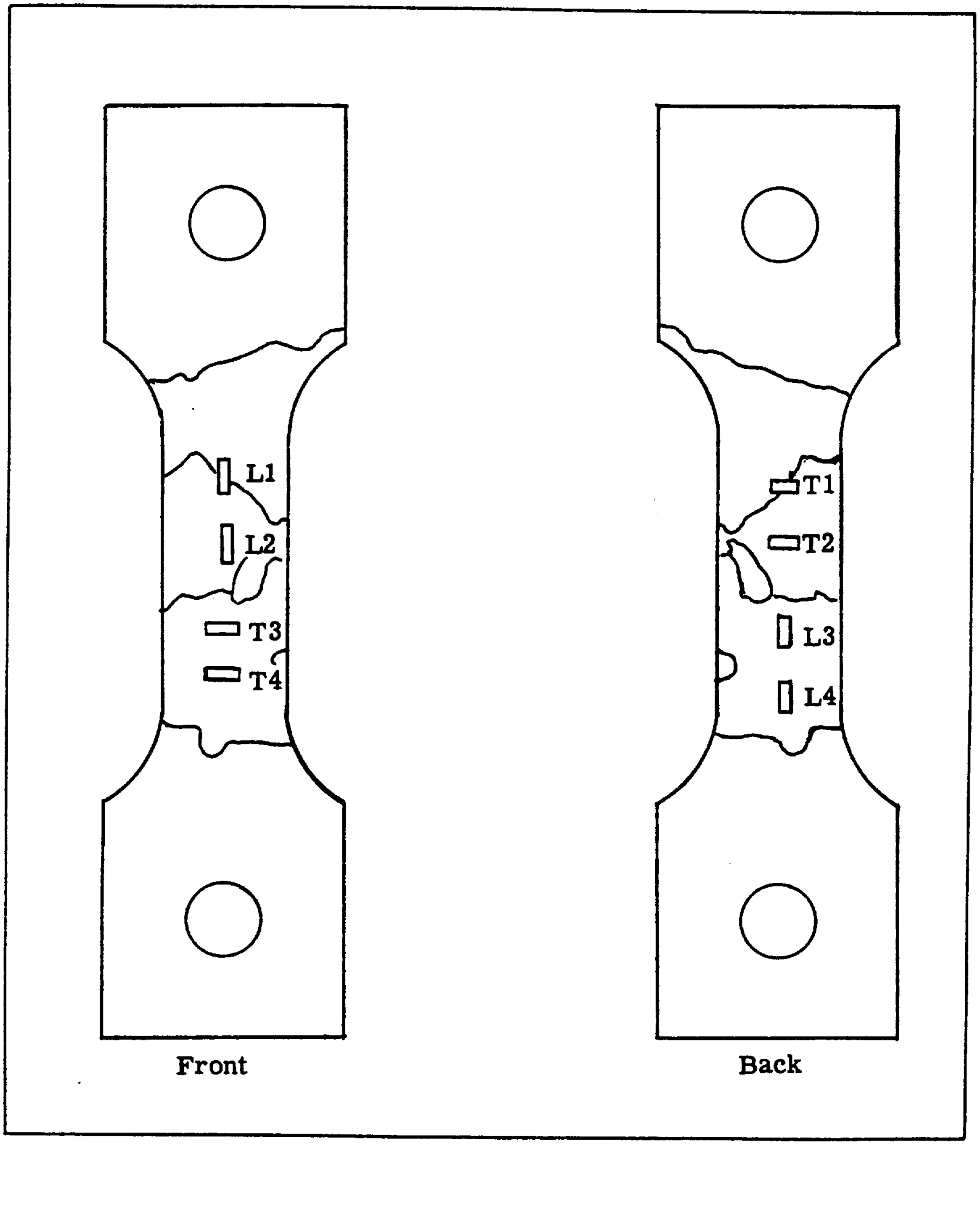


FIGURE III-29. Cubex Specimen No. 2, Showing Orientation of Gages With Reference to Cube Structure (Specimens Etched With Diversey 914)

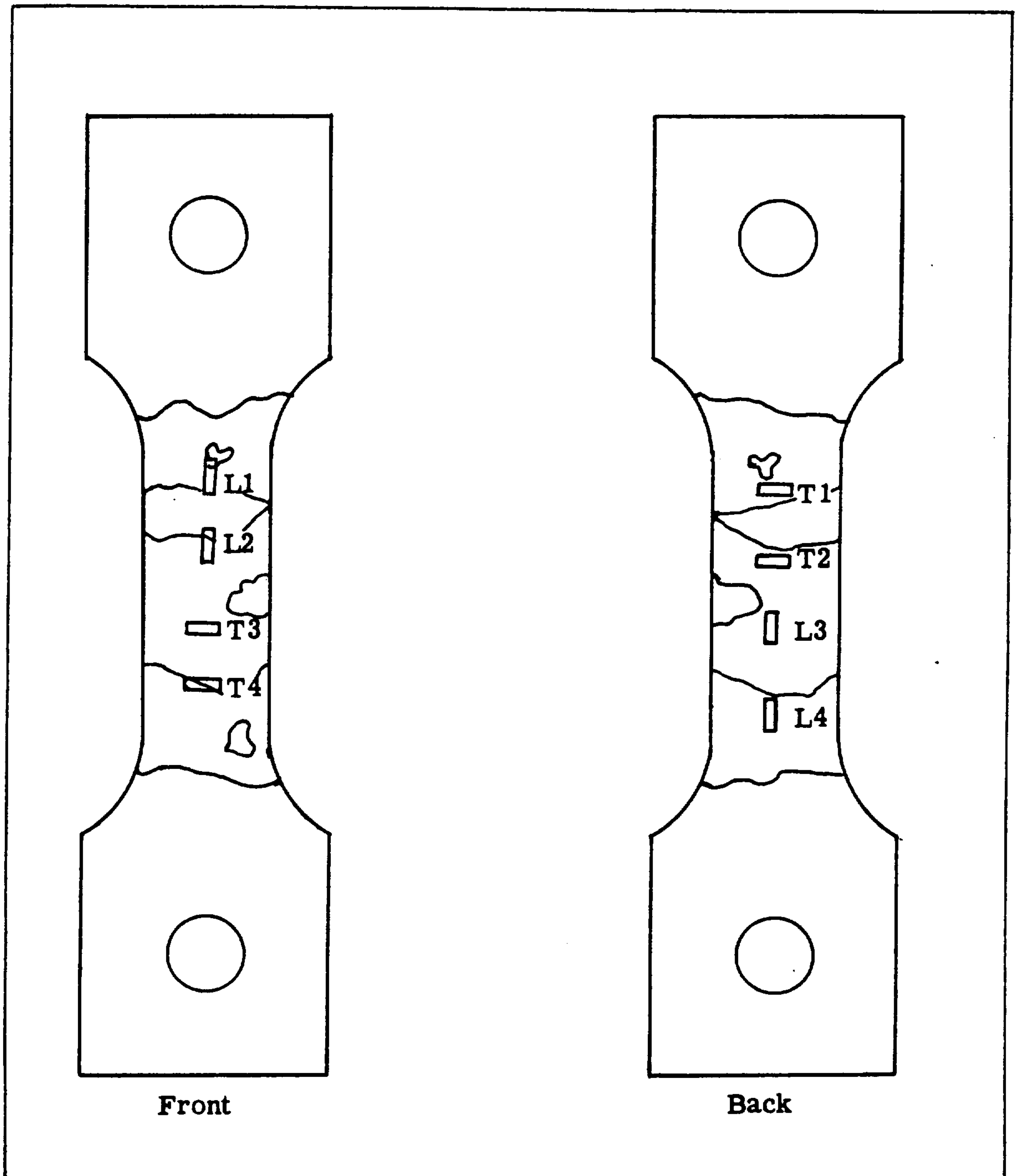


FIGURE III-30. Cubex Specimen No. 1, Showing Orientation of Gages With Reference to Cube Structure (Specimens Etched With Diversey 914)

SECTION IV

MAGNETIC MATERIALS PROPERTIES

This section presents the material properties. They are arranged as Thermophysical, Magnetic and Mechanical on Table IV-1 which is a master index of all properties listed. Each material is headed by a Materials Properties Summary where a synopsis of important parameters is available. This is valuable in screening and selecting those materials warranting further detailed analysis. This summary is important because the data presented in tabular and graphic form on each material are quite extensive.

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

IV.A.I-1

Section	A. Cubex Alloy	I. Thermophysical Properties	Curve No. or Table No. within each of the three categories
	B. Supermendur & Hiperco 50 Alloy	II. Magnetic Properties	
	C. Hiperco 27 Alloy	III. Mechanical Properties	
	D. Silicon-Iron		
	E. Maraging Steel		
	F. H-11 Steel		
	G. Nivco Alloy		

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 (substituting a, b, c, etc. within the brackets) corresponding to the material letter given above can be consulted for specific comments on the material.

References are given on each curve or table crediting the source of data. Since over 99 percent of the information was obtained on NAS 3-4162, it is referenced as such. Other sources used are also credited.

In preparing for the experiments, an analysis was made of the tests to be conducted. All equipment calibrations were checked to insure 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 two percent of the reported data. Additional controls instigated to insure useful data included: Creep-Bank specimens, leak-rate tests, and vacuum-fusion analysis of selected specimens. These precautions are discussed in Section III.

A least-squares, curve fit program for the IBM 7040 Computer was applied to fatigue, tensile, electrical resistivity, thermal expansion and specific-heat test 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.

The results of the analysis of the computer runs are as follows:

<u>Fatigue Test</u>

Out of 22 curves examined, four curves had over six percent error, with the worst being 11 percent, most others were well under six percent. Most polynomial equations were of third order or less.

<u>Tensile Test</u>

Thirty-nine sets of test data were run, of these only two had an error of approximately six percent, all others had errors of five percent of less, with the bulk of the errors being effectively zero.

The most prevalent polynomial equation selected to fit the data was of the fourth order.

Electrical Resistivity

The worst error in this case was seven percent for one case. All other cases had errors of five percent or less.

Specific Heat

Only one case has been run to date with an error of 4.4 percent. This is insufficient test data to make any general statement, but it is anticipated that this will be fairly representative.

Thermal Expansion

All fits were within four percent.

Selected polynomial expressions are printed on their respective curves for ease in using the data in computer programs or in rigorous hand calculations. No attempt was made to fit the magnetic data as smooth curves were observed in all the data analysis and polynomial expressions which can be derived do not have as broad an area of application as the other properties.

Creep data have been presented in the Larson-Miller form to facilitate long-term extrapolations. In most cases, a new Larson-Miller constant was found which represents a better fit for the data than the commonly used value of 20.

Stability tests on magnetic properties are presented up to 1000 hours. Because of the sensitivity of these tests, analytical extrapolations must be tempered with a technical understanding of the material; therefore, one interpretation of this property can be found in paragraph II. B. 1.

TABLE IV-1. Index to Magnetic Materials Properties - Tables and Curves - Listed by Page Number

Material Properties Summary	Composition, Material Name and Form	Specific Heat	Thermal Conductivity	Electrical Resistivity	DC Magnetization	AC Magnetization	Core Loss
131	3-1/4 Si-Fe	138	139	140			
	Cubex Alloy, 0.002 inch tape (SRA*)				143	152-155	141, 156-159
	Cubex Alloy, 0.002 inch tape (MFA**)				144	160-163	141, 164-167
	Cubex Alloy, 0.006 inch tape (SRA*)				146-148	176-179 184-187 192-196	141, 180-183 188-191 197-201
	Cubex Alloy, 0.006 inch tape (MFA**)				145	168-171	141, 172-175
	Cubex Alloy, 0.006 inch sheet (SRA*)				149	202-205	141, 206-209
	Cubex Alloy, 0.011 inch sheet (SRA*)				150	210-213	141, 214-217
229	49Co-49Fe-2V	229, 236	229, 232	229			
	Hiperco 50 Alloy, 0.004 sheet (SRA*)				240	242-245	246-249
	Hiperco 50 Alloy, 0.008 sheet (SRA*)				241	250-253	254-257
232	49Co-49Fe-2V	236	232	237-238			
	Supermendur, 0.002 inch tape (MFA**)				258-259	261-264 269-272	265-268 273-276
	Supermendur, 0.006 inch sheet (MFA**)				260	277-280	281-284
293	27Co-Fe	293, 299	293				
	Hiperco 27 Alloy, 0.004 inch sheet (SRA*)				305	314-317	318-321
	Hiperco 27 Alloy, 0.008 inch sheet (SRA*)				302, 306-312	322-329	302, 331-338
	Hiperco 27 Alloy, Forging (SRA*)			300-301	303		
	Hiperco 27 Alloy, Casting (SRA*)				304		
379	1Si-Fe		379	380		380	380
	AMS 5210, Casting (SRA*)	382			383-384		
389	15Ni-9Co-5Mo-0.70Al-0.70Ti-Fe			389			
	15% Nickel Maraging Steel Bar (SRA*)				397		
	15% Nickel Maraging Steel, 0.016 inch laminations (SRA*)				399	400	401
393	18Ni-8Co-4Mo-0.4Ti-Fe	393					
	18% Nickel Maraging Steel Bar (SRA*)		439	439	402		
	18% Nickel Maraging Steel, 0.014 inch laminations (SRA*)				403	404	405
427	5Cr-1Mo-0.5V-Fe AISI Grade H-11 AMS 6487, Forging (SRA*)	427	427	427	431		
	AMS 6437, 0.014 inch sheet (SRA*)				433	435-436	437-438
	AMS 6437, 0.025 inch sheet (SRA*)				434	439-440	441-442
471	23Ni-2Ti-1Zr-Co-Fe		471				
	Nivco Alloy, Forging (SRA*)	477			482		
	Nivco Alloy, 0.014 inch sheet (SRA*)				484	486	487
	Nivco Alloy, 0.025 inch sheet (SRA*)			478-481	485	488	489

*SRA - Stress Relief Annealed
**MFA - Magnetic Field Annealed

CCFR	Magnetic Stability	Poisson's Ratio	Tensile and Compressive Strength	Creep	Larson-Miller Plot	Fatigue	Goodman Diagram
				137		137	
142							
142							
142							
	151, 218-219	220	221-227				
230				231		231	
			285-289				
239				235		235	
			290-292				
296		341-346				298	
	313, 330, 339						
			347-350 354-356	347-358 361-371	357		
			351-353	359-360 372-378	359		
380			385-387	381		381	
390	398	390					
			406, 408	410-411 413-424	410	392	
394		394					
			407-409	395, 412	412	425	
429	432	429	443-444	450-451, 460			
				445-446 458-459	445-446	461, 464-469	462-463
				447-449 452-457	447-448		
473		473					
	483		490-492	496-498 500-517	496	522, 524-531	523
			493-495	499, 518-521			

MAGNETIC MATERIALS PROPERTIES SUMMARY

A. CUBEX ALLOY

A Westinghouse doubly grain oriented, 3-1/4 percent silicon iron alloy.

Availability: Limited quantities only, from the Westinghouse Electric Corporation, Pittsburgh, Pa.

Nominal Composition: 3-1/4% Si-Fe

Tested Composition: Not analyzed for exact composition. When used as a magnetic material it should be purchased to a performance requirement rather than chemical analysis.

I. Thermophysical Properties

A. Density — 7.65 grams/cc

B. Solidus Temperature — 2672°F

C. Curie Temperature — 1400°F

D. Thermal Conductivity

1.	At 72°F	17.05	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
2.	At 500°F	17.05	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
3.	At 800°F	17.05	$\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$

E. Coefficient of Thermal Expansion 72-1200°F — 7.07 in/in-°F x 10^{-6}*

F. Specific Heat

1.	At 72°F	0.109	Btu/lb-°F
2.	At 700°F	0.115	Btu/lb-°F
3.	At 900°F	0.136	Btu/lb-°F
4.	At 1100°F	0.204	Btu/lb-°F

*U.S. Steel Product 1. Temperature value for 3-1/4 percent silicon-iron.

G. Electrical Resistivity

1.	At 77°F	44.53×10^{-6} ohm-cm
2.	At 511°F	57.98×10^{-6} ohm-cm
3.	At 700°F	66.36×10^{-6} ohm-cm
4.	At 900°F	79.66×10^{-6} ohm-cm
5.	At 1100°F	89.94×10^{-6} ohm-cm

II. Magnetic Properties (All magnetic materials are stress relief annealed (SRA) unless otherwise specified)

A. D-C Properties

1. 0.002 inch thick tape-wound toroid (stress relief annealed)

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	20.4 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 500°F	19.2 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 800°F	17.6 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 1100°F	14.9 kilogauss

2. 0.002 inch thick tape-wound toroid (magnetic field annealed)

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	20.8 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 800°F	17.9 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 1100°F	14.9 kilogauss

3. 0.006 inch thick tape-wound toroid (stress relief annealed)

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	20.5 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 500°F	19.5 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 800°F	17.8 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 1100°F	15.0 kilogauss

4. 0.006 inch thick tape-wound toroid (magnetic field annealed)

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	20.6 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 500°F	19.5 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 800°F	17.6 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 1100°F	14.5 kilogauss

5. 0.006 inch thick laminations (stress relief annealed)

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	20.3 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 500°F	19.1 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 800°F	18.0 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 1100°F	15.3 kilogauss

6. 0.011 inch thick laminations (stress relief annealed)

   a. Induction (B_{tip}) for H = 250 oersteds at 72°F 19.9 kilogauss
   b. Induction (B_{tip}) for H = 250 oersteds at 500°F 19.1 kilogauss
   c. Induction (B_{tip}) for H = 250 oersteds at 700°F 18.3 kilogauss
   d. Induction (B_{tip}) for H = 200 oersteds at 1100°F 14.3 kilogauss

B. A-C Magnetic Properties (400 cycle)

1. 0.002 inch thick tape-wound toroid (stress relief annealed)

   a. Exciting volt-amperes, B = 15 kilogauss at 72°F 9.1 volt-amperes/pound
   b. Exciting volt-amperes, B = 15 kilogauss at 500°F 9.8 volt-amperes/pound
   c. Exciting volt-amperes, B = 15 kilogauss at 800°F 14.3 volt-amperes/pound
   d. Exciting volt-amperes, B = 13 kilogauss at 1100°F 22.1 volt-amperes/pound
   e. Core loss, B = 15 kilogauss at 72°F 6.8 watts/pound
   f. Core loss, B = 15 kilogauss at 500°F 5.6 watts/pound
   g. Core loss, B = 15 kilogauss at 800°F 4.4 watts/pound
   h. Core loss, B = 13 kilogauss at 1100°F 2.8 watts/pound

2. 0.002 inch thick tape-wound toroid (magnetic field annealed)

   a. Exciting volt-amperes, B = 15 kilogauss at 72°F 7.3 volt-amperes/pound
   b. Exciting volt-amperes, B = 15 kilogauss at 800°F 17.8 volt-amperes/pound
   c. Exciting volt-amperes, B = 13 kilogauss at 1100°F 19.5 volt-amperes/pound
   d. Core loss, B = 15 kilogauss at 72°F 6.1 watts/pound
   e. Core loss, B = 15 kilogauss at 800°F 4.7 watts/pound
   f. Core loss, B = 13 kilogauss at 1100°F 2.9 watts/pound

3. 0.006 inch thick tape-wound toroid (stress relief annealed)

a.	Exciting volt-amperes, B = 15 kilogauss at 72°F	18.5 volt-amperes/pound
b.	Exciting volt-amperes, B = 15 kilogauss at 800°F	55.8 volt-amperes/pound
c.	Exciting volt-amperes, B = 13 kilogauss at 1100°F	45.8 volt-amperes/pound
d.	Core loss, B = 15 kilogauss at 72°F	9.5 watts/pound
e.	Core loss, B = 15 kilogauss at 800°F	7.0 watts/pound
f.	Core loss, B = 13 kilogauss at 1100°F	3.9 watts/pound

4. 0.006 inch thick tape-wound toroid (magnetic field annealed)

a.	Exciting volt-amperes, B = 15 kilogauss at 72°F	19.3 volt-amperes/pound
b.	Exciting volt-amperes, B = 15 kilogauss at 800°F	69.8 volt-amperes/pound
c.	Exciting volt-amperes, B = 13 kilogauss at 1100°F	58.4 volt-amperes/pound
d.	Core loss, B = 15 kilogauss at 72°F	10.2 watts/pound
e.	Core loss, B = 15 kilogauss at 800°F	7.0 watts/pound
f.	Core loss, B = 13 kilogauss at 1100°F	3.8 watts/pound

5. 0.006 inch thick laminations (stress relief annealed)

a.	Exciting volt-amperes, B = 15 kilogauss at 72°F	46.5 volt-amperes/pound
b.	Exciting volt-amperes, B = 15 kilogauss at 800°F	133 volt amperes/pound
c.	Exciting volt-amperes, B = 13 kilogauss at 1100°F	75 volt-amperes/pound
d.	Core loss, B = 15 kilogauss at 72°F	11.5 watts/pound
e.	Core loss, B = 15 kilogauss at 800°F	7.8 watts/pound
f.	Core loss, B = 13 kilogauss at 1100°F	4.2 watts/pound

6. 0.011 inch thick laminations (stress relief annealed)

a.	Exciting volt-amperes, $B = 15$ kilogauss at 72°F	46 volt-amperes/pound
b.	Exciting volt-amperes, $B = 15$ kilogauss at 800°F	120 volt-amperes/pound
c.	Exciting volt-amperes, $B = 14$ kilogauss at 1100°F	250 volt-amperes/pound
d.	Core loss, $B = 15$ kilogauss at 72°F	13.0 watts/pound
e.	Core loss, $B = 15$ kilogauss at 800°F	9.8 watts/pound
f.	Core loss, $B = 15$ kilogauss at 1100°F	7.0 watts/pounds

C. Constant Current Flux Reset Properties (CCFR) 0.002 inch thick Tape-Wound Toroid (MFA)

1. At 72°F

a. B_m at 10 oersteds = 19.20 kilogauss (SAT/2)

b. $B_m - B_r = 1.10$ kilogauss

c. $H_1 = 0.42$ oersteds (AT)

d. $H_2 = 0.49$ oersteds (AT + DAT)

e. $H_0 = 0.45$ oersteds (AT + $\frac{1}{2}$ DAT)

2. At 500°F

a. B_m at 10 oersteds = 18.25 kilogauss (SAT/2)

b. $B_m - B_r = 2.0$ kilogauss

c. $H_1 = 0.28$ oersteds (AT)

d. $H_2 = 0.34$ oersteds (AT + DAT)

e. $H_0 = 0.31$ oersteds (AT + $\frac{1}{2}$ DAT)

3. At 1100° F

a. B_m at 10 oersteds = 13.85 kilogauss (SAT/2)

b. $B_m - B_r = 4.2$ kilogauss

c. $H_1 = 0.12$ oersteds (AT)

d. $H_2 = 0.165$ oersteds (AT + DAT)

e. $H_0 = 0.14$ oersteds (AT + $\frac{1}{2}$ DAT)

III. Mechanical Properties

A. Poisson's Ratio at 72°F (Average of 6 variable readings) 0.335

B. Tensile and Compressive Properties

1. At 72°F

		Longitudinal	Transverse
a.	0.02 percent offset yield strength	37,150 psi	39,050 psi*
b.	Tensile strength	40,200 psi	46,400 psi
c.	Elongation in two inches	22.0 percent	14.5 percent
d.	Modulus of Elasticity	22×10^6 psi	-
e.	Compressive yield strength	37,120 psi	40,600 psi

2. At 500°F

a.	0.02 percent offset yield strength	27,300 psi	29,800 psi
b.	Tensile strength	40,800 psi	41,200 psi
c.	Elongation in two inches	21.0 percent	38.0 percent
d.	Modulus of elasticity	13.5×10^6 psi	-
e.	Compressive yield strength	32,950 psi	30,800 psi

3. At 800°F

a.	0.02 percent offset yield strength	25,300 psi	25,200 psi
b.	Tensile strength	32,250 psi	34,350 psi
c.	Elongation in two inches	11.9 percent	10.0 percent
d.	Modulus of elasticity	9×10^6 psi	-
e.	Compressive yield strength	29,200 psi	27,500 psi

4. At 1100°F

a.	0.02 percent offset yield strength	14,750 psi	12,900 psi*
b.	Tensile strength	16,650 psi	13,350 psi
c.	Elongation in two inches	26.0 percent	11.5 percent
d.	Modulus of elasticity	6×10^6 psi	-
e.	Compressive yield strength (0.02 percent offset)	11,100 psi	11,325 psi

*Upper Yield Point

C. Creep: Material not used in highly stressed applications.

D. Fatigue: Material not used in cyclic stressed applications.

E. Normal Stress Relief Heat Treatment:

Heat to 800°C ± 10°C in an atmosphere of purified dry hydrogen, hold two hours at temperature, furnace cool to below 150°C.

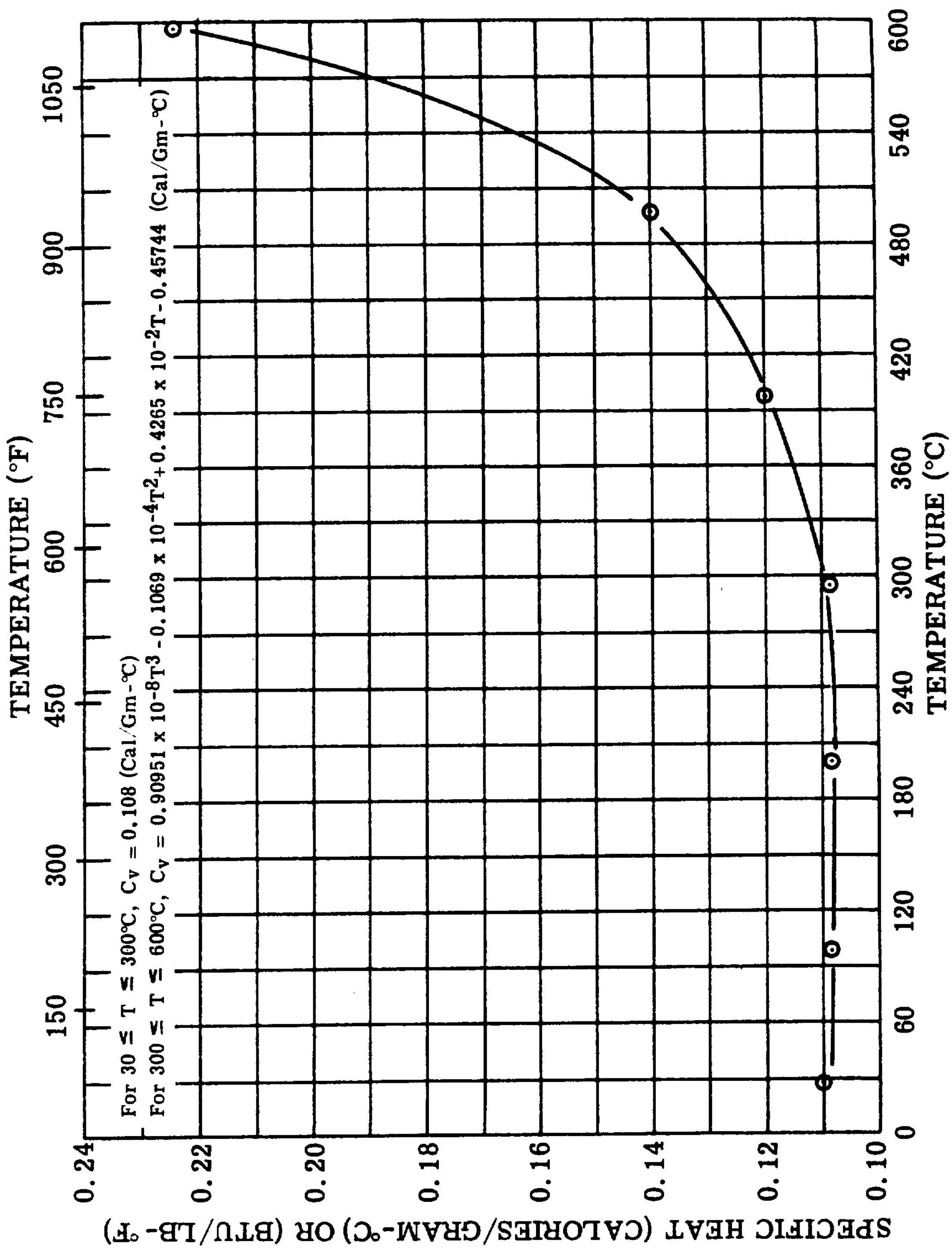


FIGURE I V. A. I-1. Specific Heat, Cubex Alloy Measured in Vacuum (10^{-5} torr)
(Reference: NAS3-4162)

Figure I V. A. I-1. Specific Heat - Cubex

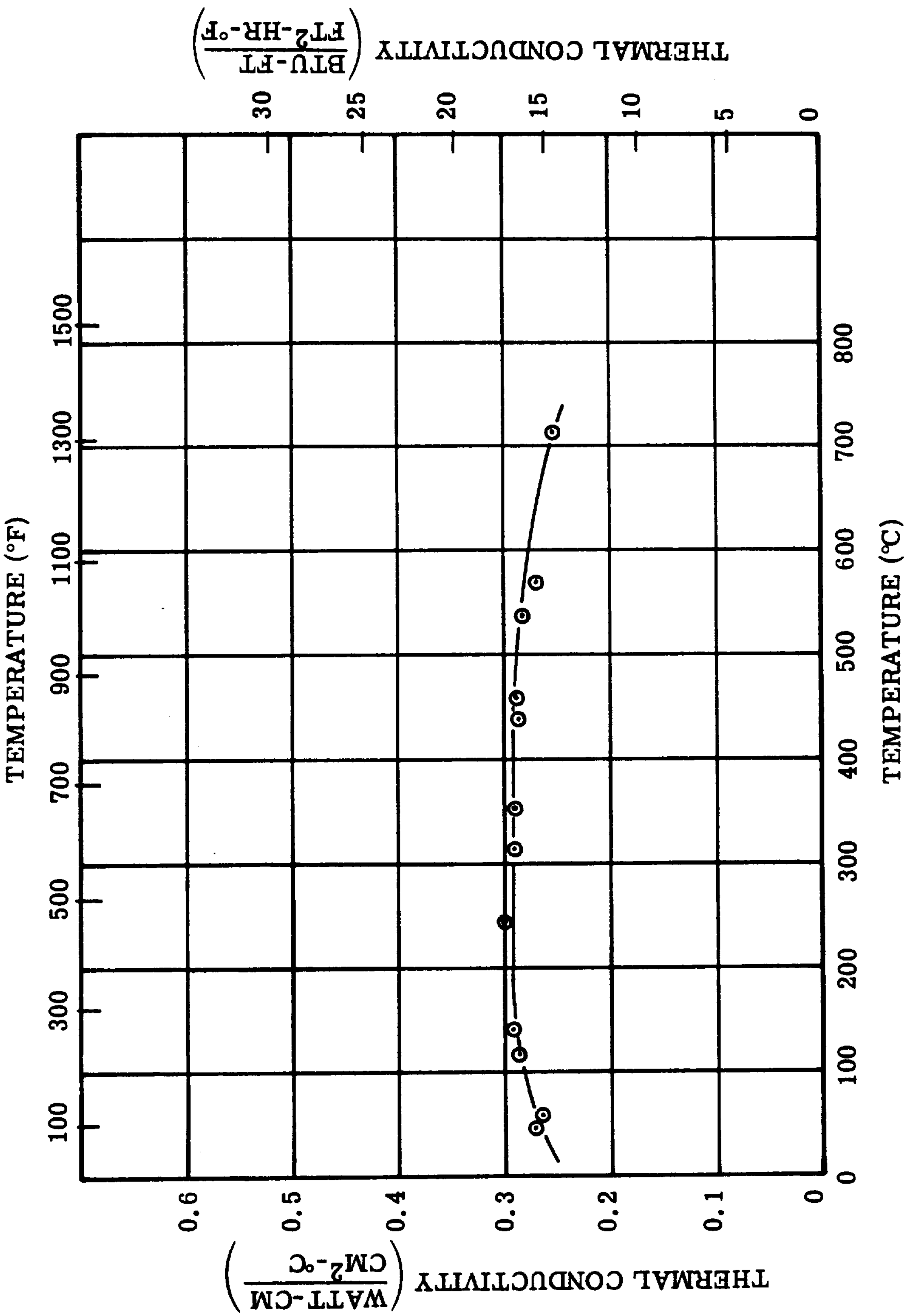


FIGURE IV. A. I-2. Thermal Conductivity of Cubex Alloy in Vacuum. (Reference: NAS 3-4162)

Figure IV. A. I-2. Thermal Conductivity - Cubex

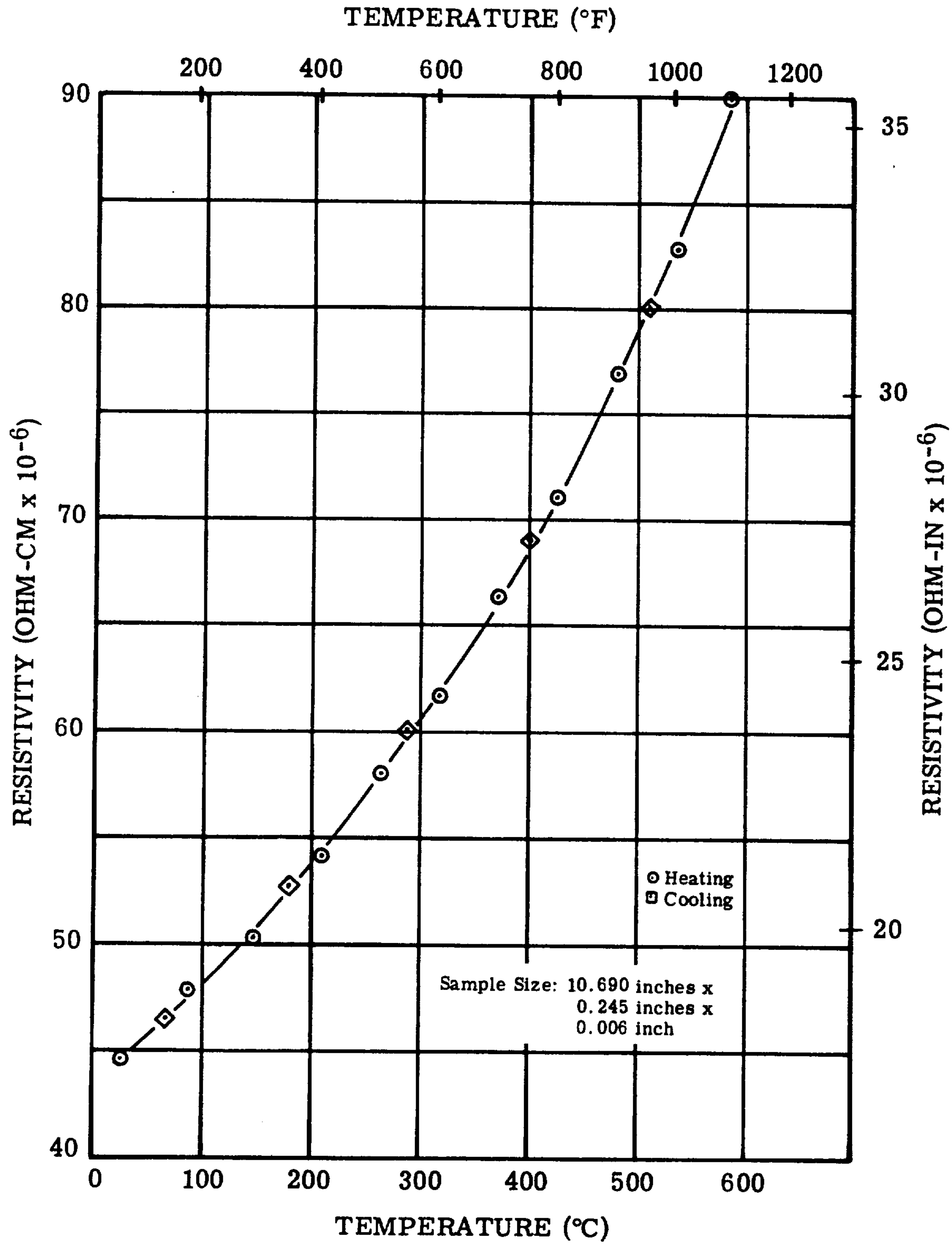


FIGURE IV.A.I-3. Electrical Resistivity of Cubex Alloy 0.006 Inch Sheet. SRA Condition, Tested in Vacuum 1×10^{-4} torr. (Reference: Westinghouse Research Laboratories Test Data)

Figure IV.A.I-3. Resistivity - Cubex

TABLE IV. A. II-1. Summary of Core Losses of Cubex Alloy
(Core Loss (Watts/Pound))

Material	400 cps 15 kilogauss		800 cps 12 kilogauss		1600 cps 12 kilogauss		3200 cps 8 kilogauss	
	72°F	1100°F	72°F	1100°F	72°F	1100°F	72°F	1100°F
Toroid, Sample No. 1 0.006 inch thick tape, SRA	9.4	--	17.5	8.8	49.0	26.5	68.0	38.0
Toroid, Sample No. 2 0.006 inch thick tape, SRA	9.8	--	17.5	8.9	50.8	26.5	70.0	39.5
Toroid, Sample No. 3 0.006 inch thick tape, SRA	9.2	--	16.0	8.8	44.4	26.1	62.5	43.5
Ring Laminations 0.006 inch thick, SRA	11.5	--	28.0	10.0	55.0	31.0	100.0	47.0
Toroid 0.002 inch thick tape, SRA	6.8	--	11.0	5.5	27.0	13.7	38.0	19.5
Toroid 0.002 inch thick tape, MFA	6.0	--	9.7	6.0	24.5	16.0	37.5	23.5
Ring Laminations 0.011 inch thick, SRA	19.2	--	39.0	22.0	28.5	--	170.0	122.0

SRA - Stress relief anneal
MFA - Magnetic field anneal

TABLE IV.A.II-2. Constant Current Flux Reset (CCFR) Properties+ of Cubex Alloy (400 cps - Sine Wave)

CUBEX ALLOY												
Core	Material Thickness in inches	Core Size	Treat-ment	Temper-ature (°F)	Test Environ-ment	H_m (Oersted)	B_m (Kilogauss)	$B_m - B_r$ (Kilogauss)	$\frac{B_r}{B_m}$	H_0 (Oersteds)	H_1 (Oersteds)	H_2 (Oersteds)
1	0.002	A	SRA	72	Air	10.0	16.15	4.52	0.720	0.570	0.474	0.696
				500	Air	10.0	15.33	6.98	0.545	0.363	0.252	0.554
				1100	Argon	10.0	11.75	6.15	0.477	0.128	0.083	0.212
				72++	Air	10.0	16.42	5.15	0.686	0.582	0.514	0.680
2	0.002	A	MFA	72	Air	10.0	19.00	1.18	0.938	0.453	0.418	0.484
				500	Argon	10.0	17.76	2.32	0.869	0.305	0.277	0.340
				1100	Argon	10.0	13.68	4.18	0.694	0.126	0.108	0.148
				72++	Air	10.0	18.96	2.80	0.852	0.509	0.448	0.567
3	0.002	B	SRA	72	Air	10.0	18.08	7.02	0.612	0.618	0.530	0.733
				500	Air	10.0	16.42	8.07	0.509	0.400	0.288	0.568
				1100	Argon	10.0	12.91	8.23	0.363	0.216	0.053	0.384
				72++	Air	10.0	17.56	6.02	0.657	0.705	0.574	0.850
4	0.002	B	SRA	72	Air	10.0	17.74	6.34	0.643	0.660	0.548	0.785
				500	Air	10.0	16.49	8.24	0.500	0.535	0.296	0.565
				1100	Argon	10.0	12.67	8.11	0.360	0.207	0.050	0.353
				72++	Air	10.0	17.59	6.27	0.644	0.618	0.532	0.720
7	0.006	A	SRA	72	Air	10.0	16.46	3.83	0.768	0.526	0.436	0.604
				500	Air	10.0	15.84	4.44	0.720	0.393	0.318	0.469
				1100	Argon	10.0	12.62	5.35	0.580	0.156	0.116	0.206
11	0.006	B	SRA	72	Air	10.0	16.52	2.66	0.839	0.473	0.272	0.669
				500	Air	10.0	15.02	8.62	0.426	0.305	0.123	0.512
				1100	Argon	10.0	12.37	7.46	0.397	0.179	0.078	0.339
				72++	Air	10.0	16.88	7.58	0.551	0.493	0.294	0.658
12	0.006	B	SRA	72	Air	10.0	16.60	7.75	0.533	0.473	0.269	0.655
				500	Air	10.0	15.49	8.53	0.449	0.358	0.160	0.571
				1100	Argon	10.0	12.63	7.62	0.397	0.193	0.070	0.515
				72++	Air	10.0	16.54	7.62	0.539	0.479	0.283	0.655

A Toroid 3-1/2 inch x 4 inch x 1/2 inch
B Toroid 1 inch x 1-1/4 inch x 1/4 inch
MFA Magnetic field anneal
SRA Stress relief anneal
\+ Test procedure for Toroidal Magnetic Amplifier Cores. AIEE No. 432. January 1959
++ Room temperature test after 1100°F exposure

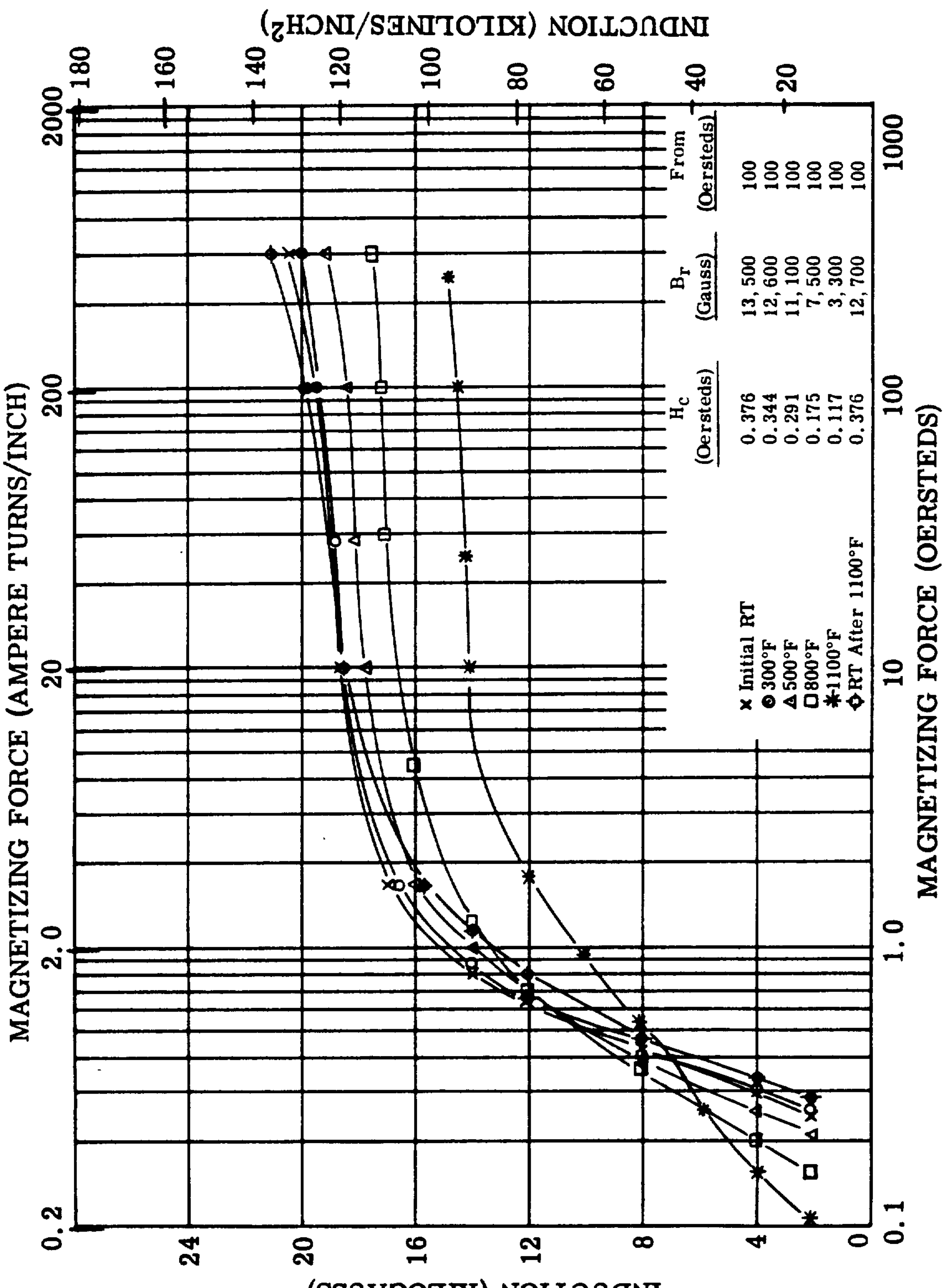


FIGURE IV.A.II-1. D-C Magnetization Curves. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon Above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-1. D-C Magnetization - Cubex

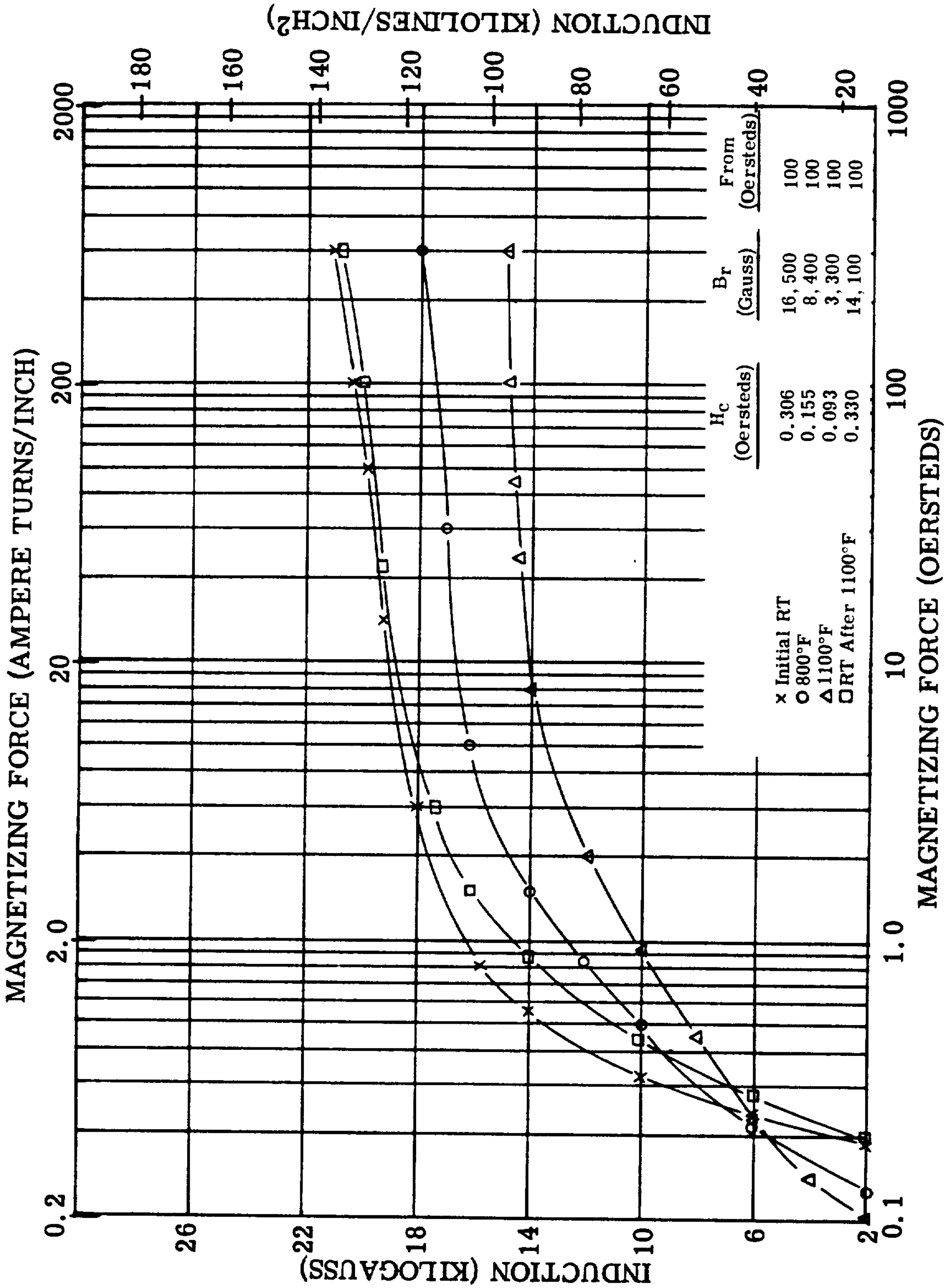


FIGURE IV.A.II-2. D-C Magnetization Curves. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-2. D-C Magnetization - Cubex

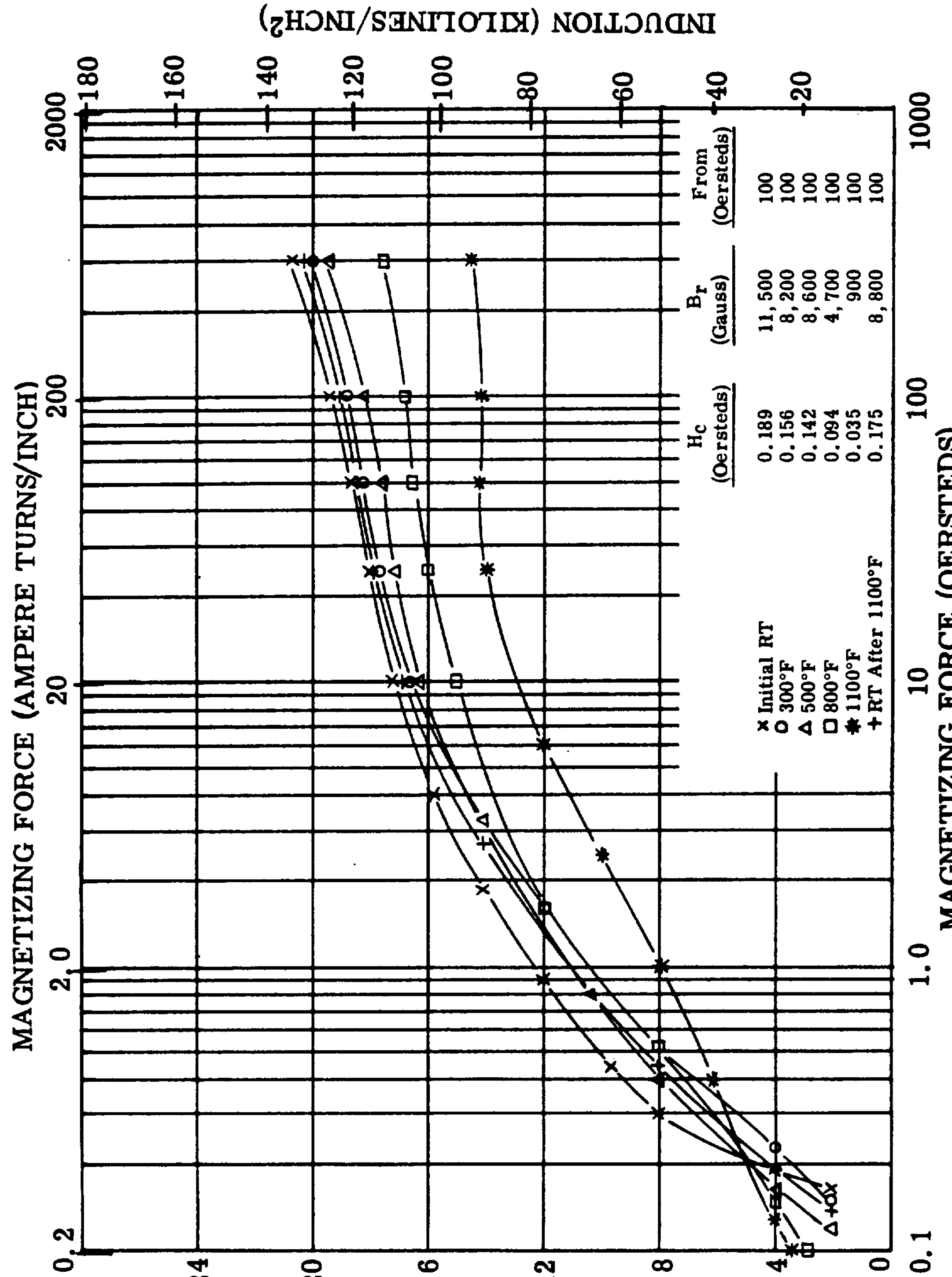


FIGURE IV. A. II-3. D-C Magnetization Curves. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500 °F, Argon Above 500 °F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-3. D-C Magnetization - Cubex

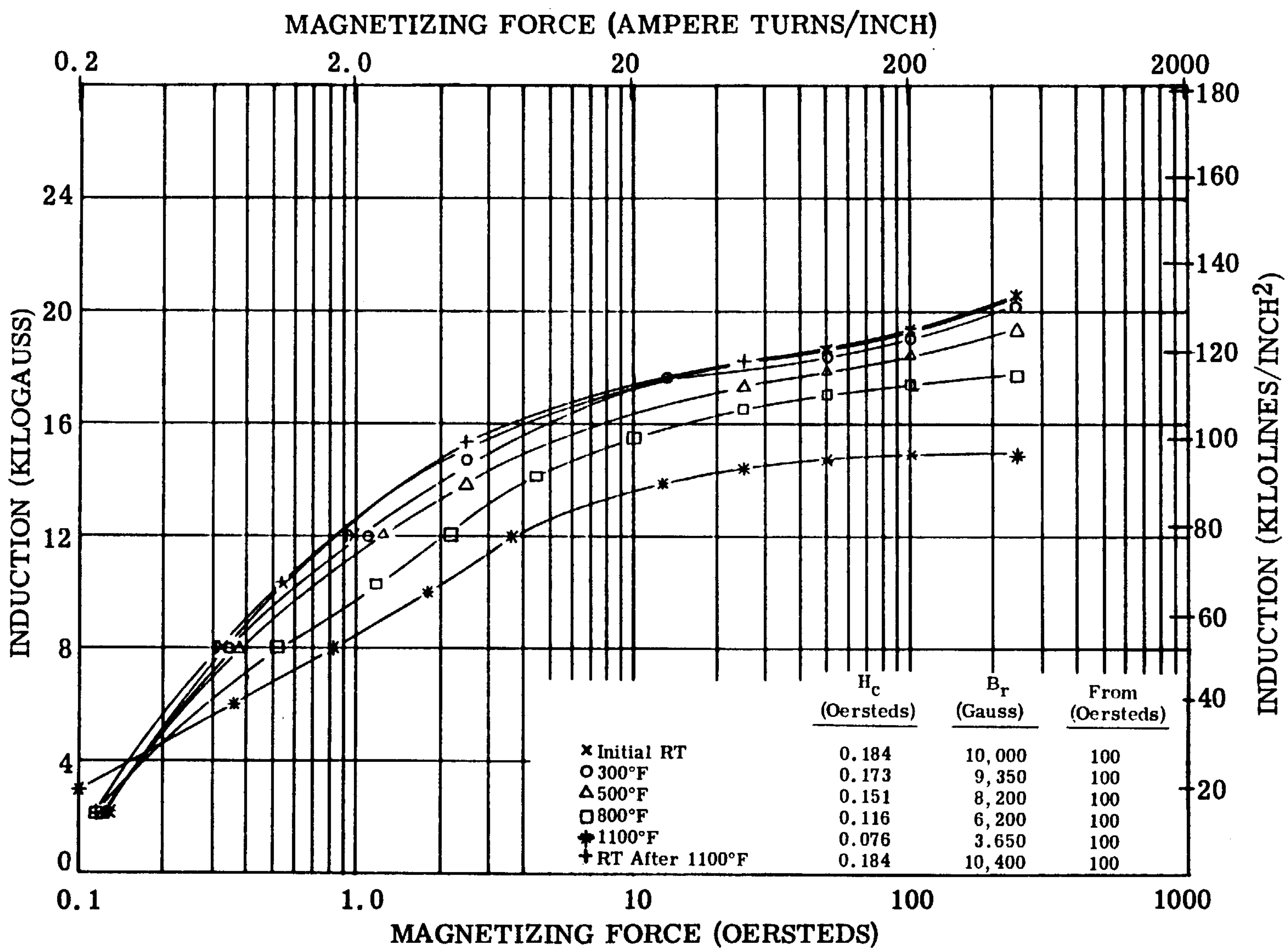


FIGURE IV. A. II-4. D-C Magnetization Curves. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-4. D-C Magnetization - Cubex

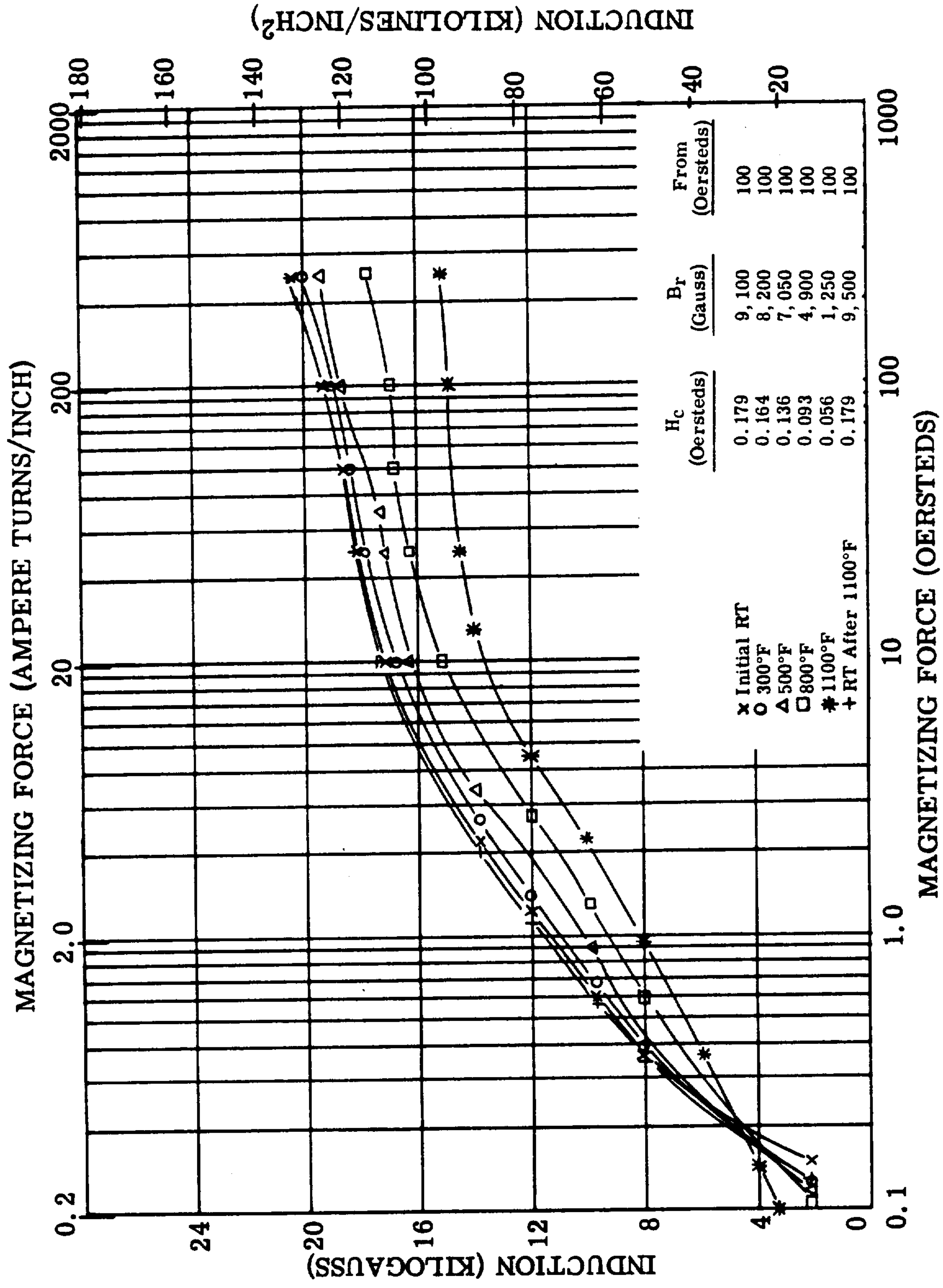


FIGURE IV. A. II-5. D-C Magnetization Curves. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-5. D-C Magnetization - Cubex

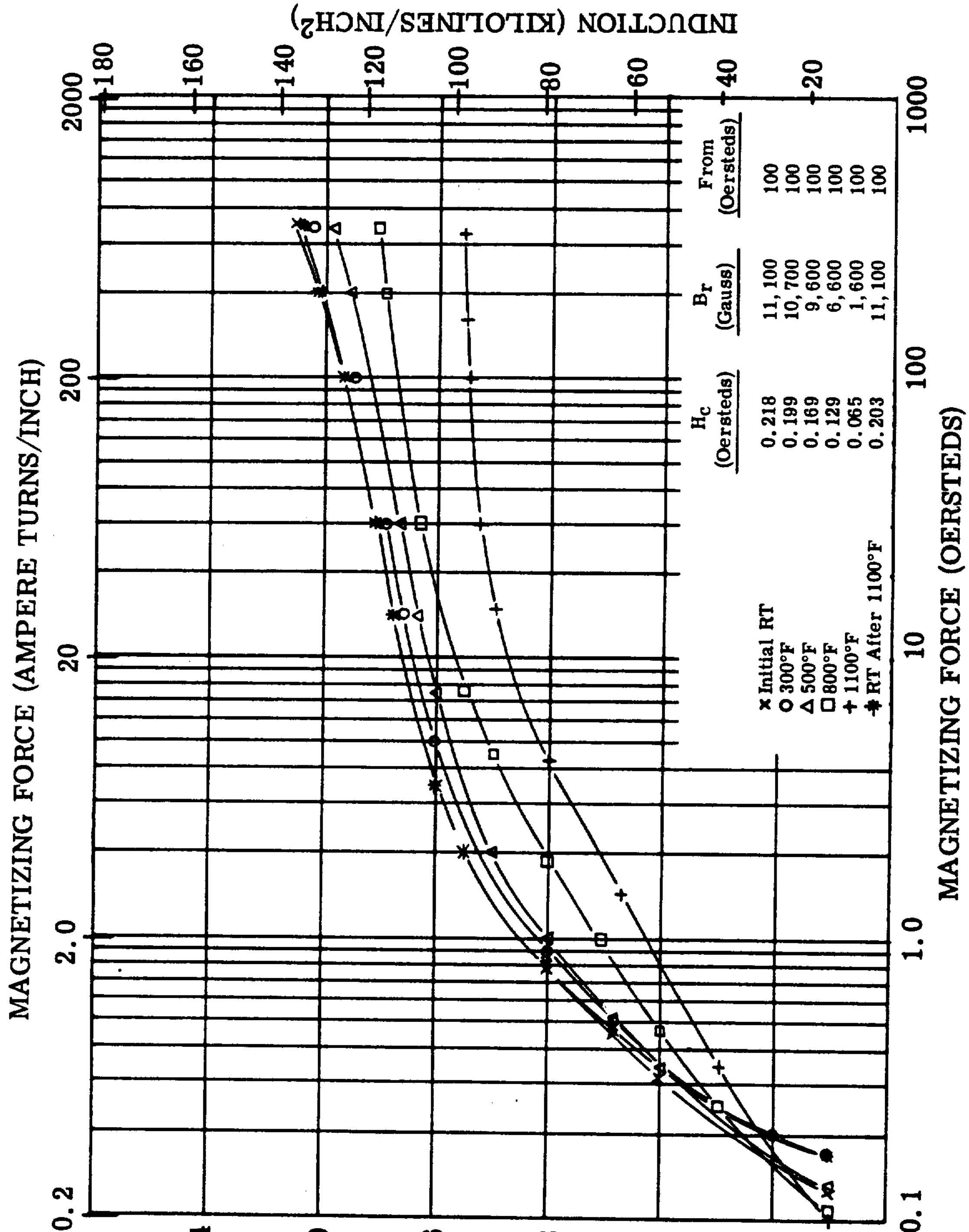


FIGURE IV. A. II-6. D-C Magnetization Curves. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-6. D-C Magnetization - Cubex

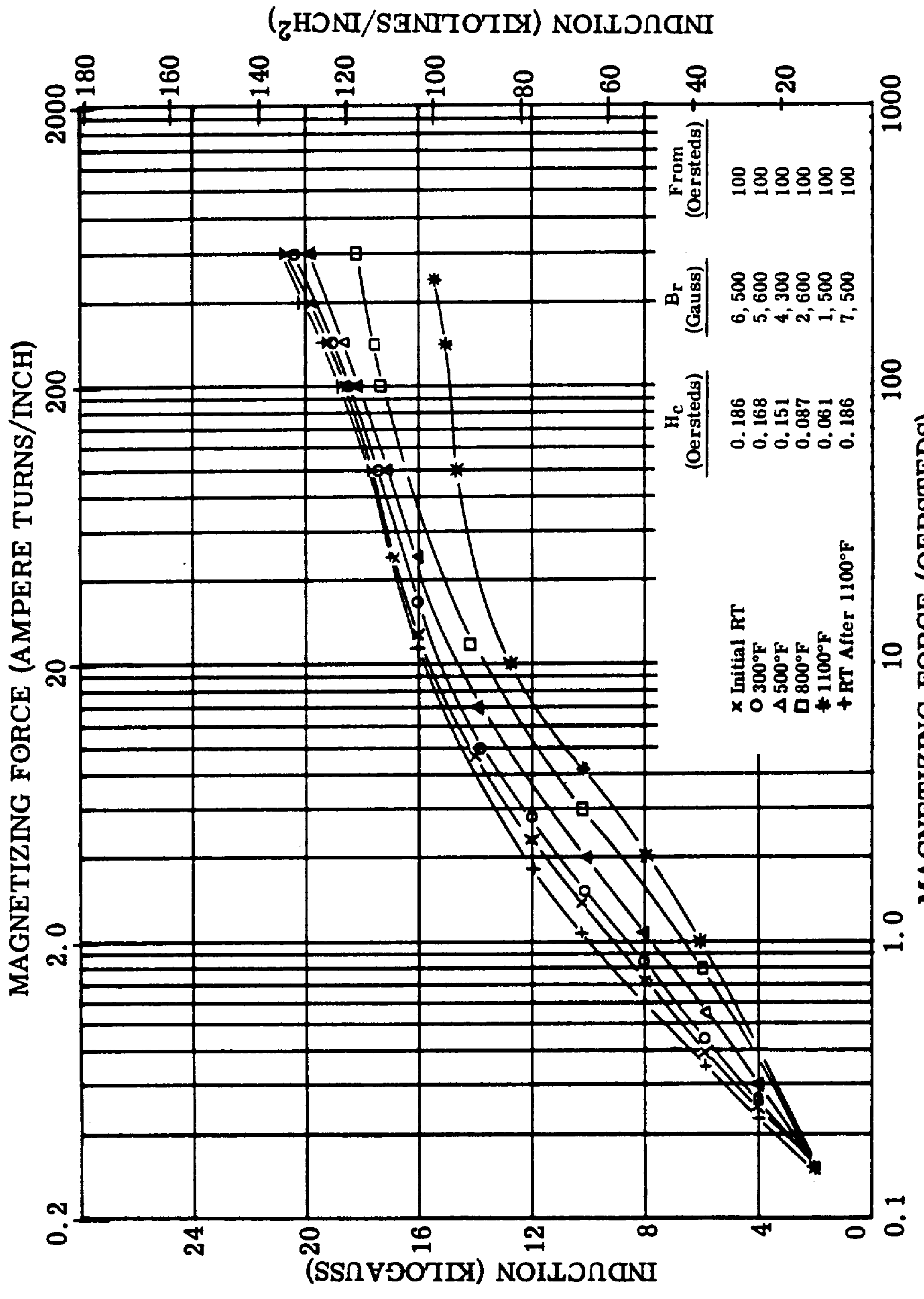


FIGURE IV.A.II-7. D-C Magnetization Curves. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-7. D-C Magnetization - Cubex

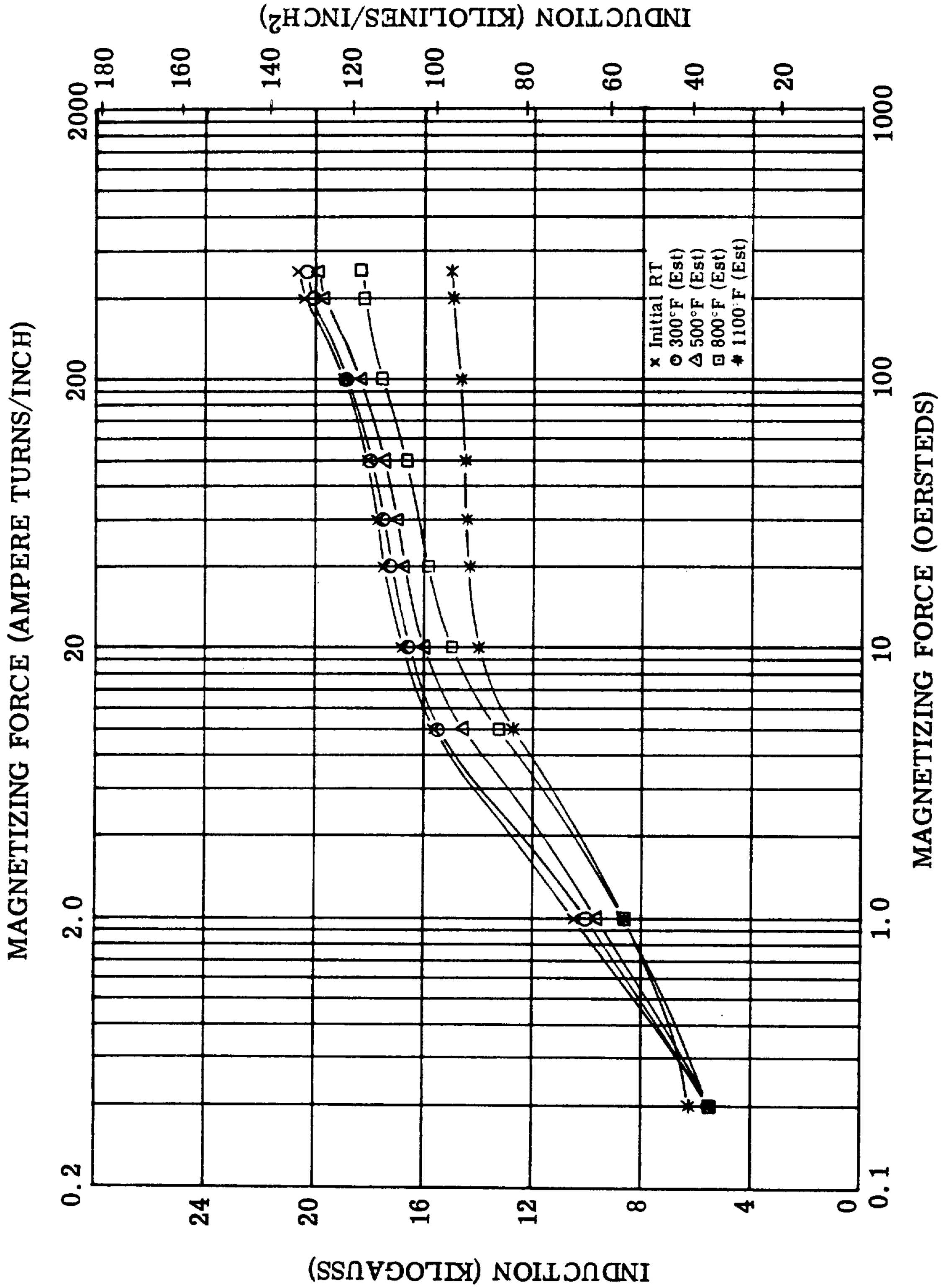


FIGURE IV.A.II-8. D-C Magnetization Curves. Cubex 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.A.II-8. D-C Magnetization - Cubex

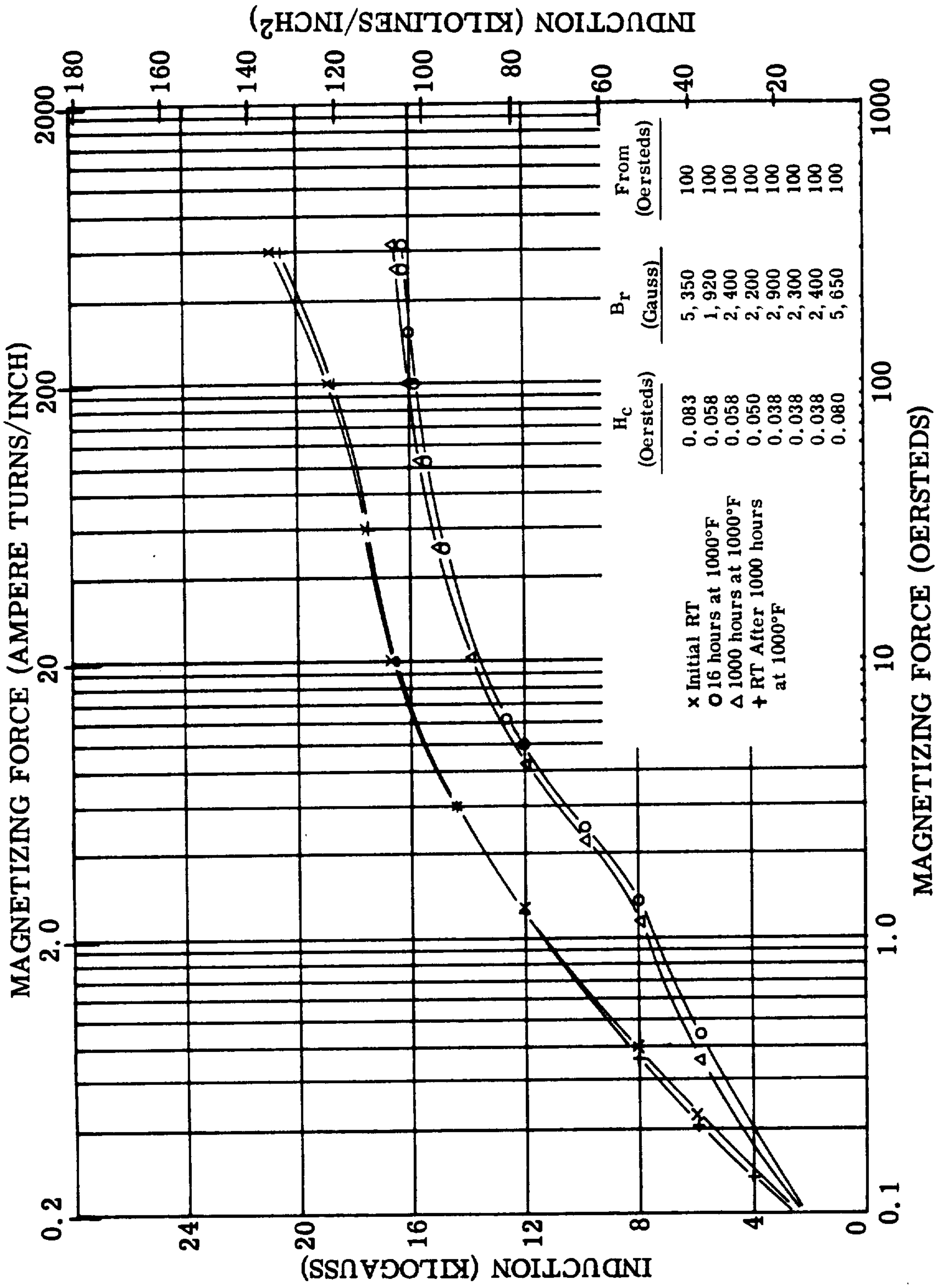


FIGURE IV.A.II-9. D-C Magnetization Curves. Cubex Alloy 0.011 Inch Laminations - Aging Test. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.A.II-9. D-C Magnetization - Cubex

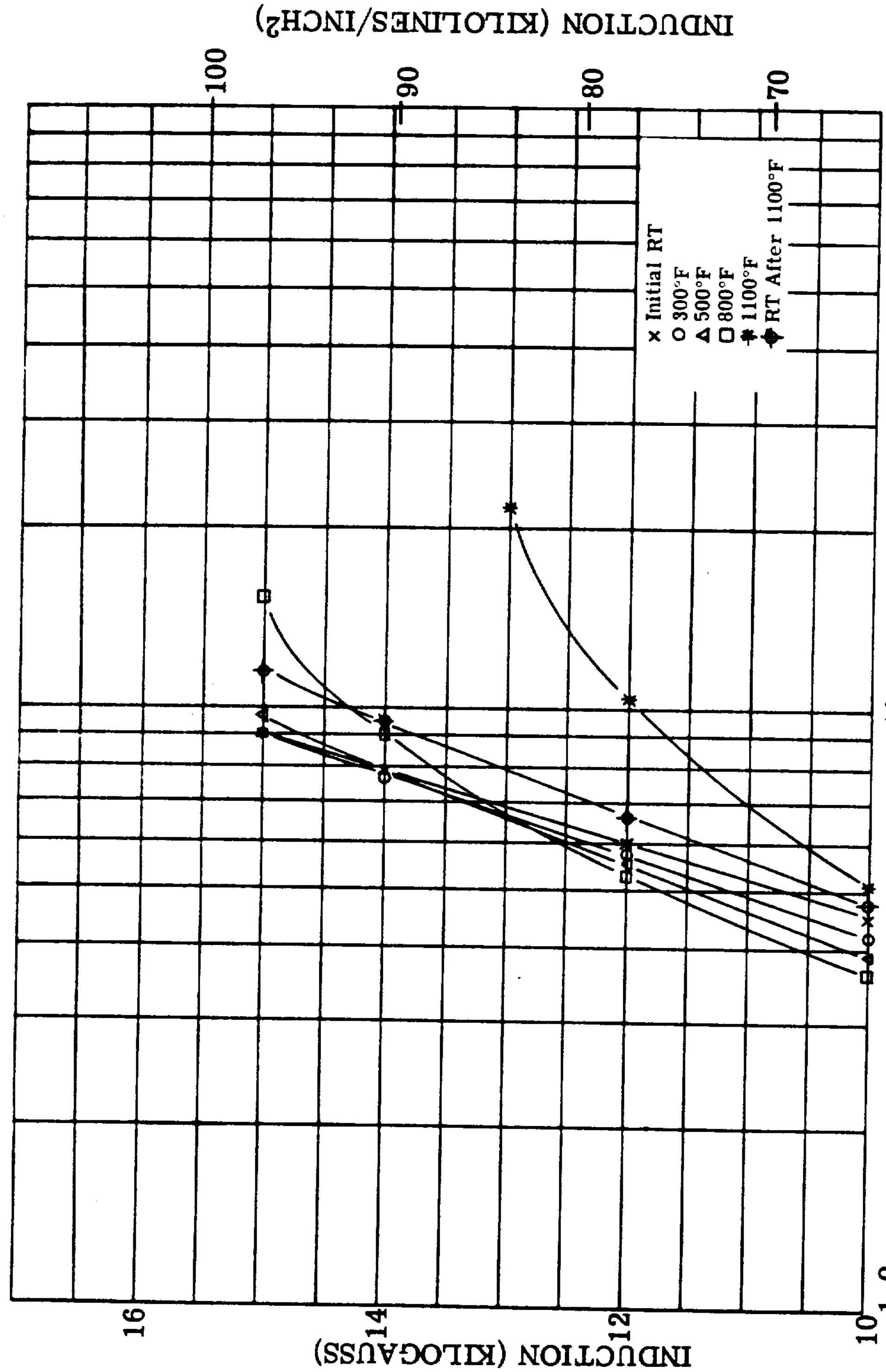


FIGURE IV.A.II-10. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-10. Exciting VA, 400 CPS. Cubex

Figure IV. A. II-11. Exciting VA, 800 CPS. Cubex

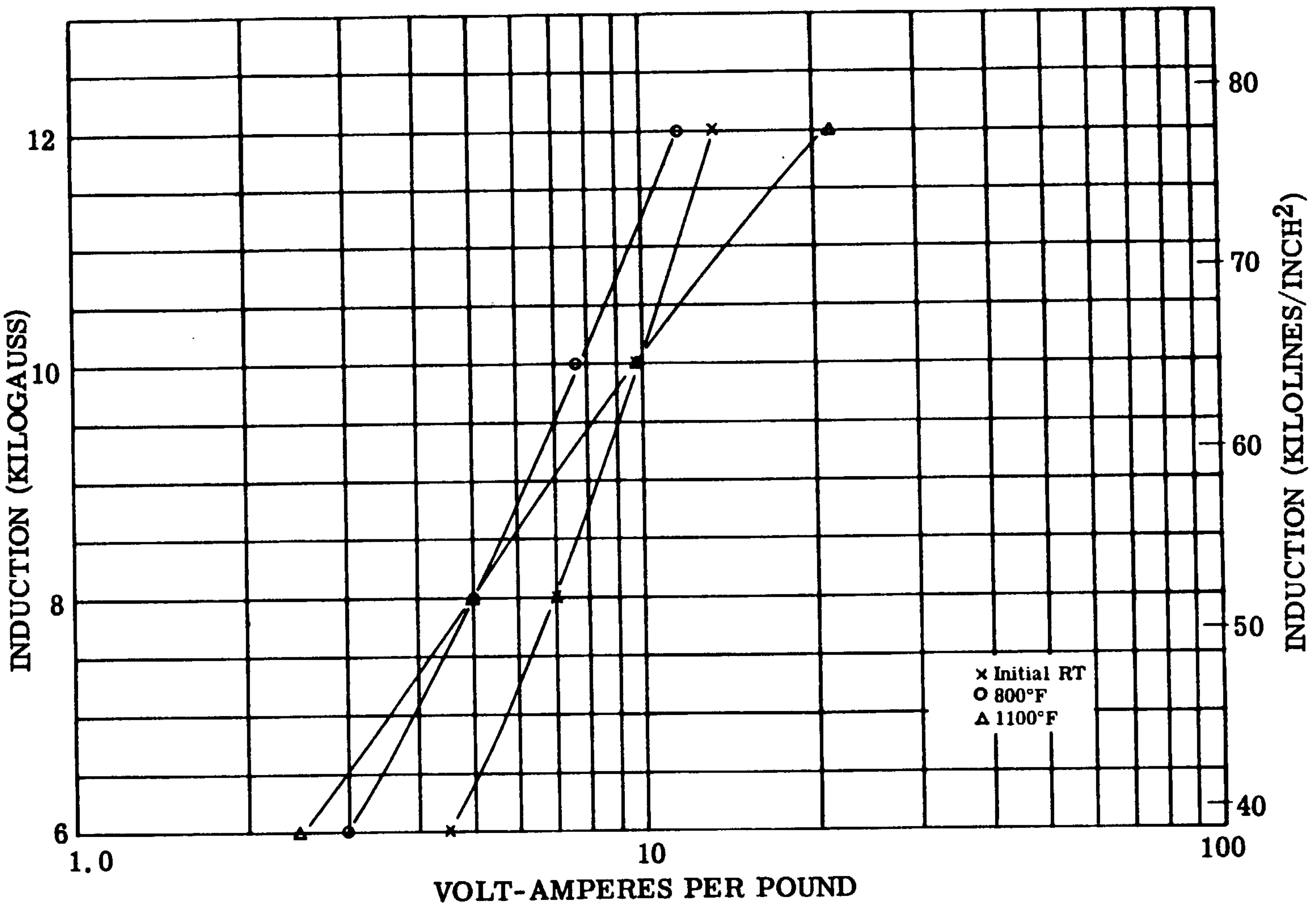


FIGURE IV. A. II-11. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

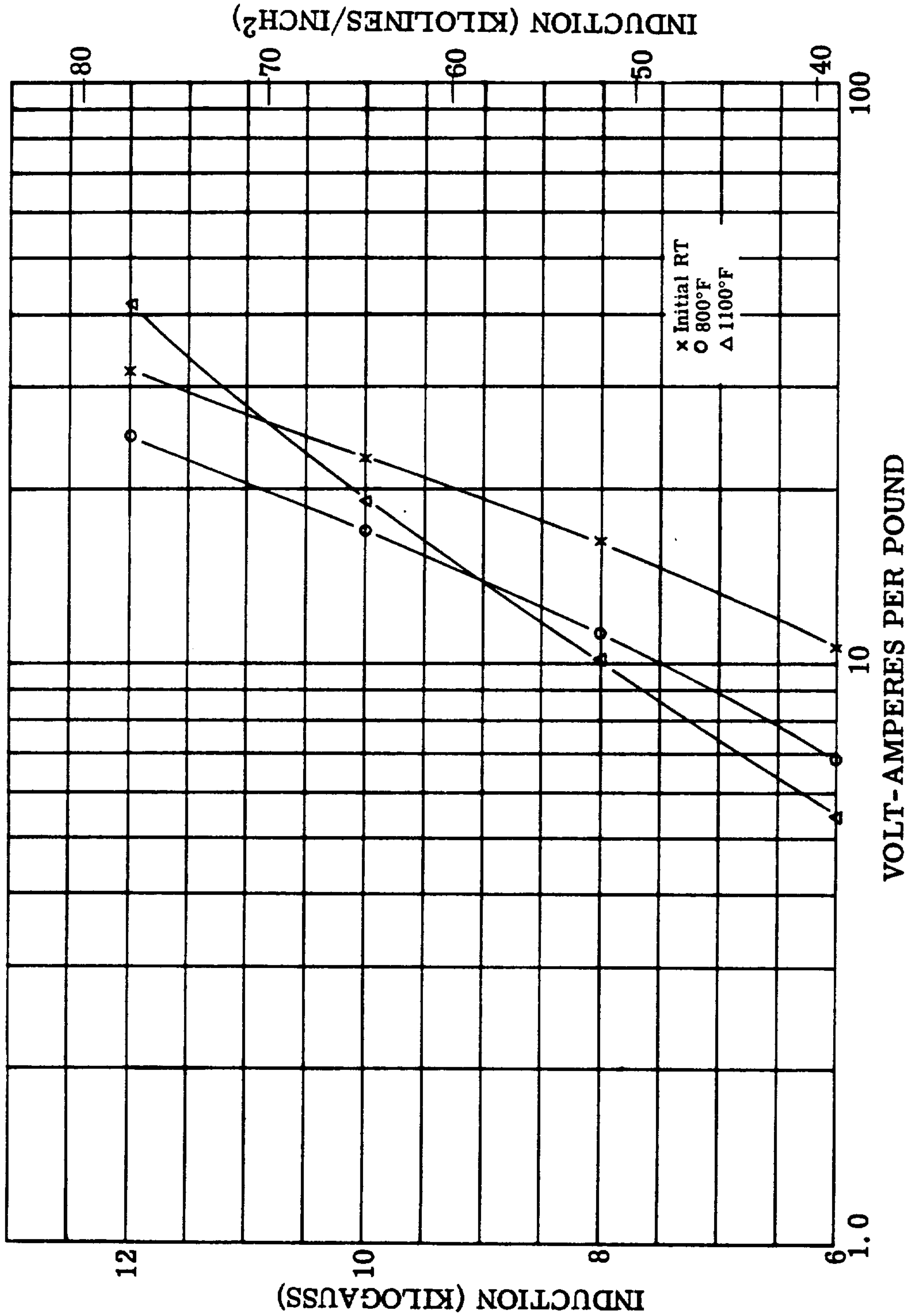


FIGURE IV.A.II-12. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-12. Exciting VA, 1600 CPS. Cubex

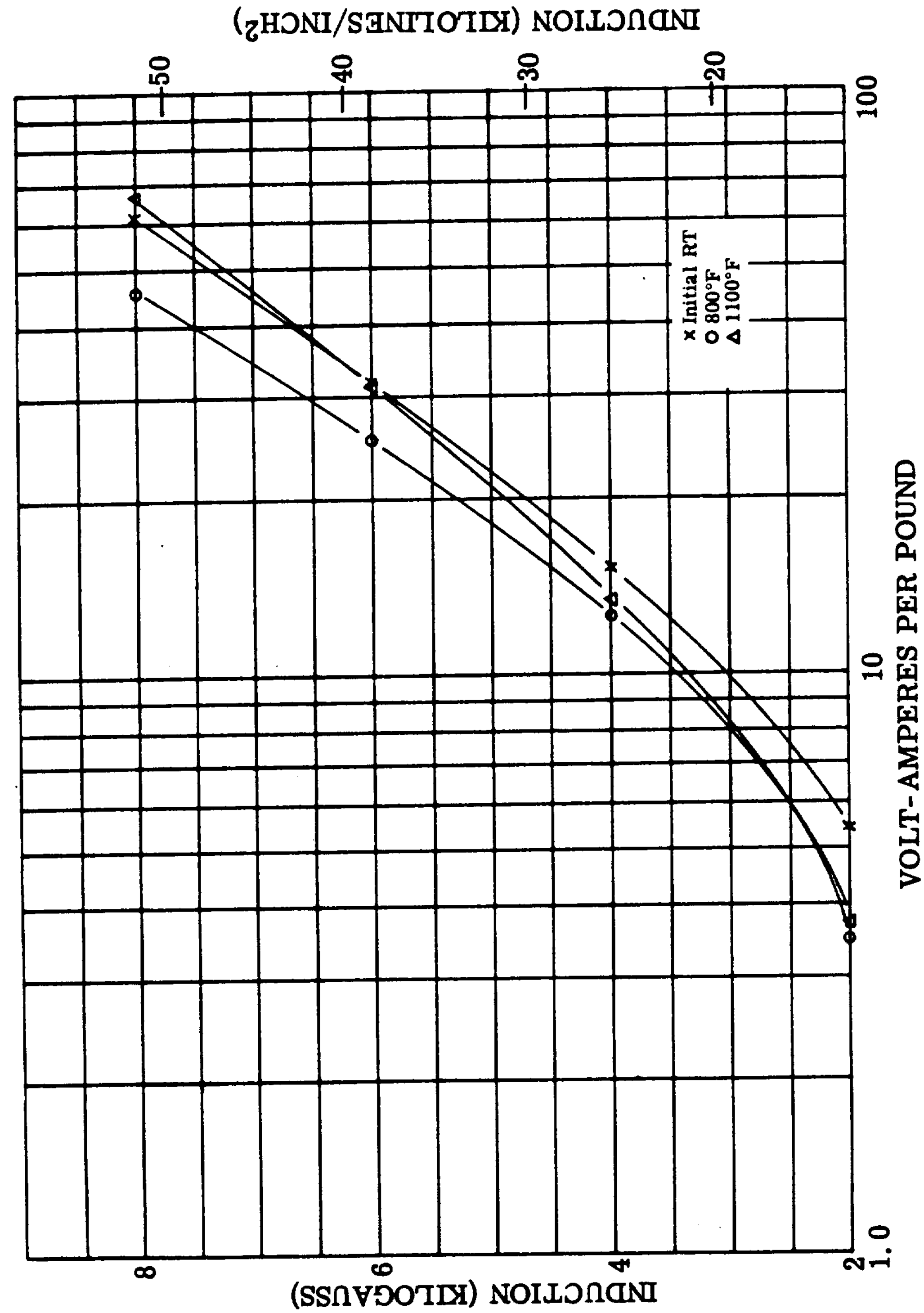


FIGURE IV.A.II-13. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-13. Exciting VA, 3200 CPS. Cubex

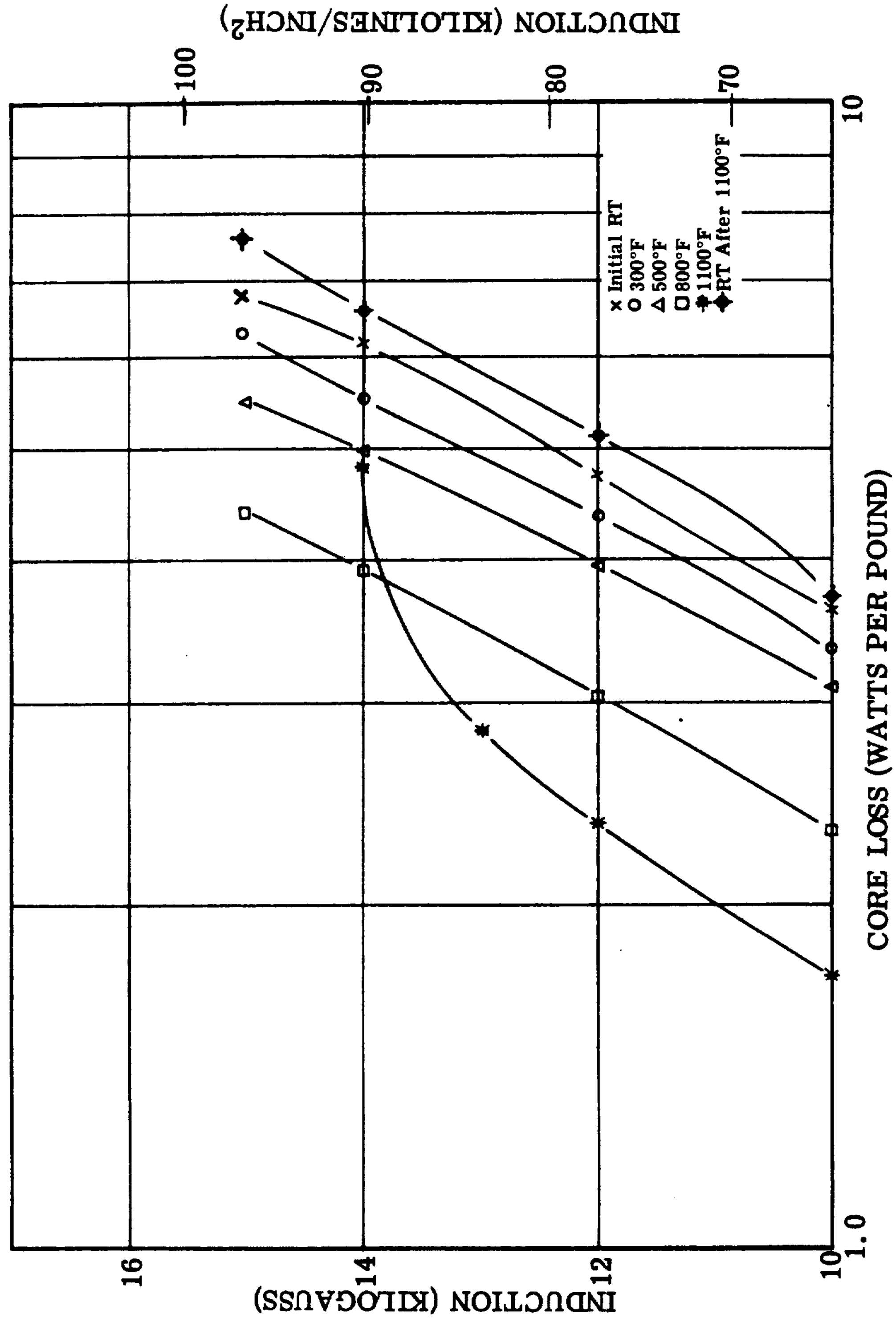


FIGURE IV.A.II-14. Core Loss, 400 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon Above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-14. Core Loss, 400 CPS. Cubex

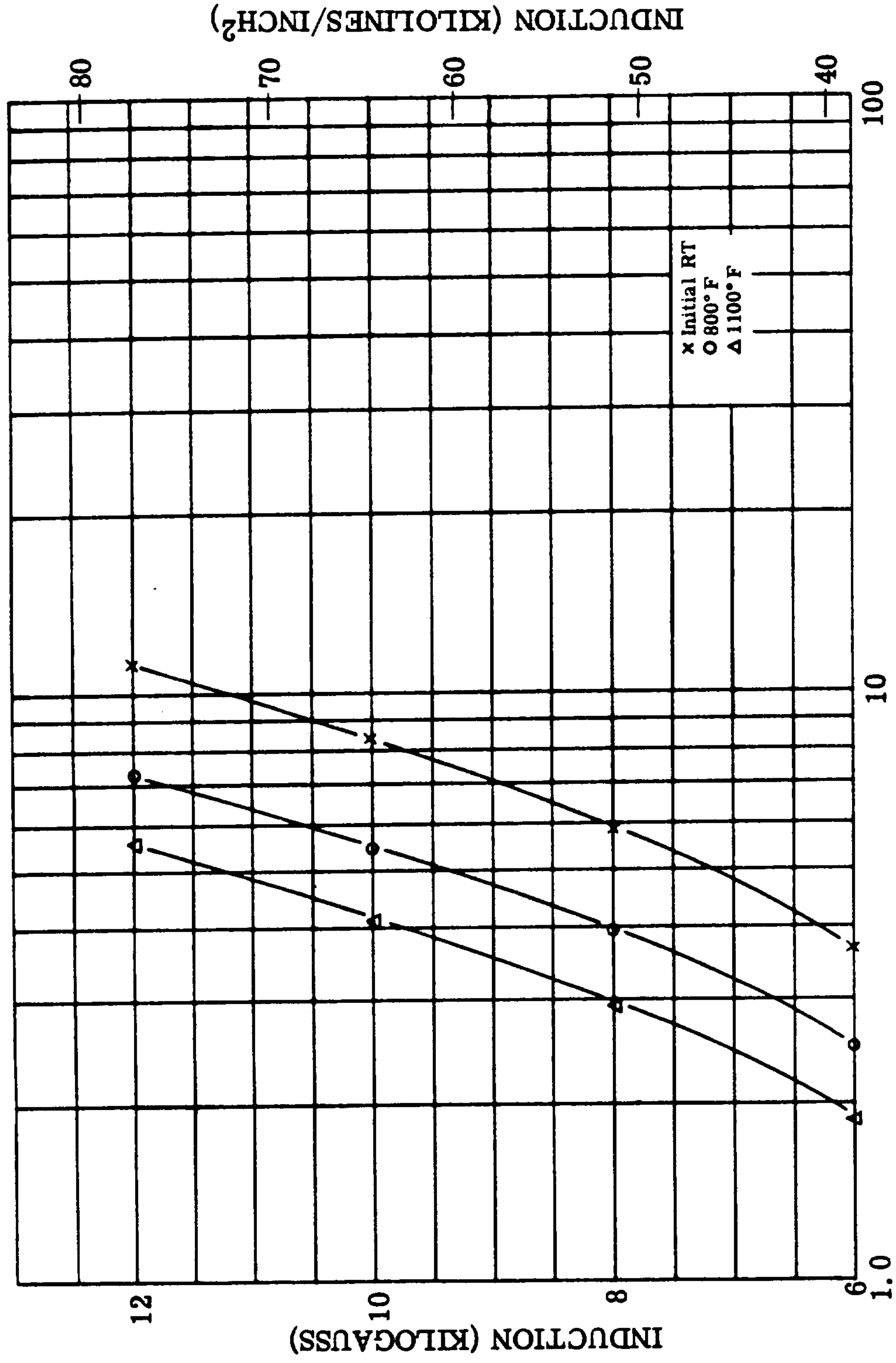


FIGURE IV.A.II-15. Core Loss, 800 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-15. Core Loss, 800 CPS. Cubex

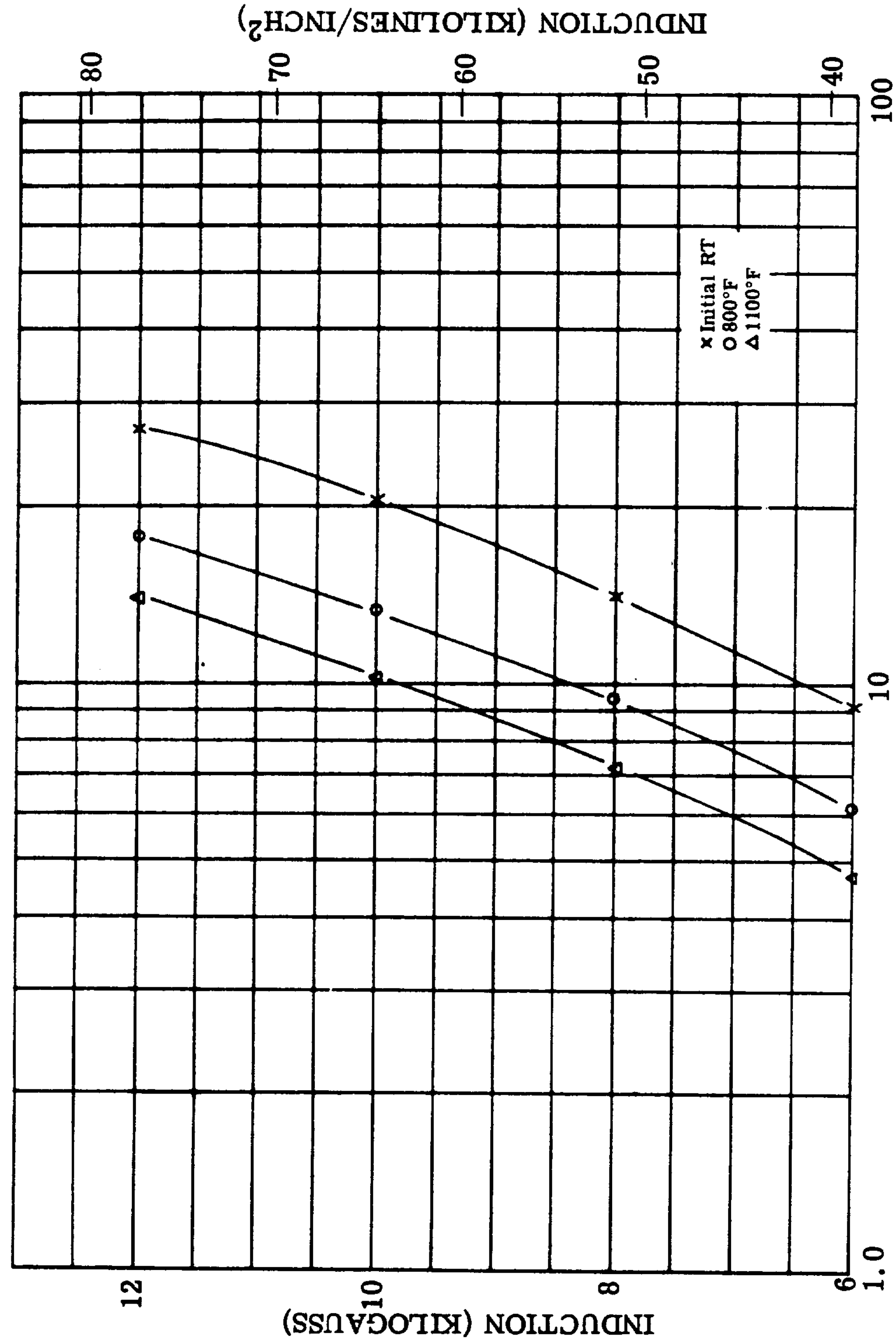


FIGURE IV.A.II-16. Core Loss, 1600 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-16. Core Loss, 1600 CPS. Cubex

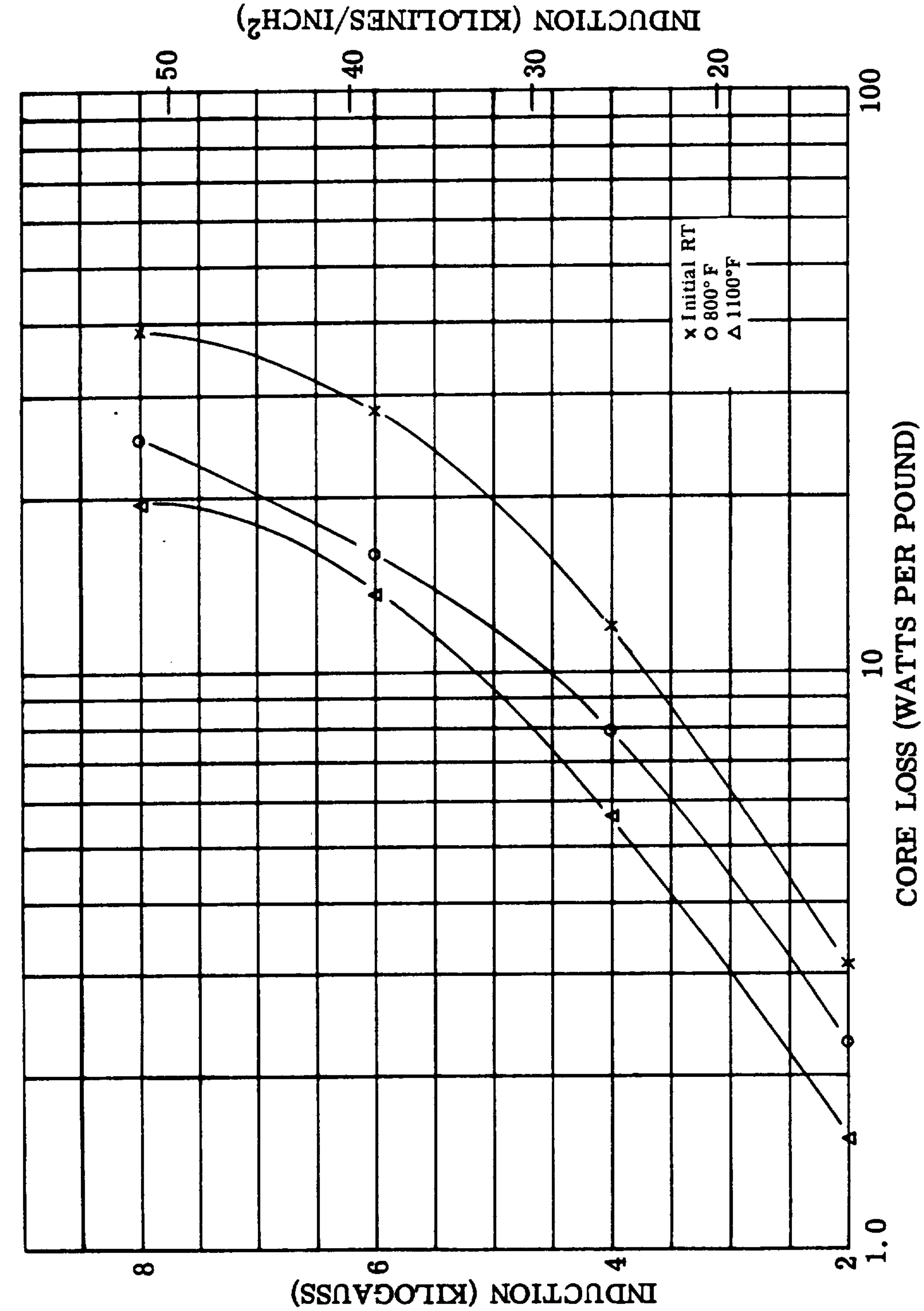


FIGURE IV. A. II-17. Core Loss, 3200 CPS. Cubex Alloy 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Air to 300°F, Argon above 300°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-17. Core Loss, 3200 CPS. Cubex

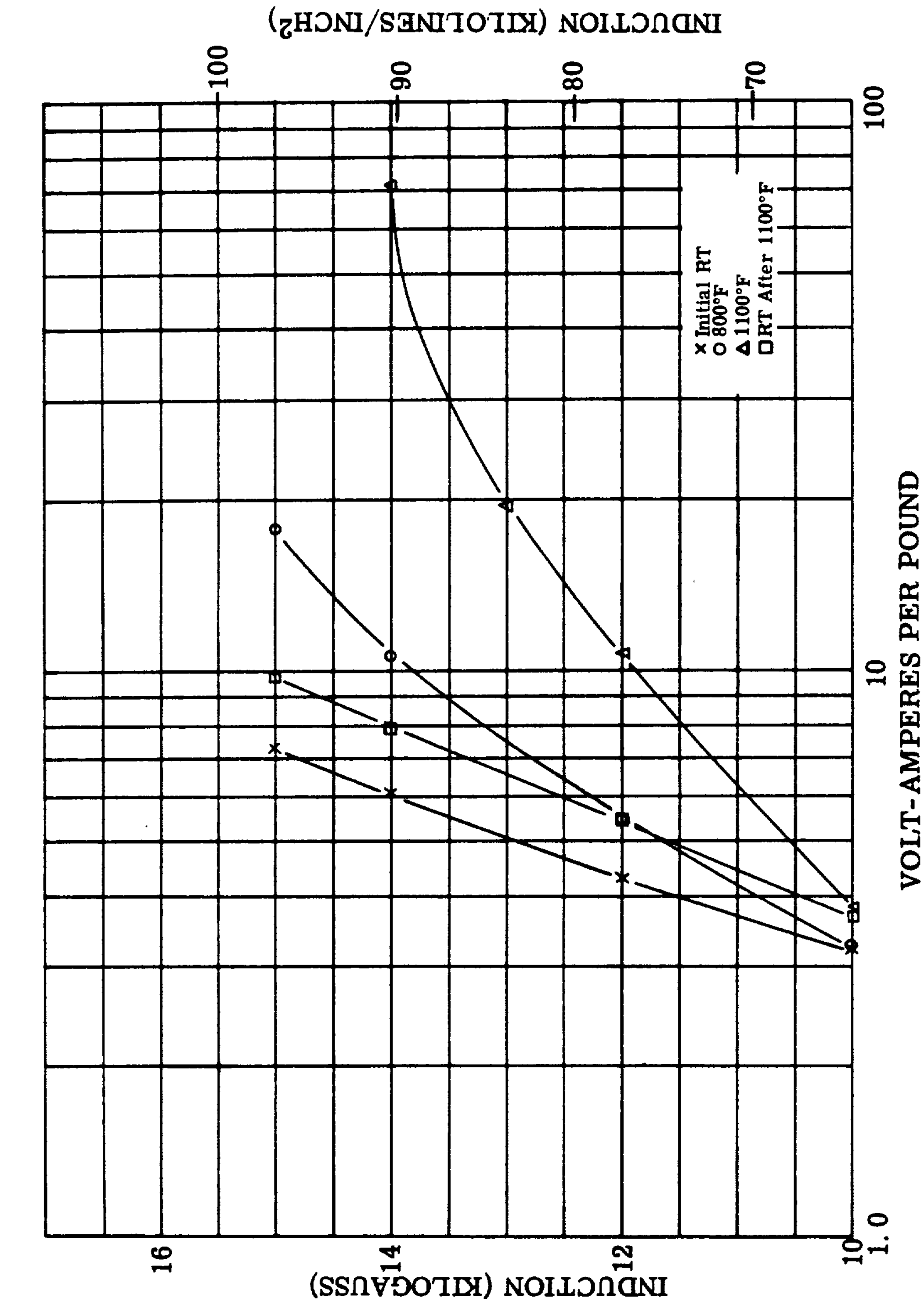


FIGURE IV.A.II-18. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-18. Exciting VA, 400 CPS. Cubex

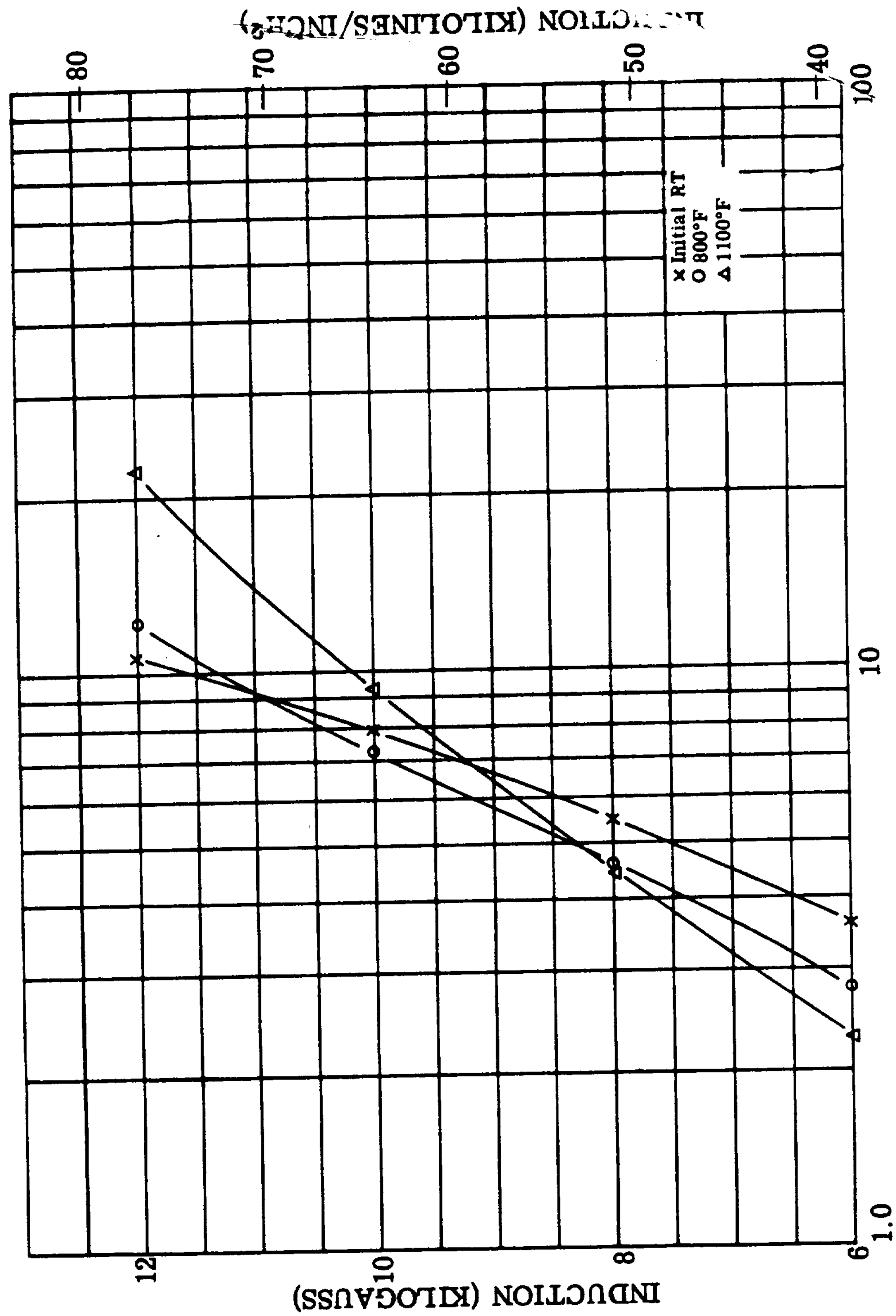


FIGURE IV.A.II-19. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-19. Exciting VA, 800 CPS. Cubex

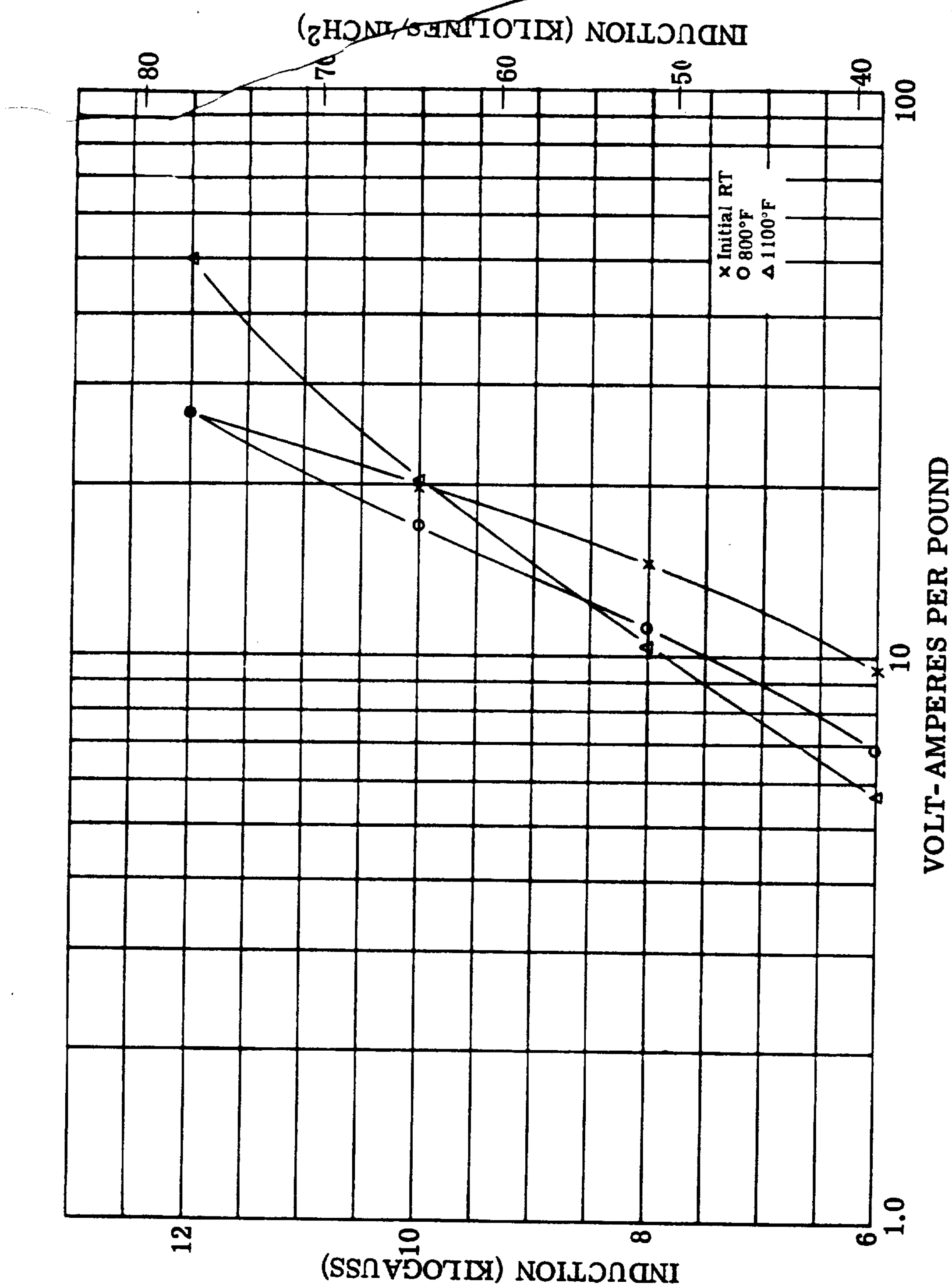


FIGURE IV.A.II-20. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-20. Exciting VA, 1600 CPS. Cubex

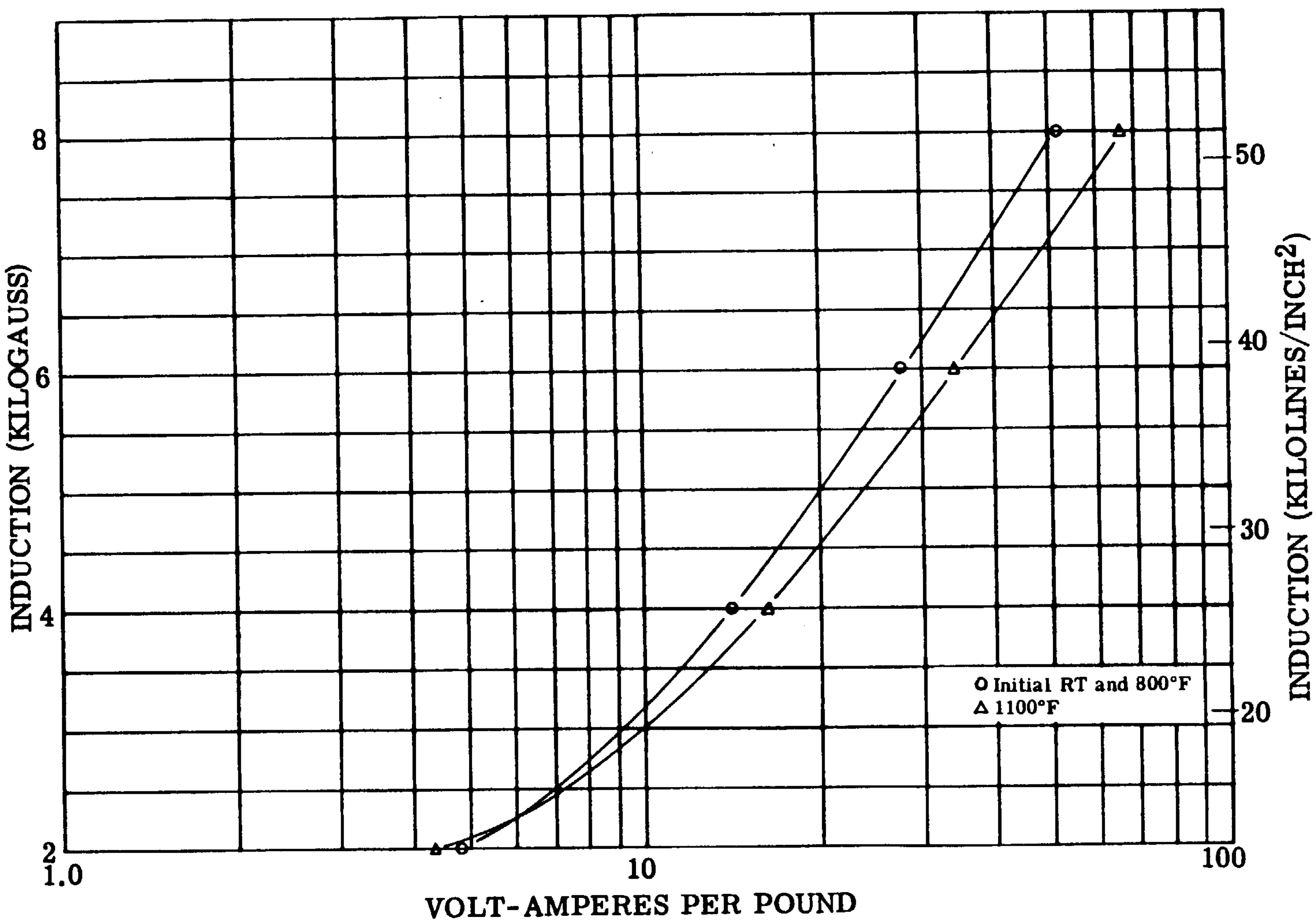


FIGURE IV. A. II-21. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-21. Exciting VA, 3200 CPS. Cubex

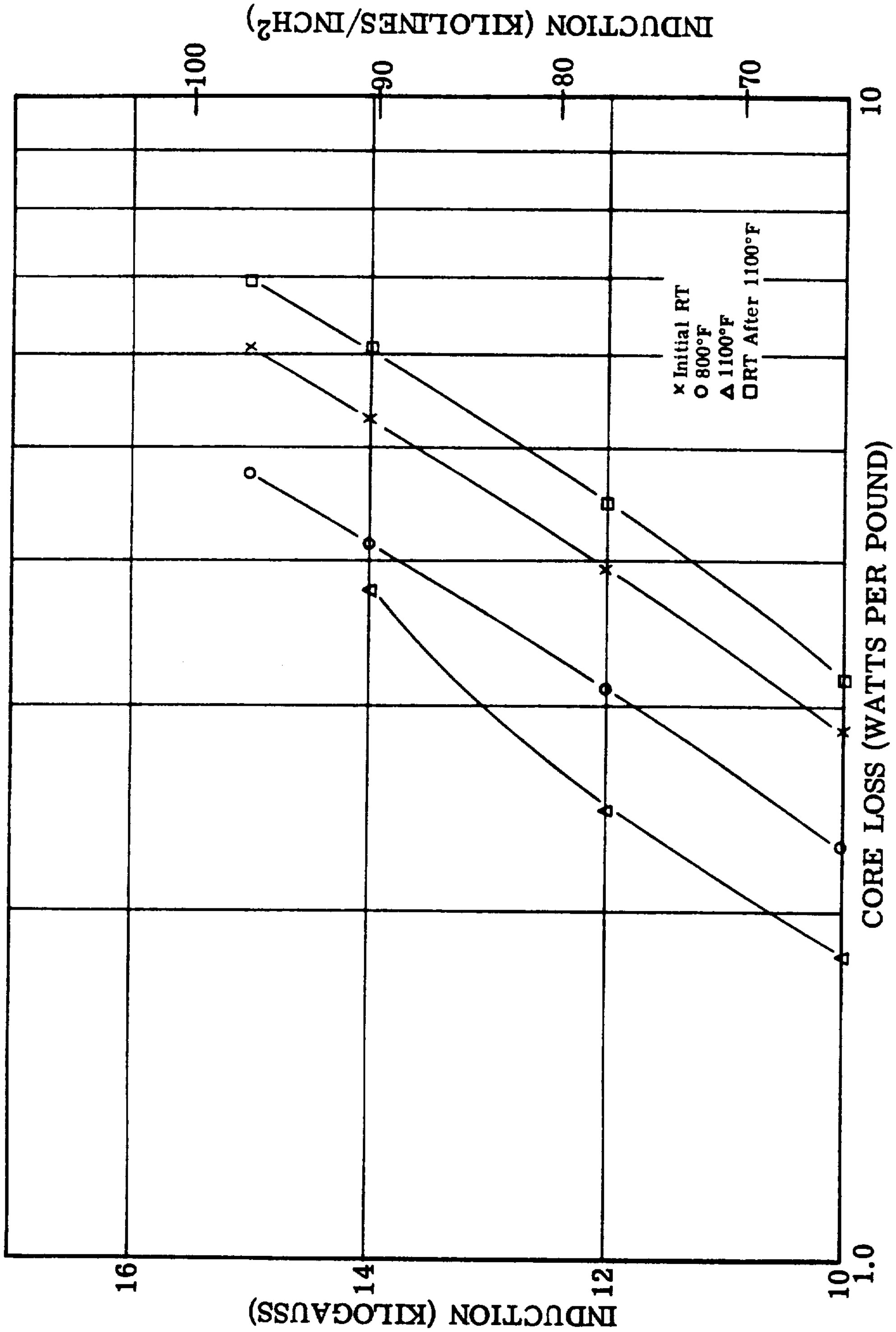


FIGURE IV.A.II-22. Core Loss, 400 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-22. Core Loss, 400 CPS. Cubex

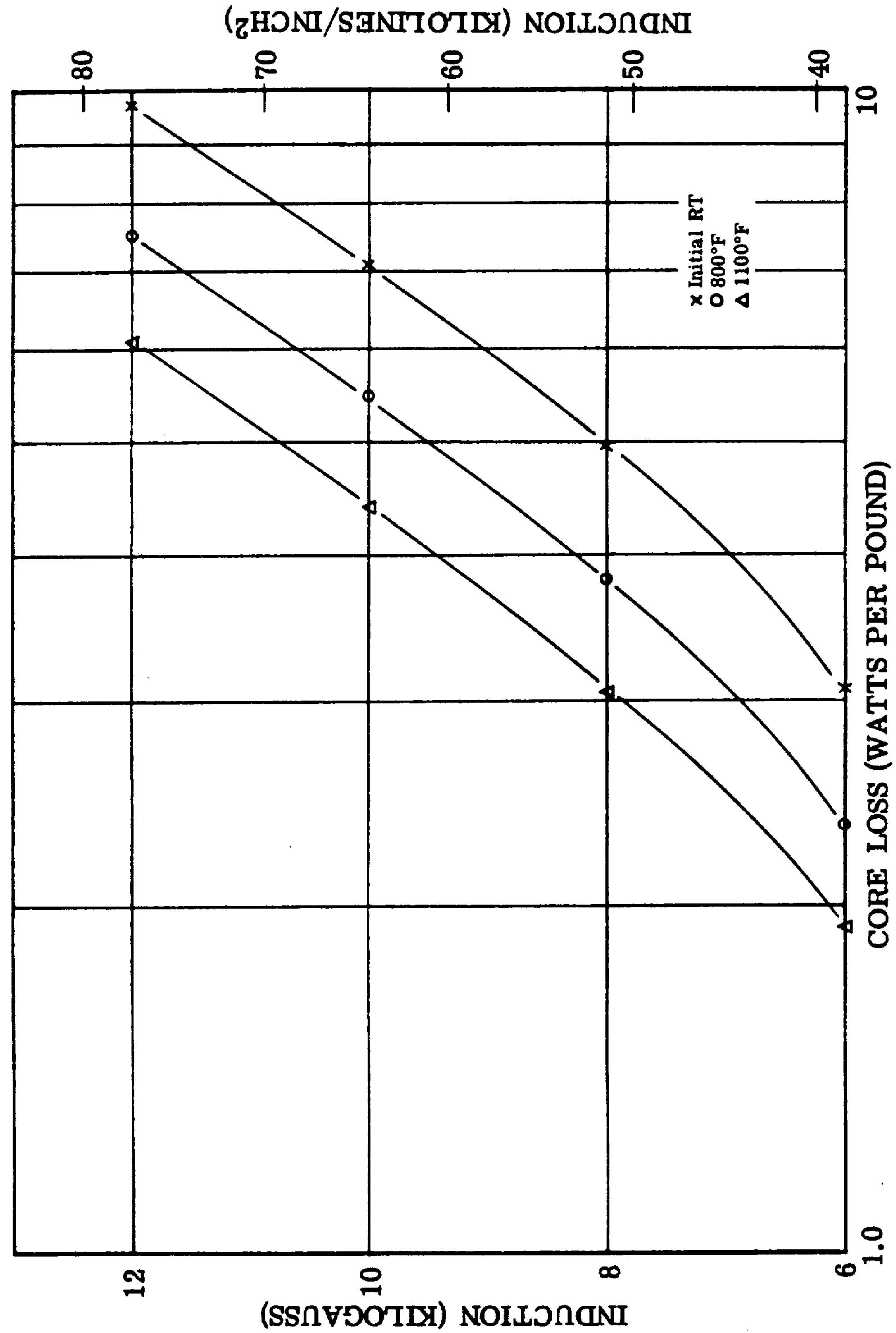


FIGURE IV.A.II-23. Core Loss, 800 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-23. Core Loss, 800 CPS. Cubex

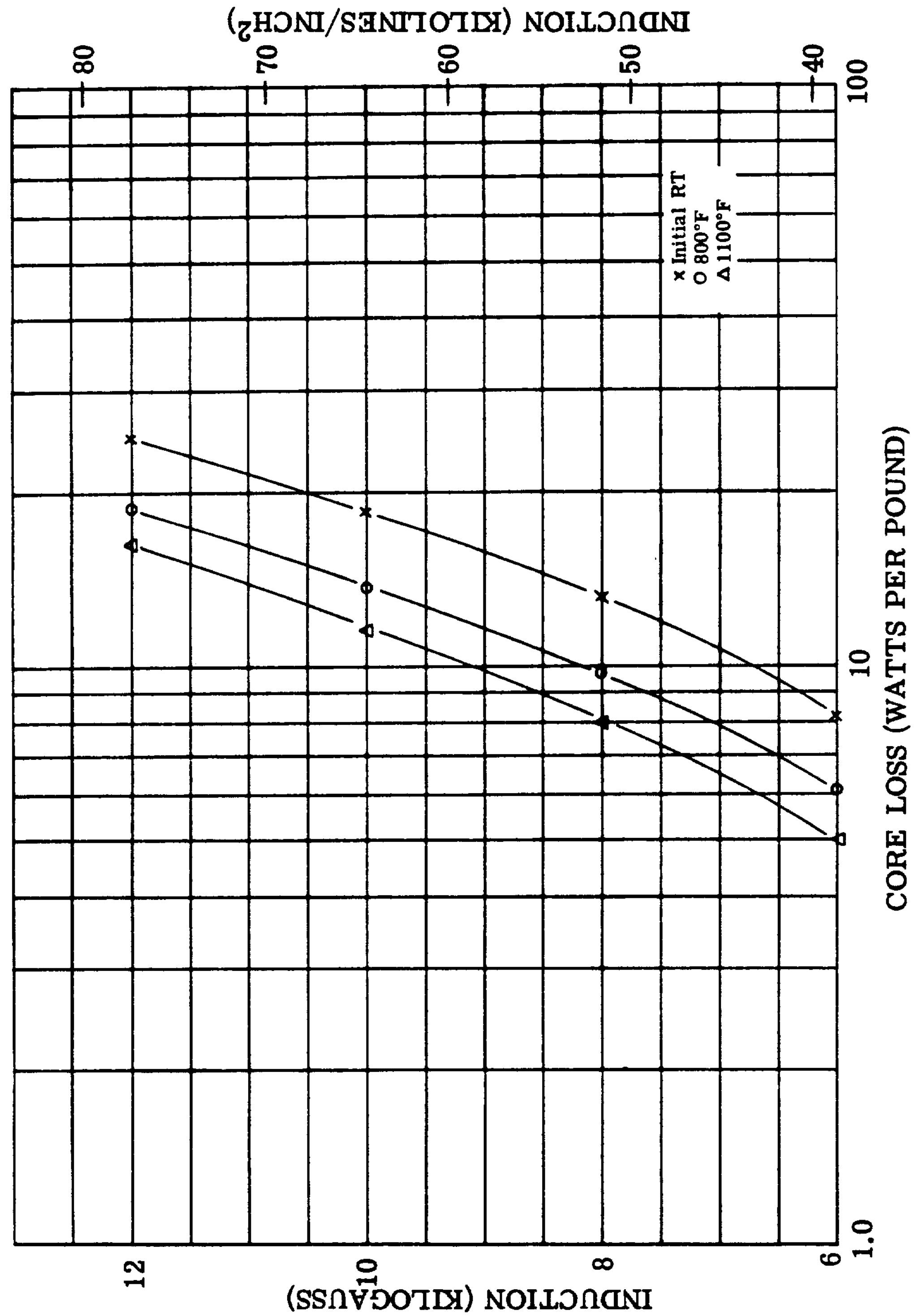


FIGURE IV.A.II-24. Core Loss, 1600 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-24. Core Loss, 1600 CPS. Cubex

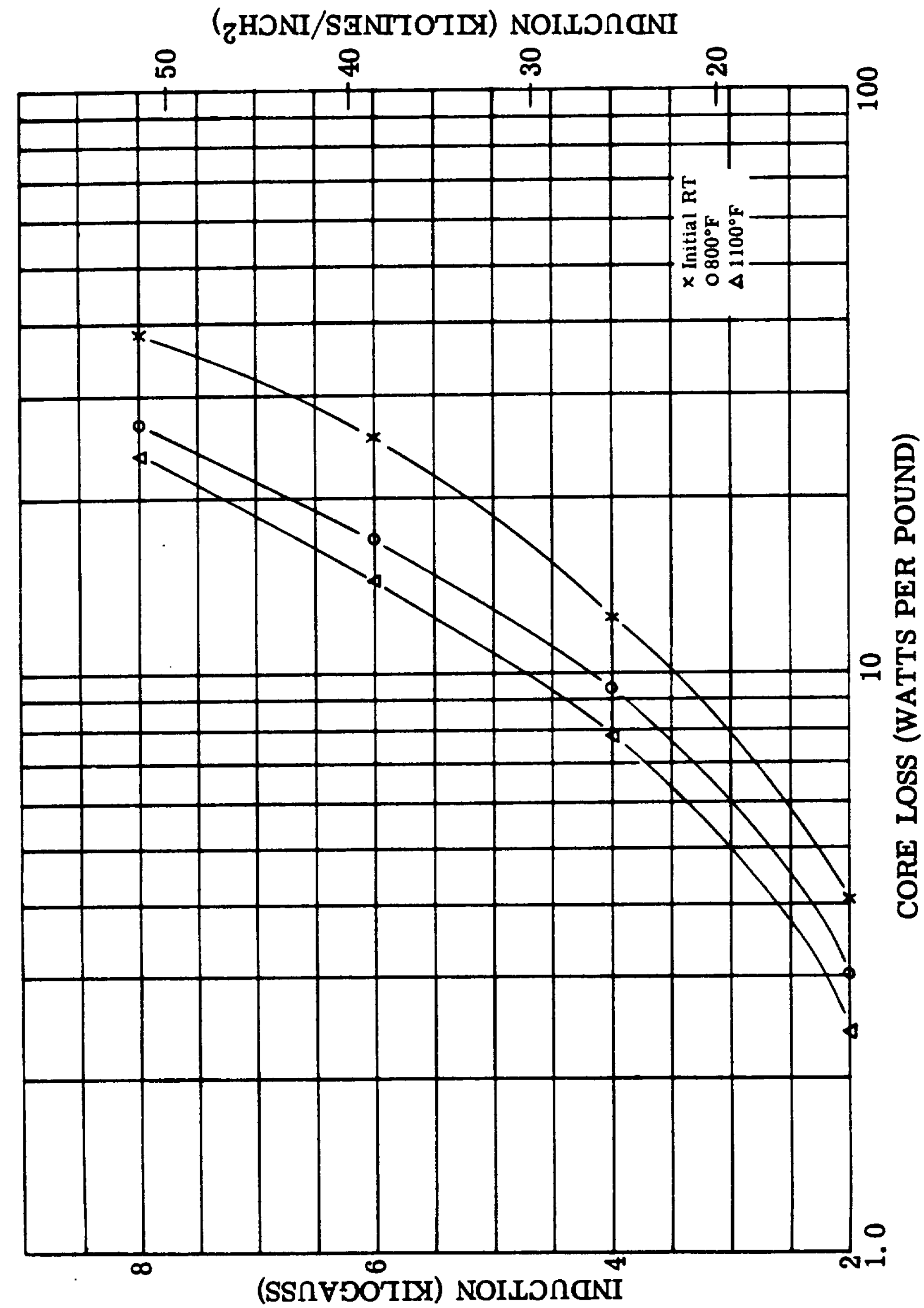


FIGURE IV.A.II-25. Core Loss, 3200 CPS. Cubex Alloy 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch - Field Annealed. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. A. II-25. Core Loss, 3200 CPS. Cubex

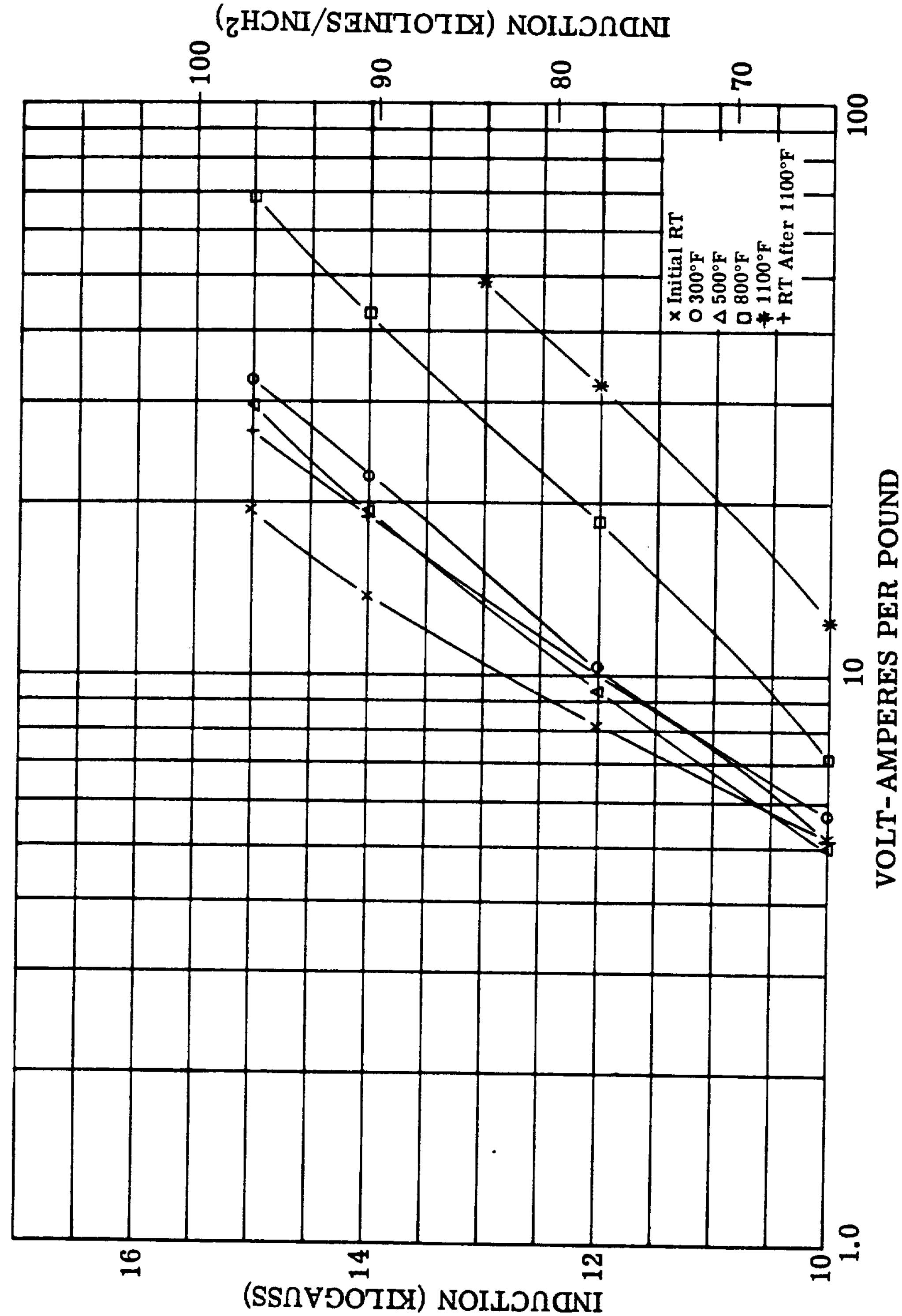


FIGURE IV. A. II-26. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-26. Exciting VA, 400 CPS. Cubex

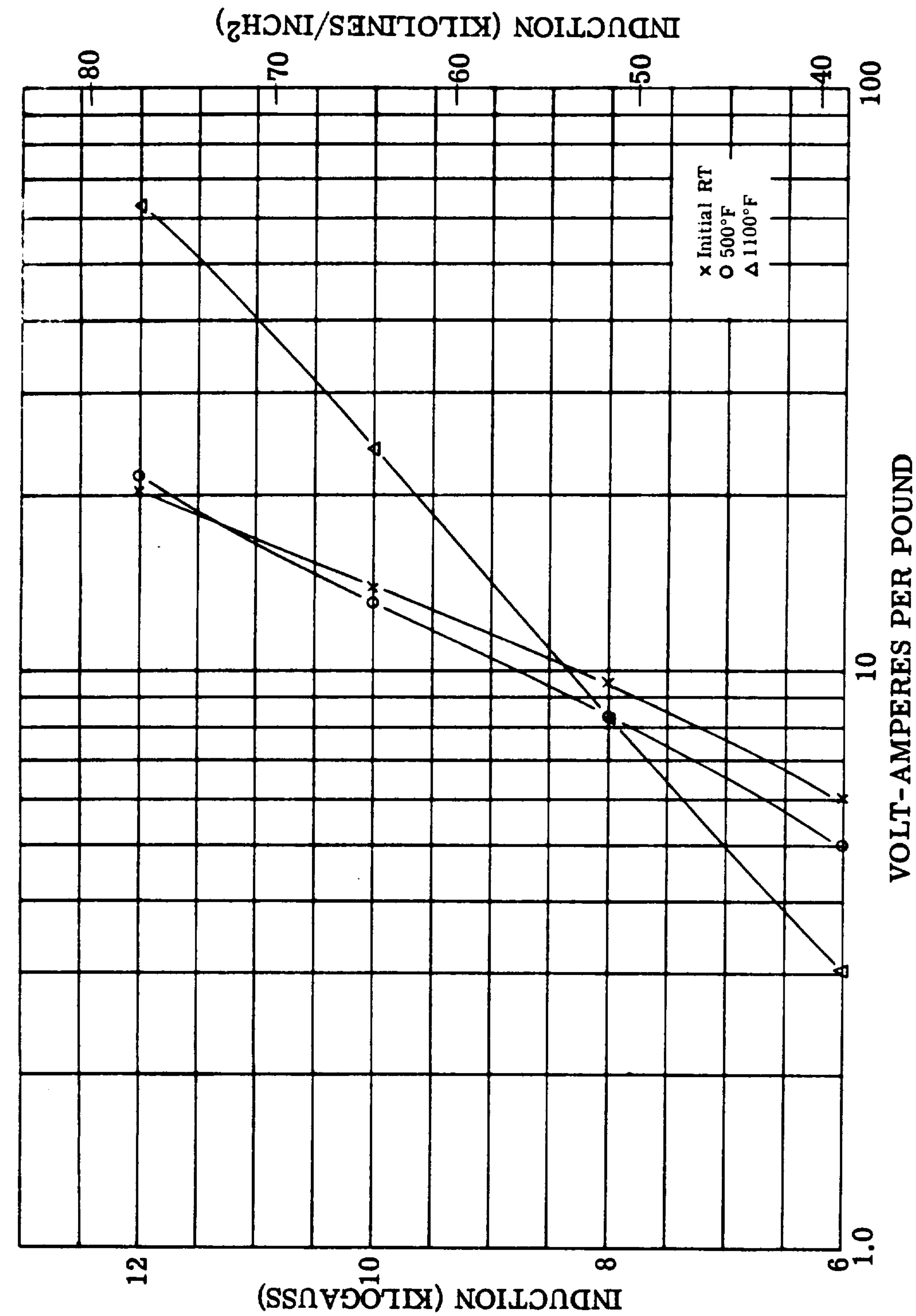


FIGURE I V. A. II-27. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-27. Exciting VA, 800 CPS. Cubex

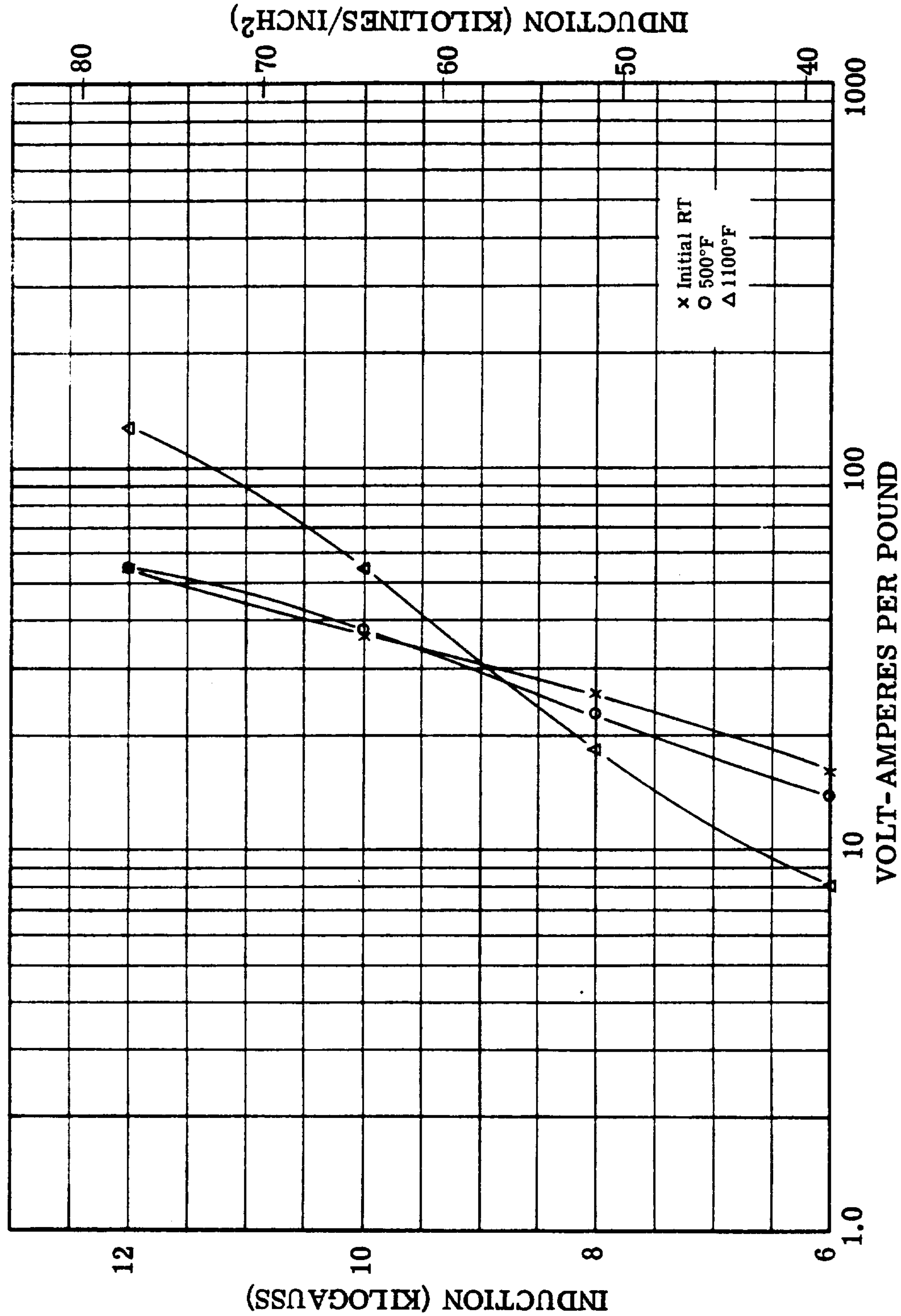


FIGURE IV. A. II-28. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-28. Exciting VA, 1600 CPS. Cubex

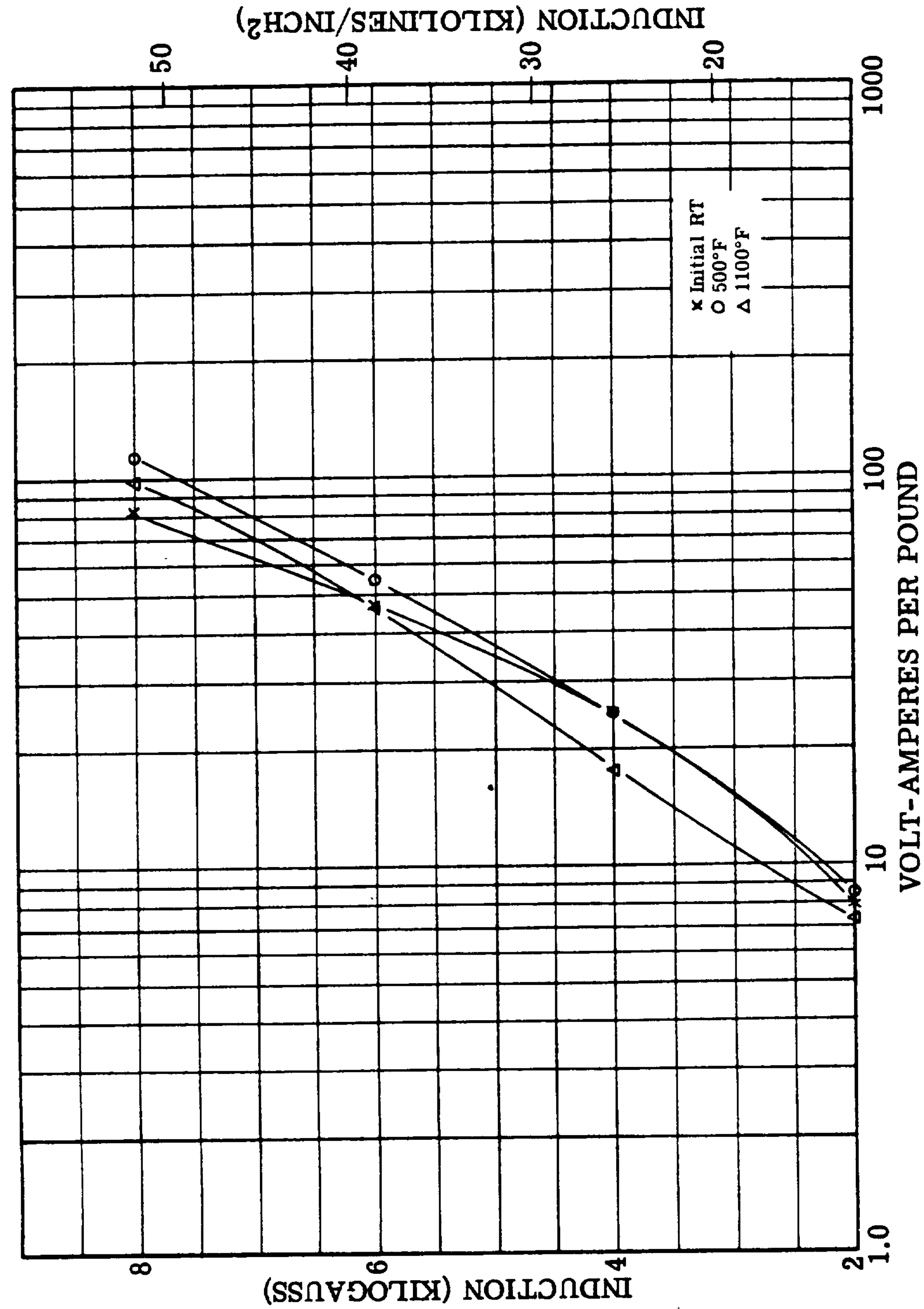


FIGURE IV. A. II-29. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-29. Exciting VA, 3200 CPS. Cubex

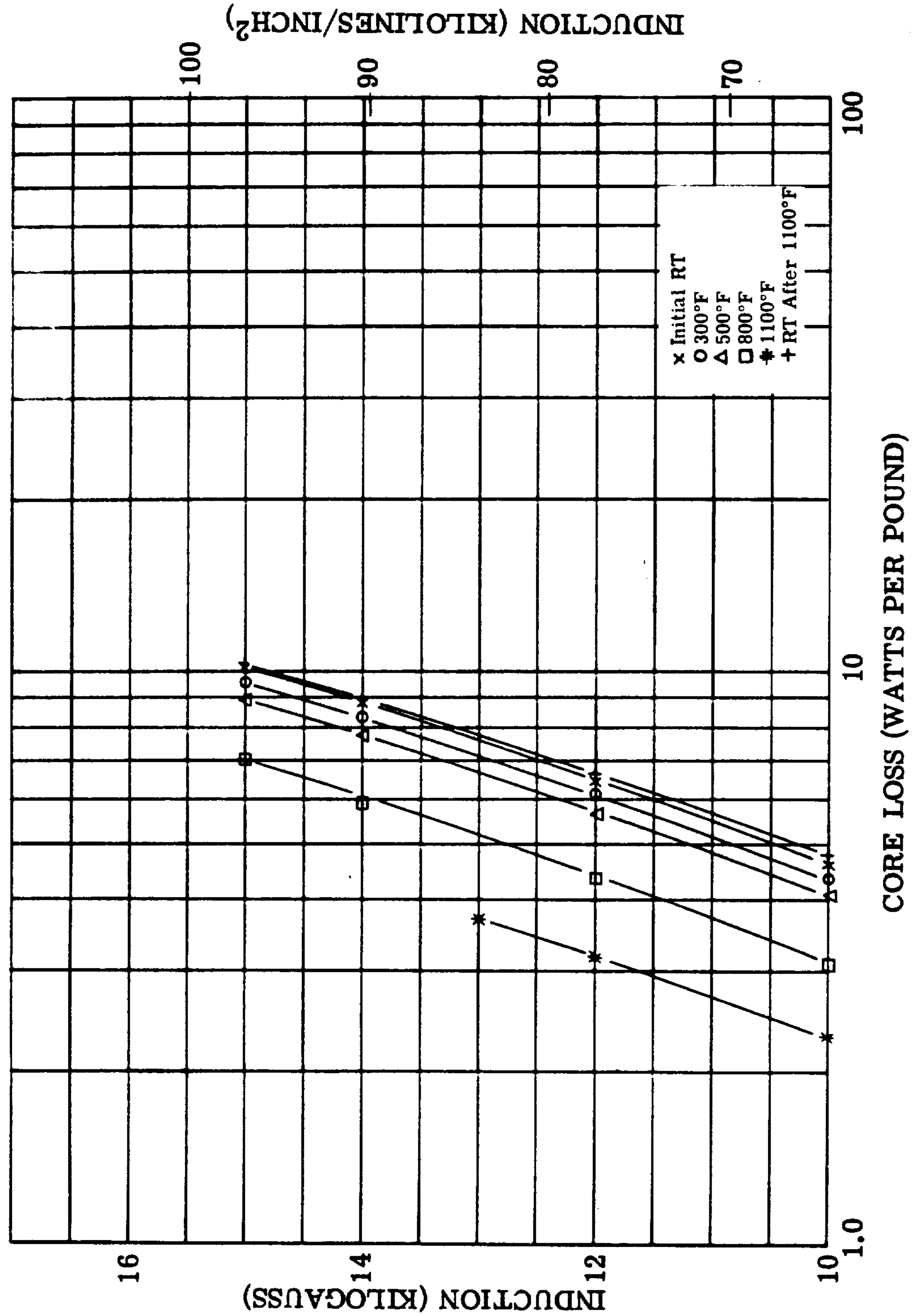


FIGURE IV. A. II-30. Core Loss, 400 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-30. Core Loss, 400 CPS. Cubex

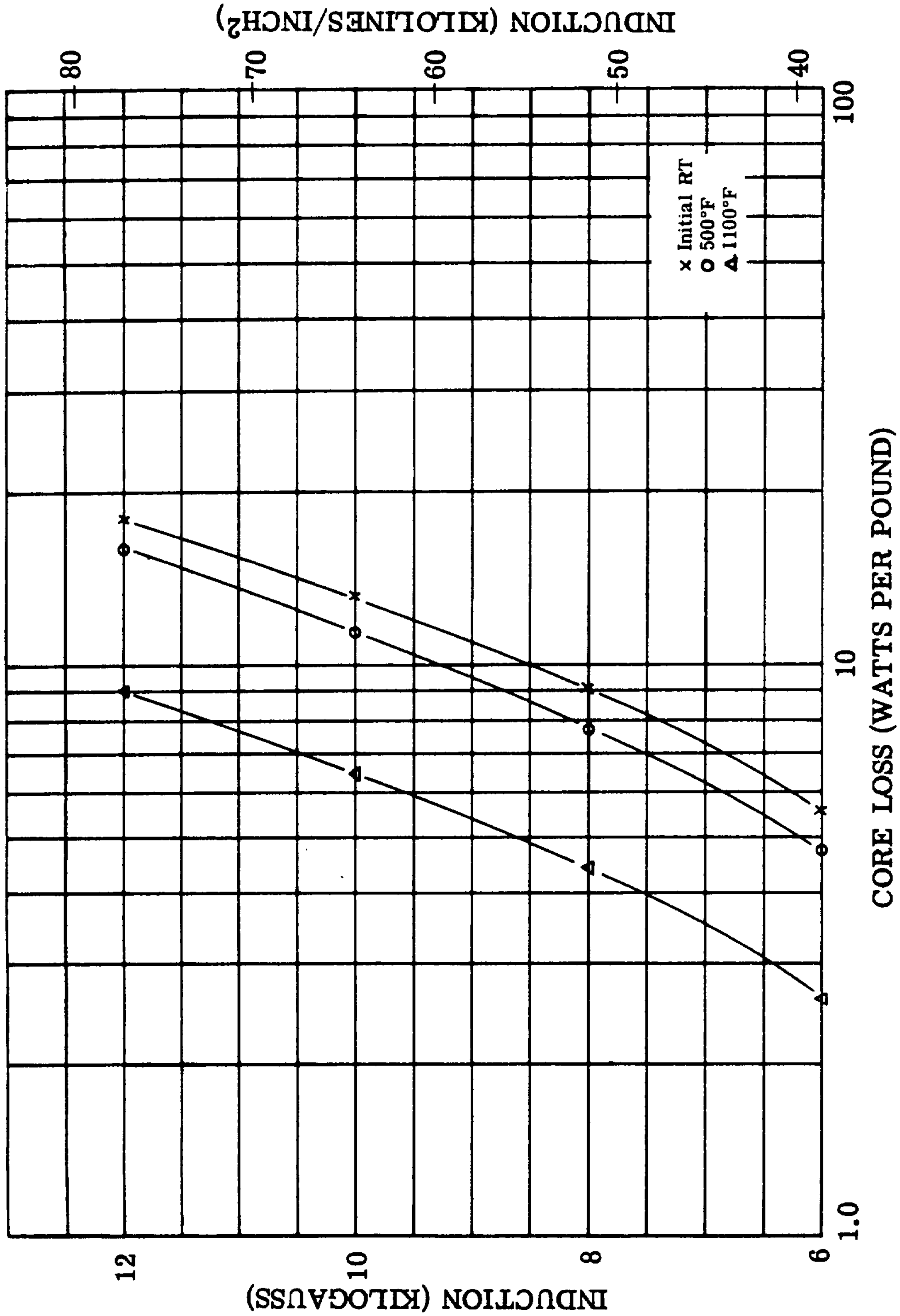


FIGURE IV. A. II-31. Core Loss, 800 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-31. Core Loss, 800 CPS. Cubex

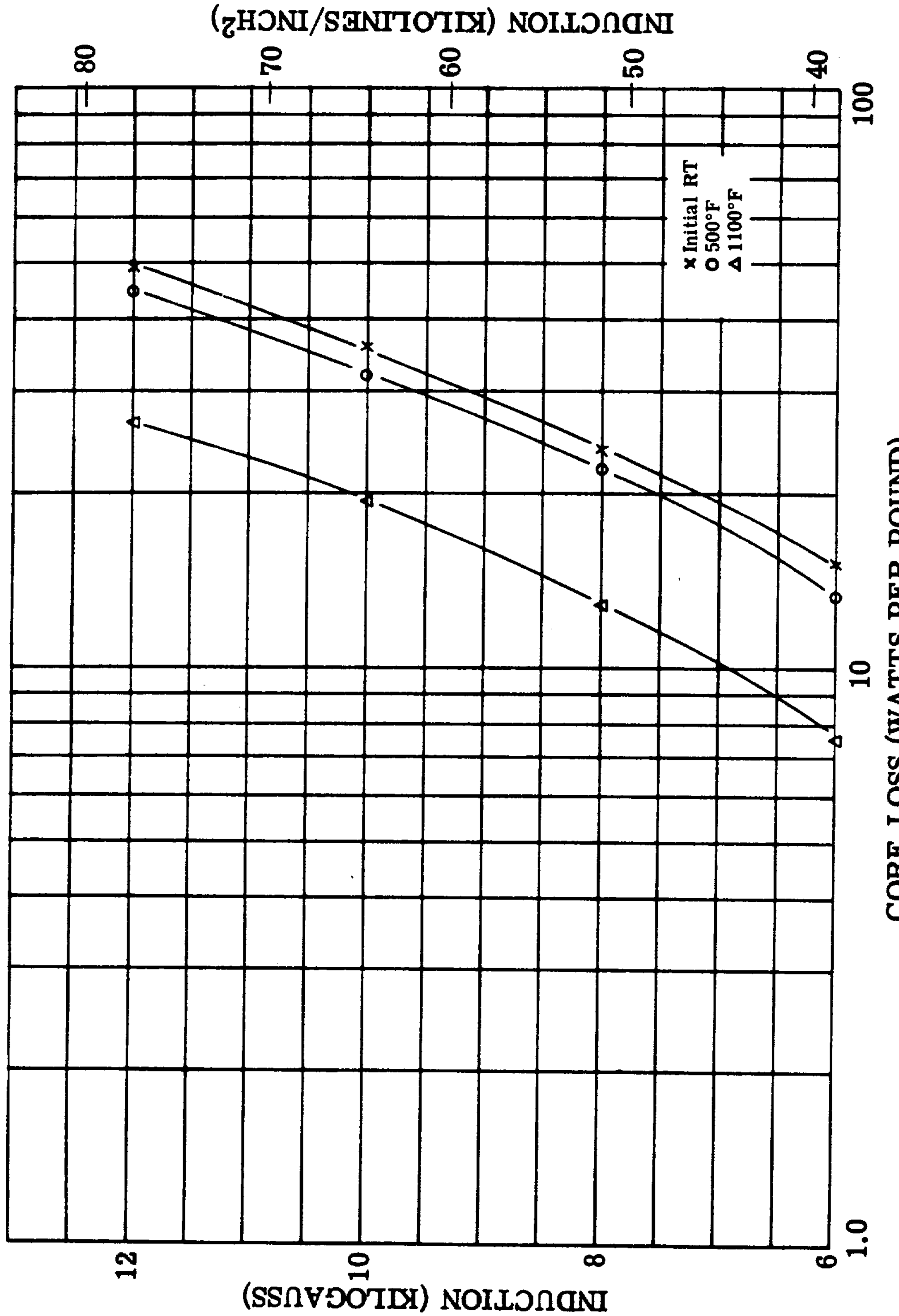


FIGURE I V. A. II-32. Core Loss, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-32. Core Loss, 1600 CPS. Cubex

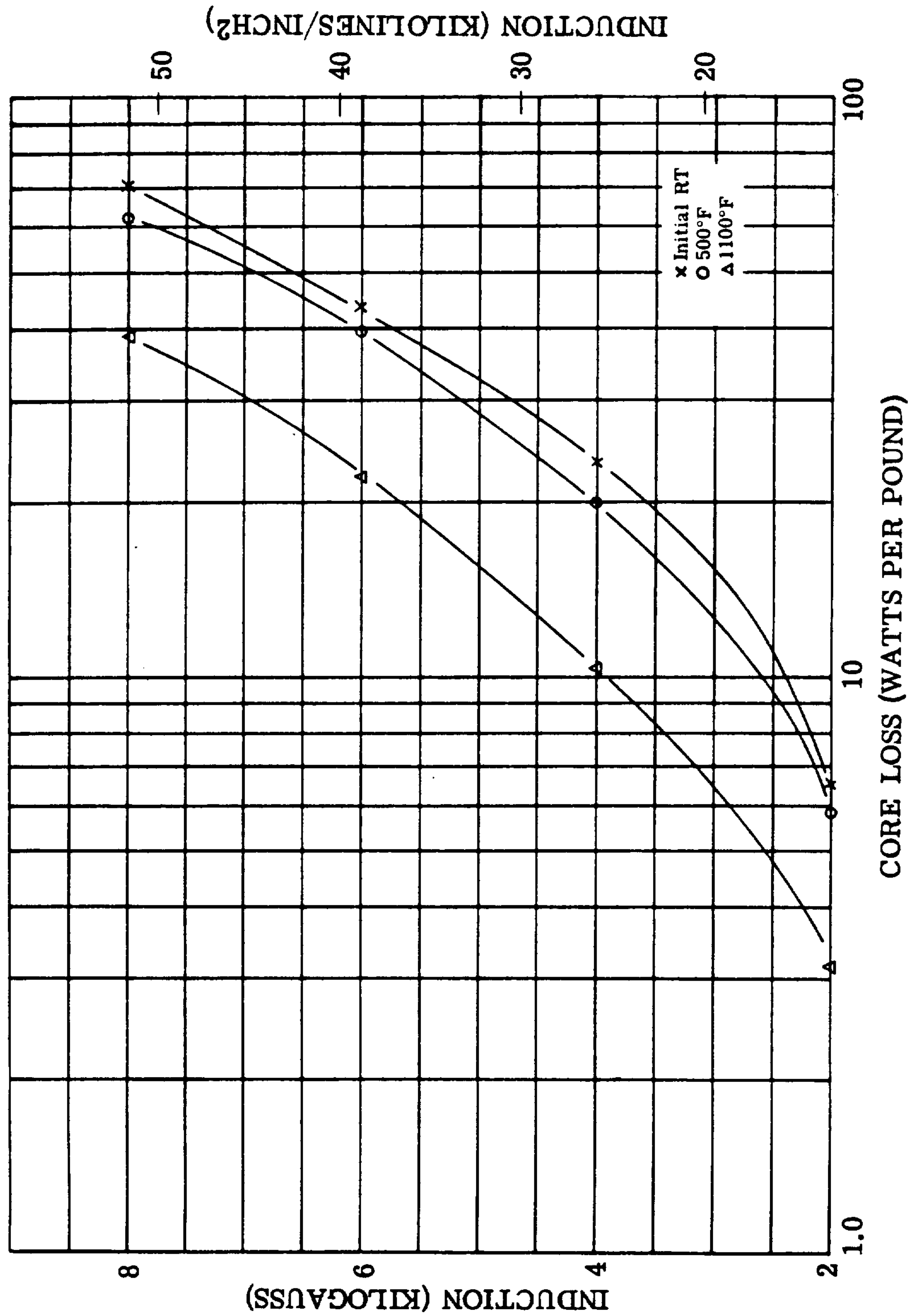


FIGURE IV. A. II-33. Core Loss, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Field Annealed. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-33. Core Loss, 3200 CPS. Cubex

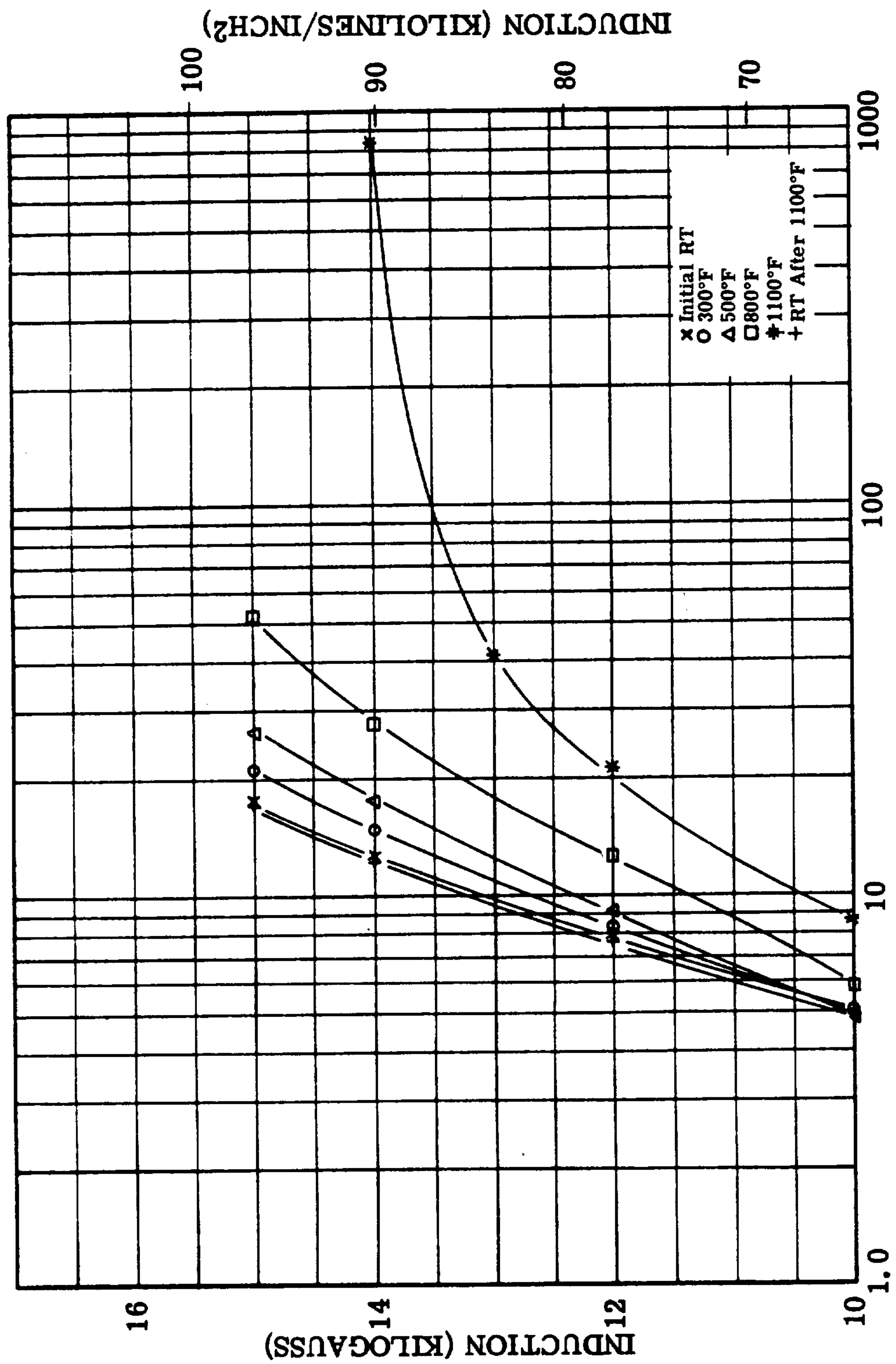
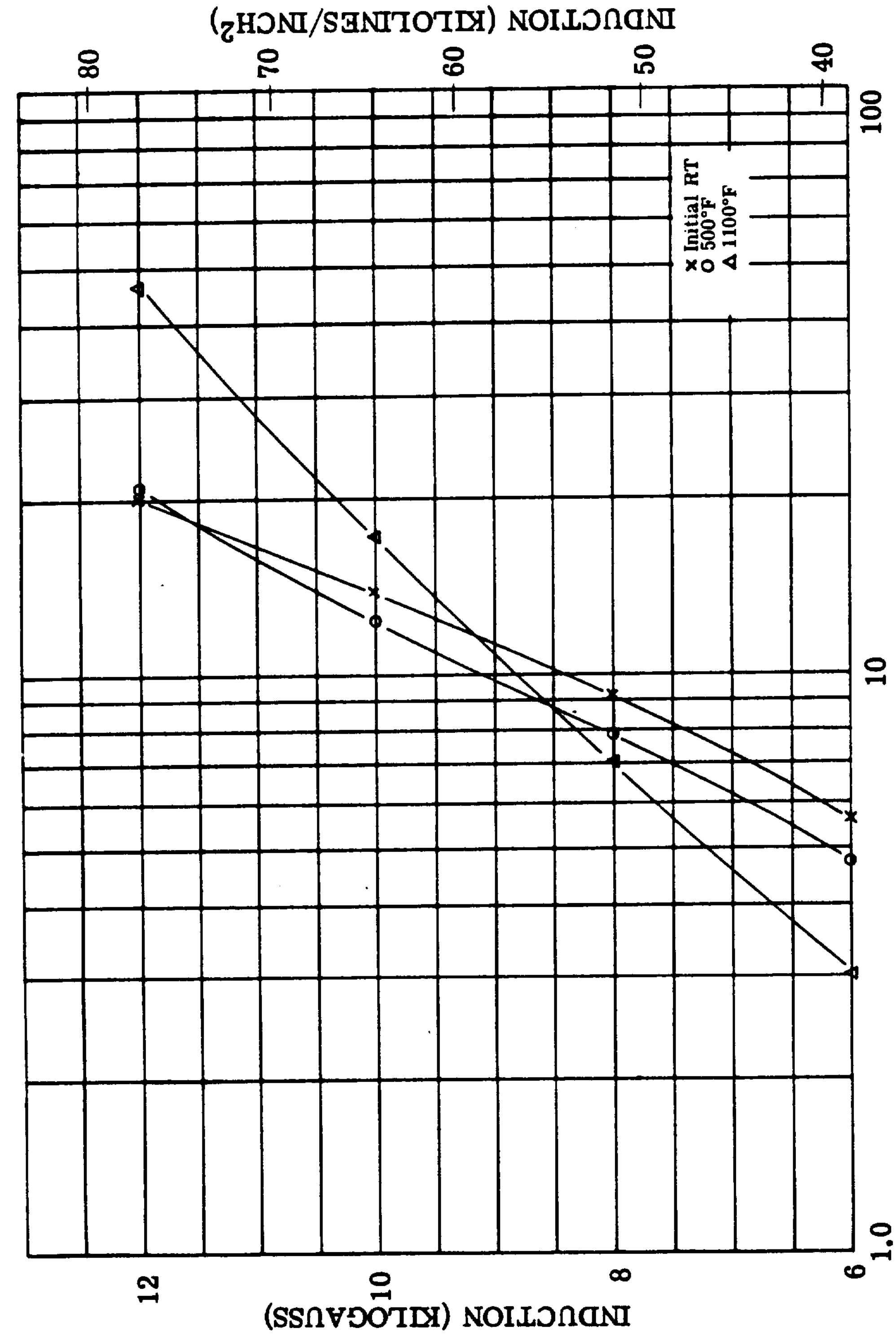


FIGURE I V. A. I I-34. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-34. Exciting VA, 400 CPS. Cubex



VOLT-AMPERES PER POUND

FIGURE IV. A. II-35. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-35. Exciting VA, 800 CPS. Cubex

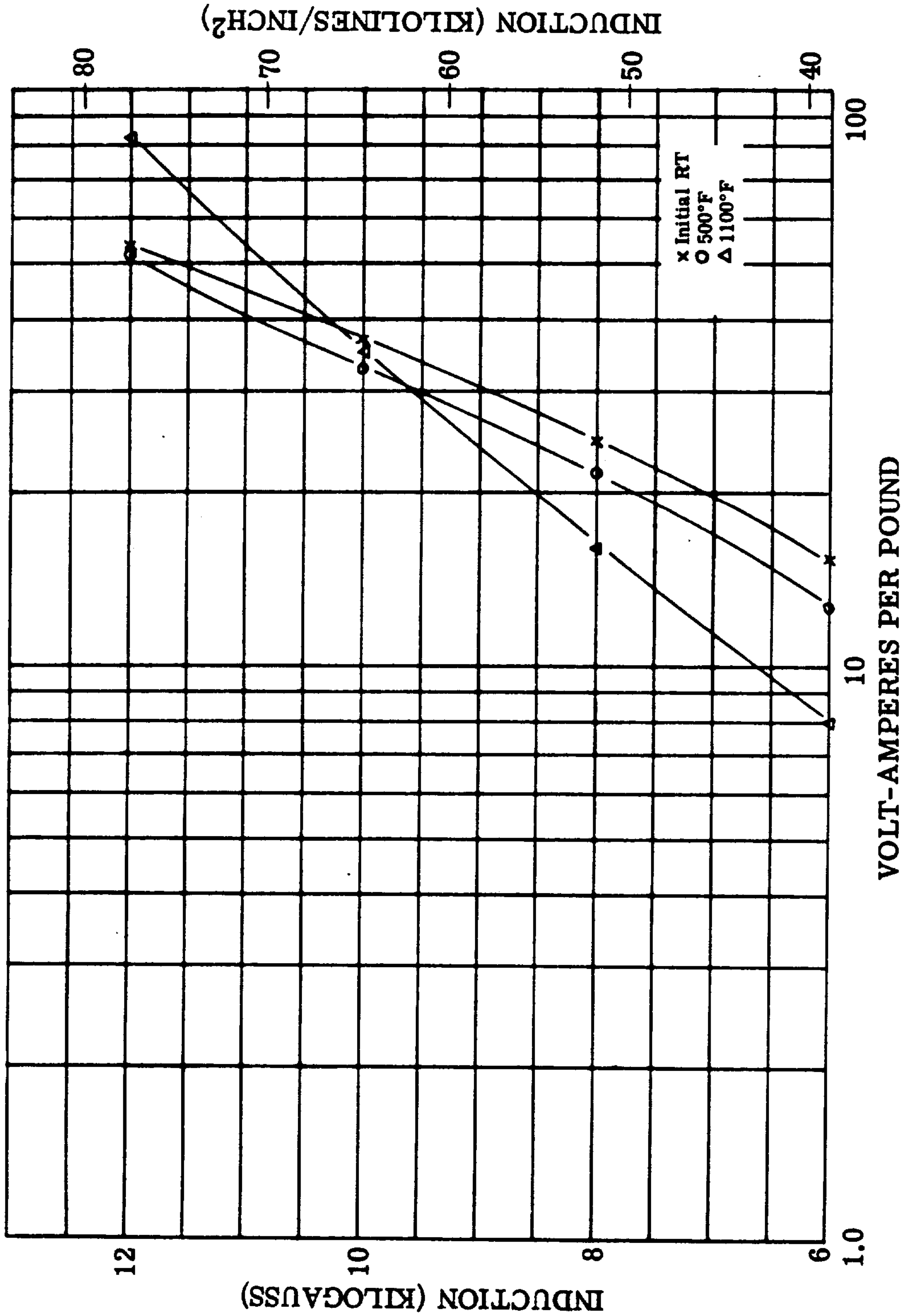


FIGURE IV. A. II-36. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-36. Exciting VA, 1600 CPS. Cubex

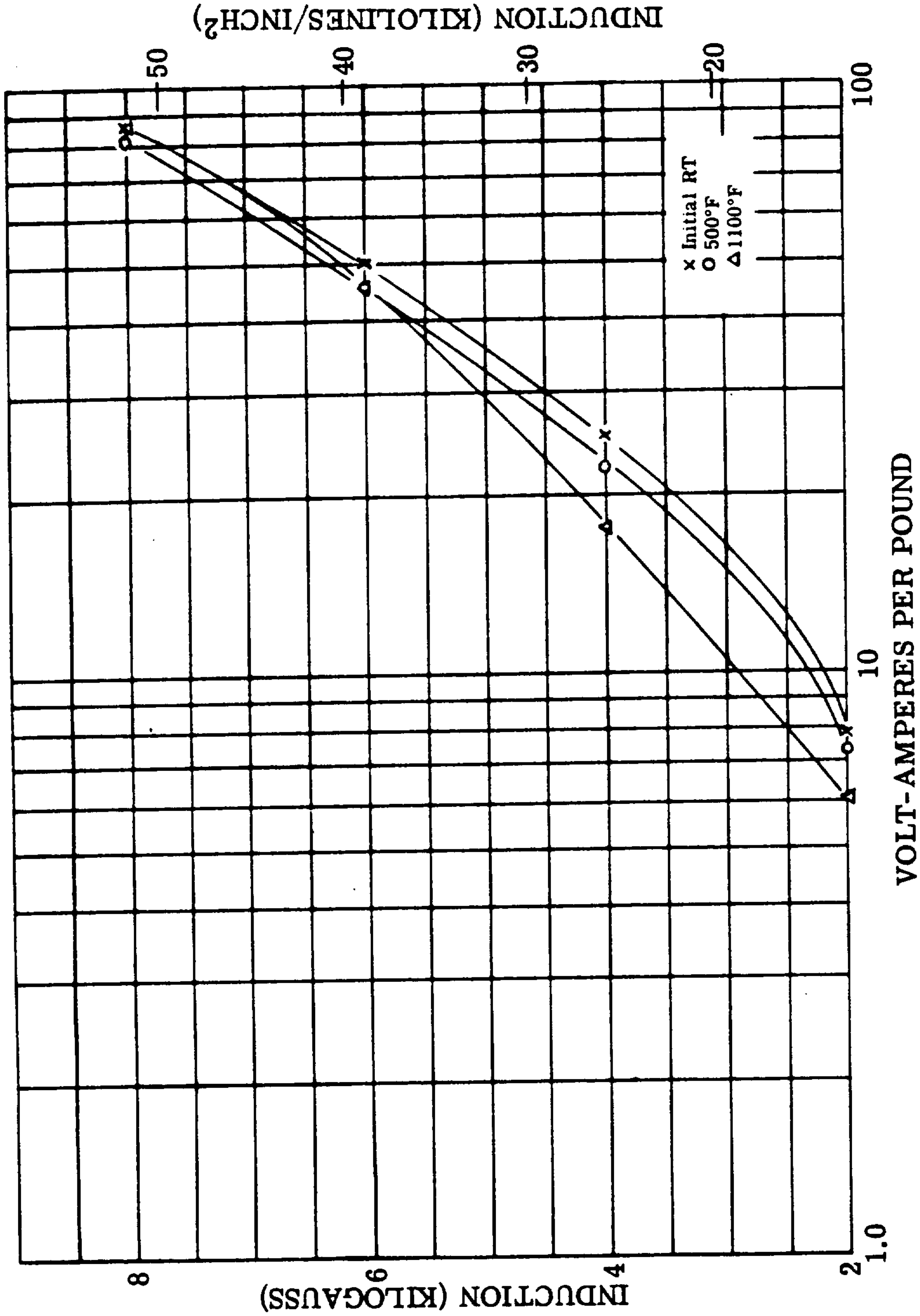


FIGURE IV. A. II-37. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-37. Exciting VA, 3200 CPS. Cubex

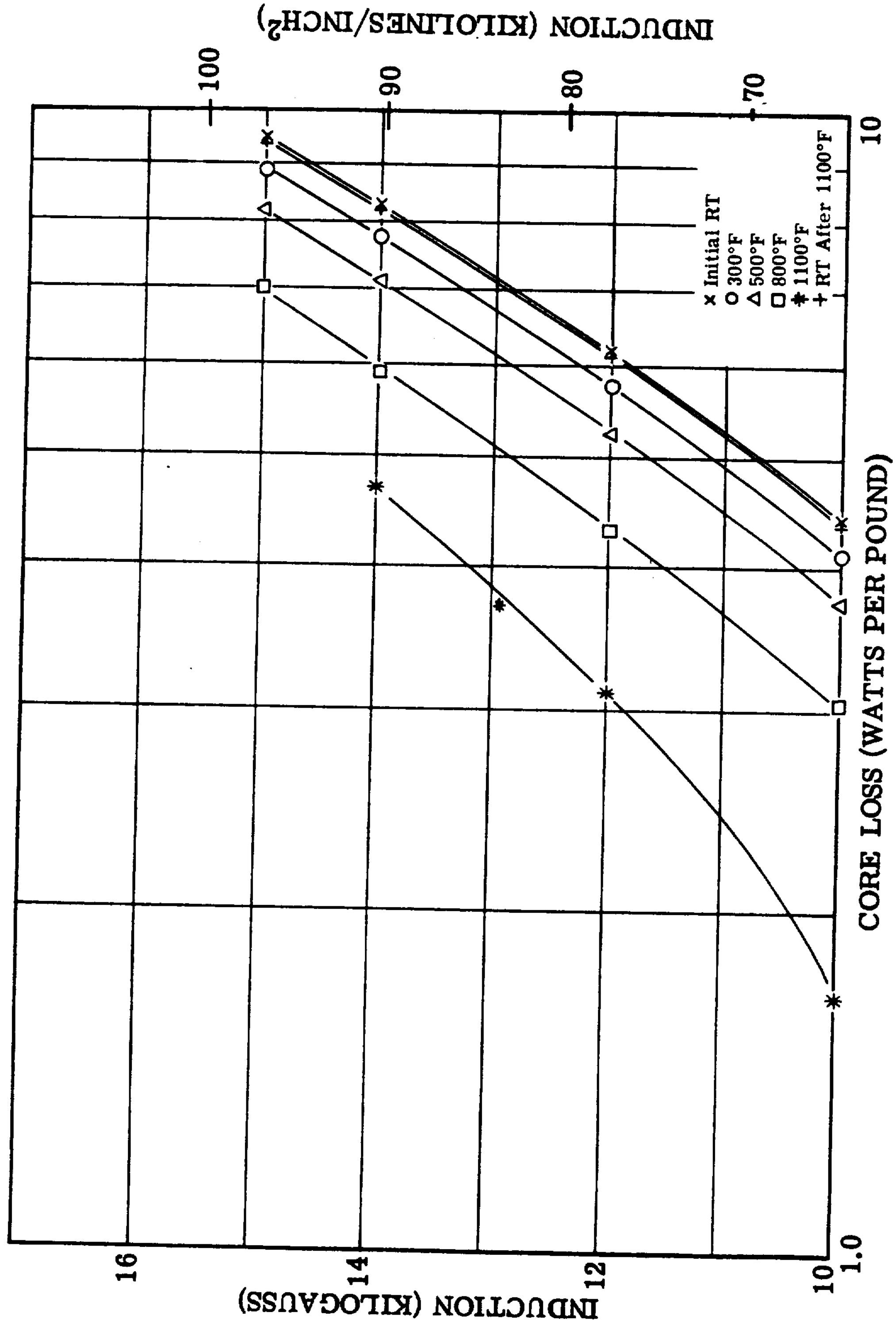


FIGURE IV. A. II-38. Core Loss, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-38. Core Loss, 400 CPS. Cubex

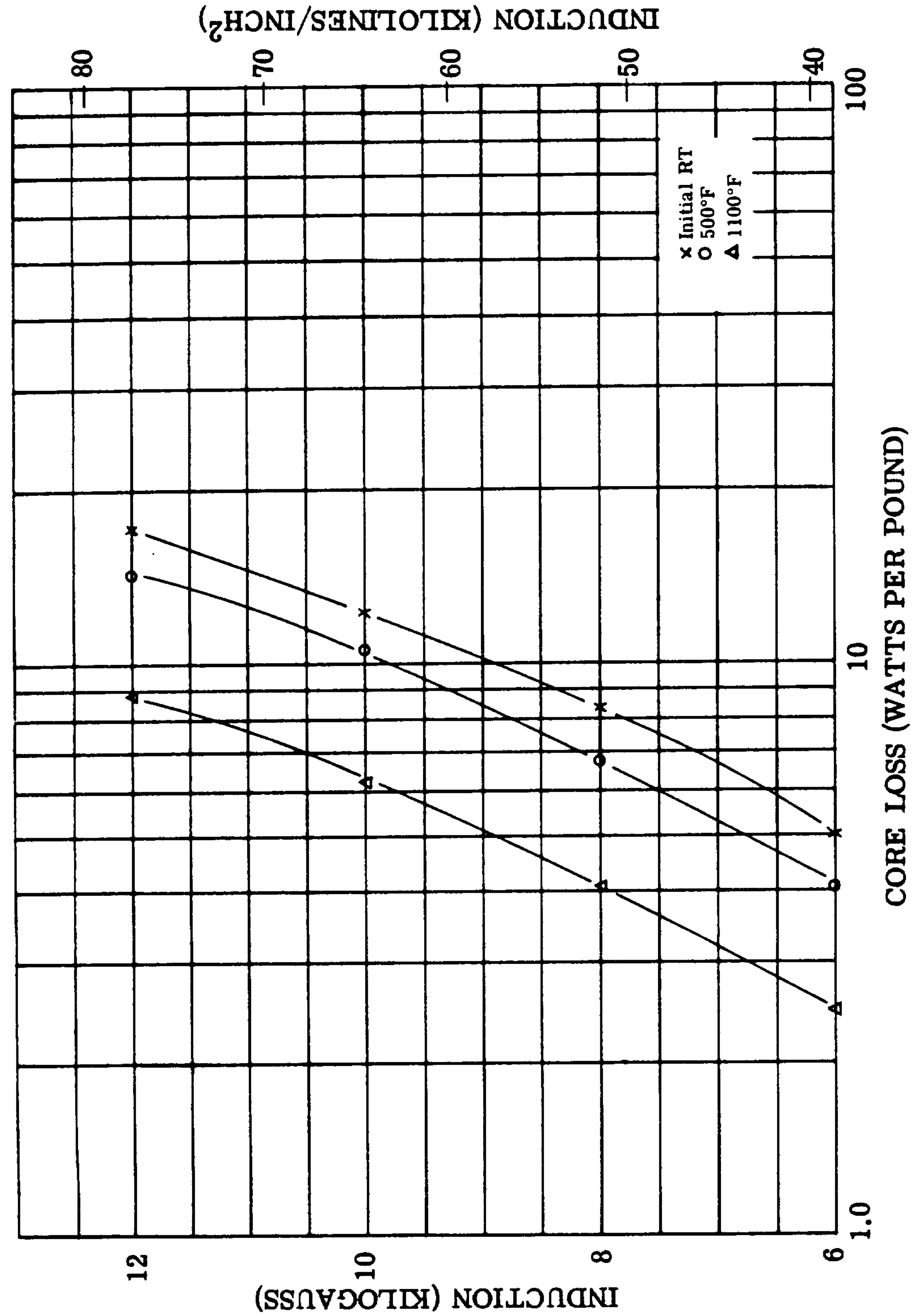


FIGURE IV. A. II-39. Core Loss, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-39. Core Loss, 800 CPS. Cubex

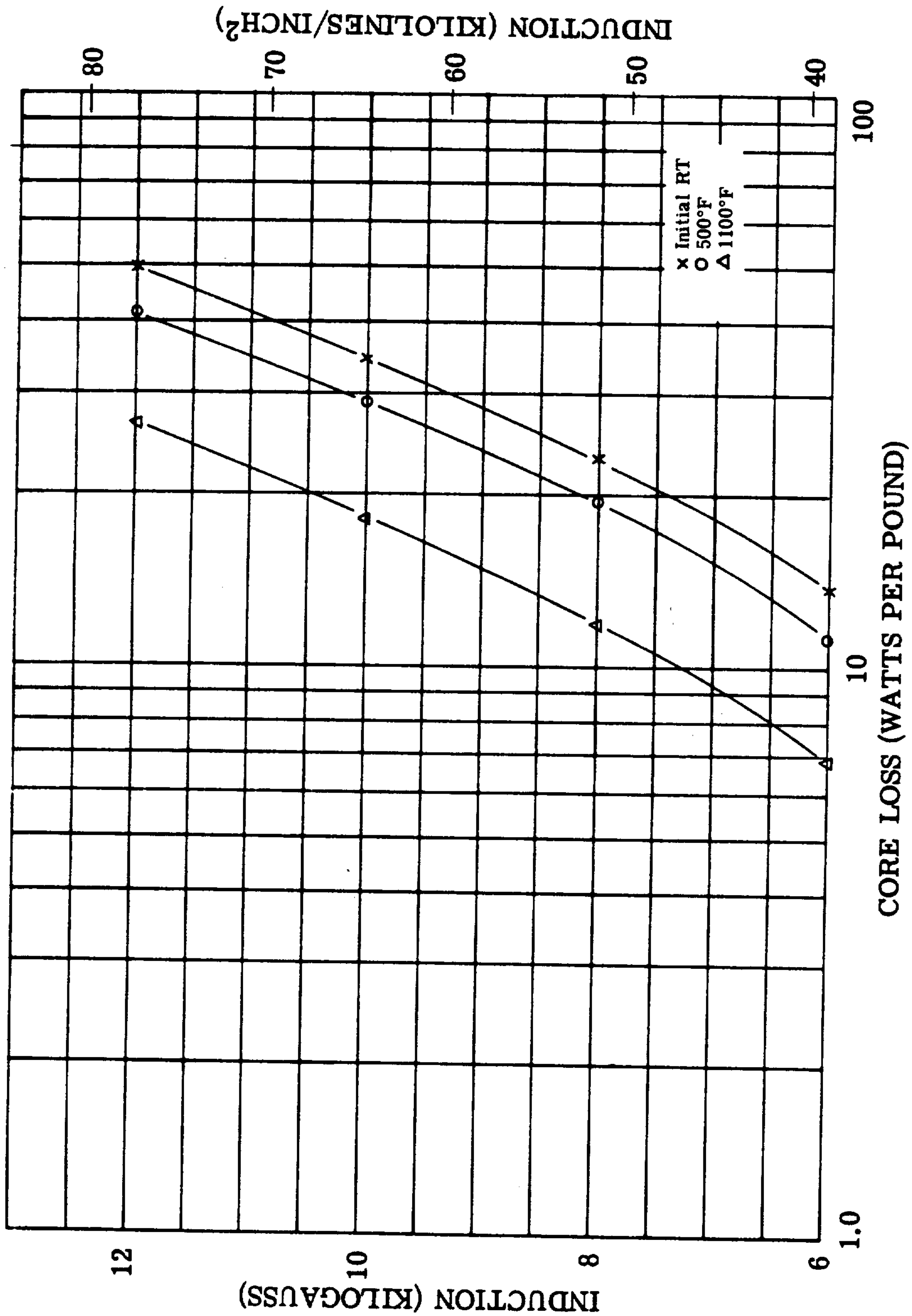


FIGURE IV. A. II-40. Core Loss, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-40. Core Loss, 1600 CPS. Cubex

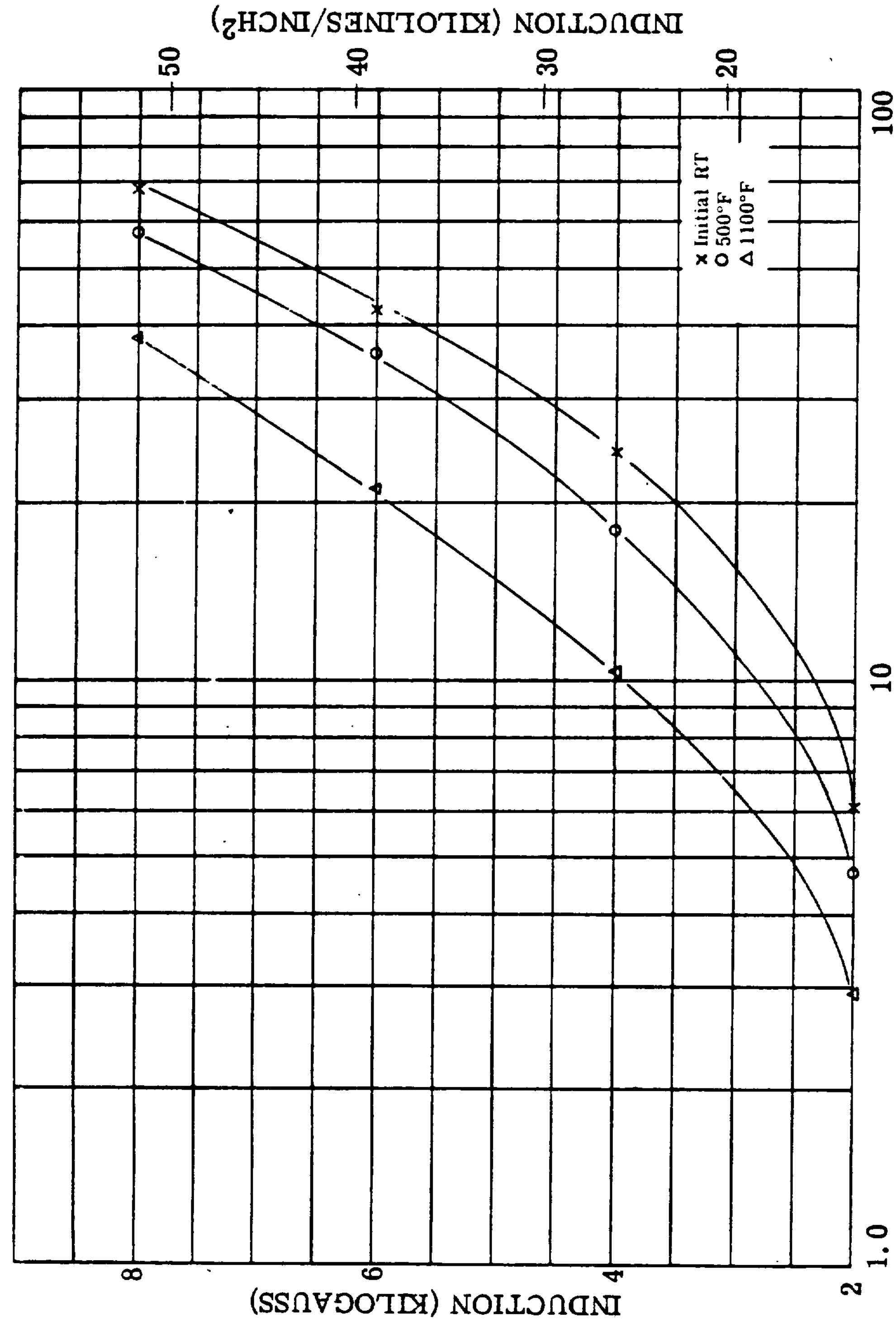


FIGURE I V. A. I I-41. Core Loss, 3200 CPS. Cubex Alloy 0. 006 Inch Tape - Sample #1. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-41. Core Loss, 3200 CPS. Cubex

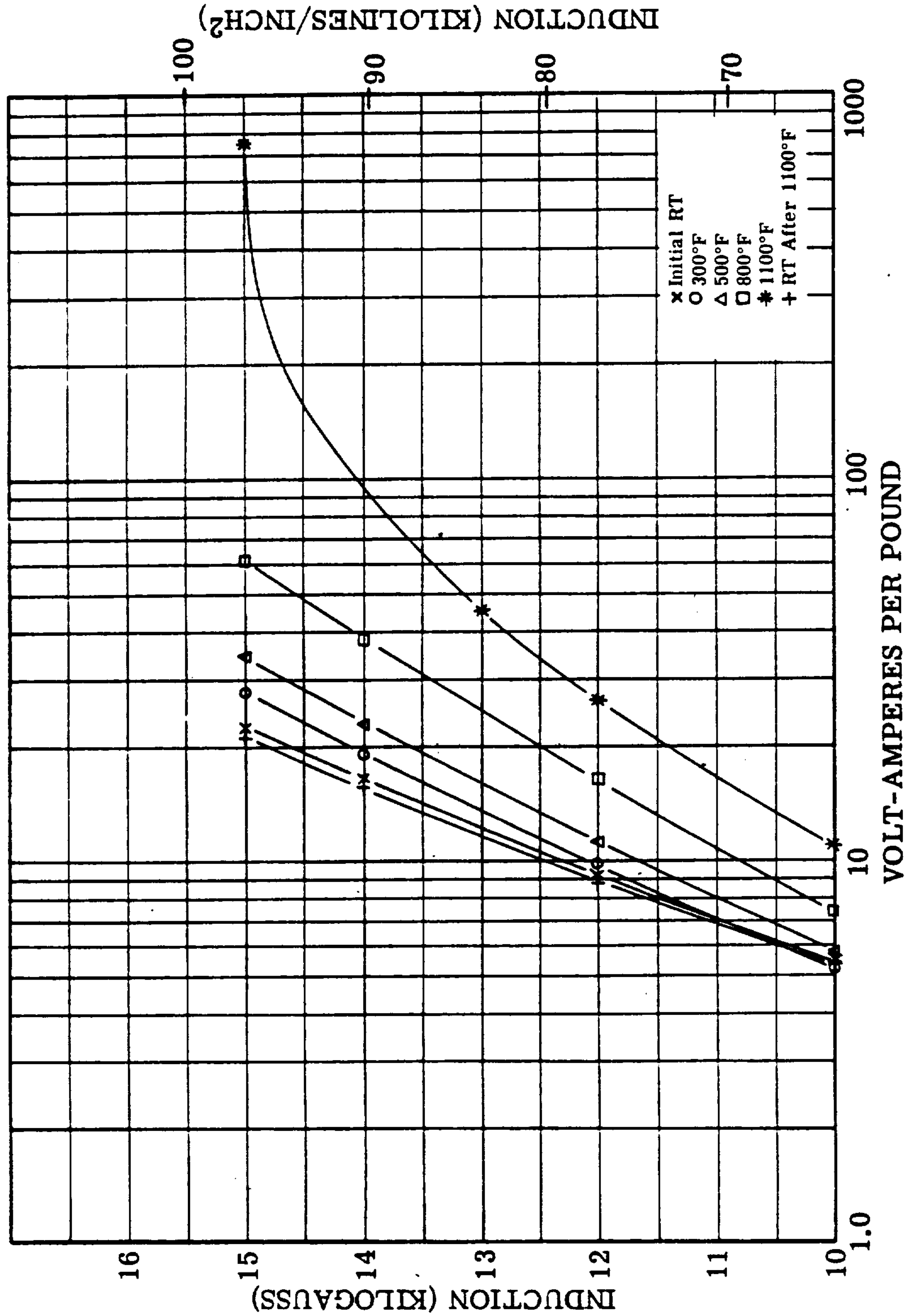


FIGURE IV. A. II-42. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-42. Exciting VA, 400 CPS. Cubex

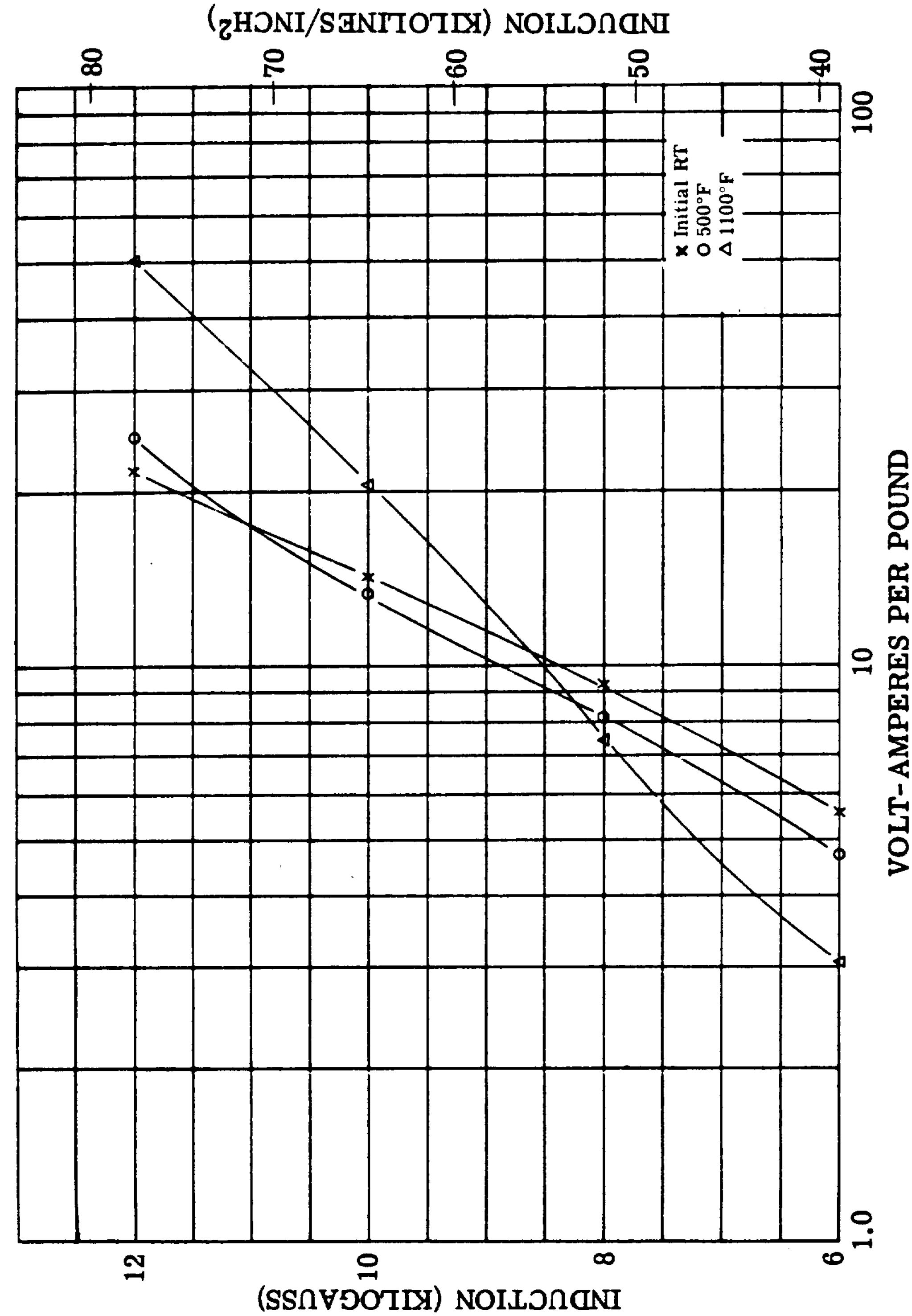


FIGURE IV. A. II-43. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-43. Exciting VA, 800 CPS. Cubex

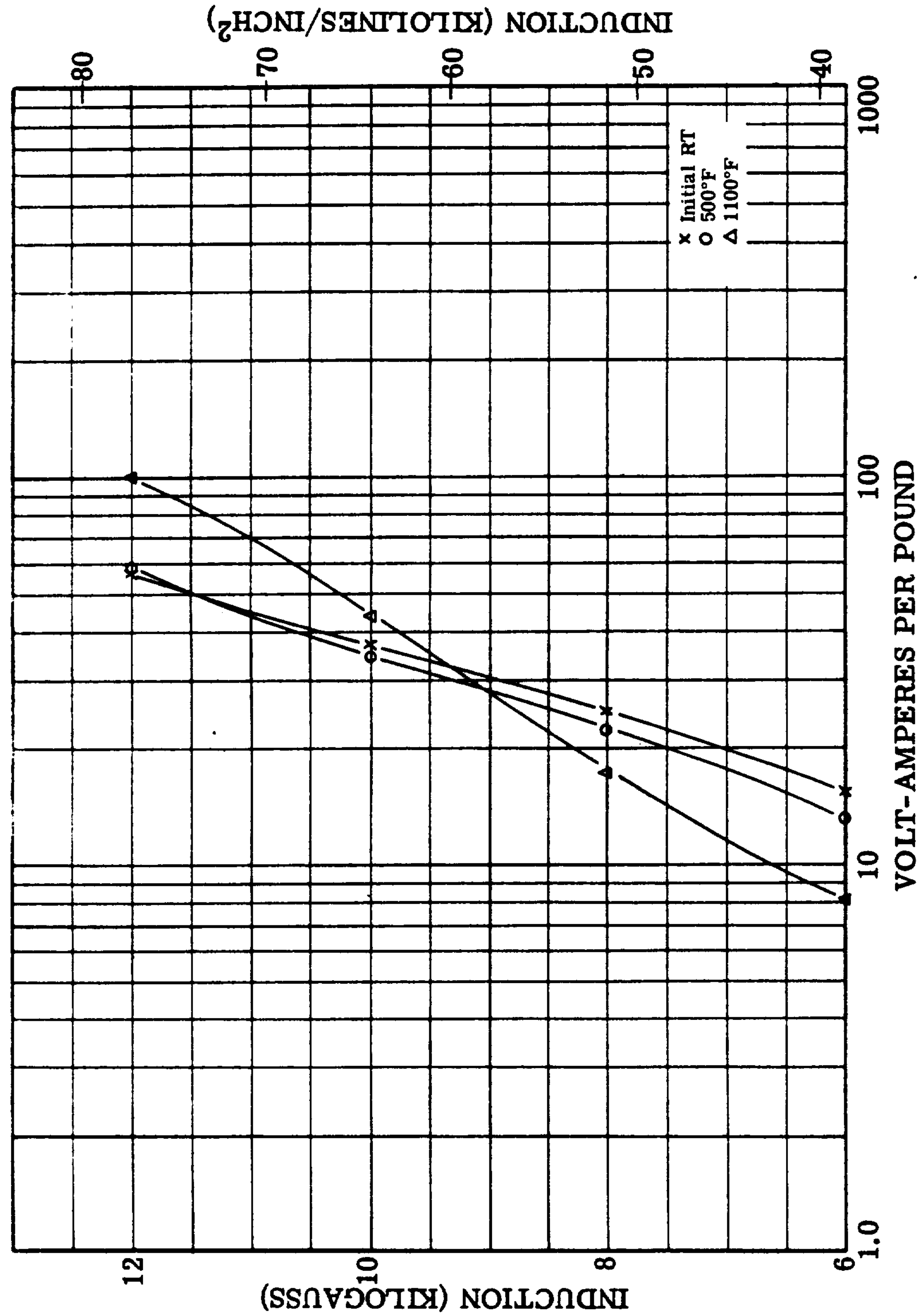


FIGURE I V. A. I I-44. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I- 44. Exciting VA, 1600 CPS. Cubex

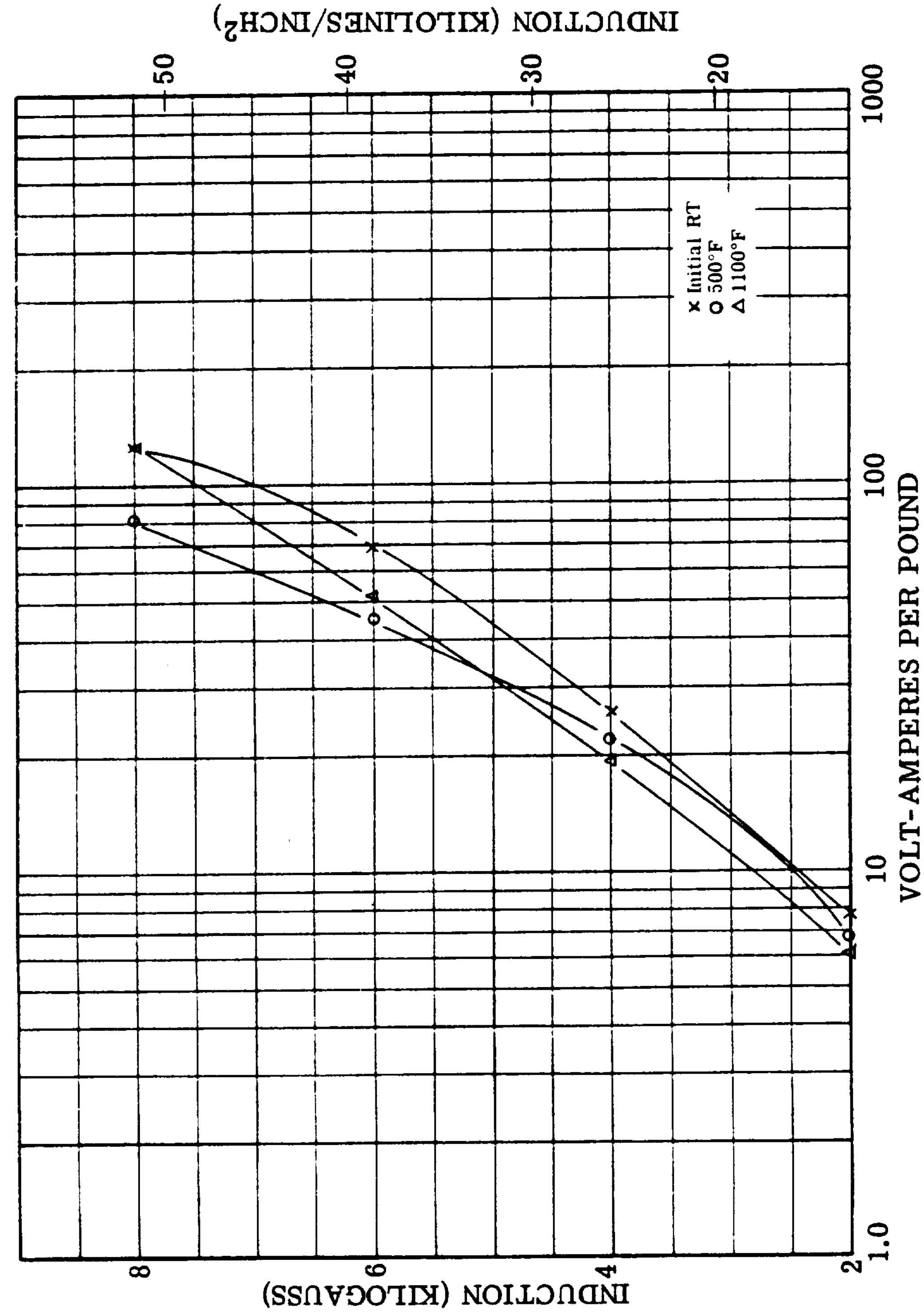


FIGURE IV. A. II-45. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-45. Exciting VA, 3200 CPS. Cubex

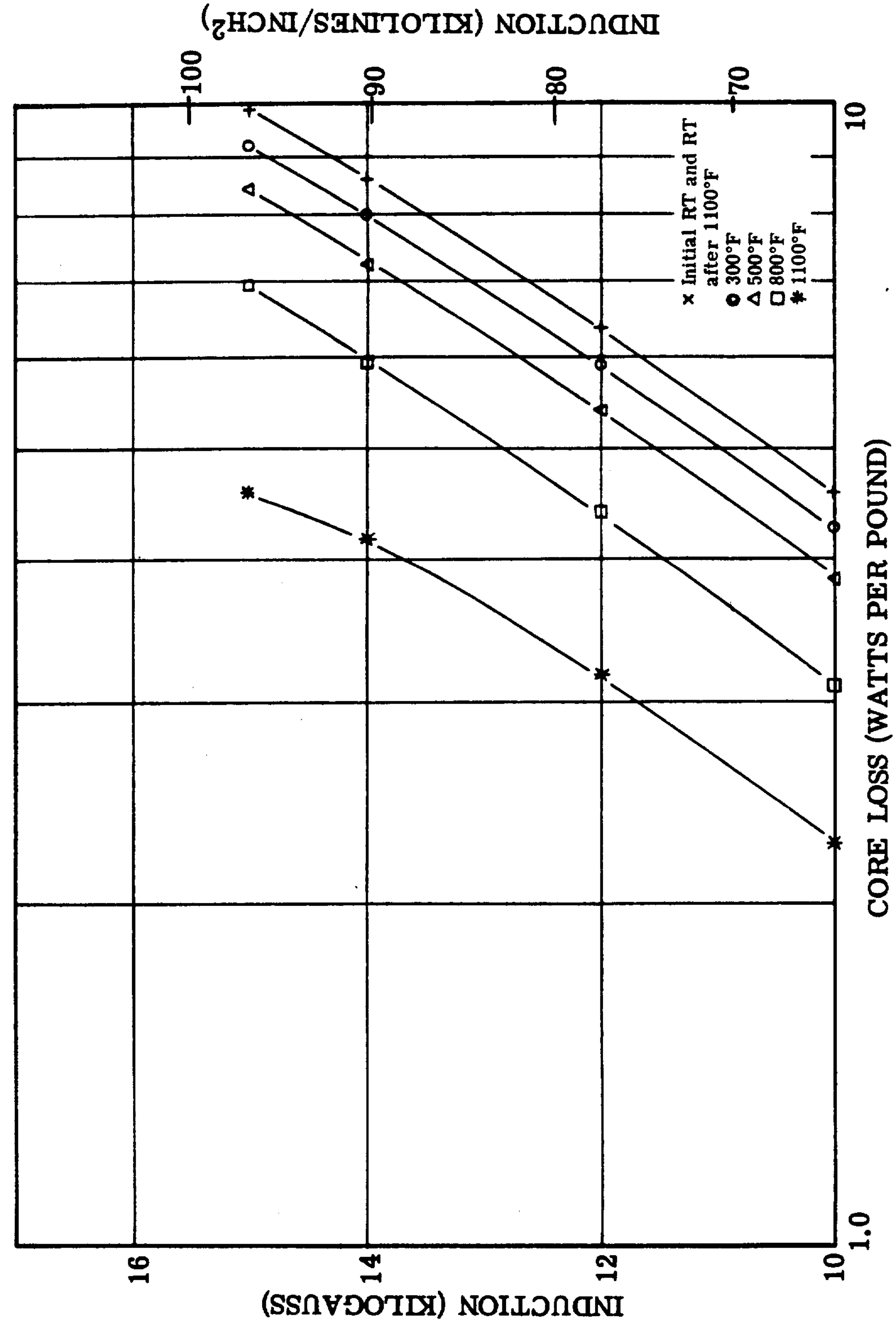


FIGURE IV. A. II-46. Core Loss, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-46. Core Loss, 400 CPS. Cubex

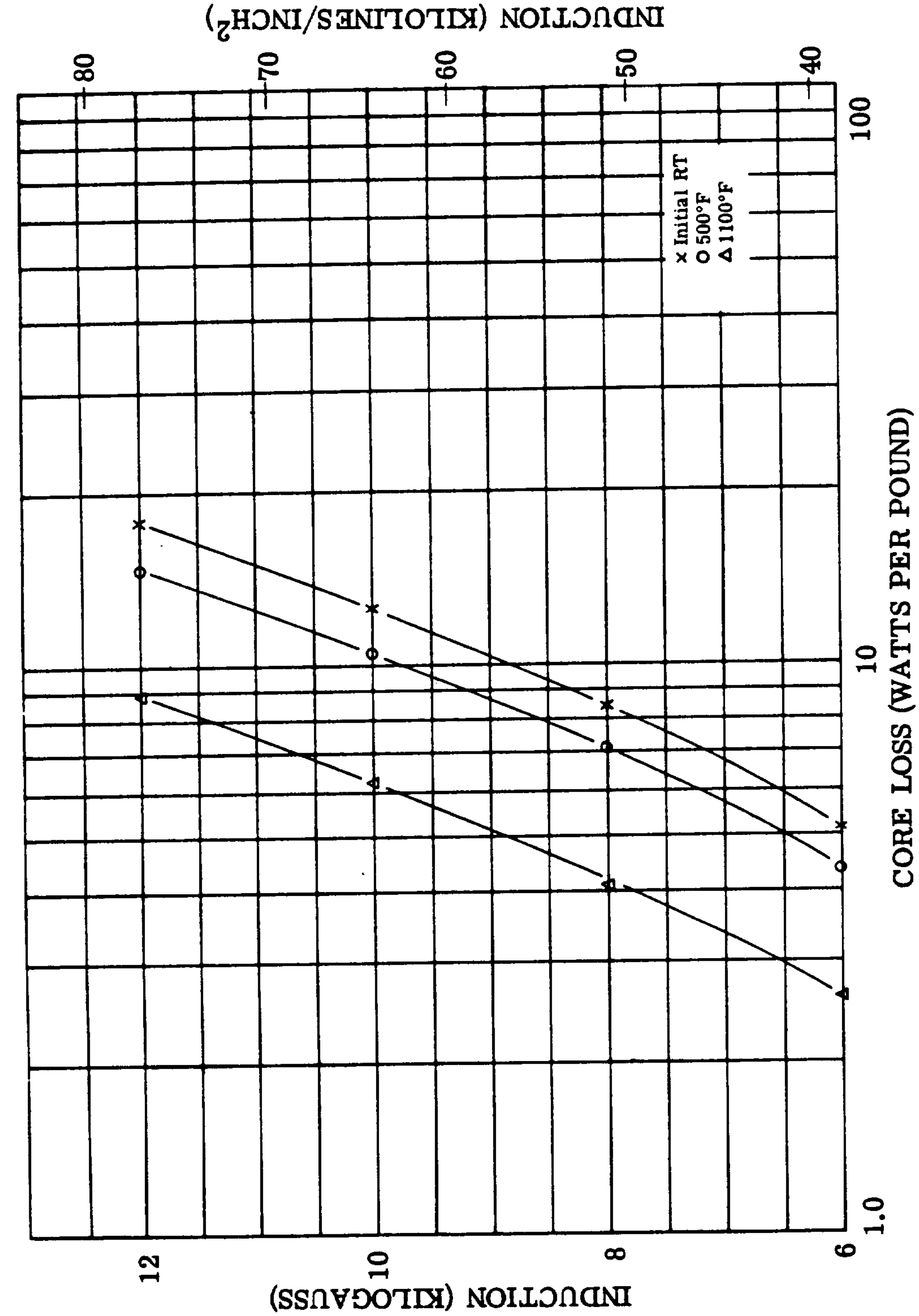


FIGURE IV. A. II-47. Core Loss, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-47. Core Loss, 800 CPS. Cubex

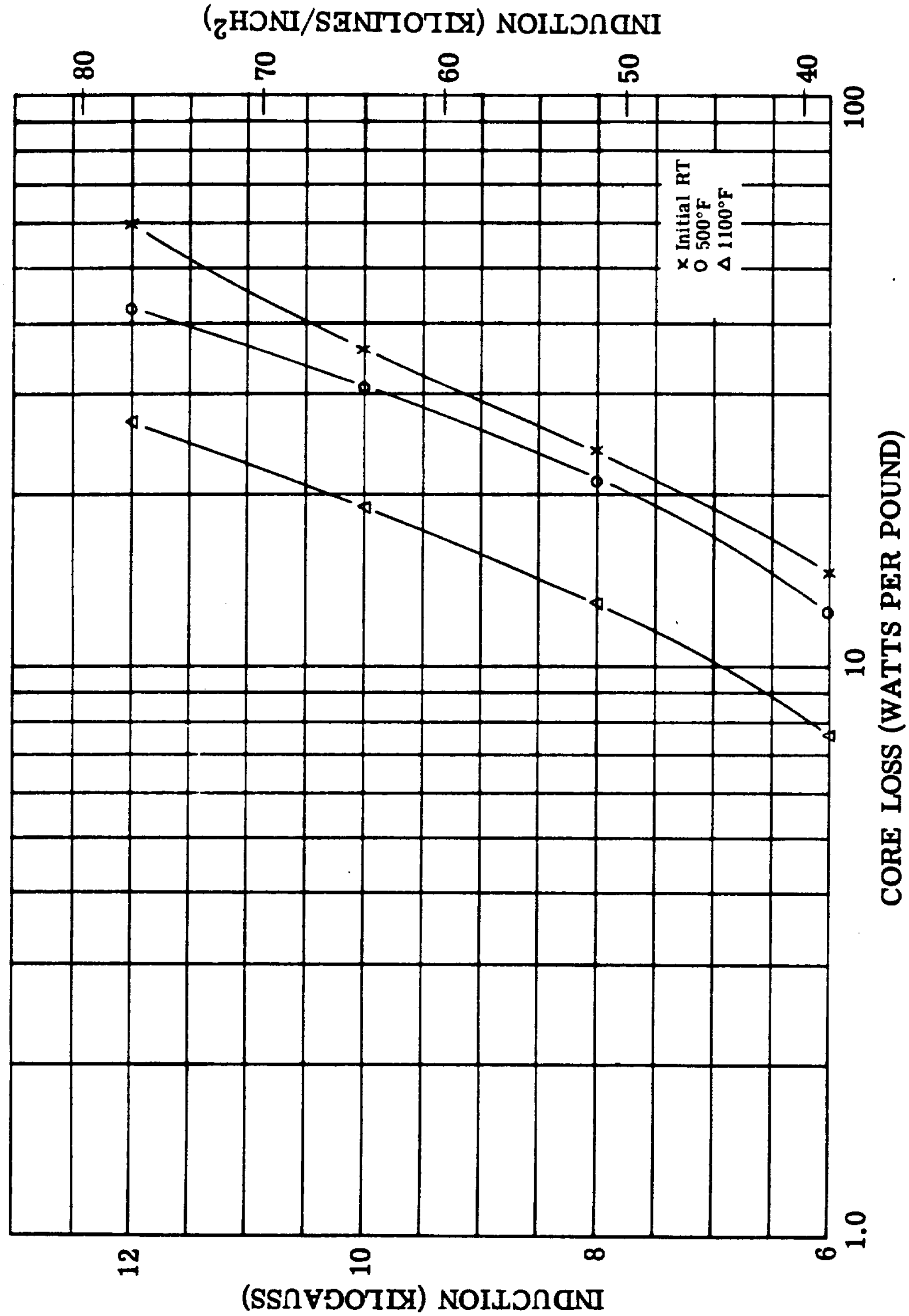


FIGURE IV.A.II-48. Core Loss, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.A.II-48. Core Loss, 1600 CPS. Cubex

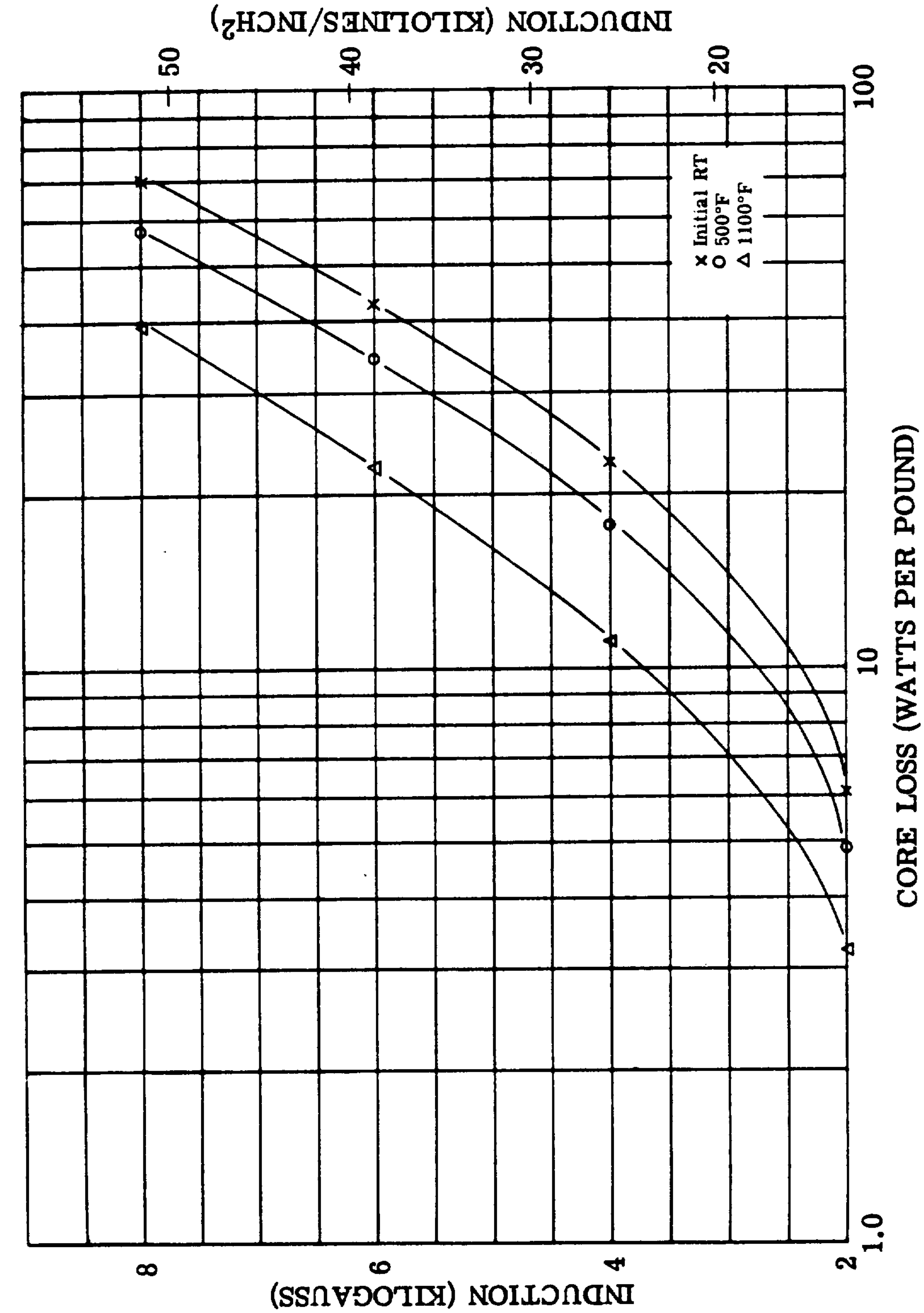


FIGURE I V. A. I I-49. Core Loss, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Sample #2. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-49. Core Loss, 3200 CPS. Cubex

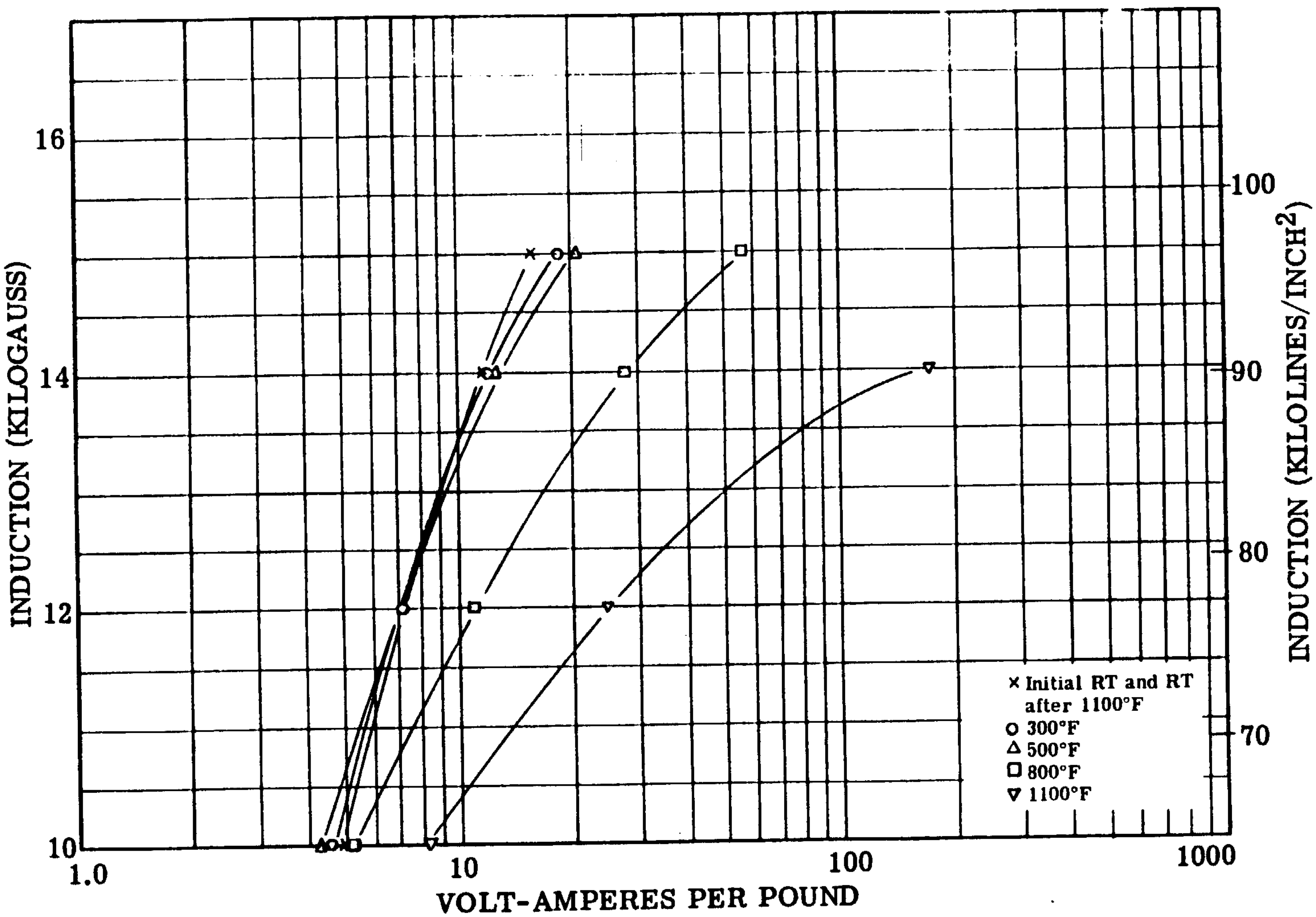


FIGURE IV. A. II-50. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-50. Exciting VA, 400 CPS. Cubex

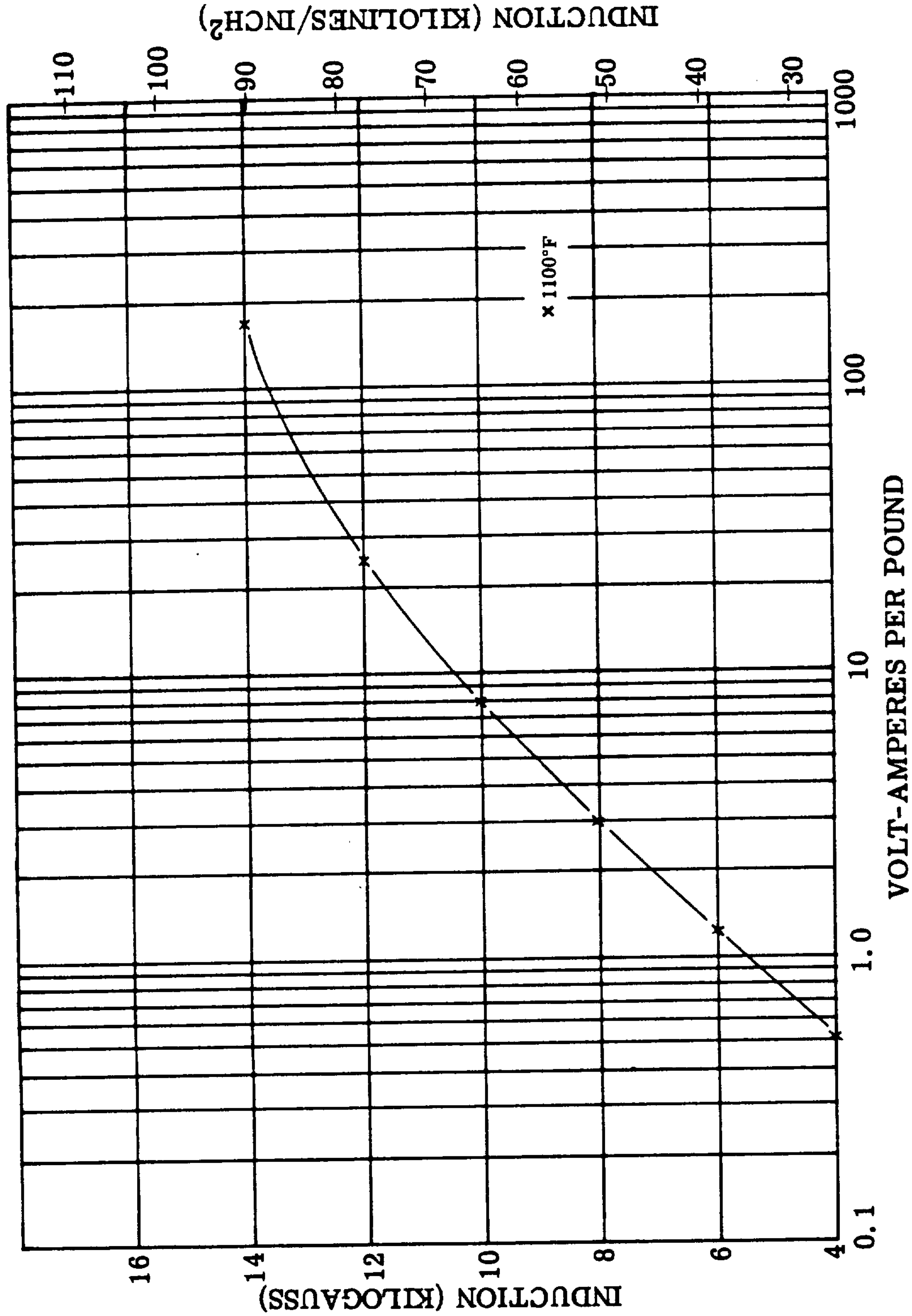


FIGURE IV. A. II-51. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-51. Exciting VA, 400 CPS. Cubex

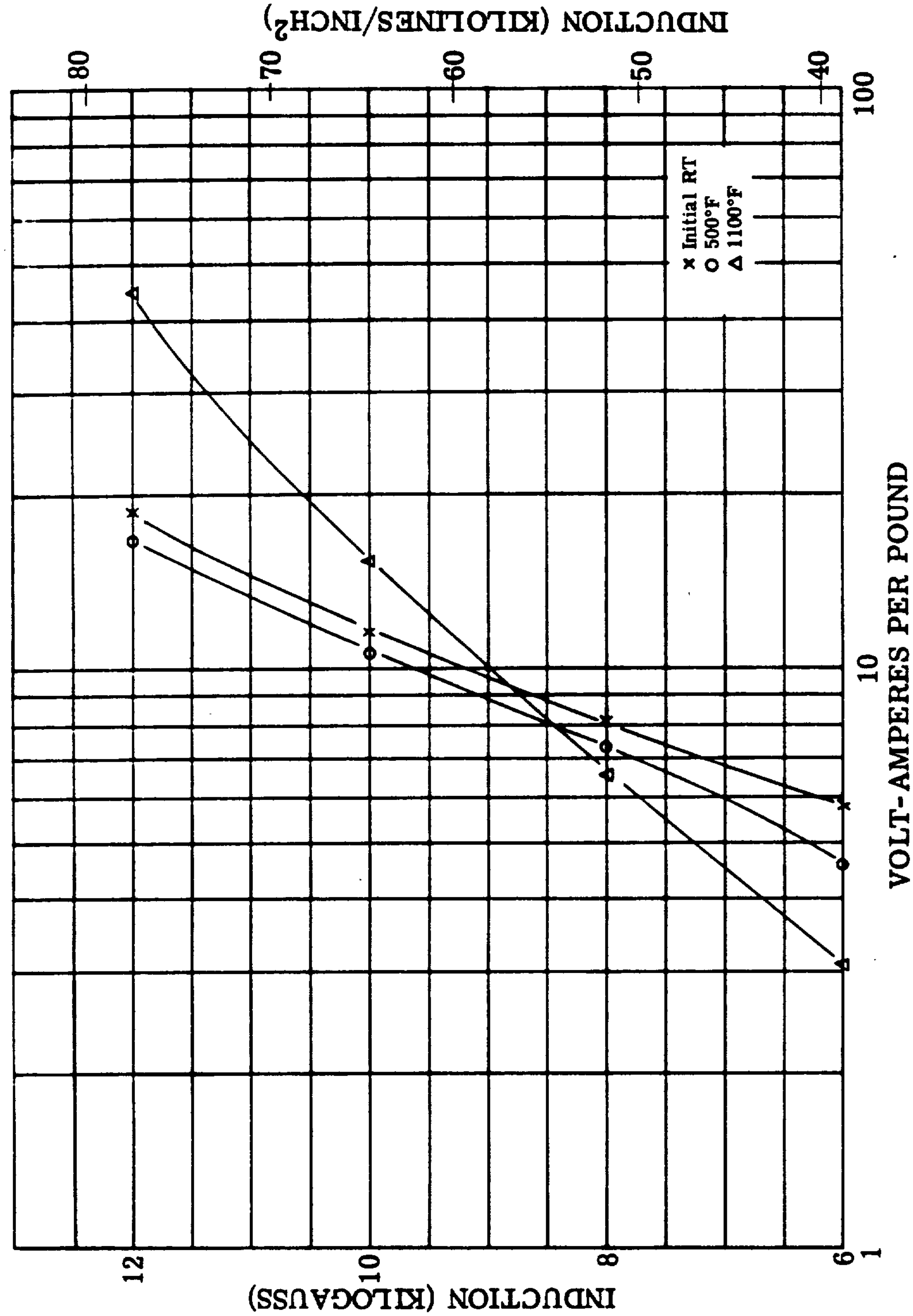


FIGURE I V. A. I I-52. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-52. Exciting VA, 800 CPS. Cubex

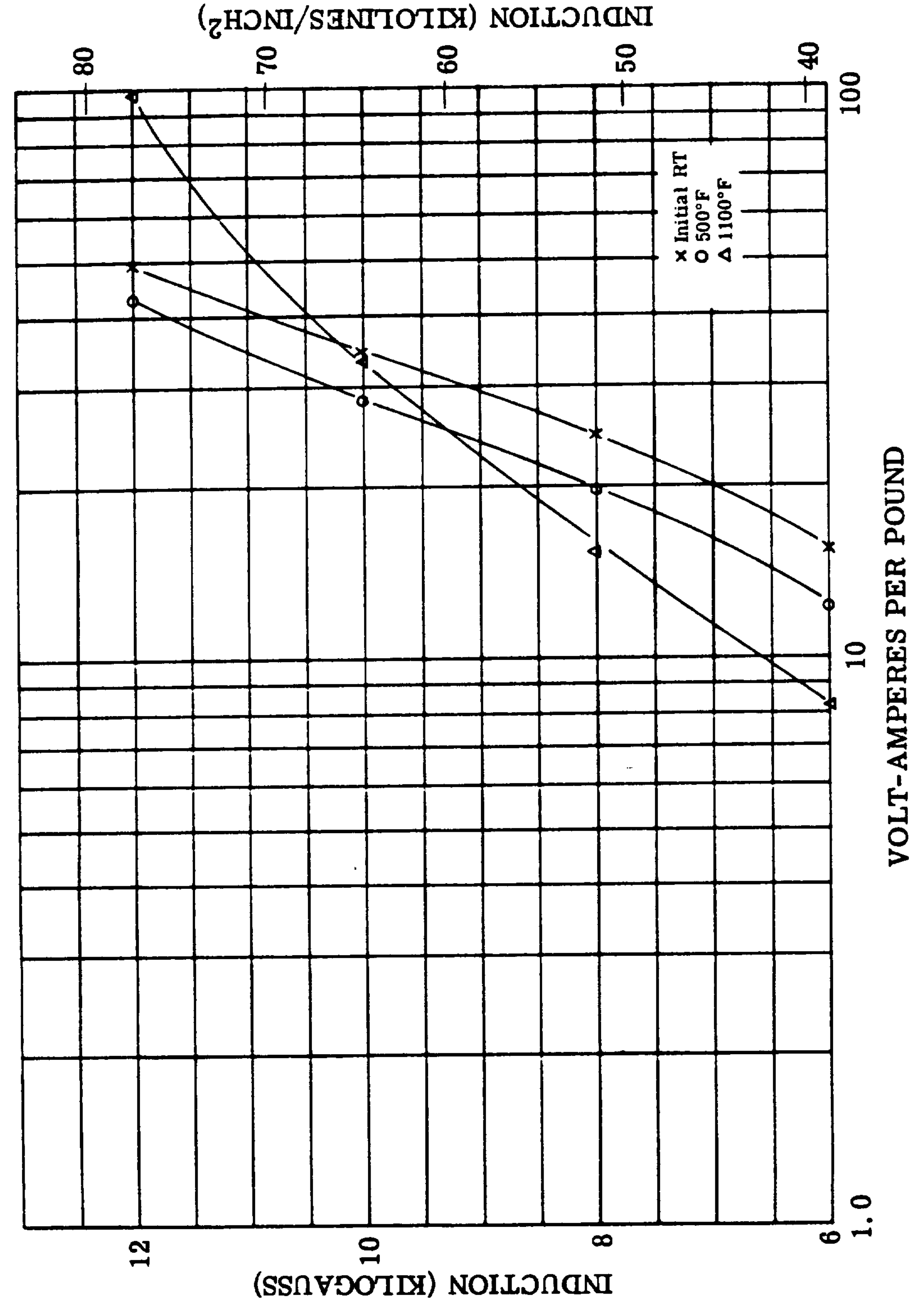


FIGURE IV. A. II-53. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-53. Exciting VA, 1600 CPS. Cubex

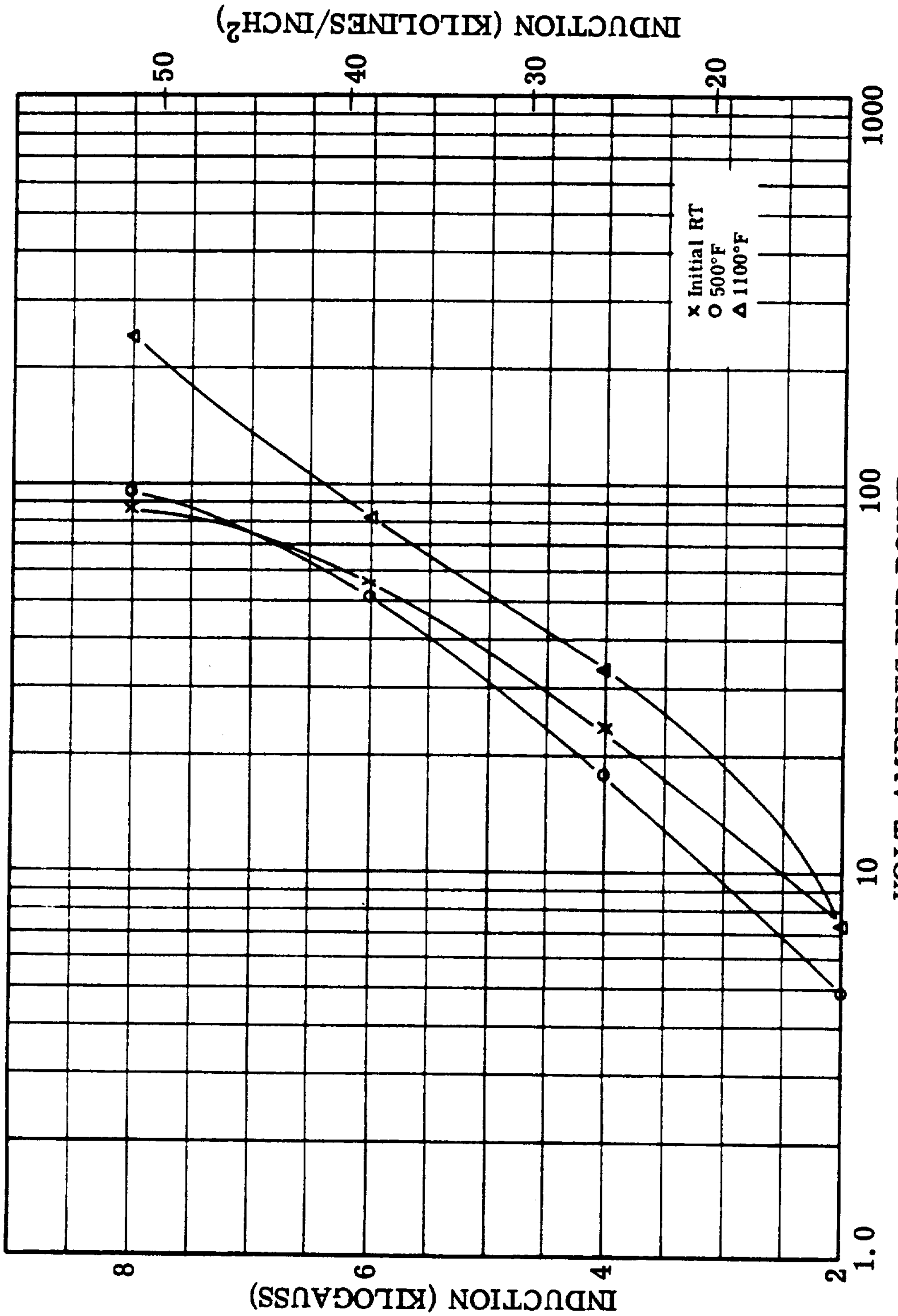


FIGURE IV. A. II-54. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-54. Exciting VA, 3200 CPS. Cubex

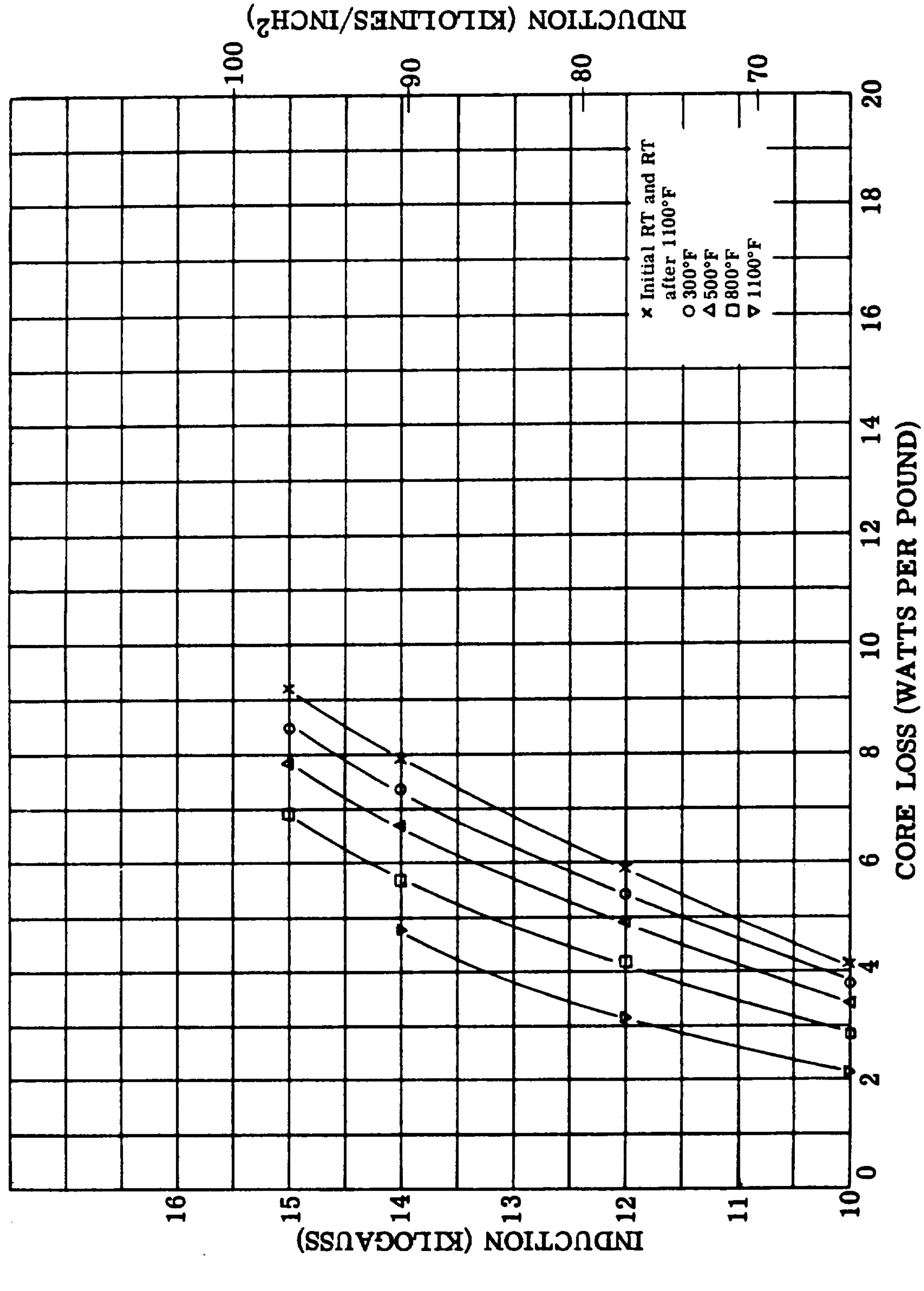


FIGURE IV. A. II-55. Core Loss, 400 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-55. Core Loss, 400 CPS. Cubex

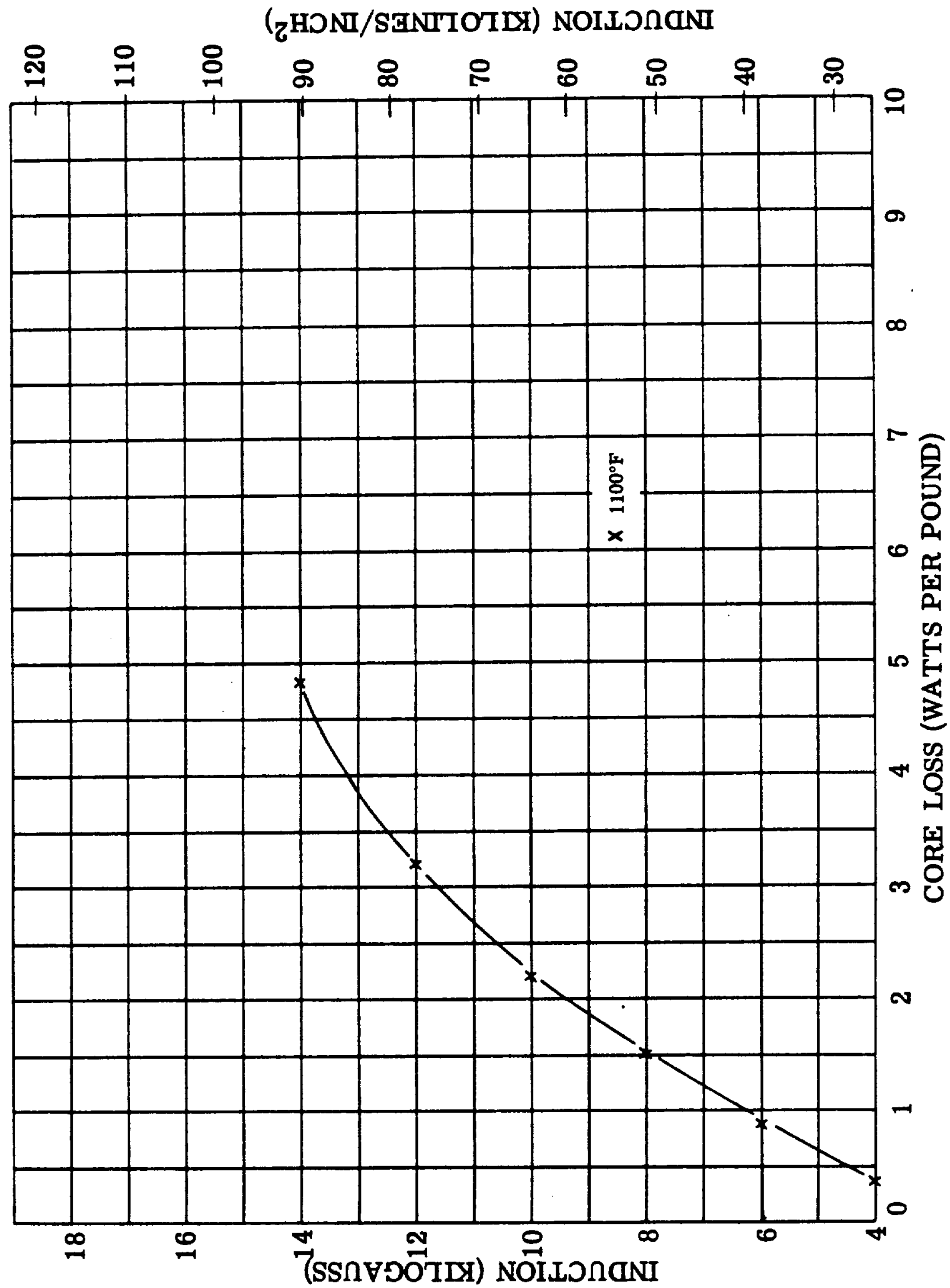


FIGURE I V. A. I I-56. Core Loss, 400 CPS. Cubex Alloy 0. 006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-56. Core Loss, 400 CPS. Cubex

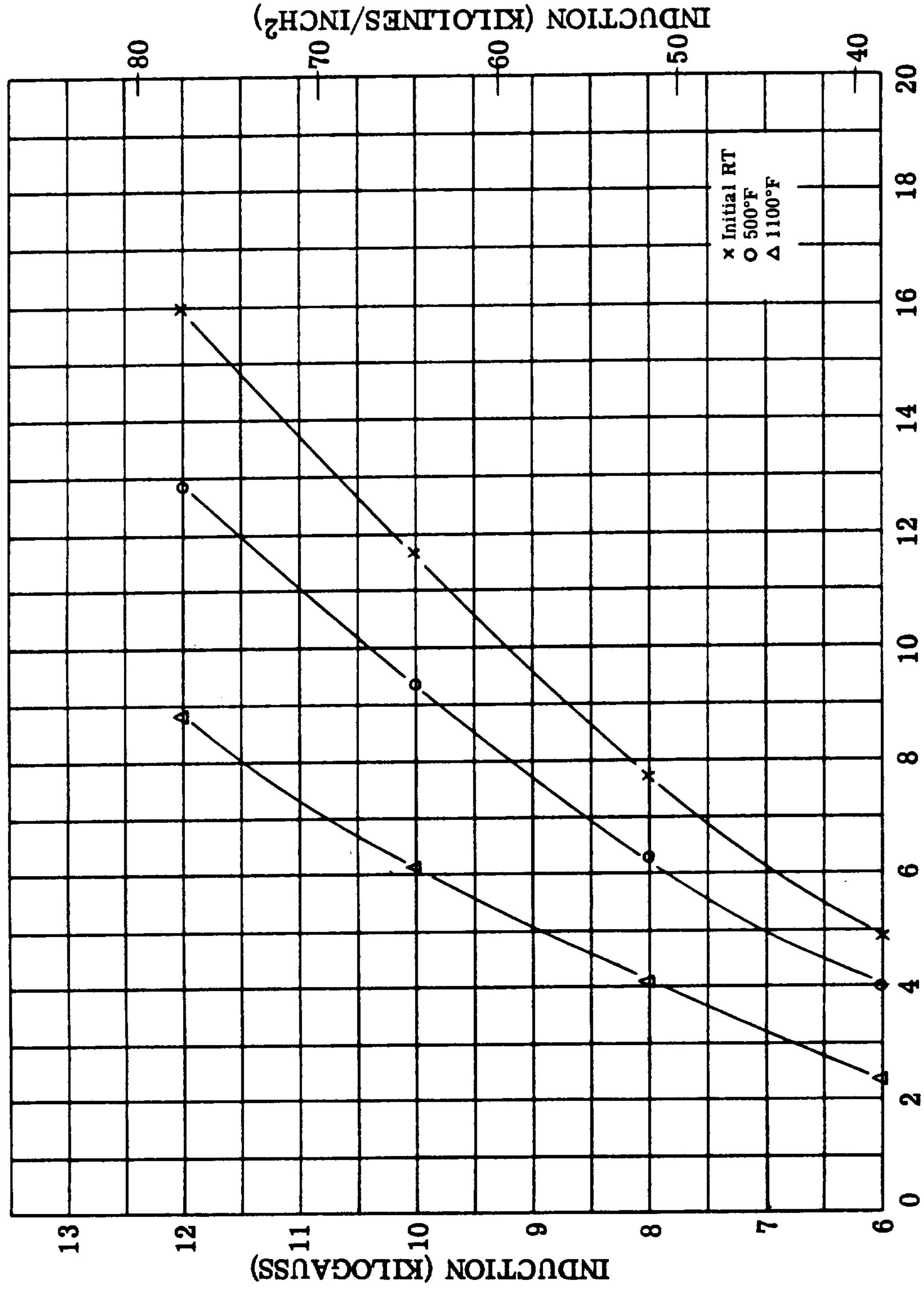


FIGURE IV. A. II-57. Core Loss, 800 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-57. Core Loss, 800 CPS. Cubex

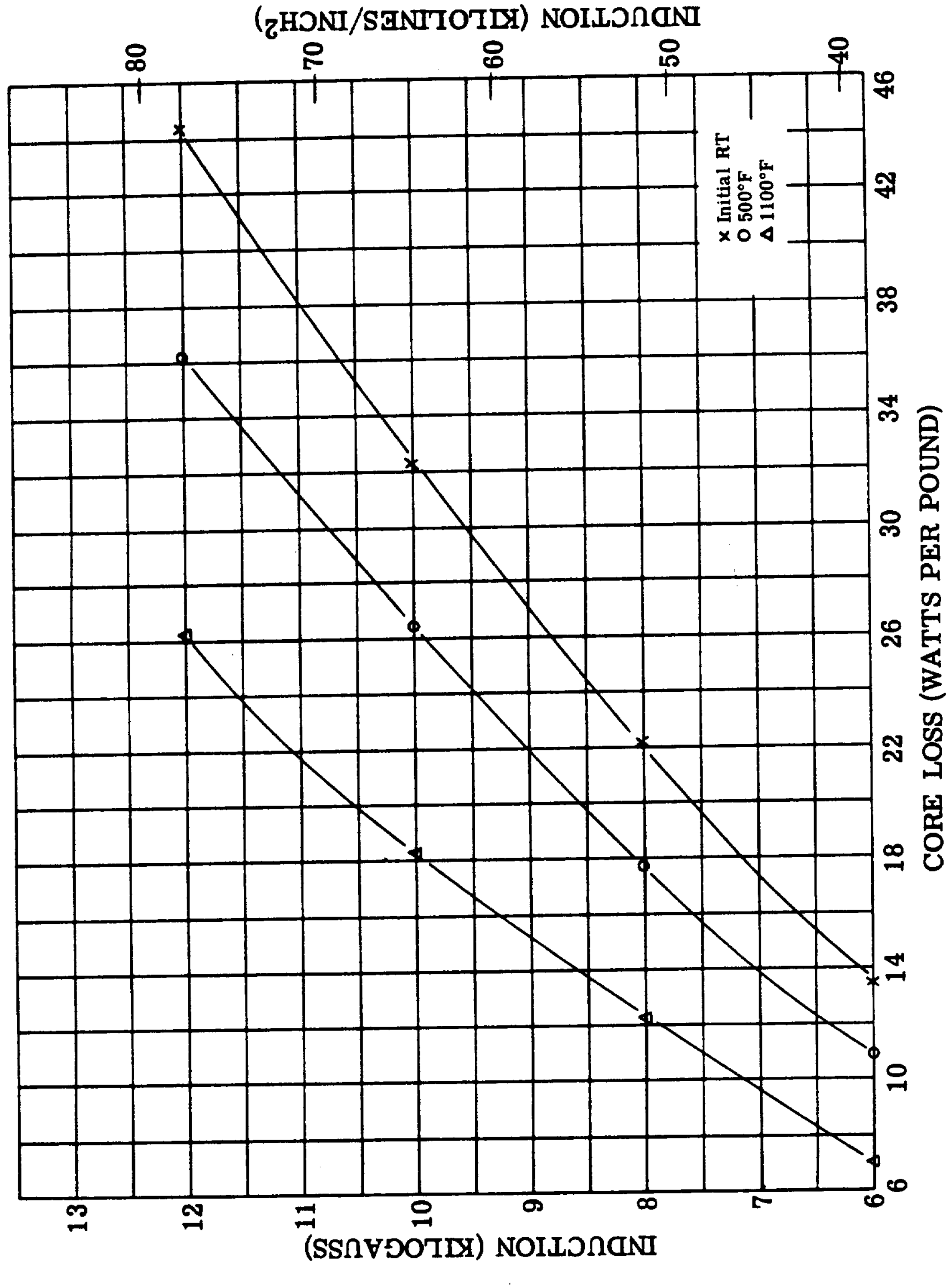


FIGURE IV. A. II-58. Core Loss, 1600 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-58. Core Loss, 1600 CPS. Cubex

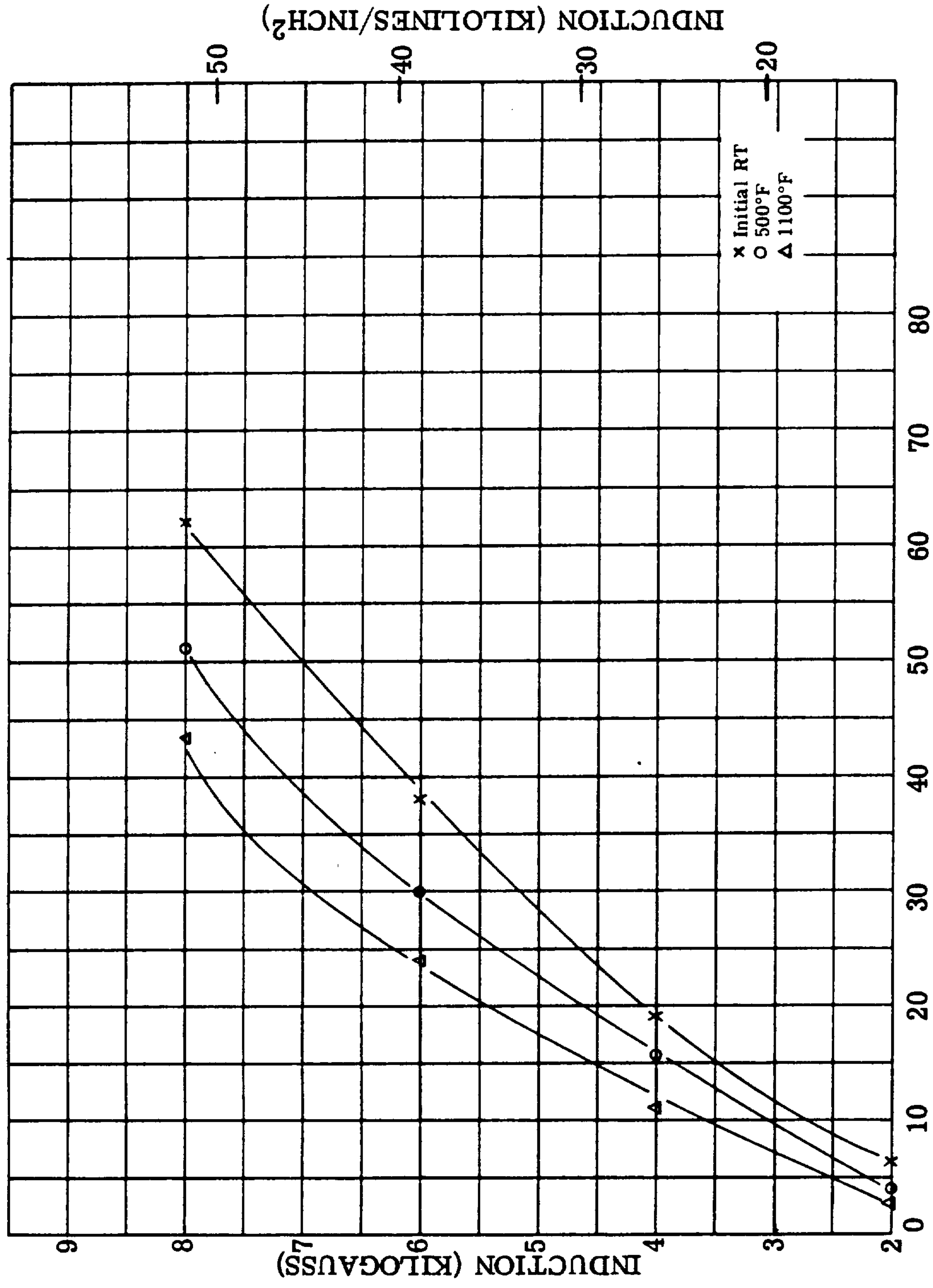


FIGURE IV. A. II-59. Core Loss, 3200 CPS. Cubex Alloy 0.006 Inch Tape - Sample #3. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-59. Core Loss, 3200 CPS. Cubex

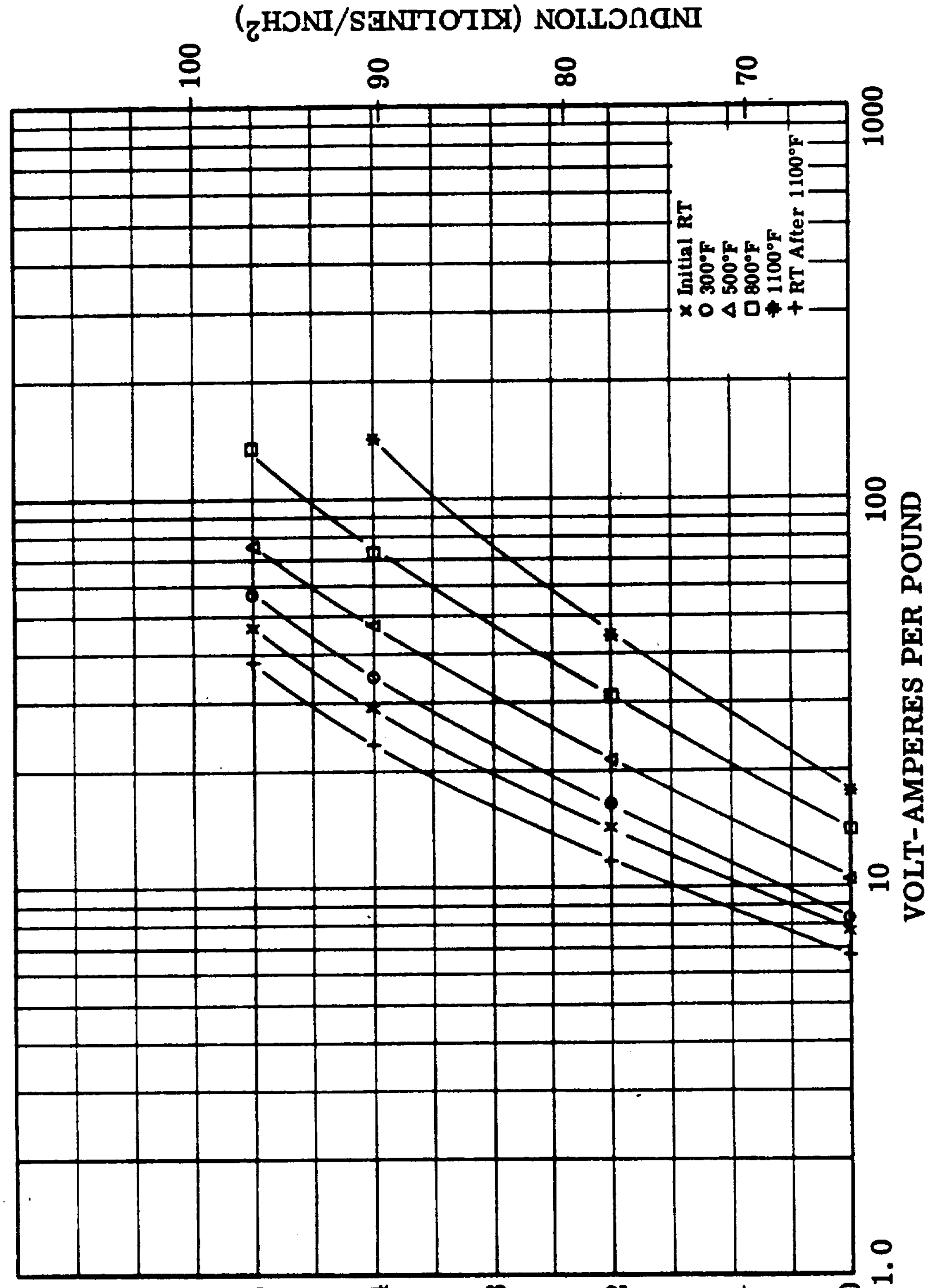


FIGURE IV. A. II-60. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-60. Exciting VA, 400 CPS. Cubex

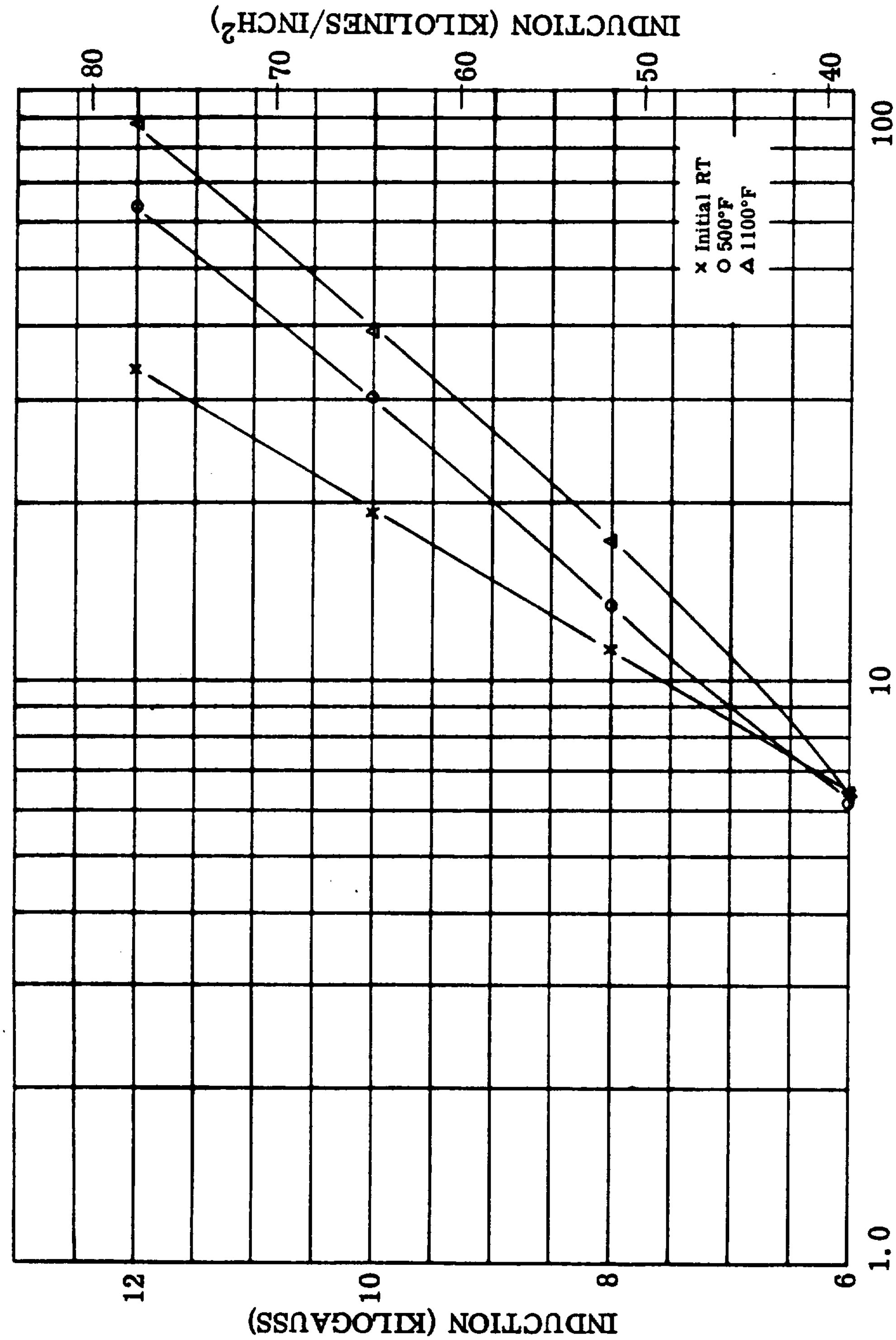


FIGURE IV. A. II-61. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-61. Exciting VA, 800 CPS. Cubex

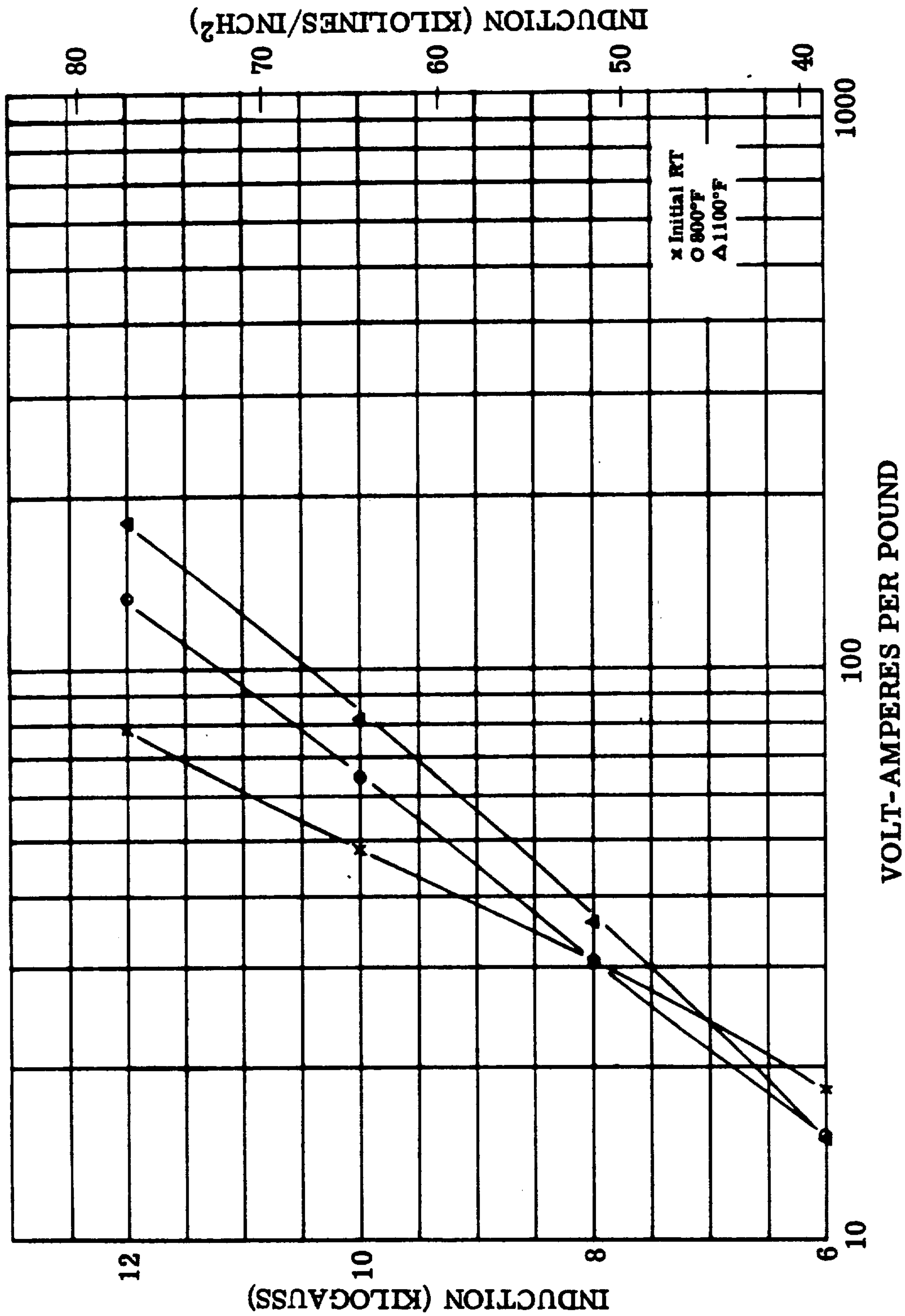


FIGURE I V. A. I I-62. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. I I-62. Exciting VA, 1600 CPS. Cubex

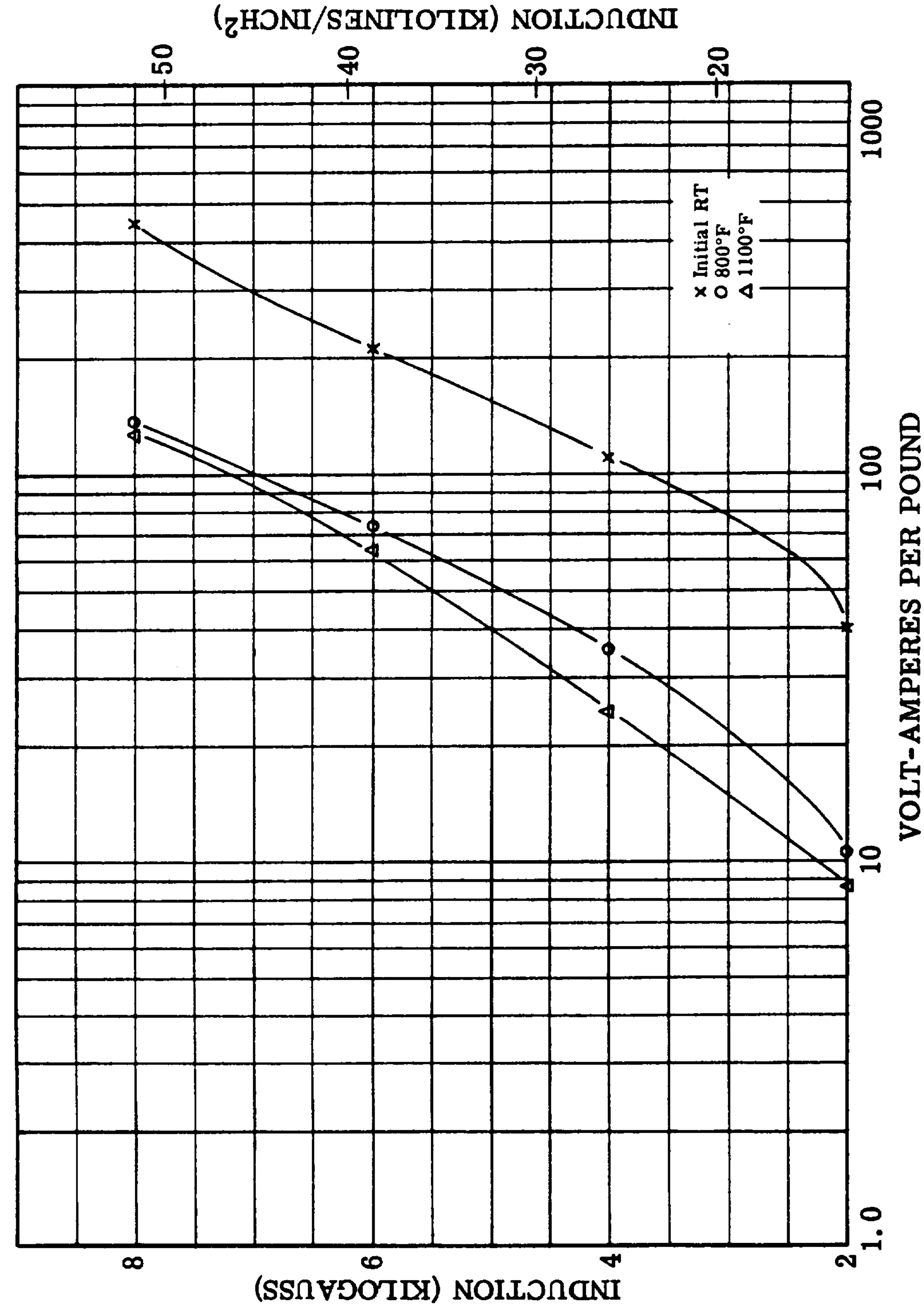


FIGURE IV. A. II-63. Exciting Volt-Amperes Per Pound, 3200 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-63. Exciting VA, 3200 CPS. Cubex

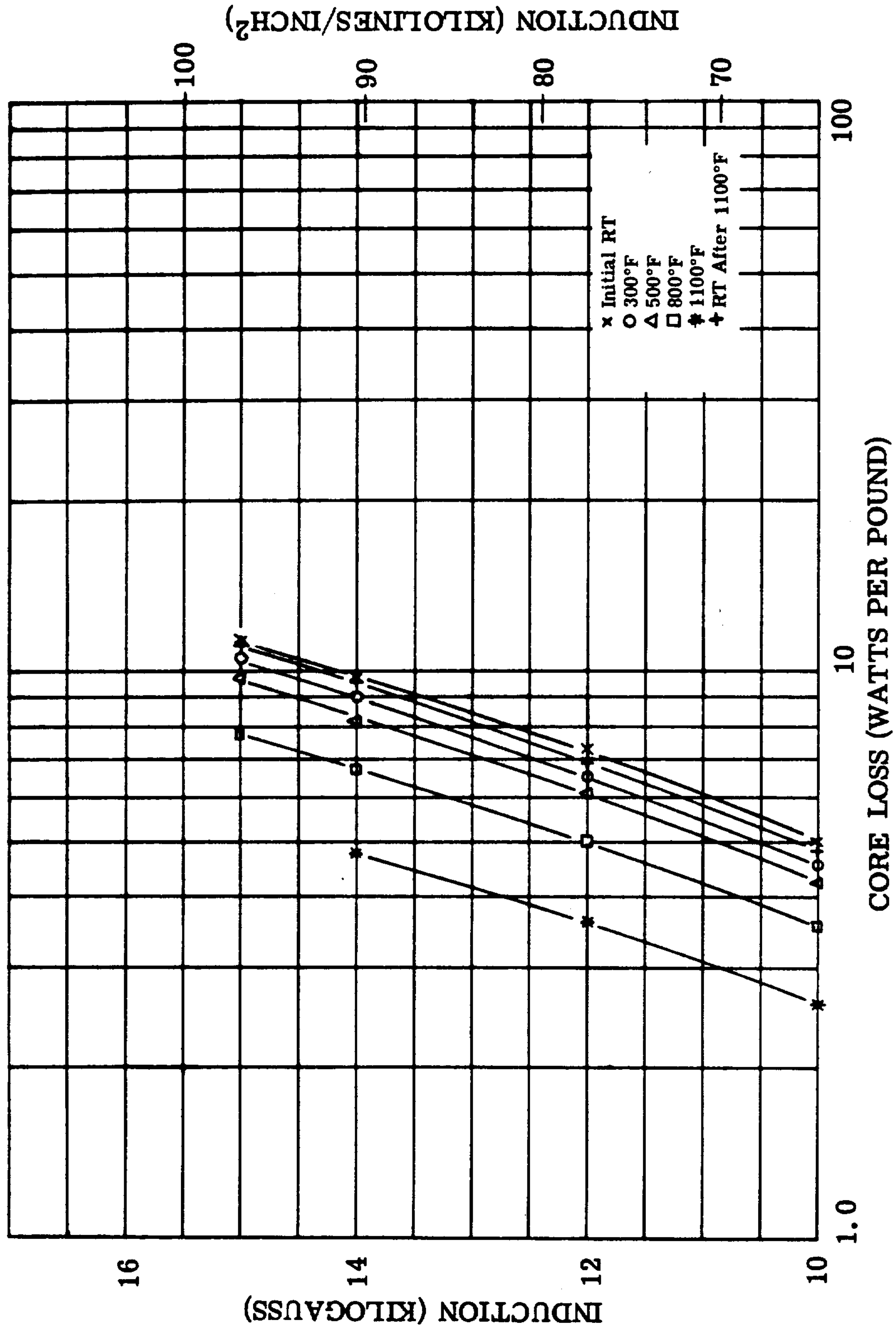


FIGURE IV. A. II-64. Core Loss, 400 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-64. Core Loss, 400 CPS. Cubex

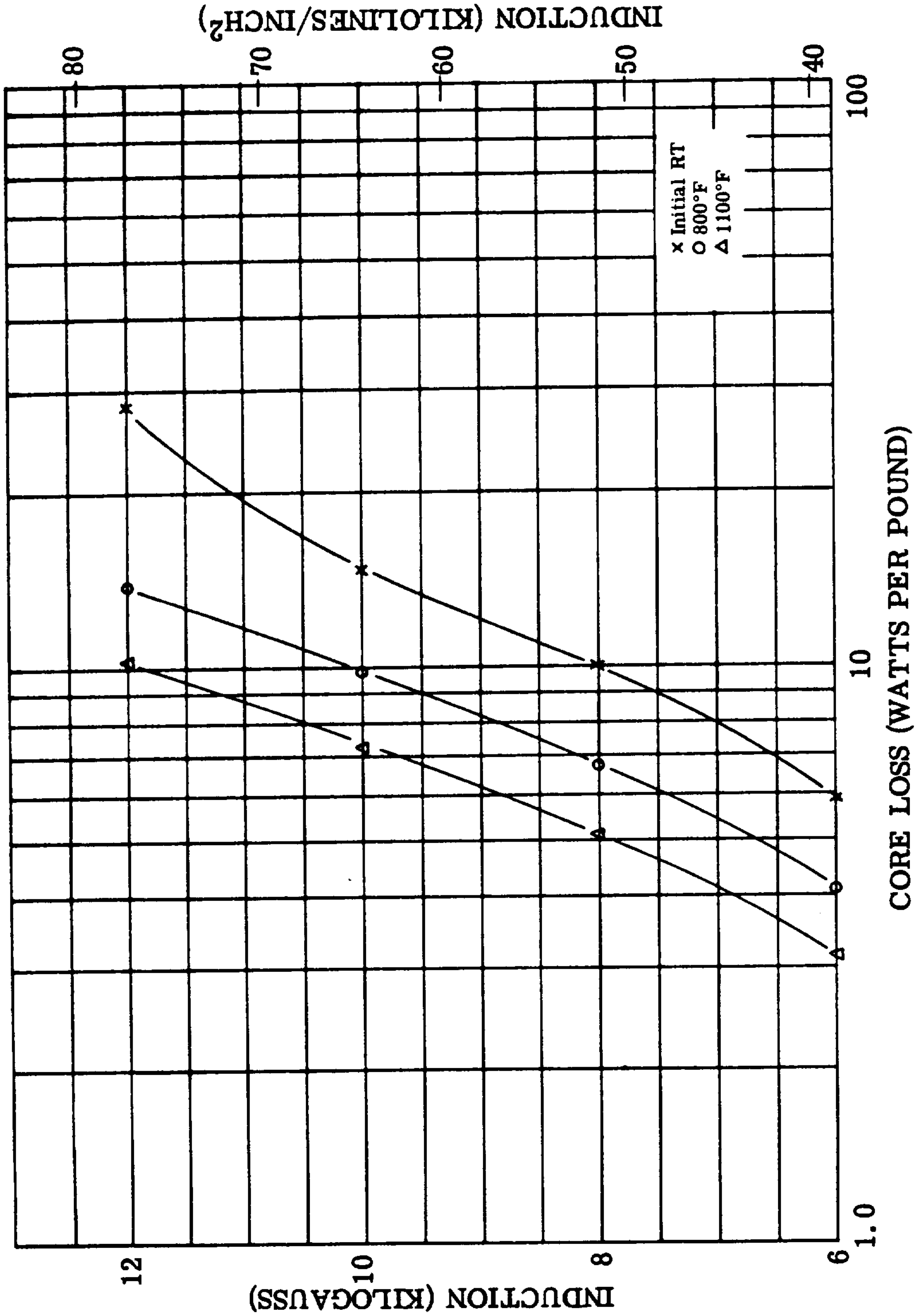


FIGURE IV. A. II-65. Core Loss, 800 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-65. Core Loss, 800 CPS. Cubex

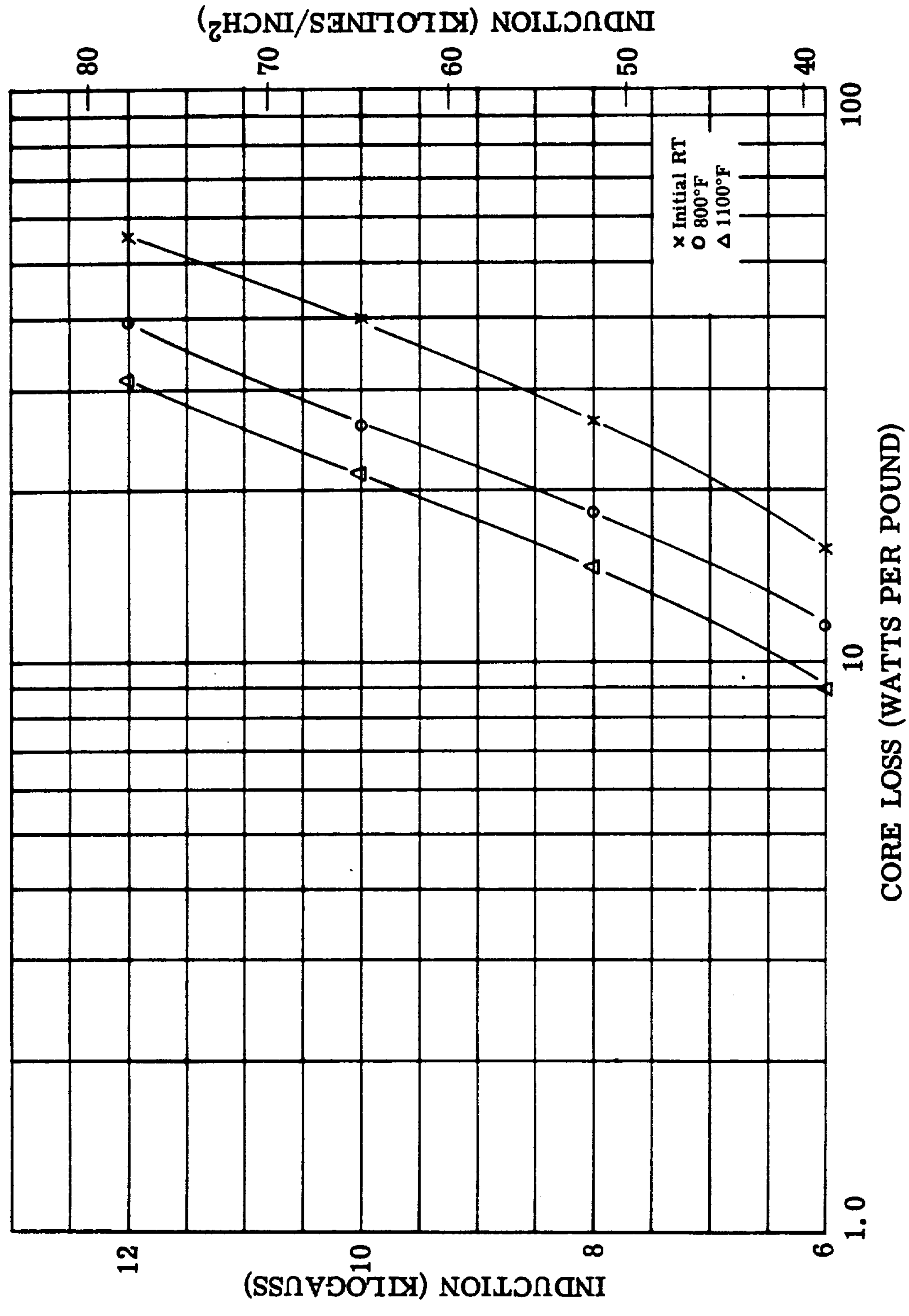


FIGURE IV. A. II-66. Core Loss, 1600 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-66. Core Loss, 1600 CPS. Cubex

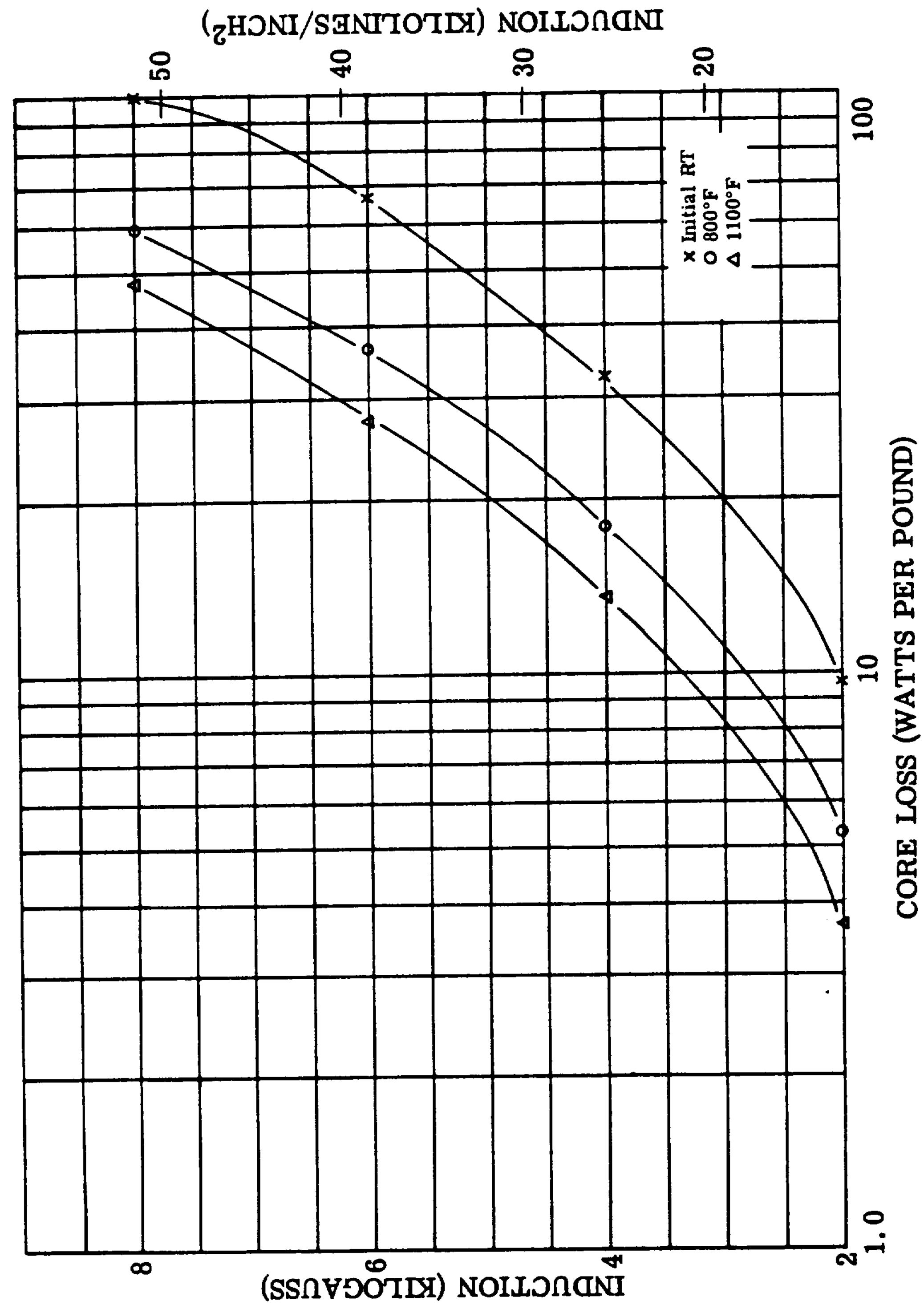


FIGURE IV. A. II-67. Core Loss, 3200 CPS. Cubex Alloy 0.006 Inch Laminations. Test Atmosphere: Air to 500°F, Argon above 500°F. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-67. Core Loss, 3200 CPS. Cubex

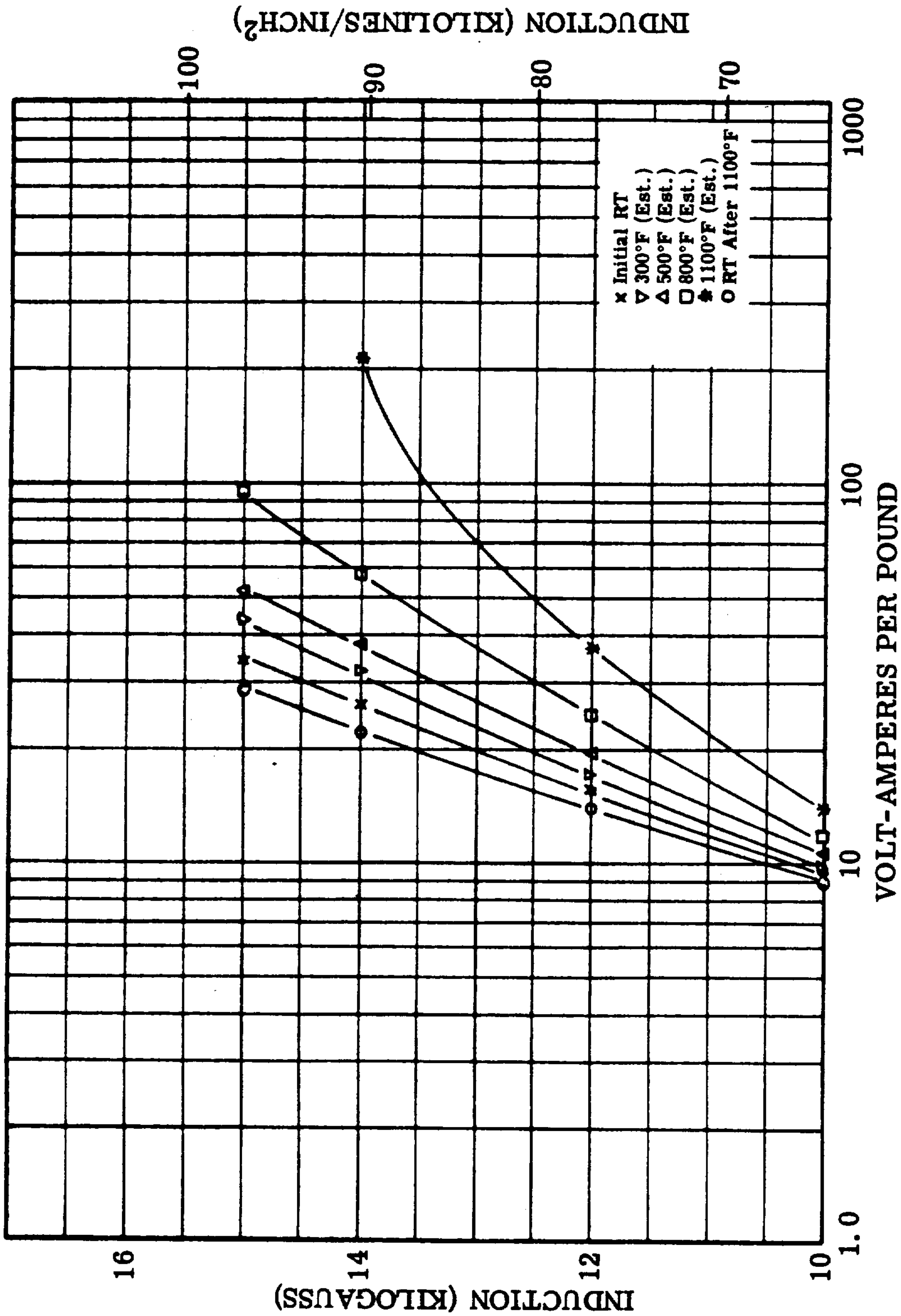


FIGURE IV.A.II-68. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-68. Exciting VA, 400 CPS. Cubex

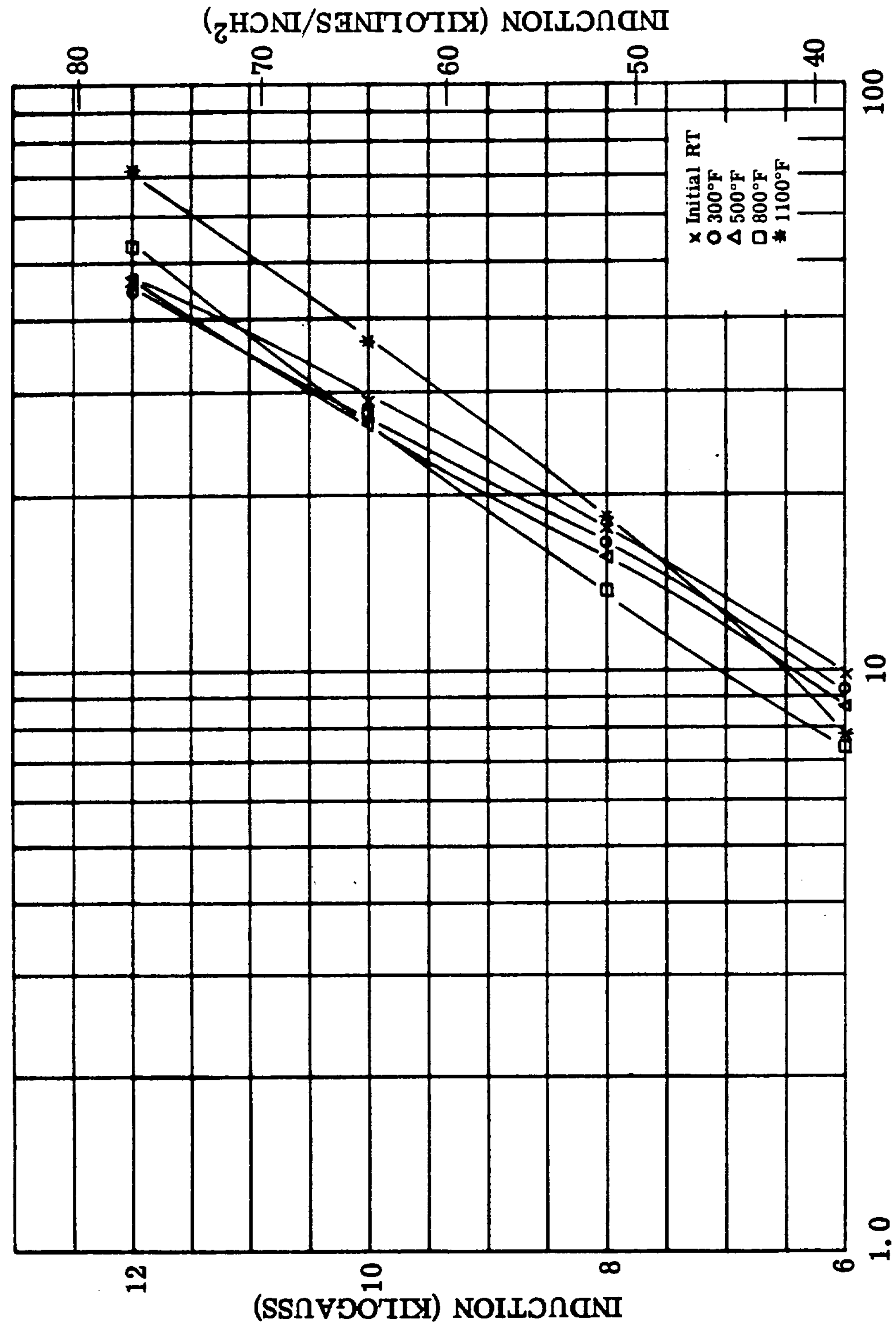


FIGURE I V. A. II-69. Exciting Volt-Amperes Per Pound, 800 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-69. Exciting VA, 800 CPS. Cubex

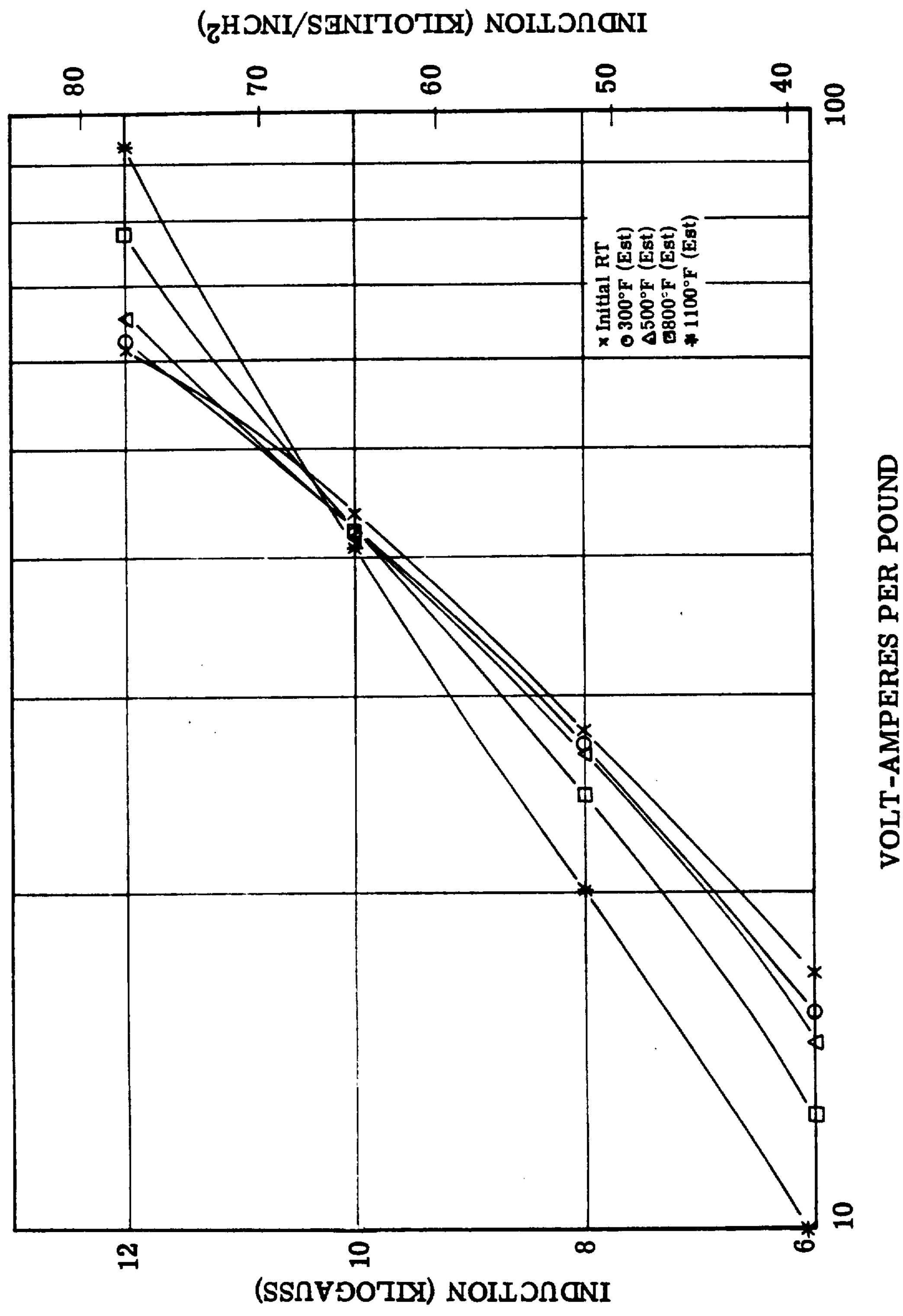


FIGURE IV.A.II-70. Exciting Volt-Amperes Per Pound, 1600 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.A.II-70. Exciting VA, 1600 CPS. Cubex

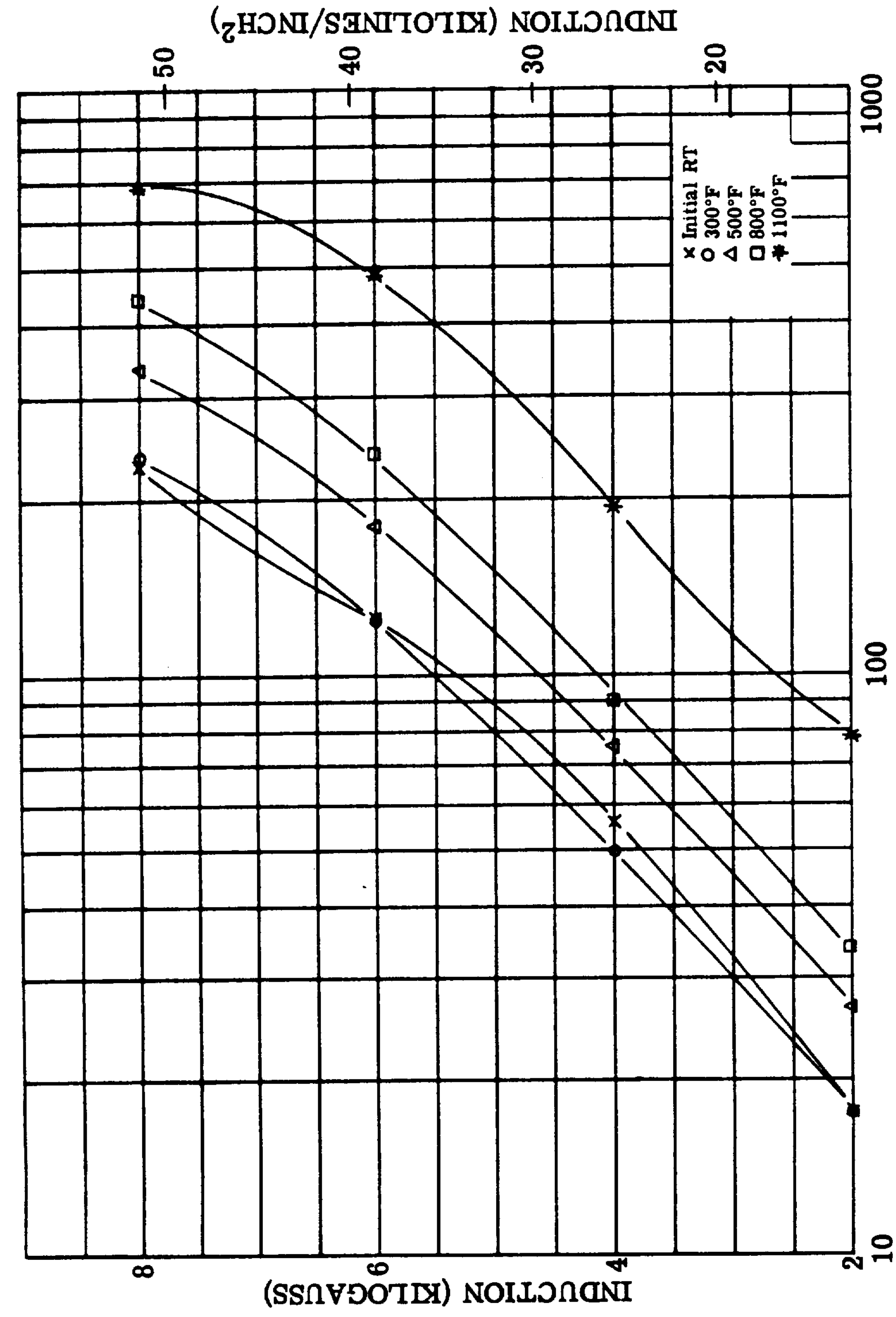


FIGURE IV. A. II-71. Exciting Volt-Amperes per Pound, 3200 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-71. Exciting VA, 3200 CPS. Cubex

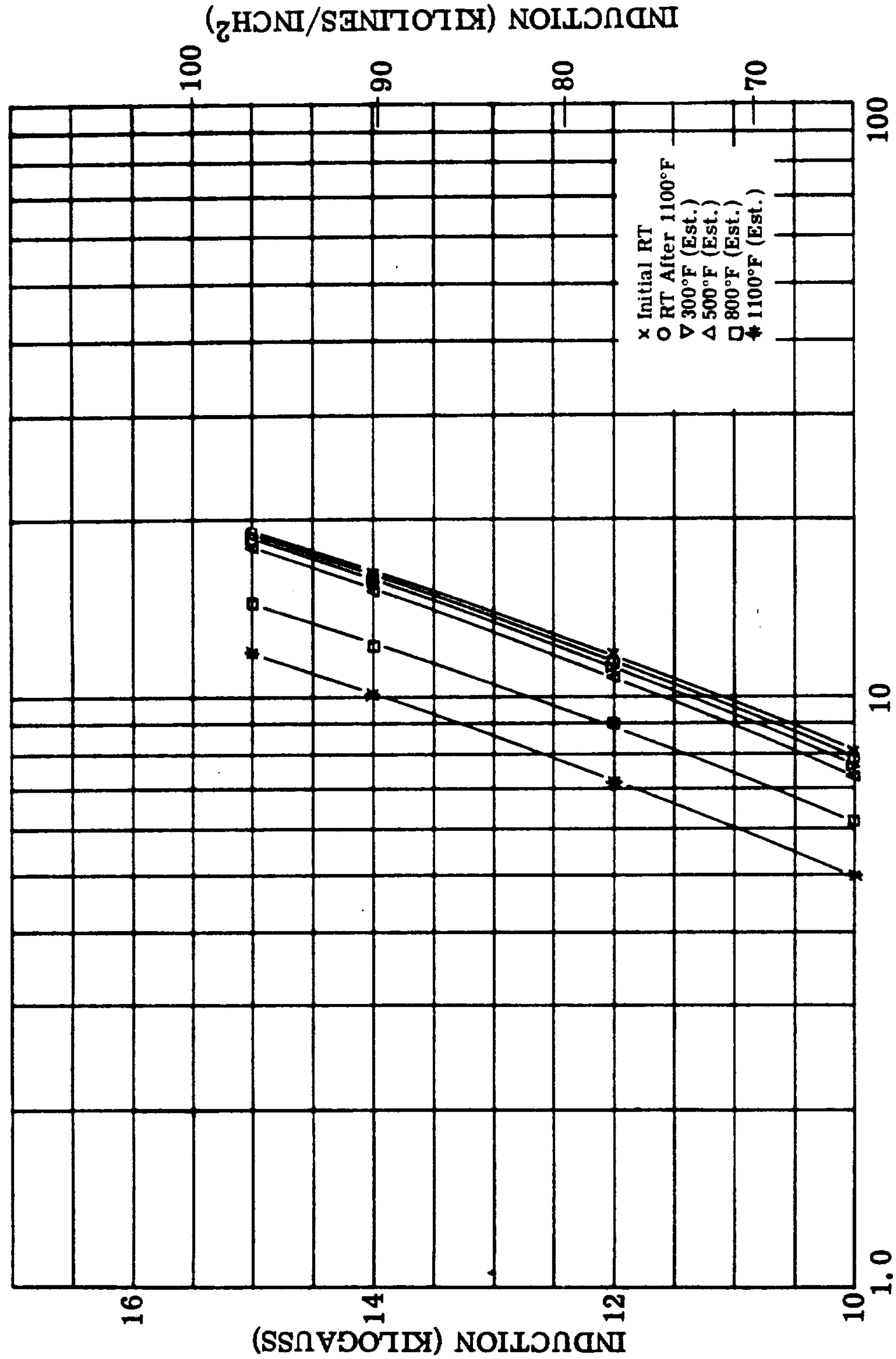


FIGURE I V. A. II-72. Core Loss, 400 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162.)

Figure I V. A. II-72. Core Loss, 400 CPS. Cubex

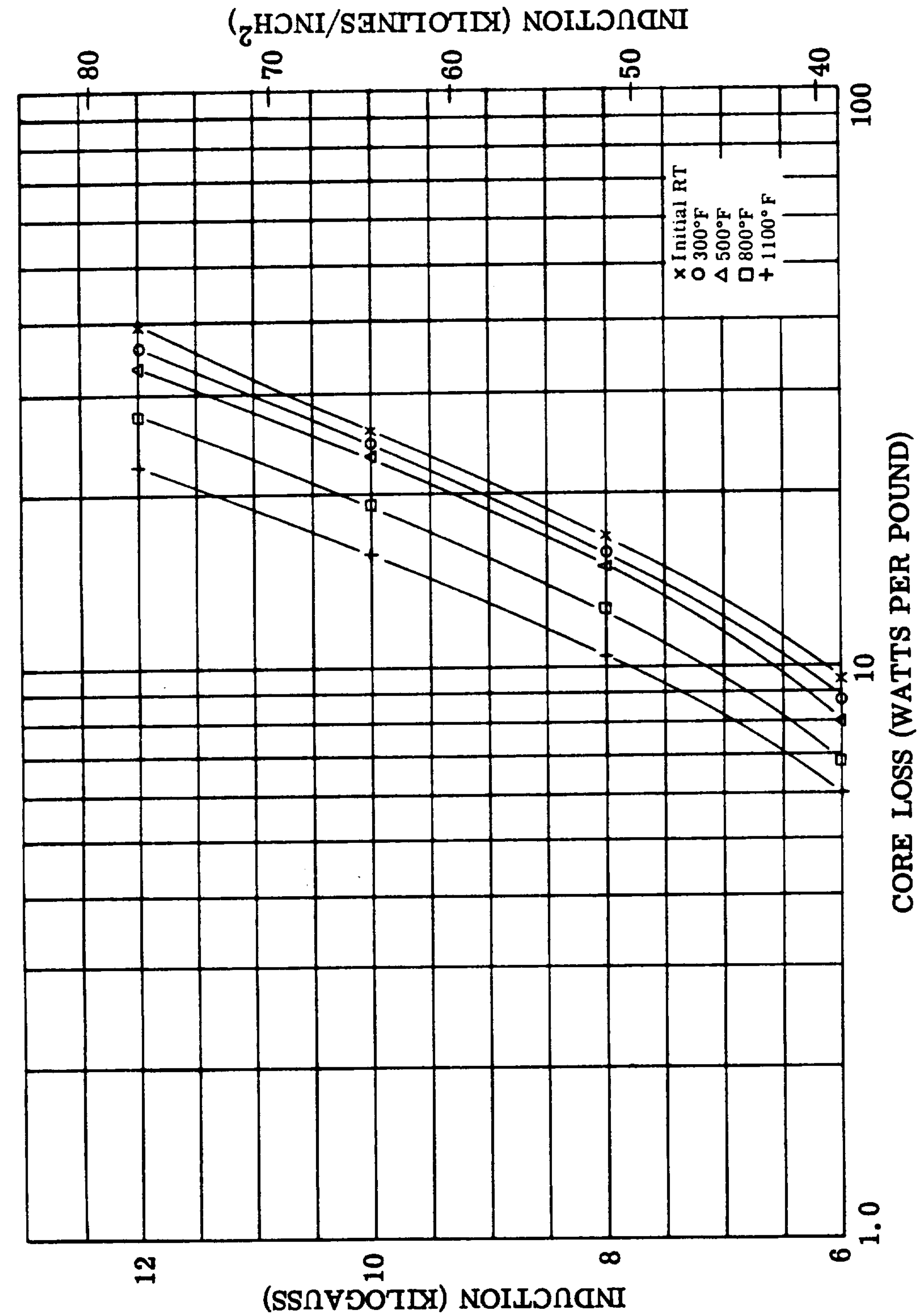


FIGURE IV. A. II-73. Core Loss, 800 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. A. II-73. Core Loss, 800 CPS. Cubex

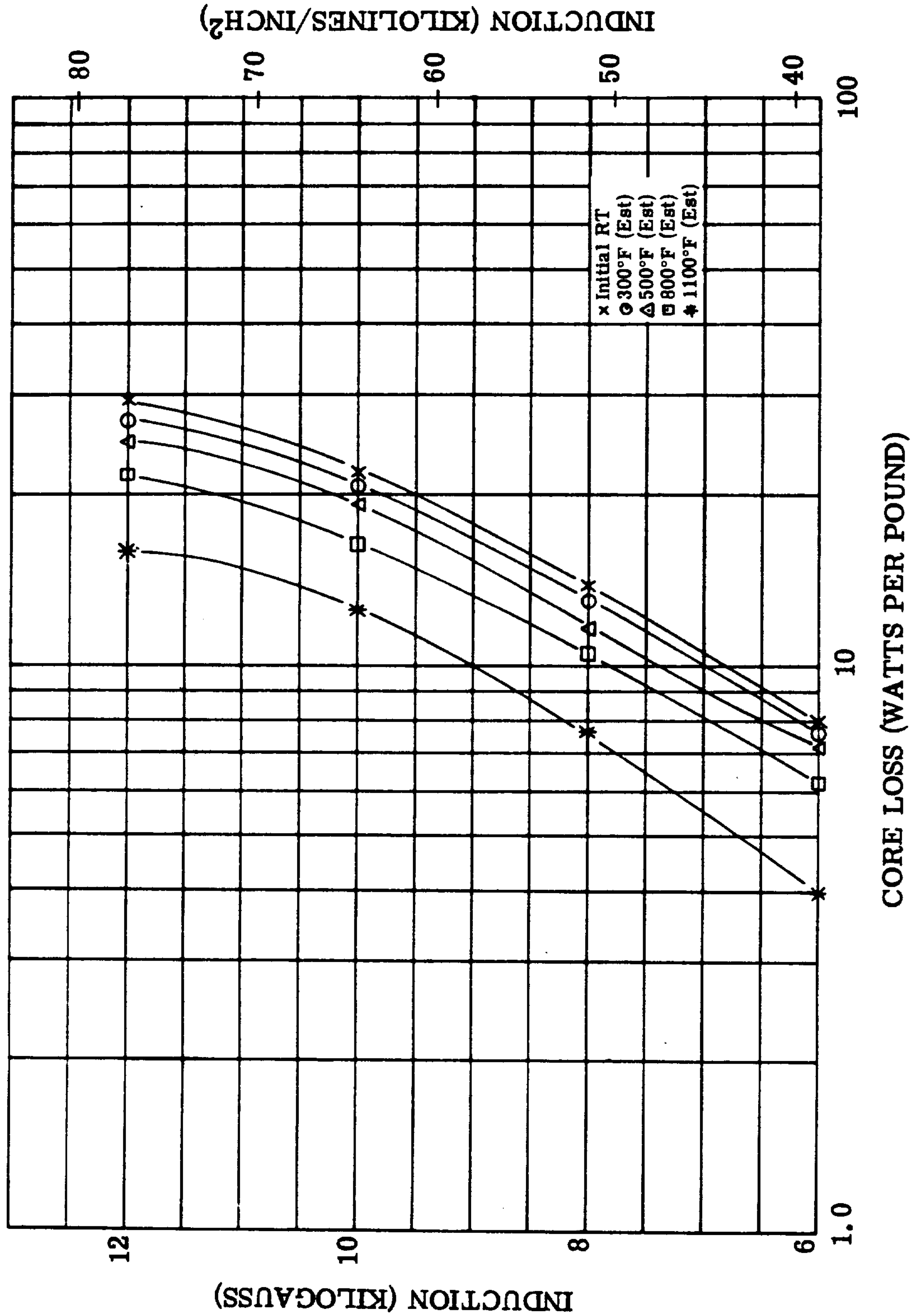


FIGURE IV.A.II-74. Core Loss, 1600 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.A.II-74. Core Loss, 1600 CPS. Cubex

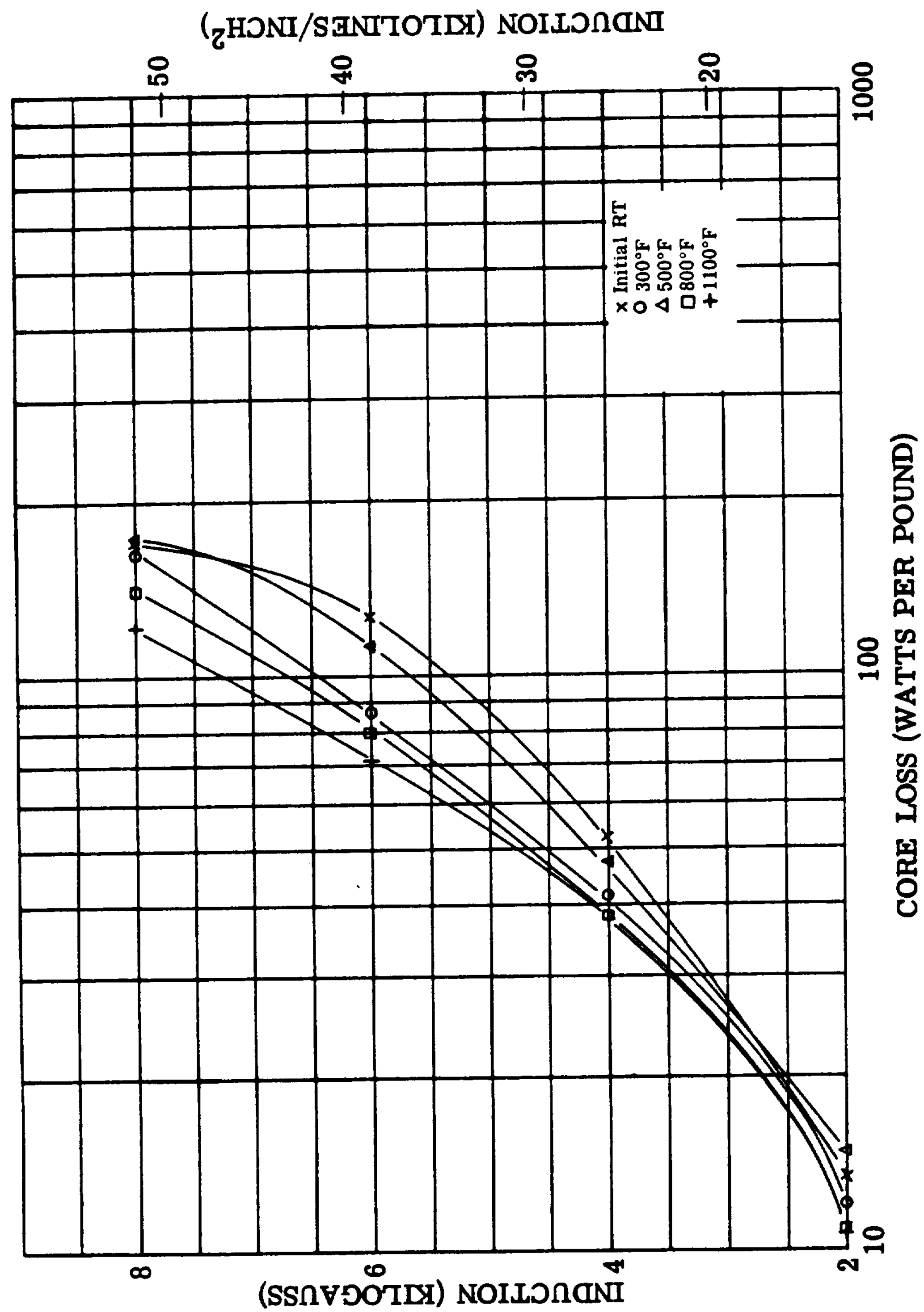


FIGURE I V. A. II-75. Core Loss, 3200 CPS. Cubex Alloy 0.011 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-75. Core Loss, 3200 CPS. Cubex

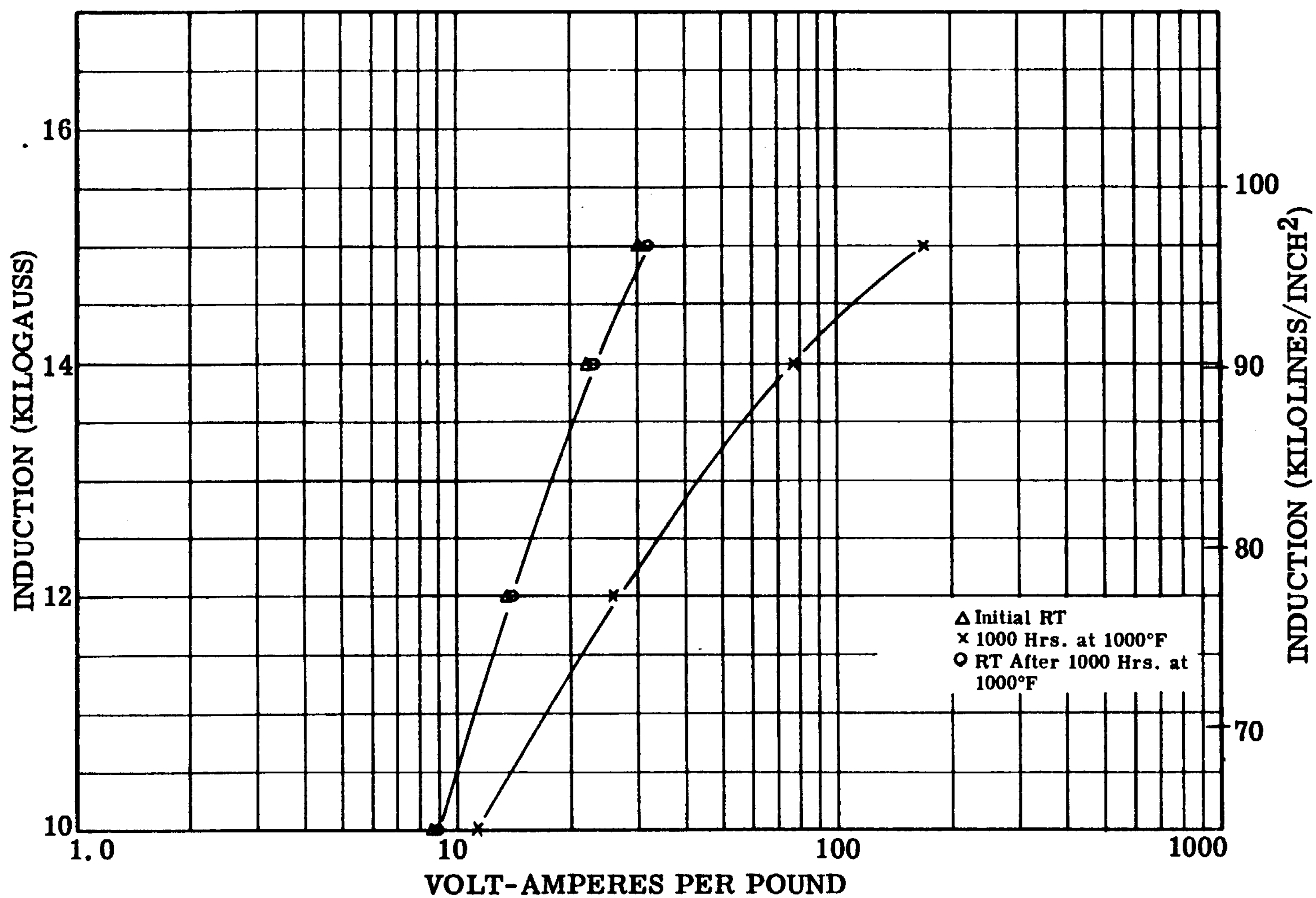


FIGURE I V. A. II-76. Exciting Volt-Amperes Per Pound, 400 CPS. Cubex Alloy 0.011 Inch Laminations - Aging Test. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-76. Exciting VA, 400 CPS. Cubex

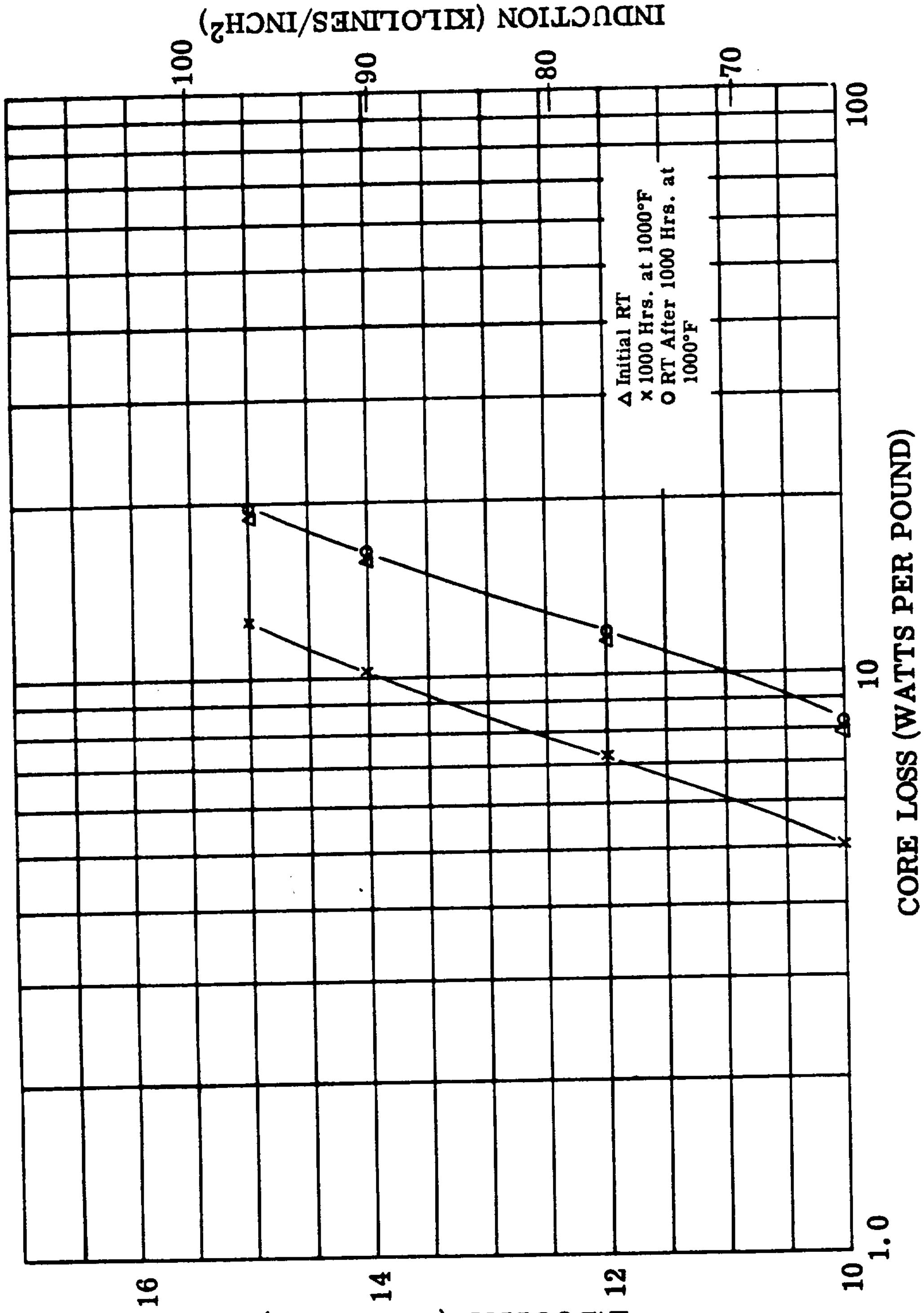


FIGURE I V. A. II-77. Core Loss, 400 CPS. Cubex Alloy 0.011 Inch Laminations - Aging Test. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. A. II-77. Core Loss, 400 CPS. Cubex

TABLE IV.A.III-1. Poisson's Ratio of 0.011 Inch Thick Cubex Alloy at Room Temperature

Specimen No.	Both Gages on One Grain	Both Gages Across Grain Boundary	Maximum*	Minimum*
1	0.325	0.362	0.419	0.325
2	0.310	0.345	0.433	0.303

*These values were calculated without regard to the location of the strain gages. (Reference: NAS 3-4162)

TABLE IV.A.III-2. Tensile Properties of 0.011 Inch Thick Cubex Sheet Tested in Air

Mark	Test Temp. (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Upper Yield Point (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (Percent)	Modulus of Elasticity (10^6 Psi)
L-1	70	37,150	-	37,800	40,200	22.0 Q	22.0
T-1	70	39,050	-	41,650	46,400	14.5 Q	-
T	70	41,850	-	42,150	47,650	13.7	-
L-2	500	24,200	27,300	-	40,800	21.0	13.5
T-2	500	29,250	29,800	-	41,200	38.0 Q	-
L-3	800	23,900	25,300	-	32,250	11.9	9.0
T-3	800	23,500	25,200	-	34,350	10.0 Q	-
L-4	1100	14,750	-	15,400	16,650	26.0	6.0
T-4	1100	12,900	-	13,350	13,350	11.5	-
L-5	1400	700	2,150	-	3,500	7.0 Q	-
L	1400	3,200	3,400	-	4,050	24.6 Q	-

Q - Quarterbreak
L - Longitudinal
T - Transverse

(Reference NAS 3-4162)

TABLE IV. A. III-3. Compression Data for 0.011 Inch Thick Cubex Sheet

TEST: ASTM E-9

	Specimen No.	Test Temperature (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Yield Point (Psi)
Longitudinal Specimens					
	1	RT	29,600	36,000	-
	2	RT	30,400	38,250	-
	3	500	25,000	31,350	-
	4	500	21,450	34,550	-
	5	800	27,550	31,550	-
	6	800	21,100	26,900	-
	7	1100	13,600	-	13,800
	8	1100	8,600	-	9,400
	9	1400	2,700	3,700	-
Transverse Specimens					
	1	RT	33,450	37,900	-
	2	RT	37,100	43,200	-
	3	500	28,700	34,200	-
	4	500	24,300	27,350	-
	5	800	20,700	25,400	-
	6	800	25,750	29,600	-
	7	1100	9,200	10,500	-
	8	1100	13,450	-	13,500
	9	1400	3,300	3,450	-
	10	1400	3,800	4,400	-

NOTE: All tests made in air. (Reference NAS 3-4162)

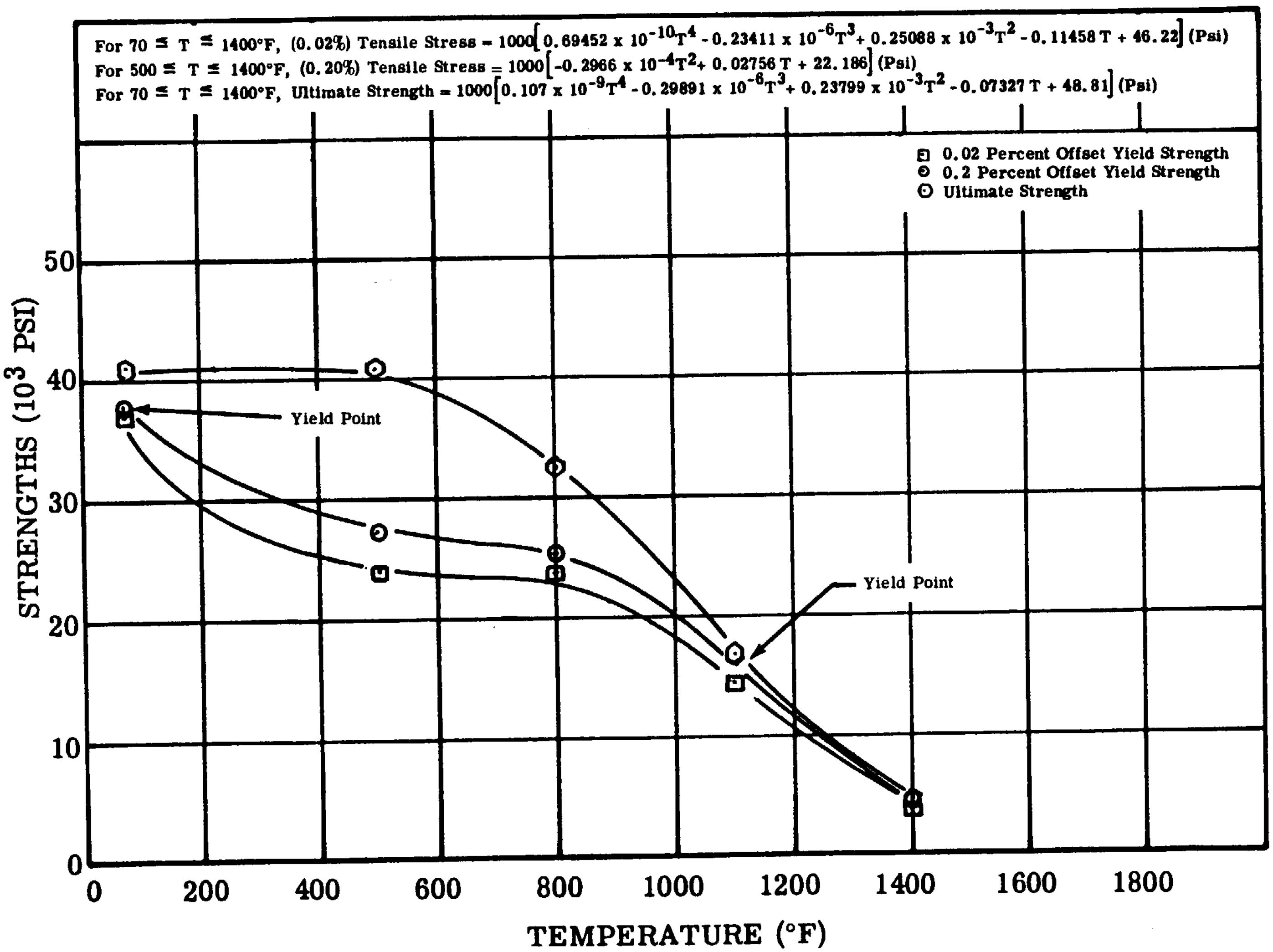


FIGURE I V. A. III-1. Tensile Strengths of 0.011 Inch Thick Cubex Sheet Tested in Air (Longitudinal). See Data Table I V. A. III-2. (Reference: NAS3-4162)

Figure I V. A. III-1. Tensile Strengths - Cubex

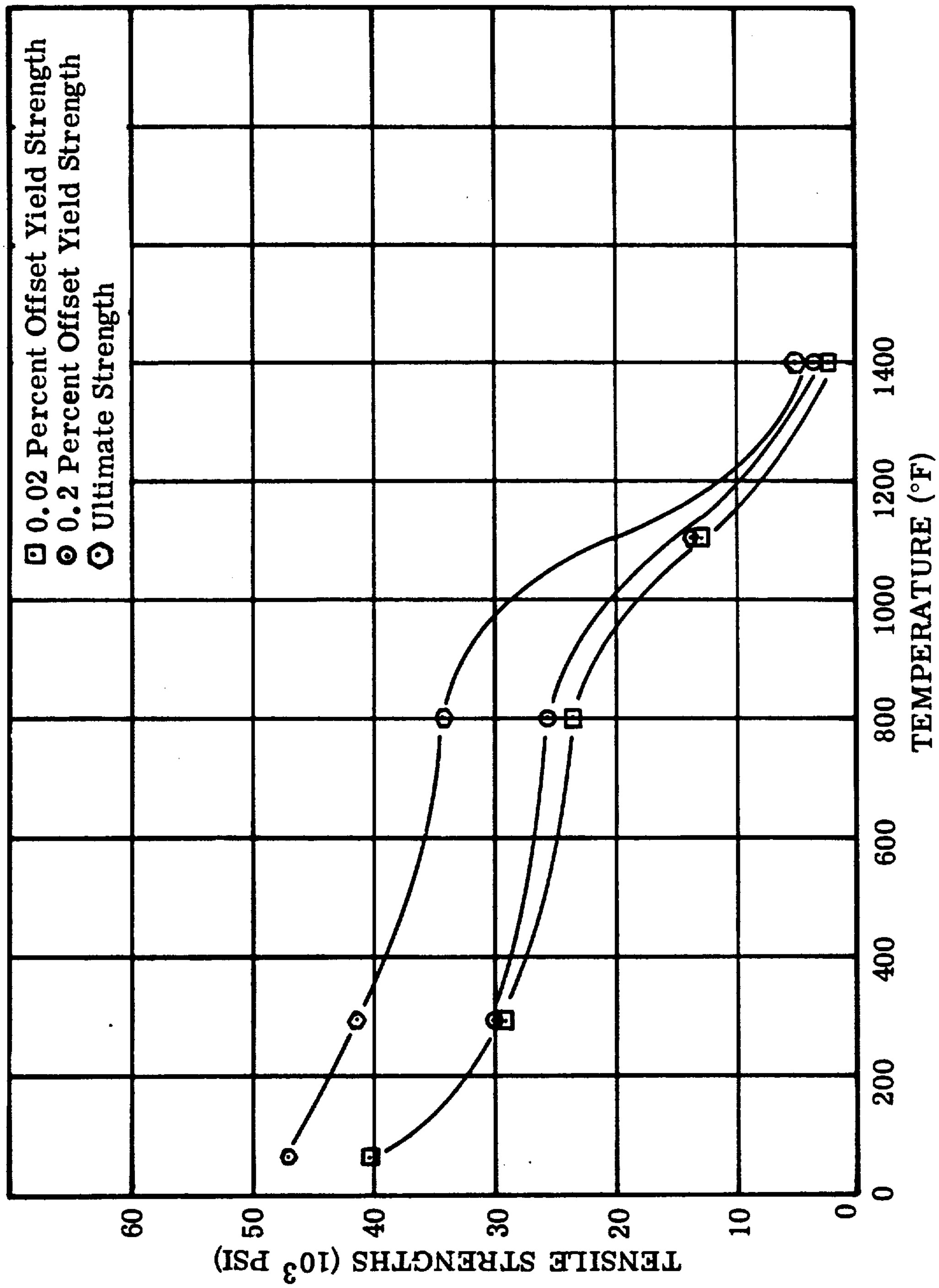


FIGURE IV.A.III-2. Tensile Strengths, 0.011 Inch Thick Cubex Sheet Tested in Air. See Data Table IV.A.III-2 (Transverse). (Reference: NAS3-4162)

Figure IV.A.III-2. Tensile Strengths - Cubex

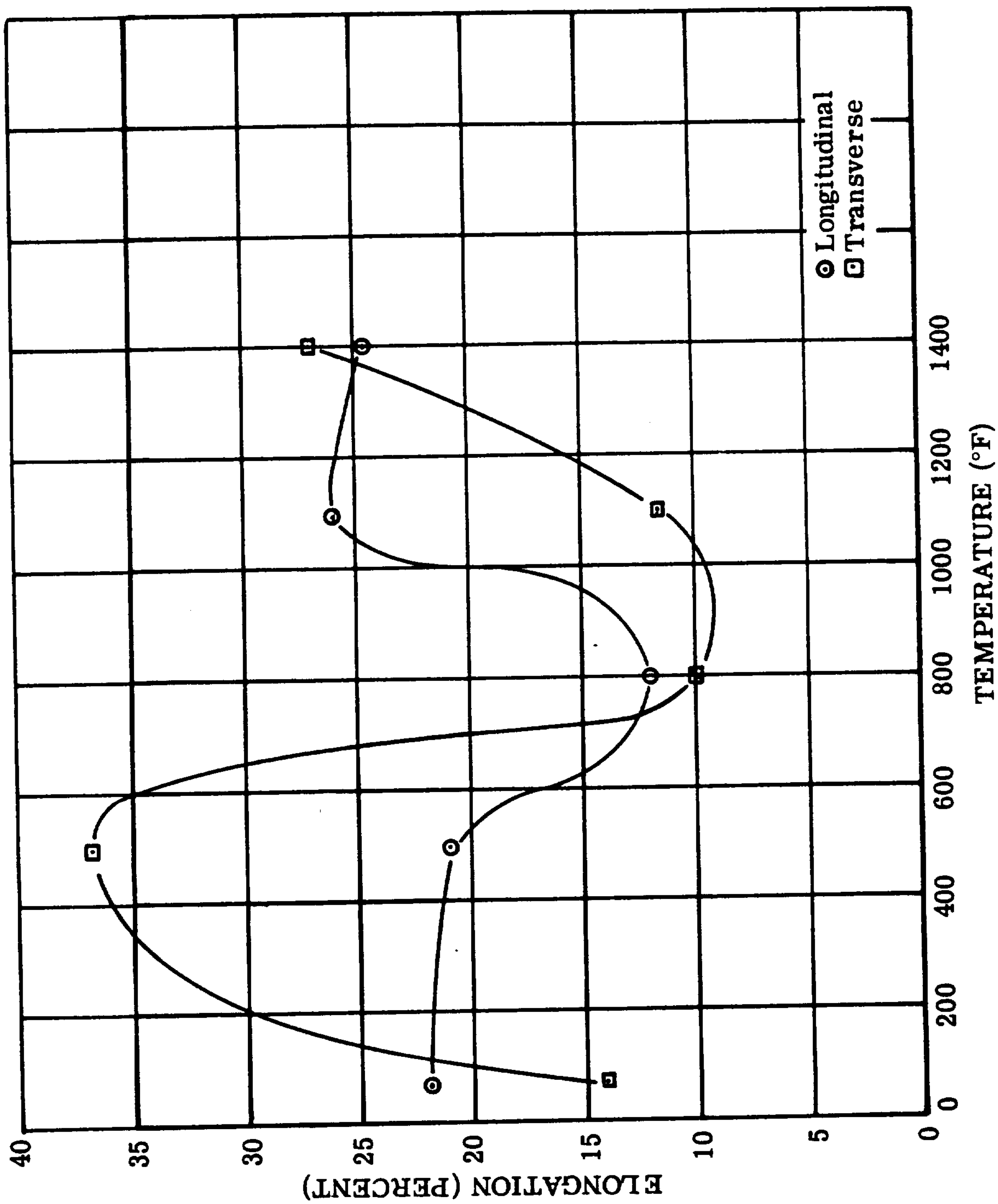


FIGURE IV. A. III-3. Tensile Ductilities of 0.011 Inch Thick Cubex Sheet Tested in Air (Longitudinal and Transverse). See Data Table IV. A. III-2. (Reference: NAS3-4162)

Figure IV. A. III-3. Tensile Elongation - Cubex

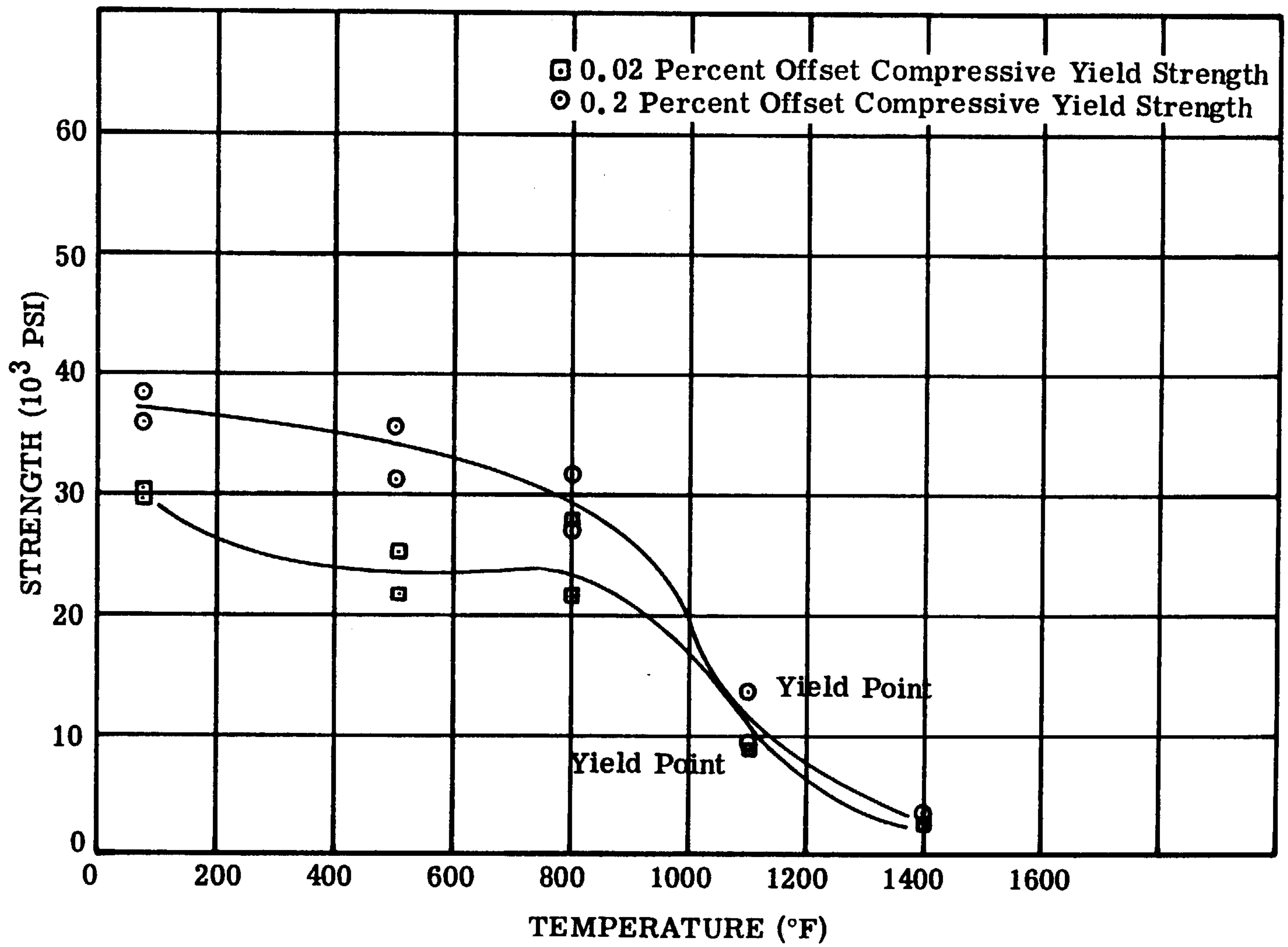


FIGURE IV. A. III-4. Compressive Strengths of 0.011 Inch Thick Cubex Sheet (Longitudinal). All tests made in air. See Data Table IV. A. III-3. (Reference: NAS3-4162)

Figure IV. A. III-4. Compressive Strengths - Cubex

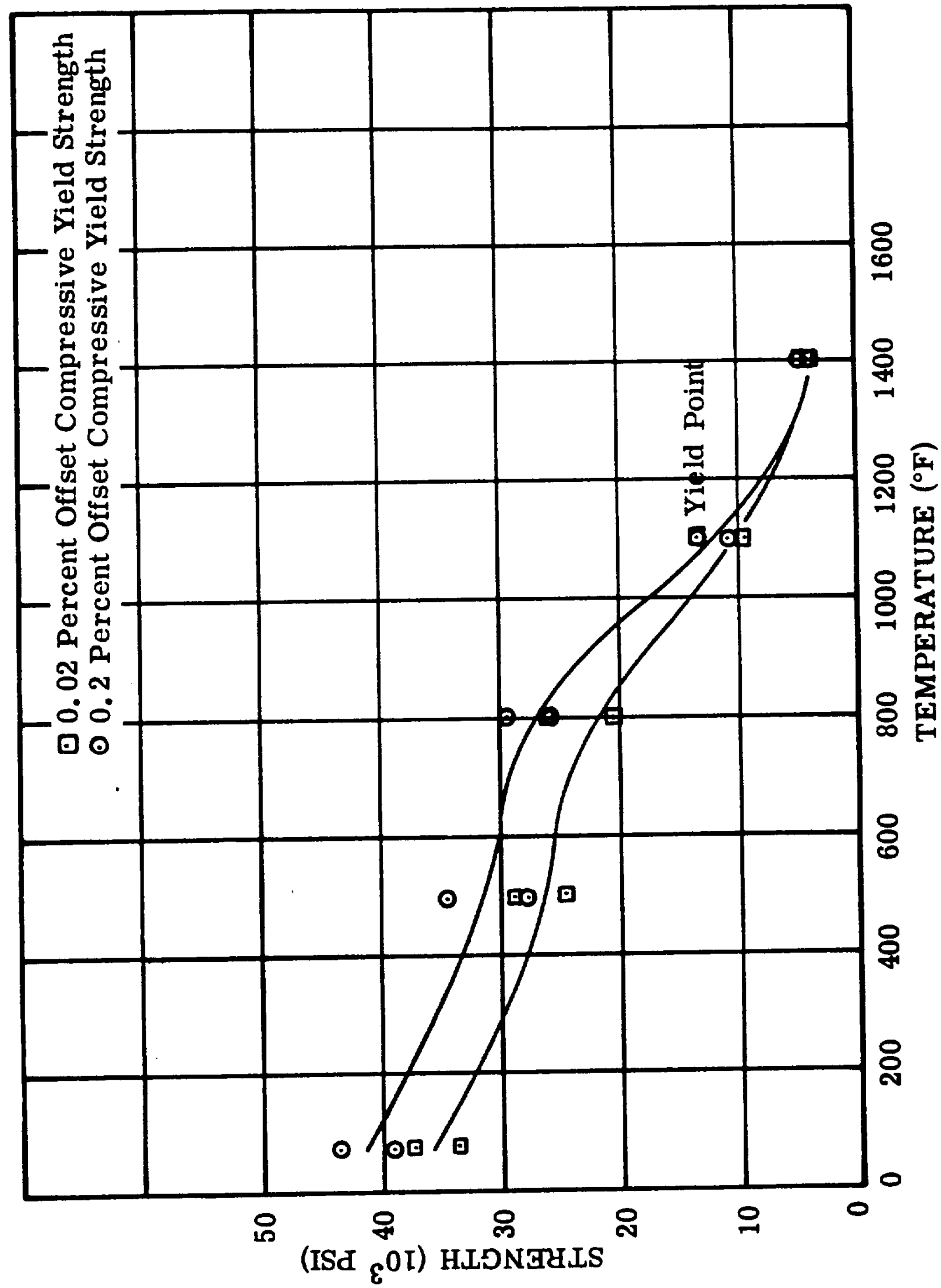


FIGURE I V. A. III-5. Compressive Strengths of 0.011 Inch Thick Cubex Sheet Tested in Air (Transverse). See Data Table I V. A. III-3. (Reference: NAS3-4162)

Figure I V. A. III-5. Compressive Strength - Cubex

B. HIPERCO 50 ALLOY

A high permeability Co-Fe-V alloy.

Availability: Commercial

Nominal Composition: 49 Co, 49 Fe, 2 V

Tested Composition:

Co	Fe	V	C	S	P
48.8	49.6	1.91	0.003	0.007	<0.002

I. Thermophysical Properties

The thermophysical properties are the same as Supermendur except for electrical resistivity, which equals 35-40 x 10^{-6} ohm-cm.

II. Magnetic Properties (All magnetic materials are stress relief annealed (SRA) unless otherwise specified)

A. D-C Magnetic Properties

1. 0.004 inch thick laminations

a. Induction (B_{tip}) for H = 300 oersteds at 72°F 24.1 kilogauss
b. Induction (B_{tip}) for H = 300 oersteds at 500°F 23.4 kilogauss
c. Induction (B_{tip}) for H = 300 oersteds at 800°F 21.9 kilogauss
d. Induction (B_{tip}) for H = 300 oersteds at 1100°F 21.5 kilogauss

2. 0.008 inch thick laminations

a. Induction (B_{tip}) for H = 300 oersteds at 72°F 23.5 kilogauss
b. Induction (B_{tip}) for H = 300 oersteds at 500°F 22.7 kilogauss
c. Induction (B_{tip}) for H = 300 oersteds at 800°F 22.4 kilogauss
d. Induction (B_{tip}) for H = 300 oersteds at 1100°F 20.8 kilogauss

B. A-C Magnetic Properties (400 cps)

1. 0.004 inch thick laminations

a. Exciting volt-amperes, B = 18 kilogauss at 72°F 55.4 volt-amperes/pound
b. Exciting volt-amperes, B = 18 kilogauss at 500°F 60.6 volt-amperes/pound
c. Exciting volt-amperes, B = 18 kilogauss at 800°F 74.7 volt-amperes/pound
d. Exciting volt-amperes, B = 18 kilogauss at 1100°F 78.0 volt-amperes/pound
e. Core loss, B = 18 kilogauss at 72°F 11.5 watts/pound
f. Core loss, B = 18 kilogauss at 500°F 10.4 watts/pound
g. Core loss, B = 18 kilogauss at 800°F 8.9 watts/pound
h. Core loss, B = 18 kilogauss at 1100°F 6.5 watts/pound

2. 0.008 inch thick laminations

a. Exciting volt-amperes, B = 18 kilogauss at 72°F 472 volt-amperes/pound
b. Exciting volt-amperes, B = 18 kilogauss at 500°F 498 volt-amperes/pound
c. Exciting volt-amperes, B = 18 kilogauss at 800°F 524 volt-amperes/pound
d. Exciting volt-amperes, B = 18 kilogauss at 1100°F 492 volt-amperes/pound
e. Core loss B = 18 kilogauss at 72°F 37.8 watts/pound
f. Core loss B = 18 kilogauss at 500°F 37.0 watts/pound
g. Core loss B = 18 kilogauss at 800°F 35.1 watts/pound
h. Core loss B = 18 kilogauss at 1100°F 32.4 watts/pound

C. Constant Current Flux Reset Properties (CCFR): Not applicable to Hiperco 50; only measured on materials used in magnetic amplifiers.

III. Mechanical Properties (0.008 inch thick sheet)

A. Tensile Properties

1. At 72°F

		Longitudinal	Transverse
a.	0.20 percent offset yield strength	41,650 psi	-
b.	Tensile Strength	41,650 psi	37,700 psi
c.	Elongation in two inches	0.5 percent	-
d.	Modulus of elasticity	28.9×10^6 psi	38.0×10^6 psi

2. At 500°F

a.	0.20 percent offset yield strength	37,950 psi	38,950 psi
b.	Tensile Strength	71,250 psi	55,250 psi
c.	Elongation in two inches	5.5 percent	1.5 percent
d.	Modulus of elasticity	27.1×10^6 psi	33.2×10^6 psi

3. At 800°F

a.	0.20 percent offset yield strength	36,750 psi	38,050 psi
b.	Tensile Strength	67,900 psi	60,150 psi
c.	Elongation in two inches	7.0 percent	4.9 percent
d.	Modulus of elasticity	27.0×10^6 psi	29.7×10^6 psi

4. At 1100°F

a.	0.20 percent offset yield strength	33,750 psi	34,700 psi
b.	Tensile Strength	62,600 psi	55,250 psi
c.	Elongation in two inches	6.0 percent	12.0 percent
d.	Modulus of Elasticity	20.0×10^6 psi	28.9×10^6 psi

B. Creep: Material is not used in highly stressed applications.

C. Fatigue: Material is not used in cyclic stressed applications where a fatigue failure could occur.

D. Normal Heat Treatment

Heat to 1400° ± 20°F in pure dry hydrogen. Hold at temperature for 1 to 4 hours, depending on furnace load, and fast cool in the hydrogen atmosphere to below 400°F.

B. (Cont.) SUPERMENDUR

A high purity high permeability Co-Fe-V alloy which responds to a field anneal.

Availability: Commercial

Nominal Composition: 49 Co, 49 Fe, 2 V

Tested Composition:

Co	Fe	V
49.5	49.5	1.0

I. Thermophysical Properties

A. Density — $0.295\ lb/in^3$ 8.20 grams/cc

B. Solidus temperature — 2700°F

C. Curie temperature — 1724°F

D. Thermal Conductivity

1. At 185°F — $17.2\ \frac{Btu\text{-}ft}{ft^2\text{-}hr\text{-}°F}$

2. At 500°F — $21.7\ \frac{Btu\text{-}ft}{ft^2\text{-}hr\text{-}°F}$

E. Coefficient of thermal expansion 72°-500°F — 5.28×10^{-6} in/in-°F

F. Specific heat

1. At 72°F — 0.098 Btu/lb-°F
2. At 500°F — 0.098 Btu/lb-°F
3. At 800°F — 0.103 Btu/lb-°F

G. Electrical Resistivity

1. At 72°F — 45.73×10^{-6} ohm-cm
2. At 500°F — 50.75×10^{-6} ohm-cm
3. At 800°F — 57.25×10^{-6} ohm-cm

II. Magnetic Properties (All Supermendur materials were received from Arnold Engineering in the fully processed condition)

A. D-C Properties

1. 0.002 inch thick tape-wound toroid

a.	Induction (B_{tip}) for H = 300 oersteds at 72°F	24.1 kilogauss
b.	Induction (B_{tip}) for H = 300 oersteds at 300°F	22.7 kilogauss
c.	Induction (B_{tip}) for H = 300 oersteds at 500°F	24.0 kilogauss
d.	Induction (B_{tip}) for H = 300 oersteds at 800°F	23.3 kilogauss

2. 0.006 inch thick laminations

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	24.1 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 300°F	24.1 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 500°F	23.7 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 800°F	23.0 kilogauss

B. A-C Magnetic Properties (400 cps)

1. 0.002 inch tape-wound toroid

a.	Exciting volt-amperes, B = 18 kilogauss at 72°F	8.2 volt-amperes/pound
b.	Exciting volt-amperes, B= 18 kilogauss at 300°F	6.8 volt-amperes/pound
c.	Exciting volt-amperes, B = 18 kilogauss at 500°F	7.5 volt-amperes/pound
d.	Exciting volt-amperes, B - 18 kilogauss at 800°F	24.8 volt-amperes/pound
e.	Core loss, B = 18 kilogauss at 72°F	7.0 watts/pound
f.	Core loss, B = 18 kilogauss at 300°F	6.2 watts/pound
g.	Core loss, B = 18 kilogauss at 500°F	7.0 watts/pound
h.	Core loss, B = 18 kilogauss at 800°F	10.8 watts/pound

2. 0.006 inch thick laminations

a.	Exciting volt-amperes, B = 18 kilogauss at 72°F	15.0 volt-amperes/pound

b. Exciting volt-amperes, B = 18 kilogauss at 300°F — 22.1 volt-amperes/pound
c. Exciting volt-amperes, B = 18 kilogauss at 500°F — 23.5 volt-amperes/pound
d. Exciting volt-amperes, B = 18 kilogauss at 800°F — 31.1 volt-amperes/pound
e. Core loss, B = 18 kilogauss at 72°F — 10.0 watts/pound
f. Core loss, B = 18 kilogauss at 300°F — 10.6 watts/pound
g. Core loss, B = 18 kilogauss at 500°F — 10.6 watts/pound
h. Core loss, B = 18 kilogauss at 800°F — 9.7 watts/pound

C. Constant current flux reset properties (CCFR) 0.002 inch thich tape-wound toroid.

1. At 72°F

   a. B_m at 5 oersteds = 23.15 kilogauss (SAT/2)
   b. $B_m - B_r$ = 3.20 kilogauss
   c. H_1 = 0.57 oersteds (AT)
   d. H_2 = 0.65 oersteds (AT + DAT)
   e. H_0 = 0.61 oersteds (AT + $\frac{1}{2}$ DAT)

2. At 500°F

   a. B_m at 5 oersteds = 24.70 kilogauss (SAT/2)
   b. $B_m - B_r$ = 1.65 kilogauss
   c. H_1 = 0.55 oersteds (AT)
   d. H_2 = 0.63 oersteds (AT + DAT)
   e. H_0 = 0.60 oersteds (AT + $\frac{1}{2}$ DAT)

3. At 1100°F

   a. B_m at 5 oersteds = 21.95 kilogauss (SAT/2)
   b. $B_m - B_r$ = 2.50 kilogauss
   c. H_1 = 0.45 oersteds (AT)
   d. H_2 = 0.55 oersteds (AT + DAT)
   e. H_0 = 0.515 oersteds (AT + $\frac{1}{2}$ DAT)

III. Mechanical Properties (0.006 inch thick sheet)

A. Tensile Properties

1. At 72°F

a.	Yield point	38,500 psi
b.	Tensile strength	43,300 psi
c.	Elongation in two inches	2.1 percent
d.	Modulus of elasticity	34.7×10^6 psi

2. At 500°F

a.	0.20 percent offset yield strength	32,800 psi
b.	Tensile strength	99,450 psi
c.	Elongation in two inches	9.8 percent
d.	Modulus of elasticity	32.8×10^6 psi

3. At 800°F

a.	0.20 percent offset yield strength	33,250 psi
b.	Tensile strength	96,250 psi
c.	Elongation in two inches	10.9 percent
d.	Modulus of elasticity	29.8×10^6 psi

4. At 1100°F

a.	0.20 percent offset yield strength	31,150 psi
b.	Tensile strength	55,100 psi
c.	Elongation in two inches	11.5 percent
d.	Modulus of elasticity	28.5×10^6 psi

B. Creep: Material not used in highly stressed applications.

C. Fatigue: Material is not used in cyclic stressed applications, or where fatigue failure could occur.

D. Normal Heat Treatment:

This alloy is heat treated in dry hydrogen under the influence of a magnetic field. This process was performed by supplier and specific details are not available. The material should be purchased to a performance requirement.

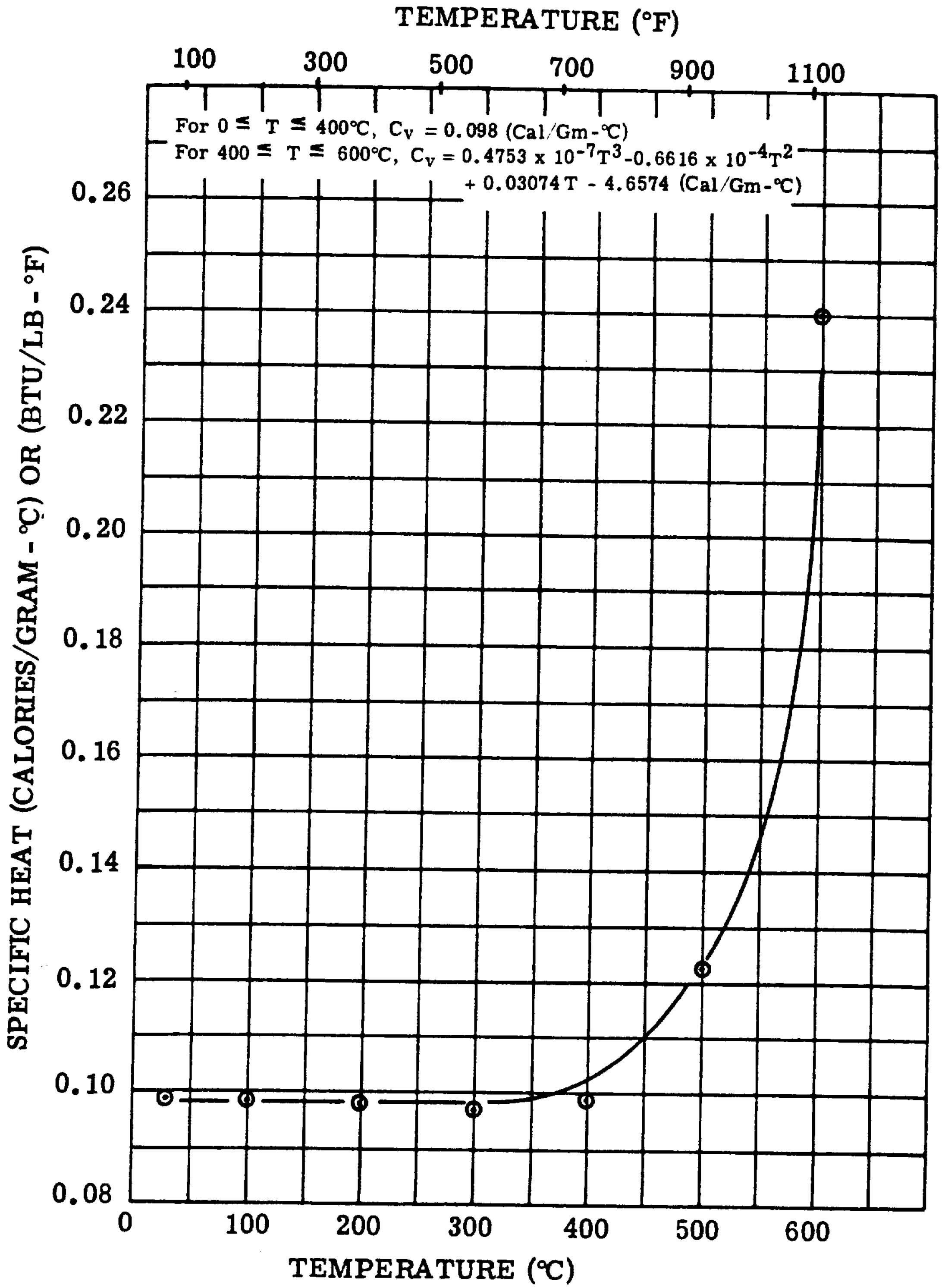


FIGURE IV.B.I-1. Specific Heat, Supermendur Rolling Stock in Vacuum (10^{-5} torr) (Reference: NAS 3-4162)

Figure IV.B.I-1. Specific Heat - Supermendur

TABLE IV.B.I-1. Electrical Resistivity of Supermendur (Field-Annealed) 2 Mil Ribbon in Vacuum (10^{-5} Torr)

Test: ASTM A344

Continuous Heating			
Width - 0.250 inches		Length - Specimen No. 1 - 12.96 inches	
Thickness - 0.002 inches		Specimen No. 2 - 11.39 inches	
Specimen 1 Temp. (°F)	Specimen 2 Temp. (°F)	Specimen 1 Resistivity (Microhm-Cm)	Specimen 2 Resistivity (Microhm-Cm)
79	77	45.79	46.818
200	200	46.46	47.59
300	300	47.28	48.63
400	400	48.44	49.95
500	500	50.01	51.49
600	600	51.94	53.30
710	703	54.34	55.44
810	803	56.80	58.03
907	900	59.39	60.77
1000	1000	62.09	63.63
1100	1100	65.56	67.08
950	946	61.05	62.22
750	746	55.61	56.81
550	550	51.40	52.43
350	350	48.32	49.31
150	150	46.18	47.16

(Reference: NAS 3-4162)

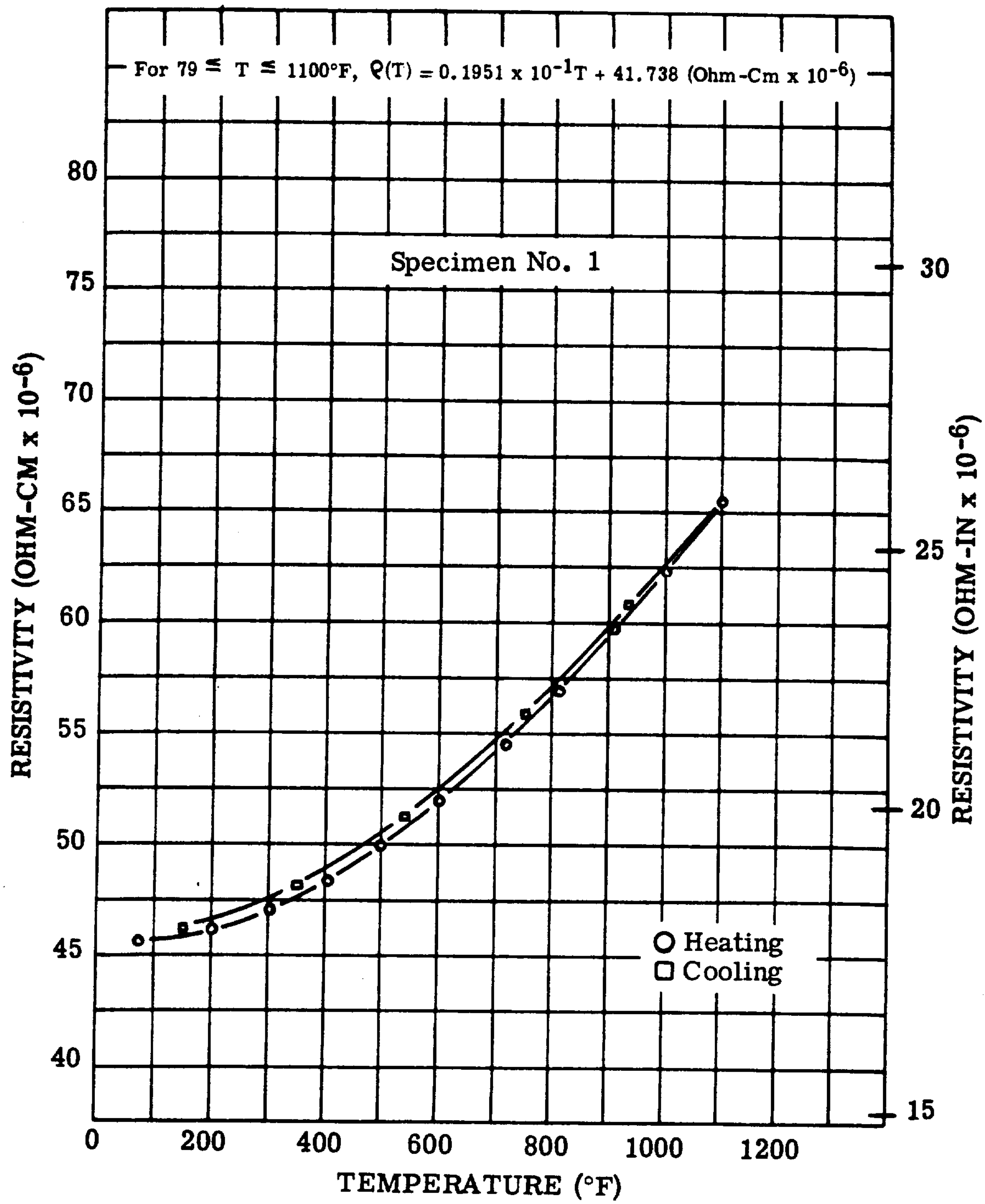


FIGURE IV. B. I-2. Electrical Resistivity of Supermendur 2 Mil Ribbon in Vacuum (10^{-5} torr). See Data Table IV. B. I-1 (Reference: NAS 3-4162)

Figure IV. B. I-2. Resistivity - Supermendur

TABLE IV.B.II-1. Constant Current Flux Reset (CCFR) Properties of Supermendur +
(400 cps - Sine Wave)

SUPERMENDUR											
Core	Material Thickness in inches	Core Size	Temperature (°F)	Test Environment	H_m (Oersteds)	B_m (Kilogauss)	B_m-B_r (Kilogauss)	$\frac{B_r}{B_m}$	H_0 (Oersteds)	H_1 (Oersteds)	H_2 (Oersteds)
1	0.002	A	72	Air	5.0	21.71	2.73	0.874	0.58	0.544	0.604
			500	Argon	5.0	24.10	1.99	0.917	0.466	0.428	0.504
			1100	Argon	5.0	21.16	2.15	0.898	0.418	0.36	0.481
			72++	Air	5.0	21.16	4.63	0.781	0.917	0.85	0.975
2	0.002	A	72	Air	5.0	22.77	2.09	0.910	0.64	0.62	0.665
			500	Argon	5.0	10.80	0.66	0.939	1.01	0.806	--
			1100	Argon	5.0	10.09	1.47	0.854	--	--	--
			72++	Air	5.0	20.84	2.77	0.867	0.906	0.88	0.941
3	0.002	B	72	Air	5.0	23.01	3.48	0.849	0.619	0.574	0.661
			500	Argon	5.0	24.18	2.52	0.896	0.49	0.443	0.51
			1100	Argon	5.0	22.05	2.88	0.879	0.526	0.462	0.641
			72++	Air	5.0	21.58	4.69	0.783	1.078	1.022	1.162
4	0.002	B	72	Air	5.0	23.21	2.89	0.875	0.602	0.573	0.627
			500	Argon	5.0	24.56	0.78	0.969	0.716	0.661	0.758
			1100	Argon	5.0	21.85	2.16	0.901	0.495	0.442	0.53
			72++	Air	5.0	20.94	3.96	0.811	1.078	1.019	1.126
5	0.006	C	72	Air	5.0	20.10	2.15	0.893	0.643	0.594	0.687
			500	Argon	5.0	19.98	1.97	0.901	0.549	0.506	0.587
			1100	Argon	5.0	17.87	2.03	0.886	0.466	0.416	0.526

A = Toroid 3-1/2 inch x 4 inch x 1/2 inch
B = Toroid 1 inch x 1-1/4 inch x 1/4 inch
C = Ring lamination stack 3-1/2 inch x 4 inch x 1/2 inch
+ Test procedure for Toroidal Magnetic Amplifier Cores, AIEE No. 432, January 1959
++ Room Temperature test after 1100°F exposure

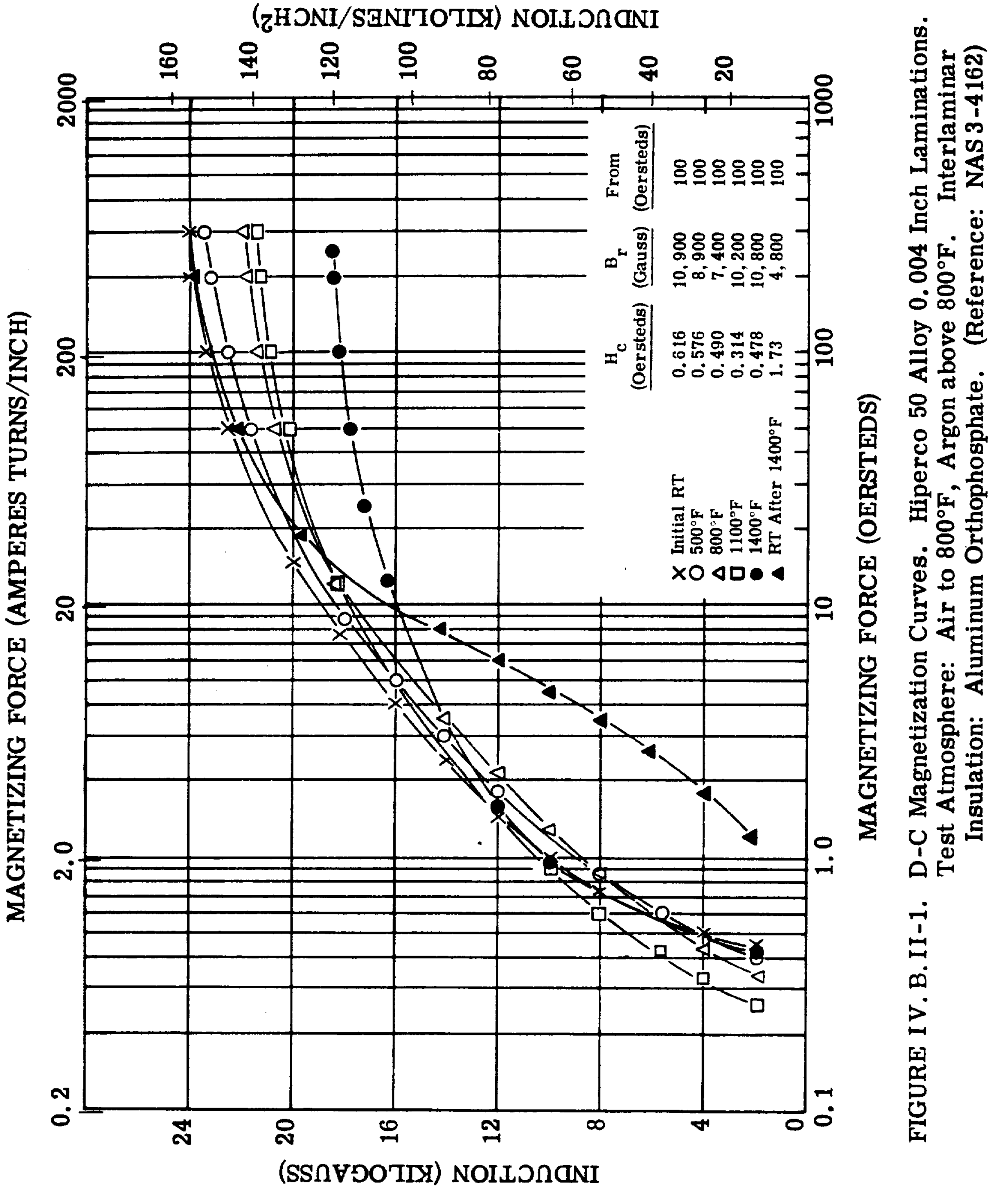


Figure IV.B.II-1. D-C Magnetization - Hiperco 50

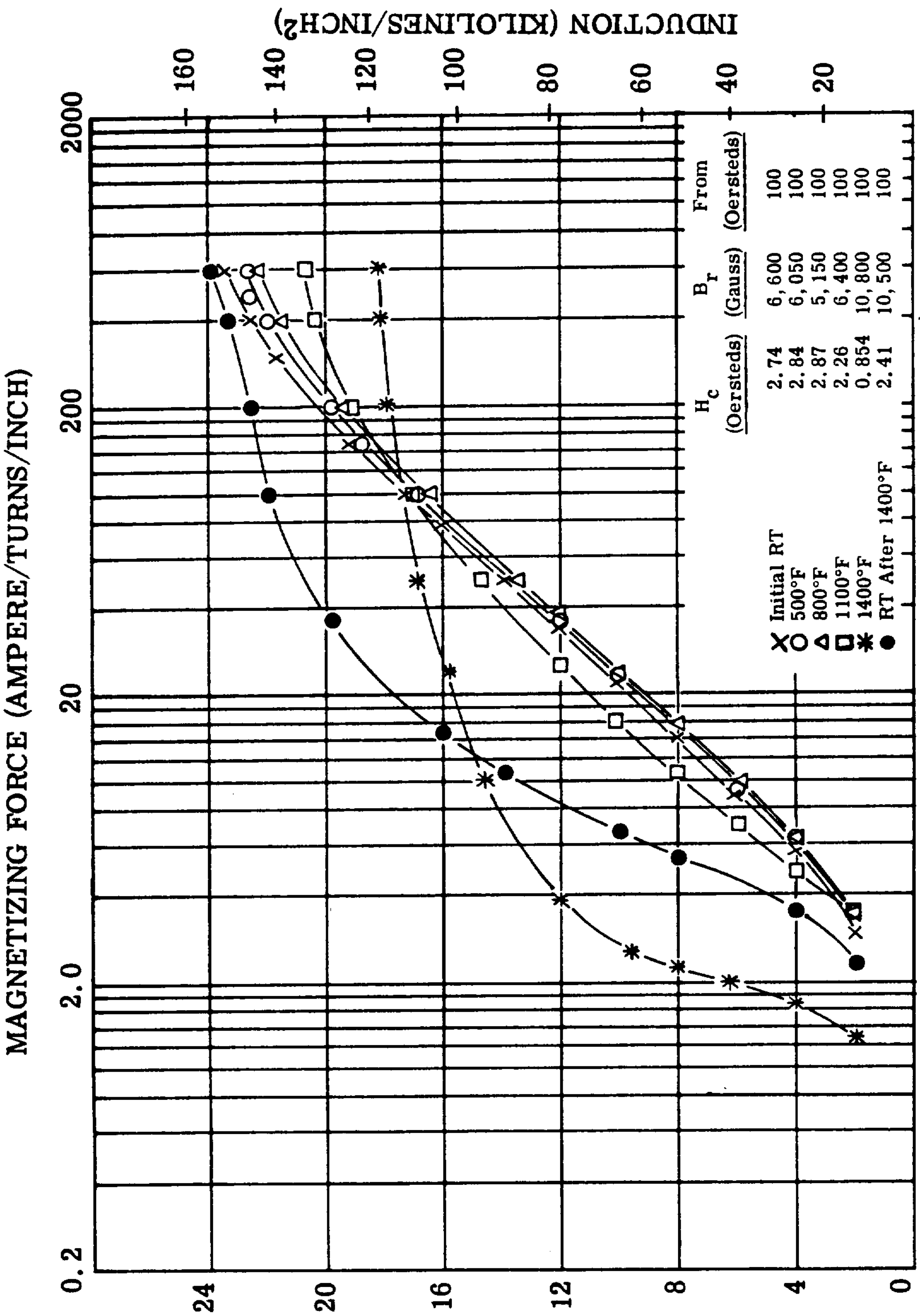


FIGURE IV.B.II-2. D-C Magnetization Curves. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.B.II-2. D-C Magnetization - Hiperco 50

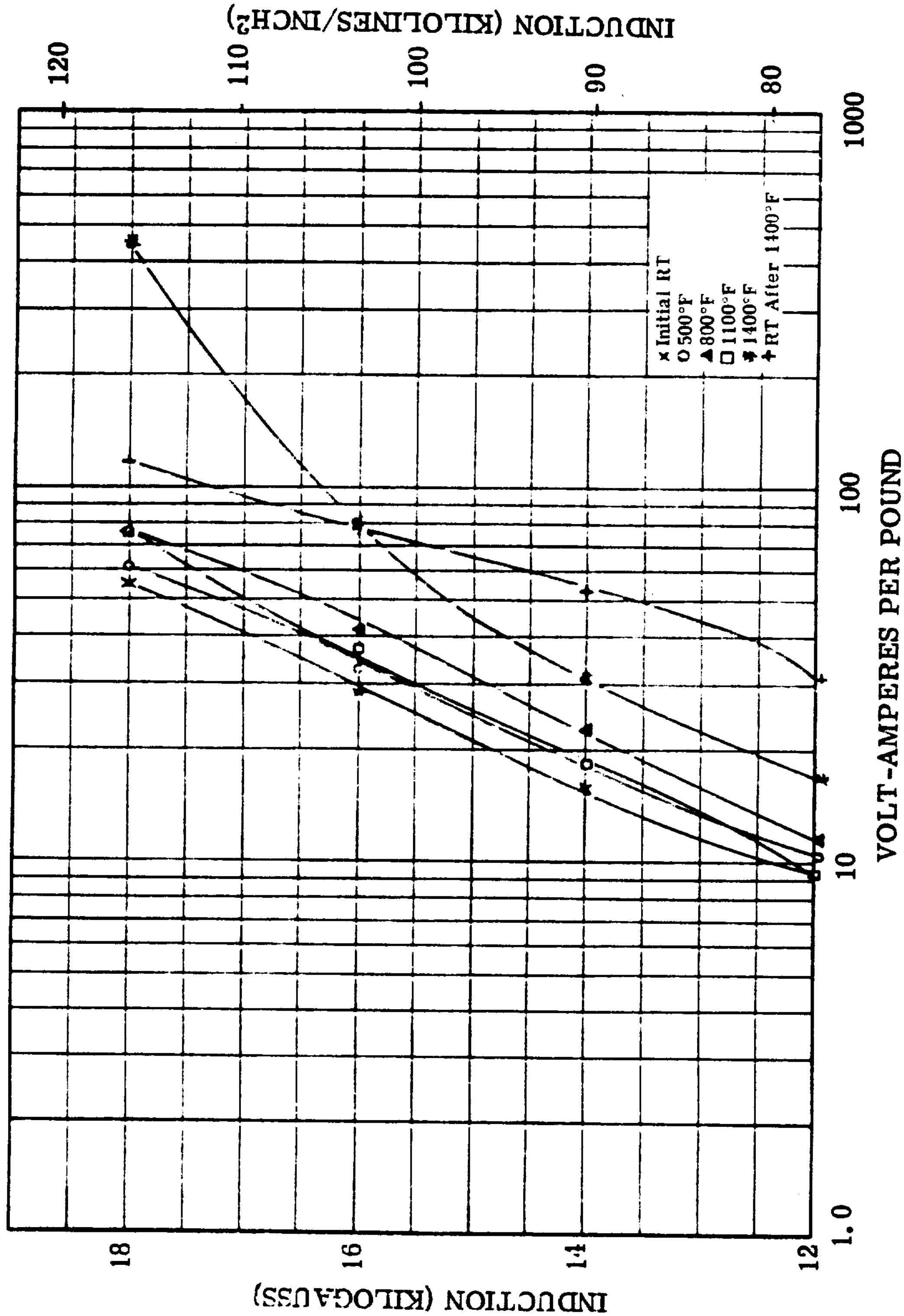


FIGURE IV.B.II-3. Exciting Volt-Amperes per Pound, 400 CPS. Hiperco 50 Alloy 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-3. Exciting VA, 400 CPS. Hiperco 50

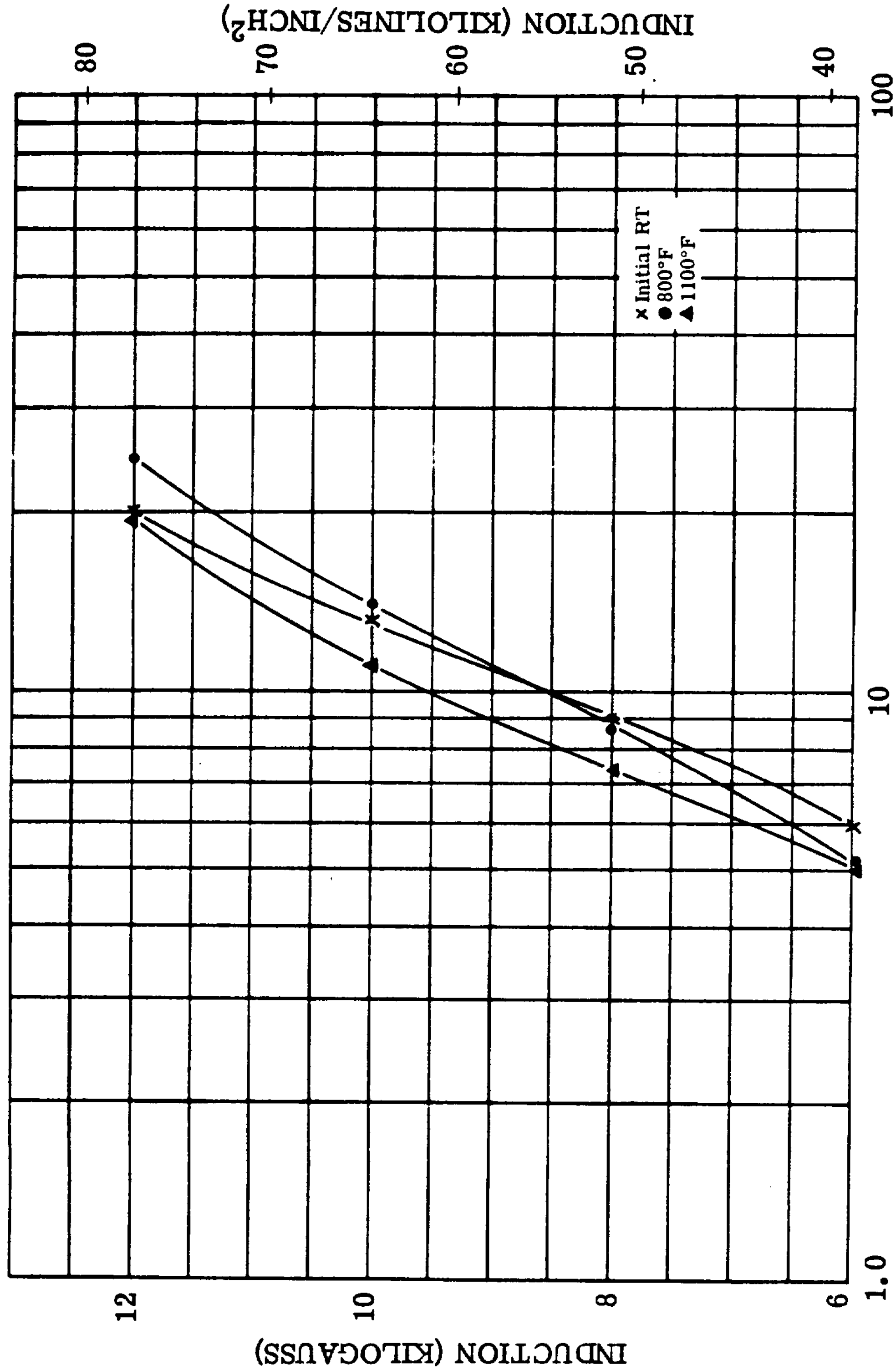


FIGURE IV.B.II-4. Exciting Volt-Amperes per Pound, 800 CPS. Hiperco 50 Alloy 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference NAS 3-4162)

Figure IV.B.II-4. Exciting VA, 800 CPS. Hiperco 50

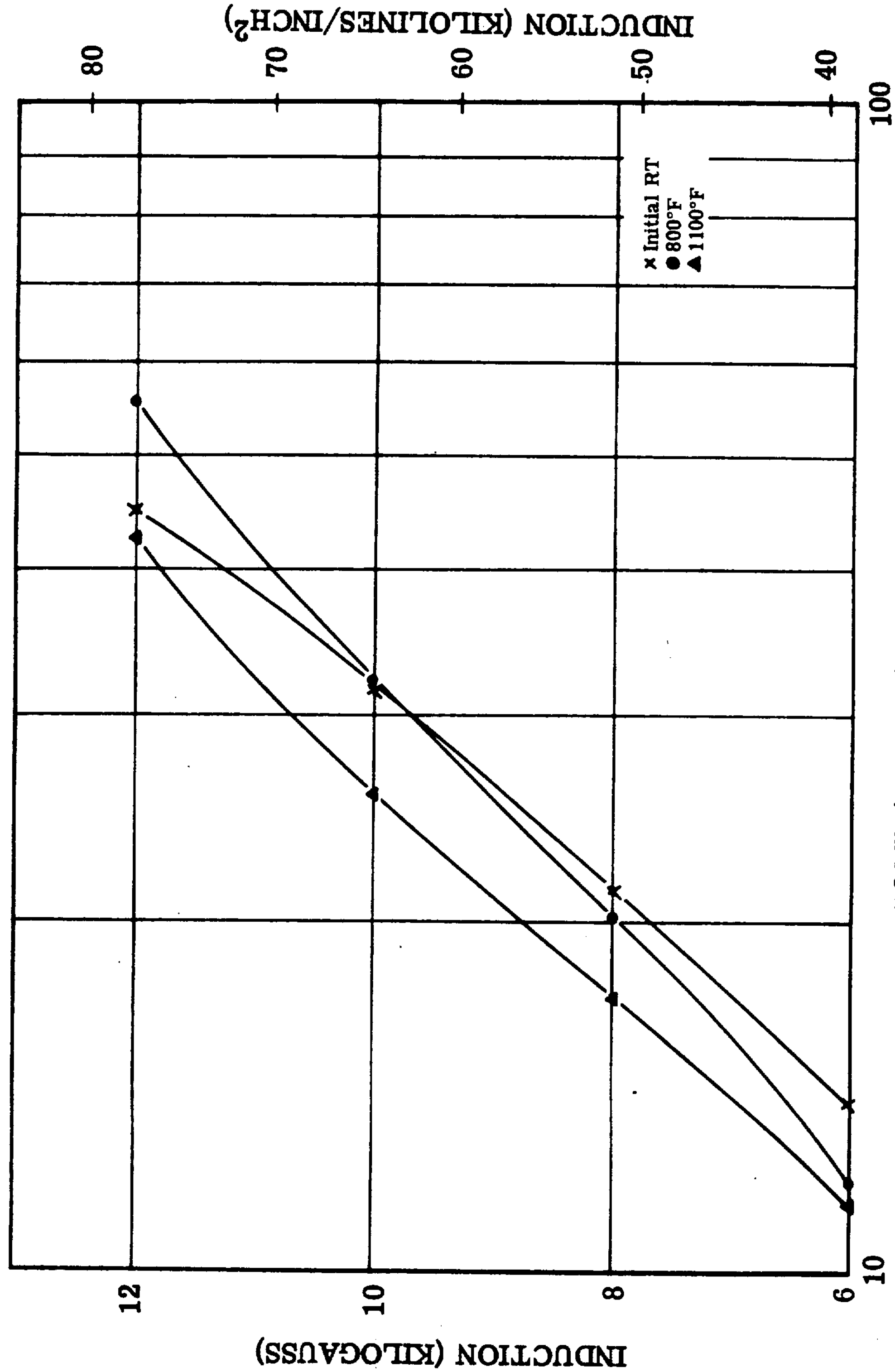


FIGURE IV.B.II-5. Exciting Volt-Amperes per Pound, 1600 CPS. Hiperco 50 Alloy 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference NAS 3-4162)

Figure IV.B.II-5. Exciting VA, 1600 CPS. Hiperco 50

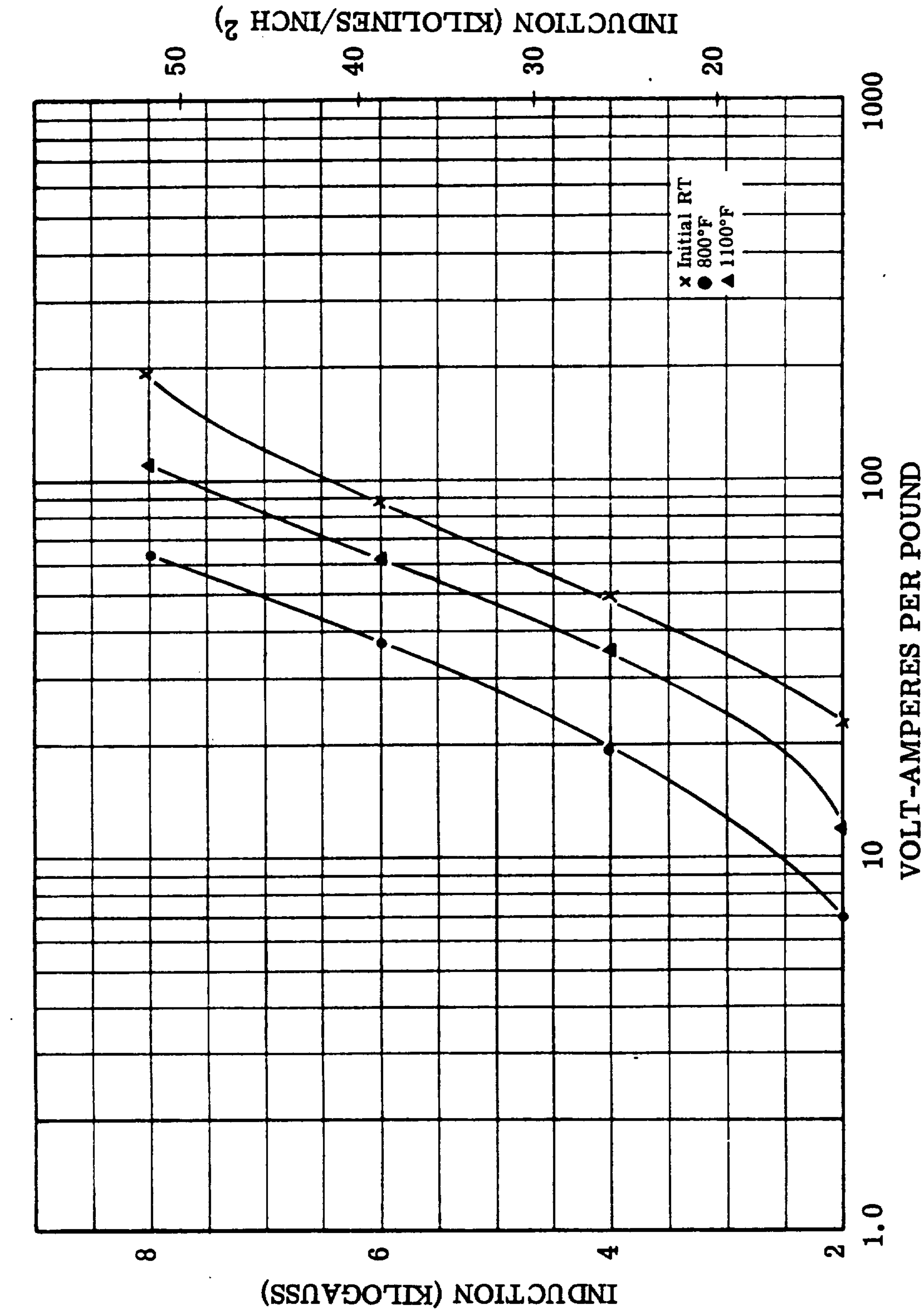


FIGURE IV.B.II-6. Exciting Volt-Amperes per Pound, 3200 CPS. Hiperco 50 Alloy 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-6. Exciting VA, 3200 CPS. Hiperco 50

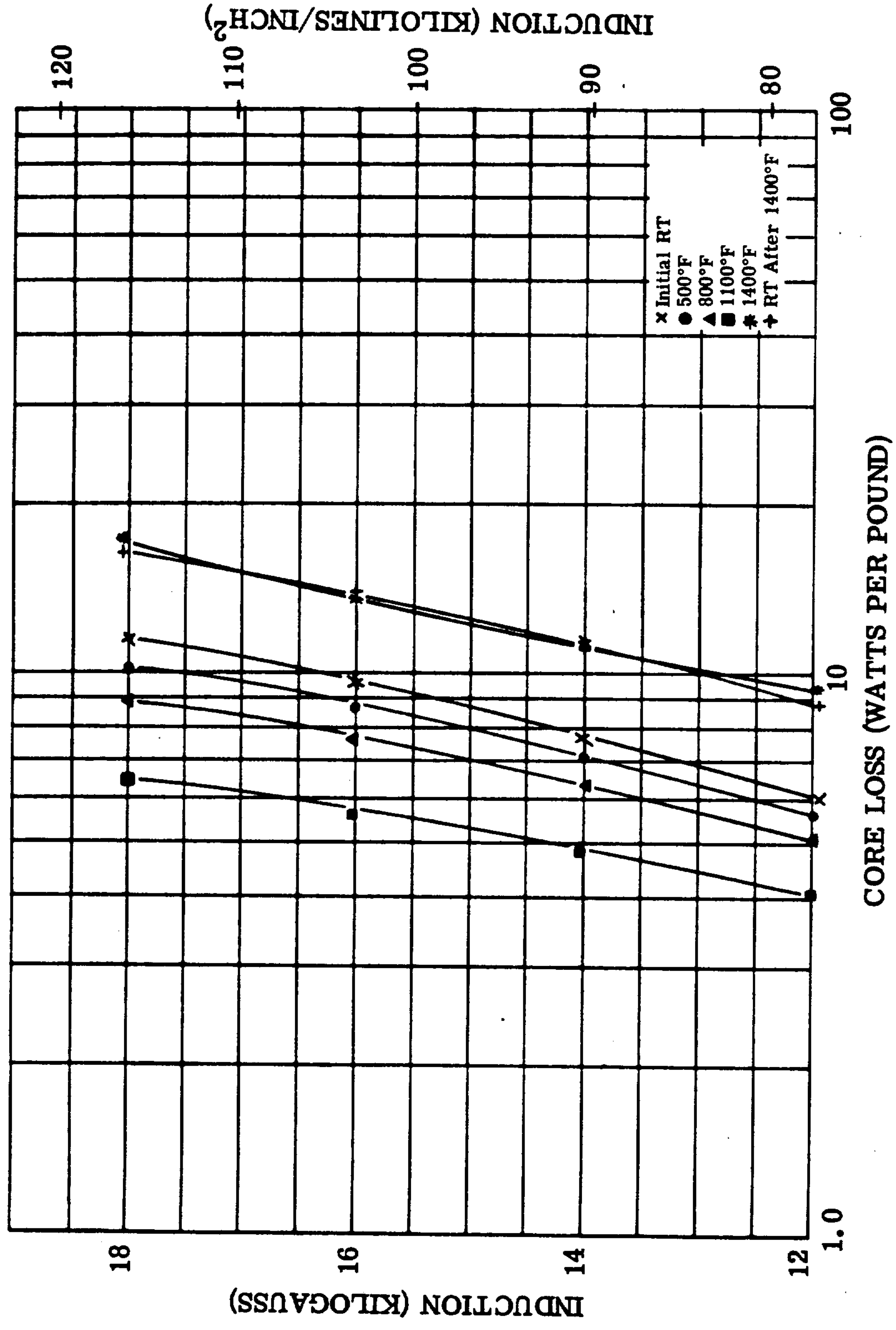


FIGURE IV.B.II-7. Core Loss, 400 CPS. Hiperco 50 Alloy 0.004 Inch Laminations.
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulations: Aluminum Orthophosphate.
(Reference: NAS 3-4162)

Figure IV.B.II-7. Core Loss, 400 CPS. Hiperco 50

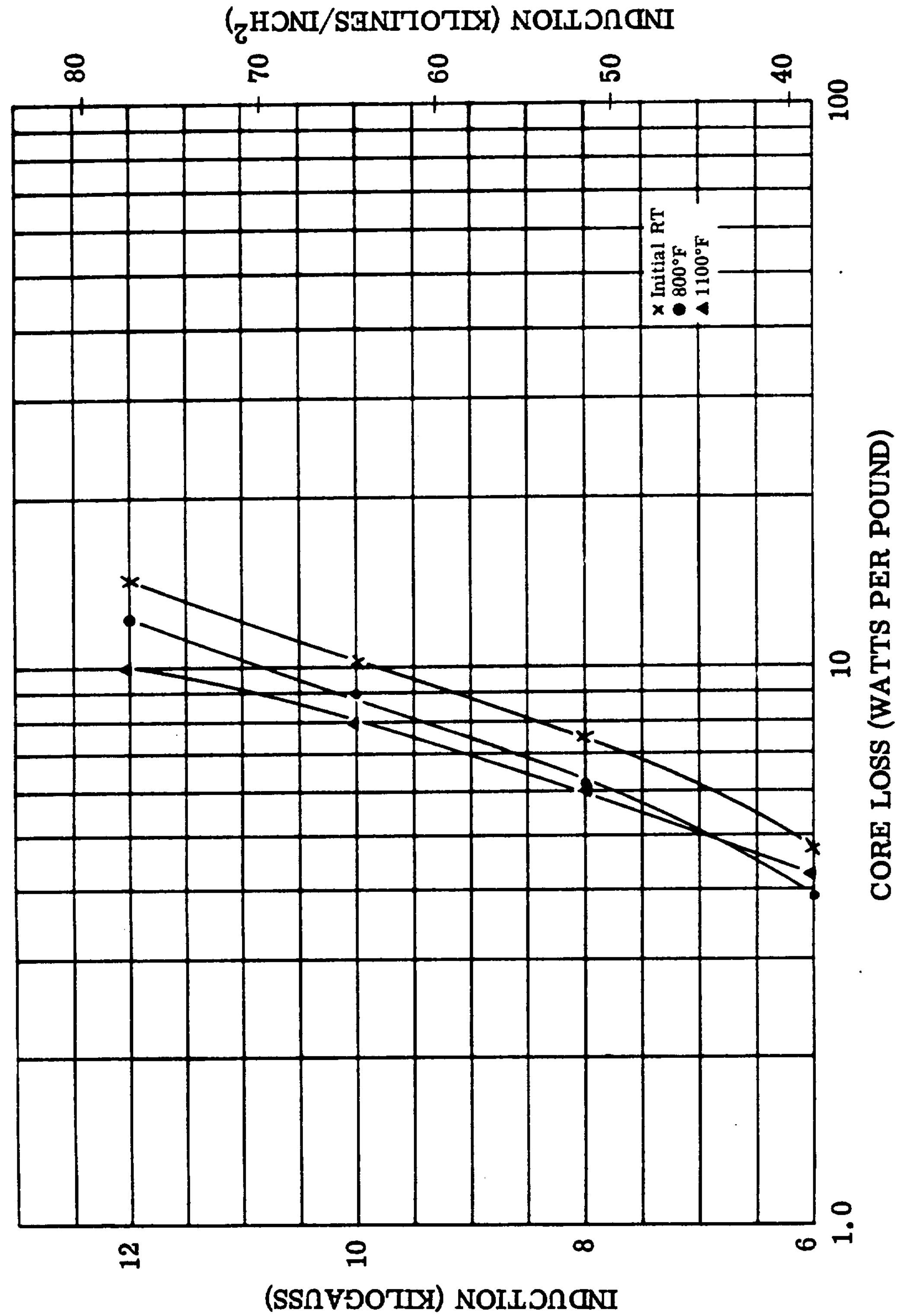


FIGURE IV.B.II-8. Core Loss, 800 CPS. Hiperco 50 Alloy 0.004 Inch Laminations.
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulation: Aluminum Orthophosphate.
(Reference: NAS 3-4162)

Figure IV.B.II-8. Core Loss, 800 CPS. Hiperco 50

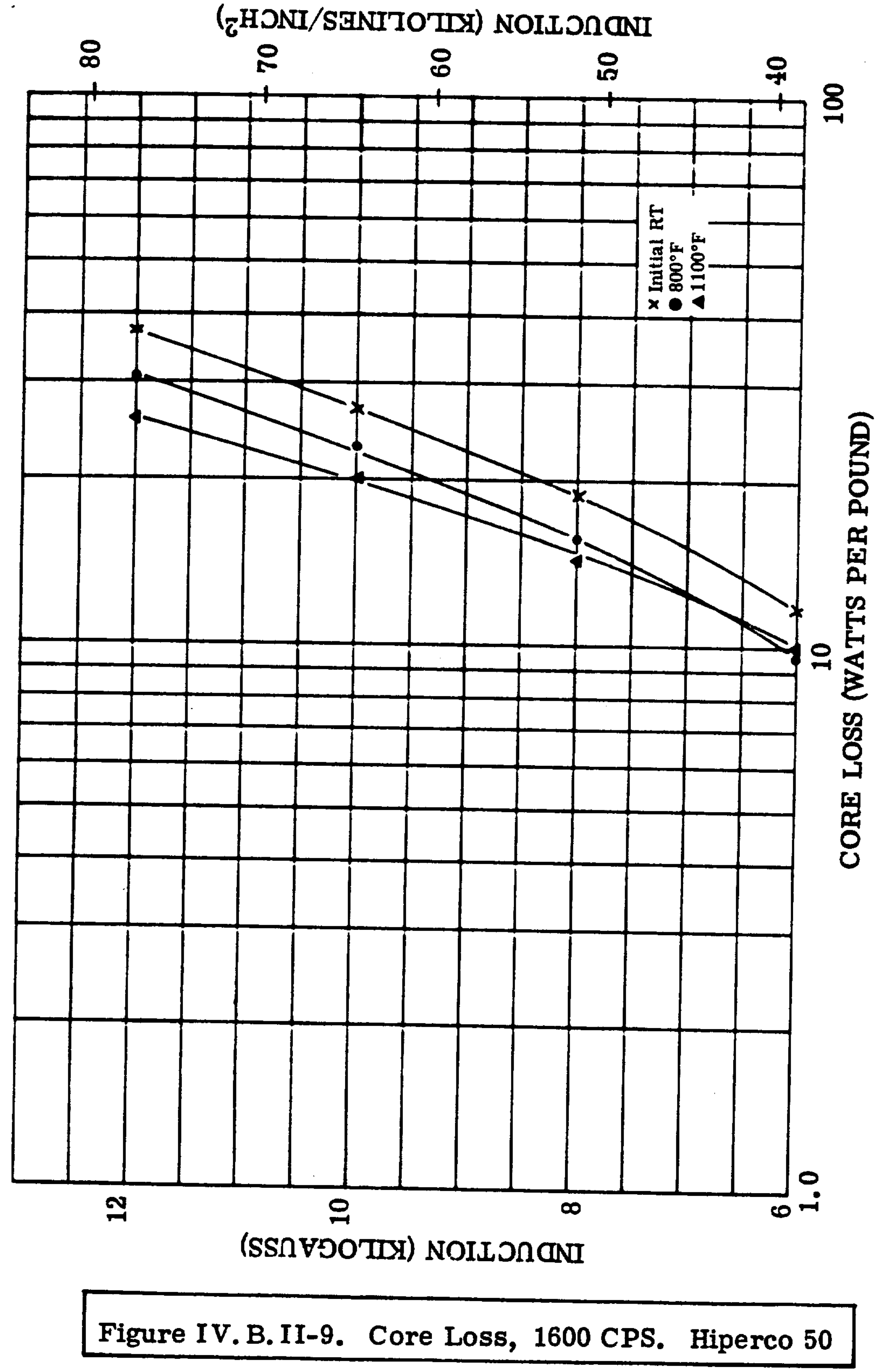


FIGURE IV.B.II-9. Core Loss, 1600 CPS. Hiperco 50 Alloy 0.004 Inch Laminations.
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulation: Aluminum Orthophosphate.
(Reference: NAS 3-4162)

Figure IV.B.II-9. Core Loss, 1600 CPS. Hiperco 50

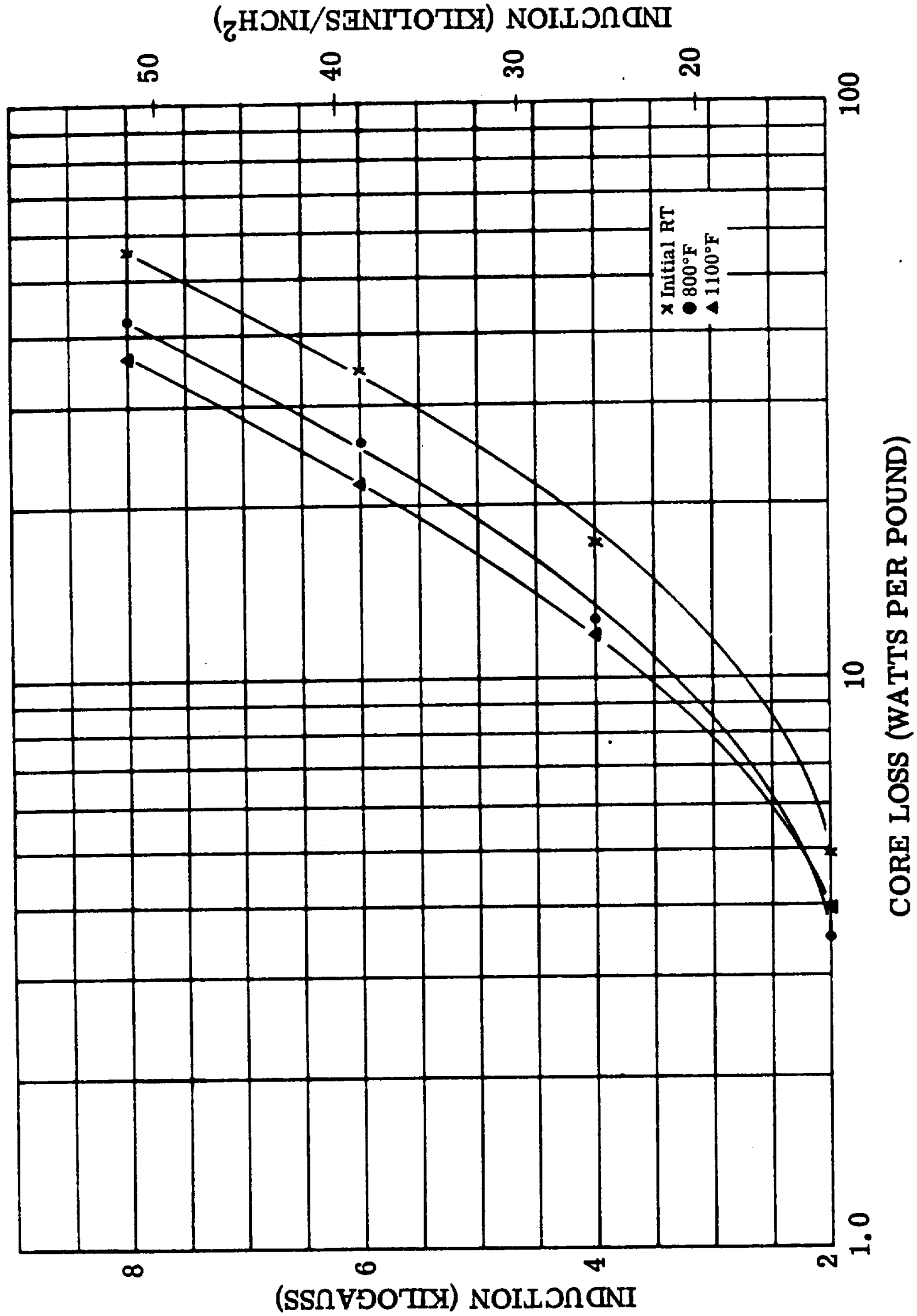


FIGURE IV.B.II-10. Core Loss, 3200 CPS. Hiperco 50 Alloy 0.004 Inch Laminations.
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulation: Aluminum Orthophosphate.
(Reference NAS 3-4162)

Figure IV.B.II-10. Core Loss, 3200 CPS. Hiperco 50

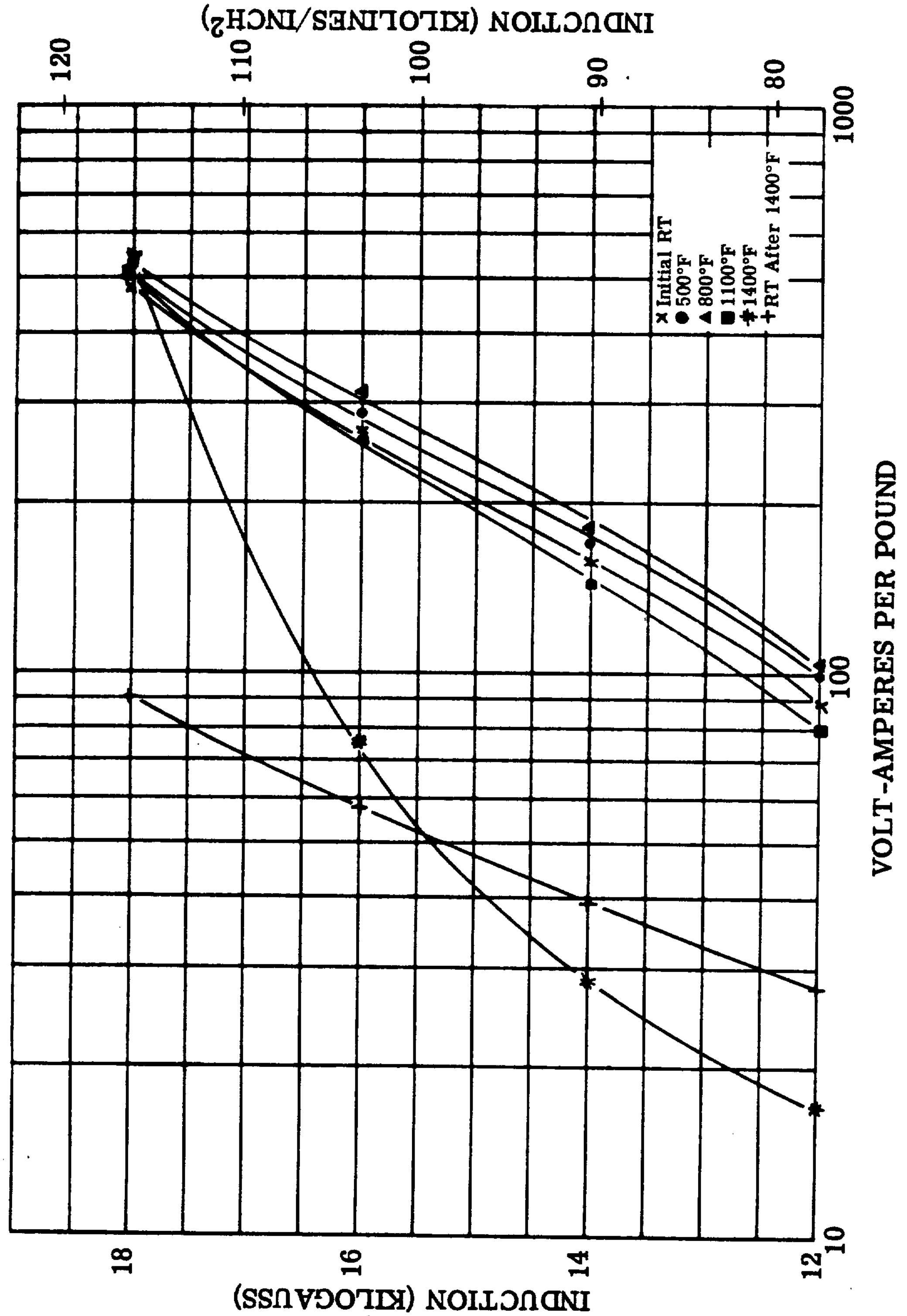


FIGURE IV.B.II-11. Exciting Volt-Amperes per Pound, 400 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-11. Exciting VA, 400 CPS. Hiperco 50

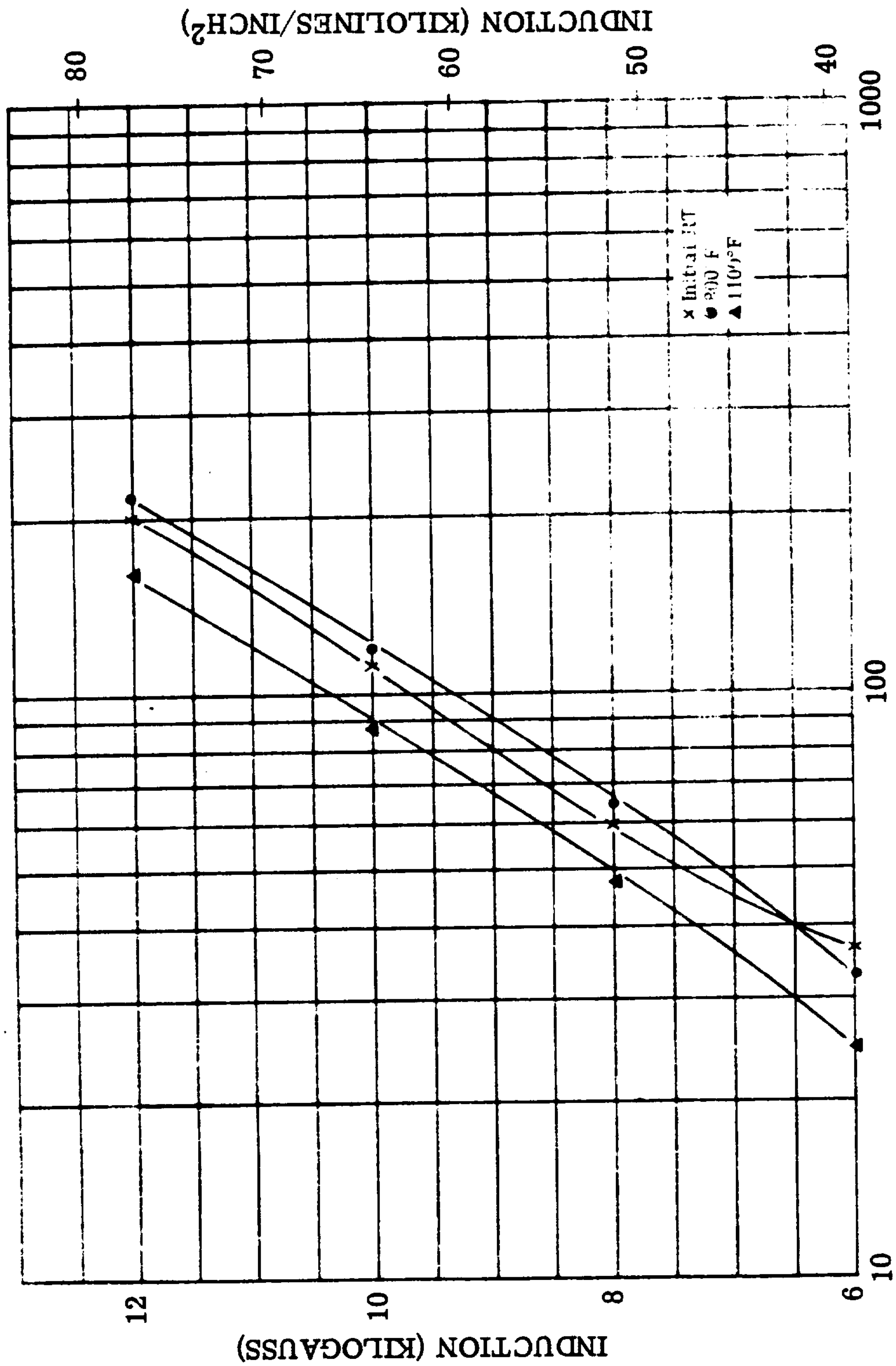


FIGURE IV.B.II-12. Exciting Volt-Amperes per Pound, 800 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-12. Exciting VA, 800 CPS. Hiperco 50

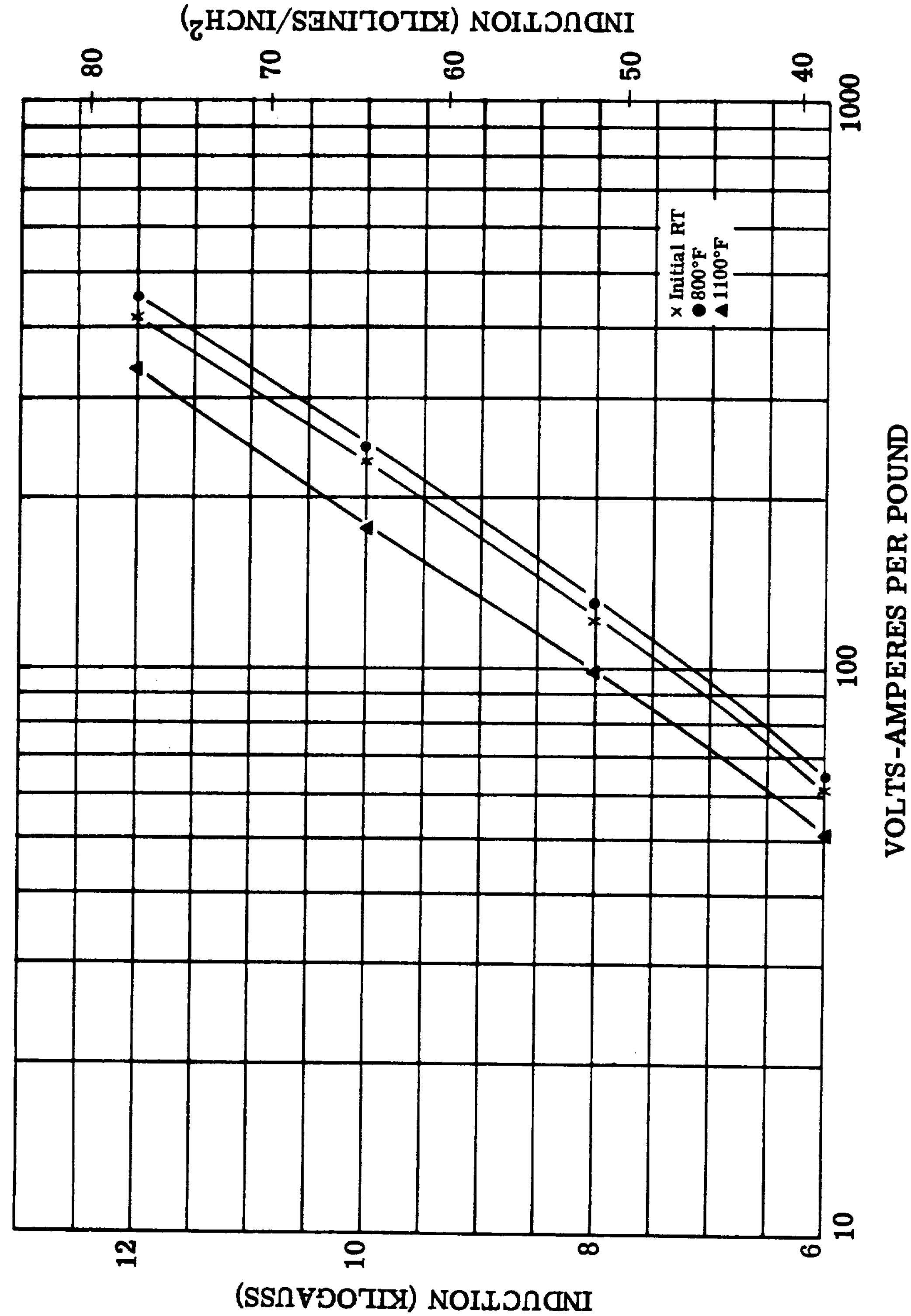


FIGURE IV.B.II-13. Exciting Volt-Amperes per Pound, 1600 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-13. Exciting VA, 1600 CPS. Hiperco 50

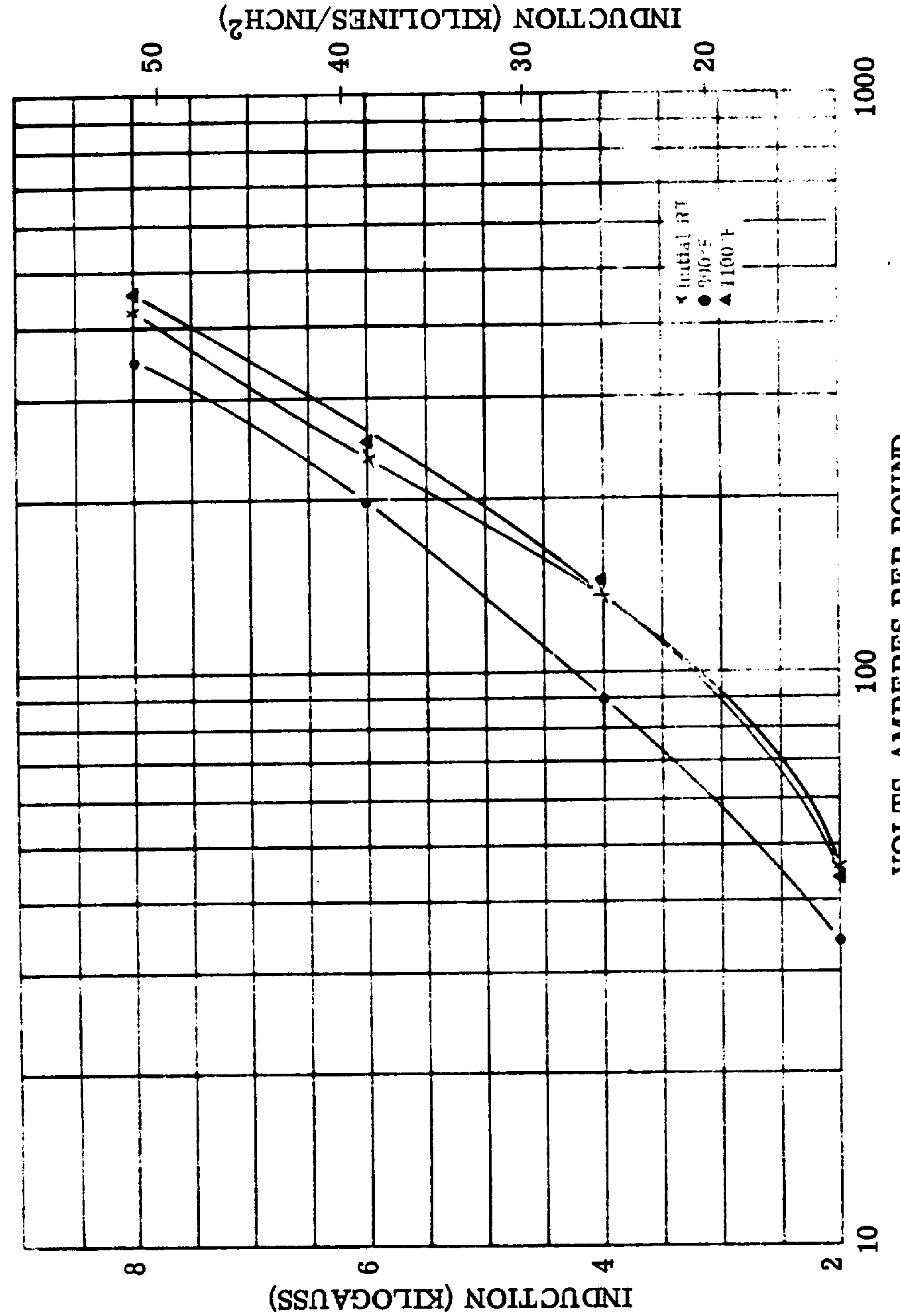


FIGURE IV.B.II-14. Exciting Volt-Amperes per Pound, 3200 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

FIGURE IV.B.II-14. Exciting VA, 3200 CPS. Hiperco 50

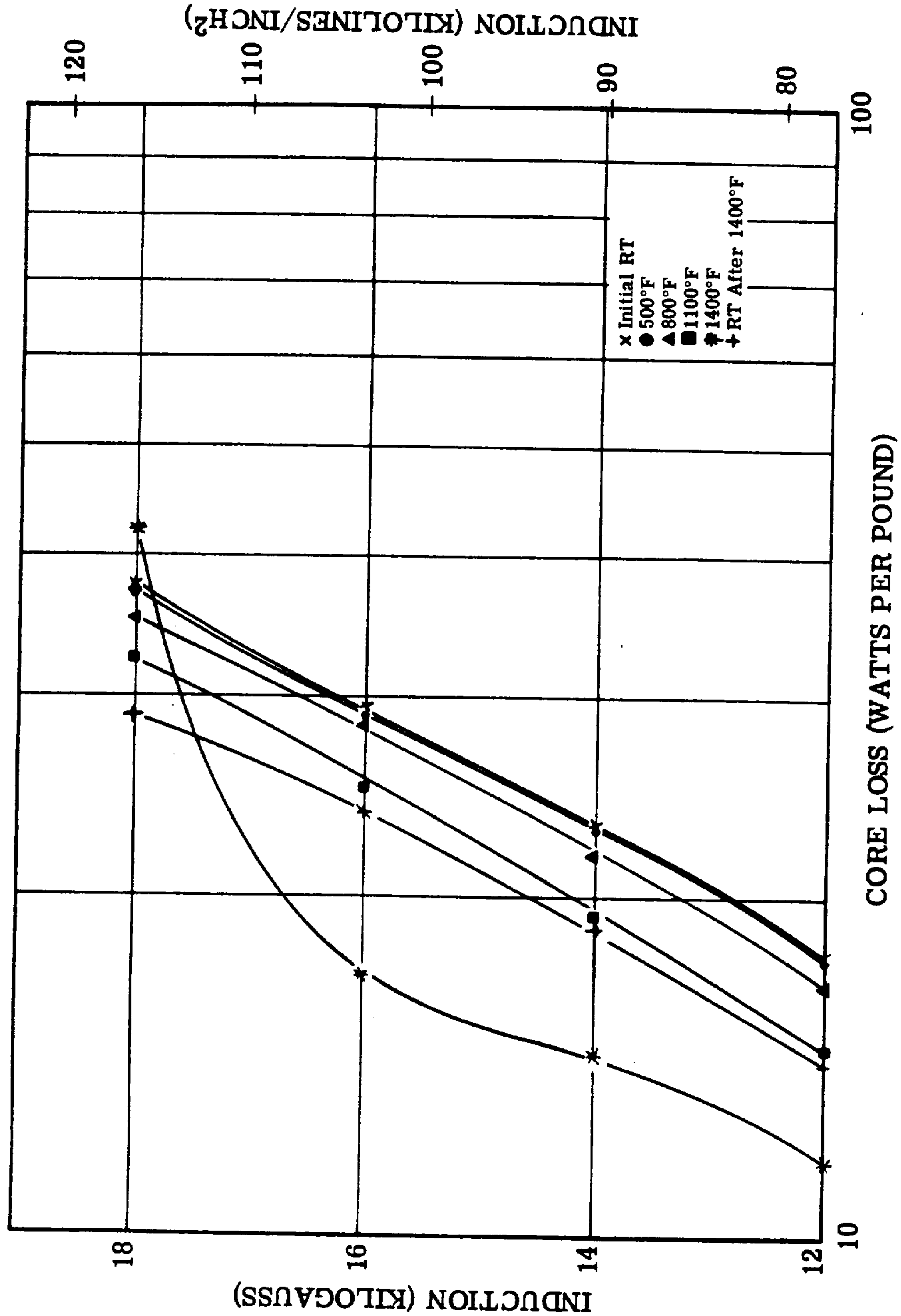


FIGURE IV. B. II-15. Core Loss, 400 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. B. II-15. Core Loss, 400 CPS. Hiperco 50

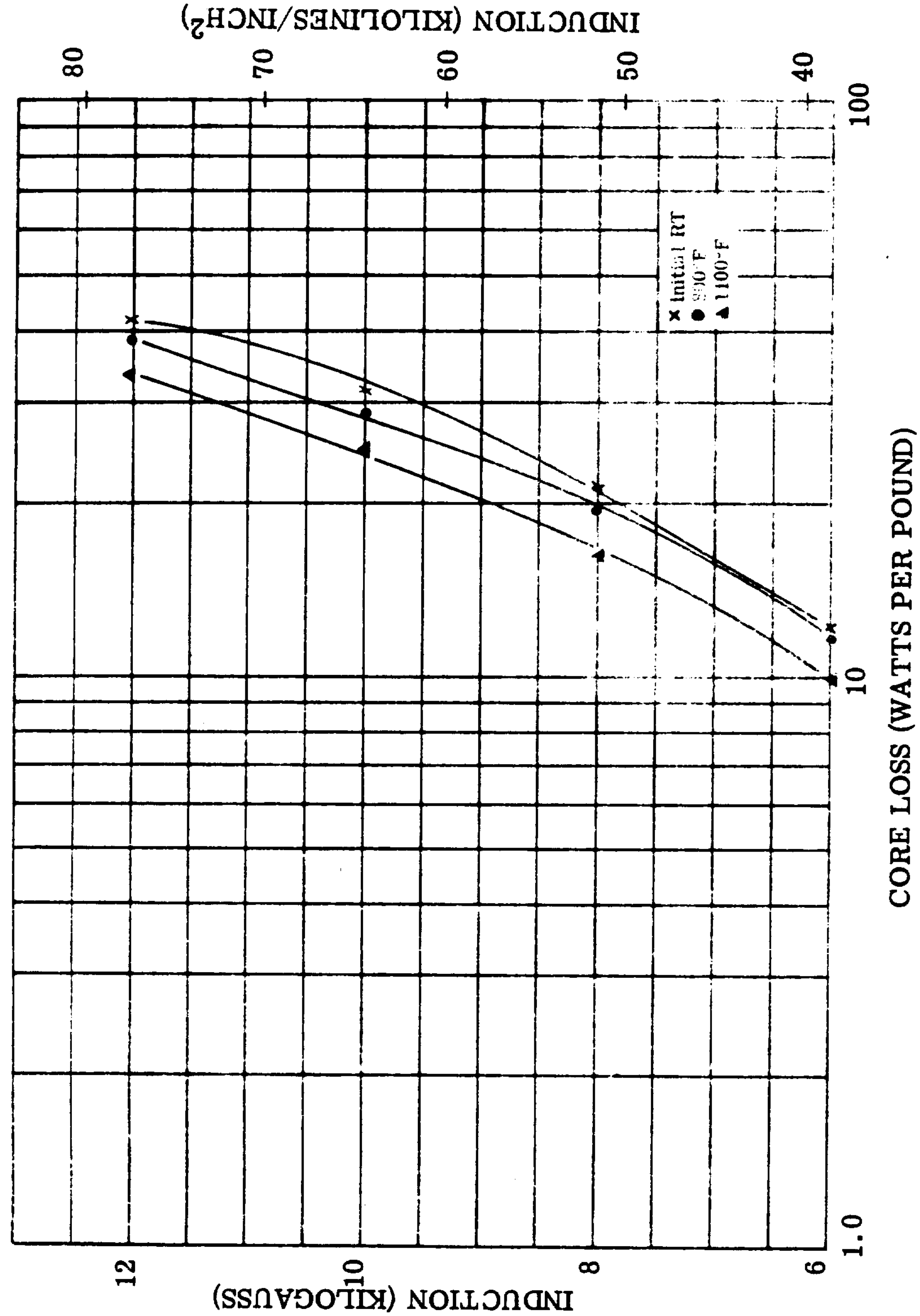


FIGURE IV.B.II-16. Core Loss, 800 CPS. Hiperco 50 Alloy 0.008 Inch Laminations
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulation: Aluminum Orthophosphate.
(Reference: NAS3-4162)

Figure IV.B.II-16. Core Loss, 800 CPS. Hiperco 50

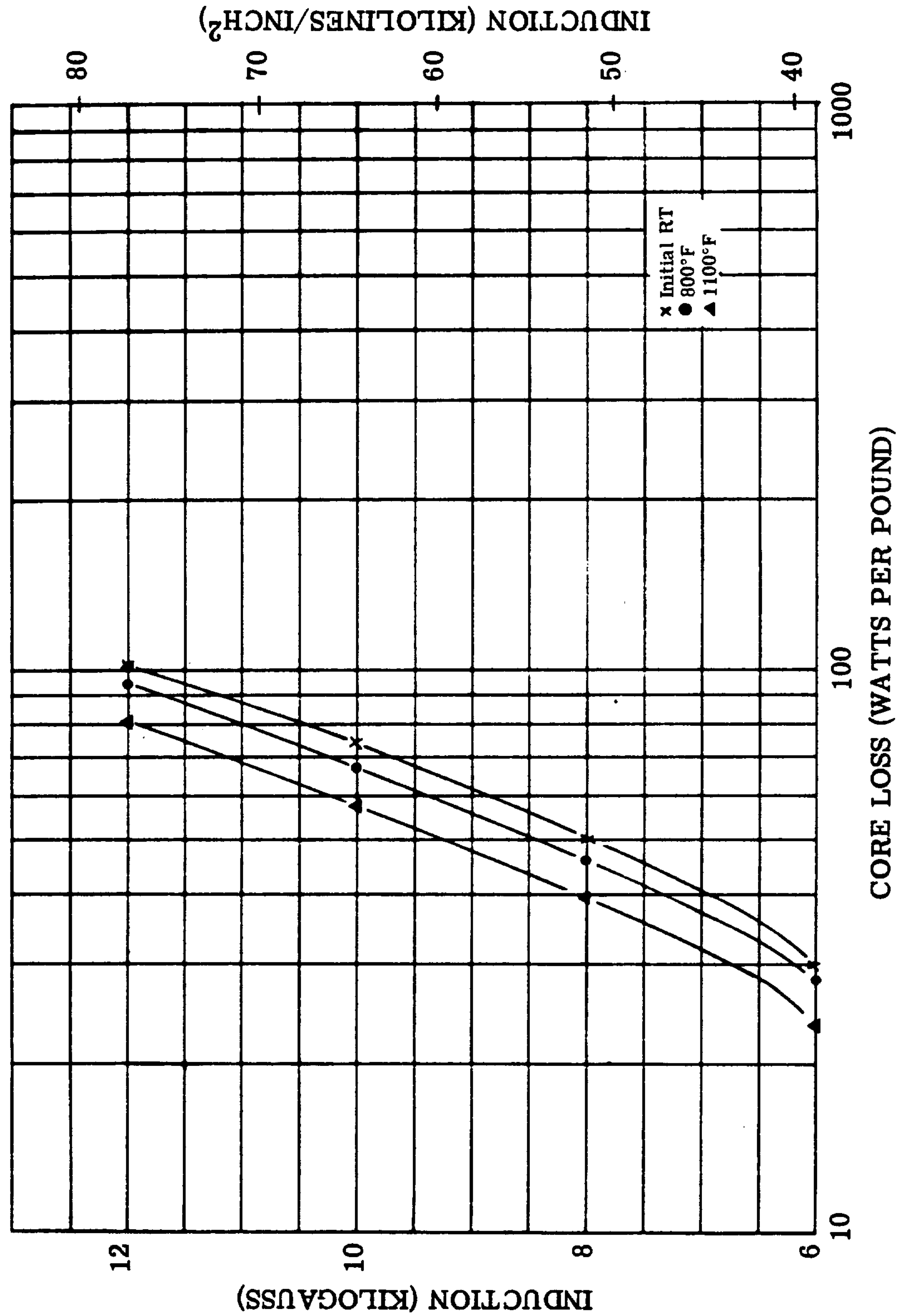


FIGURE IV.B.II-17. Core Loss, 1600 CPS. Hiperco 50 Alloy 0.008 Inch Laminations
Test Atmosphere: Air to 800°F, Argon above 800°F.
Interlaminar Insulation: Aluminum Orthophosphate.
(Reference: NAS 3-4162)

Figure IV.B.II-17. Core Loss, 1600 CPS. Hiperco 50

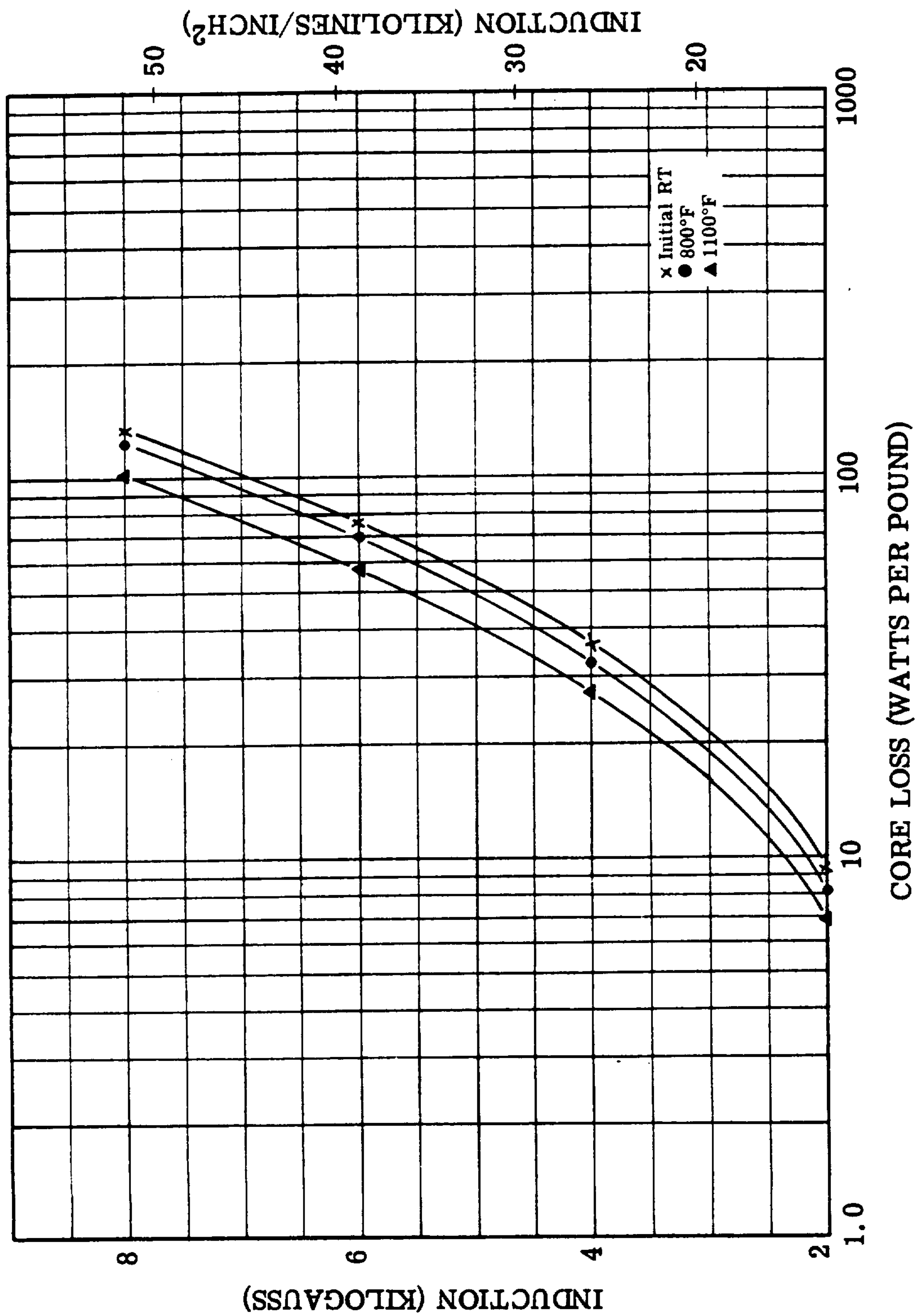


FIGURE IV. B. II-18. Core Loss, 3200 CPS. Hiperco 50 Alloy 0.008 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. B. II-18. Core Loss, 3200 CPS. Hiperco 50

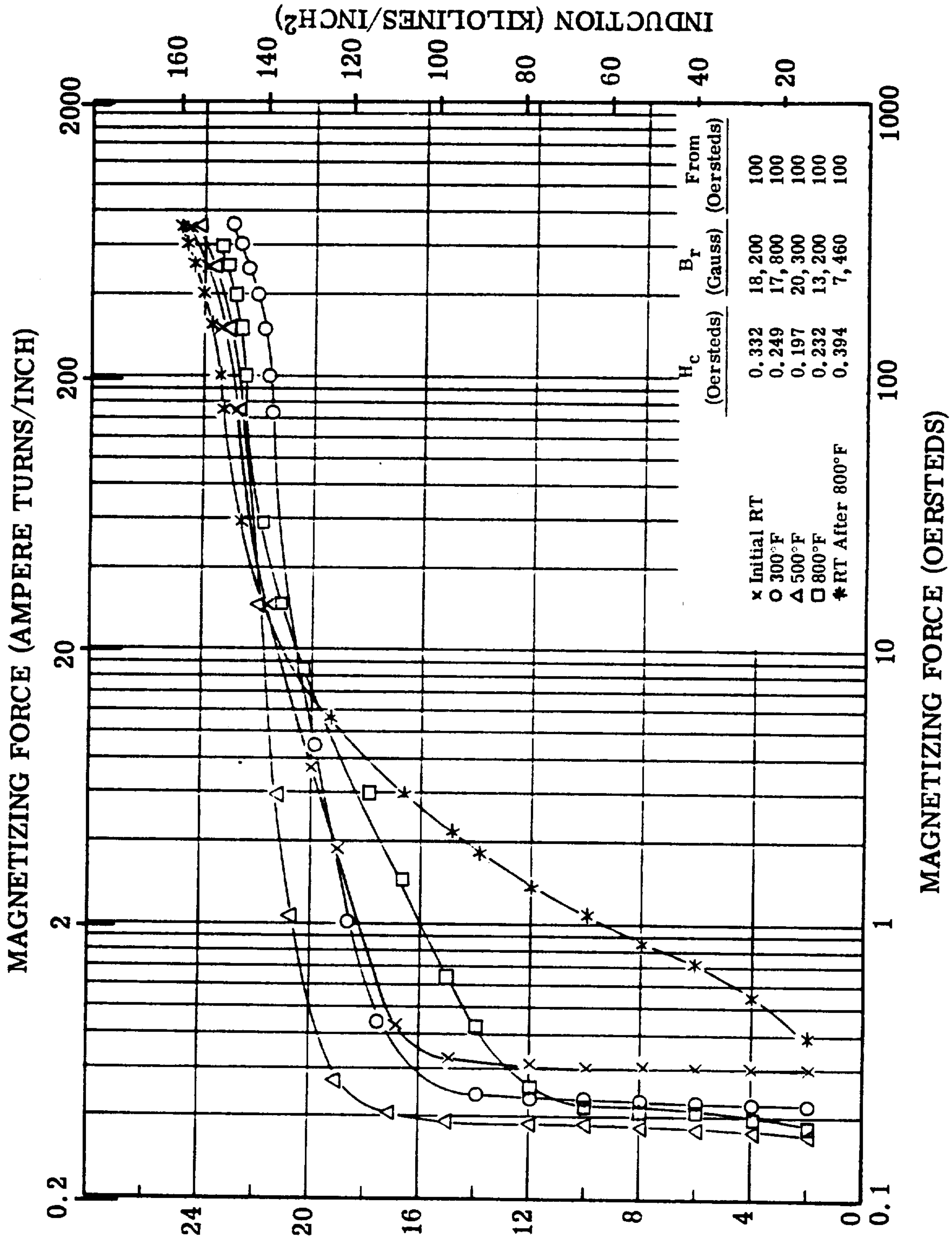


FIGURE IV.B.II-19. D-C Magnetization Curves. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-19. D-C Magnetization - Supermendur

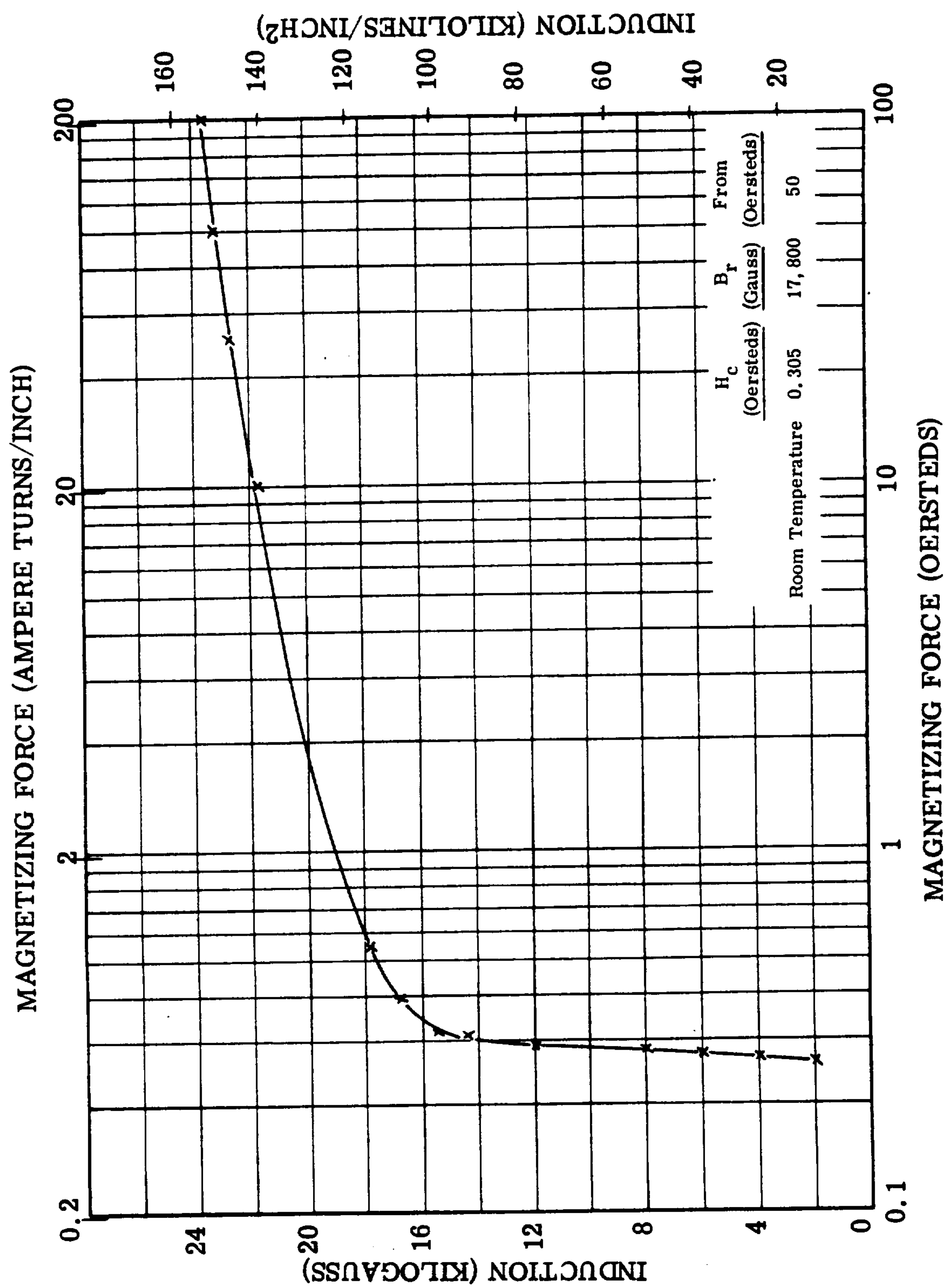


FIGURE IV.B.II-20. D-C Magnetization Curves. Supermendur 0.002 Inch Tape Toroid 1-1/2 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-20. D-C Magnetization - Supermendur

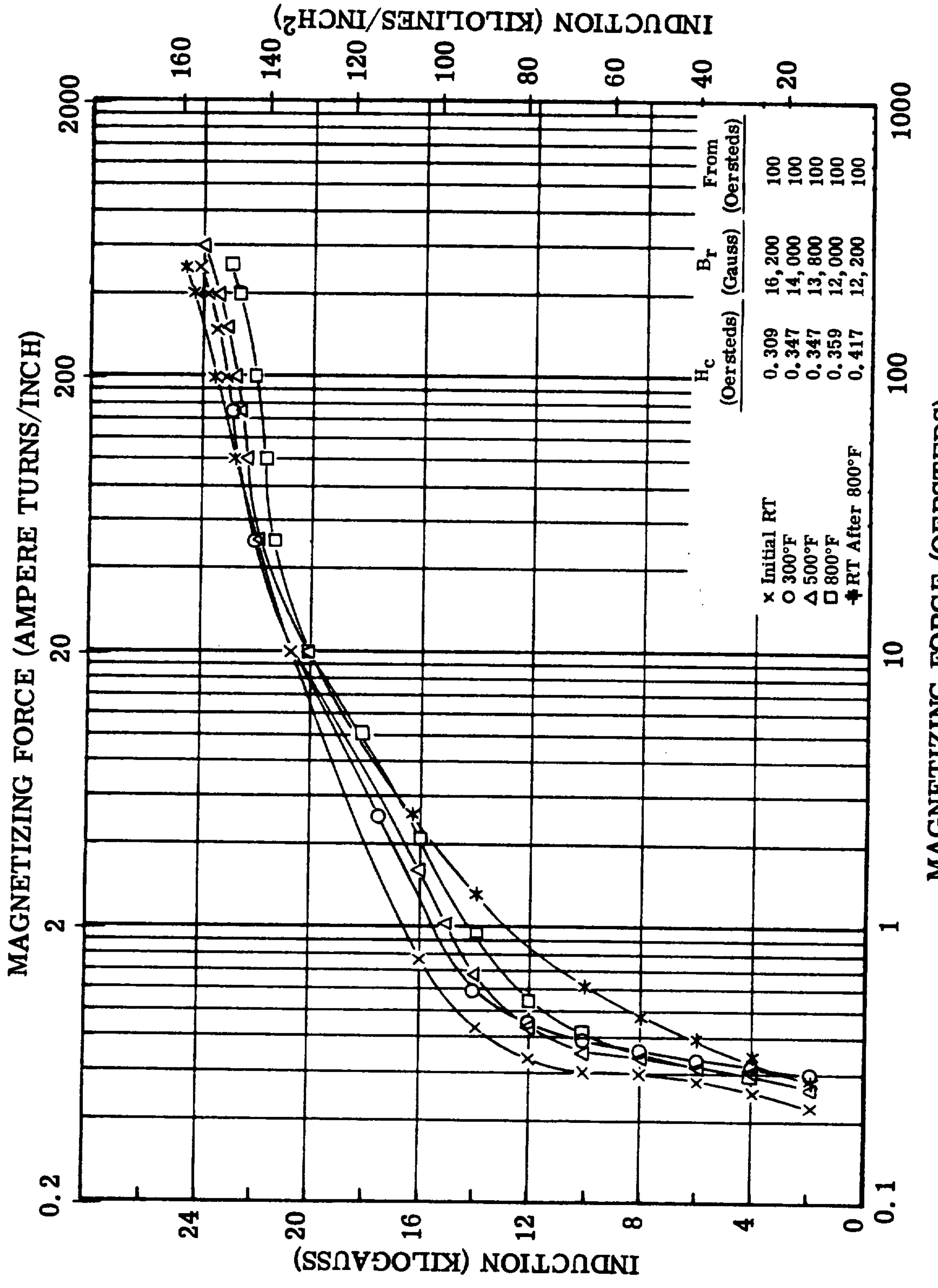


FIGURE IV.B.II-21. D-C Magnetization Curves. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-21. D-C Magnetization - Supermendur

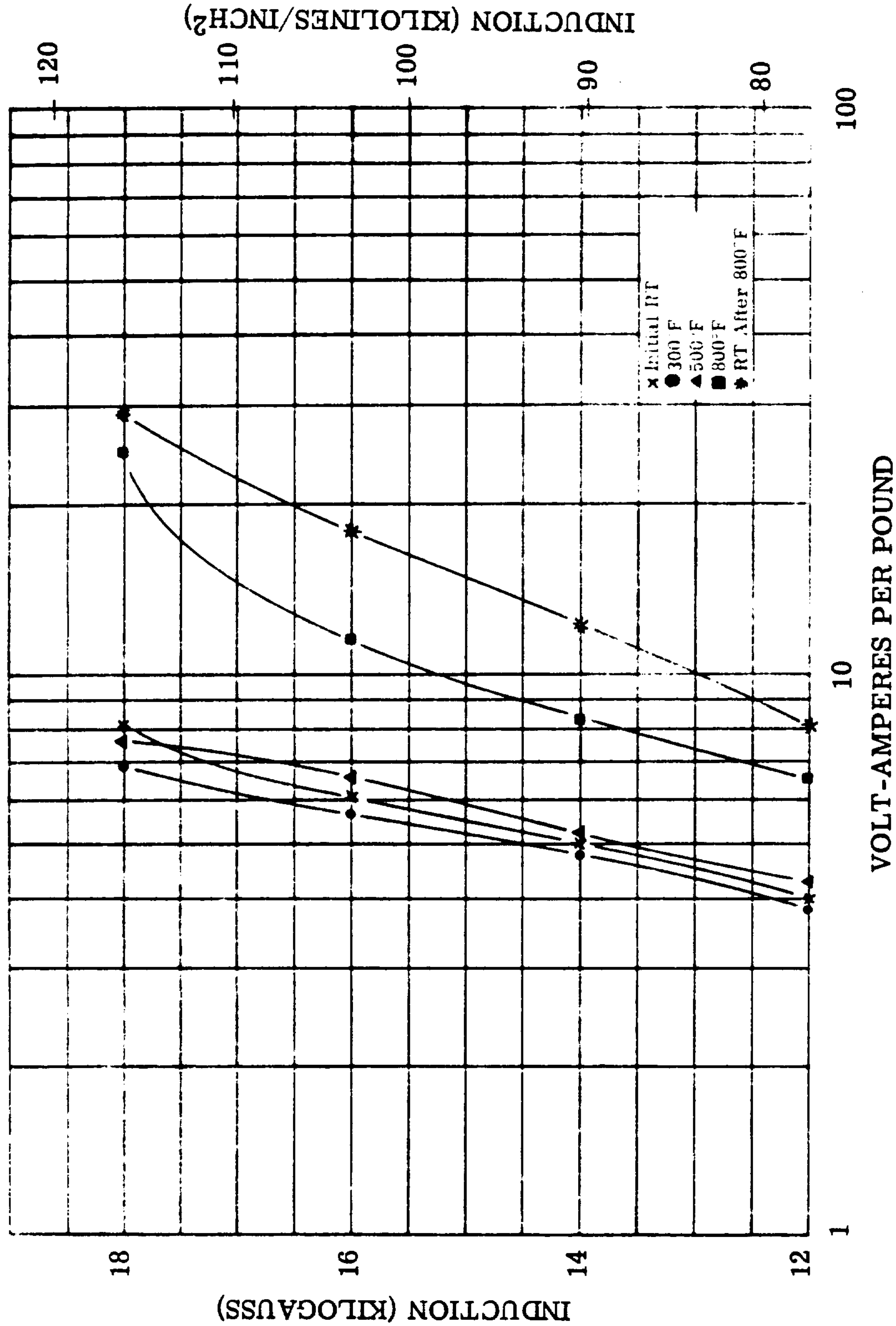


FIGURE IV.B.II-22. Exciting Volt-Amperes per Pound, 400 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon Interlaminar Insulation: Magnesium Oxide. (Reference: NAS3-4162)

Figure IV.B.II-22. Exciting VA, 400 CPS. Supermendur

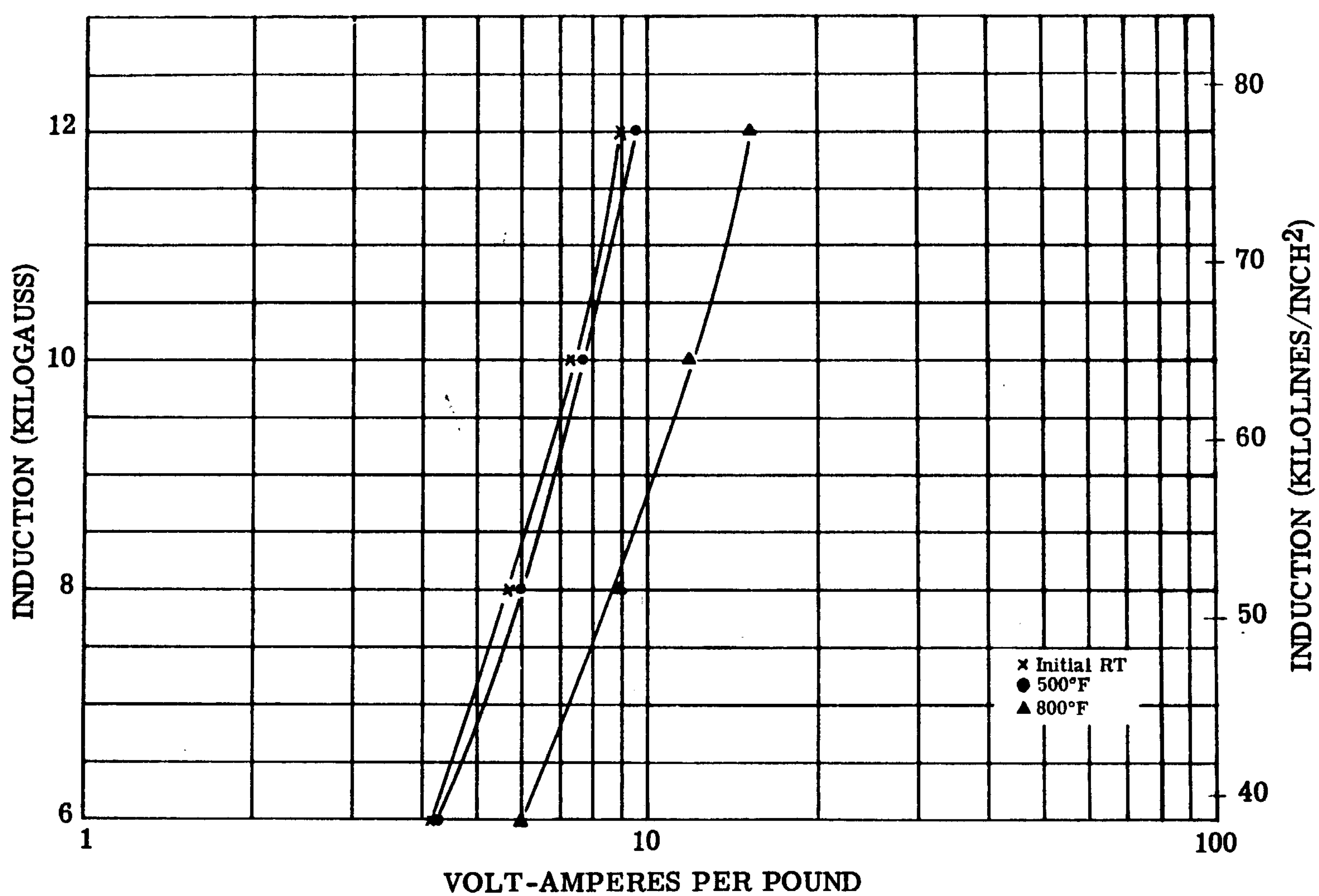


FIGURE IV. B. II-23. Exciting Volt-Amperes per Pound, 800 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-23. Exciting VA, 800 CPS. Supermendur

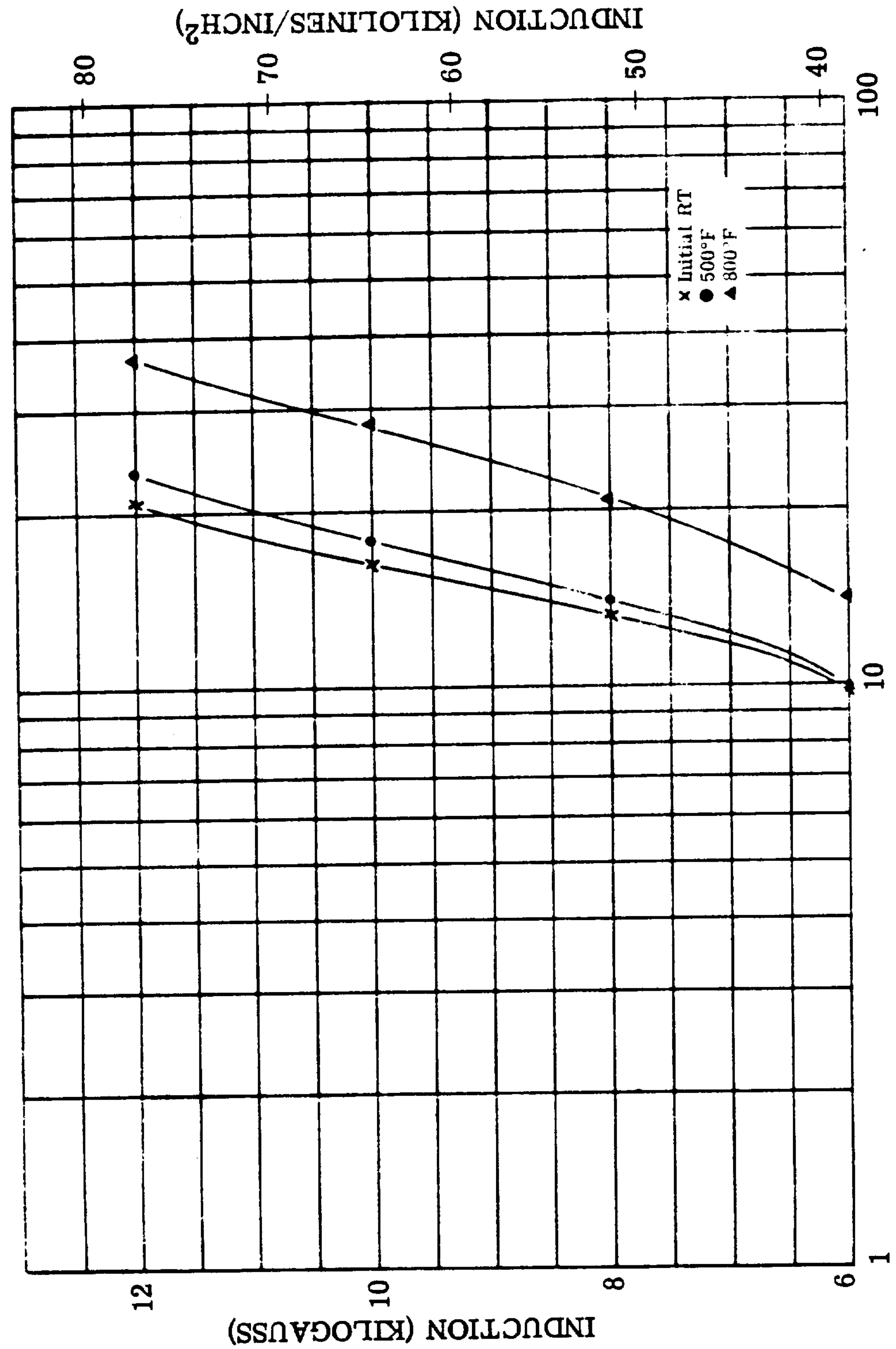


FIGURE IV. B. II-24. Exciting Volt-Amperes per Pound, 1600 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-24. Exciting VA, 1600 CPS. Supermendur

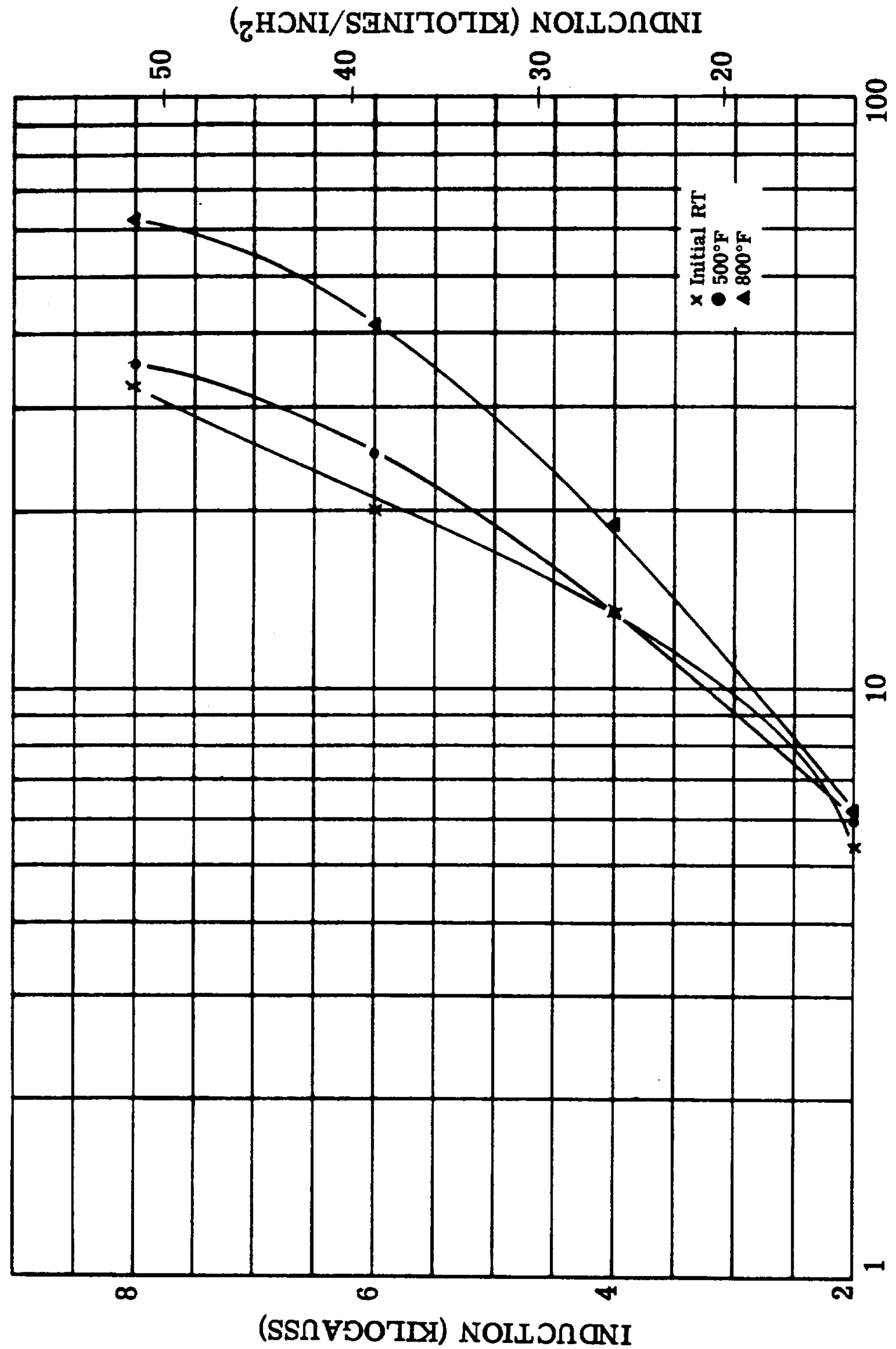


FIGURE IV.B.II-25. Exciting Volt-Amperes per Pound, 3200 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-25. Exciting VA, 3200 CPS. Supermendur

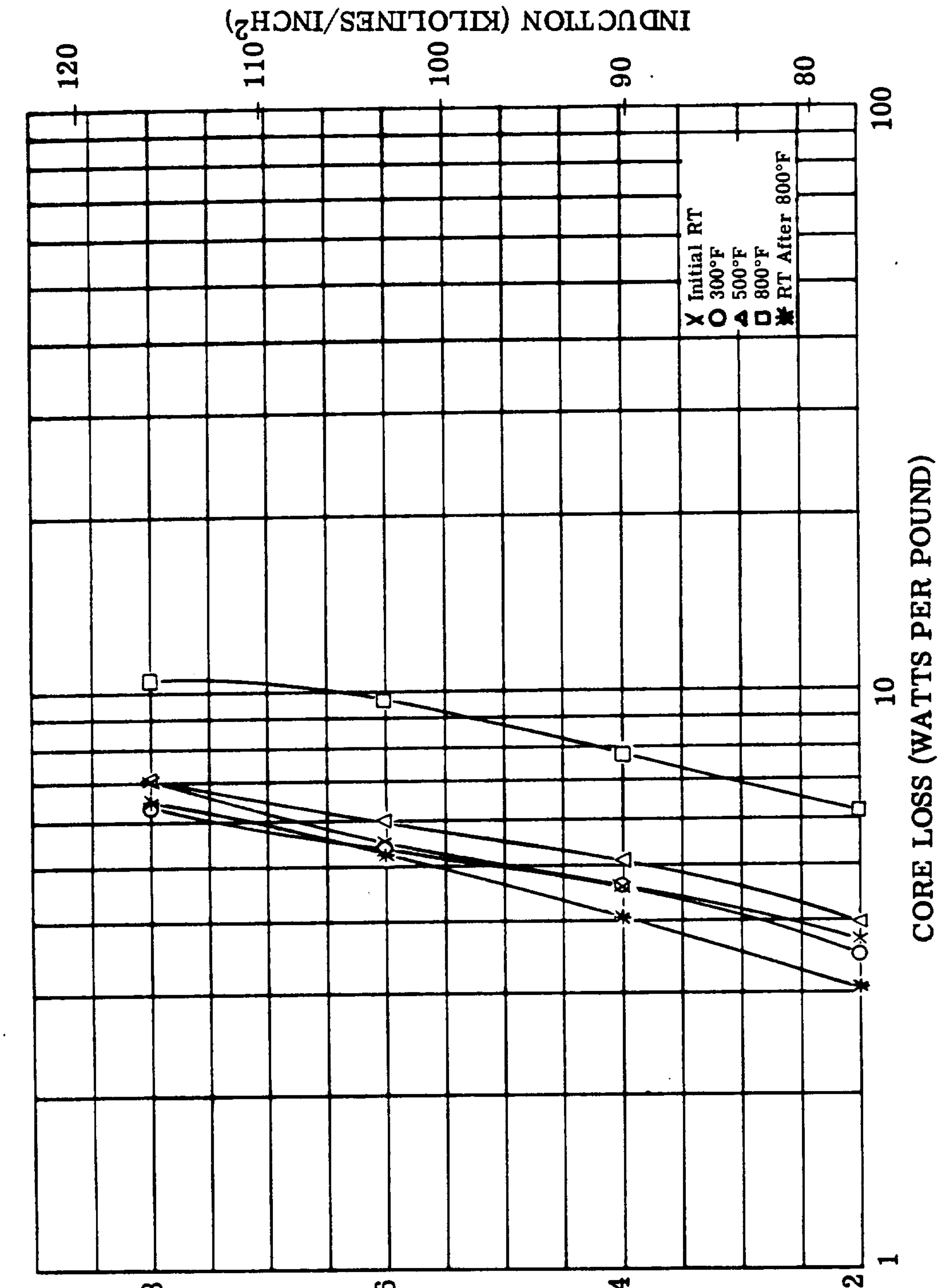


FIGURE IV. B. II-26. Core Loss, 400 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-26. Core Loss, 400 CPS. Supermendur

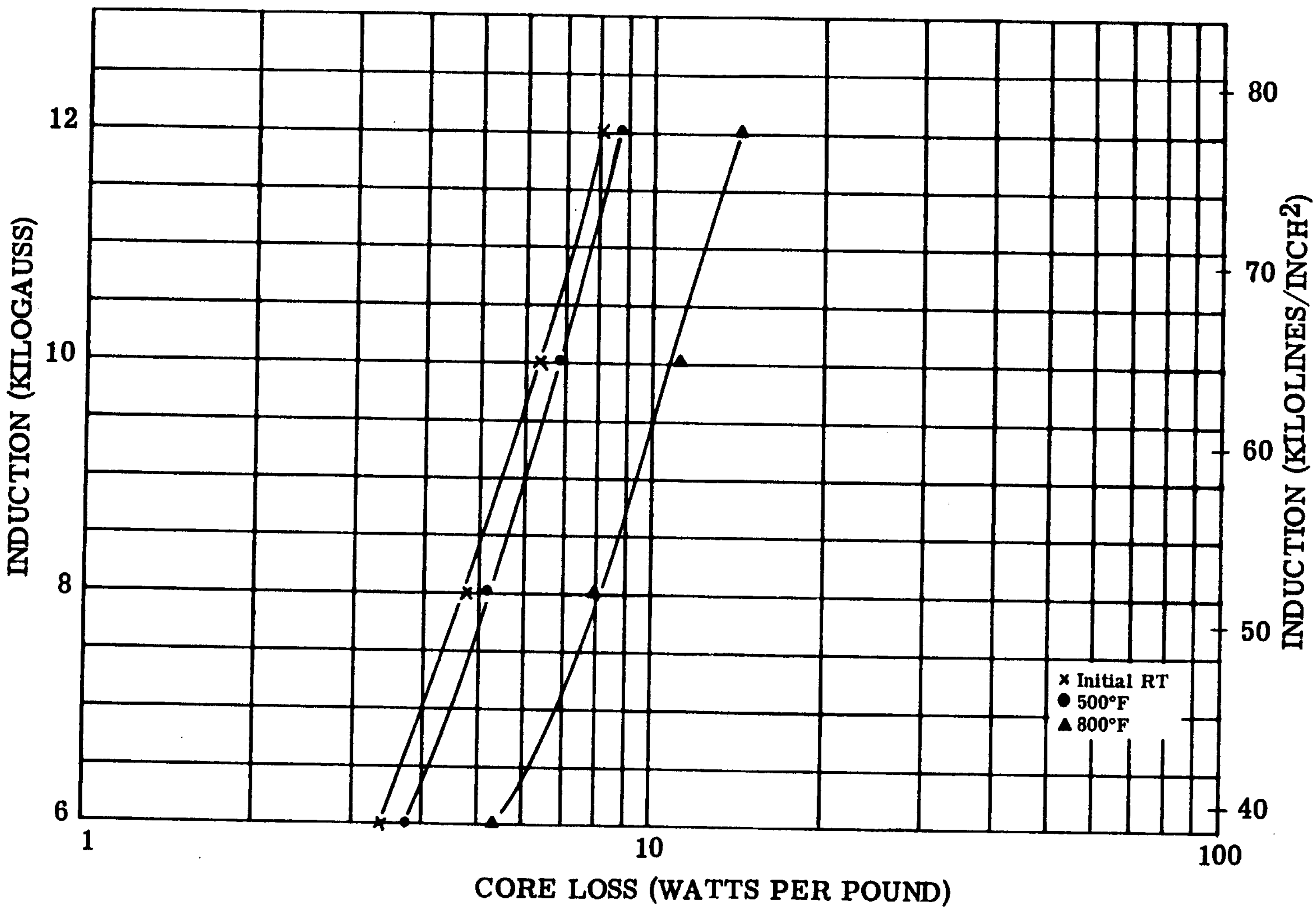


FIGURE IV. B. II-27. Core Loss, 800 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-27. Core Loss, 800 CPS. Supermendur

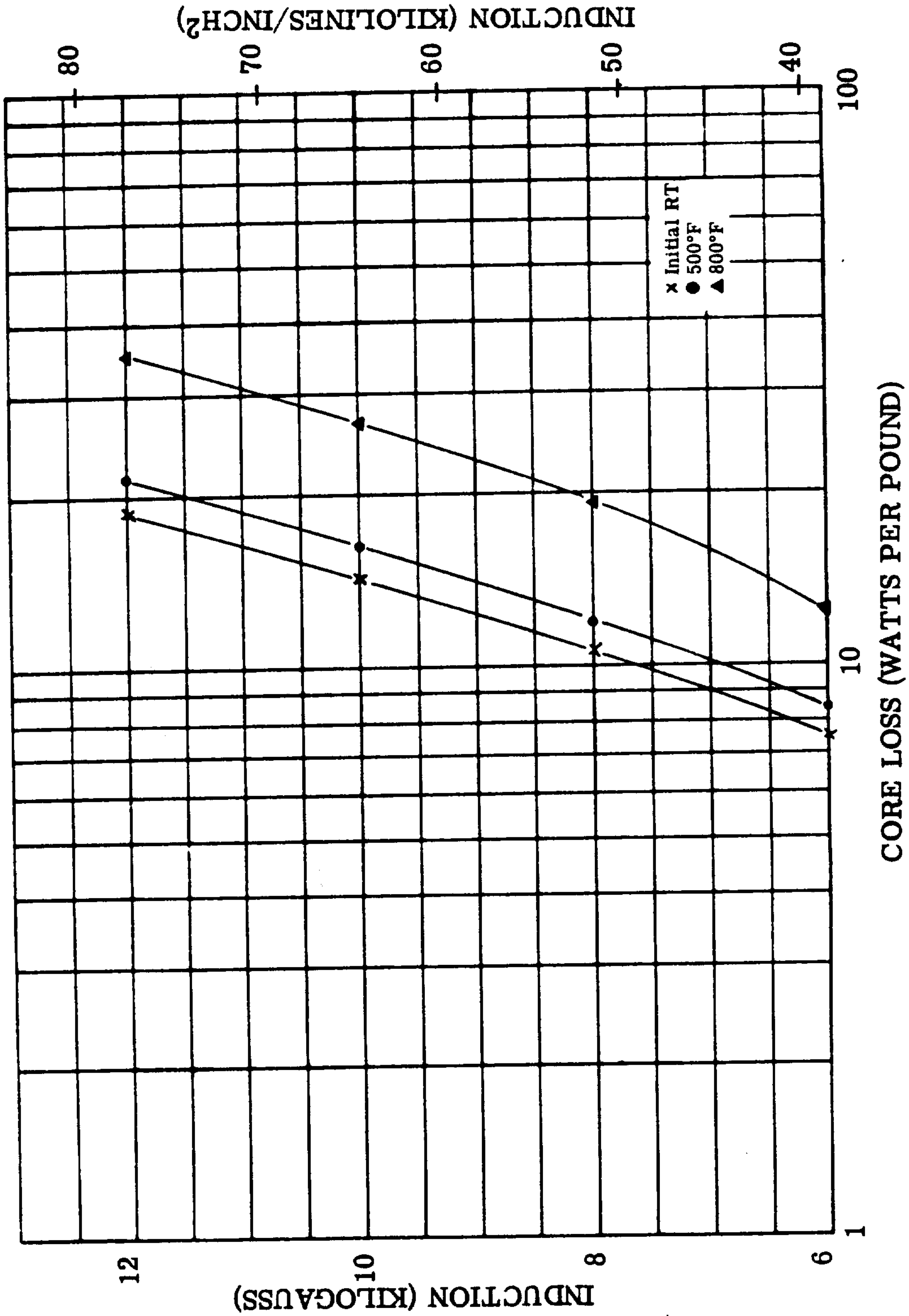


FIGURE IV. B. II-28. Core Loss, 1600 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-28. Core Loss, 1600 CPS. Supermendur

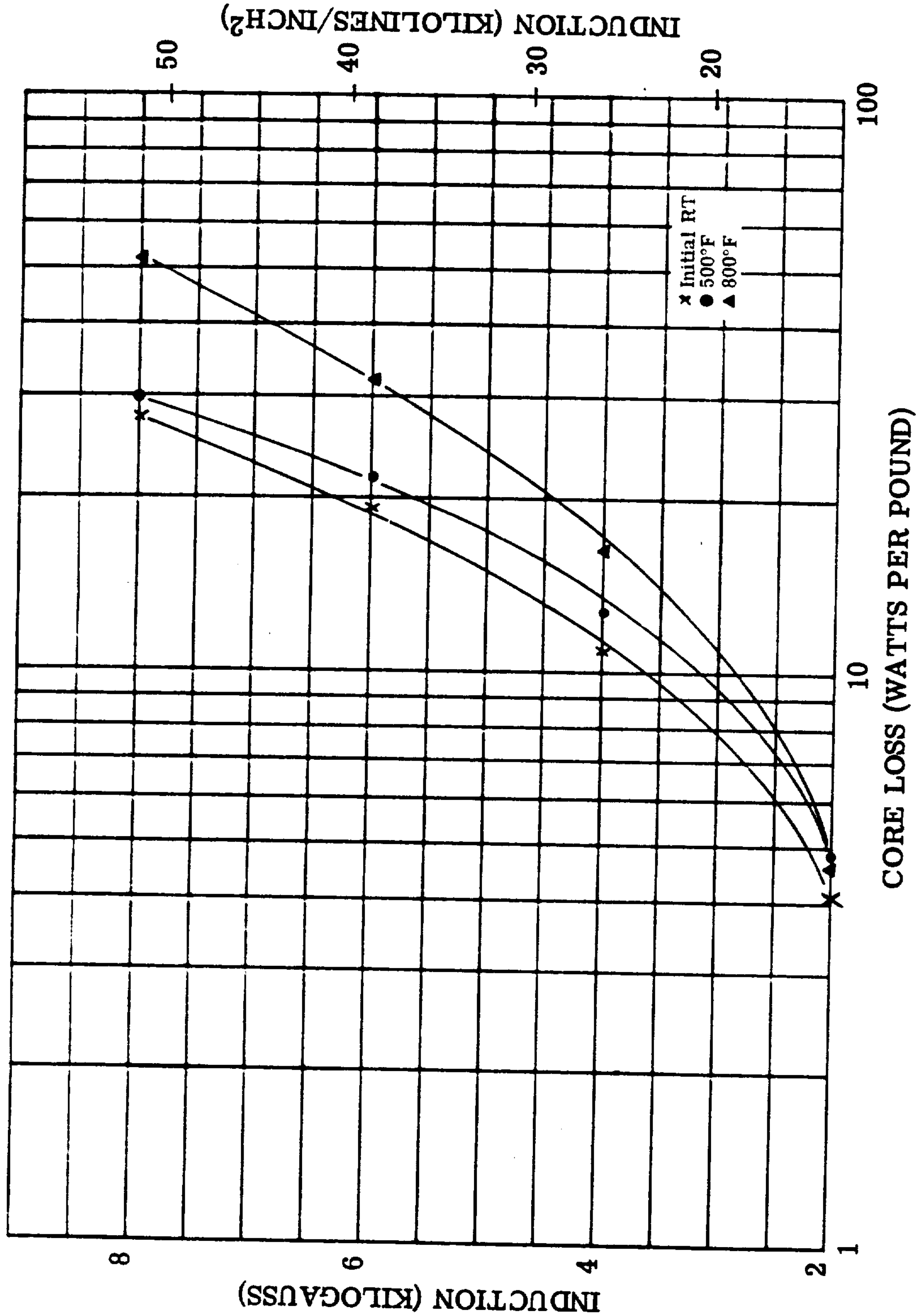


FIGURE IV. B. II-29. Core Loss, 3200 CPS. Supermendur 0.002 Inch Tape Toroid 3-1/2 x 4 x 1/2 Inch. Test Atmosphere: Argon. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-29. Core Loss, 3200 CPS. Supermendur

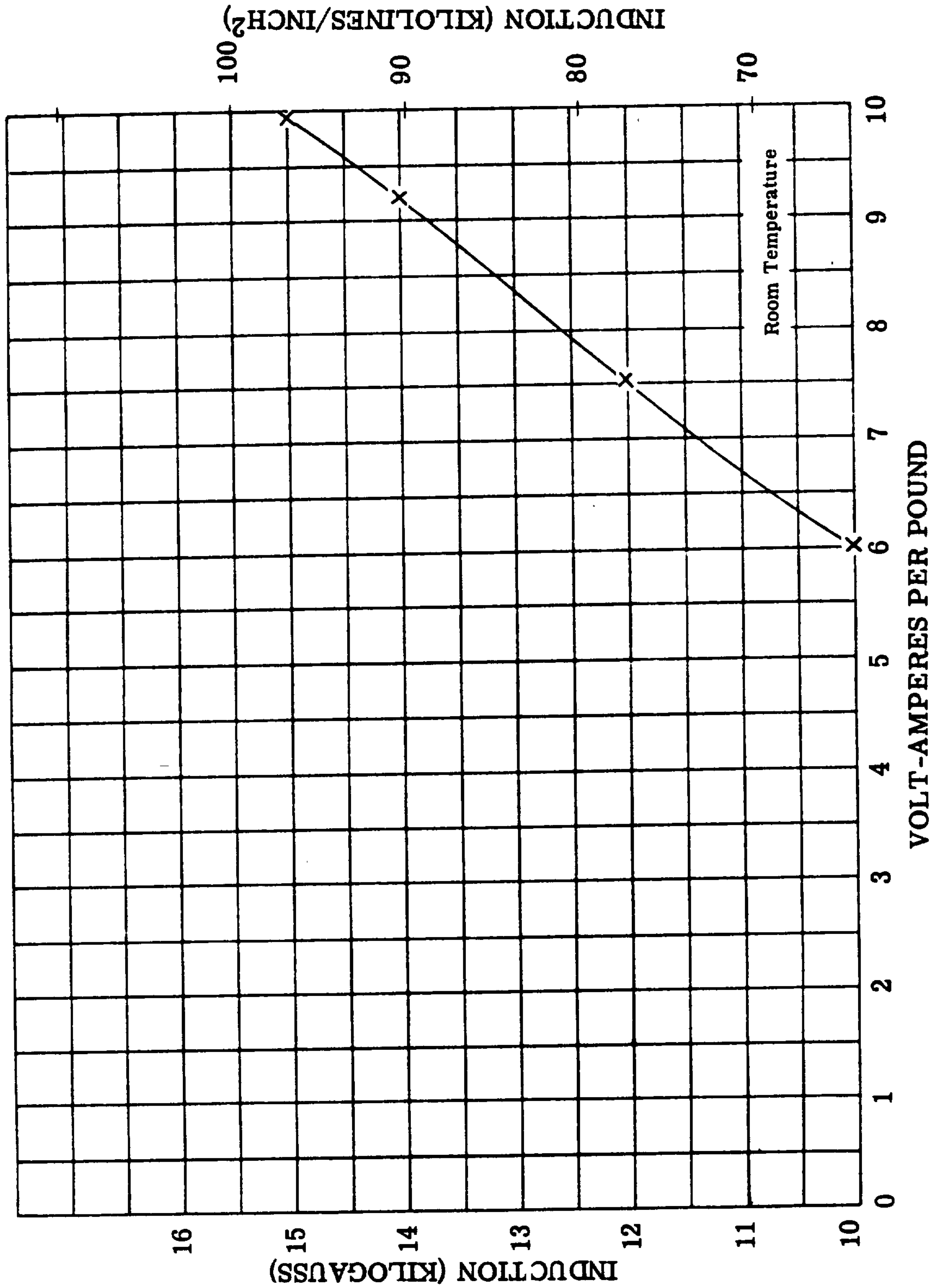


FIGURE IV.B.II-30. Exciting Volt-Amperes per Pound, 400 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS3-4162)

Figure IV.B.II-30. Exciting VA, 400 CPS. Supermendur

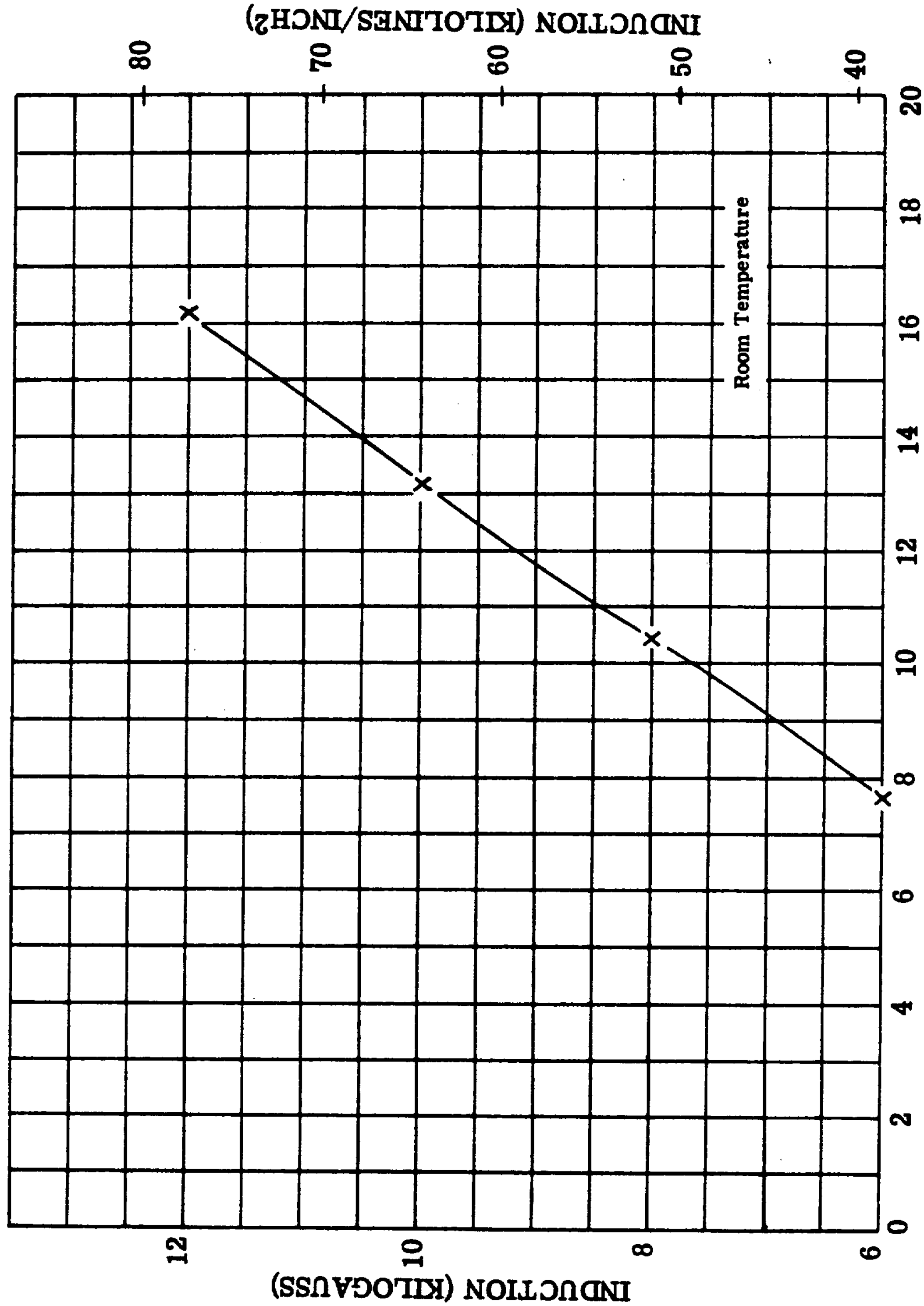


FIGURE IV.B.II-31. Exciting Volt-Amperes per Pound, 800 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-31. Exciting VA, 800 CPS. Supermendur

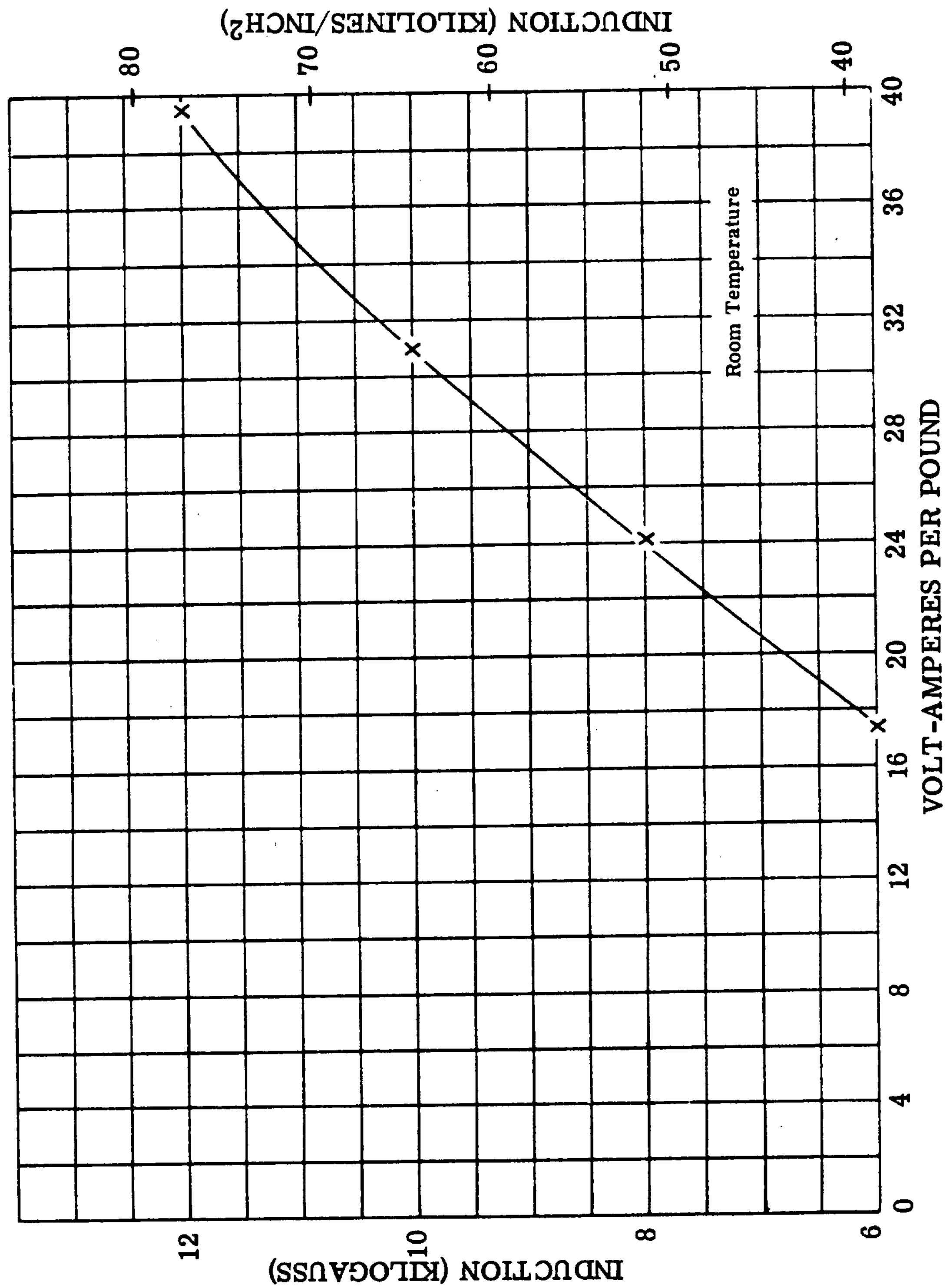


FIGURE IV. B. II-32. Exciting Volt-Amperes per Pound, 1600 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-32. Exciting VA, 1600 CPS. Supermendur

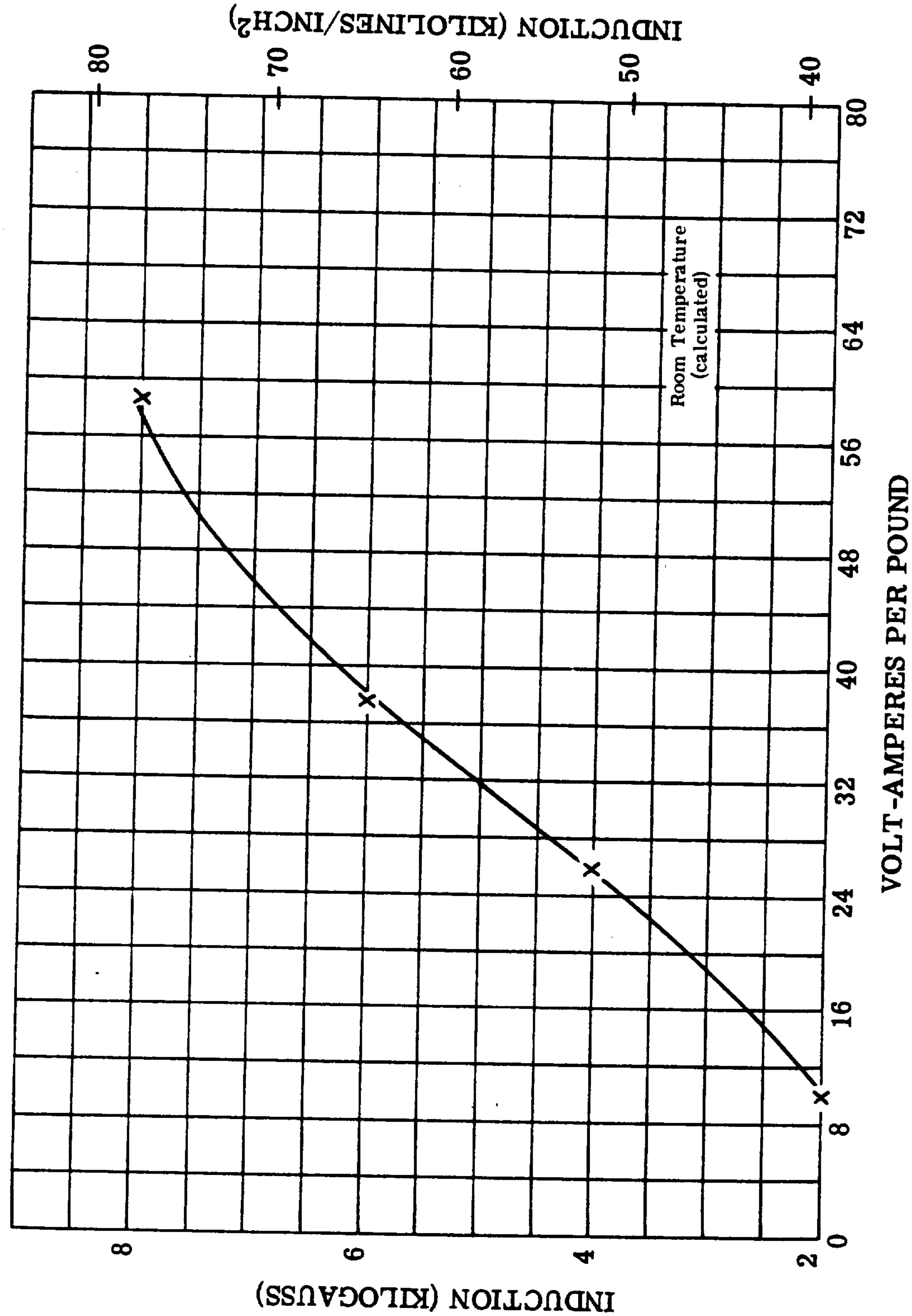


FIGURE IV.B.II-33. Exciting Volt-Amperes per Pound, 3200 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV. B. II-33. Exciting VA, 3200 CPS. Supermendur

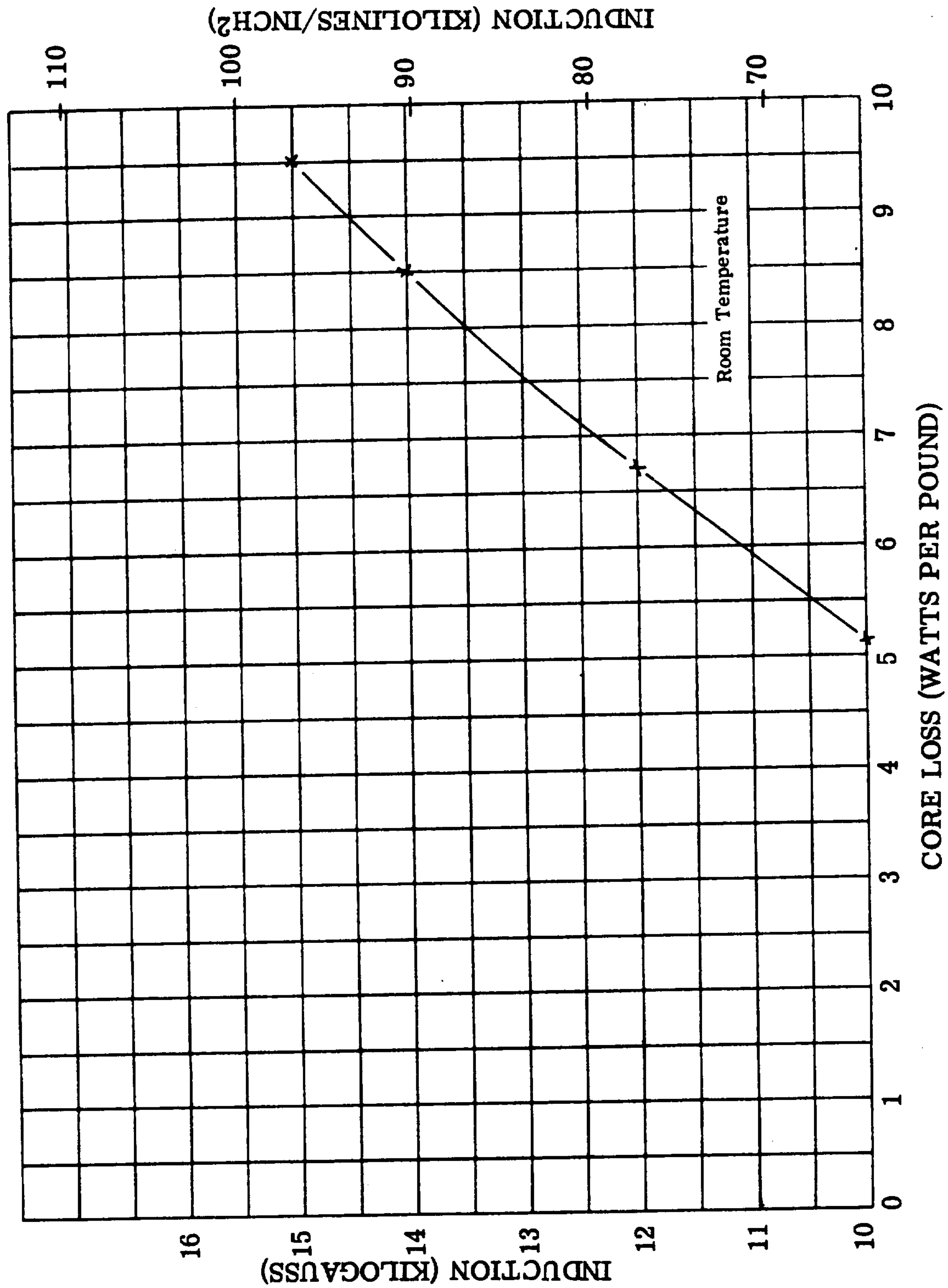


FIGURE IV.B.II-34. Core Loss, 400 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-34. Core Loss, 400 CPS. Supermendur

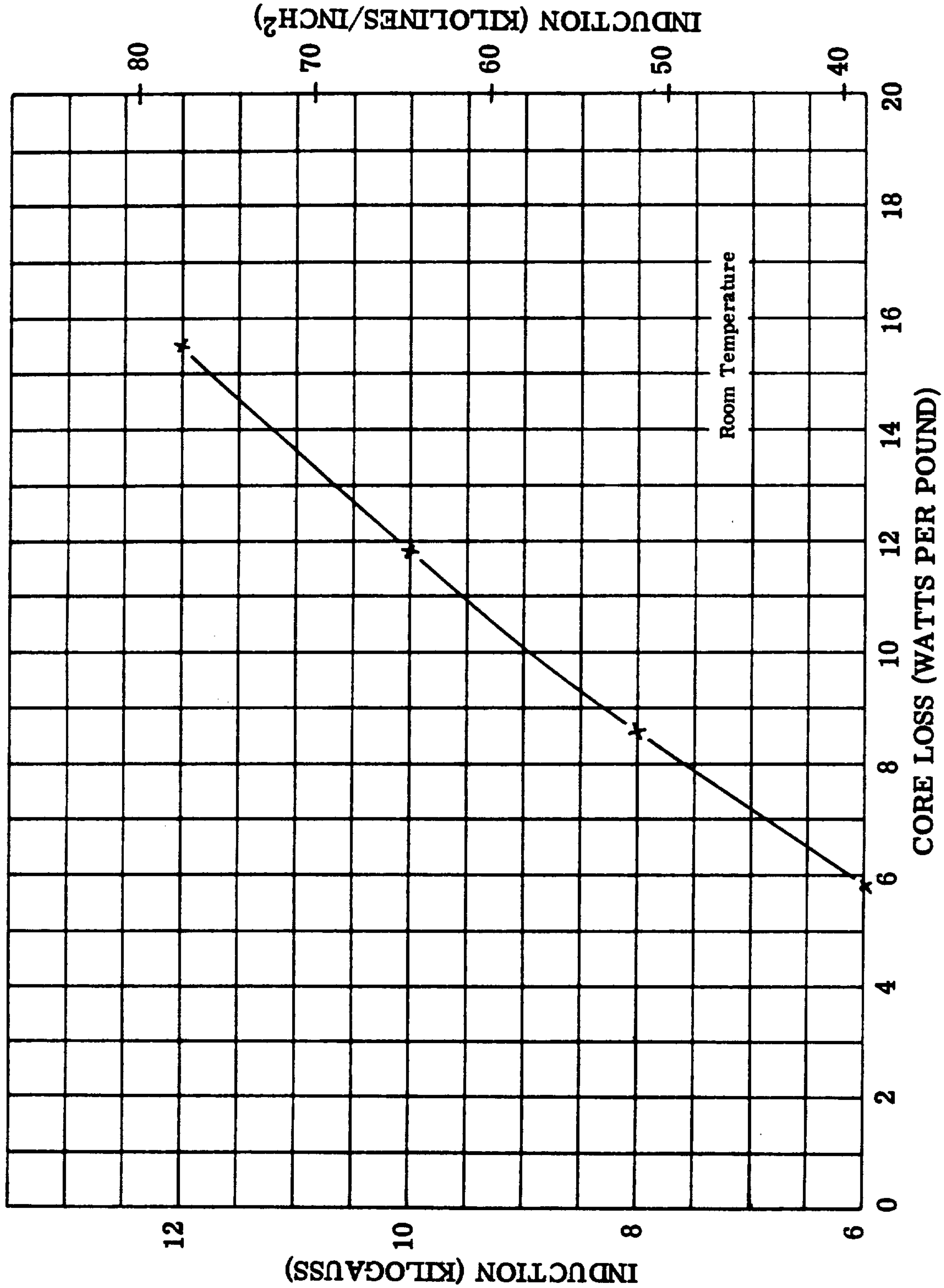


FIGURE IV.B.II-35. Core Loss, 800 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-35. Core Loss, 800 CPS. Supermendur

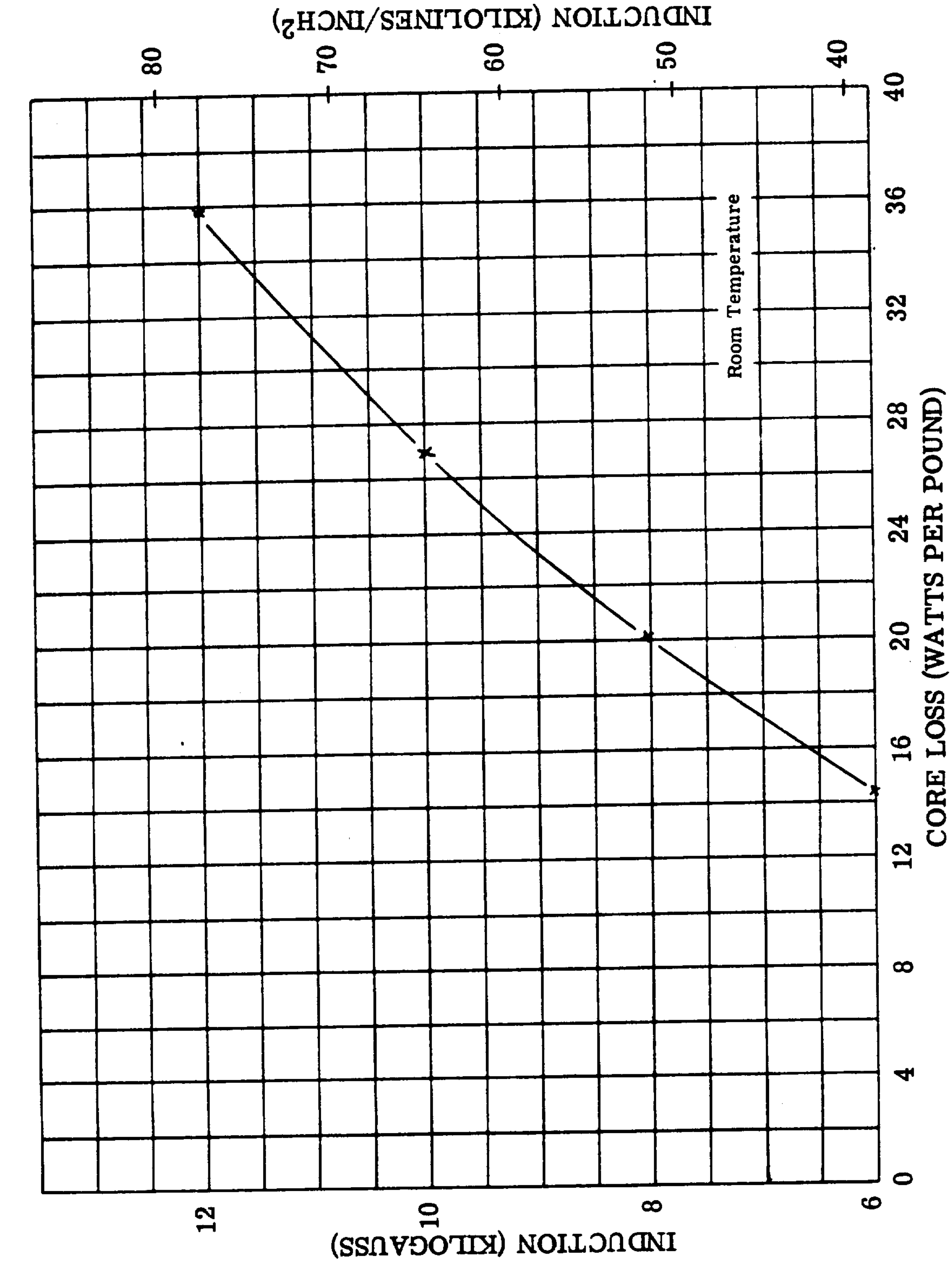


FIGURE IV.B.II-36. Core Loss, 1600 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS 3-4162)

Figure IV.B.II-36. Core Loss, 1600 CPS. Supermendur

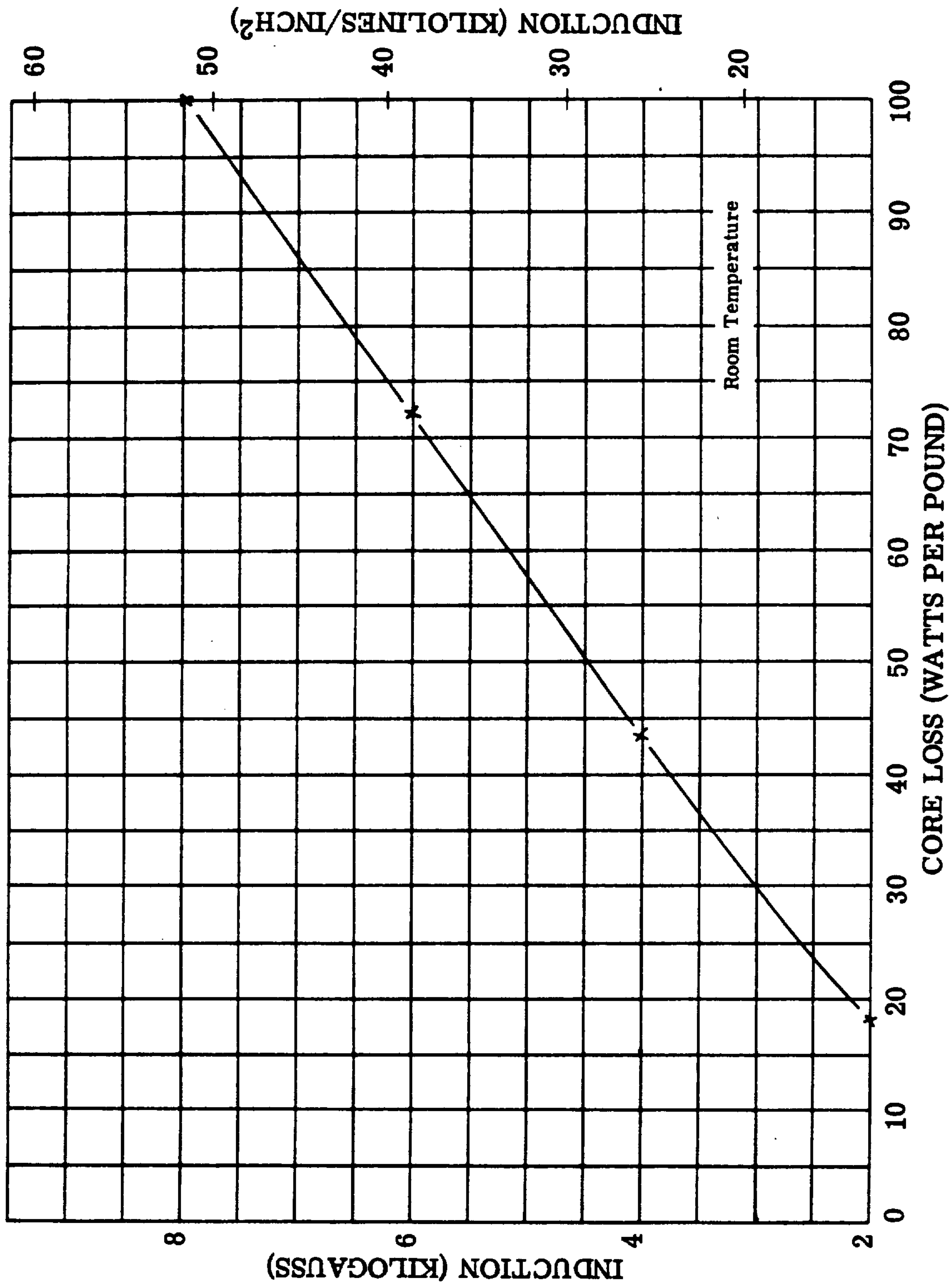


FIGURE IV.B.II-37. Core Loss, 3200 CPS. Supermendur 0.002 Inch Tape Toroid 1-1/4 x 1 x 1/4 Inch. Test Atmosphere: Air. Interlaminar Insulation: Magnesium Oxide. (Reference: NAS3-4162)

Figure IV.B.II-37. Core Loss, 3200 CPS. Supermendur

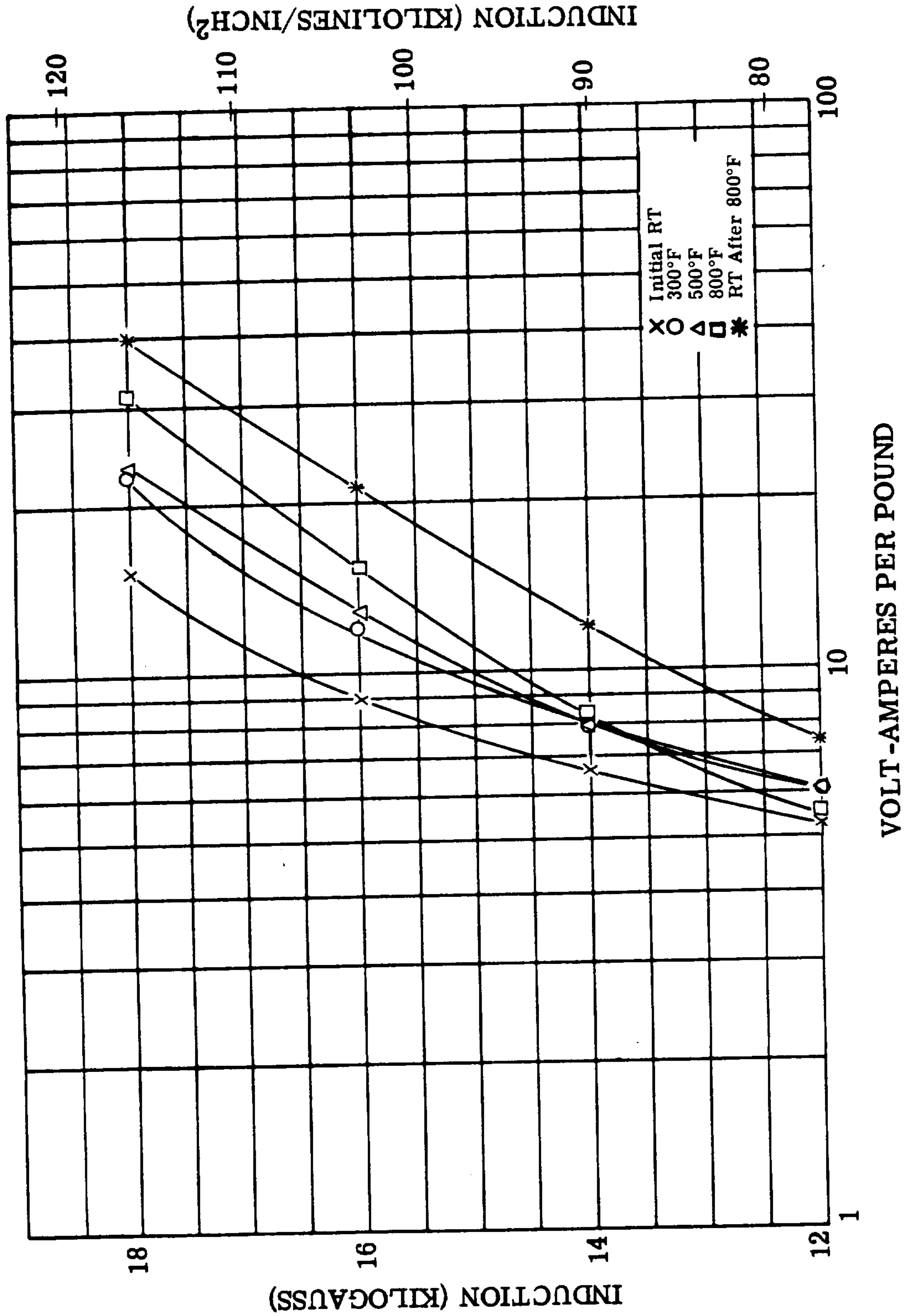


FIGURE IV.B.II-38. Exciting Volt-Amperes per Pound, 400 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-38. Exciting VA, 400 CPS. Supermendur

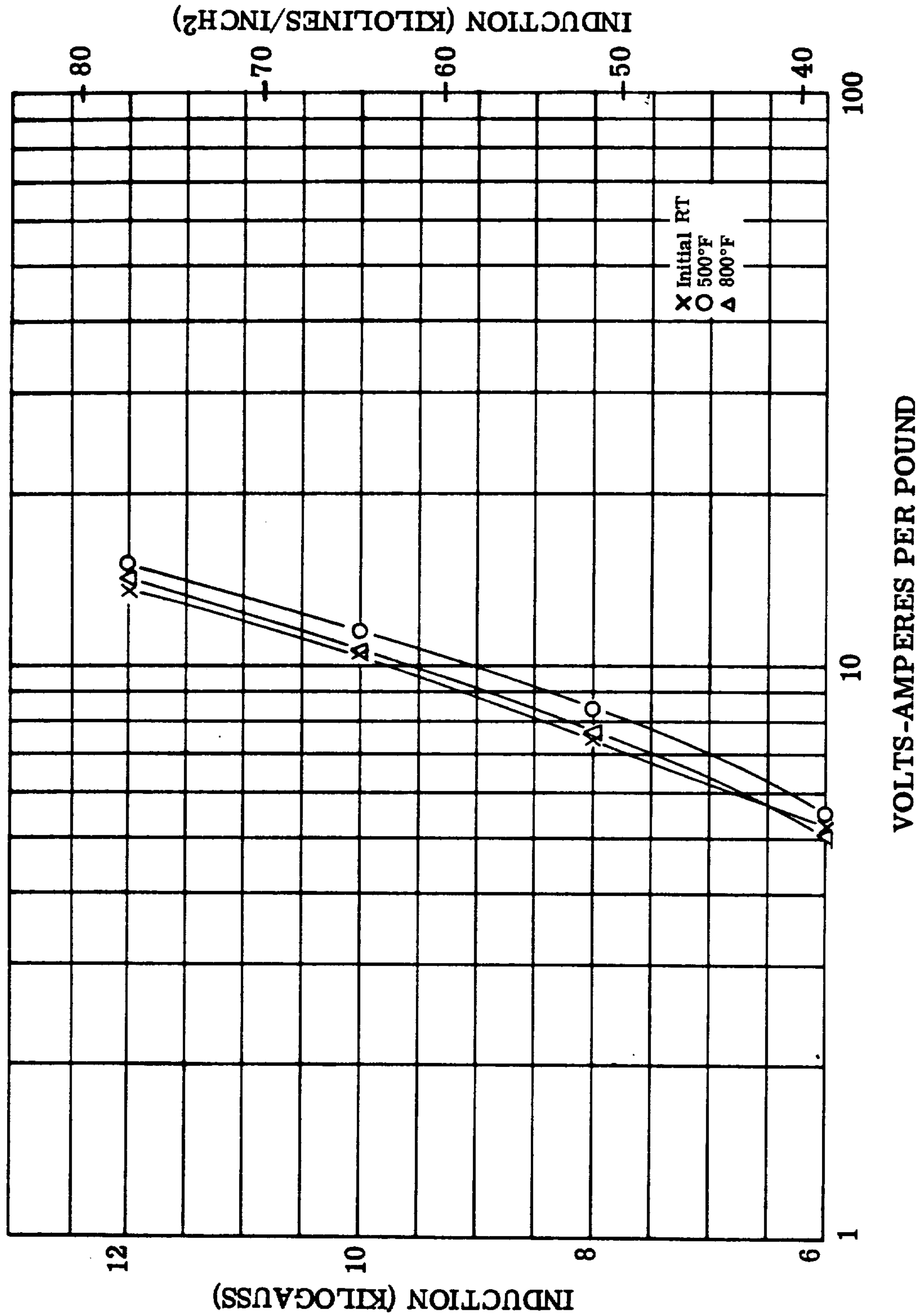


FIGURE IV. B. II-39. Exciting Volt-Amperes per Pound, 800 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV. B. II-39. Exciting VA, 800 CPS. Supermendur

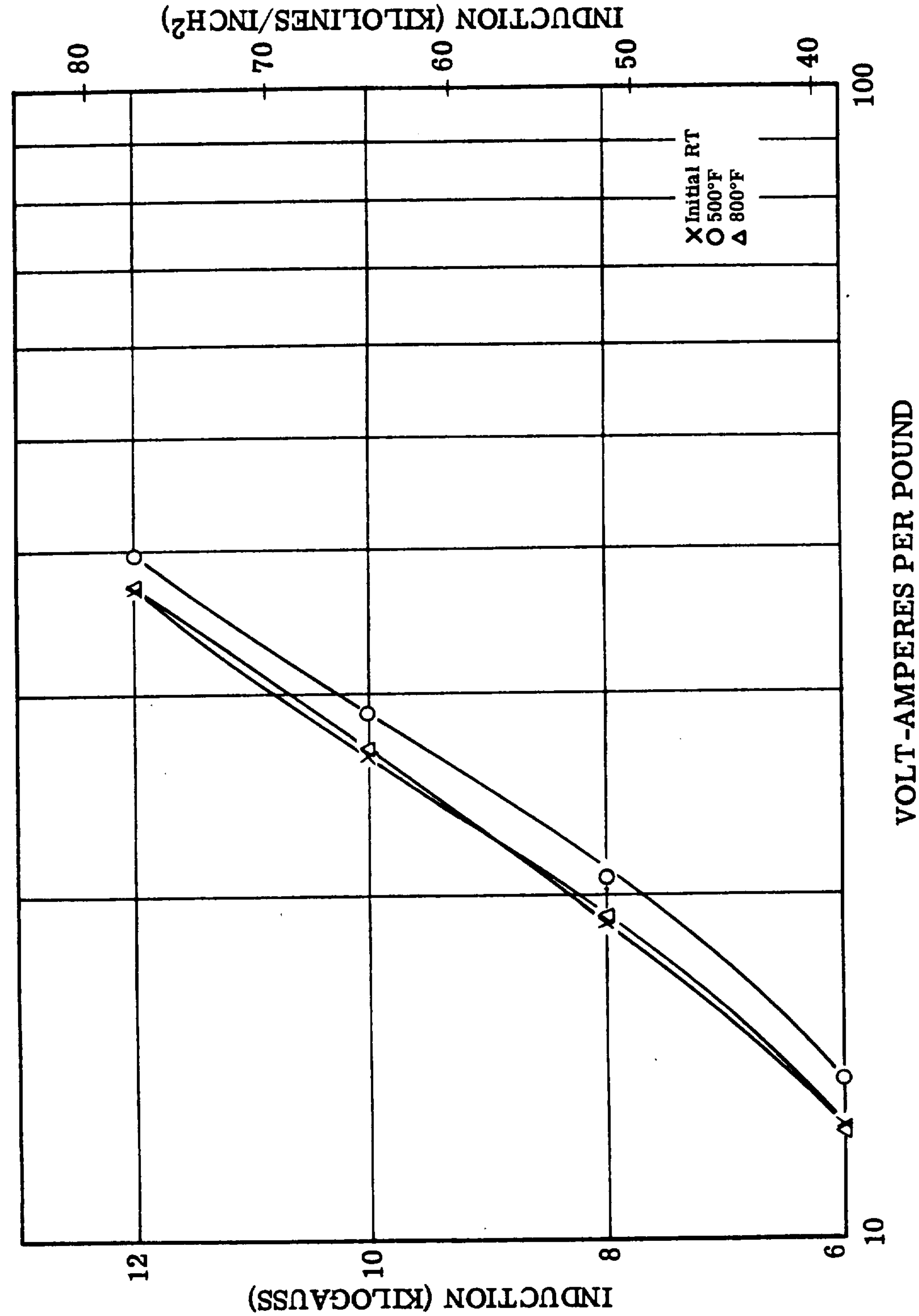


FIGURE IV.B.II-40. Exciting Volt-Amperes per Pound, 1600 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-40. Exciting VA, 1600 CPS. Supermendur

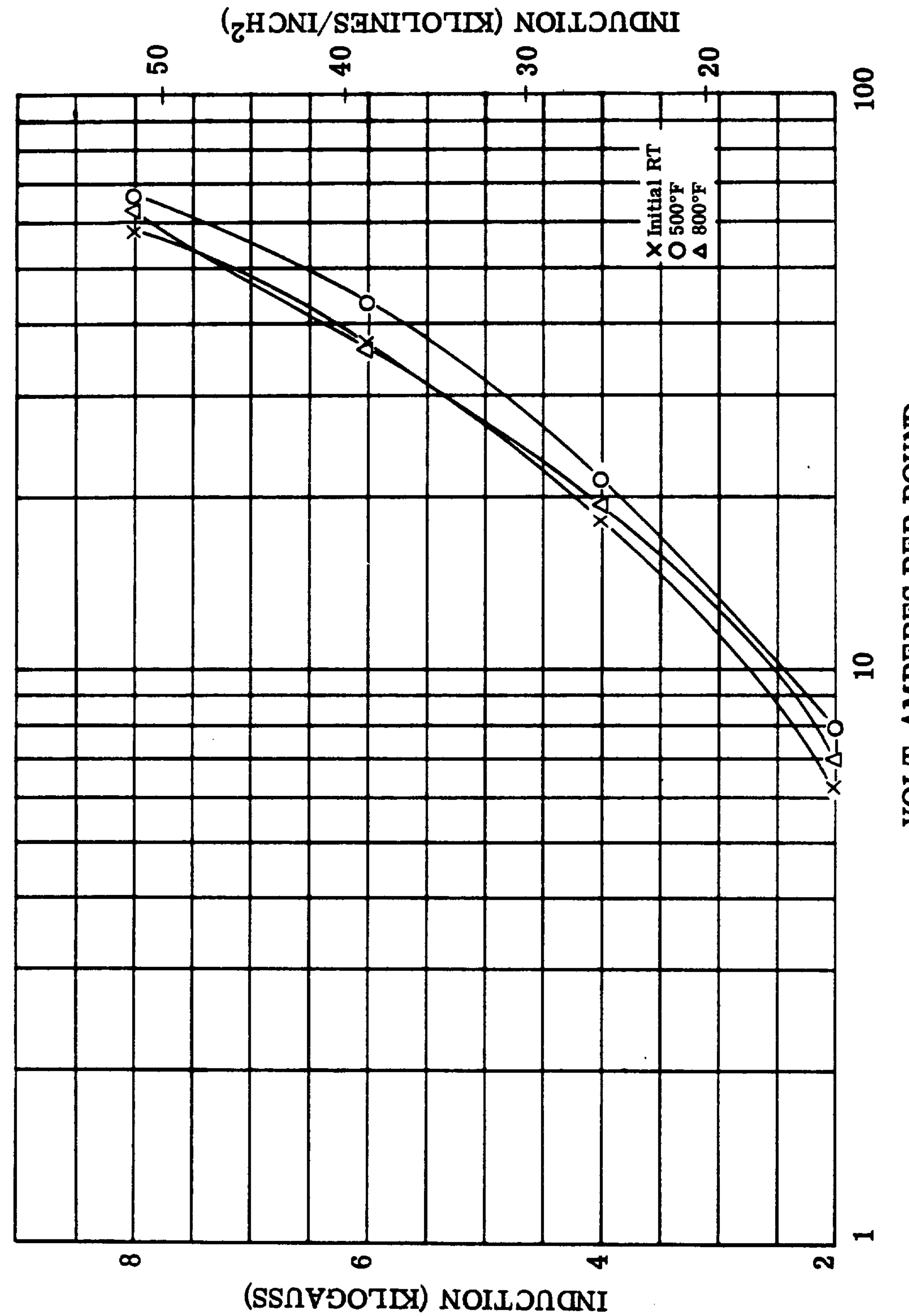


FIGURE IV.B.II-41. Exciting Volt-Amperes per Pound, 3200 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-41. Exciting VA, 3200 CPS. Supermendur

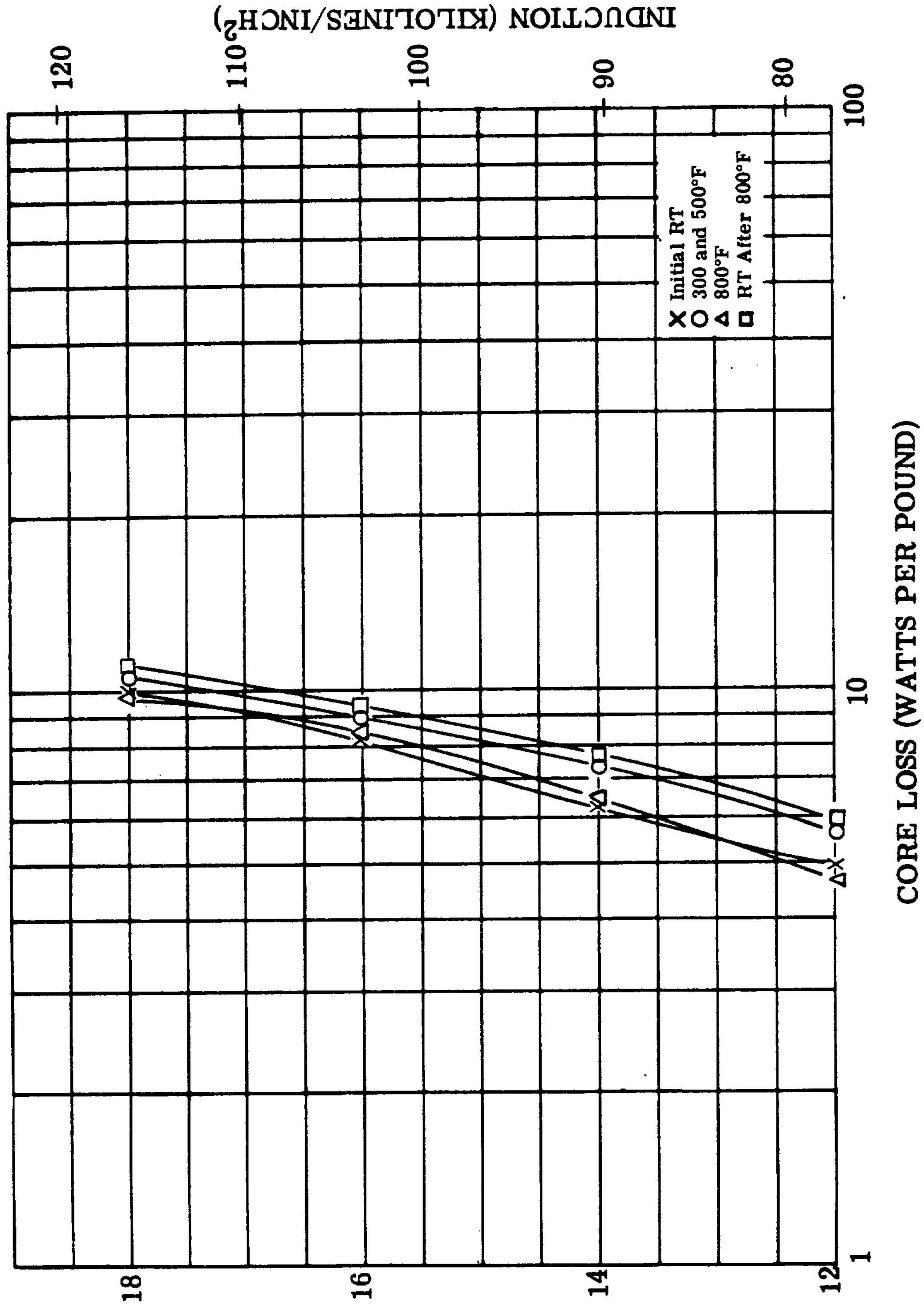


FIGURE IV.B.II-42. Core Loss, 400 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-42. Core Loss, 400 CPS. Supermendur

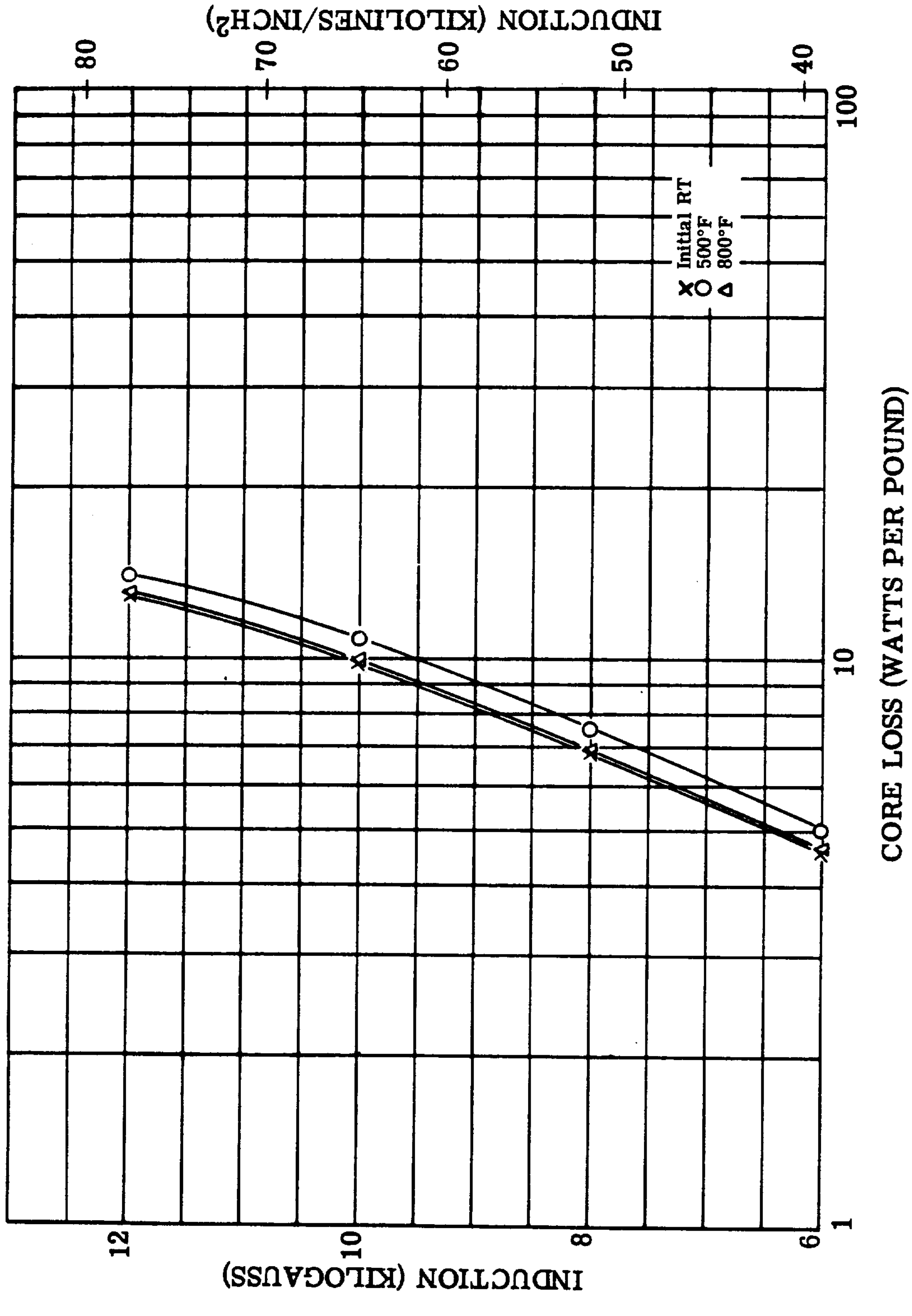


FIGURE IV.B.II-43. Core Loss, 800 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-43. Core Loss, 800 CPS. Supermendur

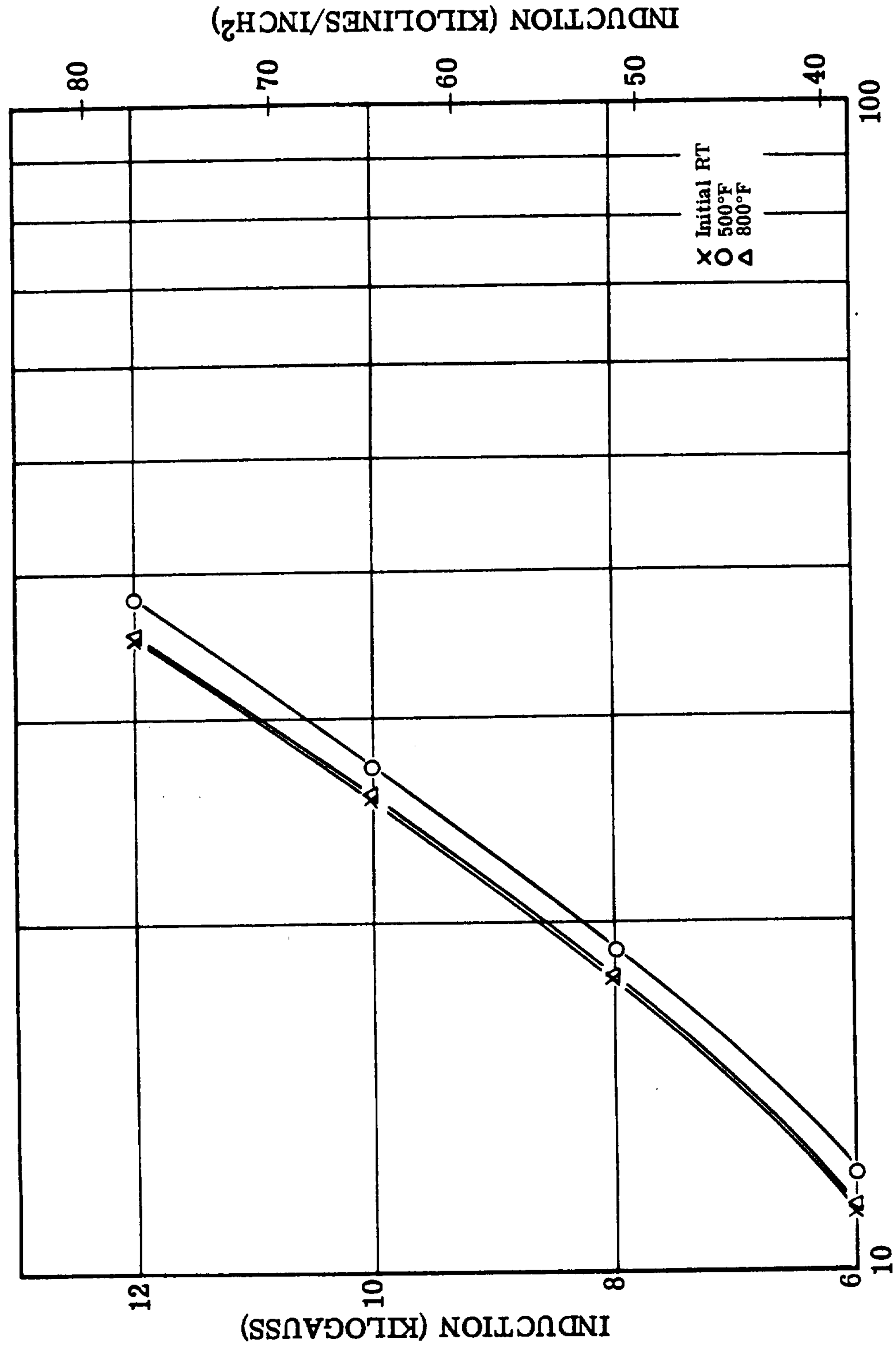


FIGURE IV.B.II-44. Core Loss, 1600 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-44. Core Loss, 1600 CPS. Supermendur

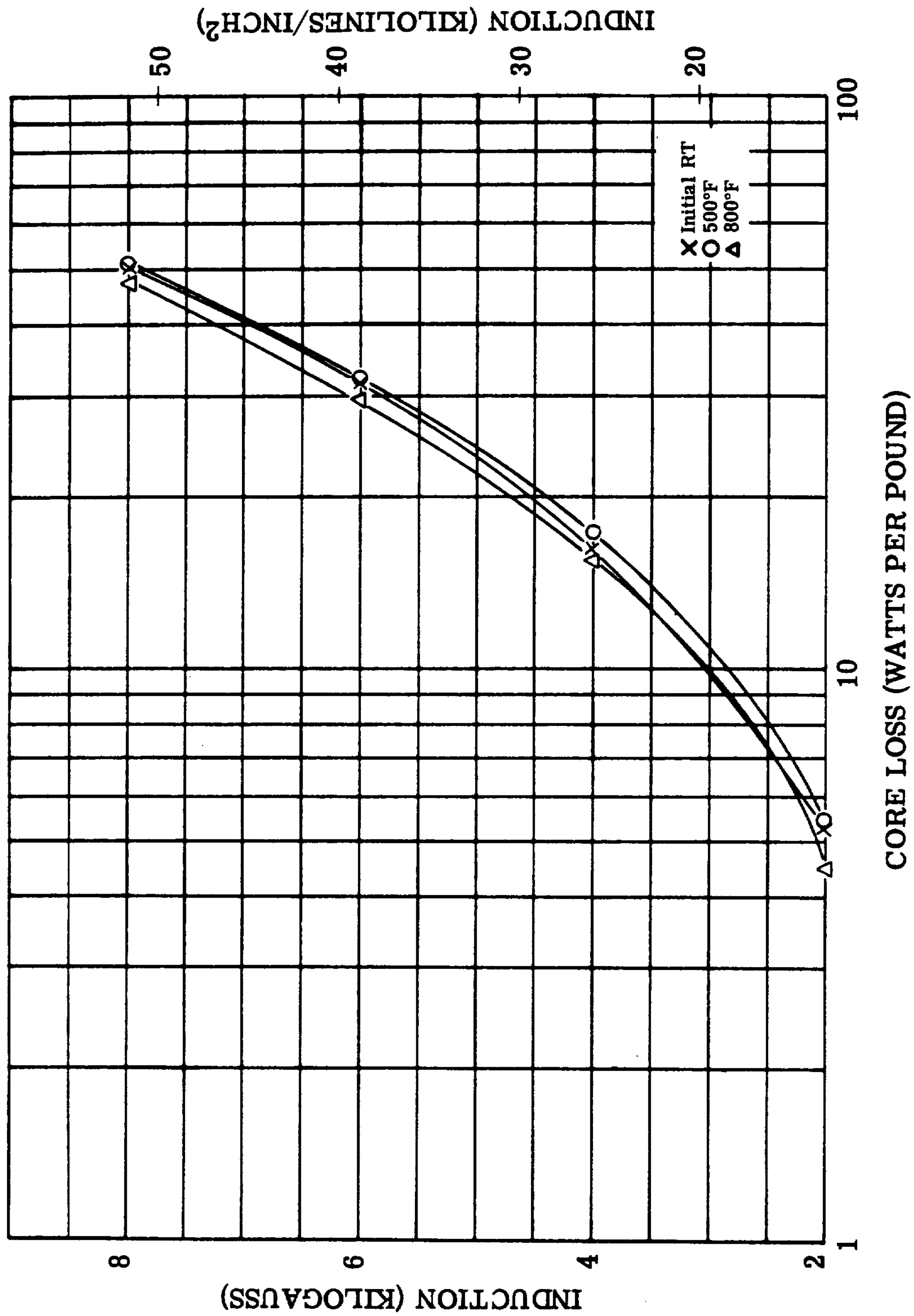


FIGURE IV.B.II-45. Core Loss, 3200 CPS. Supermendur 0.006 Inch Laminations. Test Atmosphere: Argon. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.B.II-45. Core Loss, 3200 CPS. Supermendur

TABLE IV.B.III-1. Tensile Properties of Annealed Hiperco 50 Alloy Sheet 0.008 Inch Thick Tested in Air

See Figures IV.B.III-1 to IV.B.III-4

TEST: ASTM E21

Mark	Test Temp. (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (percent)	Modulus of Elasticity (Psi)
L-1	72	41,100	41,650	41,650	0.5 Q	28.9×10^6
T-1	72	36,800	*	37,700	- Q	38.0×10^6
L-2	500	36,350	37,950	71,250	5.5 U	27.1×10^6
T-2	500	35,700	38,950	55,250	1.5 Q	33.2×10^6
L	800	30,250	36,750	67,900	7.0	27.0×10^6
T-5	800	30,600	38,050	60,150	4.9	29.7×10^6
L-4	1100	28,300	33,750	62,600	6.0 Q	20.1×10^6
T-4	1100	30,600	34,700	55,250	12.0	28.9×10^6
L-5	1400	5,450	6,400	8,400	27.0	
T-5	1400	9,750	-	10,850	9.0 Q	

Samples annealed at 875°C in dry hydrogen.
Q - Quarterbreak
U - Broke inside of end pads
* - Broke before 0.2 percent offset was reached

L - Longitudinal
T - Transverse

(Reference: NAS 3-4162)

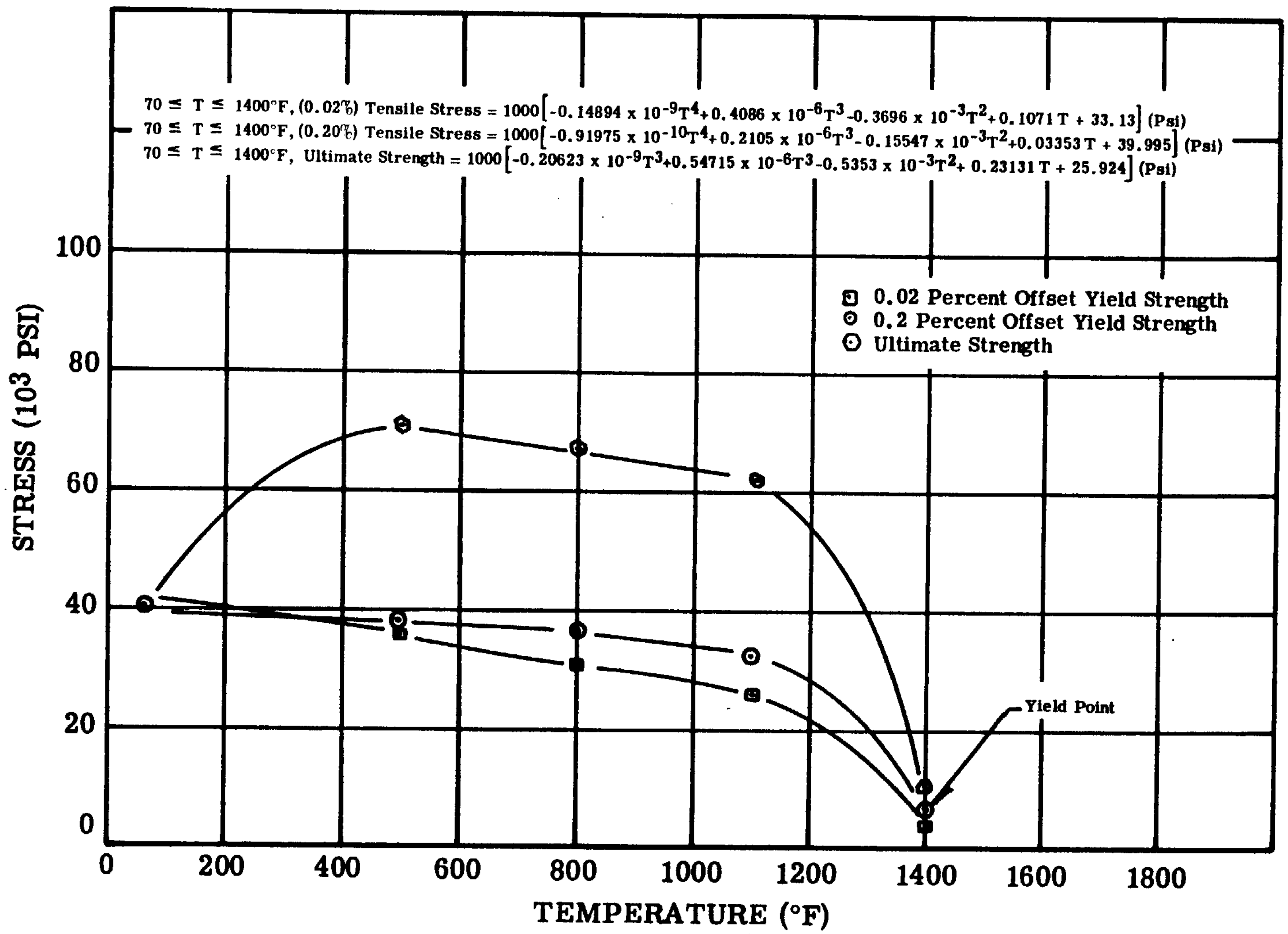


FIGURE IV.B.III-1. Longitudinal Tensile Properties of Annealed 0.008 Inch Thick Hiperco 50 Alloy Sheet Tested in Air. See Data Table IV.B.III-1. (Reference: NAS 3-4162)

Figure IV.B.III-1. Tensile Properties - Hiperco 50

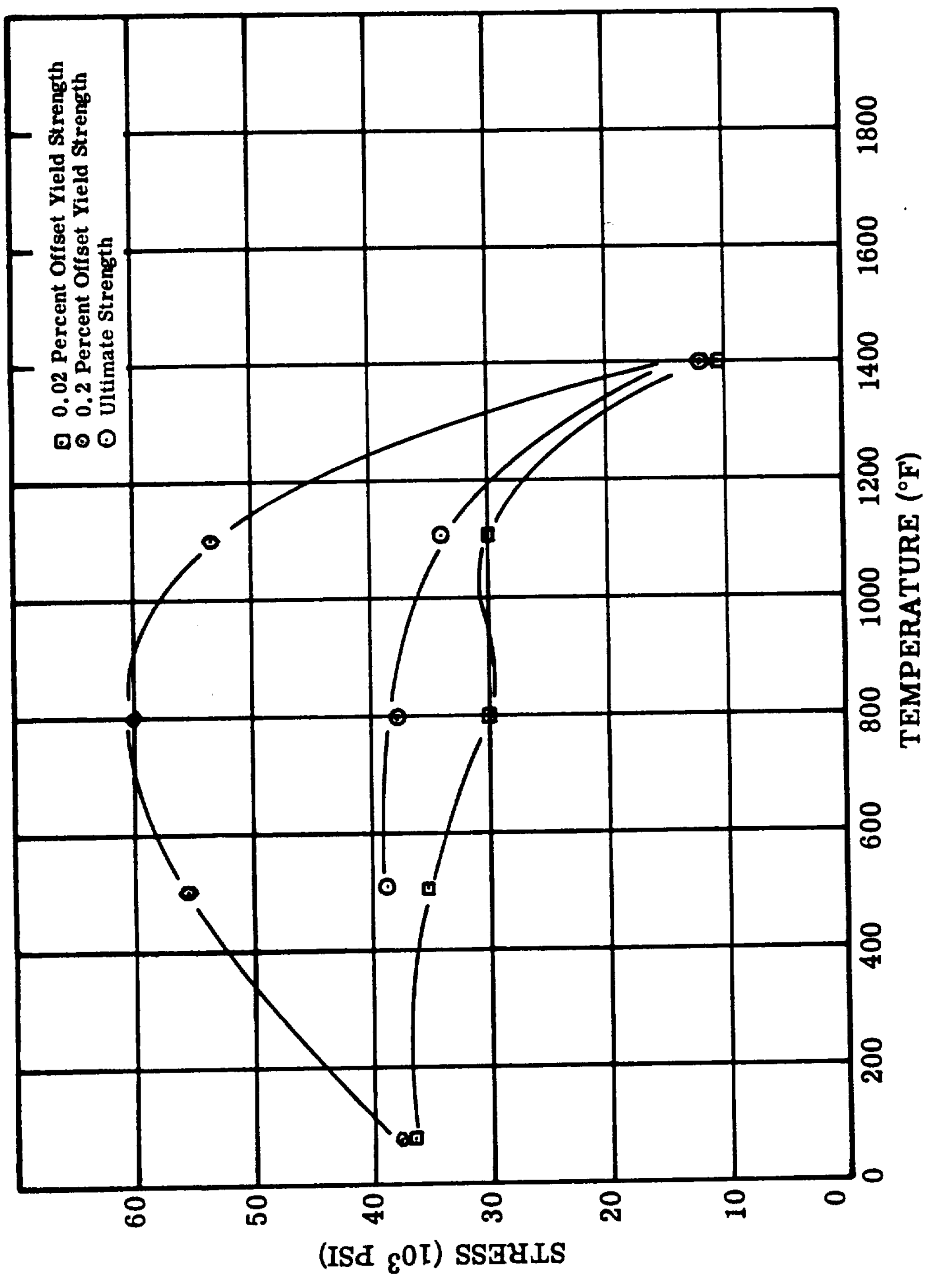


FIGURE IV.B.III-2. Transverse Tensile Strengths of 0.008 Inch Thick Annealed Hiperco 50 Alloy Sheet Tested In Air. See Data Table IV.B.III-1. (Reference NAS 3-4162)

Figure IV.B.III-2. Tensile Properties - Hiperco 50

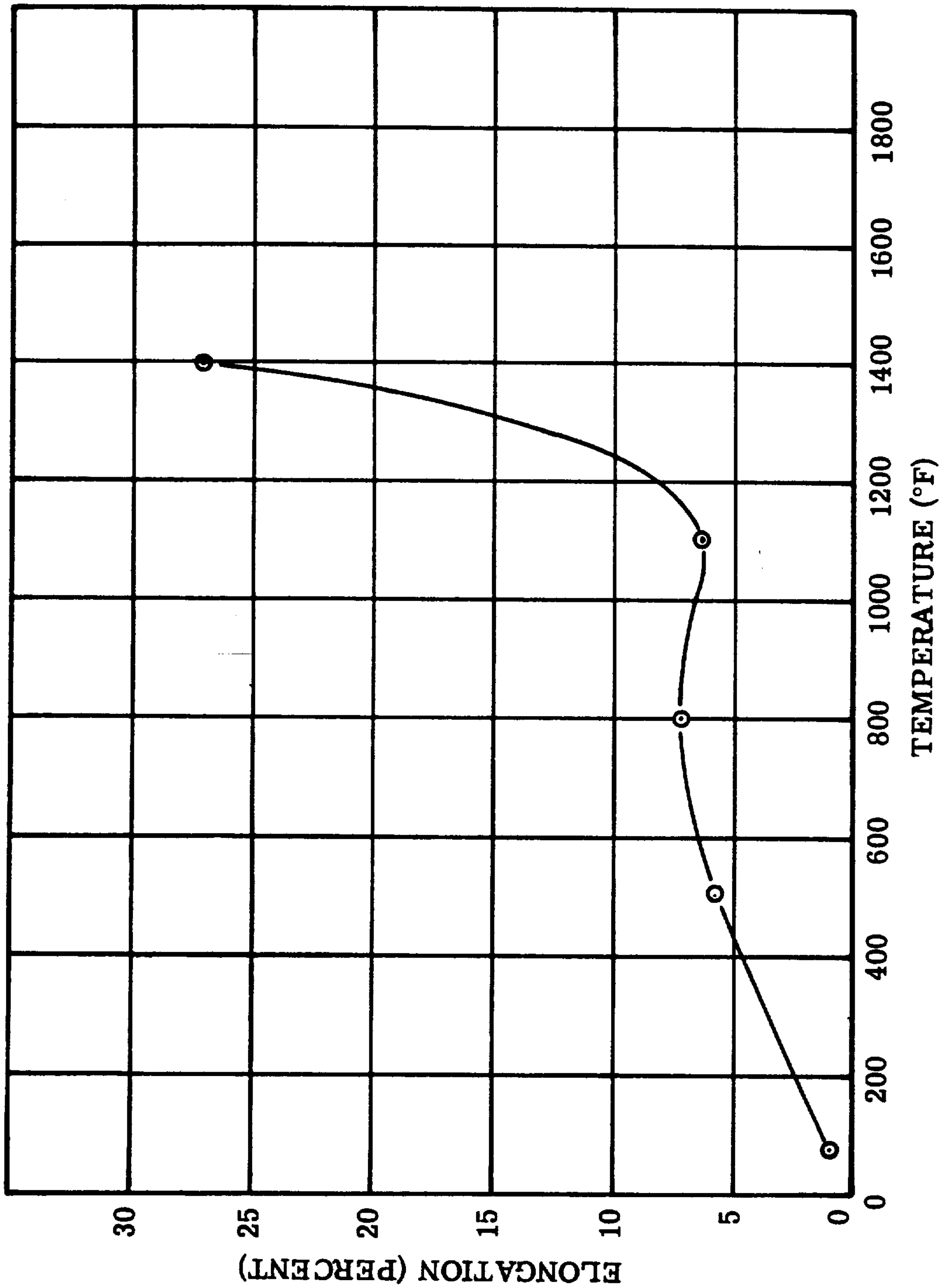


FIGURE IV. B. III-3. Longitudinal Tensile Elongation of 0.008 Inch Thick Annealed Hiperco 50 Alloy Sheet Tested in Air. See Data Table IV. B. III-1. (Reference: NAS 3-4162)

Figure IV. B. III-3. Tensile Ductility - Hiperco 50

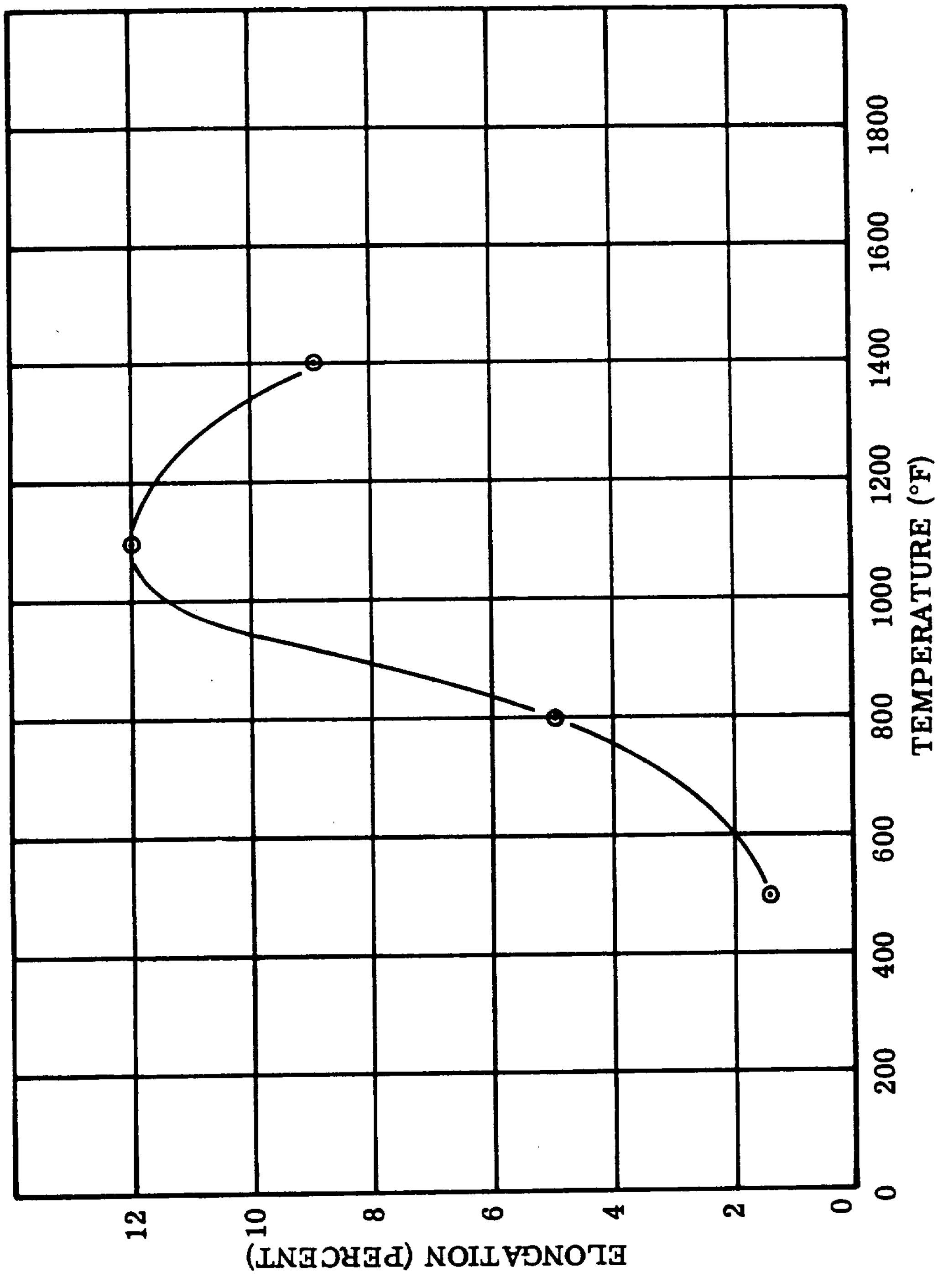


FIGURE IV. B. III-4. Transverse Tensile Elongation of 0.008 Inch Thick Hiperco 50 Alloy Sheet Tested in Air. See Data Table IV. B. III-1. (Reference: NAS3-4162)

Figure IV. B. III-4. Tensile Ductility - Hiperco 50

TABLE IV.B.III-2. Tensile Test Data for 0.006 Inch Thick Supermendur Sheet

See Figures IV.B.III-5 and IV.B.III-6

TEST: ASTM E21

Specimen No.	Test Temp. (°F)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Yield Point (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (percent)	Modulus of Elasticity (Psi)
1	72	33,800	X		35,500	0.4	34.7×10^6
2	72	37,350		38,500	51,150	3.3	
3	500	28,850	32,800		102,800	10.9*	32.8×10^6
4	500	30,000	32,700		96,150	8.7	
5	800	32,100	32,750		102,800	12.7	29.8×10^6
6	800	32,300	33,950		89,750	9.2**	
7	1100	27,600	31,150		54,100	11.5	28.5×10^6
8	1100	29,550	31,150		56,150	11.5	

Samples annealed 900°C in dry hydrogen
All tests made in air
*Broke in fillet
**Broke outside of punch marks
X Broke before 0.2 percent offset was reached (Reference: NAS 3-4162)

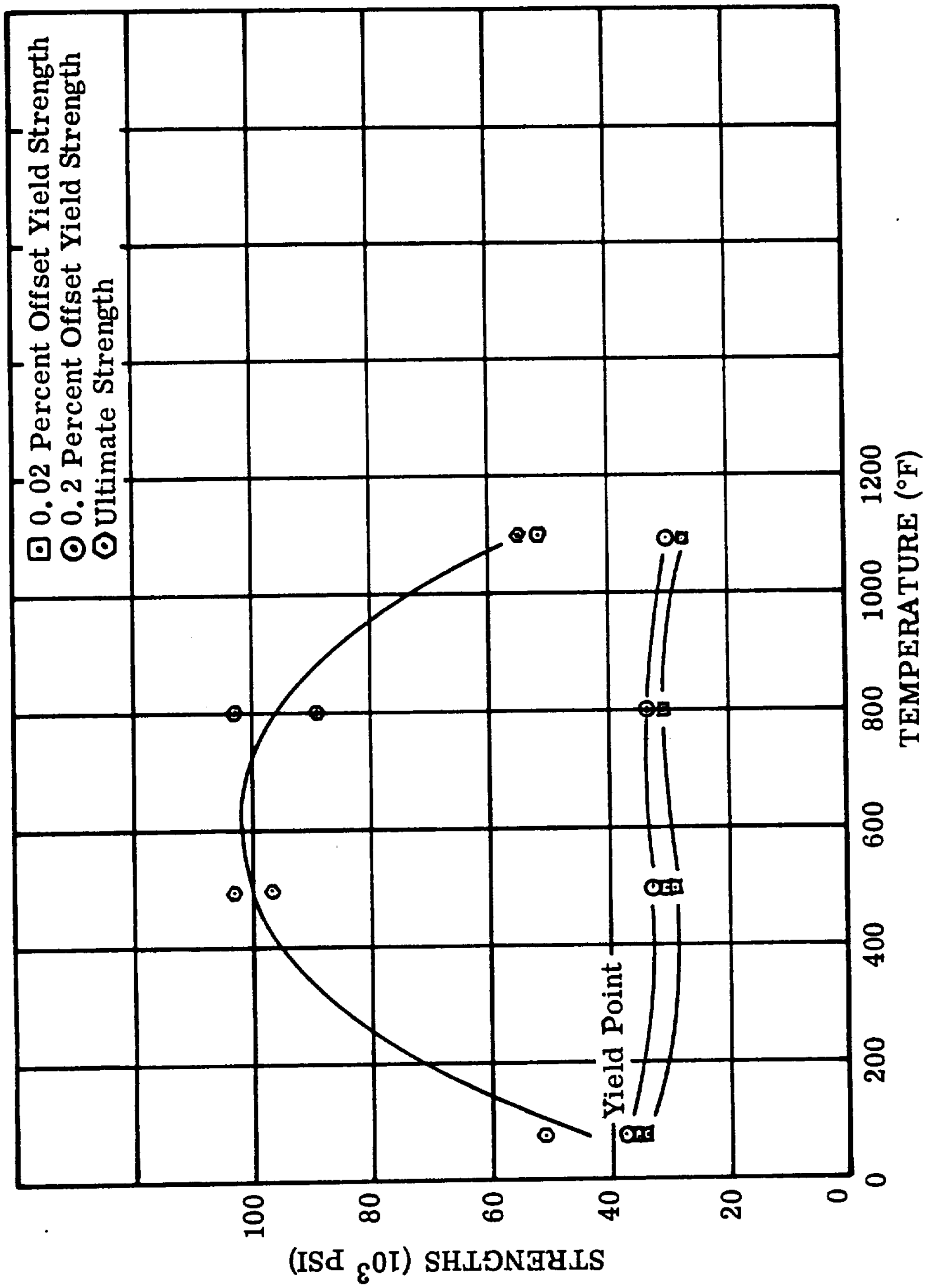


FIGURE IV.B.III-5. Tensile Properties of 0.006 Inch Thick Supermendur Sheet Tested in Air. Samples Cut Longitudinal to Rolling Direction. See Data Table IV.B.III-2. (Reference: NAS 3-4162)

Figure IV.B.III-5. Tensile Properties - Supermendur

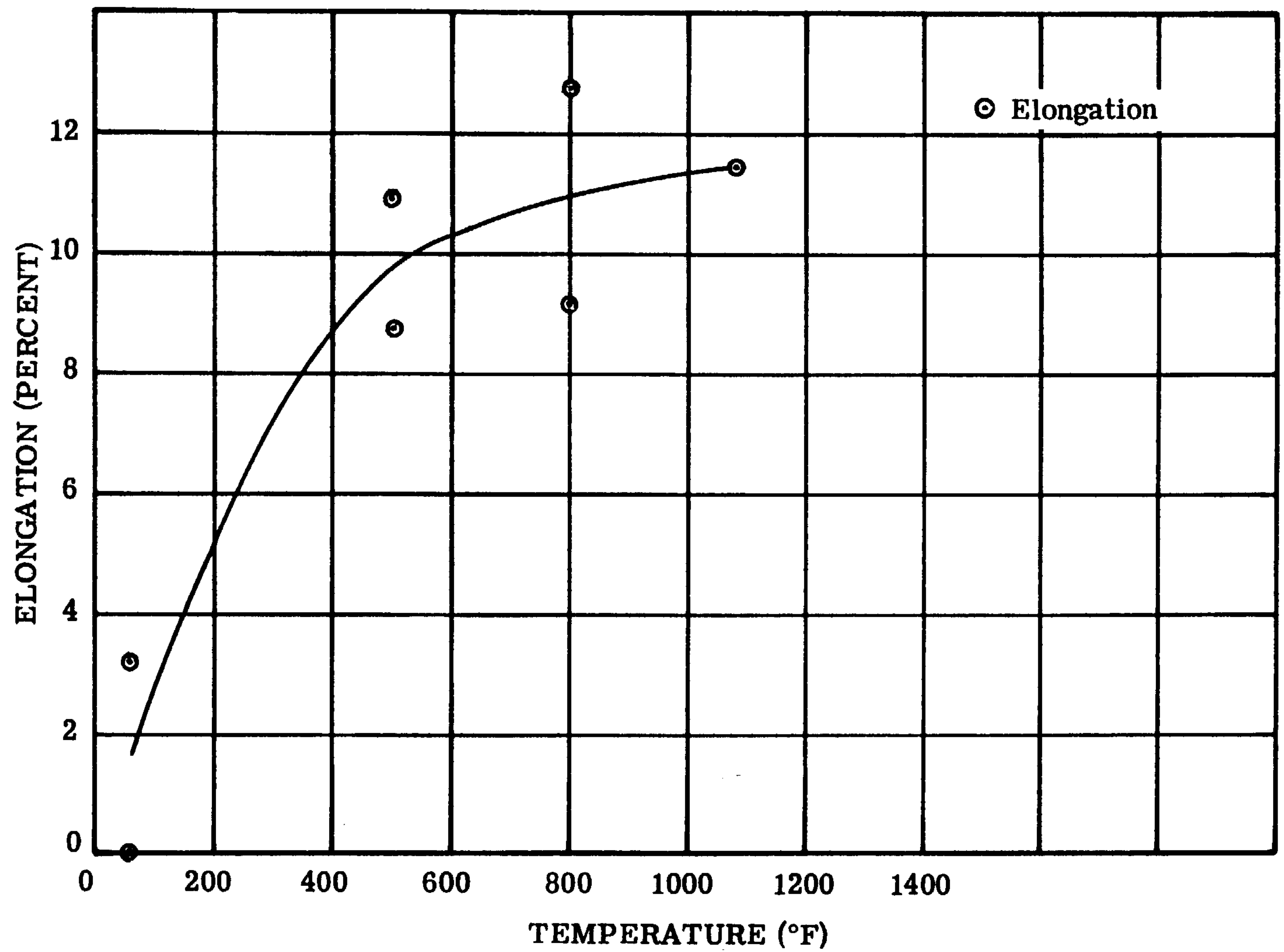


FIGURE IV. B. III-6. Tensile Elongation of 0.006 Inch Thick Supermendur Sheet Tested in Air. Samples Cut Longitudinal to Rolling Direction. See Data Table IV. B. III-2. (Reference: NAS 3-4162)

Figure IV. B. III-6. Tensile Ductility - Supermendur

C. HIPERCO 27 ALLOY
(Sheet, Bar, Forgings, and Castings)

A high permeability soft magnetic alloy manufactured only by the Westinghouse Electric Corporation, Blairsville, Pennsylvania.

Availability: Commercial, Single Source

Nominal Composition: 27 percent Cobalt-Iron

Tested Composition:

	Ni	S	Mn	C	Co	P	Cr	Fe
Bar	0.15	0.011	0.28	0.009	27.6	0.006	0.41	Bal
Sheet	0.14	0.016	0.39	0.02	26.8	0.009	0.69	Bal

I. Thermophysical Properties

A. Density — 0.285 lb/in^3 7.95 grams/cc

B. Solidus Temperature — 2732°F

C. Curie Temperature — 1697°F

D. Thermal Conductivity

1. At 72°F — 31.7 Btu-ft/ft^2-hr-°F*
2. At 1100°F — 25.2 Btu-ft/ft^2-hr-°F*

E. Coefficient of Thermal Expansion 72° - 1100°F

1. 72°-800°F — 5.96x10^{-6} in/in-°F*
2. 72°-1100°F — 6.14x10^{-6}in/in-°F*

F. Specific Heat

	Vacuum Melted Forging	Investment Casting
1. At 72°F	0.067 Btu/lb-°F	0.102 Btu/lb-°F
2. At 700°F	0.105 Btu/lb-°F	0.103 Btu/lb-°F
3. At 900°F	0.112 Btu-lb-°F	0.130 Btu/lb-°F
4. At 1100°F	0.119 Btu/lb-°F	--

*Westinghouse Electric Corp. Materials Manufacturing Dept. Product Literature Hiperco 27

G. Electrical Resistivity

	Vacuum Melted Forging
1. At 72°F	17.50×10^{-6} ohm-cm
2. At 900°F	39.56×10^{-6} ohm-cm
3. At 1100°F	50.33×10^{-6} ohm-cm

II. Magnetic Properties (All magnetic materials are stress relief annealed (SRA) unless otherwise specified)

A. D-C Properties

1. Solid Ring

a. Vacuum Melted, Forged, Annealed

1. Induction, (B_{tip}) for H = 250 oersteds at 72°F 24.9 kilo-gauss
2. Induction, (B_{tip}) for H = 250 oersteds at 500°F 24.6 kilo-gauss
3. Induction, (B_{tip}) for H = 250 oersteds at 800°F 24.0 kilo-gauss
4. Induction, (B_{tip}) for H = 200 oersteds at 1100°F 22.2 kilo-gauss
5. Induction, (B_{tip}) for H = 200 oersteds at 1400°F 19.0 kilo-gauss

b. Investment Cast, Annealed

1. Induction, (B_{tip}) for H = 250 oersteds at 72°F 23.4 kilo-gauss
2. Induction, (B_{tip}) for H = 250 oersteds at 500°F 23.2 kilo-gauss
3. Induction, (B_{tip}) for H = 200 oersteds at 800°F 22.0 kilo-gauss
4. Induction, (B_{tip}) for H = 200 oersteds at 1100°F 20.5 kilo-gauss
5. Induction, (B_{tip}) for H = 200 oersteds at 1400°F 18.2 kilo-gauss

2. Laminations

a. 0.004 Inch Thick Laminations, Annealed

1. Induction, (B_{tip}) for H = 300 oersteds at 72°F 24.2 kilo-gauss

2. Induction, (B_{tip}) for H = 300 oersteds at 500°F 23.4 kilogauss
3. Induction, (B_{tip}) for H = 300 oersteds at 800°F 22.3 kilogauss
4. Induction, (B_{tip}) for H = 300 oersteds at 1100°F 20.6 kilogauss
5. Induction, (B_{tip}) for H = 250 oersteds at 1400°F 17.6 kilogauss

b. 0.008 Inch Thick Laminations, Annealed

1. Induction, (B_{tip}) for H = 250 oersteds at 72°F 23.1 kilogauss
2. Induction, (B_{tip}) for H = 250 oersteds at 500°F 23.0 kilogauss
3. Induction, (B_{tip}) for H = 250 oersteds at 800°F 22.3 kilogauss
4. Induction, (B_{tip}) for H = 250 oersteds at 1100°F 20.8 kilogauss
5. Induction, (B_{tip}) for H = 250 oersteds at 1400°F 18.3 kilogauss

B. A-C Properties, 400 Cycle

1. 0.004 Inch Thick Laminations, Annealed

a. Exciting volt-amperes, B = 18 kilogauss at 72°F 270 volt-amperes/pound
b. Exciting volt-amperes, B = 18 kilogauss at 500°F 290 volt-amperes/pound
c. Exciting volt-amperes, B = 18 kilogauss at 800°F 325 volt-amperes/pound
d. Exciting volt-amperes, B = 18 kilogauss at 1100°F 351 volt-amperes/pound
e. Exciting volt-amperes, B = 18 kilogauss at 1400°F 315 volt-amperes/pound
f. Core loss, B = 18 kilogauss at 72°F 27.6 watts/pound
g. Core loss, B = 18 kilogauss at 700°F 23.1 watts/pound

h. Core loss, B = 18 kilogauss at 900°F 18.2 watts/pound
i. Core loss, B = 18 kilogauss at 1100°F 13.9 watts/pound

2. 0.008 Inch Thick Laminations, Annealed

a. Exciting volt-amperes, B = 18 kilogauss at 72°F 275 volt-amperes/pound
b. Exciting volt-amperes, B = 18 kilogauss at 500°F 294 volt-amperes/pound
c. Exciting volt-amperes, B = 18 kilogauss at 800°F 308 volt-amperes/pound
d. Exciting volt-amperes, B = 18 kilogauss at 1100°F 321 volt-amperes/pound
e. Exciting volt-amperes, B = 18 kilogauss at 1400°F 524 volt-amperes/pound
f. Core loss, B = 18 kilogauss at 72°F 34.7 watts/pound
g. Core loss, B = 18 kilogauss at 700°F 27.8 watts/pound
h. Core loss, B = 18 kilogauss at 900°F 23.6 watts/pound
i. Core loss, B = 18 kilogauss at 1100°F 16.2 watts/pound
j. Core loss, B = 18 kilogauss at 1400°F 14.3 watts/pound

C. Constant Current Flux Reset Properties (CCFR): Not applicable to Hiperco 27 alloy. Only measured on materials used as magnetic amplifiers.

III. Mechanical Properties, Bar Stock and Castings

A. Poisson's Ratio at 72°F 0.328

B. Tensile Properties

1. Vacuum Melted Bar Stock - 72°F

a. 0.20 percent offset yield strength 82,450 psi
b. Tensile Strength 95,000 psi
c. Elongation in two inches 28.2 percent
d. Reduction in area 75.2 percent

e.	Modulus of Elasticity	33.9×10^6 psi
f.	Compressive Modulus of Elasticity	31.4×10^6 psi
g.	0.20 percent offset compressive yield strength	97,600 psi

2. Investment Cast Bars - 72°F

a.	0.20 percent offset yield strength	43,900 psi
b.	Tensile Strength	64,200 psi
c.	Elongation in one inch	2.0 percent
d.	Reduction of area	0.80 percent

3. Vacuum Melted Bar Stock - 700°F

a.	0.20 percent offset yield strength	53,500 psi
b.	Tensile Strength	86,400 psi
c.	Elongation in two inches	25.2 percent
d.	Reduction of area	75.5 percent
e.	Modulus of elasticity	26.8×10^6 psi
f.	Compressive Modulus of Elasticity at 800°F*	27.3×10^6 psi
g.	0.20 percent offset compressive yield strength at 800°F*	80,950 psi

4. Investment Cast Bars - 700°F

a.	0.20 percent offset yield strength	37,000 psi
b.	Tensile Strength	69,800 psi
c.	Elongation in one inch	18 percent
d.	Reduction of area	33.8 percent

5. Vacuum Melted Bar Stock - 1000°F

a.	0.20 percent offset yield strength	50,050 psi
b.	Tensile Strength	64,600 psi
c.	Elongation in two inches	12.4 percent
d.	Reduction of area	41.2 percent
e.	Modulus of elasticity	23.6×10^6 psi
f.	0.20 percent offset compressive yield strength at 1100°F*	62,200 psi
g.	Compressive Modulus of elasticity at 1100°F*	25×10^6 psi

*These data obtained at the indicated temperature, not 72° or 1000°F as shown at the top of each heading.

6. Investment Cast Bars - 1000°F

a.	0.20 percent offset yield strength	33,900 psi
b.	Tensile Strength	61,300 psi
c.	Elongation in one inch	9.0 percent
d.	Reduction of area	21.8 percent

C. Creep (Vacuum melted bar stock and investment cast bars)

1. Vacuum Melted Bar Stock (Air Test*)

a.	Stress to produce 0.20 percent plastic strain in 1000 hours at 700°F	62,000 psi
b.	Stress to produce 0.20 percent plastic Strain in 10,000 hours at 700°F	53,000 psi
c.	Stress to produce 0.40 percent plastic strain in 1000 hours at 700°F	66,500 psi
d.	Stress to produce 0.40 percent plastic strain in 10,000 hours at 700°F	60,000 psi
e.	Stress to produce 0.20 percent plastic strain in 1000 hours at 900°F	33,700-36,500 psi
f.	Stress to produce 0.20 percent plastic strain in 10,000 hours at 900°F	26,800-29,200 psi
g.	Stress to produce 0.40 percent plastic strain in 1000 hours at 900°F	39,800-41,800 psi
h.	Stress to produce 0.40 percent plastic strain in 10,000 hours at 900°F	33,800-35,600 psi

2. Vacuum Melted Bar Stock (Argon and Vacuum) See C.1. above for temperatures to 900°F, above 900°F consult actual test data.

3. Investment Cast Bar Stock (Air and Vacuum See Figure IV.C.III-16).

D. Fatigue: Hiperco 27 alloy is not used in cyclic loaded applications.

E. Normal heat treatment for material used in electromagnetic generators: Heat to 1472°-1552°F in pure dry hydrogen and cool rapidly in the same atmosphere.

*Argon and Vacuum Test data are equivalent to Air Test data at 700°F and 900°F.

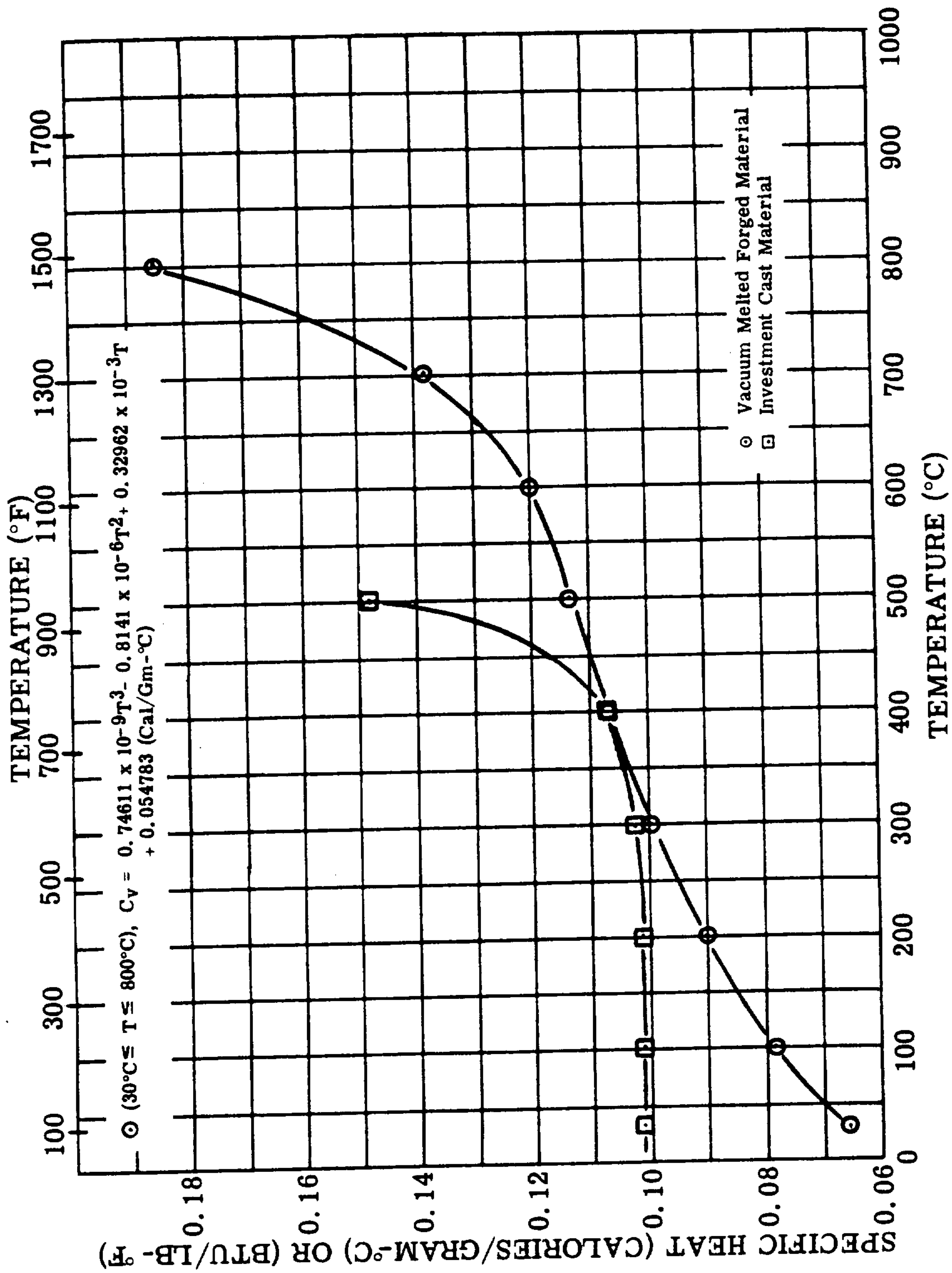


FIGURE I V. C. I-1. Specific Heat, Vacuum Melted Forged and Investment Cast Hiperco 27 Alloy Tested in Vacuum (10^{-5} Torr) (Reference: NAS3-4162)

Figure I V. C. I-1. Specific Heat - Hiperco 27

TABLE IV.C.I-1. Electrical Resistivity of Vacuum Melted Forged Hiperco 27 Alloy

TEST: ASTM B193

Specimen No. 1, Continuous Heating in Vacuum Wire Diameter - 0.1253 Inches, Test Length - 11.32 Inches		
Temperature (°F)	Resistance (Ohms)	Resistivity (Microhm-Cm)
77	0.006300	17.43
200	0.006770	18.73
300	0.007345	20.32
437	0.008369	23.15
500	0.008969	24.81
619	0.01020	28.22
705	0.01134	31.37
800	0.01265	35.00
900	0.01430	39.56
1000	0.01616	44.71
1100	0.01819	50.33
1200	0.02050	56.72
1300	0.02304	63.75
1400	0.02578	71.33
1245	0.02190	60.59
1050	0.01745	48.28
850	0.01384	38.29
650	0.01102	30.49
445	0.009010	24.93
250	0.007445	20.60
150	0.006689	18.51
79	0.006180	17.10

NOTE: The above data are plotted on Figure IV.C.I-2.

(Reference: NAS3-4162)

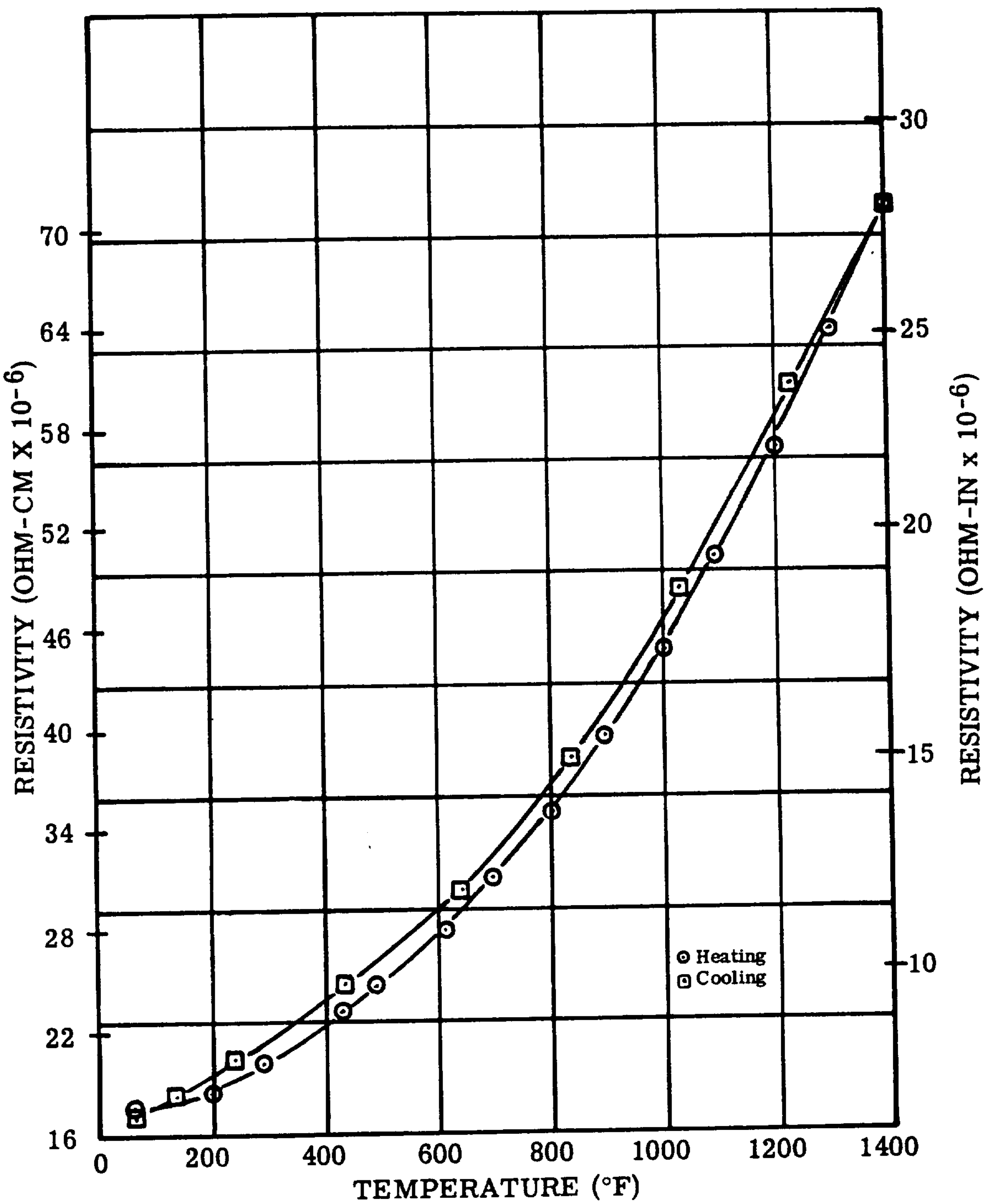


FIGURE IV.C.I-2. Electrical Resistivity of Vacuum Melted Forged Hiperco 27 Alloy Tested in Vacuum (10^{-4} torr). See Data Table IV.C.I-1. (Reference: NAS3-4162)

Figure I V. C. I-2. Resistivity - Hiperco 27

TABLE IV.C.II-1. Magnetic Properties of Hiperco 27 Alloy Ring Laminations 0.008 Inch Thick After High-Temperature Annealing and Recoating with Aluminum Orthophosphate.

Test: ASTM A343 — Atmosphere: Air at 72°F, Argon at 1000°F and 1400°F

	SAMPLE NO. 1		SAMPLE NO. 2			SAMPLE NO. 3		SAMPLE NO. 4		SAMPLE NO. 5	
	72°F	72°F After 1400°F	72°F	72°F After 1400°F	72°F After 1400°F Recoated	72°F	72°F After 1400°F Recoated	72°F	72°F After 1400°F	72°F	72°F 1000 hrs. at 1000°F
D-C Tests											
B (Kilogauss) at H = 250 Oersteds	23.15	23.1	23.3	23.0	22.6	23.2	23.1	23.1	23.1	23.4	23.0
B (Kilogauss) at H = 100 Oersteds	20.8	20.6	20.9	20.25	19.85	20.75	20.4	20.45	20.5	21.0	20.45
H (Oersteds) for B = 10 Kilogauss	2.67	1.12	3.29	2.01	3.99	3.43	1.81	5.16	3.52	5.24	5.19
H_c (Oersteds)*	1.69	1.35	1.60	1.17	1.12	1.53	0.85	1.36	1.30	1.41	1.37
B_r (Kilogauss)*	10.1	12.3	9.3	10.85	9.45	8.9	10.7	6.65	9.5	7.1	7.45
400 cps Tests											
Core Loss (Watts/lb) for B = 12 Kilogauss	18.37	17.10	17.29	22.64	20.9	16.46	16.42	18.32	15.36	18.32**	18.96
14 Kilogauss	22.72	22.45	21.93	29.04	27.0	20.58	21.34	23.4	25.9	23.4	24.44
16 Kilogauss	27.76	56.50	25.72	37.10	31.88	25.27	27.55	28.7	32.4	28.7	31.06
18 Kilogauss	33.47	70.62	30.88	46.12	42.60	30.82	33.88	34.7	40.28	34.7	39.09

Heat treatment of samples 1, 2, and 3 was conducted in a vacuum.

Heat treatment of samples 4 and 5 was conducted in hydrogen.

* Taken from an induction corresponding to a field of 100 Oersteds.

** Core loss properties were not measured originally on this sample. For comparison, core loss data in this column were taken from Sample No. 4.

(Reference: NAS3-4162)

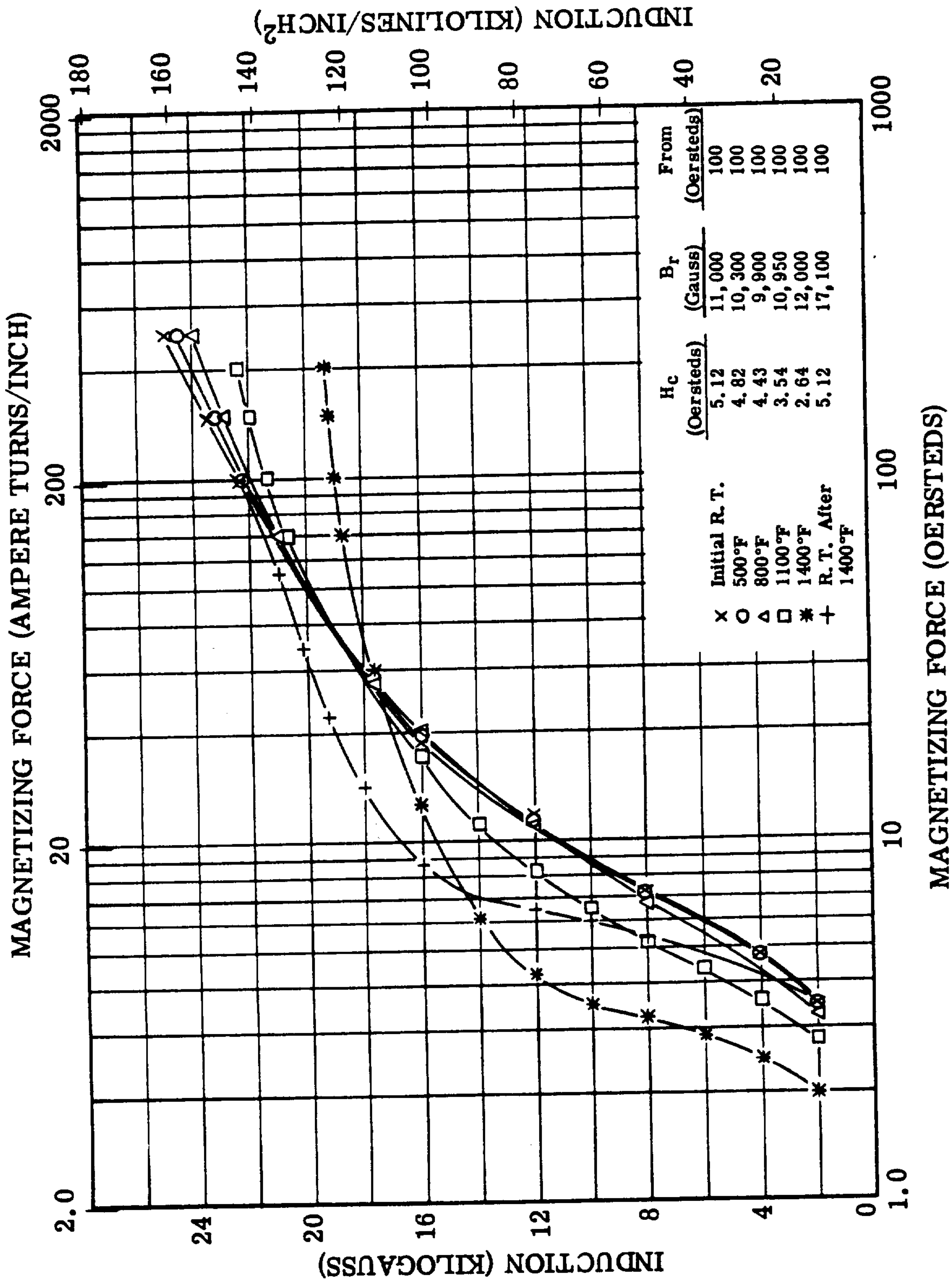


FIGURE IV.C.II-1. D-C Magnetization Curves. Hiperco 27 Alloy Forging. Test Atmosphere: Argon. (Reference: NAS 3-4162)

Figure IV.C.II-1. D-C Magnetization - Hiperco 27

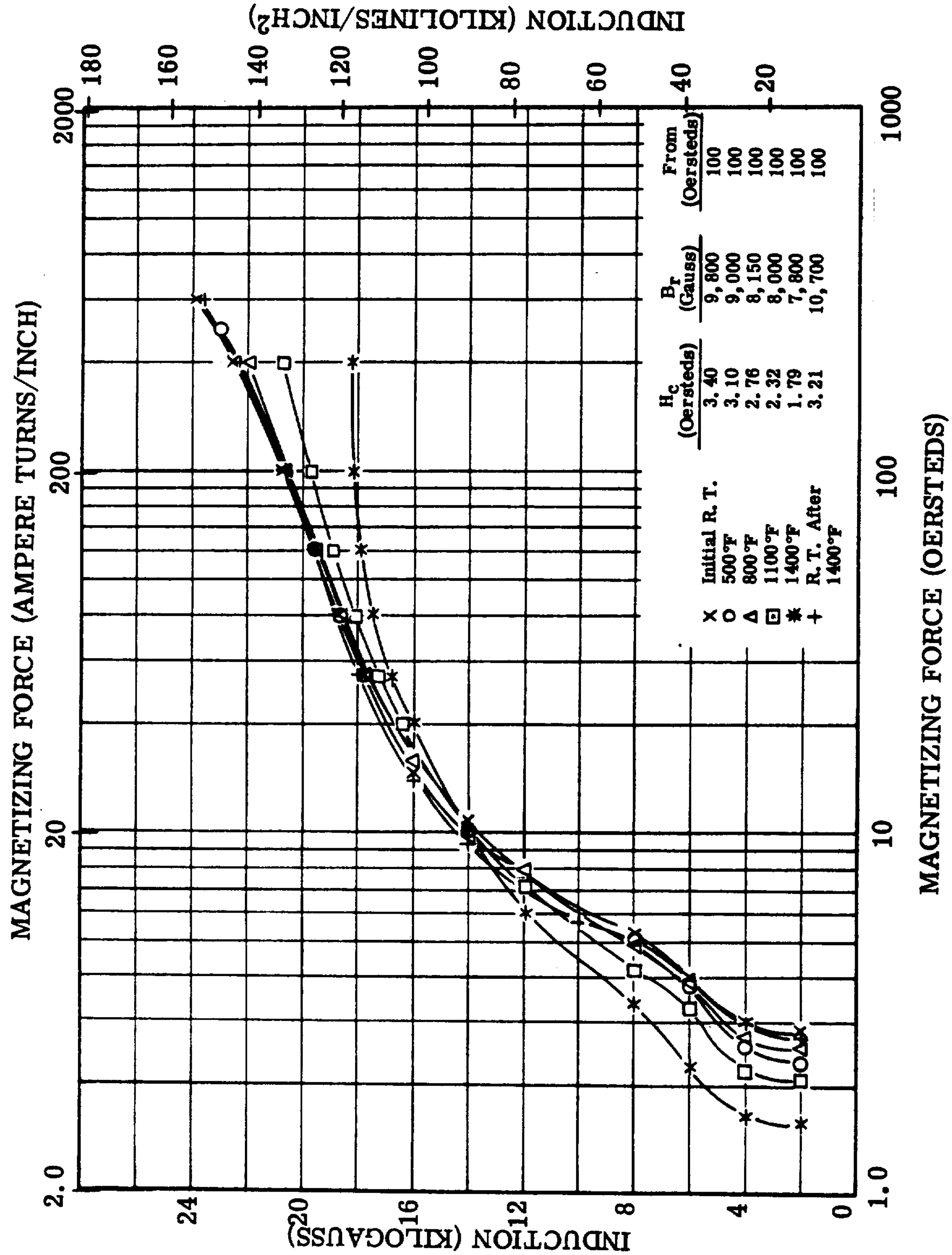


FIGURE IV.C.II-2. D-C Magnetization Curves. Hiperco 27 Alloy Casting. Test Atmosphere: Air. (Reference: NAS 3-4162)

Figure IV.C.II-2. D-C Magnetization - Hiperco 27

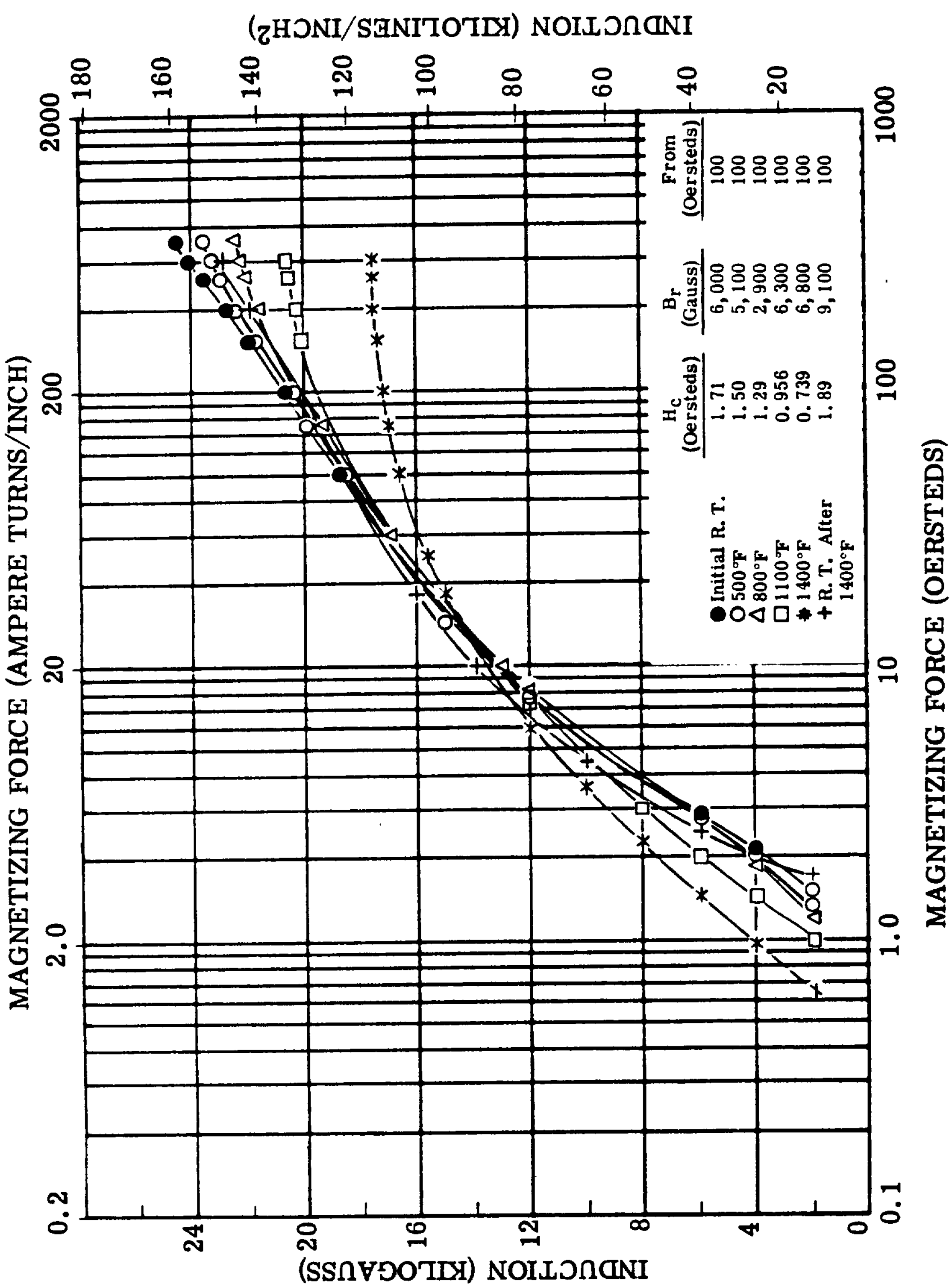


FIGURE IV.C.II-3. D-C Magnetization Curves. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS3-4162)

Figure IV.C.II-3. D-C Magnetization - Hiperco 27

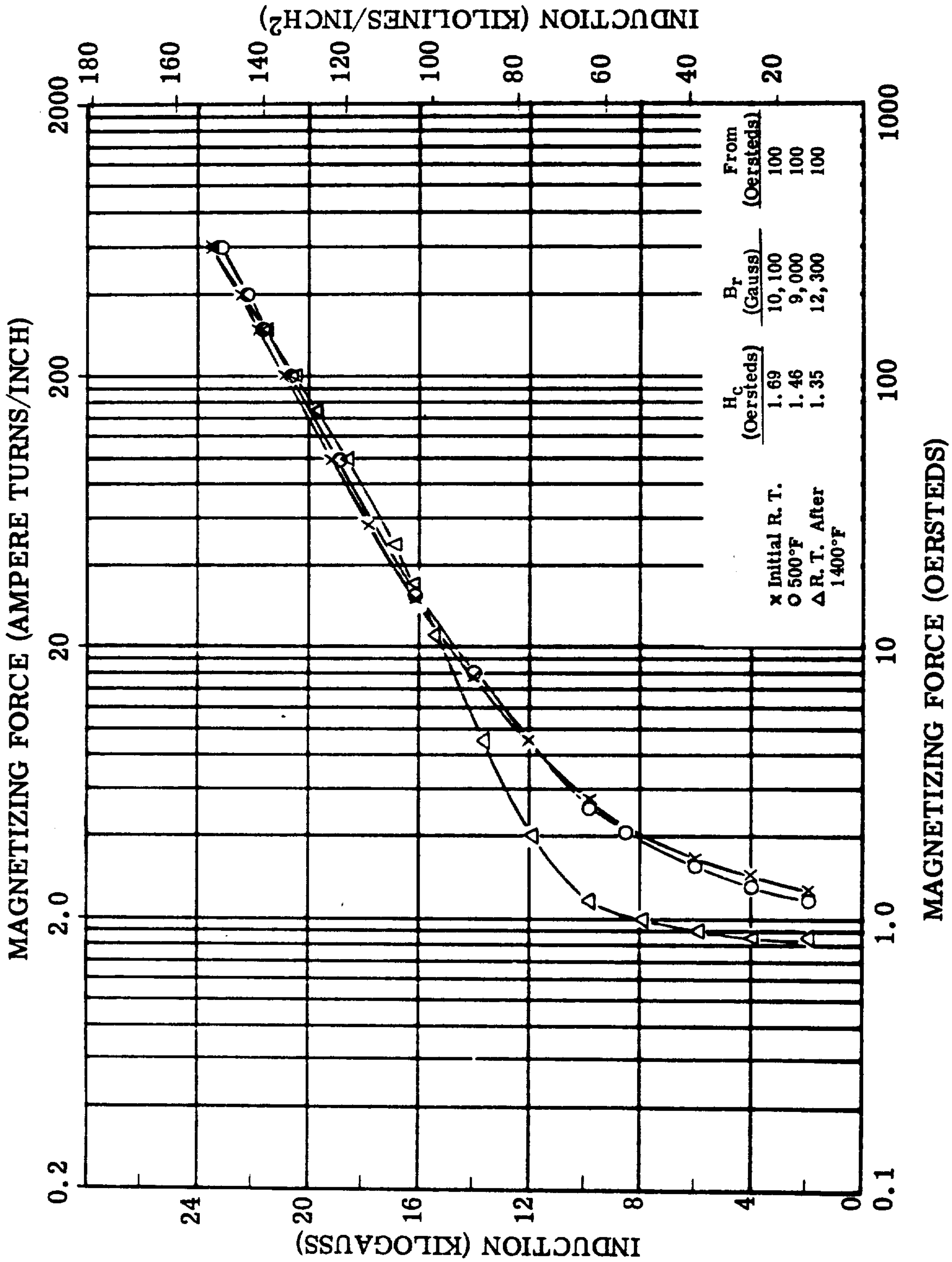


FIGURE IV.C.II-4. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #1. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-4. D-C Magnetization - Hiperco 27

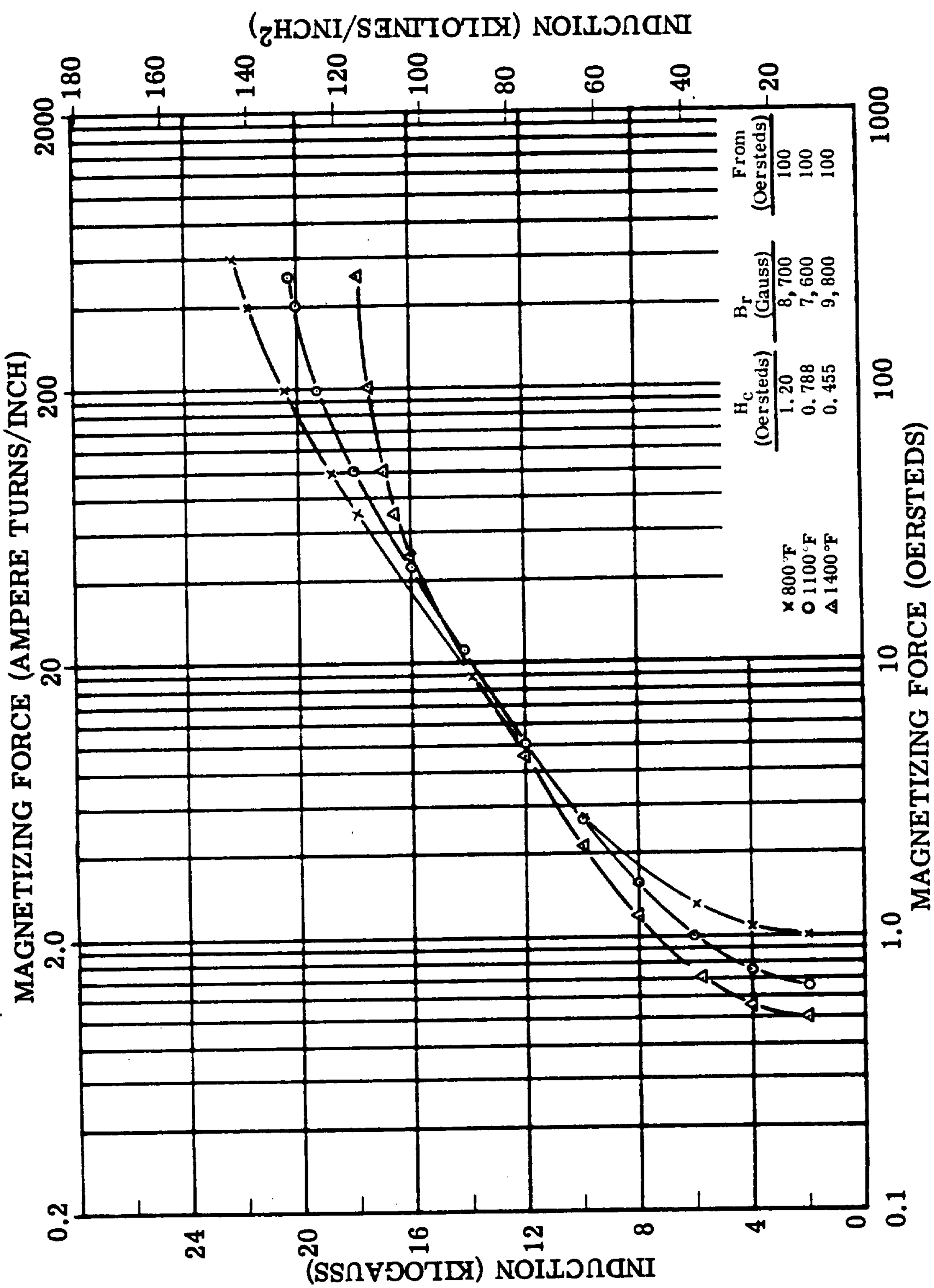
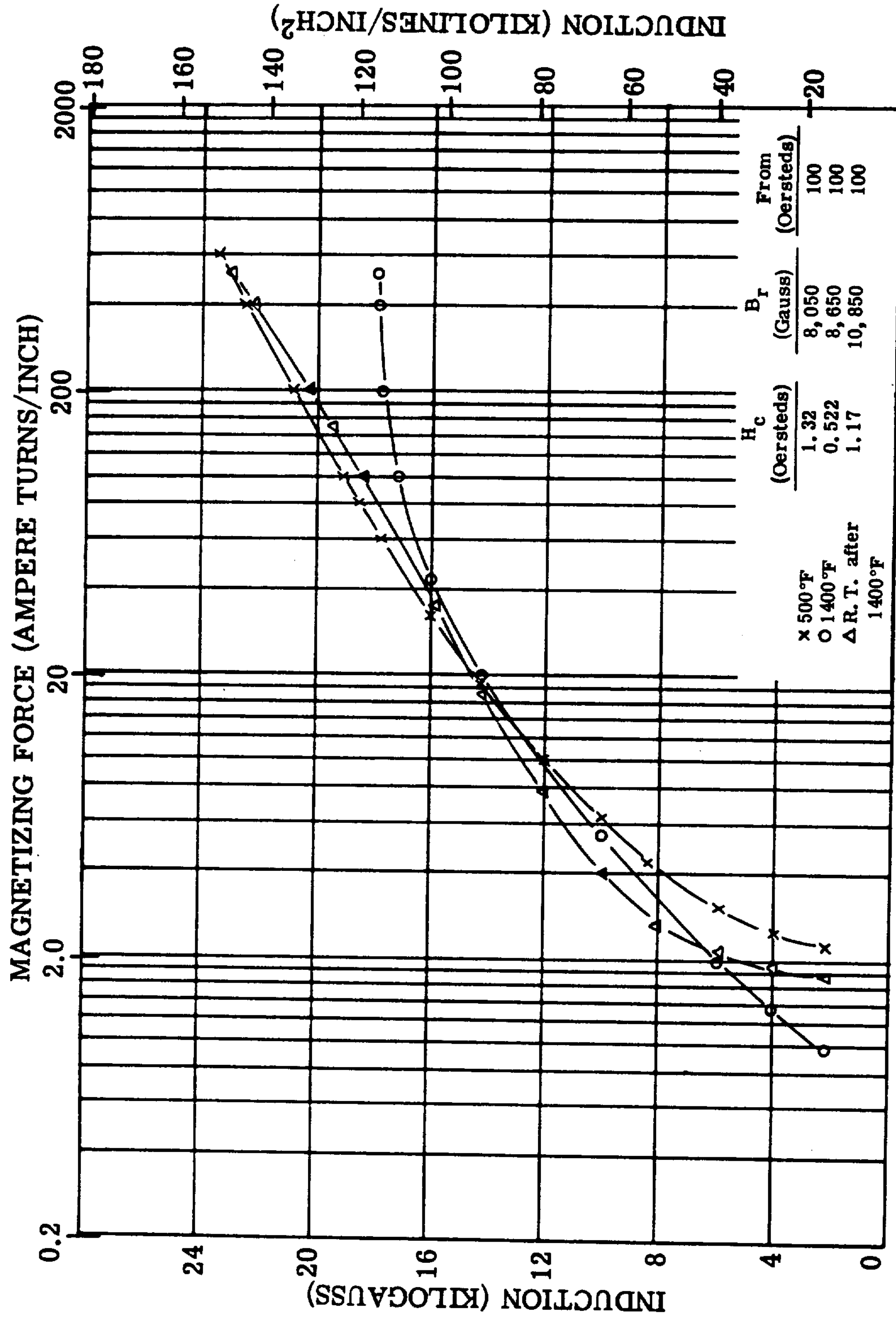


FIGURE I V. C. II-5. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #1. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure I V. C. II-5. D-C Magnetization - Hiperco 27



	H_c (Oersteds)	B_r (Gauss)	From (Oersteds)
× 500°F	1.32	8,050	100
○ 1400°F	0.522	8,650	100
Δ R. T. after 1400°F	1.17	10,850	100

FIGURE I V. C. I I-6. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #2. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. C. I I-6. D-C Magnetization - Hiperco 27

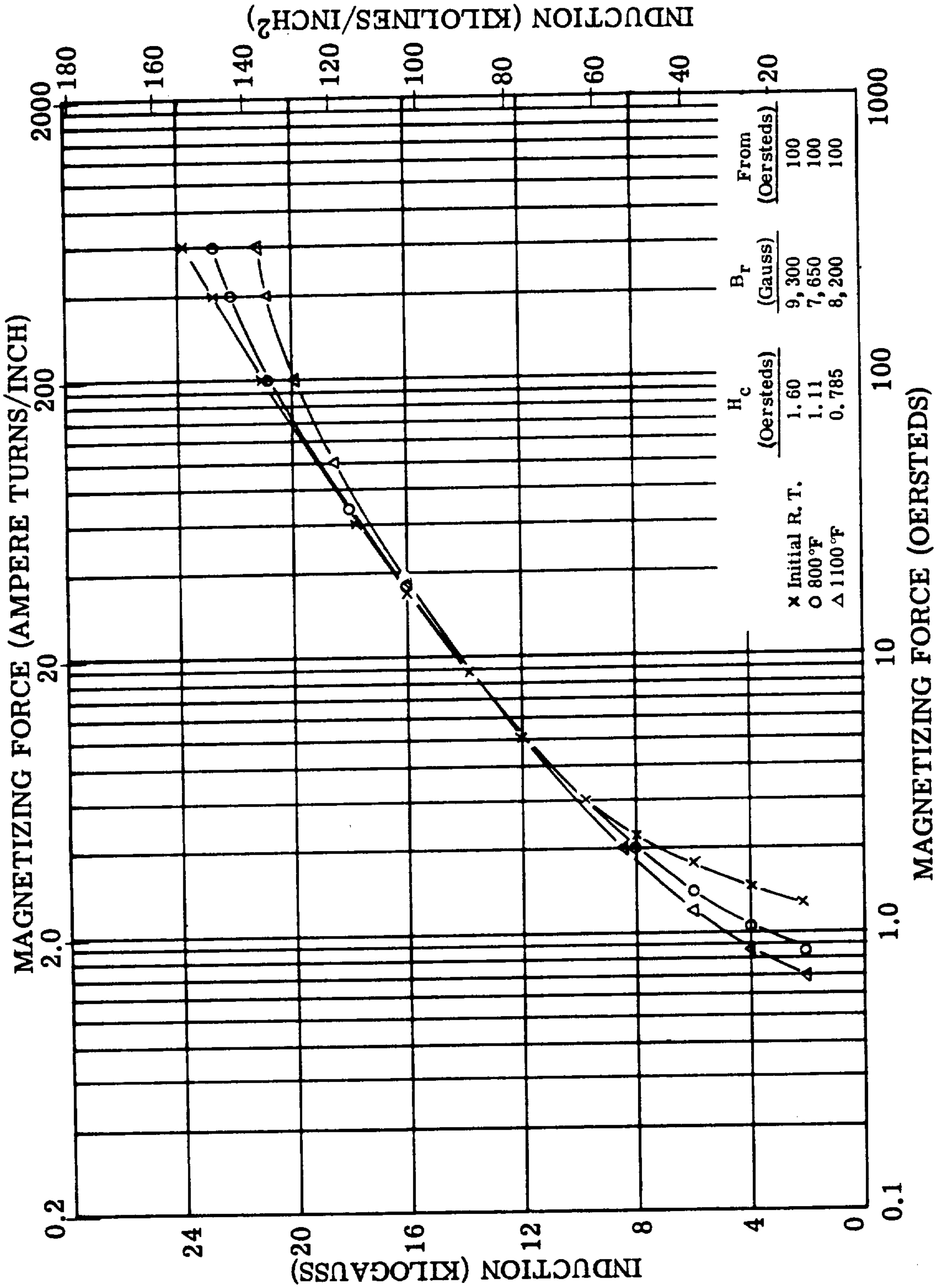


FIGURE IV.C.II-7. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #2. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-7. D-C Magnetization - Hiperco 27

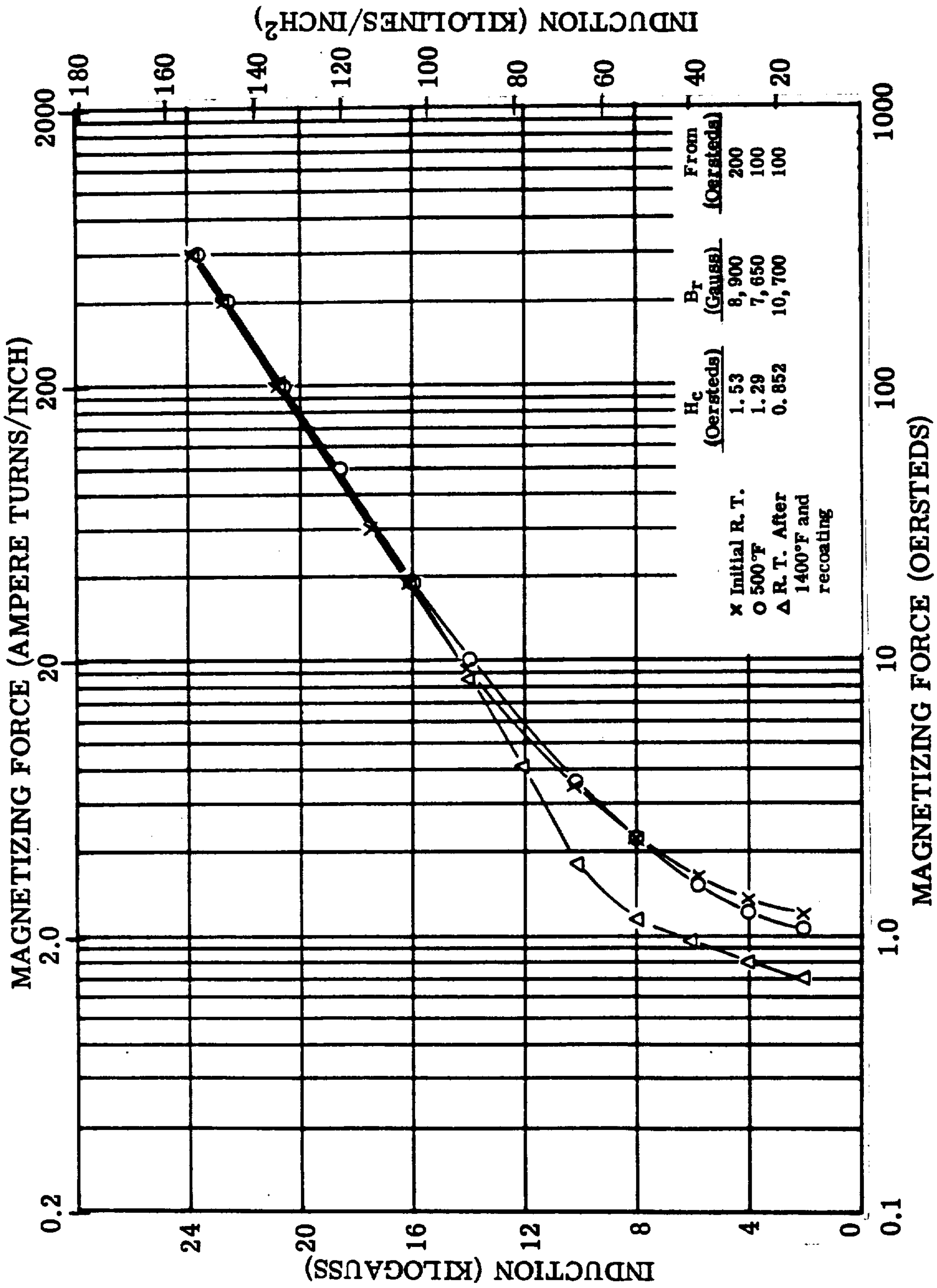


FIGURE IV. C. II-8. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. C. II-8. D-C Magnetization - Hiperco 27

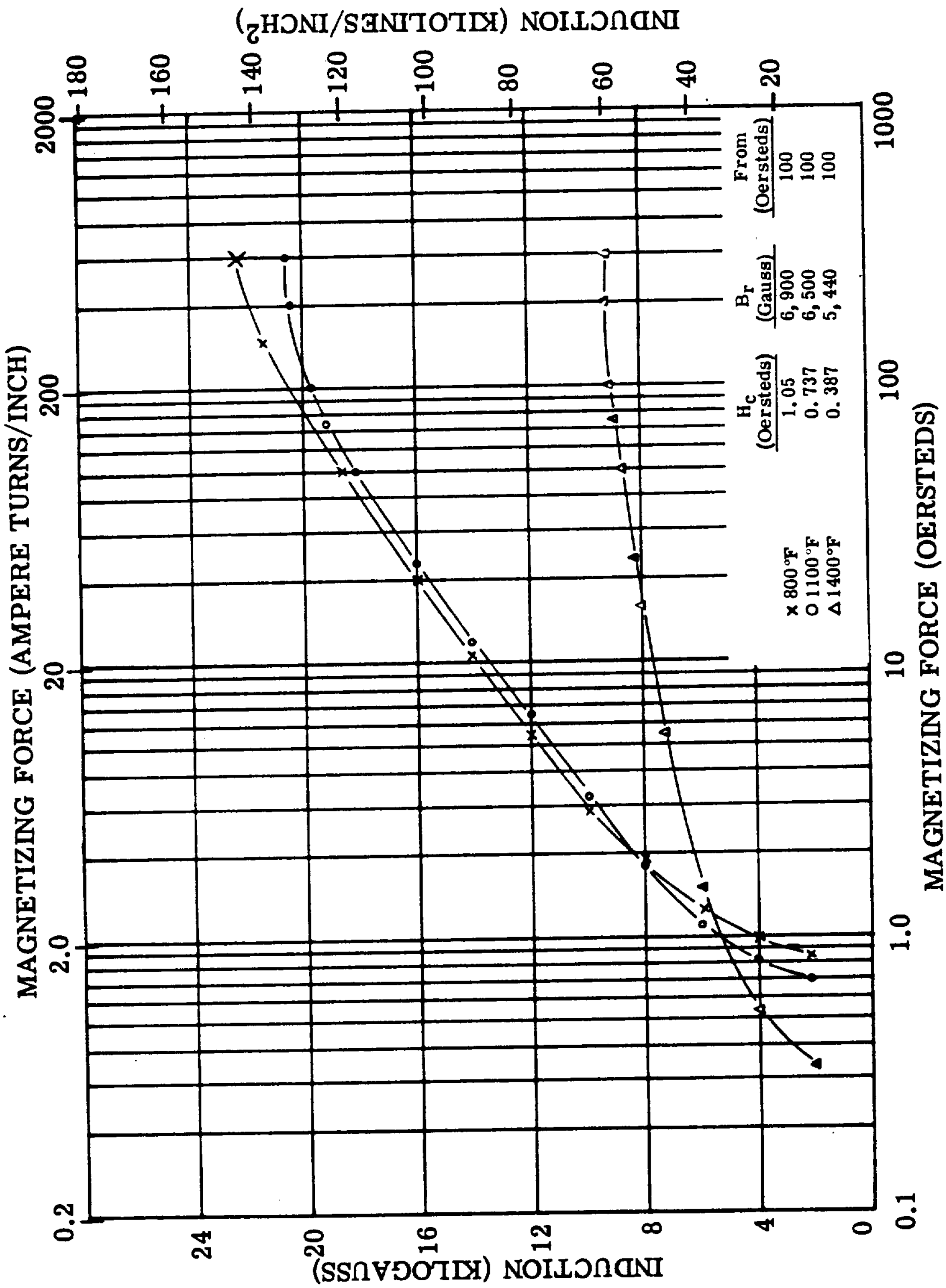


FIGURE IV. C. II-9. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. C. II-9. D-C Magnetization - Hiperco 27

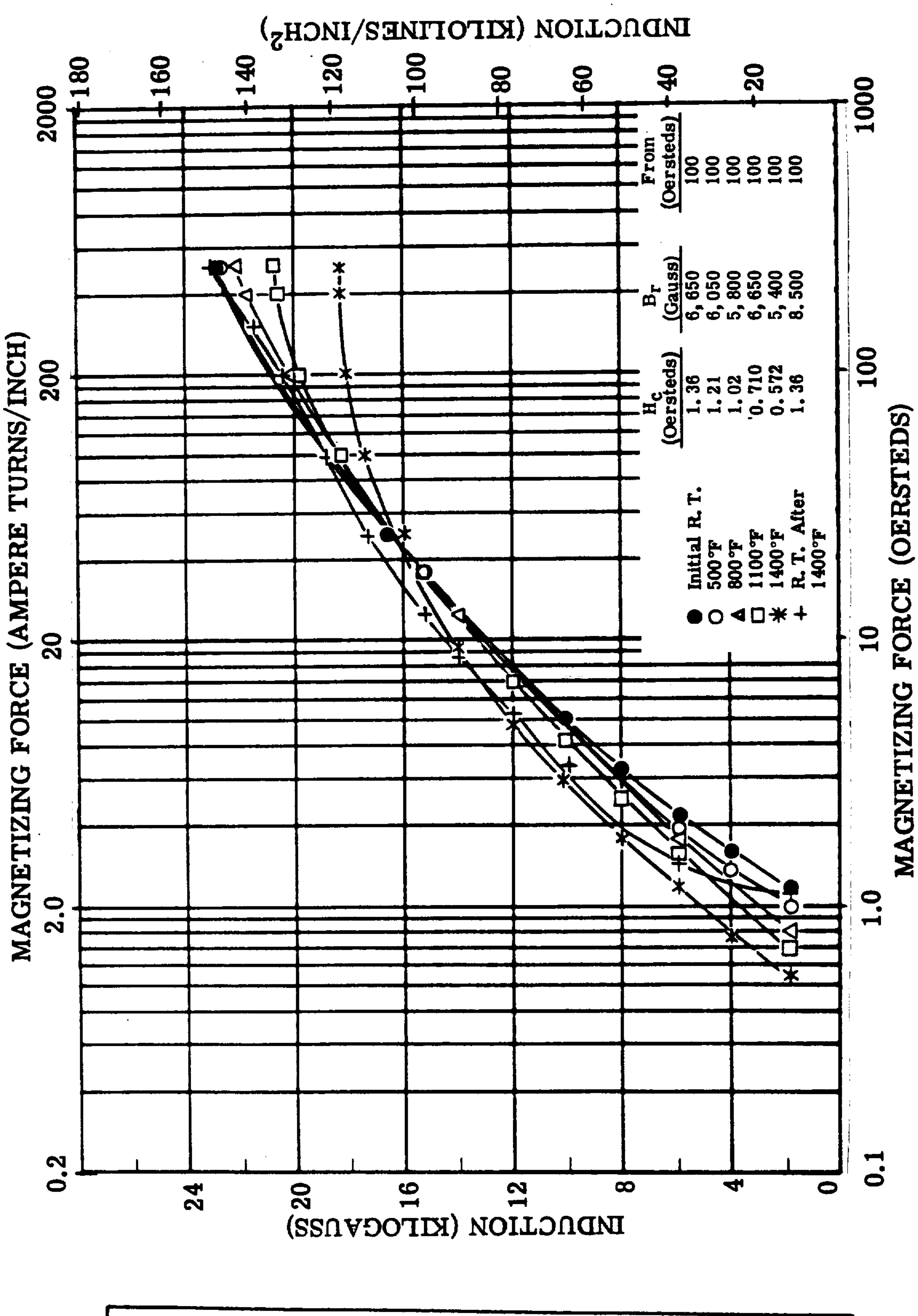


FIGURE IV. C. II-10. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-10. D-C Magnetization - Hiperco 27

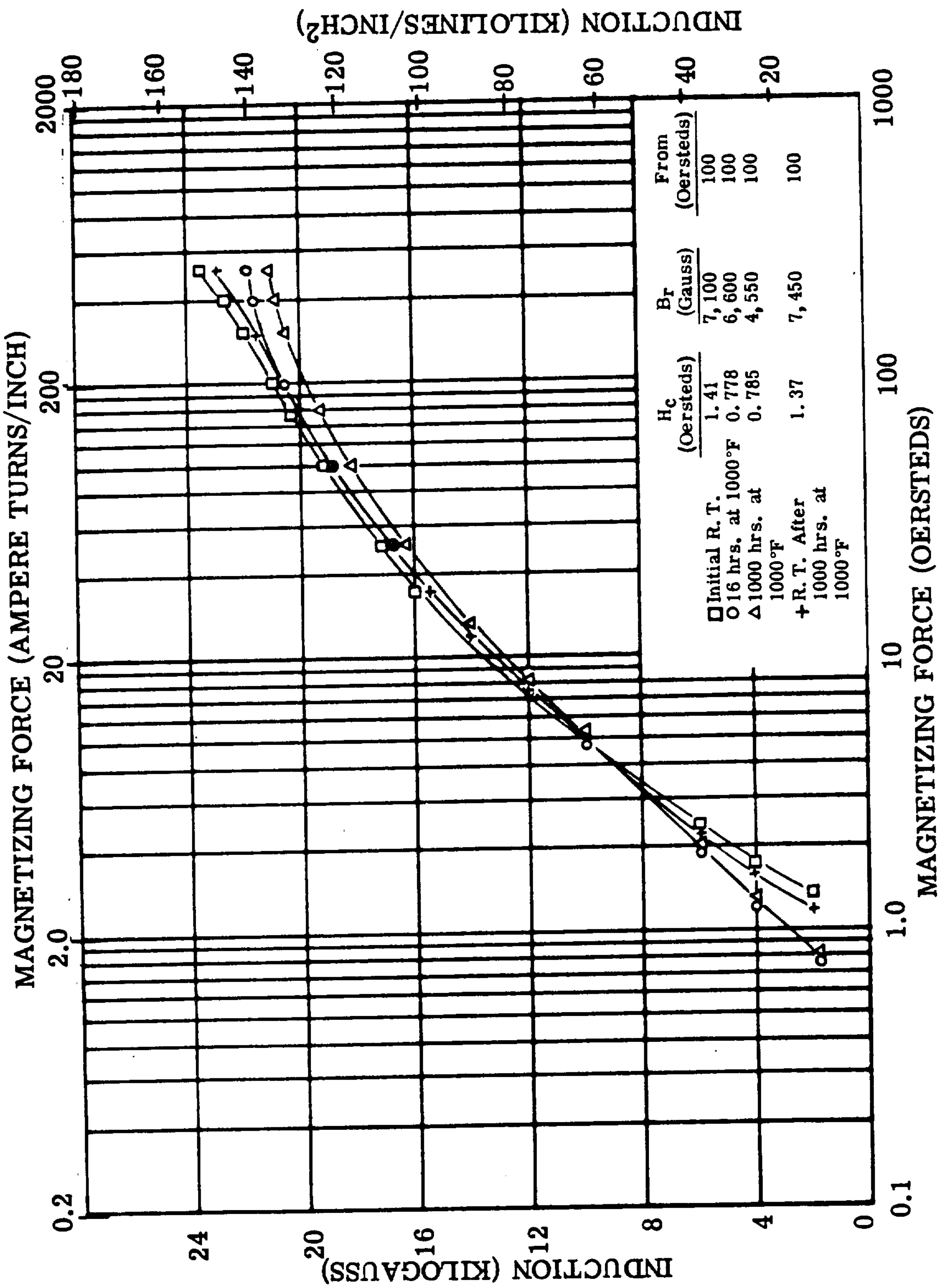


FIGURE IV. C. II-11. D-C Magnetization Curves. Hiperco 27 Alloy - 0.008 Inch Laminations - Aging Test - Sample #5. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-11. D-C Magnetization - Hiperco 27

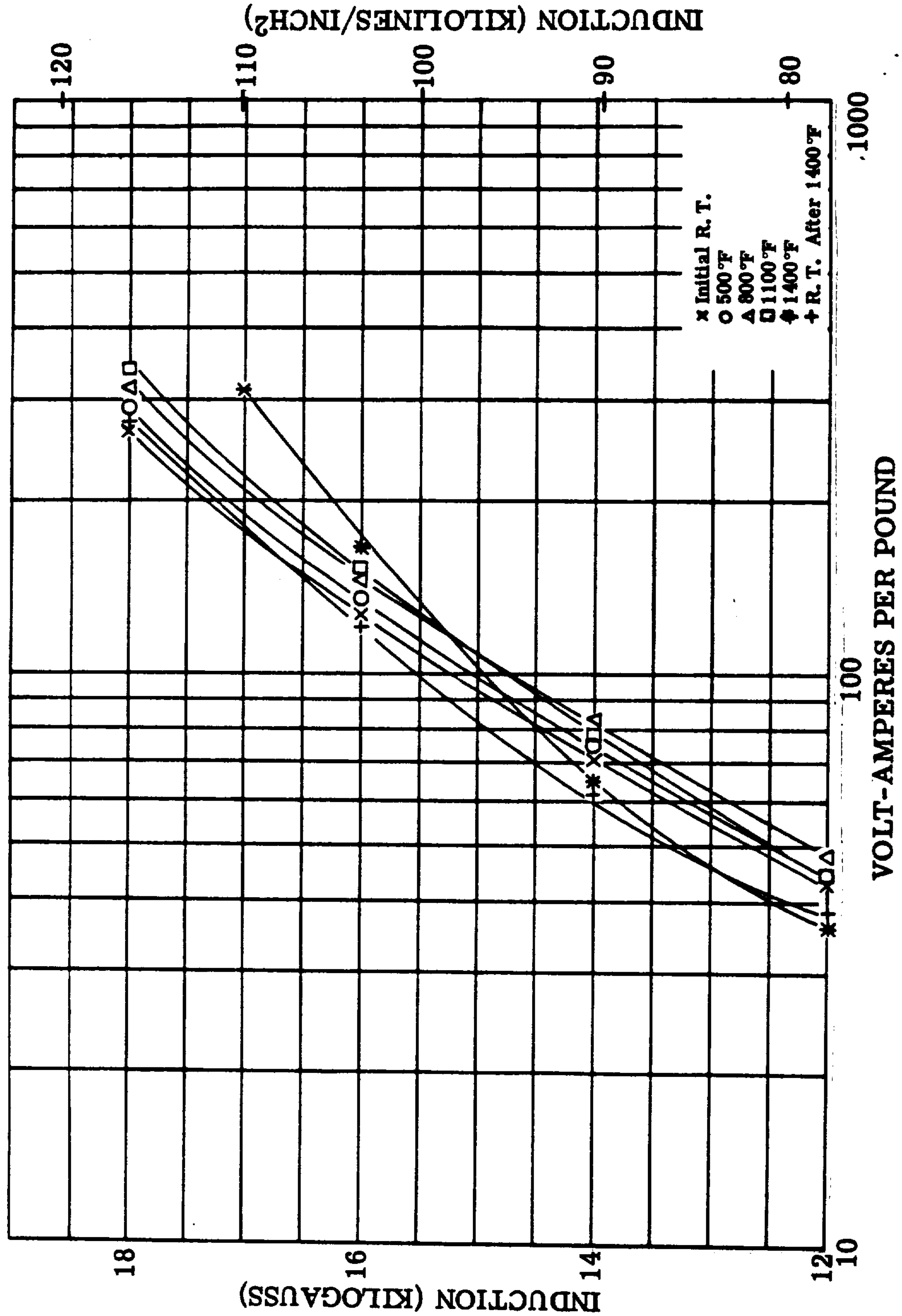


FIGURE IV. C. II-12. Exciting Volt-Amperes Per Pound, 400 CPS. Hiperco 27 Alloy - 0.004 Inch laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-12. Exciting VA, 400 CPS. Hiperco 27

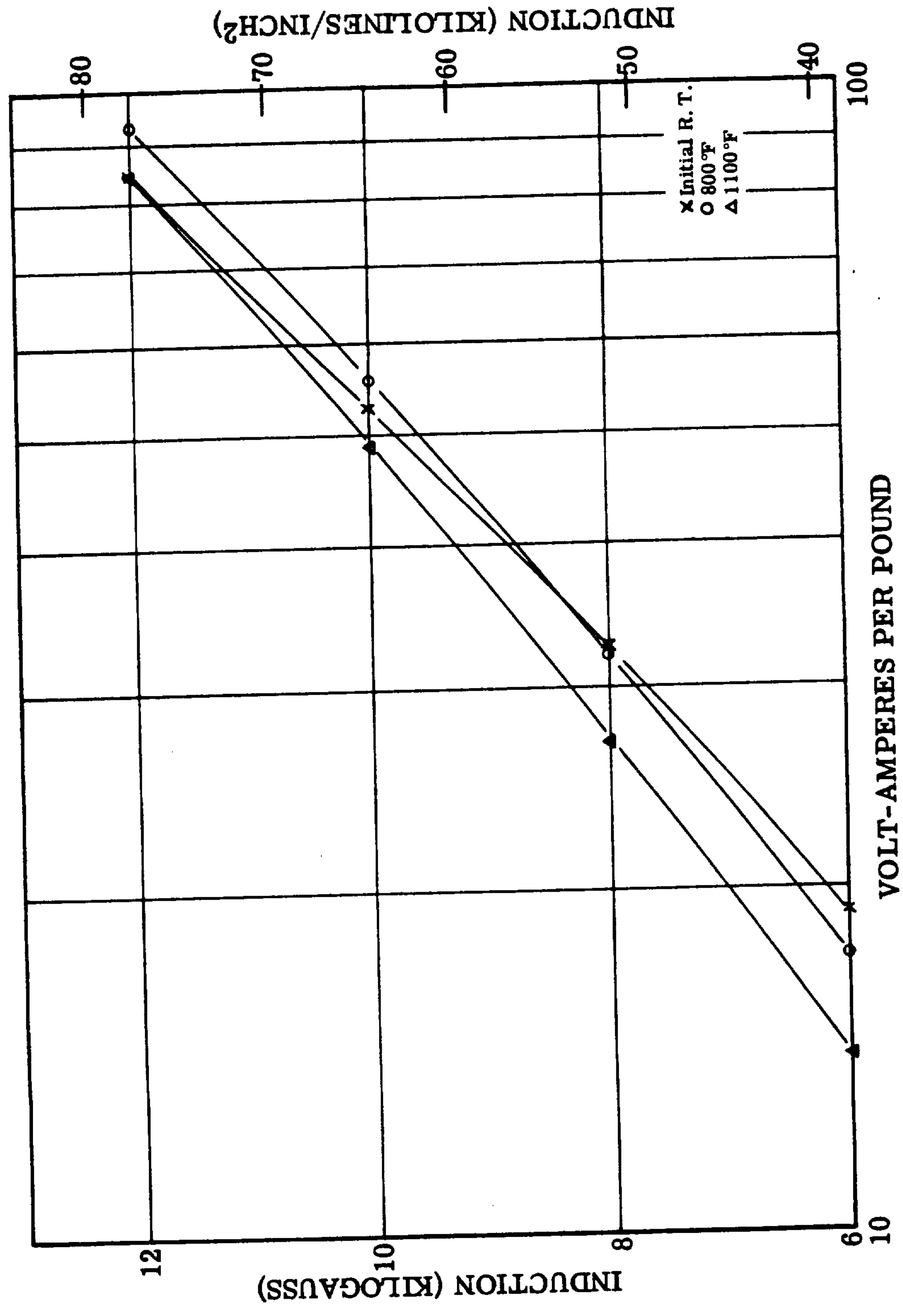


FIGURE IV.C.II-13. Exciting Volt-Amperes Per Pound, 800 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-13. Exciting VA, 800 CPS. Hiperco 27

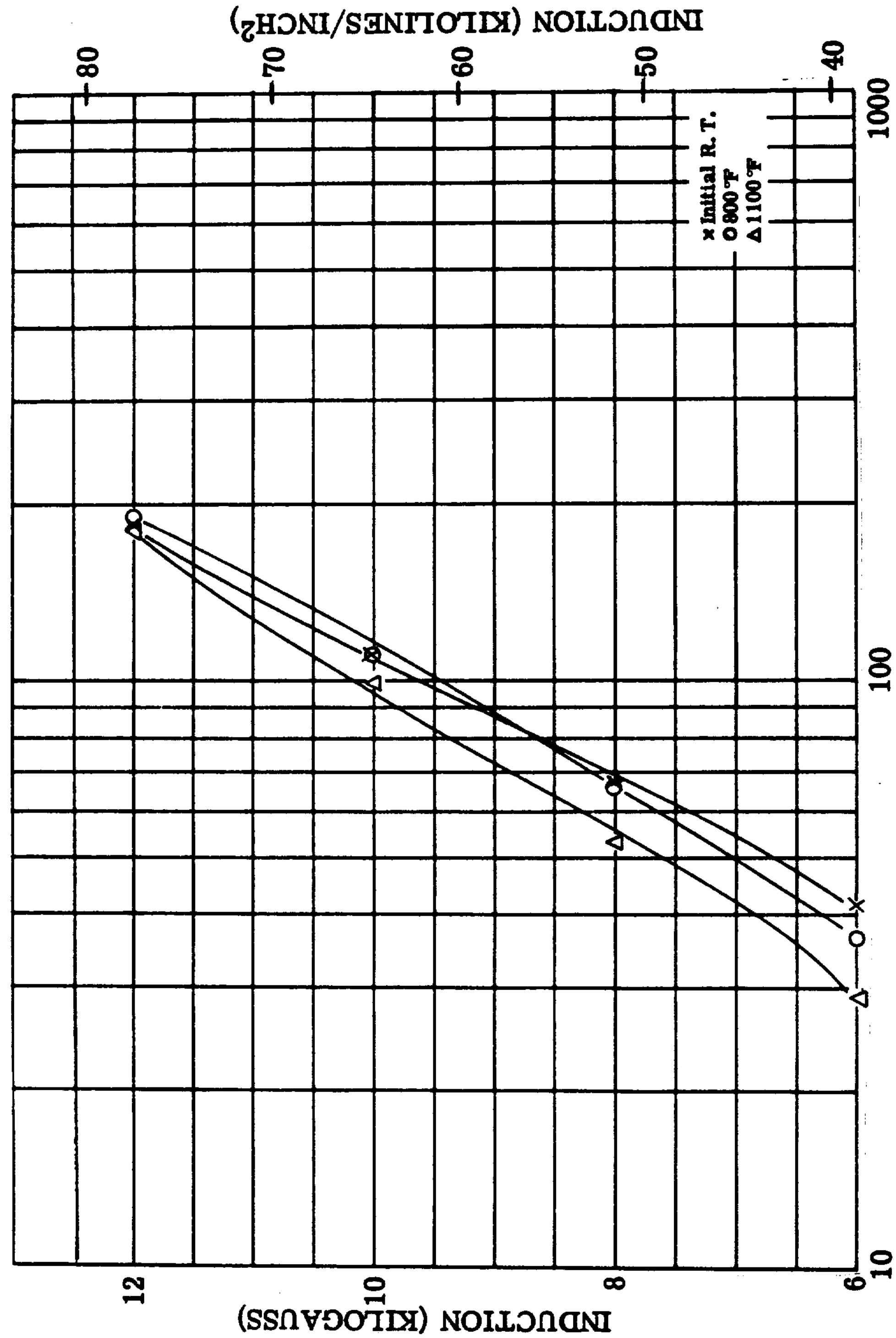


FIGURE IV. C. II-14. Exciting Volt-Amperes Per Pound, 1600 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-14. Exciting VA, 1600 CPS. Hiperco 27

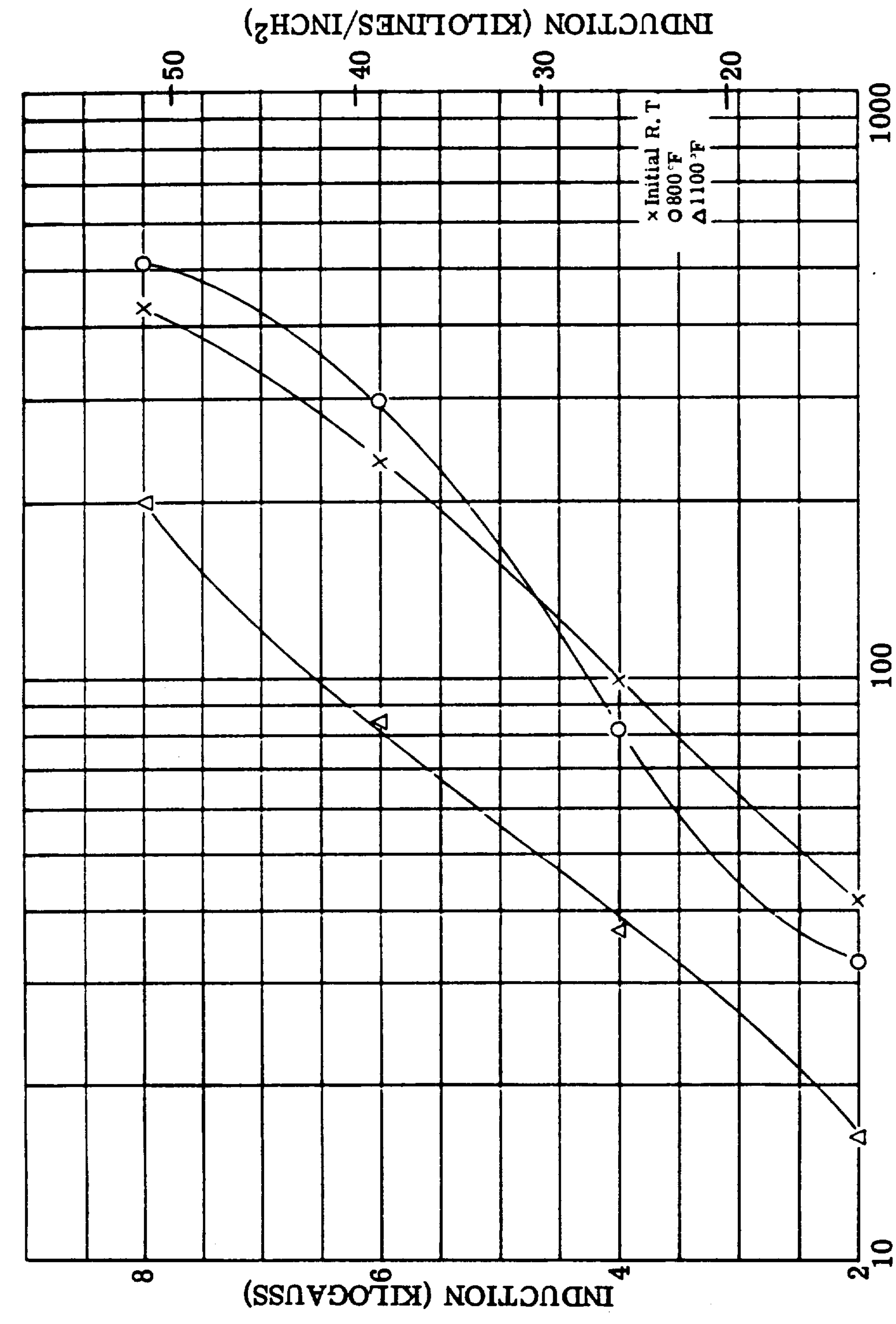


FIGURE IV.C.II-15. Exciting Volt-Amperes Per Pound, 3200 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-15. Exciting VA, 3200 CPS. Hiperco 27

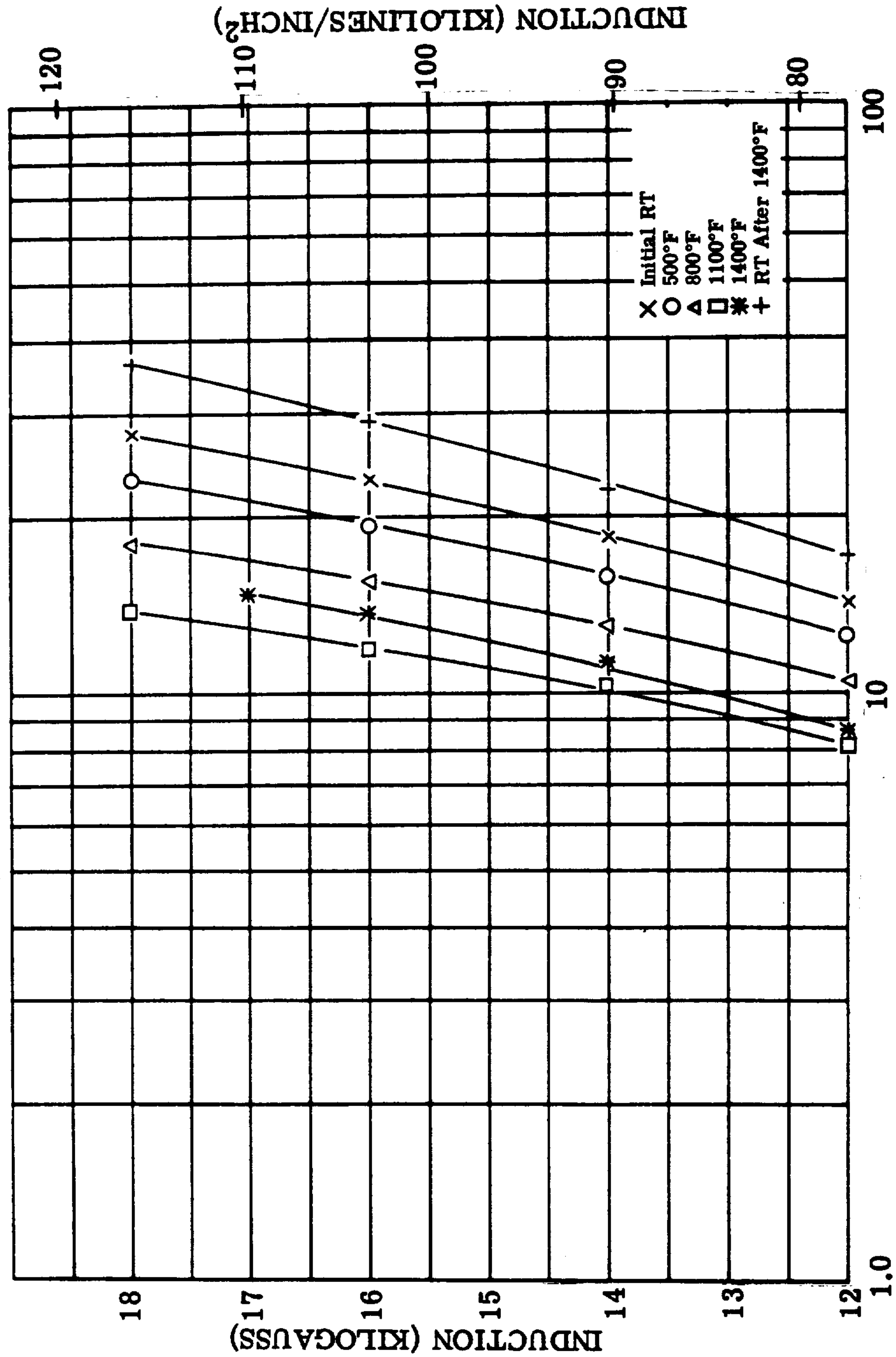


FIGURE IV. C. II-16. Core Loss, 400 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-16. Core Loss, 400 CPS. Hiperco 27

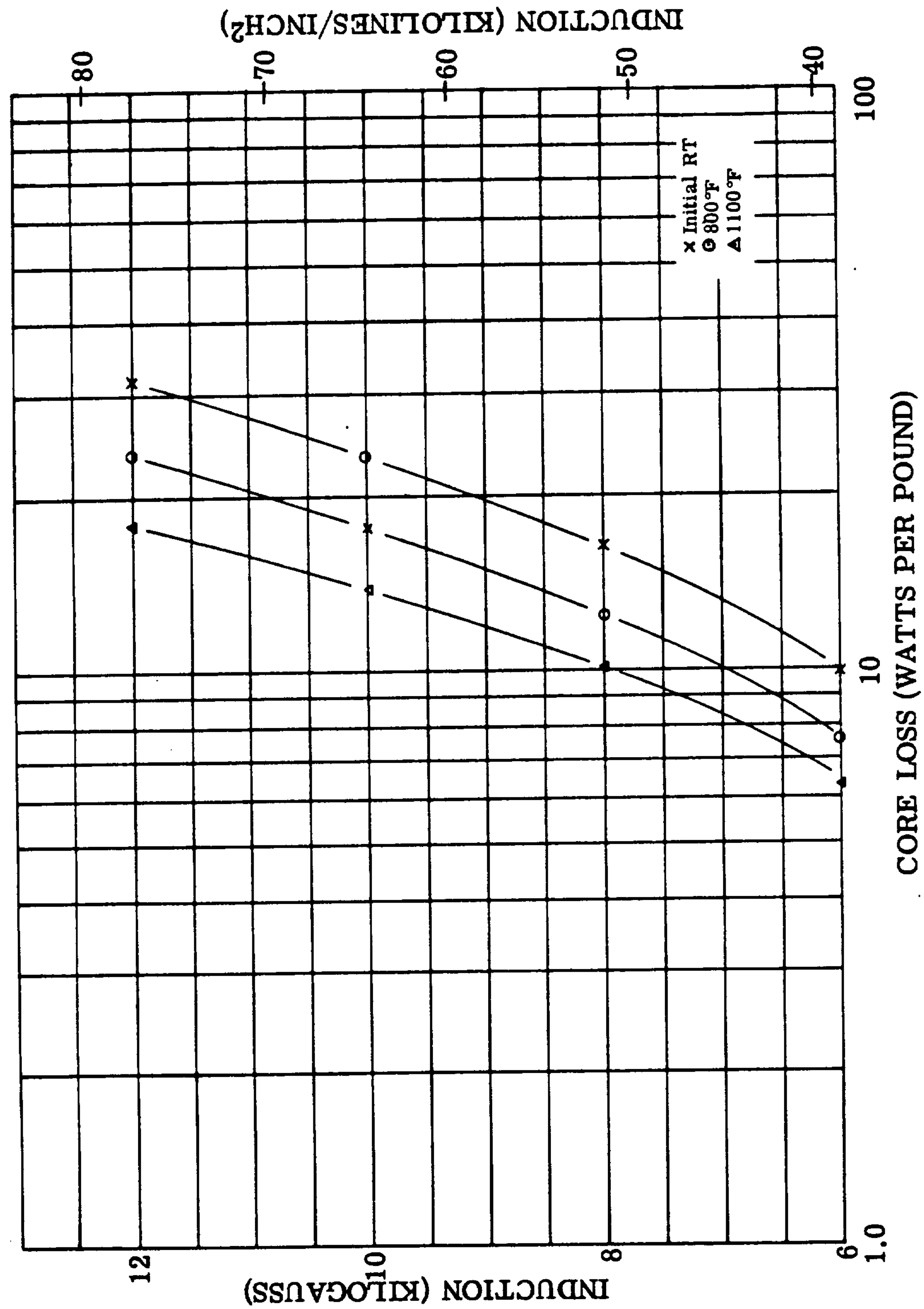


FIGURE IV.C.II-17. Core Loss, 800 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-17. Core Loss, 800 CPS. Hiperco 27

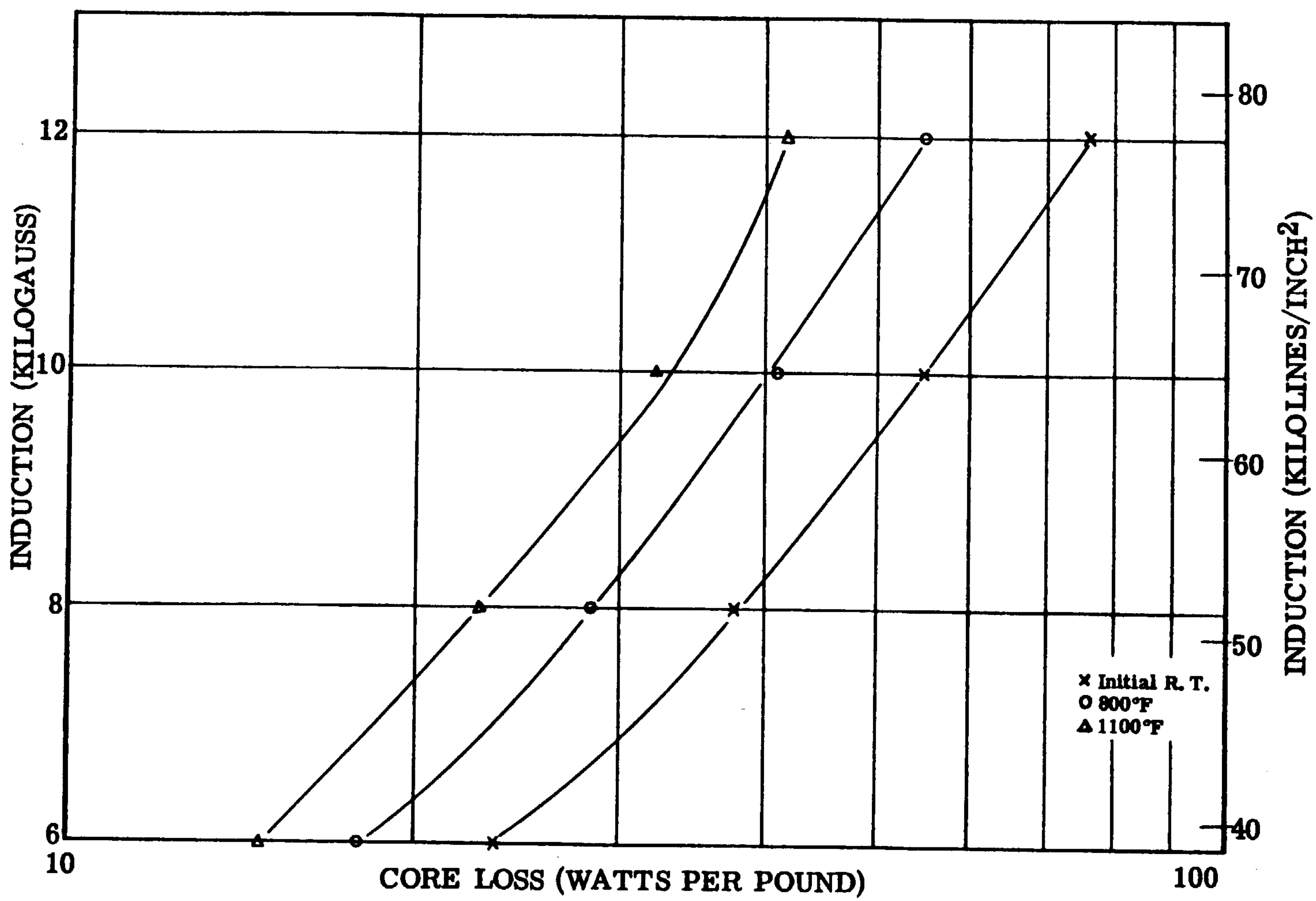


FIGURE I V. C. II-18. Core Loss, 1600 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure I V. C. II-18. Core Loss, 1600 CPS. Hiperco 27

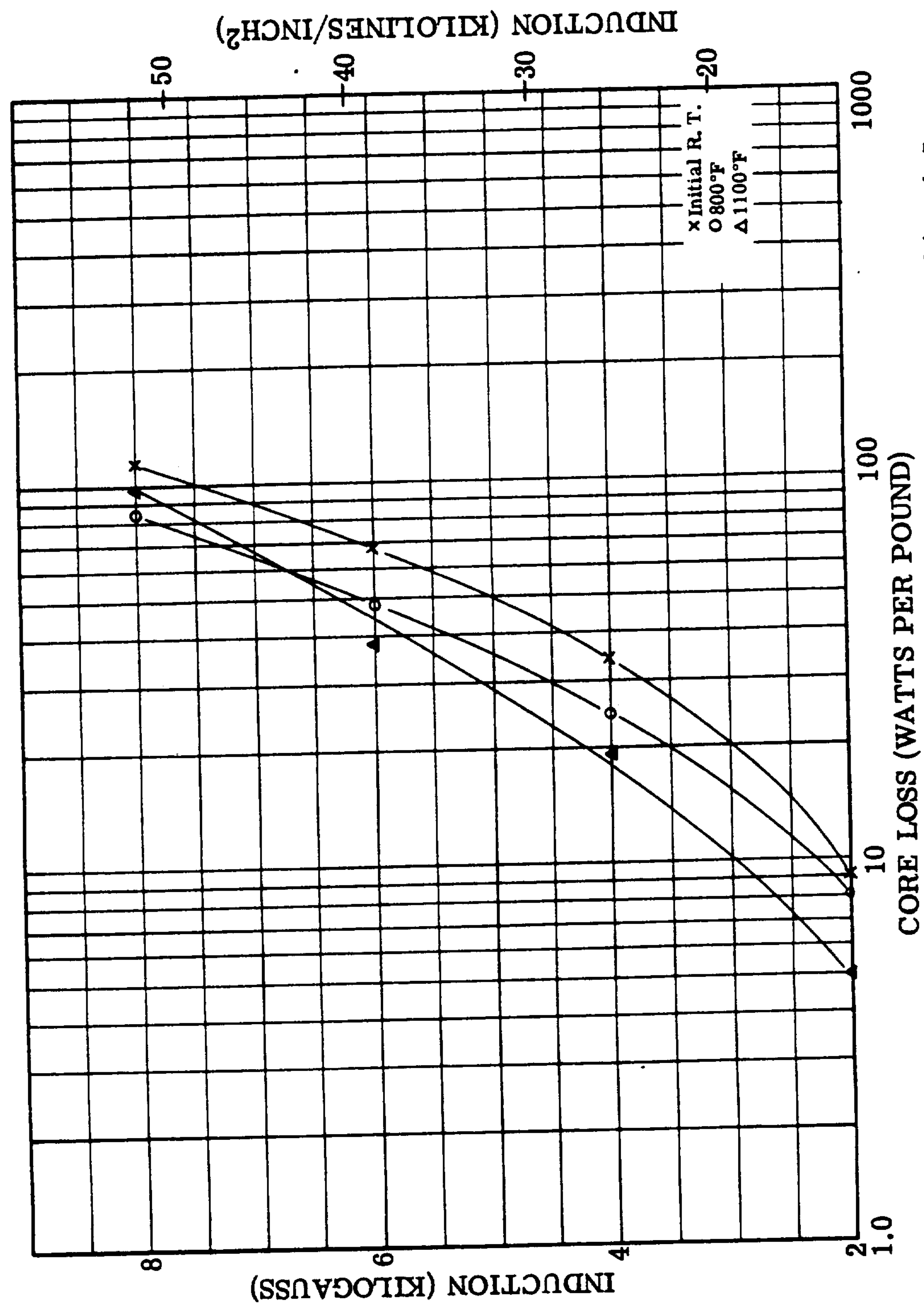


FIGURE I V. C. II-19. Core Loss, 3200 CPS. Hiperco 27 Alloy - 0.004 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800 °F. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS3-4162)

Figure I V. C. II-19. Core Loss, 3200 CPS. Hiperco 27

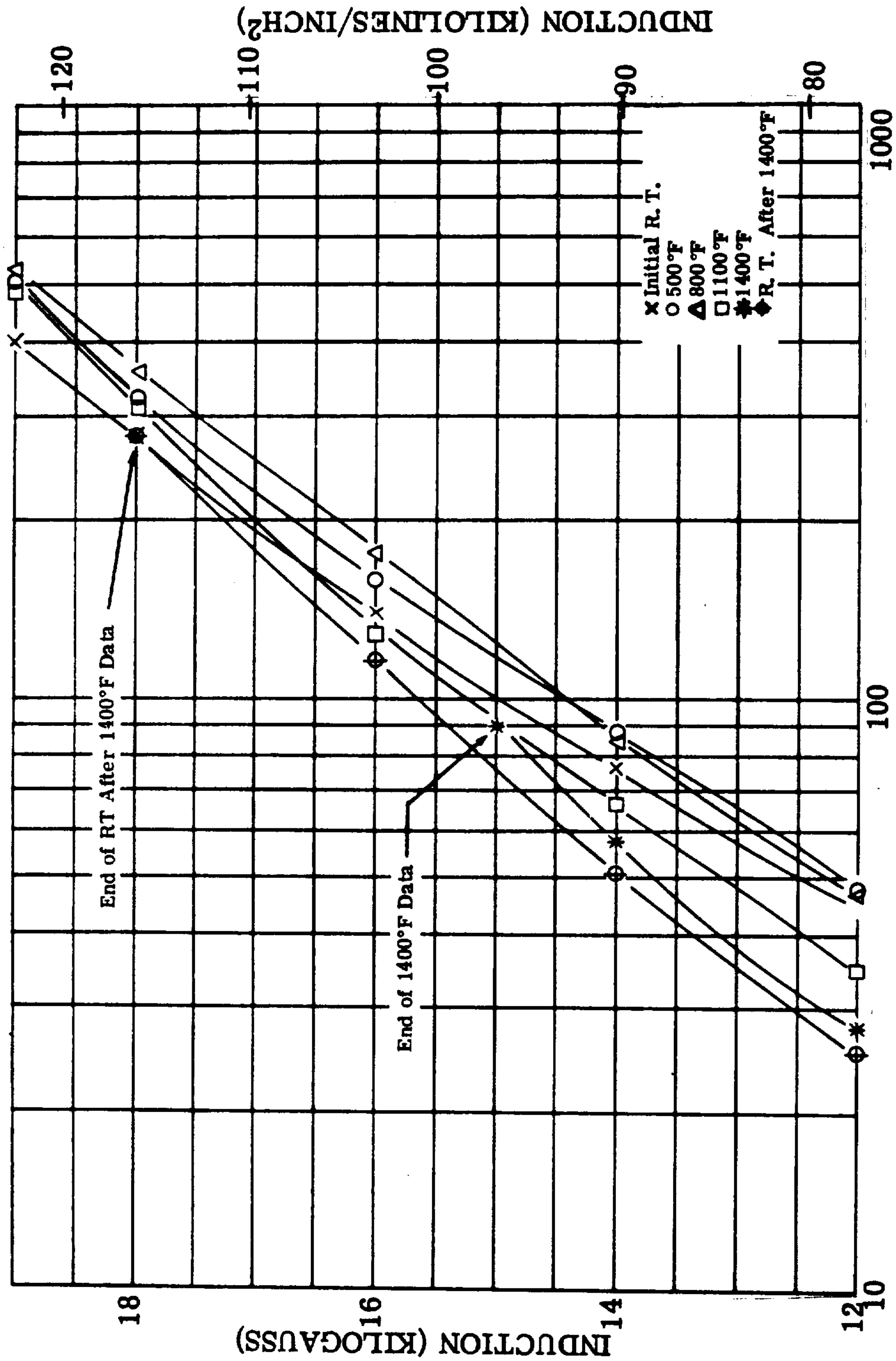


FIGURE IV.C.II-20. Exciting Volt-Amperes Per Pound, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-20. Exciting VA, 400 CPS. Hiperco 27

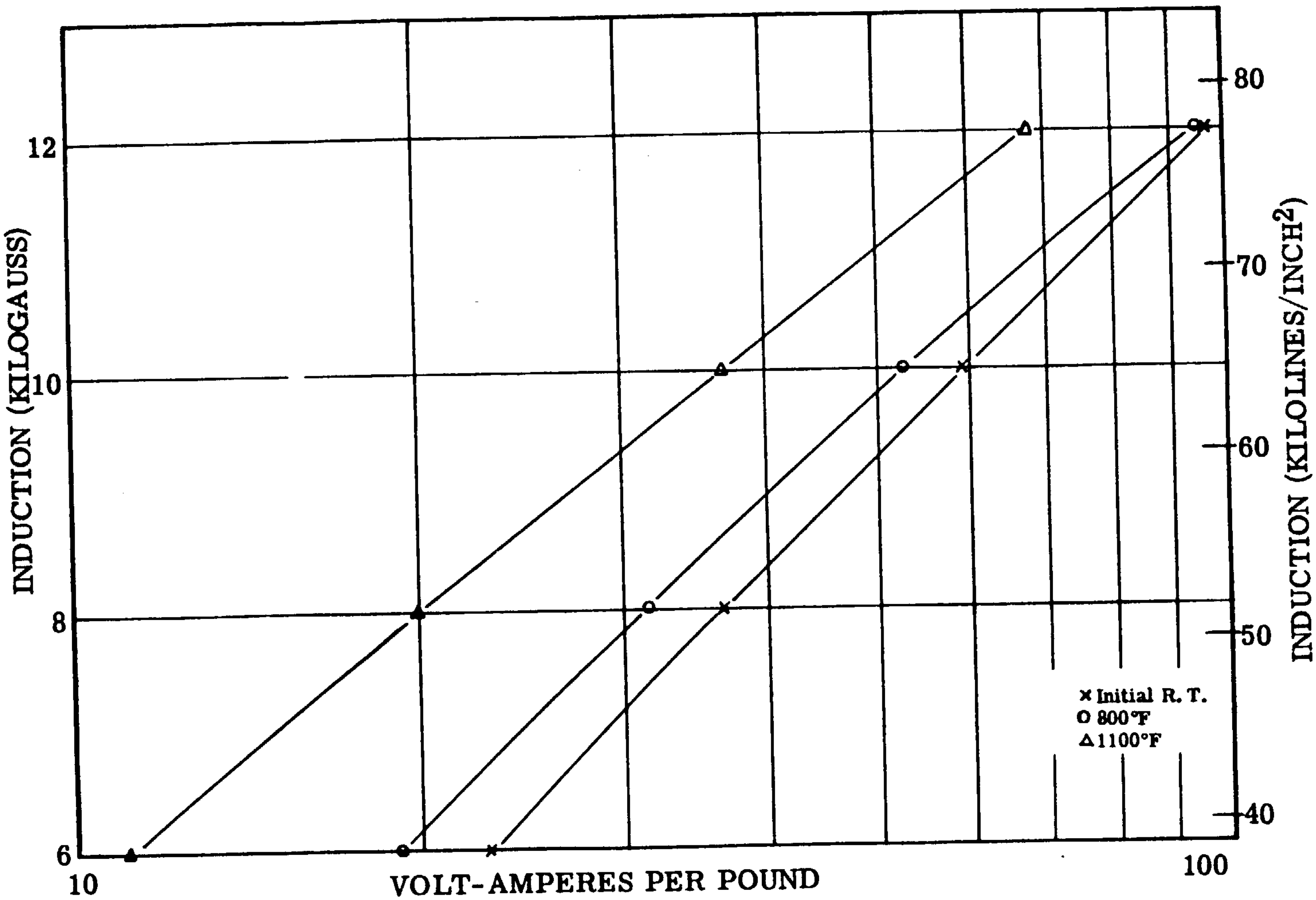


FIGURE IV.C.II-21. Exciting Volt-Amperes Per Pound, 800 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-21. Exciting VA, 800 CPS. Hiperco 27

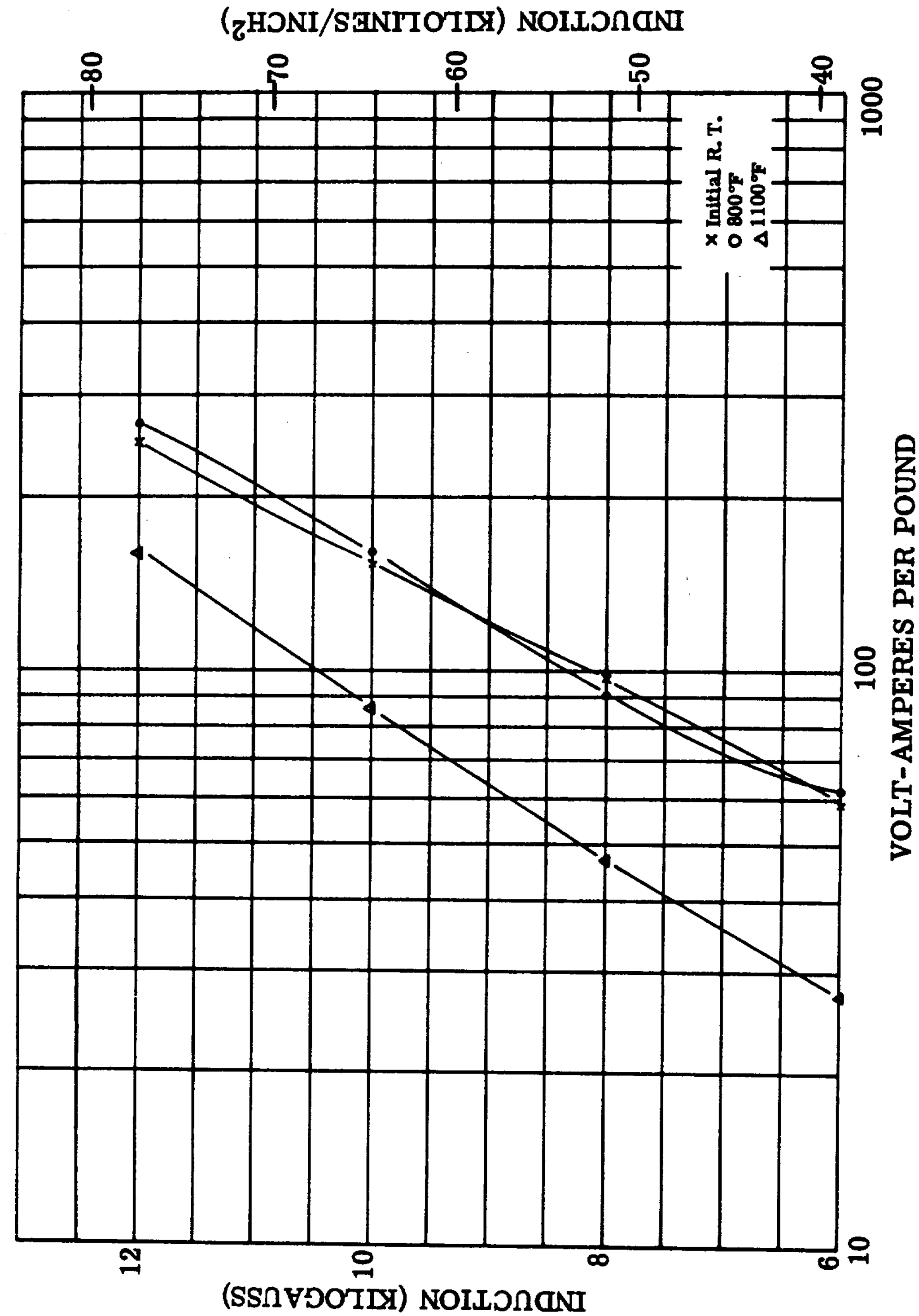


FIGURE IV.C.II-22. Exciting Volt-Amperes Per Pound, 1600 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-22. Exciting VA, 1600 CPS. Hiperco 27

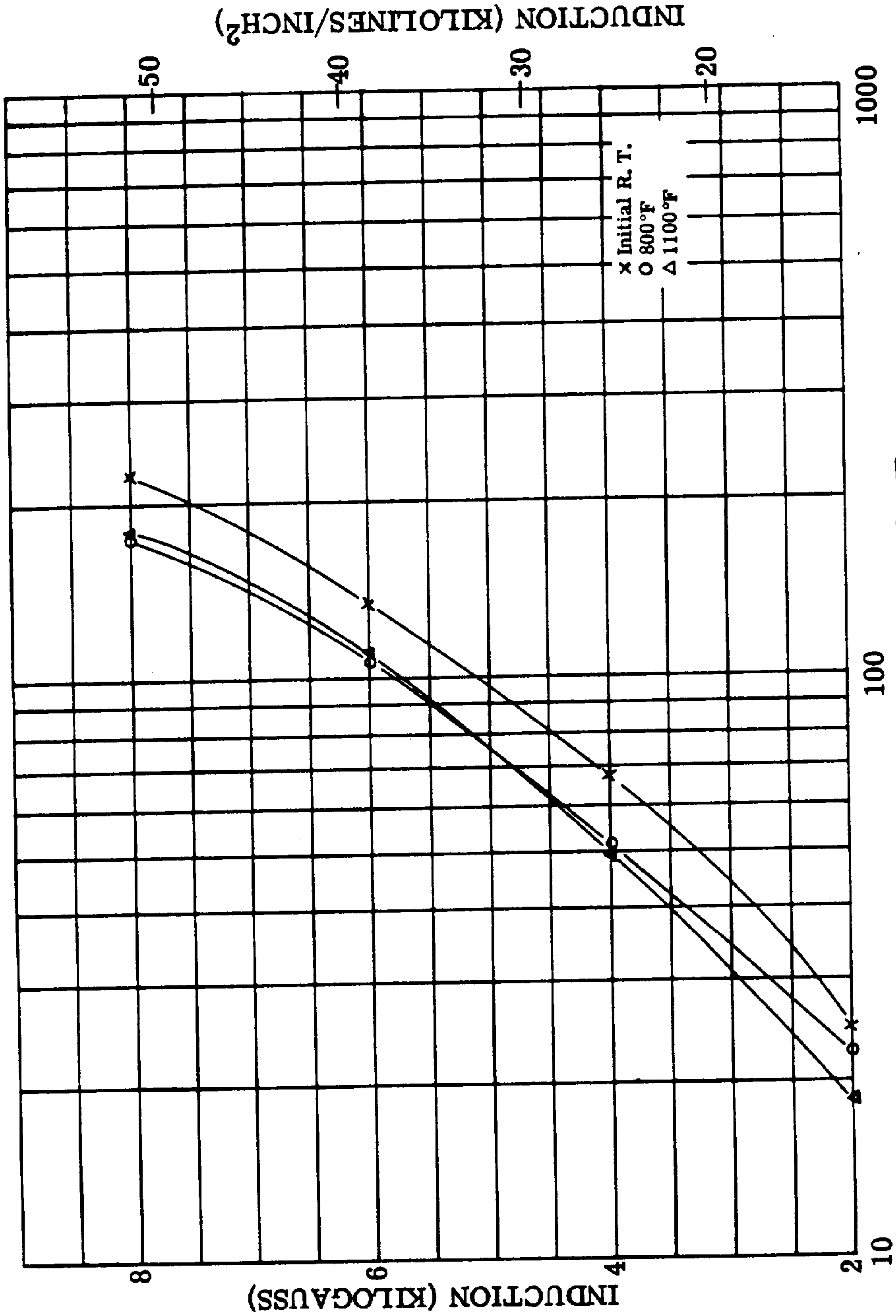


FIGURE IV.C.II-23. Exciting Volt-Amperes Per Pound, 3200 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-23. Exciting VA, 3200 CPS. Hiperco 27

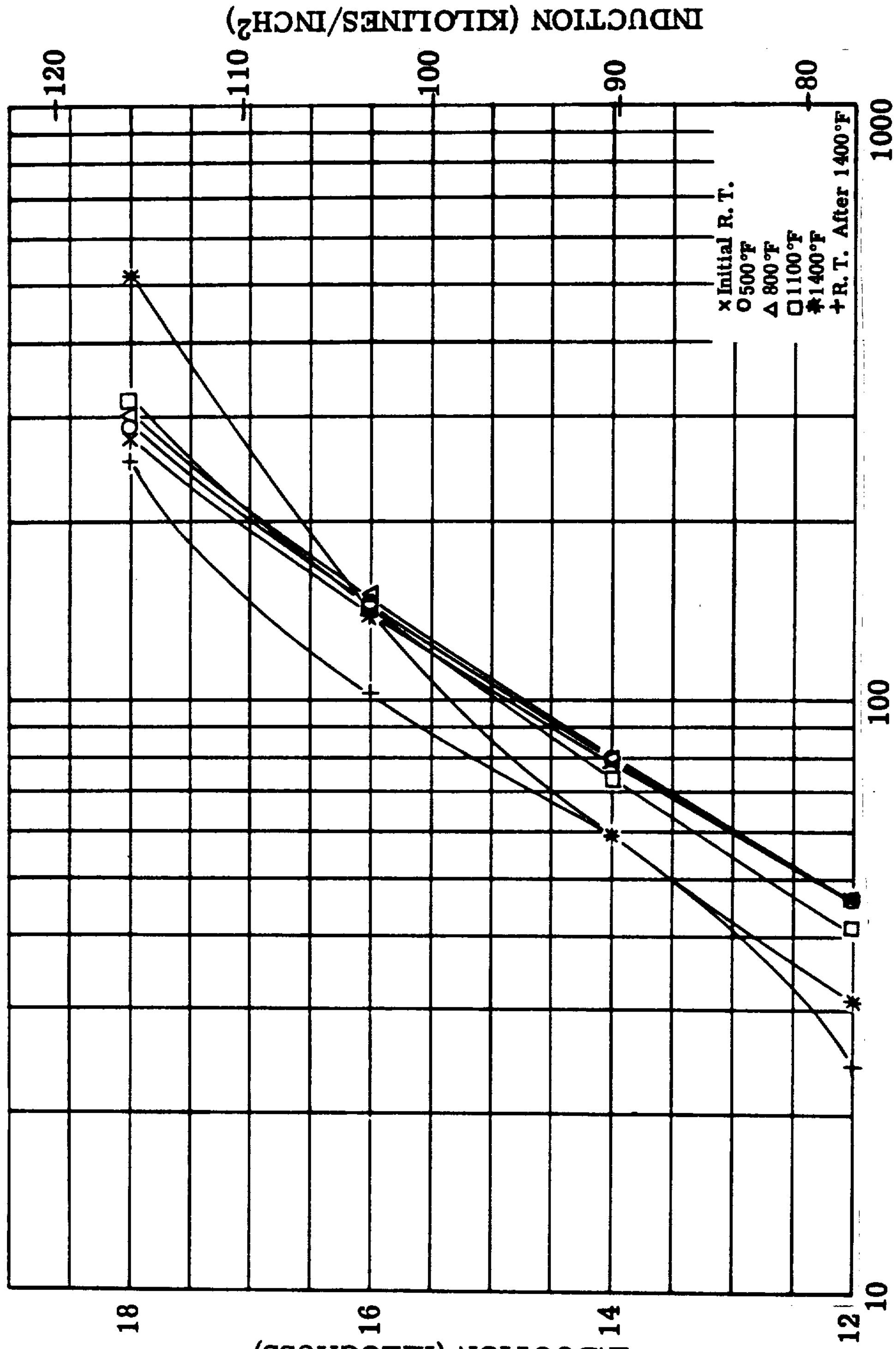


FIGURE IV.C.II-24. Exciting Volt-Amperes Per Pound, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-24. Exciting VA, 400 CPS. Hiperco 27

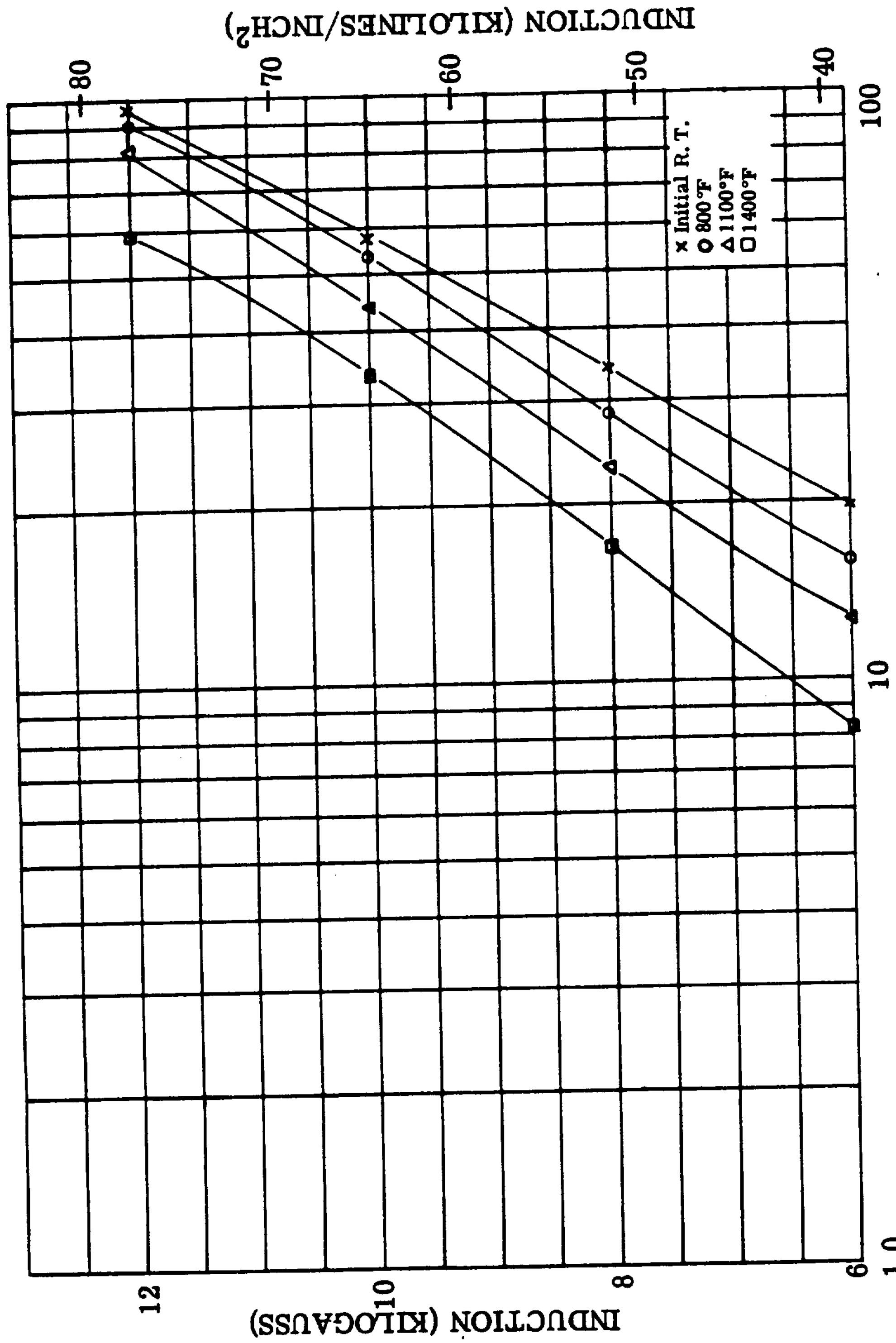


FIGURE IV.C.II-25. Exciting Volt-Amperes Per Pound, 800 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS3-4162)

Figure IV.C.II-25. Exciting VA, 800 CPS. Hiperco 27

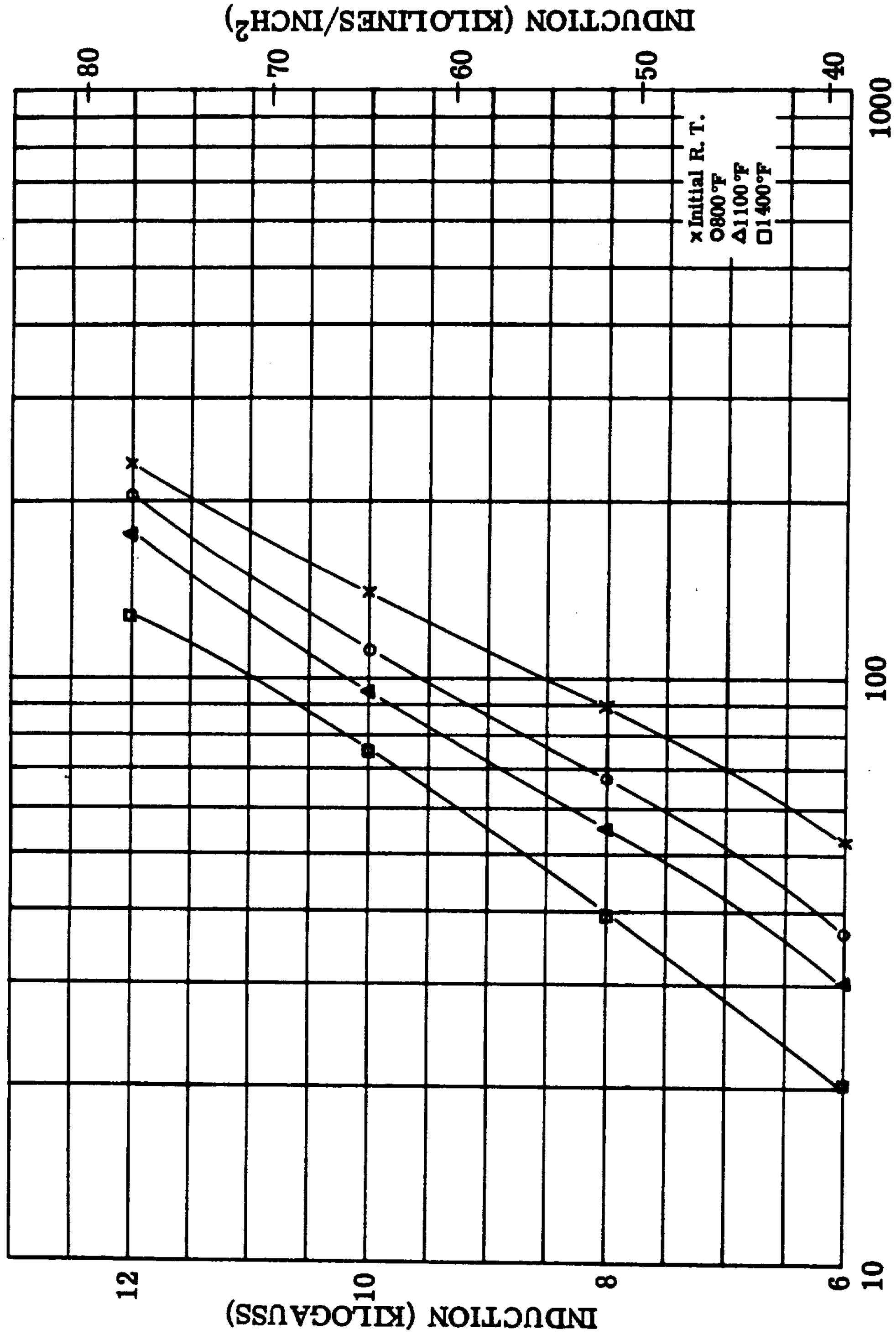


FIGURE IV.C.II-26. Exciting Volt-Amperes Per Pound, 1600 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS3-4162)

Figure IV.C.II-26. Exciting VA, 1600 CPS. Hiperco 27

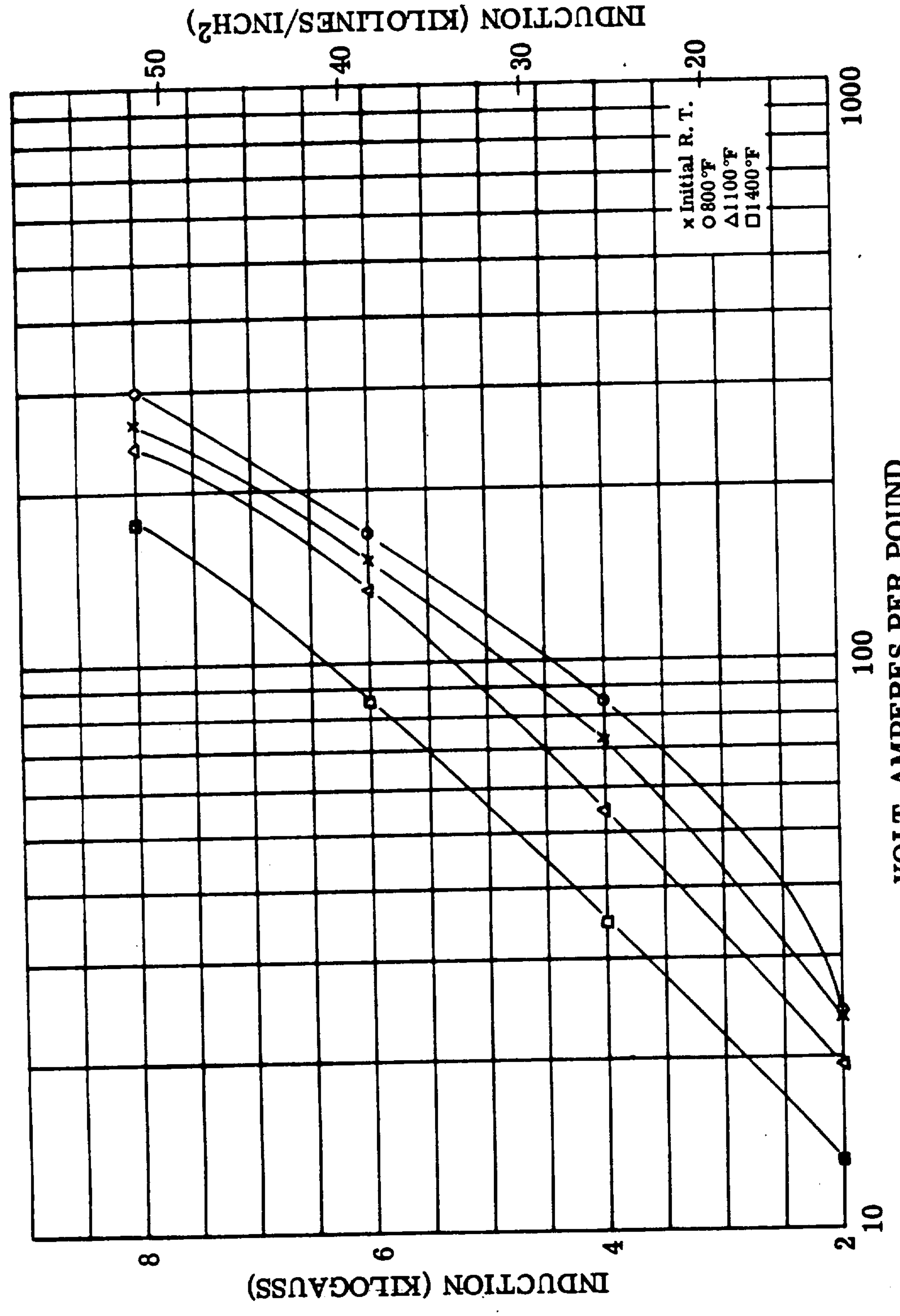


FIGURE IV.C.II-27. Exciting Volt-Amperes Per Pound, 3200 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-27. Exciting VA, 3200 CPS. Hiperco 27

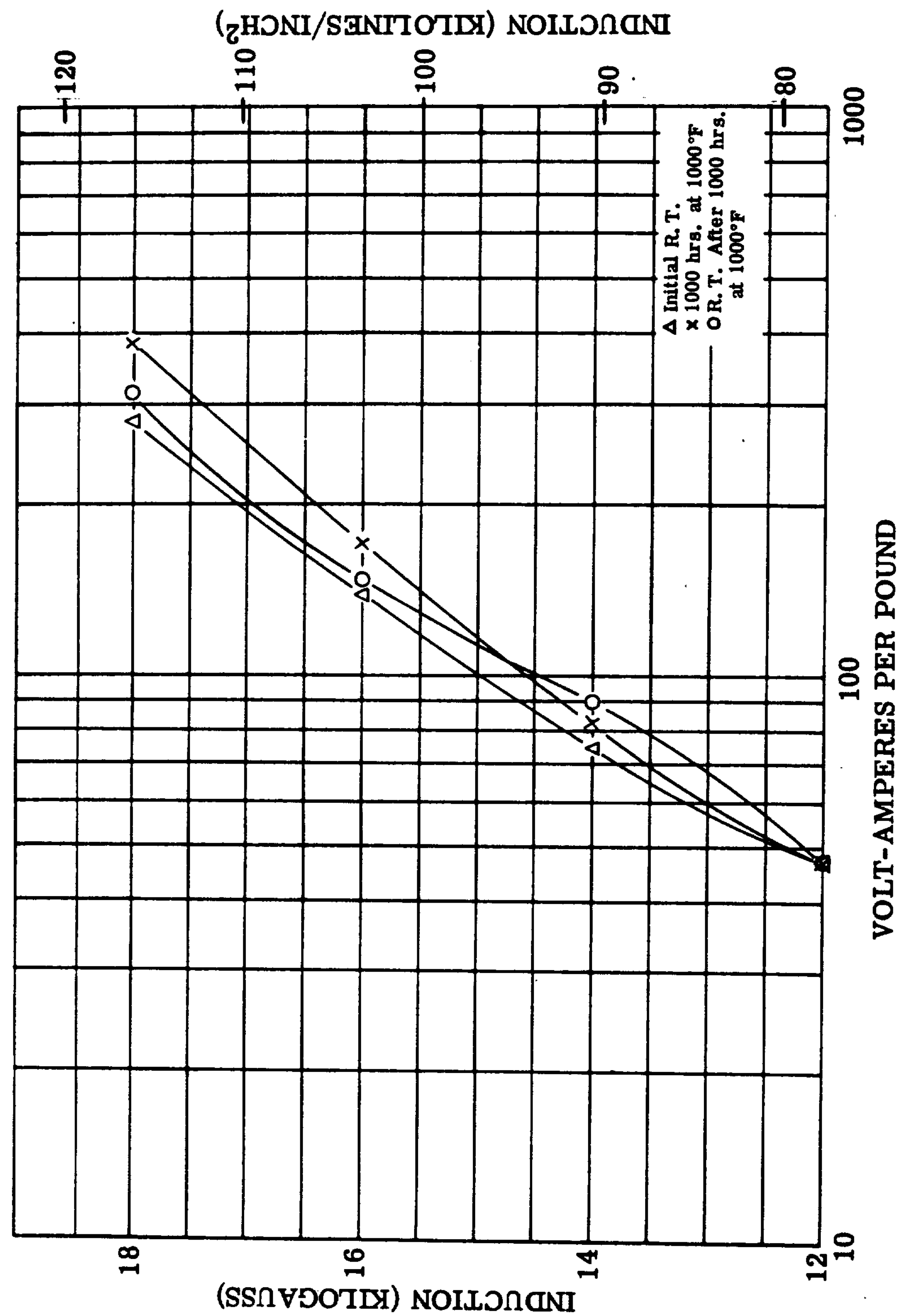


FIGURE IV.C.II-28. Exciting Volt-Amperes Per Pound, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Aging Test - Sample #5. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-28. Exciting VA, 400 CPS. Hiperco 27

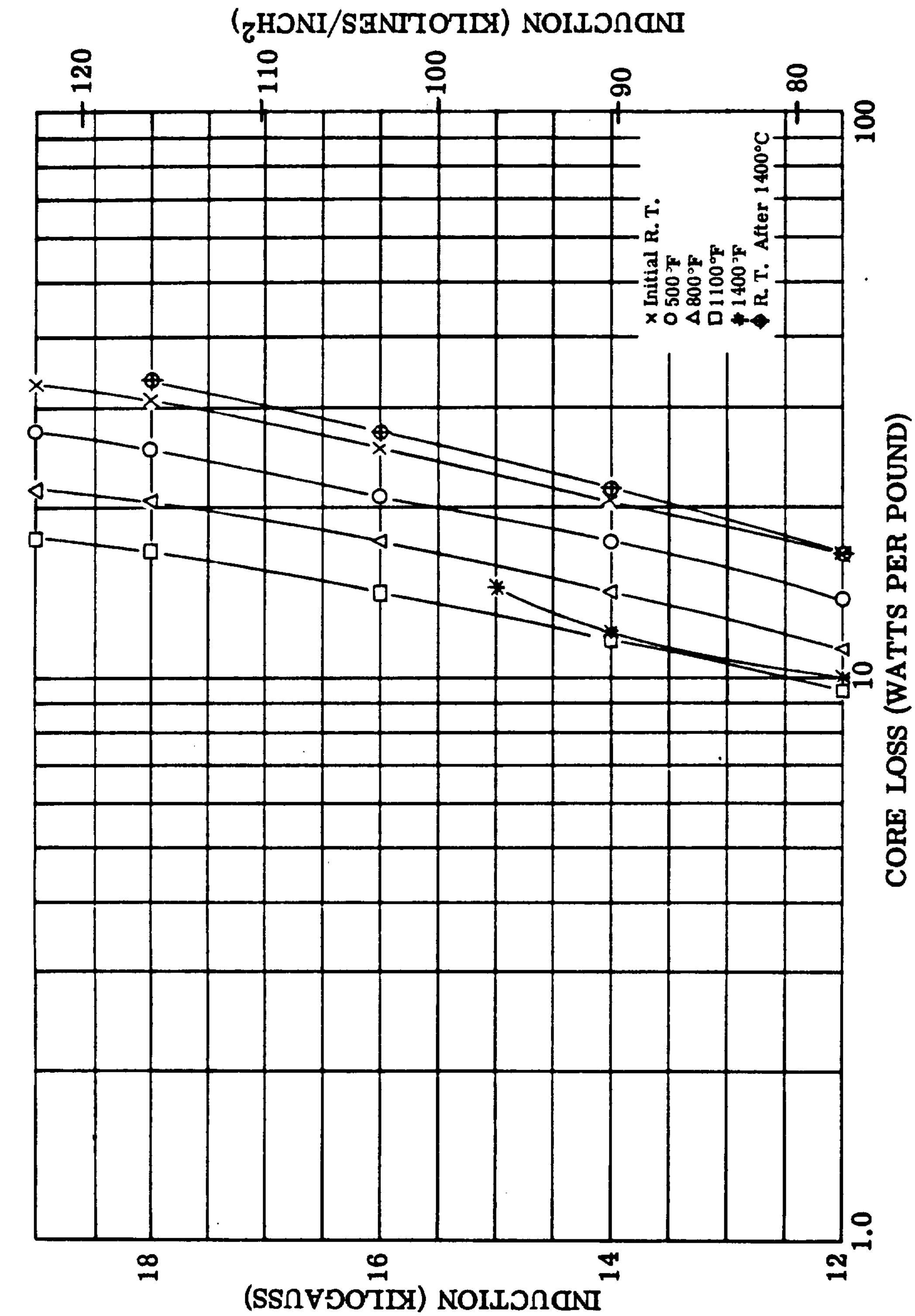


FIGURE IV.C.II-29. Core Loss, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-29. Core Loss, 400 CPS. Hiperco 27

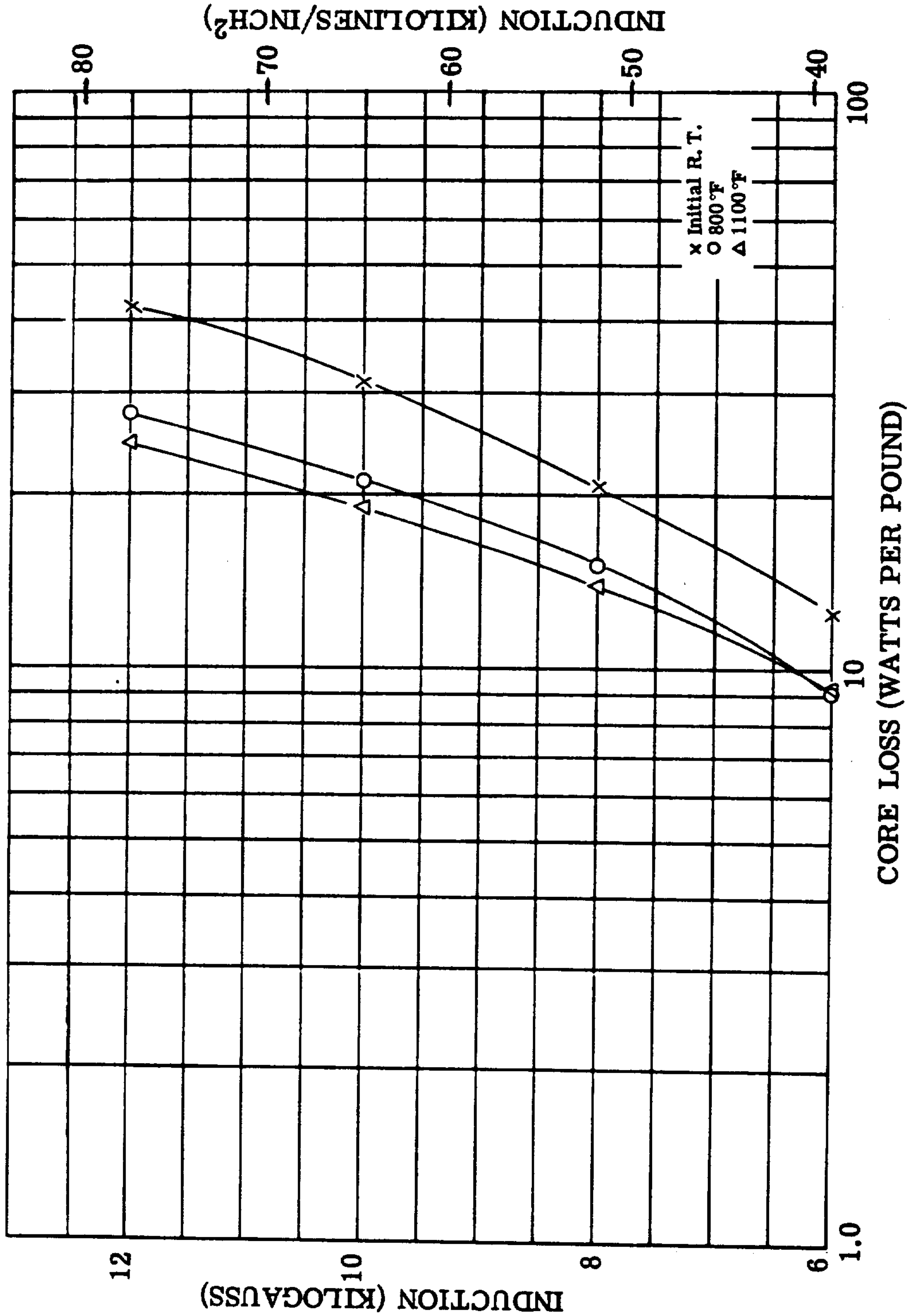


FIGURE IV.C.II-31. Core Loss, 800 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-30. Core Loss, 800 CPS. Hiperco 27

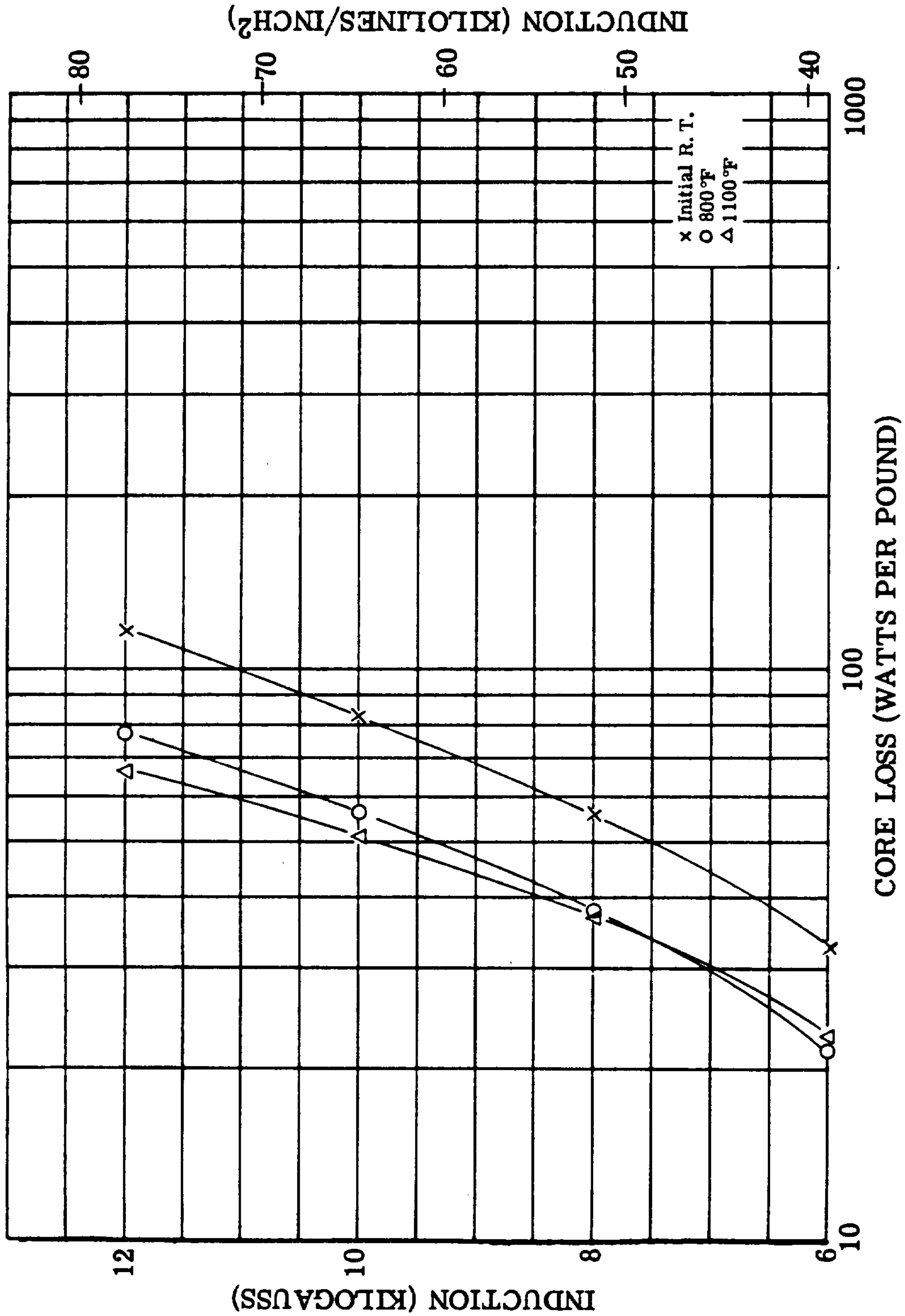


FIGURE IV.C.II-30. Core Loss, 1600 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-31. Core Loss, 1600 CPS. Hiperco 27

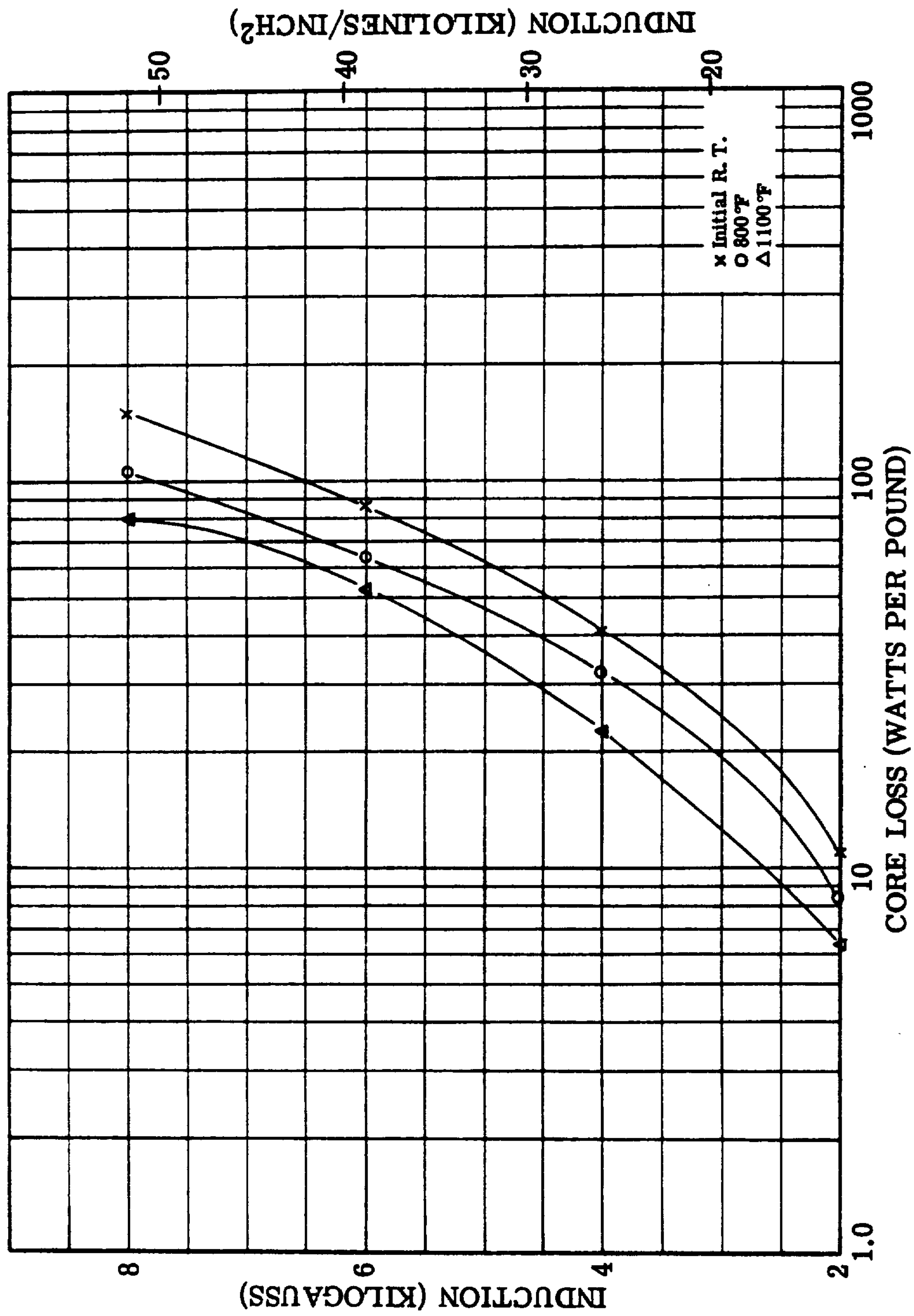


FIGURE IV.C.II-32. Core Loss, 3200 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #3. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.C.II-32. Core Loss, 3200 CPS. Hiperco 27

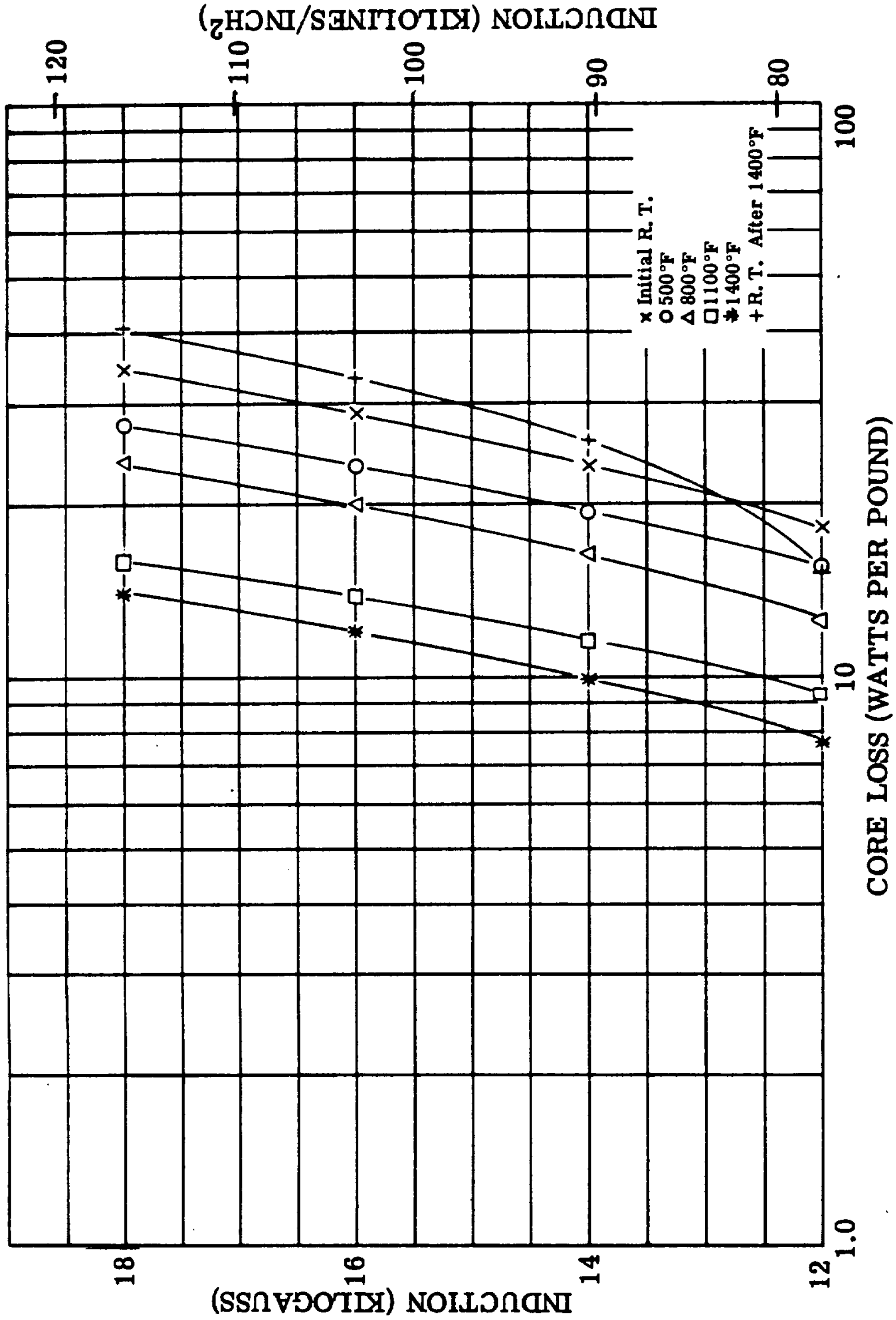


FIGURE IV.C.II-33. Core Loss, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite.
(Reference: NAS3-4162)

Figure IV.C.II-33. Core Loss, 400 CPS. Hiperco 27

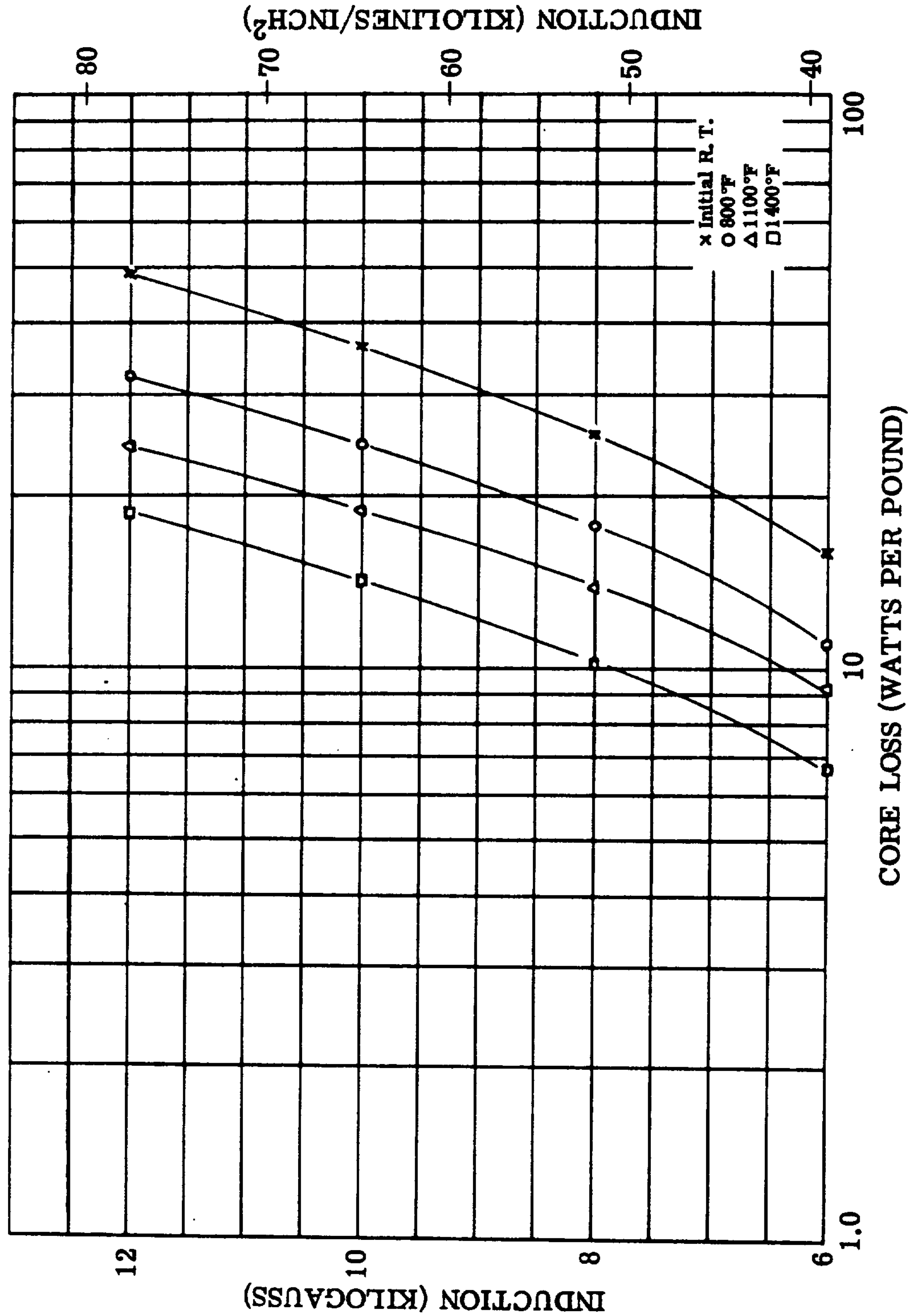


FIGURE IV.C.II-34. Core Loss, 800 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV. C. II-34. Core Loss, 800 CPS. Hiperco 27

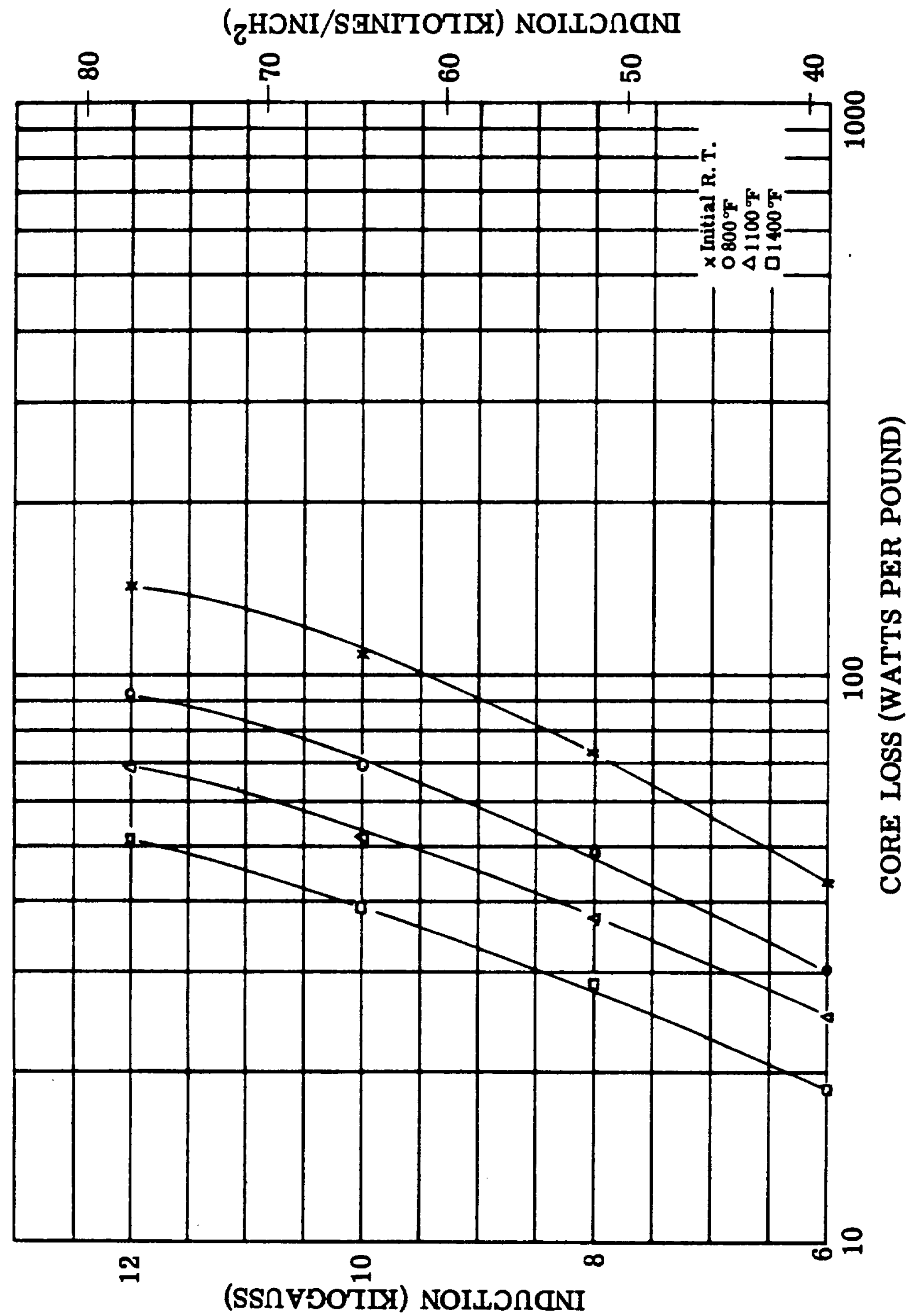


FIGURE IV.C.II-35. Core Loss, 1600 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite (Reference: NAS 3-4162)

Figure IV.C.II-35. Core Loss, 1600 CPS. Hiperco 27

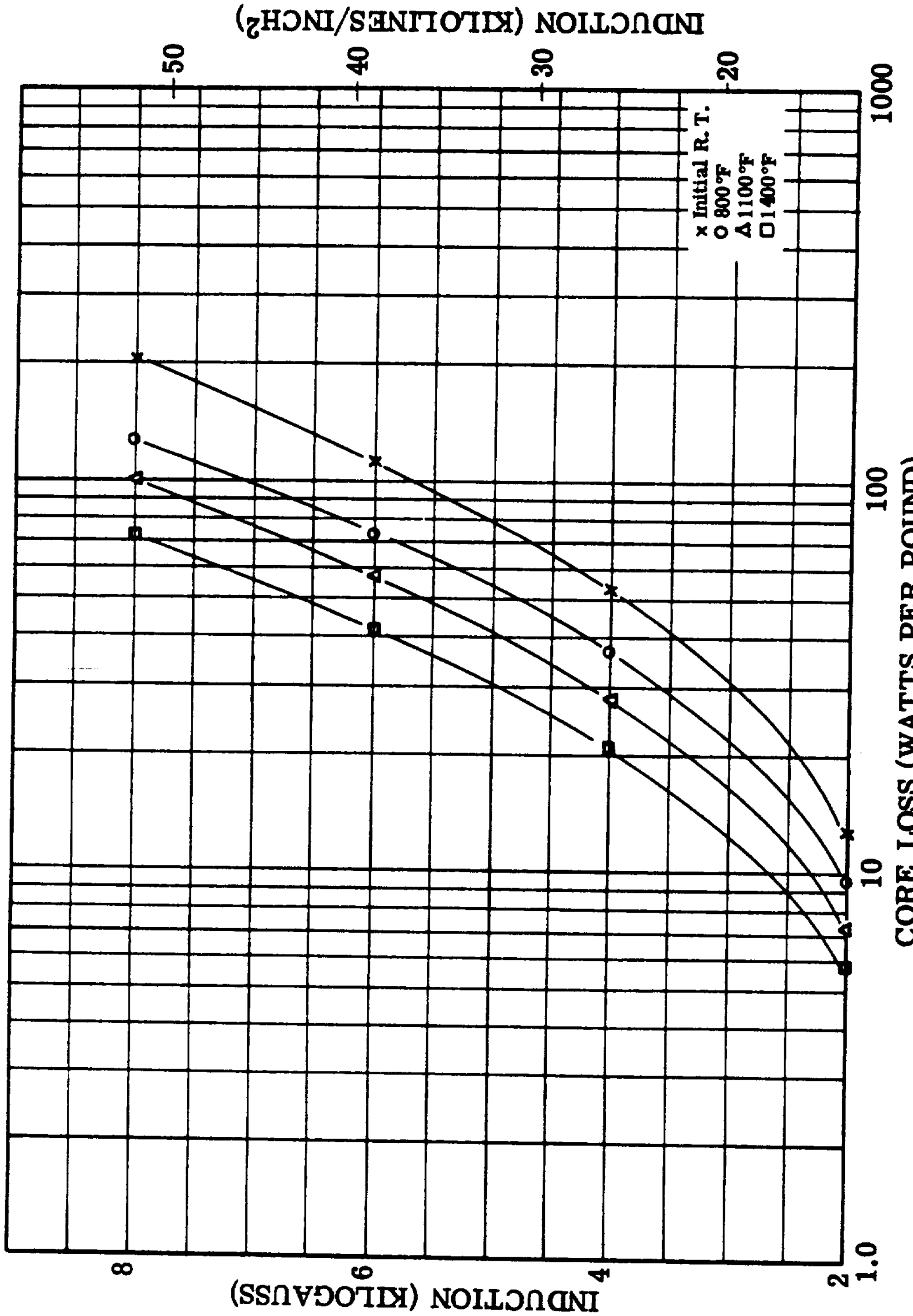


FIGURE IV.C.II-36. Core Loss, 3200 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Sample #4. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite (Reference: NAS3-4162)

Figure IV.C.II-36. Core Loss, 3200 CPS. Hiperco 27

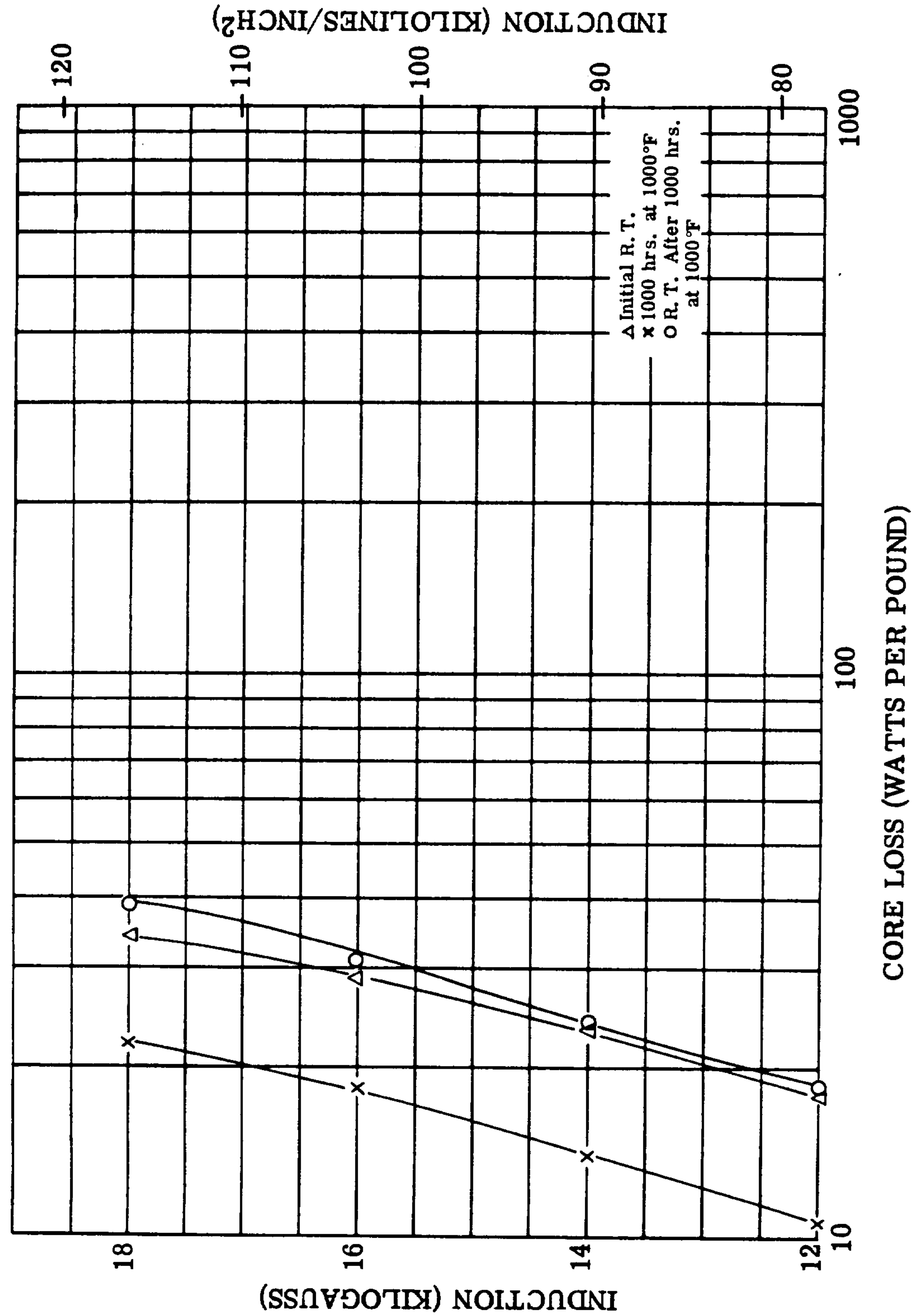


FIGURE IV.C.II-37. Core Loss, 400 CPS. Hiperco 27 Alloy - 0.008 Inch Laminations - Aging Test - Sample #5. Test Atmosphere: Argon. Interlaminar Insulation: Mica Aluminum Orthophosphate Bentonite. (Reference: NAS 3-4162)

Figure IV.C.II-37. Core Loss, 400 CPS. Hiperco 27

TABLE I V. C. III-1. Poisson's Ratio For Hiperco 27 Alloy at Room Temperature

Specimen No.	Run No.	Width (Inches)	Thickness (Inches)	Poisson's Ratio*	Average Poisson's Ratio
1	1 2 3	0. 749	0. 124	0. 305 0. 327 0. 329	0. 320
2	1 2 3	0. 749	0. 124	0. 330 0. 348 0. 328	0. 335

*These data were obtained from the stress strain plots in Figures I V. C. III-1 to -6 where $\mu = e/e_1$. μ = Poisson's Ratio
e/e_1 is the ratio of unit lateral strain to unit axial strain below the elastic limit.

(Reference: NAS3-4162)

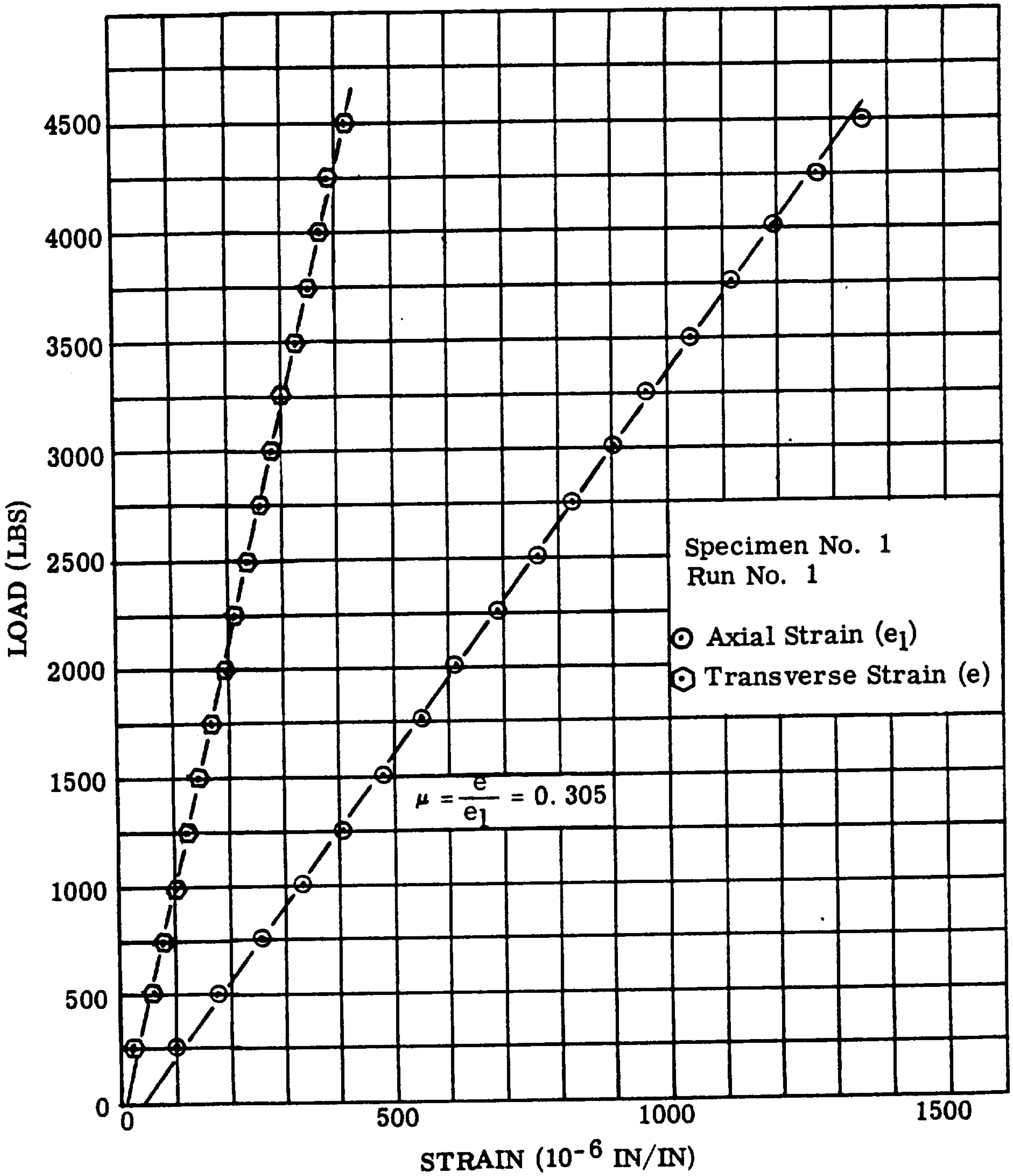


FIGURE IV. C. III-1. Elastic Strain Versus Load For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure IV. C. III-1. Poisson's Ratio - Hiperco 27

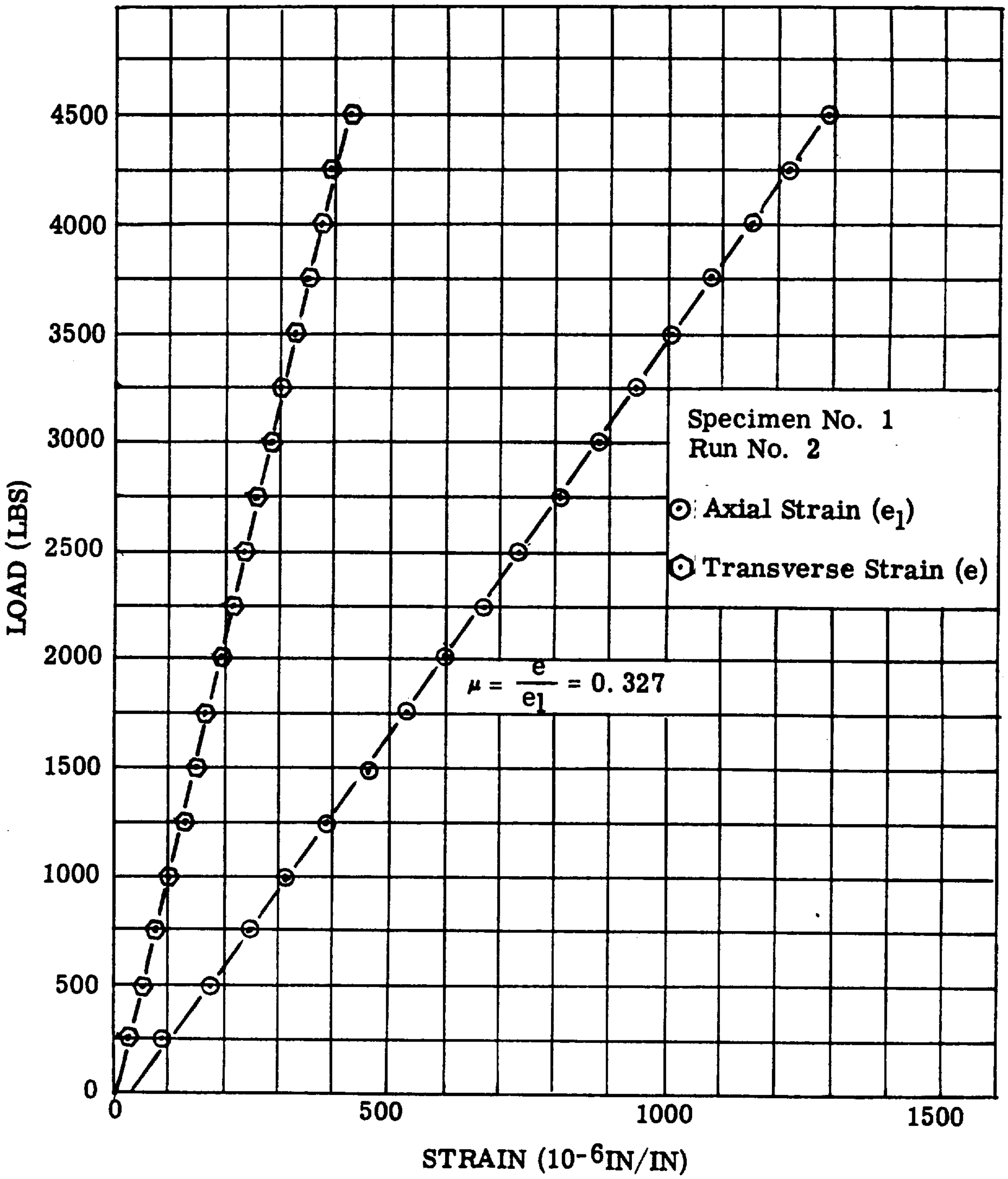


FIGURE IV. C. III-2. Elastic Strain Versus Load For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure IV. C. III-2. Poisson's Ratio - Hiperco 27

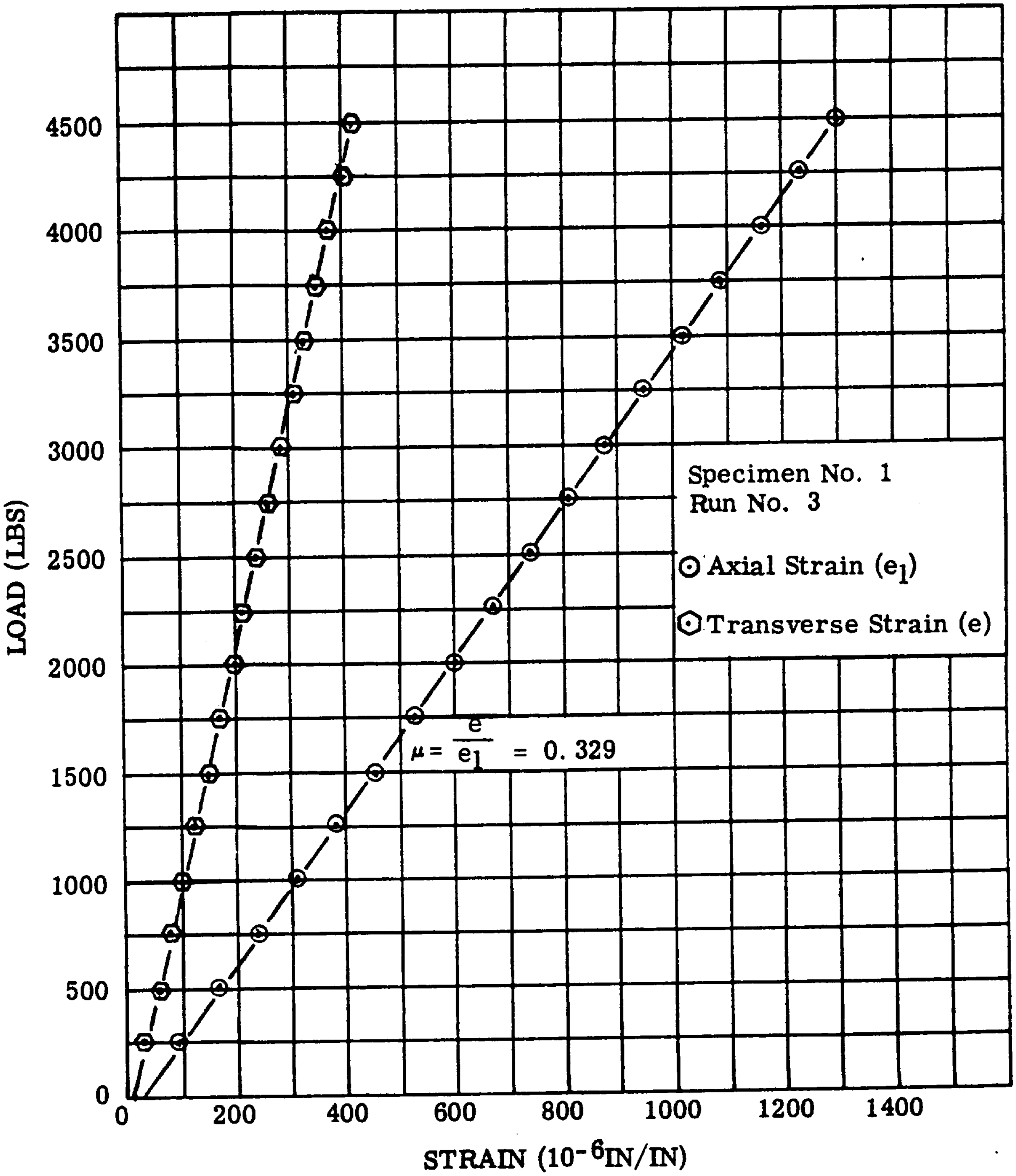


FIGURE IV. C. III-3. Elastic Strain Versus Load For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure IV. C. III-3. Poisson's Ratio - Hiperco 27

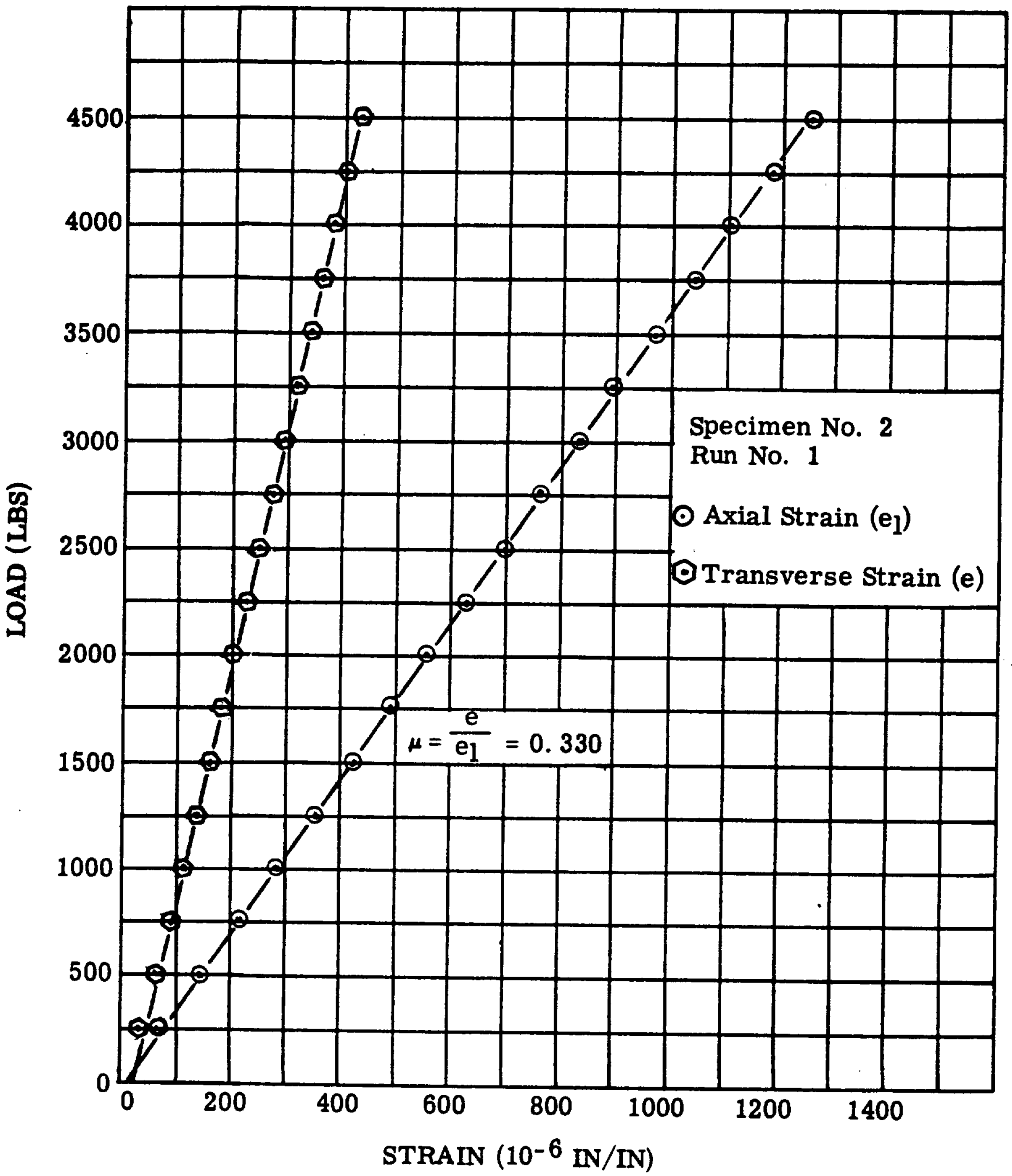


FIGURE IV. C. III-4. Elastic Strain Versus Load For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure IV. C. III-4. Poisson's Ratio - Hiperco 27

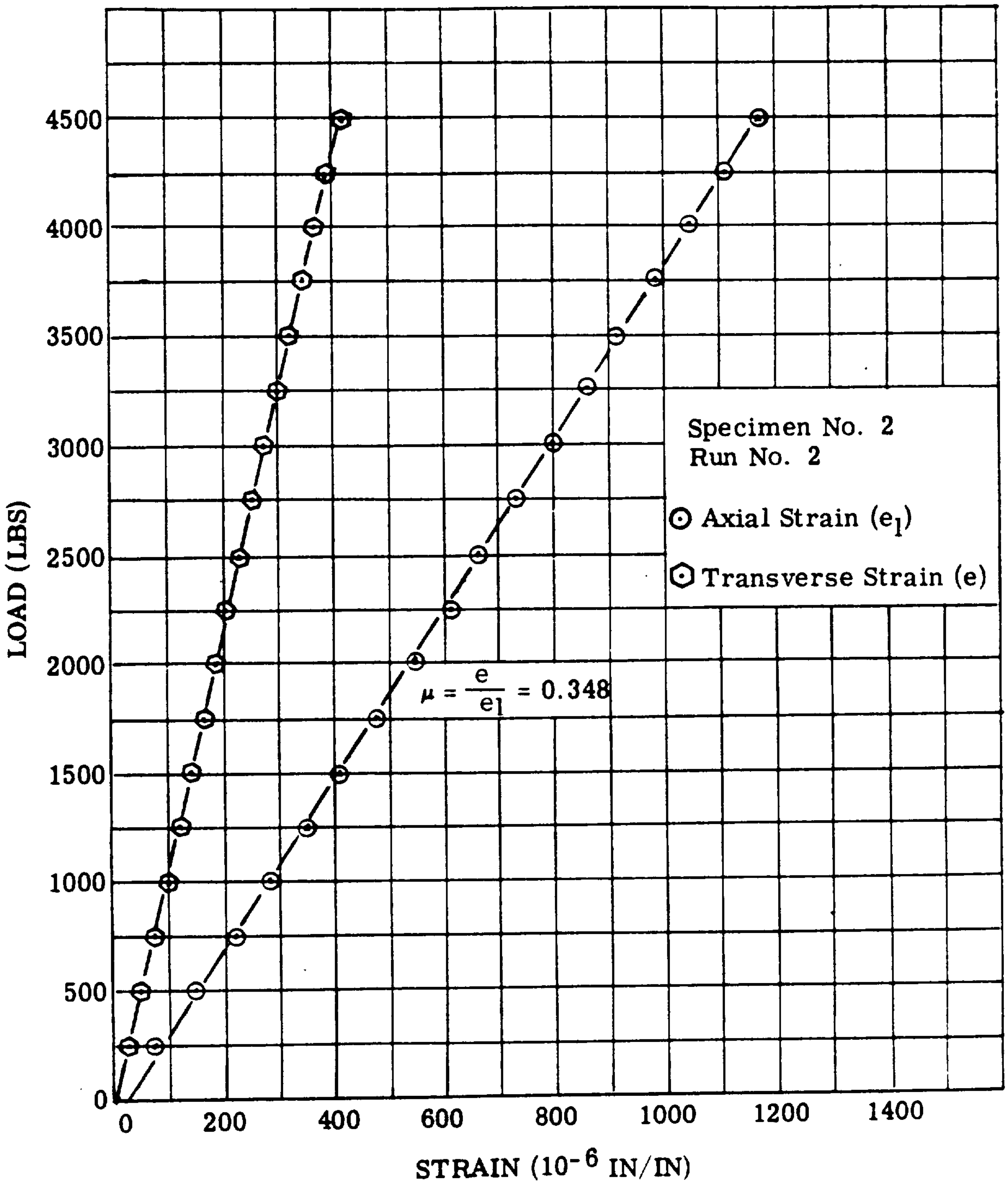


FIGURE I V. C. III-5. Elastic Strain Versus Load For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure I V. C. III-5. Poisson's Ratio - Hiperco 27

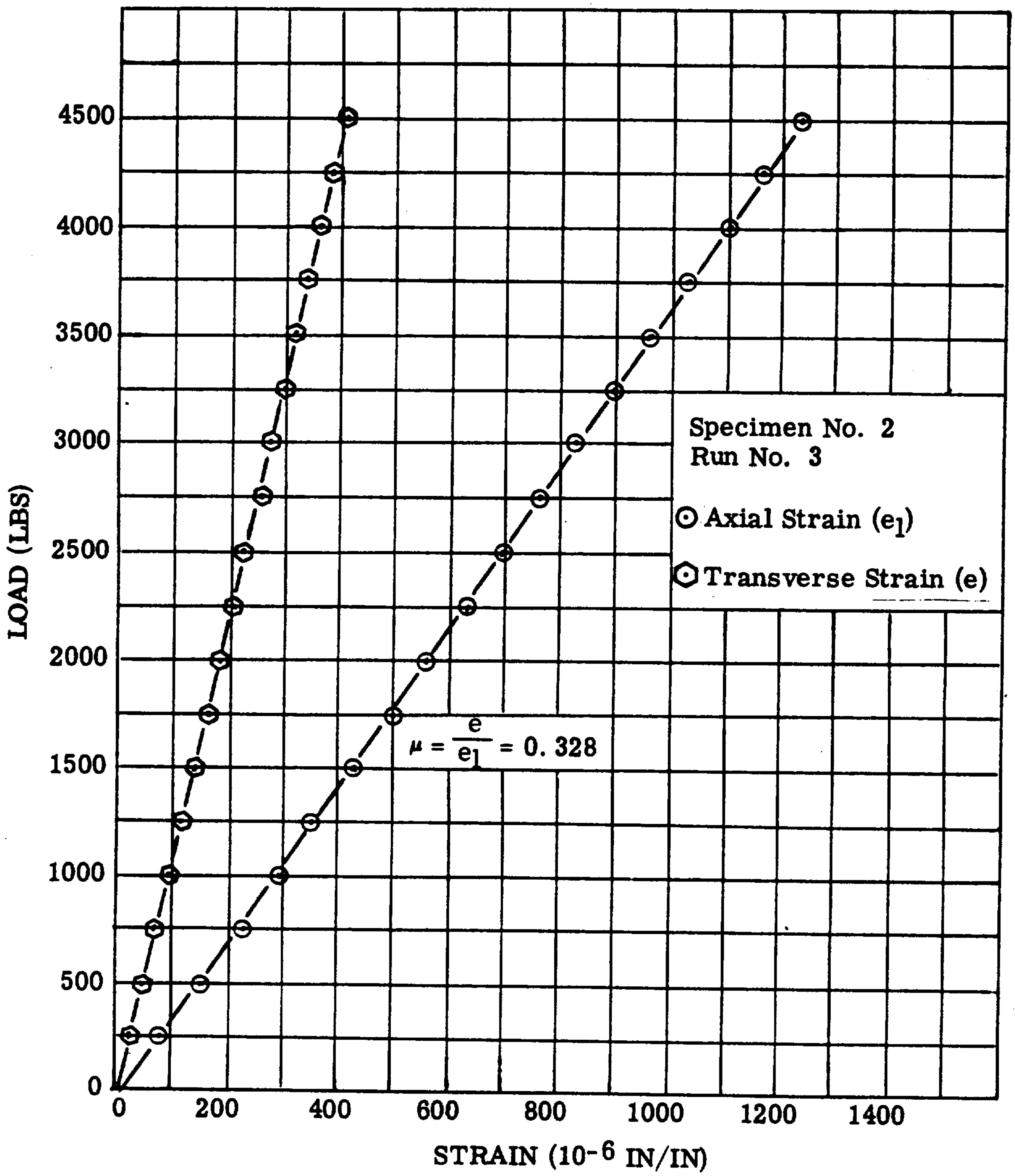


FIGURE IV. C. III-6. Elastic Load Versus Strain For Hiperco 27 Alloy Room Temperature Test (Reference: NAS3-4162)

Figure IV. C. III-6. Poisson's Ratio - Hiperco 27

TABLE IV.C.III-2. Tensile Test Data For Vacuum Melted Forged Hiperco 27 Alloy

TEST: ASTM E21 - Strain Rate: 0.005 in/in-min. to yield; 0.050 in/in-min to failure.

Specimen No.	Diameter (Inches)	Hardness (Rockwell B)	Test Temp. (°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)	Modulus of Elasticity (Psi x 10^6)	Heat No.
1	0.506	97/99	72	80,750	82,450	94,700	26.5	73.0	33.9	8067
2	0.505	95/96	72	68,600	68,760*	95,350	29.8	78.0	33.8	8027
3	0.506	95/95	500	62,550	72,500	84,550	24.1	76.4	-	8067+
4	0.506	96/96	500	74,850	81,300	89,000	19.9	74.1	-	8067+
5	0.505	96/97	700	49,550	52,200	85,950	25.1	75.5	27.5	8027
6	0.504	96/97	700	48,900	54,850	86,900	25.2	75.4	26.1	8027
7	0.505	96/97	1000	43,500	50,150	67,100	13.1	43.1	24.0	8027
8	0.505	96/97	1000	39,950	49,950	62,100	11.6	39.4	23.3	8027+
9	0.506	96/96	1400	7,950	10,850	13,050	71.5Q	89.1	-	8067+
10	0.506	96/96	1400	6,850	9,300	13,200	76.5Q	90.6	-	8067+

+ - Tested in Flowing Argon
- - Properties not required
Q - Quarter Break
* - Yield point exhibited by specimen

(Reference: NAS 3-4162)

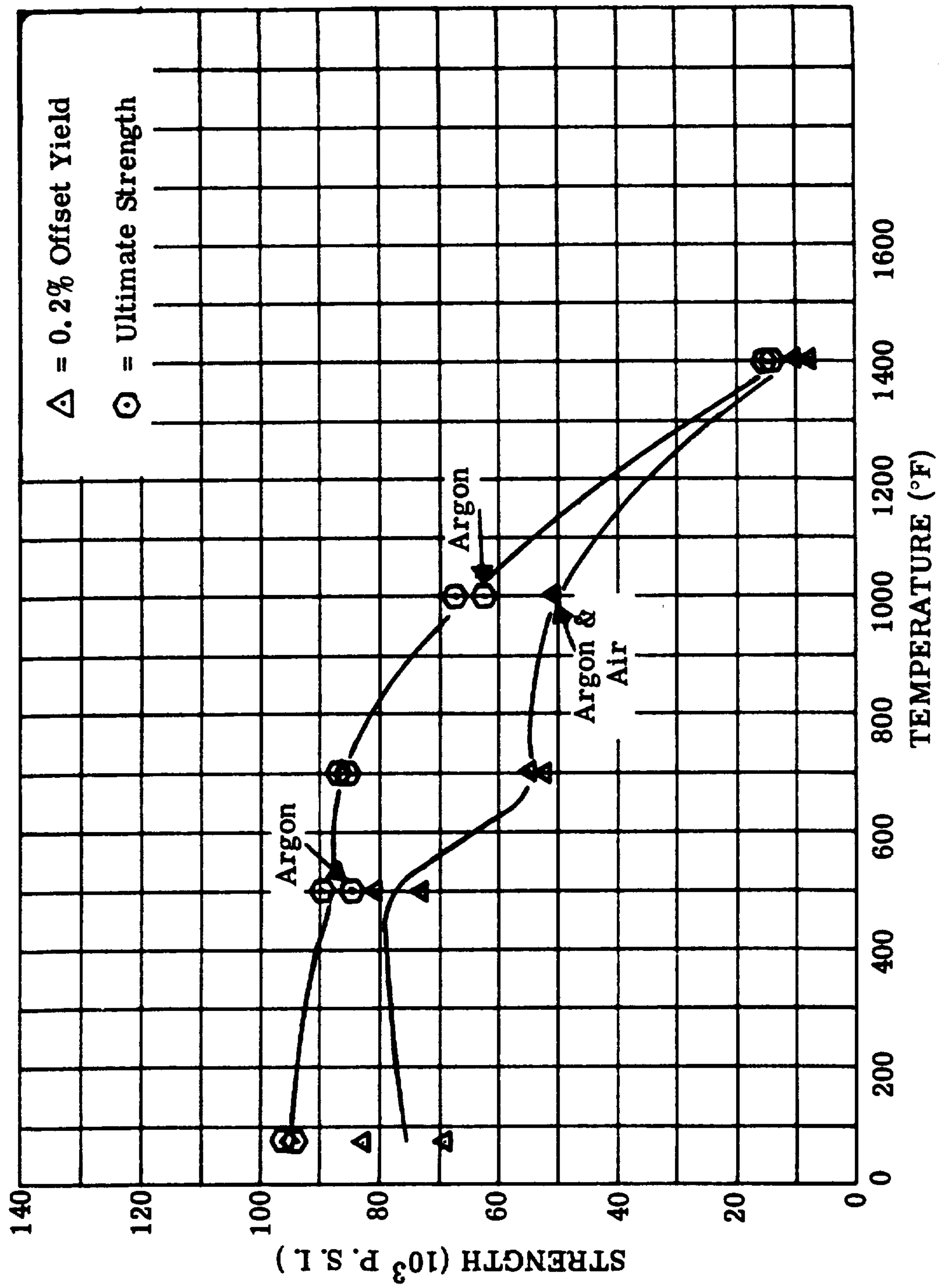


FIGURE IV.C.III-7. Tensile Strengths of Vacuum Melted Forged Hiperco 27 Alloy. Air and Argon Tests. Data Taken From Two Heats of Material. See Data Table IV.C.III-2. (Reference: NAS3-4162)

Figure IV.C.III-7. Tensile Properties - Hiperco 27

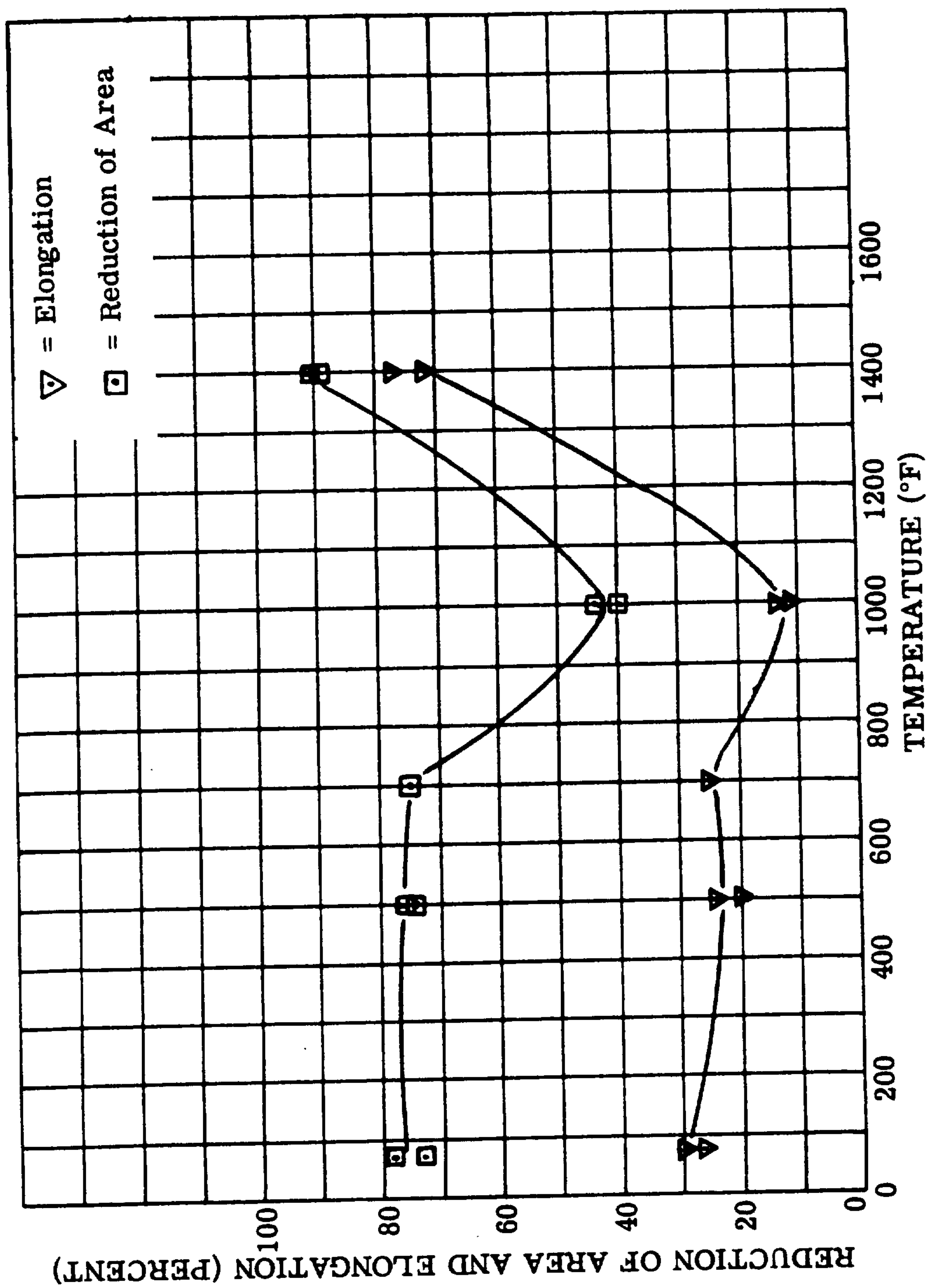


FIGURE IV. C. III-8. Tensile Elongations and Reductions of Area for Vacuum Melted Forged Hiperco 27 Alloy. Data Taken From Two Heats of Material. See Data Table IV. C. III-2. (Reference: NAS3-4162)

Figure IV. C. III-8. Tensile Ductility - Hiperco 27

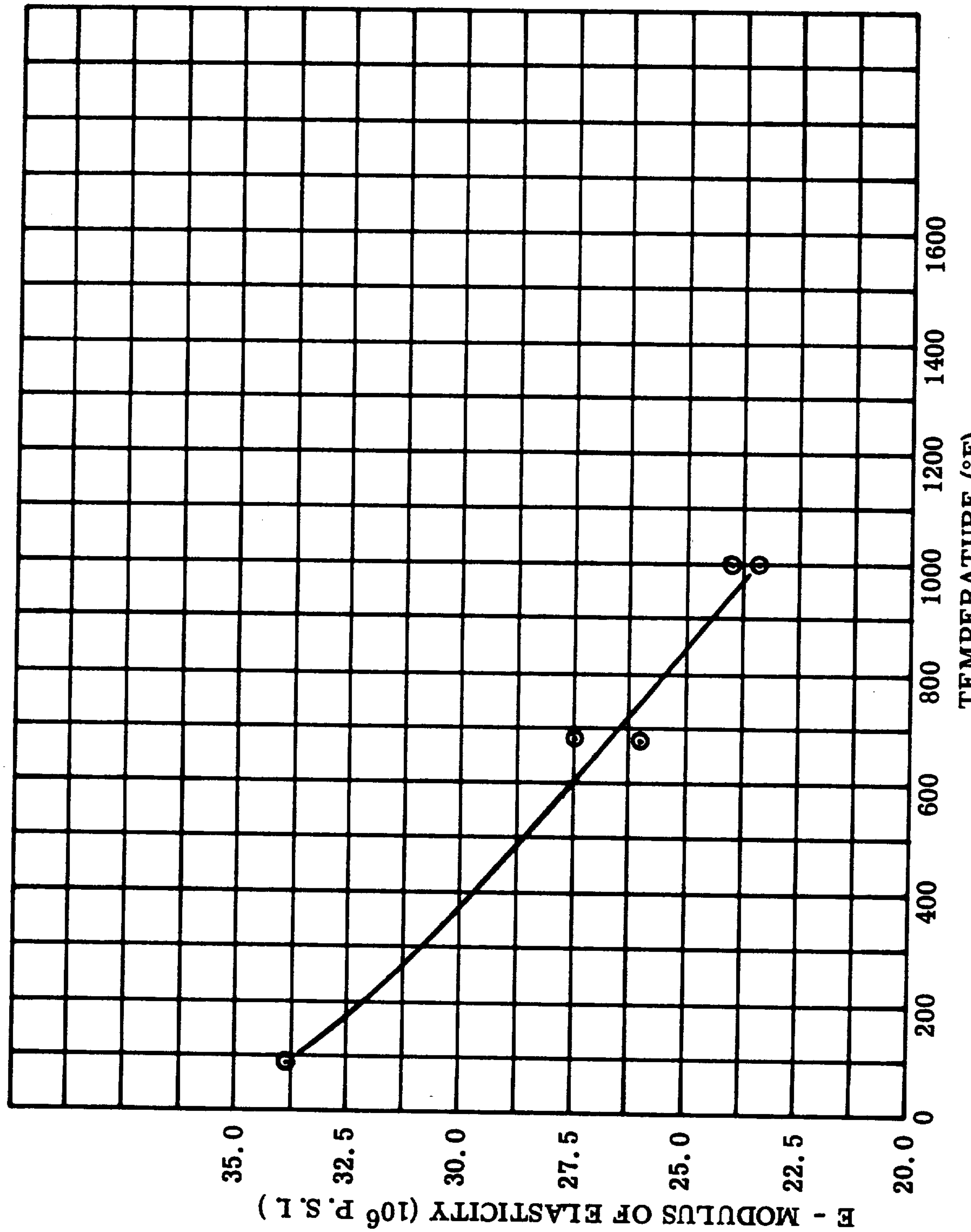


FIGURE IV. C. III-9. Modulus of Elasticity of Vacuum Melted Forged Hiperco 27 Alloy as a Function of Temperature. See Data Table IV. C. III-2. (Reference: NAS3-4162)

Figure IV. C. III-9. Young's Modulus - Hiperco 27

TABLE IV. C. III-3. Tensile Test Data For Hiperco 27 Alloy (Investment Cast and Annealed)

TEST: ASTM E21 - Strain Rate: 0.005 in/in-min to yield; 0.050 in/in-min to failure.

Spec. No.	Dia. (In.)	Hardness BHN (3000 KG)	Test Temp. (°F)	0.02 Percent Offset Yield Str. (Psi)	0.2 Percent Offset Yield Str. (Psi)	Ultimate Strength (Psi)	Elongation 1.4 Inches (percent)	Reduction of Area (percent)
1	0.250	149	72	33,800	43,200	65,800	2.4Q	1.6
2	0.250	166	72	37,800	44,600	62,750	1.5Q	0
4	0.249	153	500	26,500	35,300	73,300	27.0	59.1
5	0.250	153	500	27,900	31,550	71,900	29.2Q	48.7
6	0.250	153	700	31,250	34,100	67,400	14.4Q	28.1
7	0.251	156	700	32,850	40,000	72,200	21.5Q	39.5
8	0.250	166	1000	31,050	36,450	66,700	8.8Q	21.8
9	0.251	159	1000	26,450	31,300	55,950	9.3Q	21.8
10	0.251	159	1400	9,700	11,700	12,100	35.6Q	60.4
11	0.250	163	1400	8,850	10,850	12,300*	48.8Q	79.6

NOTE: BHN Converted from Rockwell B hardness readings

Q - Quarterbreak
* - Tested in argon atmosphere. All others tested in air. (Reference: NAS3-4162)

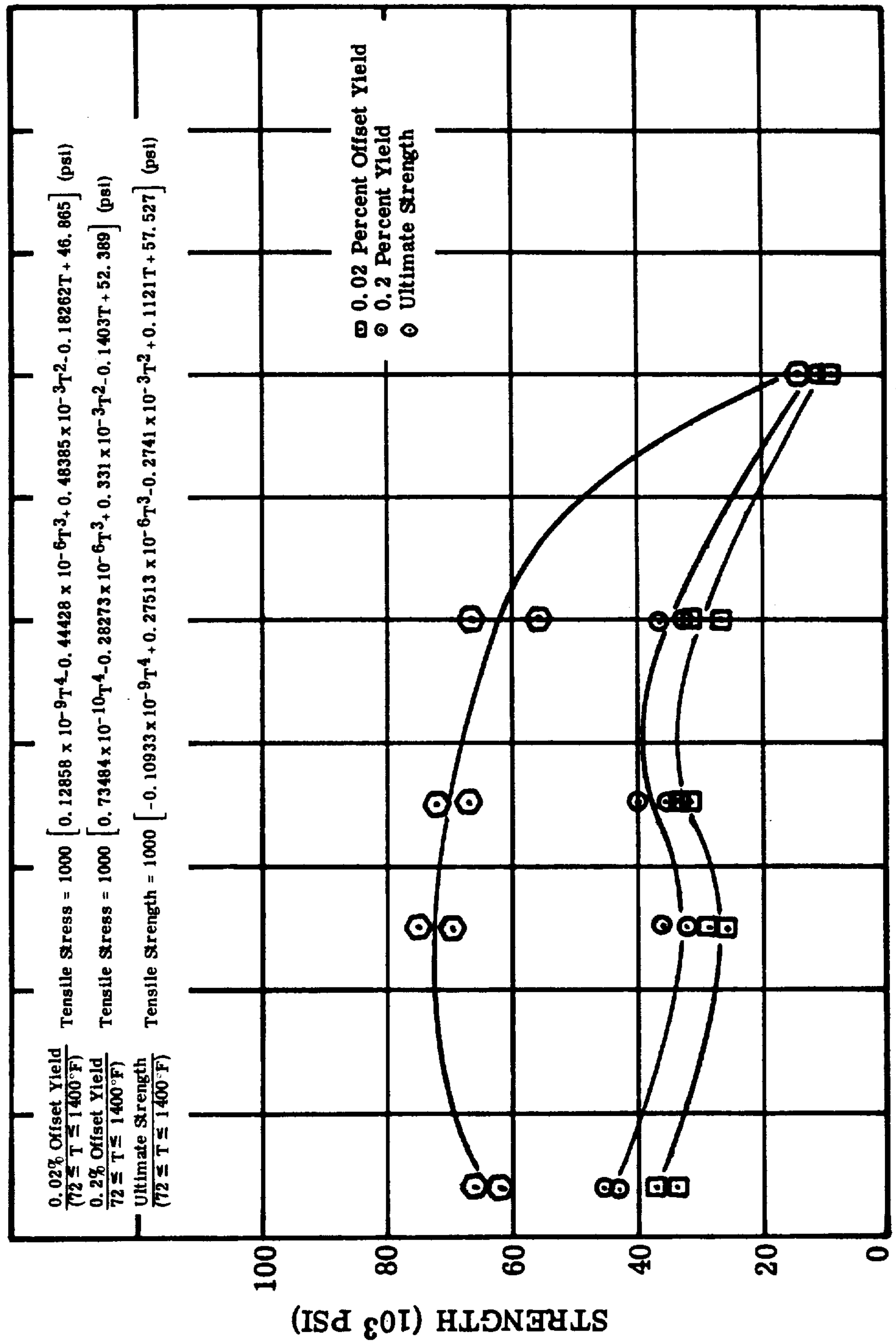


FIGURE IV. C. III-10. Tensile Strengths of Investment Cast and Annealed Hiperco 27 Alloy. Tests Made in Air. See Data Table IV. C. III-3. (Reference: NAS3-4162)

Figure IV. C. III-10. Tensile Properties - Cast Hiperco 27

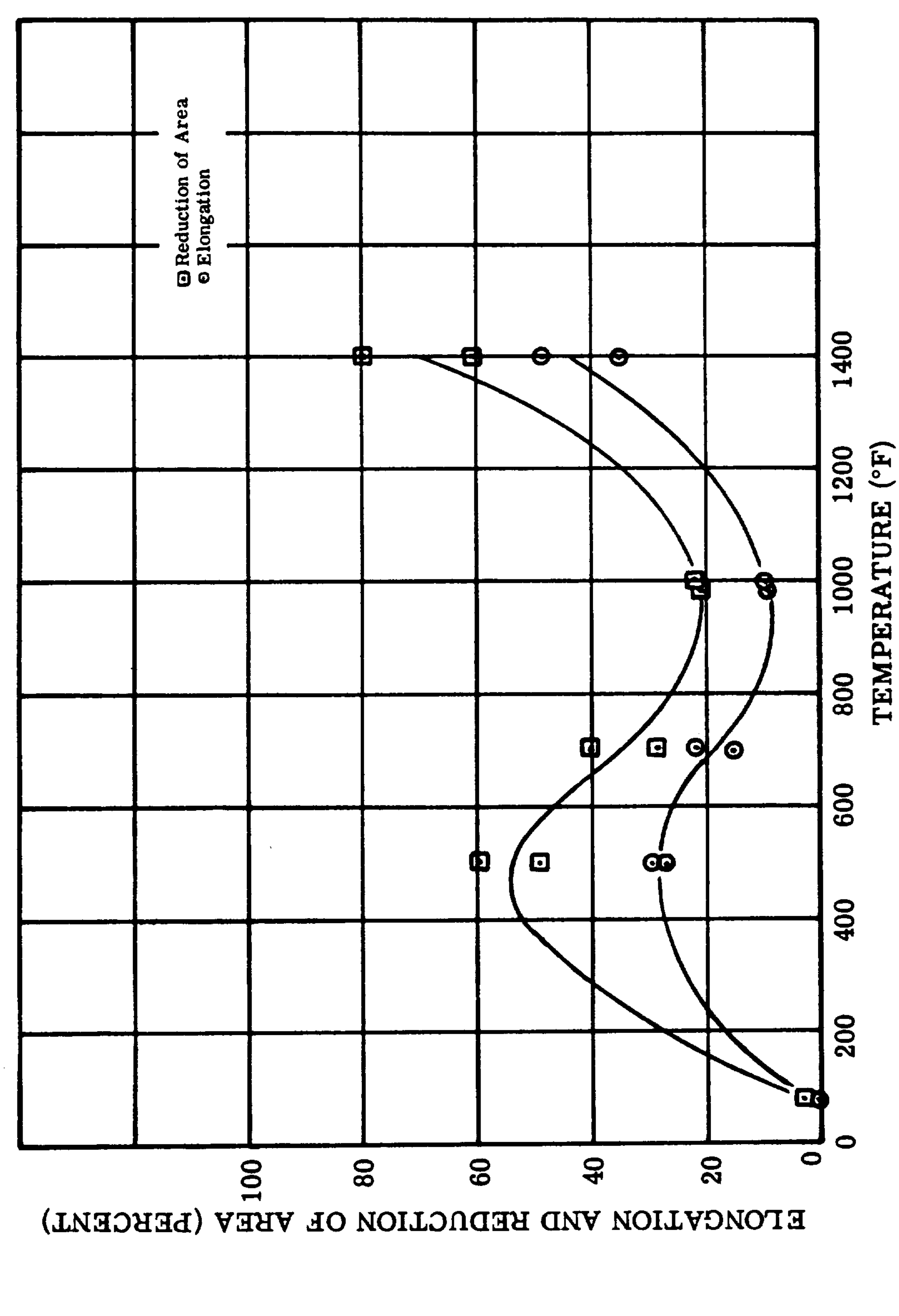


FIGURE IV. C. III-11. Tensile Elongations and Reductions of Area for Investment Cast and Annealed Hiperco 27 Alloy. Tests Made in Air. See Data Table IV. C. III-3. (Reference: NAS3-4162).

Figure IV. C. III-11. Tensile Ductility - Cast Hiperco 27

TABLE IV. C. III-4. Compression Test Data For Hiperco 27 Vacuum Melted Forged Bar Stock

TEST: ASTM E9 - Strain Rate: 0.05 in/in-min

Spec. No.	Dia. (In.)	Test Temp. (°F)	0.02 Percent Offset Yield Str. (Psi)	0.2 Percent Offset Yield Str. (Psi)	Modulus of Elasticity (Psi)
1	0.500	70	90,650	97,750	30.5×10^6
2	0.499	70	81,800	97,400	32.3×10^6
3	0.499	500	77,200	84,050	27.4×10^6
4	0.499	500	78,550	83,550	27.2×10^6
5	0.500	800	71,800	81,450	27.3×10^6
6	0.500	800	70,000	80,450	27.2×10^6
7	0.500	1100	47,350	58,300	26.0×10^6
8	0.500	1100	61,100	66,200	24.0×10^6
9	0.500	1400	10,500	15,500	18.6×10^6
10	0.500	1400	9,150	14,600	20.7×10^6

All tests made in air. (Reference: NAS3-4162)

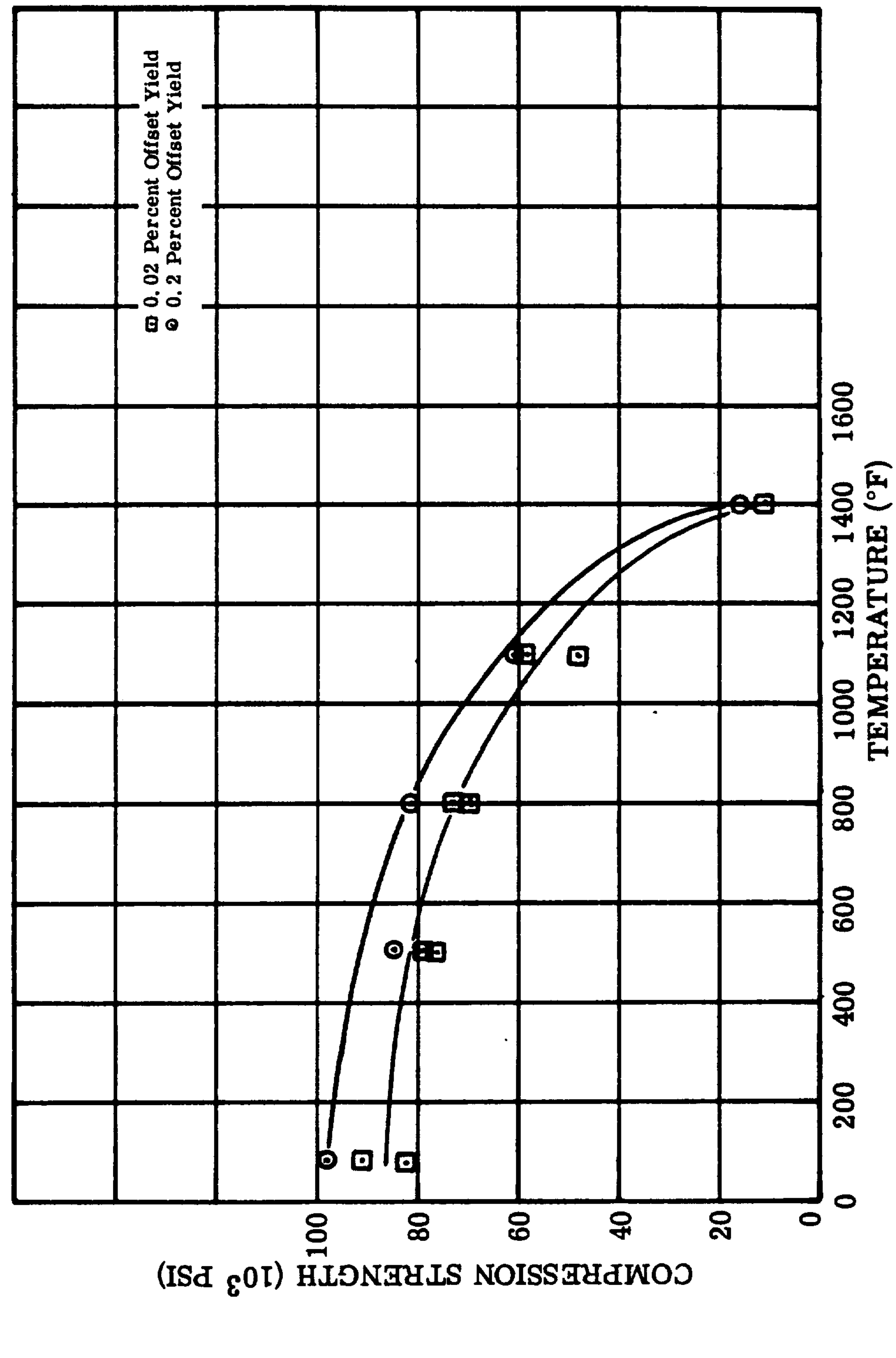


FIGURE IV. C. III-12. Compression Strengths, 0.50 Inch Diameter Hiperco 27 Alloy Vacuum Melted Forged Bar Stock. Tests Made in Air. Strain Rate: 0.05 in/in-min. See Data Table IV. C. III-4. (Reference: NAS3-4162)

Figure IV. C. III-12. Compressive Strengths - Hiperco 27

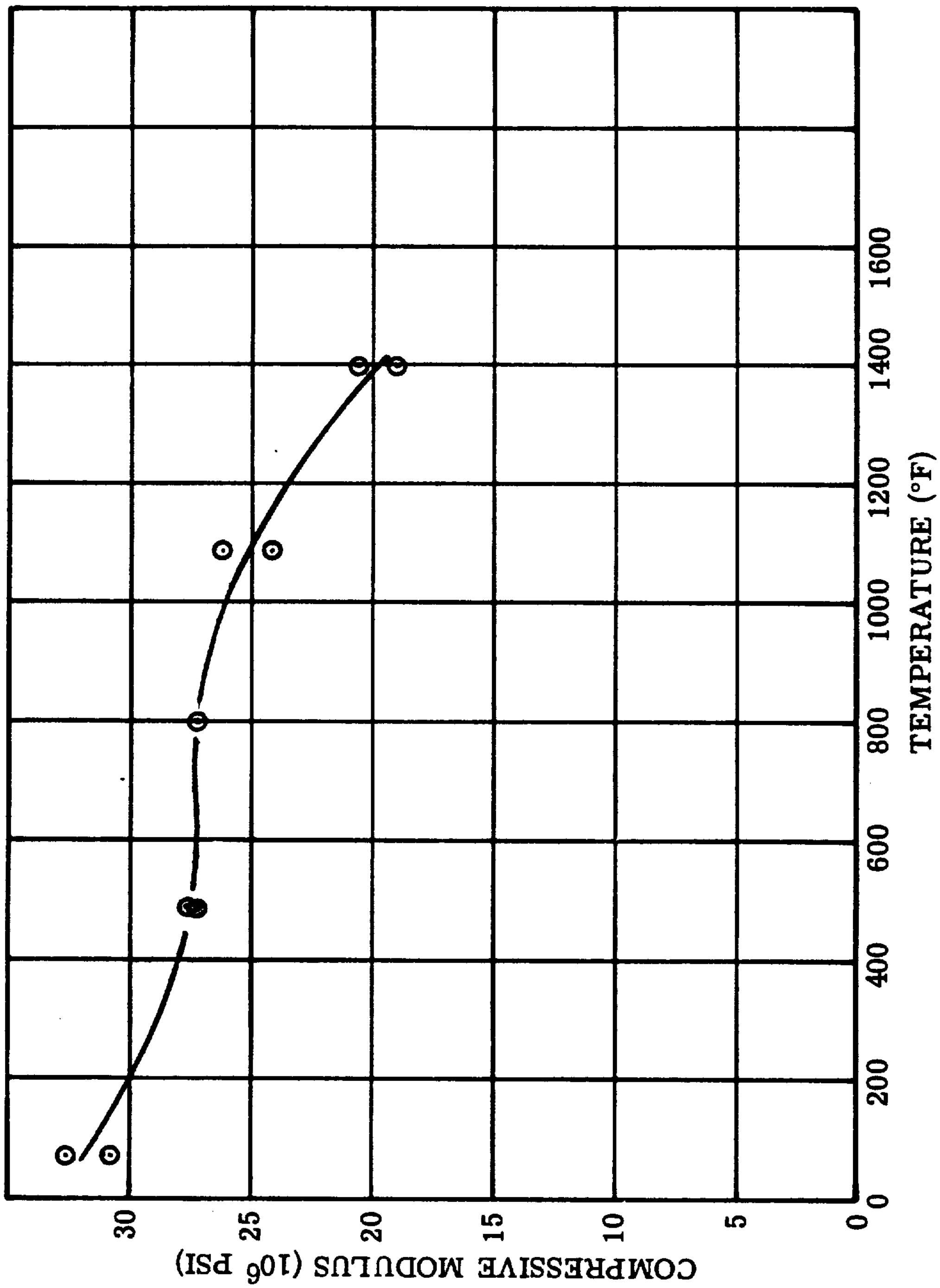


FIGURE I V. C. III-13. Compressive Modulus of Elasticity For 0.50 Inch Diameter Hiperco 27 Alloy Vacuum Melted Forged Bar Stock. Tests Made in Air. Strain Rate: 0.05 in/in-min. See Data Table I V. C. III-4. (Reference: NAS3-4162)

Figure I V. C. III-13. Compressive Modulus - Hiperco 27

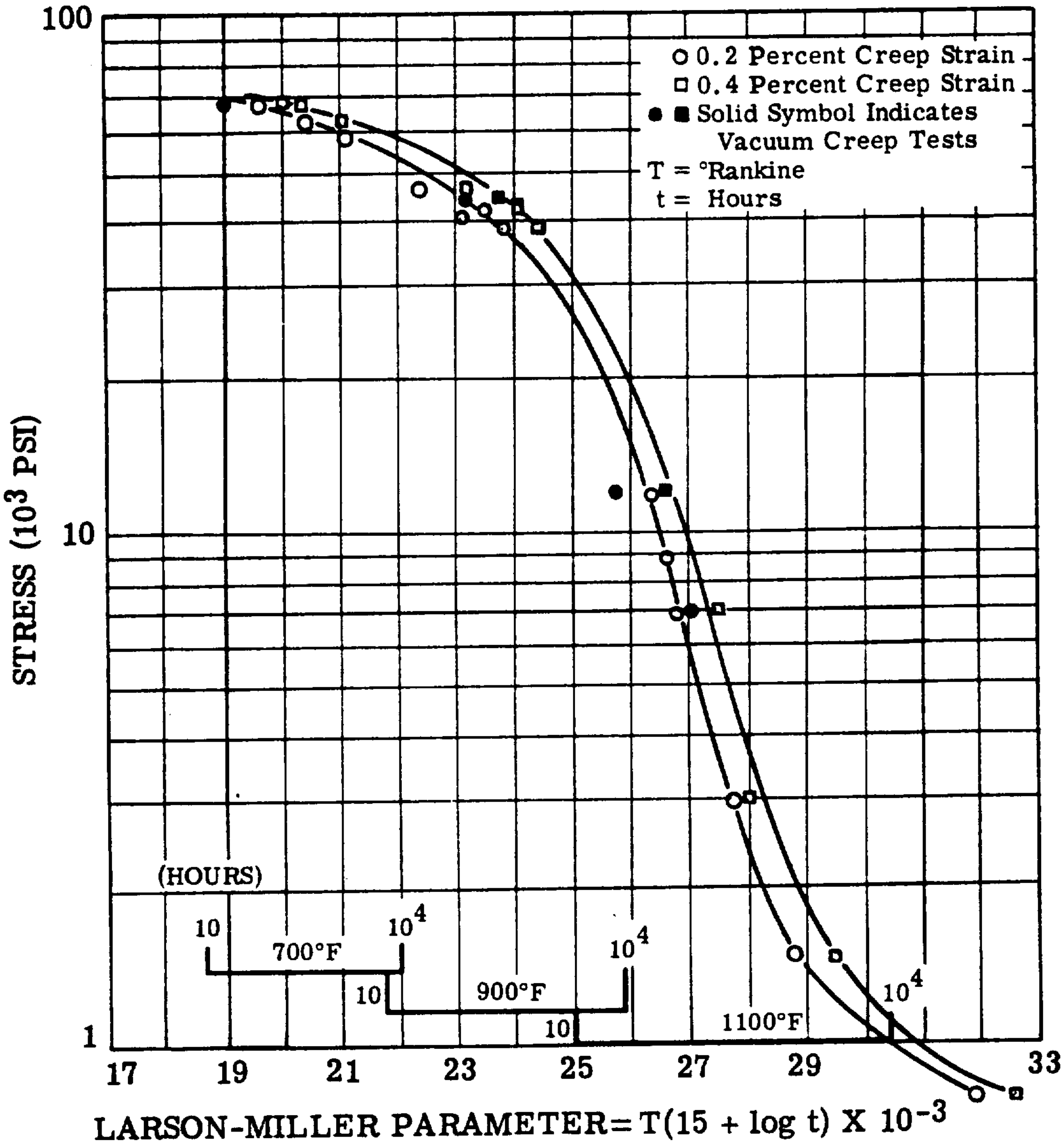


FIGURE IV.C.III-14. Larson-Miller Plot of Vacuum Melted Forged Hiperco 27 Alloy Creep Data Based on a Maximum of 2000 Hour Data. Test Points Represent Material Tested in Air, Argon and Vacuum. (Reference: NAS 3-4162)

Figure IV.C.III-14. Creep - Larson-Miller Plot - Hiperco 27

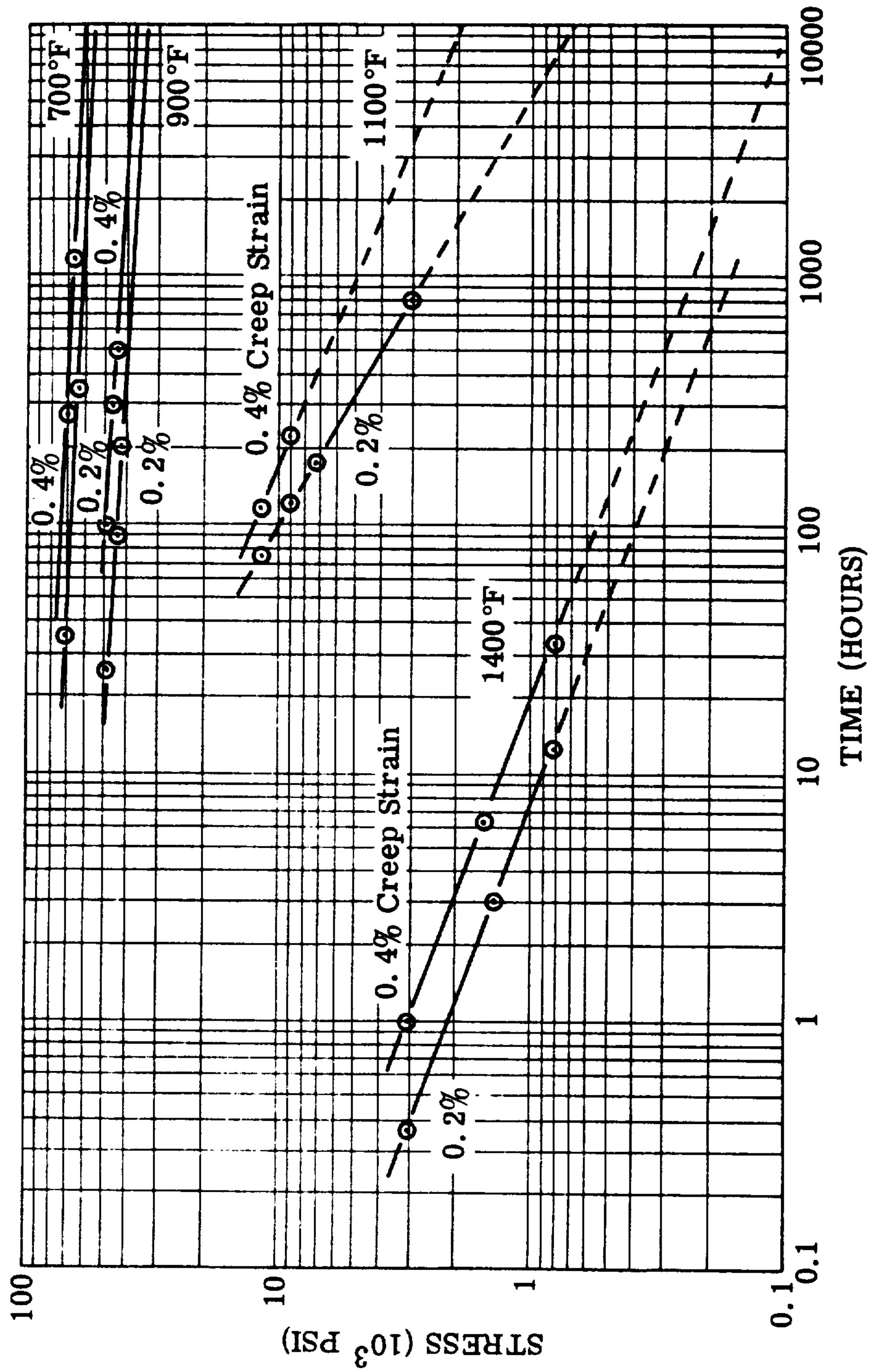


FIGURE IV.C.III-15. Stress vs. Time to Reach the Indicated Creep Strains For Vacuum Melted Forged Hiperco 27 Alloy (Reference: NAS3-4162)

Figure IV.C.III-15. Creep - Vacuum Melted Forged Hiperco 27

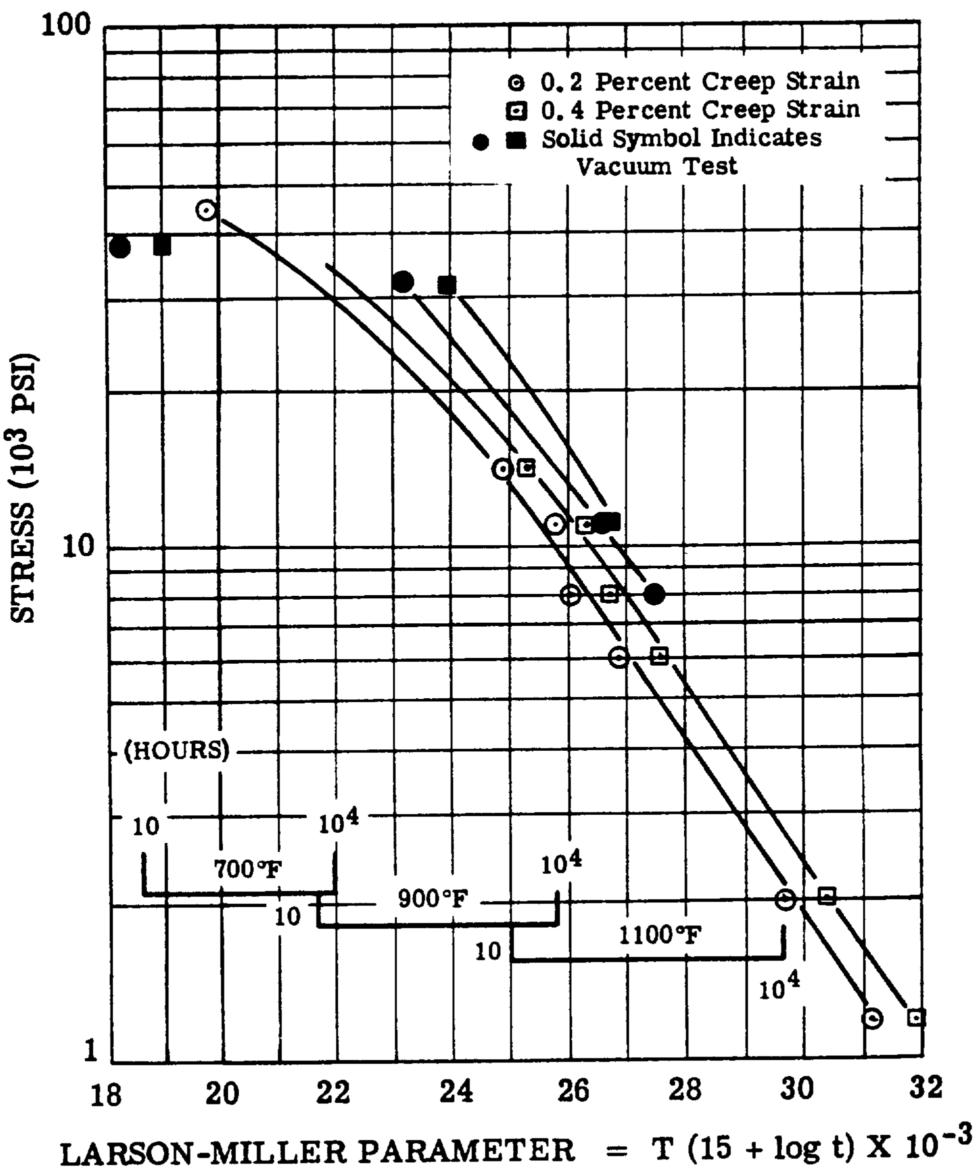


FIGURE IV.C.III-16. Larson-Miller Plot of Air and Vacuum Creep Test Data Obtained on Investment Cast Hiperco 27 Alloy Based on a Maximum of 2000 Hour Data. (Reference: NAS 3-4162)

Figure IV.C.III-16. Creep - Larson-Miller Plot - Cast Hiperco 27

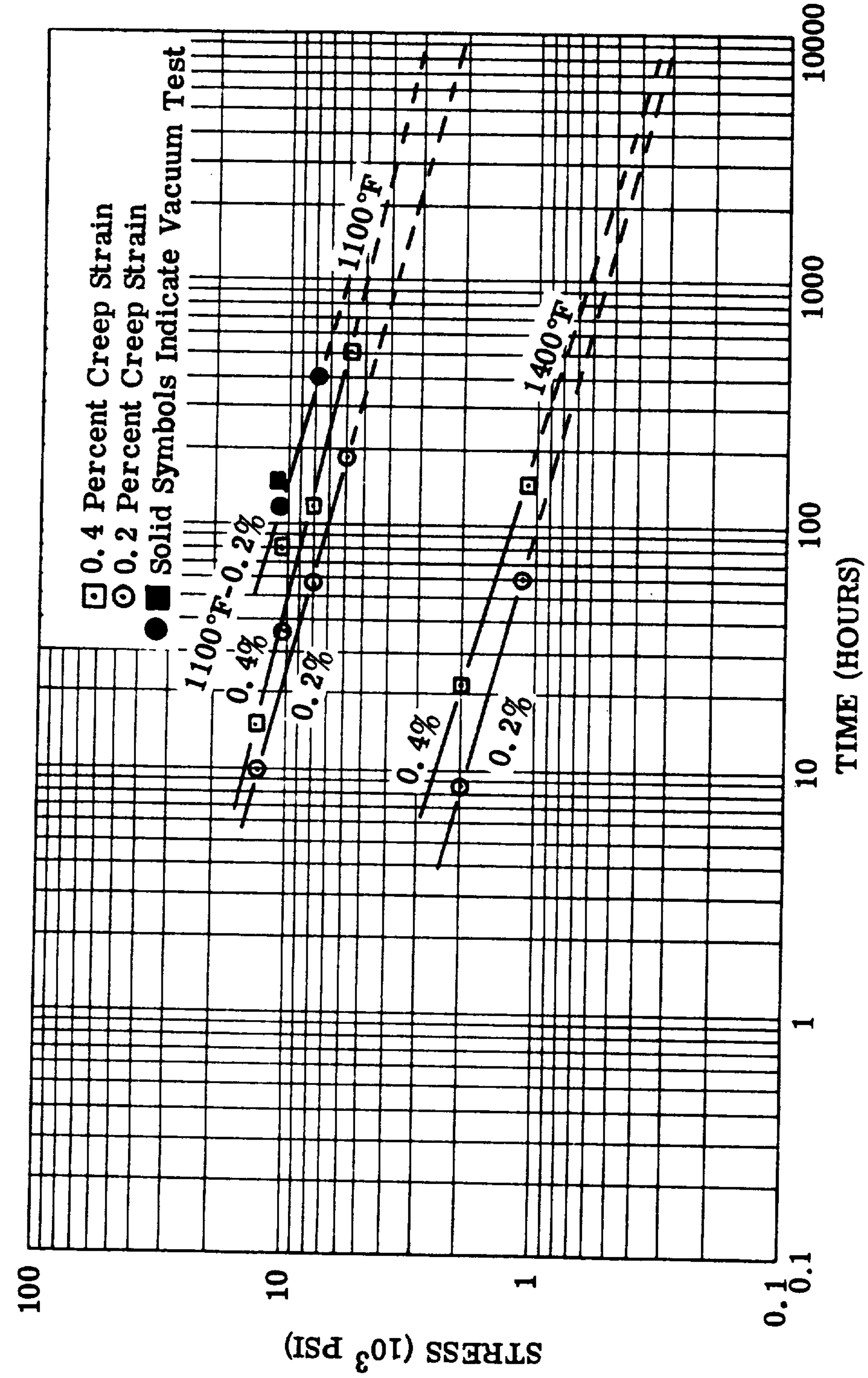


FIGURE I V. C. III-17. Stress vs. Time to Reach the Indicated Creep Strains For Investment Cast and Annealed Hiperco 27 Alloy. (Reference: NAS3-4162)

Figure I V. C. III-17. Creep - Hiperco 27

TABLE IV. C. III-5. Creep Data For Vacuum Melted Forged Hiperco 27 Alloy

TEST: ASTM E139

Temperature (°F)	700	700*	700*	700*	700	700*	700*	700	900	900*	1100
Stress (psi)	31000	40000	50000	55000	35000	46000	60000	75000	18000	40000	3000
Duration of Test (hours)	474	212	184	506	215	355	1485	141	501	1003	1024
Total Creep Strain (percent)	0.029	0.0167	0.0075	0.029	0.0291	0.0341	0.165	0.575	0.0412	0.489	0.235
Time to Cause 0.2 Percent Creep Strain (hours)	-	-	-	-	-	-	-	0	-	520	818
Time to Cause 0.4 Percent Creep Strain (hours)	-	-	-	-	-	-	-	-	-	890	-
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0	0	0.271	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV. C. III→	18	18	18	18	19	19	19	20	21	21	23

- Did not reach required strain
* Stress raised on previous specimen

(Reference: NAS3-4162)

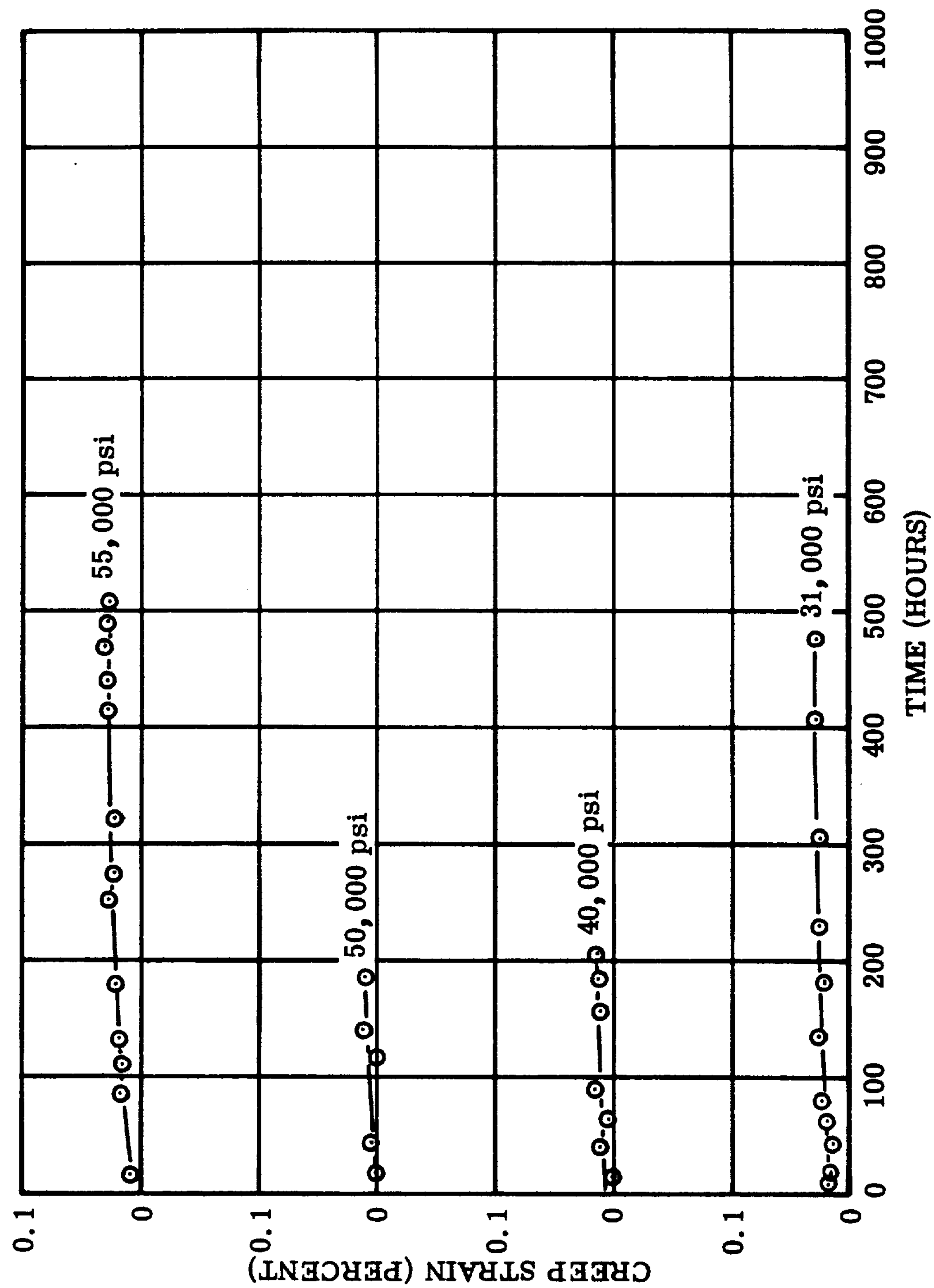


FIGURE I V. C. III-18. Creep, Vacuum Melted Forged Hiperco 27 Alloy Tested in Air at 700°F. Data Obtained by Increasing Stress on a Single Specimen. See Data Table I V. C. III-5. (Reference: NAS3-4162)

Figure I V. C. III-18. Creep - Hiperco 27

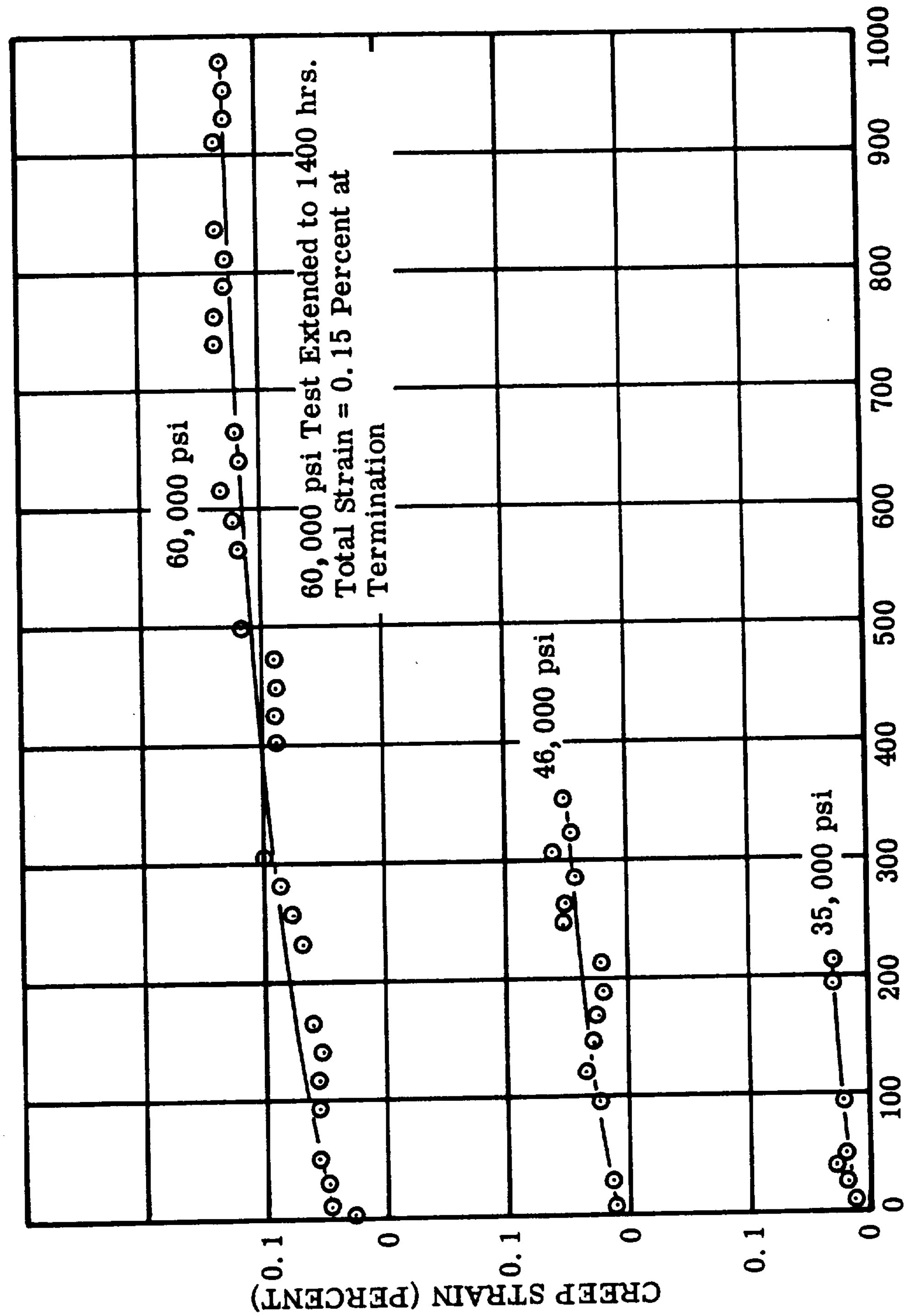


FIGURE I V. C. III-19. Creep, Vacuum Melted Forged Hiperco 27 Alloy Tested in Air at 700°F. All Data Obtained by Increased Stress on a Single Specimen. See Data Table I V. C. III-5. (Reference: NAS3-4162)

Figure I V. C. III-19. Creep - Hiperco 27

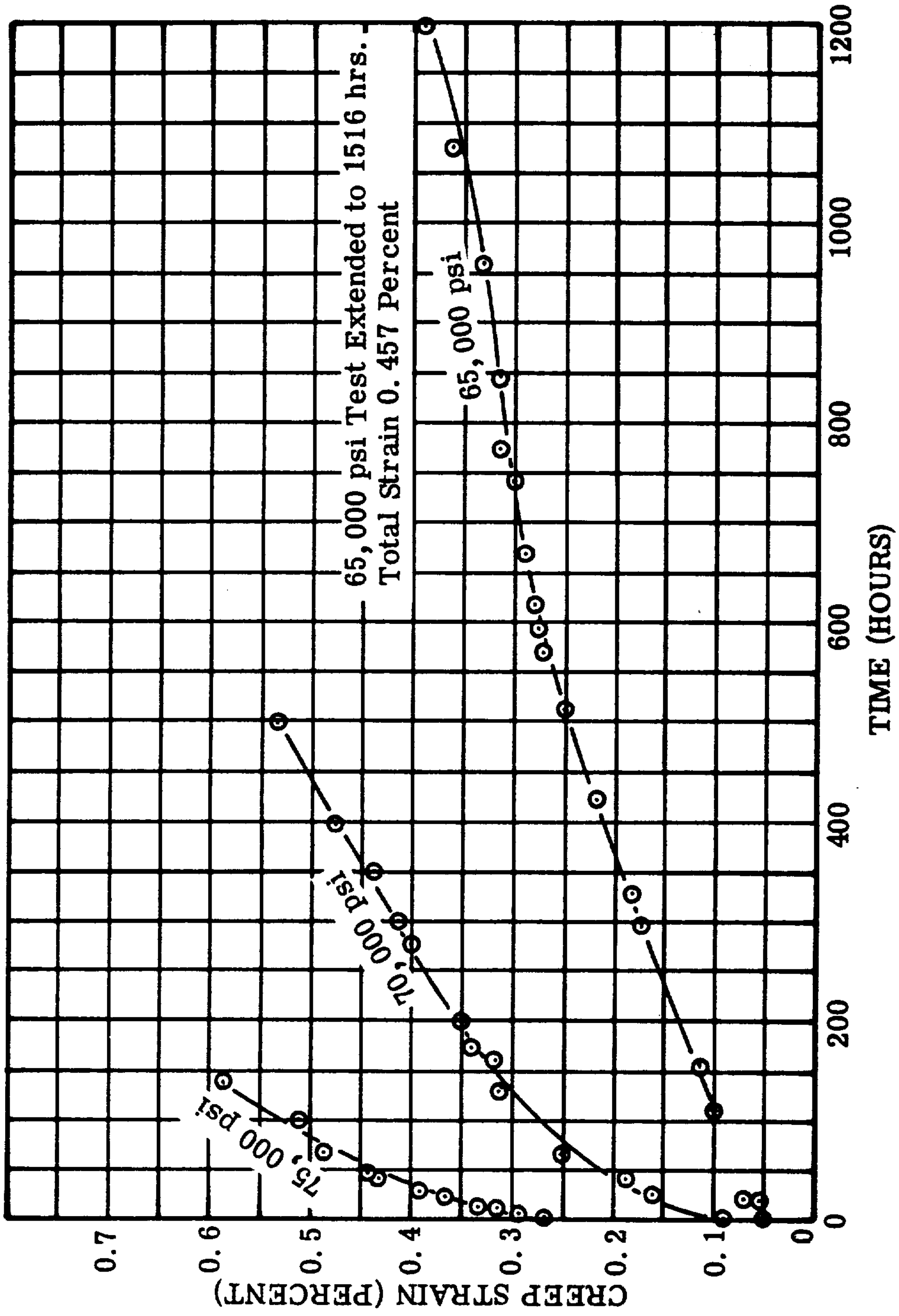


FIGURE IV.C.III-20. Creep of Vacuum Melted Forged Hiperco 27 Alloy Tested in Air at 700°F. See Data in Tables IV.C.III-5 and -6. (Reference: NAS3-4162)

Figure IV.C.III-20. Creep - Hiperco 27

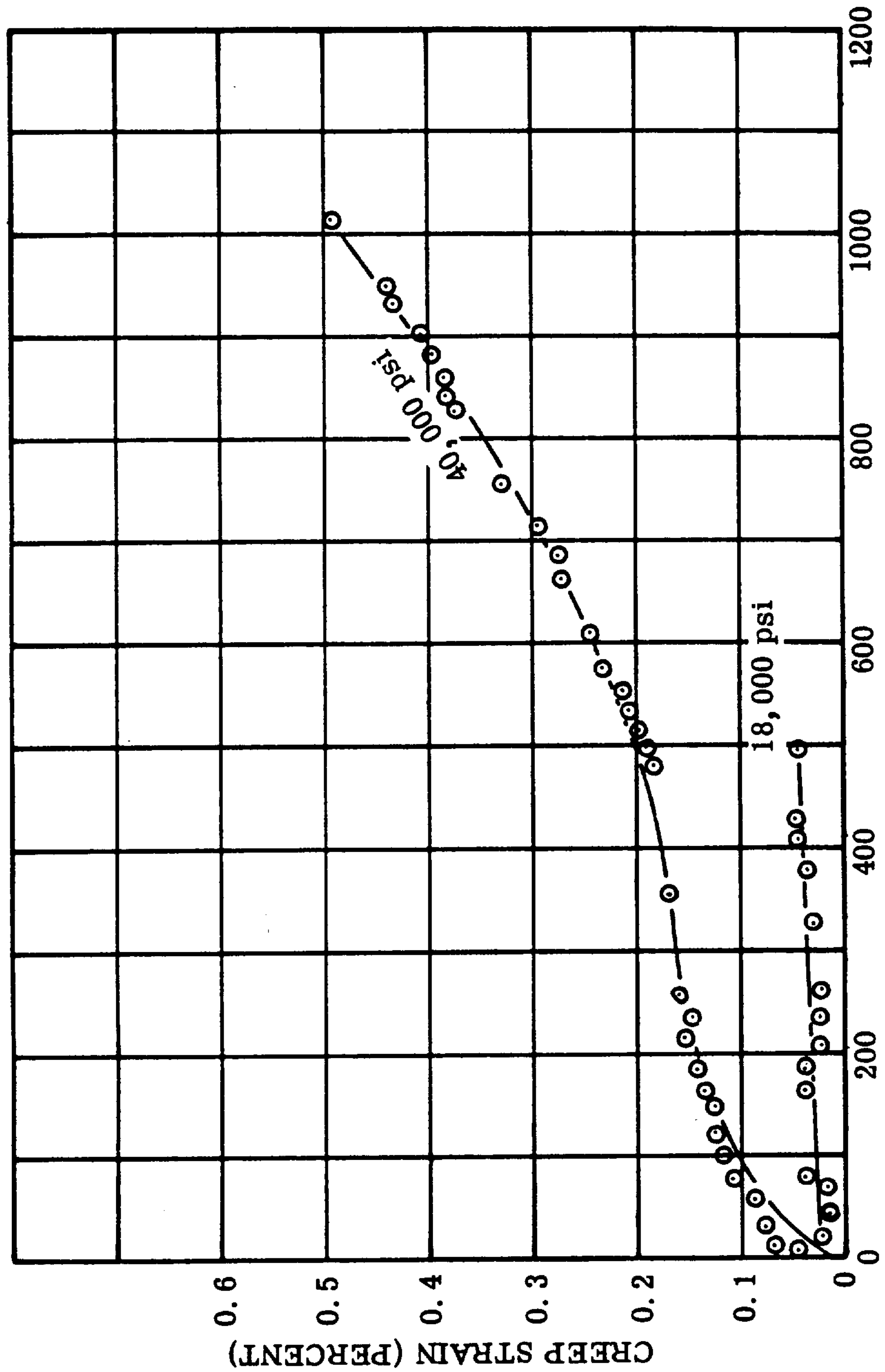


FIGURE I V. C. III-21. Creep For Vacuum Melted Forged Hiperco 27 Alloy Tested in Air at 900°F. Data Obtained by Increasing the Stress on One Specimen. See Data in Table I V. C. III-5. (Reference: NAS3-4162)

Figure I V. C. III-21. Creep - Hiperco 27

TABLE IV. C. III-6. Creep Data For Vacuum Melted Forged Hiperco 27 Alloy

TEST: ASTM E139

Temperature (°F)	900	900	900	700	700
Stress (psi)	46000	44000	48000	70000	65000
Duration of Test (hours)	447	622	143	548	1516
Total Creep Strain (percent)	0.5190	0.4848	0.4525	0.4489	0.457
Time to Cause 0.2 Percent Creep Strain (hours)	94	202	28.0	36.0	372
Time to Cause 0.4 Percent Creep Strain (hours)	303	511	118.0	276.0	1230
Plastic Strain obtained on Loading Specimen (percent)	0.0050	0.0201	0.0187	0.092	0.029
Test Atmosphere	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV. C. III →	22	22	22	20	20

(Reference: NAS3-4162)

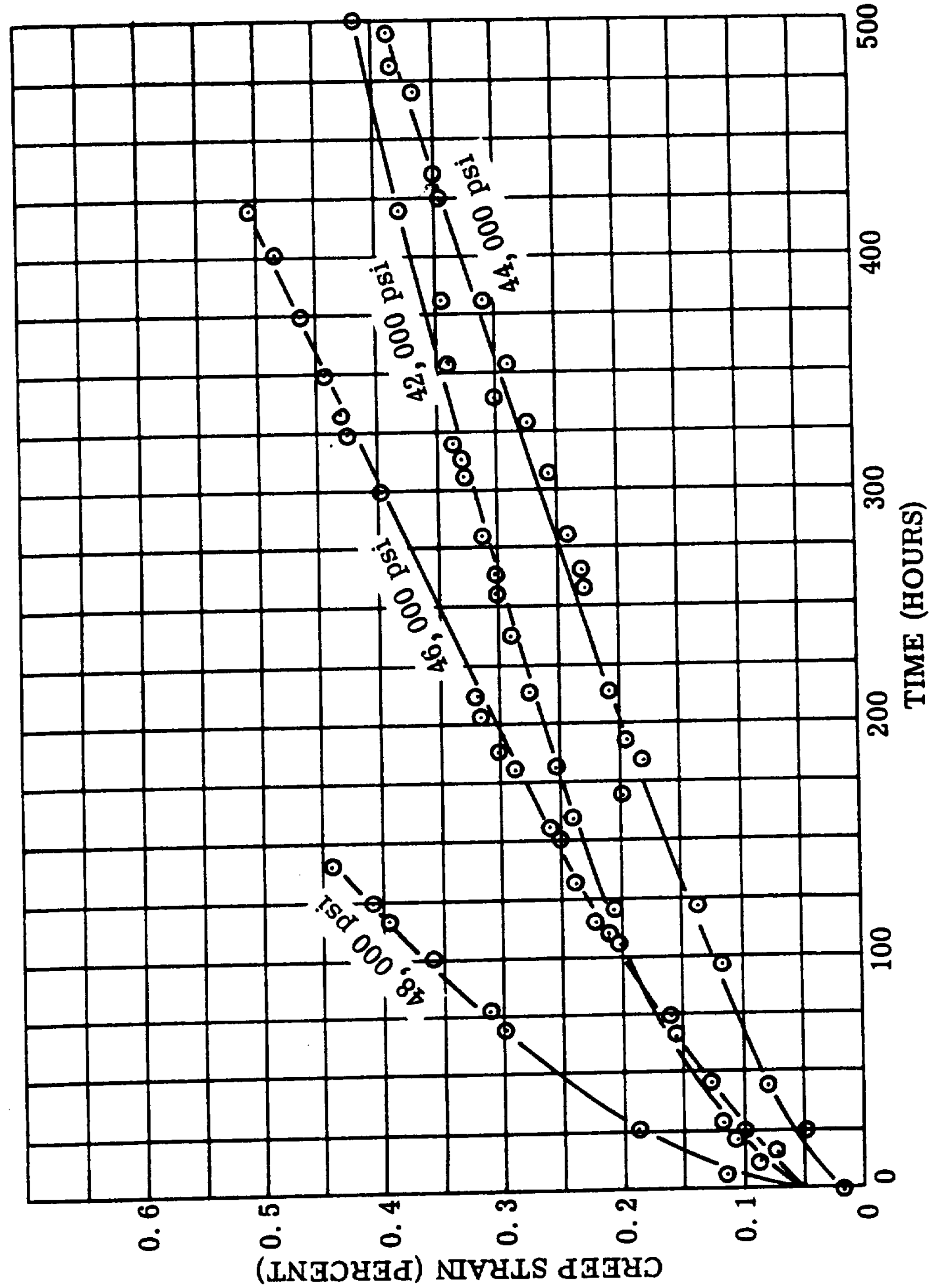


FIGURE IV.C.III-22. Creep For Vacuum Melted Forged Hiperco 27 Alloy Tested in Air at 900°F. See Data Tables IV.C.III-6 and -7. (Reference: NAS3-4162)

Figure IV.C.III-22. Creep - Hiperco 27

TABLE I V. C. III-7. Creep Data For Vacuum Melted Forged Hiperco 27 Alloy

TEST: ASTM E139

Temperature (°F)	900	1100	1100	1100	1100	1400
Stress (psi)	42000	12000	9000	7000	3000	800
Duration of Test (hours)	617	186.6	257.4	332	1024	56
Total Creep Strain (percent)	0.494	0.84	0.52	0.337	0.236	0.587
Time to Cause 0.2 Percent Creep Strain (hours)	108	76	127	182	755	14.7
Time to Cause 0.4 Percent Creep Strain (hours)	482	122	213	---	---	34.8
Plastic Strain Obtained on Loading Specimen (percent)	0	0	0	0	0	0
Test Atmosphere	Air	Argon	Argon	Argon	Air	Argon
See Strain-Time Plot in Figure I V. C. III →	22	23	23	23	23	24

(Reference: NAS3-4162)

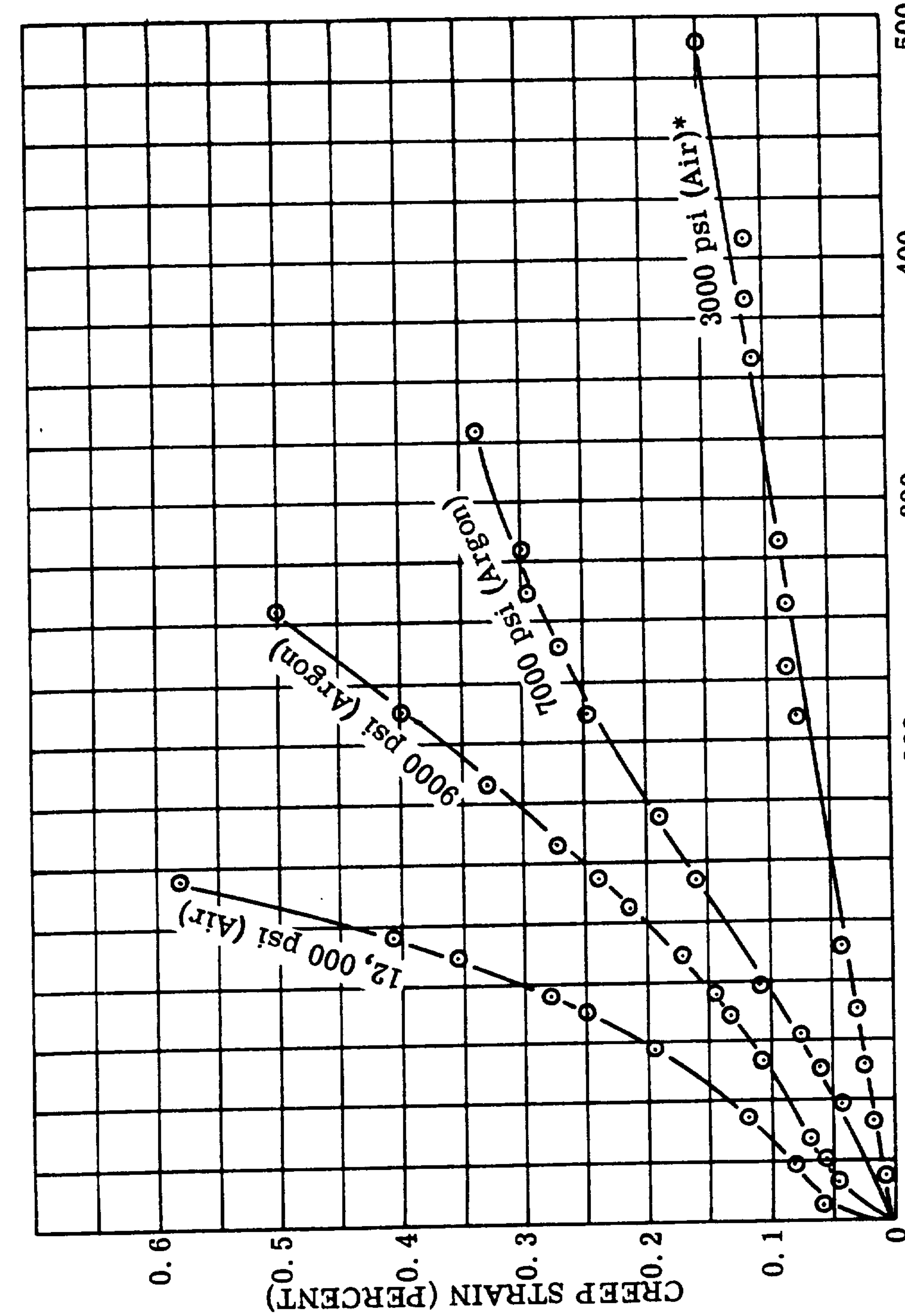


FIGURE I V. C. III-23. Creep For Vacuum Melted Forged Hiperco 27 Alloy Tested in Air and Argon at 1100°F. See Data Table I V. C. III-5 and -7. (Reference: NAS3-4162)
*Test Terminated After 1030 Hours at 0.23 Percent Creep Strain.

Figure I V. C. III-23. Creep - Hiperco 27

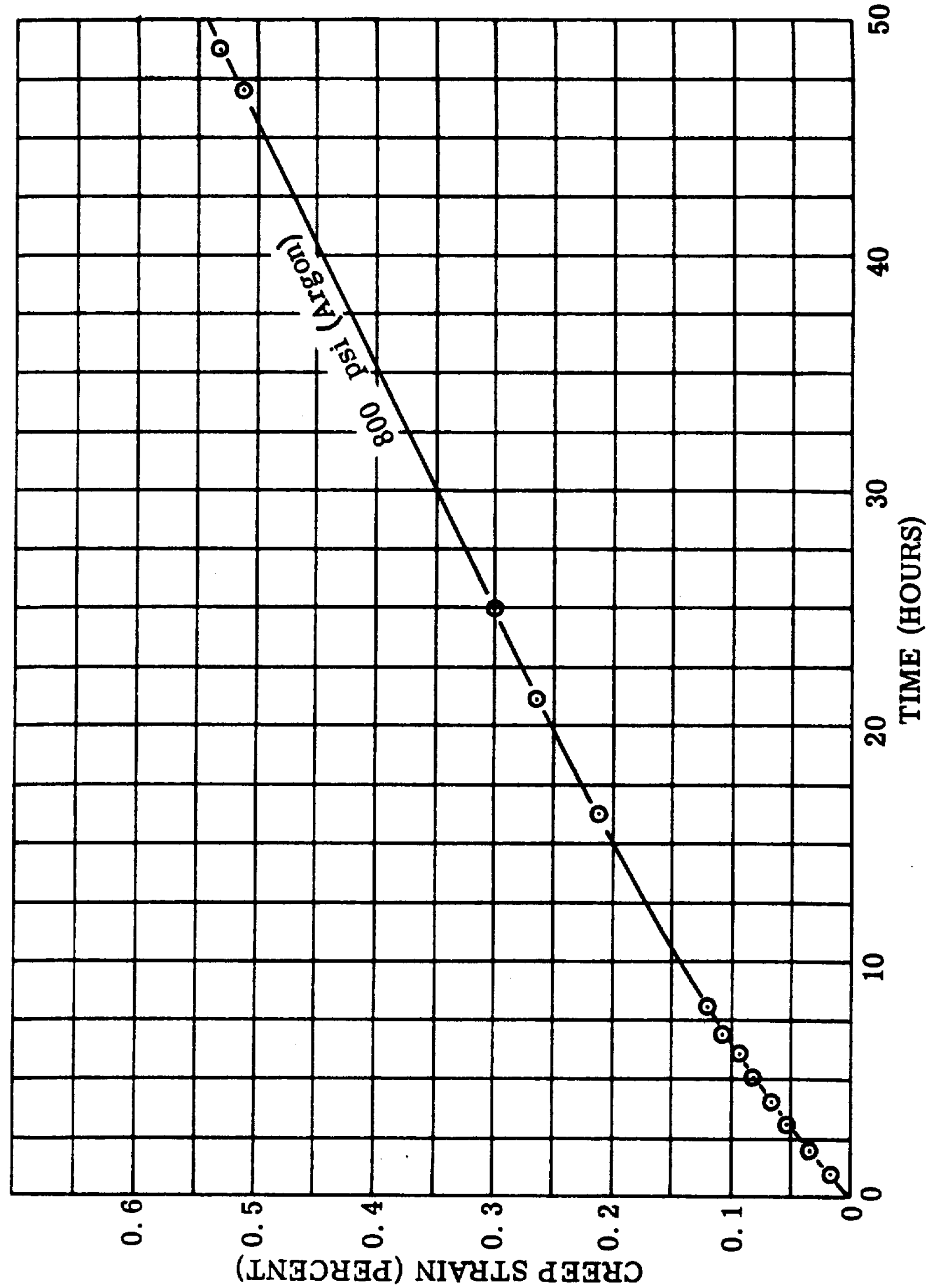


FIGURE IV.C.III-24. Creep For Vacuum Melted Forged Hiperco 27 Alloy Tested in Argon at 1400°F. See Data Table IV.C.III-7. (Reference: NAS3-4162)

Figure IV.C.III-24. Creep - Hiperco 27

TABLE IV. C. III-8. Vacuum Creep Data For Vacuum Melted Forged Hiperco 27 Bar (See Figure IV. C. III-16 For Larson-Miller Plot)

TEST: ASTM E139

Temperature	700	900	1100	1100
Stress (psi)	70,000	46,000	12,000	7000
Duration of Test (hours)	498	350	187	211
Total Creep Strain (percent)	0.73	0.60	0.80	0.19
Time to Cause 0.2 percent Creep Strain (hours)	35	130	32	220
Time to Cause 0.4 percent Creep Strain (hours)	165	240	105	(1)
Plastic Strain obtained on loading specimen (percent)		0	0	0
Test Atmosphere	Vacuum	Vacuum	Vacuum	Vacuum
See Larson-Miller Plot in Figure IV. C. III →	16	16	16	16
Larson-Miller Parameter for 0.2 percent plastic strain	19.2	23.25	25.7	27.1
Larson-Miller Parameter for 0.4 percent plastic strain	20.0	23.70	26.6	--

(1)Did not reach required strain. (Reference NAS 3-4162)

TABLE IV.C.III-9. Creep Data for Investment Cast and Annealed Hiperco 27 Alloy

TEST: ASTM E139

Temperature (°F)	900	900	700	700	700	700	700	1,100	1,100	1,100	1,100	1,100	1,400	1,400
Stress (psi)	30,000	25,000	30,000	35,000	38,000	45,000	40,000	14,000	11,000	8,000	3,000	6,000	2,000	1,200
Duration of Test (hours)	1,102	1.225	1,200	1,389	1,686	1.176	1,578	74.1	138.8	646	1,199	695	96.5	359
Total Creep Strain (percent)	0.127	0.132	0.2061	0.1482	0.14	0.306	0.106	5.845	1.876	1.9416	0.132	0.525	1.9384	0.855
Time to Cause 0.2 Percent Creep Strain (hours)	+	+	++	+	+	122	+	9.8	36	55	-	190	8.5	60
Time to Cause 0.4 Percent Creep Strain (hours)	+	+		+	+	+	+	16	73	138	-	505	22.5	166
Plastic Strain obtained on loading specimen (percent)	*	*	*	*	*	*	*	*	0.050	0	0	0	*	*
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.C.III →	27	27	++	25	25	26	26	28	28	28	28	28	29	29

*Plastic strain not included in this data
+Did not reach
++Not plotted extensometer difficulties.

(Reference NAS 3-4162)

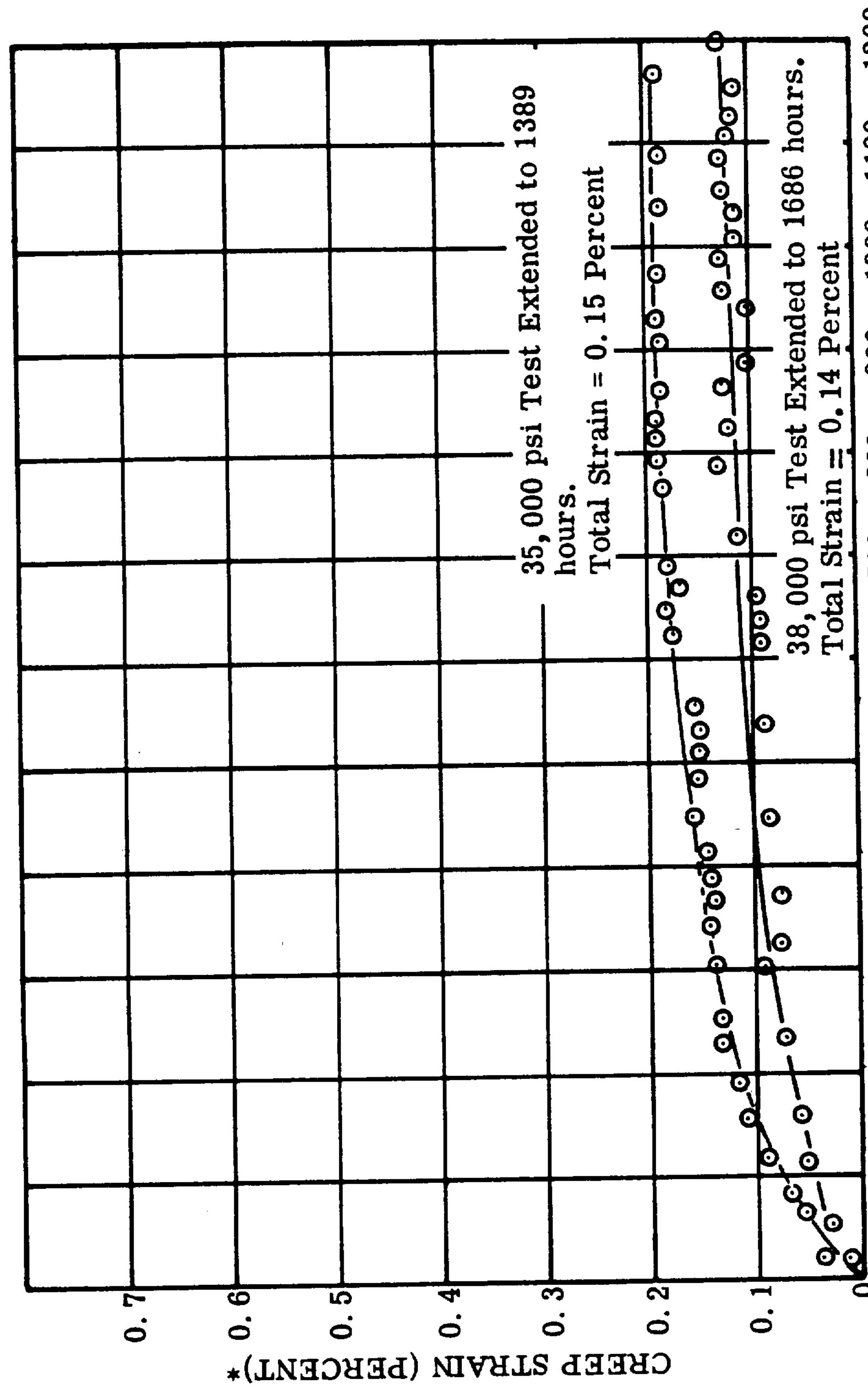


FIGURE IV.C.III-25. Creep, Investment Cast and Annealed Hiperco 27 Alloy Tested in Air at 700°F. See Data Table IV.C.III-9.
*Plastic Strain on Loading Not Included.
(Reference: NAS3-4162)

Figure IV.C.III-25. Creep - Cast Hiperco 27

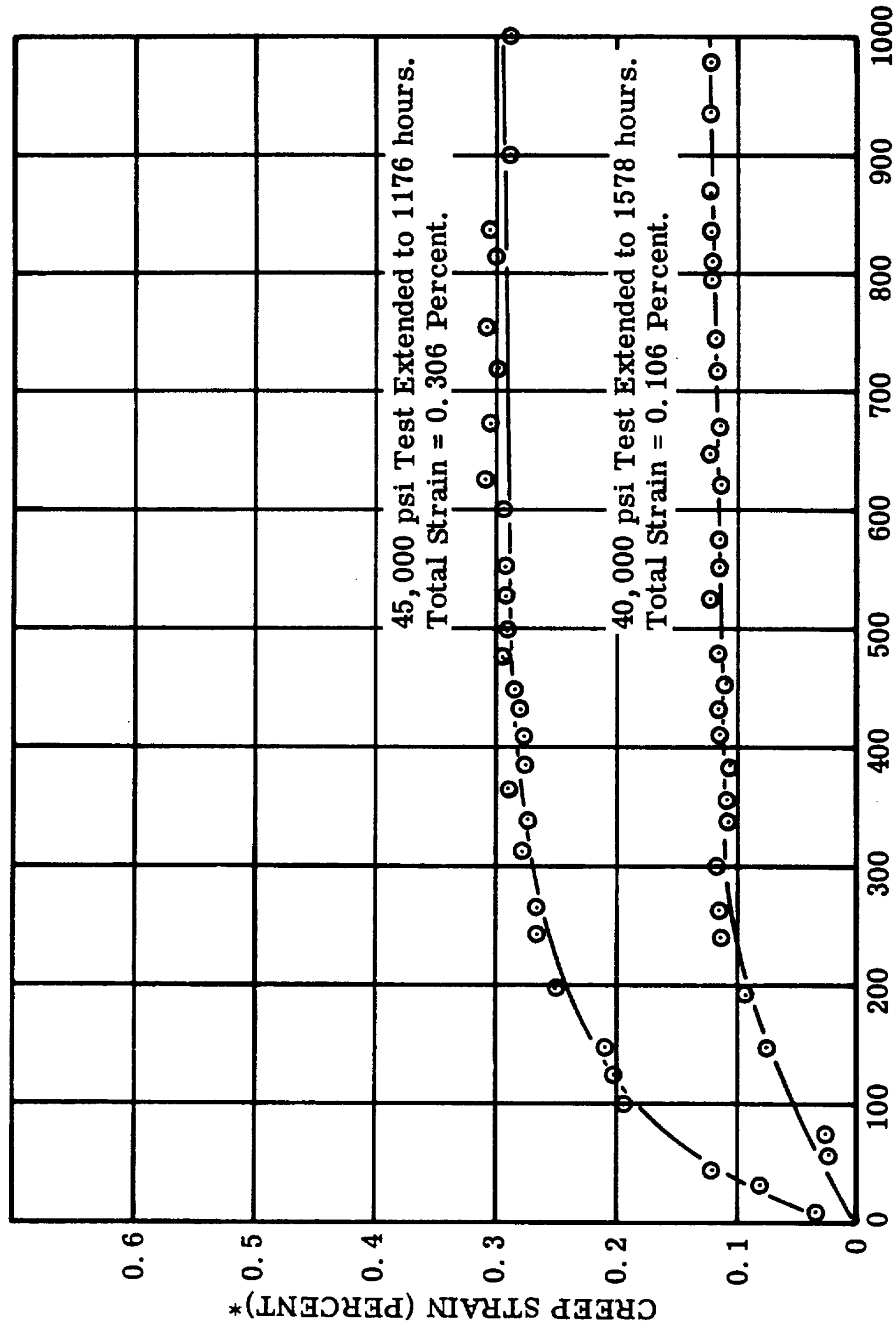


FIGURE I V. C. III-26. Creep, Investment Cast and Annealed Hiperco 27 Alloy Tested in Air at 700°F. See Data Table I V. C. III-9.
*Plastic Strain on Loading Not Included.
(Reference: NAS3-4162)

Figure I V. C. III-26. Creep - Cast Hiperco 27

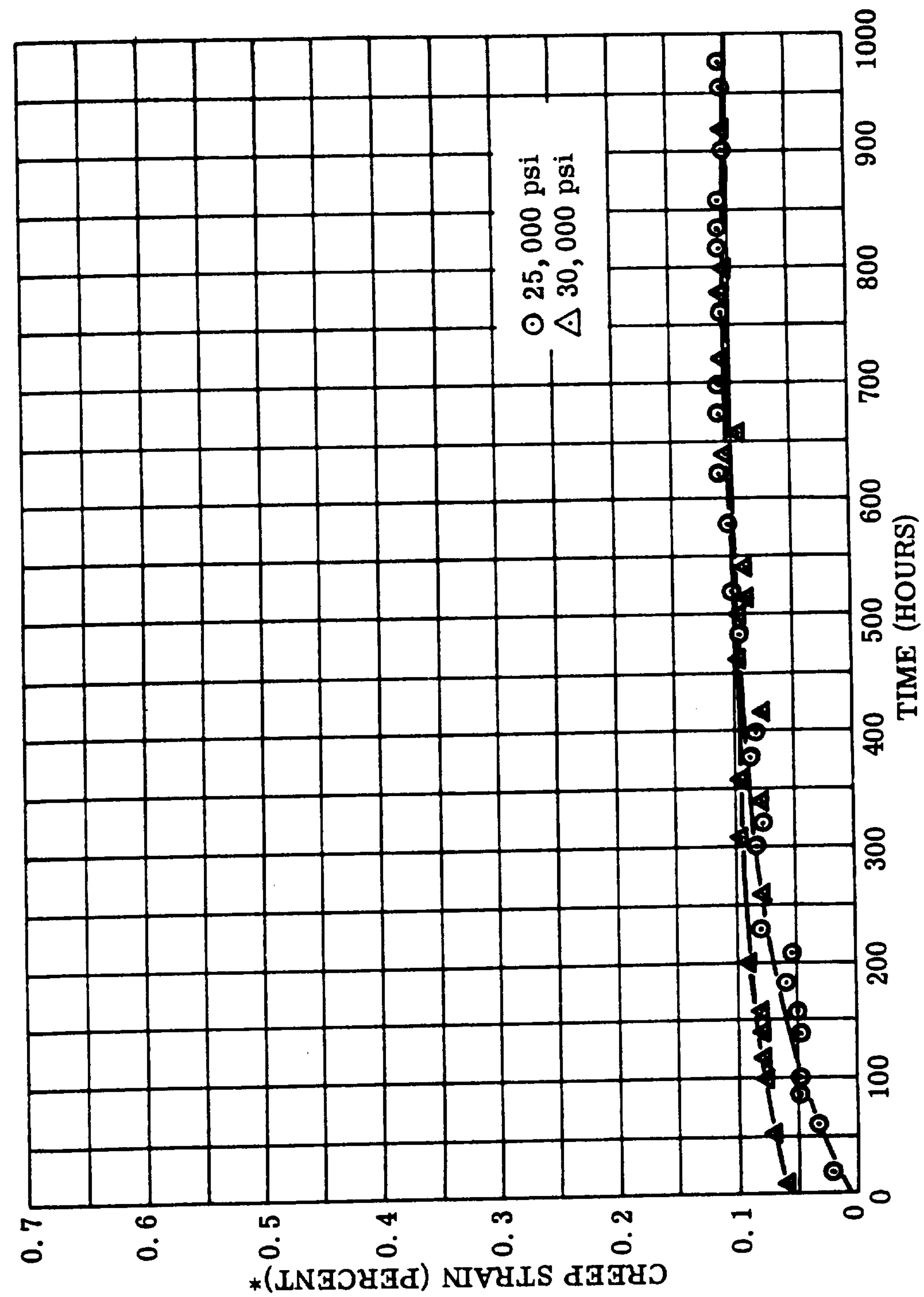


FIGURE I V. C. III-27. Creep, Investment Cast and Annealed Hiperco 27 Alloy Tested in Air at 900°F. See Data Table I V. C. III-9.
*Plastic Strain on Load Not Included.
(Reference: NAS3-4162)

Figure I V. C. III-27. Creep - Cast Hiperco 27

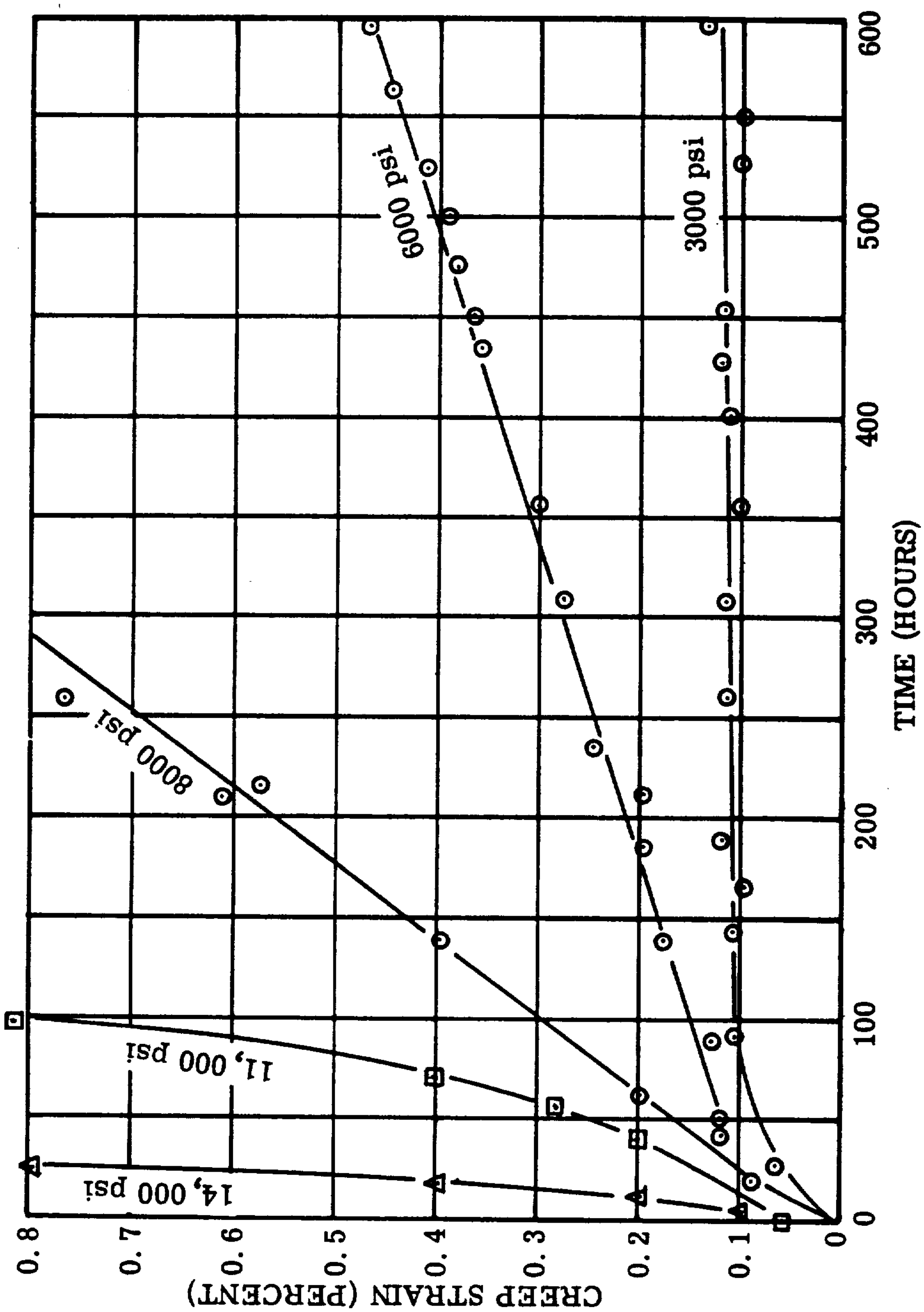


FIGURE I V. C. III-28. Creep, Investment Cast and Annealed Hiperco 27 Alloy Tested in Air at 1100°F. See Data Table I V. C. III-9. (Reference: NAS3-4162)

Figure I V. C. III-28. Creep - Hiperco 27

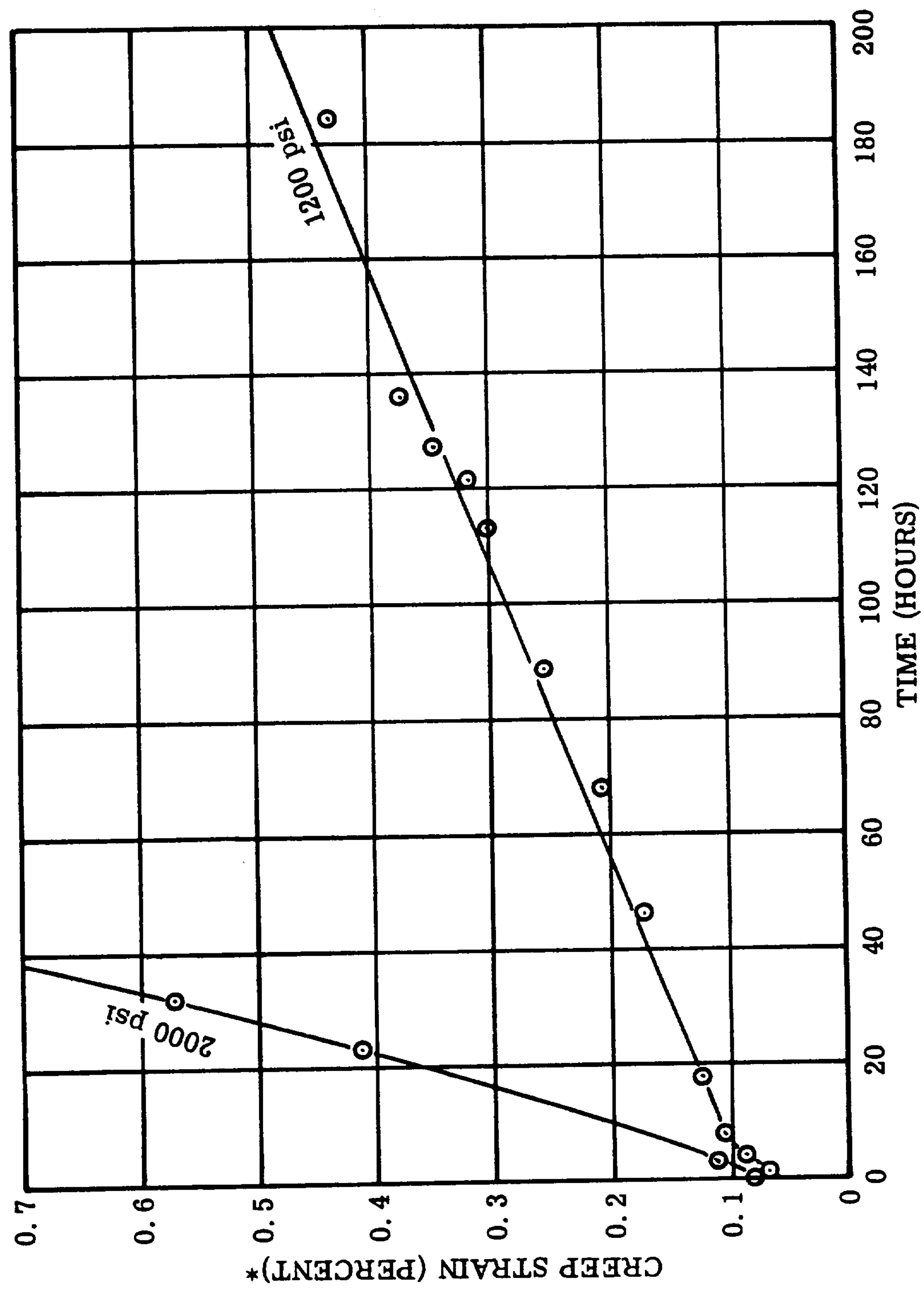


FIGURE I V. C. III-29. Creep, Investment Cast and Annealed Hiperco 27 Alloy Tested in Air at 1400°F. See Data Table I V. C. III-9.
*Strain on Load Not Included.
(Reference: NAS3-4162)

Figure I V. C. III-29. Creep - Cast Hiperco 27

TABLE IV. C. III-10. Vacuum Creep Data For Investment Cast and Annealed Hiperco 27 Alloy

TEST: ASTM E139

Temperature (°F)	700	900	1,100	1,100
Stress (psi)	36,800	32,000	8,000	11,000
Duration of Test (hours)	212	308	405	168
Total Creep Strain (percent)	0.64	0.34	0.20	0.54
Time to Cause 0.2 percent Creep Strain (hours)	1.0	115	405	120
Time to Cause 0.4 percent Creep Strain (hours)	20.0	400	(1)	148
Plastic Strain obtained on loading specimen (percent)	0.13	0.10	0	0
Test Atmosphere	Vacuum	Vacuum	Vacuum	Vacuum
See Larson-Miller Plot in Figure IV.C.III →	16	16	16	16

(1) Did not reach required strain (Reference NAS 3-4162)

D. IRON 1-PERCENT SILICON INVESTMENT CASTING (AMS 5210)

Availability:	Commercial
Nominal Composition:	1% Si-Fe
Tested Composition:	Purchased and certified to conform to Aeronautical Materials Specification 5210. Actual chemical composition not tested. When used as a magnetic material it should be purchased to a performance requirement rather than chemical analysis.

I. Thermophysical Properties

A.	Density	0.28 lb/in^3 7.75 grams/cc
B.	Solidus Temperature	2210° F
C.	Curie Temperature	1380°F
D.	Thermal Conductivity	
	1. At 72°F	23.6 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
	2. At 500°F	22.0 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
	3. At 700°F	20.8 $\frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$
E.	Coefficient of Thermal Expansion (72°-932°F)	8.0 x 10^{-6} in/in-°F**
F.	Specific Heat	
	1. At 72°F	0.10 Btu/lb-°F
	2. At 500°F	0.10 Btu-lb-°F

**American Society for Metals, Metals Handbook, 1961 Edition, pp 1207.

G. Electrical Resistivity

1.	At 72°F	21.0×10^{-6} ohm-cm*
2.	At 500°F	40.5×10^{-6} ohm-cm*
3.	At 700°F	51.0×10^{-6} ohm-cm*

II. Magnetic Properties (All magnetic materials are stress relief annealed (SRA) unless otherwise specified).

A. D-C Properties (Solid Ring)

1.	Induction (B_{tip}) for H = 300 oersteds at 72°F	21.0 kilogauss
2.	Induction (B_{tip}) for H = 300 oersteds at 800°F	19.8 kilogauss
3.	Induction (B_{tip}) for H = 300 oersteds at 1100°F	17.2 kilogauss

B. A-C Magnetic Properties

Investment-cast materials are not suitable for a-c application. Losses are very high.

C. Constant Current Flux Reset Properties (CCFR)

Not applicable to AMS 5210. Only measured on materials used in magnetic amplifiers.

III. Mechanical Properties

A. Tensile Properties

1. At 72°F

a.	0.20 percent offset yield strength	28,950 psi
b.	Tensile Strength	54,200 psi
c.	Elongation in one inch	37.2 percent
d.	Reduction of area	60.6 percent
e.	Modulus of elasticity (estimated)	28×10^6 psi

2. At 800°F

a.	0.20 percent offset yield strength	22,900 psi
b.	Tensile Strength	41,000 psi
c.	Elongation in one inch	36.7 percent
d.	Reduction of area	67.8 percent

*United States Steel, Electrical Sheet Steels Data Handbook.

B. Creep: Material not used in highly stressed applications.

C. Fatigue: Material not used in cyclic stressed applications.

D. Normal Heat Treatment per AMS 5210.

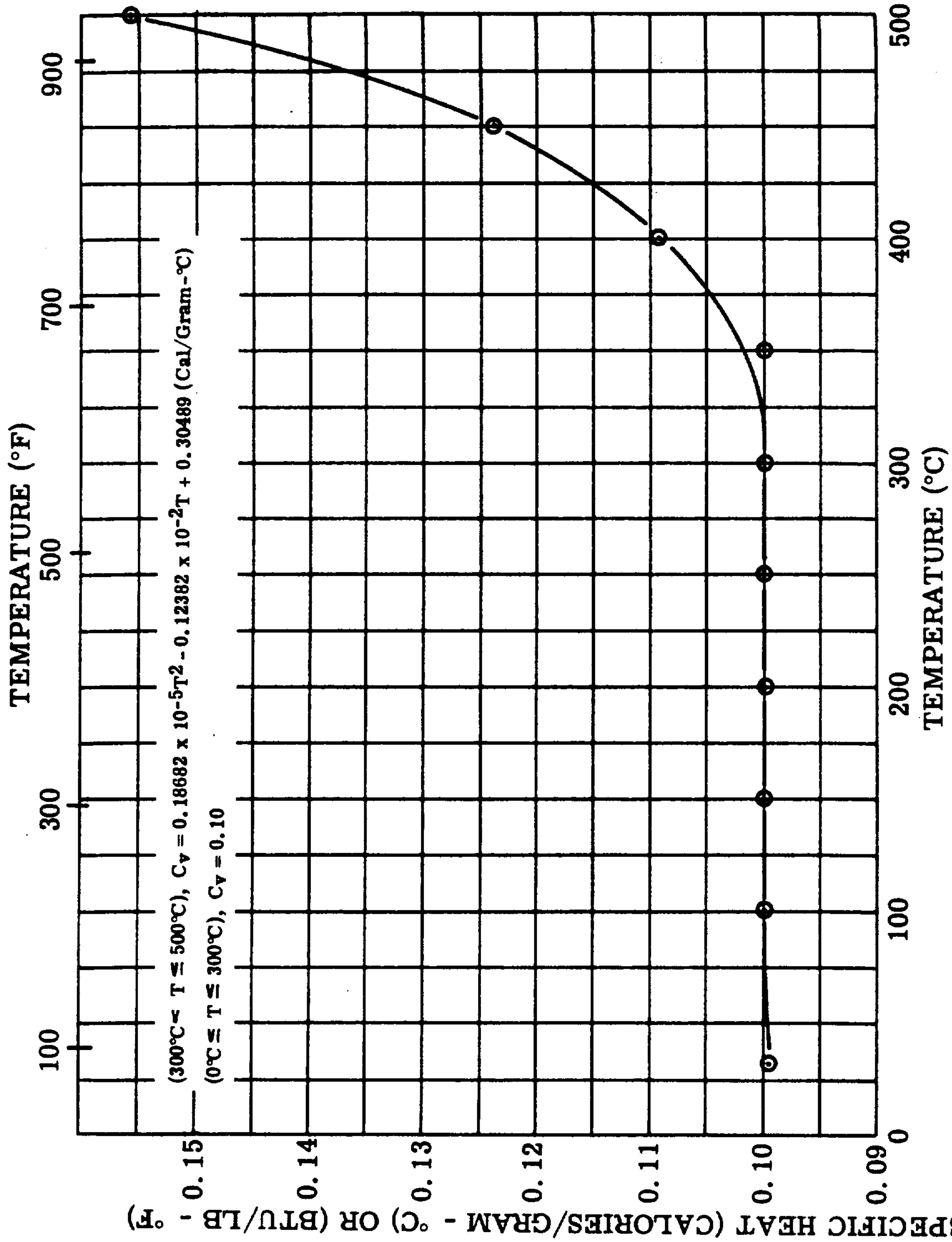


FIGURE I V. D. I-1. Specific Heat, 1 Percent Silicon Iron in Vacuum (10^{-5} Torr)
(Reference: NAS3-4162)

Figure I V. D. I-1. Specific Heat-Investment Cast Silicon Iron

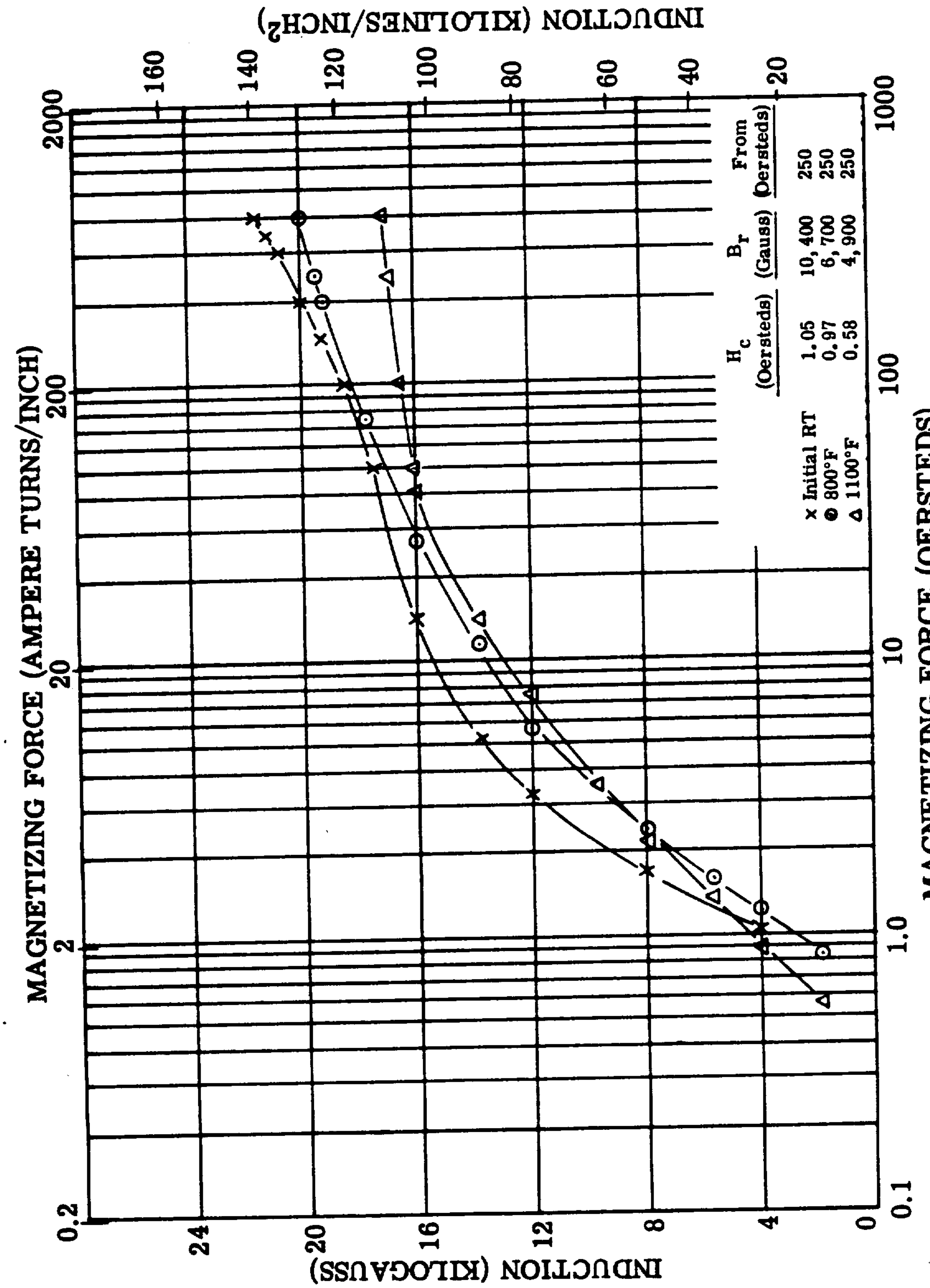


FIGURE IV.D.II-1. D-C Magnetization Curves. AMS5210 (1% Si-Fe) Casting. Test Atmosphere: Air to 800°F, Argon above 800°F. (Reference: NAS3-4162)

Figure IV.D.II-1. D-C Magnetization - AMS5210

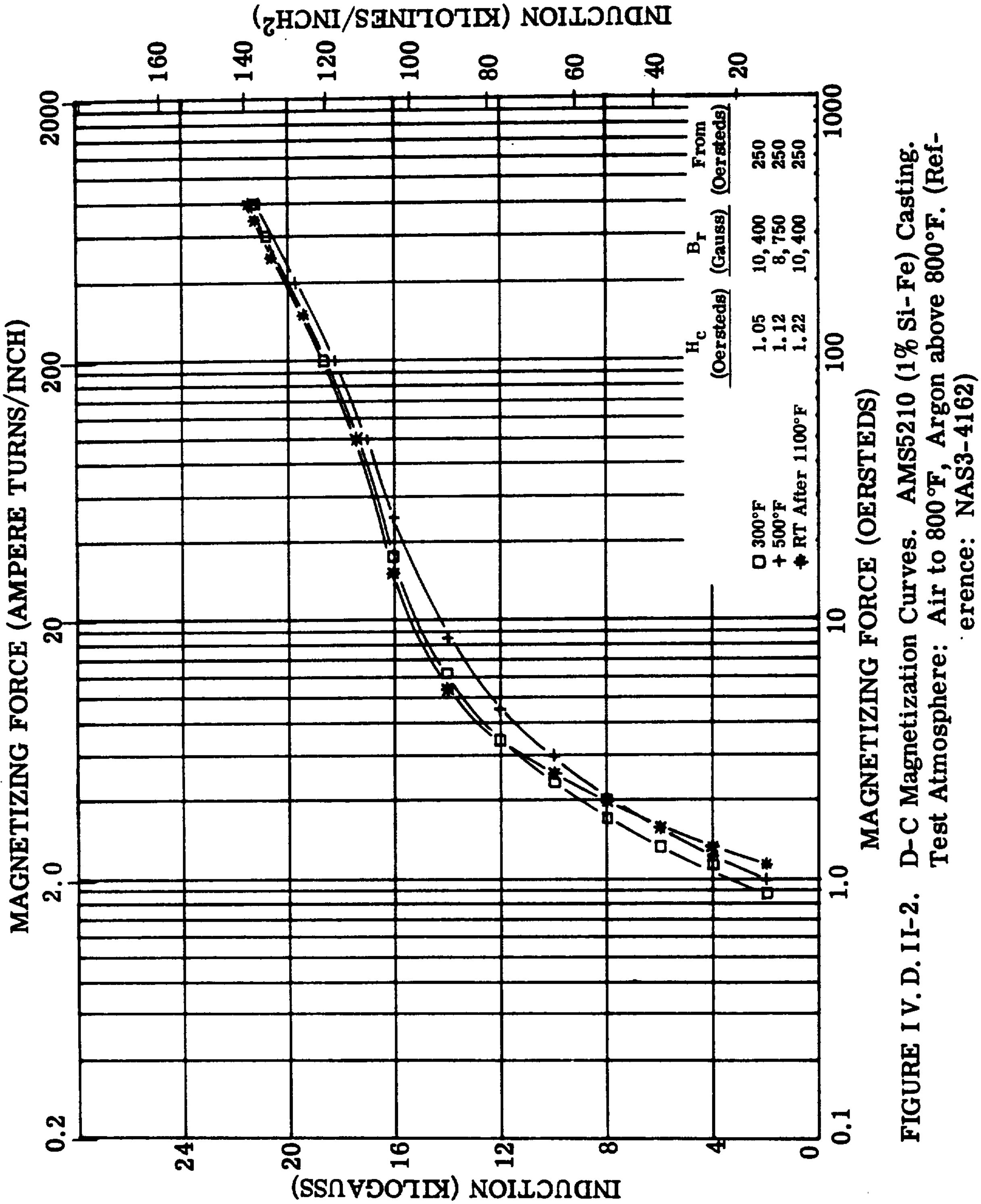


Figure IV.D.II-2. D-C Magnetization - AMS5210

TABLE IV.D.III-1. Room and Elevated Temperature Properties of AMS5210 (1% Si-Fe). See Data Figures IV.D.III-1 and IV.D.III-2.

Specimen No.	Diameter (Inches)	Test Temp. (°F)	Hardness (Rockwell B)	0.02 Percent Offset Yield Strength (Psi)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation in 1 Inch (Percent)	Reduction of Area (Percent)
1	0.252	RT	64, 65, 66	25,450	28,450	55,200	36.1	56.1
2	0.249	RT	65, 66, 66	25,850	29,450	53,200	38.3	65.1
3	0.250	500	62, 63, 65	19,250	25,250	60,700	21.5	+
4	0.248	500	65, 66, 67	22,750	26,200	62,100	22.6	44.3
5	0.251	800	64, 64, 66	20,350	23,150	41,050	36.7	61.0
6	0.251	800	62, 63, 64	19,550	22,700	41,000	36.7	74.5
7	0.248	1000	62, 63, 64	13,150	15,100	20,800	53.6	80.7
8	0.249	1000	62, 63, 63	14,100	15,950	20,400	63.0	85.2

+ Non uniform fracture area, percent reduction not calculated.

Specimens were tested with strain rates as follows:

0.005 in/in-min to yield

0.050 in/in-min to failure (Reference: NAS 3-4162)

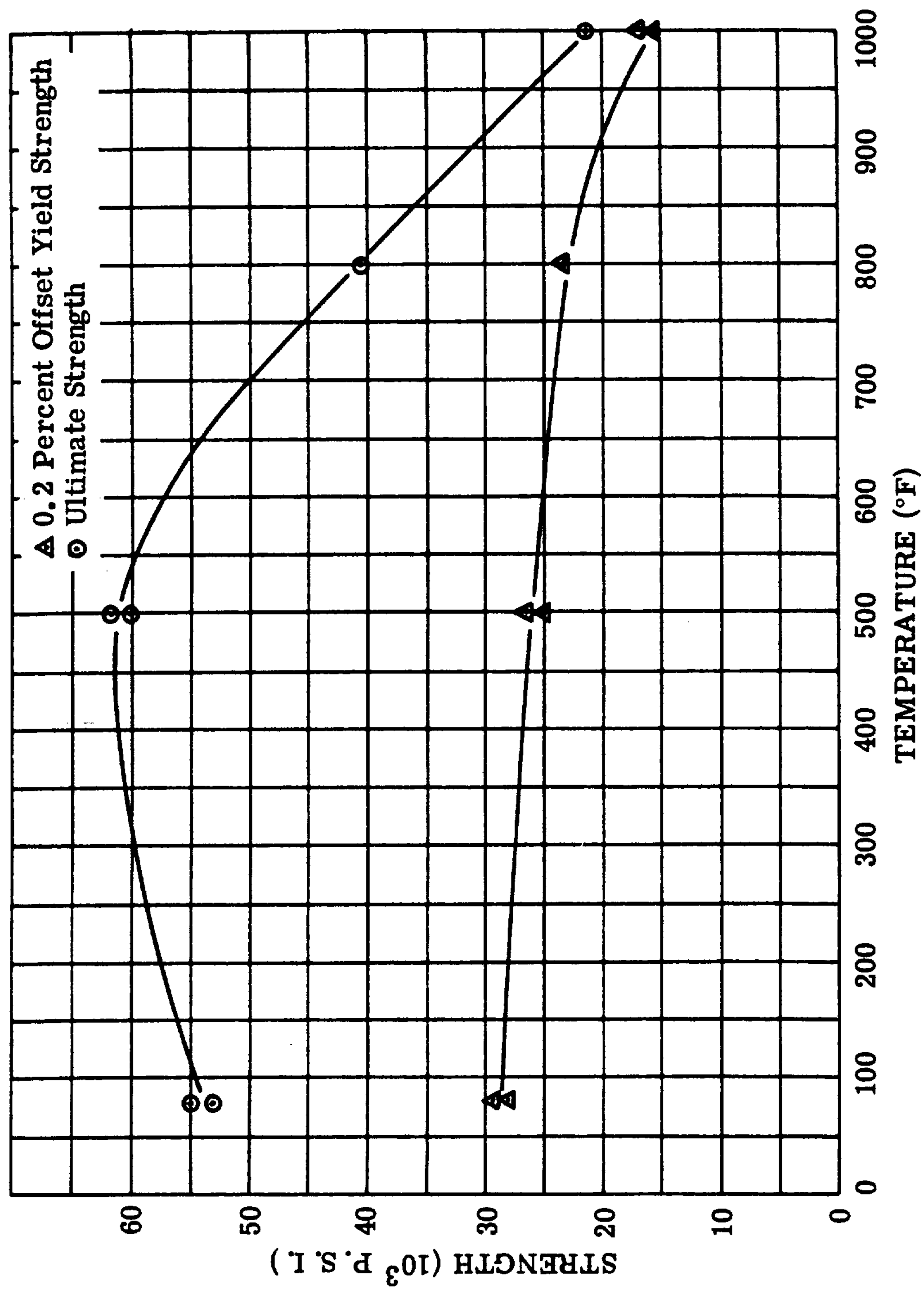


FIGURE I V. D. I I I-1. Room and Elevated Temperature Tensile Strength Properties in Air AMS5210 (1% Si-Fe) See Data Table I V. D. I I I-1. (Reference: NAS3-4162)

Figure I V. D. I I I-1. Tensile Properties - AMS5210

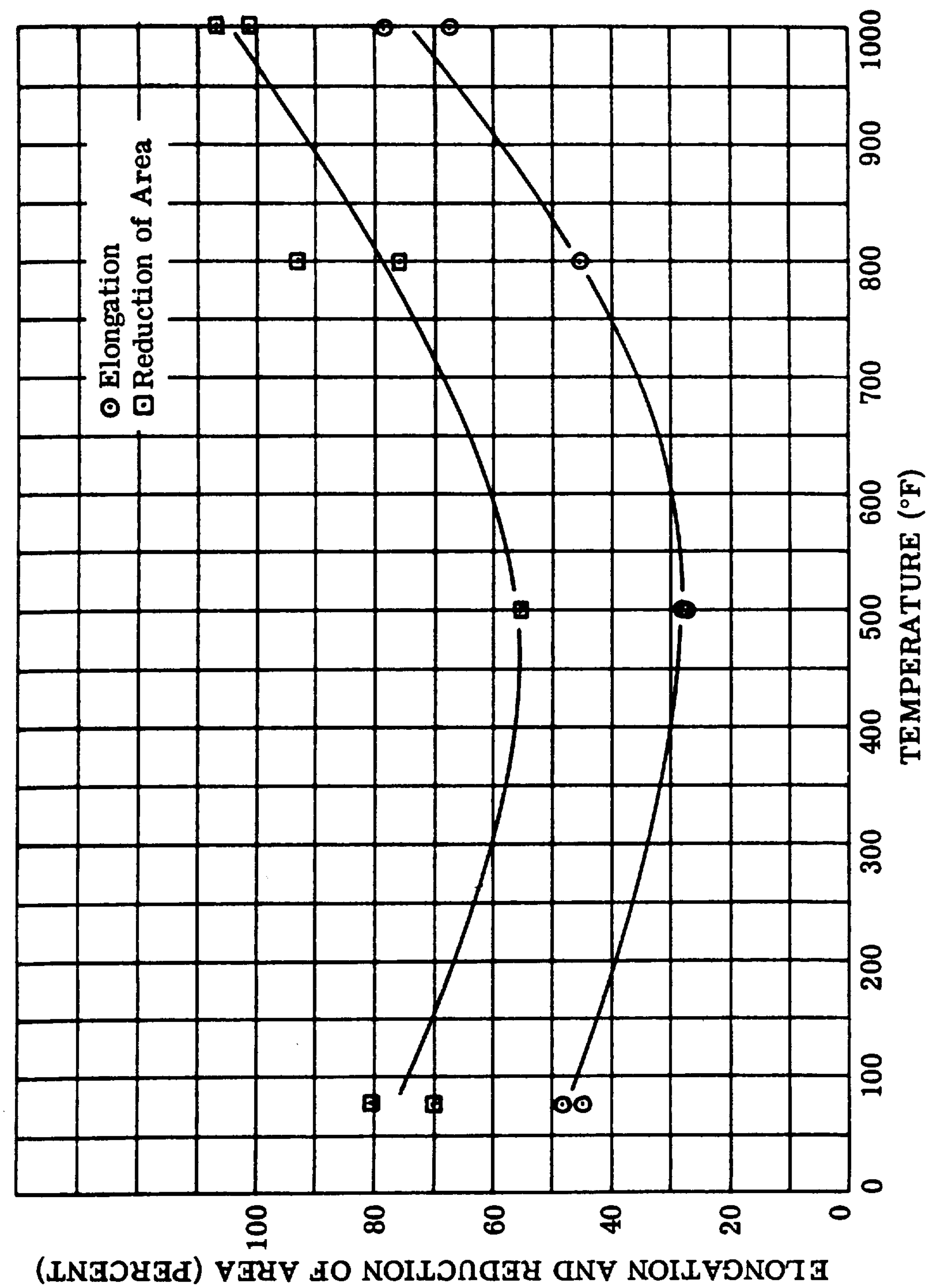


FIGURE I V. D. I I I-2. Room and Elevated Temperature Tensile Ductilities of AMS 5210 (1% Si-Fe) See Data Table I V. D. I I I-1. (Reference: NAS3-4162)

Figure I V. D. I I I-2. Tensile Ductility - AMS5210

MAGNETIC MATERIALS PROPERTIES SUMMARY

E. 15 PERCENT NICKEL MARAGING STEEL

An ultrahigh strength martensitic, age-hardenable steel, possessing high strength and increased resistance to softening at elevated temperatures.

Availability: Commercial

Nominal Composition: 9 Co, 5 Mo, 0.70 Ti, 0.70 Al, 15 Ni, Fe

Tested Composition:

Co	Mo	Ti	Al	Ni	Fe
9.0	5.0	0.70	0.70	15.0	Bal

I. Thermophysical Properties

A. Density — 0.289 lb/in^3 8.00 grams/cc

B. Solidus Temperature — approx. 2600°F

C. The Curie Temperature of Maraging steel is time temperature dependent and is not a fixed point as in Cubex or H-11 alloys.

D. Coefficient of thermal expansion — 72°-900°F 5.6×10^{-6} in/in-°F

E. Electrical Resistivity at 72°F — 38×10^{-6} ohm-cm

II. Magnetic Properties (All magnetic test materials ~~are stress relief annealed~~ were at a hardness of Rockwell c 54.5 (~~SRA~~) unless otherwise specified)

A. D-C Properties

1. Solid Ring

a. Induction (B_{tip}) for H = 250 oersteds at 72°F — 18.0 kilogauss
b. Induction (B_{tip}) for H = 250 oersteds at 700°F — 16.3 kilogauss
c. Induction (B_{tip}) for H = 250 oersteds at 900°F — 15.6 kilogauss
d. Induction (B_{tip}) for H = 200 oersteds at 1100°F — 13.0 kilogauss

2. 0.016 Inch Laminations

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	19.0 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 300°F	18.2 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 500°F	17.7 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 800°F	16.3 kilogauss

B. A-C Magnetic Properties (0.016 Inch) Laminations at 400 Cycles

1.	Exciting volt-amperes, B = 10 kilogauss at 72°F	177 volt-amperes/pound
2.	Exciting volt-amperes, B = 10 kilogauss at 300°F	180 volt-amperes/pound
3.	Exciting volt-amperes, B = 10 kilogauss at 500°F	177 volt-amperes/pound
4.	Exciting volt-amperes, B = 10 kilogauss at 800°F	181 volt/amperes/pound
5.	Core loss, B = 10 kilogauss at 72°F	108 watts/pound
6.	Core loss, B = 10 kilogauss at 300°F	106 watts/pound
7.	Core loss, B = 10 kilogauss at 500°F	104 watts/pound
8.	Core loss, B = 10 kilogauss at 800°F	102 watts/pound

C. Constant Current Flux Reset Properties (CCFR)

Not applicable to Maraging steel; measured only on materials for magnetic amplifiers.

III. Mechanical Properties

A. Poisson's ratio at 72°F 0.31

B. Tensile properties

1. At 72°F

a.	0.20 percent offset yield strength	291,000 psi
b.	Tensile strength	299,000 psi
c.	Elongation in two inches	15 percent
d.	Reduction of area	44 percent
e.	Modulus of elasticity	27.5×10^6 psi

2. At 400°F

a.	0.20 percent offset yield strength	255,000 psi
b.	Tensile strength	265,000 psi
c.	Elongation in two inches	8 percent
d.	Reduction of area	52 percent

3. At 600°F

a.	0.20 percent offset yield strength	250,000 psi
b.	Tensile strength	264,000 psi
c.	Elongation in two inches	8 percent
d.	Reduction of area	52 percent

4. At 800°F

a.	0.20 percent offset yield strength	226,000 psi
b.	Tensile strength	246,000 psi
c.	Elongation in two inches	9 percent
d.	Reduction of area	52 percent

C. Creep (Bar Stock) Air Tests

1.	Stress to produce 0.20 percent creep strain in 1000 hours at 700°F	214,000 to 219,000 psi
2.	Stress to produce 0.20 percent creep strain in 10,000 hours at 700°F	204,000 to 205,000 psi
3.	Stress to produce 0.40 percent creep strain in 1000 hours at 700°F	243,000 psi
4.	Stress to produce 0.40 percent creep strain in 10,000 hours at 700°F	230,000 psi
5.	Stress to produce 0.20 percent creep strain in 1000 hours at 900°F	14,500 to 27,000 psi
6.	Stress to produce 0.20 percent creep strain in 10,000 hours at 900°F	2800 to 7240 psi
7.	Stress to produce 0.40 percent creep strain in 1000 hours at 900°F	40,500 to 42,700 psi
8.	Stress to produce 0.40 percent creep strain in 10,000 hours at 900°F	12,000 to 18,500 psi

D. Fatigue Strength

This alloy possesses little potential for stressed applications at temperatures above 800°-850°F. The fatigue properties were therefore not determined.

E. Normal Heat Treatment - see 18 percent Nickel Maraging steel.

E. (Cont.) 18 PERCENT NICKEL MARAGING STEEL

An ultra-high-strength, martensitic, age-hardenable, steel.

Availability: Commercial

Nominal Composition: 8 Co, 4 Mo, 0.15-0.80 Ti, 18 Ni, Fe

Tested Composition: Not analyzed for exact composition. When used as a magnetic material it should be purchased to a performance requirement rather than chemical analysis.

I. Thermophysical Properties

A. Density — 0.289 lbs/in^3 7.93 grams/cc

B. Solidus Temperature — approx. 2600°F

C. The Curie Temperature of Maraging steel is time-temperature dependent and is not a fixed point as in Cubex alloy or H-11 alloys.

D. Thermal Conductivity

1. At 72°F — 8.4 Btu-ft/ft^2-hr-°F*
2. At 800°F — 11.4 Btu-ft/ft^2-hr-°F*

E. Coefficient of Thermal Expansion

1. 72°-900°F — 5.6 x 10^{-6} in/in-°F

F. Specific Heat at 32°-212°F — 0.12 Btu/lb-°F*

G. Electrical Resistivity at 72°F

(Full Hard) — 38.0 x 10^{-6} ohm-cm

*Private Communication International Nickel Co.

II. Magnetic Properties (All magnetic test materials were at a hardness of ~~materials are stress relief annealed~~ Rockwell C51-53([redacted]) unless otherwise specified)

A. D-C Properties

1. Solid Ring

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	17.6 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 800°F	15.0 kilogauss

2. 0.014 inch Laminations

a.	Induction (B_{tip}) for H = 250 oersteds at 72°F	18.1 kilogauss
b.	Induction (B_{tip}) for H = 250 oersteds at 300°F	17.6 kilogauss
c.	Induction (B_{tip}) for H = 250 oersteds at 500°F	16.8 kilogauss
d.	Induction (B_{tip}) for H = 250 oersteds at 800°F	15.1 kilogauss

B. A-C Magnetic Properties (0.014 inch laminations at 400 cycles)

1.	Exciting volt-amperes, B = 10 kilogauss at 72°F	285 volt-amperes/pound
2.	Exciting volt-amperes, B = 10 kilogauss at 300°F	294 volt-amperes/pound
3.	Exciting volt-amperes, B = 10 kilogauss at 500°F	308 volt-amperes/pound
4.	Exciting volt-amperes, B = 10 kilogauss at 800°F	336 volt-amperes/pound
5.	Core loss, B = 10 kilogauss at 72°F	116 watts/pound
6.	Core loss, B = 10 kilogauss at 300°F	118 watts/pound
7.	Core loss, B = 10 kilogauss at 500°F	119 watts/pound
8.	Core loss, B = 10 kilogauss at 800°F	118 watts/pound

C. Constant Current Flux Reset Properties (CCFR)

Not applicable to Maraging steel alloys, only measured on materials used in magnetic amplifiers.

III. Mechanical Properties (250 Grade Material)

A. Poisson's Ratio at 72°F — 0.30**

B. Tensile Properties

1. At 72°F

a.	0.20 percent offset yield strength	250,000 psi**
b.	Tensile strength	257,000 psi**
c.	Elongation in one inch	12 percent**
d.	Reduction of area	55 percent**
e.	Modulus of elasticity	27×10^6 psi

2. At 700°F

a.	0.20 percent offset yield strength	220,600 psi**
b.	Tensile strength	240,000 psi**
c.	Elongation in two inches	15 percent**
d.	Reduction of area	55 percent**

3. At 900°F

a.	0.20 percent offset yield strength	185,000 psi**
b.	Tensile strength	197,000 psi**
c.	Elongation in two inches	15 percent**
d.	Reduction of area	63 percent**

C. Creep (Bar Stock) Air Tests*

1.	Stress to produce 0.20 percent creep strain in 1000 hours at 700°F	133,000 psi
2.	Stress to produce 0.20 percent creep strain in 10,000 hours at 700°F	110,000 psi
3.	Stress to produce 0.50 percent creep strain in 1000 hours at 700°F	164,000 psi
4.	Stress to produce 0.50 percent creep strain in 10,000 hours at 700°F	128,000 psi

*All creep data are taken and calculated from a Larson-Miller plot shown in Figure IV.E.III-5.

**Allegheny Ludlum Product Literature ALMAR 18-250.

5. Stress to produce 0.20 percent creep strain in 1000 hours at 900°F — 51,400 psi
6. Stress to produce 0.50 percent creep strain in 1000 hours at 900°F — 59,000 psi

D. Fatigue Strength at 72°F for 10^7 Cycles

1. Notched Bar Air Melted Material — 45,000 psi**
2. Smooth Bar

    a. Vacuum melted material — 115,000 psi**

    b. Air melted material — 97,000 psi**

E. Normal Heat Treatment

Heat to 1500° ± 25°F, hold at uniform temperature for 1 hour, cool at any convenient rate to produce the martensitic structure at room temperature. Age harden for 3 hours at 875°- 925°F and cool.

**Allegheny Ludlum Product Literature ALMAR 18-250.

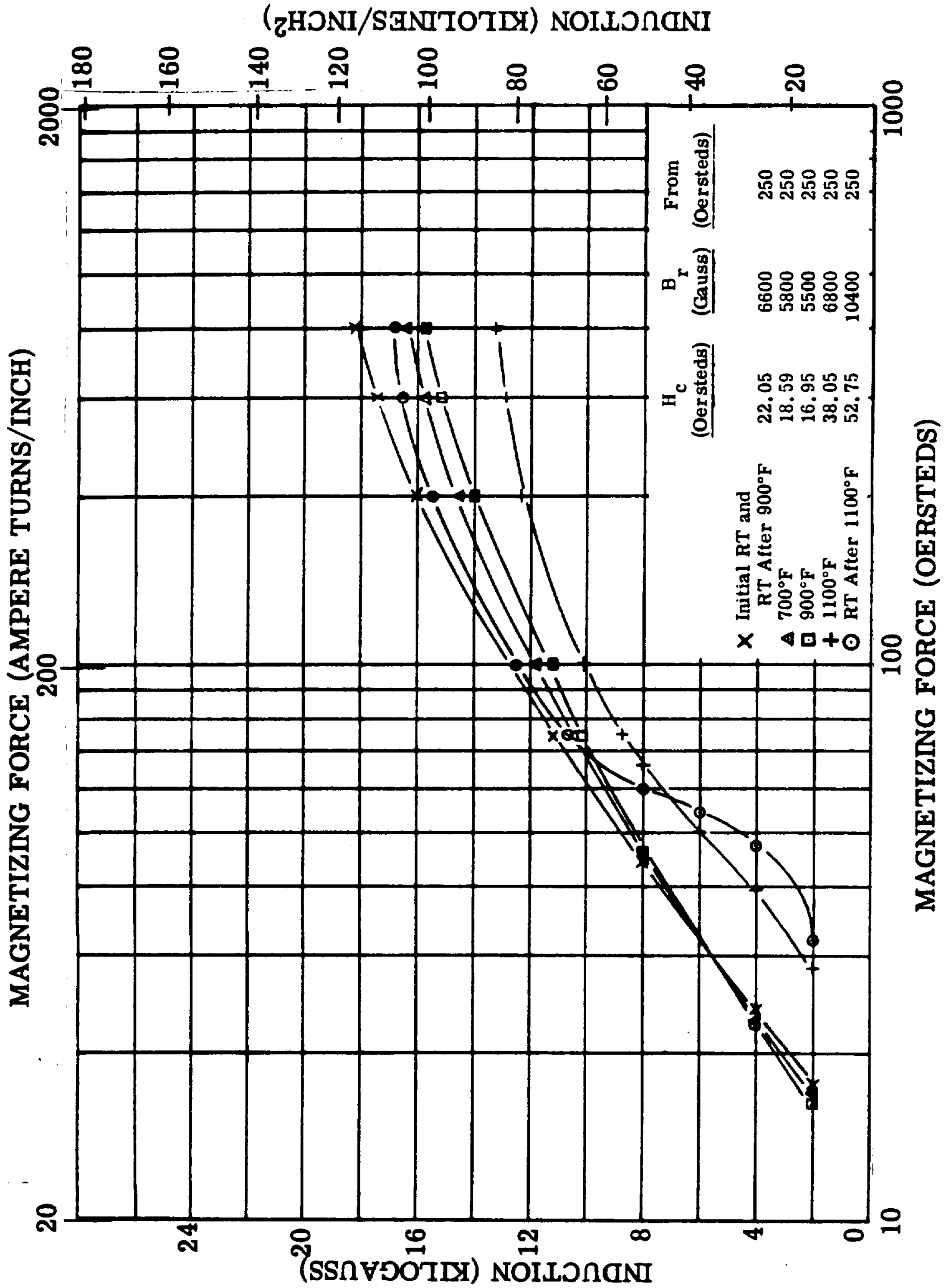


FIGURE IV.E.II-1. D-C Magnetization Curves. 15% Ni Maraging Steel - Forging Test Atmosphere: Air. (Reference: SPUR Generator Development Program, Phase III Quarterly Report, March 31, 1964)

Figure IV.E.II-1. D-C Magnetization - 15% Ni Maraging Steel

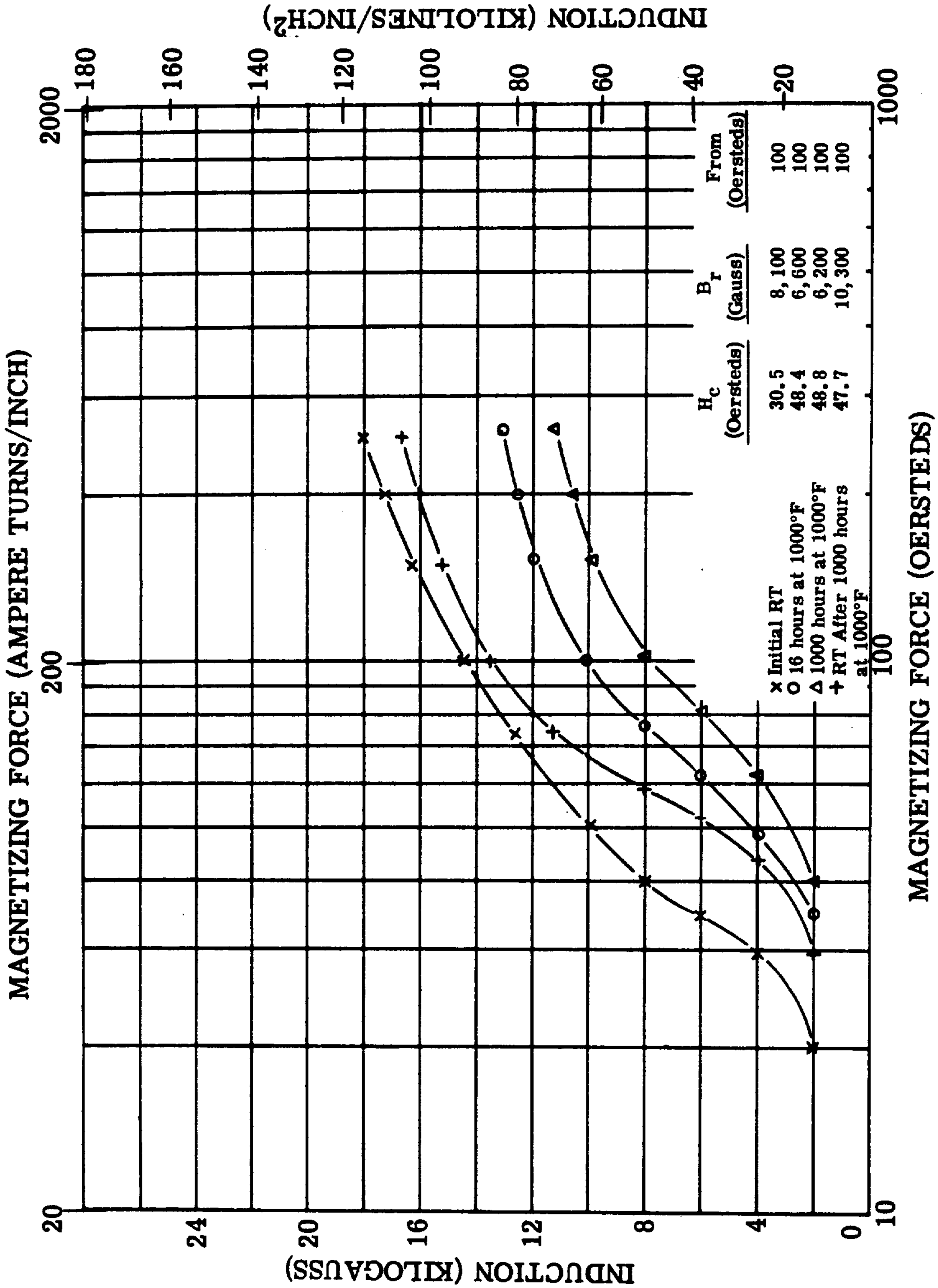


FIGURE IV.E.II-2. D-C Magnetization Curves. 15% Ni Maraging Steel Forging - Aging Test. Test Atmosphere: Argon. (Reference: NAS3-4162)

Figure IV.E.II-2. D-C Magnetization - 15% Ni Maraging Steel

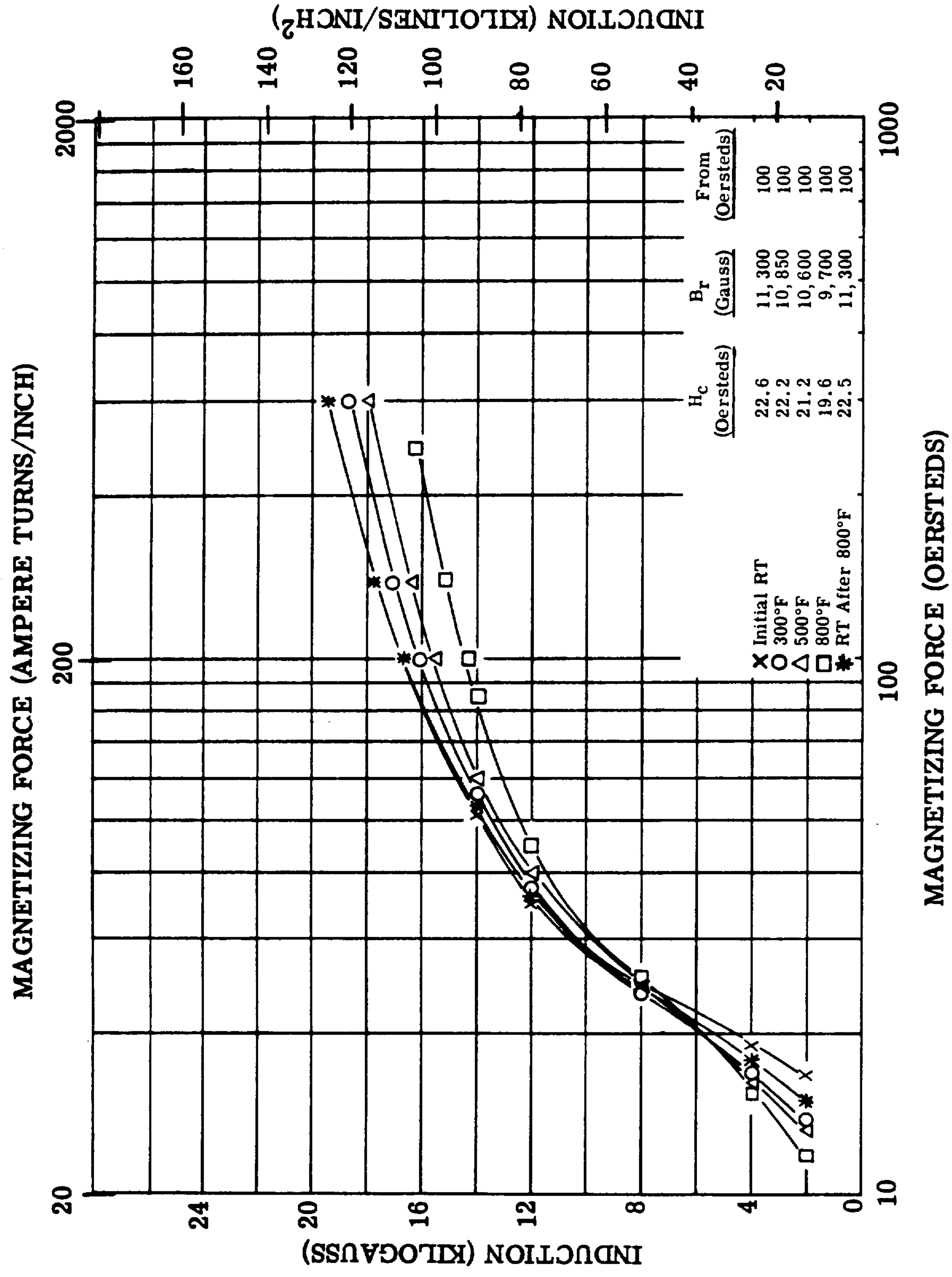


FIGURE I V. E. I I-3. D-C Magnetization Curves. 15% Ni Maraging Steel - 0.016 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure I V. E. I I-3. D-C Magnetization - 15% Ni Maraging Steel

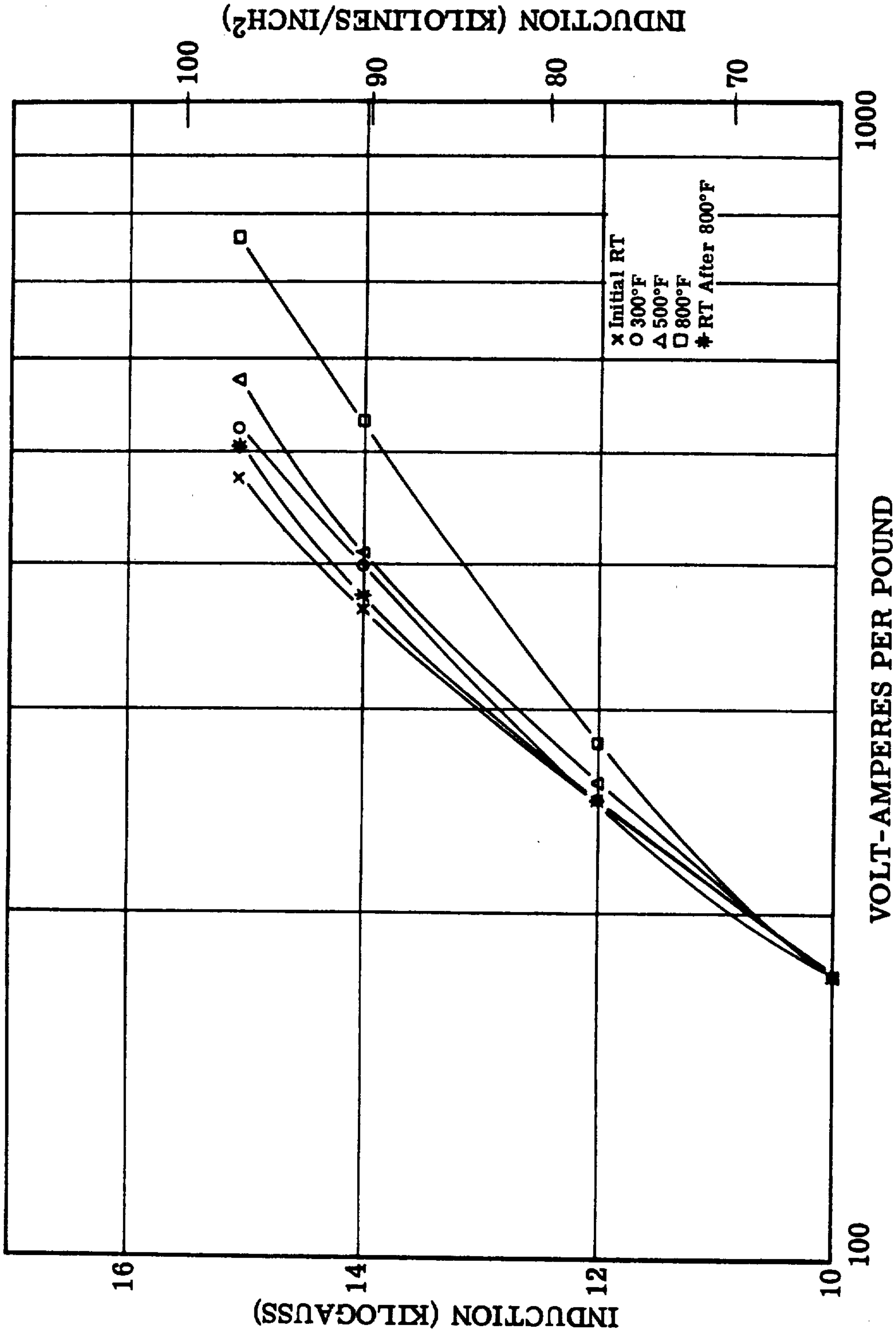


FIGURE I V. E. I I-4. Exciting Volt-Amperes Per Pound, 400 CPS. 15% Ni Maraging Steel - 0. 016 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. E. I I-4. Exciting VA, 400 CPS. 15% Ni Maraging Steel

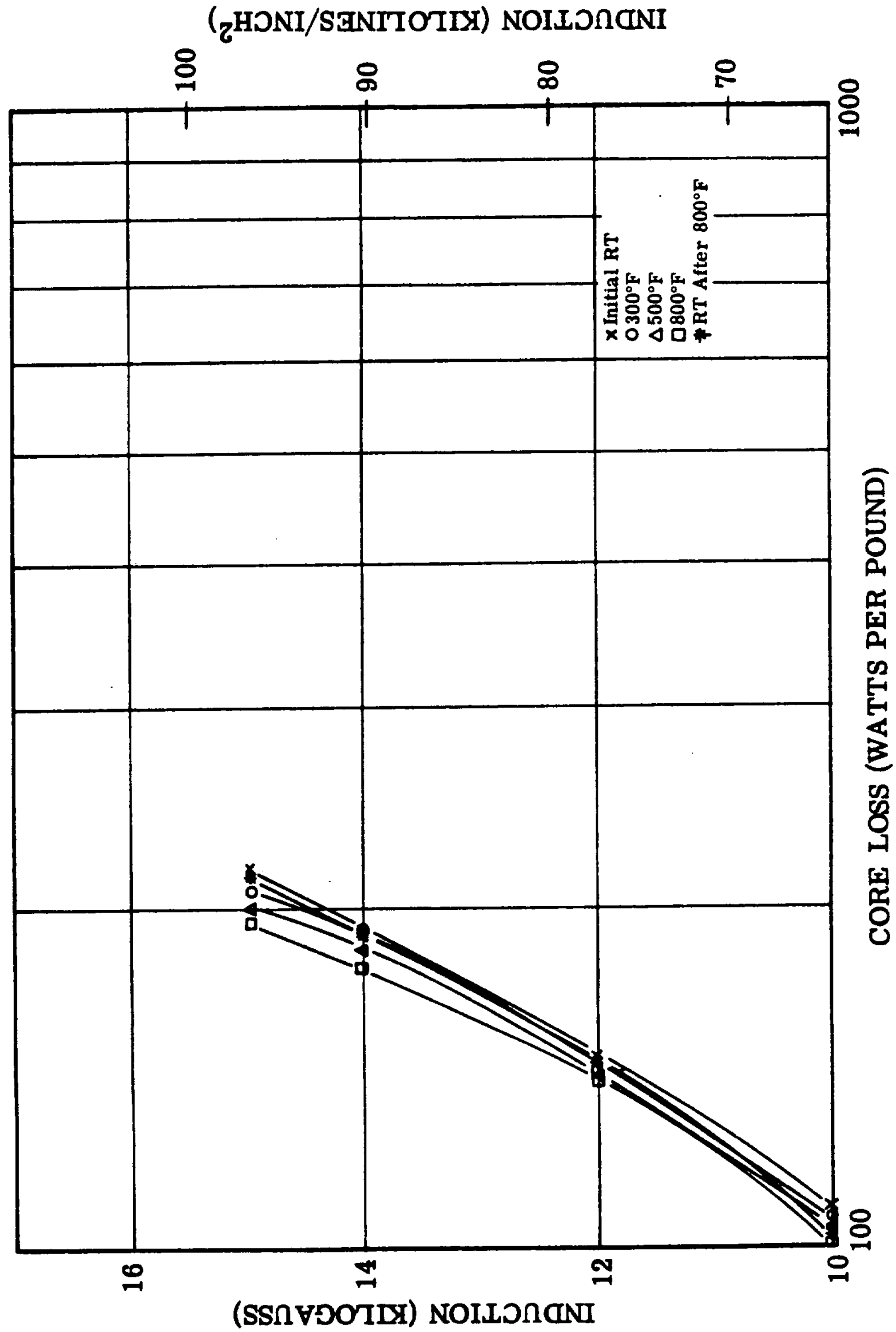


FIGURE IV. E. II-5. Core Loss, 400 CPS. 15% Ni Maraging Steel - 0.016 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. E. II-5. Core Loss, 400 CPS. 15% Ni Maraging Steel

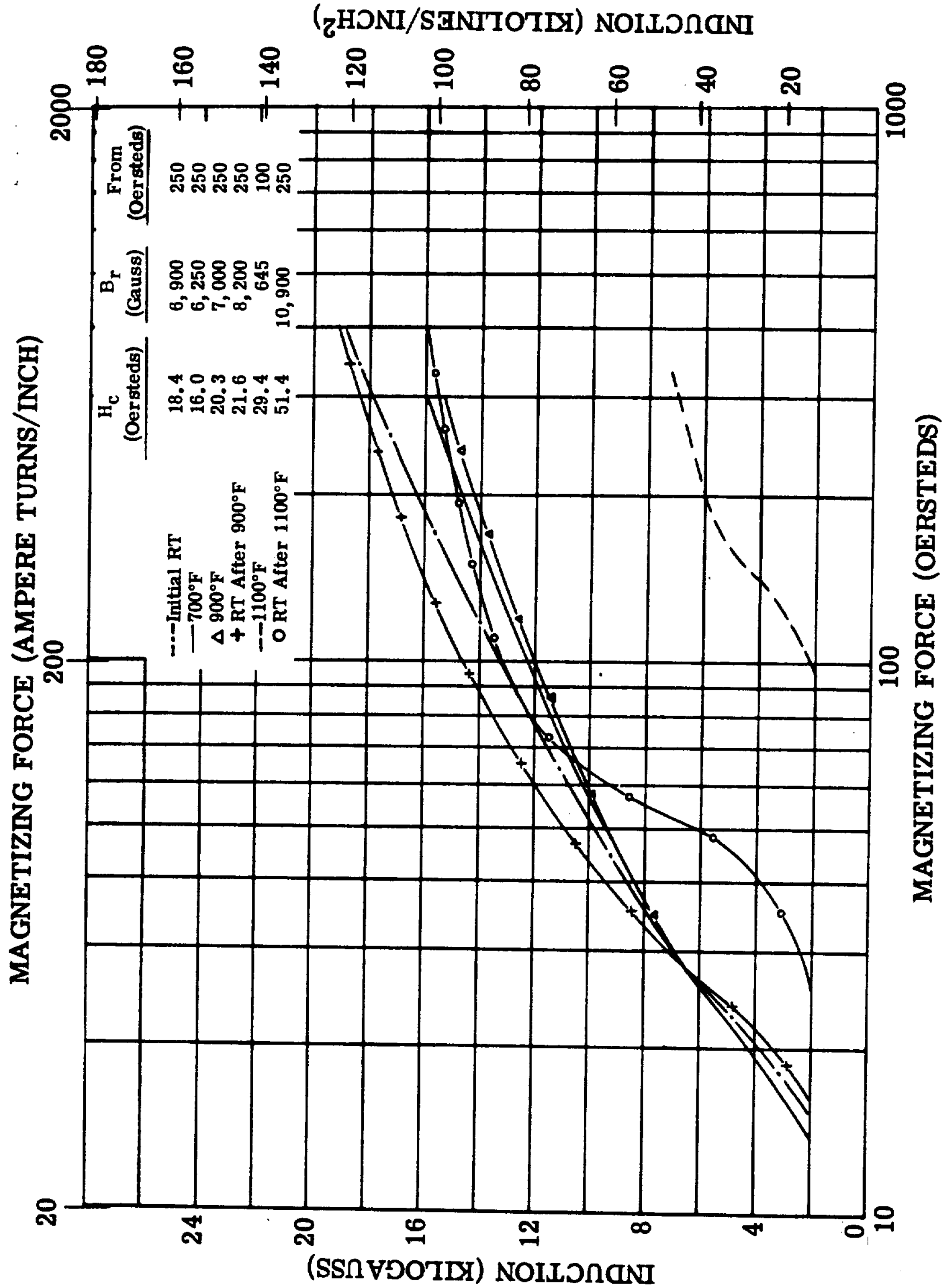


FIGURE I V. E. II-6. D-C Magnetization Curves. 18% Ni Maraging Steel - Forging. Test Atmosphere: Air. (Reference: 1963 Annual SPUR Generator Development Report)

Figure I V. E. II-6. D-C Magnetization - 18% Ni Maraging Steel

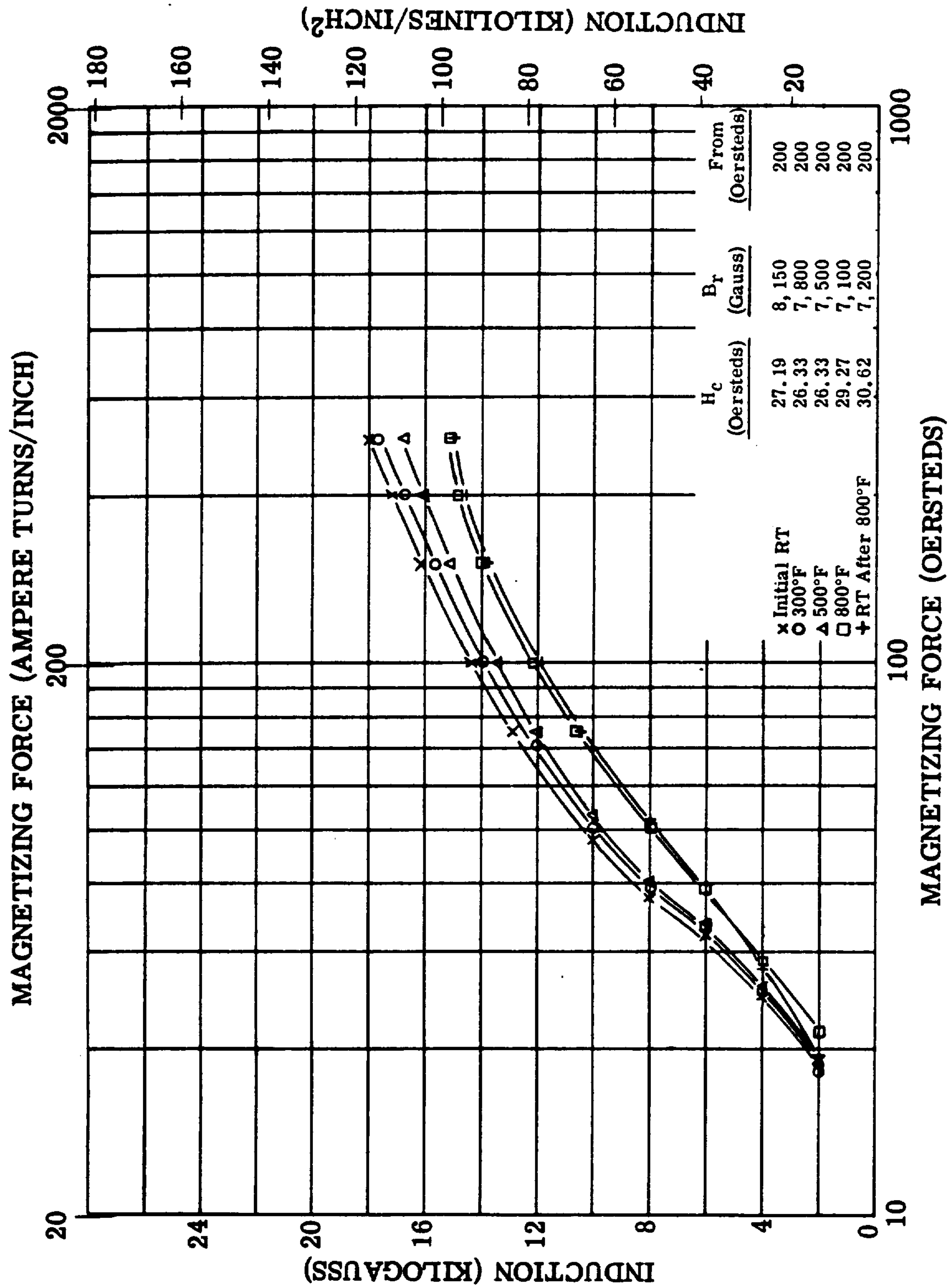


FIGURE IV.E.II-7. D-C Magnetization Curves. 18% Ni Maraging Steel - 0.014 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.E.II-7. D-C Magnetization - 18% Ni Maraging Steel

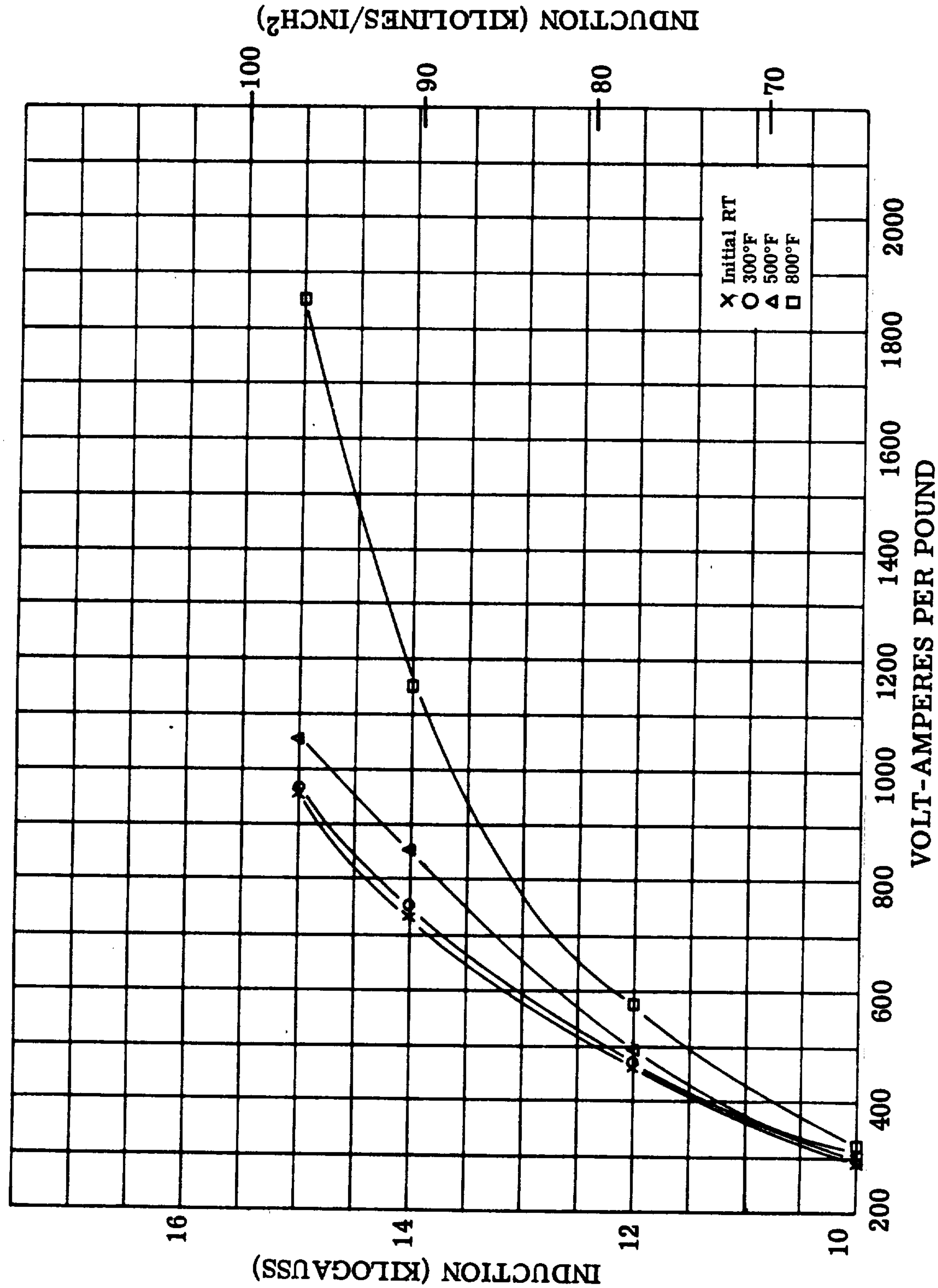


FIGURE IV.E.II-8. Exciting Volt-Amperes Per Pound, 400 CPS. 18% Ni Maraging Steel - 0.014 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.E.II-8. Exciting VA, 400 CPS. 18% Ni Maraging Steel

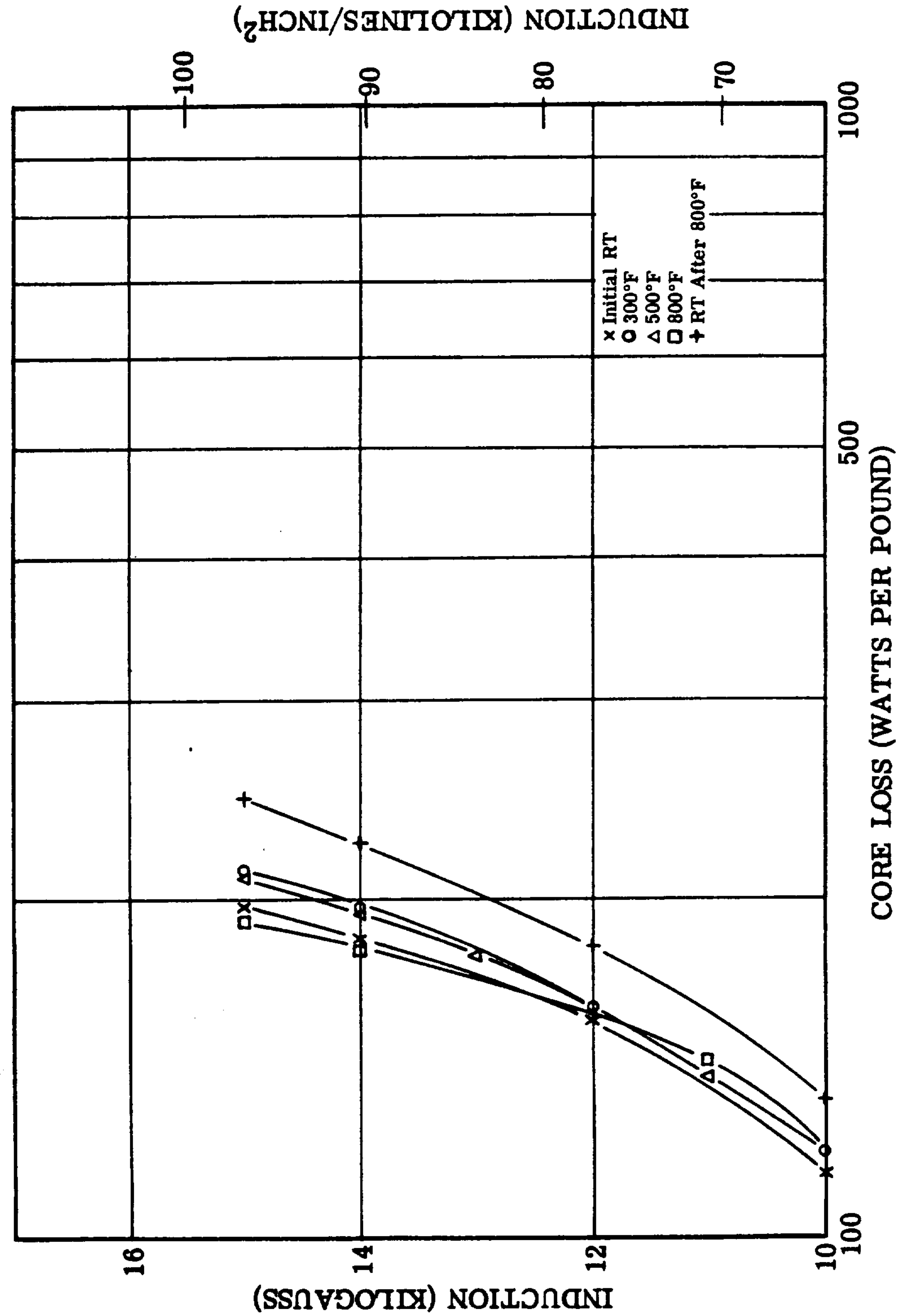


FIGURE IV.E.II-9. Core Loss, 400 CPS. 18% Ni Maraging Steel - 0.014 Inch Laminations. Test Atmosphere: Air. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.E.II-9. Core Loss, 400 CPS. 18% Ni Maraging Steel

TABLE IV.E.III-1. Tensile Properties of 15 Percent Nickel Maraging Steel With Two Different Heat Treatments, Tested in Air. See Figure IV.E.III-1.

Test Temp (°F)	0.2 Percent Offset Yield Strength (Psi)	Ultimate Tensile Strength (Psi)	Elongation (percent)	Reduction of Area (percent)	Hardness After Testing (Rockwell C)
		Condition 1			
70	291,000	299,000	15	44	
200	271,000	281,000	8	46	54.0
400	255,000	265,000	8	52	54.1
600	240,000	264,000	8	51	54.6
800	226,000	246,000	9	52	55.3
1000	177,000	192,000	15	48	55.5
		Condition 2			
70	262,000	281,000	13	50	
200	250,000	268,000	10	52	
400	235,000	255,000	9	55	
600	225,000	241,000	12	53	
800	206,000	230,000	10	54	
1000	210,000	230,000	9	53	

Condition 1: Materials held at 1500°F for 1 hour, water quenched and aged 3 hours at 900°F. Samples were held at test temperature 1 hour before test.

Condition 2: Materials held at 1800°F for 1 hour, water quenched and aged 3 hours at 900°F. Samples were held at test temperature 1 hour before test.

(Reference: Allegheny Ludlum Steel Product literature)

TABLE IV.E.III-2. Tensile Properties of 18 Percent Nickel Maraging Steel Tested in Air. See Figure IV.E.III-1.

Test Temp. (°F)	0.20 Percent Offset Yield Strength (Psi)	Ultimate Strength (Psi)	Elongation (percent)	Reduction of Area (percent)
12	250,000	257,000	6	57
200	238,000	250,000	12	59
400	228,000	240,000	11	58
600	216,000	228,000	10	57
800	196,000	210,000	12	60
1000	138,000	158,000	22	80

(Reference: Allegheny Ludlum Steel Product literature)

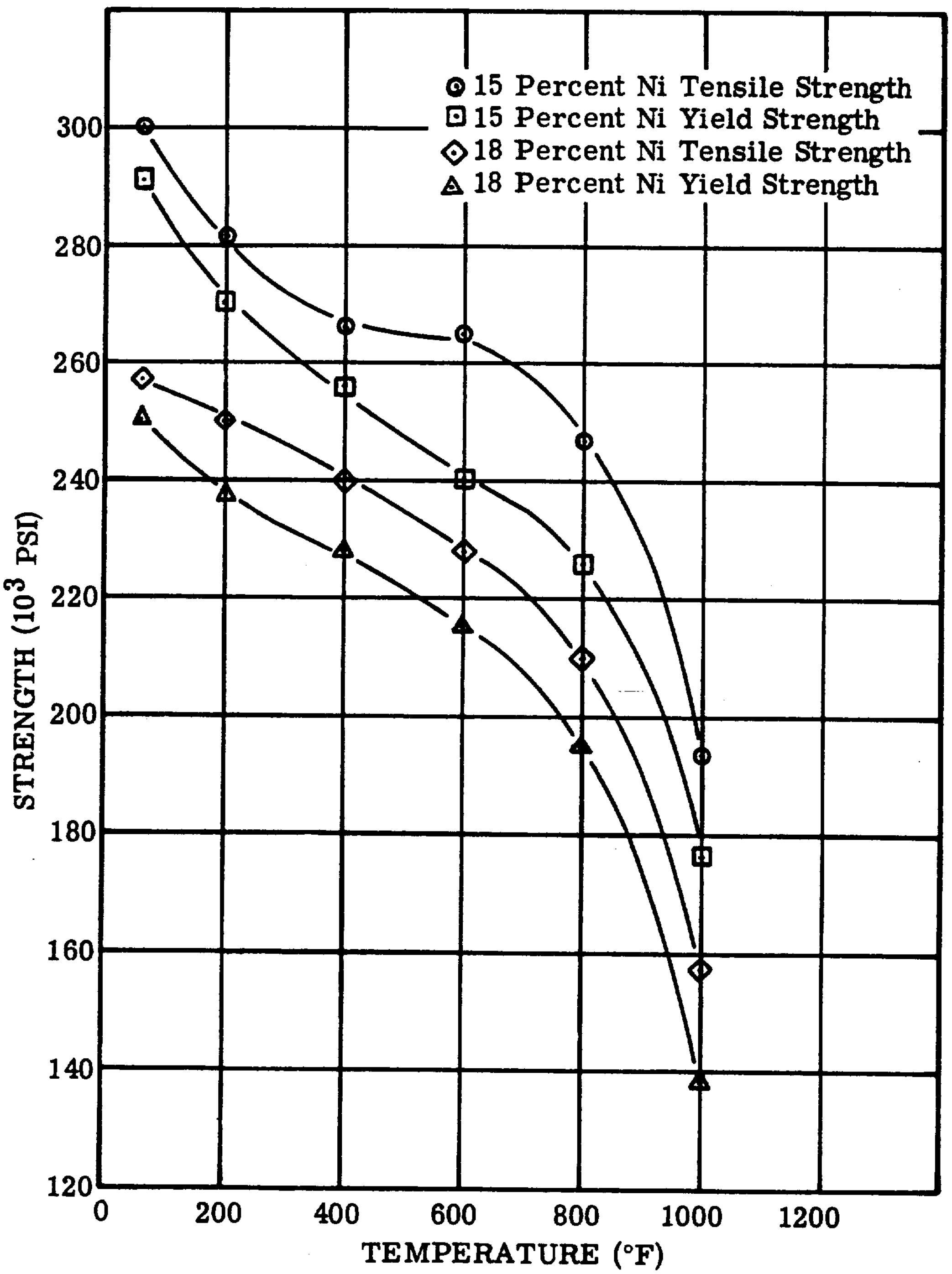


FIGURE IV.E.III-1. Tensile Strengths, 15 and 18 Percent Nickel Maraging Steels, Tested in Air. See Data Tables IV.E.III-1 and IV.E.III-2. (Reference: Allegheny Ludlum Steel Product Literature)

Figure IV.E.III-1. Tensile Properties - 15% and 18% Nickel Maraging Steel

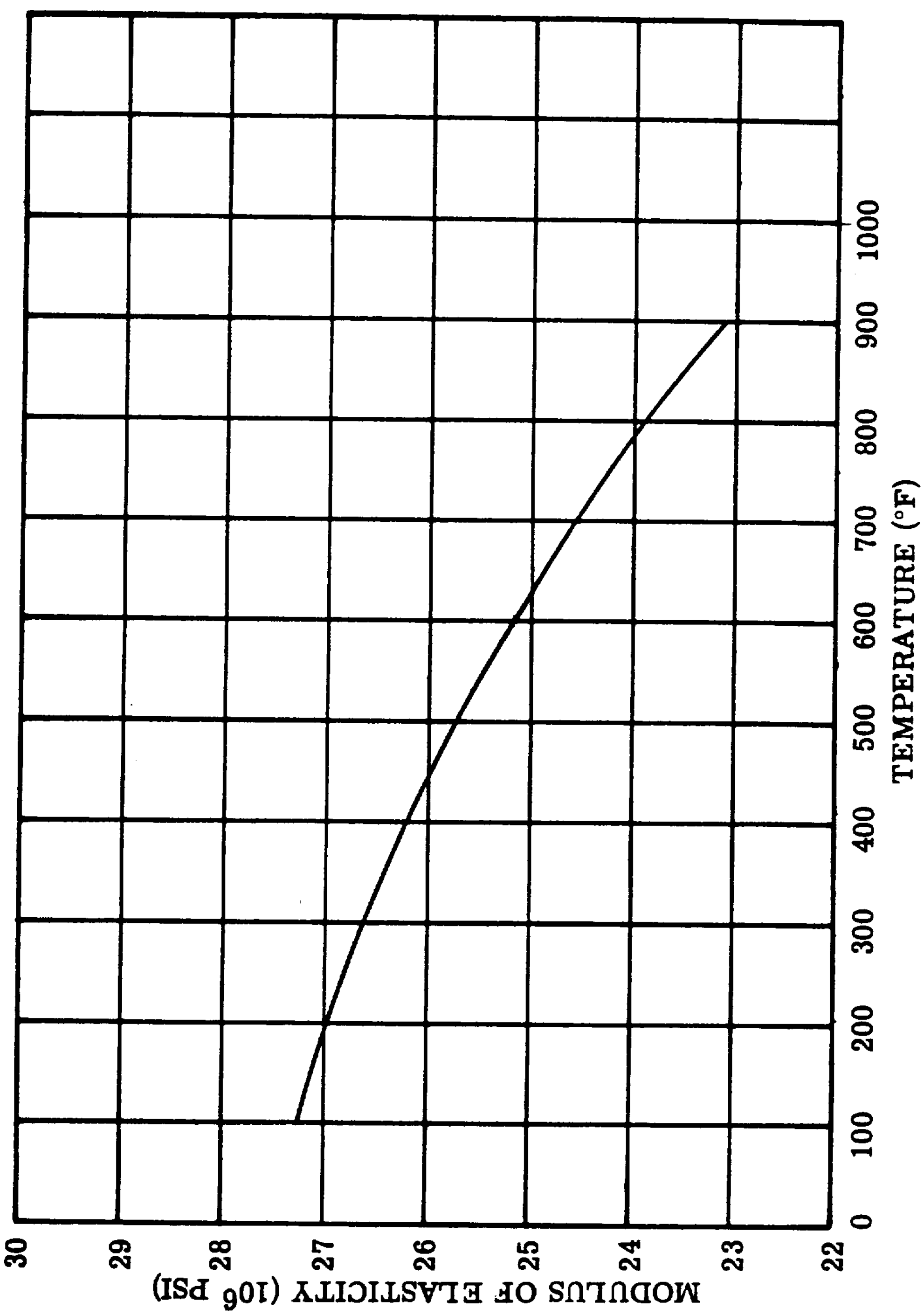


FIGURE IV.E.III-2. Dynamic Modulus of Elasticity for 18 Percent Nickel Maraging Steel 250,000 PSI Grade. (Reference: Allegheny Ludlum Steel Product Literature)

Figure IV.E.III-2. Young's Modulus - 18% Nickel Maraging Steel

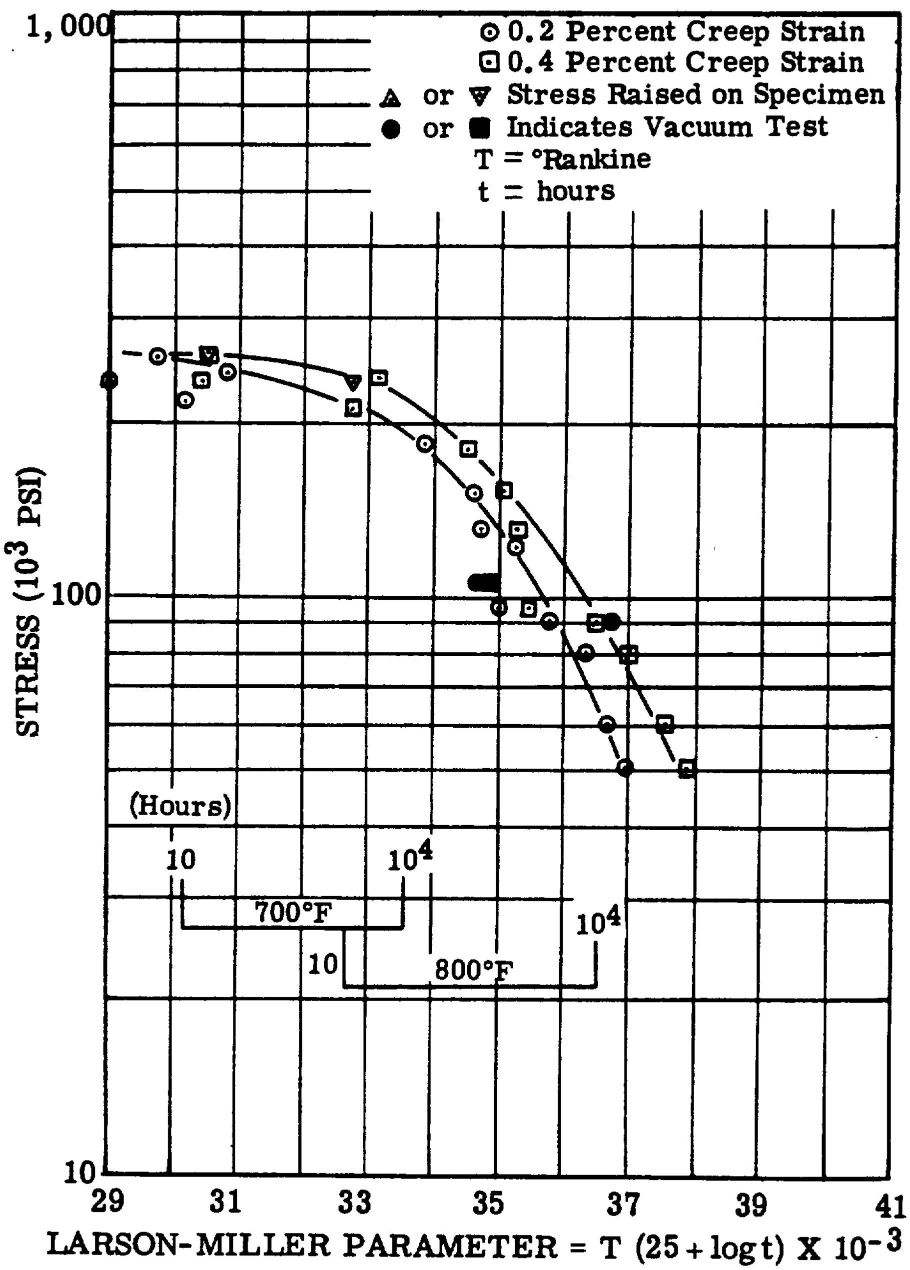


FIGURE IV.E.III-3. Larson-Miller Plot of 15 Percent Nickel Maraging Steel Creep Data Based on a Maximum of 2000 Hour Data. (Reference: NAS 3-4162)

Figure IV.E.III-3. Creep. Larson-Miller Plot - 15% Nickel Maraging Steel

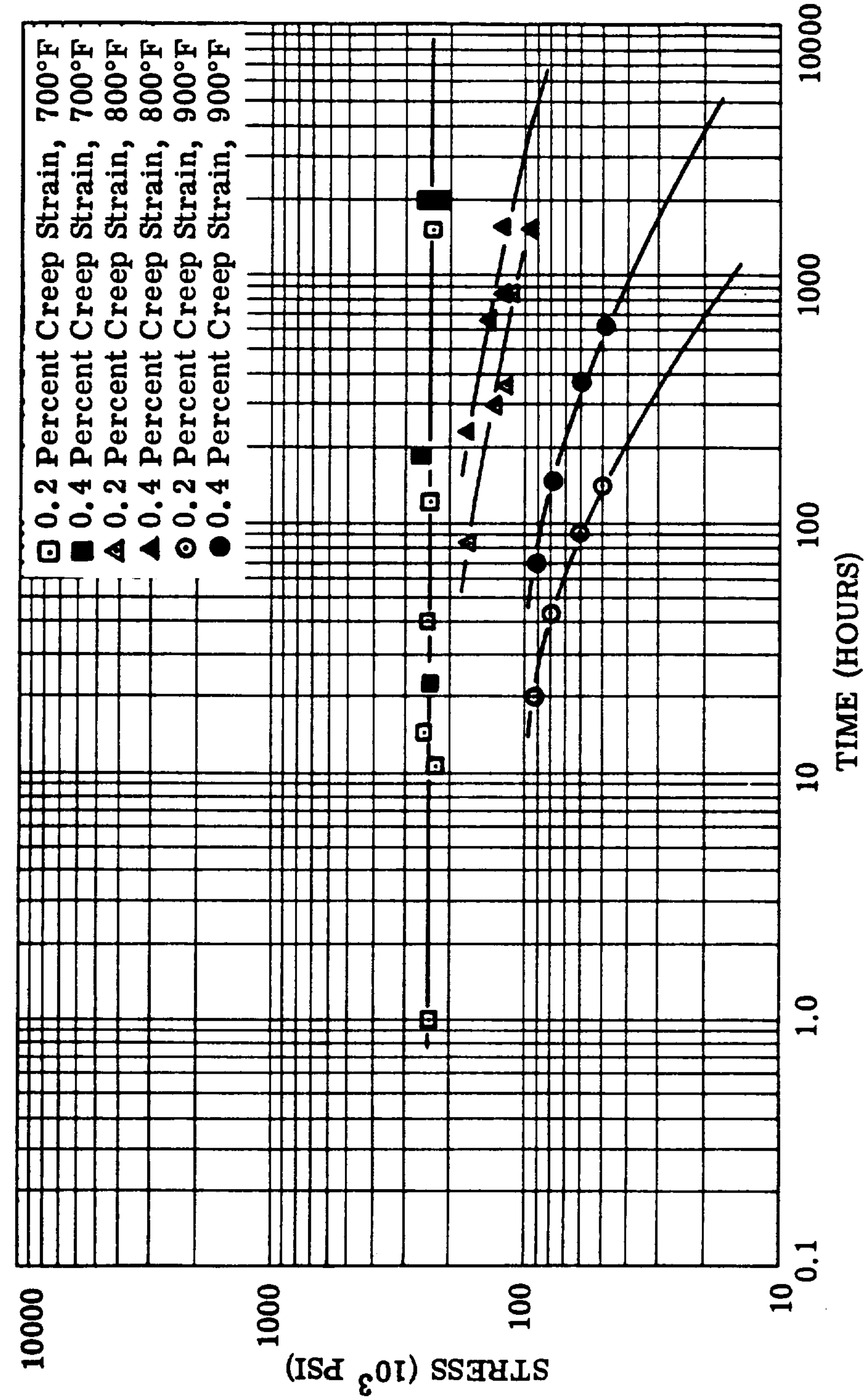


FIGURE IV. E. III-4. Stress vs. Time to 0.20 and 0.40 Percent Creep Strain For 15 Percent Nickel Maraging Steel Tested in Air. (Reference: NAS3-4162)

Figure IV. E. III-4. Creep - 15% Nickel Maraging Steel

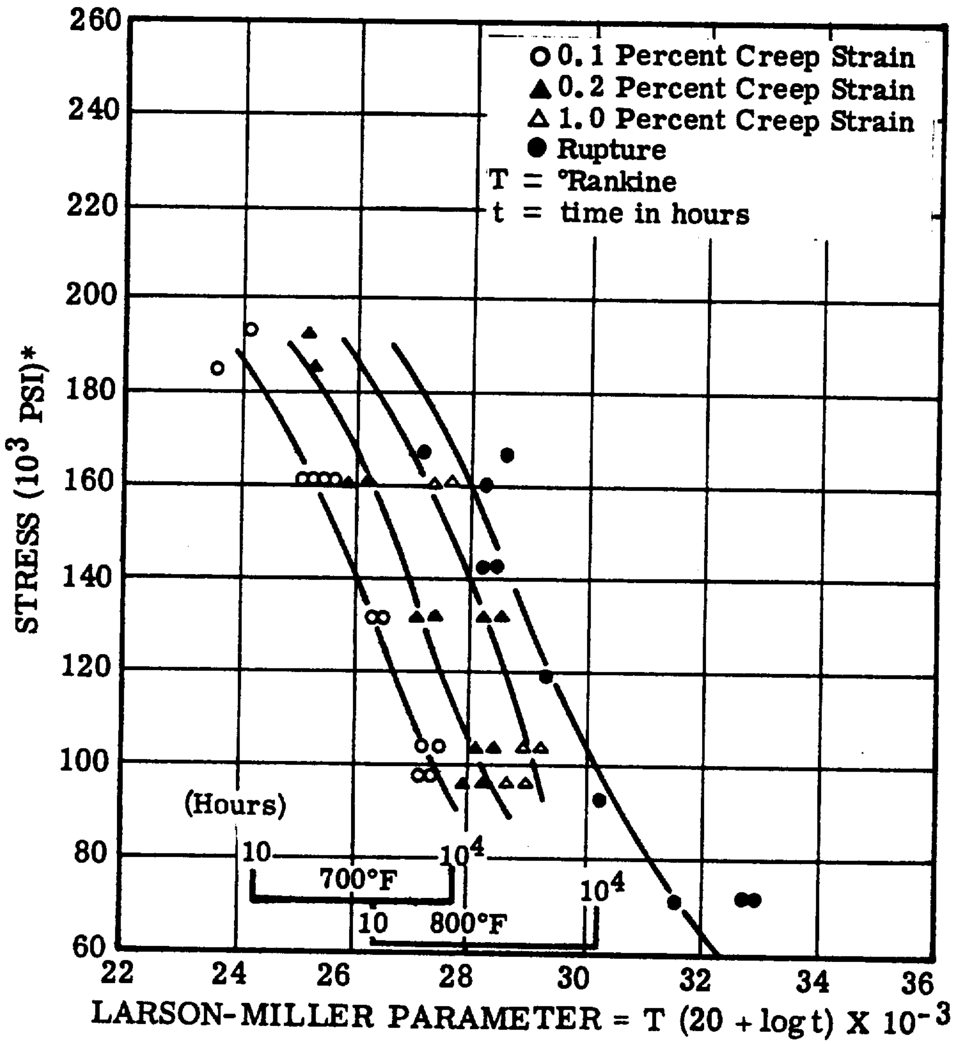


FIGURE IV. E. III-5. Larson-Miller Plot of Creep and Rupture Strengths for 18 Percent Nickel Maraging Steel Aged at 900°F for 3 Hours Based on a Maximum of 2000 Hour Data. (Reference: LM522) *For purposes of Comparison Ultimate Strength is taken at 257,000 PSI.

Figure IV. E. III-5. Creep - 18% Nickel Maraging Steel

TABLE IV.E.III-3. Creep Data for 15 Percent Nickel Maraging Steel
See Figures IV.E.III-6 to IV.E.III-9.

TEST: ASTM E139

Temperature (°F)	700	++700	700	700	800	800	800	800
Stress (psi)	150,000	230,000	240,000	216,000	120,000	130,000	150,000	180,000
Duration of Test (hours)	811	1,685*	1,385*	665*	1,920*	1,028	1,150*	314
Total Creep Strain (percent)	0.115	0.195	0.40	0.343	0.425	0.463	0.706	0.525
Time to Cause 0.2 percent Creep Strain (hours)	+	1,670	40	11	840	345	290	82
Time to Cause 0.4 percent Creep Strain (hours)	+	+	1.985**	1,920**	1,765	870	652	231
Plastic Strain obtained on loading specimen (percent)	0	0	0.0362	0.1111	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.E.III →	6	6	7	7	8	8	9	9

*Test still running
+Did not reach
++Data obtained by increasing the stress
**Extrapolated

(Reference: NAS 3-4162)

TABLE IV. E. III-4. Creep Data For 15 Percent Nickel Maraging Steel
See Figures IV. E. III-10 to IV. E. III-14.

TEST: ASTM E139

Temperature (°F)	900	900	700	700	700	800	900	900
Stress (psi)	80,000	90,000	235,000	180,000	259,000*	95,000	50,000	60,000
Duration of Test (hours)	261	140	356	332	461	1,513	838	522
Total Creep Strain (percent)	0.521	0.643	0.525	0.048	0.589	0.375	0.447	0.482
Time to Cause 0.2 percent Creep Strain (hours)	42.0	14.5	1	-	17	460	138	92.0
Time to Cause 0.4 percent Creep Strain (hours)	155	68.5	23	-	183	1,620	610	358
Plastic Strain obtained on loading specimen (percent)	0	0	0.1722	0	0.048	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.E.III →	14	14	10	10	10	11	12	13

*Data for this test obtained by increasing stress on the 180,000 psi specimen.

(Reference: NAS 3-4162)

TABLE IV. E. III-5. Vacuum Creep Data For 15 Percent Nickel Maraging Steel

TEST: ASTM E139

Temperature (°F)	800	900	900
Stress (psi)	107, 500	60, 000	90, 000
Duration of Test (hours)	283	502	192
Total Creep Strain (percent)	0.07	0.07	0.26
Time to Cause 0.2 percent Creep Strain (hours)	325 (2)	(1)	120
Time to Cause 0.4 percent Creep Strain (hours)	395 (2)	(1)	(1)
Plastic Strain obtained on loading specimen (percent)	0	0	0
Test Atmosphere	Vacuum	Vacuum	Vacuum
See Larson-Miller Plot in Figure IV. E. III-3			

(1) Did not reach required strain.
(2) Extrapolated data

(Reference: NAS 3-4162)

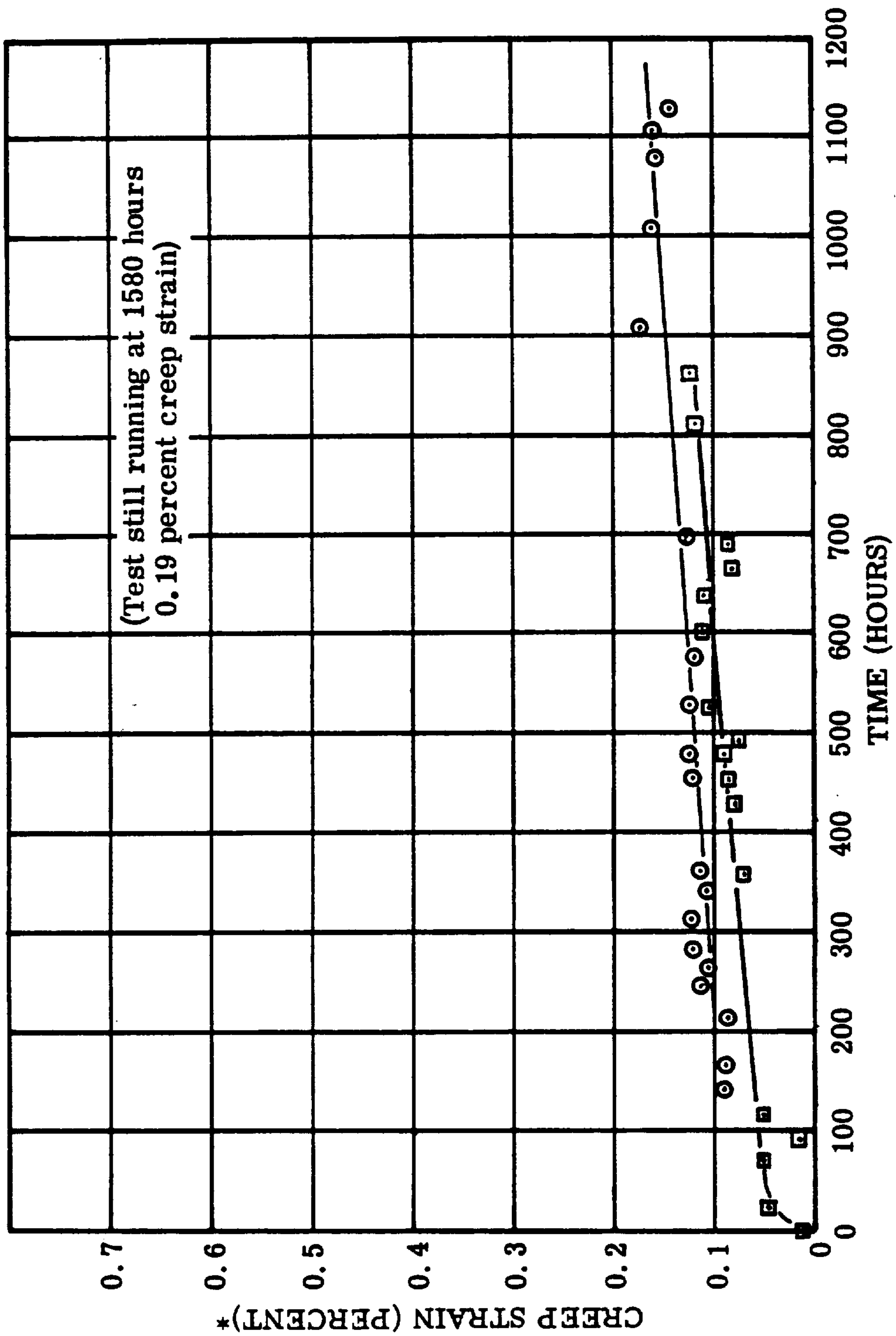


FIGURE I V. E. III-6. Creep, 15 Percent Nickel Maraging Steel Tested at 700 °F in Air. See Data Table I V. E. III-3. (Reference: NAS3-4162)
*Data Obtained by Increasing the Stress on a Single Specimen.

Figure I V. E. III-6. Creep - 15% Nickel Maraging Steel

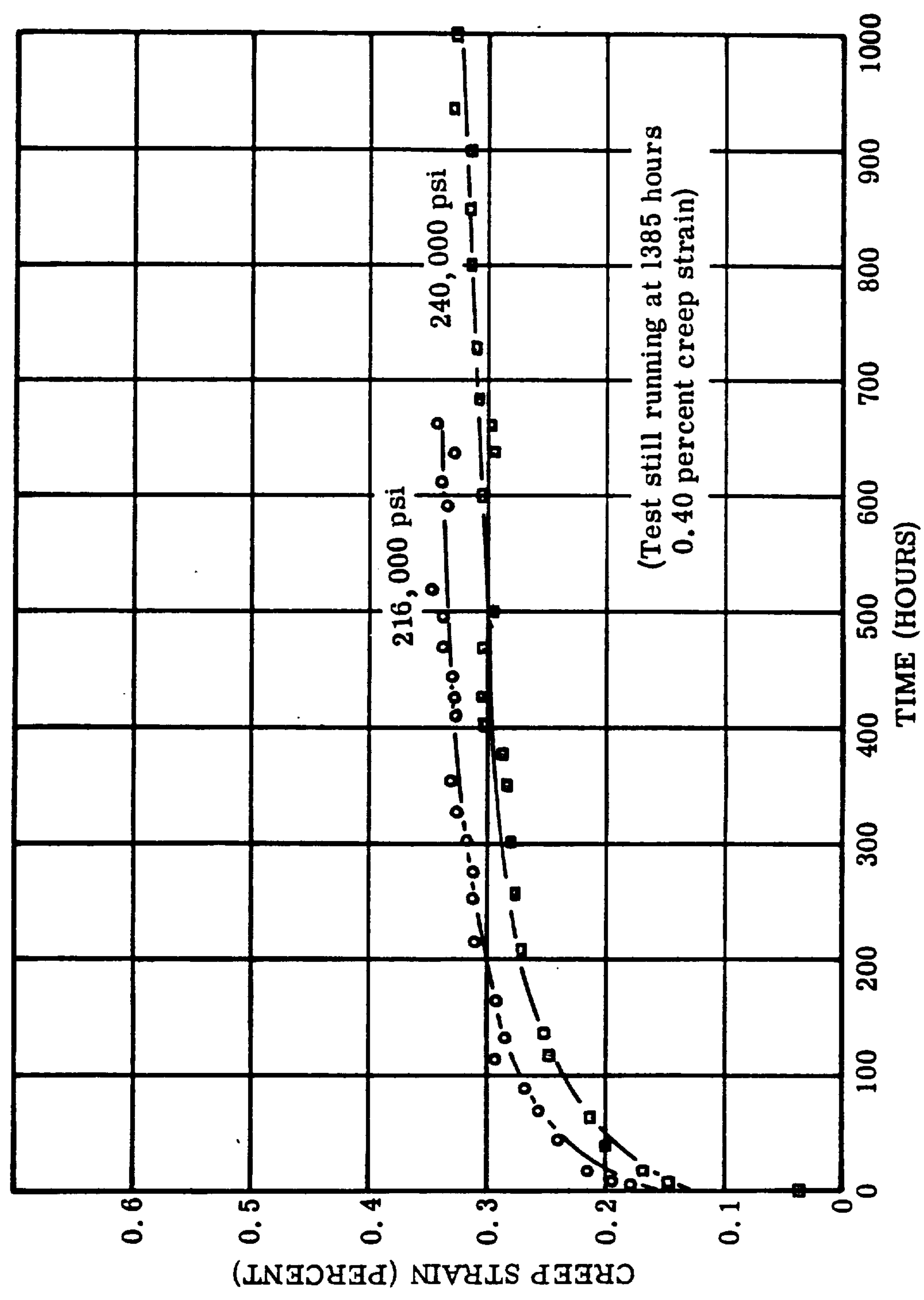


FIGURE IV.E.III-7. Creep, 15 Percent Nickel Maraging Steel Tested at 700°F in Air. See Data Table IV.E.III-3. (Reference: NAS 3-4162)

Figure IV.E.III-7. Creep - 15% Nickel Maraging Steel

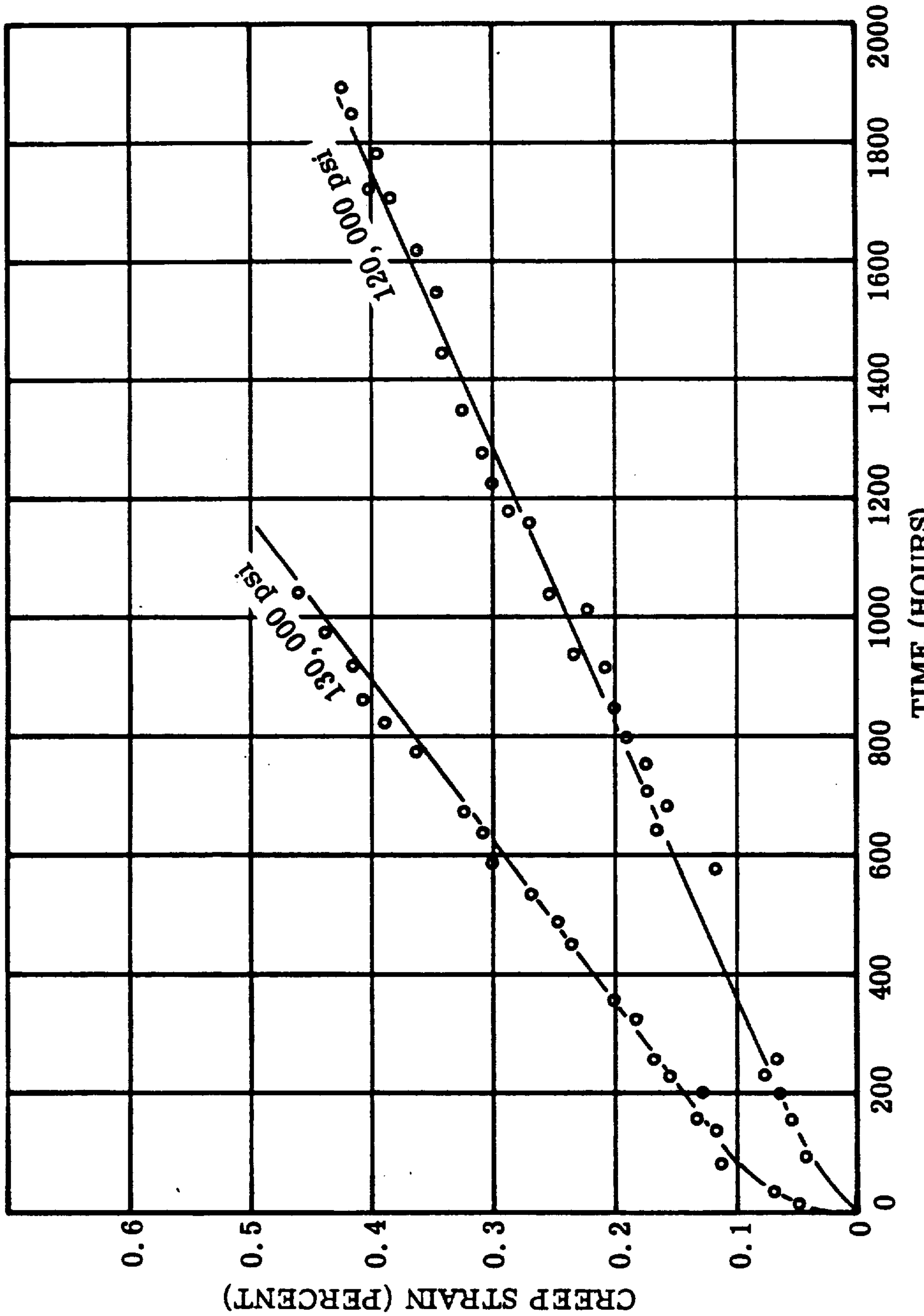


FIGURE I V. E. III-8. Creep, 15 Percent Nickel Maraging Steel Tested at 800°F in Air. See Data Table I V. E. III-3. (Reference: NAS3-4162)

Figure I V. E. III-8. Creep - 15% Nickel Maraging Steel

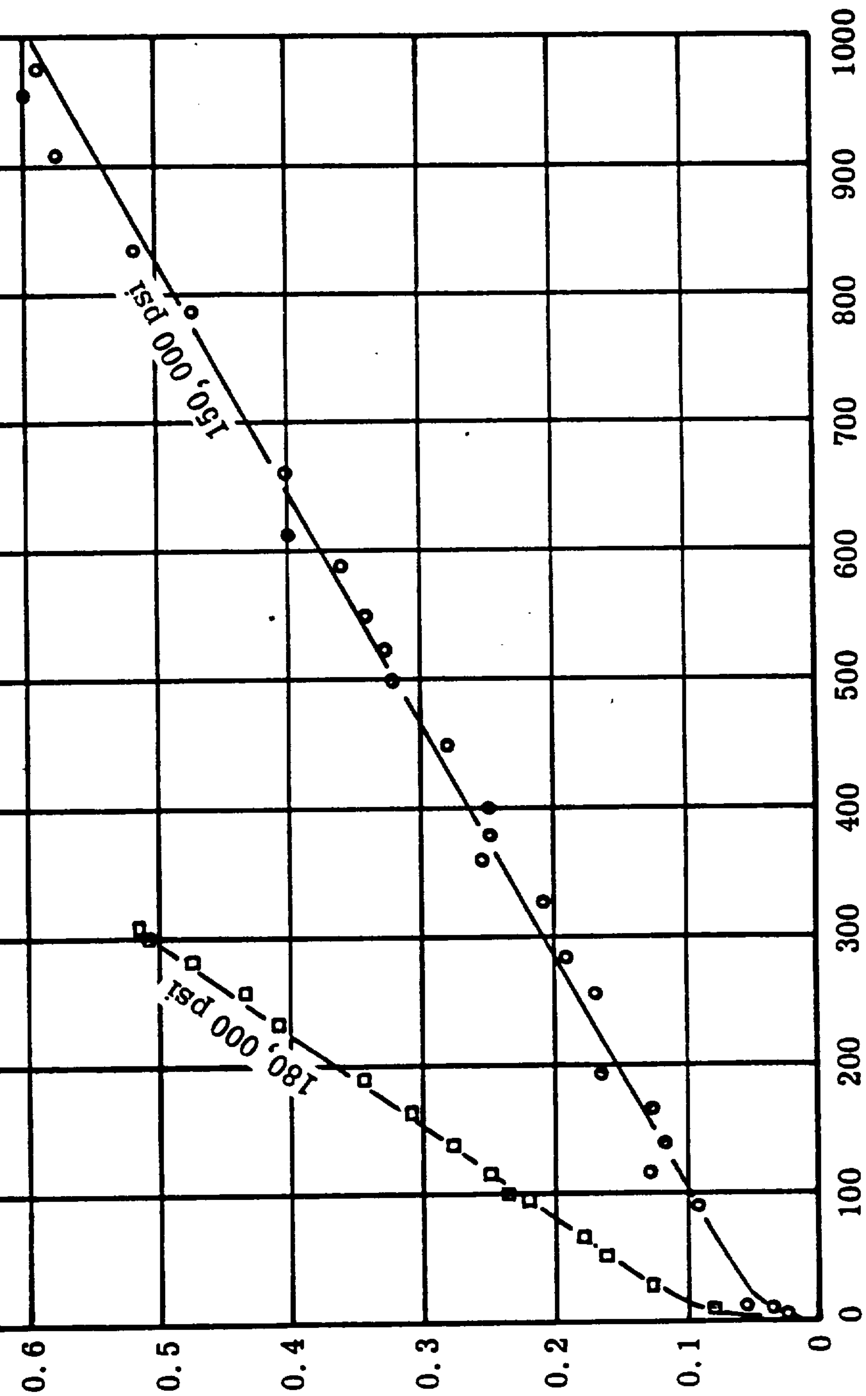


FIGURE I V. E. I I I-9. Creep, 15 Percent Nickel Maraging Steel Tested at 800°F in Air. See Data Table I V. E. I I I-3. (Reference: NAS3-4162)

Figure I V. E. I I I-9. Creep -15% Nickel Maraging Steel

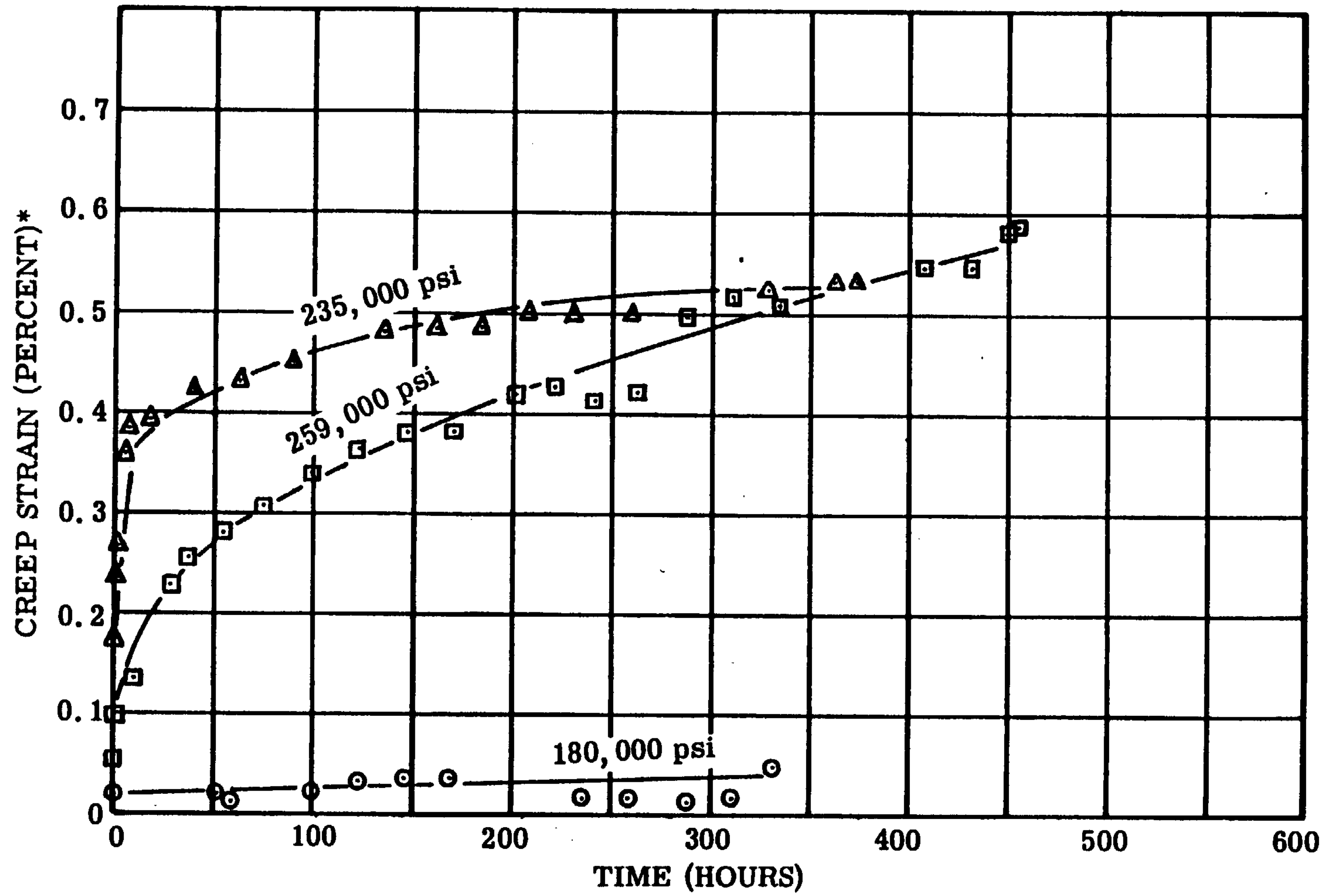


FIGURE I V. E. III-10. Creep, 15 Percent Nickel Maraging Steel Tested at 700°F in Air. See Data Table I V. E. III-4. *Data for 259, 000 PSI Curve Obtained by Raising the Stress on 180, 000 PSI Specimen After 332 Hours of Testing. (Reference: NAS3-4162).

Figure I V. E. III-10. Creep - 15% Nickel Maraging Steel

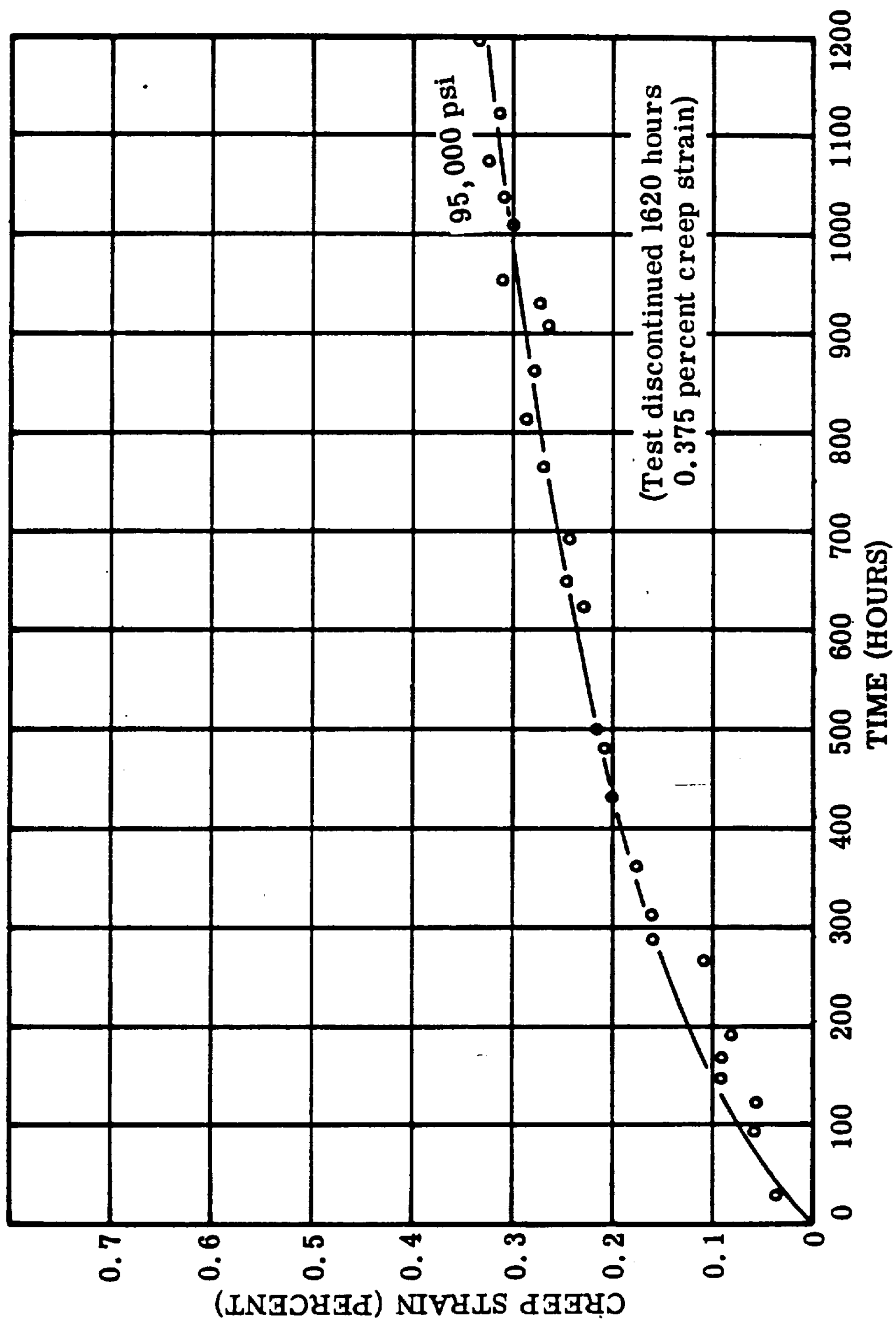


FIGURE IV.E.III-11. Creep, 15 Percent Nickel Maraging Steel Tested at 800°F in Air. See Data Table IV.E.III-4. (Reference: NAS3-4162)

Figure IV.E.III-11. Creep - 15% Nickel Maraging Steel

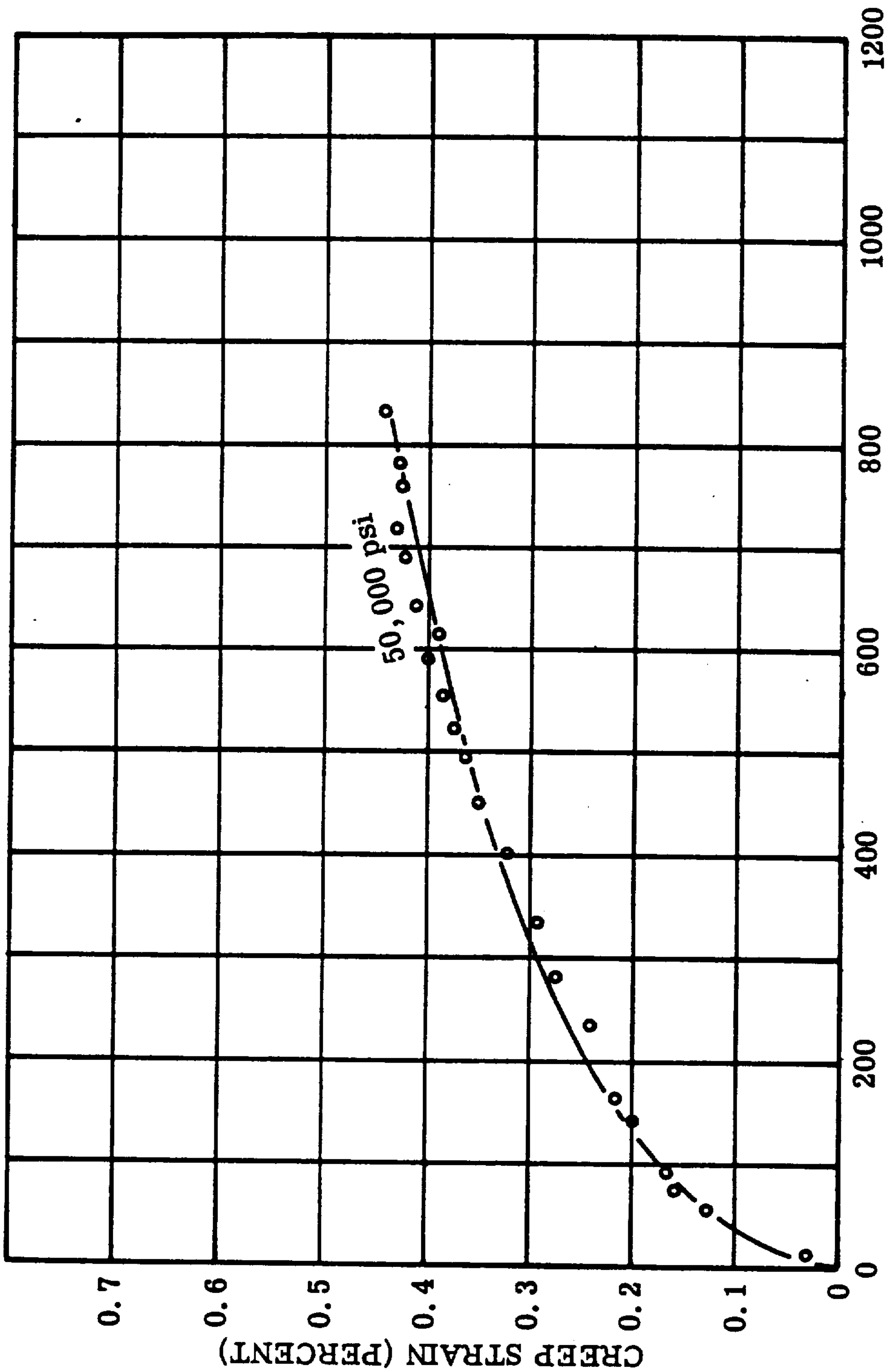


FIGURE IV.E.III-12. Creep, 15 Percent Nickel Maraging Steel Tested at 900°F in Air. See Data Table IV.E.III-4. (Reference: NAS3-4162)

Figure IV.E.III-12. Creep - 15% Nickel Maraging Steel

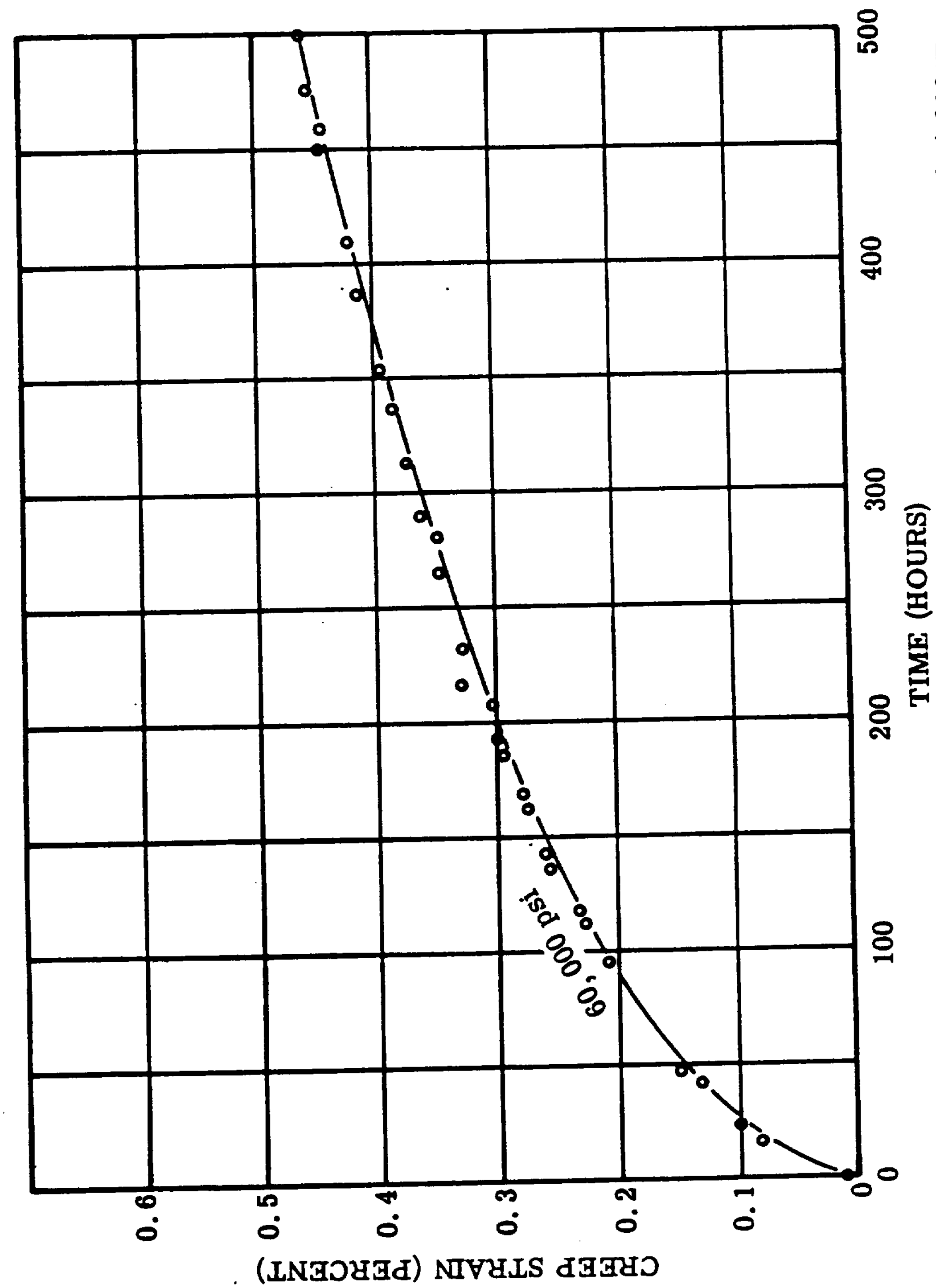


FIGURE IV. E. III-13. Creep, 15 Percent Nickel Maraging Steel Tested at 900°F in Air. See Data Table IV. E. III-4. (Reference: NAS3-4162)

Figure IV. E. III-13. Creep - 15% Nickel Maraging Steel

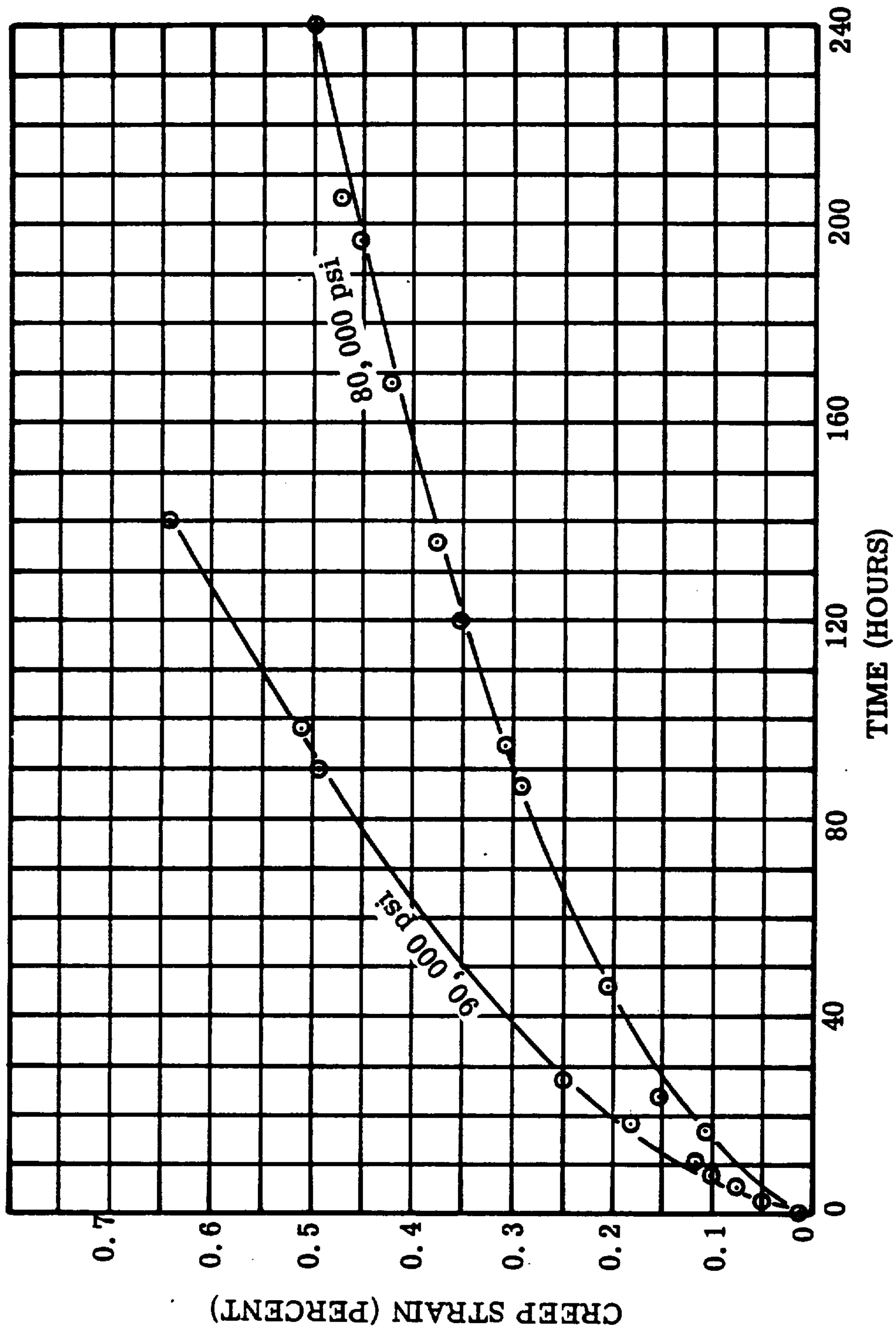


FIGURE I V. E. III-14. Creep, 15 Percent Nickel Maraging Steel Tested at 900°F in Air. See Data Table I V. E. III-4. (Reference: NAS3-4162)

Figure I V. E. III-14. Creep - 15% Nickel Maraging Steel

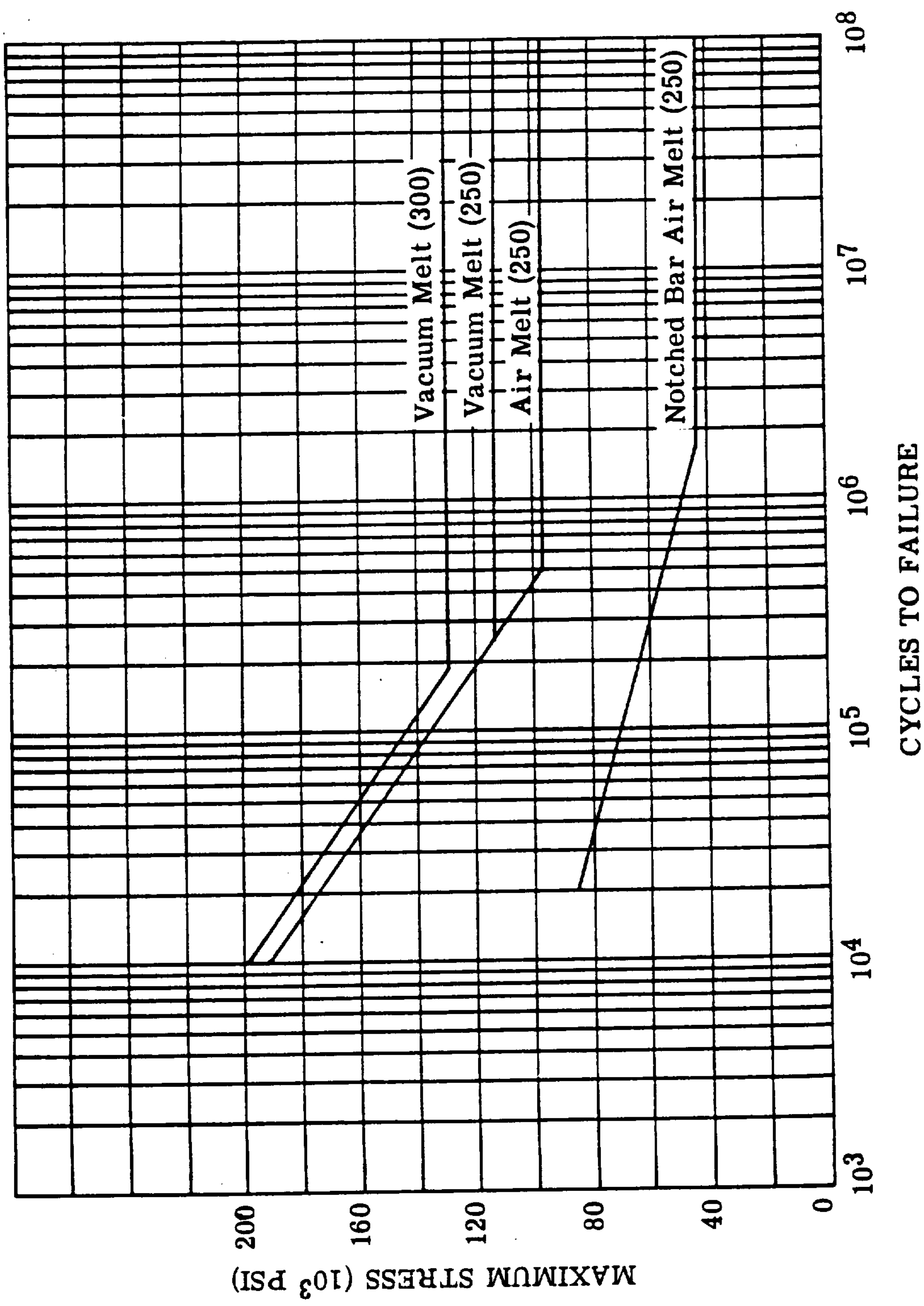


FIGURE IV, E.III-15. Fatigue Curve, 18 Percent Nickel Maraging Steel. Room Temperature Data in Air. (Reference: Allegheny Ludlum Steel Product Literature)

Figure IV.E.III-15. Fatigue - 18% Nickel Maraging Steel

MAGNETIC MATERIALS PROPERTIES SUMMARY

F. AISI GRADE H-11 STEEL, PREMIUM QUALITY (AMS 6487 AND 6437)

Availability: Commercial

Nominal Composition: 5 Cr, 1.3 Mo, 0.5 V, 0.40 C, Fe

Tested Composition:

	C	Si	Mn	S	P	Cr	U	Mo
Bar	0.40	0.87	0.20	0.006	0.010	4.89	0.53	1.30
Sheet	0.40	0.91	0.21	0.006	0.008	4.98	0.42	1.31

I. Thermophysical Properties

A. Density — $0.281\ lb/in^3$ 7.77 grams/cc

B. Solidus Temperature — 2750 ± 25°F

C. Curie Temperature — 1505° F

D. Thermal Conductivity

1. At 72°F — $17.0\ \frac{Btu\text{-}ft}{ft^2\text{-}hr\text{-}°F}$

2. At 800° F — $16.0\ \frac{Btu\text{-}ft}{ft^2\text{-}hr\text{-}°F}$

E. Coefficient of thermal expansion (72° -900°F) — 6.85×10^{-6} in/in-°F

F. Specific Heat

1. At 72°F — 0.11 Btu/lb-°F

G. Electrical Resistivity of Annealed AMS 6487

1. At 72°F — 46.5×10^{-6} ohm-cm*
2. At 500° F — 59.0×10^{-6} ohm-cm*

*Westinghouse Electric Corp. Aerospace Electrical Division, Lima, Ohio, Materials Engineering Lab Report, R. L. Stuart and L. G. Borg, 1963

3. At 700°F — 68.0×10^{-6} ohm-cm*
4. At 800°F — 71.0×10^{-6} ohm-cm*
5. At 900°F — 76.5×10^{-6} ohm-cm*

II. Magnetic Properties (All magnetic test materials ~~are stress relief annealed~~ were at a hardness of Rockwell C45 (~~SRA~~) unless otherwise specified)

A. D-C Properties (Solid Ring)

1.	Induction (B_{tip}) for H = 300 oersteds at 72°F	17.9 kilogauss
2.	Induction (B_{tip}) for H = 300 oersteds at 800°F	15.9 kilogauss
3.	Induction (B_{tip}) for H = 300 oersteds at 1100°F	13.8 kilogauss

B. A-C Properties (400 Cycle)

1. 0.014 inch thick laminations (Hardness-Rockwell C45)

a.	Exciting volt-amperes, B = 10 kilogauss at 72°F	172 volt-amperes/pound
b.	Exciting volt-amperes, B = 10 kilogauss at 800°F	157 volt-amperes/pound
c.	Exciting volt-amperes, B = 10 kilogauss at 1100°F	171 volt-amperes/pound
d.	Core loss, B = 10 kilogauss at 72°F	105 watts/pound
e.	Core loss, B = 10 kilogauss at 800°F	90 watts/pound
f.	Core loss, B = 10 kilogauss at 1100°F	75 watts/pound

2. 0.025 inch thick laminations (Hardness-Rockwell C45)

a.	Exciting volt-amperes, B = 10 kilogauss at 72°F	179 volt-amperes/pound
b.	Exciting volt-amperes, B = 10 kilogauss at 800°F	157 volt-amperes/pound
c.	Exciting volt-amperes, B = 10 kilogauss at 1100°F	185 volt-amperes/pound

*Westinghouse Electric Corp. Aerospace Electrical Division, Lima, Ohio, Materials Engineering Lab Report, R. L. Stuart and L. G. Borg, 1963

d. Core loss, B = 10 kilogauss at 72°F — 115 watts/pound
e. Core loss, B = 10 kilogauss at 800°F — 87 watts/pound
f. Core loss, B = 10 kilogauss at 1100°F — 74 watts/pound

C. Constant Current Flux Reset Properties (CCFR)

Not applicable to H-11 steel; only measured on materials used in magnetic amplifiers.

III. Mechanical Properties

A. Poisson's Ratio at 72°F — 0.281

B. Tensile Properties (Hardness-Rockwell C45)

1. At 72°F

a. 0.20 percent offset yield strength	180,000 psi
b. Tensile strength	215,000 psi
c. Elongation in 1.4 inches	15.2 percent
d. Reduction of area	29.0 percent
e. Modulus of Elasticity	30.5×10^6 psi

2. At 800°F

a. 0.20 percent offset yield strength	144,000 psi
b. Tensile strength	174,000 psi
c. Elongation in 1.4 inches	15.0 percent
d. Reduction of area	40.0 percent
e. Modulus of Elasticity	27.3×10^6 psi

C. Creep (Bar Stock)*

1. Air Atmosphere

a. Stress to produce 0.20 percent creep strain in 1000 hours at 800°F	92,000 psi
b. Stress to produce 0.20 percent creep strain in 10,000 hours at 800°F	80,000 psi
c. Stress to produce 0.40 percent creep strain in 1000 hours at 800°F	107,000 psi

*Creep Strength of Properly Fabricated and Heat Treated H-11 Sheet (AMS 6437) is only slightly lower than that of Bar Material.

d. Stress to produce 0.40 percent creep strain in 10,000 hours at 800°F — 90,000 psi

2. Vacuum Atmosphere: Same as above.

D. Fatigue (Air Atmosphere, Bar Stock)

	Smooth Bar	Notched Bar	($K_t = 3$)
1. 800°F Fatigue strength for 10^7 cycles $A = \infty$	72,000	45,000	(psi)
2. 800°F Fatigue strength for 10^7 cycles $A = 0.25$	170,000	125,000	(psi)
3. 800°F Fatigue strength for 10^7 cycles $A = 2.00$	98,000	48,000	(psi)
4. 1000°F Fatigue strength for 10^7 cycles $A = \infty$	70,000	33,000	(psi)
5. 1000°F Fatigue strength for 10^7 cycles $A = 0.25$	130,000	105,000	(psi)
6. 1000°F Fatigue strength for 10^7 cycles $A = 2.00$	100,000	40,000	(psi)

E. Normal Heat Treatment for Use as Inductor Rotor Material and Resultant Hardness.

Preheat in reducing atmosphere to 1200°F - 1300°F, heat to 1850° ± 25°F in a neutral or slightly reducing (carbon potential 0.40)* atmosphere and hold for 1 hour and air-blast quench to room temperature. Temper three times at 1075°-1150°F to achieve a hardness of Rockwell C44-45.5.

*Reference: A.S.M. Metals Handbook, Vol. 2, 1964, pp 89-91.

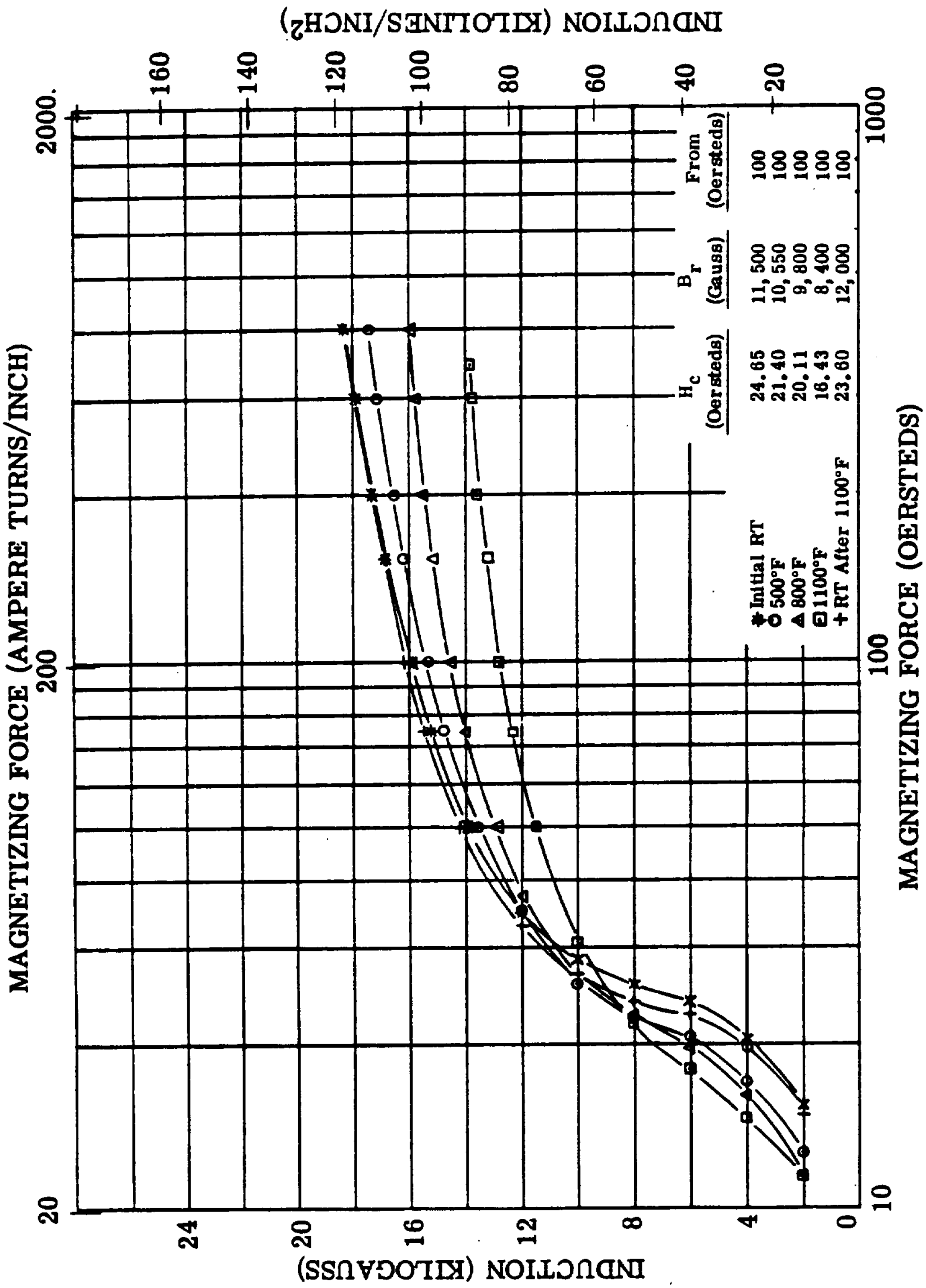


FIGURE IV. F. II-1. D-C Magnetization Curves. H-11 Steel Forging. Test Atmosphere: Air to 500°F, Argon above 500°F. (Reference: NAS3-4162)

Figure IV. F. II-1. D-C Magnetization - H-11 Steel Forging

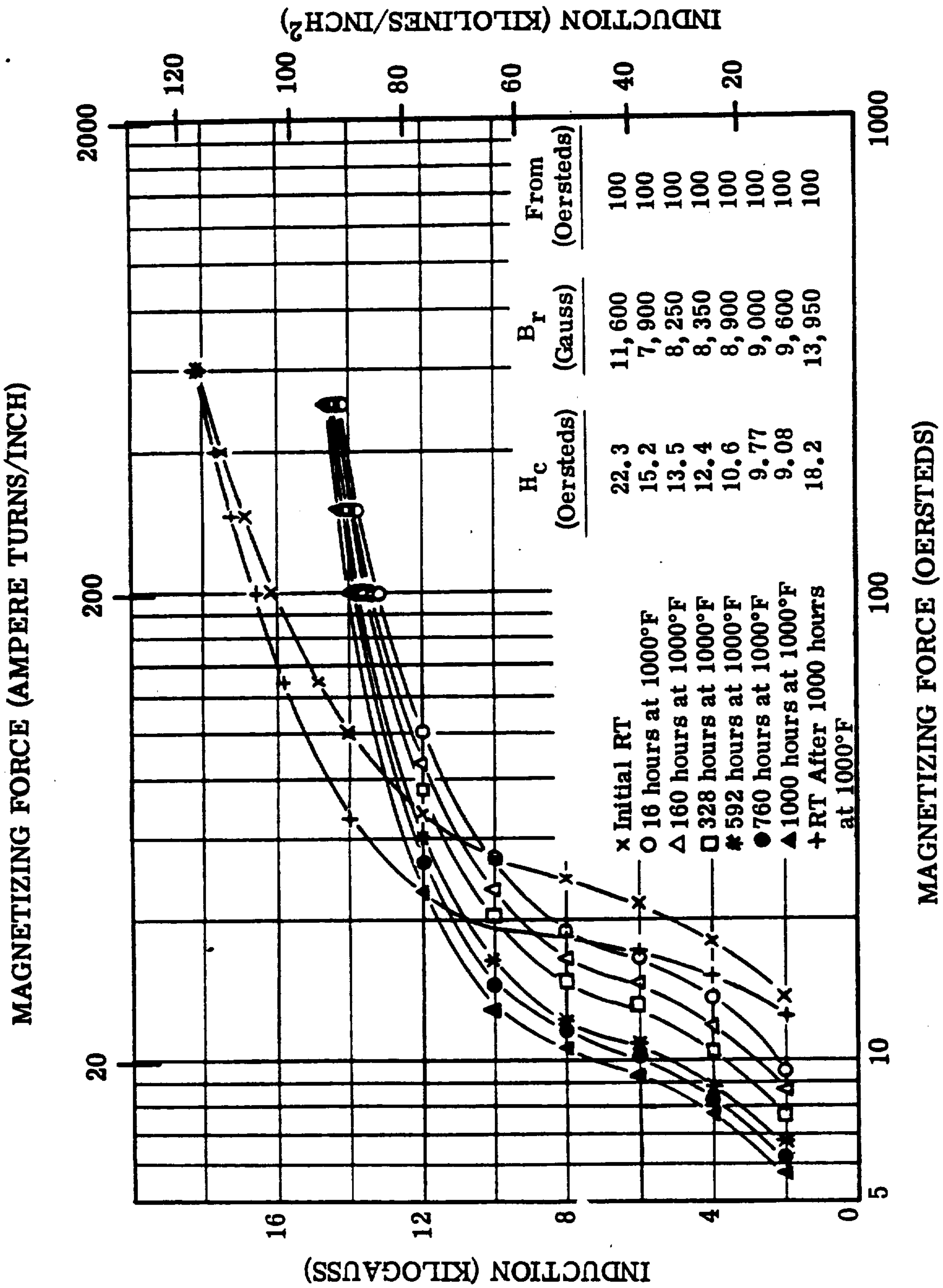


FIGURE IV.F.II-2. D-C Magnetization Curves. H-11 Steel Forging - Stability Test. Test Atmosphere: Argon. (Reference: NAS 3-4162)

Figure IV.F.II-2. D-C Magnetization - H-11 Steel

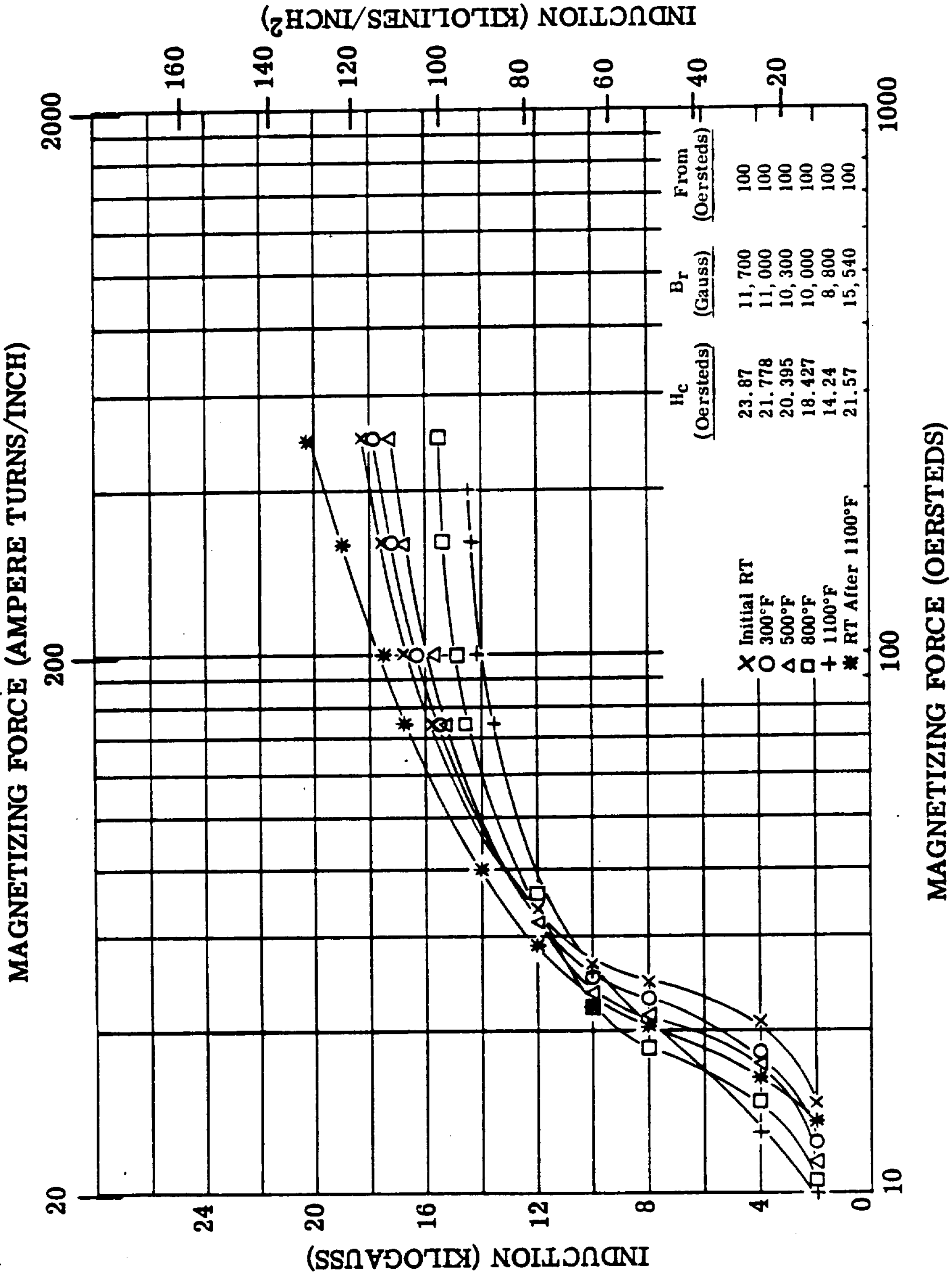
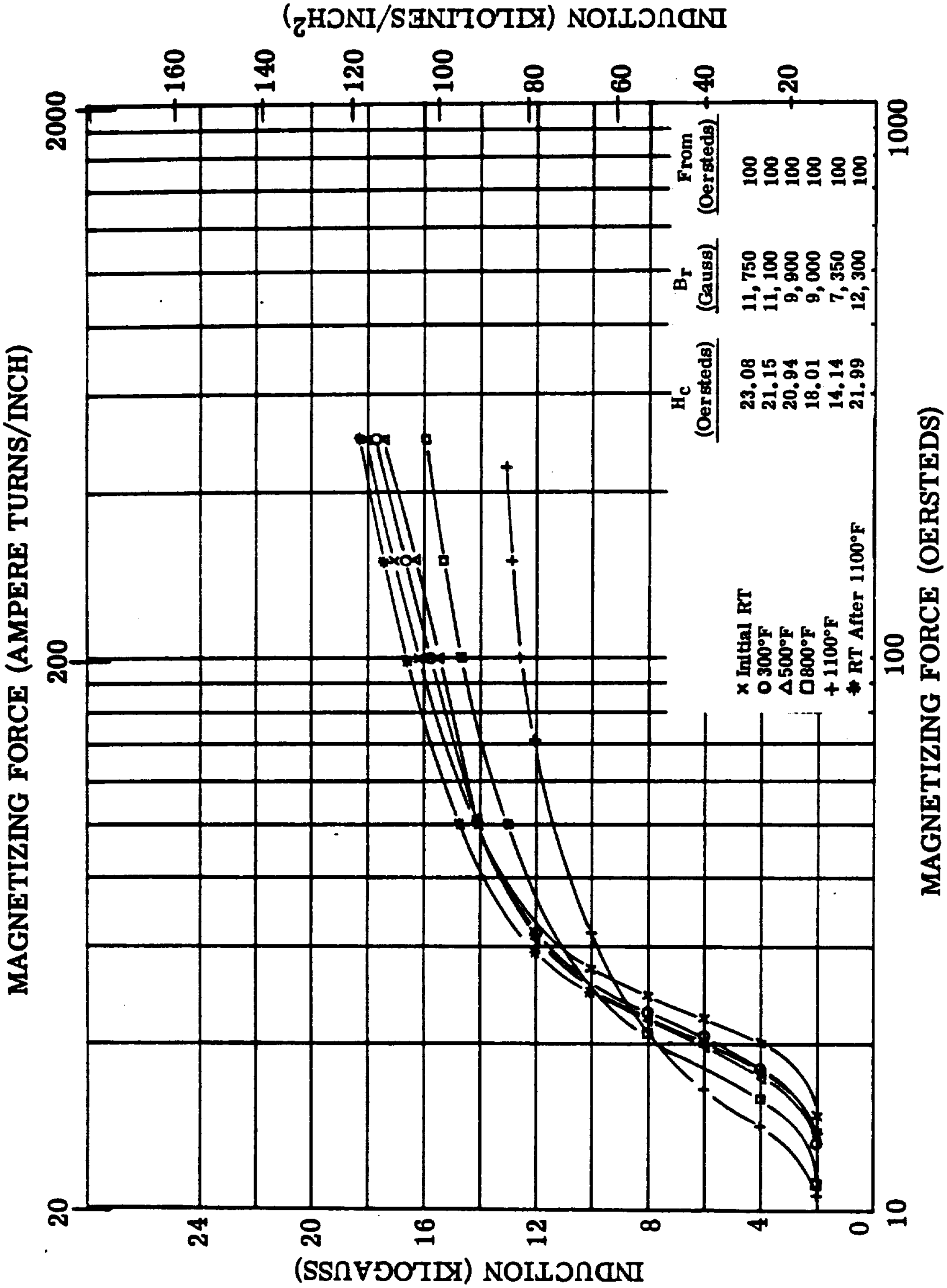


FIGURE IV.G.II-3. D-C Magnetization Curves. H-11 Steel - 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.F.II-3. D-C Magnetization - H-11 Steel



H_c (Oersteds)	B_r (Gauss)	From (Oersteds)
23.08	11,750	100
21.15	11,100	100
20.94	9,900	100
18.01	9,000	100
14.14	7,350	100
21.99	12,300	100

FIGURE IV. F. II-4. D-C Magnetization Curves. H-11 Steel - 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-4. D-C Magnetization - H-11 Steel

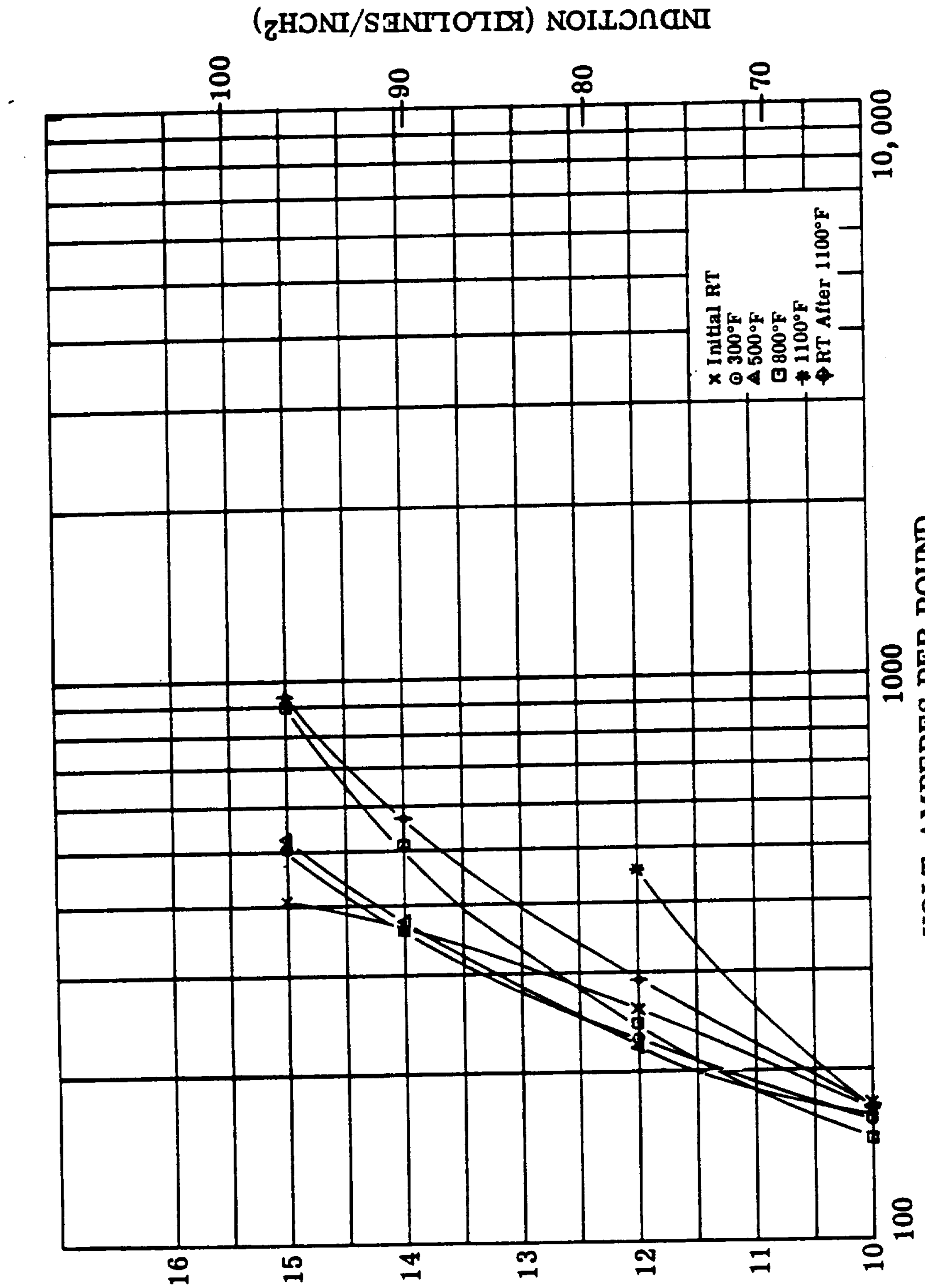


FIGURE IV. F. II-5. Exciting Volt-Amperes Per Pound, 400 CPS. H-11 Steel - 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-5. Exciting VA, 400 CPS. H-11 Steel

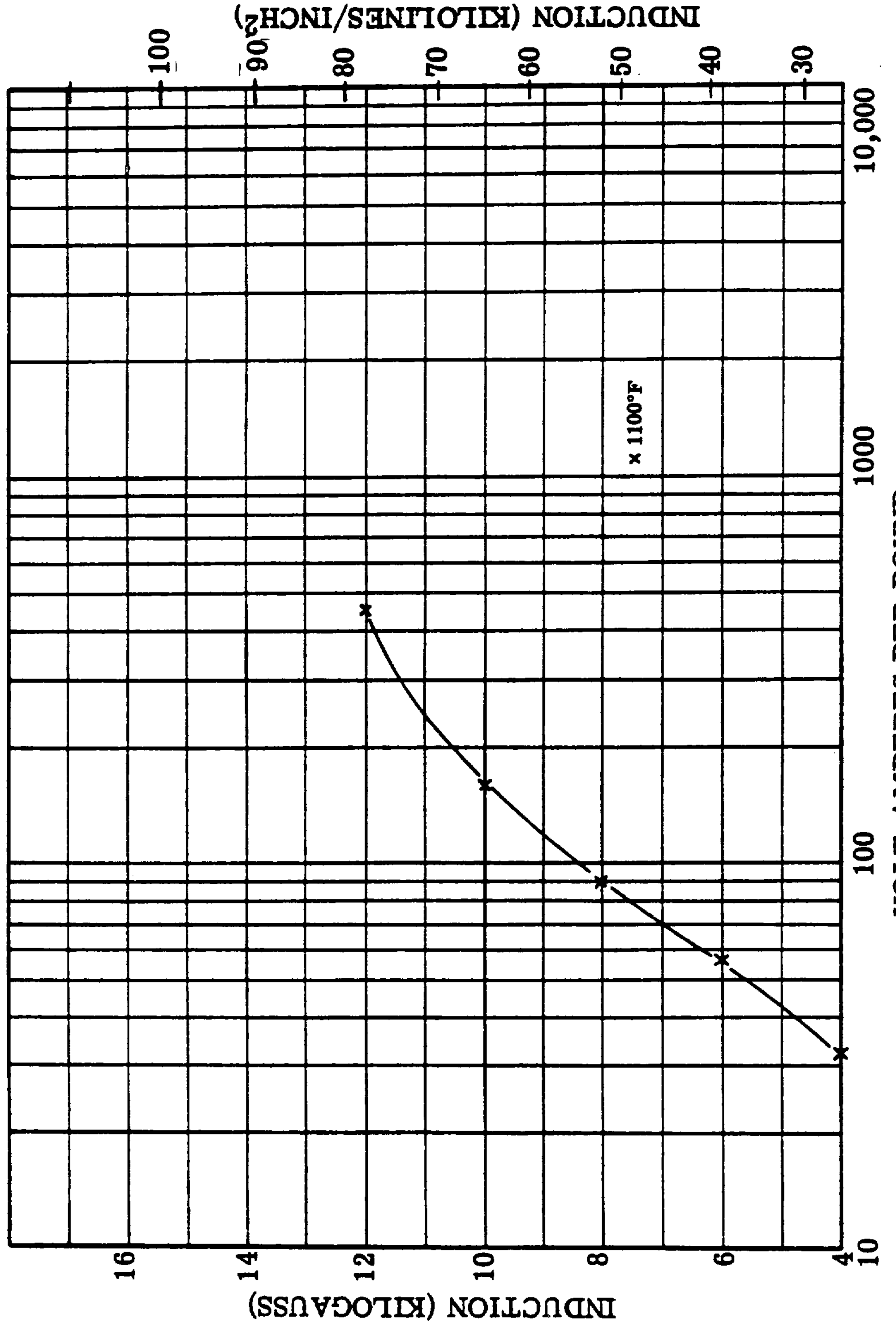


FIGURE IV. F. II-6. Exciting Volt-Amperes Per Pound, 400 CPS. H-11 Steel - 0.014 Inch Laminations at 1100°F. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-6. Exciting VA, 400 CPS. H-11 Steel

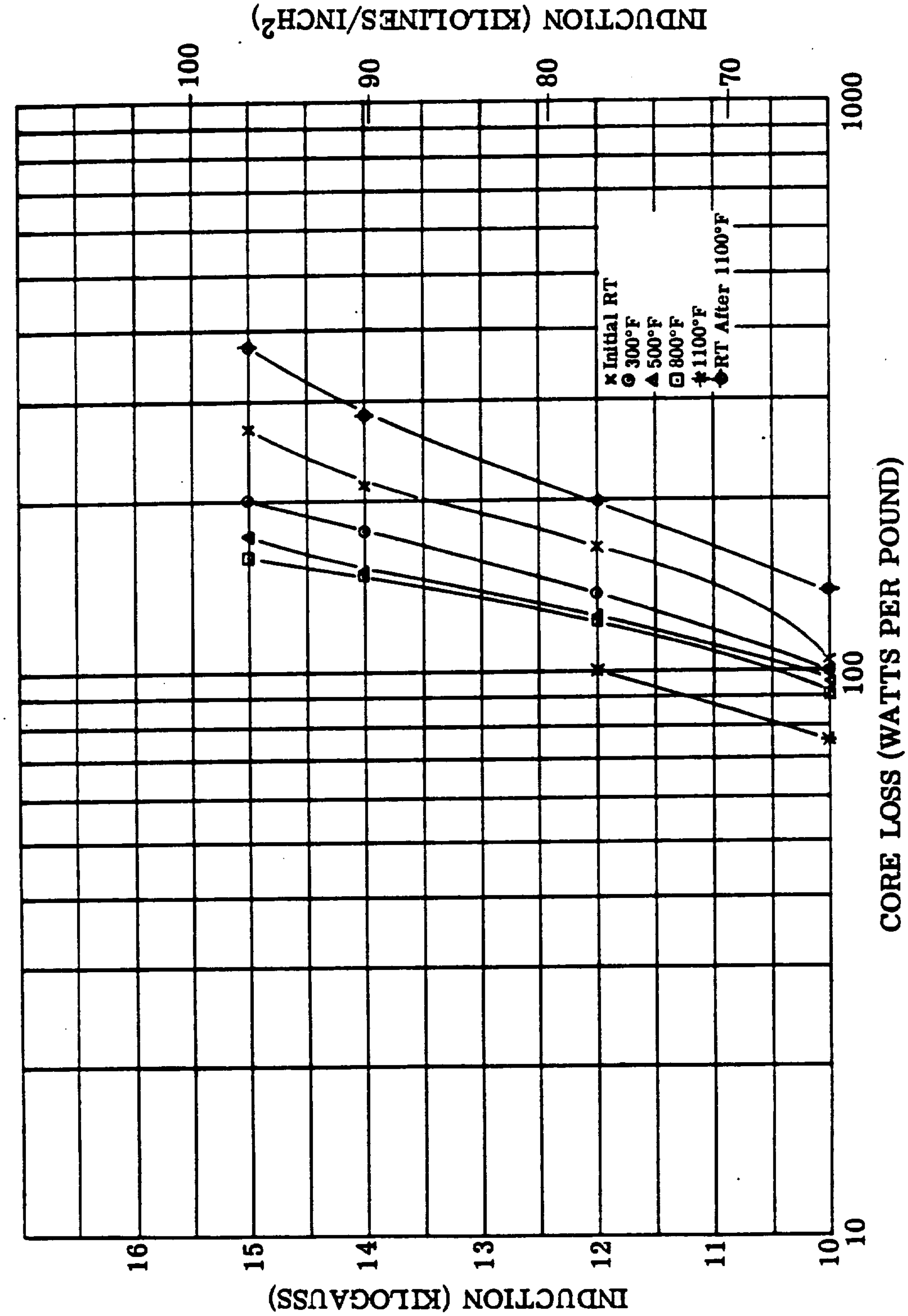


FIGURE IV. F. II-7. Core Loss, 400 CPS. H-11 Steel - 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-7. Core Loss, 400 CPS. H-11 Steel

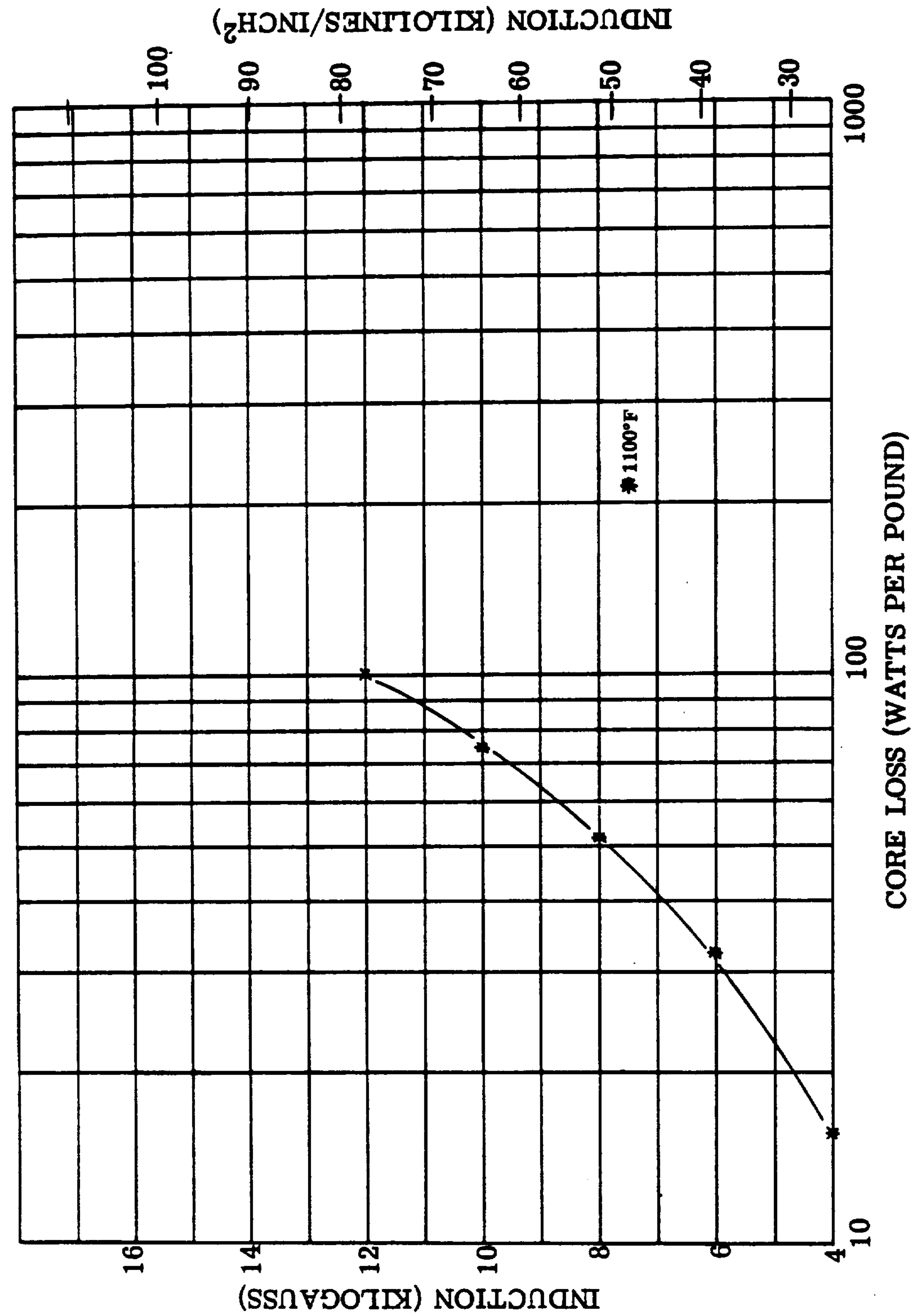


FIGURE I V. F. I I-8. Core Loss, 400 CPS. H-11 Steel - 0.014 Inch Laminations at 1100°F. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure I V. F. I I-8. Core Loss, 400 CPS. H-11 Steel

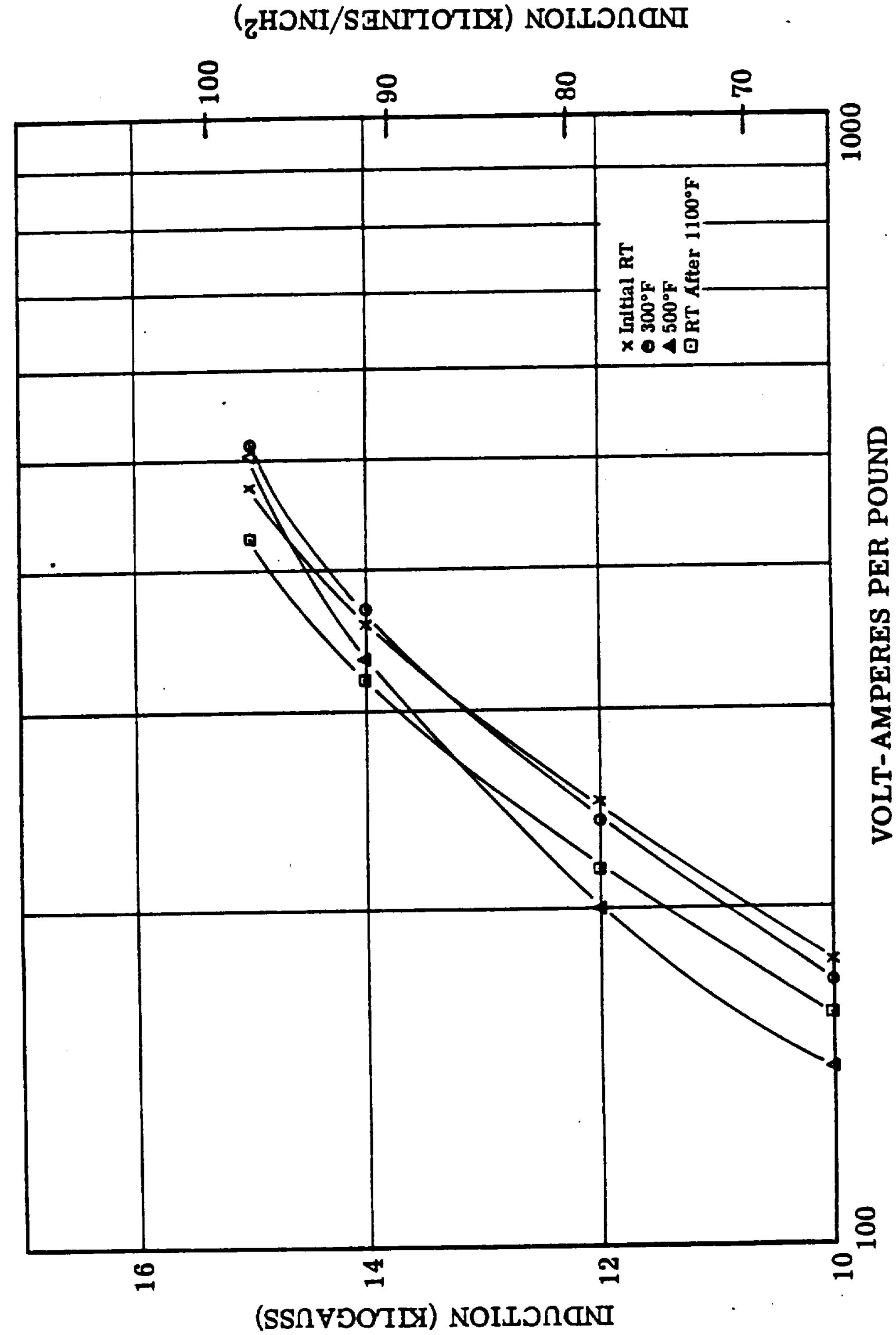


FIGURE IV. F. II-9. Exciting Volt-Amperes Per Pound, 400 CPS. H-11 Steel - 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon Above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-9. Exciting VA, 400 CPS. H-11 Steel

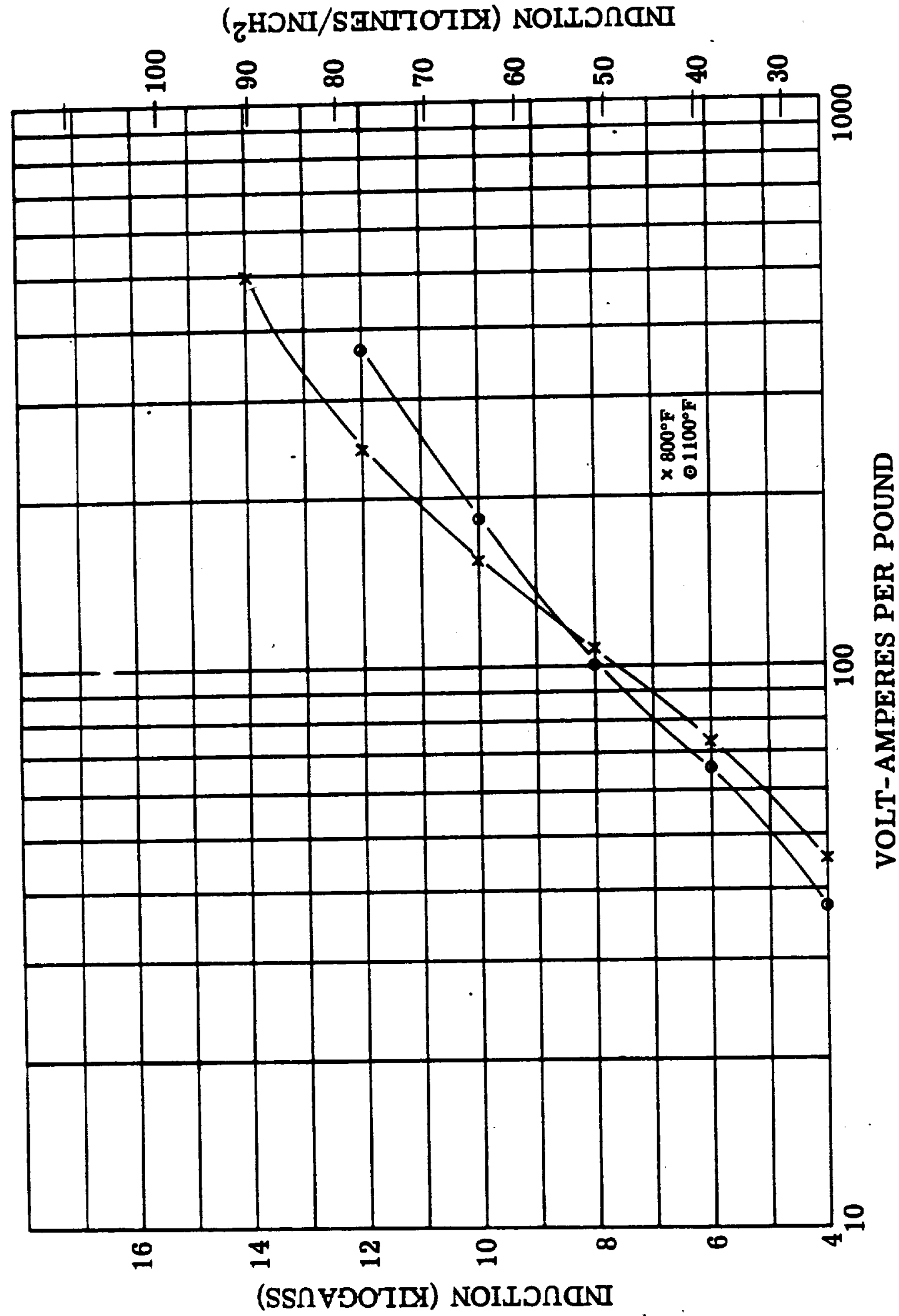


FIGURE IV. F. II-10. Exciting Volt-Amperes Per Pound, 400 CPS. H-11 Steel - 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-10. Exciting VA, 400 CPS. H-11 Steel

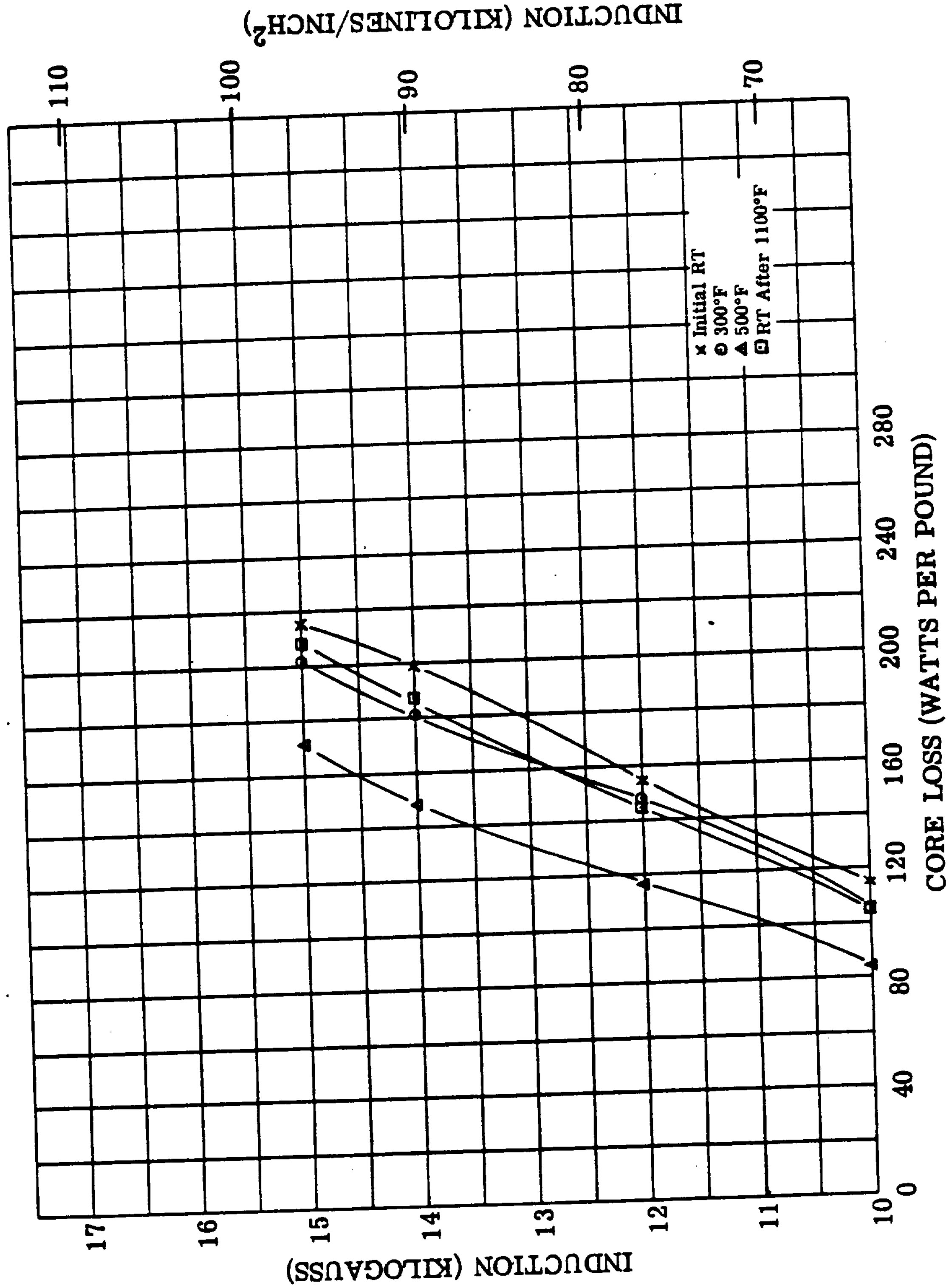


FIGURE IV. F. II-11. Core Loss, 400 CPS. H-11 Steel - 0. 025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-11. Core Loss, 400 CPS. H-11 Steel

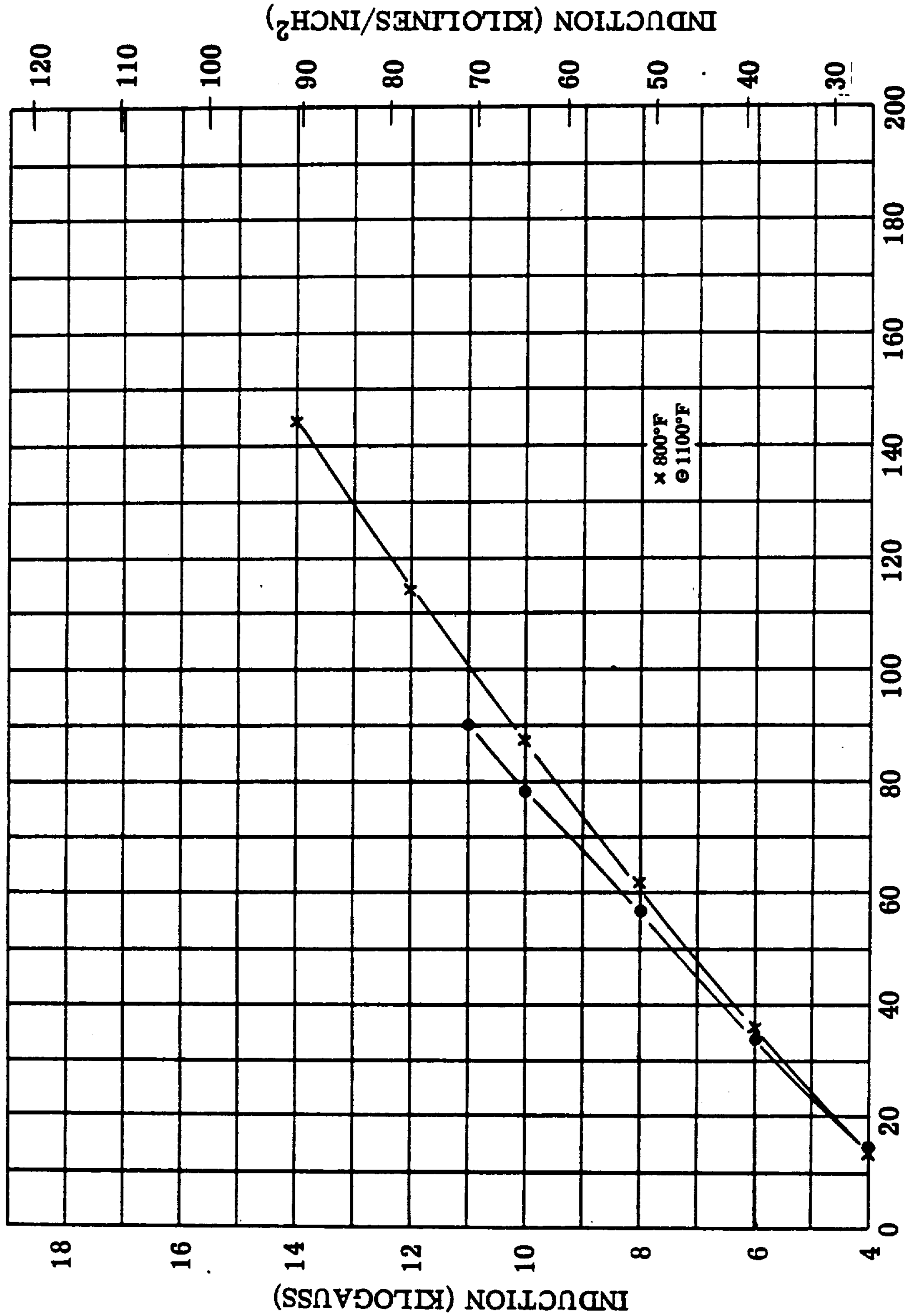


FIGURE IV. F. II-12. Core Loss, 400 CPS. H-11 Steel - 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV. F. II-12. Core Loss, 400 CPS. H-11 Steel

TABLE IV. F. III-1. Tensile Properties of AMS6487 (H-11) Bar (All Tests Made in Air.) See Figure IV. F. III-1

Test Temperature (°F)	0.2 Percent Offset Yield Strength (Psi)	Tensile Strength (Psi)	Elongation 1.4 Inches (Percent)	Reduction of Area (Percent)
72	175,000	212,000	15.5	*
72	185,000	217,000	17.5	34
72	183,000	211,750	16.0	31
72	174,000	213,280	18.5	34
72	183,670	218,980	8.5	14.3
800	154,080	178,572	16.0	30.3
800	150,000	180,000	17.0	40.
800	127,246	163,672	13.6	50.4
900	118,181	154,645	*	53.1
900	117,352	152,450	15.6	67.5
900	131,048	168,061	13.6	60.5
1000	92,778	128,385	27.6	72.5
1000	102,862	137,003	20.1	65.5

*Broken at gage mark

(Reference: LM 529)

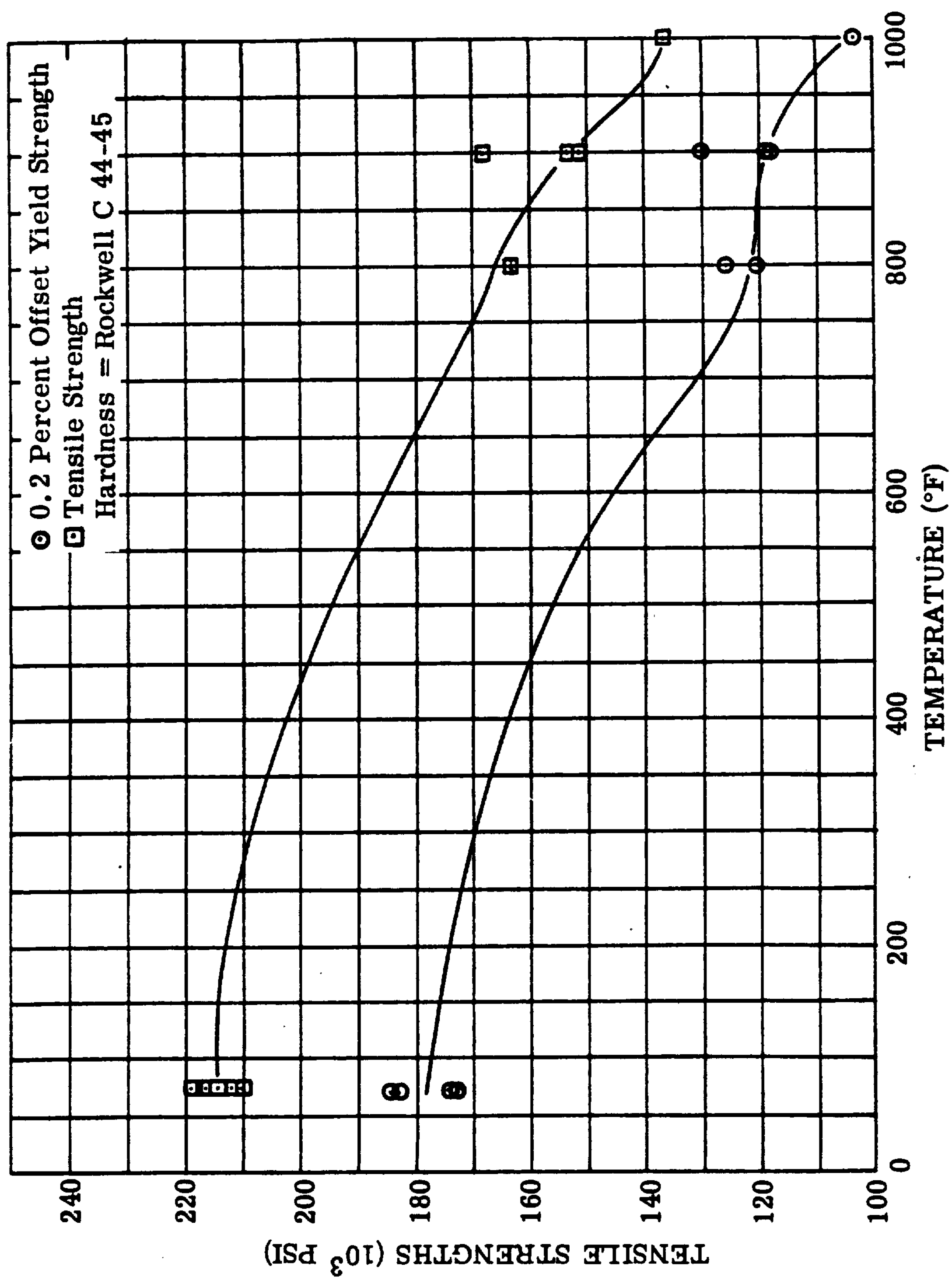


FIGURE IV. F. III-1. Tensile Strengths For AMS6487 (H-11) Bar. All Samples Tested in Air. See Data Table IV. F. III-1. (Reference: LM529)

Figure IV. F. III-1. Tensile Strengths - AMS6487 (H-11)

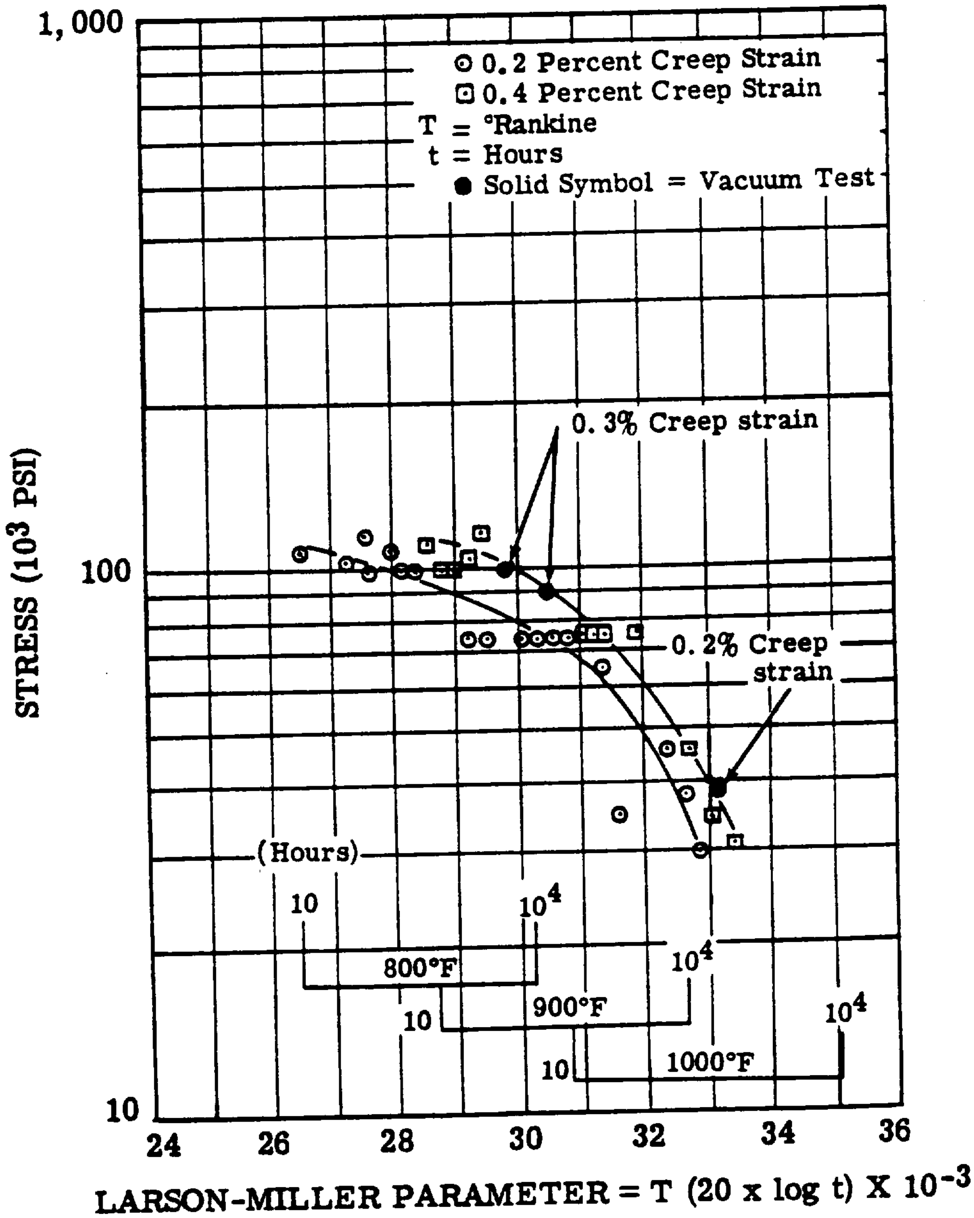


FIGURE IV.F.III-2. Larson-Miller Plots of AMS 6487 (H-11 Bar) Air and Vacuum Creep Data Based on a Maximum of 2000 Hour Data. See Tables IV.F.III-3, -4, and -5. (References: NAS 3-4162 and LM529)

Figure IV.F.III-2. Larson-Miller Parameter - H-11 Steel

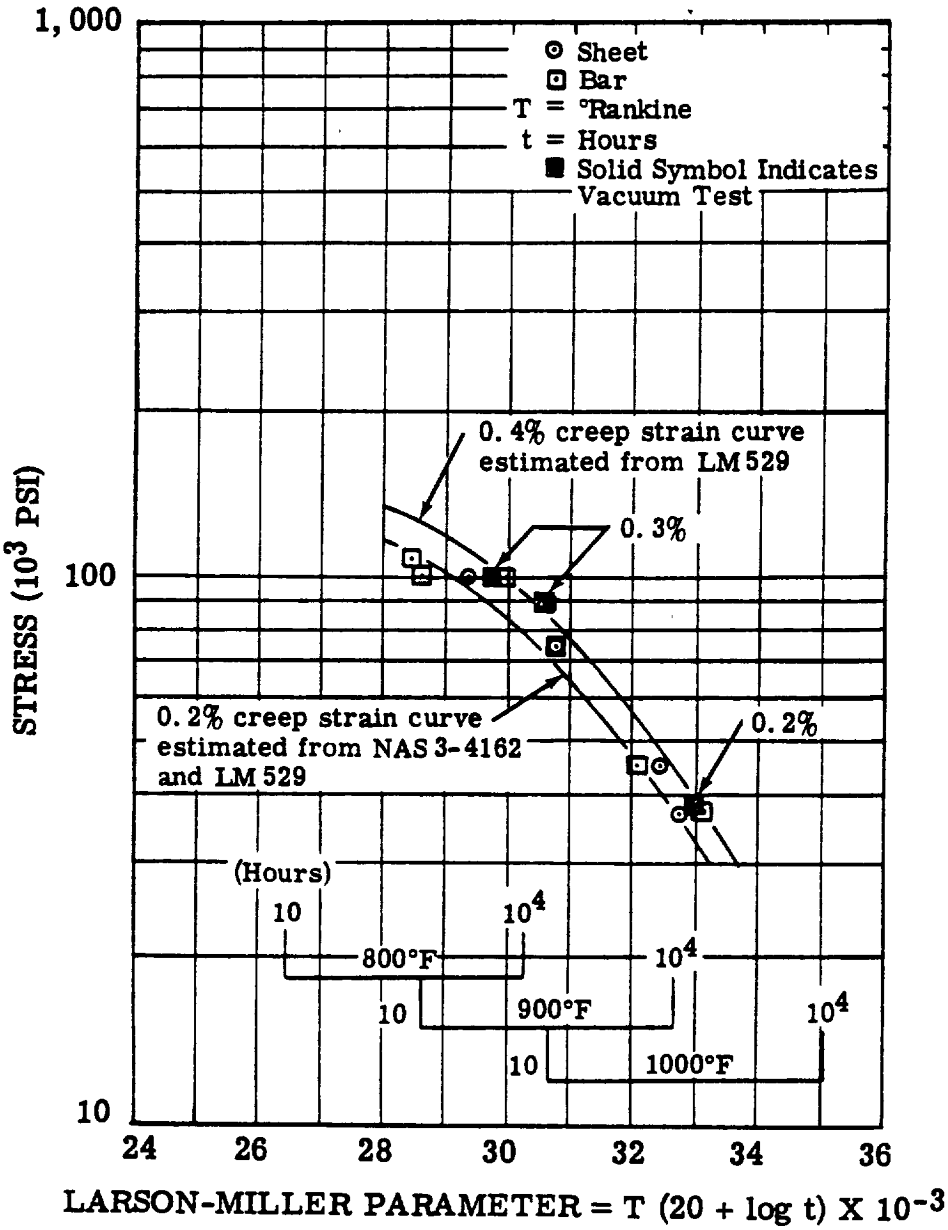


FIGURE IV.F.III-3. Comparative Larson-Miller Plots of Air and Vacuum Creep Test Data for 0.25-0.35 Percent Strain on Sheet and Bar H-11 Based on a Maximum of 2000 Hour Data. Note: All Bar Data From LM529. See Data Tables IV.F.III-2, -3, and -5. (Reference: NAS 3-4162 and LM529)

Figure IV. F. III-3. Larson-Miller Parameter - H-11 Steel

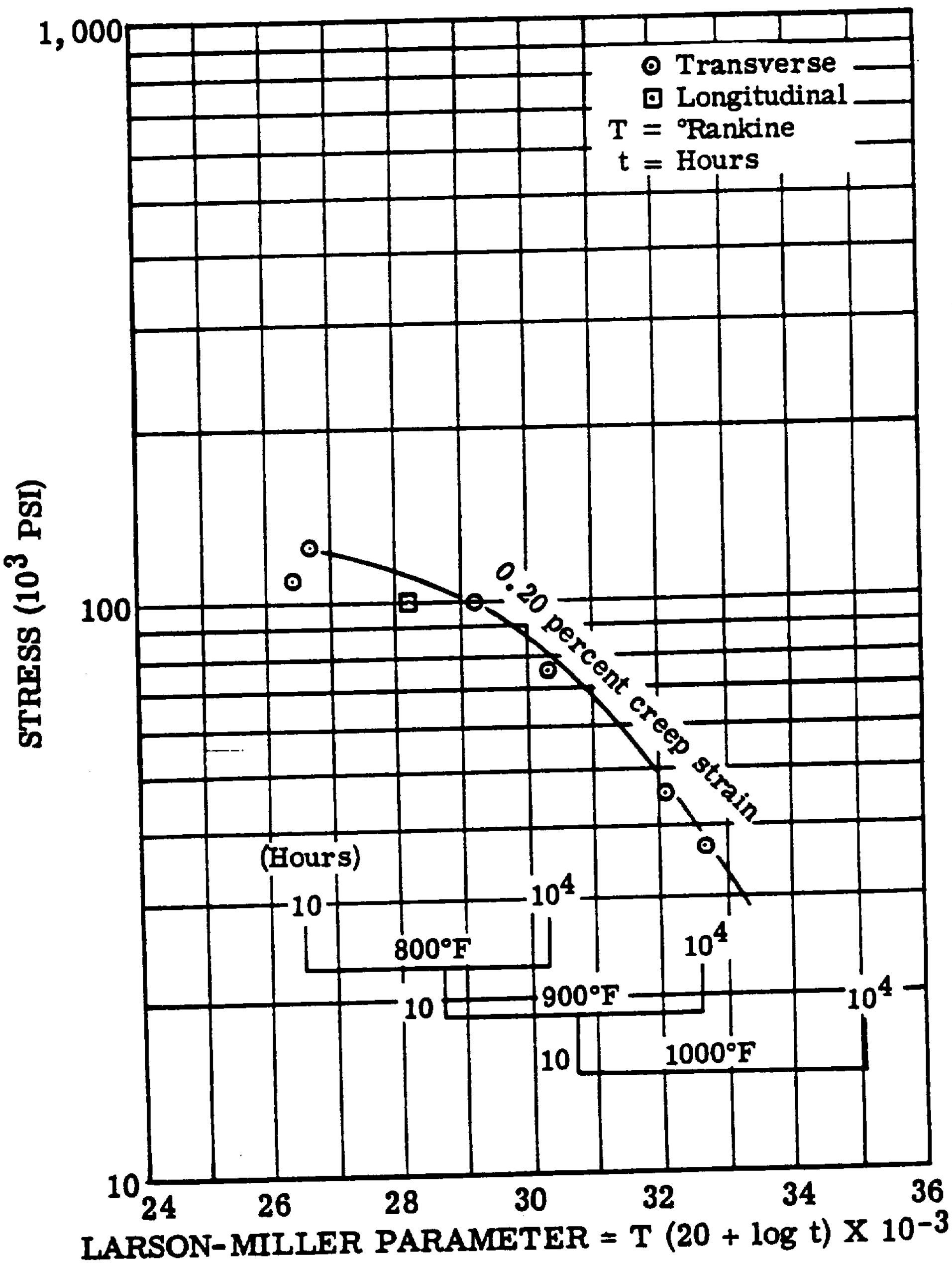


FIGURE IV. F. III-4. Larson-Miller Plot for Air Tested 0.025 Inch H-11 Sheet Creep Data Based on a Maximum of 2000 Hour Data. See Data Table IV. F. III-3. (Reference: NAS 3-4162)

Figure IV. F. III-4. Larson-Miller Parameter - H-11 Steel

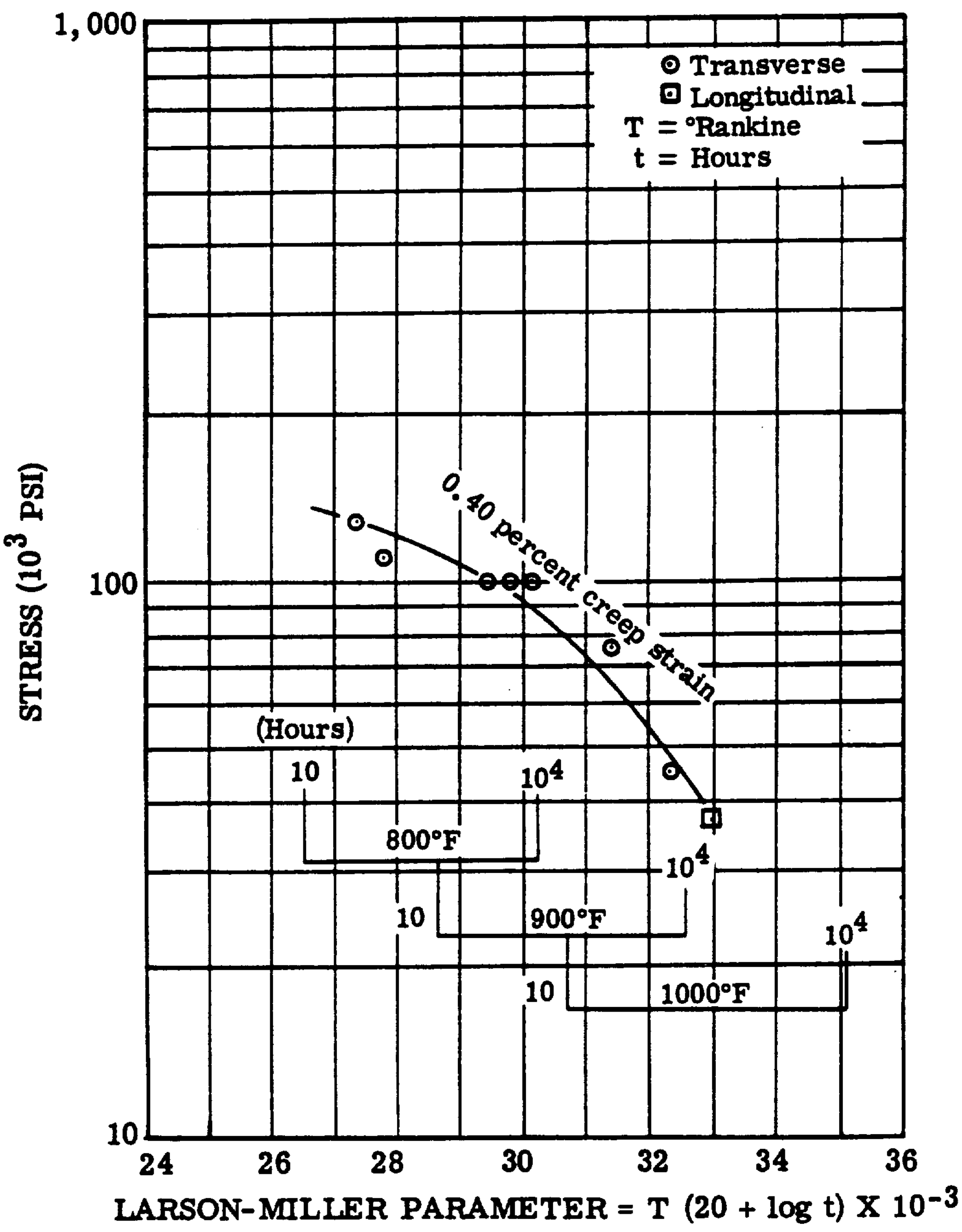


FIGURE IV. F. III-5. Larson-Miller Plot for Air Tested 0.025 Inch H-11 Sheet Creep Data Based on a Maximum of 2000 Hour Data. See Table IV. F. III-3. (Reference: NAS 3-4162)

Figure IV. F. III-5. Larson-Miller Parameter - H-11 Steel

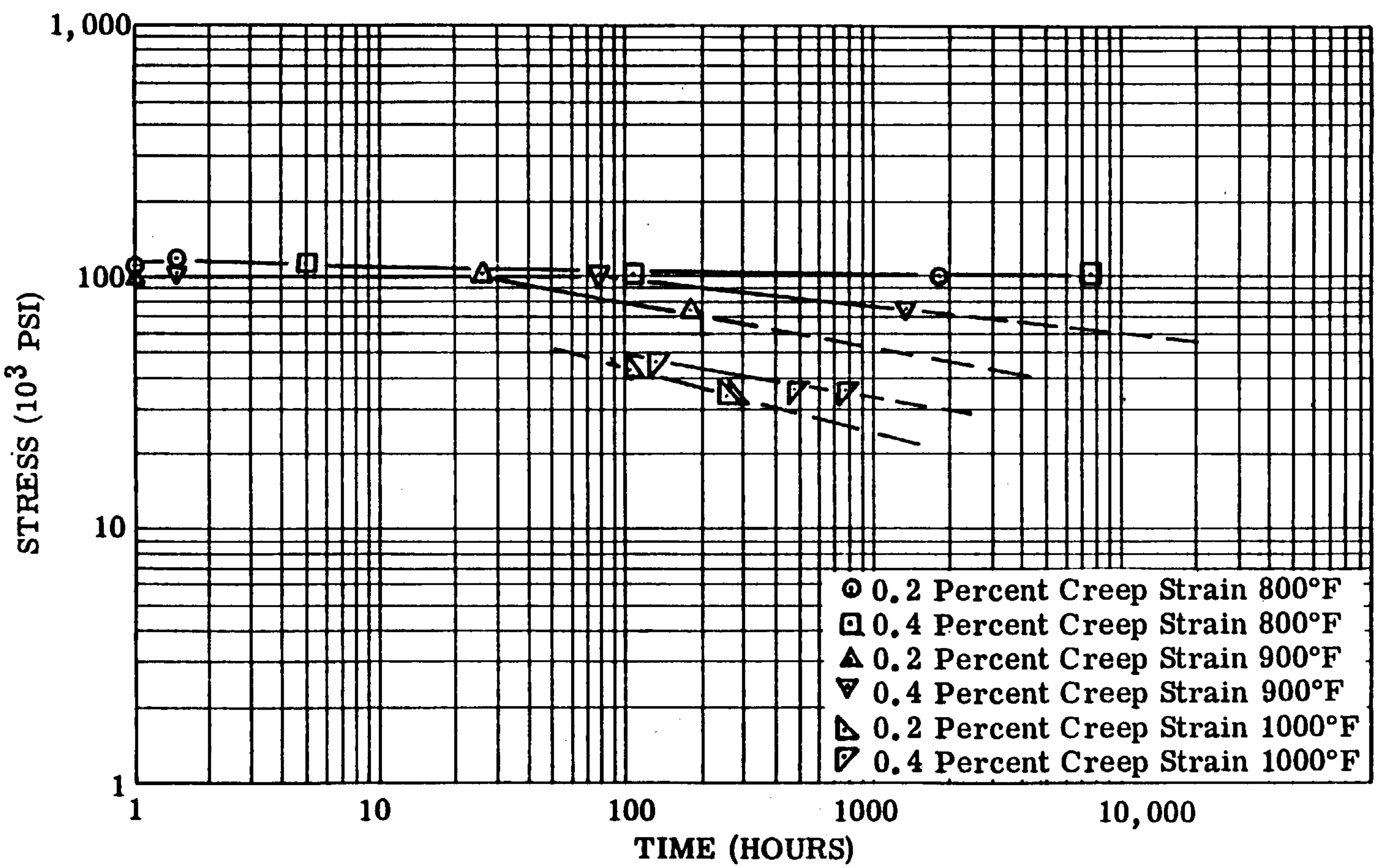


FIGURE IV. F. III-6. Creep Stress-Time Plot for 0.025 Inch Thick AMS6437 (H-11) Sheet. Heat Treated to Rockwell C45. Tested in Air. Longitudinal and Transverse Specimens. See Data Tables IV. F. III-2 through -4. (Reference: NAS3-4162)

Figure IV. F. III-6. Creep - AMS6437 (H-11) Steel

TABLE I V. F. III-2. Creep Data For AMS6487 (Bar H-11) as Compared to Creep Data For AMS6437 (Sheet H-11). See Figures I V. F. III-7 to I V. F. III-11 (Sheet 1 of 2)

TEST: ASTM E139

Identification	Test Temperature (°F)	Stress (Psi)	Test Time (Hours)	Creep Strain (Percent)
Sheet (transverse)	1000	45,000	160	0.327
Forged (40)	1000	45,000	100	0.300
Sheet (transverse)	1000	37,000	330	0.363
Sheet (longitudinal)	1000	37,000	329	0.298
Forged (86)	1000	37,000	500	0.225
Sheet (transverse)	900	100,000	171	0.681 (100 hrs - 0.462)
Sheet (longitudinal)	900	100,000	140	0.909 (100 hrs - 0.705)
Forged (63)	900	100,000	100	0.340
Sheet (transverse)	900	75,000	520	0.315
Forged (82)	900	75,000	500	0.280
(83)	900	75,000	500	0.325
(95)	900	75,000	500	0.370
(94)	900	75,000	500	0.340
(99)	900	75,000	500	0.375
Sheet (transverse)	800	128,000	289	0.912 (100 hrs - 0.861)
Forged (90)	800	128,000	250	0.25
Sheet (transverse)	800	110,000	260	0.54

TABLE IV. F. III-2. Creep Data For AMS6487 (Bar H-11) as Compared to Creep Data For AMS6437 (Sheet H-11). See Figures IV. F. III-7 to IV. F. III-11 (Sheet 2 of 2)

TEST: ASTM E139

Identification	Test Temperature (°F)	Stress (Psi)	Test Time (Hours)	Creep Strain (Percent)
Forged (39)	800	110,000	250	0.38
(68)	800	110,000	250	0.331
Forged (73)	800	110,000	250	0.256
(74)	800	110,000	250	0.244
(71)	800	110,000	250	0.203
(72)	800	110,000	250	0.344
(79)	800	110,000	250	0.286
(80)	800	110,000	250	0.316
Sheet (transverse)	800	100,000	2058	0.210
Forged (36)	800	100,000	500	0.250
(88)	800	100,000	500	0.246
(89)	800	100,000	1000	0.462
(92)	800	100,000	500	0.229
(93)	800	100,000	500	0.360

Nominal Hardness = Rockwell C45

(Reference : NAS 3-4162 and LM 529)

TABLE IV. F. III-3. Creep Data 0.025 Inch AMS6437 (H-11) Sheet

TEST: ASTM E139

Temperature (°F)	800	800	800	900	900	1,000	1,000	900+	1,000+	800	900
Stress (psi)	128,000	110,000	100,000	100,000	75,000	45,000	37,000	100,000	37,000	128,000	75,000
Duration of Test (hours)	289	260	2,058	171	520	160	330	140	329	811**	1,149**
Total Creep Strain (percent)	0.907	0.541	0.210	0.682	0.315	0.325	0.349	0.908	0.304	--	--
Time to Cause 0.2 percent Creep Strain (hours)	16	9.7	1,757	29	194	106	247	1	266	--	--
Time to Cause 0.4 percent Creep Strain (hours)	52	109	7,780*	79	1,359*	138	359	16	388	--	--
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0	0	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV. F. III→	7	7	7	8	8	9	10	8	11	None	None

+Longitudinal specimens
*Extrapolated value
**Did not reach 0.20 percent strain

(Reference NAS3-4162)

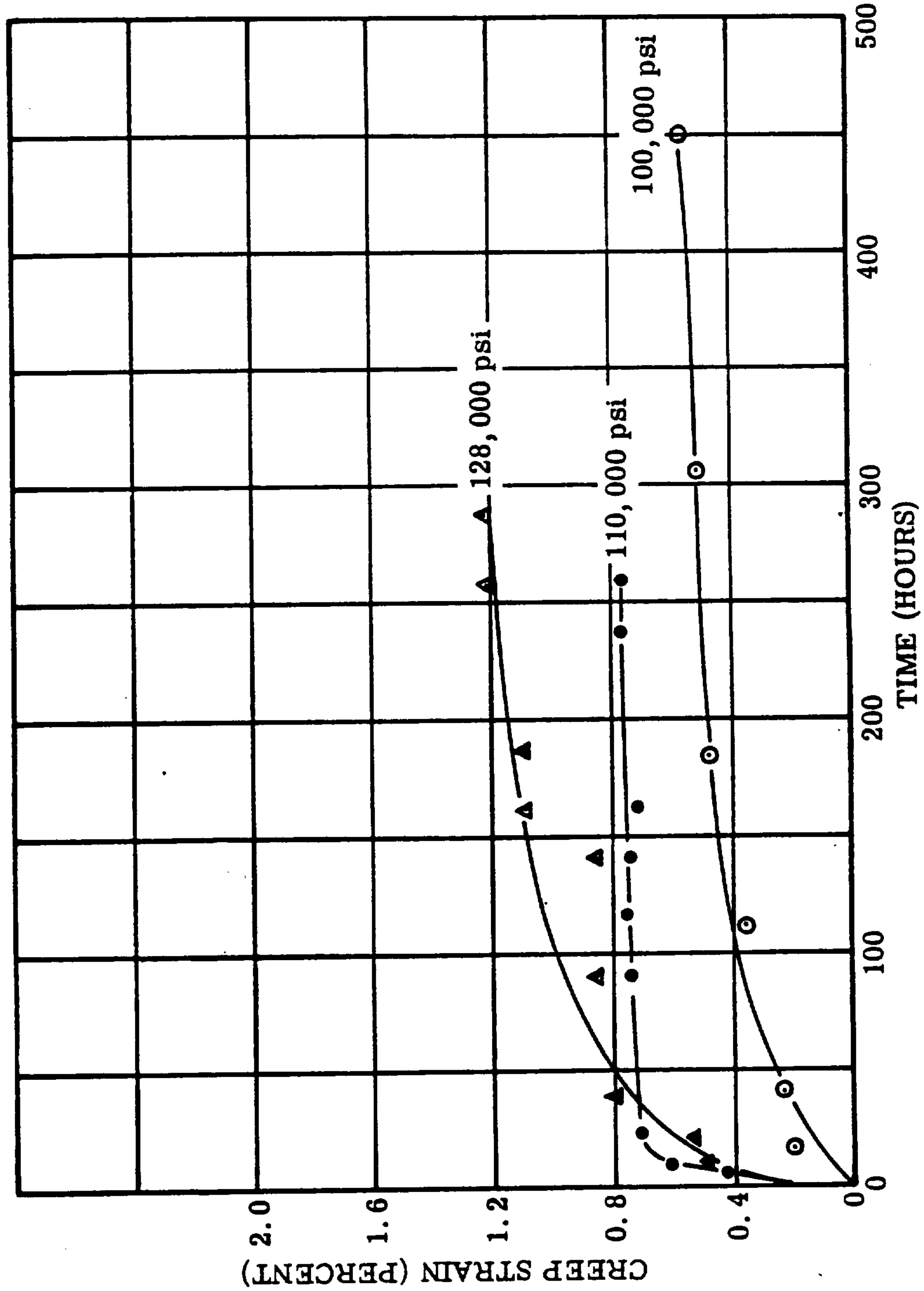


FIGURE IV.F.III-7. Creep, AMS6437 (H-11) Sheet 0.025 Inch Thick Transverse Specimens Tested in Air at 800°F. See Data Table IV.F.III-3. (Reference: NAS3-4162)

Figure IV.F.III-7. Creep - AMS6437 (H-11 Sheet)

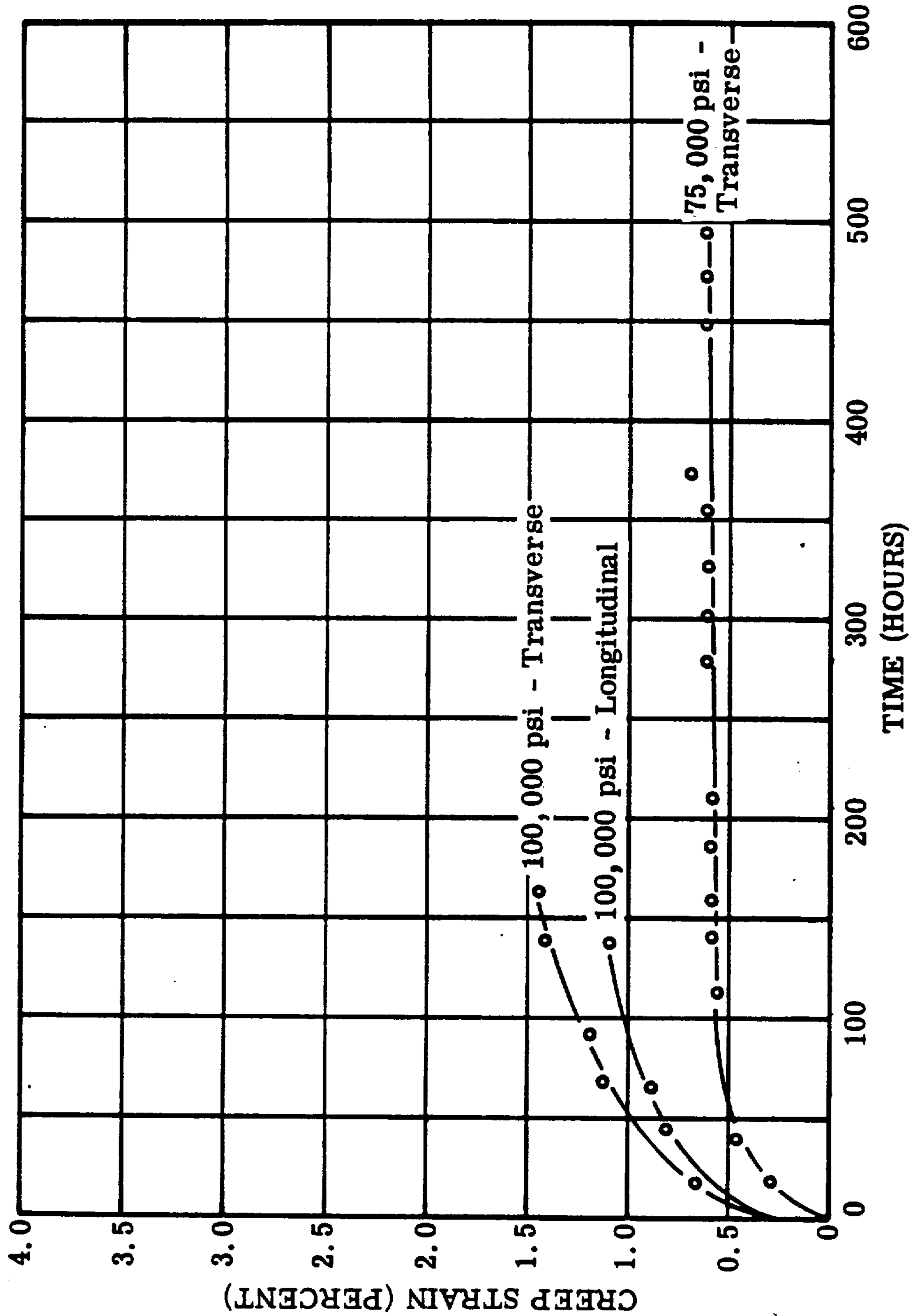


FIGURE IV. F. III-8. Creep, AMS6437 (H-11) Sheet 0.025 Inch Thick, Transverse and Longitudinal Specimens Tested in Air at 900°F. See Data Table IV. F. III-3. (Reference: NAS3-4162)

Figure IV. F. III-8. Creep - AMS6437 (H-11) Steel

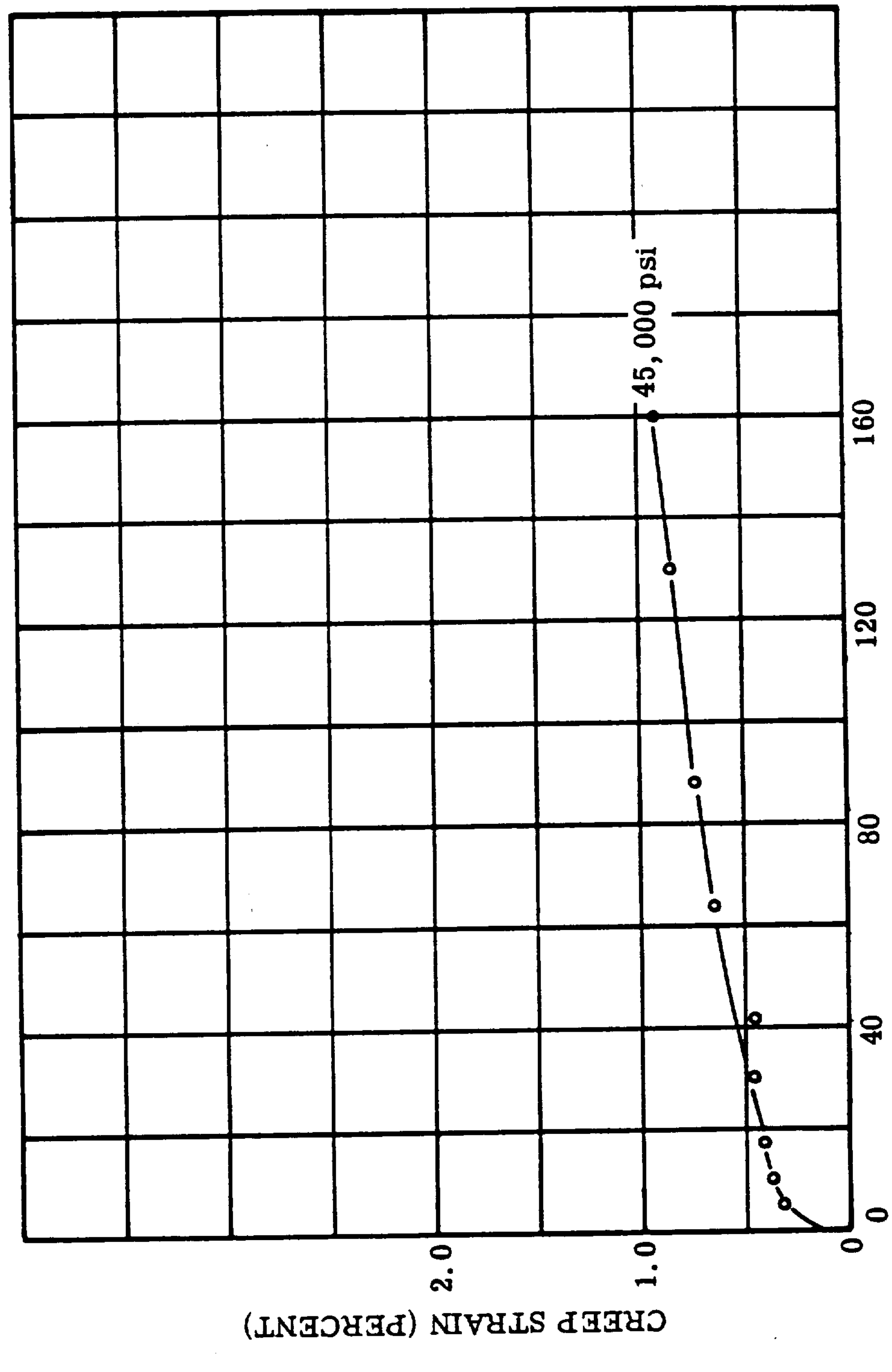


FIGURE I V. F. III-9. Creep, AMS6437 (H-11) Sheet, 0.025 Inch Thick. Transverse Specimen Tested in Air at 1000°F. See Data Table I V. F.III-3. (Reference: NAS3-4162)

Figure I V. F. III-9. Creep - AMS6437 (H-11) Steel

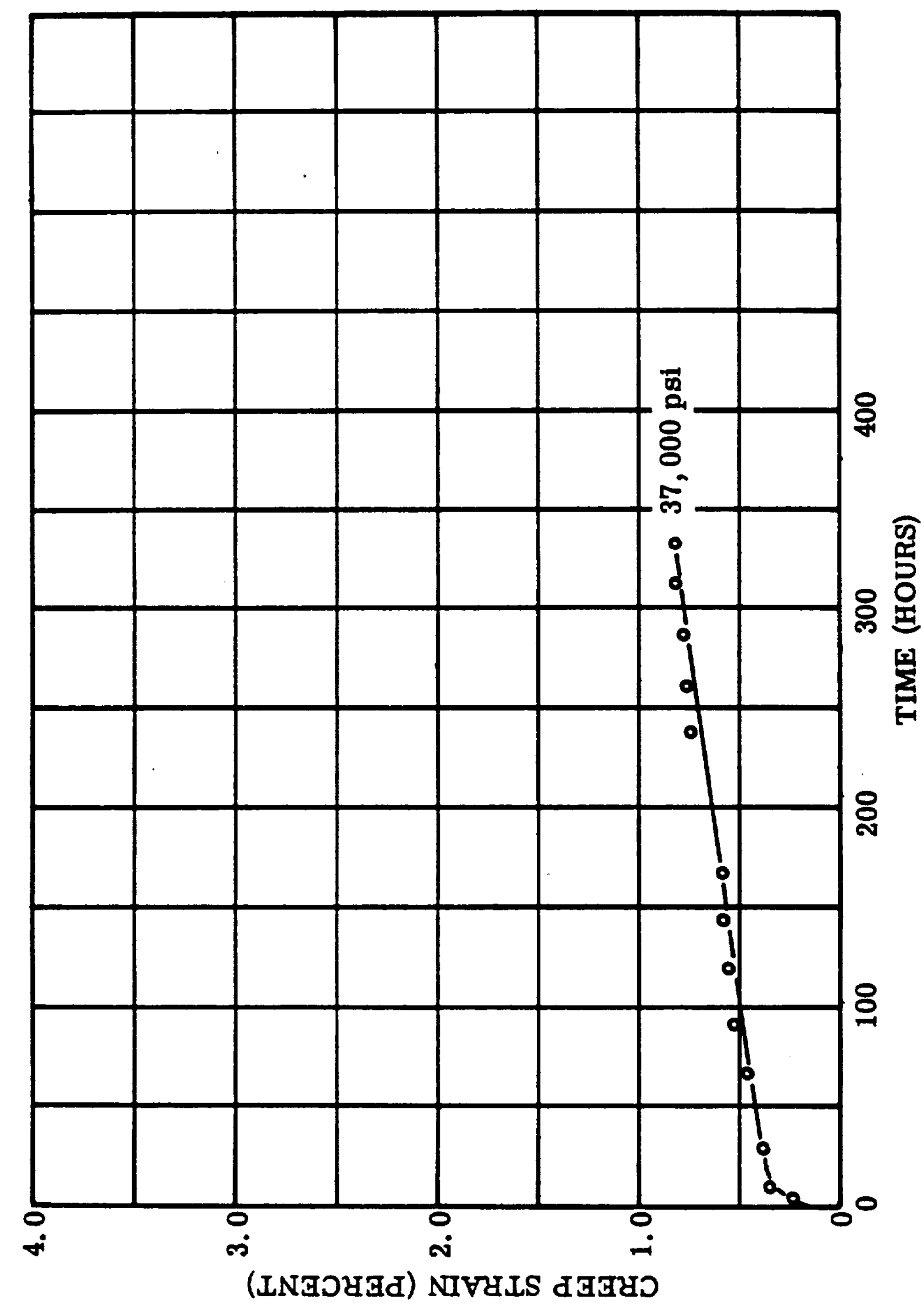


FIGURE IV. F. III-10. Creep, AMS6437 (H-11) Sheet 0.025 Inch Thick. Longitudinal Specimen Tested in Air at 1000°F. See Data Table IV. F. III-3. (Reference: NAS3-4162)

Figure IV. F. III-10. Creep - AMS6437 (H-11) Steel

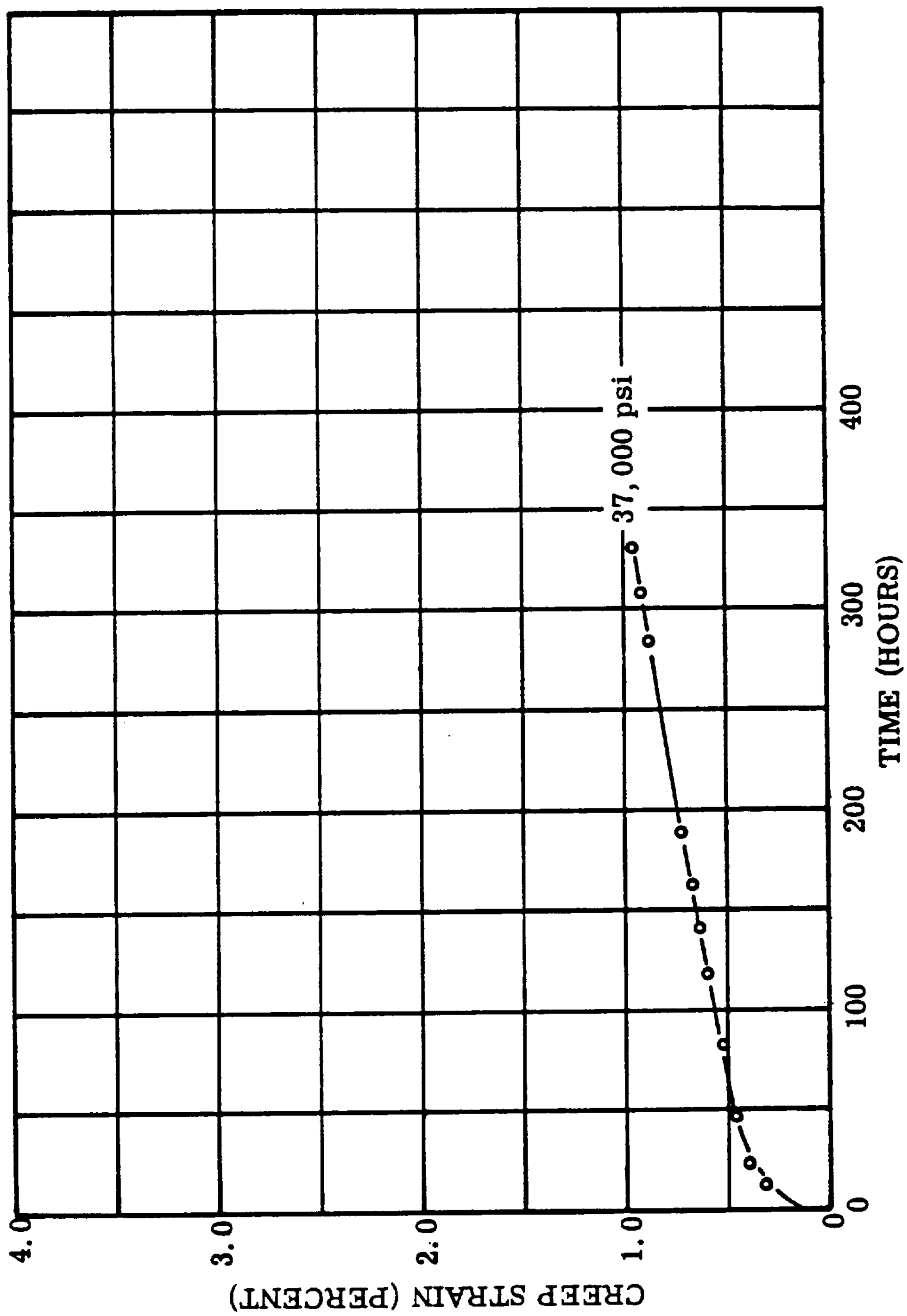


FIGURE IV.F.III-11. Creep, AMS6437 (H-11) Sheet, 0.025 Inch Thick. Transverse Specimen Tested in Air at 1000°F. See Data Table IV.F.III-3. (Reference: NAS3-4162)

Figure IV.F.III-11. Creep - AMS6437 (H-11) Steel

TABLE I V. F. III-4. Creep Data AMS6487 (H-11) Bar
(Sheet 1 of 2)

TEST: ASTM E139

Temperature (°F)	800	800	800	800	800	900	900	1,000
Stress (psi)	100,000	100,000	100,000	110,000	110,000	75,000	75,000	35,000
Duration of Test (hours)	501	1,000	500	249	249	500	500	500
Total Creep Strain (percent)	0.256	0.462	0.229	0.256	0.245	0.279	0.324	0.438
Time to Cause 0.2 percent creep strain (hours)	282	100	393	124	166	253	208	45
Time to Cause 0.4 percent creep strain (hours)	1,234*	684	1,133	572*	536*	878*	673*	419
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air
Specimen Number	88	89	92	73	74	82	83	85

*Extrapolated

(No Reference Curves Available)

TABLE IV. F. III-4. Creep Data AMS6487 (H-11) Bar
(Sheet 2 of 2)

TEST: ASTM E139

Temperature (°F)	900	900	900	1,000	1,000	800	900	900
Stress (psi)	75,000	75,000	75,000	35,000	38,000	110,000	75,000	65,000
Duration of Test (hours)	505	501	500	500	500	1,002	1,005	2,500
Total Creep Strain (percent)	0.372	0.291	0.220	0.333	0.419	0.364	0.324	0.349
Time to Cause 0.2 percent creep strain (hours)	135	34	231	41	212	13	475	1,165
Time to Cause 0.4 percent creep strain (hours)	565	1,059*	2,921	749	475	1,749*	1,296*	2,958*
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air
Specimen Number	99	100	101	102	124	120	122	123

*Extrapolated

(Reference: LM529)

TABLE IV. F. III-5. Vacuum Creep Data For AMS6487 (H-11) Bar

TEST: ASTM E139

Temperature (°F)	850	900	1,000
Stress (psi)	100,000	90,000	37,000
Duration of Test (hours)	502	170	650
Total Creep Strain (percent)	0.30	0.30	0.20
Time to Cause 0.2 percent creep strain (hours)	260	136	650
Time to Cause 0.4 percent creep strain (hours)	(1)	(1)	(1)
Plastic Strain obtained on Loading specimen (percent)	0	0	0
Test Atmosphere	Vacuum	Vacuum	Vacuum
See Larson-Miller Plot in Figure IV. F. III-2 and -3			

(1) Did not reach required strain. (Reference NAS 3-4162)

TABLE IV. F. III-6. Fatigue Data for H-11 Alloy, For Use in Plotting Goodman Type Diagrams

Temperature (°F)	Fatigue Specimen	Stress Ratio (A)	Stress for 10^7 Cycles (Psi)	Stress Alternating (Psi)	Stress Mean (Psi)
800	Smooth Bar	∞	83,000		
800	Notch Bar	∞	48,000		
800	Smooth Bar	0.25	170,000	34,000	136,000
800	Notch Bar	0.25	128,000	25,600	102,400
800	Smooth Bar	2.0	100,000	66,000	34,000
800	Notch Bar	2.0	50,000	33,000	17.000
1000	Smooth Bar	∞	76,000		
1000	Notch Bar	∞	32,000		
1000	Smooth Bar	0.25	137,000	27,400	109,600
1000	Notch Bar	0.25	111,000	22,200	88,800
1000	Smooth Bar	2.0	113,000	75,333	37,667
1000	Notch Bar	2.0	33,000	22,000	11,000

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

(Reference NAS 3-4162)

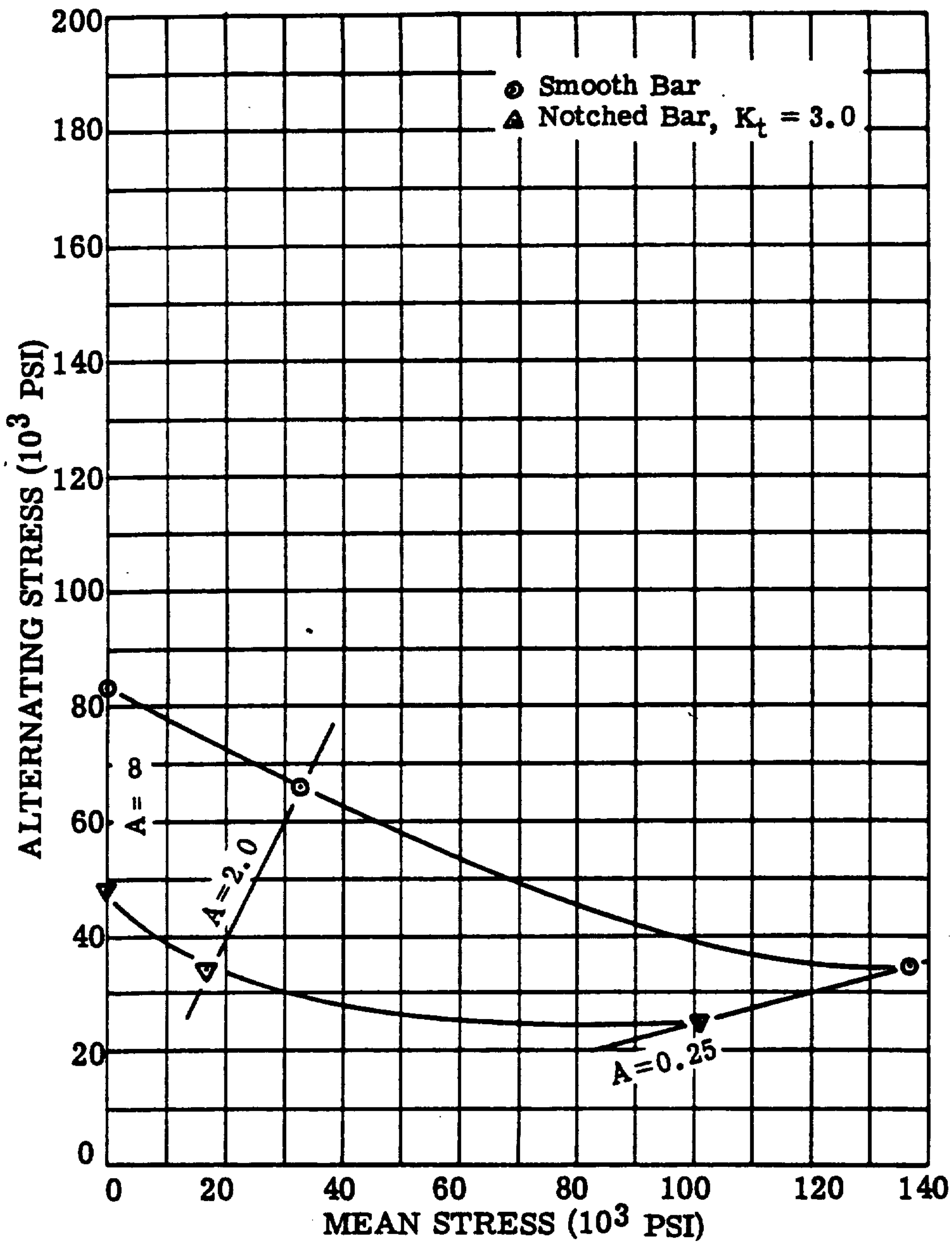


FIGURE IV. F. III-12. Modified Goodman Type Diagram For AMS6487 (H-11) Alloy. Test Temperature 800°F. Data For 10^7 Cycles. See Data Table IV. F. III-6. Test Sample Hardness - Rockwell C(44.5-45.5) Air Test. (Reference: NAS3-4162)

Figure IV. F. III-12. Fatigue - H-11 Steel

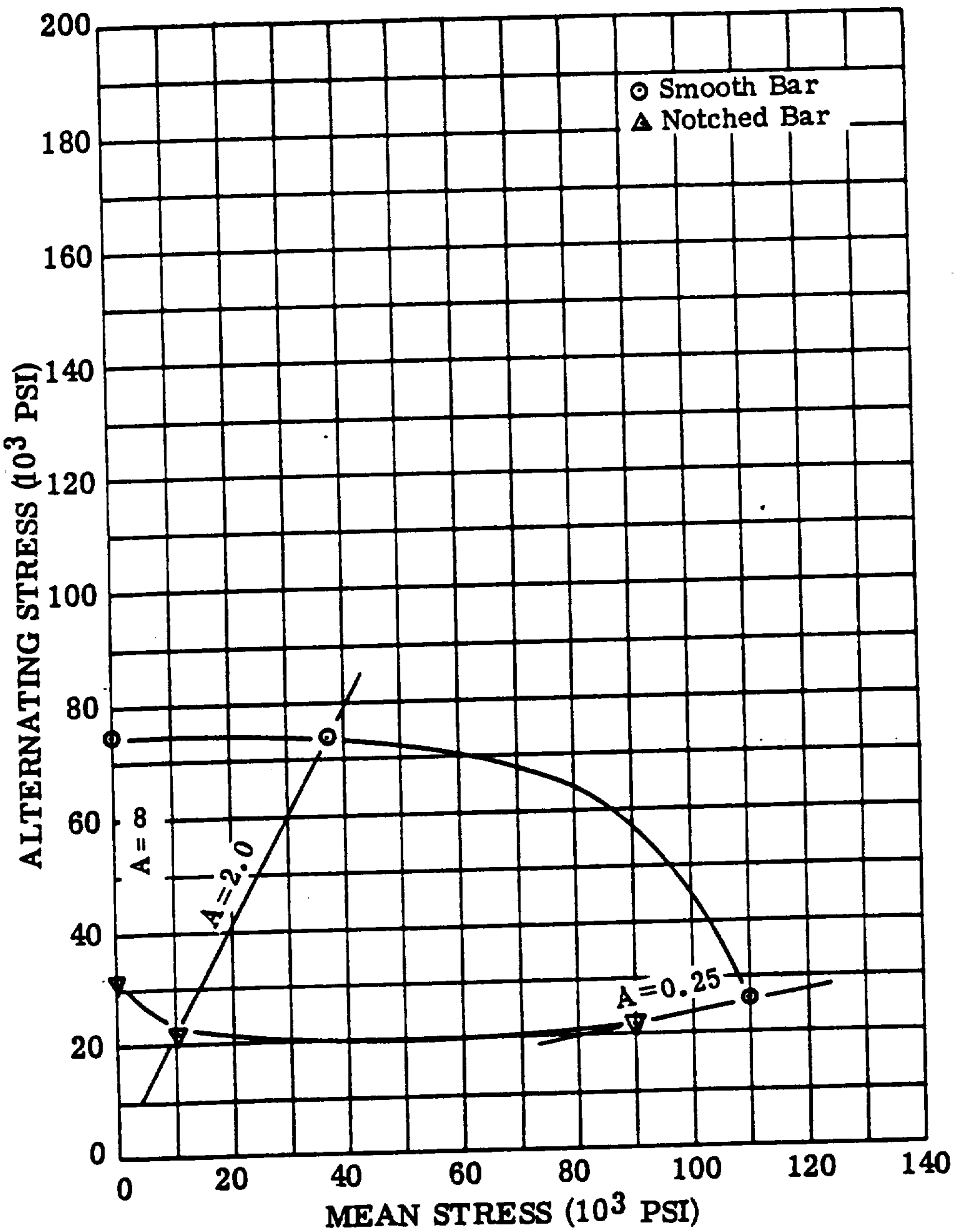


FIGURE I V. F. III-13. Modified Goodman Type Diagram For AMS6487 (H-11) Alloy. Test Temperature 1000°F. Data For 10^7 Cycles. See Data Table I V. F. III-6. Test Sample Hardness - Rockwell C(44.5-45.5) Air Test. (Reference: NAS3-4162)

Figure I V. F. III-13. Fatigue - H-11 Steel

TABLE IV. F. III-7. Fatigue Data For AMS6487 H-11 Alloy. Smooth Bar Samples. See Data Plots Figures IV. F. III-14 to IV. F. III-17.

TEST: ASTM STP 91

Specimen No.	Test Temp. °F	Stress Ratio (A)	Max. Stress (Psi)	Cycles to Failure (N)
246	800	∞	72,000	9,891,000
245	800	∞	74,000	5,032,000
242	800	∞	78,000	2,736,000
111	800	∞	82,000	1,332,000
103	800	∞	84,000	4,680,000
100	800	∞	89,000	1,130,000
104	800	∞	94,000	138,000
102	800	∞	100,000	60,000
101	800	∞	110,000	19,000
109	800	0.25	169,600	12,047,000
115	800	0.25	171,350	922,000
113	800	0.25	172,450	186,000
112	800	0.25	175,150	4,000
107	800	0.25	175,150	2,000
130	800	2.00	97,995	10,000,000*
123	800	2.00	108,866	628,000
124	800	2.00	108,866	1,155,000
108	800	2.00	112,250	1,213,000
122	800	2.00	115,015	1,386,000
117	800	2.00	120,050	572,000
119	800	2.00	124,932	190,000
133	800	2.00	135,000	166,000
248	1000	∞	70,000	6,241,000
128	1000	∞	80,000	1,566,000
118	1000	∞	82,000	663,000
110	1000	∞	90,000	783,000
116	1000	∞	100,000	33,000
114	1000	∞	110,000	3,000
129	1000	0.25	130,000	5,634,000
241	1000	0.25	134,210	7,974,000
126	1000	0.25	140,000	58,000
127	1000	0.25	152,000	29,000
134	1000	0.25	160,750	15,000
125	1000	0.25	170,000	2,000
247	1000	2.00	96,400	3,094,000
244	1000	2.00	102,000	941,000
138	1000	2.00	108,000	3,424,000
135	1000	2.00	114,000	1,600,000
137	1000	2.00	120,000	826,000
136	1000	2.00	129,000	394,000
243	1000	2.00	135,000	5,000

$A = \text{Stress Ratio} = \dfrac{\text{Alternating Stress}}{\text{Mean Stress}}$ N = Number of cycles to failure

*No failure

(Reference NAS 3-4162)

TABLE IV. F. III-8. Fatigue Data For AMS6487 H-11 Alloy Notched Bar** Samples. See Data Plots Figures IV. F. III-14 to IV. F. III-17.

TEST: ASTM STP 91

Specimen No.	Test Temp. °F	Stress Ratio (A)	Max. Stress (Psi)	Cycles to Failure (N)
203	800	∞	40,000	7,761,000
208	800	∞	44,000	14,000,000*
202	800	∞	46,000	12,245,000
206	800	∞	50,000	35,000
215	800	∞	50,000	24,000,000*
222	800	∞	55,800	15,000
207	800	∞	60,000	7,000
211	800	∞	65,000	4,000
221	800	0.25	125,250	9,656,000
256	800	0.25	130,000	1,000,000
223	800	0.25	131,250	5,100,000
225	800	0.25	135,750	396,000
227	800	0.25	140,400	92,000
231	800	0.25	147,000	75,000
237	800	2.00	44,000	7,873,000
252	800	2.00	45,900	13,086,000*
240	800	2.00	47,000	10,000,000*
255	800	2.00	48,250	1,601,000
257	800	2.00	49,950	14,885,000*
220	800	2.00	52,500	50,000
228	800	2.00	65,000	13,000
226	1000	∞	32,000	5,272,000
218	1000	∞	33,600	14,995,000
239	1000	∞	33,000	10,000,000*
219	1000	∞	34,600	127,000
217	1000	∞	37,000	30,000
224	1000	∞	41,000	8,000
235	1000	0.25	103,950	13,733,000*
258	1000	0.25	105,000	1,108,000
232	1000	0.25	110,000	1,145,000
229	1000	0.25	120,300	570,000
233	1000	0.25	126,500	914,000
254	1000	0.25	128,000	2,181,000
234	1000	0.25	129,950	1,040,000
236	1000	0.25	140,000	958,000
263	1000	0.25	140,000	109,000
230	1000	2.00	35,100	10,221,000*
251	1000	2.00	40,200	19,533,000*
249	1000	2.00	46,200	1,559,000
238	1000	2.00	50,100	1,380,000
250	1000	2.00	60,000	21,000
253	1000	2.00	54,895	77,000

$A = \text{Stress Ratio} = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$

N = Number of cycles to failure

*No failure

**Stress concentration factor $K_t = 3.0$

(Reference NAS 3-4162)

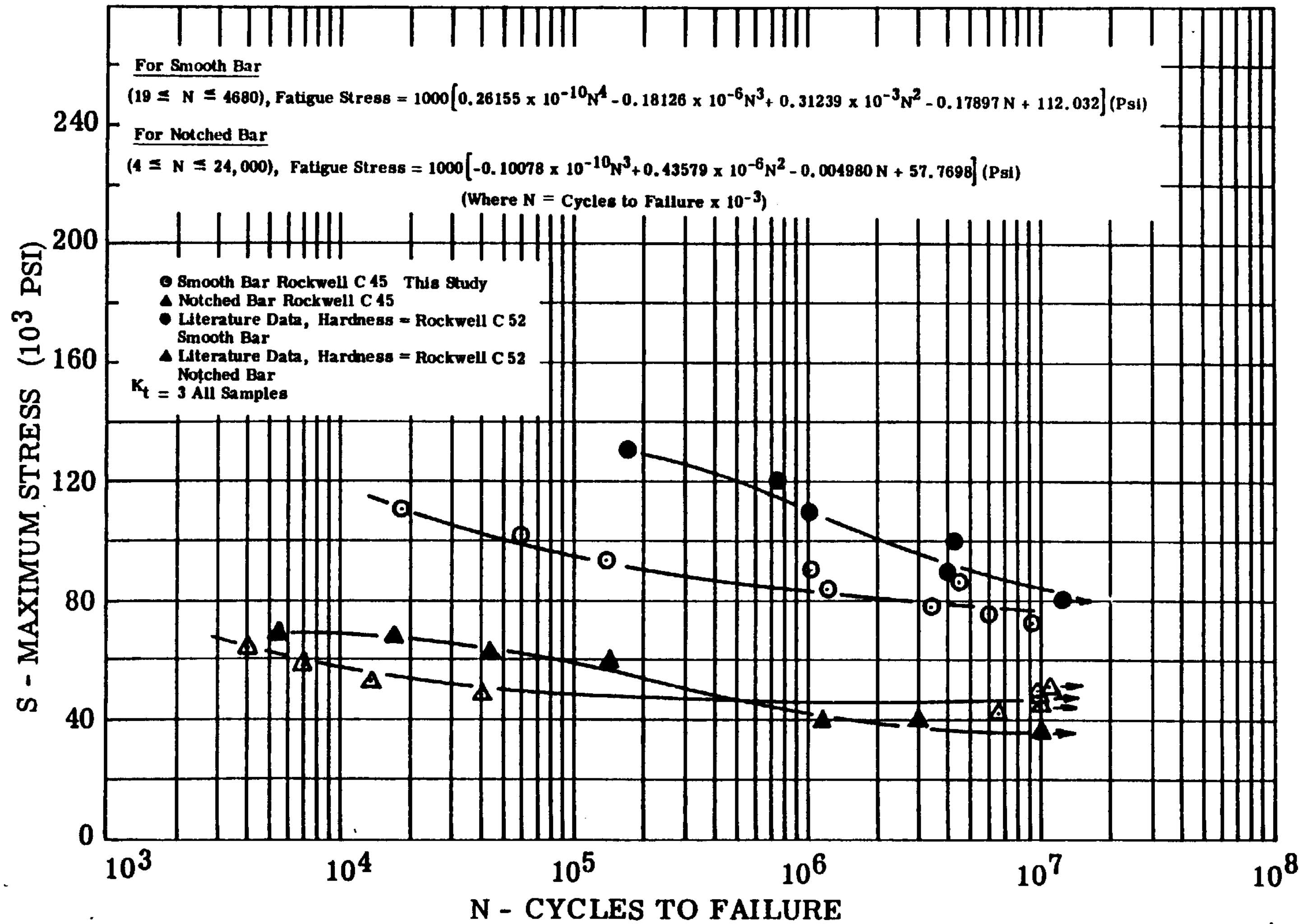


FIGURE I V. F. III-14. S-N Diagram For Notched and Smooth Bar AMS6487 (H-11) at Rockwell C 45 Tested at 800°F in Air. Stress Ratio A = $\frac{\text{Alternating Stress}}{\text{Mean Stress}}$ = ∞ . See Data Tables I V. F. III-7 and -8. (Reference: NAS3-4162 and LM503)

Figure I V. F. III-14. Fatigue - AMS6487 - (H-11) Steel

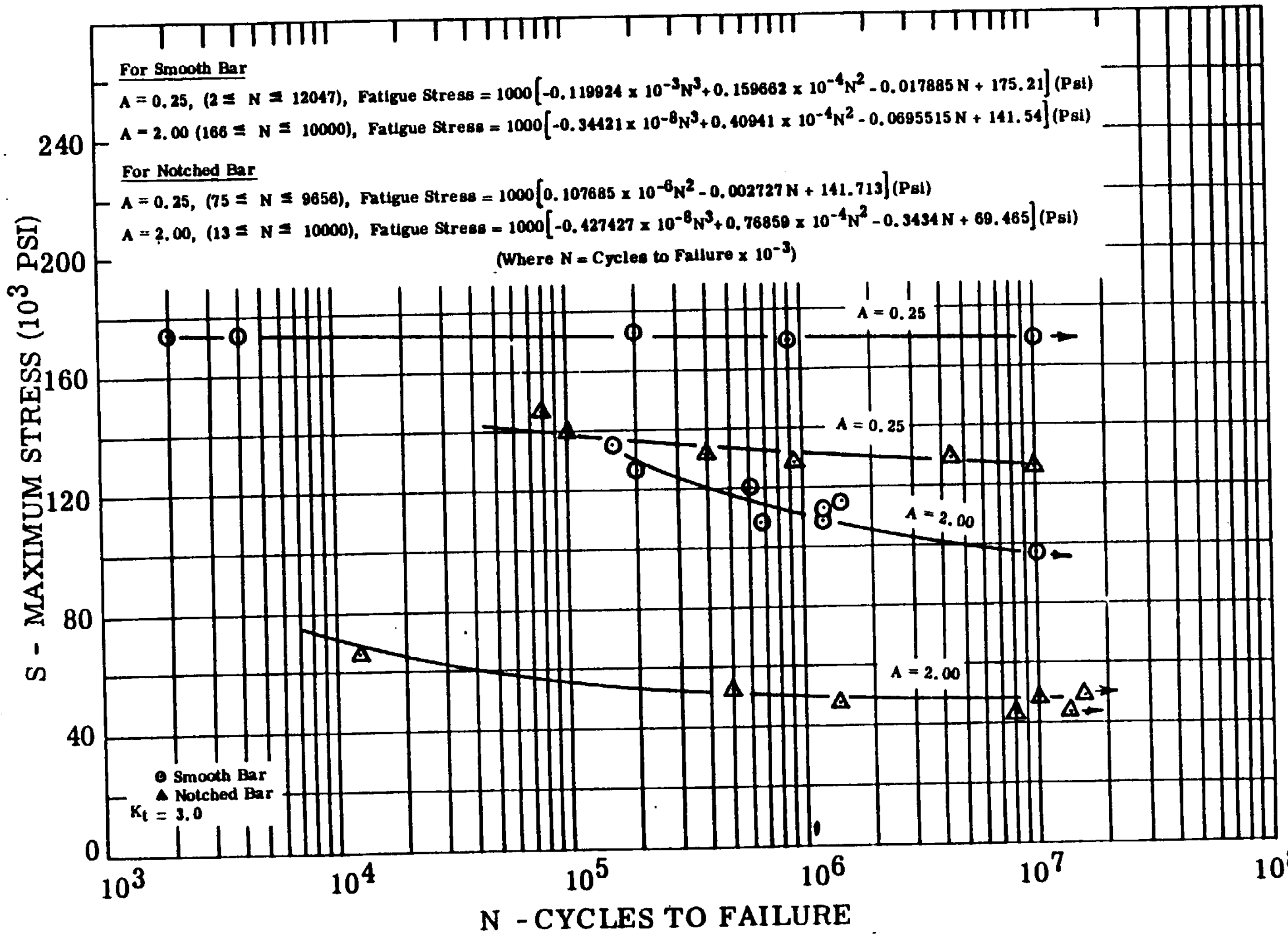


FIGURE I V. F. III-15. S-N Diagram For Notched and Smooth Bar AMS6487 (H-11) at Rockwell C 45 Tested at 800°F in Air. Stress Ratio A = $\frac{\text{Alternating Stress}}{\text{Mean Stress}}$ = 0.25 and 2.00. See Data Tables I V. F. III-7 and -8. (Reference: NAS3-4162)

Figure I V. F. III-15. Fatigue - AMS6487 (H-11) Steel

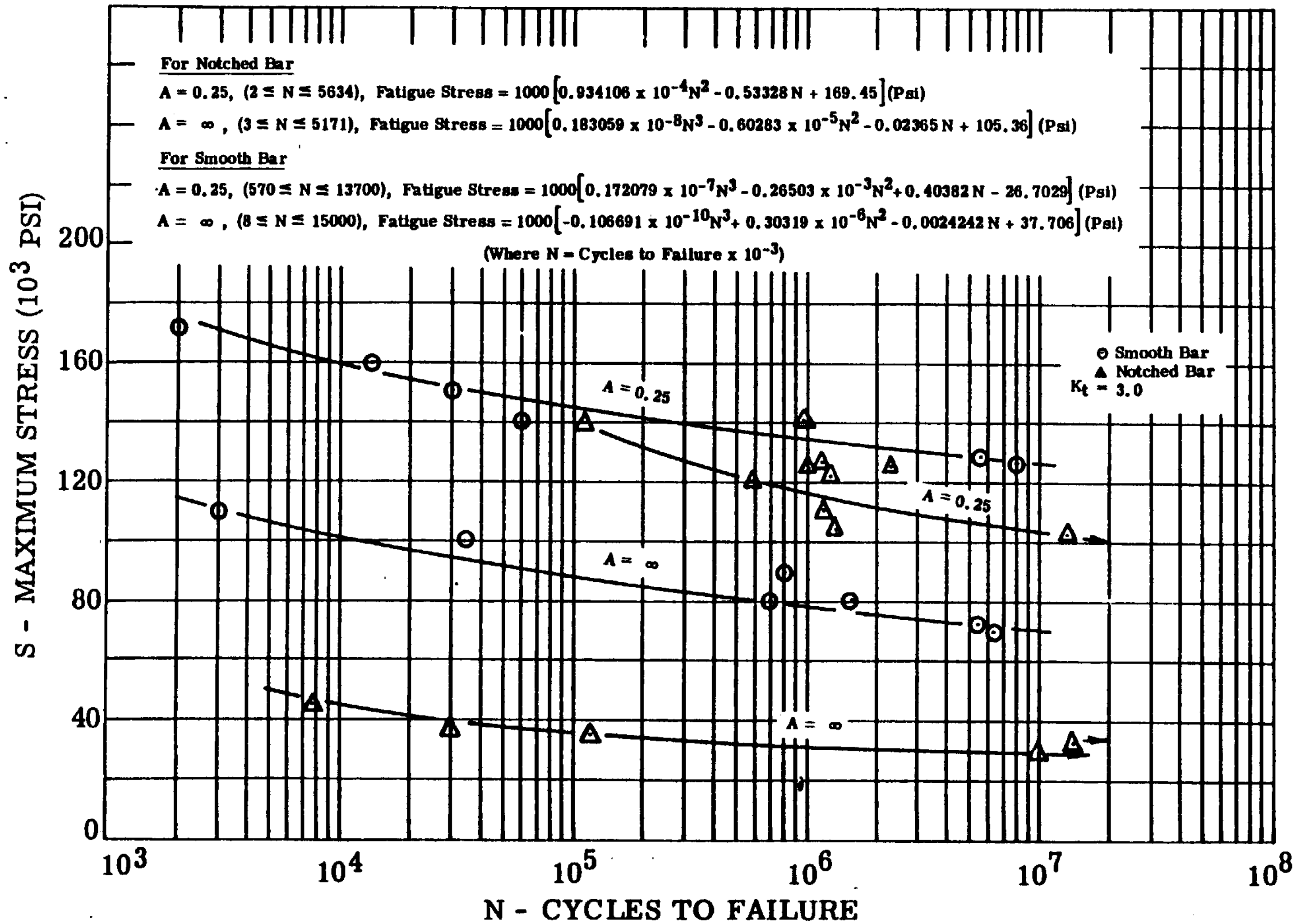


FIGURE IV. F. III-16. S-N Diagram For Notched and Smooth Bar AMS6487 (H-11) at Rockwell C 45 Tested at 1000°F. Stress Ratio $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}} = 0.25$ and ∞. Tests Made in Air. See Data Tables IV. F. III-7 and -8. (Reference: NAS3-4162)

Figure IV. F. III-16. Fatigue - AMS6487 (H-11) Steel

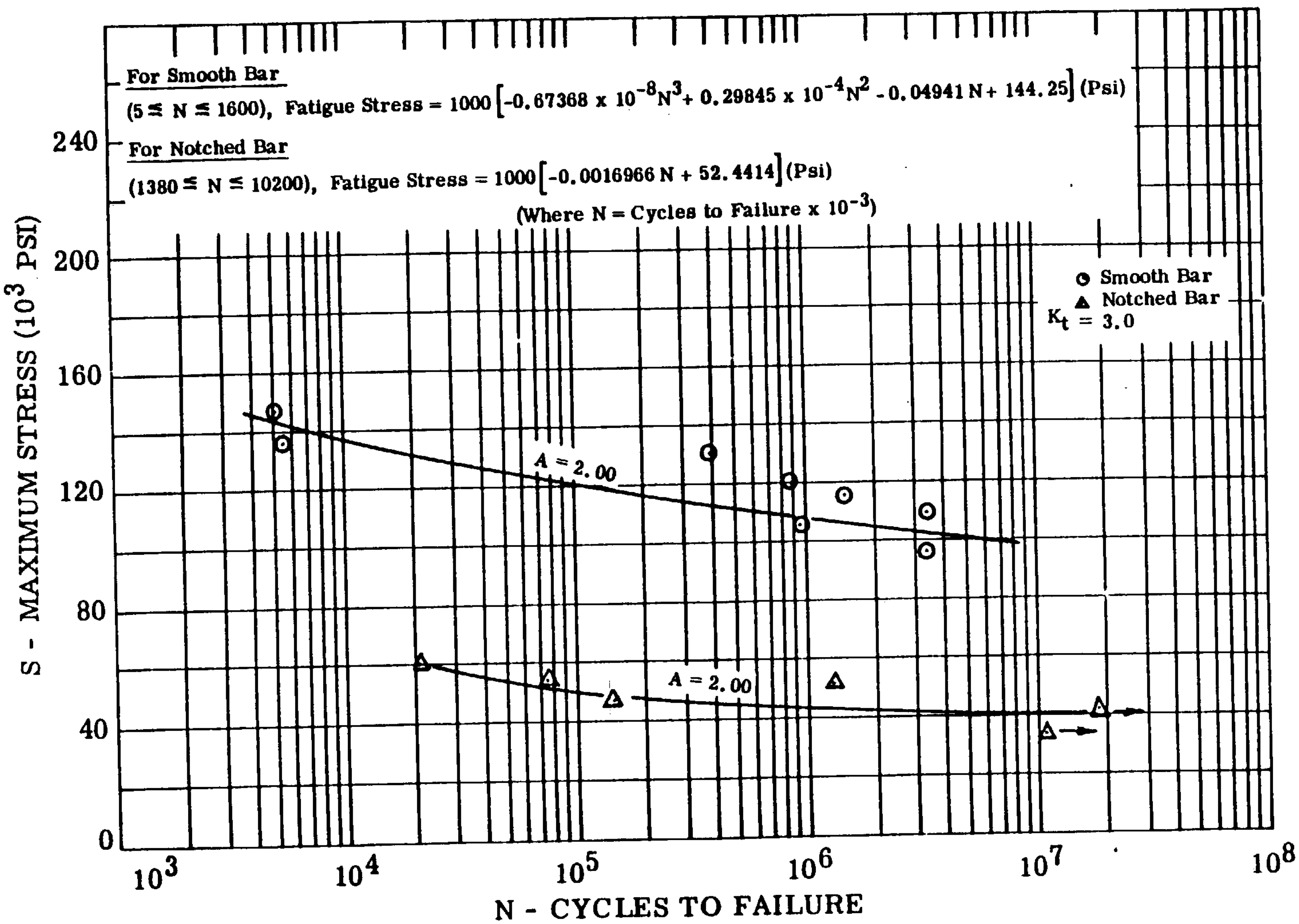


FIGURE IV. F. III-17. S-N Diagram For Notched and Smooth Bar AMS6487 (H-11) at Rockwell C45 Tested at 1000°F. Stress Ratio $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}} = 2.00$. Tests Made in Air. See Data Tables IV. F. III-7 and -8. (Reference: NAS3-4162)

Figure IV. F. III-17. Fatigue - AMS6487 (H-11) Steel

MAGNETIC MATERIALS PROPERTIES SUMMARY

G. NIVCO ALLOY

A high-temperature, steam-turbine, blading alloy manufactured by the Westinghouse Electric Corporation, Blairsville, Pennsylvania.

Availability: Commercial-Single source

Nominal Composition: 23 Ni, 2 Ti, 1 Zr, balance Co.

Tested Composition:

	Ni	Zr	Al	Ti	Co
Bar	23.5	1.03	0.25	2.04	Bal
Sheet	23.9	~1.00	0.33	1.96	Bal

I. Thermophysical Properties

A. Density — 0.312 lb/in^3 — 8.61 grams/cc

B. Curie Temperature — 1800°F

C. Thermal Conductivity

1. At 72°F — $25.5 \frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$**
2. At 900°F — $18.7 \frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$**
3. At 1100°F — $17.8 \frac{\text{Btu-ft}}{\text{ft}^2\text{-hr-°F}}$**

D. Coefficient of Thermal Expansion 72°-1200°F — 7.40×10^{-6} in/in-°F

E. Specific Heat

1. At 72°F — 0.102 Btu/lb-°F
2. At 900°F — 0.111 Btu/lb-°F
3. At 1100°F — 0.124 Btu/lb-°F

**Westinghouse Materials Manufacturing Dept. product literature.

F. Electrical Resistivity

1. At 72°F — 27.98×10^{-6} ohm-cm
2. At 900°F — 52.27×10^{-6} ohm-cm
3. At 1100°F — 60.73×10^{-6} ohm-cm

II. Magnetic Properties (All magnetic test materials were at a hardness of Rockwell ~~are stress relief annealed~~ C 38-42 ~~(SRA)~~) unless otherwise specified)

A. D-C Properties (Solid Ring)

1. Induction (B_{tip}) for H = 300 oersteds at 72°F — 12.6 kilogauss
2. Induction (B_{tip}) for H = 300 oersteds at 800°F — 12.0 kilogauss
3. Induction (B_{tip}) for H = 300 oersteds at 1100°F — 11.6 kilogauss
4. Induction (B_{tip}) for H = 230 oersteds at 1400°F — 9.9 kilogauss

B. A-C Properties (400 cps)

1. 0.014 inch thick laminations

a. Exciting volt-amperes, B = 6 kilogauss at 72°F — 183.0 volt-amperes/pound
b. Exciting volt-amperes, B = 6 kilogauss at 800°F — 113.0 volt-amperes/pound
c. Exciting volt-amperes, B = 6 kilogauss at 1100°F — 98.0 volt-amperes/pound
d. Exciting volt-amperes, B = 6 kilogauss at 1400°F — 27.3 volt-amperes/pound
e. Core loss, B = 6 kilogauss at 72°F — 96.0 watts/pound
f. Core loss, B = 6 kilogauss at 800°F — 63.0 watts/pound
g. Core loss, B = 6 kilogauss at 1100°F — 54.5 watts/pound
h. Core loss, B = 6 kilogauss at 1400°F — 51.0 watts/pound

2. 0.025 inch thick laminations

a. Exciting volt-amperes, B = 6 kilogauss at 72°F — 149.0 volt-amperes/pound

b. Exciting volt-amperes, B = 6 kilogauss at 900°F — 94.8 volt-amperes/pound
c. Exciting volt-amperes, B = 6 kilogauss at 1100°F — 77.0 volt-amperes/pound
d. Exciting volt-amperes, B = 6 kilogauss at 1400°F — 42.0 volt-amperes/pound
e. Core loss, B = 6 kilogauss at 72°F — 80.0 watts/pound
f. Core loss, B = 6 kilogauss at 900°F — 51.6 watts/pound
g. Core loss, B = 6 kilogauss at 1100°F — 41.3 watts/pound
h. Core loss, B = 6 kilogauss at 1400°F — 27.0 watts/pound

C. Constant Current Flux Reset Properties (CCFR)

Not applicable to NIVCO alloy, only measured on materials used in magnetic amplifiers.

III. Mechanical Properties

A. Poisson's Ratio at 72°F — 0.320

B. Tensile Properties (Bar Stock)

1. At 72°F in air

a. 0.20 percent offset yield strength — 112,400 psi
b. Tensile strength — 165,400 psi
c. Elongation in 1.4 inch — 30.7 percent
d. Reduction of area — 43.6 percent
e. Modulus of Elasticity — 29.1×10^6 psi

2. At 900°F in air

a. 0.20 percent offset yield strength — 89,200 psi
b. Tensile strength — 133,800 psi
c. Elongation in 1.4 inch — 21.0 percent
d. Reduction of area — 43.7 percent
e. Modulus of elasticity — 25.7×10^6 psi

3. At 1100°F in air

a.	0.20 percent offset yield strength	89,900 psi
b.	Tensile strength	124,600 psi
c.	Elongation in 1.4 inch	24.3 percent
d.	Reduction of area	47.0 percent
e.	Modulus of elasticity	18.6×10^6 psi

4. High temperature modulus of elasticity

a.	At 1400°F	9.7×10^6 psi
b.	At 1600°F	4.2×10^6 psi

C. Creep (Bar Stock and Sheet - 0.025 Inch)

1. Bar Stock

a.	Stress to produce 0.20 percent creep strain in 1000 hours at 900°F	92,000 psi
b.	Stress to produce 0.20 percent creep strain in 10,000 hours at 900°F	90,000 psi
c.	Stress to produce 0.20 percent creep strain in 1000 hours at 1100°F	69,000 [redacted] psi
d.	Stress to produce 0.20 percent creep strain in 10,000 hours at 1100°F	58,000 [redacted] psi
e.	Stress to produce 0.40 percent creep strain in 1000 hours at 900°F	100,000 psi
f.	Stress to produce 0.40 percent creep strain in 10,000 hours at 900°F	95,000 psi
g.	Stress to produce 0.40 percent creep strain in 1000 hours at 1100°F	75,800 psi
h.	Stress to produce 0.40 percent creep strain in 10,000 hours at 1100°F	63,000 [redacted] psi

2. Sheet, 0.025 inch thick*

a. Stress to produce 0.2 percent creep strain in 1000 hours at 1100°F	29,300 psi
b. Stress to produce 0.2 percent creep strain in 10,000 hours at 1100°F	16,200 psi

3. Creep (argon or vacuum).

See Section C above for temperatures to 1100°F; above 1100°F consult actual test data.

D. Fatigue (Air or Argon Test Atmosphere)

	Smooth Bar	Notched Bar ($K_t=3$)
1. 900°F fatigue strength for 10^7 cycles $A = \infty$	60,000	35,000
2. 900°F fatigue strength for 10^7 cycles $A = 0.25$	135,000	135,000
3. 1000°F fatigue strength for 10^7 cycles $A = \infty$	60,000	35,000
4. 1000°F fatigue strength for 10^7 cycles $A = 0.25$	128,000	120,000
5. 1100°F fatigue strength for 10^7 cycles $A = \infty$	60,000	30,000
6. 1100°F fatigue strength for 10^7 cycles $A = 0.25$	108,000	95,000

E. Heat Treatment

1. Normal heat treatment for use as solid inductor rotor material in solid form and resultant hardness. Heat to 1725° ± 25°F, hold at temperature for one hour and water quench. Age 25 hours at 1225° ± 5°F. (Hardness = approximately 38-42 Rockwell C).

*The creep for sheet represents a very limited number of tests. Initial creep data for material which had been solution annealed, quenched, cold finished and aged was unexpectedly poor and is not worth presenting here. The above sheet creep data were obtained with completely reheat treated test bars. While the sheet creep properties do not approach those of forged bar stock, a considerable reduction in creep rate is measured. A complete discussion of Nivco alloy sheet and creep data are found in Sections II and III.

2. Special heat treatment for use as laminated rotor or stator materials. Heat to 1900° ± 25°F, hold at temperature for one hour and water quench. Age 25 hours at 1225° ± 5°F. (Aged hardness = approximately 38-42 Rockwell C.)

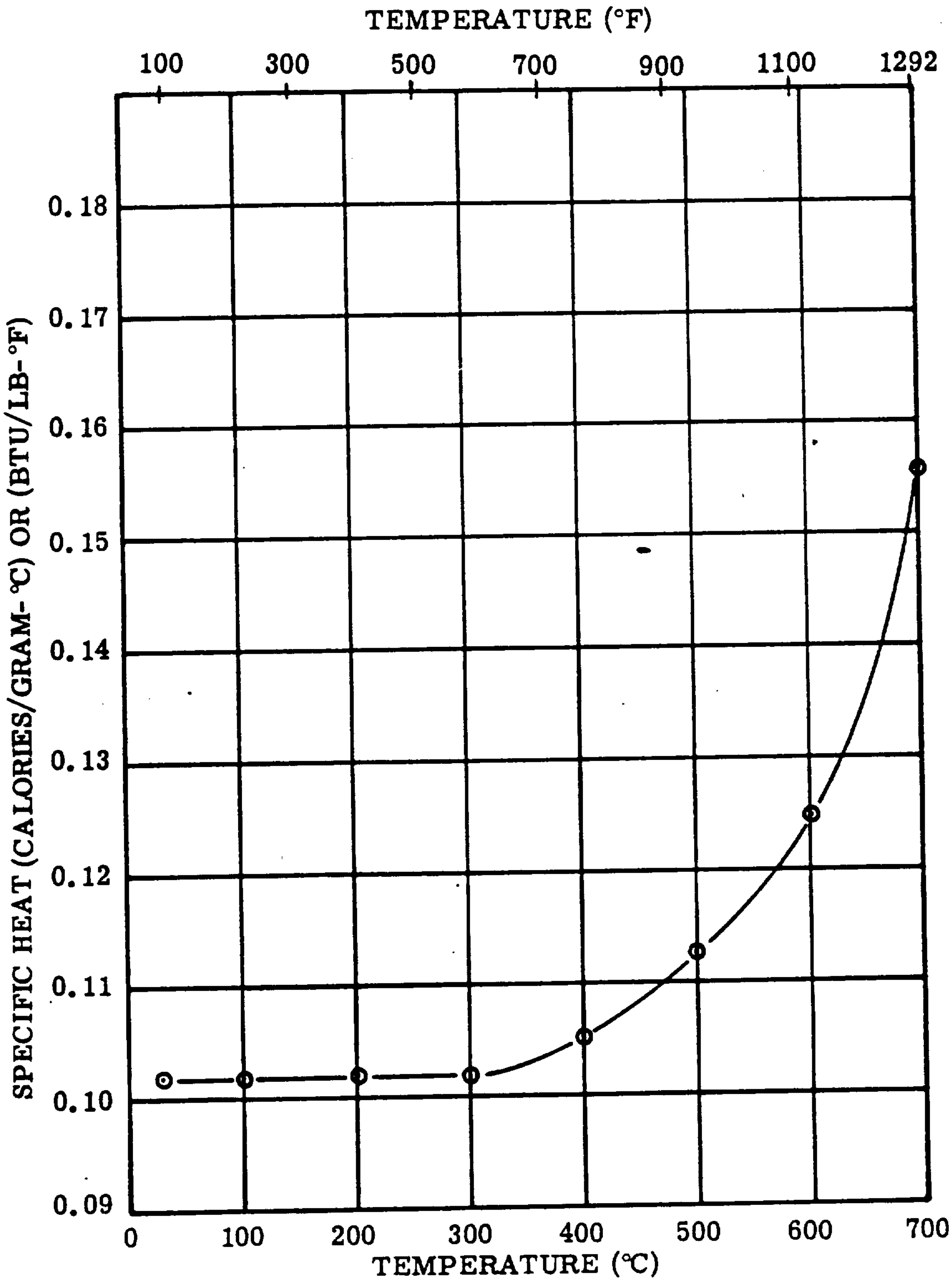


Figure IV. G. I-1. Specific Heat of Nivco Forging in Vacuum

Figure IV. G. I-1. Specific Heat - Nivco

TABLE IV.G.I-1. Electrical Resistivity of Nivco Ribbon in Vacuum

Specimen No. 1, Continuous Heating

Width - 0.247 Inch, Thickness - 0.0255 Inches, Length - 11.54 Inches

Temperature (°F)	Resistance (Ohm)	Resistivity (Microhm-Cm)
78	0.01313	18.20
200	0.01471	20.39
300	0.01666	23.10
400	0.01863	25.83
500	0.02116	29.33
603	0.02373	32.89
700	0.02642	36.63
800	0.02920	40.48
900	0.03231	44.79
1004	0.03610	50.04
1100	0.03942	54.65
1200	0.04305	59.68
1300	0.04693	65.06
1400	0.04993	69.22
1500	0.05410	75.00
1600	0.05751	79.73
1450	0.05368	74.42
1250	0.04912	68.10
1044	0.04221	58.51
850	0.03660	50.74
635	0.03100	42.97
450	0.02655	36.81
250	0.02302	31.91
150	0.02130	29.53
79	0.02017	27.96

NOTE: The above data are plotted in Figure IV.G.I-2

(Reference: NAS 3-4162)

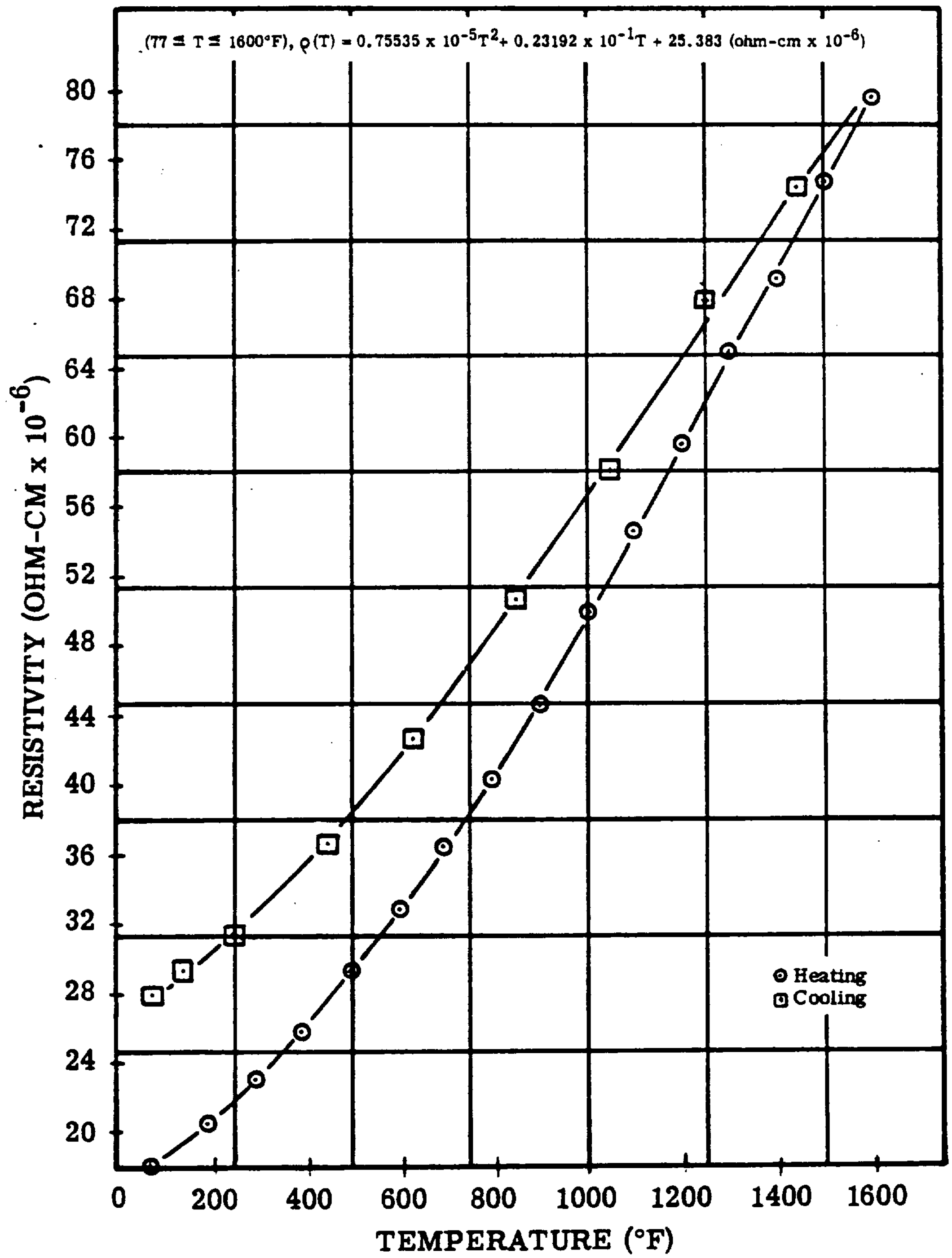


FIGURE IV.G.I-2. Electrical Resistivity of Nivco Ribbon in Vacuum, Specimen No. 1, First Test. See Data Table IV.G.I-1. (Reference: NAS 3-4162)

Figure IV.G.I-2. Resistivity - Nivco

TABLE IV.G.I-2. Electrical Resistivity of Nivco Ribbon in Vacuum

Specimen No. 1, Continuous Heating

Width - 0.247 Inches, Thickness - 0.0255 Inches, Length - 11.54 Inches

Temperature (°F)	Resistance (Ohm)	Resistivity (Microhm-Cm)
77	0.02025	28.07
200	0.02184	30.28
300	0.02370	32.86
406	0.02565	35.56
500	0.02771	38.41
600	0.02989	41.44
700	0.03246	45.00
821	0.03566	49.43
900	0.03792	52.57
1000	0.04080	56.56
1100	0.04381	60.73
1200	0.04660	64.60
1300	0.04895	67.86
1400	0.05293	73.38
1500	0.05575	77.29
1600	0.05832	80.85
1450	0.05360	74.31
1234	0.04900	67.93
1050	0.04262	59.09
850	0.03681	51.03
650	0.03155	43.74
450	0.02704	37.49
250	0.02319	32.15
150	0.02141	29.68
75	0.02031	28.16

NOTE: The above data are plotted in Figure IV.G.I-3

(Reference: NAS 3-4162)

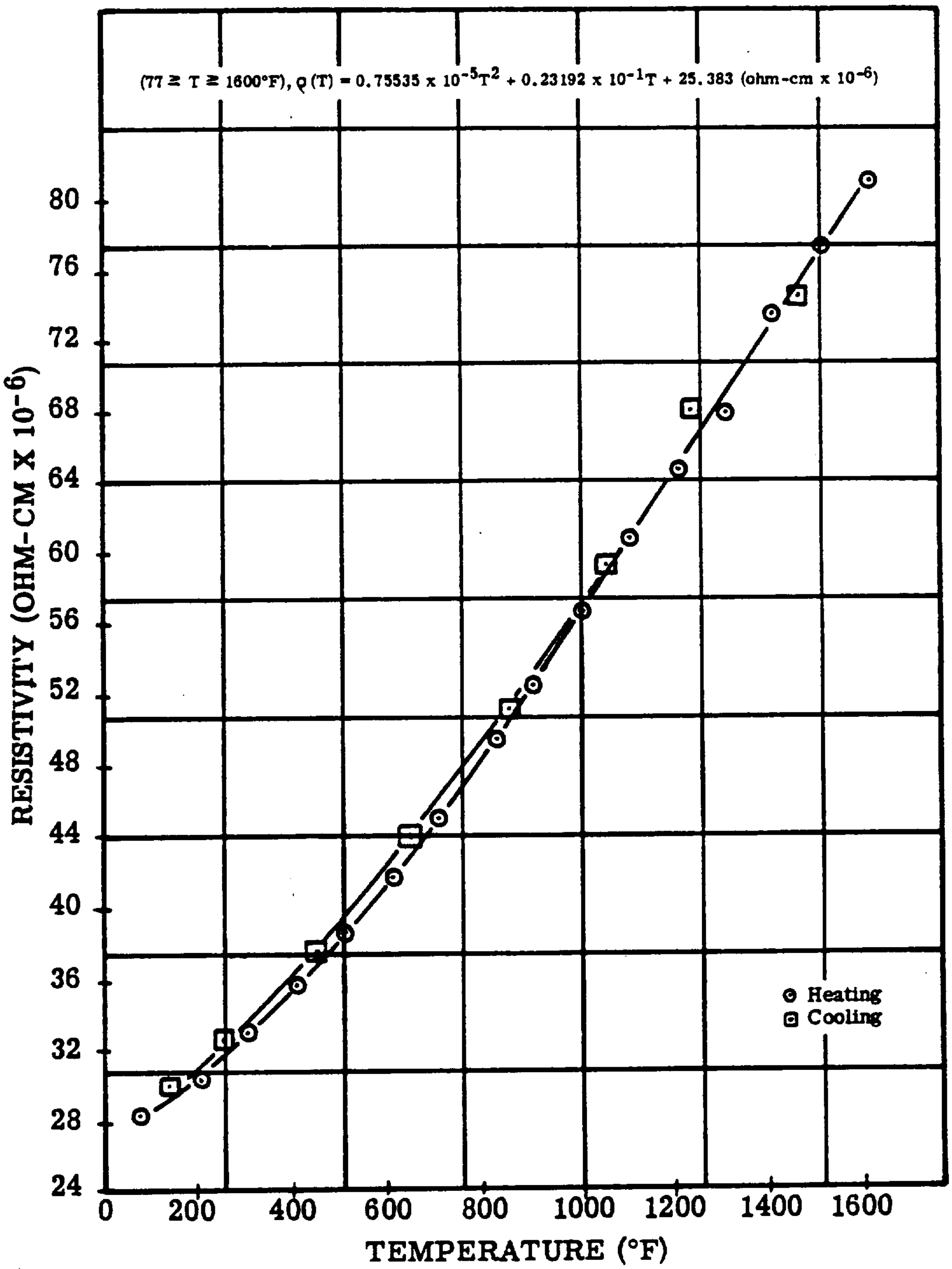


FIGURE IV.G.I-3. Electrical Resistivity of Nivco Ribbon in Vacuum, Specimen No. 1, Second Test. See Data Table IV.G.I-2. (Reference: NAS 3-4162)

Figure IV.G.I-3. Resistivity - Nivco

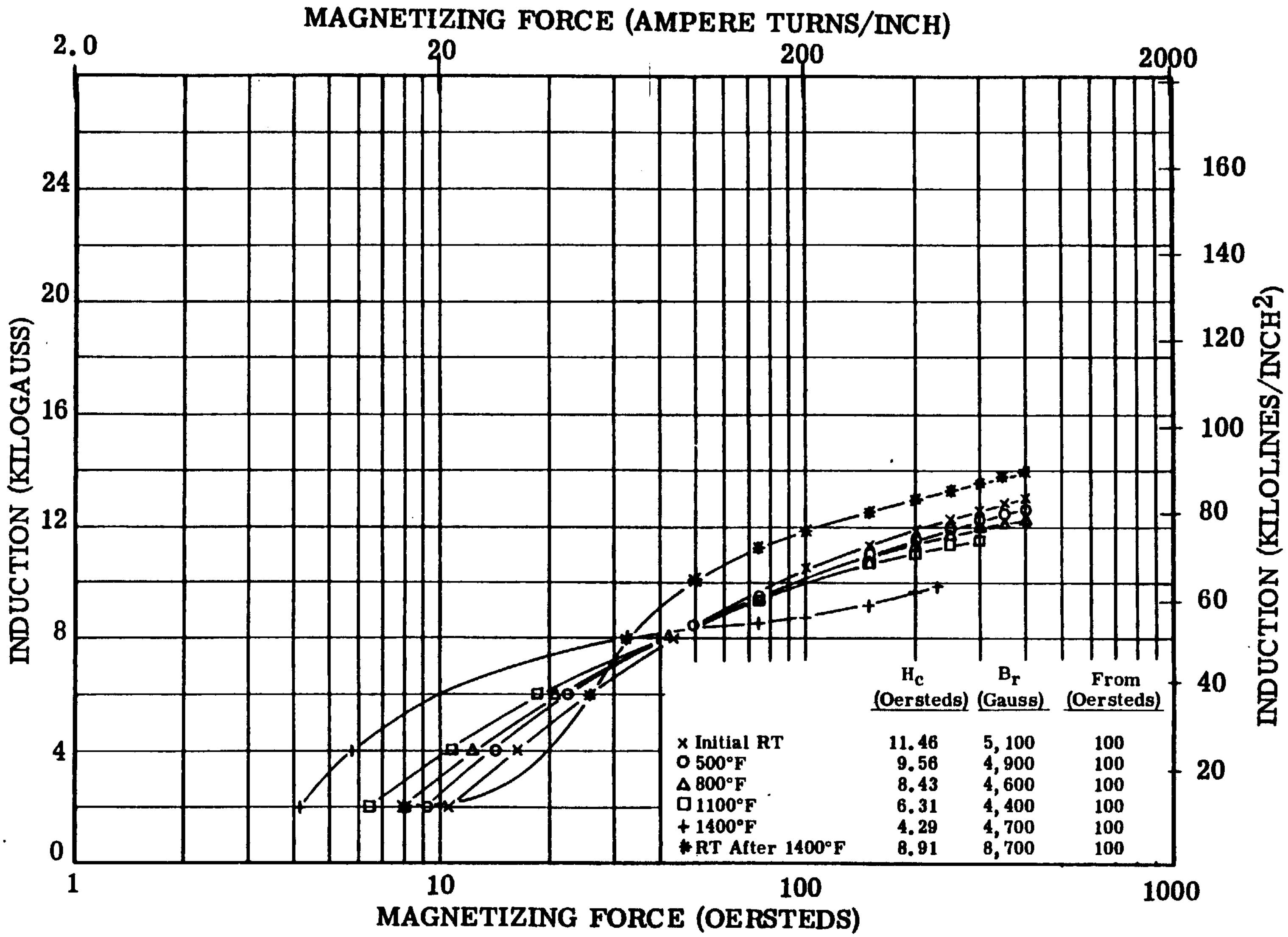


FIGURE IV.G.II-1. D-C Magnetization Curves. Nivco Forging. Test Atmosphere: Air to 800°F, Argon Above 800°F. (Reference: NAS 3-4162)

Figure IV.G.II-1. D-C Magnetization - Nivco

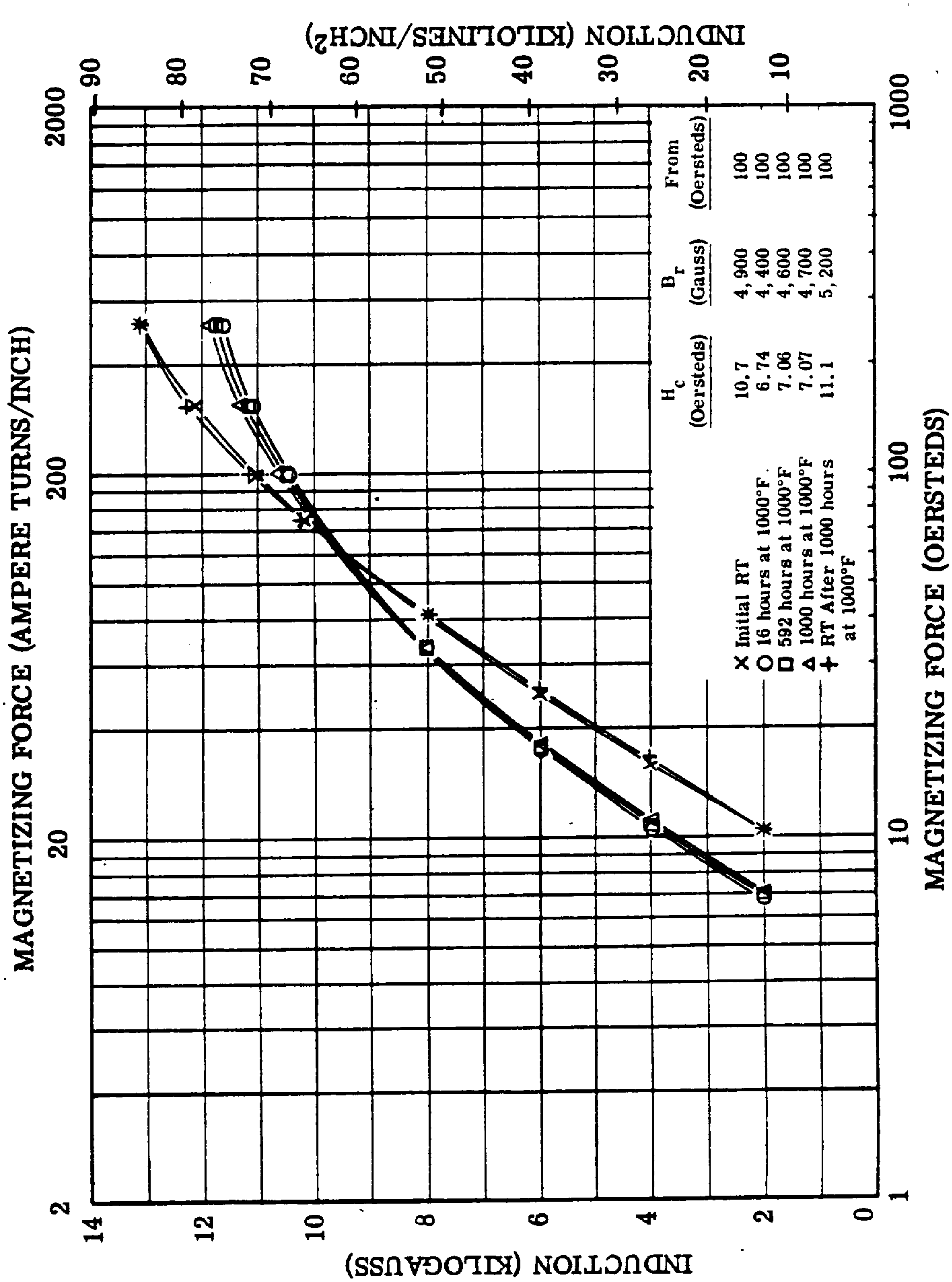


FIGURE IV.G.II-2. D-C Magnetization Curves. Nivco Forging - Aging Test. Test Atmosphere: Argon. (Reference: NAS 3-4162)

Figure IV.G.II-2. D-C Magnetization - Nivco

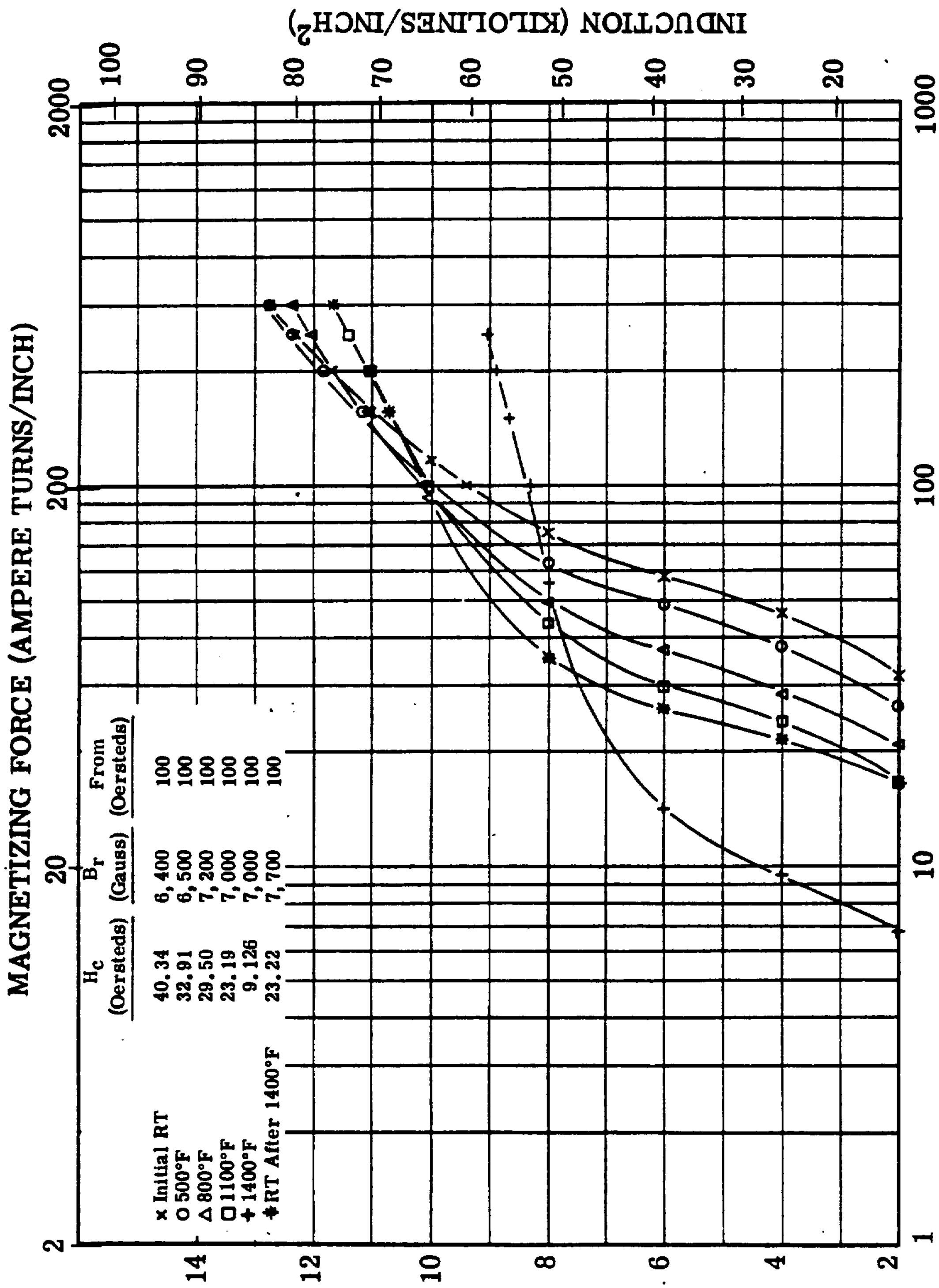


FIGURE IV.G.II-3. D-C Magnetization Curves. Nivco Alloy 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.G.II-3. D-C Magnetization - Nivco

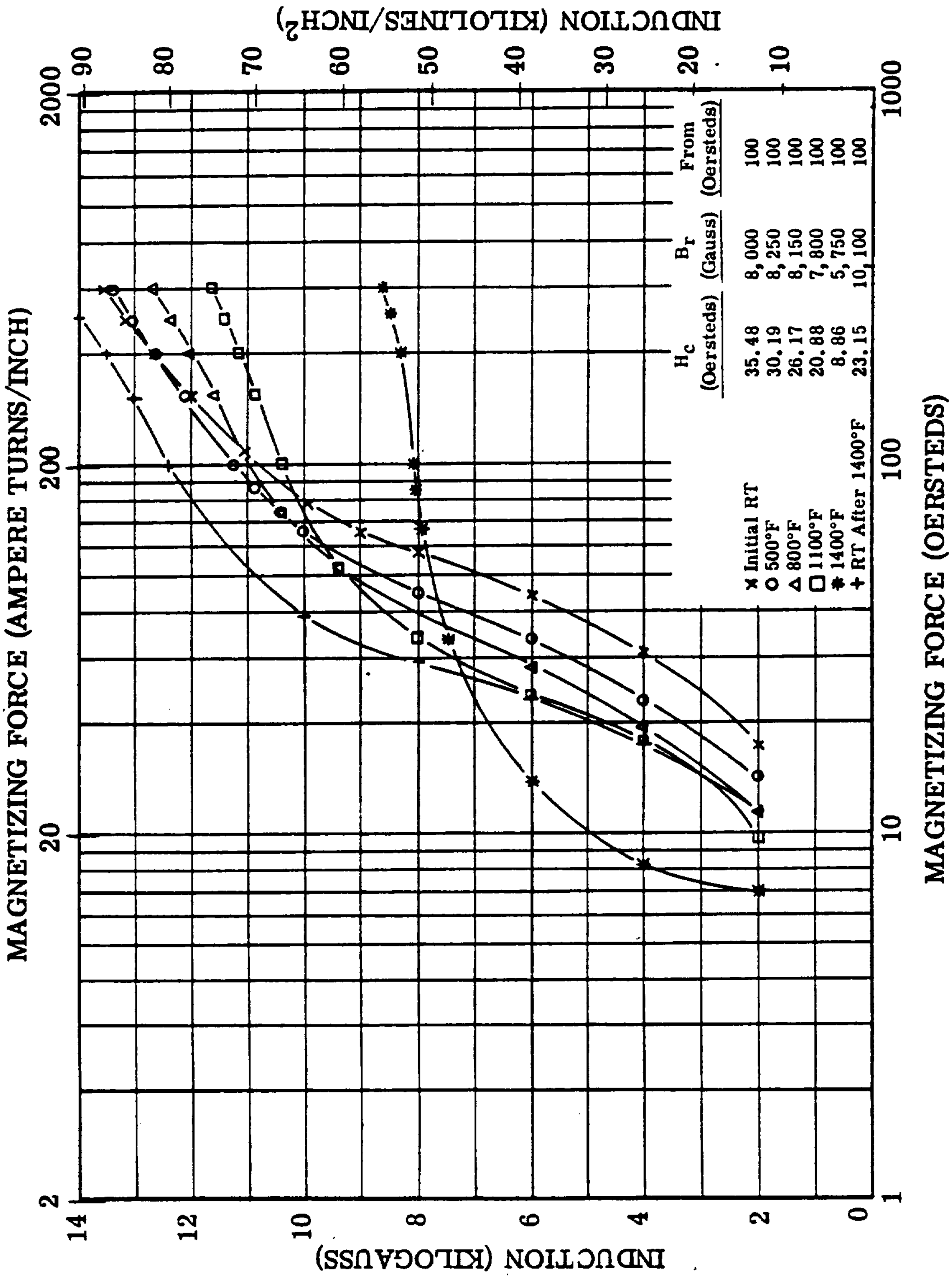


FIGURE IV.G.II-4. D-C Magnetization Curves. Nivco Alloy 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.G.II-4. D-C Magnetization - Nivco

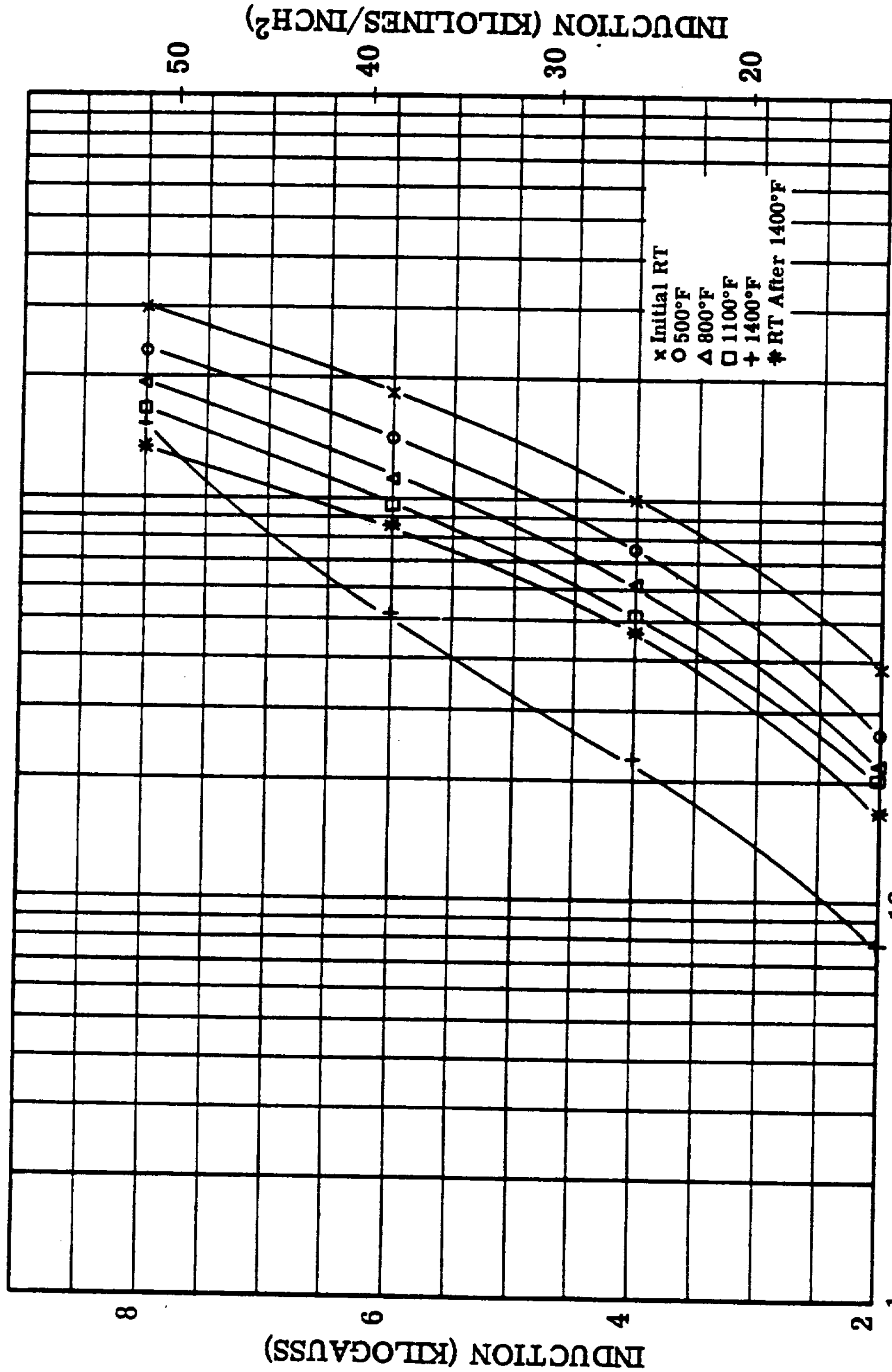


FIGURE IV.G.II-5. Exciting Volt-Amperes per Pound, 400 CPS. Nivco Alloy 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS3-4162)

Figure IV.G.II-5. Exciting VA, 400 CPS. Nivco

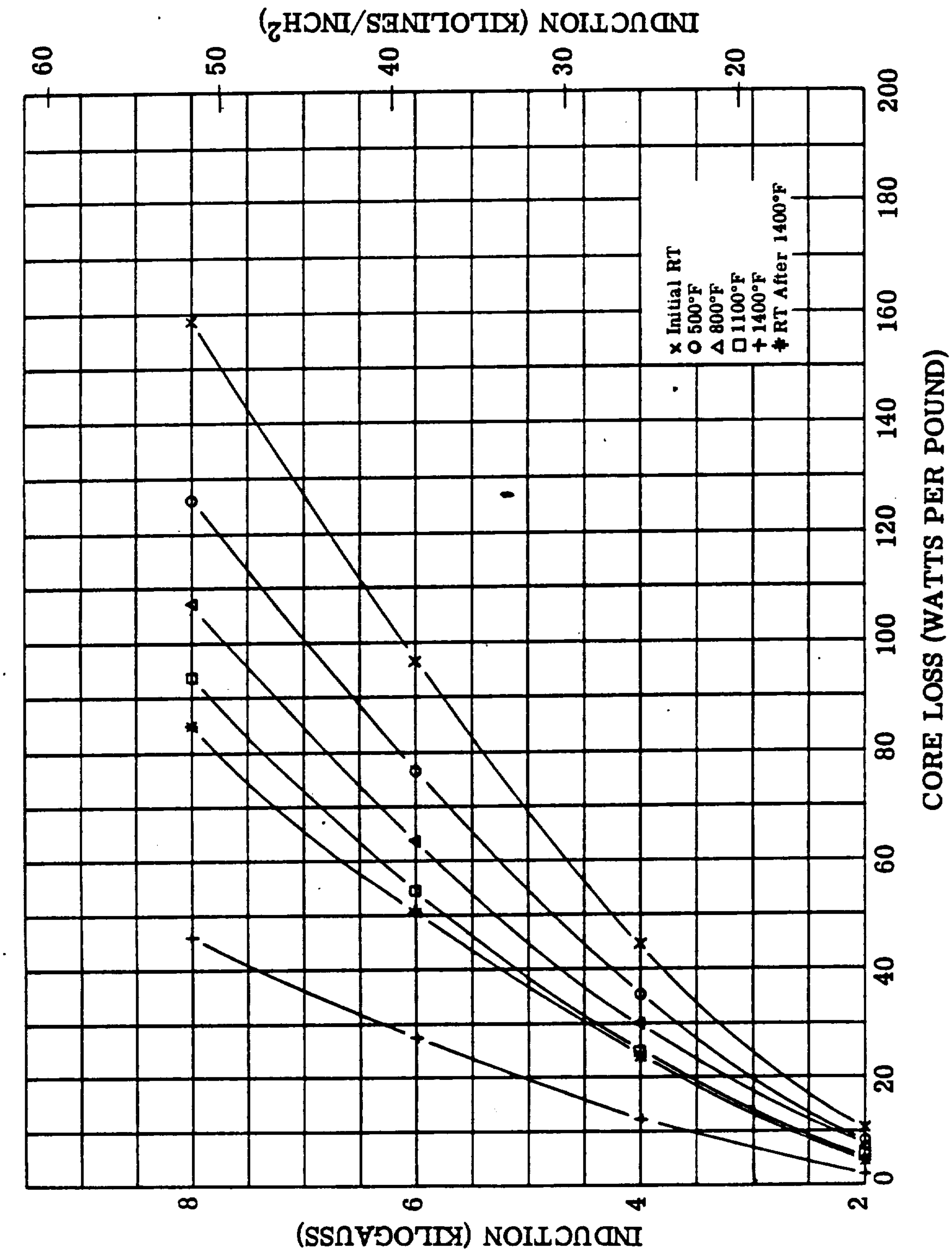


FIGURE IV.G.II-6. Core Loss, 400 CPS. Nivco Alloy 0.014 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.G.II-6. Core Loss, 400 CPS. Nivco

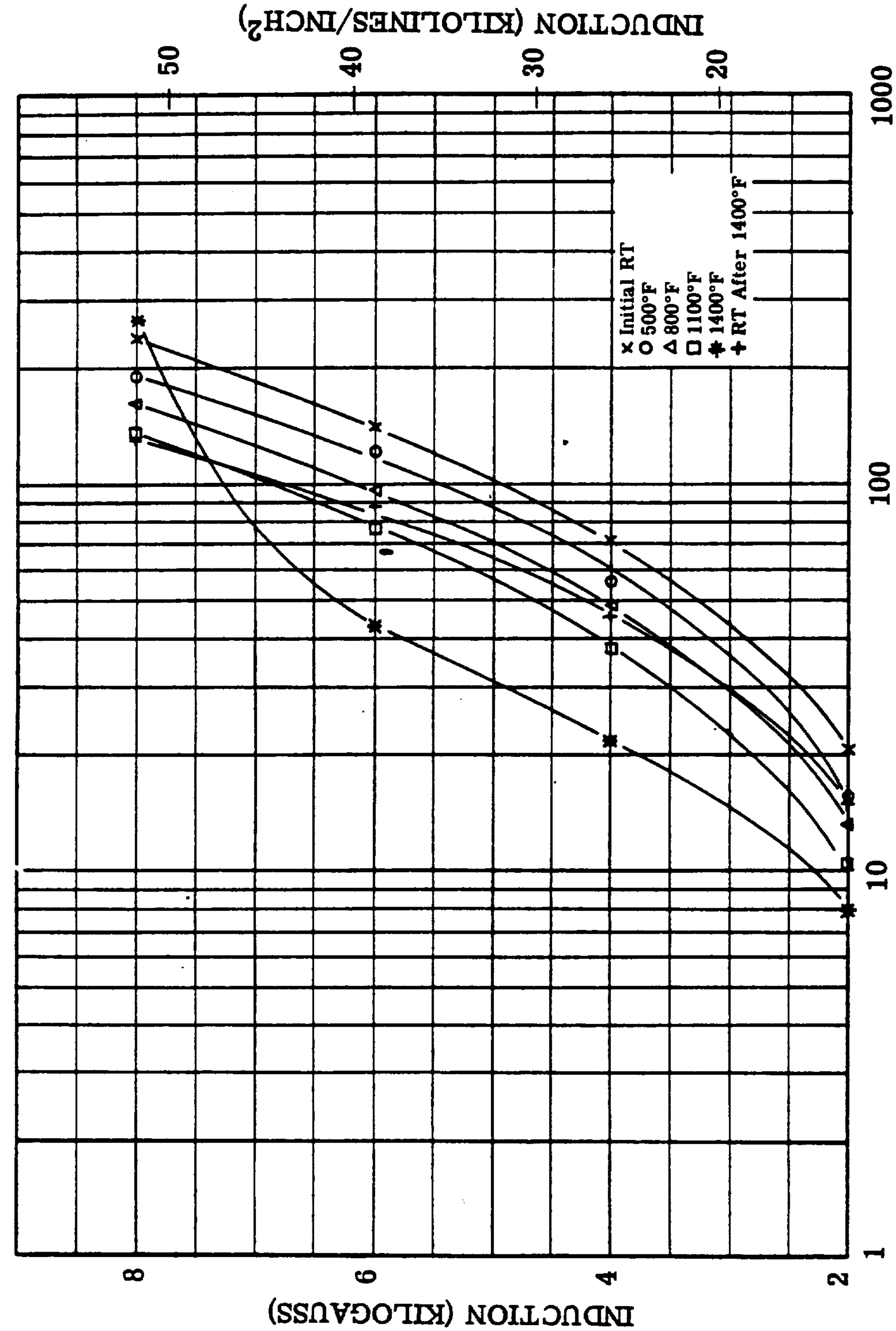


FIGURE IV.G.II-7. Exciting Volt-Amperes per Pound, 400 CPS. Nivco Alloy 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.G.II-7. Exciting VA, 400 CPS. Nivco

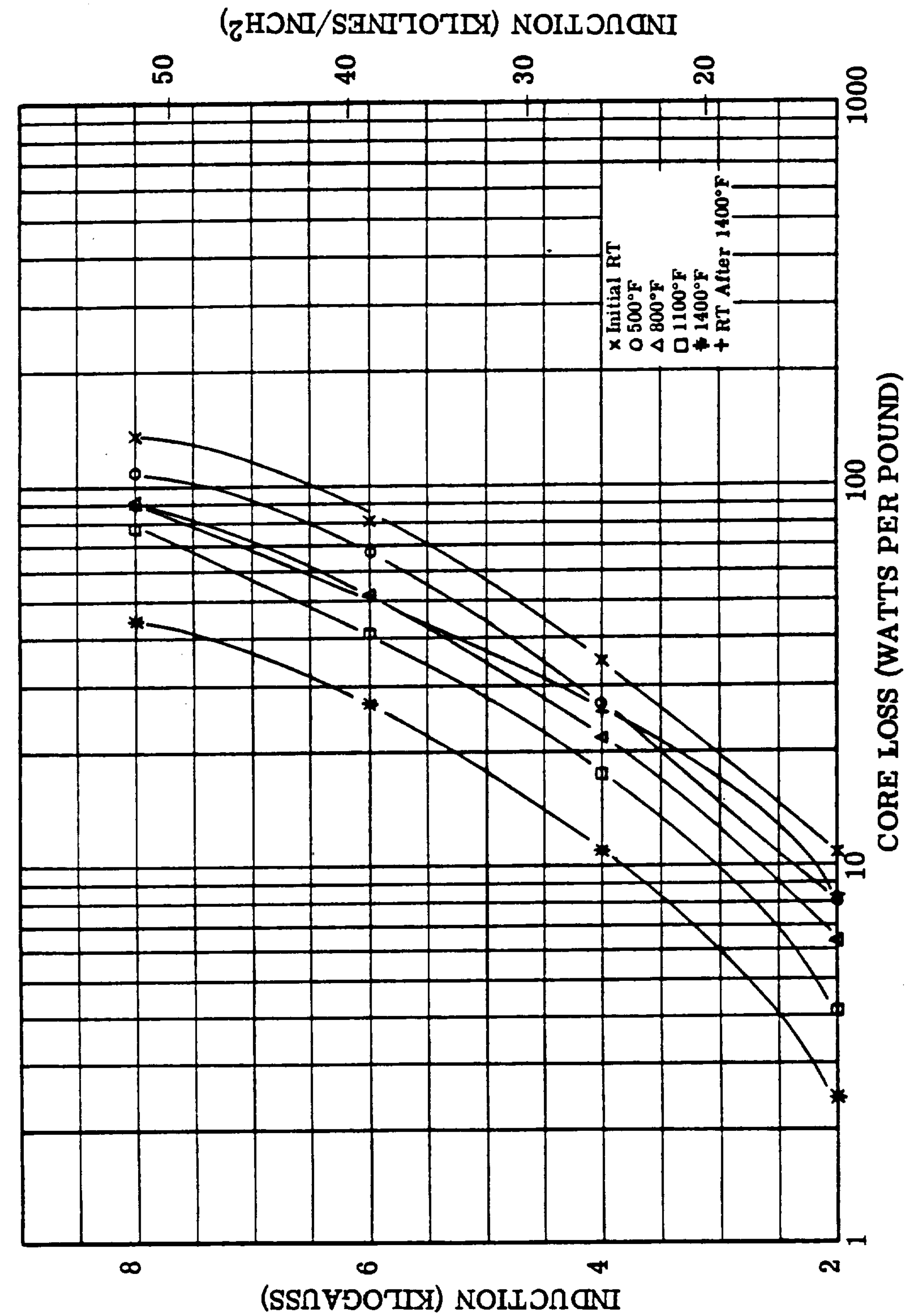


FIGURE IV.G.II-8. Core Loss, 400 CPS. Nivco Alloy 0.025 Inch Laminations. Test Atmosphere: Air to 800°F, Argon above 800°F. Interlaminar Insulation: Aluminum Orthophosphate. (Reference: NAS 3-4162)

Figure IV.G.II-8. Core Loss, 400 CPS. Nivco

TABLE IV.G.III-1. Tensile Test Data for Nivco Forging

TEST: ASTM E21 - Strain Rate: 0.005 in/in-min to yield; 0.050 in/in-min to failure

Spec. No.	Dia. (In.)	Hardness BHN (3000 KG)	Test Temp. (°F)	0.02 Percent Offset Yield Str. (Psi)	0.2 Percent Offset Yield Str. (Psi)	Ultimate Strength (Psi)	Elongation 1.4 inches (percent)	Reduction of Area (percent)
5	0.357	316	R. T.	104,700	112,400	166,350	31.3	44.9
6	0.357	316	R. T.	99,900	112,400	164,350	30.1	42.4
1	0.358	336	900	83,150	91,750	136,300	21.4	43.6
7	0.357	302	900	66,950	86,600	131,350	20.7	43.7
2	0.358	331	1100	84,500	94,150	127,850	24.6	45.2
8	0.358	316	1100	69,500	85,650	121,400	24.0	48.9
3	0.358	321	1400	22,600	29,000	43,700	47.9Q	73.9
9	0.357	321	1400	40,350	43,550	54,650	37.4	68.9
4	0.358	326	1600	12,950	15,750	20,800	57.6	94.3
10	0.357	321	1600	12,400	16,200	23,150	90.2	93.9

Q - Quarterbreak

All tests made in air.

(Reference: NAS3-4162)

Figure IV.G.III-1. Tensile - Forged Nivco

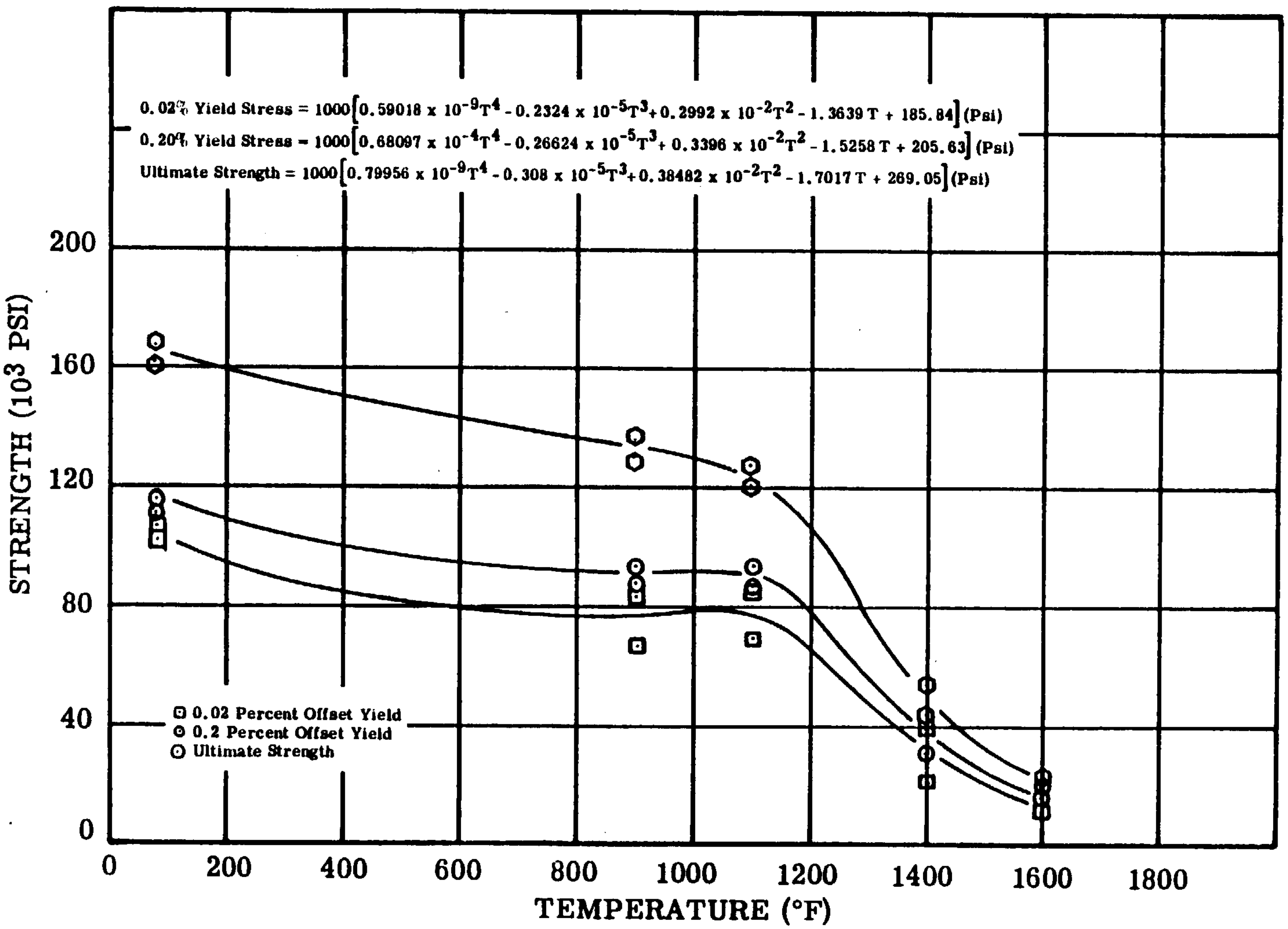


FIGURE IV.G.III-1. Effect of Temperature on Tensile Properties of Nivco Forging. Tests Made in Air. See Data Table IV.G.III-1. (Reference: NAS 3-4162)

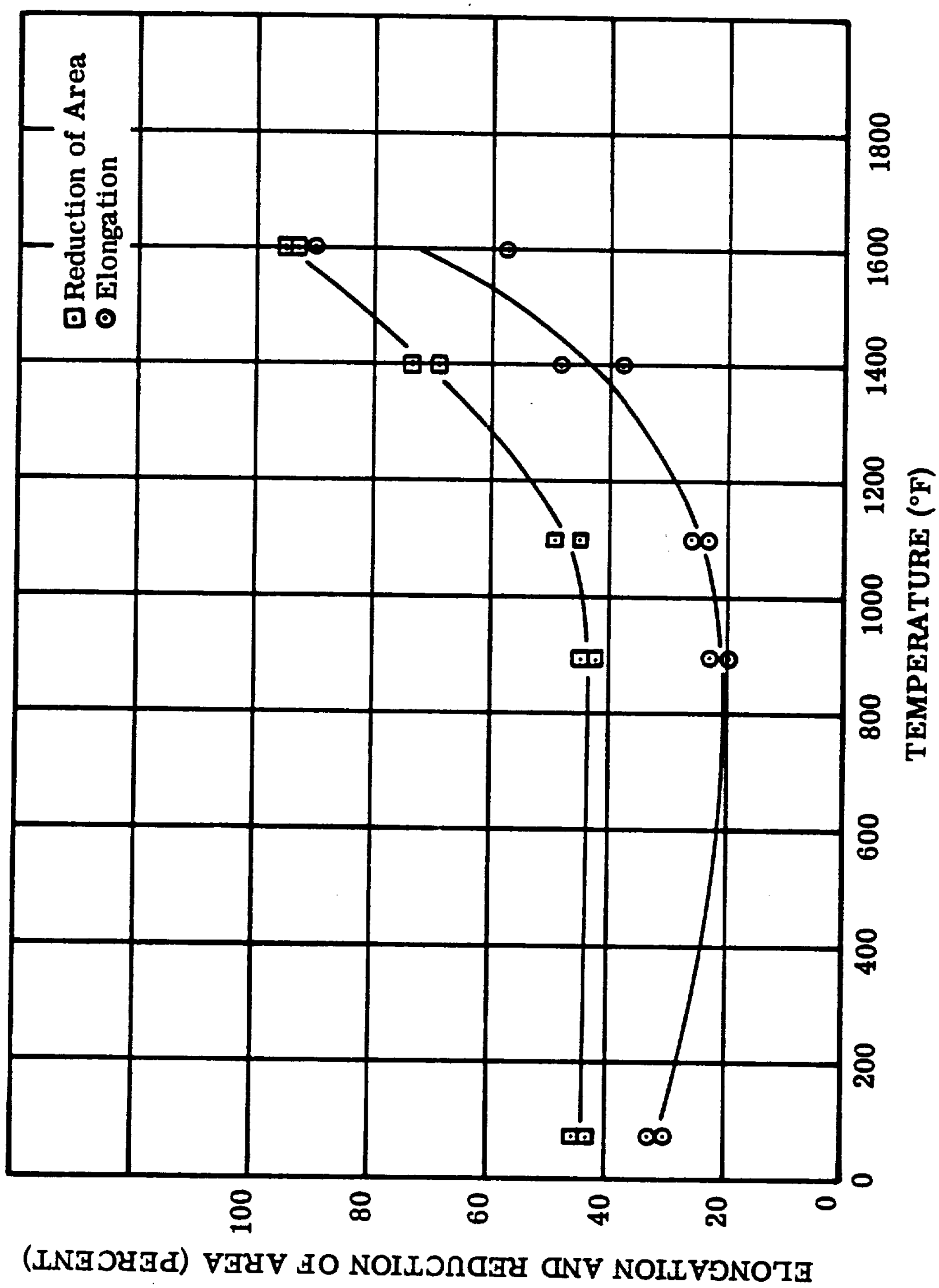


FIGURE IV. G. III-2. Effect of Temperature on Tensile Properties of Nivco Forging. Tests Made in Air. See Data Table IV. G. III-1. (Reference: NAS 3-4162)

Figure IV. G. III-2. Elongation and Reduction of Area - Forged Nivco

TABLE IV.G.III-2. Tensile Test Data for Nivco 0.025 Inch Transverse Sheet Material

TEST: ASTM E21 - Strain Rate: 0.005 in/in-min to yield; 0.050 in/in-min to failure

Mark	Test Temp. (°F)	0.02 Percent Offset Yield Stress (Psi)	0.2 Percent Offset Yield Stress (Psi)	Ultimate Strength (Psi)	Elongation in 2 Inches (percent)
26 T	80	103200	151900	A	A
4 T	80	155300	171900	180950	2.7
30 T	900	73700	109750	126450	12.2
31 T	900	71900	105950	125300	9.8 Q
32 T	1100	54100	79100	101200	10.1
33 T	1100	B	B	107550	13.2
27 T	1400	23250	34950	44150	25.0 Q
34 T	1400	25400	35350	43550	35.0
35 T	1600	10000	13950	20000	52.4
36 T	1600	9450	14100	19950	64.1

A = Broke in grips.
B = Curve unreliable. Extensometer slipped on specimen.
Q = Quarterbreak.

All tests made in air.

(Reference: NAS3-4162)

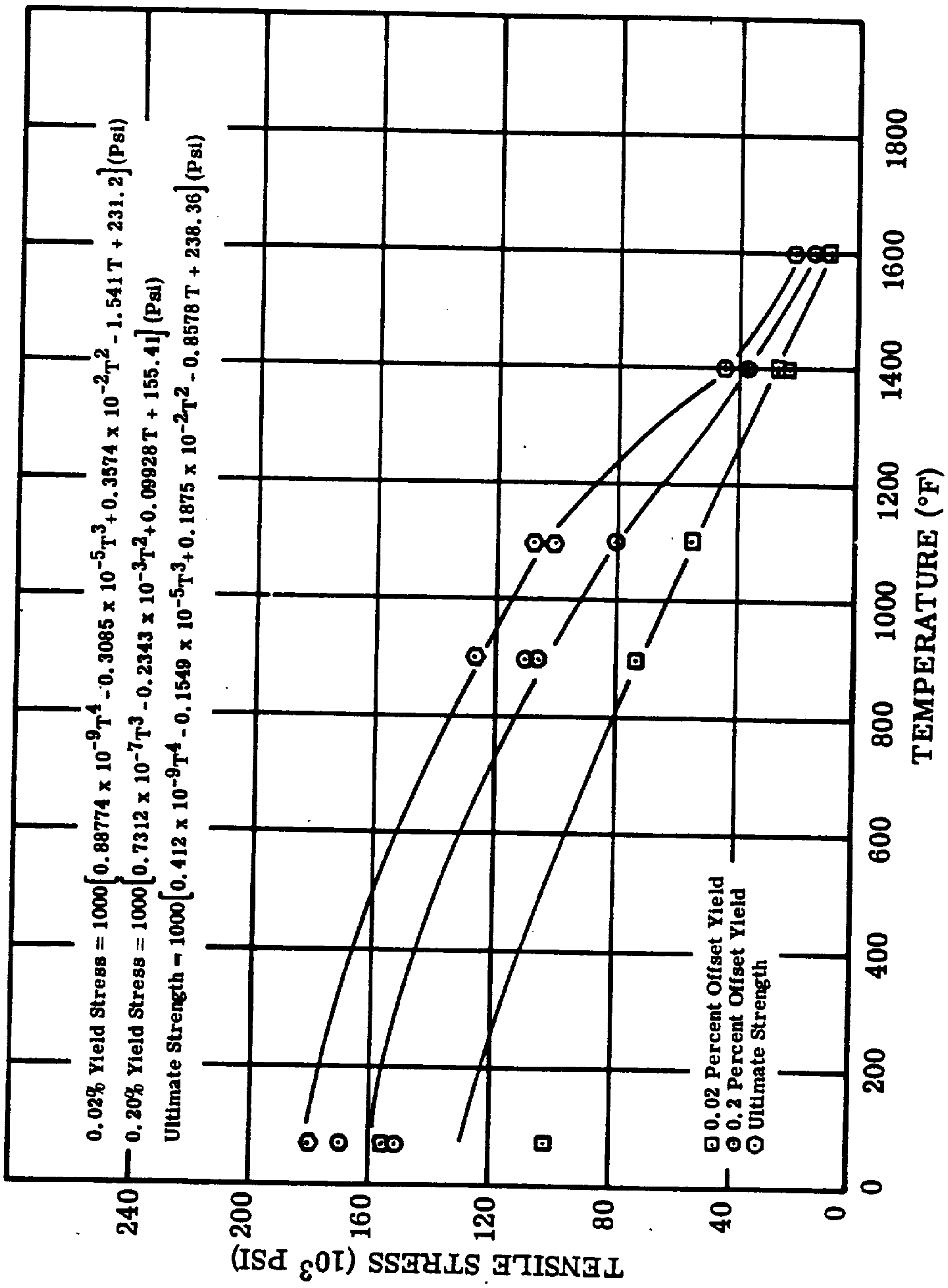


FIGURE IV.G.III-3. Effect of Temperature on Tensile Properties of 0.025 Inch Nivco Transverse Sheet. Tests Made in Air. See Data Table IV.G.III-2. (Reference: NAS 3-4162)

Figure IV.G.III-3. Tensile - Transverse Nivco Sheet

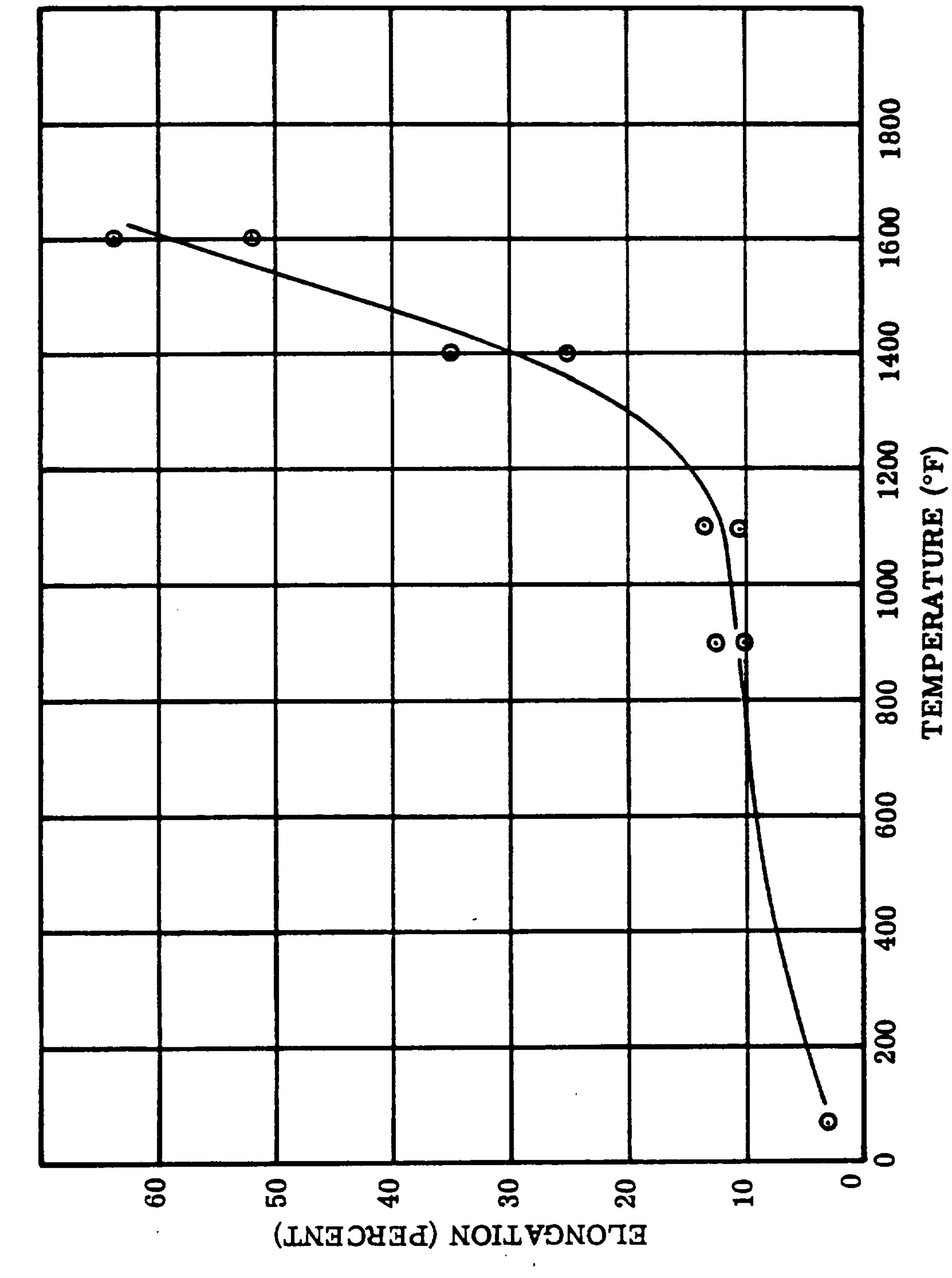


FIGURE IV.G.III-4. Effect of Temperature on Tensile Properties of 0.025 Inch Nivco Transverse Sheet. Tests Made in Air. See Data Table IV.G.III-2. (Reference: NAS 3-4162)

Figure IV.G.III-4. Elongation - Transverse Nivco Sheet

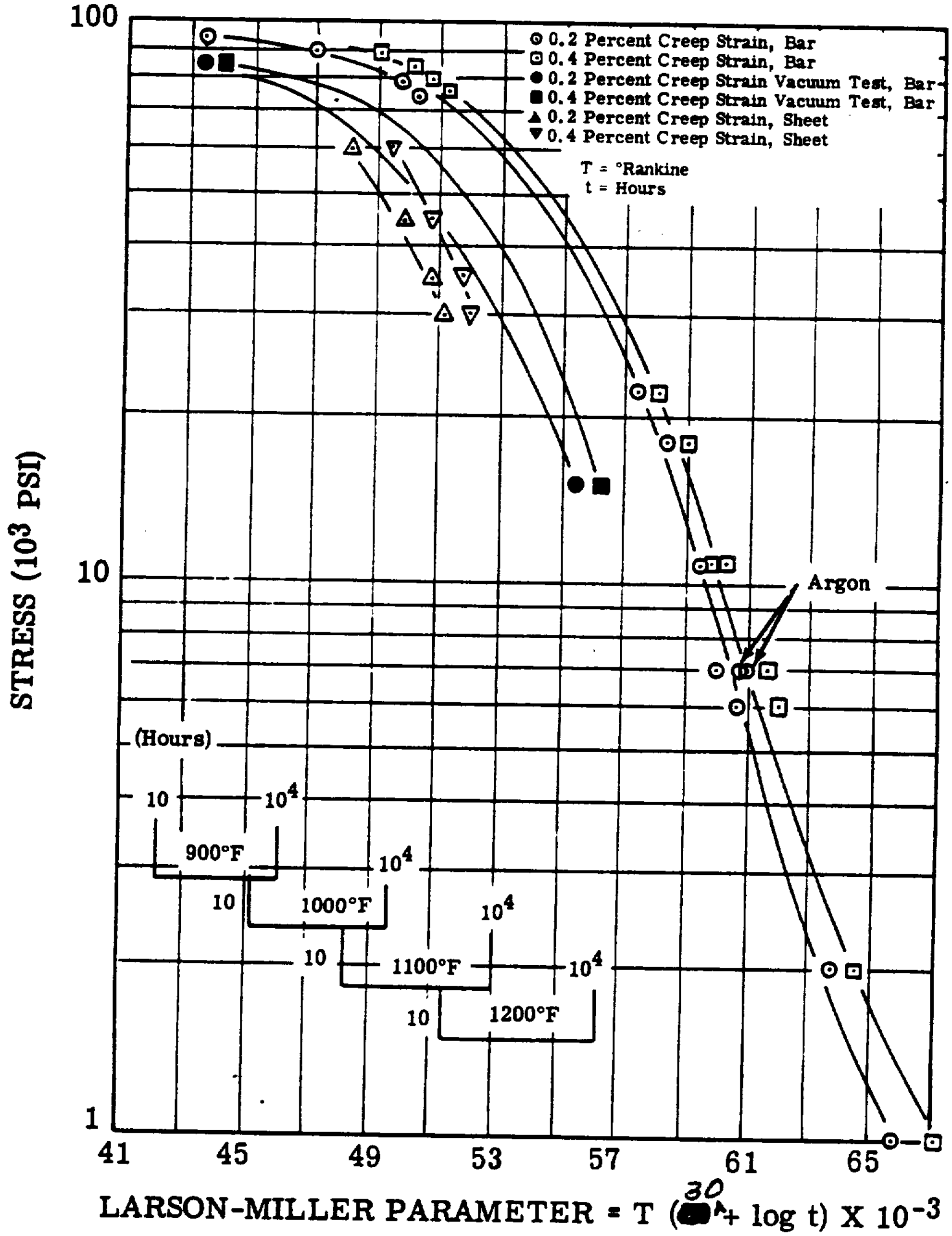


FIGURE IV.G.III-5. Larson-Miller Plot of Forged Nivco Bar and Nivco Sheet Creep Data Based on a Maximum of 2000 Hour Data. Test Points Represent Material Tested in Air, Argon and Vacuum. (Reference: NAS 3-4162)

Figure IV.G.III-5. Creep - Larson-Miller Plot - Nivco

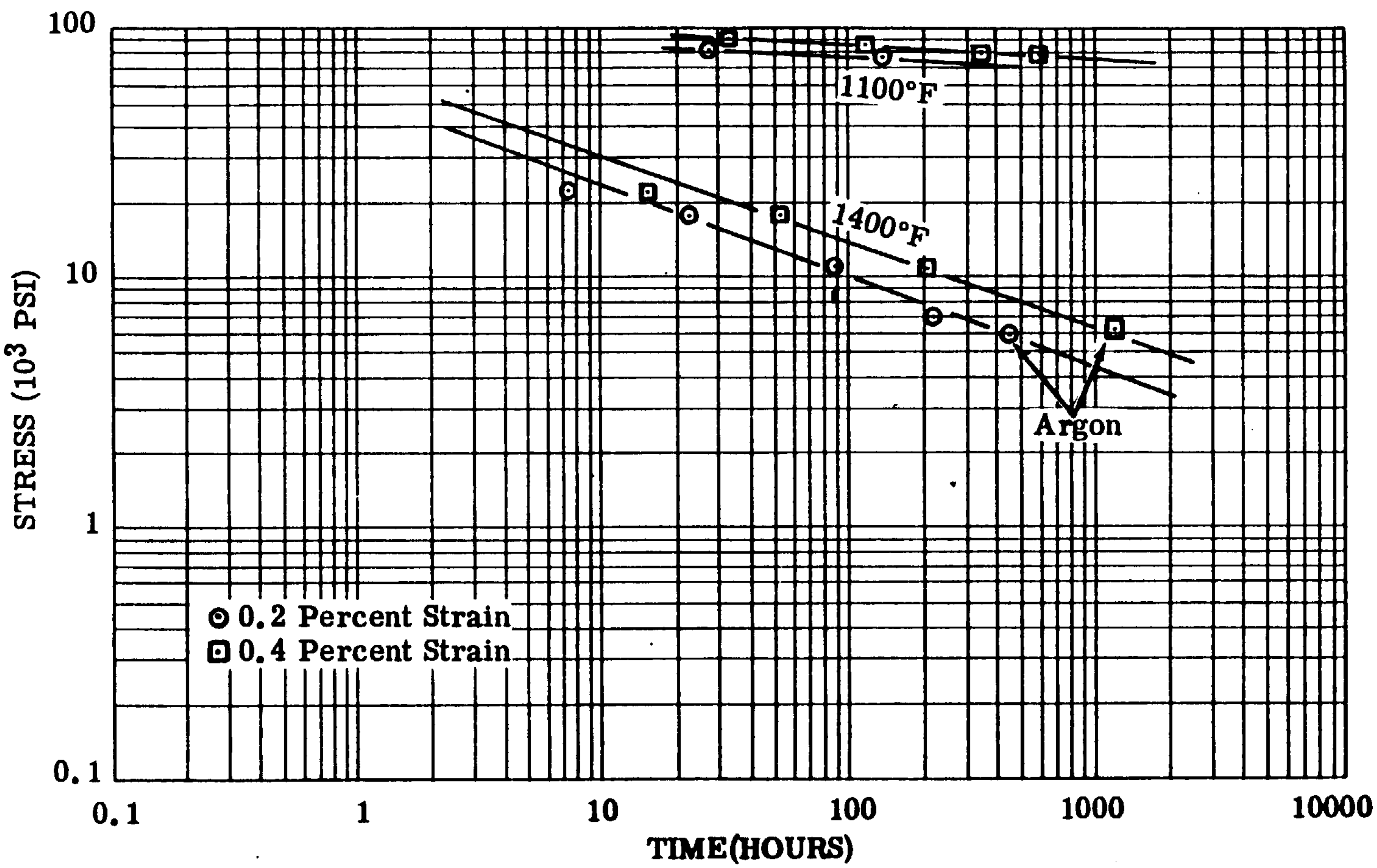


FIGURE IV.G.III-6. Stress Versus Time to Reach Indicated Creep Strain for Forged Nivco Bar, Tested at 1100°F and 1400°F in Air and Argon. (Reference NAS 3-4162)

Figure IV.G.III-6. Creep - Nivco Bar

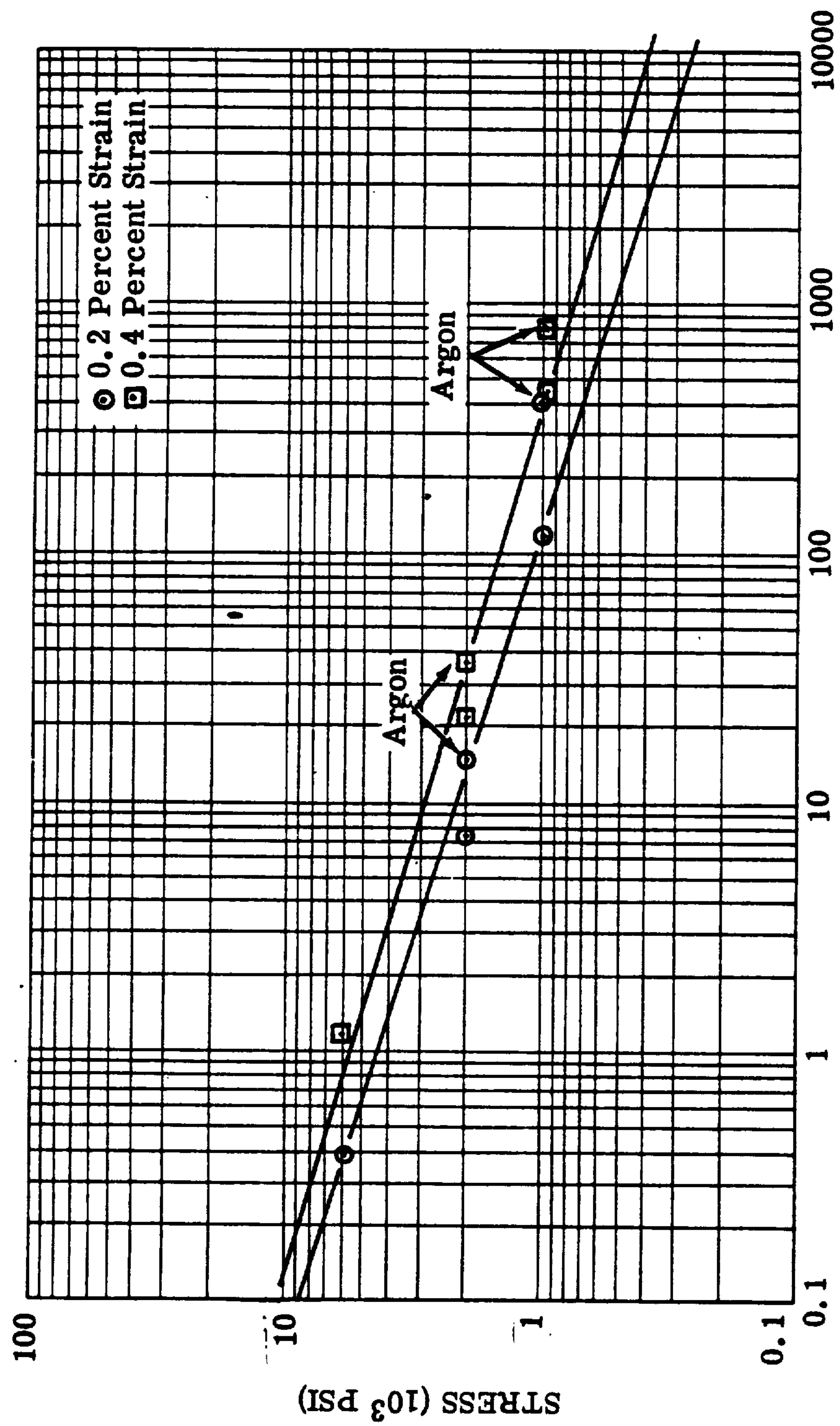


FIGURE IV.G.III-7. Stress Versus Time to Reach Indicated Creep Strain for Forged Nivco Bar Tested at 1600°F in Air and Argon. (Reference: NAS 3-4162)

Figure IV.G.III-7. Creep - Nivco Bar

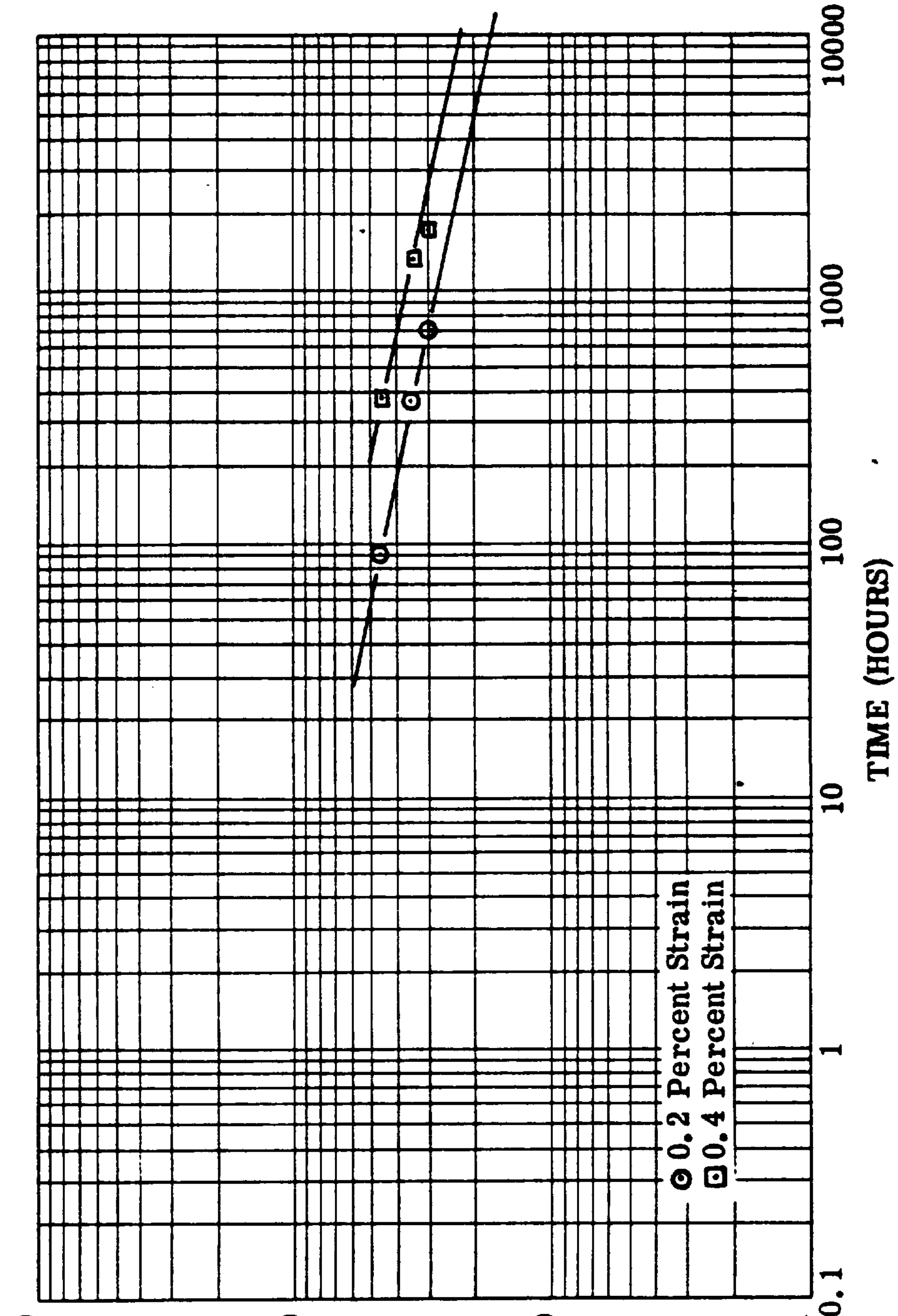


FIGURE IV.G.III-8. Stress Versus Time to Reach Indicated Creep Strain for Nivco Sheet Tested at 1100°F in Air. (Reference: NAS 3-4162)

Figure IV.G.III-8. Creep - Nivco Sheet

TABLE IV.G.III-3. Creep Data for Forged Nivco Bar

See Figures IV.G.III-9 to IV.G.III-14

TEST: ASTM E139

Temperature	900	900	900*	900	900*	1100	1100*	1100	1000	1100	1100
Stress (psi)	95,000	80,000	100,000	90,000	104,500	65,000	88,000	78,000	85,000	80,000	90,000
Duration of Test (hours)	1,204	692	1,202	789	1,149	674	305	713	773.7	526	70.9**
Total Creep Strain (percent)	0.263	0.013	0.209	0.111	0.502	0.108	0.667	0.459	2.710	0.518	0.9756
Time to Cause 0.2 percent Creep Strain (hours)	96	-	325	-	0	-	39	149	27	69	1.3
Time to Cause 0.4 percent Creep Strain (hours)	-	-	-	-	4	-	162	594	120	350	32.2
Plastic Strain obtained on loading specimen (percent)	0.118	0	0	0.0368	0.333	0	0.0436	0	0.0102	0	0.0588
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.G.III→	9	10	10	11	11	12	12	13	13	13	14

-Did not reach required strain
*Stress raised on previous specimen
**Notch failure

(Reference: NAS 3-4162)

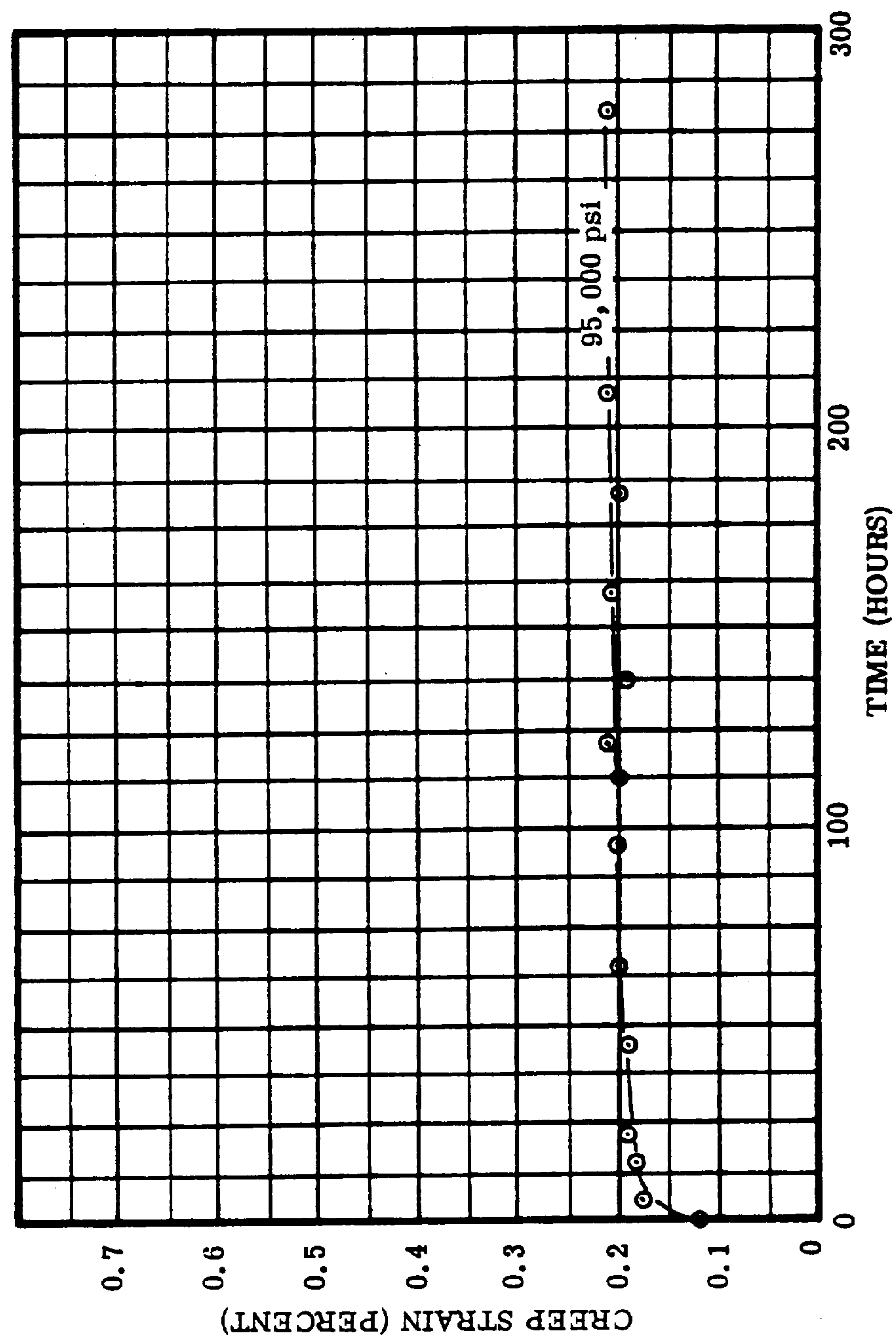


FIGURE IV.G.III-9. Creep, Forged Nivco Bar Tested at 900°F in Air. See Data Table IV.G.III-3. (Reference: NAS3-4162)

Figure IV.G.III-9. Creep - Nivco Bar

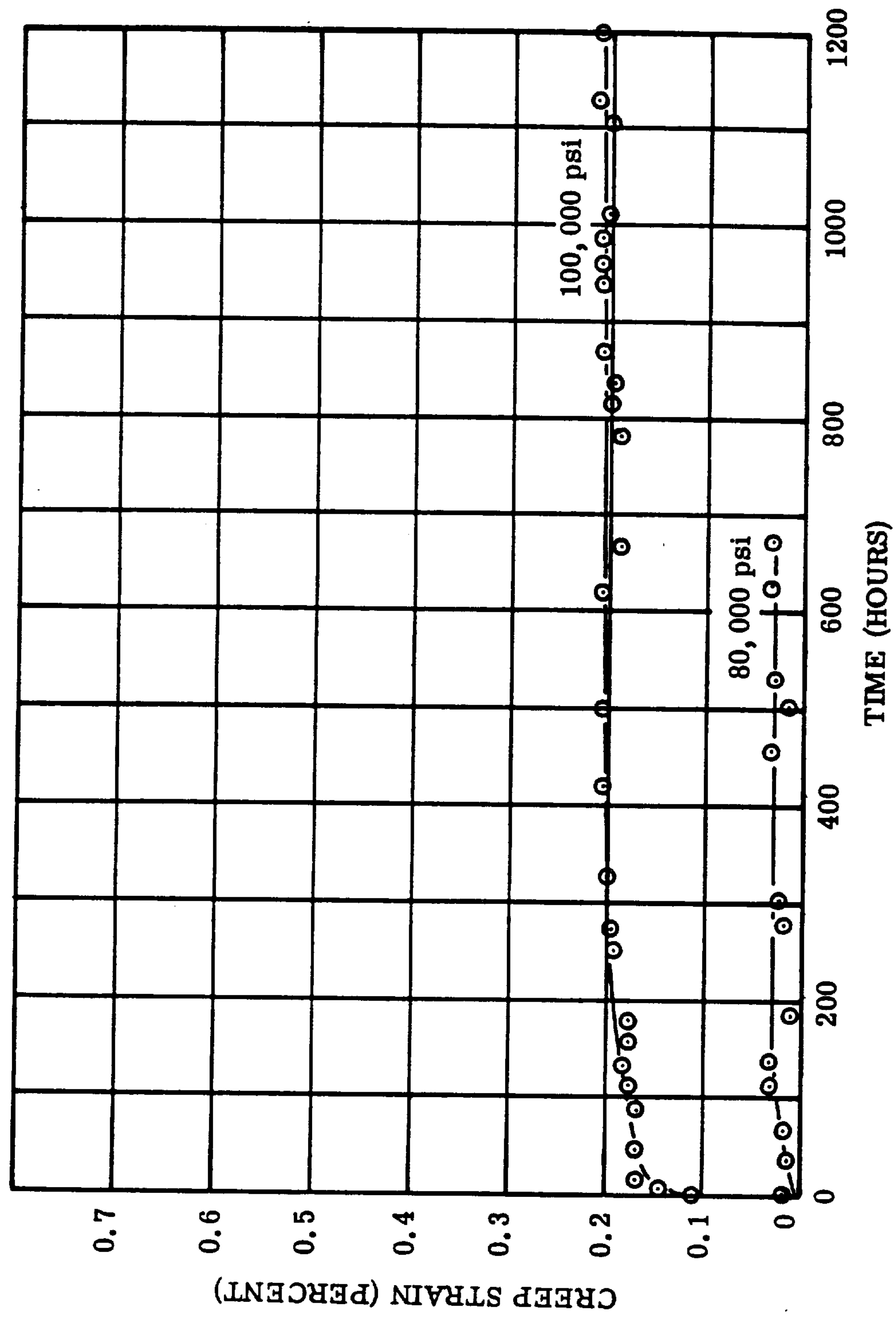


FIGURE IV.G.III-10. Creep, Forged Nivco Bar Tested at 900°F in Air. See Data Table IV.G.III-3. (Reference: NAS 3-4162)

Figure IV.G.III-10. Creep - Nivco Bar

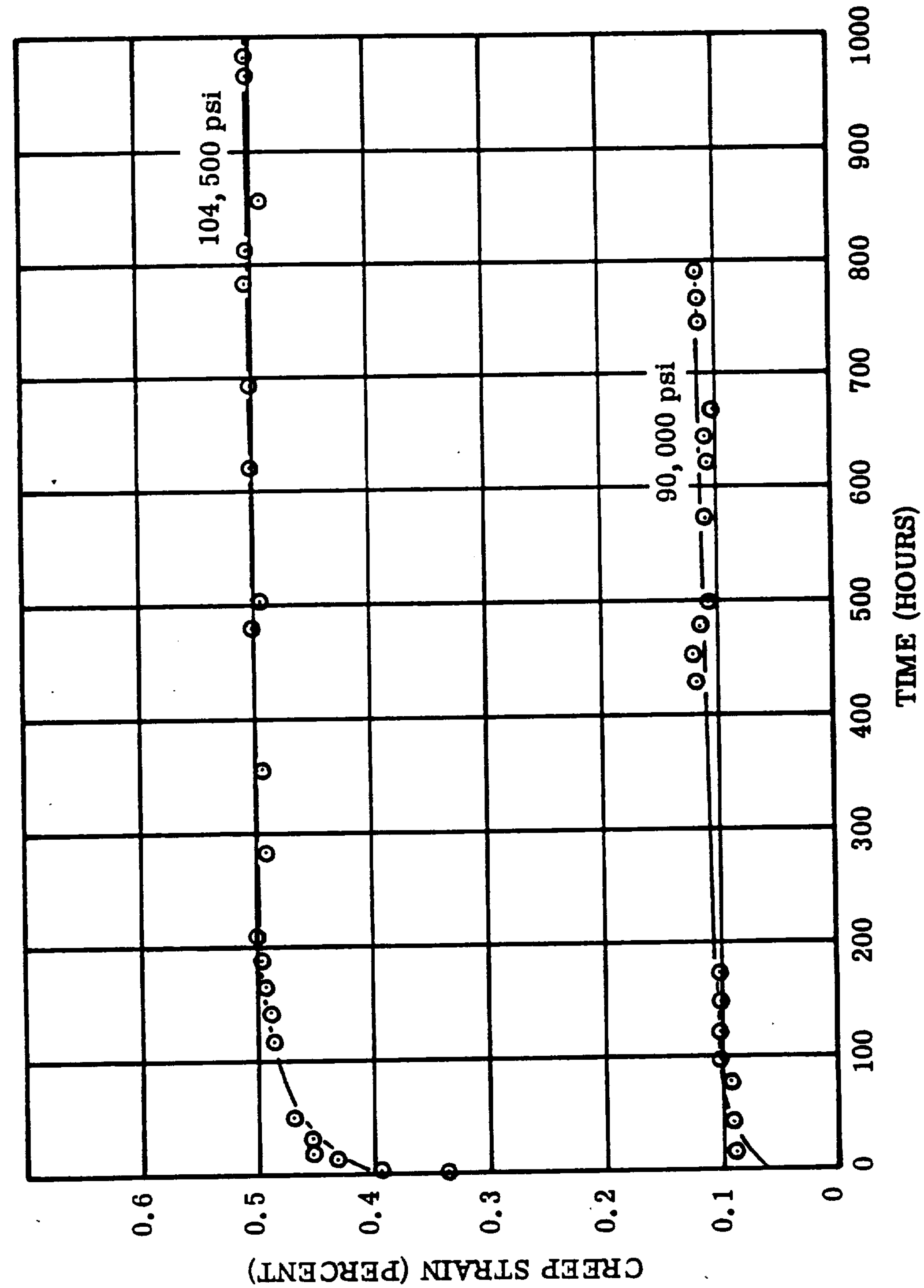


FIGURE IV.G.III-11. Creep, Forged Nivco Bar Tested at 900°F in Air. Data Obtained by Increasing Stress on One Specimen. See Data Table IV.G.III-3. (Reference: NAS3-4162)

Figure IV.G.III-11. Creep - Nivco Bar

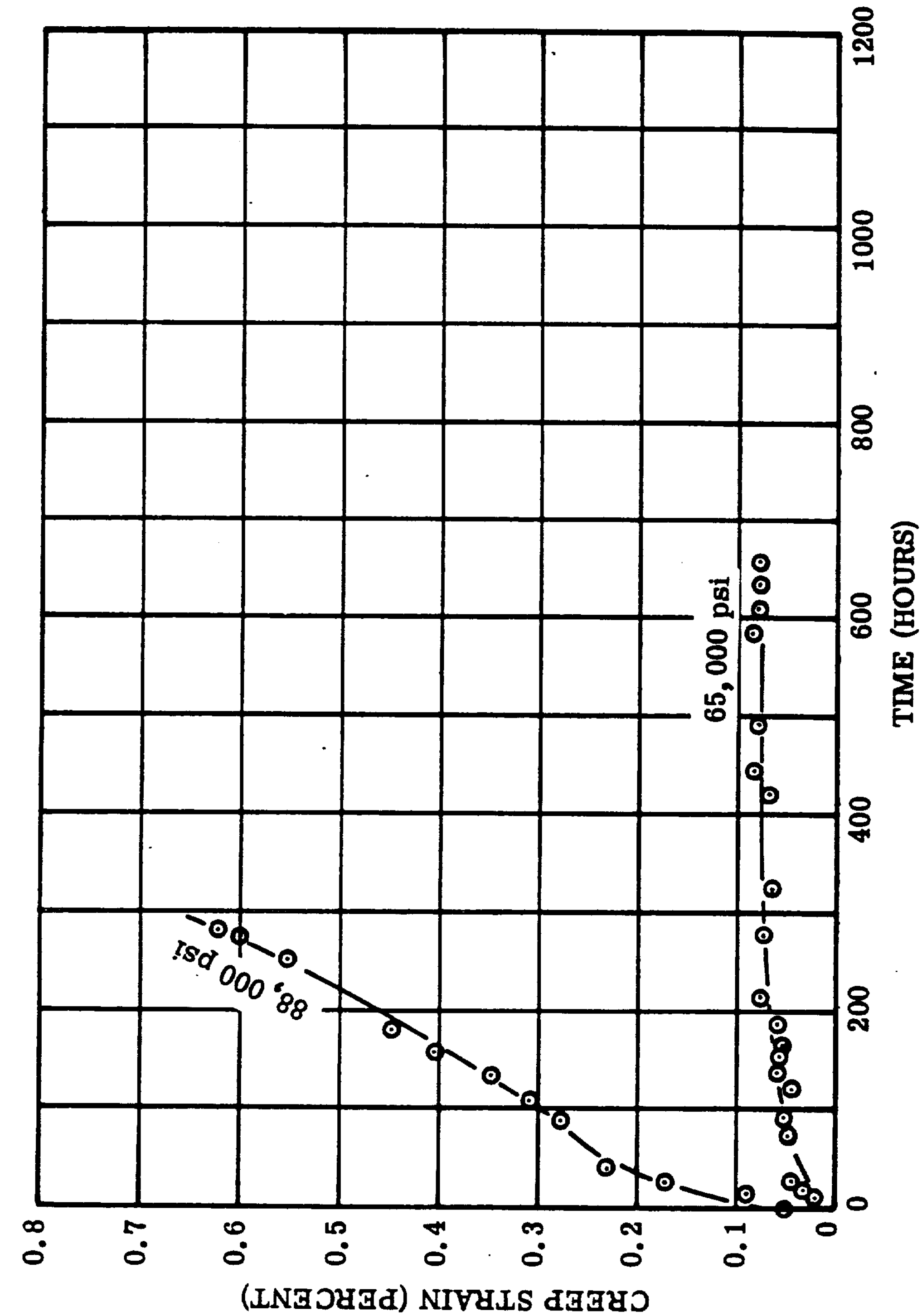


FIGURE IV.G.III-12. Creep, Forged Nivco Bar Tested at 1100°F in Air. Data Obtained by Increasing Stress on a Single Specimen. See Data Table IV.G.III-3. (Reference: NAS 3-4162)

Figure IV.G.III-12. Creep - Nivco Bar

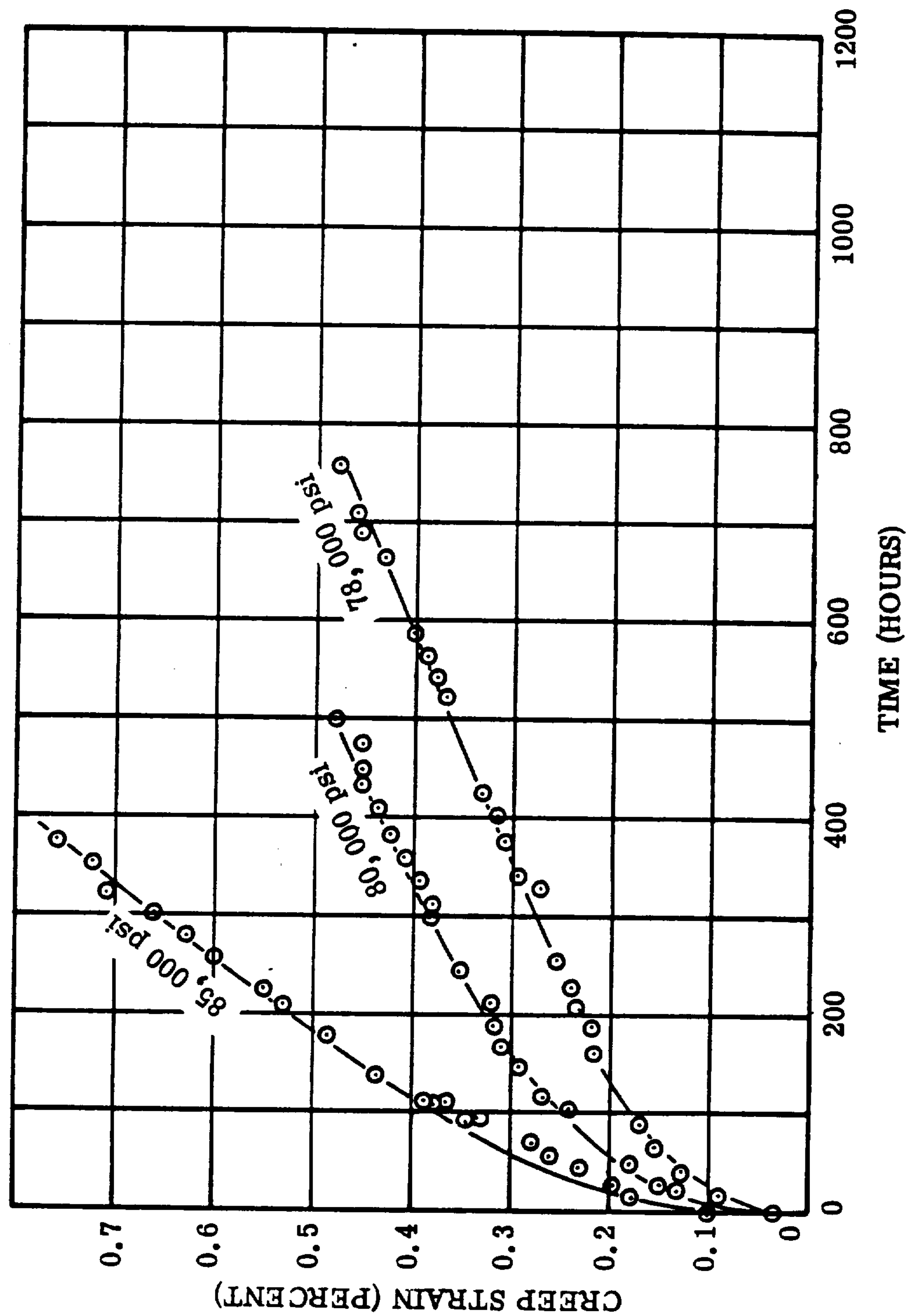


FIGURE IV.G.III-13. Creep, Forged Nivco Bar Tested at 1100°F in Air. See Data Table IV.G.III-3. (Reference: NAS 3-4162)

Figure IV.G.III-13. Creep - Nivco Bar

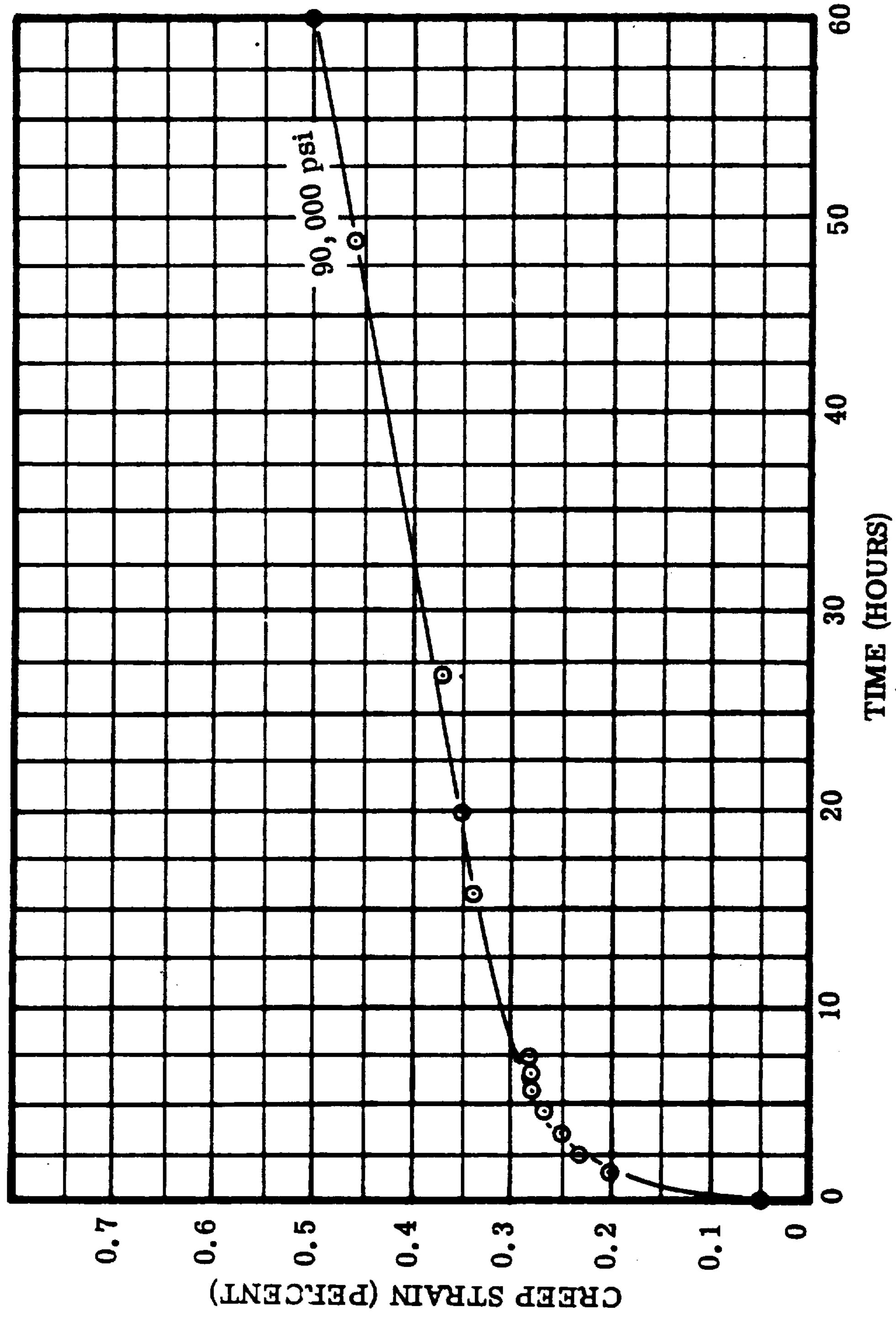


FIGURE IV.G.III-14. Creep, Forged Nivco Bar Tested at 1100°F in Air. See Data Table IV.G.III-3. (Reference: NAS 3-4162)

Figure IV.G.III-14. Creep - Nivco Bar

TABLE IV.G.III-4. Creep Data for Forged Nivco Bar

See Figures IV.G.III-15 and IV.G.III-16

TEST: ASTM E139

Temperature (°F)	1400	1400	1400	1400	1600**	1600	1600
Stress (psi)	22,000	18,000	11,000	7,000	11,000	6,000	2,000
Duration of Test (hours)	48	120	240	214	1.75	20.7	119
Total Creep Strain (percent)	2.35	1.18	0.47	0.1920	7.37	5.91	1.43
Time to Cause 0.2 percent Creep Strain (hours)	7.2	23	87.5	217.0*	0.05	0.4	7.6
Time to Cause 0.4 percent Creep Strain (hours)	16	51	202		0.09	1.25	21.6
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.G.III→	15	15	15	15	--	16	16

*Extrapolated
**Data not plotted. Test duration too short to obtain valid stress-time data.

(Reference: NAS 3-4162)

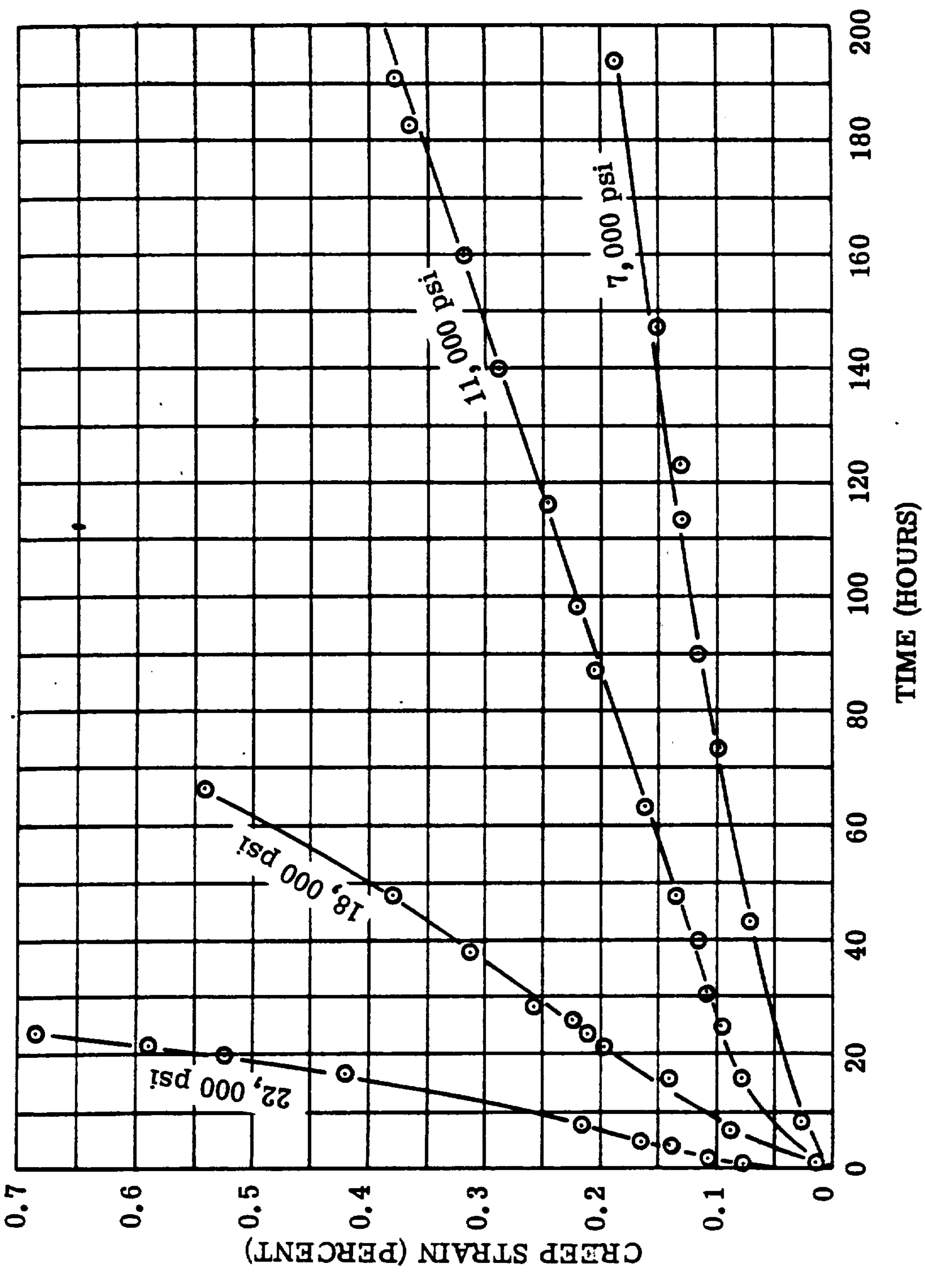


FIGURE IV.G.III-15. Creep, Forged Nivco Bar Tested at 1400°F in Air. See Data Table IV.G.III-4. (Reference: NAS 3-4162)

Figure IV.G.III-15. Creep - Nivco Bar

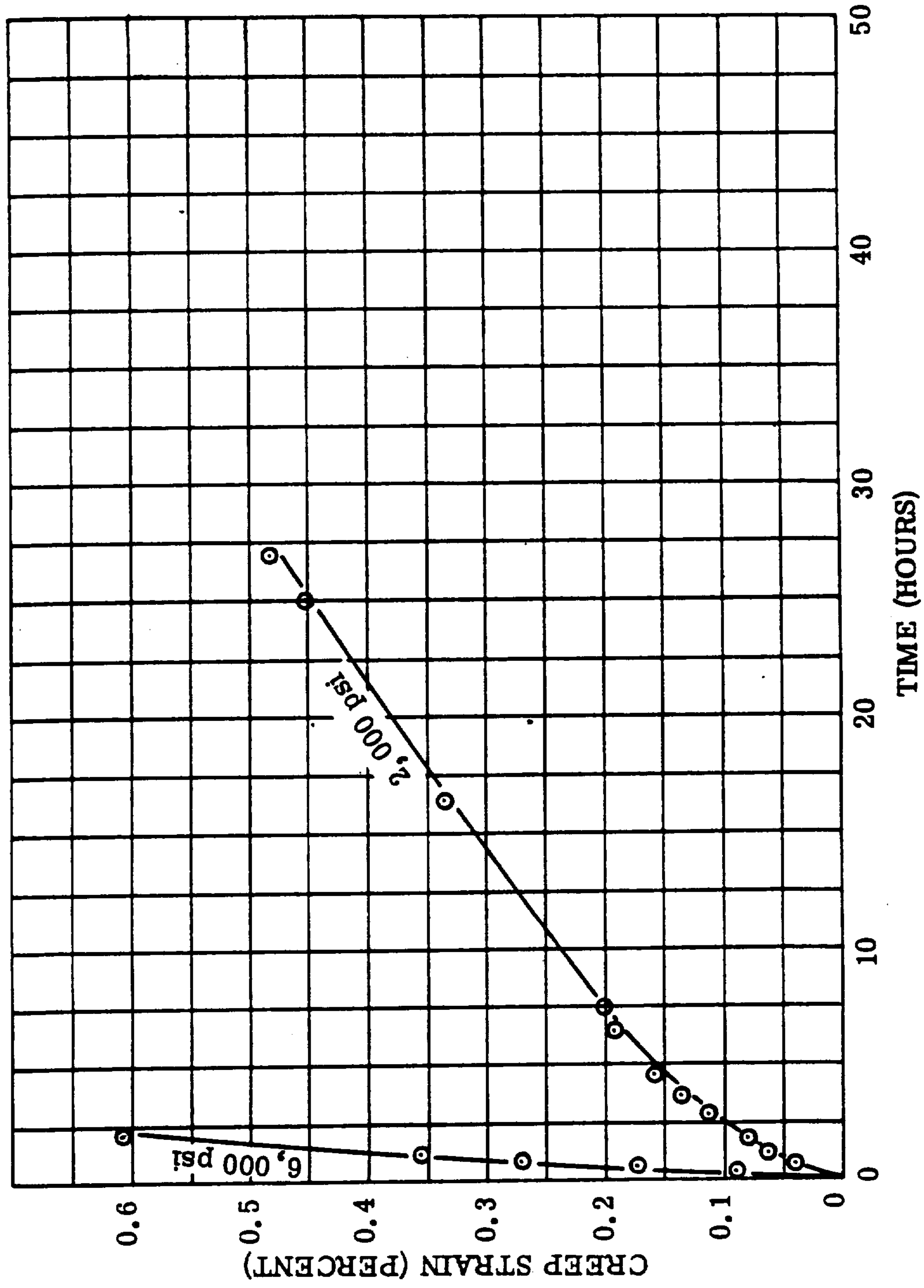


FIGURE IV.G.III-16. Creep, Forged Nivco Bar Tested at 1600°F in Air. See Data Table IV.G.III-4. (Reference: NAS3-4162)

Figure IV.G.III-16. Creep - Nivco Bar

TABLE IV.G.III-5. Air and Argon Creep Data for Forged Nivco Bar

See Figures IV.G.III-17 to IV.G.III-22

TEST: ASTM E139

Temperature (°F)	1600	1600	1600	1400	1400	900	900	900
Stress (psi)	1,000	1,000	2,000	3,000	6,000	98,000	98,000	96,000
Duration of Test (hours)	497	1,267	169	1,031	1,512	1,031	910	719
Total Creep Strain (percent)	0.431	0.437	1.92	0.0911	0.448	0.272	0.993	0.500
Time to Cause 0.2 percent Creep Strain (hours)	115	410	15.7	-	460	0	0	0
Time to Cause 0.4 percent Creep Strain (hours)	437	1,215	36.2	-	1,189	-	0	0
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0	0.200	0.928	0.4303
Test Atmosphere	Air	Argon	Argon	Argon	Argon	Air	Air	Air
See Strain-Time Plot in Figure IV.G.III →	17	17	18	19	20	21	21	22

(Reference NAS 3-4162)

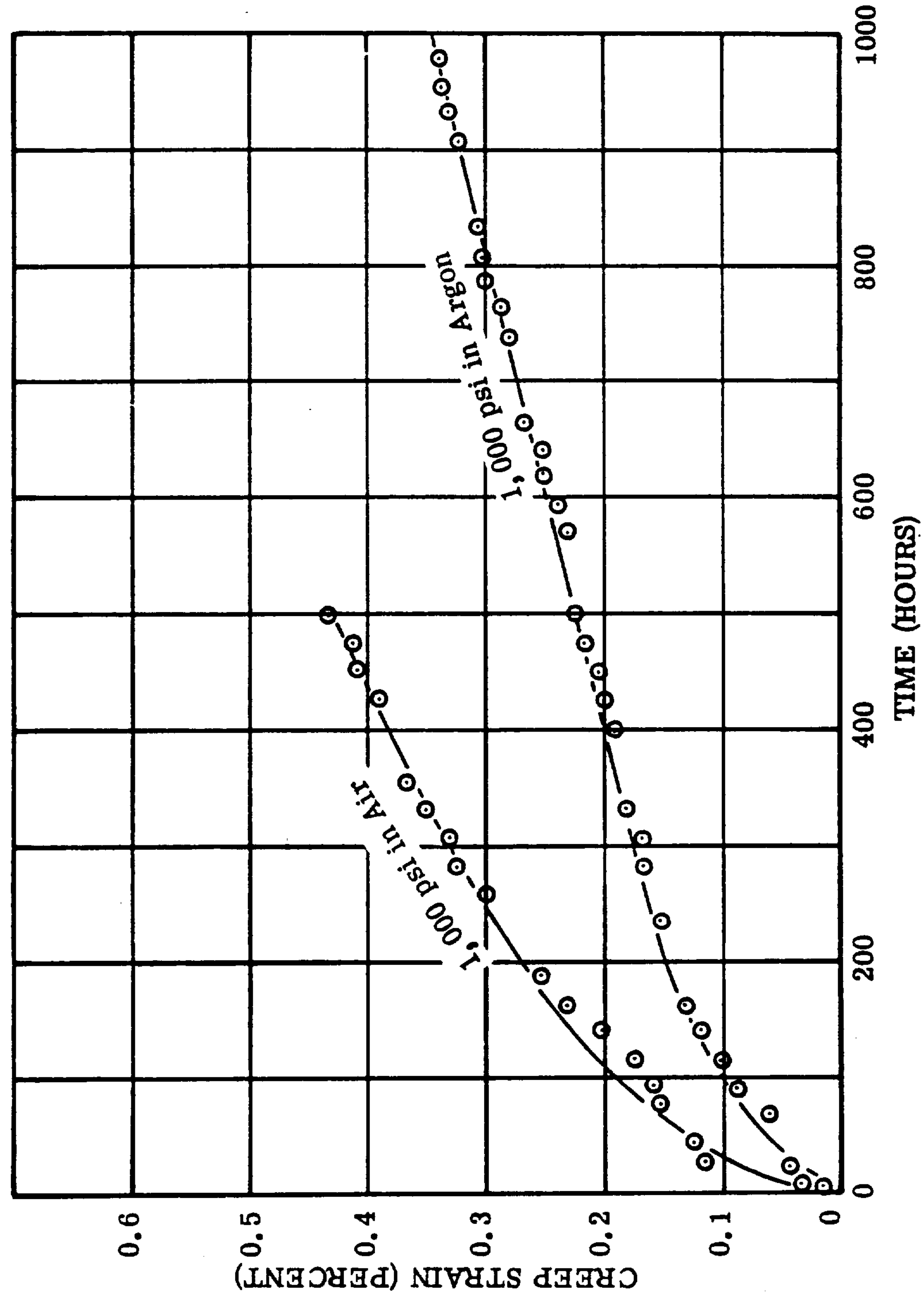


FIGURE IV.G.III-17. Creep Curves for Forged Nivco Bar Tested at 1600°F in Air and Argon. See Data Table IV.G.III-5. (Reference: NAS 3-4162)

Figure IV.G.III-17. Creep - Nivco Bar

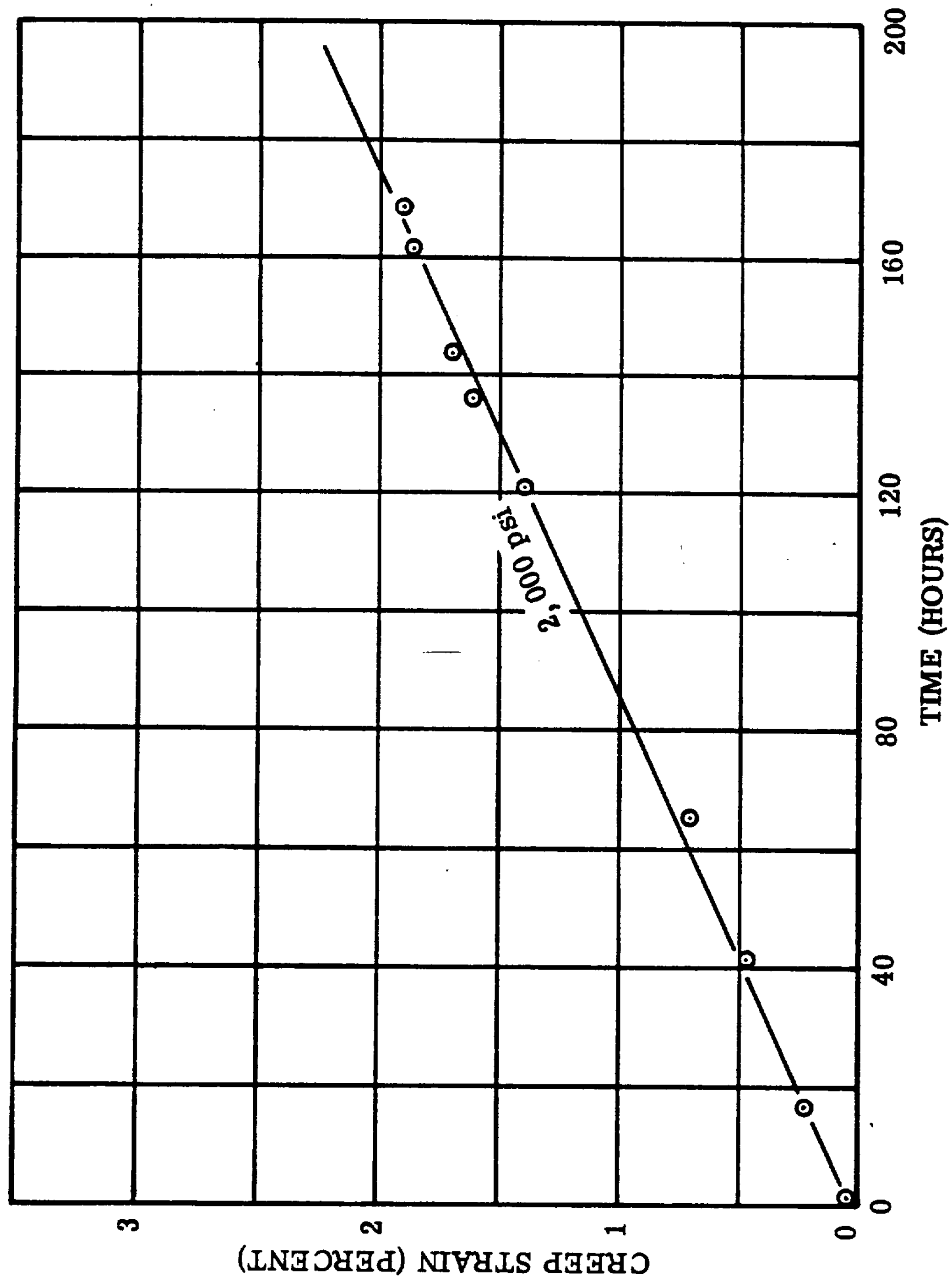


FIGURE IV.G.III-18. Creep Curve for Forged Nivco Bar Tested at 1600°F in Argon. See Data Table IV.G.III-5. (Reference: NAS3-4162)

Figure IV.G.III-18. Creep - Nivco Bar

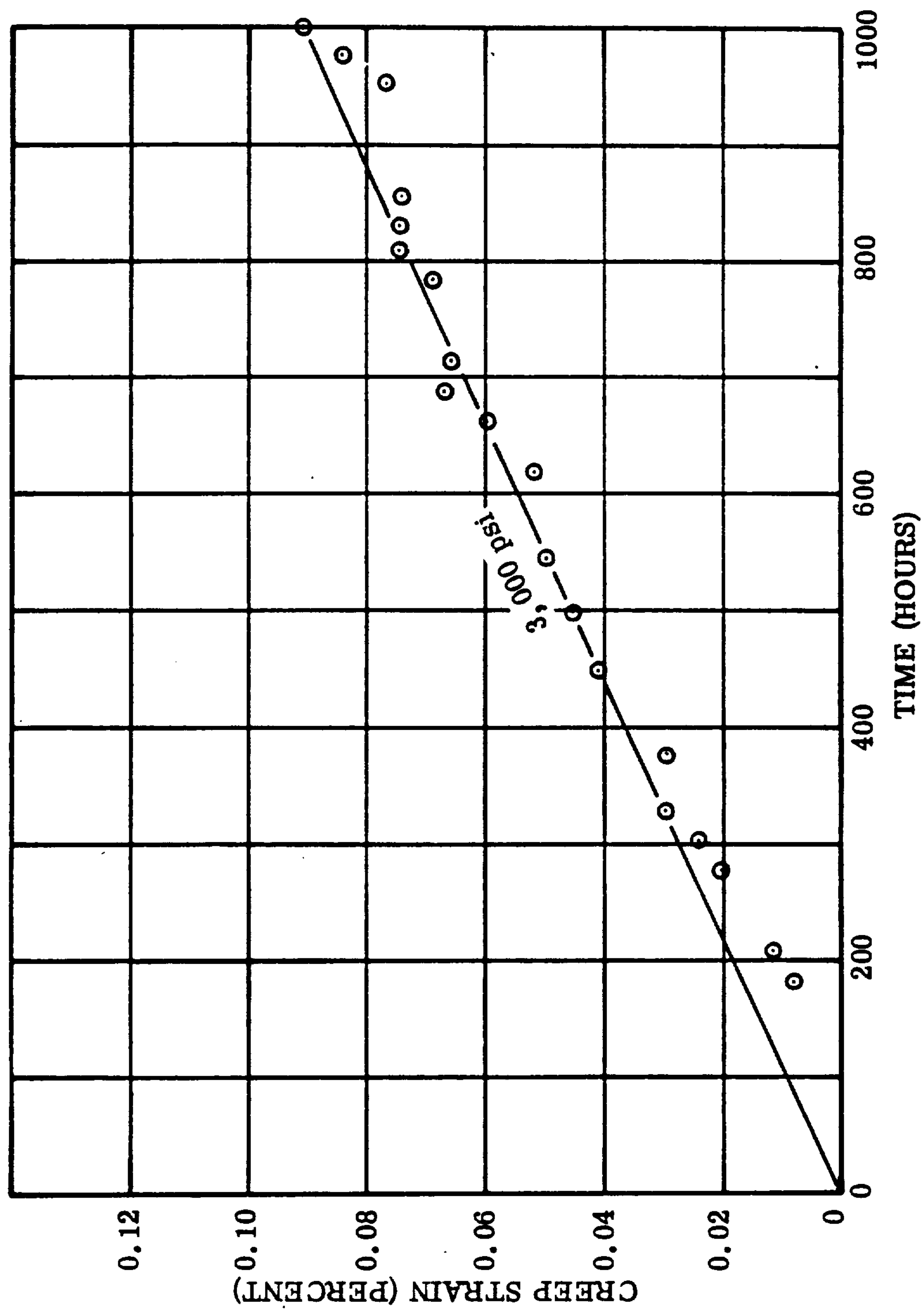


FIGURE IV.G.III-19. Creep Curve for Forged Nivco Bar Tested at 1400°F in Argon. See Data Table IV.G.III-5. (Reference: NAS 3-4162)

Figure IV.G.III-19. Creep - Nivco Bar

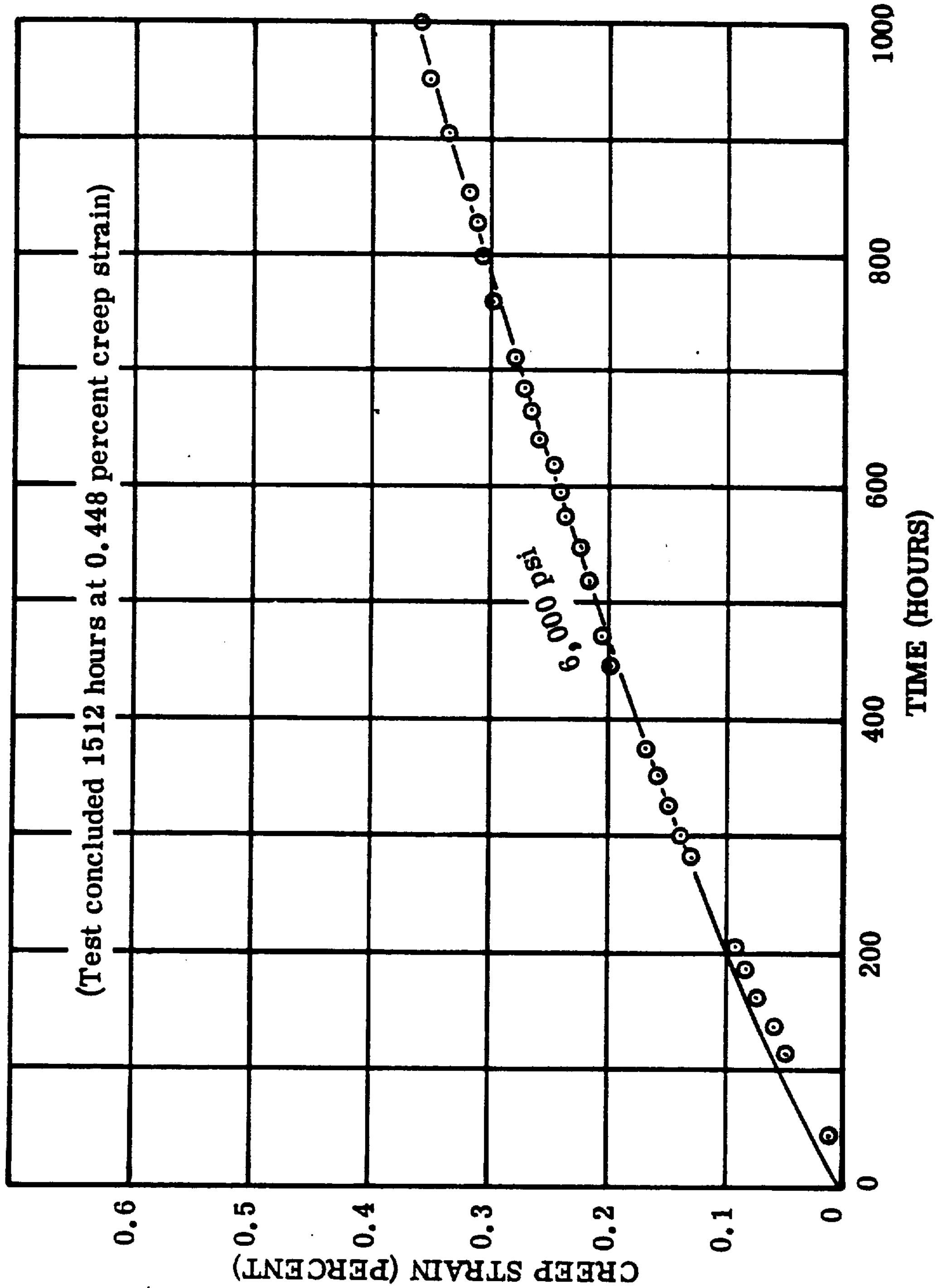


FIGURE IV.G.III-20. Creep Curves for Forged Nivco Bar Tested at 1400°F in Argon. See Data Table IV.G.III-5. (Reference: NAS 3-4162)

Figure IV.G.III-20. Creep - Nivco Bar

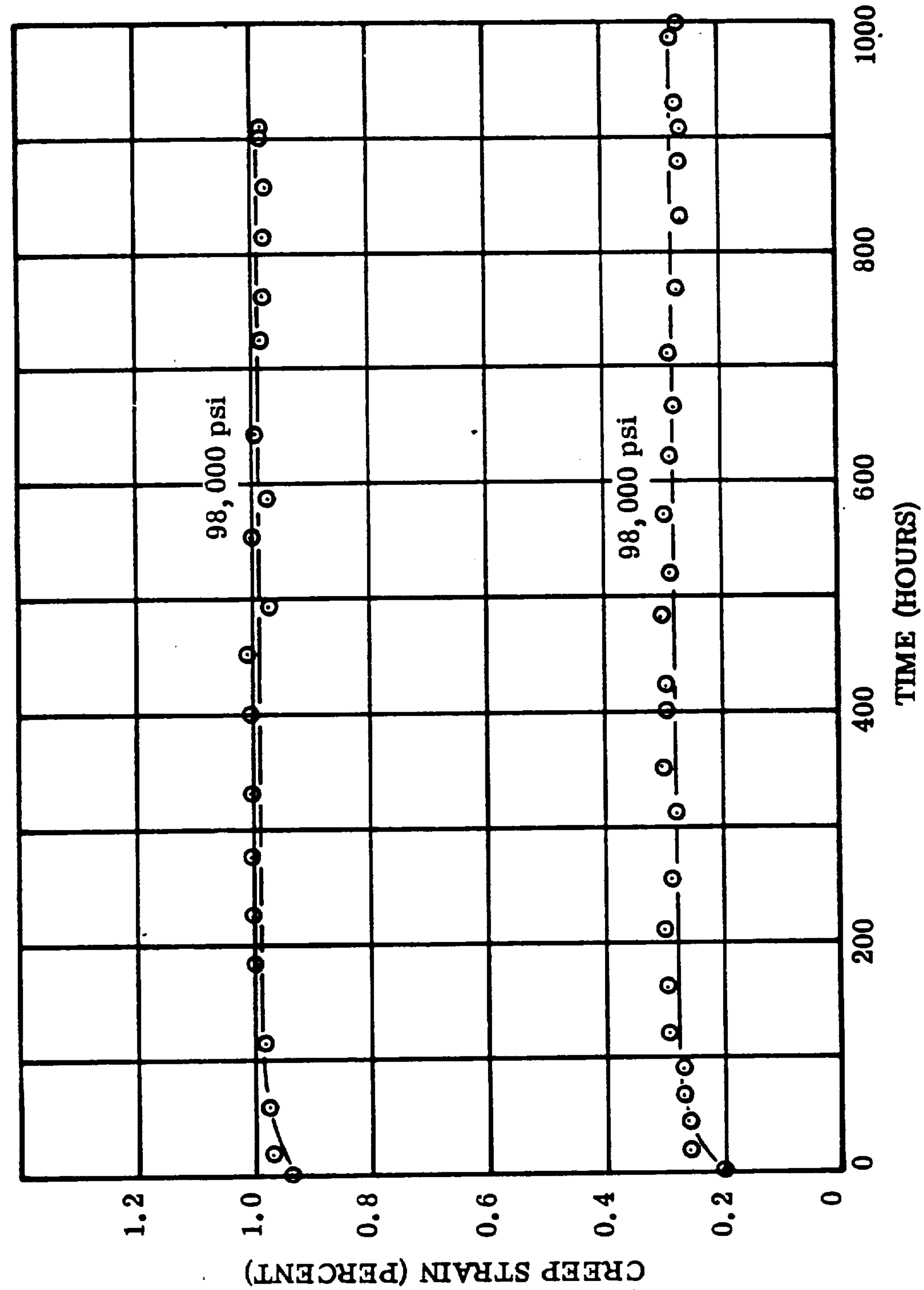


FIGURE IV.G.III-21. Creep Curves for Forged Nivco Bar Tested at 900°F in Air. See Data Table IV.G.III-5. See Section II.B.3.g.5 for Discussion of Scatter. (Reference: NAS3-4162)

Figure IV.G.III-21. Creep - Nivco Bar

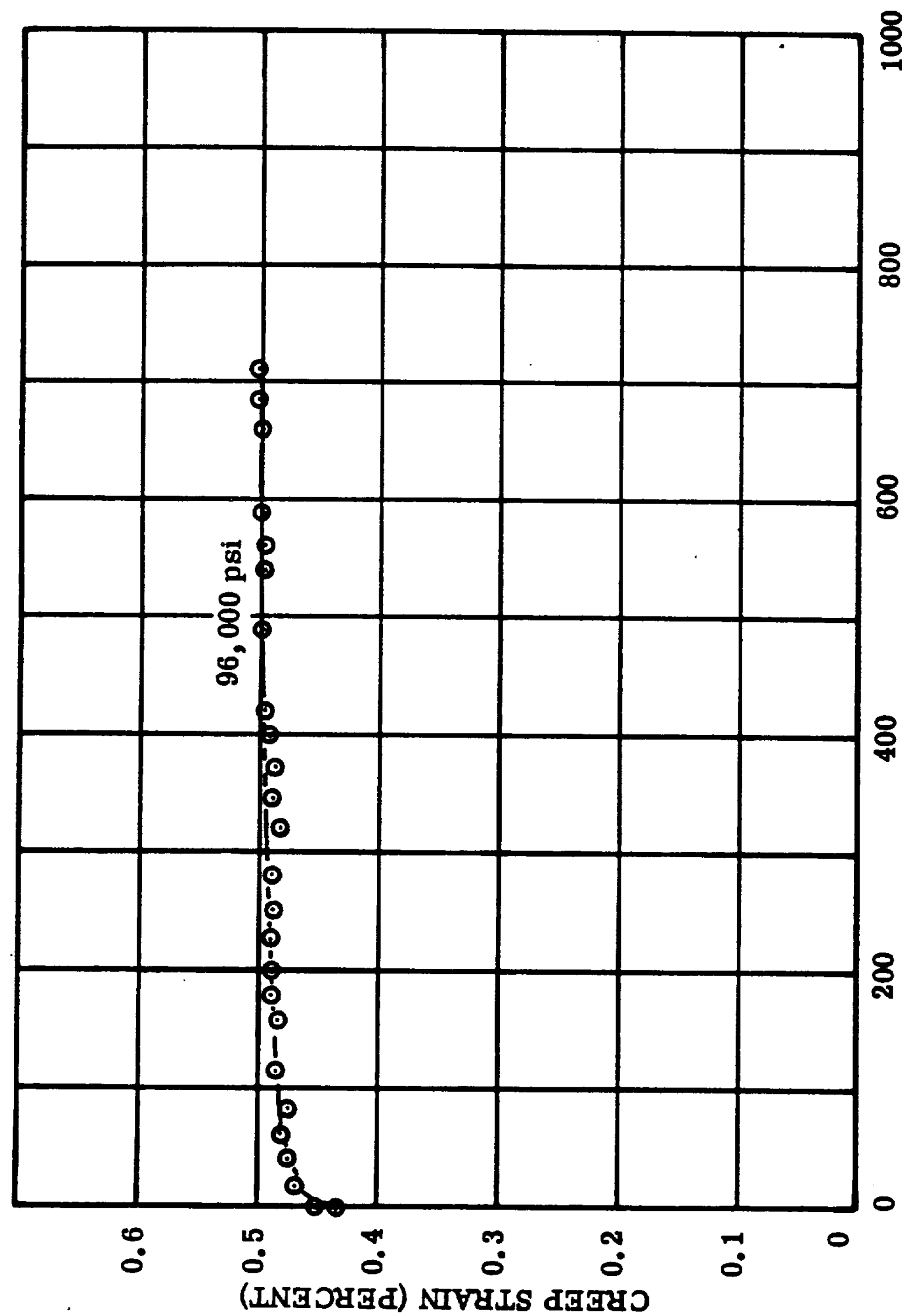


FIGURE IV.G.III-22. Creep, Forged Nivco Bar Tested at 900°F in Air. See Data Table IV.G.III-5. (Reference: NAS 3-4162)

Figure IV.G.III-22. Creep - Nivco Bar

TABLE IV.G.III-6. Vacuum Creep Data for Forged Nivco Bar

TEST: ASTM E139

Temperature (°F)	900	1100	1400	1400
Stress (psi)	85,000	80,000	8,000	16,000
Duration of Test (hours)	496	356	163	5
Total Creep Strain (percent)	0.66	0.07	0.10	0.52
Time to Cause 0.2 percent Creep Strain (hours)	65	(1)	(1)	0.65
Time to Cause 0.4 percent Creep Strain	225	(1)	(1)	1.95
Plastic Strain obtained on loading specimen (percent)	0	0	0	0
Test Atmosphere	Vacuum	Vacuum	Vacuum	Vacuum
See Larson-Miller Plot Figure IV.G.III→	5	5	5	5
Larson-Miller Parameters* for 0.2 percent Plastic Strain	43.3	(1)	(1)	55.5
Larson-Miller Parameters* for 0.4 percent Plastic Strain	44.0	(1)	(1)	56.4

(1)Did not reach required strain.
* Larson-Miller Constant = 30 (Reference: NAS 3-4162)

TABLE IV.G.III-7. Creep Data for Nivco Sheet Tested in Air

See Figures IV.G.III-23 to IV.G.III-25

TEST: ASTM E139

Temperature (°F)	900	1100	1100	1100	1100**
Stress (psi)	45,000	30,000	35,000	45,000	60,000
Duration of Test (hours)	1,410+	1,123	1,172+	668+	163
Total Creep Strain (percent)	0.124	0.2790	0.372	0.589	0.6460
Time to Cause 0.2 percent Creep Strain (hours)	*	690	360	91	8
Time to Cause 0.4 percent Creep Strain (hours)	*	1,770++	1,387++	389	111
Plastic Strain obtained on loading specimen (percent)	0	0	0	0	0
Test Atmosphere	Air	Air	Air	Air	Air
See Strain-Time Plot in Figure IV.G.III→	23	24	24	24	25

+Test incomplete
++Extrapolated
*Did not reach required strain
**Longitudinal specimen

(Reference: NAS 3-4162)

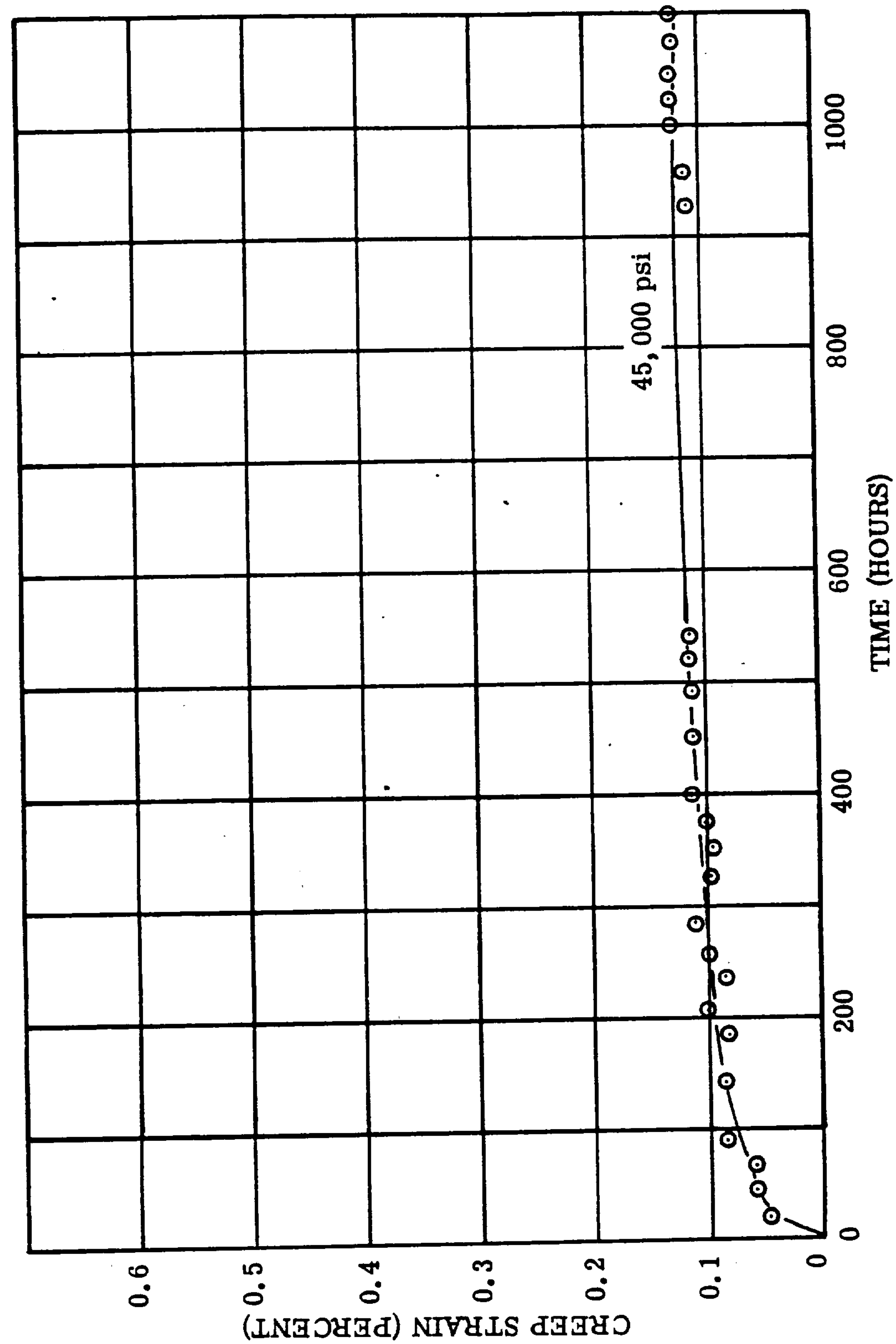


FIGURE IV.G.III-23. Creep, Nivco Sheet Tested at 900°F in Air. See Data Table IV.G.III-7. (Reference: NAS3-4162)

Figure IV.G.III-23. Creep - Nivco Sheet

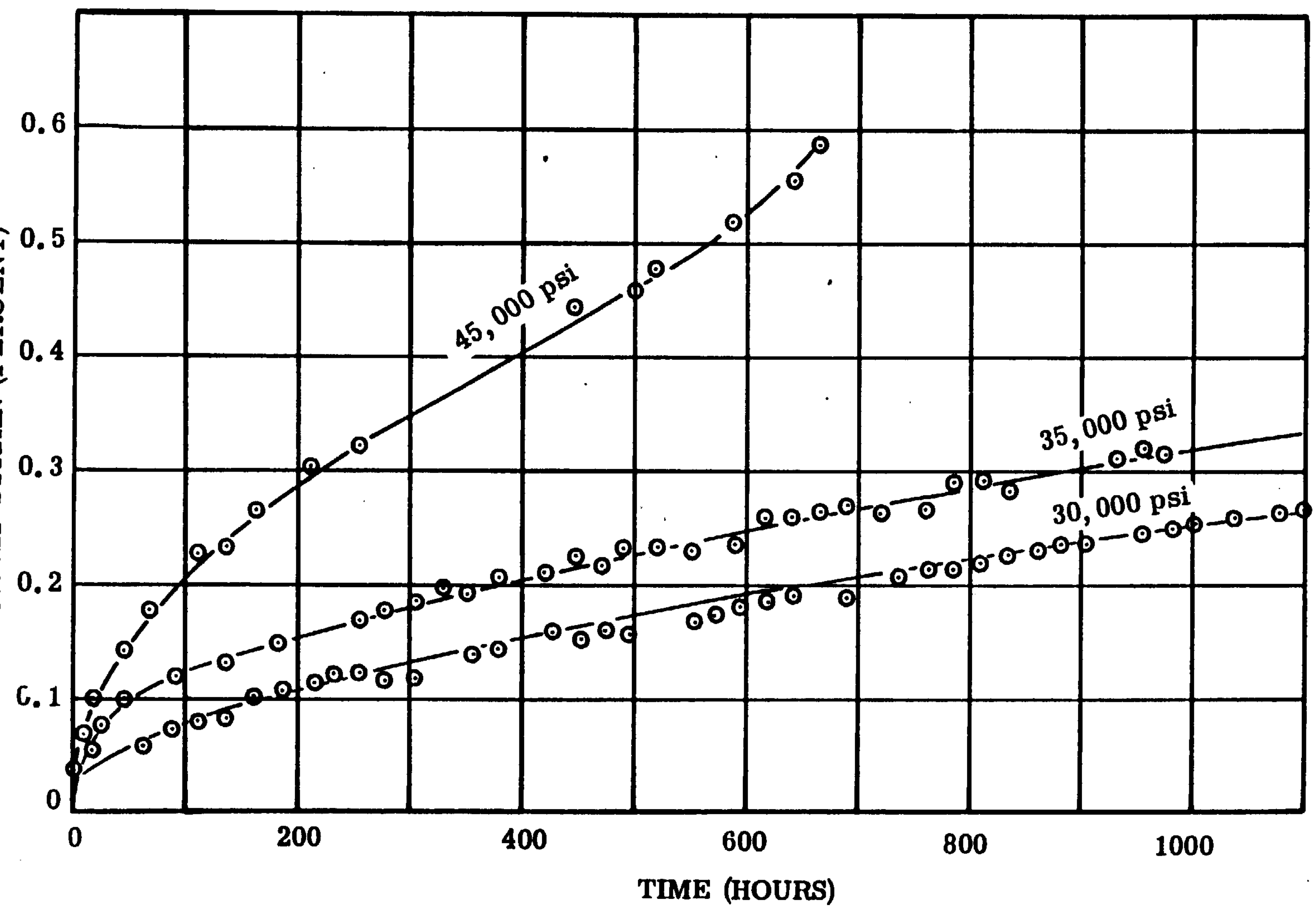


FIGURE IV.G.III-24. Creep, Nivco Sheet Tested at 1100°F in Air. See Data Table IV.G.III-7. (Reference: NAS 3-4162)

Figure IV.G.III-24. Creep - Nivco Sheet

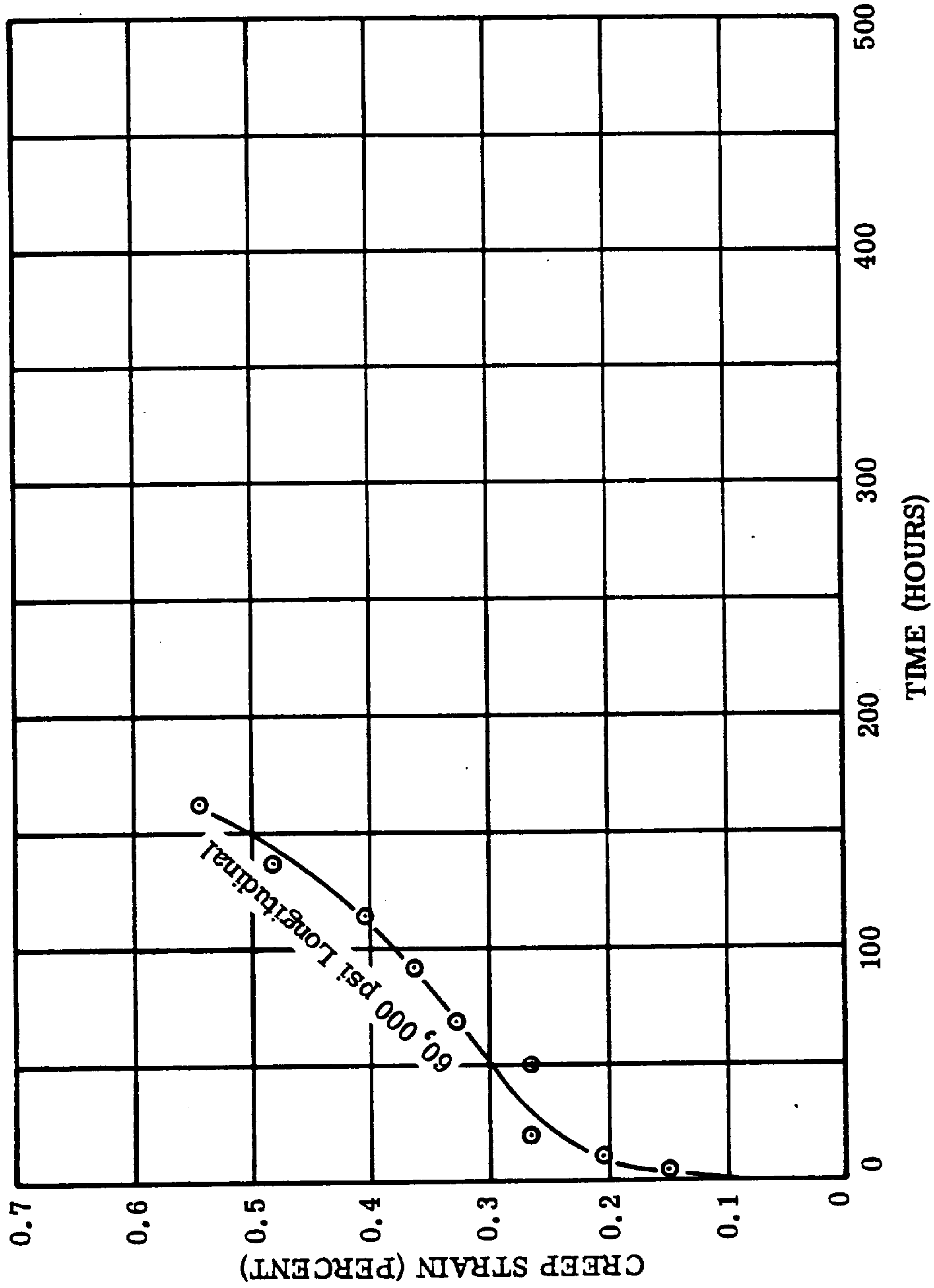


FIGURE IV.G.III-25. Creep, Nivco Sheet (Longitudinal) Tested at 1100°F in Air. See Data Table IV.G.III-7. (Reference: NAS3-4162)

Figure IV.G.III-25. Creep - Nivco Sheet

TABLE IV.G.III-8. 900°, 1000° and 1100°F Fatigue Test Data for 10^7 Cycles on Smooth and Notched Bar Forged Nivco Specimens

Temperature (°F)	Fatigue Specimen	Stress Ratio (A)[1]	Stress for 10^7 Cycles (Psi)	Stress Alternating (Psi)	Stress Mean (Psi)
900	Smooth Bar	∞	63,000		
900	Notch Bar	∞	40,000		
900	Smooth Bar	0.25	133,000	26,600	106,400
900	Notch Bar	0.25	133,000	26,600	106,400
1000	Smooth Bar	∞	67,000		
1000	Notch Bar	∞	33,000		
1000	Smooth Bar	0.25	129,000	25,800	103,200
1000	Notch Bar	0.25	129,000	25,800	103,200
1100	Smooth Bar	∞	62,000		
1100	Notch Bar	∞	32,000		
1100	Smooth Bar	0.25	108,000	21,600	86,400
1100	Notch Bar	0.25	95,000	19,000	76,000

(1) $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$

(Reference: NAS 3-4162)

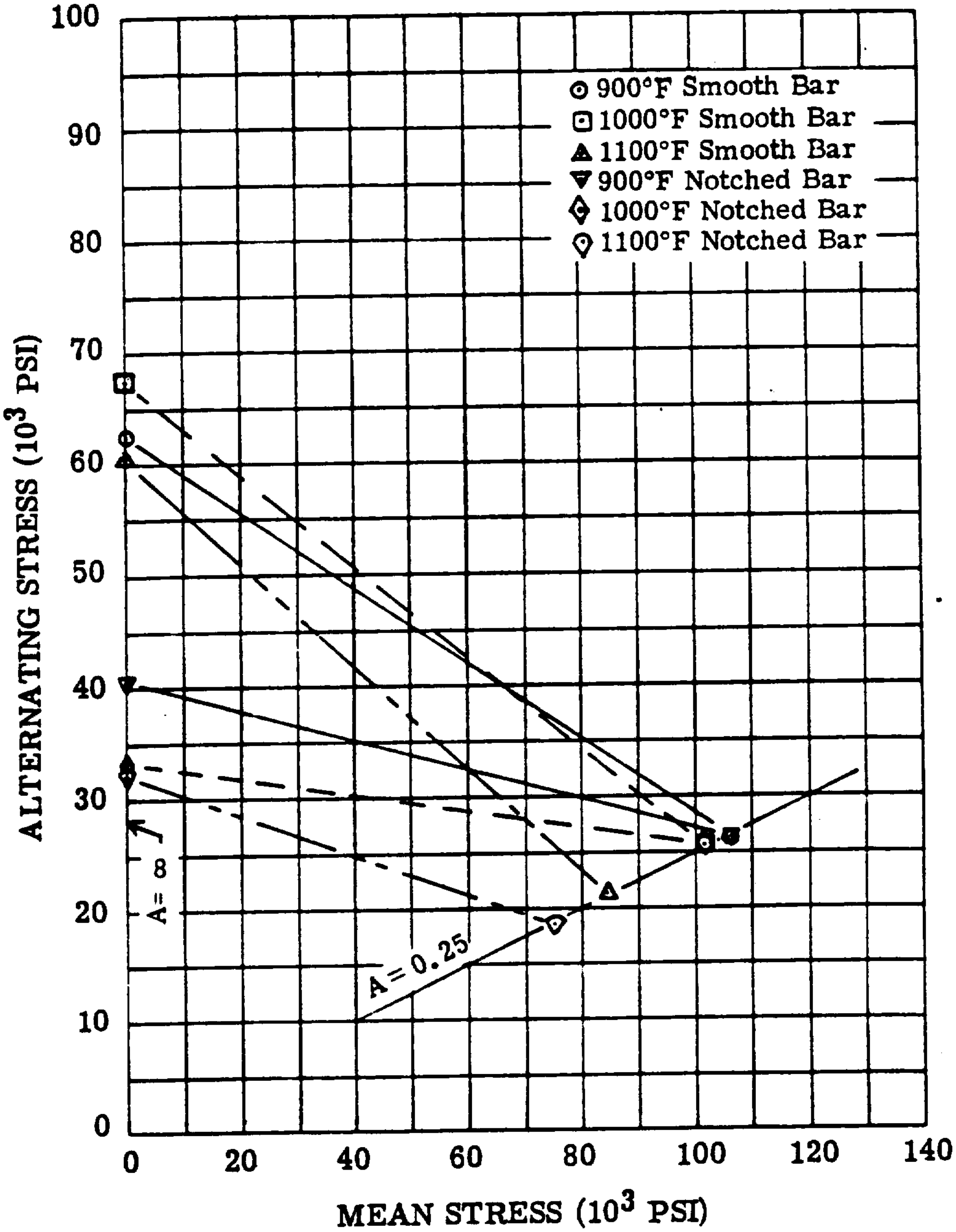


FIGURE IV.G.III-26. Modified Goodman Type Diagram for Forged Nivco Alloy. Test Temperature of 900°F, 1000°F, and 1100°F for 10^7 Cycles. See Data Table IV.G.III-8. (Reference: NAS 3-4162)

Figure IV.G.III-26. Fatigue - Nivco Bar

TABLE IV.G.III-9. 900°, 1000° and 1100°F Fatigue Test Data for Nivco Smooth Bar Specimens in Air

TEST: ASTM STP91

Specimen No.	Test Temp. °F	Stress Ratio (A)(1)	Max. Stress (Psi)	Cycles to Failure
300	900	∞	100,000	1,500
304	900	∞	80,000	84,000
305	900	∞	70,000	662,000
325	900	∞	65,000	3,194,000
327	900	∞	60,000	2,415,000
335	900	∞	55,000	10,000,000*
307	900	0.25	150,000	23,000
316	900	0.25	146,250	10,000
314	900	0.25	143,750	204,000
312	900	0.25	142,000	4,532,000
333	900	0.25	138,650	9,000
334	900	0.25	136,700	263,000
310	900	0.25	135,000	18,000,000*
308	1000	∞	90,000	7,000
309	1000	∞	80,000	96,000
313	1000	∞	74,000	563,000
306	1000	∞	69,750	3,639,000
311	1000	∞	66,000	7,250,000
337	1000	∞	62,000	1,665,000
340	1000	∞	62,000	11,360,000
320	1000	0.25	150,000	6,000
322	1000	0.25	146,250	8,000
318	1000	0.25	143,750	553,000
302	1000	0.25	135,900	828,000
332	1000	0.25	129,950	4,488,000
321	1000	0.25	128,000	12,474,000
317	1100	∞	82,000	31,000
314	1100	∞	74,000	200,000
319	1100	∞	70,000	722,000
341	1100	∞	68,000	3,299,000(2)
323	1100	∞	66,000	4,500,000
343	1100	∞	64,000	4,885,000(2)
303	1100	∞	62,000	8,690,000
324	1100	0.25	134,750	28,000
330	1100	0.25	129,950	159,000
329	1100	0.25	125,800	299,000
342	1100	0.25	120,000	103,000
326	1100	0.25	120,000	716,000
331	1100	0.25	115,500	637,000
336	1100	0.25	113,000	3,657,000
338	1100	0.25	112,000	1,605,000
328	1100	0.25	110,000	9,830,000*

(1) $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$

(2) Argon atmosphere

* No failure

(Reference: NAS 3-4162)

TABLE IV.G.III-10. 900°, 1000° and 1100°F Fatigue Test Data for Nivco Notched Bar Specimens in Air

TEST: ASTM STP91

Specimen No.	Test Temp. °F	Stress Ratio (A)(1)	Max. Stress (Psi)	Cycles to Failure
400	900	∞	55,000	18,000
402	900	∞	50,000	23,000
406	900	∞	45,000	62,000
404	900	∞	42,500	108,000
409	900	∞	40,000	10,330,000*
428	900	∞	36,000	55,000
418	900	∞	33,000	12,000,000*
438	900	0.25	165,000	17,000
413	900	0.25	150,000	121,000
416	900	0.25	145,000	148,000
405	900	0.25	142,000	78,000
420	900	0.25	139,750	8,790,000
410	900	0.25	135,000	10,000,000*
435	1000	∞	49,750	12,000
425	1000	∞	40,000	56,000
412	1000	∞	37,500	10,045,000*
408	1000	∞	35,000	9,791,000
411	1000	∞	35,000	15,000,000*
403	1000	∞	30,000	9,729,000*
427	1000	0.25	152,000	33,000
439	1000	0.25	145,000	240,000
422	1000	0.25	134,000	955,000
419	1000	0.25	125,000	7,490,000
417	1000	0.25	122,000	8,004,000
441	1000	0.25	118,000	10,000,000*
437	1100	∞	45,000	16,000
424	1100	∞	40,000	36,000
434	1100	∞	37,000	12,250,000
414	1100	∞	35,000	2,419,000
426	1100	∞	35,000	2,849,000
433	1100	∞	30,000	10,000,000*
436	1100	0.25	144,000	4,000
423	1100	0.25	134,000	120,000
440	1100	0.25	128,000	65,000
415	1100	0.25	120,000	980,000
421	1100	0.25	114,000	805,000
429	1100	0.25	106,000	705,000
432	1100	0.25	106,000	822,000
407	1100	0.25	100,000	1,450,000
430	1100	0.25	90,000	2,825,000
401	1100	0.25	80,000	15,000,000*

(1) $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$

* No failure

(Reference: NAS 3-4162)

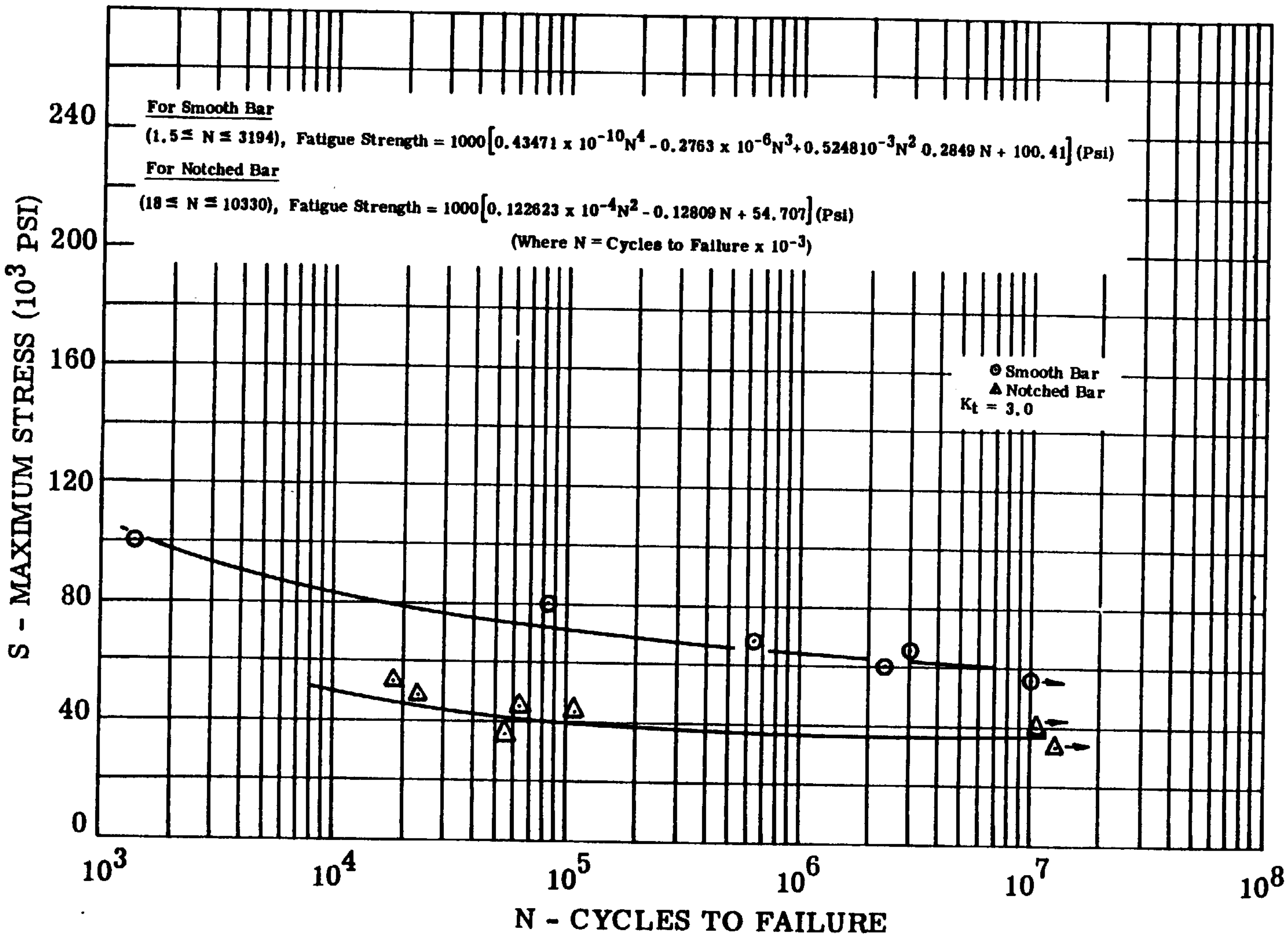


FIGURE IV.G.III-27. S-N Diagram of Smooth and Notched Nivco Bar at 900°F. Stress Ratio = ∞. Tests Made In Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS 3-4162)

Figure IV.G.III-27. Fatigue - Nivco Bar

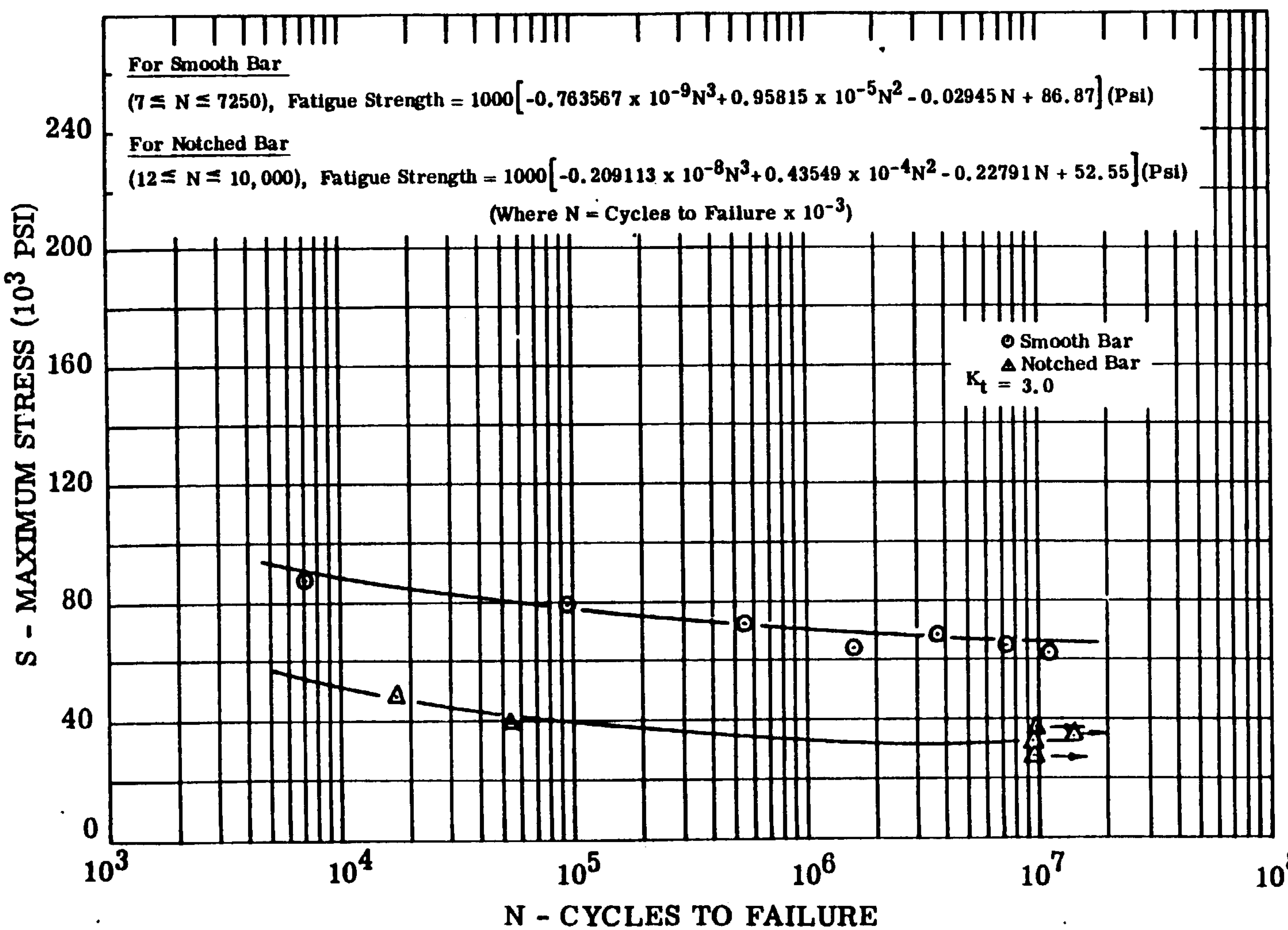


FIGURE IV.G.III-28. S-N Diagram of Smooth and Notched Nivco Bar at 1000°F. Stress Ratio = ∞. Tests Made in Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS3-4162)

Figure IV.G.III-28. Fatigue - Nivco Bar

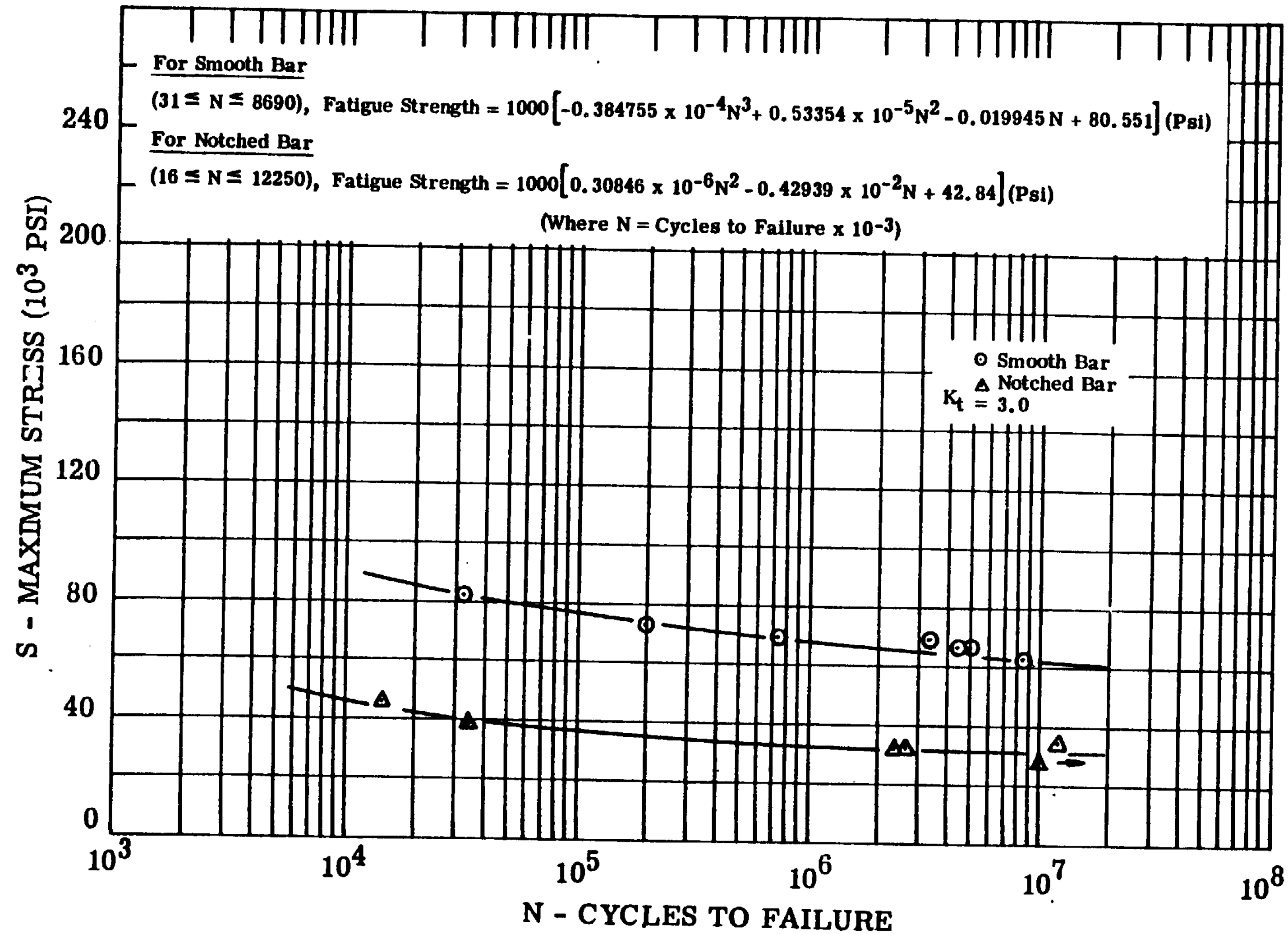


FIGURE IV.G.III-29. S-N Diagram of Smooth and Notched Nivco Bar at 1100°F. Stress Ratio = ∞. Tests Made in Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS 3-4162)

Figure IV.G.III-29. Fatigue - Nivco Bar

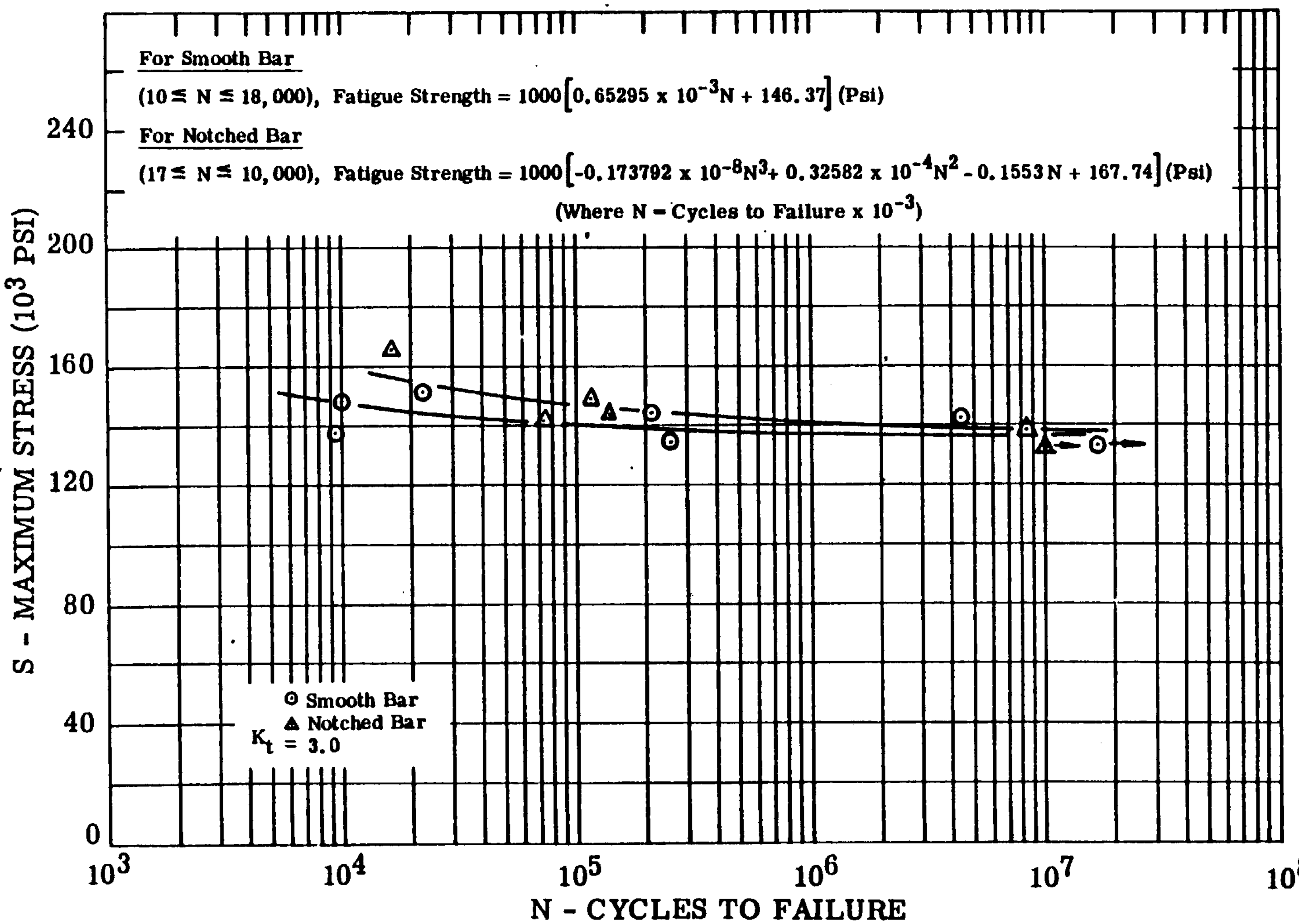


FIGURE IV.G.III-30. S-N Diagram of Smooth and Notched Nivco Bar at 900°F. Stress Ratio = 0.25. Tests Made in Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS 3-4162)

Figure IV.G.III-30. Fatigue - Nivco Bar

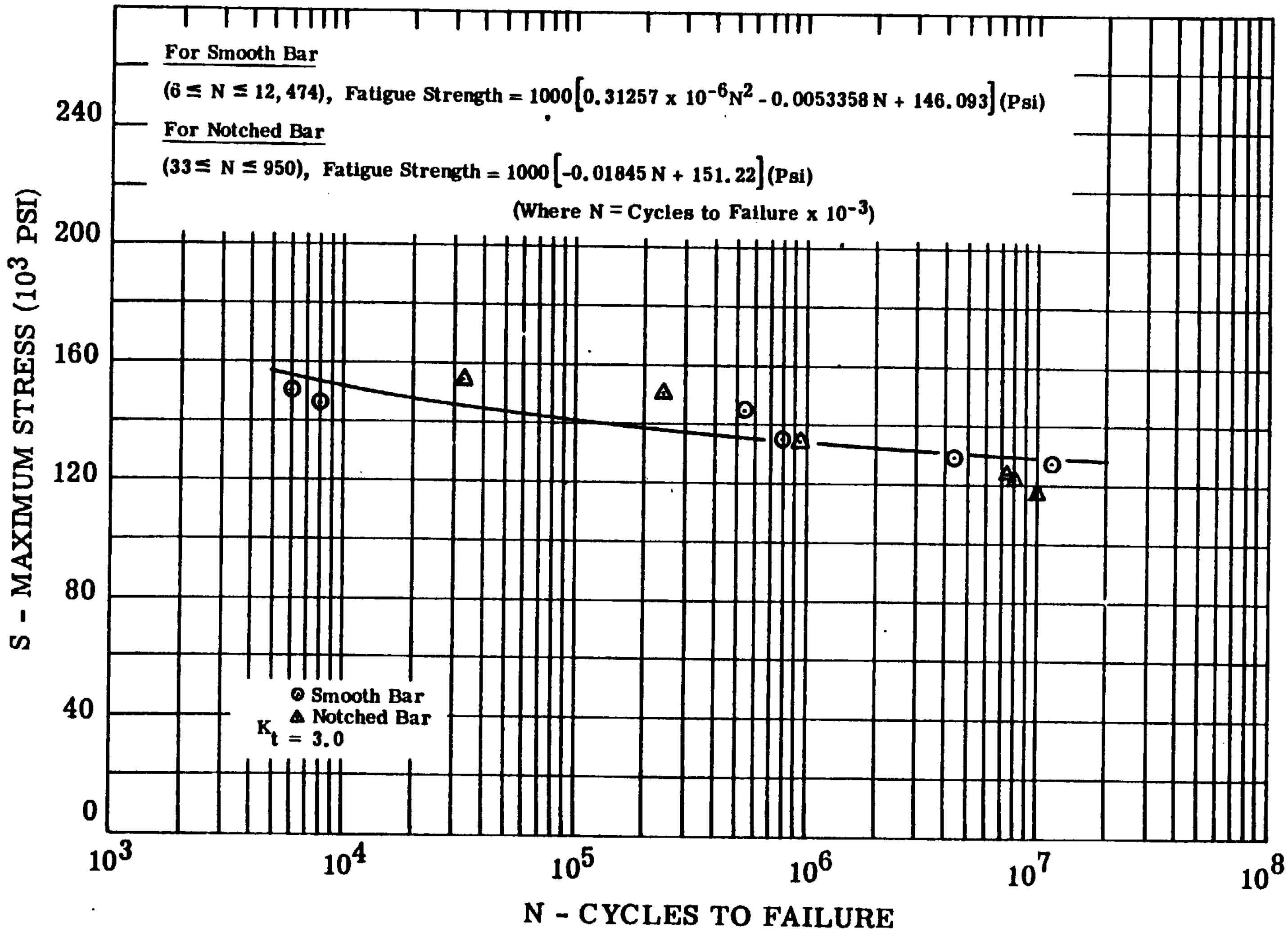


FIGURE IV.G.III-31. S-N Diagram of Smooth and Notched Nivco Bar at 1000°F. Stress Ratio = 0.25. Tests Made in Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS 3-4162)

Figure IV.G.III-31. Fatigue - Nivco Bar

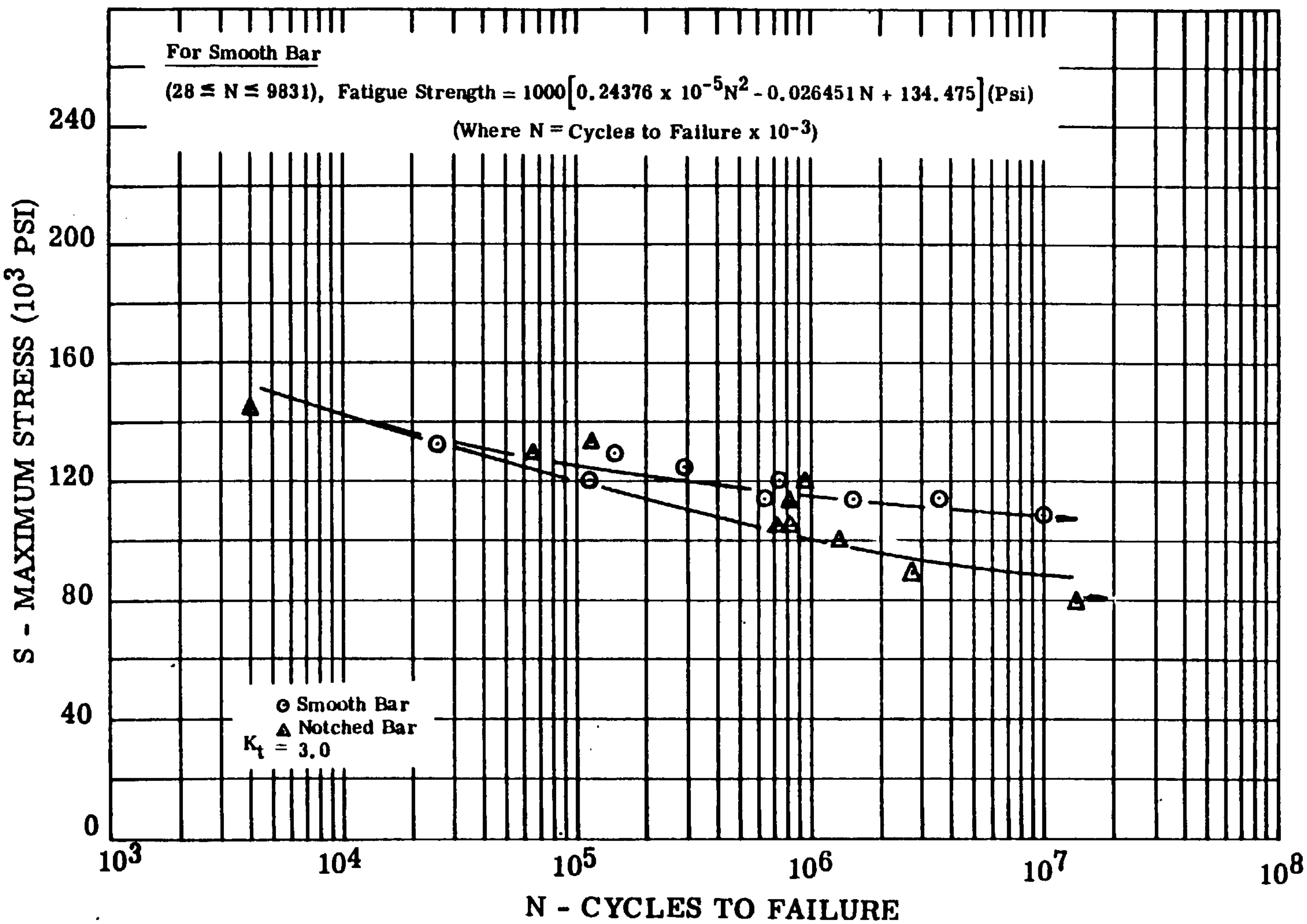


FIGURE IV.G.III-32. S-N Diagram of Smooth and Notched Nivco Bar at 1100°F. Stress Ratio = 0.25. Tests Made in Air. See Data Tables IV.G.III-9 and IV.G.III-10. (Reference: NAS 3-4162)

Figure IV.G.III-32. Fatigue - Nivco Bar

APPENDIX A

SYMBOLS AND DEFINITIONS

Symbols

A	Amperes
A	Stress Ratio (see definitions)
A-C	Alternating Current
AT	H_1
B	Magnetic Induction in Kilogauss
B_d	Remanent Induction (see definitions)
BHN	Brinell Hardness Number
B_m	Maximum Induction, measures at H_m (1)
B_r	Residual Magnetic Induction, or (from saturation) the Retentivity (see definitions)(1)
$\frac{B_r}{B_m}$	Loop Squareness Ratio(1)
B_s	Saturation Magnetic Induction
B_{tip}	Maximum Induction Reached During Magnetization
BTU	British Thermal Unit
°C	Degrees Centigrade
Cal	Calorie
cc	Cubic Centimeter
$\frac{\text{CC-ATM}}{\text{sec}}$	Vacuum Leak Rate, Cubic Centimeter - Atmosphere per Second
CCFR	Constant Current Flux Reset
cm	Centimeter
cps	Cycles per Second
C_v	Specific Heat at Constant Volume (for solids)
DAT	$H_1 - H_2$
D-C	Direct Current
e	Transverse Strain (see definition of μ)
e_1	Axial Strain (see definition of μ)
°F	Degrees Fahrenheit

G_m	Gram
H	Magnetic Coercive Force in Oersteds
H_c	Coercive Force (see definitions)
H_m	Peak Field Intensity (1)
H_0	Reset Magnetic Field Intensity (see definitions)(1)
H_1, H_2	(See definitions)(1)
Kg	Kilogauss
Ksi	Kips per Square Inch
K_t	Stress Concentration Factor (see definitions)
Kva	Kilovolt Amperes
$\frac{\Delta L}{L}$	Change in length divided by original length in thermal expansion measurements.
MFA	Magnetic Field Annealed
N	Number of Cycles in a Fatigue Test
Oe	Oersted
Ohm-cm	Ohm Centimeters - Units of electrical resistivity
Ohm-in	Ohm Inches - Units of electrical resistivity
PPM	Part per Million
psi	Pounds per Square Inch
Rockwell B	Hardness in Rockwell "B" scale units
Rockwell C	Hardness in Rockwell "C" scale units (see definitions R_c)
S	Stress
SAT	B_m
SRA	Stress Relief Annealed
T	Temperature
t	Time
V	Volt
VA	Volt Amperes
W	Watt
α	Coefficient of Thermal Expansion - Alpha
κ	Thermal Conductivity - Kappa
μ	Poisson's Ratio (see definitions) - Mu
ρ	Electrical Resistivity - Rho

Definitions

A	Stress ratio: defined as the ratio of alternating stress to mean stress in a biased fatigue test.
B_d	Remanent induction; the magnetic induction that remains in a magnetic circuit after removal of an applied magnetomotive force.
B_r	Residual magnetic induction; the magnetic induction remaining when the magnetizing force is reduced to zero.
$B_m - B_r$	Flux density change measured at zero reset magnetic field intensity. It is a measure of squareness and is utilized to determine the squareness ratio.[1]
Creep Strain	Total non-recoverable plastic deformation corrected for thermal expansion and elastic strain.
Fatigue Strength	The maximum stress that can be sustained for a specified number of cycles without failure, the alternating stress being completely reversed within each cycle. For this program, fatigue strength was determined for 10^7 cycles.
Gain	$= \dfrac{\Delta B_2 - \Delta B_1}{H_2 - H_1}$, a measure, in terms of permeability, of loop steepness.[1]
H_0	Reset magnetic field intensity required to produce a cyclic change of induction (ΔB_0) equal to 1/2 the maximum flux density change.[1]
H_1	Equivalent to the reset magnetic field intensity required to produce a cyclic change of induction (ΔB_1) equal to 1/3 the maximum flux density change.[1]
H_2	Equivalent to the reset magnetic field intensity required to produce a cyclic change of induction (ΔB_2) equal to 2/3 the maximum flux density change.[1]
H_c	Magnetization force at which the magnetic induction is zero.
R_c	Hardness value in Rockwell "C" scale units using a 150 Kilograms load and diamond Braille indenter.

Stress Concentration Factor K_t — The ratio of the greatest stress, in the region of a notch or stress riser, as determined by advanced theory, photoelasticity or direct measurement of elastic strain, to the corresponding nominal stress. Stress concentration factor for NAS 3-4162 was calculated by the theory of elasticity.[2]

μ — $= e/e_1 =$ Poisson's ratio. The absolute value of the ratio of transverse strain to the corresponding axial strain in a body subjected to uniaxial stress in the elastic portion of the stress-strain curve.

<u>References:</u>

(1) G. E. Lynn, et al, "Self-Saturating Magnetic Amplifiers", Westinghouse-McGraw Hill Engineering Books for Industry, New York, 1960. pp 127-128

(2) R. E. Peterson, "Stress Concentration Design Factors", John Wiley and Son Inc., New York, N. Y., 1953

<u>General References:</u>

Metals Handbook Vol. 1, 1961, 8th Edition, ASM.

The American Society for Testing Materials Specifications.

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:

Reference on Magnetic Materials

1) Ferromagnetism, book by R. M. Bozorth, 1951
2) Cobalt Monograph, book edited by Cobalt Information Center, Brussels, Belgium and Columbus, Ohio, Battelle Memorial Institute, 1960
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5) ASM Review of Metal Literature - 1953 to 1963
6) Engineering Index - 1952 to 1962
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8) International Critical Tables of Numerical Data, Physics, Chemistry and Technology
9) Proceedings of IEE/APS Conference on Magnetism and Magnetic Materials - 1956 to 1963 (Supplements to Journal of Applied Physics)
10) Magnetic Materials Files of the Westinghouse Research and Development Center - 1949 to 1963
11) Log Book of Magnetic Measurements Laboratories, Westinghouse Research and Development Center
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13) Physikalishche Berichte (German Physical Abstracts) - 1952 to 1963
14) Zietschrift für Angewandte Physik (German Journal of Applied Physics) - 1950 to 1962
15) Zeitschrift für Metallkunde (German Journal on Physical Metallurgy) - 1946 to 1963
16) Stahl and Eisen (German Steel & Iron Institute Journal) - 1946 to 1963
17) Russian Journal for Physics of Metals and Metallorgraphy (most of the Russian papers on magnetic materials are published in this journal) - 1954 to 1963
18) Journal of the Physical Society of Japan - 1958 to 1963
19) Nuclear Science Abstracts - 1956 to 1963

20) ASM Computer Information Searching Service
21) Thermophysical Properties Research Center (TPRC)
22) Electronic Properties Research Center (EPRC)
23) Mechanical Properties Data Center (MPDC)
24) Defense Metals Information Center (DMIC)

The bibliography was prepared for IBM punched cards. It deviates from the conventional practive for presenting references, but is of added value because of the additional information which it provides. Titles of papers often deceive the reader, therefore, a "key word" 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 of Descriptor	Author
		Title	
		Periodical, Report or Book References	Property Information

The property information code prints in column 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 material to which the reference pertains: LM or RM being magnetic 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.

Three printouts are presented in this Appendix: one listing the references in numerical sequence; a second listing authors in alphabetic order; and a third listing the key words in alphabetic order.

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LM7	SI-FE CUBEX MAGNETIC PROPERTIES OF TRANSFORMER STEEL WITH A CUBE TEXTURE RUSSIAN METAL PHYSICS AND METALLOGRAPHY VOL 15 P55 1963	KUNAROV AND LIVSHITZ	5
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	(W) RESEARCH LABS MAGNETIC MATERIALS FILES DEC 1960			6
RM81	MARAGING STL NICKEL	INTERNATIONAL NICKEL CO		
	PRELIMINARY DATA SHEET NOMINAL 200KSI YIELD STRENGTH 18PERCENT NI MAR STEEL			
	INTERNATIONAL NICKEL CO PUBL NO TL-12 P1-3 NOV 2 1962		1	
RM82	SUPERMENDUR STRIP	WESTINGHOUSE SPECIALTY TRANSFORMER DEPT TECH DATA		
	SUPERMENDUR CORES			
	(W) SPECIALTY TRANSFORMER DEPT TECH DATA 1960			5

RM83 SUPERMENDUR FACAROS G TRAPP R H
PILOT SCALE DEVELOPMENT OF SUPERMENDUR
(W) MATERIALS MFG DEPT REPORT NO 8-98839-031-C JULY 27 1959 1 5

RM84 HIPERCO 27 FACAROS G TRAPP R H
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(W) MATERIALS MFG REPORT 8-98839-021-C 5

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THERMAL EXPANSION OF SUPERMENDUR
(W) PERFORMANCE LABS REPORT NO LI-1792 JUNE 9 1961 6

RM86 HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB
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(W) RESEARCH LABS FILES MAGNETIC TEST NO 4149 MAR 1 1960 5

RM87 MARAGING STL NICKEL INTERNATIONAL NICKEL CO
TENTATIVE DATA ON 18 PERCENT NICKEL MARAGING STEEL
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RM88 HIPERCO 27 CASTINGS RABENOLD D G
MAGNETIC AND TENSILE PROPERTIES OF HIPERCO 27,35,50 INVESTMENT CASTINGS
WESTINGHOUSE MATERIALS MFG DEPT REPT 6-98831-200 FEB 24 1961 1 5

RM89 HIPERCO 50 CASTING RABENOLD D G
MAGNETIC AND TENSILE PROPERTIES OF HIPERCO 27,35,50 INVESTMENT CASTINGS
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RM90 HIPERCO 27 WESTINGHOUSE MATERIALS MFG DEPT
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WESTINGHOUSE MTLS MFG DEPT BULLETIN 52-150 OCT 1961 5

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MAGNETIC ALLOYS AND CASTINGS
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RM103 HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB
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RM104 HIPERCO 27 CASTING WESTINGHOUSE RESEARCH LAB
WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES
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RM105 HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB
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COBALT-BASE ALLOYS FOR SPACE POWER SYSTEMS
JOURNAL OF METALS V15 NO 12 P 928-34 DEC 1963 12

LM526	H-11 STEEL	ALLEGHENY LUDLUM CORP STAFF		
	POTOMAC A HIGH STRENGTH STEEL			
	ALLEGHENY STEEL CORP TECHNICAL BULLETIN 1959		12	6
RM26	MARAGING STEEL FORG	ALLEGHENY LUDLUM STEEL CORP		
	ALMAR MARAGING STEELS			
	DATA PUBLISHED BY ALLEGHENY LUDLUM STEEL CORP 1962		12345678	
RM24	MARAGING STEEL	ALLEGHENY LUDLUM STEEL CORP		
	ALMAR 15 (280HT)			
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LM502	MARAGING STEEL	ARNOLD S V		
	AGING RESPONSE OF 18(NI-CU-MO STEEL			
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RM56	SUPERMENDUR STRIP	ARNOLD ENGINEERING CO		
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	SOFT MAGNETIC MATERIALS AT LOW TEMPERATURE			
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	ZT F METALLKUNDE VOL 45 P651 1954			67
RM17	COBALT	BATTELLE MEMORIAL INSTITUTE		
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       FATIGUE AND DYNAMIC CREEP OF HIGH STRENGTH STEELS
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RM37   SUPERMENDUR STRIP         CHEN C W
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LM528  MARAGING STEEL            DETERT,K
       INVESTIG OF TRANSFORMATION AND PPTN PROC 18NI MARAGING STEEL
       WESTINGHOUSE RESEARCH LABS REPT NO 64-1B1-445-R1 JULY 1964  1   567
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	PROPERTIES OF MARAGING STEELS		
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RM83	SUPERMENDUR	FACAROS G TRAPP R H	
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RM84	HIPERCO 27	FACAROS G TRAPP R H	
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LM508	H-11 STEEL	FAROR R J ACHBACH W P	
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	DMIC 116R SEPT 30 1960		123
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	INTERNAL FRICTION AND YOUNGS MODULUS OF HEXAGONAL AND CUBIC COBALT		
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LM515	H-11 STEEL	FIRTH STERLING STAFF	
	FIRTH STERLING HWD2		
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RM35	MARAGING STEEL FORG	FLOREEN S DECKER R F	
	MARAGING STEEL FOR 1000F SERVICE		
	TRANSACTIONS OF ASM V56 NO 3 P403-11 SEPT 1963		12
LM501	MARAGING STEEL	FLOREEN S DECKER R F	
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	ASM TRANSACTIONS QUARTERLY V56 P403-11 SEPT 1963		12
RM107	COBALT-TUNGSTEN	FRECHE J C ASHBROOK R L KLIMA S J	
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LM518 MARAGING STEEL INTERNATIONAL NICKEL CO STAFF
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LM517 MARAGING STEEL INTERNATIONAL NICKEL CO
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LM523 MARAGING STEEL JONES R L
EVALUATION OF 18 NICOMO (300) 9NI-4CO H-11 AND SAE4340 STEEL FORGINGS
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LM524 H-11 STEEL JONES R L
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LM520  NI-MARAGING                  LATROBE STEEL CO
       THE 18 PERCENT NICKEL MARAGING STEELS
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RM71   SUPERMENDUR STRIP            LAURIENTE M LYNN G E
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RM60    COBALT                   STAFF MATERIALS IN DESIGN ENGINEERING
        COBALT AND COBALT BASE SUPER ALLOYS
        MATERIALS IN DESIGN ENGINEERING P114 OCT 1962                     1  4 6

RM59    NIVCO                    STAFF MATERIALS IN DESIGN ENGINEERING
        COBALT BASE SUPERALLOYS CAST WROUGHT
        MATERIALS IN DESIGN ENGINEERING P115 OCT 1962                     123  67

RM64    MARAGING STEEL           STAFF MATERIALS IN DESIGN ENGINEERING
        ULTRA HIGH STRENGTH STEELS-WROUGHT
        MATERIALS IN DESIGN ENGINEERING OCT 1962                          1  4 6

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RM44	HIPERCO 50 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5742 (W) RESEARCH LABS MAGNETIC TEST NO 5742 SEPT 6 1962	5
RM43	HIPERCO 50 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5402 (W) RESEARCH LABS MAGNETIC TEST NO 5402 MARCH 19 1962	5
RM42	NIVCO FORGING (W) RESEARCH LAB RESEARCH LABS MAGNETIC TEST NO 4790 (WESTINGHOUSE) RESEARCH LABS MAGNETIC TEST NO 4790 FEB 20 1961	5
RM41	NIVCO FORGING (W) RESEARCH LAB RESEARCH LABS MAGNETIC TEST NO 4790 (WESTINGHOUSE) RESEARCH LABS MAGNETIC TEST NO 4790 FEB 17 1961	5
RM54	NIVCO FORGING WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC TEST NO 4080 (W) RESEARCH LABS MAGNETIC TEST NO 4080 DEC 17 1959	5
RM52	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE MATERIALS ENGINEERING DEPT CURVE NO 366317 (W) MATERIALS ENGRG DEPT CURVE NO 366317 NOV 24 1950	5

RM49	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5072 (W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 16 1961		5
RM48	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5072 (W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 16 1961		5
RM79	HIPERCO 27 WESTINGHOUSE RESEARCH LAB RESEARCH LABS MAGNETIC MATERIALS FILES WESTINGHOUSE (W) RESEARCH LABS MAGNETIC MATERIALS FILES DEC 1960		6
RM77	HIPERCO 50 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES AUG 26 1960	1	567
RM86	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS FILES MAGNETIC TEST NO 4149 (W) RESEARCH LABS FILES MAGNETIC TEST NO 4149 MAR 1 1960		5
RM63	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC TEST NO 4149 (W) RESEARCH LABS MAGNETIC TEST NO 4149 FEB 2 1960		5
RM75	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5
RM103	HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5
RM104	HIPERCO 27 CASTING WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5
RM76	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5

RM105	HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB	
	WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES	
	WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES 9/1/60	2 5
RM61	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB	
	WESTINGHOUSE RESEARCH LABS MAGNETIC TEST NO 4149	
	(W) RESEARCH LABS MAGNETIC TEST NO 4149 FEB 3 1960	5
RM39	SUPERMENDUR STRIP (W) RESEARCH LABS	
	RESEARCH LABS-MAGNETICS DEPT FILES	
	RESEARCH LABS-MAGNETICS DEPT FILES SEPT 1 1960	567
RM28	NIVCO 10 FORGING STAFF WESTINGHOUSE	
	WESTINGHOUSE DATA REPORT	
	WESTINGHOUSE DATA REPORT AUG 10 1962	1234567
RM34	MARAGING STEEL FORG STAFF R AND D CENTER (W)	
	SPACE/AERONAUTICS	
	R AND D CENTER HANDBOOK P219 1963-64	1
RM32	HIPERCO 27 FORGING STAFF R AND D CENTER (W)	
	RESEARCH MAGNETICS DEPT FILES TECH DATA	
	RESEARCH MAGNETICS DEPT FILES TECH DATA FEB 2 1960	12 6
RM31	HIPERCO 27 STRIP STAFF R AND D CENTER (W)	
	RESEARCH MAGNETICS DEPT FILES TECHNICAL DATA	
	RESEARCH MAGNETICS DEPT FILES TECH DATA FEB 12 1960	1 56
RM30	SUPERMENDUR STRIP STAFF R AND D CENTER (W)	
	RESEARCH MAGNETICS DEPT FILES TECHNICAL DATA	
	RESEARCH MAGNETICS DEPT FILES TECHNICAL DATA SEPT 1 1960	5
RM25	MARAGING STEEL FORG WESTINGHOUSE	
	RESEARCH LABS MAGNETIC TEST SHEET	
	TEST SHEET =6270 OCT 3 1963	5
RM19	CUBEX STAFF	
	(W) RESEARCH TEST RECORDS	
	TEST CONDUCTED ON AUG 29 1963	5

LM28	IRON 1 SILICON	WESTINGHOUSE STAFF		
	WESTINGHOUSE MAGN TEST CURVES NO 529309			
	WESTINGHOUSE INTERNAL INFORMATION MAR 4 1962			5
RM1	CUBEX	STAFF		
	(W) RESEARCH LABORATORY TEST RECORDS			
	(W) RESEARCH LAB TEST RECORDS AUG 8,1962		1	
RM3	CUBEX	STAFF		
	CUBEX CORES FOR TRANSFORMERS AND REACTORS			
	(W) TECHNICAL DATA SHEET 44-651 P1-4 NOV 1962			5
RM4	CUBEX	STAFF		
	(W) RESEARCH TEST RECORDS			
	TEST CONDUCTED IN MARCH 1962			6
RM82	SUPERMENDUR STRIP	WESTINGHOUSE SPECIALTY TRANSFORMER DEPT TECH DATA		
	SUPERMENDUR CORES			
	(W) SPECIALTY TRANSFORMER DEPT TECH DATA 1960			5
RM5	CUBEX	STAFF		
	(W) RESEARCH TEST RECORDS			
	1962-1			5
RM22	MARAGING STEEL FORG	WITHERELL C E CORRIGAN D A ET AL		
	WORKING WITH MARAGING STEELS-WELDING			
	METAL PROGRESS V84 NO 1 P81-3 JULY 1963			4
RM68	MARAGING STEEL FORG	WITHERELL C E FRAGETTA W A		
	WELDABILITY OF 18 PERCENT NICKEL MARAGING STEEL			
	WELDING JOURNAL SUPPLEMENT V41 NO 11 P481S-487S NOV 1962			4
RM20	COBALT	YOUNG R S		
	COBALT ITS CHEMISTRY METALLURGY AND USES			
	REINHOLD PUBLISHING CORP N Y P64-71 1960		12	5678
LM22	GENERAL	ZAIKOVA V A FALALER G A ET AL		
	DEPENDENCE OF MAGNETIC PROPERTIES ON THICKNESS OF MAGNETIC SHEET			
	PHYSICS OF METALS AND METALLOGRAPHY VOL 13 P521-28 APR 1962			5

RM60 COBALT STAFF MATERIALS IN DESIGN ENGINEERING
COBALT AND COBALT BASE SUPER ALLOYS
MATERIALS IN DESIGN ENGINEERING P114 OCT 1962 1 4 6

RM27 COBALT BOZORTH R M
FERROMAGNETISM
D VAN NOSTRAND CO INC P261-67 1951 1 567

RM57 COBALT PETERS R L
NOMOGRAPH THERMAL CONDUCTIVITY AT ANY TEMPERATURE
MATERIALS IN DESIGN ENGINEERING P 90-91 FEB 1962 6

RM62 COBALT SHEET SEAGLE S R MERLIN R C ET AL
ELECTRON BEAM MELTING
JOURNAL OF METALS V11 NO 11 P816 NOV 1962 1 4

LM527 NI-CO-FE ALLOYS SCHAFER E
RESISTIVITY AND MAGNETIC DATA OF VARIOUS MATERIALS
ELECTRONIC PROP INFORMATION CENTER DATA SHEET DEC 1963 5 7

RM107 COBALT-TUNGSTEN FRECHE J C ASHBROOK R L KLIMA S J
COBALT-BASE ALLOYS FOR SPACE POWER SYSTEMS
JOURNAL OF METALS V15 NO 12 P 928-34 DEC 1963 12

RM106 COBALT CAMPBELL J E GOODWIN H B WAGNER H J ETAL
INTRODUCTION TO METALS FOR ELEVATED TEMPERATURES
DMIC BATTELLE MEMORIAL INSTITUTE REPT 160 OCT 27 1961 1

RM94 COBALT SAVITSKY E M
THE INFLUENCE OF TEMP ON THE MECHANICAL PROPERTIES OF METALS AND ALLOYS
BOOK STANDFORD UNIV PRESS P134-6 1961 1

LM24 50 CO-FE VACUUMSCHMELZE
PROPERTIES OF NI-FE SI-FE AND CO-FE AT HIGH FREQUENCIES AND HIGH TEMPS
HANDBOOK SOFT MAGNETIC MATERIALS P 182 AND 214 1957 5

LM13 COBALT SAMBONGI T MITUE T
MAGNETIC ANNEALING EFFECT IN COBALT
J PHYS SOC JAPAN VOL 16 P 1478 1961 5

LM11	COBALT	GRAHAM C D JR		
	MAGNETIC ANNEALING OF COBALT			
	J PHYS SOC JAPAN VOL 16 P 1481 1961			5
RM78	COBALT	HAMPEL C A		
	RARE METALS HANDBOOK 2ND EDITION			
	RARE METALS HANDBOOK 2ND EDITION P126 1961		12	67
RM15	COBALT	MANTELL C L		
	ENGINEERING MATERIALS HANDBOOK			
	ENGINEERING MATERIALS HANDBOOK P 13 1958		1	567
RM40	COBALT	FINE M E GREENER E H		
	INTERNAL FRICTION AND YOUNGS MODULUS OF HEXAGONAL AND CUBIC COBALT			
	TRANS AIME V212 P477 AUG 1958		1	
RM38	COBALT	HAMPEL C A		
	RARE METALS HANDBOOK			
	RARE METALS HANDBOOK P117 1954			67
RM20	COBALT	YOUNG R S		
	COBALT ITS CHEMISTRY METALLURGY AND USES			
	REINHOLD PUBLISHING CORP N Y P64-71 1960		12	5678
RM17	COBALT	BATTELLE MEMORIAL INSTITUTE		
	COBALT MONOGRAPH			
	COBALT MONOGRAPH 1960		12	6
LM10	COBALT	SAMBONGI T MITUE T		
	STRESS ANNEALING EFFECT IN COBALT			
	J PHYS SOC JAPAN VOL 16 P2066 1961			5
LM14	27 AND 35 PERCENT CO	FE HALL R C		
	EFFECT OF TEMP ON AC AND DC MAGNETIC PROPERTIES			
	(W) REPORTS AD209618 AD202259 AD216073 1958-59			5
RM1	CUBEX	STAFF		
	(W) RESEARCH LABORATORY TEST RECORDS			
	(W) RESEARCH LAB TEST RECORDS AUG 8,1962		1	

RM4 CUBEX STAFF
(W) RESEARCH TEST RECORDS
TEST CONDUCTED IN MARCH 1962 6

RM5 CUBEX STAFF
(W) RESEARCH TEST RECORDS
1962-1 5

LM26 CUBEX KRIVONOSOVA E G LIVSHITZ B G
HYSTERESIS ANISTROPY OF DEFORMED FE-SI CRYSTALS
PHYSICS METALS AND METALLOGRAPHY USSR V14 P930-1 JUNE 1962 0

RM3 CUBEX STAFF
CUBEX CORES FOR TRANSFORMERS AND REACTORS
(W) TECHNICAL DATA SHEET 44-651 P1-4 NOV 1962 5

RM19 CUBEX STAFF
(W) RESEARCH TEST RECORDS
TEST CONDUCTED ON AUG 29 1963 5

RM10 CUBEX STAFF (W)
RESEARCH TEST RECORDS WESTINGHOUSE
(W) RESEARCH TEST RECORDS TESTS CONDUCTED SEPT 3,1963 5

RM72 CUBEX PAULIK N
CUBEX HIGH TEMPERATURE TEST
UNPUBLISHED WESTINGHOUSE RESEARCH REPORT MAY 10 1963 5

LM16 CUBEX GANZ DIETER
EFFECT OF DIRECTION ON MAGN PROPERTIES OF FE-SI SHEETS CONT 3 SI
ZT F ANGEWANDTE PHYSIK VOL 14 P 313-322 MAY 1962 5

LM18 CUBEX KOKSHAROVA I K
CUBE TEXTURE FORMATION IN TRANSFORMER STEELS
PHYSICS OF METALS AND METALLOGRAPHY USSR VOL 14 P464-65 1962 5

LM7 CUBEX KUNAROV AND LIVSHITZ
MAGNETIC PROPERTIES OF TRANSFORMER STEEL WITH A CUBE TEXTURE
RUSSIAN METAL PHYSICS AND METALLOGRAPHY VOL 15 P55 1963 5

LM23 CUBEX MAKUSZEQICZ M J
EFFECT OF SOME IMPURITIES ON GRAIN GROWTH AND ANISOTROPHY OF 3.25 SI FE
IRON AND STEEL INDUSTRY JOURNAL BRITISH V200 P 223-28 MAR 1962 0

LM17 CUBEX KUNAKOV Y N LIVSHITZ B L
ROLE OF SURFACE ENERGY DURING THE CUBE TEXTURE FORMATION IN SI-FE
PHYSICS OF METALS AND METALLOGRAPHY USSR VOL 14 P727-32 1962 5

LM29 GENERAL VONSOVSKIY S V
METAL PHYSICS AND ITS CONTRIBUTION TO MATERIAL BASIS OF COMMUNISM
PHYSICS OF METALS AND METALLORGRAPHY V14 P322-26 1962 5

LM22 GENERAL ZAIKOVA V A FALALER G A ET AL
DEPENDENCE OF MAGNETIC PROPERTIES ON THICKNESS OF MAGNETIC SHEET
PHYSICS OF METALS AND METALLOGRAPHY VOL 13 P521-28 APR 1962 5

LM529 H-11 (W) ELEC. AIRRESEARCH MFG.
SPUR GEN. DEVEL. PROG QUARTERLY TECH. PROG REPT MAY 15 JULY 64
JULY 15, 1964 12 5 9

LM503 H-11 BRODRICK R F
FATIGUE AND DYNAMIC CREEP OF HIGH STRENGTH STEELS
ASD-TDR-62-480 AUGUST 1962 23

LM12 H-11 KOVACS A LAURENT P
INFLUENCE OF FATIGUE ON MAGNETIC PROPERITES OF STEELS
C R ACAD SCI PARIS VOL 235 P 1224-26 1952 5

RM104 HIPERCO 27 CASTING WESTINGHOUSE RESEARCH LAB
WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES
(W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960 12 5

RM103 HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB
WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES
(W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960 12 5

RM105 HIPERCO 27 FORGING WESTINGHOUSE RESEARCH LAB
WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES
WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES 9/1/60 2 5

RM75	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5
RM79	HIPERCO 27 WESTINGHOUSE RESEARCH LAB RESEARCH LABS MAGNETIC MATERIALS FILES WESTINGHOUSE (W) RESEARCH LABS MAGNETIC MATERIALS FILES DEC 1960		6
RM86	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS FILES MAGNETIC TEST NO 4149 (W) RESEARCH LABS FILES MAGNETIC TEST NO 4149 MAR 1 1960		5
RM84	HIPERCO 27 FACAROS G TRAPP R H WESTINGHOUSE MATERIALS MFG REPORT 8-98839-021-C (W) MATERIALS MFG REPORT 8-98839-021-C		5
RM63	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC TEST NO 4149 (W) RESEARCH LABS MAGNETIC TEST NO 4149 FEB 2 1960		5
RM76	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES (W) RESEARCH LABS MAGNETIC MATERIALS FILES MAY 18 1960	12	5
RM61	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB WESTINGHOUSE RESEARCH LABS MAGNETIC TEST NO 4149 (W) RESEARCH LABS MAGNETIC TEST NO 4149 FEB 3 1960		5
RM48	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5072 (W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 16 1961		5
RM49	HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB (W) RESEARCH LABS MAGNETIC TEST NO 5072 (W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 16 1961		5
RM51	HIPERCO 27 HARDING W C WESTINGHOUSE METALLURGICAL MEMO NO 886 (W) MATERIALS ENGRG DEPT MEMO NO 886 FEB 2 1945	1	5 7

RM52 HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB
WESTINGHOUSE MATERIALS ENGINEERING DEPT CURVE NO 366317
(W) MATERIALS ENGRG DEPT CURVE NO 366317 NOV 24 1950 5

RM46 HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB
(W) RESEARCH LABS MAGNETIC TEST NO 5072
(W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 15 1961 5

RM47 HIPERCO 27 STRIP WESTINGHOUSE RESEARCH LAB
(W) RESEARCH LABS MAGNETIC TEST NO 5072
(W) RESEARCH LABS MAGNETIC TEST NO 5072 AUG 15 1961 5

RM55 HIPERCO 27 STRIP TRAPP R H ROBENOLD D G FACAROS G
SOFT MAGNETIC MATERIALS FOR 930 F PLUS
MATERIALS IN DESIGN ENGINEERING P 113-115 MAY 1962 1 567

RM13 HIPERCO 27 STRIP CLARK J J FRITZ J F
EFFECT OF TEMP ON THE MAGNETIC PROPERTIES OF SILICON-FE CO-FE AL-FE ALLOYS
(W) ENGINEERING MATERIALS REPORT 5941-3015-A AUG 12,1959 5

RM70 HIPERCO 27 BOZORTH R M
FERROMAGNETISM (BOOK)
D VAN NOSTRAND CO INC P190-205 1951 1 567

RM36 HIPERCO 27 STRIP CHEN C W
SOFT MAGNETIC COBALT IRON ALLOYS
(W) RES LABS SCIENTIFIC PAPER 63-141-441-PL MAY 23 1963 1 4567

RM32 HIPERCO 27 FORGING STAFF R AND D CENTER (W)
RESEARCH MAGNETICS DEPT FILES TECH DATA
RESEARCH MAGNETICS DEPT FILES TECH DATA FEB 2 1960 12 6

RM31 HIPERCO 27 STRIP STAFF R AND D CENTER (W)
RESEARCH MAGNETICS DEPT FILES TECHNICAL DATA
RESEARCH MAGNETICS DEPT FILES TECH DATA FEB 12 1960 1 56

RM11 HIPERCO 27 STRIP PAVLIK N
HIGH TEMPERATURE STABILITY OF MAGNETIC MATERIALS
J APPLIED PHYSICS VOL 32 =3 P3725-35 MAR 1961 5

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RM18    HIPERCO 27 STRIP       STAFF (W) R + D CENTER
        RESEARCH LABS MAGNETIC TEST SHEET NO 6322
        TEST SHEET NO 6322 SEPT 30,1963                                  5

RM88    HIPERCO 27 CASTINGS    RABENOLD D G
        MAGNETIC AND TENSILE PROPERTIES OF HIPERCO 27,35,50 INVESTMENT CASTINGS
        WESTINGHOUSE MATERIALS MFG DEPT REPT 6-98831-200 FEB 24 1961     1   5

RM90    HIPERCO 27             WESTINGHOUSE MATERIALS MFG DEPT
        MAGNETIC ALLOYS AND CASTINGS
        WESTINGHOUSE MTLS MFG DEPT BULLETIN 52-150 OCT 1961              5

RM102   HIPERCO 50             BOZORTH R M
        FERROMAGNETISM (BOOK)
        D VAN NOSTRAND CO INC  P190-205  1951                            1   567

RM69    HIPERCO 50             HALL R C CONARD G P LIBSCH J F
        ORDERING AND MAGNETIC HEAT TREATMENT OF 50 PERCENT IRON-50 PERCENT CO ALLOY
        JOURNAL OF METALS P985-989 SEPT 1955                             5

RM89    HIPERCO 50 CASTING     RABENOLD D G
        MAGNETIC AND TENSILE PROPERTIES OF HIPERCO 27,35,50 INVESTMENT CASTINGS
        WESTINGHOUSE MTLS MFG DEPT REPT 6-98831-200 FEB 24 1961          1   5

RM91    HIPERCO 50 CASTING     WESTINGHOUSE MTLS MFG DEPT
        MAGNETIC ALLOYS AND CASTINGS
        WESTINGHOUSE MTLS MFG DEPT BULLETIN 52-150                       5

RM77    HIPERCO 50 STRIP       WESTINGHOUSE RESEARCH LAB
        WESTINGHOUSE RESEARCH LABS MAGNETIC MATERIALS FILES
        (W) RESEARCH LABS MAGNETIC MATERIALS FILES AUG 26 1960           1   567

RM44    HIPERCO 50 STRIP       WESTINGHOUSE RESEARCH LAB
        (W) RESEARCH LABS MAGNETIC TEST NO 5742
        (W) RESEARCH LABS MAGNETIC TEST NO 5742 SEPT 6 1962              5

RM45    HIPERCO 50 STRIP       WESTINGHOUSE RESEARCH LAB
        (W) RESEARCH LABS MAGNETIC TEST NO 5787
        (W) RESEARCH LABS MAGNETIC TEST NO 5787 SEPT 29 1962             5
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RM43 HIPERCO 50 STRIP WESTINGHOUSE RESEARCH LAB
(W) RESEARCH LABS MAGNETIC TEST NO 5402
(W) RESEARCH LABS MAGNETIC TEST NO 5402 MARCH 19 1962 5

LM20 IRON COBALT KELLER H HILLMANN H
FE-CO WITH LOW COERCIVE FORCE
ZT F ANGEWANDTE PHYSIK VOL 14 P243-45 APR 1962 5

LM21 IRON COBALT OCSENFELD R
CAUSES OF ABNORMAL MAGNETIC LOSS PHENOMENA IN SI CONT EL SHEETS
ARCHIV F D EISENHUTTENWESEN NOT DATED 0

LM19 IRON COBALT PSHEUTCHENKOVA G V
TEMP DEPENDENCE OF MAGNETIC INDUCTION OF FE-CO ALLOYS
PHYSICS OF METALS AND METALLOGRAPHY USSR VOL 14 P797-99 1962 5

LM25 IRON COBALT PSHENTCHENKOVA G V SKOKOV A D
TEMPERATURE DEPENDENCE OF MAGNETIC INDUCTION OF FE-CO ALLOYS
PHYSICS OF METALS AND METALLOGRAPHY V 14 P797-99 1962 5

LM27 IRON-50COBALT ASSMUS AND GSCHEIDER
SOFT MAGNETIC MATERIALS AT LOW TEMPERATURE
VACUUMSCHMELZE CO LAB REPORT NO 01/15 SEPT 21 1962 0

LM14 27 AND 35 CO-FE HALL R C
EFFECT OF TEMP ON AC AND DC MAGNETIC PROPERTIES
ASTIA REPORTS AD209618 AD216073 1958-59 5

LM3 IRON COBALT BAER G THOMAS H
PROPERTIES AND PHASE RELATIONS OF FE-CO ALLOYS WITH 50 CO
ZT F METALLKUNDE VOL 45 P651 1954 67

LM28 IRON 1 SILICON WESTINGHOUSE STAFF
WESTINGHOUSE MAGN TEST CURVES NO 529309
WESTINGHOUSE INTERNAL INFORMATION MAR 4 1962 5

RM87 MARAGING STEEL INTERNATIONAL NICKEL CO
TENTATIVE DATA ON 18 PERCENT NICKEL MARAGING STEEL
MARAGING STEEL DATA BOOK NOV 1962 1 3 5

RM81 MARAGING STEEL INTERNATIONAL NICKEL CO
PRELIMINARY DATA SHEET NOMINAL 200KSI YIELD STRENGTH 18PERCENT NI MAR STEEL
INTERNATIONAL NICKEL CO PUBL NO TL-12 P1-3 NOV 2 1962 1

LM502 MARAGING STEEL ARNOLD S V
AGING RESPONSE OF 18(NI-CU-MO STEEL
WATERTOWN ARSENAL LAB REPORT NO WAL-TR320.1/11 FEB 1963 1

LM504 MARAGING STEEL HALL A M ET AL
REPORT ON MEETING TO REVIEW MARAGING STEEL PROJECTS
DMIC MEMO 162 DEC 28 1962 12 4

LM525 MARAGING STEEL MAY J A
MARAGING STEEL IN ELEVATED TEMPERATURE AIRFRAME DESIGN
NORTH AMERICAN AVIATION CORP JULY 1963 23

LM528 MARAGING STEEL DETERT,K
INVESTIG OF TRANSFORMATION AND PPTN PROC 18NI MARAGING STEEL
WESTINGHOUSE RESEARCH LABS REPT NO 64-181-445-R1 JULY 1964 1 567

RM50 MARAGING STL FORGING WESTINGHOUSE RESEARCH LAB
(W) RESEARCH LABS MAGNETIC TEST NO 6181
(W) RESEARCH LABS MAGNETIC TEST NO 6181 JULY 18 1963 5

LM522 MARAGING STEEL MOON D P CAMPBELL J E
THE MECHANICAL PROPERTIES OF 18 NICKEL MARAGING STEELS
DMIC PRELIMINARY DRAFT JULY 22,1963 1234 6

LM523 MARAGING STEEL JONES R L
EVALUATION OF 18 NICOMO (300) 9NI-4CO H-11 AND SAE4340 STEEL FORGINGS
GENERAL DYNAMICS PRELIMINARY INFORMATION JULY 24,1963 3

LM521 MARAGING STEELS DRENNEN D C ROACH D B
PROPERTIES OF MARAGING STEELS
DMIC MEMORANDUM 156 JULY 2,1962 1 6

LM501 MARAGING STEEL FLOREEN S DECKER R F
MARAGING STEEL FOR 1000 DEG F SERVICE
ASM TRANSACTIONS QUARTERLY V56 P403-11 SEPT 1963 12

LM520 MARAGING STEEL LATROBE STEEL CO
THE 18 PERCENT NICKEL MARAGING STEELS
LATROBE STEEL CO TECHNICAL BULLETIN DEC 1962 1 4 6 8

LM518 MARAGING STEEL INTERNATIONAL NICKEL CO STAFF
18 PERCENT NICKEL MARAGING STEEL INTERIM DATA SHEET
INTERNATIONAL NICKEL CO STAFF NOV 26 1962 1 34567

LM517 MARAGING STEEL INTERNATIONAL NICKEL CO
MARAGING STEELS
INTERNATIONAL NICKEL TECHNICAL DATA SHEET JUNE 1962 1 4 6

RM67 MARAGING STEEL NOVAK C J DIRAN L M
WHAT ARE THE EFFECTS OF RESIDUAL ELEMENTS IN MARAGING STEELS
JOURNAL OF METALS V15 NO3 P200-204 MAR 1963 1

RM65 MARAGING STEEL STAFF MATERIALS IN DESIGN ENGINEERING
THE MARAGING STEELS
MATERIALS IN DESIGN ENGINEERING P107-110 MAY 1962 1 345678

RM64 MARAGING STEEL STAFF MATERIALS IN DESIGN ENGINEERING
ULTRA HIGH STRENGTH STEELS-WROUGHT
MATERIALS IN DESIGN ENGINEERING OCT 1962 1 4 6

RM74 MARAGING STEEL PUZAK P P LOYD K B
FUNDAMENTAL STUDY OF WELD JOINT BEHAVIOR
REPORT ON NAVAL RESEARCH LABS PROGRESS P31-36 SEPT 1963 1

RM68 MARAGING STEEL FORG WITHERELL C E FRAGETTA W A
WELDABILITY OF 18 PERCENT NICKEL MARAGING STEEL
WELDING JOURNAL SUPPLEMENT V41 NO 11 P481S-487S NOV 1962 4

RM53 MARAGING STEEL STAFF MATERIALS IN DESIGN ENGINEERING
AUSTENITIC STAINLESS STEELS AND MARAGING STEELS
MATERIALS IN DESIGN ENGINEERING MARCH 1963 1

RM12 MARAGING STEEL DECKER R F EASH J T GOLDMAN A J
18 PERCENT NICKEL MARAGING STEEL
TRANSACTIONS OF ASM VOL 55 NO 1 P 58-76 MAR 1962 1 4 8

RM7 MARAGING STEEL 18 NI FIELD J
DISCUSSION OF PAPER 18 PERCENT MARAGING STEEL
TRANSACTIONS OF ASM VOL 55 NO 4 P1010-11 DEC 1962 1

RM26 MARAGING STEEL FORG ALLEGHENY LUDLUM STEEL CORP
ALMAR MARAGING STEELS
DATA PUBLISHED BY ALLEGHENY LUDLUM STEEL CORP 1962 12345678

RM22 MARAGING STEEL FORG WITHERELL C E CORRIGAN D A ET AL
WORKING WITH MARAGING STEELS-WELDING
METAL PROGRESS V84 NO 1 P81-3 JULY 1963 4

RM21 MARAGING STEEL FORG SPARKS R B
WORKING WITH MARAGING STEELS-FORGING
METAL PROGRESS V84 NO 1 P74-7 JULY 1963 4

RM34 MARAGING STEEL FORG STAFF R AND D CENTER (W)
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